What is "Roentgen Systems" ?

In 1895 the german physicist Wilhelm Conrad Roentgen discovered the X-rays.

Compared to light, X-rays are very short electromagnetic waves with high energy.
They have the ability to penetrate solid objects.

The degree of penetration depends on
- the thickness of the object
- the density of the object
- the energy of the X-ray quanta.

X-rays have become an invaluable tool for medical imaging and industrial non-destructive testing.

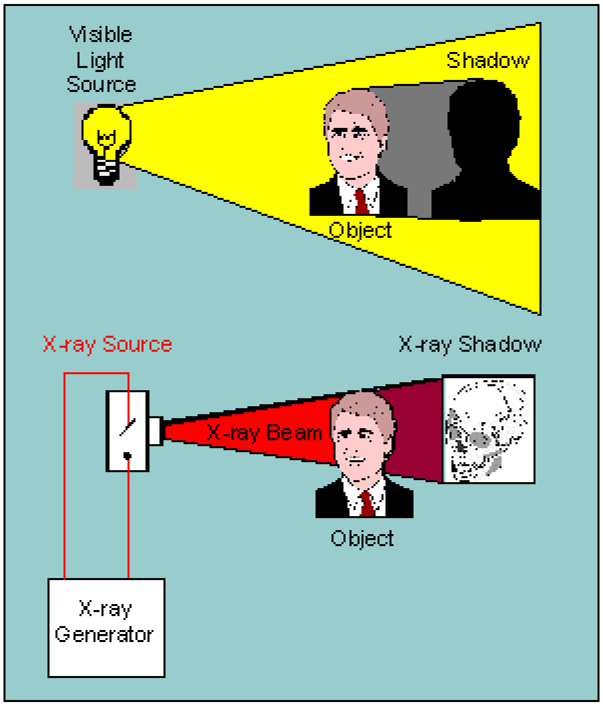
The systems needed for medical imaging with X-rays are designated as
- Roentgen Systems (RS) or
- X-ray Systems.

What is "Roentgen Systems" ?

The illustration shows the difference between light and X-rays:

If a visible light energy shines from a source toward an object, the object casts a shadow. Since visible light cannot penetrate solid objects, the shadow is in the shape of the outer perimeter of the object.

With X-rays however, the parts of the body are penetrated according to thickness and density. Thus an X-ray shadow (X-ray image) is build up after the patient which can be made visible on film or via a Television Imaging System.



end of chapter "What is Roentgen Systems?"

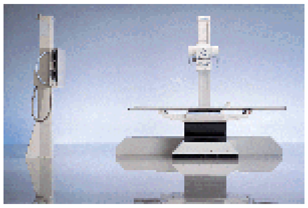
.

Introduction **Examination Units** 1/8

The design of an X-ray system depends
on the medical application.

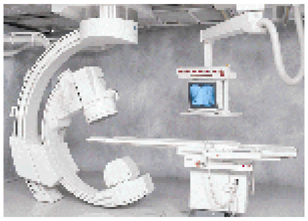
Our products are subdivided into :

- General Radiography systems



Example:
MULTIX TOP

- Radiography / Fluoroscopy
  and Angiography systems



Example:
MULTISTAR TOP

- Systems for special medical applications

Example:
MAMMOMAT

..

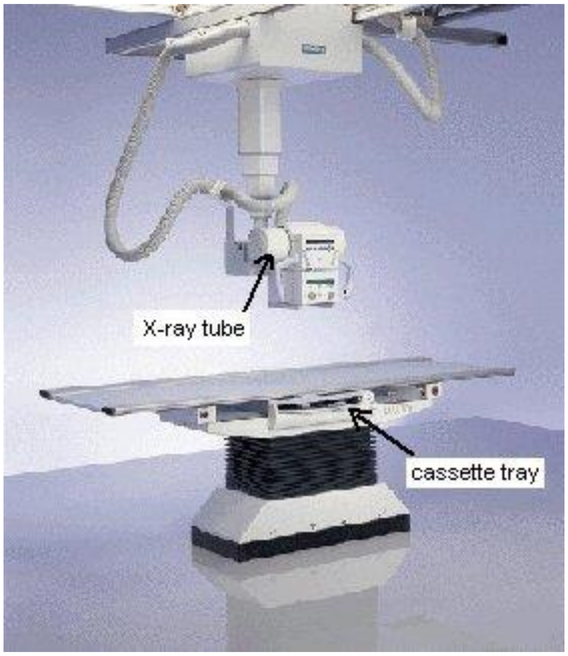
Introduction **Examination Units** 2/8

General Radiography systems:

General Radiography systems are used for

Example: MULTIX TOP

- Skeletal diagnosis
- Lung diagnosis
- Traumatology (wounds and injuries).



With these examinations, the patient is positioned on the table under visual control, and the image is recorded on radiographic film.
For this, the *film cassette* is placed on the cassette tray (*Bucky tray*) underneath the patient, and an exposure is released. After film processing, the radiograph is viewed on a viewing box.

Because of the direct exposure of the X-ray film inside the cassette, this is referred to as **direct technique**. A system providing this functionality is called an **exposure system**.
Notice the split-up responsibility: the radiographer produces the radiograph which is later evaluated by the radiologist.

.

Examination Units

Radiography / Fluoroscopy and Angiography systems:

Radiography / Fluoroscopy (RF) and Angiography systems are used for
- Routine diagnosis
- Angiography

Example: SIRESKOP CX
(system for routine diagnosis and interventional technique)

- Interventional Radiography

Routine diagnosis :
This covers the range of standard examinations, for example the examination of function and shape of the organs (gastrointestinal diagnosis).

Angiography :
This is the X-ray visualization of the heart and the blood vessels following the administration of *contrast medium*.
For studying the contrast medium flow, a series of exposures is needed.

Interventional Radiography :
This is an alternative to surgery and is used, for example, to reopen occluded blood vessels using *catheters*.

▼ ▲

.

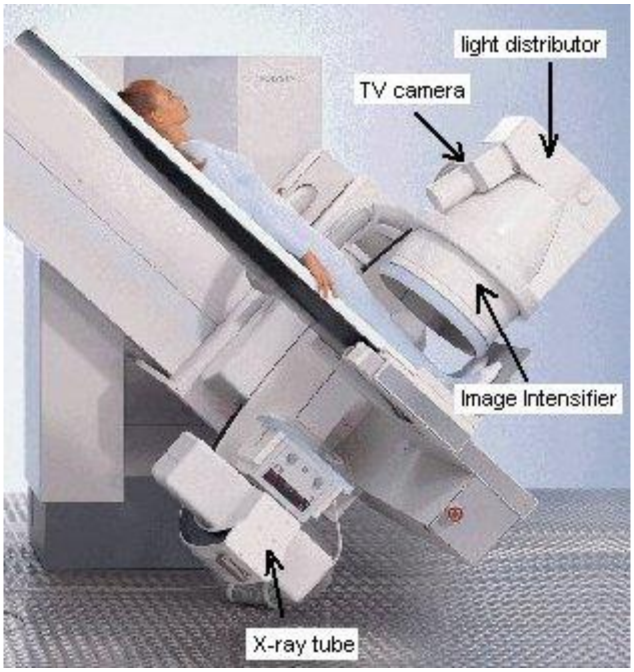
Radiography / Fluoroscopy and Angiography systems:

Common to these examinations is the need of real time imaging by means of **fluoroscopy** to follow the flow of contrast

Example: POLYSTAR T.O.P.
(multipurpose system for all conventional applications including angiography)

medium or positioning catheters.
For this, an image intensifier is combined with a TV-system providing real time X-ray imaging.
For diagnosis as well as archiving, radiographs of the findings have to be provided.
According to the imaging techniqe used, we differentiate between indirect technique and DFR.

Indirect Technique:
Using an image intensifier, the X-ray image is converted into visible light and received by a 100 mm sheet film camera. Using a 35mm cine camera, dynamic studies of the heart can be recorded.
Today, these systems are being replaced by DFR-technique
(DFR = Digital Fluoro Radiography).



Radiography / Fluoroscopy and Angiography systems:

- **DFR (Digital Fluoro Radiograhy):**
  A combination of image intensifier and a TV chain featuring *digital image processing* is capable of "digital fluoroscopy" and "digital radiography". Meaning, the radiographs are stored on hard disk instead of film.

Example: MULTISTAR TOP
(sytem for angiography)

- **C-arm units** provide various "viewing directions" through the body without the need of turning the patient on the table.
  This feature is needed for angiographic examinations of the head and the heart.

.

Systems for special medical applications:

SIEMENS has a lot of systems for special medical applictions.
The main difference to the previous described systems
is the mechanical construction.

Examples:

- Surgery systems:
  used for a wide field of applications
  for surgical diagnostics.

Example:
SIREMOBIL

- Urology systems:
  for all urological diagnostic and
  interventional procedures,
  e.g. display of kidneys, renal pelvis,
  renal ducts, and bladder.

Example:
MODULARIS
Uro

.

Systems for special medical applications:

- Mammography systems:
  used to generate images of the female
  breast for the diagnosis and early
  detection of breast cancer.

Example:
MAMMOMAT

- Mobile Generators :
  for sports clinic, plaster room, intensive-care unit, casualty department or operating theatre.

Example:
MOBILETT Plus

.

Introduction **Examination Units** 8/8

Systems for special medical applications:

- Lithotripsy systems:
  used for crushing of stones in the gallbladder or kidneys with shock waves.

Example:
LITHOSTAR MODULARIS

End of "Examination Units"

.

.

Introduction **Examination Units**

Systems for special medical applications:

SIREMOBIL

back

.

Introduction

Examination Units

Systems for special medical applications:

MODULARIS Uro

back

.

Introduction **Examination Units**

Systems for special medical applications:

MAMMOMAT

back

.

Introduction **Examination Units**

Systems for special medical applications:

MOBILETT Plus

back

.

Introduction **Examination Units**

Systems for special medical applications:

LITHOSTAR MODULARIS

back

.

Introduction

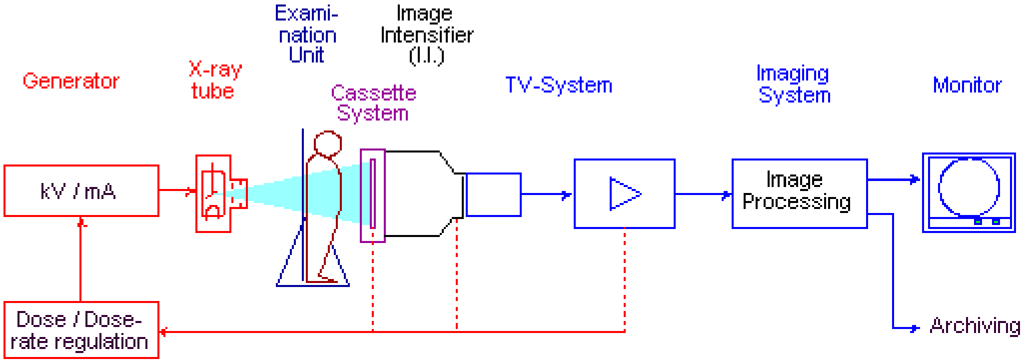
The X-ray Imaging Chain

The block diagram below shows the the **X-ray Imaging Chain** of a modern X-ray system.

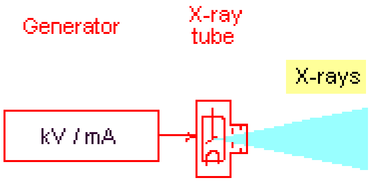
On the following pages, we will develop this blockdiagram step by step.

You will become familiar with terms like
exposure system, fluoroscopy, indirect technique etc.

The circuits that are needed to control and operate an X-ray system
are described in the chapter "Principle Diagram".



Generation of X-rays:

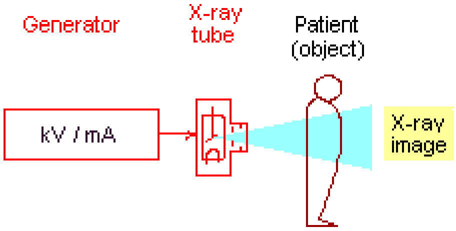


- X-rays are generated in the **X-ray tube**.

  Principle:
  In the cathode electrons are produced by heating up the filament.
  Due to a high voltage difference between anode and cathode the electrons are accelerated towards the anode.
  When they hit the anode X-rays are produced.

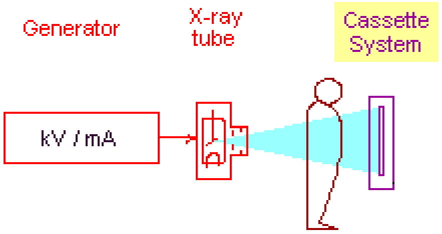
- The high tension (KV) between anode and cathode and the X-ray tube current (mA) are generated by the **Generator**.

X-ray Image:



- With a patient (object) in the X-ray beam, the X-rays are absorbed, depending on the thickness and the density of the object and on the energy of the radiation.
- Thus an invisible **X-ray image** (shadow) is formed behind the patient.

Cassette System:

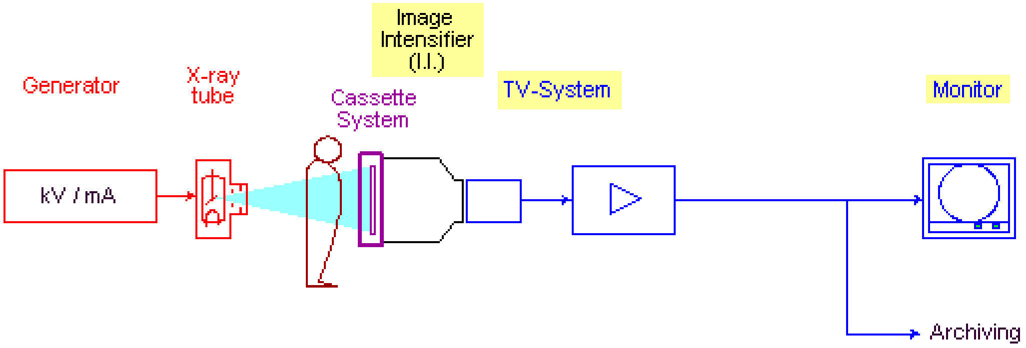


- X-ray images can be made visible with X-ray films (film cassette).

  Only after processing the film, the formation of the image is completed. Therefore, in direct technique, exposure of the film and film processing have to match.

  X-ray film, film cassette and the control are designated as **Cassette system.**
- The method of generating images on film is called **"Direct Technique"** and the X-ray systems are designated as **"Exposure Systems".**

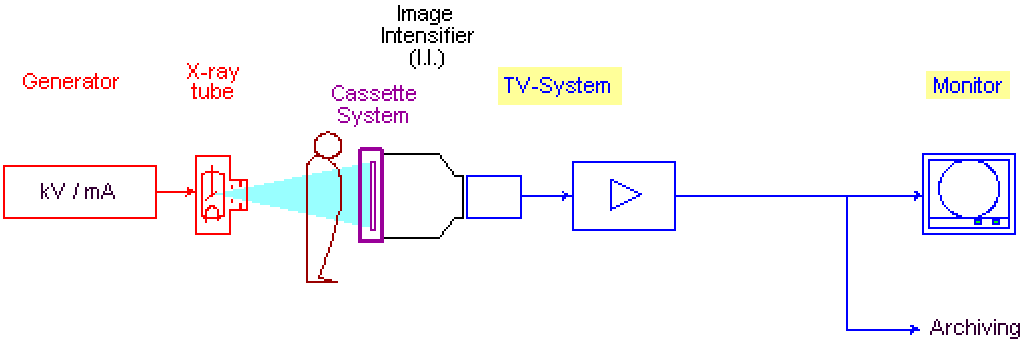
Image Intensifier (I.I.), TV-system, Monitor:



- With the components Image Intensifier, TV-system and Monitor, the examination can be viewed on a monitor screen.
  The electrical signal from the TV-system can be also sent to a hardcopy camera for archiving purposes.

- **Image Intensifier (I.I.):** This is a tube that converts the X-rays on the input screen into a small optical image at the output screen.
  The diameter of that image is appr. 25 mm.

Image Intensifier (I.I.), TV-system, Monitor:



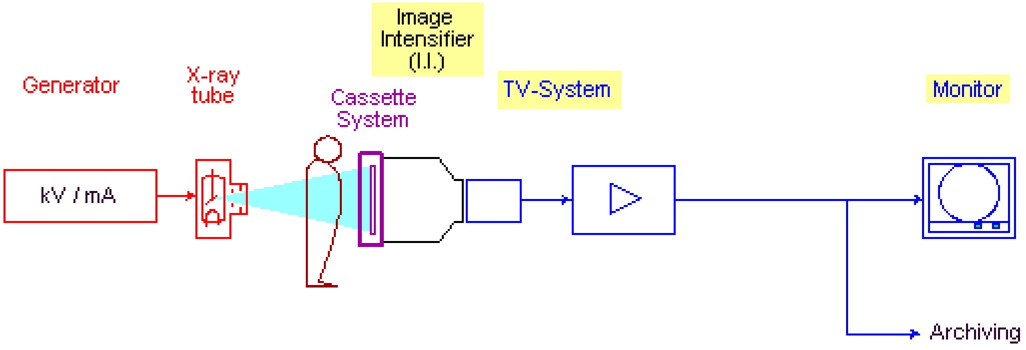
- **TV-system, Monitor:**
  The TV-system consists of TV-camera and Camera Control Unit (C.C.U.).
  The TV-camera is mounted at the image intensifier, and the Camera Control Unit is located in a cabinet.

  A pickup tube or CCD-sensor (semiconductor) in the camera converts the I.I. output image into an electrical signal.
  In the C.C.U., this signal is further processed and then fed to both the Monitor for image display and to the hardcopy camera for archiving.

.

The X-ray Imaging Chain

Image Intensifier (I.I.), TV-system, Monitor:



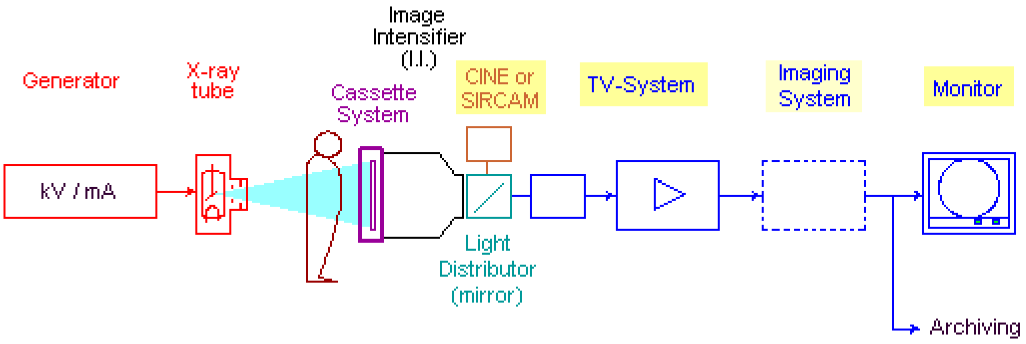
With Image Intensifier technique the following radiation modes are possible:

- **Fluoroscopy (Fluoro):**
  This is continuous or pulsed radiation at a relative low dose rate (intensity) for orientation, interventions or to see dynamic processes.
  Because of the low dose rate and low tube load, long fluoro sequences (appr. 20 min.) are possible.

.

The X-ray Imaging Chain

Image Intensifier (I.I.), TV-system, Monitor:



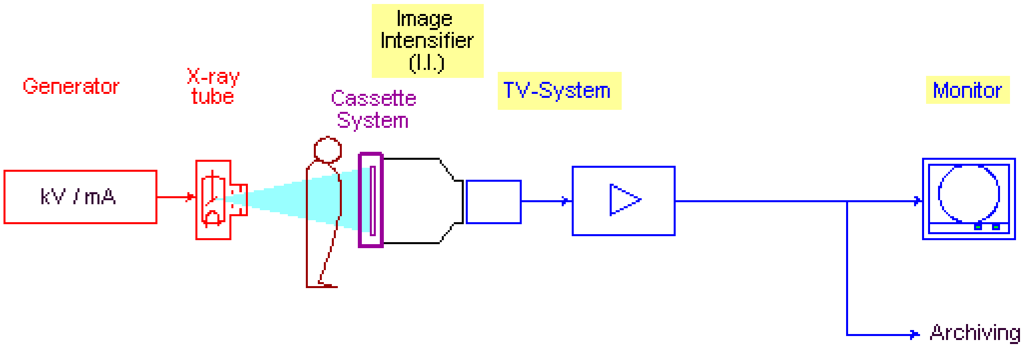
- **Indirect Technique:**
  The radiographs received from the Image Intensifier are recorded on

Cine or Sircam Cameras. The TV-system is simply used for monitoring.
Today, these systems are being replaced by DFR-technique (Digital Fluoro Radiography).
The transmission of the light to Cine or Sircam Camera and to the TV-System
is done with the aid of a *Light Distributor*.

- **DFR (Digital Fluoro Radiograhy):**
  A combination of Image Intensifier, TV chain **and Imaging System** is capable of "digital fluoroscopy" and "digital radiography". Meaning, the radiographs are stored on hard disk instead of film.

.

Image Intensifier (I.I.), TV-system, Monitor:

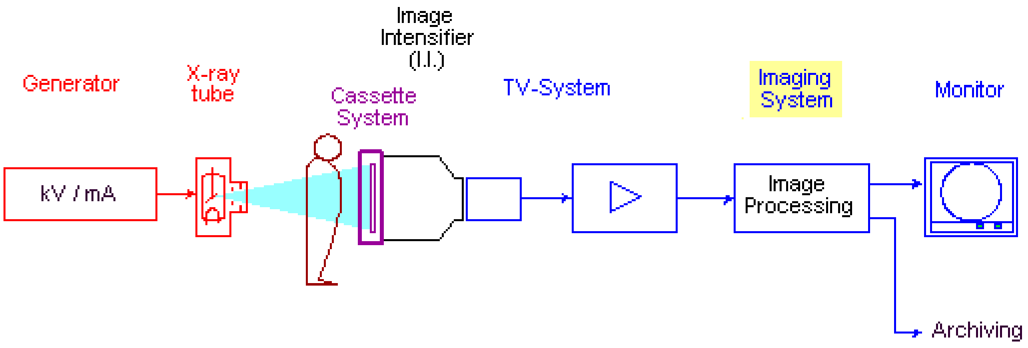


The main differences of indirect technique and DFR to fluoroscopy are:
+ Short exposure times (<1.0s) for avoiding blurring due to movement.
+ Relatively high dose level for decreasing *quantum noise.*
- High tube load calls for brakes between the individual exposures letting the anode cool down.

Conclusion:
The fluoroscopy mode is mainly used for positioning and interventions,
the indirect technique and DFR modes for diagnosis.

.

Imaging System:



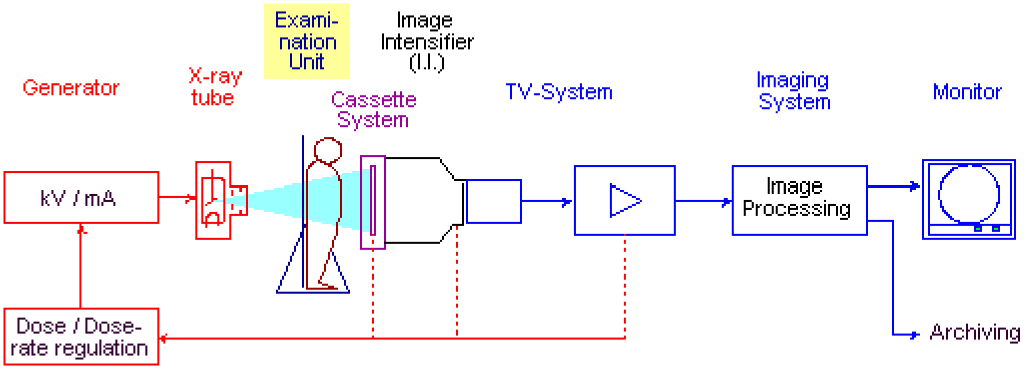
In our high end systems an **Imaging System** is integrated for digital fluoroscopy and digital radiography. Imaging systems enable :

- Pulsed radiation (also possible with Cine or Sircam Cameras)
- New examination modes, e.g. *Digital Subtraction Angiography* (DSA)
- Image manipulations during the real time examination (Acquisition) or afterwards (Postprocessing). Image manipulations are, for example, edge enhancement, zooming and windowing (digital brightness and contrast control).
- Archiving on Digital Hardcopy Camera (Laser Cameras) and CD-ROM

- Transfer via a hospital`s network (SIENET) for archiving or postprocessing on other imaging systems.

.

Examination Unit :



The **Examination Unit** carries and aligns X-ray tube assembly, Cassette System, Image Intensifier and patient.

It comprises all functions concerning the spatial movements of parts of an X-ray system.

end of chapter "Imaging Chain"

.

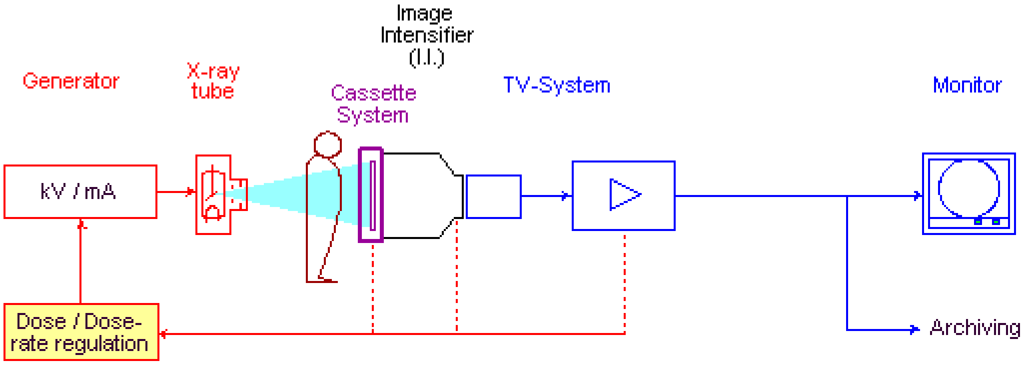
.

.

Introduction

Dose/Dose Rate Regulation

1/4



The radiation intensity is designated as dose rate (intensity per time), the amount of X-ray quanta per exposure as dose.
For good image quality a certain amount of dose or dose rate is required.
If, for example, the intensity or the energy of the X-rays is too little, the body cannot be penetrated, and the image is underexposed.

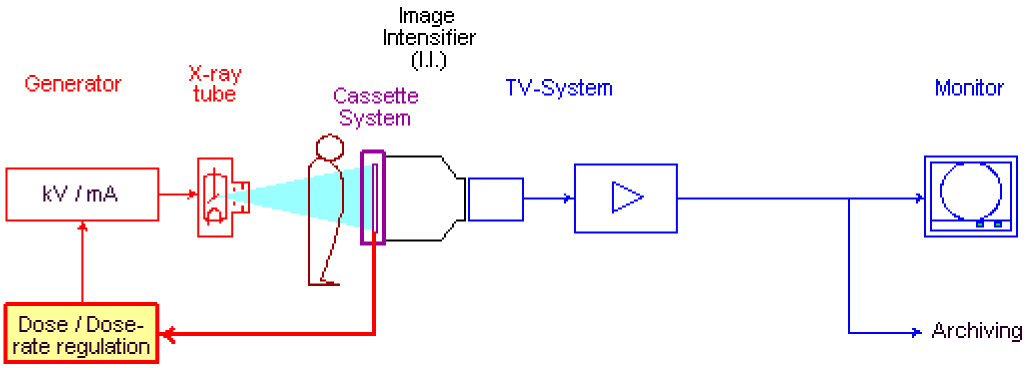
Our X-ray systems have circuits regulating dose or dose rate.
This ensures that, independent on the object's properties, the contrast and brightness of the image displayed is nearly constant.

.

Introduction

Dose/Dose Rate Regulation

2/4

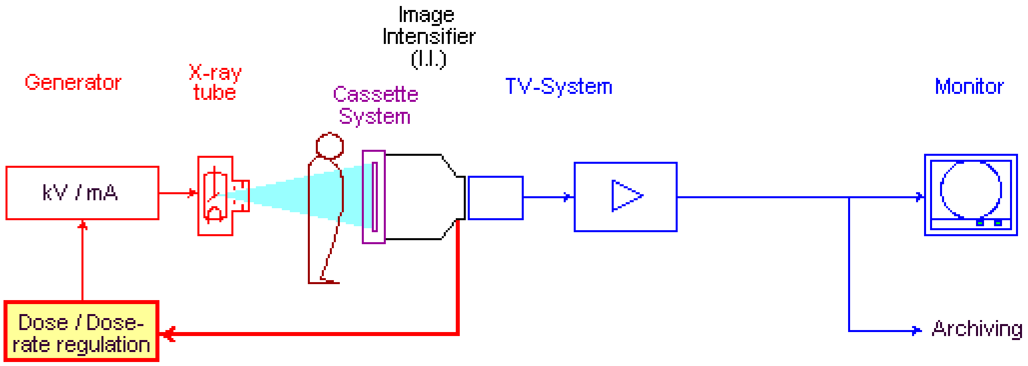


There are three possibilities of dose/doserate regulation:

1. **Automatic exposure control with ionization chamber for direct technique.**
   The automatic exposure control terminates each exposure as soon as the film has been exposed for optimum density.
   The measurement of the radiation is performed with a ionization chamber which is located in the cassette system.

.

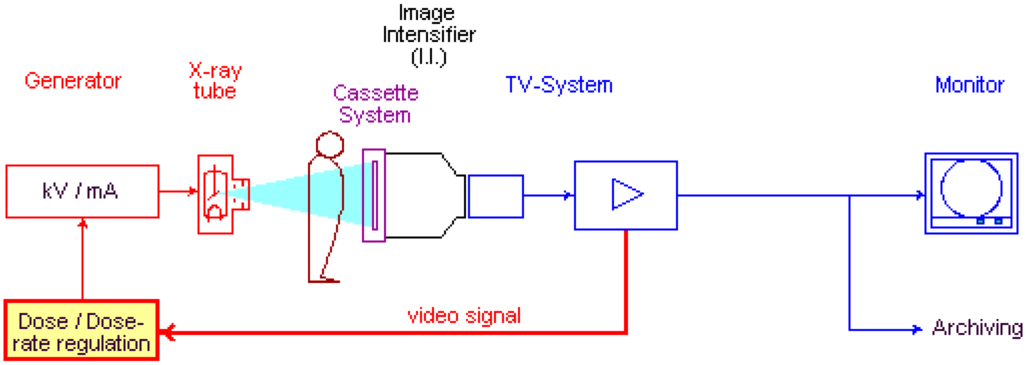
Dose/Dose Rate Regulation



2. **Automatic Dose Rate / Dose Regulation (ADR) for Image Intensifier technique with light measurement from the I.I. output**.
   Instead of measuring the dose, the light at the I.I. is measured by a *photo multiplie*r or a photo diode array.
   Thus a given light level represents a certain dose rate.
   This is the most common method of dose / dose rate regulation in our systems.

.

Dose/Dose Rate Regulation



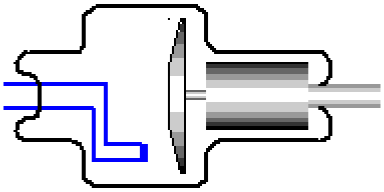
3. **Automatic Dose Rate Regulation (ADR) for simple fluoroscopy units**

   Regulation takes place by measuring the video signal (B-signal) from the TV-system.

End of "Dose Regulation"

Radiation Generation

The X-Ray Tube

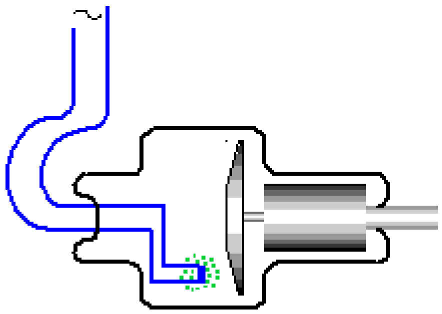


This is a typical X-ray tube as used in diagnostic systems.

Inside the **glass envelope**, it features a rotating **tungsten anode** and, opposite to it, the **cathode filament**.

As with vacuum tubes in general, a perfect **vacuum** is crucial to the tube`s function.

The Thermionic Cathode



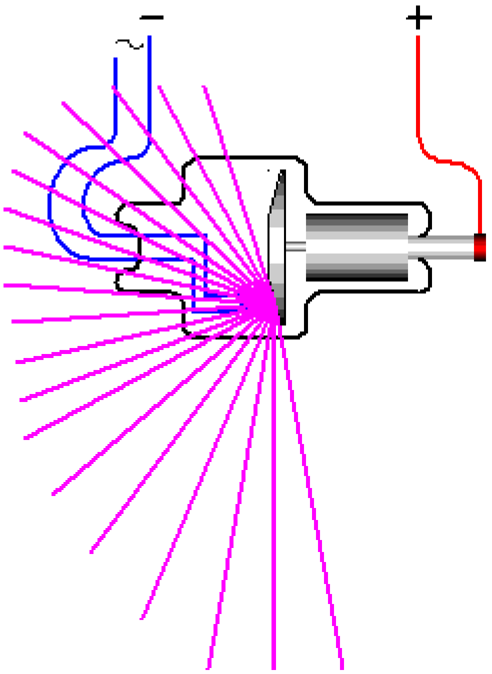
The **free electrons** required to produce radiation are emitted by heating-up the filament.

The filament is made from tungsten which allows for extreme temperatures without vaporizing easily. The amount of electrons emitted is a direct function of the **filament temperature**.

The temperature is controlled by the **filament current** (2A ... 4A) .

There is, however, a significant delay in temperature response to the controlling current. Therefore, when not radiating, the filament is always kept on a **standby** temperature just below the point of emitting electrons.
And shortly before radiation, the filament temperature is boosted up the value desired. This procedure is called "**preparation**".

High-Voltage



When applying high-voltage (40kV ... 150kV), the electrons emitted by the cathode are accelerated towards the anode. They are "charged" with **kinetic energy**.

This energy is released when the electrons interact with the tungsten atoms of the anode. Slamming into the anode about 99% of their kinetic energy is converted into **heat**, and only 1% is **X-rays**, or, more properly speaking, **bremsstrahlung** radiation.

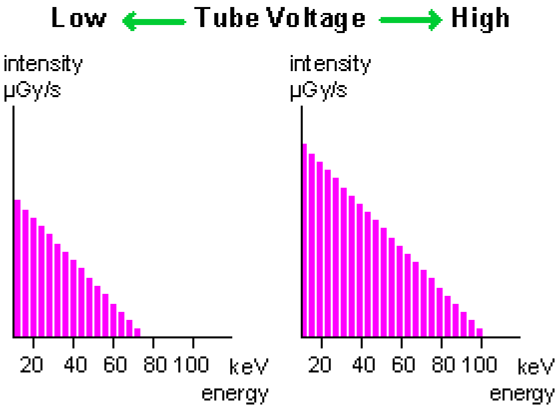
The german word "bremsstrahlung" depicts the nature of this kind of radiation: The electrons are stopped "bremsen" to produce radiation "strahlung".

The radiation diverges form the point of interaction, the **focal spot**, as shown.

End of the paragraph "Radiation Generation"

.

Controlling the Radiation Energy



The **tube voltage** required to produce radiation is stated as **kV** while the various energies of the **bremsstrahlung** spectrum are stated as **keV**.

Annotation
The **measurement** of **radiation intensity** is based on the ability of X-rays to ionize air, that is to make the air inside a measurement chamber electrically conductive providing a dose rate proportional current for measurement..

The Effect of Tube Voltage

The nature of **bremsstrahlung** radiation is to provide the complete **spectrum** of X-ray energies up to the value determined by the tube voltage (e.g. 70kV, left or 100kV, right image). All electrons are accellerated equally, and possess the same kinetic energy. The key, however, is how they interact with the anode material:

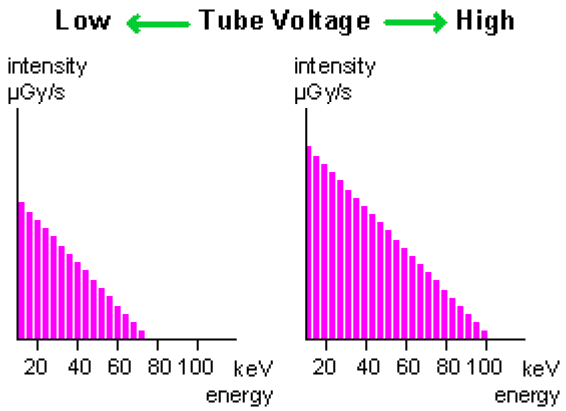
- If an electron passes close by an atom`s kernel, it gives off all its energy in a single event, and we get radiation of maximum possible energy, e.g. 100 **k**ilo **e**lectron **V**olts (keV). This is a rare event, and we get very little intensity of this energy.
- If an electron flies through the vast space between the atoms and interacts only in deeper layers, heat is all we get. This is more likely to happen, and thus we get 99% of heat. This part of the

The unit for dose rate is Gray/s (Gy/s), and the unit for dose is Gy (Gy).

spectrum isn't shown on the graphs.

- If an electron gives off only part of its energy when interacting in the first atomic layers, we get radiation of lower energies (keV) but increased intensity as depicted by the graphs.

Controlling the Radiation Energy



Te effect of Tube Voltage

In practice, one must always keep in mind that the **tube voltage** selected sets the **limit** of the energy spectrum only.

Bremsstrahlung radiation provides always a **spectrum** of **lower energies** with **increasing intensity**.

Given the same amount of electron flow, a **high tube voltage** grants a **higher X-ray output** as proven by the graphs.
Compare the 40keV and 60keV intensity in both diagrams. Equal electron flow is identified by identical slope of the spectrums.

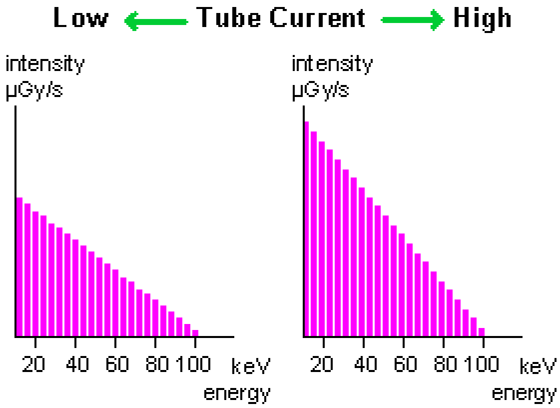
In the radiographic business, radiation is often called **soft** or **hard** according to their peak energy and their ability to penetrate soft tissue or hard bones.

- For the corret contrast of a radiograph, the kV selected must match the organ examined.

Controlling the Radiation Intensity

The effect of Tube Current

If one likes to keep the radiation quality, e.g. 100keV and alter the intensity only, the number of the electrons producing the radiation has to be altered.



The **amount of electrons** and the **intensity** of the radiation are proportionally related.

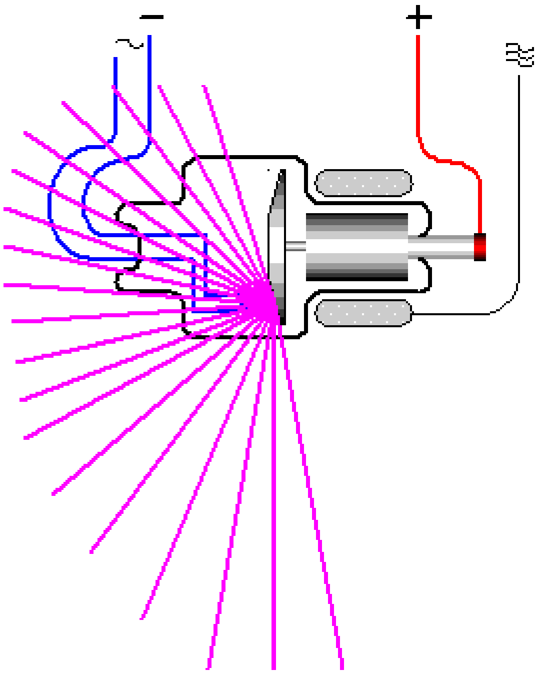
Technically, the electron flow is what we call the **tube current** ($I_{R\ddot{o}}$). As learned above, the tube current is controlled by the **filament current** (I_H), heating up the filamet and giving off electrons.

- Examination wise, the tube current has to be adapted to the patient size. A thick patient requires more tube current than a slim one.

For production of radiation, the
- tube voltage (kV) determines its energy and the
- tube current (mA) determines its intensity.

End of the paragraph "Radiation Control"

Rotating Anode



The **target area** (focal spot), the electrons are slamming into, is **heated-up** rapidly. When exceeding a temperature of 3400°C, the tungsten starts melting, giving off gases which destroy the vacuum and lead to tube failure.

To prevent this, the heated-up target area is continuosly replaced by a cooled-down area, using a **rotating anode**. During one rotation, the heat sinks from the surface to deeper parts of the anode preparing the surface for a new onslaught of electrons.

Electrically, the anode is an asynchronous motor operated by the **Anode Starter** device.

Anode Rotation

Focal Track

The image shows the anode of a modern X-ray tube.

Due to the continuous heating-up and cooling-down of the focal spot, the anode surface becomes rough during use. So, the focal track can be identified against the shiny background.

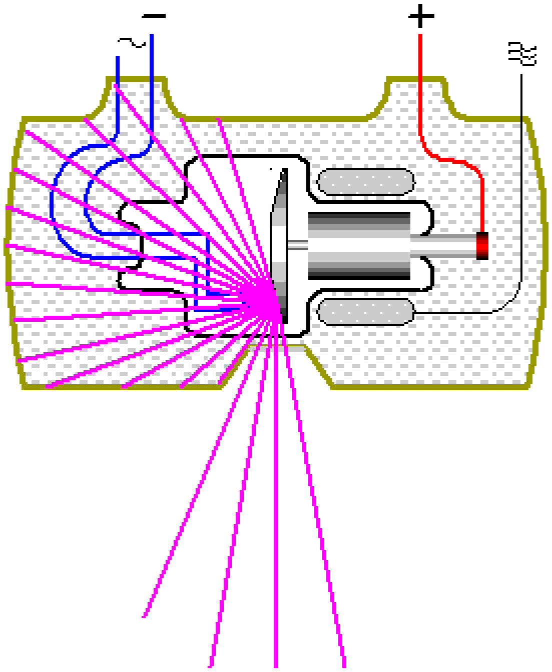
The temperature increase inside the focal spot area also effects local expansion of the metal resulting in mechanical stress which may lead to the anode splitting up. The radial slots in the anode are intended to relief this stress.

Underneath the metal part of the anode, a carbon layer is seen, intended to increase the thermal capacity of the anode.

End of the paragraph "Anode Rotation"

Tube Assembly

The Tube Housing



Operating an X-ray tube is rather dangerous:

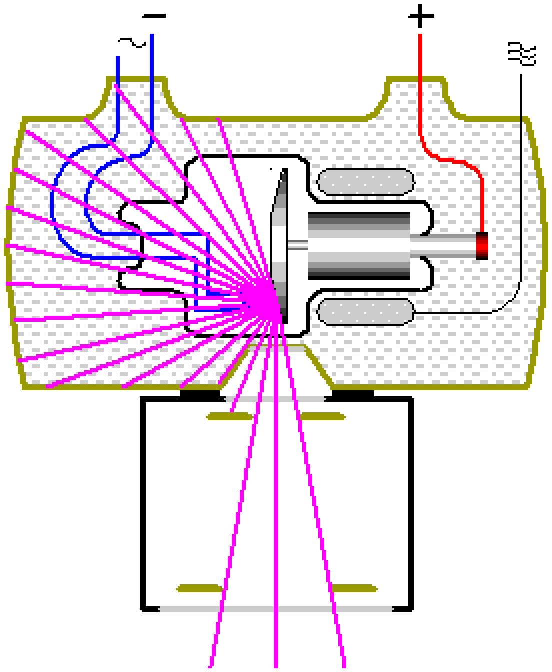
1. The **ionizing X-rays** are emitted all over the place.
2. **High voltage**, up to 150kV, is applied.

For safe handling, the X-ray tube is placed in a housing lined with lead to absorb the radiation. Because of weight restrictions, the lead shielding cannot be perfect. According to the standards the **leakage radiation** must not overpass 1mGy/h at maximum operating conditions.

For insulation of the high voltage, the tube housing is filled with **insulating oil**. Additionly, the oil serves as a heat sink.

The **useful radiation beam** leaves the tube housing via the **radiation outlet**. Here, you see a cone for narrowing the oil layer attenuating the useful radiation. The outlet window is made from radiolucent material.

The Collimator



When it comes to **radiation protection**, the **collimater** plays an important role:

It is used to narrow the radiation field to a size needed for the examination at hand. For this it is equipped with sets of lead plates providing either a round or a square-shaped radiation field.

These **collimating plates** are either motorized or operated manually. In automatic mode, the image-receiver size is detected, and the collimating plates are operated accordingly.

Memorize following basic rule of radiation protection:

- **The radiation field must never be larger than the size of the image receiver!**

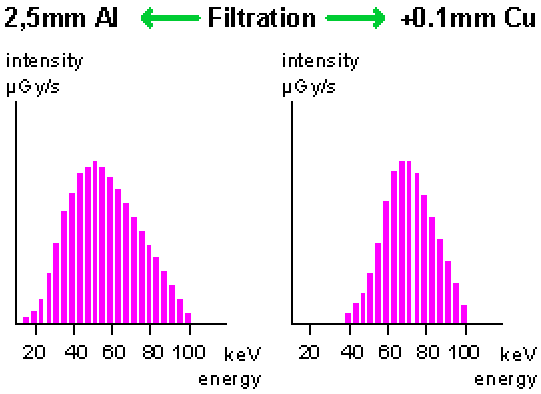
End of the paragraph "Tube Assembly"

The Use of Filters

All the radiation **absorbed inside the body**, without having a chance of penetration and forming an image, is **harmful** radiation only!

In order to make the radiation "less harmful", filters are used. The soft radiation is absorbed inside the filter while the hard radiation passes only slightly effected.

As seen in the left graph, Aluminum attenuates the very soft radiation drastically. The radiation



spectrum shown is the result of 100kV tube voltage in combination with a filtration equivalent to **2.5mm Aluminum**.
According to international regulations, this is the **minimum amount of filtration** and must be guaranteed by the tube assembly.

Additional **filtration with copper** can be employed to make the radiation "safer". Notice the shift of the peak intensity to higher keV by absorbing the lower energies. So, the **radiation quality is hardened-up** by increasing the amount of filtration.

.

Conclusion

When interacting with body cells, X-rays are harmfull!

In a very concentratad form, you have learned the physical and technical basics of X-rays as required in our trade and needed to understand the following chapters.

More, and detailed information you will find later in the chapter dealing with the X-ray tube.

End of the Chapter X-Ray Physics

.

.

Principle Diagram of an X-ray System

Introduction For a field service engineer dealing with a wide selection of various X-ray equipment, it is helpful to understand the **basic functionality of an X-ray system**.
One will see quickly that - despite of the differences in application, design and technology - the functions performed are almost the same. That applies even more to modern systems where nearly all the functionality means software and is hidden from the eyes of the service engineer.

Hence, a sound base on these fundamentals guarantees survival.

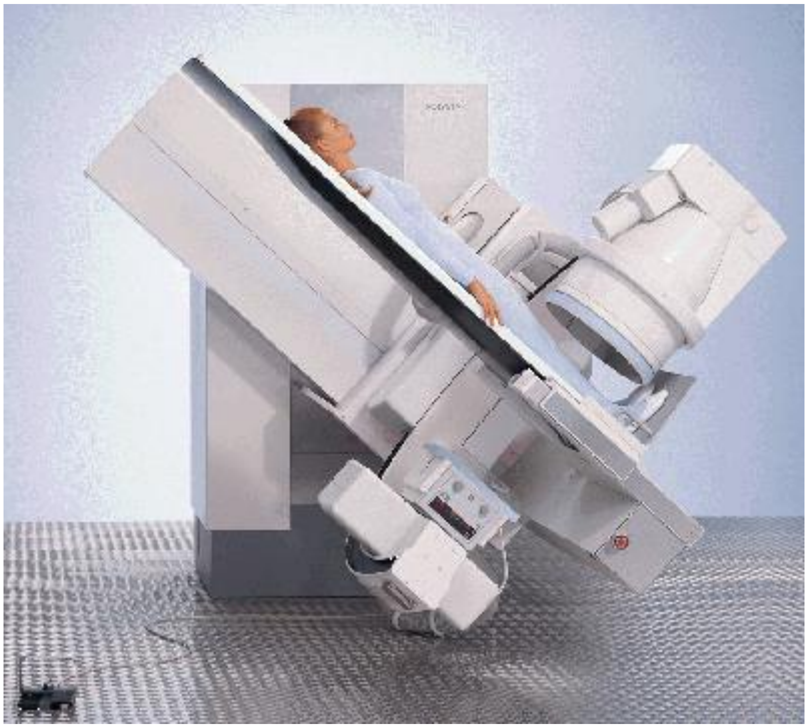
Block diagram

With most of the system's functionality being software, there is still a lot of hardware which has to be connected properly forming an X-ray system. While the original diagrams deal with the subsystems only, the block diagram introduced here **deals with the complete system**. Despite of being a rather simple diagram, all modern and complex X-ray systems evolve from this concept.

Functional units

While a block diagram reflects the hardware mainly, the functionality of a system describes the interaction of several components at a time.
Knowing the functionality, knowing **what a system is supposed to do** is the base for trouble shooting successfully.

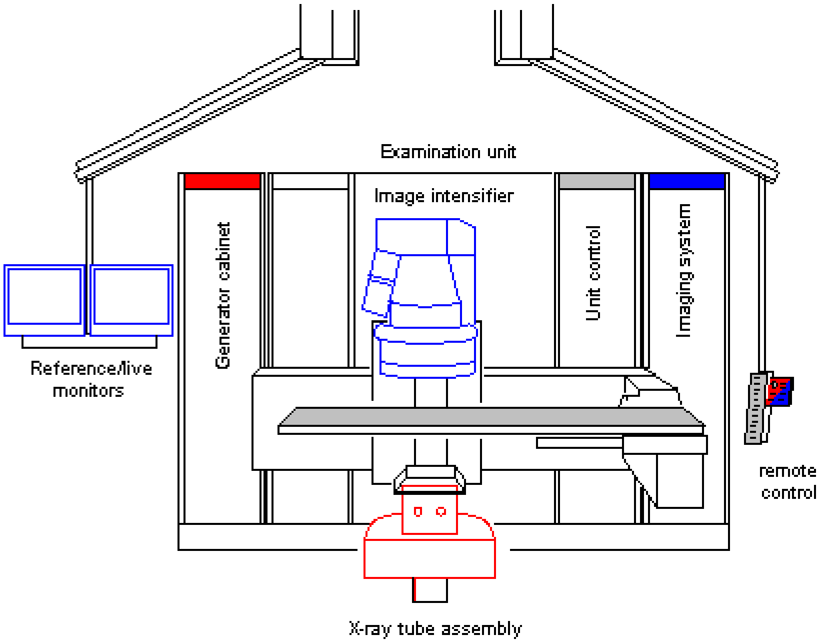
The POLYSTAR System



Talking about the POLYSTAR system, we refer to the **examination unit** POLYSTAR because it is the most obvious part of the system. It handles patient support and X-ray beam alignment and is operated by the radiologist.

However, it takes more than just an examination unit to make up an X-ray system.

An X-ray System



The drawing shows the **sub-systems** making up an installation.

The **generator** cabinet (red) houses the controls to operate the x-ray tube.

Inside the **unit control** (grey), all the drive controls of the examination unit are found.

The **imaging system** cabinet (blue) holds all thesubsystems required for imaging.

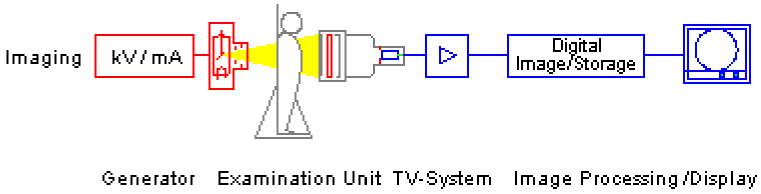
The **remote control** is able to communicate with all parts of the system.

To find out how it works, you have to work with the block diagram.

End of the chapter "Introduction"

.

The X-ray Imaging Chain



Generator and tube assembly:
Radiation of certain quality is generated and has to be collimated to a size fitting the organ examined.

Examination unit:
It carries and aligns all the three: X-ray tube assembly, image receiver and patient.

TV-System:

Image processing:
In most of the modern units, digital image processing is integrated. Processing means noise reduction, edge enhancement and image storage.
These features improve the ordinary fluoroscopy image significantly and they also contribute to dose saving.
In exposure (radiographic) mode, digital imaging has the

Image display:
Monitors are used for both on-line and off-line evaluation while the output to a hard copy camera serves as a backup or hand-out.

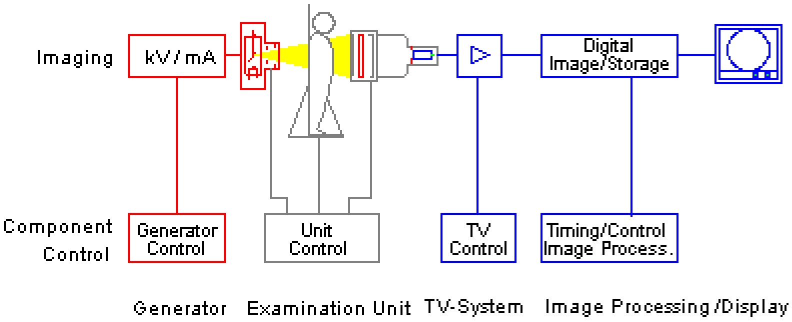
The image received from the image intensifier is processed for optimum image contrast.

capability to replace the ordinary screen-film radiographs.

.

Basic Functions **Block diagram** 2/6

Component Control, the Sub-Systems



Every component of the X-ray imaging chain has its own control stages. Together they form a **sub-system**:

- Generator
- Examination unit
- TV-system

- Image processing and display

These sub-systems are quite different in technology and the scope of functionality. We, therefore, differentiate between "low-end" and "high-end" systems.
A sub-system is capable of performing several tasks under its own responsibility. Every of these self contained tasks is defined as a functional unit.

A **functional unit** is identified by:

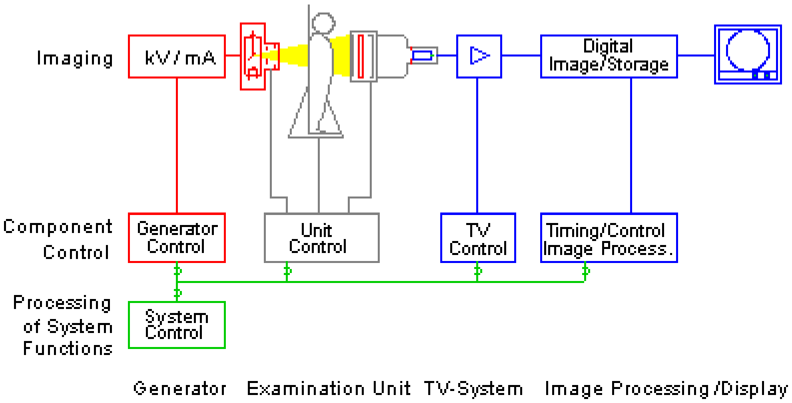
- Performing a task of complete functionality,
- being able to receive and report data concerning the task, and

- having full responsibility of the tasks safety. I.e. on recognizing a problem, an error routine is started.

.

Basic Functions **Block diagram** 3/6

Processing of system functions, the XCU



The individual sub-systems are linked together by a **local area network** (**XCS**) forming an X-ray system.

Thus, every sub-system of the installation is connected to the **system controller** (**XCU**).

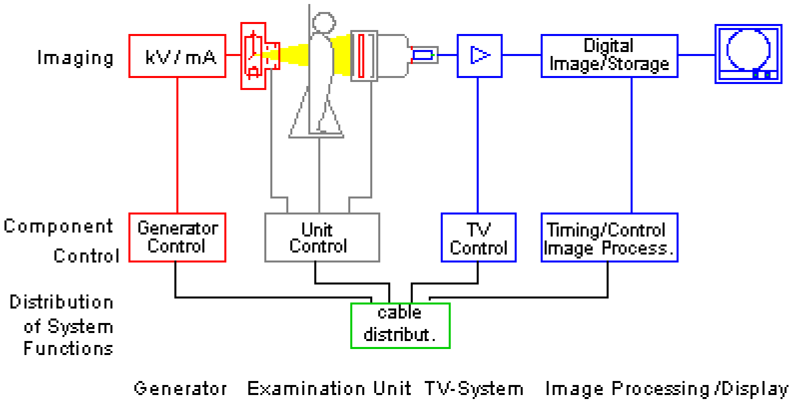
The system controller is a self-contained micro computer. In larger systems, it has its own hard disk drive and floppy disk drive.
On a logical level, there are always two-point connections between the system controller and the individual sub-system.

No direct communication between the sub-systems is possible. Hence, all the high-level **system functionality** is provided by the system controller only.

more info?

.

System Functions with Old Systems, kk-Cables



In the past - before the wide scale introduction of computers - the functionality was inherent to the sub-systems themselves. Communication between the individual components of a system was achieved by a set of standardized cables (kk-cables) running form the components to a system distribution cabinet.
By "programming" connections on terminals, system functions were distributed to the components involved.

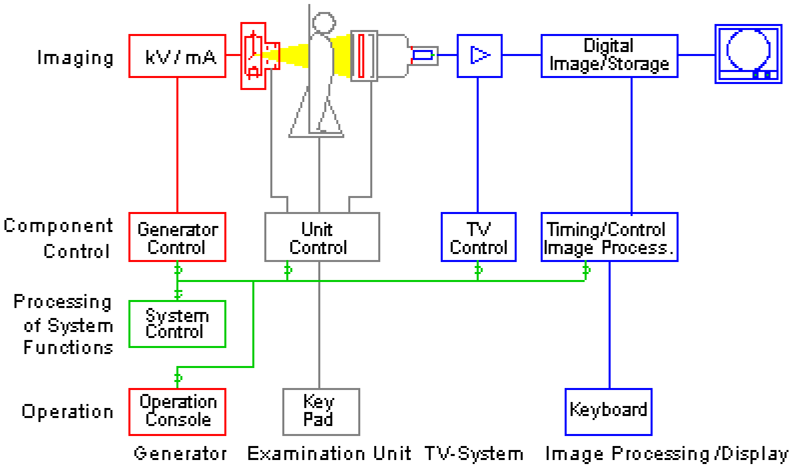
In the field you also may find "transitions" from old to new technology, where old type of equipment, having its own functionality, fits to a modern local area network by means of an interface. Here, in many cases the system functionality may be reduced.

exit info

.

System Operation

All operations concerning **system functions** are handled via the **local network** and the system controller. Therefore, they can be released from any input facility of the system.



Pure **unit based functions,** on the other hand, are dealt with **directly** between input device and unit control. The system controller is notified about these actions anyway and may inhibit the operation for safety reasons.

Input / output devices:

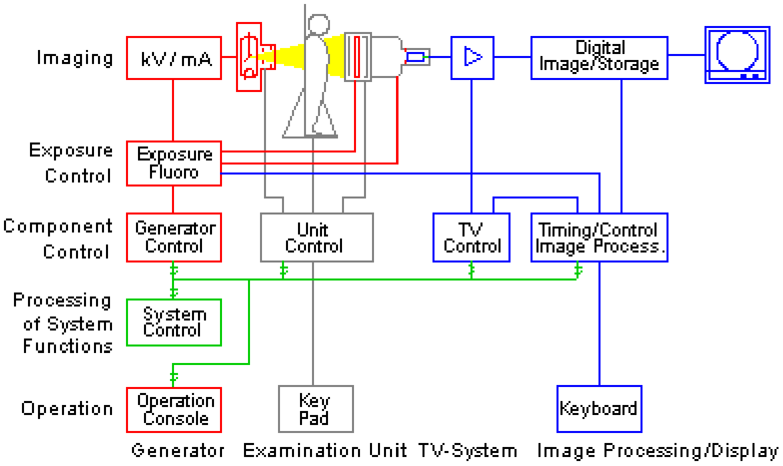
- The generator is operated via a touch screen console.
- Exposure and fluoroscopy is released by a foot switch or switches located at the examination unit.
- The unit control is either a remote desk or a table side control.

- The imaging system is operated via a keyboard while the output is seen on the monitor.

.

Exposure control, hardware timing

Normally, all the communication between sub-systems is routed via the system controller and the serial network.
This transmission, however, fails when precision timing is asked for.



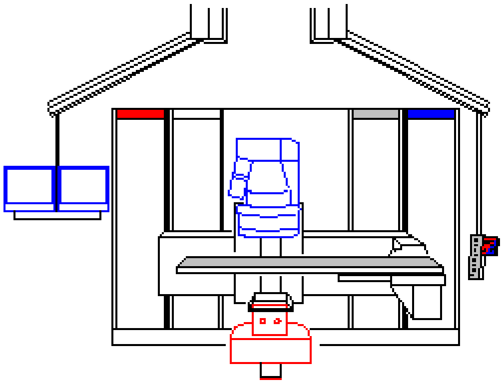
This is especially the case with **radiation control** in both fluoroscopic and exposure mode. Additionally, precise synchronization with the digital imaging system is required.

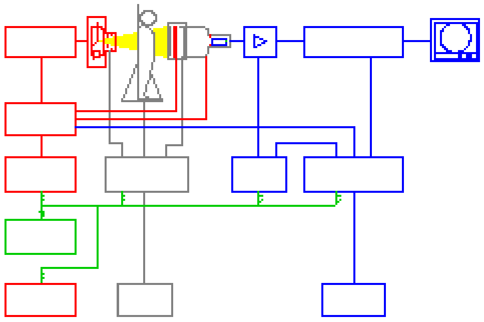
For **time critical signals**, direct connections are used bypassing the system controller. Theses are:

- The inputs to the dose (rate) regulating system, the IONTOMAT,
- and the synchronization between radiation release and image acquisition.

.

Block diagram





In this chapter, you have learned how the **sub-systems**

- **generator**,
- **examination unit** with tube assembly and image intensifier,
- **imaging system** and
- **system controller**

The left image shows how a POLYSTAR system looks like while the principle diagram on the right tells you how the components are connected hardware wise.

However, neither of these images is able to tell you what is **going on inside the system** when making fluoroscopy or doing radiographs.

are put together to form an **X-ray system**.

The **functionality of the system** is something that has to be learned and memorized.

End of the chapter "Block Diagram"

.

.

Basic Functions, Func. Unit **System Controller** 1/2

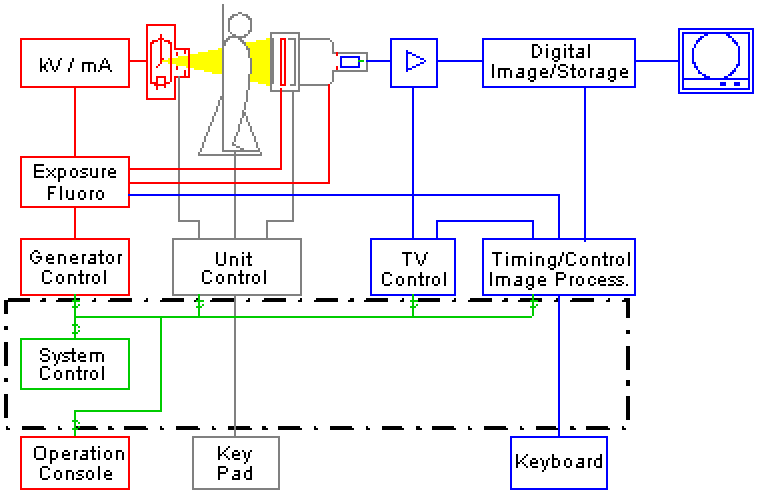
The system controller

All the high-level system functionality is provided by the software of the **XCU System Controller** (X-ray Control Unit).

Here, all component data are received, processed and commands issued to the components.

All vital system information is stored on the system´s hard disk drive.

Additionally, a central **service-PC** interface is provided allowing access to all subsystems connected.

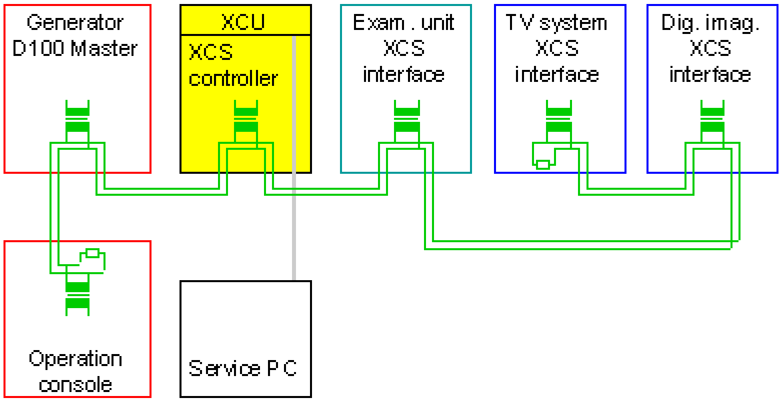


The XCS network (X-ray Communication System) is a serial local area network. Like a telephone system, it connects two partners at a time. Here, one of the partners is always the XCU. Communication takes place via transceiver (transmitter/receiver) and a shielded twisted pair cable. The transmission protocol and data integrity is also handled by the XCS.

.

Basic Functions, Func. Unit **System Controller** 2/2

Block Diagram of XCS Connections



Using transceivers, the XCS-network is electrically isolated from the individual subsystems. Looping through the signal on every board, all transceivers are switched in parallel providing common information to all partners.
For proper function, the network has to be terminated by a resistor at every end.
On the logic level, the XCS controller exchanges **telegrams** with one of the partners at a time only.

Additionally to the transceivers, the dedicated XCS interfaces contain unit specific **interpretation software**.
All partners have to report an **OK message** periodically, else they are removed from the system list, and the system functionality is reduced accordingly.
The **service PC** is switched through to the XCU directly and can thus be used to troubleshoot a faulty XCS system.

more info?

End of "System Controller"

.

Basic Functions, Func. Unit **System Controller** 1/3

The XCU tasks:

For better illustration, take the function fluoroscopy:

- Provision of initialization data to the functional unit.

According to the system configuration, dose rate and fluoro mode are selected. In the digital imaging system noise reduction and edge enhancement are set.

- Supervising the functionality of all units

After initialization and during operation, all units have to report their OK-status periodically. Else it is removed from the list and the system functionality is reduced.

- Central processing of operation inputs and outputs.

At fluoro request, the OK-status of all systems concerned is checked. In case of an open door, a message is displayed.
With fluoro release, the yellow radiation indication lamp is turned on.

exit info

.

Basic Functions, Func. Unit **System Controller** 2/3

The XCU tasks:

... during fluoroscopy:

• Provision of job parameters to the functional units by running internal tasks.	During fluoroscopy, the XCU is informed about any deviation in dose rate on the II input. It then calculates new values for kV and mA based on the "fluoro curve" the customer has selected and the load rating of the focal spot selected. Another internal task is updating the fluoro-time display continuously.
• Issuing jobs to the functional units.	The high voltage inverter is told to keep fluoro going and set new kV. The filament heating circuit also gets a new mA value.
• Evaluation of feedback from the units and initialization of error routines if needed.	If, after a lengthy fluoro session, the X-ray tube assembly´s temperature sensor may report excessive heat the XCU decides either to light up a warning light, or to terminate fluoroscopy.
• Control and synchronization of all tasks concerning several units.	Before starting fluoroscopy, the XCU has to: 1. set filament heating and tube voltage, 2. set the dose rate and TV iris in the exposure control, 3. set TV- and post processing parameters, 4. set the maximum radiation field size in the collimator control according to the II-format selected, 5. start the fluoro time display, and, 6. finally, activate radiation.

exit info

.

The XCU tasks:	**... during fluoroscopy:**
• Filing away of configuration data and system condition after power-off.	As mentioned above, all data concerning the configuration of all the sub-systems is stored on the system controllers hard disc. This also includes parameters adjusted in individual components. If, for instance, the C-MOS RAM of a component controller is corrupted, a correct set of data is down-loaded from the XCU.
• Provision of a central service interface.	During operation, the system reports all warnings and errors encountered to an error-log file. Every entry is tagged with the unit code, time and date and is, therefore, the base for trouble shooting. Via the service-PC interface, access to the various sub systems is provided which is used for trouble shooting, adjustments and software upgrades.

exit info

End of more info "System Controller"

.

Basic Functions, Func. Unit **System Operation** 1/3

The Examination

e.g. SIRESKOP SX

It normally takes three steps for an X-ray examination:

First, the **patient** is positioned on the table and contrast medium is administered.

Secondly, the flow of the contrast medium is followed using **fluoroscopy**, and at certain passages, **exposures** are taken.

Third, the **radiographs** are evaluated.

Except for the evaluation, all this is controlled by the radiologist using table-side control elements.

.

Basic Functions, Func. Unit **System Operation** 2/3

The Evaluation

e.g. FLUOROSPOT

The resulting **radiographs are evaluated** in the control-room, and patient data are added to the images.

In practice, the **patient data** are entered prior to the evaluation, along with the selection of the fluoroscopy mode, the **exposure data** and post-processing **parameters**.

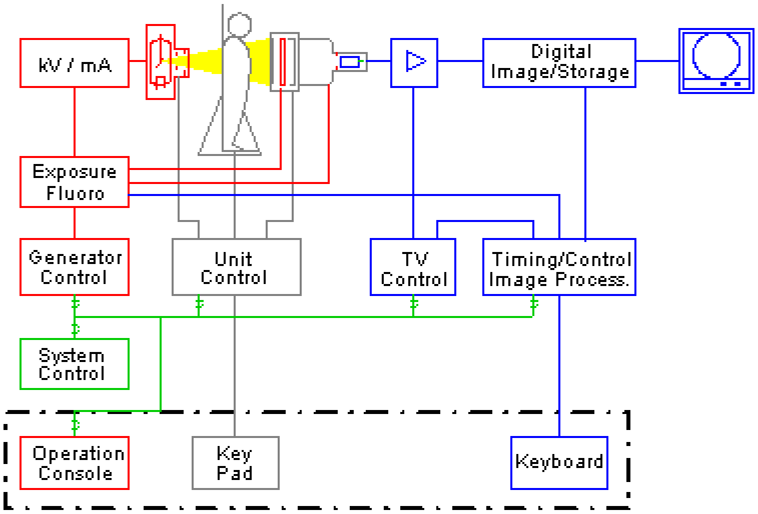
Standard sets of examination data are stored as **Organ Programs** and can be called up from the generator console or from the table-side control.

Functional Unit
System Operation

This functional unit processes all **user inputs** to the system as well as the **system outputs** to the user.
It comprises:

- Control levers and buttons as well as displays of digital or analog nature to control the **examination unit**. They may be split up in several individual operating consoles or combined in a single one.

- The **generator** operating console can either be composed of individual keys and displays or be a touch screen device.



- The **imaging system**, normally, is operated via keyboard and mouse using the monitor as output for both, images and text.
  The imaging system doesn't only provide on-line and off-line processing parameters, it also handles the patient data.

more info?

End of "System Operation"

The XCU tasks:	**... during fluoroscopy:**
The user commands are received by the input device and transferred to the input processor (hardware).	In our example, fluoroscopy is released by a button on the control handle.
The input processor converts them into a function code and hands them over to the XCS interface which in turn sends them via XCS-net to the XCU.	The command is received by the unit's processor board, handed over to the communication board, converted into an XCS- telegram and put on the network.
Here, the actions required are released. One of which is to update the display.	When fluoro is released, one of the jobs to do is to update the display on the generator console.

The message is sent via XCS.	For this, the XCU issues a command containing the display parameters: kV, mA and fluoro time.
• The information is processed by the display data management, handed over to the display control and is finally displayed (hardware).	The message is decoded by the control console processor and the display is updated.

exit info *End of info "System Operation"*

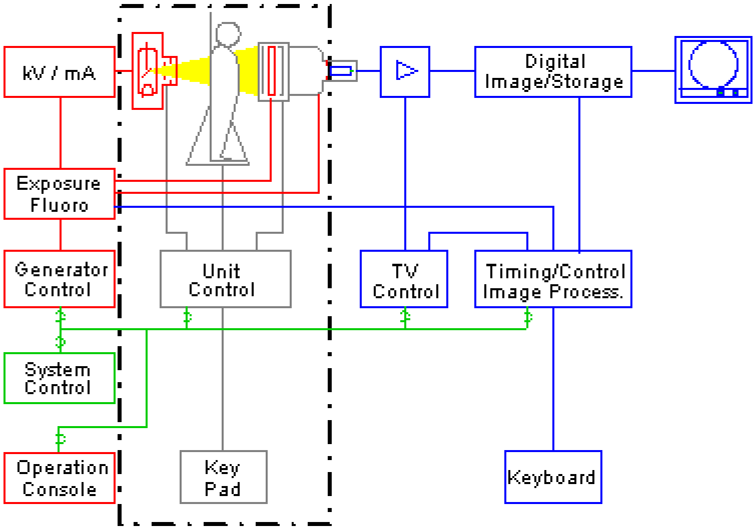
.

Basic Functions, Func. Unit **Examination Unit** 1/3

Examination unit
(unit geometry)

This functional unit comprises all functions concerning the spatial movements of parts of an X-ray system.

The individual components are designed with intrinsic safety features; i.e. on loss of communication every movement has to be stopped immediately.



The **motion control** concerns following components:

- Movement of X-rax tube unit
- Movement of patient support
- Movement of imaging system (spotfilm device)

- Combined movements

.

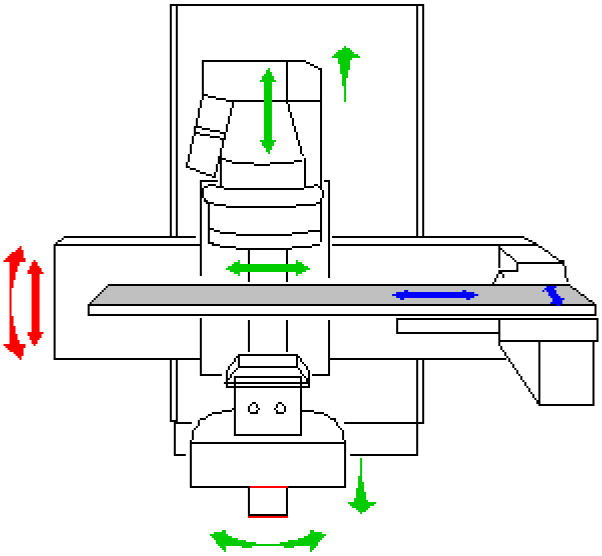
Basic Functions, Func. Unit **Examination Unit** 2/3

Four basic **sub functions** are defined and demonstrated best with the POLYSTAR:

1. Motion control

- **System**
  ... height
  ... tilt
- **C-arm**
  ... rotation
  ... angulation
  ... II in/out
  ... longitudinal
- **Table top**
  ... longitudinal
  ... transverse

2. Collision calculation
Knowing the actual position of any movement at any time, the collision protection avoids collision between the components themselves, between components and wall, floor or ceiling and with the patient resting on the table top.



3. The additional **position report** serves for a correct display on the consoles.

4. Measurement of distance and angle

- System tilt
- C-arm angulation and rotation

- Source image distance (SID)

.

Basic Functions, Func. Unit **Examination Unit** 3/3

The **motion modes** are divided in four groups and illustrated with the SIRESKOP:

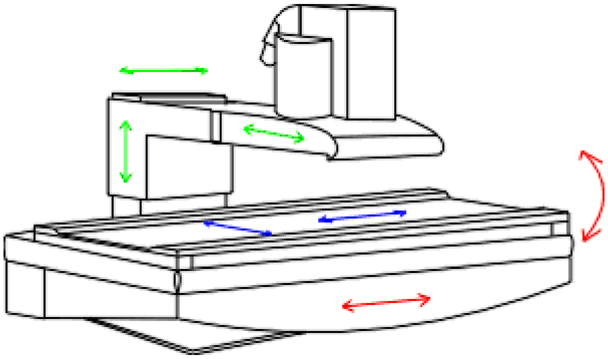
1. Manual movement without motorized support and report.

- Spotfilm device transverse
- Compression

2. Manual movement **with brake control**

- Spotfilm device transverse, centered to the table top

3. Manual motion **with motorized support**



SIRESKOP movements:

- **Spotfilm device**
  transverse, longitudinal and compression
- **Table top**

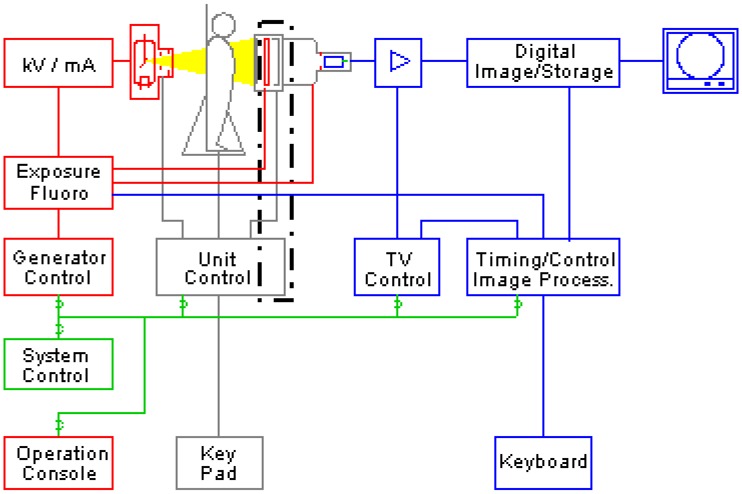
- Spotfilm device longitudinal	transverse and longitudinal
4. Motorized positioning with position report	- **System** tilt (always combined with longitudinal)
- All other movements	

▲ *End of "Examination Unit"*

.

Basic Functions, Func. Unit **Cassette System** 1/4

Cassette System



The functional unit "cassette system" comprises all functions required to detect, identify and position a film-screen cassette including subdivisions.

C-arm units, providing DFR-technique only, don't have a cassette system.

Basically there are two, technically different cassette systems:

Bucky tray, exposure units
Here, the cassette is placed on the tray and manually pushed into position by the radiographer.
The functional unit detects presence and size of the cassette. The cassette may be exposed and is than removed manually.

Spotfilm device, fluoroscopy units
The cassette is inserted manually into the cassette slot. All subsequent movements are motorized motions.
The cassette size is identified and brought into parking position.
The film can either be exposed in one single exposure or in a series of subdivisions. For this, the individual subdivisions have to be centered to the radiation field before exposure. After exposure, the cassette is moved into loading position where it can be removed by the radiographer.

▼

.

Basic Functions, Func. Unit **Cassette System** 2/4

Cassette identification

- Detection of cassette insertion or removal	This function is not always implemented. It is intended to inform the XCU about a cassette change to prevent double exposure. Else, every cassette is recognized as fresh and unexposed.

Format identification	During insertion or transport of a cassette, height and width are measured to identify type and orientation.
Validity check	Due to mechanical shortcomings, not all the formats can be accepted. Mixture of inch- and cm-cassettes or specific subdivisions.
Detection of cassette identification	Cassettes may be identified by means of a bar code. If the spotfilm device is able to detect

.

Basic Functions, Func. Unit	**Cassette System**	3/4

Motorized cassette positioning

Movement from loading to parking position	With some units there are two loading positions, a left-loading and a right-loading position. Standard is left-loading only. In series mode, used for dynamic studies of the contrast medium flow, the cassette is moved directly from one exposure position to the next one. Important features of the cassette drive system are: 1. The time required to travel from parking to exposure position 2. Positioning time in series 3. Precision of positioning
Covering the Image Intensifier	During movement of the cassette carriage as well as in loading position the image intensifier is partly covered. The XCU has to be notified about this situation and fluoroscopy is blocked accordingly.

.

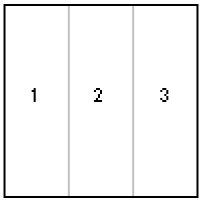
Basic Functions, Func. Unit	**Cassette System**	4/4

Determination of subdivisions

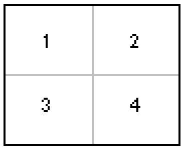
(Spotfilm device only)

Subdividing the film for several exposures is used when

- serial mode is selected and the exposures take place in rapid



3 x 1



2 x 2

succession

- or, when the area examined is so small that several radiographs fit on one film.

According to the cassette inserted, its orientation and the mechanical abilities of the spotfilm device, the valid subdivisions are determined.

In order to get correctly exposed subdivisions on the film, for every individual subdivision both the field size and the position of the cassette carriage are calculated.

Subdivision formats

The Subdivision is defined by m x n; where m is the number of subdivisions in width and n the number of subdivisions in height with respect to the patient.
Additionally, the subdivisions are counted from left to right and top to bottom. These numbers are used by the XCU to tell the cassette carriage drive which field to position for exposure.

more info?

End of "Cassette System"

.

Basic Functions, Func. Unit **Cassette System** 1/1

Functionality of the XCU

Exposure counter, management of subdivision positions	Based on the sub formats possible with the cassette loaded, the XCU calculates the following: - Number of exposures possible with the format selected - Unexposed sub divisions during an exposure sequence - Mixture of subdivisions possible when different formats are selected on the same cassette.
Collimator control	Adjustment of correct radiation field size, i.e. controlling of tube-side and film-side collimating in full size as well as in sub divisions.
Control of Exposure sequence	Synchronization of radiation, collimator control and cassette movement in single- and series-mode.
Management of system operation	Evaluation of operation commands as selection of subdivisions, single/series exposure release. Provision of operation data as subdivisions possible, sub formats, positions and number of exposures.
Synchronization of fluoroscopy release	Besides other events, the XCU keeps track of following conditions regarding the cassette system: - Reports of fluoroscopy blocking respectively fluoroscopy release condition of the cassette system. - Cassette movement from loading to parking position and vice versa.

exit info

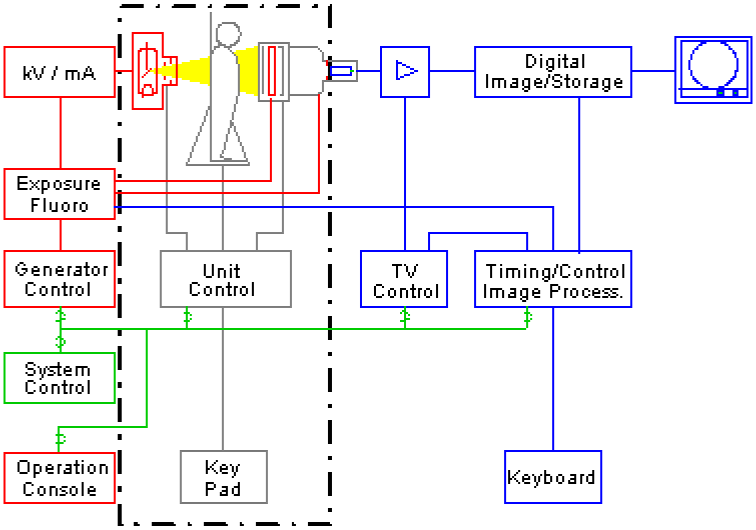
End of more info "Cassette System"

.

Examination unit
(unit geometry)

This functional unit comprises all functions concerning the spatial movements of parts of an X-ray system.

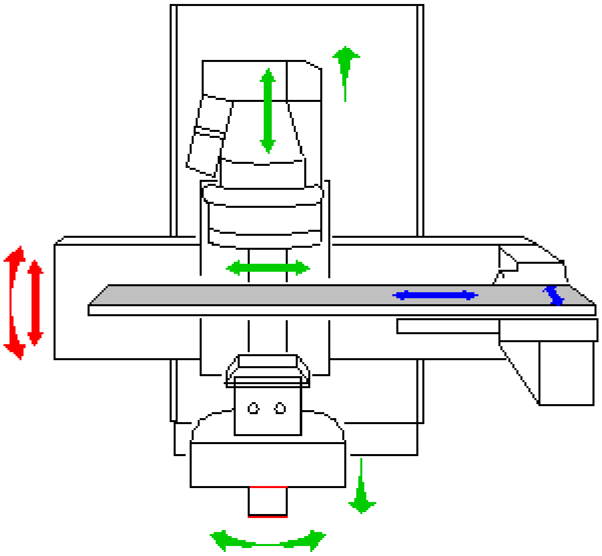
The individual components are designed with intrinsic safety features; i.e. on loss of communication every movement has to be stopped immediately.



The **motion control** concerns following components:

- Movement of X-rax tube unit
- Movement of patient support
- Movement of imaging system (spotfilm device)
- Combined movements

Four basic **sub functions** are defined and demonstrated best with the POLYSTAR:



1. Motion control

- **System**
  ... height
  ... tilt
- **C-arm**
  ... rotation
  ... angulation
  ... II in/out
  ... longitudinal
- **Table top**
  ... longitudinal
  ... transverse

2. Collision calculation
Knowing the actual position of any movement at any time, the collision protection avoids

3. The additional **position report** serves for a correct display on the consoles.

collision between the components themselves, between components and wall, floor or ceiling and with the patient resting on the table top.

4. Measurement of distance and angle

- System tilt
- C-arm angulation and rotation
- Source image distance (SID)

.

The **motion modes** are divided in four groups and illustrated with the SIRESKOP:

1. Manual movement without motorized support and report.

- Spotfilm device transverse
- Compression

2. Manual movement **with brake control**

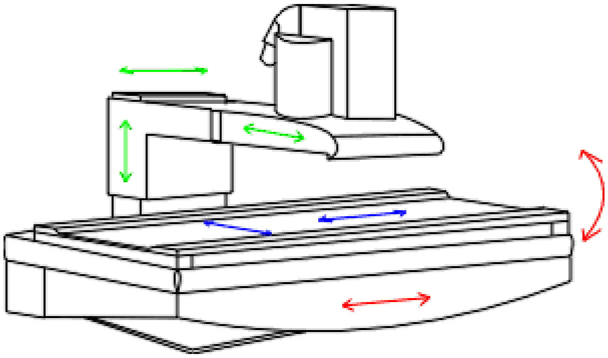
- Spotfilm device transverse, centered to the table top

3. Manual motion **with motorized support**

- Spotfilm device longitudinal

4. Motorized positioning with position report

- All other movements



SIRESKOP movements:

- **Spotfilm device**
  transverse, longitudinal and compression
- **Table top**
  transverse and longitudinal
- **System**
  tilt (always combined with longitudinal)

End of "Examination Unit"

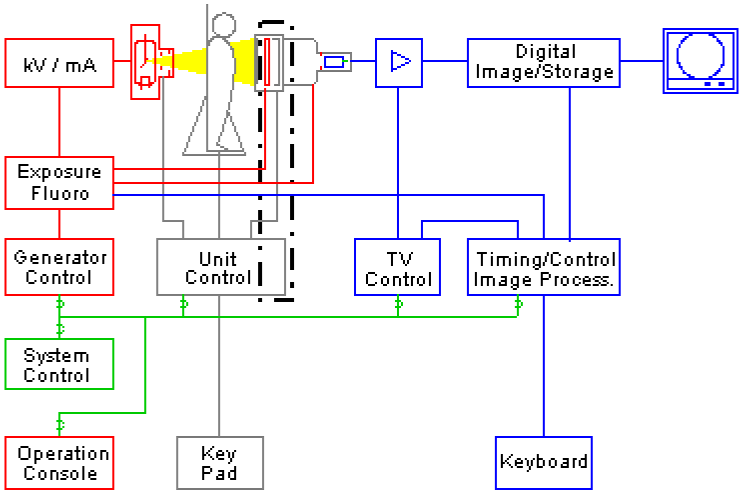
.

more info? ...next ...back

.

.

Cassette System



The functional unit "cassette system" comprises all functions required to detect, identify and position a film-screen cassette including subdivisions.

C-arm units, providing DFR-technique only, don't have a cassette system.

Basically there are two, technically different cassette systems:

Bucky tray, exposure units
Here, the cassette is placed on the tray and manually pushed into position by the radiographer.
The functional unit detects presence and size of the cassette. The cassette may be exposed and is than removed manually.

Spotfilm device, fluoroscopy units
The cassette is inserted manually into the cassette slot. All subsequent movements are motorized motions.
The cassette size is identified and brought into parking position.
The film can either be exposed in one single exposure or in a series of subdivisions. For this, the individual subdivisions have to be centered to the radiation field before exposure. After exposure, the cassette is moved into loading position where it can be removed by the radiographer.

.

Cassette identification

- Detection of cassette insertion or removal

This function is not always implemented. It is intended to inform the XCU about a cassette change to prevent double

	exposure. Else, every cassette is recognized as fresh and unexposed.
• Format identification	During insertion or transport of a cassette, height and width are measured to identify type and orientation.
• Validity check	Due to mechanical shortcomings, not all the formats can be accepted. Mixture of inch- and cm-cassettes or specific subdivisions.
• Detection of cassette identification	Cassettes may be identified by means of a bar code. If the spotfilm device is able to detect

.

Basic Functions, Func. Unit **Cassette System** 3/4

Motorized cassette positioning

• Movement from loading to parking position	With some units there are two loading positions, a left-loading and a right-loading position. Standard is left-loading only. In series mode, used for dynamic studies of the contrast medium flow, the cassette is moved directly from one exposure position to the next one. Important features of the cassette drive system are: 1. The time required to travel from parking to exposure position 2. Positioning time in series 3. Precision of positioning
• Covering the Image Intensifier	During movement of the cassette carriage as well as in loading position the image intensifier is partly covered. The XCU has to be notified about this situation and fluoroscopy is blocked accordingly.

.

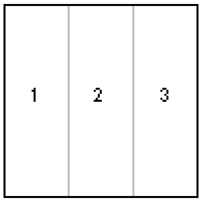
Basic Functions, Func. Unit **Cassette System** 4/4

Determination of subdivisions

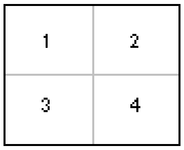
(Spotfilm device only)

Subdividing the film for several exposures is used when

- serial mode is selected and the exposures take place in rapid succession
- or, when the area examined is so small that several radiographs fit on one film.



3 x 1



2 x 2

According to the cassette inserted, its orientation and the mechanical abilities of the spotfilm device, the valid subdivisions are determined.

In order to get correctly exposed subdivisions on the film, for every individual subdivision both the field size and the position of the cassette carriage are calculated.

Subdivision formats
The Subdivision is defined by m x n; where m is the number of subdivisions in width and n the number of subdivisions in height with respect to the patient.
Additionally, the subdivisions are counted from left to right and top to bottom. These numbers are used by the XCU to tell the cassette carriage drive which field to position for exposure.

more info?

End of "Cassette System"

.

Basic Functions, Func. Unit **Cassette System** 1/1

Functionality of the XCU

Exposure counter, management of subdivision positions	Based on the sub formats possible with the cassette loaded, the XCU calculates the following: - Number of exposures possible with the format selected - Unexposed sub divisions during an exposure sequence - Mixture of subdivisions possible when different formats are selected on the same cassette.
Collimator control	Adjustment of correct radiation field size, i.e. controlling of tube-side and film-side collimating in full size as well as in sub divisions.
Control of Exposure sequence	Synchronization of radiation, collimator control and cassette movement in single- and series-mode.
Management of system operation	Evaluation of operation commands as selection of subdivisions, single/series exposure release. Provision of operation data as subdivisions possible, sub formats, positions and number of exposures.
Synchronization of fluoroscopy release	Besides other events, the XCU keeps track of following conditions regarding the cassette system: - Reports of fluoroscopy blocking respectively fluoroscopy release condition of the cassette system.

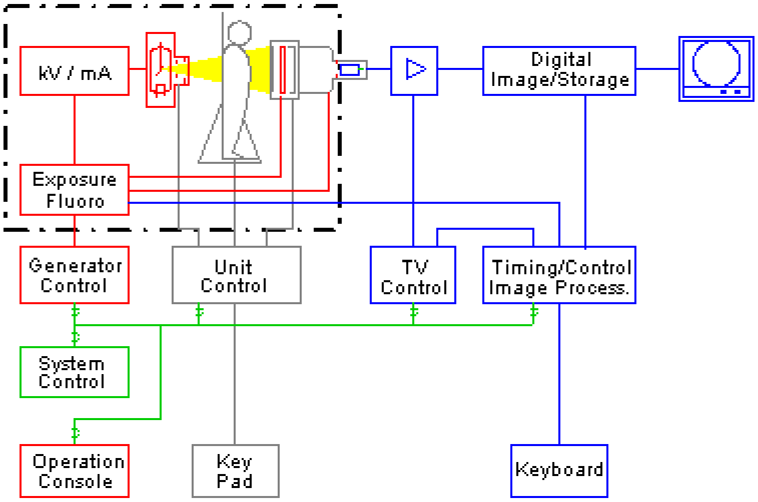
- Cassette movement from loading to parking position and vice versa.

exit info *End of more info "Cassette System"*

.

Basic Functions, Func. Unit **Radiation Generation** 1/7

Generator



The functional unit "generator" manages all functions required to produce radiation:

- **Generation** of radiation in various modes
- Measurement and **control** of radiation
- **Monitoring** of radiation
- **Adjustment** of X-ray tube and radiation sensors

Generation of radiation

This part is intended to generate radiation of specific quality, set by tube specific kV and mA.

Modes of operation

Basically we differentiate between two modes of operation:

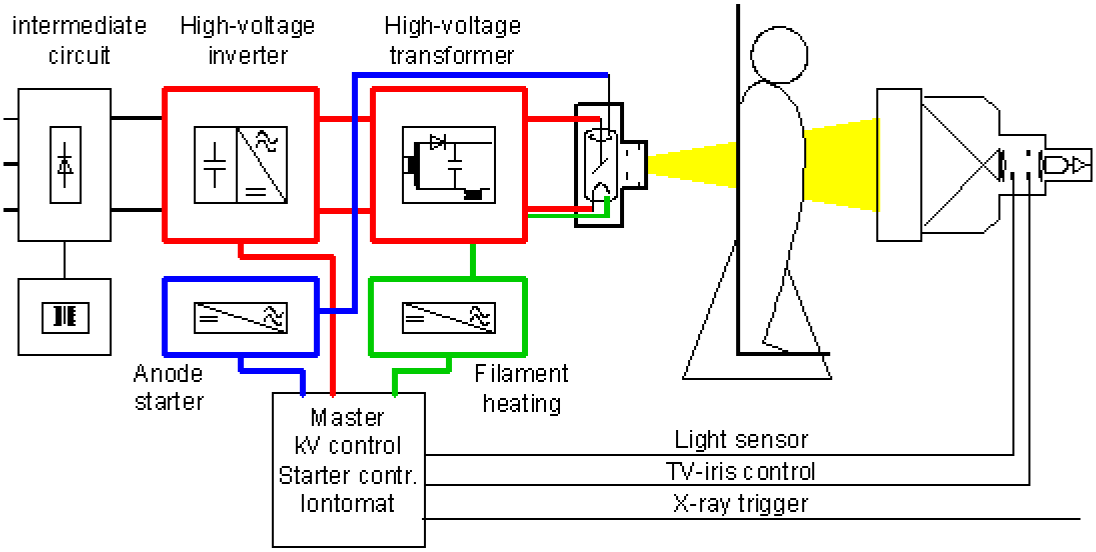
- **Continuous** radiation as with fluoroscopy and
- **Pulsed** radiation, for instance Iontomat exposures.

More info on "Generator Adjustment"

.

Basic Functions, Func. Unit **Radiation Generation** 2/7

Radiation generation



The **X-ray tube assembly** is the source of radiation. It is supplied by the high-voltage transformer via high-voltage cables and a rotating-anode cable.

Following components are involved in **producing radiation**:

- Anode starting device
- kV-control

- filament heating circuit

.

Sub-components

- **Anode starter** Block diagram	The starting device is to speed up the anode to the desired RPMs (revolutions per minute) at shortest possible time. Only then the focal spot can be loaded with nominal load. The RPMs set depend upon the operation mode: - 30 Hz in fluoroscopy mode - 70 Hz exposure mode, standard tubes - 180 Hz high speed tubes
- **kV control** Block diagram	The tube voltage required to produce radiation is generated by means of an inverter. It is active as long as radiation is required. The operation data are either obtained from the XCU - as a response to a user input- or from the exposure control.
- **Filament heating** Block diagram	Heating the cathode, the electron flow required to generate radiation is obtained. The operation data is obtained from the generator control. With begin of radiation, the regulation is switched over from filament current to tube current regulation. To speed up the transition from standby to exposure, a push mode is used.

Basic Functions, Func. Unit **Radiation Generation** 4/7

Radiation control, modes of operation

- **Fluoroscopy** – Fluoroscopy means radiation - continuous or pulsed - over a longer period of time, up to several minutes, at low levels of radiation and tube load. It is used for positioning or *interventions*.
  Pulsed fluoroscopy runs at various frame rates (frames per second) ranging from 0,5fps to 30fps.
  Regulation is based on the customer selected fluoro curve.

- **Exposure** – Here, the radiation only lasts a short period of time in terms of ms, however at high tube loads.
  It is used for diagnosis and documentation.
  There is to be differentiated between

  - Single exposure
    Just one exposure is made either in Iontomat mode or with given exposure data (mAs-mode).

  - Series
    For dynamic studies of contrast medium flow, exposures are taken with rates from 0.5 to 8 fps.

Basic Functions, Func. Unit **Radiation Generation** 5/7

Operation techniques

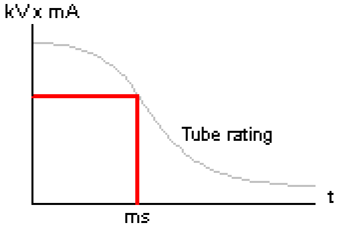
Exposure parameters set manually or calculated automatically

- **3-Point Technique** – All the three exposure parameters: **kV**, **mA** and **ms** are set manually. The generator may block some combinations to prevent overloading of the X-ray tube. Exposure is terminated on reaching the mAs product calculated.
- **2-Point Technique** – Only **kV** and **mAs** are set while the generator calculates a mA/ms combination according to the tube rating. Exposure is terminated on reaching the mAs product.
- **1-Point Technique** – Only the **kV** is set. Over-heating the tube is prevented by reducing the tube current continuously during exposure (falling load). Exposure is terminated by the IONTOMAT reaching the set dose.
- **0-Point Technique** – Same as above, however, with the **kV calculated** on the patient thickness measured during fluoroscopy.

Control modes

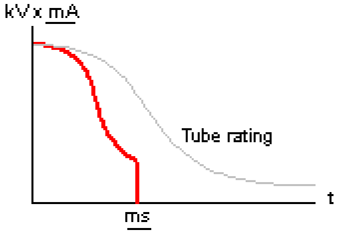
For not over-loading the focal spot during exposure, a tube rating curve is used to calculate the optimum mA and ms combination from the mAs value set for an exposure.

- **Constant load**



The tube load (kV&mA) is kept constant during exposure. For this, all the exposure data - kV, mA, and ms - are calculated before exposure.
This mode is possible in 2- and 3-Point-Technique. Termination either with mAs or Iontomat.

- **Falling load**

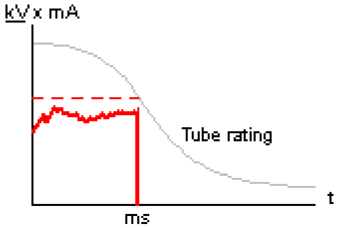


During exposure, the tube load is reduced (mA falling while the kV is kept constant). For each focal spot, an Initial-Load table is set during configuration.
Falling load is possible with 0- and 1-Point-Technique. With set kV, maximum values are calculated for mAs and ms. The Iontomat terminates the exposure.

.

Control modes

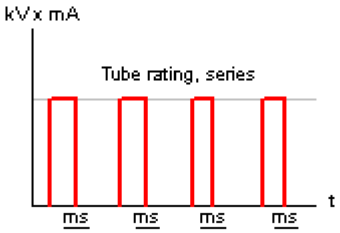
- **Plani IONTOMAT**



This means tomography with automatic exposure control. A mode possible in tomography and DFR-tomography. In this mode, kV, tomo time and limit mAs are set; the exposure is terminated by the timer.
Exposure is controlled by the Iontomat. The mA is kept constant, radiation is pulsed at a fixed rate and the dose rate controlled via pulse width modulation.

- **Constant load series**

This mode is possible in 1-Point-Technique, DSA, and peripheral angiography.
During exposure, kV and mA are constant while the exposure time is controlled by the IONTOMAT. If required, exposure data are corrected between exposures. "Shutter Open Phase" or maximum exposure time are limiting the exposure time.



In serial mode, the tube rating is based on frame rate and maximum scene time.

more info?

End of "Radiation Generation"

.

Basic Functions, Func. Unit **Radiation Generation** 1/1

Summary of exposure control and supervision

Operation mode	Control mode	Exposure data	Limitation/ monitoring	Termination by		
				ms	mAs	Iont.
Direct techn. falling load	falling load	kV, mAmax	mAsmax, msmax	MON	MON	**OFF**
mAs mode (2/3Point, mAs tomo)	constant load	kV, mA	mAs, ms	MON	**OFF**	
3-Point with Iontomat	constant load	kV, mA	mAsmax, msmax	MON	MON	**OFF**
Plani Iontomat	Plani Iontomat	kV, mA	mAsmax, ms	**OFF**	MON	
DFR-0-Point	constant load series	kV, mAmax	mAsmax, msmax scene time	MON	MON	**OFF**
DFR-1-Point	falling load	kV, mAmax	mAsmax, msmax	MON	MON	**OFF**
DFR-tomography	Plani Iontomat	kV, mA	mAsmax, ms	**OFF**	MON	
DSA constant time	constant load series	kV, mA	mAsmax, ms scene time	**OFF**	MON	
Peripheral angiography	constant load series	kV, mA	mAsmax, msmax scene time	MON	MON	**OFF**

OFF = normal termination, MON = backup system

exit info more info on "Generator Adjustment"

.

Basic Functions, Func. Unit **Radiation Generation** 1/4

Adjustment of X-ray-tube and radiation sensors

For not overloading the tube and keeping the dose on a precise level, some adjustments have to be done.

- Calibration of X-ray tube

All procedures mainly effect the filament heating circuit. The values found are stored by the system controller and downloaded to the master (D100) during initialization.

- Preheating

The filament used for fluoroscopy is adjusted to give emission when high voltage is applied (70kV, 1mA). The other filament is adjusted just below emission.

• Adaptation of filament characteristics	Starting from a standard filament-heating curve, correction values are learned for every focal spot and stored by the XCU.
• Pushing	To get the filament heated up sufficiently during preparation, it is necessary to push up the filament current for a certain amount. This push factor is determined and stored again.

exit info

.

Basic Functions, Func. Unit **Radiation Generation** 2/4

Adjustment of X-ray-tube and **radiation sensors**	All known detector systems are accepted: 1-, 2-, 3-pin type of ionization chamber, HSE (semiconductor radiation detector), photo multiplier, B-signal regulation and photo-diode-array (PDA).
• Direct technique	Up to three film-screen combinations of different speed are accepted by the Iontomat. For each of these, a density of 1.0 above fog level is programmed. Additionally, the kV-response must be corrected.
• Indirect technique	Here, the light level at the II-output is measured using a photo multiplier or a photo diode array. In some systems, the brightness information is obtained from the TV-system.
• Calibration	Iontomat and sensor are calibrated to a reference dose rate. During this procedure a lookup table is created for all different Zoom sizes and dominant combinations the sensor is capable of.
• Programming of dose (rate)	All the various dose rates in fluoro mode - pulsed and continuous - and in DFR modes - single, series, Tomography and DSA - are programmed only.

exit info

.

Basic Functions, Func. Unit **Radiation Generation** 3/4

Additional functions

• Display of tube system selected	Using relay contacts, an interface is provided to identify the tube stand selected.
• Control of room light	A relays contact is provided for operating the room light in an on/off function from the operation panel.
• Delayed termination of fluoroscopy	In order to perform a complete LIH (Last Image Hold) cycle, the actual termination of fluoroscopy is somewhat delayed.

exit info

.

Basic Functions, Func. Unit **Radiation Generation** 4/4

Tasks performed by the system controller (XCU)

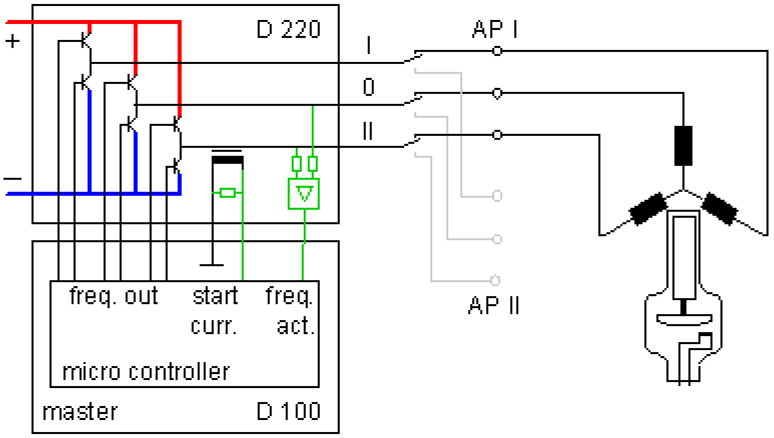
System management	Providing exposure data and Iontomat data Providing fluoroscopy data Tube selection Radiation release
Fluoroscopy	DL-clock DL actual data display Averaging the fluoro data and update display Monitoring fluoroscopy
Exposure control	Synchronization of exposure release with other components Collection of actual data for printout Tube load calculation Water value calculation Integration of dose-area product pulses and controlling the display

exit info *End of more info "Generator Adjustment"*

.

Basic Functions, Func.Unit **Radiation Generation** 1/1

Block Diagram of Anode Starter

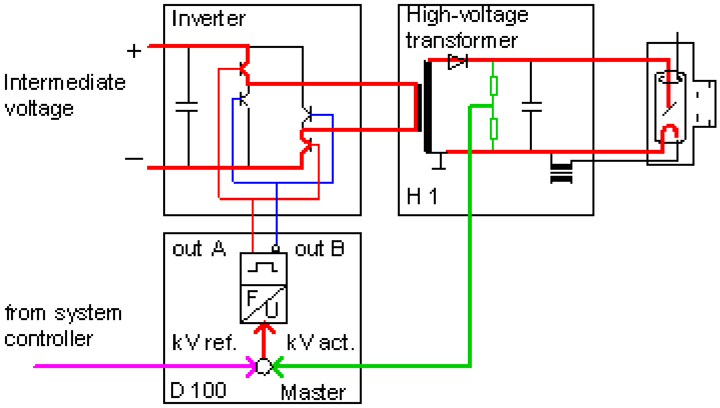


The anode starting device is an inverter supplied by the intermediate circuit.
The proper switching sequence contolling the stator of the X-ray tube is generated by the micro controller on the master board D100.
During start-up, the stator current is monitored.
After start-up, the rotor is free wheeling generating a speed dependent frequency which, in turn, is measured by the micro controller.
Underpassing a minimum frequency, the anode is sped up again for a short period of time.
Deceleration is achieved by applying DC voltage to the rotor until the anode is stopped.

exit info

.

Block Diagram of kV Control



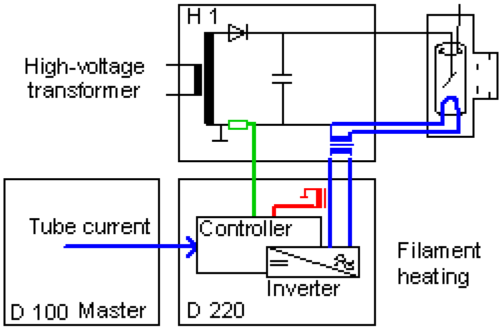
The high votage transformer is supplied by an inverter controlled by a mixed analog/digital control circuit on the master board D100.
The **kV reference** is issued by the system controller (XCU) and converted into an analog signal by the micro controller on board D100.

Comparing the kV reference with the **actual** value obtained from a voltage divider inside the high voltage transformer, a **control** voltage is obtained. This analog signal is converted into a frequency triggering the pulse train controlling the inverter.

exit info

.

Block Diagram of Filament Heating



Again, an inverter is used to controll the x-ray tube current. A transformer inside the high voltage tank isolates the control stages from the high voltage.
There are three defined stages in filament heating:

Standby

As long as no radiation is required, the filament is kept just below emission temperature.

To speed up the transition from standby to exposure temperature, a high push current is applied to the filament for a short period of time.
In all these modes, the filament current is controlled by measuring the **swing current** of the inverter.

Exposure

Exposure starts with applying high voltage, starting the tube current flow at the same time.

Preparition
Prior to an exposure, the filament is heated up to generate precisely that amount of emission producing the tube current desired during exposure.

Now, the **tube current** is used to control the filament heating.
This kind of regulation is used during fluoroscopy, also.

exit info

.

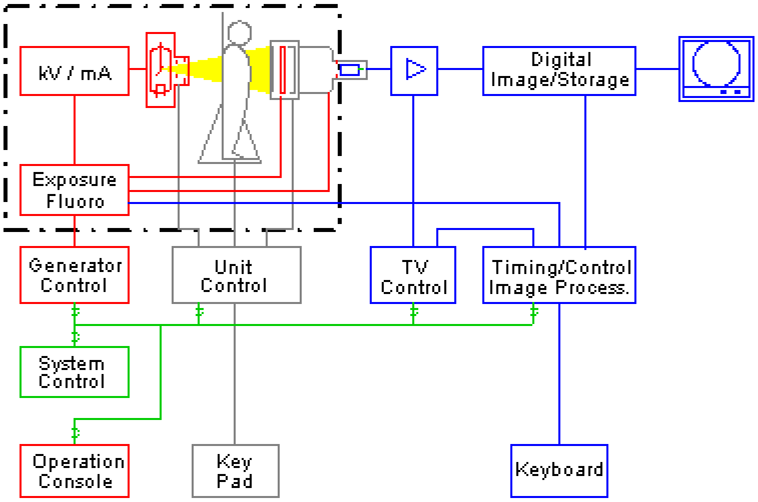
Basic Functions, Func. Unit **Radiation Control** 1/7

Controlling the **amount of radiation** applied during **fluoroscopy and exposure**, is part of the functional unit "Generator".

There are two modes of operation:

- mAs - mode and
- automatic exposure control (IONTOMAT)

In **mAs mode**, the tube **output** is controlled while the dose in the image receiver plane is unknown. This mode is used only in direct technique, when the hand or foot under examination is directly placed on the film-cassette. An experienced radiographer knows which exposure data to set.

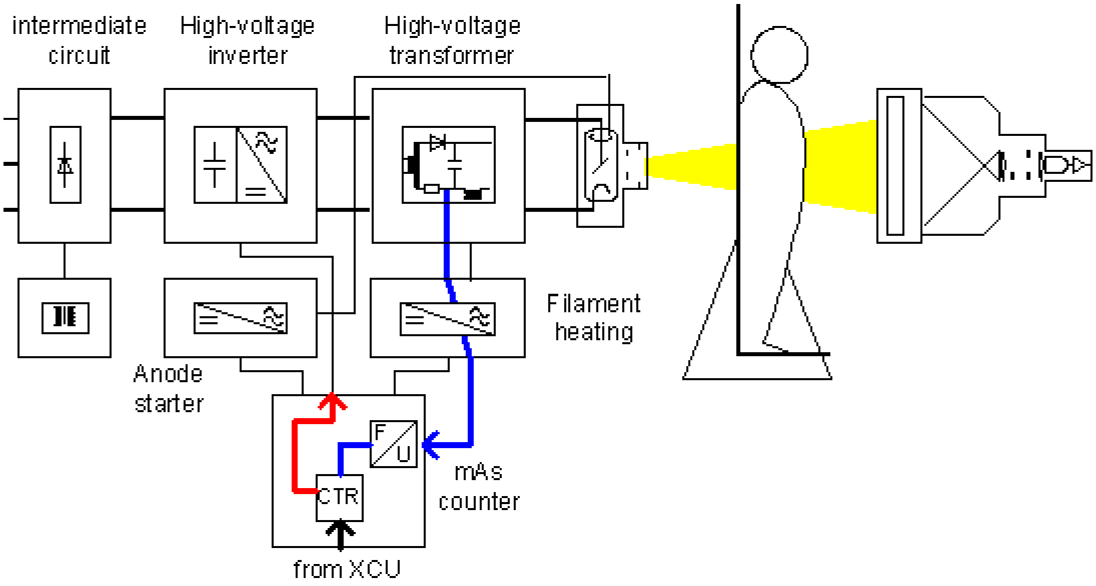


Automatic exposure control is the standard. Here, the **dose** is controlled for correct exposure while the tube load (mAs) depends on the patient size.
In **direct technique**, using film-screen cassettes, the dose is measured by means of an ionisation chamber in front of the cassette.
In **indirect technique**, DFR, the light at the **image intensifier output** is measured instead.

.

Basic Functions, Func. Unit **Radiation Control** 2/7

Radiation control during exposure, mAs counter

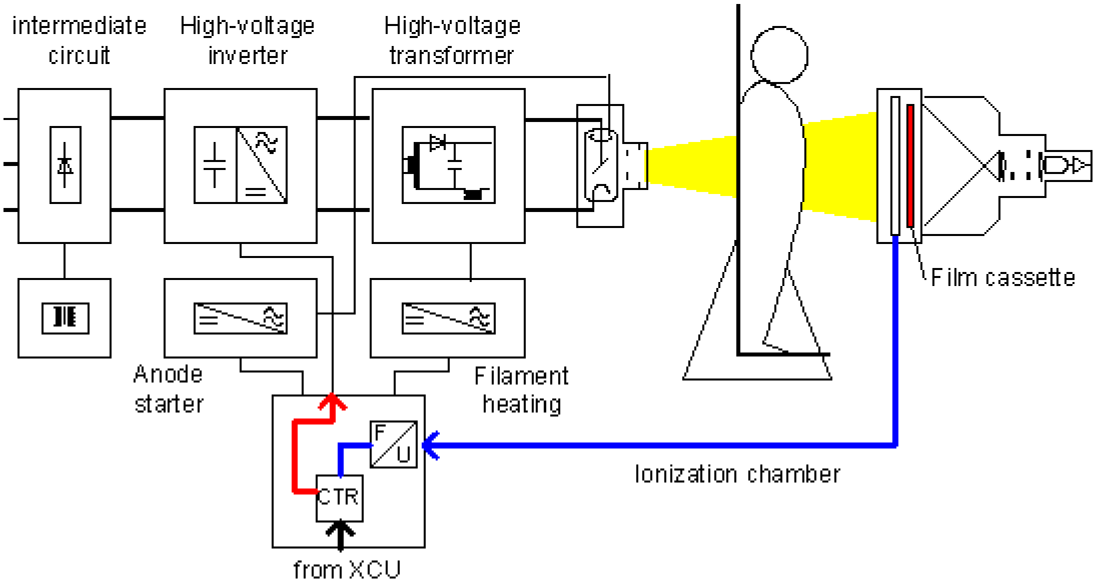


As mentioned earlier, the tube current is measured during exposure to control the filament heating.
The same signal is used to control the mAs counter set by the XCU (black).

The voltage (blue) is converted into a **frequency** representing the tube current.
The pulses generated **decrement** the counter until it reaches zero.
The high-voltage inverter is blocked (red) **terminating** the exposure.

Basic Functions, Func. Unit **Radiation Control** 3/7

Dose control during exposure, film-screen combinations



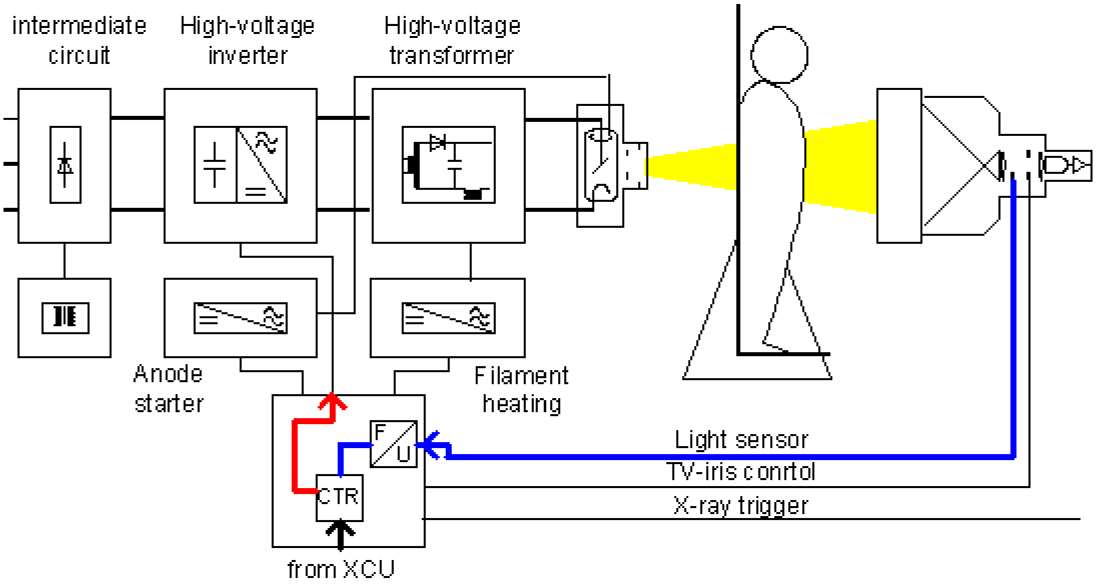
Knowing the dose requirement for a given film-screen combination, the XCU sets a **counter** to a value representing the dose (black arrow). During exposure the **ionization current** is measured (blue)and converted into a proportional voltage, repersenting a certain dose rate.

The voltage is converted into a **frequency** representing the dose rate.
The pulses generated **decrement** the counter until it reaches zero.
Now, the high-voltage inverter is blocked (red) **terminating** the exposure.

.

Basic Functions, Func. Unit **Radiation Control** 4/7

Dose control during exposure, image intensifier mode



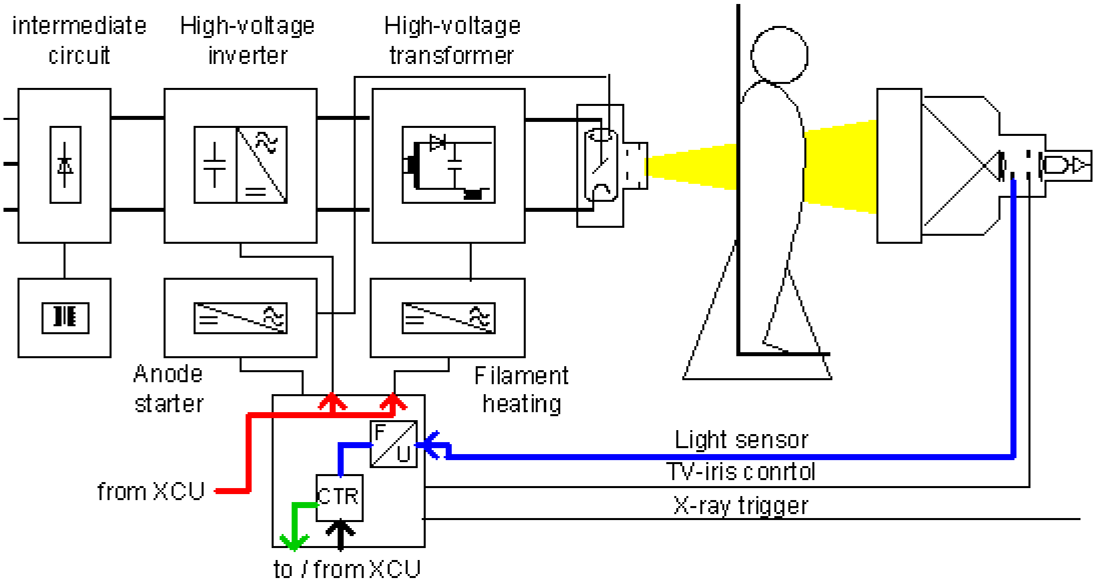
Knowing the dose requirement for a given organ program, the XCU sets a **counter** to a value representing the dose (black arrow). During exposure the **light intensity** on the II output is measured (blue), representing a certain dose rate.

The voltage measured is proportional to the light intensity, and is converted into a **frequency**.
The pulses generated **decrement** the counter until it reaches zero.
Now, the high-voltage inverter is blocked (red) **terminating** the exposure.

.

Basic Functions, Func. Unit **Radiation Control** 5/7

Dose Rate control during fluoroscopy, Autom. Dose-Rate Regulation (ADR)



In fluoroscopy mode, the XCU calculates the **20ms-dose** from the programmed fluoro dose-rate level and sets the counter accordingly. As with exposure mode, the light is measured and the counter decremented (blue).

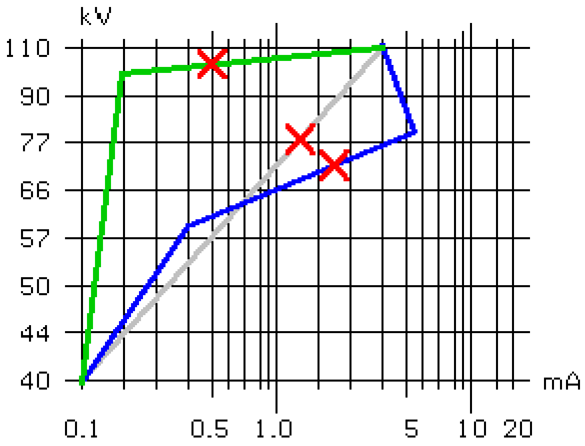
After every 20ms of measurement, the counter value, representing the **deviation** from the selected dose, is transferred to the XCU (green). The XCU corrects the **kV and mA** parameters (red) until the dose-rate deviation is zero.

Fluoro Curves

With increasing patient thickness, more and more radiation is absorbed inside the body, and the radiation behind the body, the image intensifer input dose, decreases degrading the image quality.
As seen above, the **ADR** keeps the light output (i.e. the dose-rate input) of the image intensifier constant by adapting the X-ray tube output.

By combining different kV/mA values, as demonstrated in the graph, significant influence in **radiation quality** is obtained. The red crosses represent three different fluoro-kV obtained with the same patient but different fluoro curves.

Antiisowatt
The gray, linear curve continuously increases the tube output from 4W to 440W and serves



Dose reduced curve
The green, high-kV curve provides a radiation less harmful, however, with reduced contrast. Despite of the curve name, the input dose is not reduced.
Contrast curve

for calibration mainly.

The blue curve tries to keep the 60kV to 80kV range with varying patient size for optimum contrast.

▼ ▲ more info?

.

Exposure Points and Water Values

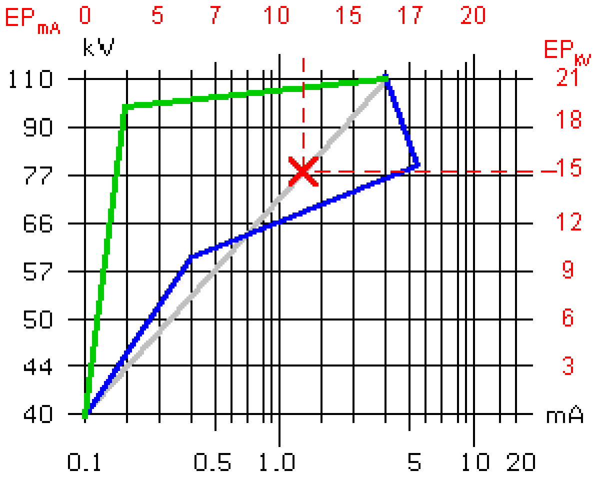
As you recall, exposure parameters are kV and mAs. Unfortunately, an increase of 10mAs has different results when starting from 1mAs or from 40mAs. To become independent from the mA or the kV scale, a neutral, dose related scale has been introduced: the exposure point scale.

One **exposure point** (EP) is one increment to the ten fold of **dose**:

- 10 EP = factor 10
- 3 EP = factor 2
- 1EP = factor 1.26

By calibrating the kV scale and mAs scale this way, the same dose is obtained by decreasing kV one step and compensating it by increasing one step mAs.

In fluoroscopy, the same scheme is used as is demonstrated on the graph.



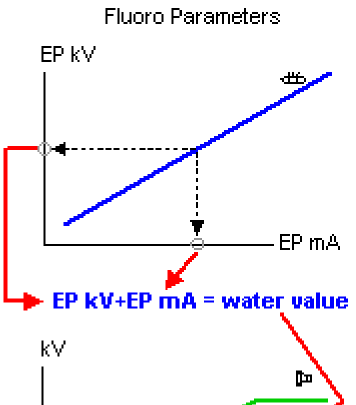
During fluoro adjustment, the system is calibrated to 20 cm of water; resulting in a given kV/mA combination. Any other combination with the same curve indicates a different amount of absorber. An increase of 1cm water is compensated by 1EP. Therefore, the **water value** is the sum of EP_{mA} + EP_{kV}. When selecting a different curve, a new kV/mA combination is found, resulting in the same water value.

▼ Exit info

.

0-Point Technique
Calculation of Exposure kV

Before exposure, the **exposure data** have to be set. That is, kV for image contrast and dose (or



mAs) for correct exposure.

With full-automatic exposure control, even the **optimum kV** is found automatically using the fluoro parameters:

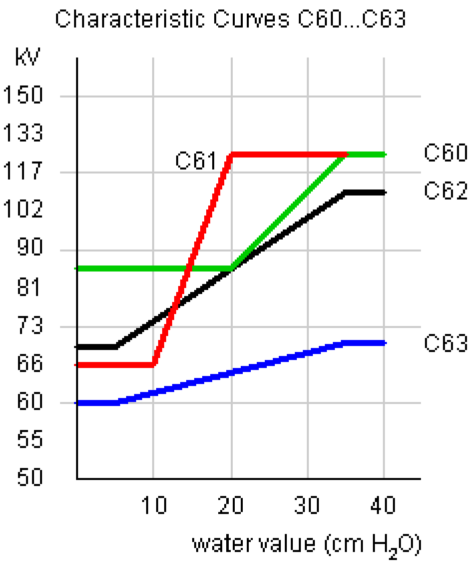
- **During fluoroscopy**, the water value is calculated representing the patient thickness.
- Using an **exposure curve**, the optimum kV for this patient is found.

- According to the organ programm selected, focal spot and dose requirement are konwn. So, the **exposure data** are **calculated and set** during fluoroscopy.

.

Exposure curves

Special characteristic curves have been developed for the following organs:		
Stomach/Intestine 1	C60	85...125 kV
Thorax	C61	66...125 kV
Stomach/Intestine 2	C62	70...109 kV
Gallbladder/Kidney	C63	60...70 kV



As demonstrated, the optimum kV not only depends on the **patient size**, it also depends on the **organ under examination**.

So, the **organ program** contains a lot of information:

- **Fluoro mode**
  Continuous or pulsed radiation, fluoro curve, dose-rate and post-processing parameters

- **Exposure data**
  Focal spot, dose, maximum exposure time, exposure curve and post-processing parameters

Basic Functions, Func. Unit **Radiation Control** 4/5

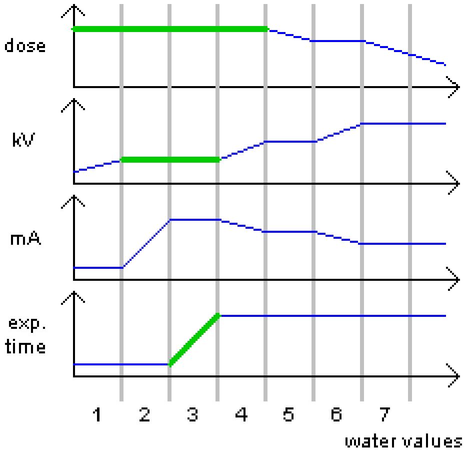
Calculation of Exposure Data

Based on the **organ program**, the kV derived from the exposure curve and the **water value** of the patient, exposure data are calculated.
In series mode, the actual exposure time is compared to the set time, and the difference is used to correct the **exposure data for the next exposure** following a regulation curve. This very mode is also used during pulsed fluoroscopy.

The full range of patinent sizes (water values) is divided into 7 steps. The individual parameters are set following their specific curve:

- In stage 1, all curves are at their lowest values; the Iontomat switches shortest exposure time, mA are minimum (10mA) and **kV** is used for compensation.

- In stage 2, the set kV are reached, while exposure time and kV are still minimum. The **mA** adapts to the water value.



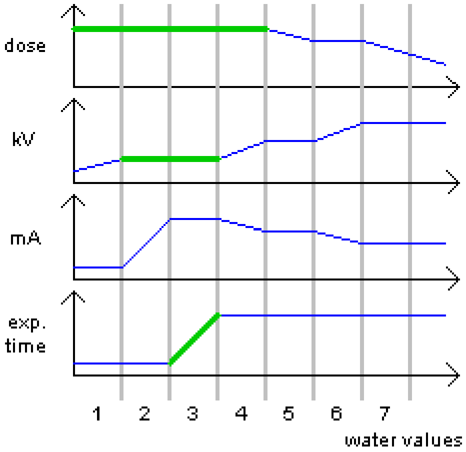
- Up to stage 3, the exposure time is still minimum while mA has reached maximum value. This is due to the fact that one always tries to get the shortest possible exposure time. Only with the mA at maximum **exposure time** is extended.

Exit info

Basic Functions, Func. Unit **Radiation Control** 5/5

Calculation of Exposure Data

- In stages 2 and 3, the kV are kept constant. This is the range of **optimum radiation quality** and image quality. Here, the **mA**-curve in combination with the **ms**-curve serve for a continuous increase in mAs.
- With beginning of stage 4, the limit of mA and ms is reached. In order to penetrate heavier patients the **kV** have to be raised until the maximum is reached at stage 5.
- Stages 5 through 7 can be used in combination with a **DFR** (Digital Fluoro-Radiography) system only and are a measure against extremely heavy



patients.

- Stage 5
  In the DFR system, a step is programmed where the kV is no longer increased and the **dose** reduced instead. Compensated by opening the TV iris.

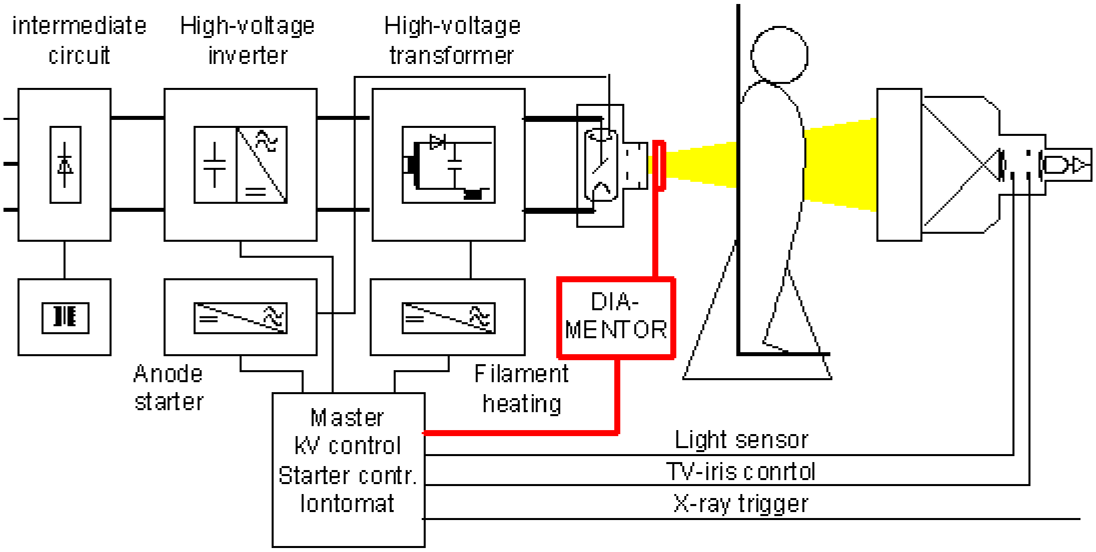
- In stage 6, **kV** is increased again up to the maximum. If this doesn't help, with all tube parameters at maximum, the only way out is to reduce the **dose** again.

Exit info *End of info "Radiation Control"*

.

Basic Functions, Func. Unit **Radiation Control** 7/7

Radiation monitoring



DIAMENTOR is used for area-dose-product measurement, which is basically the skin dose. The ionization chamber is directly attached to the collimator and connected to a control unit which generates dose dependent pulses.

The generator integrates these pulses during exposure, series and fluoroscopy. They are displayed on the console; during fluoroscopy the display is updated every 200ms.

End of "Radiation Control"

.

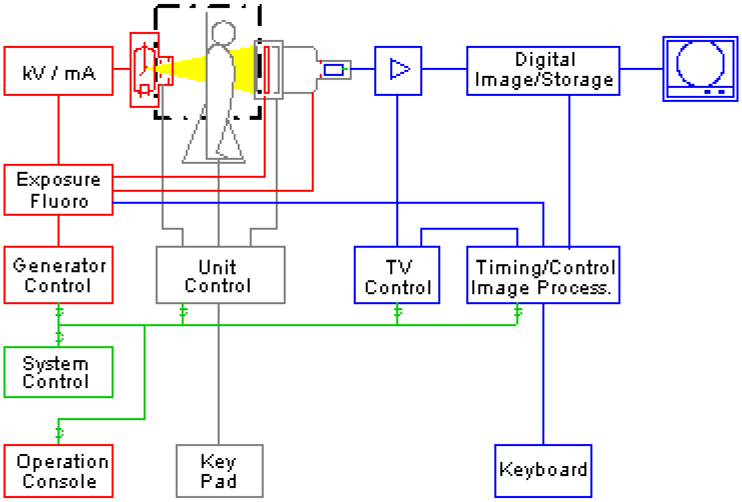
Basic Functions. Func. Unit **Radiation Collimation** 1/4

Radiation collimation

This function includes all systems **manipulating** the radiation beam after leaving the X-ray tube assembly, be it **quality** wise or in its **dimensions.**

Basically, these manipulations take place at two different locations:

- In between focal spot and patient, i.e. by the component collimator. This is referred to as **primary collimation** and its main task is setting the radiation field size.



- Between patient and target, inside the spotfilm device. The **secondary collimation**; its purpose is to improve image quality by reducing the amount of scattered radiation.

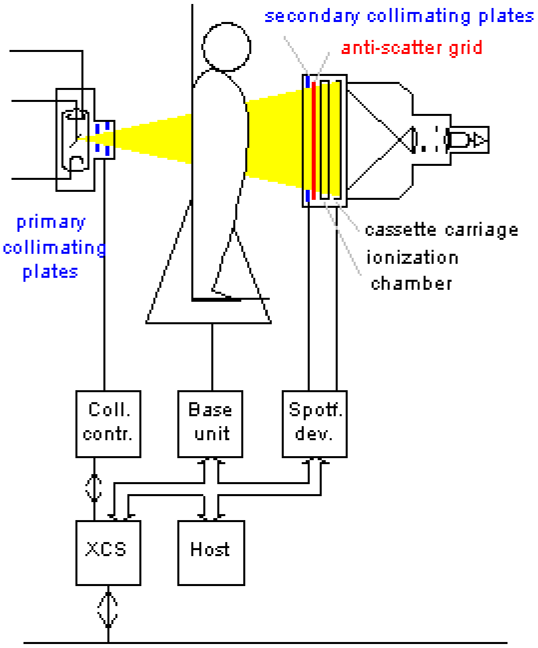
[Basic Functions]. Func. Unit **Radiation Collimation** 2/4

The collimator and the secondary collimating plates

A glance at the hardware:
The **collimator** is mounted to the tube housing and centered to the focal spot. The collimator control is connected to the XCS interface of the examination unit. The remote control for operation, not shown here, is also connected there.
Hence, the collimator can be controlled manually or by the XCU/XCS system in automatic mode.

Inside the **spotfilm device**, we have got the set of **secondary collimating plates** and the **anti-scatter grid**. Both are controlled by the spotfilm device controller.

For calculation of maximum and minimum field size, the **actual SID** (Source Image Distance) must be known to the system controller.



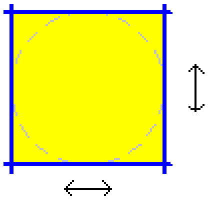
.

Collimating the radiation field

Collimating modes:

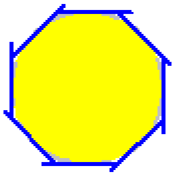
The radiation field is collimated at its outer limits. As a rule, **the radiation field size must not be larger than the area utilized for evaluation.**
I.e. not larger than the film size or the area seen on the monitor.

Square field



Square shaped field size with **cassette- and image intensifier** systems.
In this case we always deal with two collimating plates:
The **height plates**, setting the field size in longitudinal patient direction and the **width plates** setting the width of the field.
The primary collimating system is always the tube side **collimator** altering the **radiation field size** continuously.
While the purpose of the **film side collimating** system is to reduce the amount of **scattered radiation** hitting the target. According to the design, the plates are operated continuously or provide openings of fixed size.

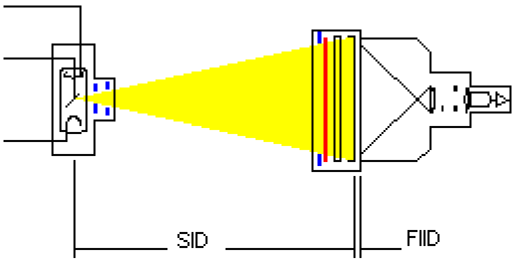
Circular field



Circular field size with **image intensifiers only**
The circular field is always set by the **tube side collimator**.
However, it may be combined with the square field plates inside the spotfilm device.

.

Geometric conditions



The geometric conditions of a tube-target system are identified by the following conditions:
The **SID** (Source Image Distance) indicates the distance from the focal spot to the film plane.
Normally, it can either be altered manually or by a motor.

For calculation of the relative field size of both the focus side plates and the film side plates, the XCU requires following parameters:
- Distance between focus and focus side plates
- Distance between target and target side plates

The FIID tells the distance between film and image intensifier input plane. In pure II-systems the distance is zero. Both these values are constant while the SID, also required for calculation, is variable.

▲ more info

End of "Radiation Collimation"

.

Basic Functions. Func. Unit **Radiation Collimation** 1/4

Geometric conditions

- **Maximum field size** Knowing the geometric conditions - SID and target size - the XCU controls the maximum field size for all collimators under its command thus preventing from over framing the target area.
  Using sub divisions on cassettes or selecting zoom on an image intensifier, smaller maximum field sizes have to be considered. The XCU calculates the respective maximum field sizes for both the focus side collimator and the collimating plates in the spotfilm device. Field sizes between minimum and maximum are set by the collimating system without involvement of the XCU.
  There may be different maximum field sizes for the rectangular field, depending on the cassette inserted, and the iris, corresponding to the field selected.
- **Minimum field size** This condition is met when a field of 3cm by 3cm is adjusted.
- **Blocking of fluoroscopy** If inside the spotfilm device either the collimating plates or the cassette carriage travel through the radiation beam, fluoroscopy must be blocked.

▼ exit info

.

Basic Functions. Func. Unit **Radiation Collimation** 2/4

Radiation Manipulation

Filtration of radiation

This function allows for altering the radiation quality by introducing filters of different material and thickness into the radiation beam. The XCU can be programmed to assign filtration and mode of operation as well as introduce filters when selected from the operation console.

Suppression of scattered radiation

A scattered radiation grid filters a high amount of scattered (omni directional) radiation out of the radiation beam by letting only radiation originating from the focus passing. Control wise, there are three different types of grids known:

- Fixed grid which is not motor driven. It is always in the radiation beam.
- Movable grid which can be moved in or out the radiation beam by a motor.

- Oscillating grid. The same as above. Additionally, it starts oscillating with preparation for blurring the grid lines during exposure. Exposure release has to be synchronized with the grid motion.

▼ ▲ exit info

.

Basic Functions. Func. Unit **Radiation Collimation** 3/4

Additional Functions

Radiation field indication	With over table units a light field is used to simulate size and location of the radiation field during exposure. The lamp operation is controlled by the collimator control.
Search run	For self testing and internal calibration of field size monitoring, the collimating system performs a search run during initialization. After successful initialization the system reports its status to the XCU and receives the data for maximum field size.
Manual operation	Collimators for over-table units provide manual adjustment of field size. This is not interfered with by the XCU since the collimator control has been informed about maximum field size by the XCU before.

▼ ▲ exit info

.

Basic Functions. Func. Unit **Radiation Collimation** 4/4

Tasks of the system controller (XCU)

- Monitoring the operation and condition of the collimating system, update the display.
- Controlling the format automatic in accordance with the mode selected, the cassette inserted, subdivision selected and II-field selected.
  That means calculation of maximum field sizes for the rectangular field and the iris system as well as releasing or blocking movement of the collimating plates.
- In peripheral angiography, field sizes have to be assigned to the steps and recalled later.
- Interpretation of fluoro release or blocking signal from the spotfilm device.

- Controlling the grid position in/out; eventually synchronize exposure release with oscillating grid movement.

▲ exit info

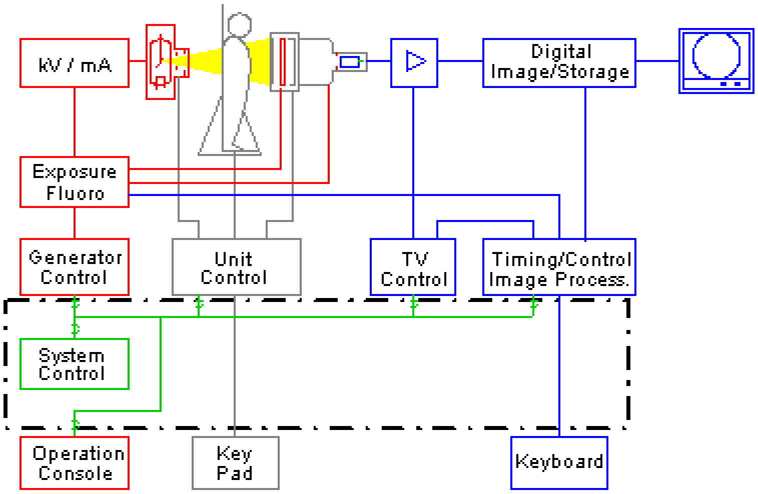
End of more info on "Radiation Collimation"

.

System controller

Radiation release, be it **fluoroscopoy** or **exposure**, requires a lot of action inside the X-ray system and is, therefore, handled by the **XCU**.
While the location of the **fluoro/exposure switches** depends very much on the kind of the examination unit, the actions initiated are always the same:

By exchanging **XCS telegrams**, the readiness of all systems is chequed. Next, commands are issued to the generator, the examination unit and the TV-system, and finally, the **fluoro/exposure sequence** is started.



.

Generator

Standby

As explained above, four stages are involved in generation and control of radiation:

- The **anode starting** device,
- the **filament heating** circuit,
- the **high voltage inverter**,
- and the **IONTOMAT**.

Function	Anode rotation	Filament heating	High voltage	Dose control IONTOMAT
standby	x	preheating	off	x

During standby, **filament heating** is the only active system. It keeps the filament on a temperature just below emission of electrons.

.

Basic Functions, Func. Unit **Radiation Release** 3/9

Generator

Fluoroscopy

Fluoroscopy (the signal is called **DL** in the diagrams) is started by **activating the high-voltage inverter**.

Next, filament heating is switched over from controlling the filament temperature to controlling the X-ray tube current.

Then, slow-speed anode rotation is started.

The IONTOMAT is in dose rate control mode.

Function	Anode rotation	Filament heating	High voltage	Dose control IONTOMAT
standby	x	preheating	off	x
DL fluoro	30Hz	mA control	on	dose rate control

.

Basic Functions, Func. Unit **Radiation Release** 4/9

Generator

Preparaition

When starting an exposure, the X-ray tube has to be prepared first, that is:
The **anode is accellerated** to exposure speed.
100Hz = Normal tubes
180Hz = Rapid tubes
The **filament** is heated up to **exposure heating**. To shorten this procedure, a high **push-current** is applied for a

Function	Anode rotation	Filament heating	High voltage	Dose control IONTOMAT
standby	x	preheating	off	x
DL fluoro	30Hz	mA control	on	dose rate control
VK prep	100Hz 180Hz	push curr. exp. heating	off	drift compensation

short time.

Also, the IONTOMAT is prepared for measurement by compensating any previously measured drift.

The preparation phase is **completed after 0,7s**, and exposure can be released.

.

Basic Functions, Func. Unit **Radiation Release** 5/9

Generator

Exposure Start

During preparition, the **examination unit** is also busy:
The cassette carriage is moved from parking postion to exposure postion, and, with tomography, the column moves in start position.

Finally, with everything prepared for exposure and the **VK+0.7s** signal arriving from the generator, the **grid starts** oszillating, and the **exposure signal** is returned to the generator.
With tomography, the column has to reach the correct angle additionally

Function	Anode rotation	Filament heating	High voltage	Dose control IONTOMAT
standby	x	preheating	off	x
DL fluoro	30Hz	mA control	on	dose rate control
VK prep	100Hz 180Hz	push curr. exp. heating	off	drift compensation
Examination unit starts the exposure when: The **grid is oszillating** or the correct **tomo angle** is reached				

.

Basic Functions, Func. Unit **Radiation Release** 6/9

Generator

Exposure release

With the **HK** signal returned

Function	Anode rotation	Filament heating	High voltage	Dose control IONTOMAT
standby	x	preheating	off	x

from the examination unit, the generator activates the **high-voltage inverter** starting the radiation.
Filament heating switches to **tube current control**, and the IONTOMAT measures the **dose accumulated**.

During series, lasting about 10 to 30 seconds, the anode speed is checked from time to time and boosted up if needed.

DL fluoro	30Hz	mA control	on	dose rate control
VK prep	100Hz 180Hz	push curr. exp. heating	off	drift compensation
Examination unit starts the exposure when: The **grid is oszillating** or the correct **tomo angle** is reached				
HK exposure	speed control	mA control	on	dose measurement

.

Generator

End of exposure

On **reaching the dose** programmed, the **IONTOMAT terminates** the exposure by switching off the high-voltage inverter.

Filament heating returns to temperature control and keeps the exposure heating for releasing another exposure immediately if needed. This is done by releasing the exposure switch halfway and pressing down again.

Function	Anode rotation	Filament heating	High voltage	Dose control IONTOMAT
standby	x	preheating	off	x
DL fluoro	30Hz	mA control	on	dose rate control
VK prep	100Hz 180Hz	puch curr. exp. heating	off	drift compensation
Examination unit starts the exposure when: The **grid is oszillating** or the correct **tomo angle** is reached				
HK exposure	speed control	mA control	on	dose measurement
end of **exposure**	speed control	exp. heating	off	dose termination

.

Generator

End of preparation

Releasing the exposure

Function	Anode rotation	Filament heating	High voltage	Dose control IONTOMAT
standby	x	preheating	off	x

switch completely ends preparation, and starts the **braking** procedure of the **rotating anode**.

The generator returns to **standby** condition.

If the fluoro switch is still activated, fluoro is activated again after a short delay.

As mentioned above, all this sequence is completely controlled by the **XCU** via exchange of **XCS telegrams**.

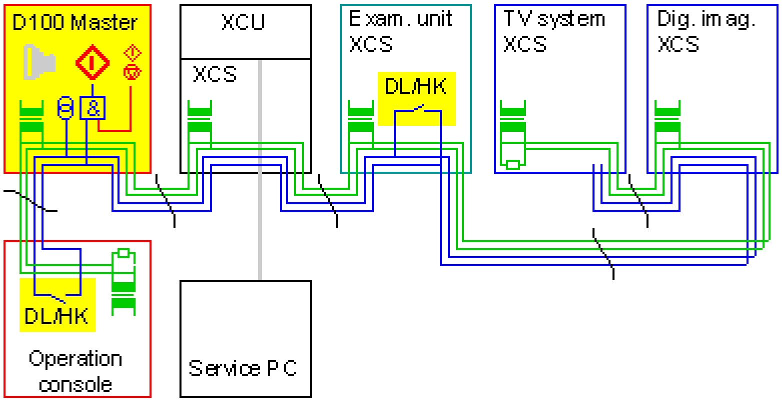
DL fluoro	30Hz	mA control	on	dose rate control
VK prep	100Hz 180Hz	push curr. exp. heating	off	drift compensation
Examination unit starts the exposure when: The **grid is oszillating** or the correct **tomo angle** is reached				
HK exposure	speed control	mA control	on	dose measurement
end of **exposure**	speed control	exp. heating	off	dose termination
end of **prep**	braking	preheating	off	x

.

Block Diagram of Hardware Radiation Release

Accidental release of radiation must be avoided at all costs. Therefore, a hardware radiation release circuit has been introduced which has to agree with the XCS telegrams.

The cables making up the XCS system (green) are also used to transport the hardware radiation release signal (blue).



For **release of radiation**, two conditions have to be met. First, either fluoroscopy (DL) or the main contact (HK) have to be activated closing the current loop and providing the **hardware radiation release**.

This can be done from the generator console or from the examination unit. Second, the **software radiation release** must agree to release radiation. The AND-gate on the D100 board shows this condition. Only then, high voltage is produced.

In exposure mode, **radiation is terminated** by the IONTOMAT upon reaching the set amount of dose. Fluoroscopy is ended by releasing the fluoro switch opening the DL contact.

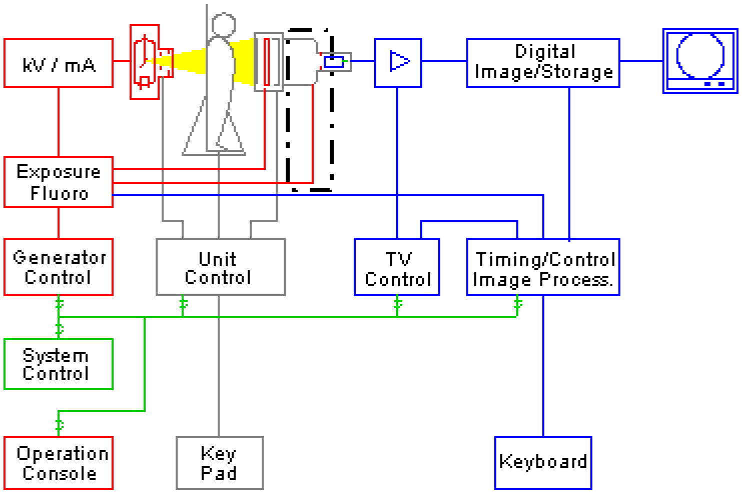
End of "Radiation release"

.

Image intensifier system

This function comprises the control of the image intensifier and exposure:

- Image intensifiers feature a **zoom function** by changing power supply voltages of the electron lens.
- For **dose (rate) control**, a **photo-diode array** is used measuring the light output of the image intensifier.
- Since different dose levels are used in fluoro as well as exposure mode, the **TV-iris diaphragm** is used to provide **constant light level** for the TV-camera.



The zoom function is the only real image intensifier function since it effects the power supply.

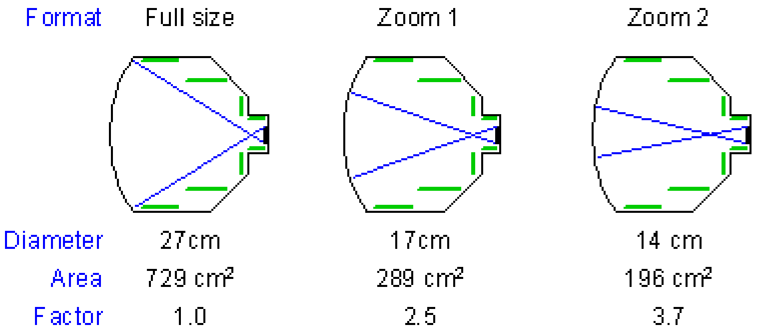
Photo diode array and TV-iris diaphragm, on the other hand, are part of the functional unit image intensifier while the belong to the generator hardware-wise.

.

Zoom formats

When **zooming**, a small area of the input screen is projected to the output screen, thus **enlarging the image** on the monitor.
The reduced input area, on the other hand receives less X-ray photons resulting in **reduced brightness**.

This must be compensated by **increasing the dose rate** accordingly.
For fluoroscopy, the optimum dose rate is 174nGy/s at the



Format	Full size	Zoom 1	Zoom 2
Diameter	27cm	17cm	14 cm
Area	729 cm²	289 cm²	196 cm²
Factor	1.0	2.5	3.7

Format		40	33	30	**27**	22	17	14
Zoom factor		0.5	0.65	0.7	**1.0**	1.5	2.5	3.7
Fluoro dose rate	[nGy/s]	87	113	120	**174**	255	440	650
	[µR/s]	10	13	14	20	30	50	75
Exposure	[nGy]	435	565	610	**870**	1270	2190	3220

27cm format. With other II-formats, the dose (rate) is altered according to the **zoom factor**.

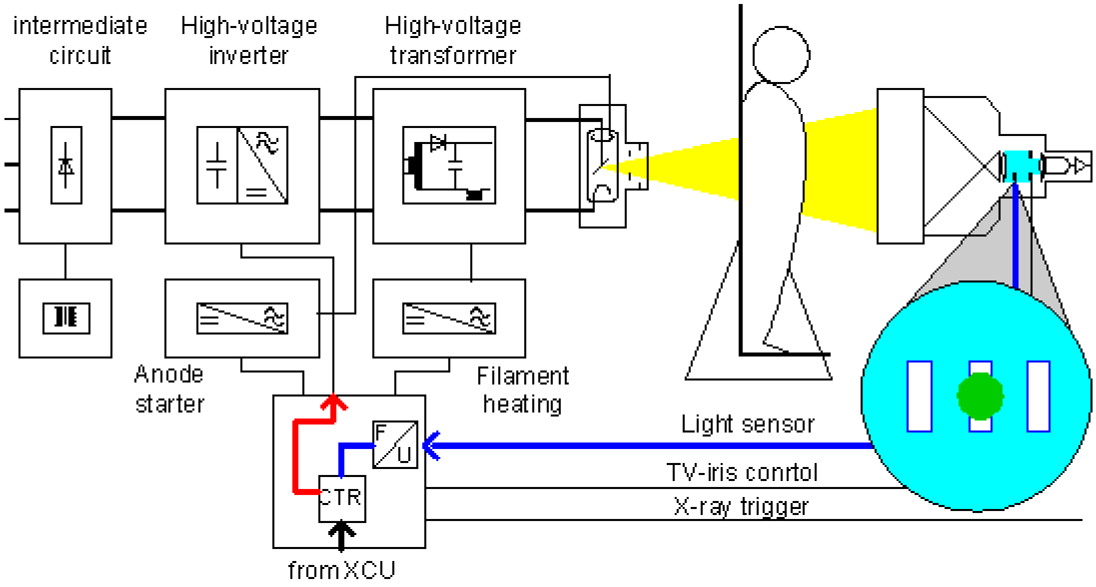
In DFR, dose 100 is preferred; some examinations may call for different dose levels, however.

dose 100	[μR]	50	65	70	100	150	250	370

.

Basic Functions, Func. Unit **Image Intensifier** 3/4

Photo Diode Array



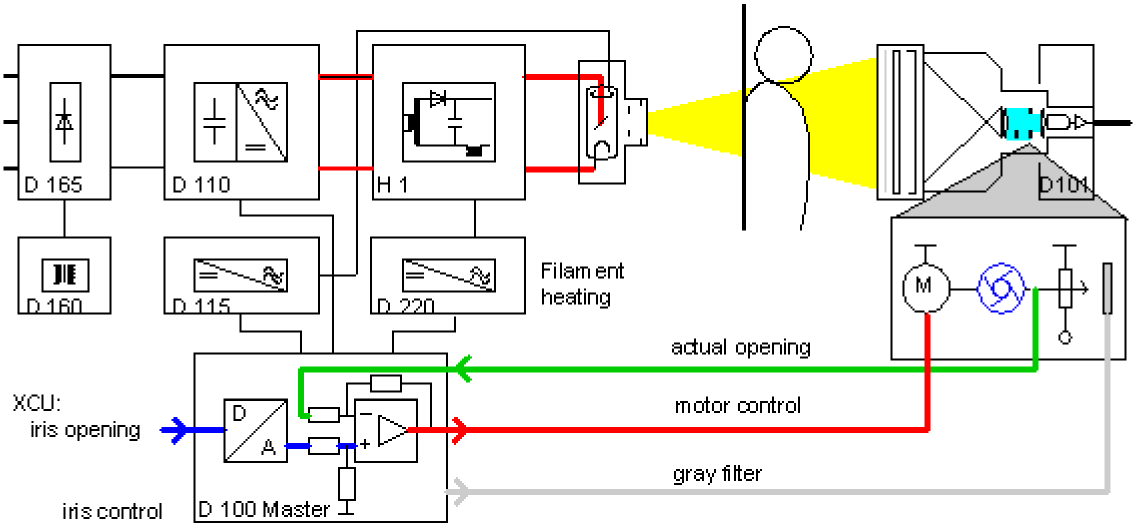
The photo diode array provides **light-sensitive spots** (dominants) on the **image intensifier output**. Only the light inside the selected dominant is measured and serves for dose (rate) regulation.

There is a **circular dominant** (green), and there are three **rectangular domintants** (white) which can be combined or selected individually.

.

Basic Functions, Func. Unit **Image Intensifier** 4/4

TV-Iris Diaphragm



For optimum performance, the **TV-camera** must allways be operated at the **same light level**. The image intensifier, however, operates at **different dose levels** for the same reason.

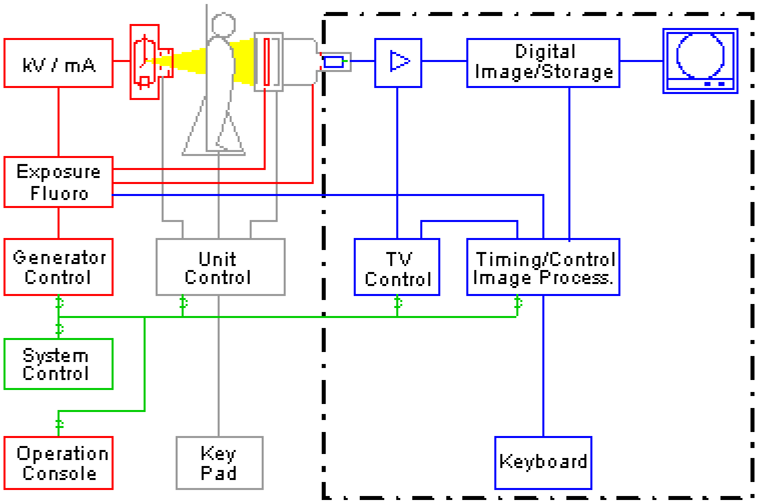
To cope with the various light levels, an **iris diaphragm** is installed in front of the TV-camera. The diaphragm size is controlled by the XCU. To extend the useful range of the iris, a **gray filter** is moved into the light beam.

End of "Image Intensifier"

Video system

This functional unit is used to control the imaging system as a part of the complete X-ray system.
In larger systems, the imaging processor may even be a work station or a PC of its own.

Today, we differentiate between two TV-systems of different scope of functionality:



Low-end systems, providing **fluoroscopy** only. However, with digital image

High-end systems, Digital Fluoro Radiography systems (DFR),

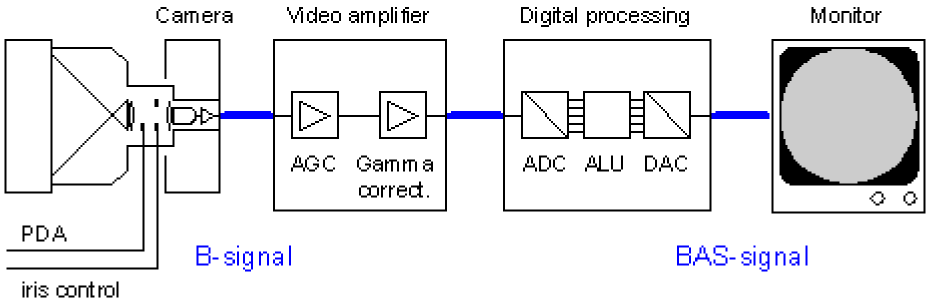
Besides of **post processing** the image, these DFR systems are able to store **patient data** processing, featuring **Last Image Hold** (LIH) and **noise reduction**.

providing **digital radiographs** additionally by adding **image memory** and archiving on hard disc.

and **output the image** to a hard copy camera or a local area network.

.

Block Diagram of the Video System



Camera

Today, **CCD chips** are replacing the **pick-up tubes** used in the past. Regardless of the image device used, the camera output signal (**B-signal**) is an **analog signal** providing the signal flow to control a monitor.

Video amplifier

The X-ray image picked-up from the image intensifier, however, doesn't have the **contrast needed**. So, the analog **signal is shaped** before it is digitized.

Digital processing

Once the image is digitized, it is open for a wide range of **manipulations** aimed to **enhance information**. This is not possible with the ordinary X-ray film.

After being processed, the signal is converted back to **analog**, forming the **BAS-signal** needed by the monitor.

Monitor

The typical X-ray monitor is high resolution black and white monitor.

.

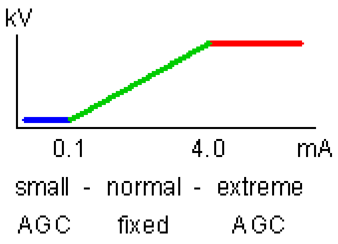
Video amplifier

AGC

Analog signal processing

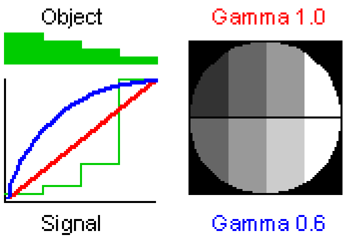
As explained in the chapter radiation control, various **patient sizes** are compensated by **different kV&mA** combinations (green) during **fluoroscopy** providing a constant light level at the image intensifier output. In this case, the video amplifier operates on a **fixed gain** to provide the desired **monitor brightness**.

If, however, the patients are too big (red) or too thin (blue) the regulation is at its **limits** and the B-signal is incorrect.



Now, the **Automatic Gain Control** (AGC) is activated to maintain a **constant BAS-signal** to the monitor.

Gamma correction

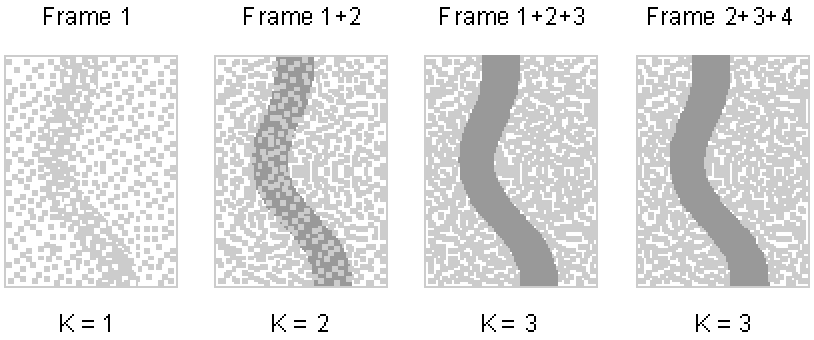


Since the **absorption** of radiation is **not proportional** to the absorber thickness, the image contrast at the II-output leaves to be desired (green signal).
Using **linear gain**, gamma 1.0 (red), most of the important information is **too dark** on the monitor.
Nonlinear gain, **gamma 0,6** (blue), makes the dark areas more transparent and provides **better overall contrast**.

.

Basic Functions, Func. Unit **Video System** 4/7

Noise Reduction **Digital Image Processing**



In **fluoroscopy**, we operate at a low dose rate. And as every single image has integrated too little X-ray photons to be perfect, the image has a high amount of "quantum noise".

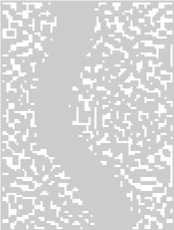
Based on the fact that two successive images mainly differ in the noise pattern, this noise can be reduced by **digitally integrating** images.

The images above demonstrate the integration effect of one, two and three images, referred to as K-factor. With K = 3, the last three frames are kept in image memory while earlier frames are discarded.
The disadvantage of integration shows up at **fast moving objects** which **are blurred** or smeared.

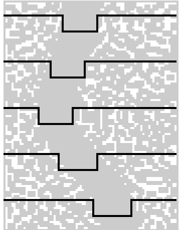
.

Edge Enhancement

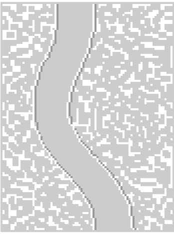
Digital Image Processing



Original



Edge Detection



Edge enhancement

Low contrast images can be improved by **electronically outlining contours**. For this, every pixel of every line is evaluated for being part of a pixel line.

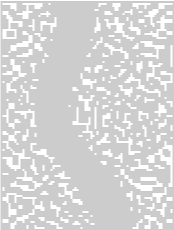
The pixels next to a line are displayed with increased contrast according to the amount of edge enhancement set.

Edge enhancement makes an image more crispy. However, overdoing edge enhancement makes a line contour just black and white erasing all information along this line.

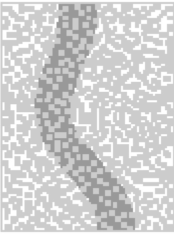
.

Windowing

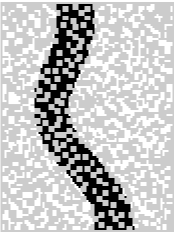
Digital Image Processing



Wide window low contrast



Standard



Small window high contrast

In DFR systems, the basic contrast and brightness setting of the **monitor** is adjusted to display the full video signal and must **not be touched**.

Contrast and brightness are set by windowing instead. That is, only a part, **a window**, of the

By assigning window settings to an **organ program**, image contrast and brightness can be optimized for every kind of examination.
Again, when overdoing windowing, information is lost in white or black parts of the image.
Therefore, it's not wise to program a window too narrow.

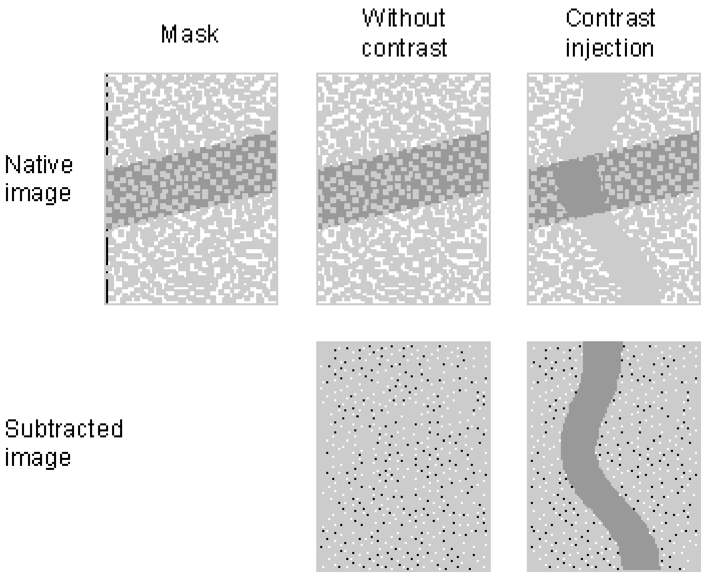
digital gray scale is converted into the standard black and white video signal.

.

Digital Subtraction Angiography

Digital Image Processing

DSA is used to **isolate** a vessel filled with contrast medium from the anatomical background.
This cannot be done with a single image, instead a series of images is needed.



The last image of the upper row, displaying the native images, shows the contrast filled vessel partly covered by a rib. Evaluation is rather difficult.
Using subtraction, the **mask** is subtracted from the image, removing all the information but the noise. The noise pattern is different in every image.
The last image shows the **contrast medium** only since it is the **only difference** to the mask. Now, the evaluation is not obstructed any longer.

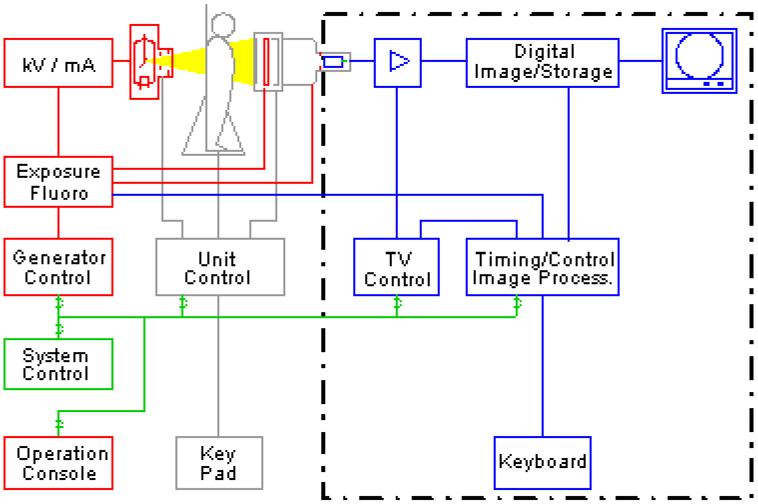
more info?

End of chapter "Video system"

.

Time critical signals

The signals listed next are time critical and therefore transferred via direct hardware connections. Time critical means that they serve for synchronization or operate on high transfer rates and therefore cannot be handled by XCS.



- **Radiation on**
  Indicates the time during which radiation is activated.

- **Beam current blocking**
  Inhibits the read out of the target during exposure, the image is stored on the target.

- **Vertical synchronization**
  This pulse is used to synchronize all components taking part in image acquisition.

exit info

.

Basic Functions, Func. Unit **Video System** 2/4

Tasks of a DFR-system:

- **Image acquisition** The image received from the image intensifier is stored on the target of the pick-up tube. An electron beam reads the information scanning the target. While reading, it also charges the target anew. Various scanning modes are used: interlaced, progressive and slow progressive.

- **Image processing** Before processing, the images are digitized. Using various filtration techniques, noise is reduced and edges are enhanced. Finally, the contrast is optimized by windowing.
  A very special way of contrast enhancement is DSA (Digital Subtraction Angiography). Here, two images of exactly the same region of the body are subtracted from each other. The only difference is that one image - the mask - is taken before contrast injection. After subtraction, only the contrast medium filling the vessel is displayed.

- **Image display** There are two major advantages of DFR over conventional film:

  1. The on-line feature; the immediate display.

  2. The post processing feature; the image manipulation without

the need of redoing the exposure.

▼ ▲ exit info

.

Basic Functions, Func. Unit **Video System** 3/4

Tasks of a DFR-system:

Controlling interfaces	As mentioned earlier, a precise timing of radiation release, scanning the target, analog to digital conversion, image processing and display is asked for. This is all controlled by the DFR timing device. Other tasks of the DFR system are: • Storing the Images in memory for immediate access. • Archiving of images and patient data on the imaging hard disk. • Transfer of images to the HCC (Hard Copy Camera). • Transfer of images and patient data to the digital archives of the hospital.
Entry of patient data	The images must be affixed with patient data. This correct assignment must be guaranteed by the DFR system.
Operation	The table side controls are used to select standard imaging programs and to control the image display. Post processing of images and entry of patient data is performed at the operation console in the control room. All table side image controls can also be performed here.

▼ ▲ exit info

.

Basic Functions, Func. Unit **Video System** 4/4

Organ program dependent parameters provided by the XCU:

Operation mode	Single, series, tomography, peristepping and perivision
Fluoroscopy program	Fluoro normal, Supervision, roadmap, pulsed fluoro, noise reduction parameters, windowing, filtration, number of look-up table and frame rate
Exposure parameters	Frame rate, dose per frame, exposure time, scene time, density correction - with peristepping additionally frame rate per step
Image processing parameters	Windowing parameters, filtration, native/subtraction image, number of look-up table and matrix size

▲ exit info

End of more info "Video System"

.

.

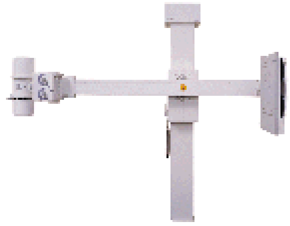
Examination Units **Classes** 1/2

Preface As the name implies, examination units are used for the examination of patients. In a way, to the radiologist, they are a tool for the production of X-ray images. And, as with tools, there are various examination units for different applications.
The large number of different examination units can be grouped, however, in three general classes:

- Exposure units
- Universal units

- C-arm units

AD 1906
In this very early design, dating back to 1906, the imaging system is a cassette holding intensifying screens and light sensitive glass plate. And the patient, in turn, holds the cassette himself.



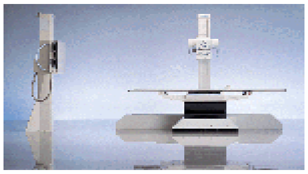
90 years later
Today, an adequate system looks like this. We have got the same basic elements: X-ray tube, collimator and a cassette. However, many improvements have been made in detail resulting, first of all, in a significant improvement of radiation protection and, secondly, in the ease of operation. As to the image quality, well, some of the pioneer radiologists claim the old radiographs being better.

for more info, click on the images

.

.

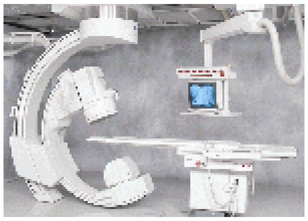
Examination Units **Classes** 2/2



Exposure units
With a system like this, one has to aim the radiation beam (simulated by a light beam) at the body region under examination, set the exposure data and release the exposure. Then the film is processed and only after that it can be evaluated on a viewing box. No fluoroscopy is possible here; so, this is an exposure unit identified by having a **Bucky tray** only.

Universal units

In cases where the anatomic situation requires a special projection, or the timing of exposures depends on the flow of contrast medium, fluoroscopy is required. Using an image intensifier in combination with a TV-system, real time X-ray viewing is provided. Fluoroscopy is mainly used for orientation, whereas the radiograph, providing better image quality, is used for evaluation. Universal units are identified by having a **spotfilm device**, housing the cassette carriage and the image intensifier.



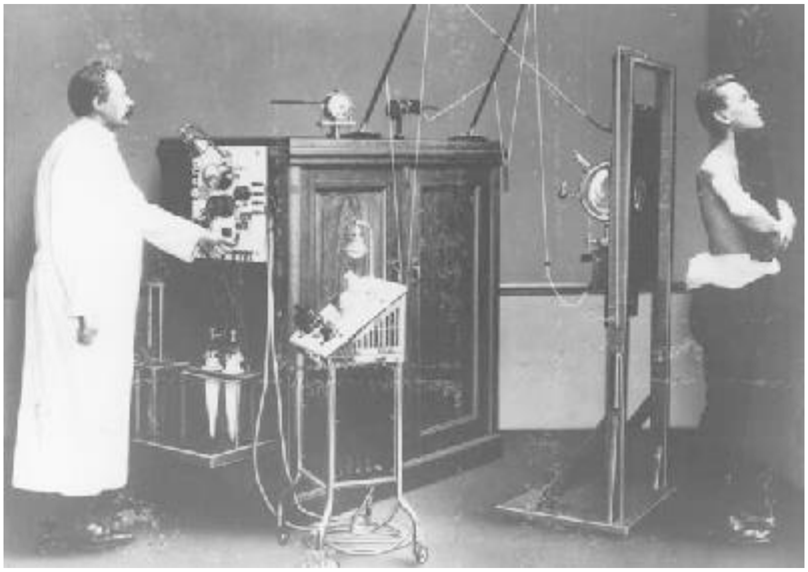
C-Arm Units

are identified by having X-ray tube and image intensifier mounted on a **c-shaped arm** encompassing the patient resting on a table. They are straight TV-based units. Both, fluoroscopy and exposures result from a digital TV-system. Due to the design, they allow for nearly unlimited projection directions.

for more info, click on the images ¶

.

AD 1906



This photograph shows a very early X-ray system:

- The control console on a trolley,
- the high voltage transformer inside the cabinet,
- the X-ray tube on a floor stand with lead shield.
- The patient, holding the film cassette in front of his chest.

Table of events:

- 1895, Roentgen discovers X-rays.
- around 1900, intensifying screens are widely used.
- 1917, cellulose nitrate film replaces glass plates.

exit info

.

.

Vertix UM

This modern, straightforward, manually operated exposure unit reflects all the major improvements achieved over the decades:

- A rotating anode tube in a shielded housing.
- A multi leaf collimator for radiation field limitation.
- A bucky tray holding the anti scatter grid (invented 1921 by Potter and Bucky) and the cassette.
- Variable SID due to a carriage riding on the column centring tube and Bucky tray.

- Variable adjustment of height and projection angle.

exit info

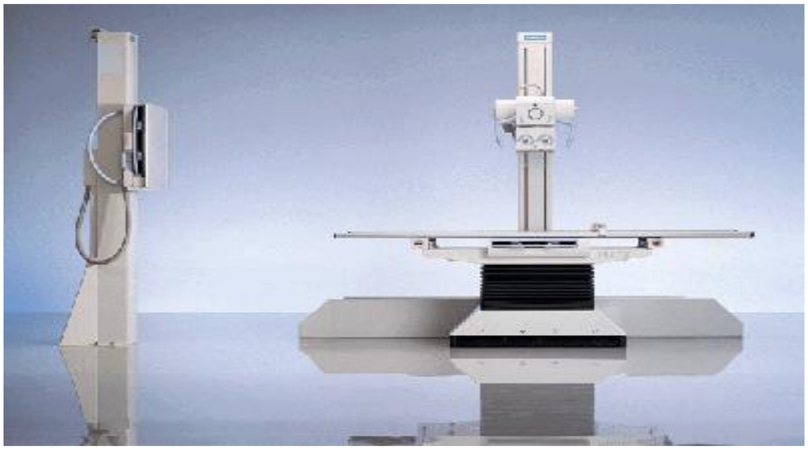
.

.

Multix PRO

The radiographic table is designed for exposures of all anatomical regions as well as for orthopaedics and trauma diagnostics.

Expanded to include a Bucky wall stand, it becomes an optimal workstation for routine thorax, abdominal, pelvic, cranial, spinal, and peripheral examinations.



exit info

.

.

Sireskop SX

Extending the radiographic capabilities by fluoroscopy, the universal units are used widely for dynamic studies of the gastrointestinal system as well as the peripheral circulatory system.

exit info

.

.

Multistar

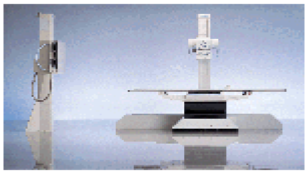
Basically, c-arm units can perform the same examinations as universal units. A limitation may be the absence of a cassette system (thorax exposures).
The real advantage of the c-arm units, however, is the nearly unlimited range of projection directions. Therefore, they are mainly used for examinations of the circulatory system.

exit info

.

VERTIX UM

MULTIX TOP



MULTIX PRO

MAMMOMAT

▼

.

.

Examination Units **Exposure Units** 2/6

VERTIX UM

The VERTIX UM is a stand alone exposure unit combining the advantages of an omni directional unit with a Bucky table.
When used in conjunction with a mobile patient table, the system is highly suited for use with emergency/trauma patients.

The unit consists of a wall mounted stand carrying the tiltable exposure system on a transverse arm.
Opposite to earlier systems, with this new model all movements:

- height,
- rotation and
- SID

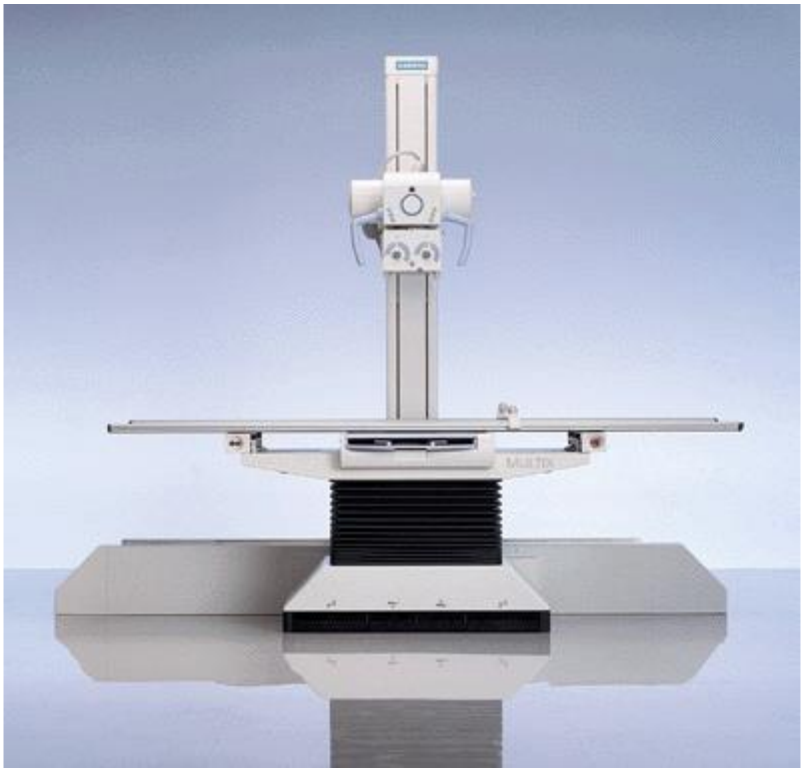
are completely motorized.

▼ ▲ to page 1

.

.

MULTIX PRO



MULTIX PRO is primarily intended for examinations on patients in lying positions (recumbent). For this, it is equipped with a floating table top and a built in Bucky tray. Variable table height allows for easy patient access.
The floor mounted tube stand and the Bucky tray are coupled for synchronized movement including tomography.

▼ ▲

.

.

VERTIX PRO

The wall stand VERTIX PRO is used for chest, spine and other radiography on standing patients.

Very often it is used as an extension to MULTIX systems using the same x-ray tube. It is suitable for either wall-mounted or free-standing installation as seen here.

to page 1

.

.

Examination Units Exposure Units 5/6

MULTIX TOP	MULTIX TOP Ceiling-mounted solution for optimum table access, variable table heights. Automatic Cassette Size Sensing (ACSS) is used to control the collimator. Electronic coupling of tube and Bucky tray allows for tomography.

to page 1

.

.

Examination Units

Exposure Units

MAMMOMAT 300

MAMMOMAT 300 is tailor made for high volume screening and high quality images for diagnosis of early breast cancer.
Optimized patient access and projection flexibility, coupled with simple handling, are just a few of many built-in benefits:

- Optimized compression
- Motorized isocentric rotation of swivel arm

- Flexible system layout

to page 1 ¶

.

Examination Units

Universal Units

1/5

Overtable Units

SIREGRAPH CF

SIREGRAPH TOP

Undertable Units

SIRESKOP SX

The **Universal R/F Stands** (radiography/fluoroscopy) are split up into two groups:

- The Overtable units, having the imaging system arranged like ordinary exposure units, and
- the undertable units with the x-ray tube underneath the table and the spotfilm device above.

▼

.

.

Overtable Units (OT-Units)

The introduction of image intensifiers in the early fifties proved a mayor breakthrough in medical diagnosis leading to the development of the first OT-units.

With these units, the x-ray tube is positioned always above the table on a stand mounted to the base unit. The spotfilm device - housing the image intensifier and the cassette carriage - is located below the table top and synchronized with the tube stand.
The large SID (115 ... 150cm) offers excellent projection geometry with minimized geometric unsharpness. Oblique beam projections, including tomography, are possible.

In general, **OT-units are remote controlled** during examination. However, all mayor unit movements can be performed using a table-side control.

Undertable Units (UT-Units)

With UT-units, the x-ray tube is always located below the table providing a fixed distance between focal spot and table top. Riding in the same carriage is the spotfilm device. So, tube, cassette and image intensifier can be moved along the patient always being centered to each other. Due to the design, the center beam is always perpendicular to the table top.

All unit movements as well as radiation release are controlled on the table-side controls. During examination, **the radiologist stands next to the patient**.

Common to both systems is the floating table top in combination with the shiftable center beam. In addition, the table base can be tilted from upright position (90°) to horizontal (0°) and Trendelenburg (head lower than feet) -15° to -90°.

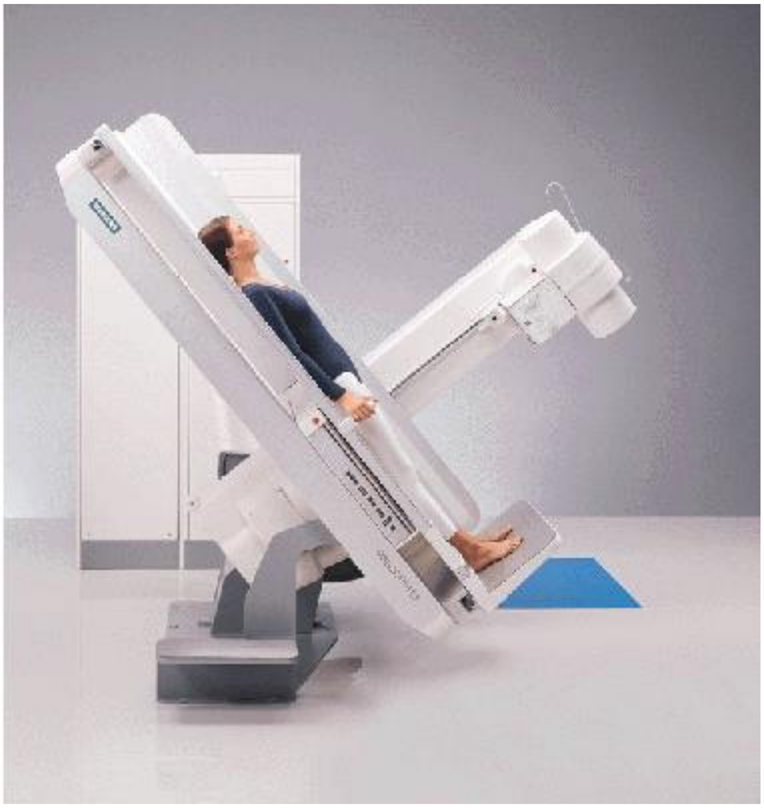
▼ ▲

.

.

SIREGRAPH CF

Being an OT-unit of uncomplicated design, the SIREGRAPH CF is part of the low-end class R/F systems using cassettes as imaging system (direct technique).



- Fixed table height
- Tilt range 90° to -18°
- SID 115, 135, 150cm
- Oblique projections up to ±40° with automatic parallax correction of the image intensifier.

The spotfilm device can be equipped either with 23cm or 33cm image intensifiers and a Videomed DI (CCD chip camera) for fluoroscopy only.
In combination with the 33cm II, the Videomed SX can be connected providing full DFR (Digital Fluoro Radiography) functionality.

▼ ▲ to page 1

.

.

SIREGRAPH TOP

The SIREGRAPH TOP represents the high-end universal R/F diagnostic system.
It can be delivered either with a spotfilm device (TOP 33) for both, direct technique (cassettes exposures) and indirect technique (image intensifier exposures), or with an image receptor carriage (TOP 40) for indirect technique only.

- Variable table height
- Tilt range 90° to -90°
- variable sped of

movements
- SID 115, 135, 150cm
- Oblique projections up to ±40° with automatic parallax correction of the image intensifier.

- Peripheral angiography

▼ ▲ to page 1

.

.

SIRESKOP SX

The SIRESKOP SX represents the high-end UT-units.
In combination with a 33cm image intensifier, the spotfilmdevice contains a cassette carriage and the system can be used for both, direct and indirect technique.
Equipped with a 40cm II, it serves DFR (Digital Fluoro Radiography) only.

- Tilting range 90° to -90°
- Long examination range of spotfilm device.
- Large focus to table-top distance for

optimum geometric conditions.

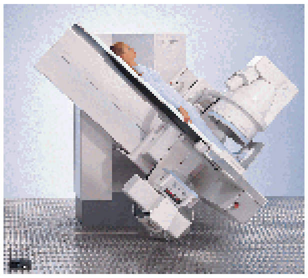
- Tableside control of the complete system, including generator and imaging functions.

▲ to page 1 ¶

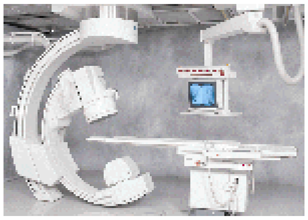
.

.

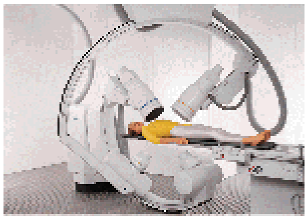
SIREMOBIL



POLYSTAR



MULTISTAR

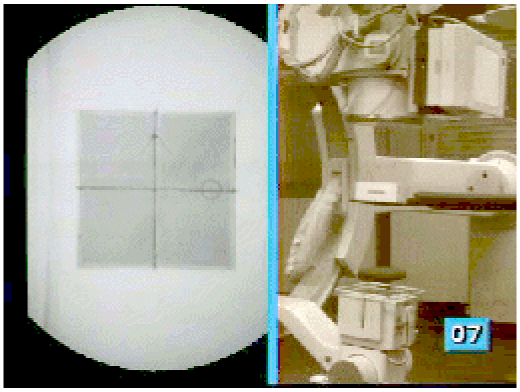


BICOR

▼

.

.

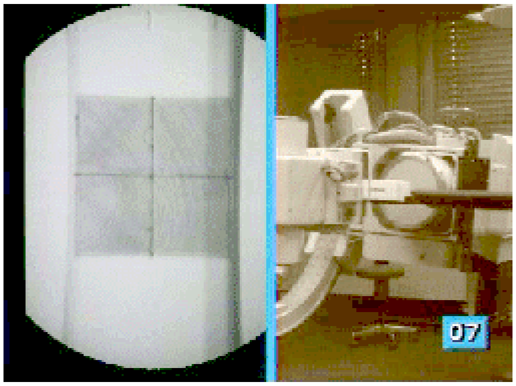


Isocentric Positioning

The purpose of C-arm units is to provide multidirectional projections without repositioning the patient.

Frontal View

X-rays are used to make the hidden visible. For better orientation on the object, a frontal projection is chosen for the first study.

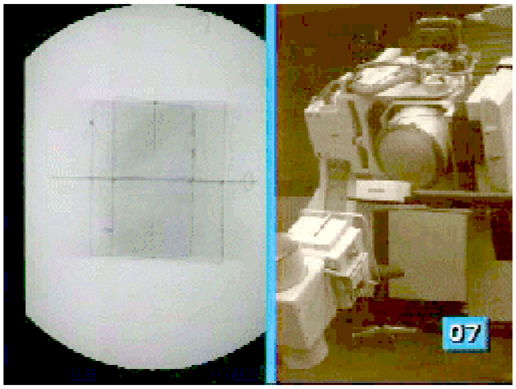


Lateral View

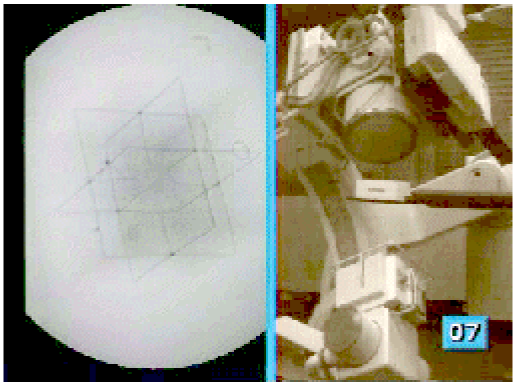
Since X-ray images are two-dimensional only, a second view is taken in lateral projection permitting spatial correlation.

.

.



Oblique Projection
C-arm units additionally provide oblique beam directions. So, superimposed structures can be projected free from overlapping. Complex structures may call for double angle projection.



Double Oblique Projection
To ensure that the object remains invariably in the image center, when changing projection, it must be positioned isocentrically, that is exactly in the fulcrum of the C-arm system.

See a video-clip (13MB, MPEG viewer required)

.

SIREMOBIL

The mobile C-arm image intensifier system for multidirectional projections and digital image storage offers a wide field of applications for surgical diagnostics:
General, orthopaedic and paediatric surgery; neurosurgery, trauma, cardiac and vascular surgery. It is used in emergency rooms and intensive care wards, as well as in endoscopy or veterinary medicine.

to page 1

.

.

MULTISTAR

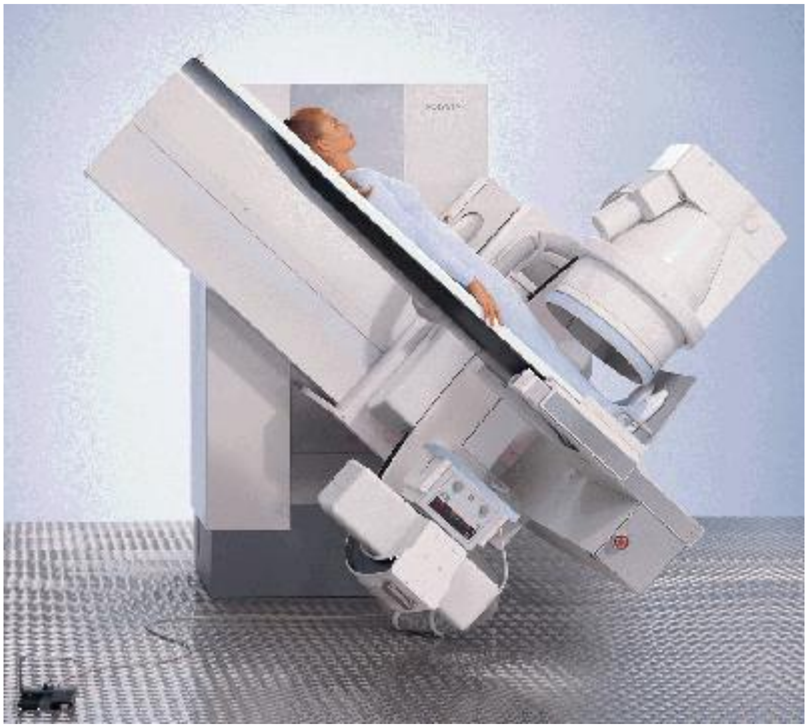
The MULTISTAR system fulfils the requirements for general angiography and card-angiography. The C-arm is ceiling-mounted and has two interlocking C-arms for multidirectional, isocentric projections.

For examinations of the upper part of the body, the c-arm approaches the table from the head side, as demonstrated on the image. Else, the ceiling mounted c-arm is rotated 90° to the rear and the c-arm approaches the patient laterally.

to page 1

.

POLYSTAR



This multifunctional workstation is suitable for both undertable and overtabel exposures. As a +90°/-90° tilting table and integrated C-arm for multidirectional, isocentric projections, the POLYSTAR system is suitable for all interventional examinations, digital angiography and conventional X-ray diagnostics.

Images are generated with a 40 cm large-format image intensifier and a fully integrated digital imaging system.

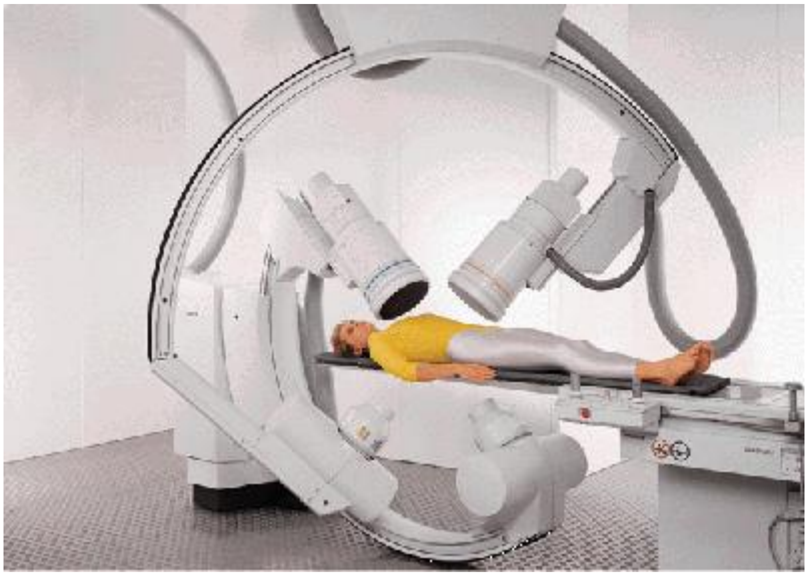
▼ ▲ to page 1

.

.

BICOR

The BICOR and COROSCOP are dedicated systems for cardiac catheterization. These systems are suitable for all diagnostic and interventional* requirements involving cardiac catheterization.



The BICOR is the bi-plane configuration with two isocentric, multidirectional c-arms. The second c-arm is ceiling mounted.

*Interventional technique is the combination of diagnostic and therapeutic procedures using catheters.

▼ ▲

.

.

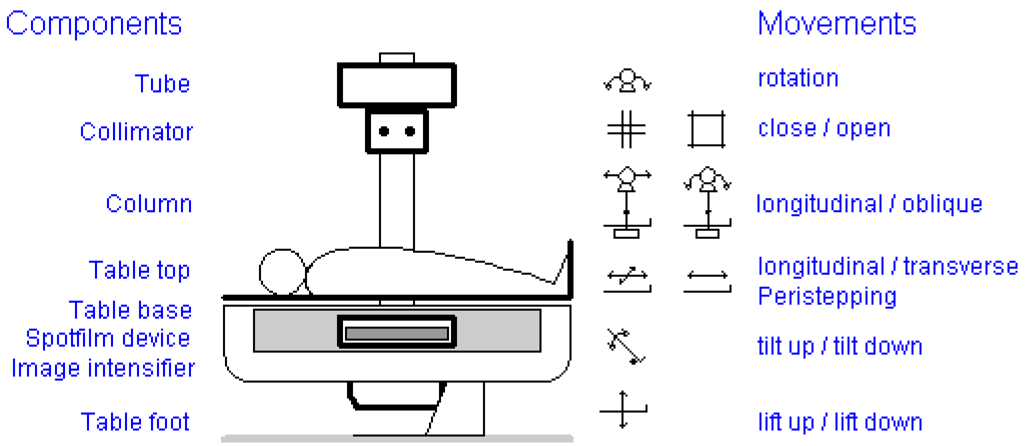
COROSCOP

The COROSKOP is a single plane system for card angiography with a floor-mounted c-arm support.

▲ to page 1 ¶

.

Components and Movements of the Basic Unit



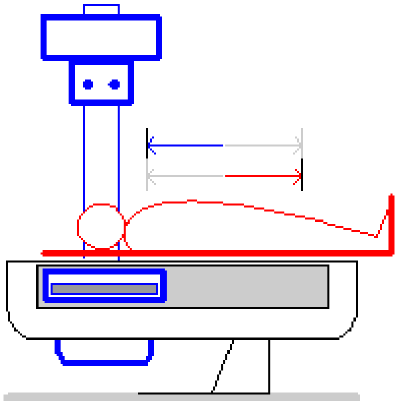
The image shows the components making up an examination unit. Despite of the large variation in examination units, the basic components are identical.
With this SIREGRAPH-type unit, direct technique using film-screen cassettes and indirect technique by means of the image intensifier are combined. Today, units featuring indirect technique only are getting more and more popular.

The movements available are very much dependent upon the specific examination unit. The functions listed above, however, are common to most of the units.

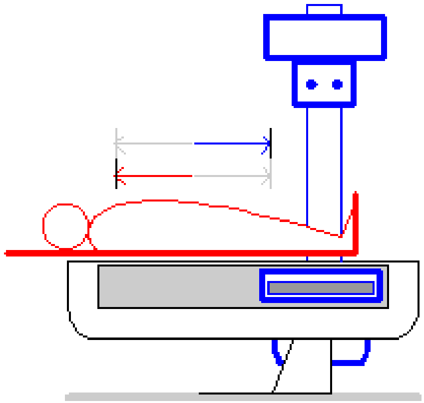
.

.

Examination Range



The longitudinal travel of the spotfilm device depends upon the length of the table base.
The longitudinal travel of the table top is around 50 to 80cm footwards and headwards.



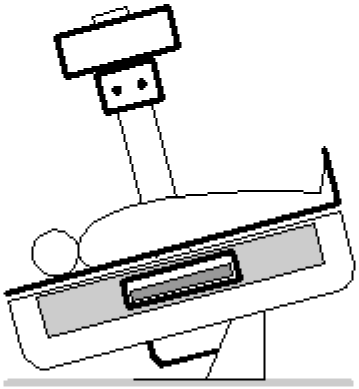
The complete examination range is determined by the combined movement of spotfilm device and table top.

▼ ▲

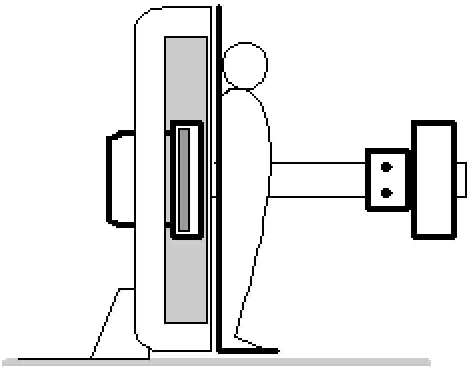
.

.

Tilting Range



Starting from horizontal position, the unit is tilted head down (Trendelenburg) to a minimum of -



The +90° upright position is standard for all universal systems.

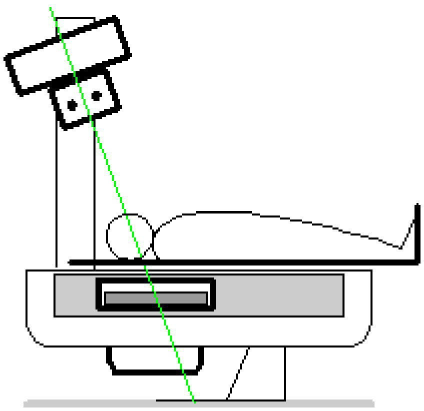
15°.
Complex units allow for -90° head down position by shifting the table base footwards during tilting.

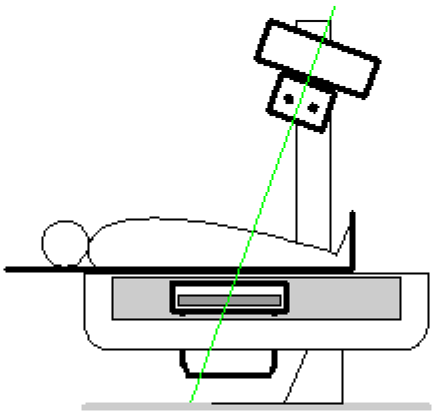
Here, the examination range is given by the length of the table base, and for skull examinations the patient has to sit on the raised foot rest.

.

.

Oblique Projection





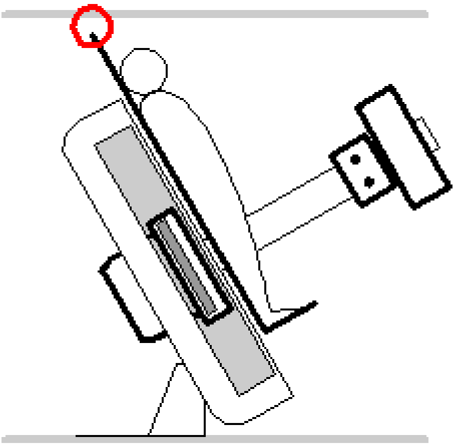
Some examinations, e.g. skull and knee joint require oblique projections.
The unit control is responsible for correct alignment of radiation beam and spotfilm device.

Due to the design principle, the center beam is no longer perpendicular to image plane.
As mentioned earlier, oblique beam directions are not possible with undertable units.

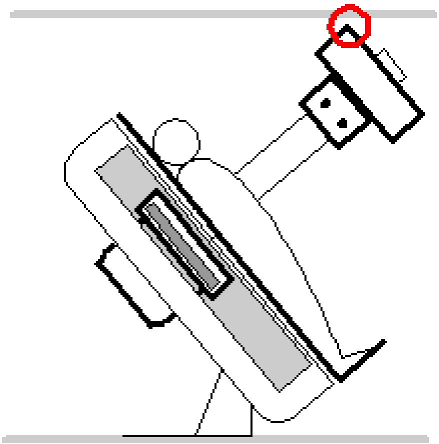
.

.

Collision Detection



A room height of three meters has proved to be optimal. This dimension is sufficient for all radiological purposes.
A lower room height may restrict the medical applications of the system.



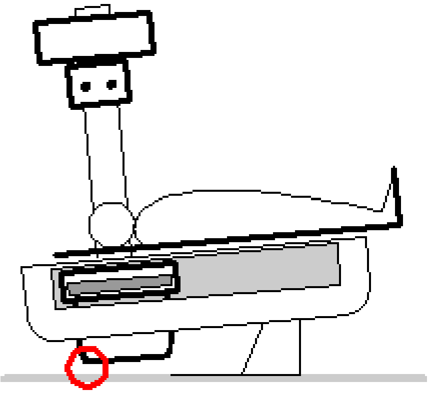
During start-up, the system has to be adapted to the actual room height, and the collision detection restricts movements in combination with the tilt angle.

▼ ▲

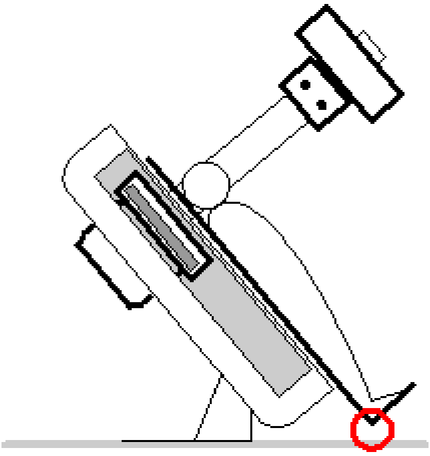
.

.

Collision Detection



As with the ceiling, there is also danger of collision with the floor. The closest distance allowed is 12 cm; any movement closer must be



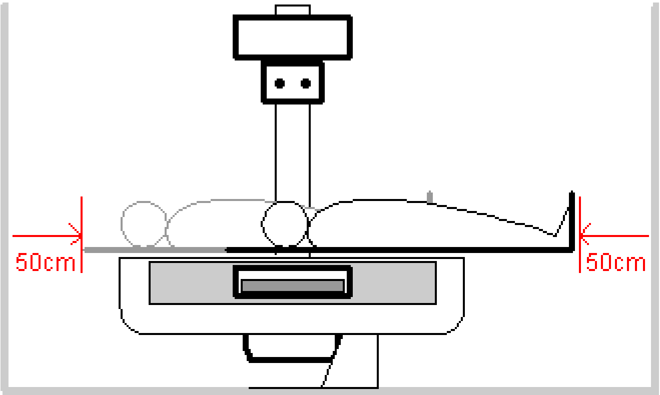
In the left image with the image intensifier in head end position, tilting downwards is stopped, or with the unit tilted to maximum, the headwards combined with an audible warning.

travel of the spotfilm device is blocked.
In the right hand image, tilting upwards is blocked until the table top is flush with the table base.

.

.

Collision Detection



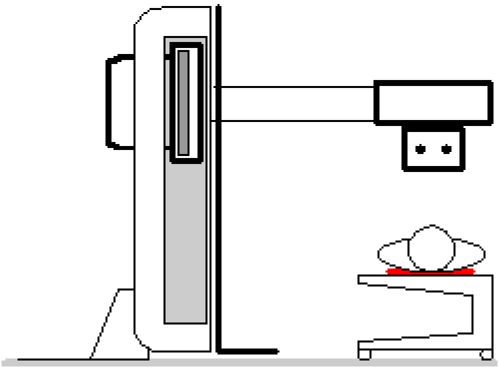
In a narrow room, the longitudinal travel of the table top must be restricted to allow for 50 cm of space between wall and table top.

In very narrow rooms, a restriction of maximum SID may be required in upright position to prevent collision of tube and wall.

.

.

Tube Rotation



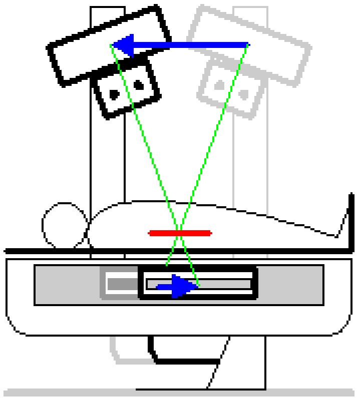
Immobile patients, or emergency cases are examined on a trolley very often. For this, the tube can be rotated in upright position.

This is a function provided by overtable units only.

¶

.

Tomography, Tomographic Exposure



Tomography is defined as:
High-definition imaging of a slice located at a defined tomographic height above the table plane with defocusing the structures located above and below the targeted slice. Tomo angle, e.g. 40° and 20°.

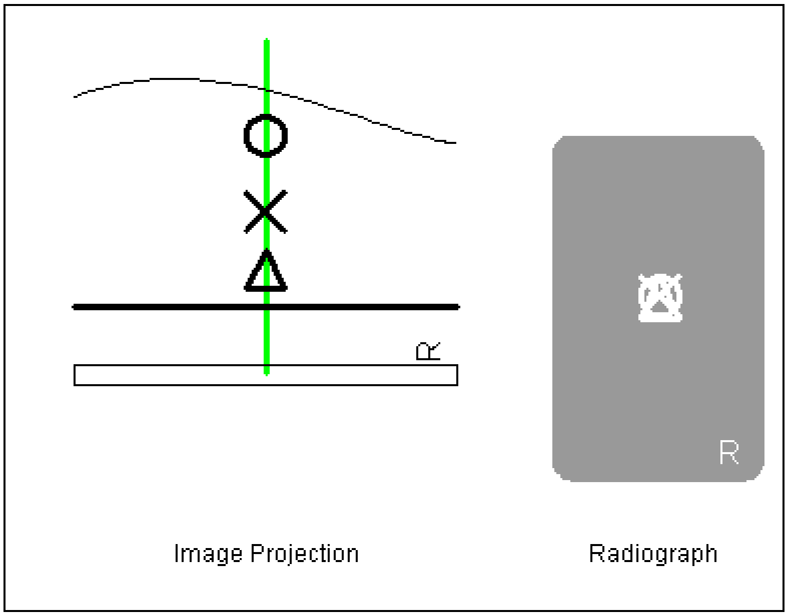
Zonography:
Same as tomography, but with smaller tomographic angles, e.g. 8°, for displaying thicker anatomical slices.

Principle:
During exposure, tube and spotfilm device travel in opposite directions on planes parallel to the table top with the center beam always directed to the center of the film cassette.
The center of rotation demarcates the tomographic layer.
Following an explanation of function:

.

.

Bucky Exposure



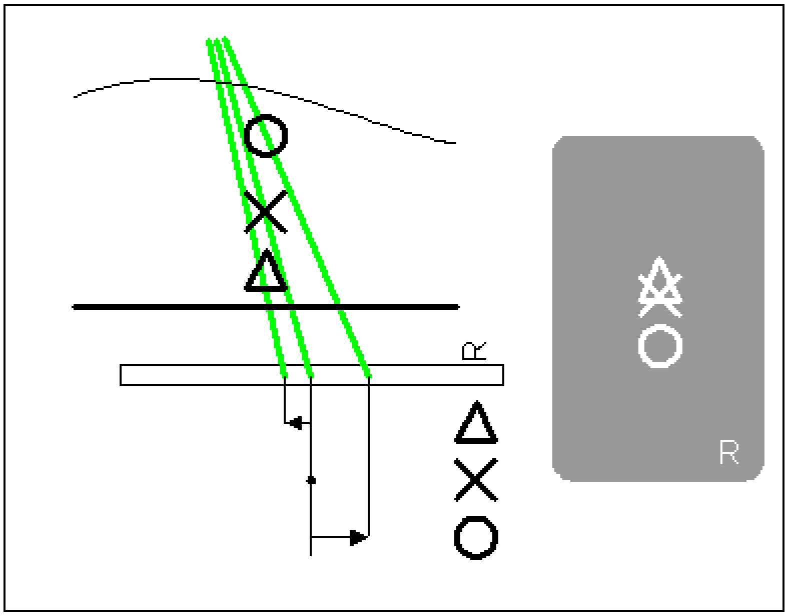
In an ordinary, perpendicular Bucky radiograph, all objects lying in the path of a radiation beam are projected on top of each other on the film.

The evaluation of only one of these objects may prove difficult.

.

.

Cranial Oblique Projection (towards the skull)



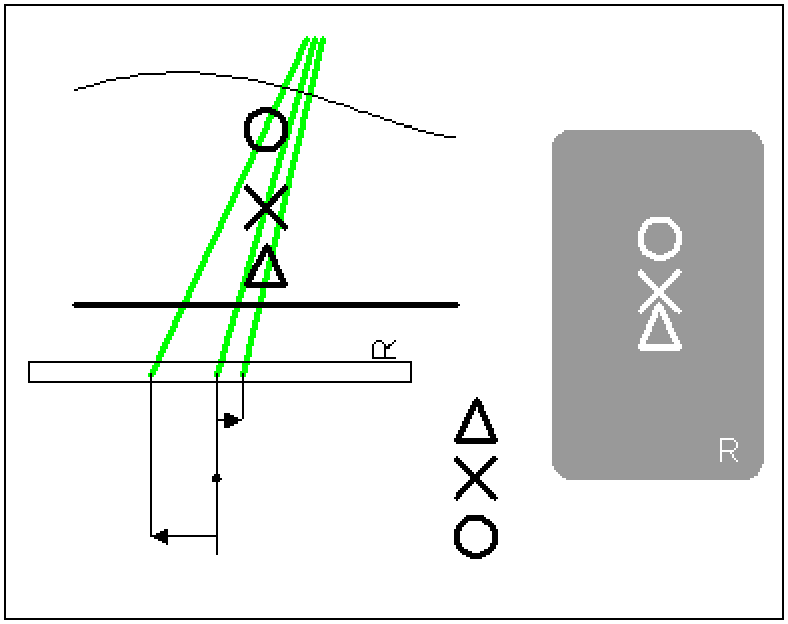
Using oblique projection, the various objects are projected onto different locations on the film. This technique is widely used in angiographic examinations of the skull and the hart (*see isocentric positioning in "C-arm units"*).

The object offset on the film depends on both, the projection angle and the distance of the objects to each other.

.

.

Caudal oblique projection (towards the feet)



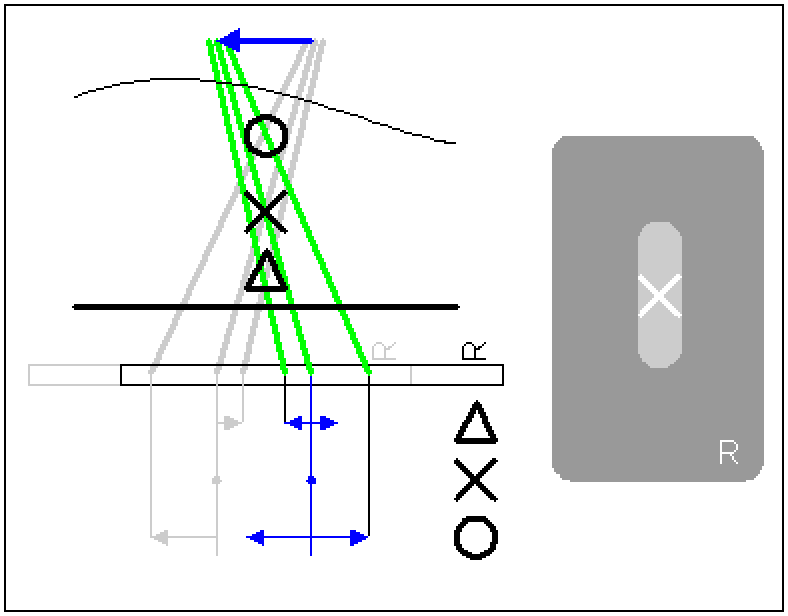
Tilting the projection direction to the other side, changes the projection sequence on the film.

Only the location of the object in the fulcrum, the center of rotation, remains unchanged on the film.

.

.

Tomographic Exposure



During tomographic exposure, the projection angle is continuously changed. Resulting in a blurred reproduction of all objects, except the one in the fulcrum. This one is always projected at the same spot on the film despite of the movement of tube and film.

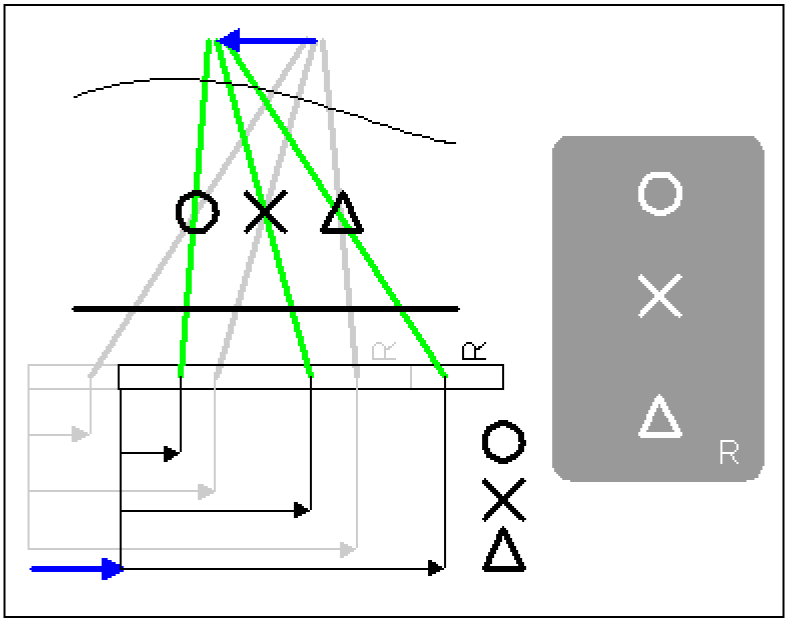
As explained above, the amount of blurring depends upon the the length of travel, i.e. the tomographic angle. A large tomo angle, e.g. 40°; causes a long blurring track and leaves only a small layer of sharpness.
On the other hand, an angle of 8° causes little blurring only and results in a thick tomographic layer.

▼ ▲

.

.

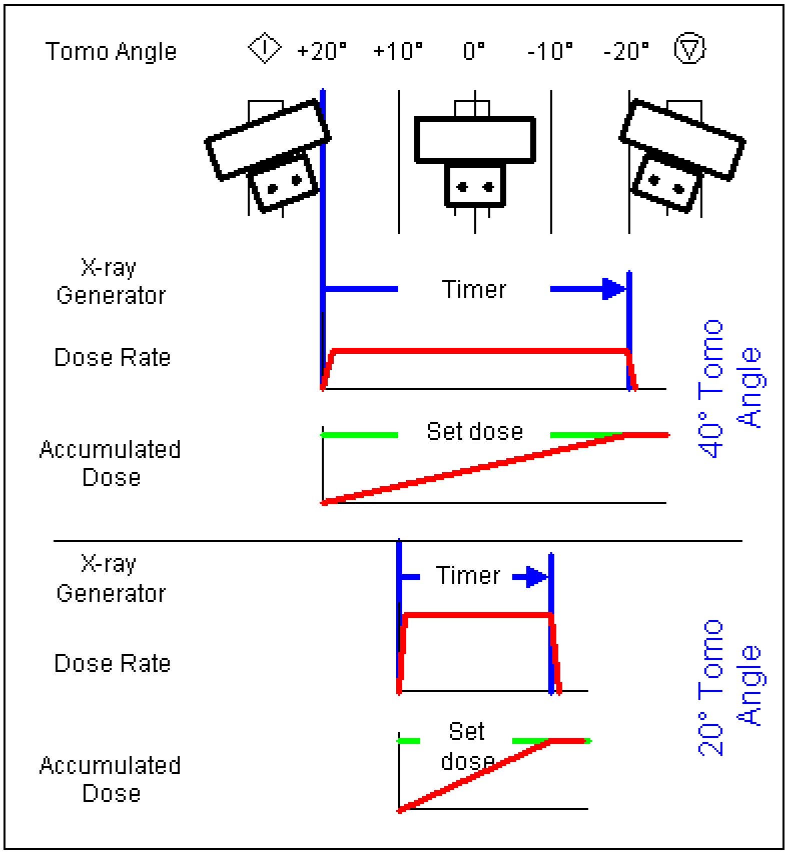
Tomographic layer



As seen above, the object right in the fulcrum is always projected to the same spot on the film during movement.
The same applies to all objects in the fulcrum plane. Their location on film also remains unchanged. However, due to changes in the geometrical conditions, they slightly change in size.

.

.



Control Sequence

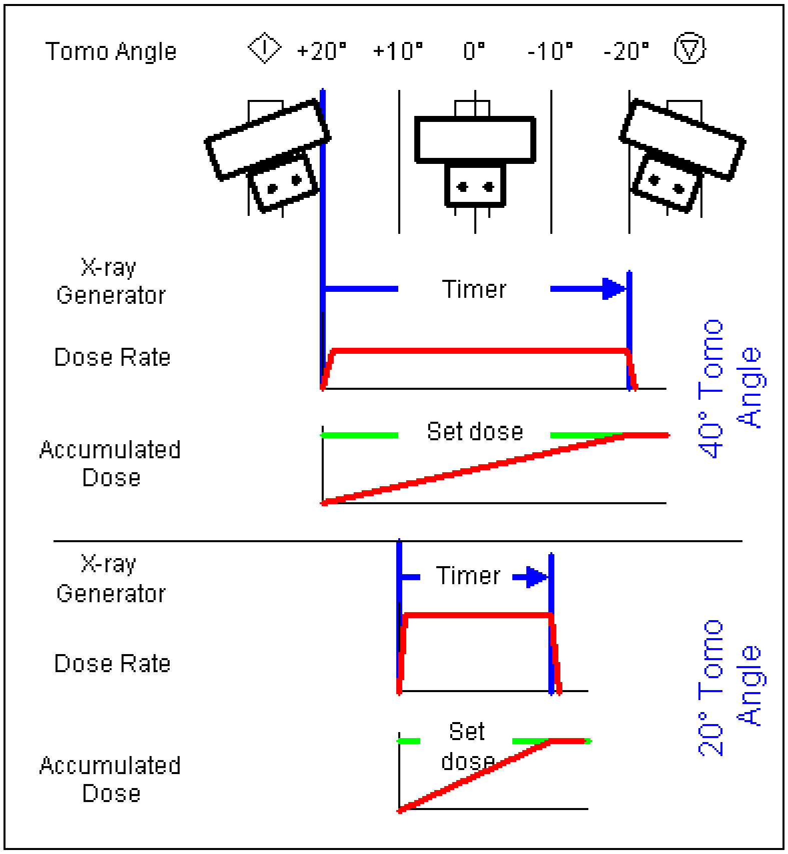
Selecting a tomo program, the speed and angel information is transferred to the examination unit while the information about the time required is passed on to the generator.

On "preparation", the column travels to maximum oblique position.
With "exposure release", the column speeds up, triggers the generator when reaching 20° position and keeps on running with the predetermined speed until reaching the end position.

Triggered, the generator starts the exposure with a dose rate calculated on both, the dose requirement of the film and the pre-set tomo time.

.

.



With the system adjusted correctly, we should have reached our goal:

- The exposure is ended at 20° position (column speed) and
- the film is exposed correctly (exposure control).

The 20° tomography is basically alike. Only the generator has to produce twice the amount of dose rate for providing the dose required in half of the exposure time.

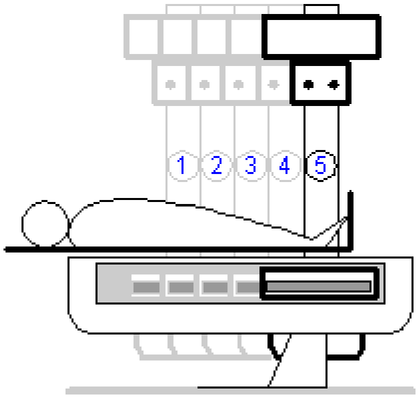
¶

.

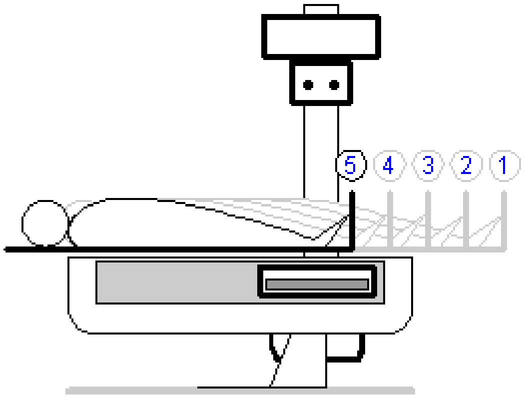
.

Examination Units **Peripheral Angiography** 1/3

Peristepping with X-ray system moving



Peristepping with table top moving



Angiography of the legs is referred to as peripheral or extremity angiography.
For this, contrast medium is injected, and its flow is followed up by the X-ray imaging system.

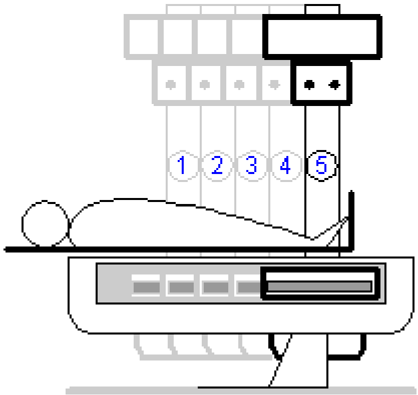
Technically, either the X-ray system or the patient is moved during examination depending on the complexity of the unit.
However, angiography on a patient resting is always preferable.

.

.

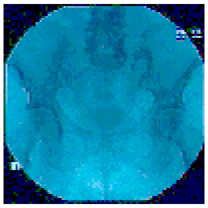
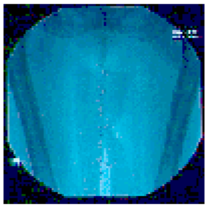
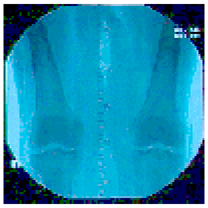
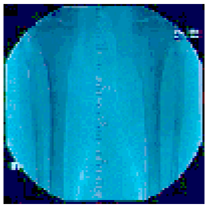
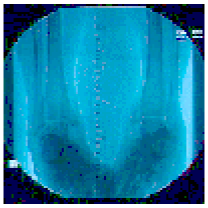
[Examination Units](#) **Peripheral Angiography** 2/3

Anatomical relation



As demonstrated, the full length of the leg must be covered by the stepping procedure. The step width is related to the size of the image intensifier.

Both the rate of exposures and their timing have to be synchronized with the movement.
Modern systems offer a last image hold function allowing for a visual control of the examination progress.

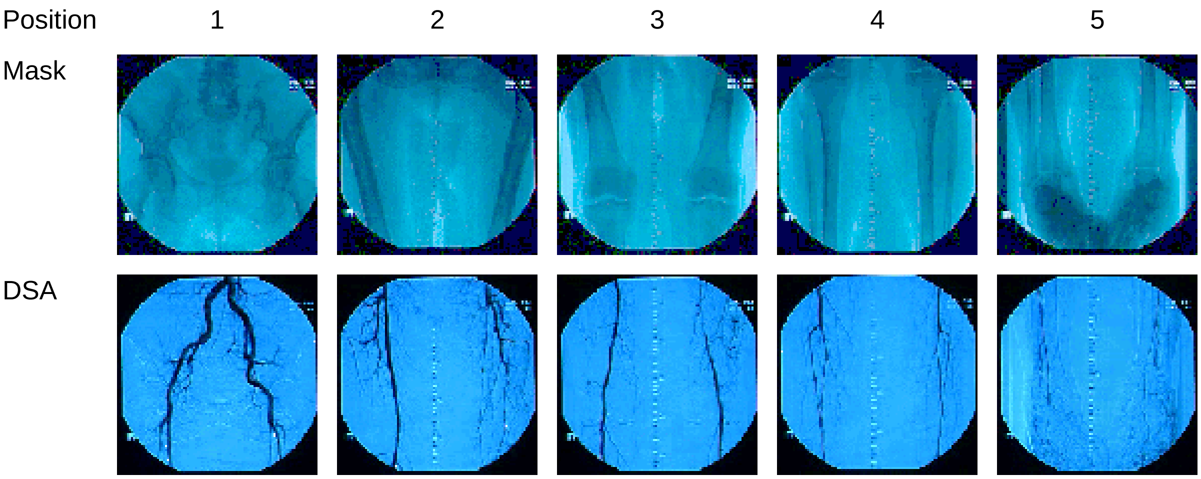
Position	1	2	3	4	5
X-ray image					

.

.

[Examination Units](#) **Peripheral Angiography** 3/3

DSA Digital Subtraction Angiography



Today, peripheral angiography is performed in DSA mode. That is, images are taken without contrast medium in a first run. Next, contrast is injected, and stepping is released under visual control of the contrast medium flow.

Due to the high computing speed of modern imaging systems, subtraction is performed "on line":
By subtracting the mask from the filled image (with contrast medium) the background information is eliminated, and only the difference - the vessel filled with contrast medium - remains.

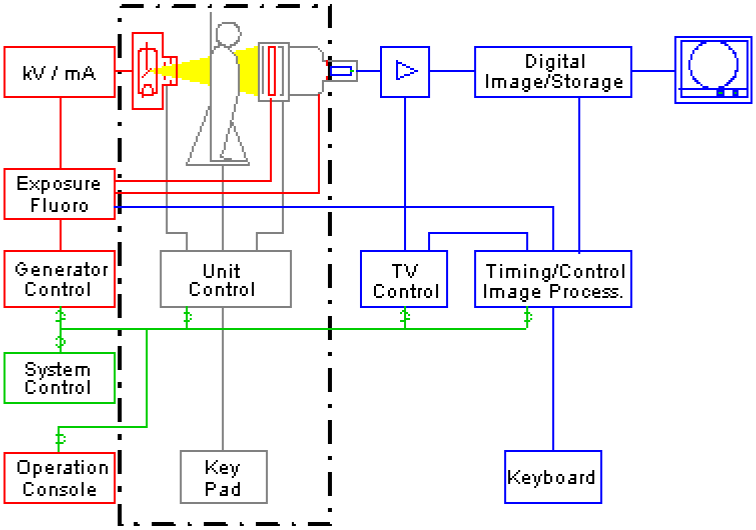
¶

.

.

Examination Units **Drives** 1/9

System environment



e.g. SIRESKOP **System**

Being the radiologists tool, the examination unit represents the complete X-ray system. In fact, however, it is only part of it.

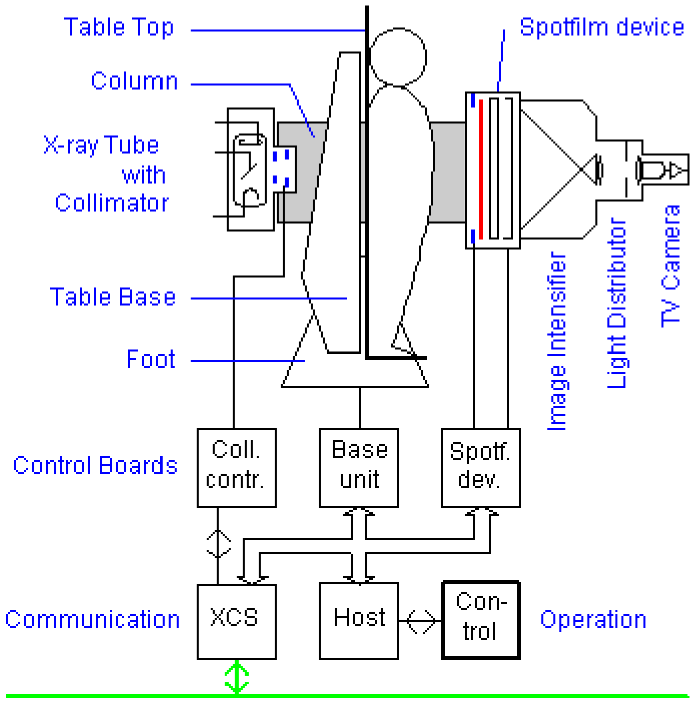
The system control is handled by the system controller (XCU), while the **unit control** is responsible for the unit movements including collision detection and safety circuits.

The **unit** movements are controlled by either a table side key pad or a remote control.

.

.

Unit Environment



e.g. SIRESKOP **Subsystem**

The **operation commands** are transmitted from the control console/pad to the host via serial transmission.
Checking the current situation, the **host** releases or blocks the movement selected.
During movement, the host controls the speed and supervises the movements progress.
The **drive controls** for each individual motor are located on several control boards.

Each of the three major components

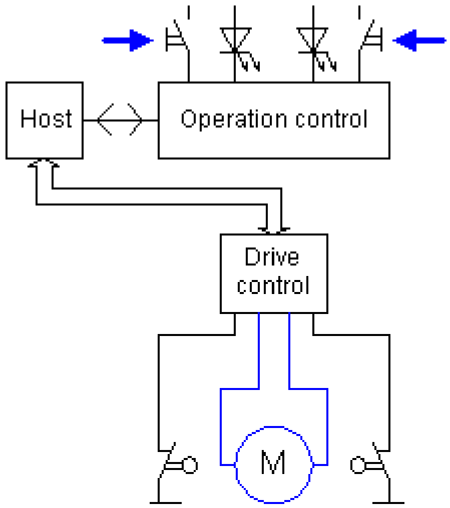
- collimator
- base unit and
- spotfilm device

has got its own set of control boards.

.

.

Small Drives



With modern units, all movements are computer controlled:

- The key pressure is detected by the operation control and transferred to the host via serial communication.
- The host decides to release or inhibit the movement. Releasing the movement, a command is returned to the operation control to light up the appropriate LED.
  Another command to the drive control starts the movement.

In general DC motors are used, however, sometimes manufacturing costs call for AC motors. With this simple kind of drives, the movement is stopped by switches when the end of mechanical range is reached.
Typical applications are:

- Table top transverse and
- grid in/out.

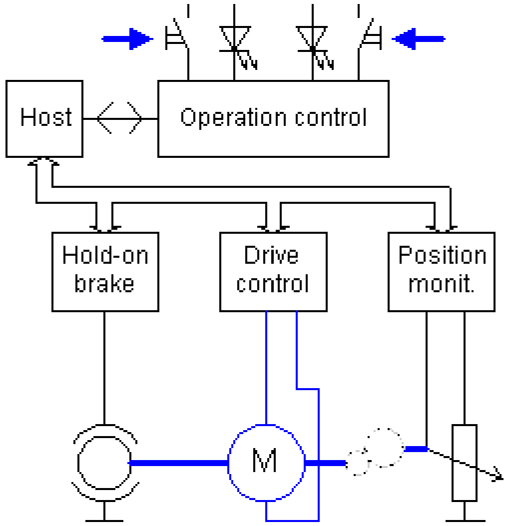
▼ ▲

.

.

Examination Units Drives 4/9

Medium Drives



This is the standard drive, used again and again.

To make sure that the drive is locked invariably in its position, a **hold-on brake** is is energized continuously. It is released only before the motor starts running and engaged again after the movement has been completed.

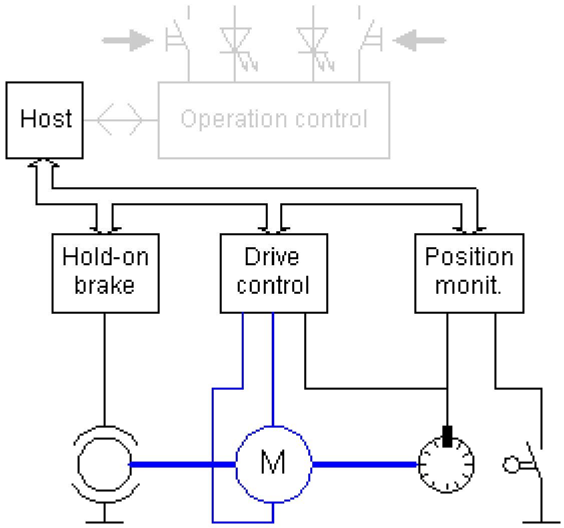
Both progress of the movement (supervision of movement) and actual position of the drive (collision detection) are monitored by a **potentiometer**.
Notice, that the potentiometer is always located behind the transmission. So, a slippy transmission or a movement without actuation can be detected.

The **motor** speed is set by the host and controlled by pulse width modulation. Start and stop characteristics sometimes are optimized using ramp functions.

.

.

...Encoder Controlled



In general, encoder controlled drives are used in situations where the movement is completely controlled by the host and where accurate positioning is required.
A typical application is the cassette carriage drive inside the spotfilm device.

Since the **encoder** is located on the motor shaft its pulse train reflects the motor **speed** perfectly. Counting the pulses, the actual **position** is monitored. Normally, two pulse channels are provided having a slight offset. This serves for detection of rotation.

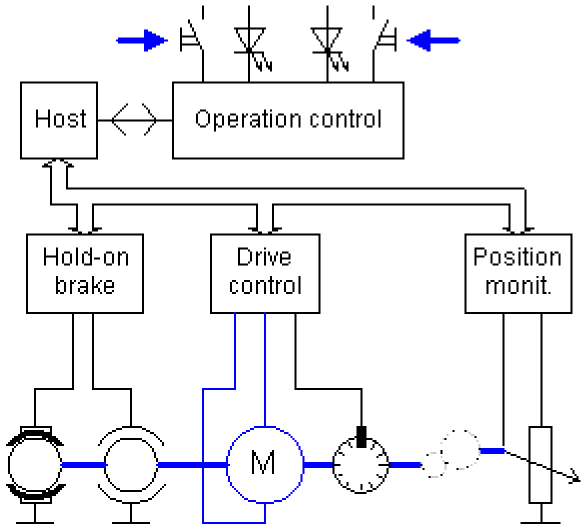
On initialization, the motor starts a search run at slow speed. When it hits the **search run switch,** located at the end of the mechanical range, the position counter is set to this reference position.

Due to the speed feedback the drive control is able to vary speed and direction of rotation for precise positioning.

.

.

Power Drives



These drives are used to operate heavy loads as system lift and system tilt.

For keeping the drive in place when the power is off, a permanent magnet on the motor shaft is used as a **locking brake**. With power on, the locking brake is electrically disengaged and the hold-on brake takes over.

Using the speed feedback of the encoder, the drive control acts as a **four-quadrant drive**; i.e. acceleration and speed are regulated by pulse width modulation while deceleration is achieved by changing the polarity.

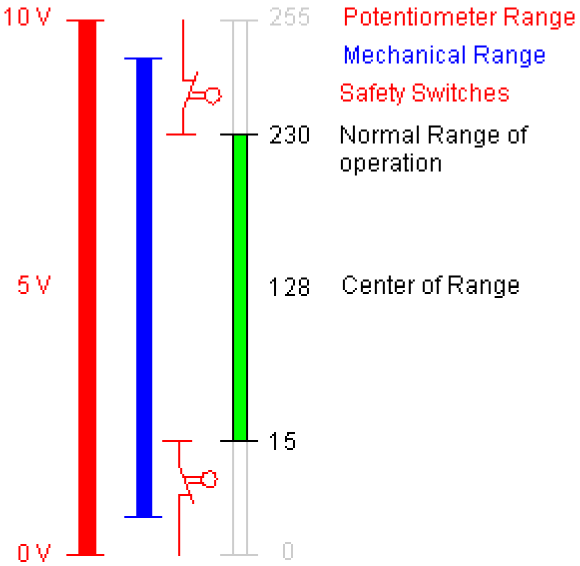
Drives of this kind are ideal when **combined, synchronized movement** of several drives is required. For instance, shifting the table base during tilting.

▼ ▲

.

.

Position Monitoring



All drives of the base unit use potentiometers for position monitoring since a search run procedure carries the risk of injuring people.

The **potentiometers** used are of the 10-turn type with the mechanical range somewhat larger than the mechanical range of the movement. This is achieved by a specific design of the potentiometer transmission. The analog information is digitised before used by the computer. Normally, the computer allows for movements within the **normal range of operation** only.

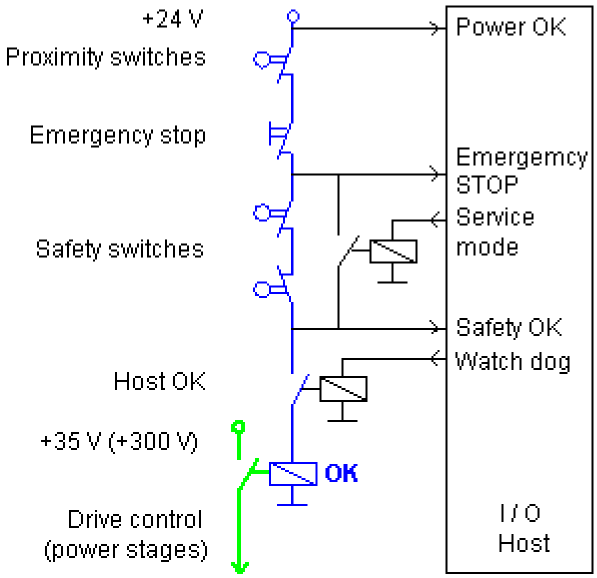
The **safety switches** are operated only in case of malfunction and cut off the power before the drive hits the **mechanical end** stop.

In the **center** of a movement, position monitoring should always read 128. This is also the position to adjust the potentiometer.

.

.

Safety Circuit



The purpose of this circuit is to integrate all safety relevant functions in one common circuit and cut off the power supply of all drives if only one function is disturbed.

Proximity switches
This means collision protection with obstacles standing on the floor. For this, there are several switches located at strategic points of the table base. Additionally one may have contacts defining the parking position of a tube stands.

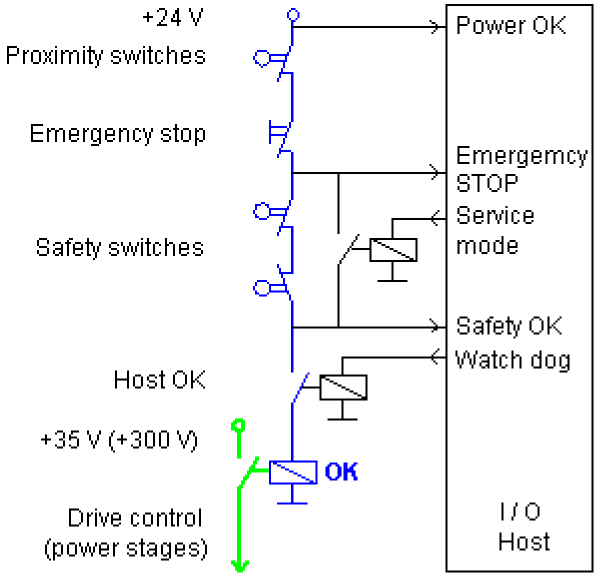
Emergency STOP
These switches are located at the table base and at the control consoles as well.

Safety switches
As explained above, all major drives of the table base are equipped with these switches, and all of them are connected in series.

.

.

Safety Circuit



Host OK
This is a "safety switch" of the computer system. A so called watch dog procedure must be processed by the software periodically keeping the relay energized. If the software hangs up, the relay drops off after a while stopping all movements.

Service mode
Using a special service mode, the drives can be operated over the full mechanical range at slow speed.

Input to the host
The host is informed about the unit condition via various inputs and generates appropriate error messages in case of malfunction.

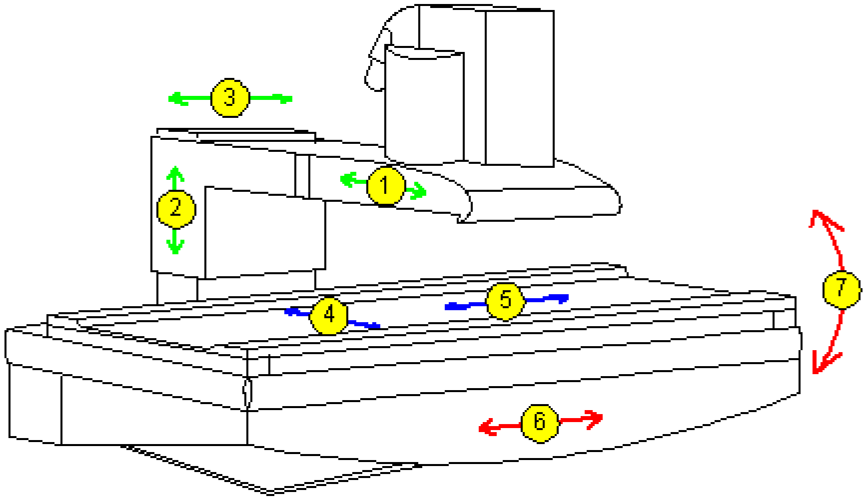
.

.

Examination Units **Base Unit** 1/10

Movements

Undertable unit SIRESKOP



Manual movements

1. Spotfilm device transversal

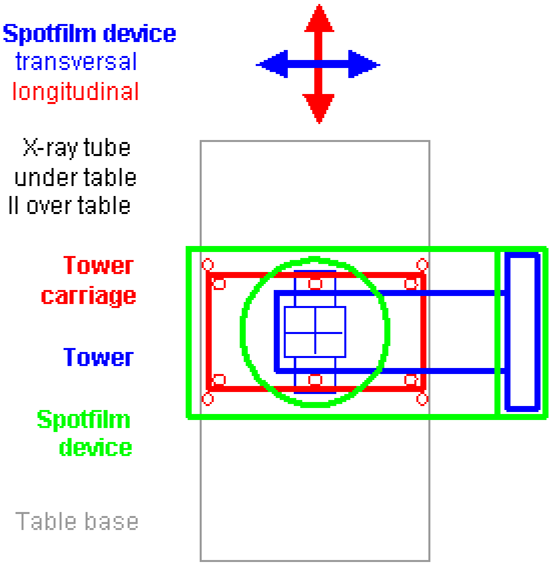
Motorized movements

4. Table top transversal
5. Table top longitudinal

.

.

Spotfilm device transversal



In case of undertable units, the radiologist **operates the spotfilm device** directly using a handle. During examination, the radiation beam is moved transversally and longitudinally following the flow of the contrast medium.

This top view shows the tower carriage travelling inside the table base, holding the tower. This is the **longitudinal movement**.

The tower, holding tube and spotfilm device, **moves transversally** inside the tower carriage.

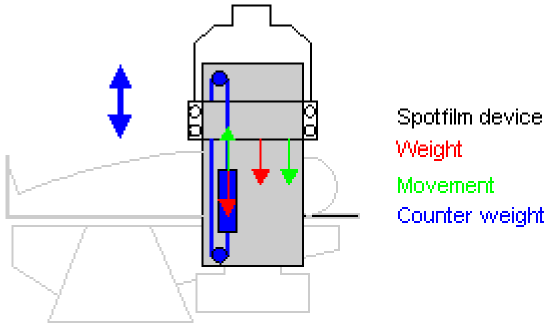
This transversal movement is completely missing in overtabel units. Table top transverse is used instead.

to page 1

.

.

Compression



The Spotfilm device has a weight of about 150kg and is heavily attracted by the gravity. For balancing, a **counter weight** is introduced. This relatively simple design effectively compensates the spotfilm device's tendency to fall down.

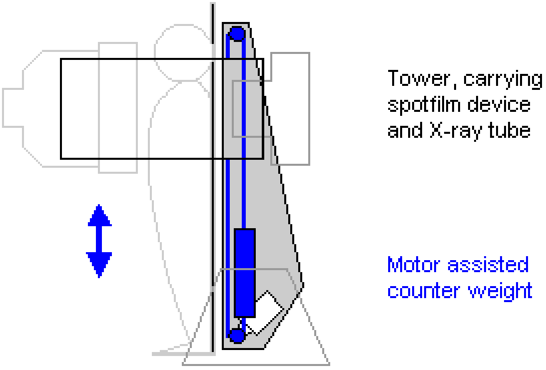
However, the proper weight of the column is doubled and, additionally, the momentum of the spotfilm device movement is increased. To overcome these problems, spring loaded devices are sometimes used; having problems of their own.

▼ ▲ to page 1

.

.

Spotfilm device longitudinal



Basically, spotfilm movements of undertable units are all manual. However, due to the significant weight and the inherent momentum of tower with spotfilm device **a motor assists** the movement whenever the handle is moved in longitudinal direction.

The **position monitoring** detects possible collision and may even upright the table base from head down position before colliding with the floor.

Overtable units

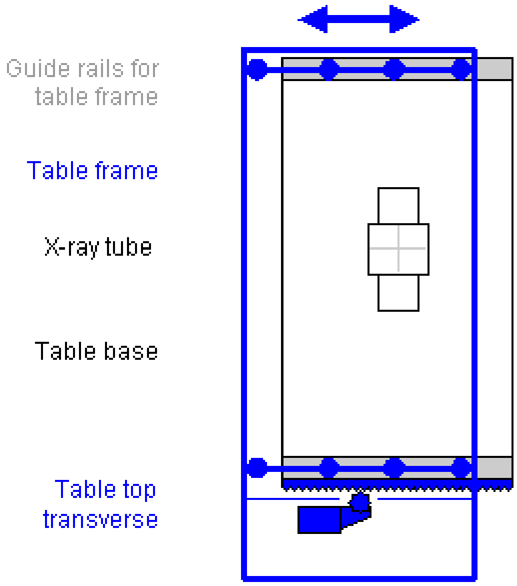
Here, the spotfilm device movement is a drive as any other. With some units we have a sequenced action. That is, when the spotfilm device reaches the limit, table top longitudinal is started automatically with the same key pressure.

▼ ▲ to page 1

.

.

Table top transversal



Between table base and table top supporting the patient lies the **table frame** providing transversal movement.

The design shown here uses a rack and pinion gear for this. This is a simple, straight forward design, however, it supports only the foot side of the table frame. More complex systems support both ends resulting in smoother performance.

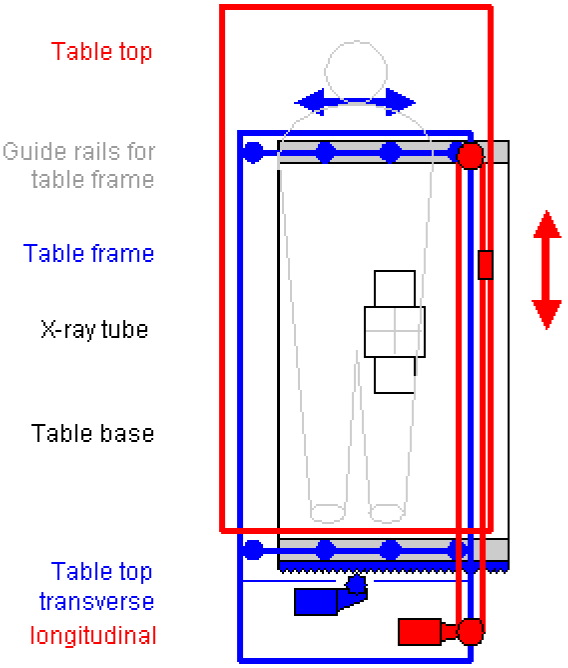
The electrical drive is a simple one using end switches since position monitoring is not required.

▼ ▲ to page 1

.

.

Table top longitudinal



Mechanical wise, table top longitudinal is a simple motor and chain affair between table frame and table top.

The drive, however, is somewhat more complex since it requires position monitoring for **collision detection** with floor, ceiling and wall in combination with the tilt movement.

▼ ▲ to page 1

.

.

System tilt

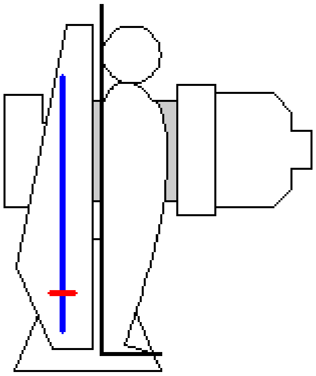
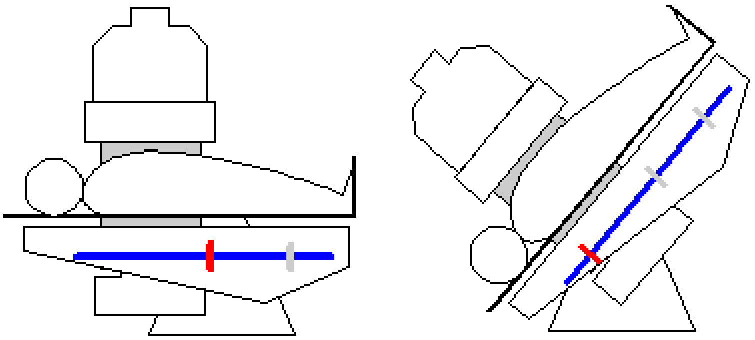


Table base longitudinal is a movement required only **in combination with tilting**. As demonstrated, the table base is shifted along the blue line when tilting. Providing a wide tilting range (down to -90° head down position) and a

Table base longitudinal



In modern units, the longitudinal movement is achieved by its own drive, electronically coupled to the tilt movement. Mechanical solutions where used in old systems.

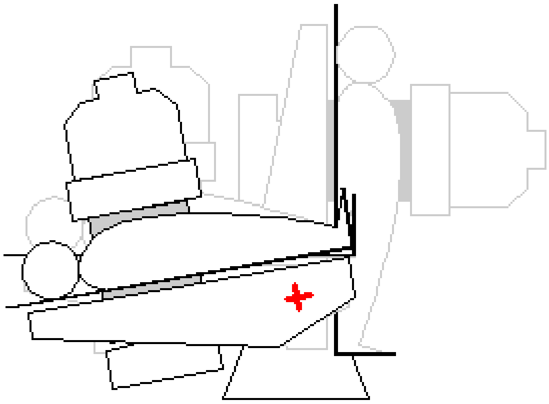
low table height at the same time.

▼ ▲

.

.

System tilt



Simple units having a tilt drive only are limited in the head down position. They usually allow for a **maximum of -15°** Trendelenburg position which is sufficient for most examinations.

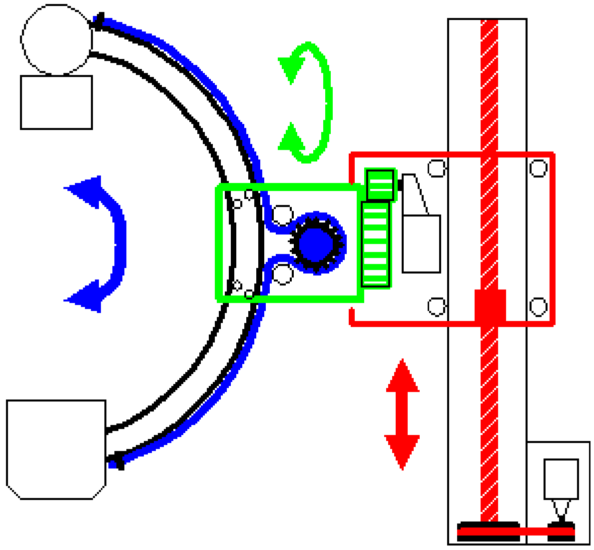
With this unit, a lot of room space is required in horizontal position and full headwards excursion of the table top.

▼ ▲ to page 1

.

.

C-arm units



In C-arm units, we find three typical design solutions:

Orbital movement of the C-arm
A toothed belt, fixed to the ends of the arm, is wound around a toothed wheel.

Angulation, rotation
Here, a straight forward transmission consisting of toothed wheels is used.

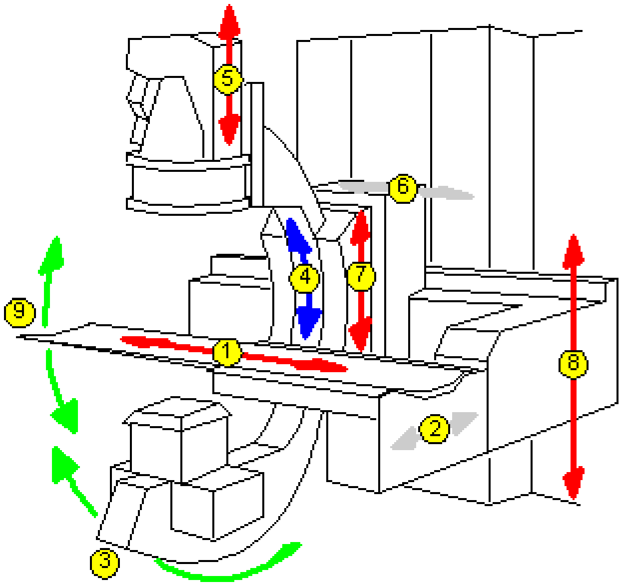
Lift movement
This is a spindle and nut affair driven by a belt.

With the exception of self-locking gear boxes, all drives are equipped with locking magnets. Speed regulation and position monitoring are standard.

.

.

e.g. POLYSTAR



The image demonstrates how the various drive designs are used:

Spindle drives
1. Table longitudinal
5. Image intensifier lift
7. Isocenter lift
8. System lift

Toothed wheel drives
3. Isocenter angular
9. System tilt

Toothed belt drive
4. Isocenter orbital

Rack and pinion drives
2. Table transverse
6. Isocenter longitudinal

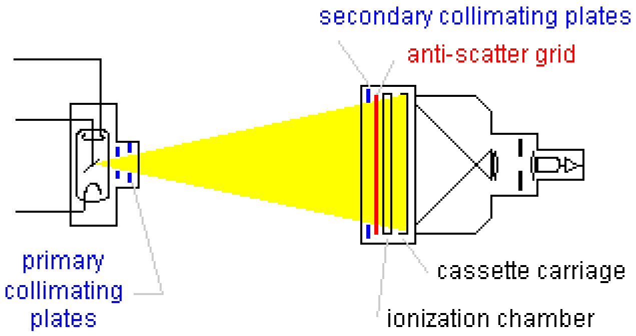
to page 1

¶

.

.

Subsystems



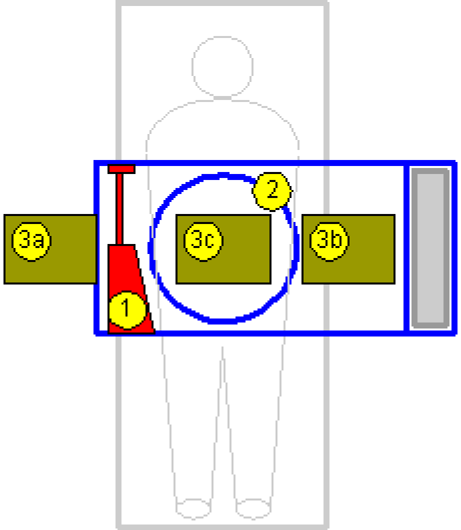
The spotfilm device houses following subsystems:

- Secondary collimating plates. Function wise they are part of the collimating system.
- The anti scatter grid. It is used to suppress the scattered radiation and can be moved in and out.
- The **ionization chamber** which is used to measure the amount of radiation in direct technique.
- The **cassette carriage** as a part of the cassette system, holding and positioning the cassette.

.

.

Functions



Numerous designs of spotfilm devices exist; each reflecting the respective state of the art.

The overtable spotfilm device introduced here is of modern design; identified by only a minimum of mechanical parts and extensive use of software control.

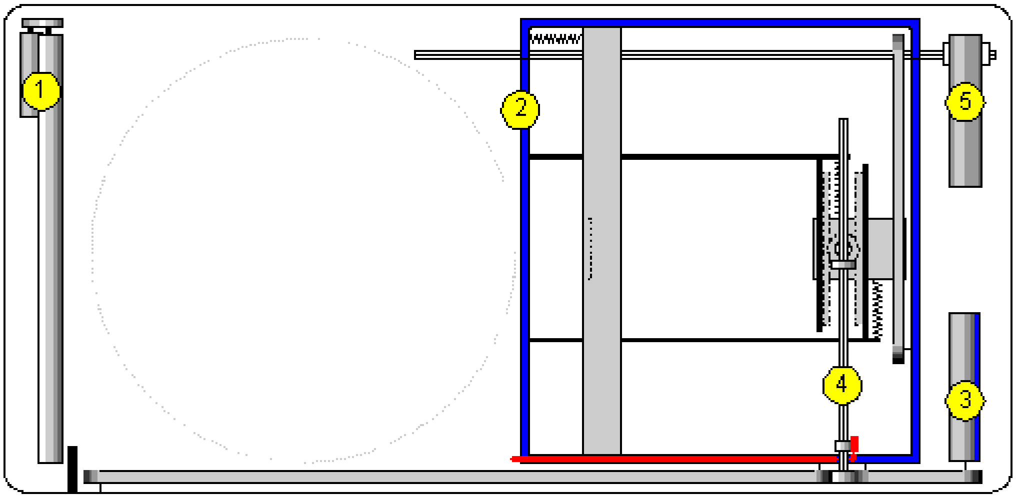
1. **Control pad** for all unit controls including vital system functions and a handle for moving the spotfilm device manually.
2. **Image intensifier** for fluoroscopy and indirect exposure techniques.

3. **Cassette system** in front of the image intensifier:
   3a Cassette feeding
   3b Park position
   3c Exposure position

¶

Cassette system

Subassemblies



1. Feeding rollers
A pair of rollers to catch the cassette and push it

2. Cassette carriage
travelling inside the spotfilm device carrying the

into the cassette jaws and, after exposure, eject the cassette.

cassette holding jaws system (4).

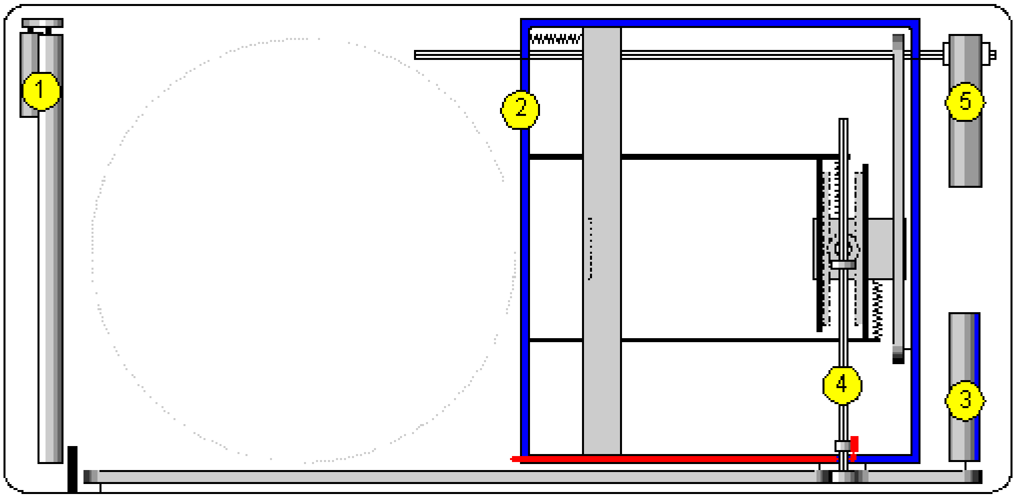
3.Cassette carriage drive
operating both the cassette carriage and the jaws system.

.

.

Cassette system

Subassemblies



4. Jaws system
is receiving the cassette, holds it firmly during transport and hands it over to the feeding rollers after exposure.

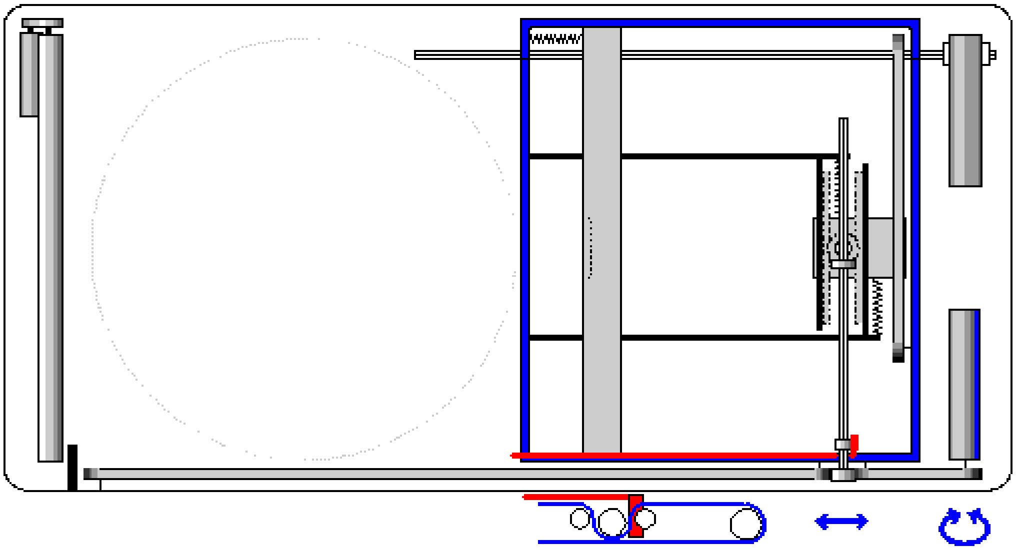
5. Cassette lift
centers the cassette in exposure position. When subdividing the cassette, it centers to the subdivided fields.

.

.

Park position

Cassette carriage drive



The drive is encoder controlled for both speed and position. A belt connects motor and jaws drive (see detail). With the jaw´s drive locked as shown, any motor rotation makes the cassette carriage move.

During movement, the position counter is continuously updated by the encoder pulses. Depending on the actual position, the motor speed is varied.

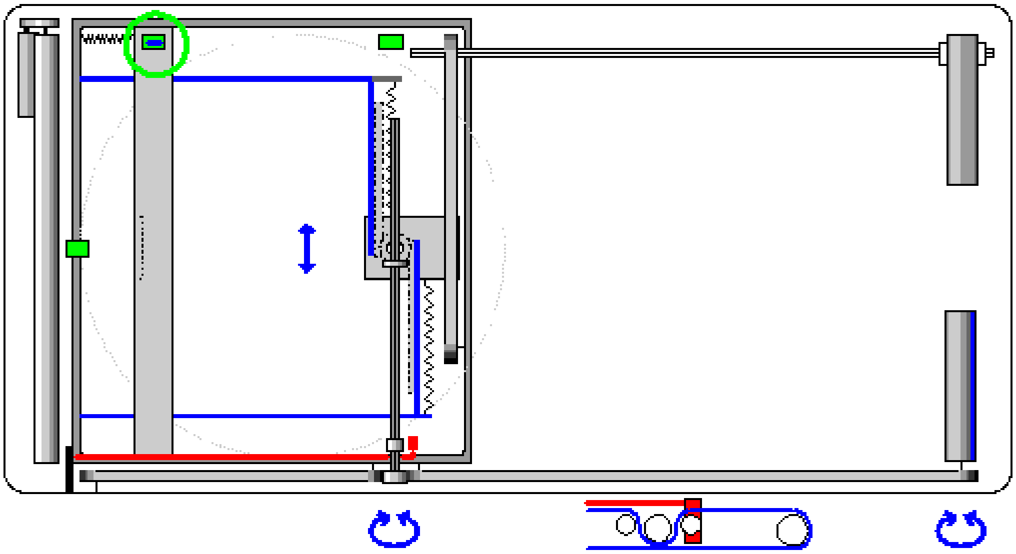
▼ ▲

.

.

Load position

Jaws drive



Hitting the end stop in load position, the carriage is stopped mechanically, and the jaws drive is unlocked.
With the motor still running, the jaws drive starts rotating and forces the spring loaded jaws open by means of a rack and pinion gear.

The movement is stopped when the jaws are fully open which is recognized by the position counter reaching a pre-set limit value.
In this cassette slider position, vane (green circle) interrupts a light barrier signalling that no cassette is inserted.

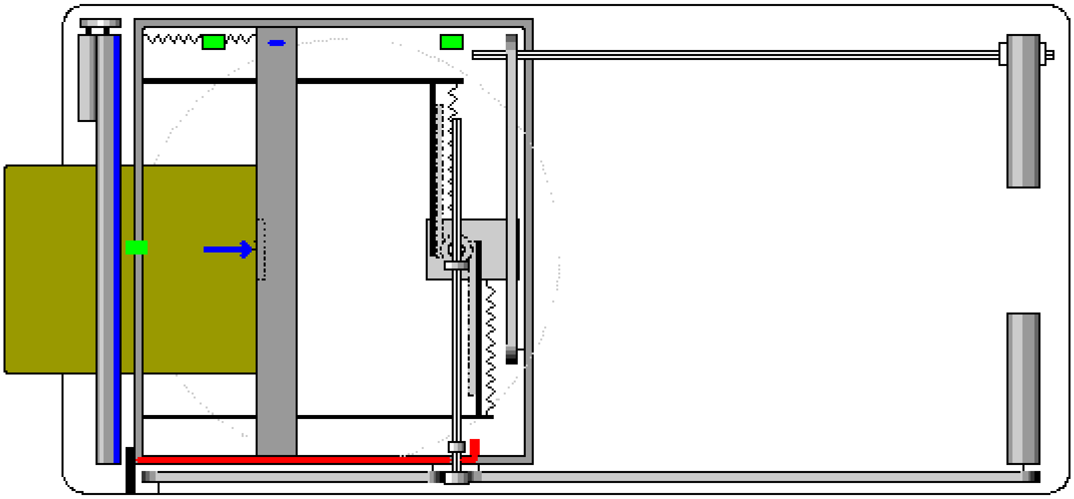
▼ ▲

.

.

Cassette feeding

Feeding rollers



The cassette is manually forced between the pair of rubber rollers activating a switch, and the motor starts feeding the cassette.
The cassette's front end is received by the cassette slider keeping the cassette in level while the jaws are still open.

With the slider moving out of it's rest position, i.e. the light barrier, successful cassette insertion is detected.
After feeding-in the cassette completely, the rollers drop back in rest position deactivating the switch, and the next step is initiated.

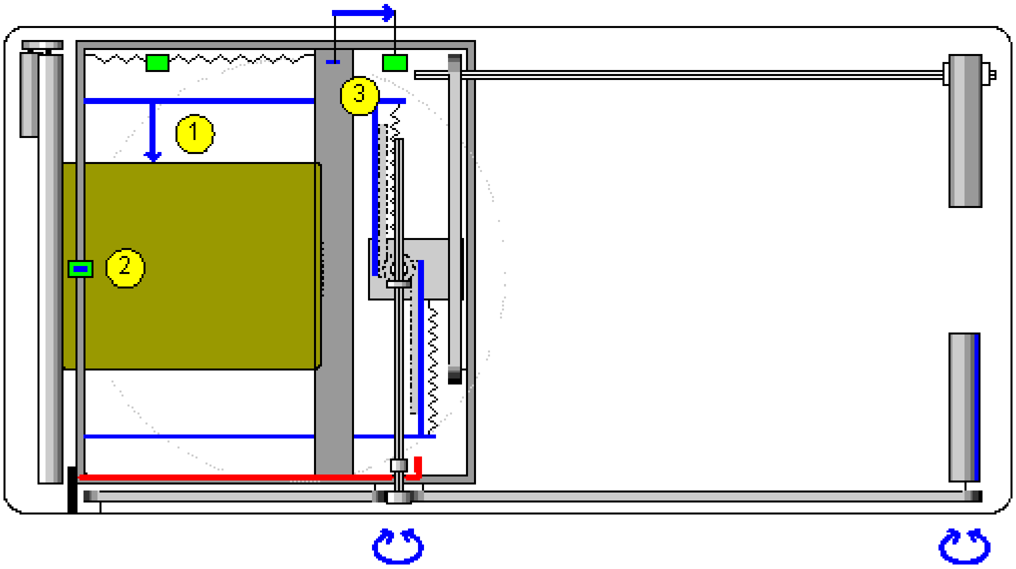
▼ ▲

.

.

Format sensing

Control of subdivisions and field size



The information of cassette size is vital to the collimator control as well as for subdividing the cassette for several exposures.
Format sensing is carried out while the cassette carriage travels from load to park position using the position sensing counter.

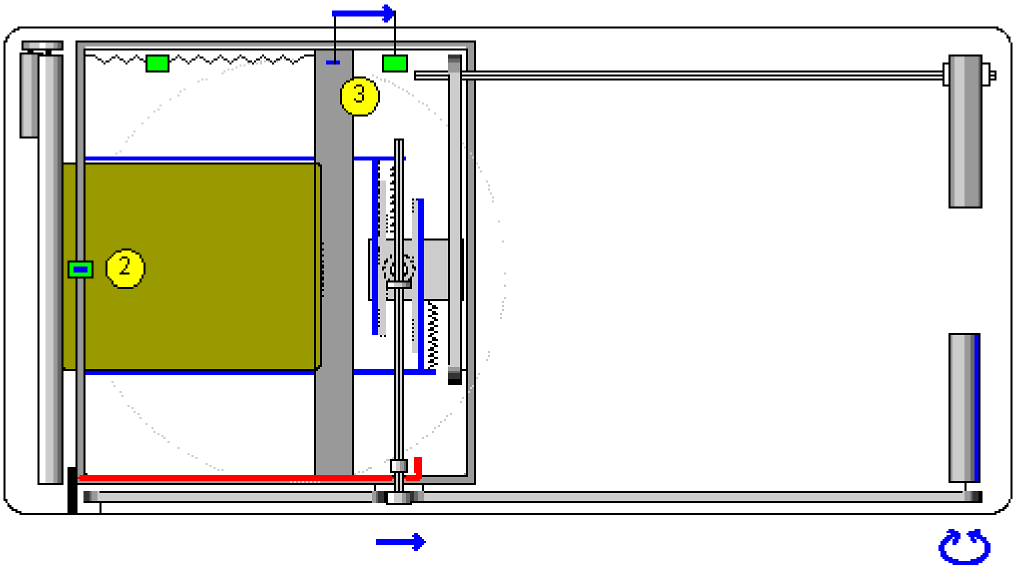
1. Starting the motor, the jaws are closed until they hold the cassette tightly and the jaws system is mechanically locked.
All the way, the encoder pulses are counted indicating the cassette height. The more pulses, the smaller the cassette.

.

.

Format sensing

Control of subdivisions and field size



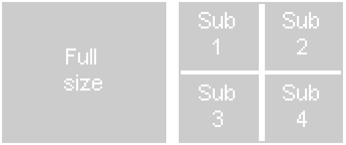
2. With the jaws locked by the cassette, the cassette carriage starts moving and it's vane leaves the light barrier. This ends the height measurement and starts the width measurement.
3. Again, the encoder pulses are counted until the vane on the cassette slider interrupts the light barrier. A large cassette requires a small way to travel resulting in a small width value. The motion is ended when the cassette carriage reaches the park position.

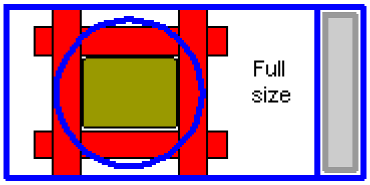
▼ ▲

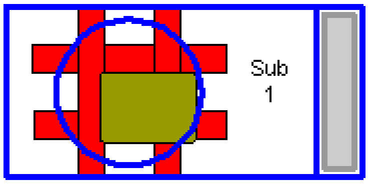
.

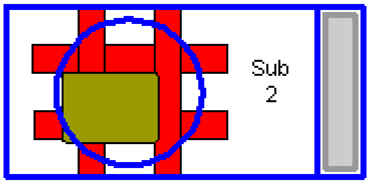
.

Subdivisions



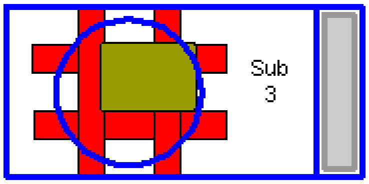


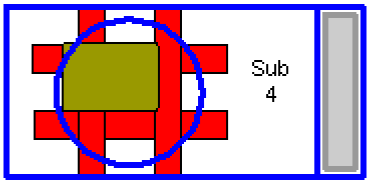




Sets of **secondary collimating plates** (red) are located inside the spotfilm device in front of the cassette plane serving for a close collimating of the radiation beam. Keep in mind that the field size in general is set by tube side primary collimating plates.

For saving film, several small exposures are brought onto one





single film.

For this, first the radiation **field size** is set accordingly and next, the appropriate cassette **exposure position** is set by a combined movement of cassette carriage and cassette lift.

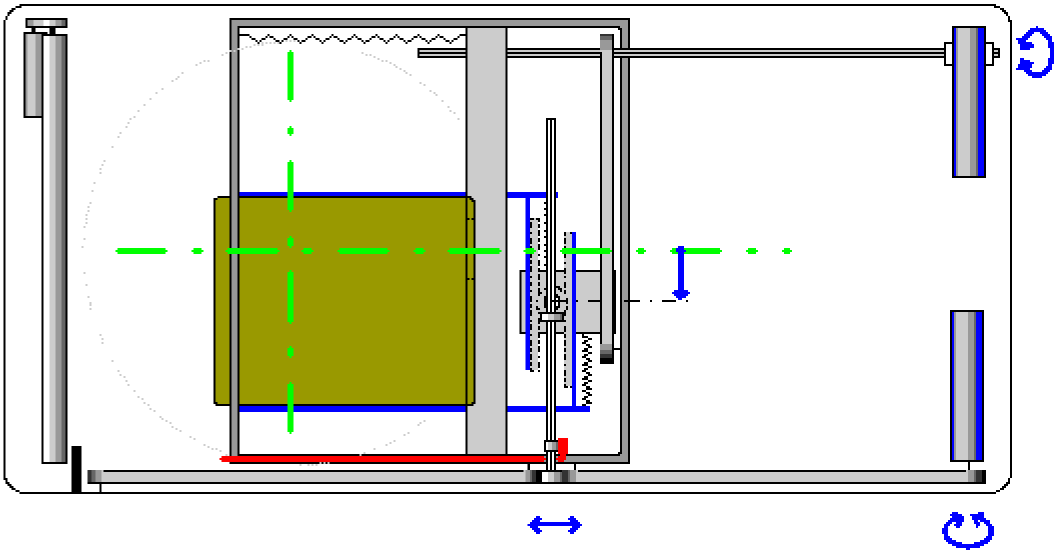
to page 1

.

.

Subdivisions

Cassette lift



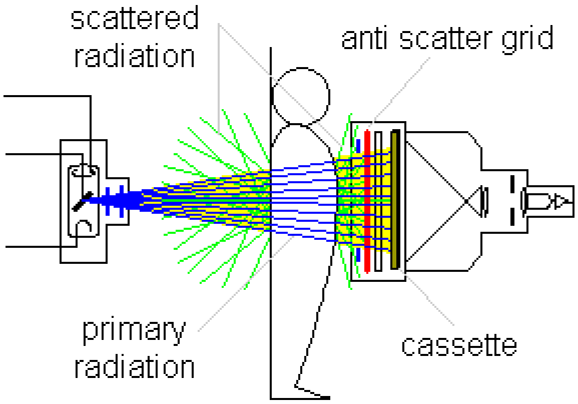
The **cassette lift** is, again, an encoder controlled drive positioning the complete jaws system in longitudinal direction. For subdivisions, the jaws system has to be offset from center position by ¼ of the cassette height.

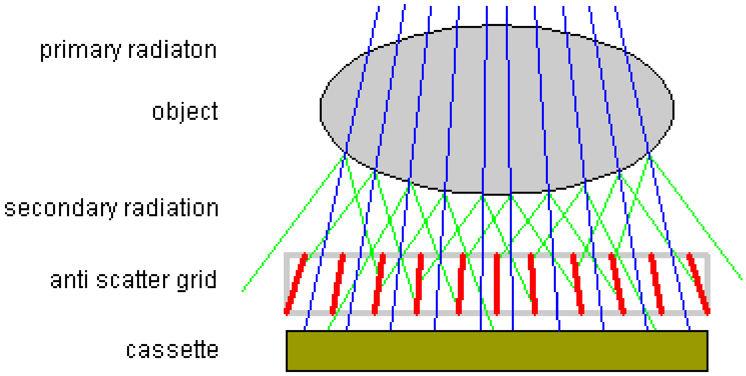
The **cassette carriage**, also, has to stop in a "decentered" position. Again, the amount of offset is ¼ of cassette width.
In serial mode, the cassette is moved from one exposure position to the next without returning to the park position in between the exposures.

to page 1 ¶

.

.



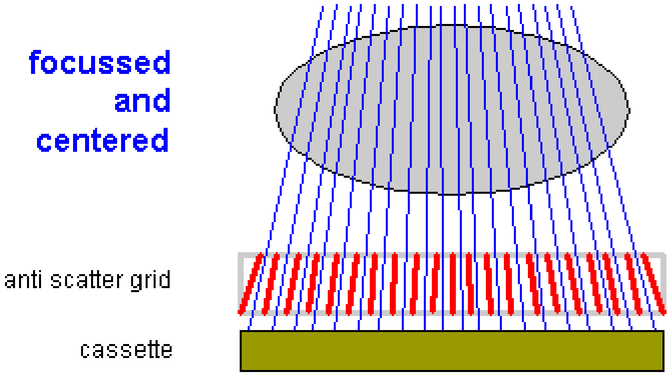


Anti scatter grid

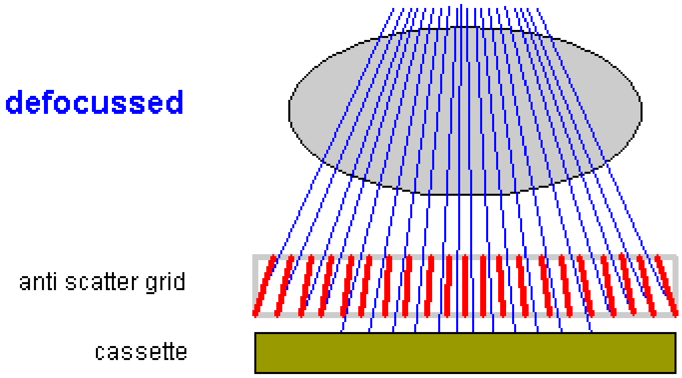
Scattered radiation is an unwanted product of the interaction between primary radiation and matter, e.g. the patient. It is identified by being of lower energy and undirected. Being proportional to the amount of primary radiation, there is more scattered radiation when entering than on leaving the patient.
If scattered radiation hits the cassette, it causes an homogeneous layer of "fog" on the film, reducing the image contrast.
To prevent this, the anti scatter grid has been introduced trapping most of the undirected radiation in its lead stripes (red).

.

.



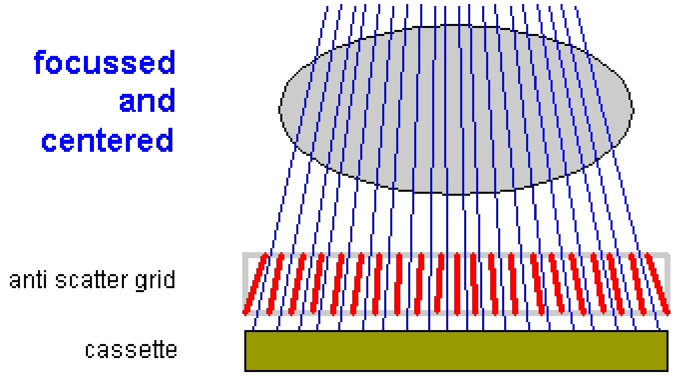
Anti scatter grid
The **lead stripes** are arranged to be in line with the primary radiation offering a minimum of resistance to the radiation. The radiolucent gap between the individual stripes characterizes the **selectivity** of a grid. That is its ability to suppress scattered radiation.
Naturally, the lead stripes absorb some of the primary



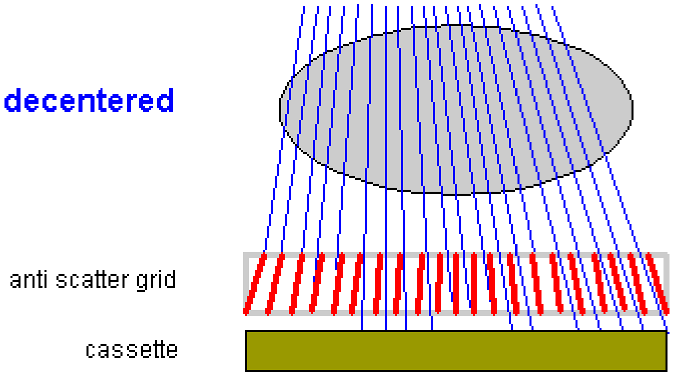
radiation and become visible on the film as fine, white lines superimposed to the object. There are two ways to overcome this problem: Either, a large number of very thin stripes is used, or the grid is moved during exposure thus being blurred.
When **altering the SID**, beam direction and strip alignment don't match any more resulting in pronounced vignetting on the film.

.

.



Anti scatter grid
The amount of scattered radiation depends very much on the volume of tissue penetrated. So, a baby produces very little scattered radiation compared to an adult person. Additionally, the grid absorbs a significant amount of primary radiation. For reducing the dose absorbed, the grid is moved out when babies and small children are examined.

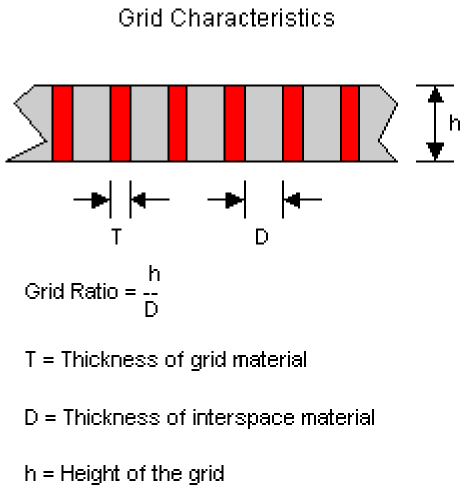


As demonstrated on the image left, **centring** moveable grids correctly is essential for good image quality. Else, unevenly distributed densities on the film result.
A grid must never be installed upside down. Hence, the side facing the X-ray tube is labelled.

.

.

Examination Units **Spotfilm Device** 15/15



Anti scatter grid

The **grid identification** label reads:

PB 12 / 40 fo 115

Meaning:
PB = Grid material is lead
12 = Grid ratio
40 = Grid stripes per cm
fo = Focussing distance
115 = 115 cm

The **grid ratio**, ranging from 8 to 17, is the selectivity characteristic. A high value means good suppression of scattered radiation. However at the cost of high absorption and reduced focussing range. Inside the **focussing range** around the nominal focussing distance, the amount of vignetting resulting can be tolerated.

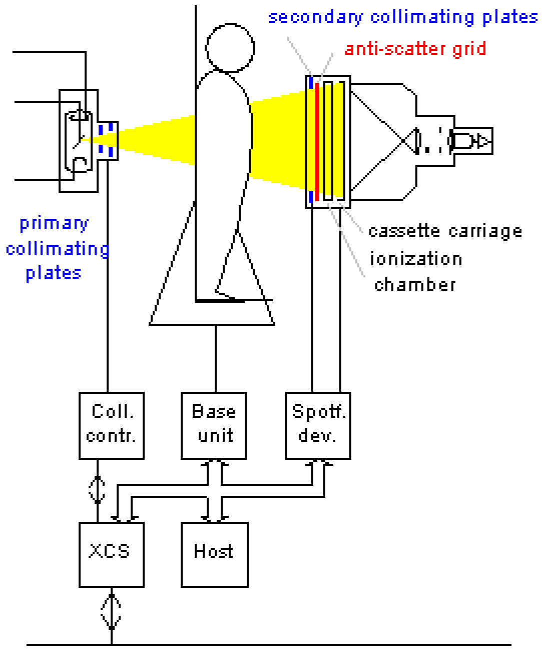
to page 1 ¶

.

.

Examination Units **Collimator** 1/5

Manipulation of Radiation Beam



This function includes all systems manipulating the radiation beam after leaving the X-ray tube assembly, be it quality wise or in its dimensions.
Basically, these manipulations take place at two different locations:
In between focal spot and patient, i.e. by the collimator. This is referred to as primary collation and its main task is setting the radiation field size. Hence, it is vital to radiation protection.
Between patient and target, inside the spotfilm device. This secondary collation improves the image quality by reducing the amount of scattered radiation.

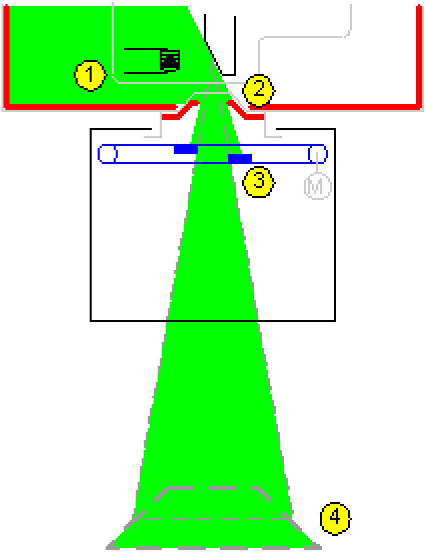
The collimator is a stand alone subassembly getting it's commands from the system controller XCU via the XCS network.

see: Principal Diagram| Radiation Manipulation

.

.

Variable Aperture Diaphragm



Starting from the focal spot, the X-rays diverge in all directions. Only a small part of them is used to produce a radiograph.
All the rest of the radiation, being harmful only, is effectively blocked by lead lining inside the tube housing (1).

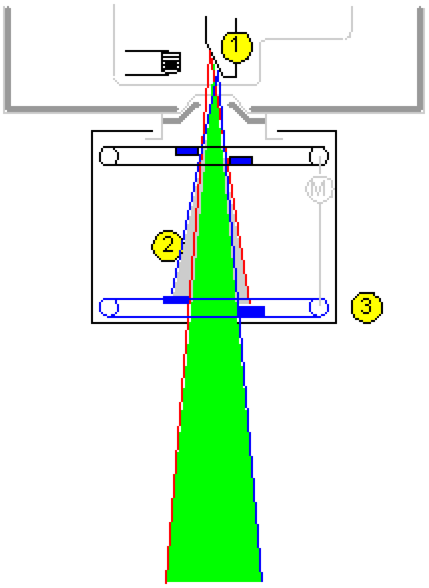
The radiation leaving the port of the X-ray tube housing is collimated by a lead cone (2) setting the maximum possible field size.
The actual field size (4) is set by two sets of lead shutters of which only one is shown (3). The two lead plates are operated symmetrically to the center beam. The operation is either manual or, when remote controlled, motor driven using microprocessor controlled stepper motors.

This simple kind of diaphragm is called "double slot collimator".

.

.

(Multileaf) Collimator



In real life, the the focal spot isn't the idealized point but has physical dimensions.

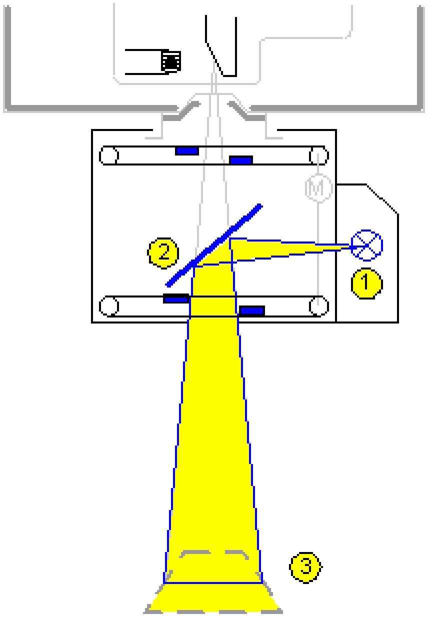
Because of this, the radiation doesn't originate from one point only but from all locations inside the focal spot. Taking tow extreme locations (1), the picture shows that the radiation beams are slightly diverging instead of running parallel. This would result in a halo (2) of decreasing intensity surrounding the radiation field.

A second set of shutters (3) is used to block off this radiation. All standard collimators use this double set of diaphragms providing a clearly defined radiation field.

.

.

Light Localization



All overtable units offer the ability to position the patient without fluoroscopic control using the light localizer.

The light required is generated by a powerful lamp (1) and directed to the object by a mirror (2) positioned in the radiation beam.

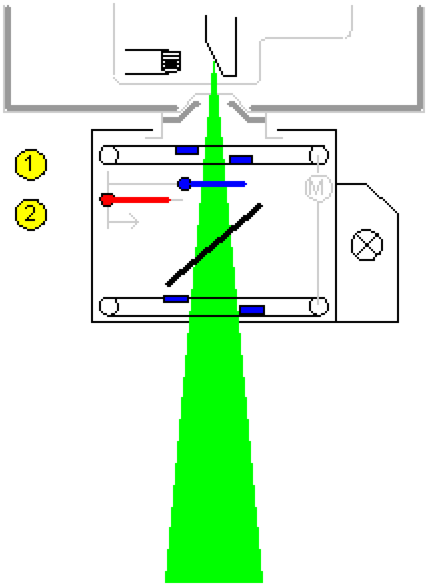
In the end, size and location of the light field must agree with the radiation field during exposure.

An automatic timer switches off the lamp after about 30 seconds to extend the lamp's life span.

.

.

Radiation Filtration

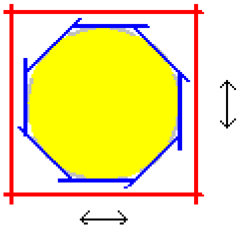
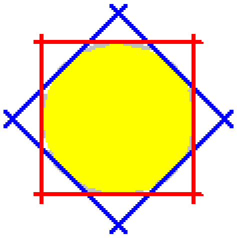


Another aspect of radiation protection is "beam hardening". This means to suppress the soft, low energy spectrum of the bremsstrahlung radiation.
Soft radiation is mainly absorbed inside the body with only little contribution to creating the X-ray image. In other cases, however, the soft radiation, whatever little it is, is essential for image contrast and a safe diagnosis.

To vary the amount of prefiltration, copper filters can be moved in and out the radiation beam. Standard is a 0.1mm Cu filter (1) and a 0.2mm Cu filter (2) which can be combined to a total of 0.3mm Cu additional filtration.
By law, the inherent filtration, i.e. without additional filters in the radiation beam, must be equivalent to 2.5mm Al.

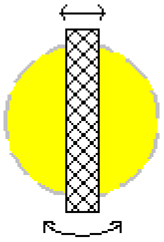
The multileaf collimator shown here is the standard for exposure units. Dedicated angiography collimators have an extended functionality, see: Principal Diagram| Radiation Manipulation

.

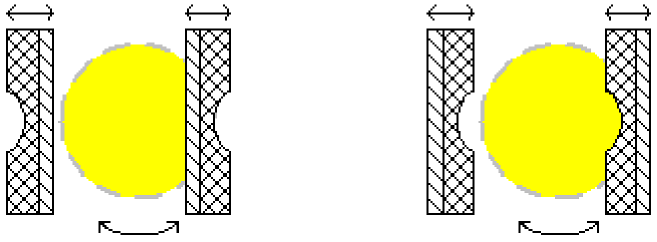
Collimating the radiation field	There are two different types of circular collimators available:
Independent system 	Independent of the square field, an iris system provides circular collimating. In *fluoroscopy*, the iris limits the field size to the zoom format selected while the square field is completely open. With *cassette exposures*, the iris is completely open while the square field is set to the cassette size.
Dependent system 	In combination with the square field - used for cassette exposures - a set of four additional plates, offset by 45° forms an octagonal radiation field. In either case the radiation field is oriented centrally to the center beam.

.

Partial filtration of the radiation field	By means of this function, parts of the radiation field can be covered by semi transparent plates of different material and shape. Following types of plates are defined:
Finger plate	Wedge- and heart contour plates



This plate can be moved freely inside the radiation field, additionally, it can be rotated. Normally, it is used during peripheral angiography to prevent excessive radiation between the legs.

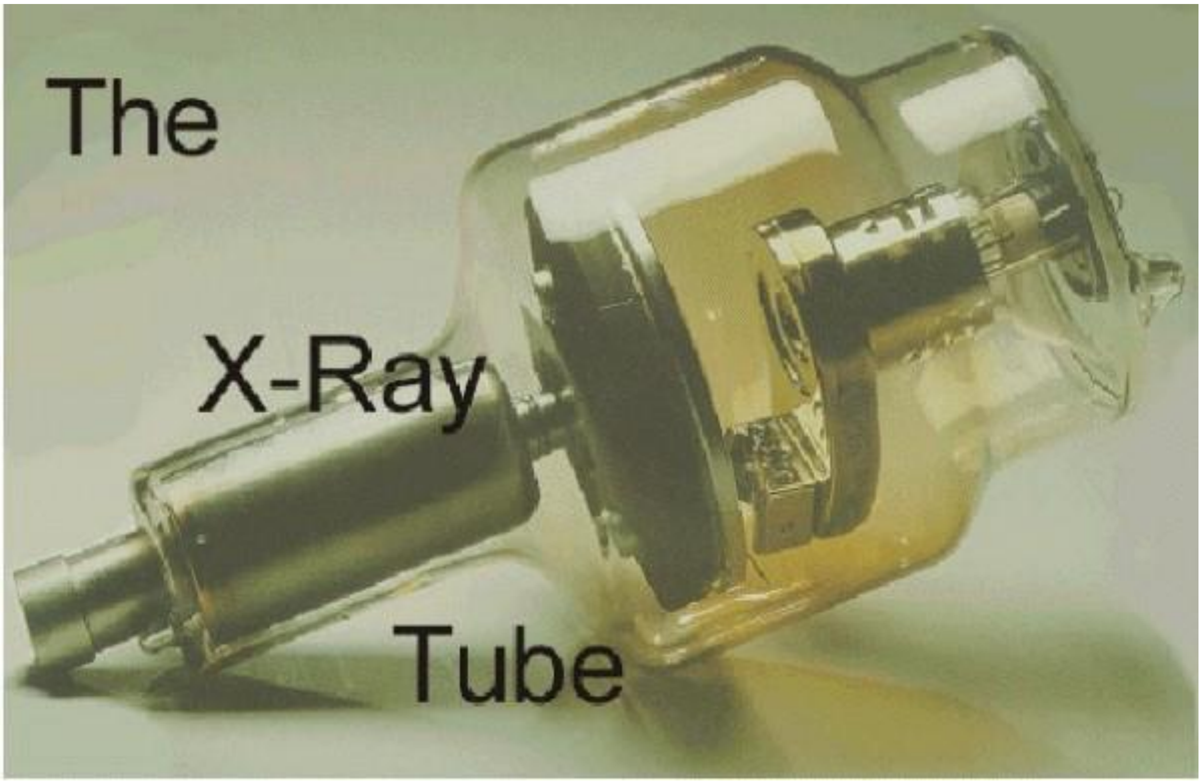


These plates are used to cover very transparent areas at the outer parts of the image. They can be moved individually and rotated as well. One side of these plates is wedge shaped providing a continuous increase in absorption, while the other side is curved to fit round objects on the image. The transition from contour to straight wedge is done by swapping the left right positions.

.

The X-Ray Tube

Introduction



.

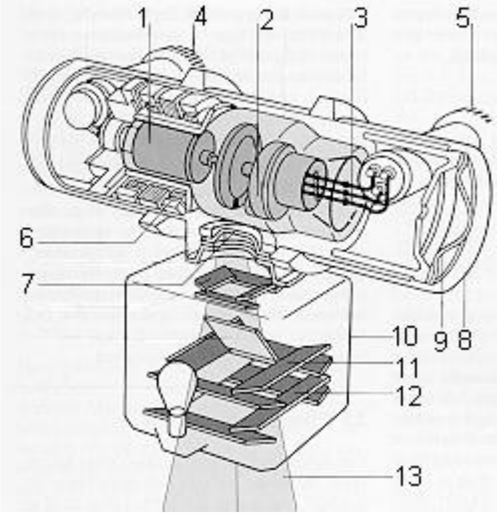
Introduction

The source of the radiation is the x-ray tube which is enclosed by the tube housing.
The design of the tube assembly may differ but its construction is generally the same.
Remarkable are the two kind of horns which jut out to one side. These are the connector sockets for the high-tension cables.

Perpendicular to them is the x-ray window. The flange on it is to fix a beam-limiting device.
The two centric rings around the housing serve to attach a tube holder for mounting the tube assembly to a column or table.

.

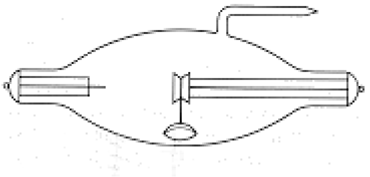
Introduction

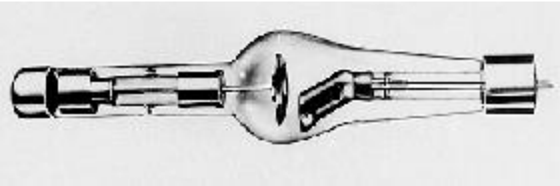


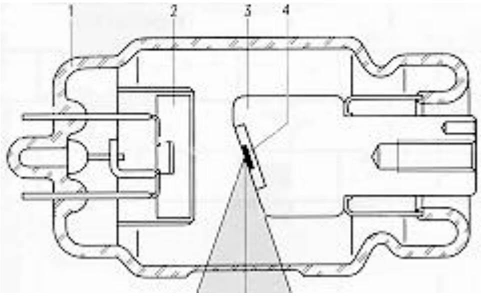
1	Rotor with anode disc
2	Cathode
3	Filament supply leads
4	High tension outlet anode side
5	High tension outlet cathode side
6	Stator winding
7	Radiation window
8	Protective casing of the tube assembly
9	Expansion bellows
10	X-ray beam collimator
11+12	Lead plates to limit the radiation field
13	Useful x-ray beam

In the cut housing you see the x-ray tube fixed in the centre. The anode side sticks into the stator coil (**6**) for the rotating anode motor and is fastened in a bayonet holder.
The tube is supplied via HT(High Tension) cables (**4** + **5**), which includes the high tube voltage and filament current (**3**).
The collimator(**10**) limits the x-ray beam to the necessary image size to avoid excessive irradiation of the patient.
More details are described in the following subchapters.

.







1 Evacuated glass envelope **2** Cathode
3 Anode **4** Target

The innovations on x-ray tubes keep always abreast with the newest technology. Even some of the basic principles changed since 1895 when professor W. C. Roentgen started using x-rays.

The first tubes were gasfilled ones which used the glass envelope as the target (top left).
The efficency was, of course, very poor and it took minutes to expose a film correctly.

The tube on the right was one of the smallest ever produced and measured just 6 cm in lenght (here magnified). It had already an embedded Tungsten target.

The image on the bottom left shows the first rotating anode tube.

.

The different tube types nowadays are closely connected with the various medical applications. Some examples shall clarify this:

1. **Mammography** diagnostic needs a special radiation spectrum which cannot be produced with normal x-ray tubes.
As well, small x-ray sources are necessary to reproduce even finest object details.

2.; **3**.; **4**. Tubes for normal diagnostic application

5. A tube used for **Computed Tomography** (CT), produced in the beginning of the 90th.

6. Examinations in **Angiography** ask for tubes with very high heat storage capacity - **Megalix Cat -** because of long fluoroscopic times and serial exposures.

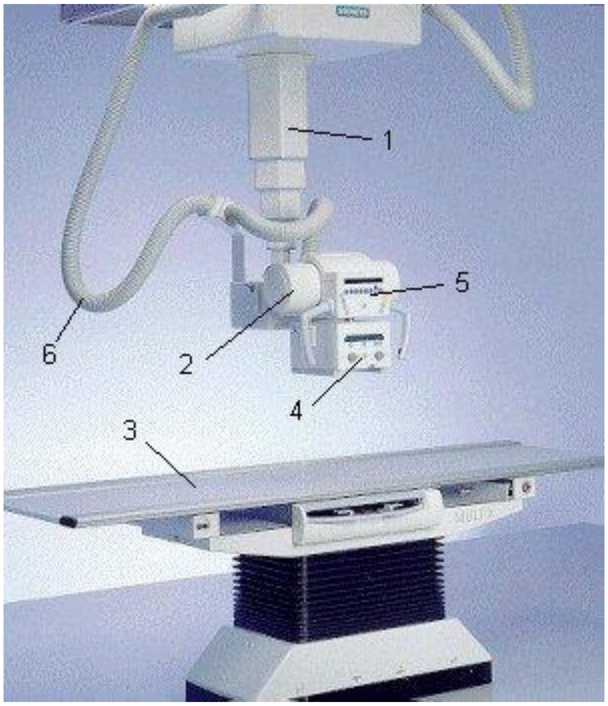
.

Milestones in tube innovations by Siemens

1896	First patent for x-ray tube with adjustable vacuum	1957	Patent for the BIANGULIX principle (two focal paths on different anode angles)
1904	Paten for use of solid Tungsten as anode material	1962	Introduction of Rhenium-Tungsten composite anode with 8,500 rpm
1909	First ion tube utilizing a Tungsten target	1971	First modern rotating anode tube in glass-metal technology (Mammography)
1919	Patent for a shock-proofed and radiation- protected housing	1972	Patent for a stress-reliefed anode
1923	Patent for the first double-focus tube	1973	Introduction of CALOREX anode with graphite backing
1927	First rotating anode tube	1978	First super high-speed anode tube;17,000rpm
1933	Introduction of the world-renowned **Heliosphere**	1981	Patent for first 3-focus rotating anode tube
1937	First **grid-controlled** 150 kV rotating anode tube	1985	MEGALIX high energy tube with 1 MJoule heat storage capacity
1940	First rotating anode tube with 100 mm disk diameter	1997	MEGALIX Cat with rotating anode based on spiral groove bearing (continuous rotation)

.

Introduction



Here you see a modern x-ray system consisting of the x-ray tube assembly (**2**) installed to a ceiling column (**1**) and the patient table (**3**).
With the collimator (**4**) close to the x-ray window the operator sets the radiation field size.
The cable harness (**6**) contains all necessary supplies and controls for

- tube assembly;
- collimator;
- ceiling column;
- operating console (**5**).

More details in chapter 3 "Examination Units".

.

Introduction

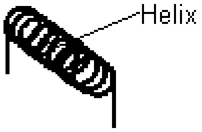
In the following subchapters you will learn the tube assembly in more details.
Are not disappointed if you found some new terms here . Most of them are explained in the "X-Ray Basics". If not, please, let us know.

Just carry on and much success!

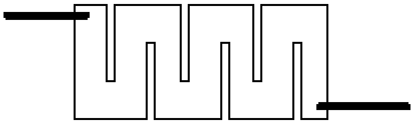
End of Subchapter "Introduction"

.

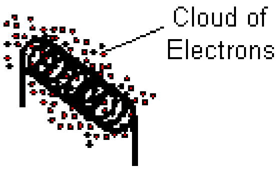
Cathode and Filament Helix



To obtain x-rays high-speed electrons are needed which bombard a target (anode). They are produced by heating-up a tungsten wire (filament) so that it emits electrons.
Helix is called the spiral wire. It is mainly made out of tungsten in x-ray tubes.

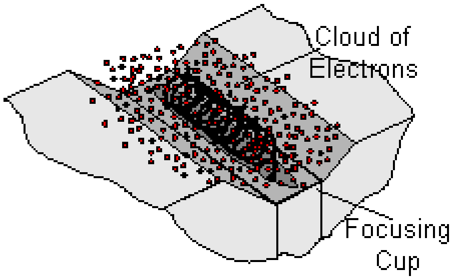


Another electron source is the flat emitter instead of a helix.
It is used for modern Mammography tubes and allows a better x-ray intensity distribution as with the spiral. Therefore, the image quality increases.
The filament in this case is meander-shaped.



The electrons form a cloud surrounding the filament. They fall back to the helix as long as no high tension accelerates them towards the anode.

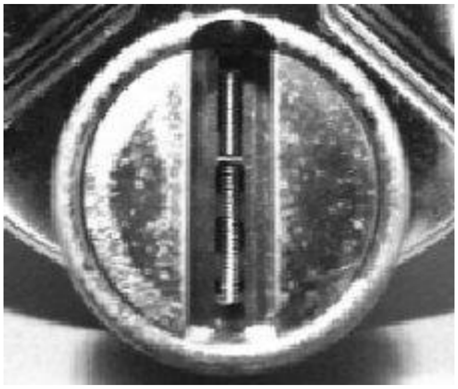
.

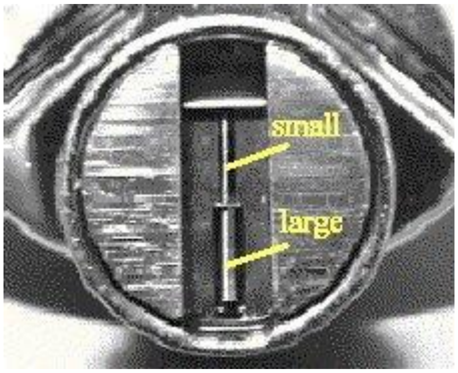


The cathode (focusing cup) focuses the electrons on the target when positive High Tension attracts them towards the anode.

This picture shows a original cathode.
The filament or helix is visible in the so-called focusing cup on the bottom.

.





The helix size has a decisive influence on the focal spot dimension (see "Formation of focal Spot") and affects the image quality significantly. That´s, why most of the x-ray tubes are equipped with more than one filament with various sizes for different applications:
· a small one with low output for better geometric resolution (small filament)
· a larger filament for higher output capacity.
Besides the sizes x-ray tubes posses two types of helixes :
· with a wire of 0,3 mm diameter (left picture) · a helix with a 0,22 mm wire (right picture)
The smaller wire allows reduced helix sizes, and thus, finer focal spots.

.

The arrangement of the two helixes depends on the tube type.
The tubes vary as well in the form of their focusing cup.
There are general differences which are expressed in the tube names:

PANTIX both filaments parallel, or just one single filament

BIANGULIX both filaments in-line

"BI-" comes from greek and means "two", "-ANGULIX" (angulus) "angle".

.

OPTILIX both filaments parallel

MEGALIX with two parallel helixes or
with three, two in-line and the third parallel

Each filament has its individual characteristic even with the same tube type.
The temperature of the filament determines the number of electrons produced, thus, the tube current when high tension is supplied.

The filament current is responsible for the helix temperature.
As mentioned, we differ between two currents in the tube:

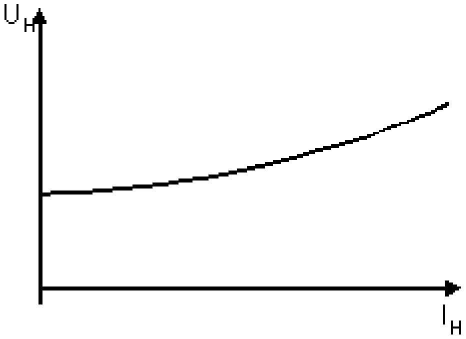
Filament Current ----------- I_H or **I_f** *("H", "f"stands for **h**eating or **f**ilament)*

Tube Current -------------- $I_{Rö}$ *("Rö" stands for the german word for tube: "**R**öhre")*

I_H is measured in A(or mA) and $I_{Rö}$ in mA.
The tube current determines the number of x-ray quanta produced. That is, the radiation quantity. Together with the kV it is responsible for doserate.

.

Cathode and Filament



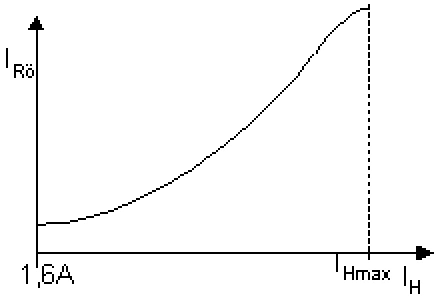
This graph shows the filament characteristic.
The filament impedance R_H is non-linear, that is, small with low temperature and increases slightly with higher power (higher temperature).

The filament voltage U_H ranges from about 10 to 20 V.

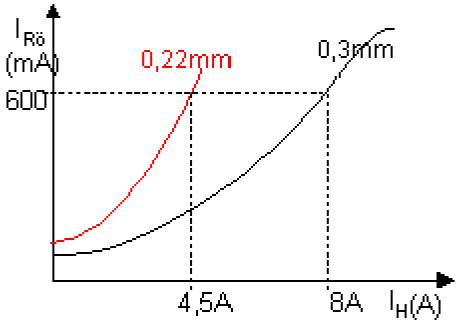
The helix temperature determines the tube current flow and depends on the filament power P_H.
$P_H = U_H \times I_H$ or, since $U_H = R_H \times I_H$, one can also say $P_H = R_H \times I_H^2$.
So, only the RMS value of the filament current represents the filament temperature. This has to be taken into consideration in the filament regulation circuit later.

.

Cathode and Filament



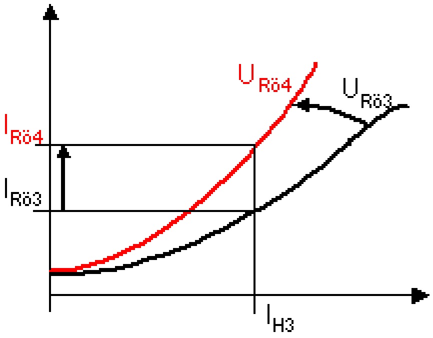
Here you see the relation between the filament current I_H and tube current $I_{Rö}$. They have a non-linear dependency.
The maximum filament current I_{Hmax} depends on the helix-material´s melting point. The operating temperature must always be far below to avoid evaporation of material.
The curve shows the most interesting part only.
So, the X-scale does not start with zero.

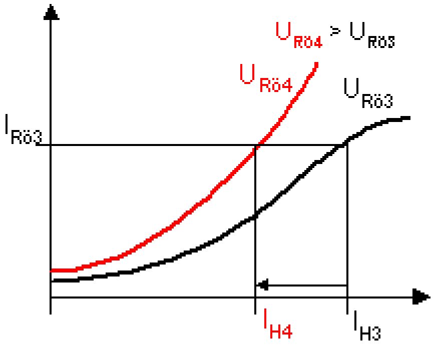


The filament current varies with the type of helix.
Example
To obtain the tube current $I_{Rö}$ = 600mA, a filament current I_H is needed
· for a 0,22 mm helix wire: **4,5 A** but
· for a 0,3 mm type: **8 A**.
On the other hand, there is normally only a small difference between both filaments in the same tube.

.

Cathode and Filament

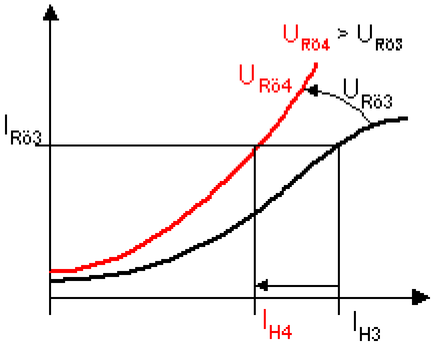


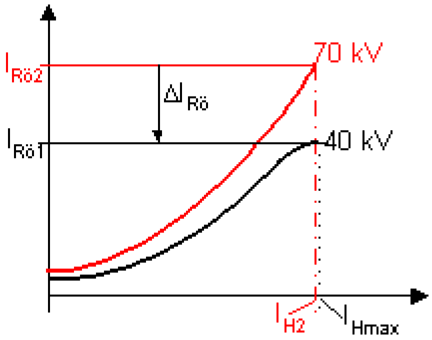


The left curve shows that the tube current changes as well with the supplied tube voltage $U_{Rö}$ at **constant** filament current I_{H3}: $U_{Rö3}$ -- $I_{Rö3}$; $U_{Rö4}$ -- $I_{Rö4}$
This occurs in the roentgen-diagnostic voltage range and is called **"**Space Charge Effect**"**.
It is without any importance in modern generators due to the build-in regulation circuits for the tube voltage and filament current.
When the operator changes the kV-value the filament current is automatically adapted in order to keep the tube current constant (right graph).

.

Cathode and Filament



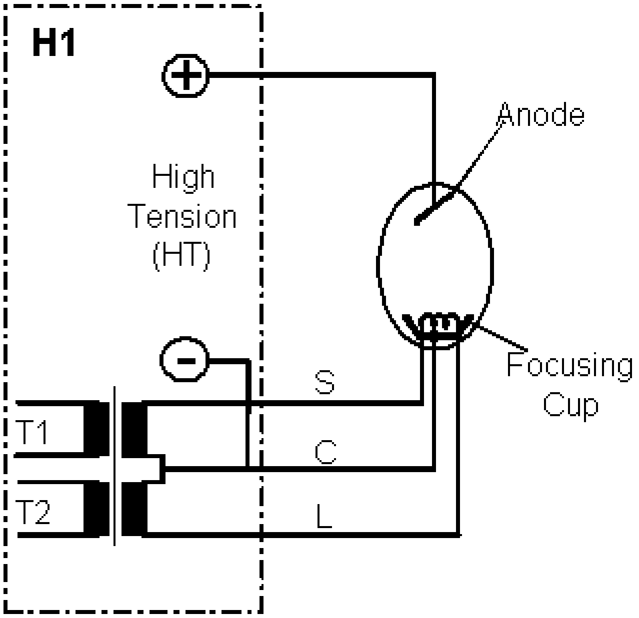


Example

When the tube voltage is changed from $U_{Rö3}$ to $U_{Rö4}$ then I_H automatically drops down from I_{H3} to I_{H4} , what keeps the tube current $I_{Rö3}$ constant. Vice versa, I_H is increasing when less kV are being selected.
With relatively low tube voltage $U_{Rö}$ (<70 kV) the electrical field strenght between anode and cathode becomes relatively low. This results in a decrease of the tube current ($DI_{Rö}$), since less electrons are being attracted by the anode, which can not be compensated with a higher filament current because the filament current reached already I_{Hmax} .
As a consequence, the maximum tube output is reduced when less than 70 kV are selected.

.

Cathode and Filament



S --- connection for **S**mall filament (focus)
C --- **C**ommon lead (cathode)
L --- supply for **L**arge filament Focus

T1 --- transformer for small focus
T2 --- transformer for large focus

Each filament of a double focus tube needs its own supply.

Two specially isolated transformers T1, T2 in the high tension tank H1 separate the primary low voltage side from the secondary high tension (HT).
The HT is connected to common lead for both filaments and the focusing cup. Both, filaments and focusing cup, perform the cathode. It lies on a negative polarity in relation to ground.

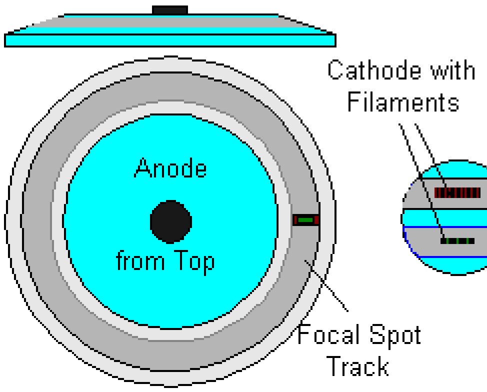
.

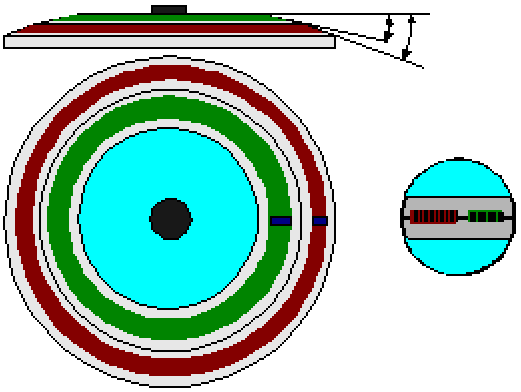
The X-Ray Tube **Cathode and Filament** 11/11

End of Subchapter "Cathode and Helix"

.

More Info **Cathode and Filament** 1/2





Pantix
This name is used for rotating anodes with only one anode angle with either one or two focal spots.
In the double focus tube the filaments are then parallel and, therefore, the focal spots on the anode almost superimposed.

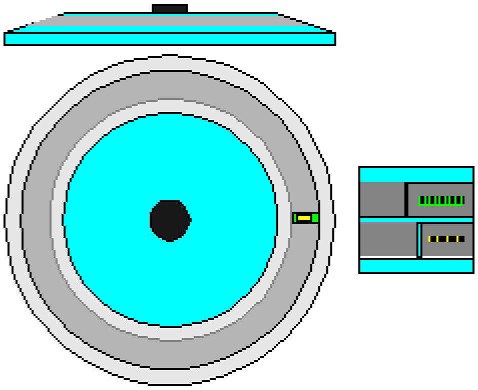
Biangulix stands for a two angled anode.
The filaments are physically in-line. Both focal spots are on different focal tracks, so are the centre beams.
As a consequence, the radiation fields have different positions on the image plane.

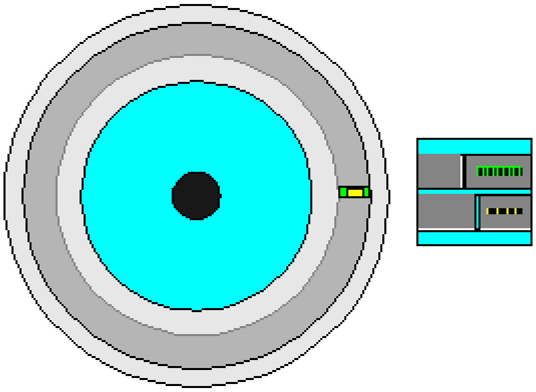
exit info?

.

More Info

Cathode and Filament





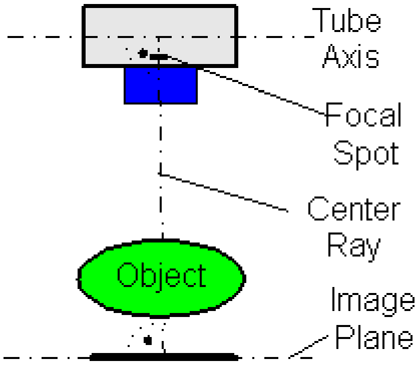
Optilix-tubes have a new developed anode (see chapter "Anodes"), and only one angle. Both foci are superimposed due to a specially designed focusing cup.

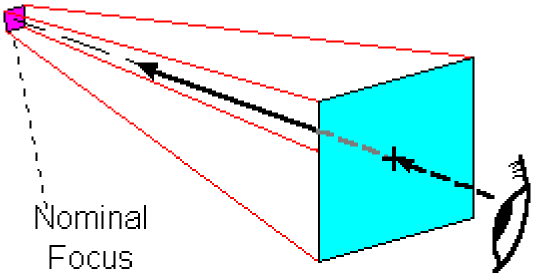
The **Megalix** is used in angiography.
Based on the Optilix, it has a larger anode disk (120 mm diameter instead of 100 mm) and two or three foci but only one angle.
The name comes from its heat storage capacity of 1,000,000 Joule.

exit info?

.

Formation of Focal Spot





Before we speak about the focal spot something has to be clarified:

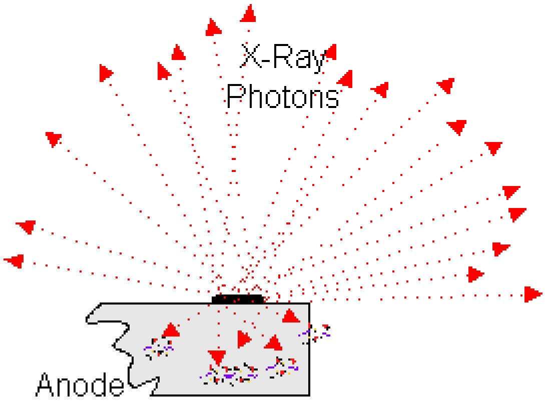
* In conventional x-ray diagnostic the **image plane** is mostly parallel to the tube axis (anode axis).

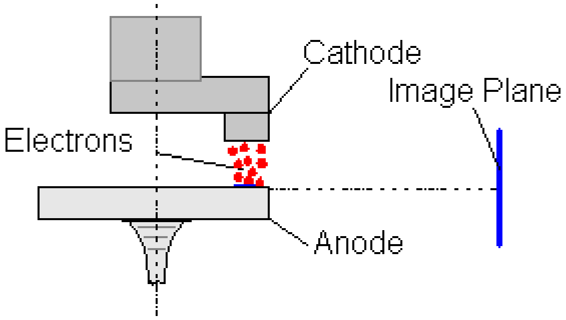
* With a correct mechanical alignment of the x-ray system the center of the x-ray source (focal spot) meets the middle of the image. Both are connected by an imaginary line, called **"Center Ray"**. It is perpendicular to the tube axis and the image plane.

* The radiation source, viewed from the image center, is more or less a square. This is why the same sharpness shall be achieve in both dimensions.
This is the so-called **"Nominal Focus"** which is given in the data sheets for each individual tube.

.

Formation of Focal Spot

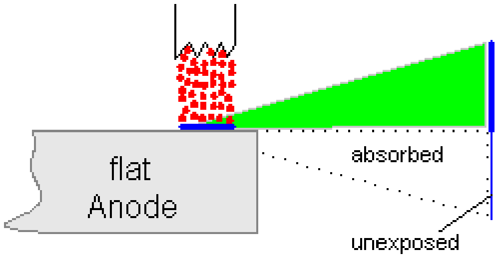




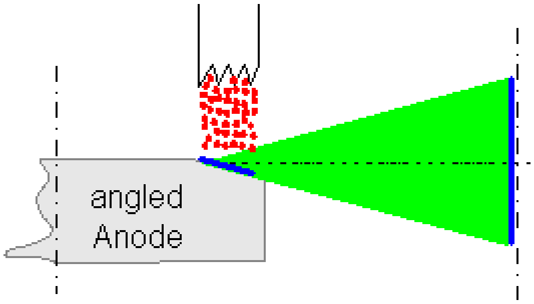
How is this focal spot formatted?
Some general considerations first.
X-rays emanate from a small source -- the focus -- in all directions. Radiation travelling into the anode are absorbed there. Only quanta leaving the anode can contribute to the image.
To generate radiation, we need an electron source - the cathode. It has to be placed opposite to the anode, so that the accelerated electrons bombard the anode in the focal spot.
The image plane in our case is on the right side parallel to the tube axis.

.

Formation of Focal Spot

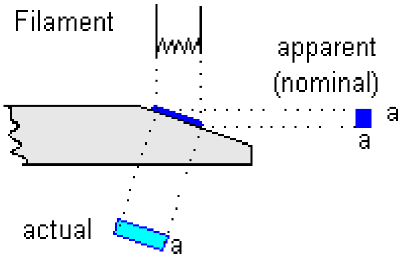


Since the radiation require to cover an image some distance away, it is fairly clear that the beam of radiation used must be conical.
A flat anode surface absorbs some of the radiation in the direction towards the image.



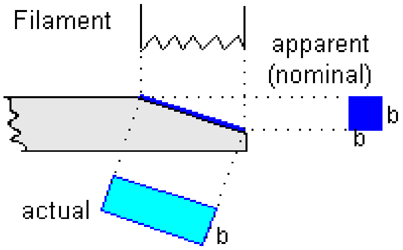
This necessitates an angled face to the anode.
Now, two requirements are fulfilled:
- the center beam can meet the center point of the image
- image plane and anode axis are parallel to each other

Formation of Focal Spot



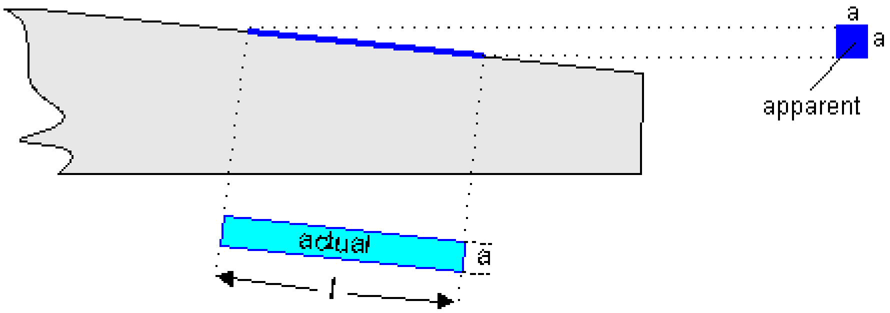
This angled face assists somewhat in resolving the conflicting requirements regarding the focal area:

* On the one hand, we need a small **apparent** focal spot for higher image sharpness. But this reduces the bombarded area (actual) and so the tube output (rating).



* On the other hand, higher tube rating is needed for shorter exposure time or thicker objects which requires a larger **actual** focal spot area and therefore a larger apparent focus.
The so-called **"Line Focus Principle"** solves this conflict to a certain extent.

Formation of Focal Spot

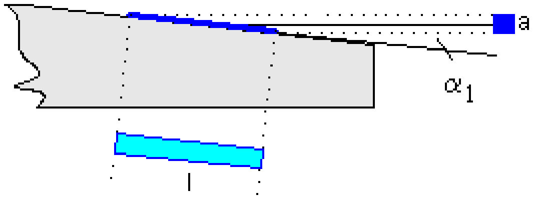


To present a square focus "a x a" as viewed from the image, a rectangle of the length "l" several times the width "a" is required on the anode face.

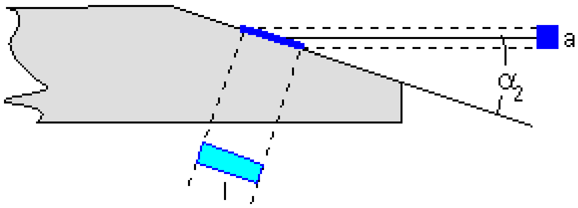
From the illustration it can be seen that the apparent (nominal) focal area is smaller than the actual focal area (bombarded by the elctrons).
The latter determines the tube rating.

This is called the **"Line Focus Principle".**

Formation of Focal Spot



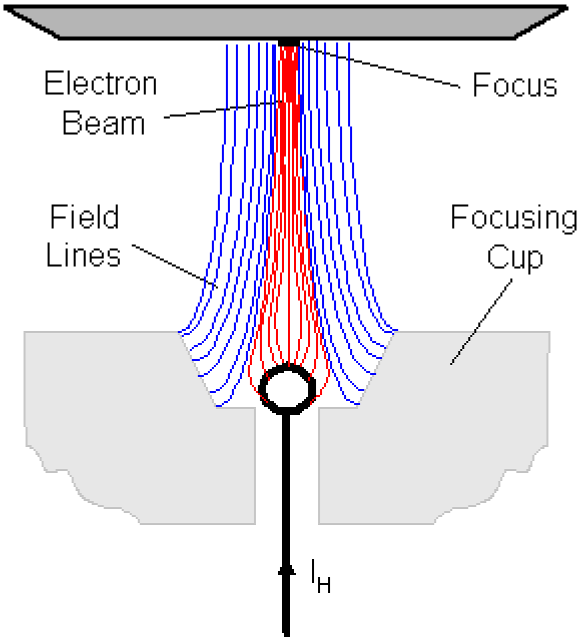
Obviously, if the anode angle is made shallower (a_1) the bombarded area (with the length "l") is even greater for a specific size of apparent focus.
With a given nominal focus (length "a") the actual focus length "l" depends on the helix dimension and the anode inclination "a ".
The formular is
l = a/sin a



The nominal focal spot size is measured according to IEC 336 standard (International Electrotechnical Commission), and given without any unit, e.g. 1,2 , which stands for a 1,2 x 1,2 mm focal spot.

▼ ▲ more info?

Formation of Focal Spot



The cathode-cup focuses the electrons onto the anode -- the target.
The size of the electron stream, accelerated towards the anode, depends on the filament size and the number of electrons per unit time - the tube current.

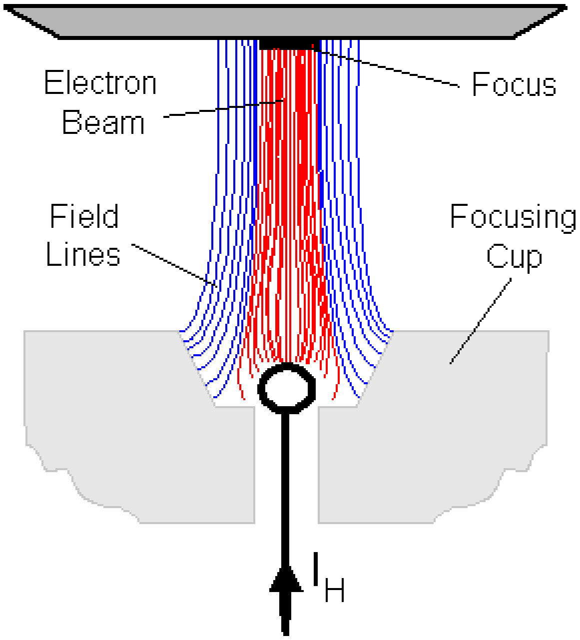
The more electrons the beam consists of the higher is the repulsion between them. This increases the cross section of the stream and, consequently, the bombarded area on the anode.
According to this fact, the focal spot size varies to a certain extent with the tube current.

Click here
to see the effect of higher tube current.

▼ ▲

.

Formation of Focal Spot



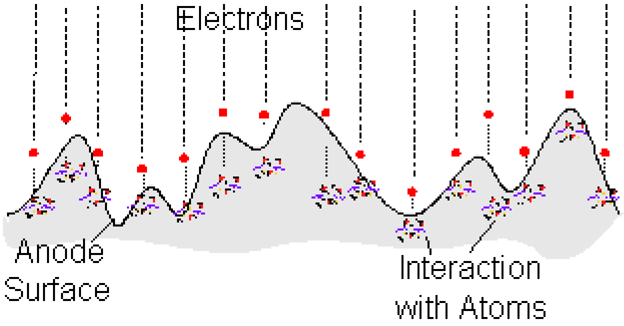
The cathode-cup focuses the electrons onto the anode -- the target.
The size of the electron stream, accelerated towards the anode, depends on the filament size and the number of electrons per unit time - the tube current.

The more electrons the beam consists of the higher is the repulsion between them. This increases the cross section of the stream and, consequently, the bombarded area on the anode.
According to this fact, the focal spot size varies to a certain extent with the tube current.

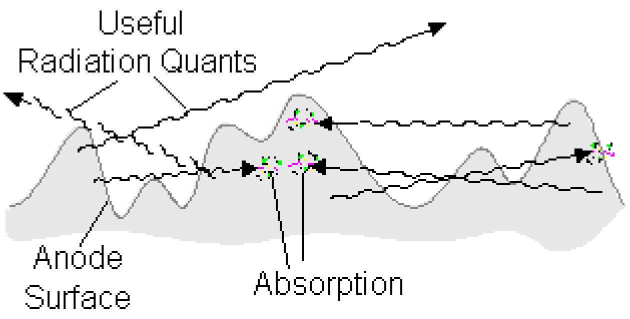
Click here
to see the effect of lower tube current.

.

Formation of Focal Spot



Lets have a closer look to the target where the radiation is produced.
The high speed electrons penetrate into the anode only to a depth of some micrometer. Within this distance they react with the target atoms loose fractions of their energy and x-ray quanta are produced.
From the electrons point of view the anode surface looks like mountains.

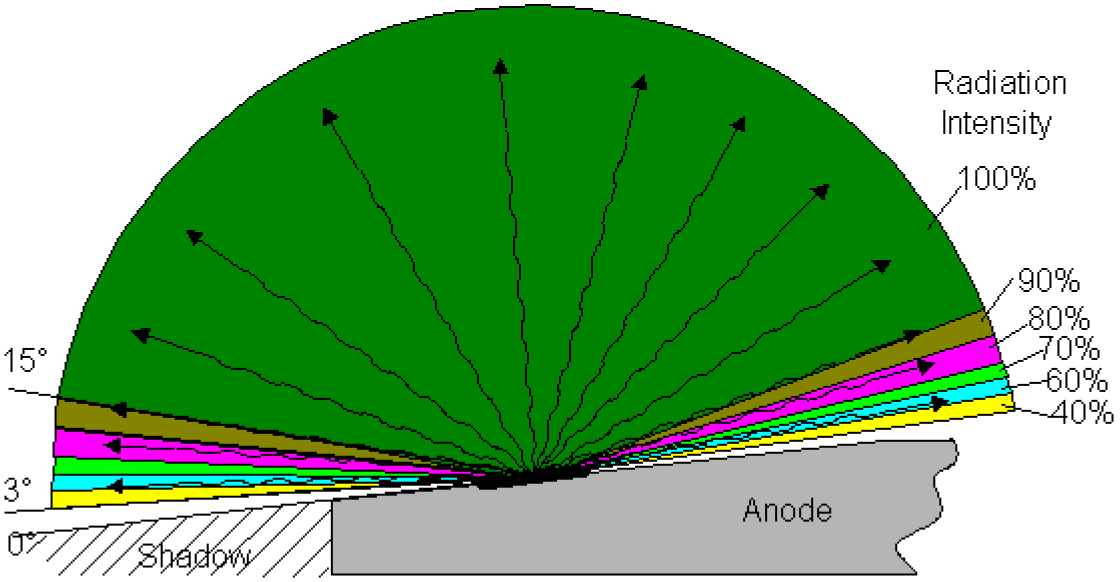


The produced quanta travel in all directions. The pitty is, if they leave the anode more or less parallel to its surface they need to penetrate the uneven surface first to become a useful photon. But most of them are absorbed here. The consequence is that close to anode face no or little radiation is obtained.
This is called the **"Heel Effect"**.

▼ ▲ more info?

.

Formation of Focal Spot



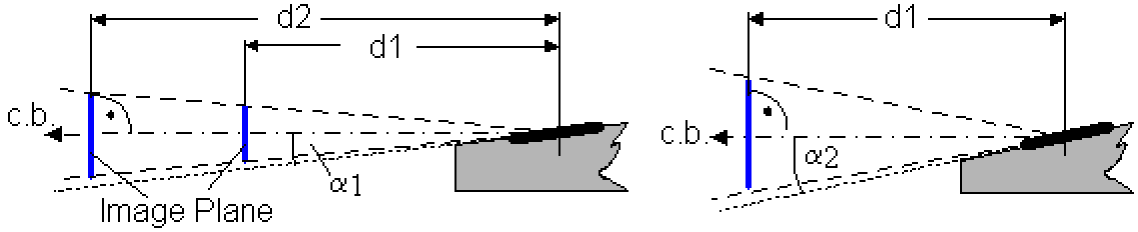
If we were able to measure the radiation intensity at a constant distance, starting from the anode surface and moving towards the cathode, we would find the intensity distribution above. In the elongation of the anode surface appears the anode shadow.

Due to the heel effect, no radiation can be measured between 0° and 3°. Then the intensity increases more and more until 100% are reached at around 15°.

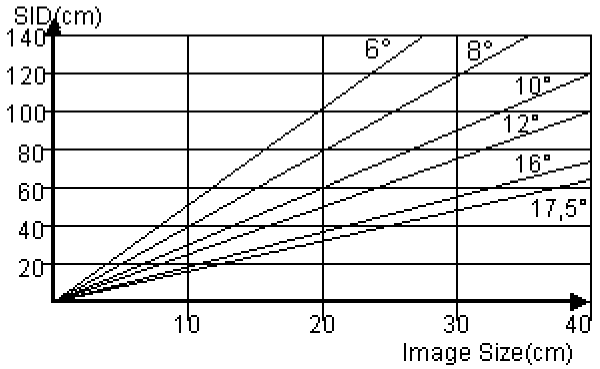
▼ ▲

.

Formation of Focal Spot



The anode inclination angle and the heel effect have a significant influence on the maximal covered image size. With the requirements for the center beam (c.b.) (page 1) it is obvious that the obtainable image size is limited with a small angle a1 in a given distance d1. With a higher source-image distance (SID) d2 or greater anode angle a2 larger images can be exposed.



The diagram on the left shows the dependency of image size on anode angle and distance. This has especially to be taken into account with SIDs between 65 and 100 cm as with **Under-Table Units**.

Question:

Can a 35x35 cm film be fully exposed with the following given factors?

1. anode angle 12°........... **2.** SID 70 cm

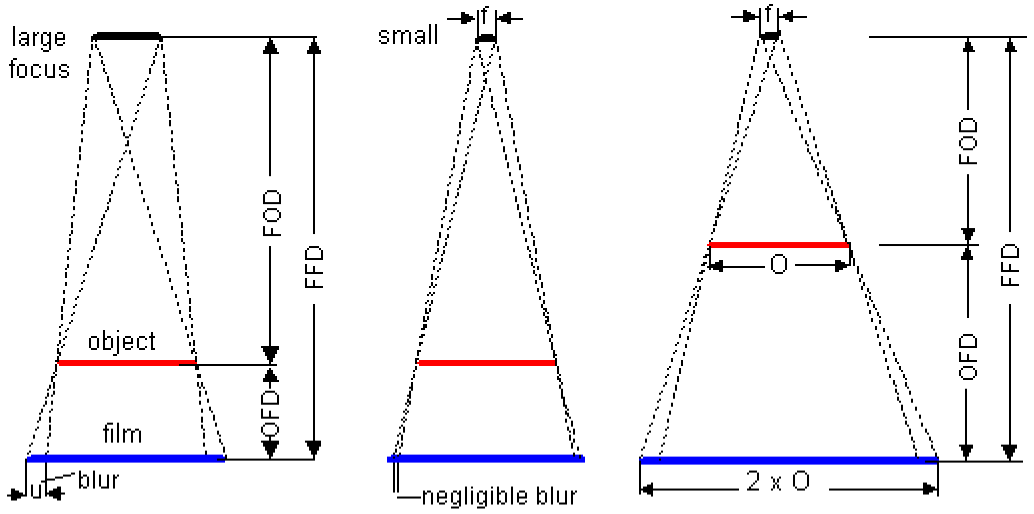
Click here for the answer.

.

The X-Ray Tube

Formation of Focal Spot

11/16



The focal spot size affects the geometric sharpness of the image. The smaller the spot is the better is the radiographic definition.
It is still acceptable, if a sharp object edge is displayed on an x-ray image with a blur of 0,3 mm.

Questions: Focus-Film Distance FFD (or SID) ---- 115 cm

Example 1: Object-Film Distance OFD = 20 cm

Example 2: OFD = FOD

Which individual focal spots are required in order to do not exceed the acceptable blur?

Formula for geometric blur **"u"** with the focal spot **"f"** is: ....u = f × OFD/FOD

Click here for the answers.

.

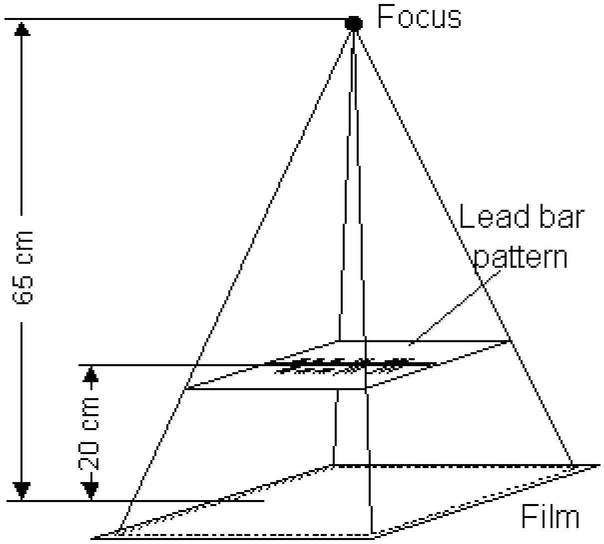
Formation of Focal Spot

0,3 mm only!! Isn´t that incredibly small?

Those conditions are only used for special applications in the roentgen diagnostic, when the object should be magnified on image. This is necessary with very small objects like blood vessels in the brain.

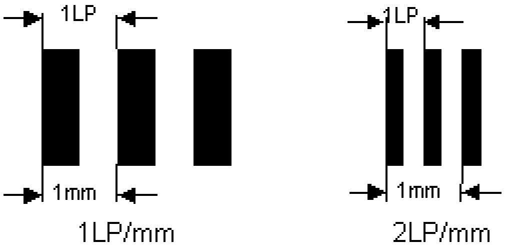
The usual distances are about the same as with the first example on the last page.

An enlargement more than factor 1,2 is not wanted for most of the examinations.



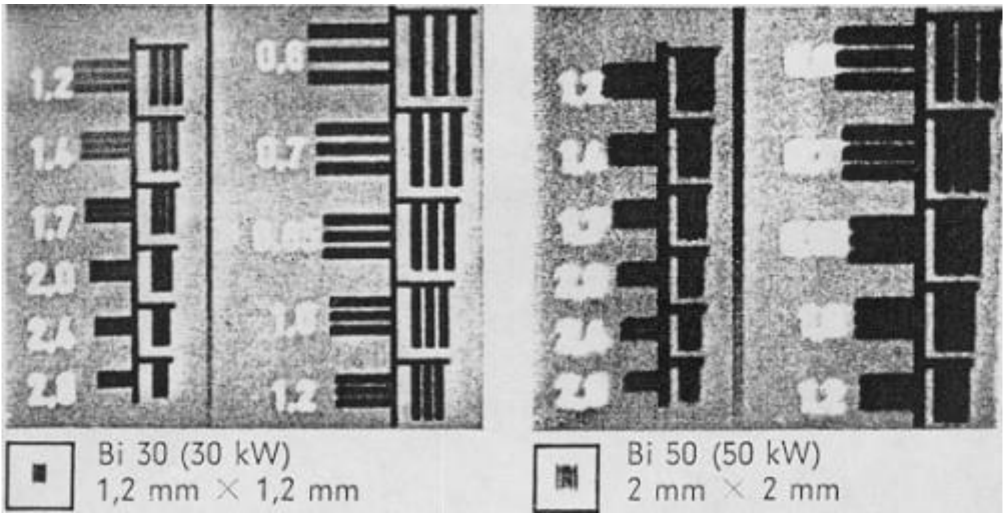
Radiographs of a lead-bar pattern on the next page show the influence of the focus size on the resolution. The measuring conditions on the left are the same as usually obtained with fluoroscopic under-table units.

The unit LP/mm (Line Pairs) explains how many pairs of leadlines are recognisable on the image: the more the better.



.

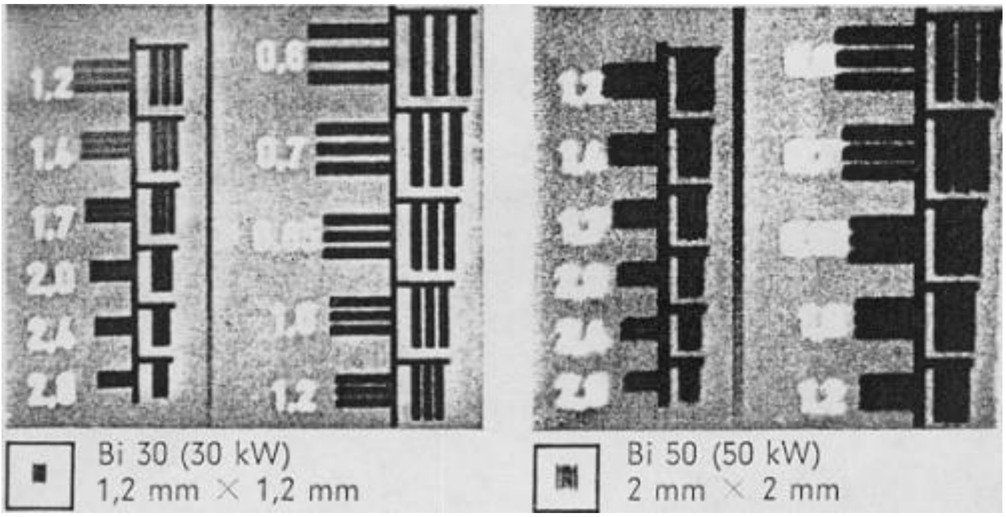
Formation of Focal Spot



Which focal spot size is used normally depends on the object and the examination method. This requires different focal spots.
Thicker and/or denser objects need higher electrical power to obtain an acceptable result in a specific exposure time. More power can only be applied to a larger focal spot area.
Fine object differences ask for higher image definition. This requires a small focus, with the consequence of a lower output.
To solve these demands economically, most x-ray tubes are double focus tubes:
a small focus with low power (small bombarded area) and a larger one with higher output.

.

Formation of Focal Spot



The example above is taken with a tube which had a rotating anode and two foci .
On the bottom of the picture you see the photographs of the two different foci:
- the small (30 kW) for higher definition
- the large (50 kW) for more power.

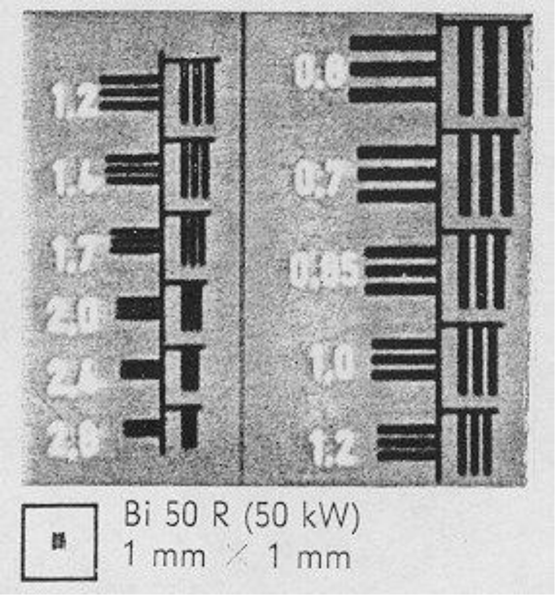
The difference in the resolution is significant:

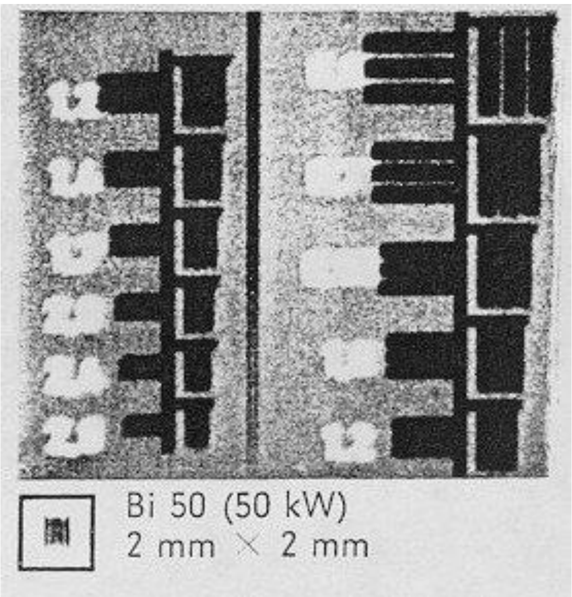
- with the 1,2 focus we can just still distinguish the lead bars at 1,7 LP/mm in both dimensions,

.

The X-Ray Tube

Formation of Focal Spot





Customers always ask for improvements.
Concerning the tube, this means for example smaller focal spots and more output.
On the left you find the 50 kW focus from page 14, and on the right the same output but with a four times smaller focus area .
How this can be achieved is described in the next chapter "Anodes".

.

The X-Ray Tube

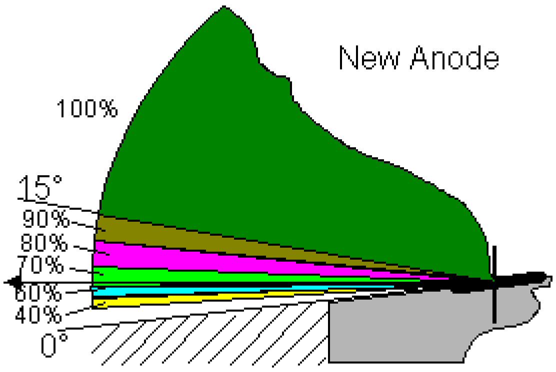
Formation of Focal Spot

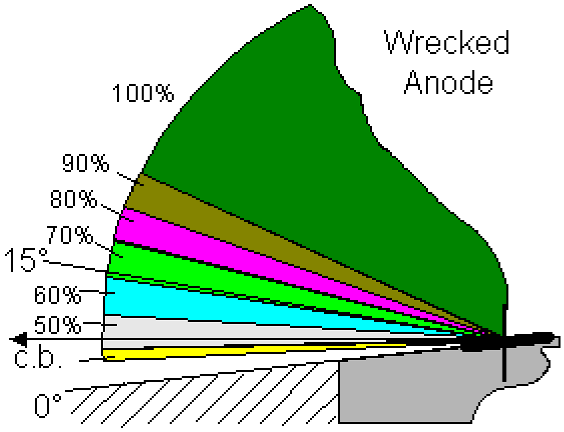
End of Subchapter "Formation of Focal Spot"

.

More Info

Formation of Focal Spot





With a new anode the intensity reaches in our example about 70% in the center beam (c.b.).
But the **Heel Effect** becomes even worse with a worn-out pure Tungsten anode (only certain tubes).
Such an anode gets a rougher surface with the age, what results in a reduction of radiation output.
The Heel effect increases and the intensity is reduced. In the center beam we would then possibly measure only 50% (the percentage depends on the condition of the surface).

***"The tube lost doserate"!** but the necessary dose can be achieved.*
Dose is doserate multiplied by time. That means, an exposure done with a wrecked anode needs only longer time for the correct blackening.

Again, this happens only with pure Tungsten anodes!! (chapter "Anodes")

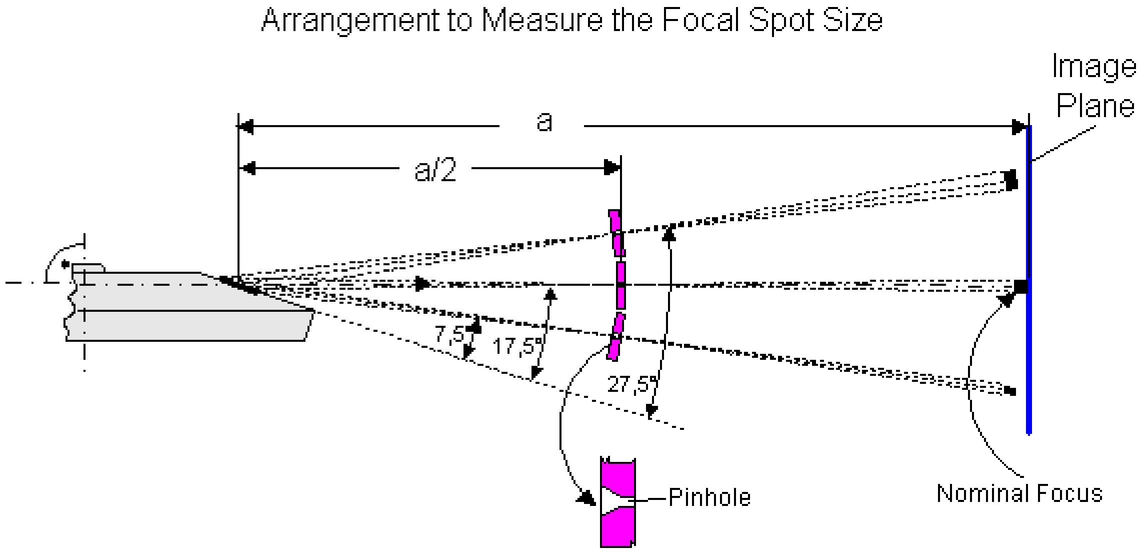
exit info?

.

, Formation of Focal Spot 3/4

More Info

Formation of Focal Spot

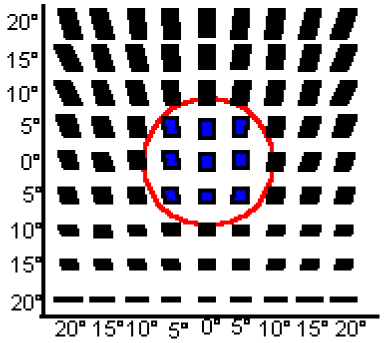


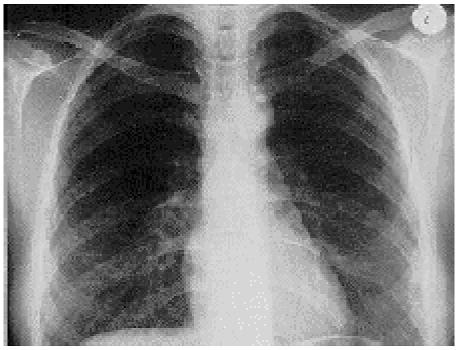
The sketch shows a similar measuring arrangement as required for the IEC 336 standard.
Focal spots are correctly compareable only when their determination standard was the same.
A very small hole in a metallic plate (pinole camera) is placed in the middle between source and image plane (film).
The spot in the center beam depicts the "Nominal Focus".
The focal spot of each tube type is photographed in this way.

.

More Info

Formation of Focal Spot





When the pinhole camera is moved step by step over a fixed film and the film is exposed on the various positions the result on the left is achieved.
The black spots on film represent the true size of the focus in this specific position..
The focal spot is a square only in the center beam and changes its form more the larger the distance from the film center is.
But these changes in size are not visible on a radiologic image. Why?

be close to each other and their distance to the radiation source is relativly large.
In this case only the innerst nine spots of the picture top left will contribute to the image. Their size is similar.
Secondly, the objects in the human body domnot have uniform density and size, and have different distances to the image plane, so that small differences in the focal spot sizes do not play a significant rule in the roentgen diagnostic.
As an example, a lung exposure is shown on the

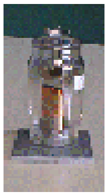
Firstly, the geometric factors are quite different. left.
In reality, object and image plane (film) should

exit info?

.

The X-Ray Tube

The Anode

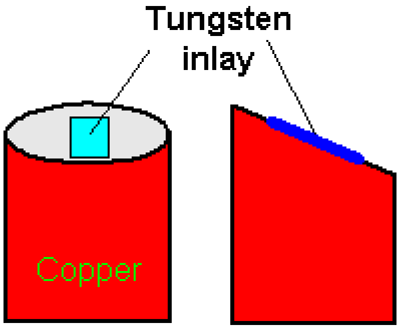


Stationary anode

Rotating anode

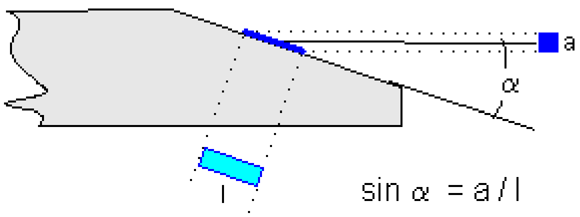
In general we differ between stationary and rotating anodes.
The stationary anode consist of a block of copper for the heat distribution and an inlay of pure tungsten - the focal spot.
Tungsten is selected because:
1. its high atomic number increases the efficiency of the radiation production (see chapter "X-Ray Physics").
2. the very high melting point allows high power rating (see "Electrical Values").
Only units with low tube output use stationary anodes in the x-ray diagnostic, as in dental examinations, surgery for extremities, and orthopaedy.
The output is limited to about 2 kW because of its small focal area which has to bear the thermal load when bombarded by electrons.

Most modern diagnostic x-ray tubes have a rotating anode.



The X-Ray Tube

The Anode



It follows an example to compare the maximum output between a stationary and a rotating anode with about the same nominal focal spot.
· anode angle: 12°
· nom. focal spot (f.s.) "a" : 0,65 (mm)

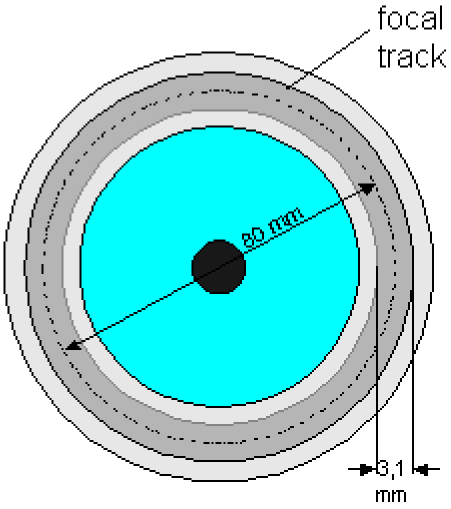
The actual f.s. length "l" is calculated with
l = a / sin 12°

l = 0,65 / 0,208
l = 3,1 mm

The actual f.s. area (bombarded) is then
0,65 × 3,1 = 2 mm^2

A stationary anode with this focal spot can be loaded with 1,3 kW at most for a specific time, according to offical data.

.



With a rotating anode of 100 mm diameter and the f.s. length of 3,1 mm the bombarded area increases to 780 qmm.

Mean diameter of the focal track: about 80 mm.

Calculation:

length "l" × (mean diameter) x p = focal track
3,1 mm × 80 mm × 3,14 = 780 mm^2

At a rotation of 9000 rpm a maximum power of **40 kW** can be supplied to this area without exceeding the thermal limits of the material.

With the stationary anode just **1,3 kW** are possible.

.

Stationary anode

1,3 kW / 3,1 mm^2 x unit time = 0,042 kW/mm^{2}sec

Rotating anode

40 kW / 3,1 mm^2 x unit time = 1,29 kW/mm^{2}sec

The maximum output is always related to 0,1 sec (see chapter 6 "Electrical values").

The fundamental advantage of the rotating anode is that a much higher thermal load can be applied per unit time and focal area.

The loading is related to the
- diameter of the focal track,
- maximum thermal stress of the material, and
- speed of rotation.

This makes possible
· more load per unit time for a given focus size or
· a reduced focal size for a given load per

unit time

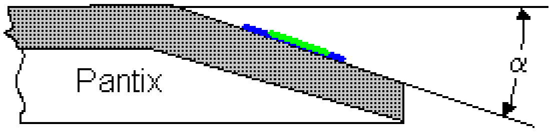
We now confine the following explanations to the modern diagnostic x-ray tubes with rotating anodes.

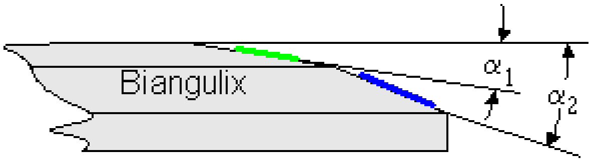
.

The Anode

This is a fragment of a pure Tungsten anode.

The anode itself received several new designs in the past.
1. The old anodes were made of pure Tungsten. This material is very brittle and the surface can easily be wrecked with an overload. This results in a loss of doserate.
Its heat storage capacity reached about 100 kJ.
They are only produced for replacements.
Tungsten anodes were available as
· **Pantix**- (abbreviation **P**) and
· **Biangulix**- (**Bi**) anodes
(see as well "Cathode and helix", page 4)





The Pantix has only one anode angle even with two focal spots. They use the same track. Therefore, both foci are effected when an overload wrecked the surface.

The Biangulix has two anode angles. If one focal spot was overloaded and the track is roughened the second spot is not influenced, as it happens with the Pantix.

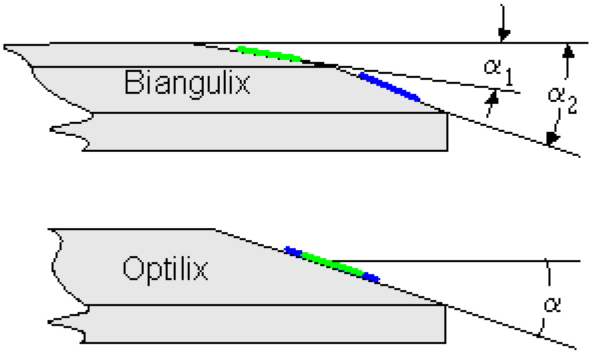
.

The Anode

2. New anodes have, just for the surface, an alloy of **R**henium-**T**ungsten (about 1 mm thick) and the body consists of **M**olybdenum – the **RTM** compound disk.
Its benefits are:

- higher loadability with the same anode weight (up to 250 kJ)
- anode aging is significantly reduced

Thereby, little loss in intensity occurs, even after heavy usage.



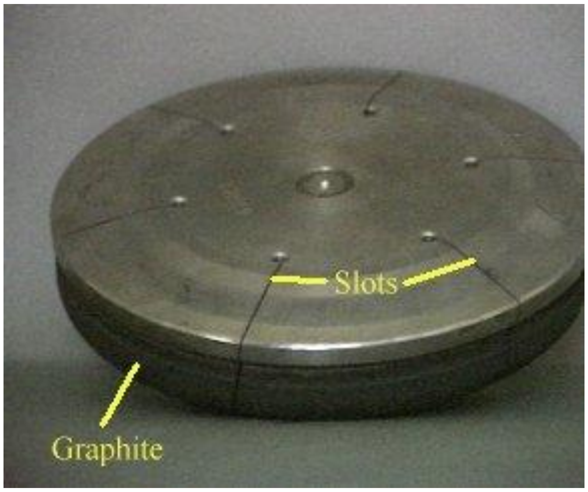
Two different types were produced:
· **Biangulix** (**Bi**), and
· **Optilix** (**Opti**), with an additional layer of graphite (see next page).

The Optilix is a two foci tube with only one angle. Both focal spots are superimposed since the surface is more heat resistant now.

The tubes mostly delivered are the Optilix.

.

The Anode

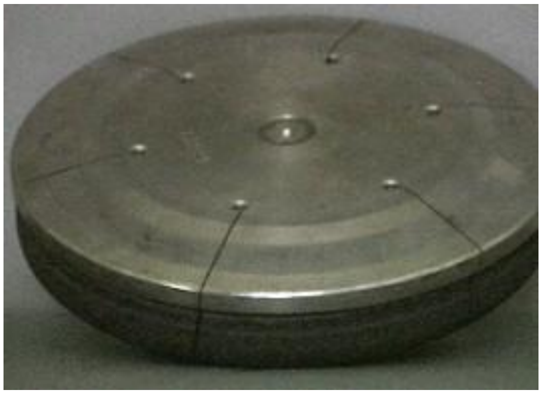


3. For certain applications, an additional layer of graphite is joint to the back side of the RTM disc – the CALOREX anode.
This almost doubles the heating storage capacity of the anode with only a slight increase in weight (450 kJ).
This is used for the Biangulix and Optilix anodes.
4. High load puts a lot of thermal stress on a cold anode disc. Even the RTM disc may possibly crack then.

Artificial radial slots prevent the disc for being destroyed in such cases. The slots are oblique to prevent electrons to pass them and destroy the glas envelope.
Those anodes are called "stress relieved".
It is applied to both, RTM- and CALOREX-discs in Biangulix and Optilix tubes.

Those anodes need to rotate even during fluoroscopy.

.



(same scale like left image)

5. For higher anode loadability, important in angiography, a larger anode with 120 mm diameter and graphite was designed. It reaches a capacity of 1000 kJ or 1 MJ.
Therefore, the given tube name is "Megalix".

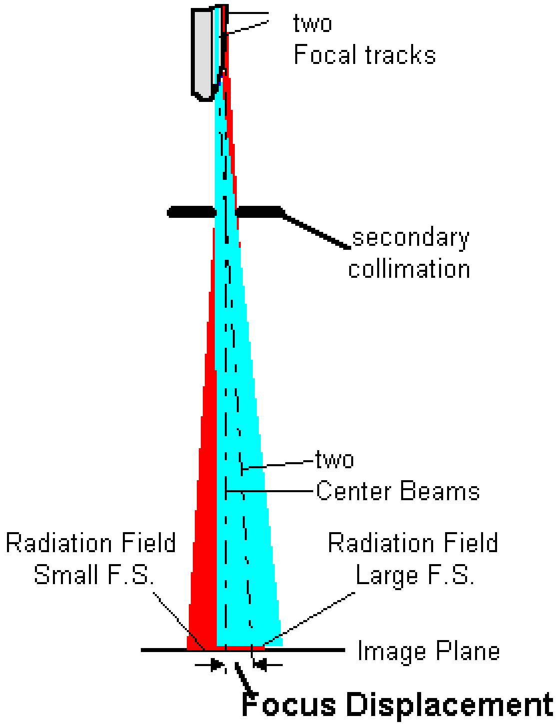
6. A special design was the Polyphos-Tube. Used for a Single Tank Head, it had to be a small but highly loadable anode.
Its diameter was just 60 mm and the CALOREX design was applied, too.

.

.

Focus displacement

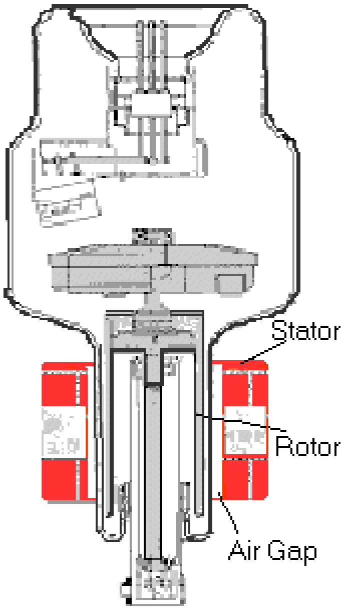
The disadvantage of the Biangulix anode are the different positions of the radiation source. That means, the radiation field is displaced in the image plane when switching from one focus to the other – **focus displacement.**
No focus displacement occurs with Pantix and Optilix tubes.



.

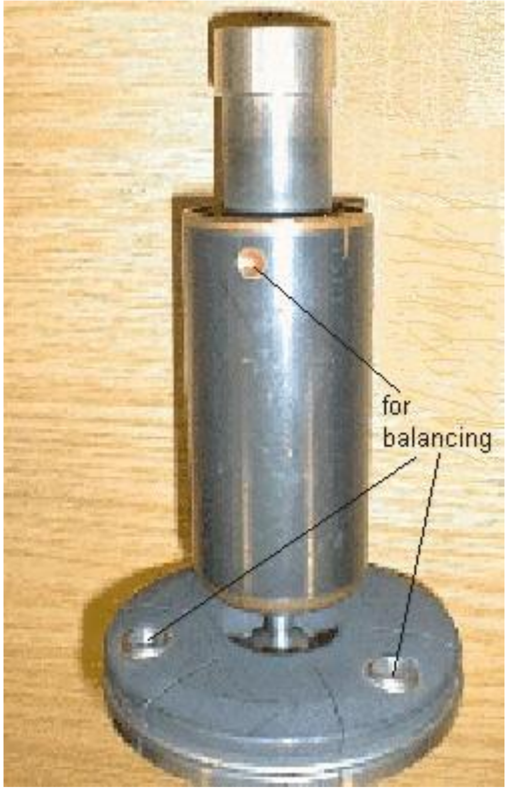
The radiological examination finally determines over the best suitable anode(tube) type.
For further information see chapter "Types and designations".

End of Subchapter "The Anode"



In principle, the rotating anode is the moving part of an electric motor, running in a vacuum. The rotor carries the anode.

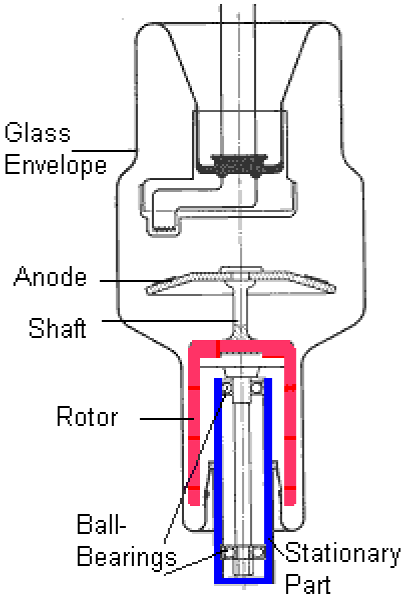
An external electromagnetic field, produced by a winding (stator) outside the glass envelope, drives the rotor. Both together work as an asynchronous motor.
The air gap between rotor and stator isolates both from each other, since the winding is electrically close to ground and the anode lays on high potential during operation. On the other hand the gap reduces the efficiency of the rotating anode motor significantly.
Due to this distance, the power supply for the motor must be relatively high, in order to speed up the anode in an acceptable short time.



An optimal rotation is achieved when a body rotates without creating axial forces. To reach those condition, a "balancing" takes place during the tube manufactoring process. This means, material is added to or removed from the anode and the rotor, till the centre of gravity almost coincides with the artificial axis of rotation.
Only then, do no vibrations occur.
Practically, this is never achievable during operation.

.

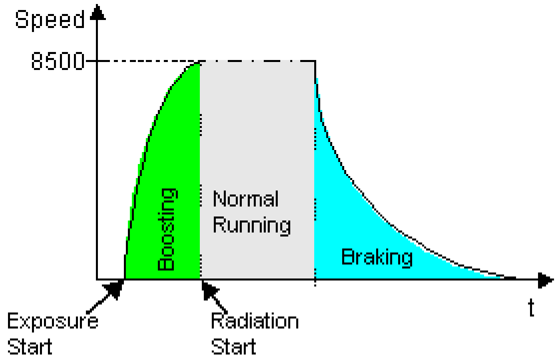
Anode Motor



The Rotor consists of a copper cylinder and rests in ball bearings for smooth movement.
The bearings cannot be lubricated with ordinary grease because it would affect the vacuum and, as a consequence, the high tension characteristics of the tube.
Soft metals such as lead and silver are applied to separate the ball bearings and the running surfaces, in order to prevent the possibility of "jamming" in the vacuum.
This form of lubrication limits the life time of the bearings in the x-ray tube to about 1000 hours.
Therefore, the running time needs to be as short as possible, which does not allow continuous rotation.
The rotation is controlled when a radiography is started.

.

Anode Motor



The control works so, that the anode only rotates when radiation is required and is braked immediately afterwards.

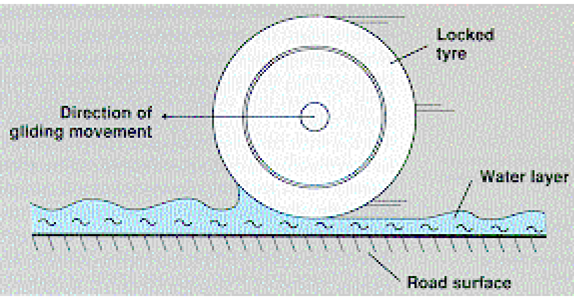
The high inertia of the heavy metal disc leads to some delay in getting the rotor up to speed. This "Boosting" takes up to 2,5 sec, depending on the type of starting device and anode. Radiation can only be started in the grey area zone after the anode reached it final speed.

The thermic loading of the anode should not heat up the ball bearings too much. Here, the thin shaft serves as a barrier for heat transport.

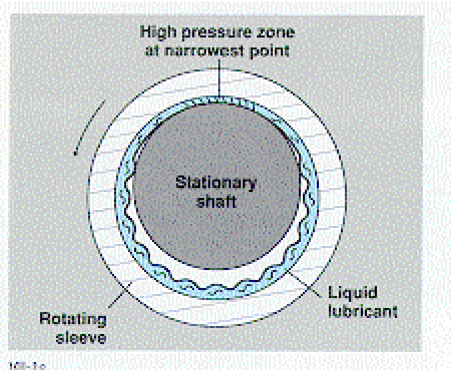
The bearings conduct as well the tube current, flowing between the stationary part of the motor (positive high tension) and the anode.

.

Anode Motor



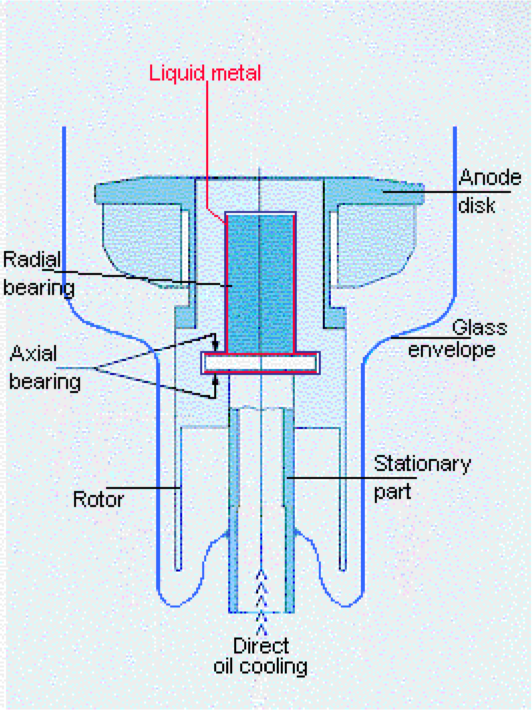
The latest innovation in x-ray diagnostic tubes is the **spiral groove bearing** used instead of ball bearings.
Its principle function is based on the effect of aquaplaning on wet road surfaces. Wheels with high speed entering a puddle of water lose their grip.



This effect can also be employed in bearings for reducing the friction. The lubricant used is a gallium-based liquid metal alloy which does not evaporate in vacuum.

.

Anode Motor

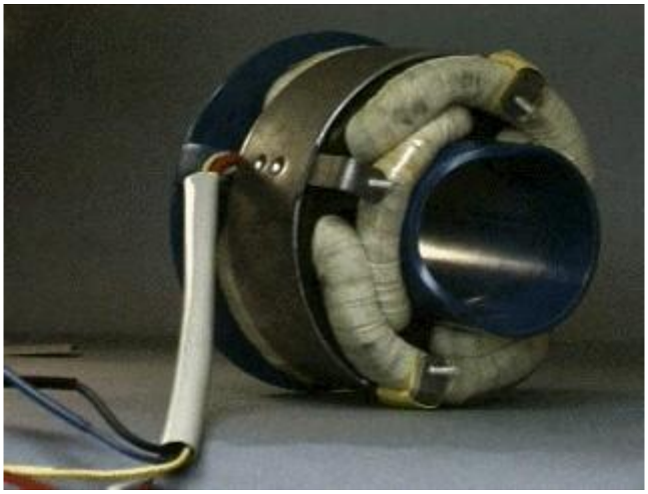


The spiral grooves on the stationary shaft (axial and radial bearing) keep the lubricant (red coloured) in place during the rotation.
The advantage of low noise and only little friction allows the anode to run continuously, which saves waiting time during the anode acceleration.

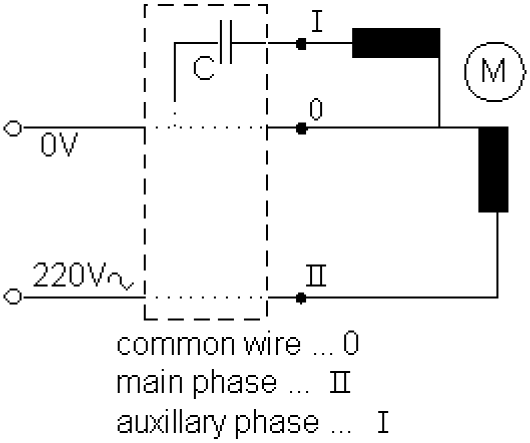
With those construction a direct oil cooling of the anode is possible as well, since the stationary shaft is hollow.

.

Anode Motor



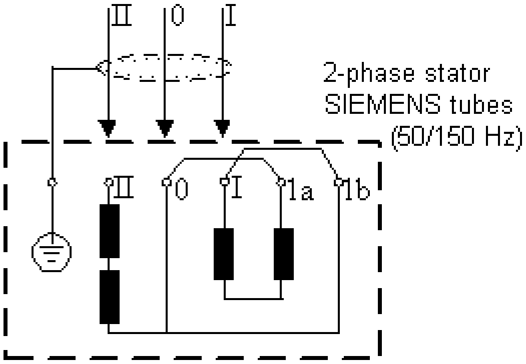
The stator consist of several windings which are equally spread out around the neck of the tube. They induce a rotating electro-magnetic field which interacts with the rotor, causing it to rotate synchronously.
The simpliest power supply is a 220 V AC source. It was used in old generators for the normal speed anode.



A capacitor C provides the stator with a second phase.
The current in the two phases I and II have a phase shift of 120° to each other, which produces the rotating field.
The value of the capacitor depends on the type of stator coil.
This stator is called "two-phase stator".

.

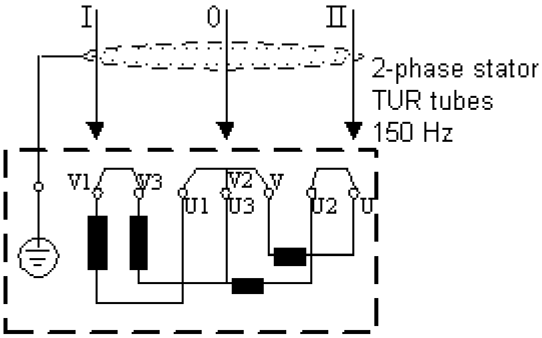
Anode Motor



A two-phase stator can drive the anode with different speeds depending on the formular

$$n_{max} = 60 \times \text{frequ.}_{line}$$

The "normal running tube" with a 50 Hz line consequently rotates with 3000 rpm.
But, because of the large air gap between stator and rotor and the short acceleration time, there is a slip of about 6%.
Thus, the anode runs only on 2800 rpm.

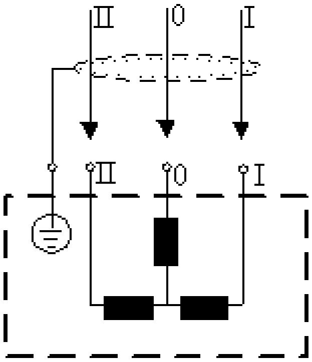


For higher speed ("rapid tube"), the frequency of the power supply is changed to 150 Hz. This results in 8500 rpm.

There is a 20% increase of speed with a 60 Hz line frequency.

The company "TUR" produced x-ray tubes among other things and was taken over by SIEMENS.

.

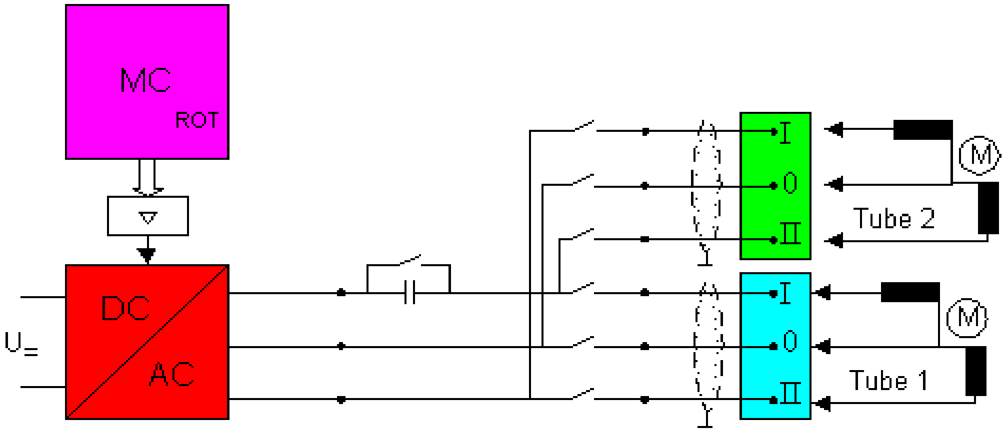


3-phase stator

The latest innovation is a three phase stator for rapid speed, which does not need the phase shift capacitor anymore and has a better efficiency.
It reduces the acceleration time for the anode to the half and was used with the Megalix tube for the first time.

This image shows the terminals at the anode side of the tube housing to connect the stator supply.
A special stator cable has to be connected here according to the proper technical documentation.

.

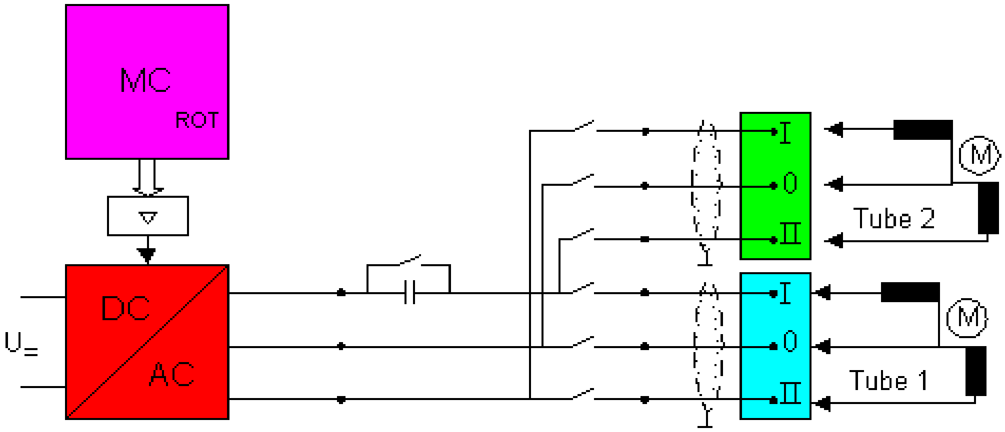


The starting device supplies the motor, controls and monitors the rotation.
The rapid rotation formerly required a special power supply to produce 150 Hz with high power to run the anode at 8500 rpm.

Today, a DC-AC converter supplies the power, controlled by a microcontroller MC.
This device is able to produce every common frequency with two or three phases.

.

Anode Motor

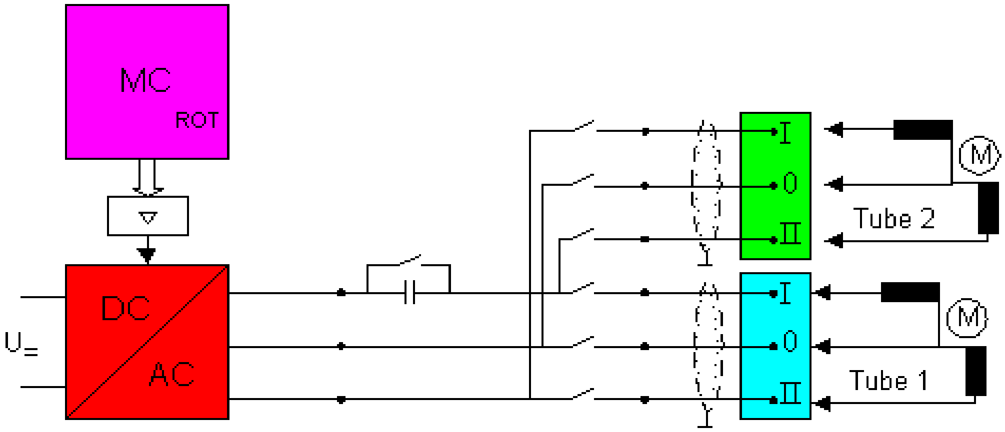


Depending on the type of generator, the anode starting device alternatively supplies up to four different tubes.
All necessary tube data are nowadys stored in an EEPROM .
The microcontroller MC switches and controls the starting device according to the tube type selected.
This includes

· the acceleration time (boosting)	· normal running (to overcome friction)
· anode braking	· fluoroscopy rotation
· monitoring	

.

Anode Motor

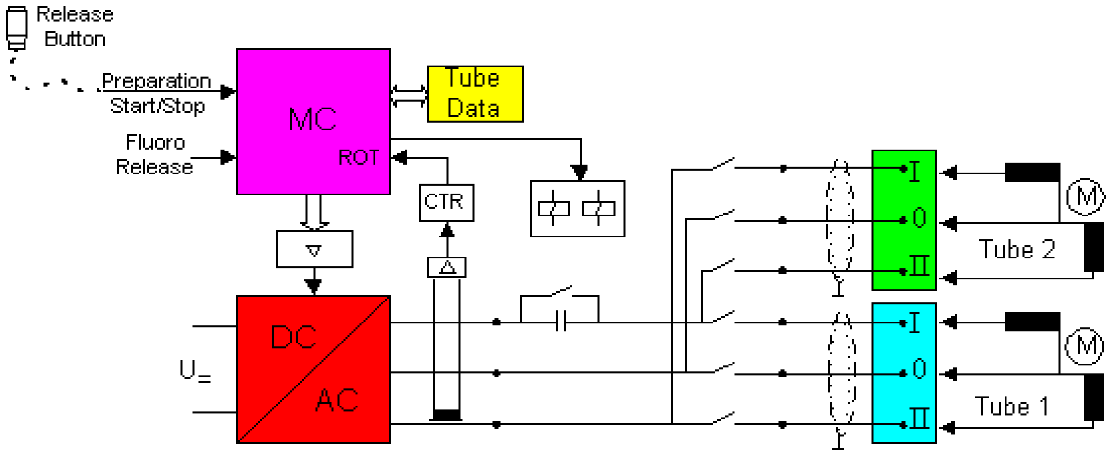


With the exposure start signal, the anode is accelerated with high power to reach the final speed in an acceptable time. The counter CTR starts counting the time when the current in phase II reaches a certain value. If the current is too low we can assume, that the nominal speed was not reached, what requires to block the radiation start.
After about one second the counter delivers the ROT signal which enables the MC to start radiation. In the same time, the power for the motor is reduced just to keep the anode running. This lowers the noise and heat production of the stator.

.

.

Anode Motor



After the exposure is finished and the switch released again, the DC-AC converter is switched to supply a DC voltage to the stator. This induces an eddy-current in the rotor which brakes the anode to a standstill in order to save the ball bearings.

Most anodes, especially the stress relieved one, rotate as well during fluoroscopy. This is achieved with low power and about 20 Hz.

.

The X-Ray Tube **Anode Motor** 14/15


The three spots on the innerst focal track are the result of a high load applied to a non rotating anode

Why must the rotation be monitored and the exposure blocked when the anode does not run with the correct speed?
The advantage of a rotating anode is the increased load which can be applied to the focal spot (see subchapter "The Anode"). If this load is fed to a ***not moving*** anode the surface would melt and destroyed. The consequence is, material evaporates which ruins the tube vacuum.

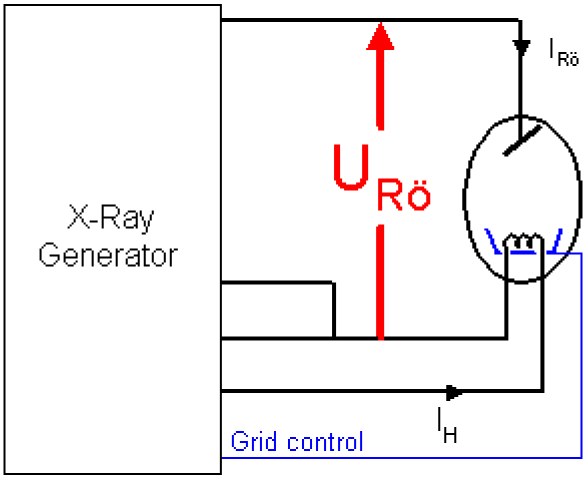
A direct measurement of the revolution is not necessary since the correct speed is reached when the supply and rotor work properly.
With a mechanical defect of the ball bearings the tube has to be replaced anyway.

.

The X-Ray Tube **Anode Motor** 15/15

End of Subchapter "Anode Motor"

The X-Ray Tube **Electrical Values** 1/21



A x-ray diagnostic generator provides all electrical values the tube needs to generate radiation, as there are:

o filament current to release electrons -- $\mathbf{I_H}$

o tube voltage - anode voltage or high tension - to accelerate the electrons -- $\mathbf{U_{Rö}}$

o electrical power to obtain radiation with sufficient dose rate -- ($\mathbf{I_{Rö}}$)

o a grid voltage for special application

Changing the first three varies the radiation characteristic. The latter controls the radiation. The most important is the tube voltage, supplied between anode and cathode. In technical documentations the german abbreviation $\mathbf{U_{Rö}}$ is very often used for it; and its unit is **kV**.

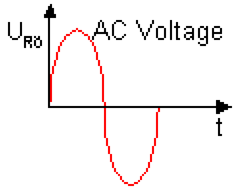
.

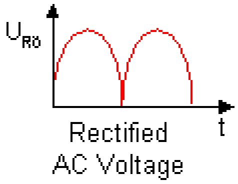
Electrical Values

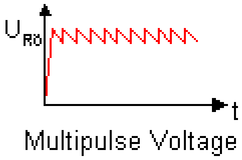
$E_e = e * U_{Röp} = E_{qmax}$ $E_q = h * f_q$

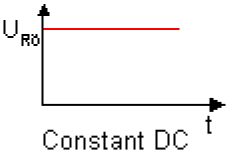
E_e ....electron energy
E_q ....quantum energy
E_{qmax} ....maximum quantum energy
$U_{Röp}$ ....peak tube voltage
e...............electron charge ($1{,}6 \times 10^{-19}$ As)
h..............Planck´s constant ($6{,}23 \times 10^{-34}$ Js)
f_q.................quantum frequency

The **tube voltage** determines the speed of the electrons and therefore their energy E_e, which is responsible for the penetration power E_q of the x-ray quanta (the radiation quality).
The high tension in the roentgen diagnostic ranges from 25 kV till 150 kV.







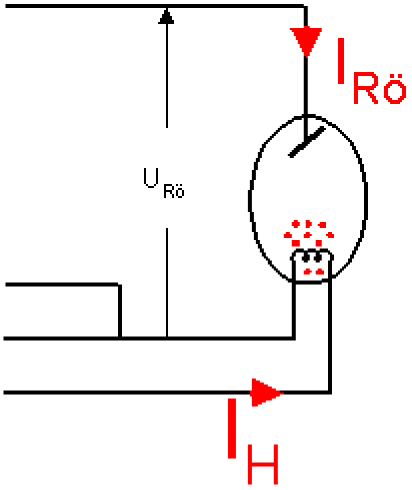


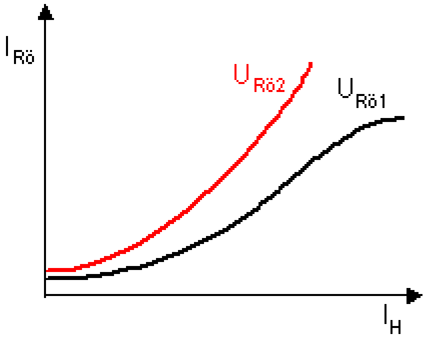
Any form of voltage can be used. But the best radiation yield is of course achieved with constant DC. All accelerated electrons have the same speed in this case.
The kV selected and displayed at the generator console is always given in peak values ($U_{Röp}$).
Only they produce the highest electron speed and therefore the quanta with maximum energy (E_{qmax}).
As you already know, the image quality depends on the quanta energy.

.

Electrical Values

Tube current
How many electrons the filament releases, depends on the temperature of the helix, thus, from the filament current **I_H**.
The higher the filament current the greater will the tube current $I_{Rö}$ be, when HT is supplied.
We just remind again the heating characteristic, which is explained already in more details in the section "cathode and helix".
More emphasis is here put on the tube characteristic.



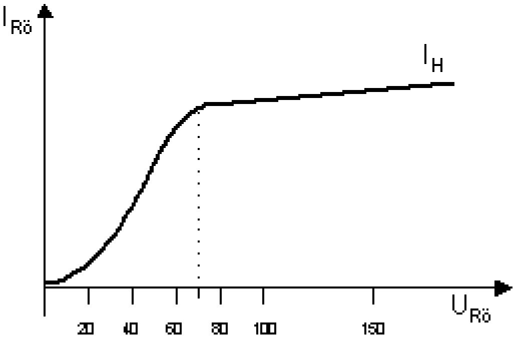


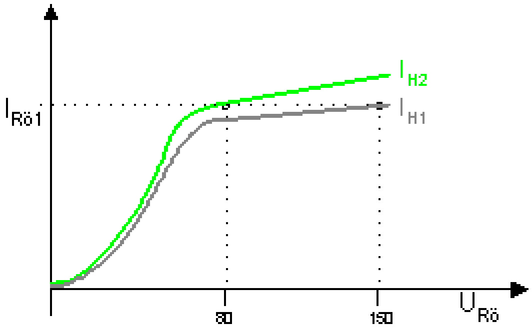
The relation between the three values
$I_{Rö}$, $U_{Rö}$, I_H
can be seen in two different graphs.

1. the heating characteristic $I_{Rö}$ over I_H where $U_{Rö}$ is the parameter.

.

Electrical Values



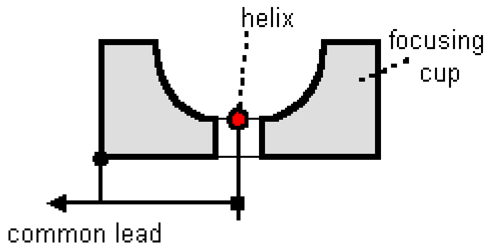


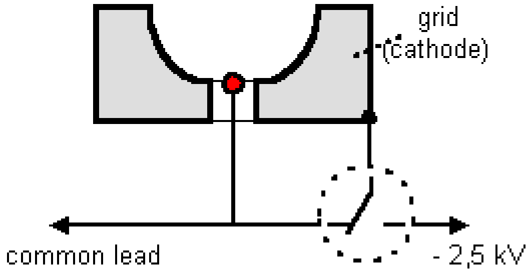
2. the tube graph $I_{Rö}$ over $U_{Rö}$ with I_H as constant parameter (left)
The tube characteristic shows, that, with a constant filament current, the tube current changes as well with the tube voltage. The alteration is more significant with lower kV but is generally present in the diagnostic kV range.
This is due to the so-called "Space Charge Effect".
At what kV-value the curve reaches a linearity (here 70 kV) depends on the construction of the focusing cup.
With modern x-ray diagnostic generators this effect is compensated through feed-back regulation

circuits for both the HT and the tube current. They keep those values constant.

.

Electrical Values

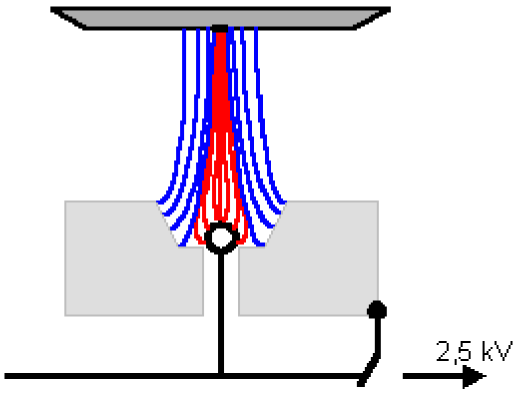


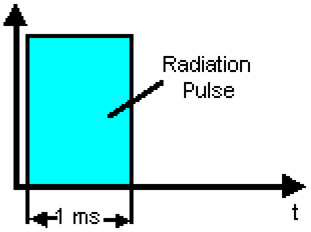


In card angiography high image sequences are required to make fast moving objects visible with an acceptable image quality (like heart valves or heart malfunctions).
Switching the radiation with a frequency up to 100 Hz and normal x-ray tubes is only possible with enormous effort.
A special tube is employed for such diagnostic methodes, the **Grid Controlled X-Ray Tube.**
It difference lies in the connection to the focusing cup.
The cathode and the common lead for the filament supply are normally connected (left sketch).
But they are separated in the grid controlled tube (right). The cathode block serves here as a grid and has two different potential levels refering to the filament:
1. **filament level** with radiation on (like the right sketch)
2. a **negative voltage** up to **2,5 kV**
An electronic switch controls the grid supply. 2,5 kV block the electron flow completely.
Lower voltages reduce the size of the electron beam and therefore as well the focal spot.
Both possibilities are used in the roentgen diagnostics.

.

Electrical Values





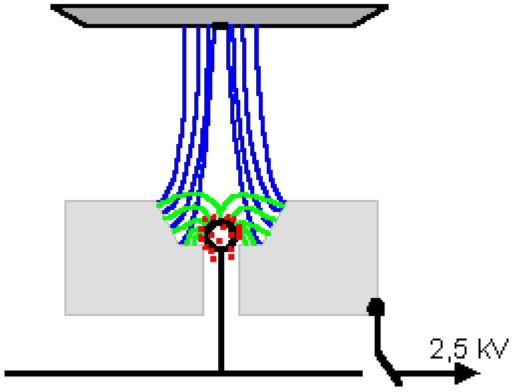
The electric field lines (blue) force the electrons (red) to bombard the anode in the focal spot area. This electron stream can be either restricted to reduce the focal area or interrupted to switch the radiation off.
The latter is applied when high image frequencies are required in card angiography.

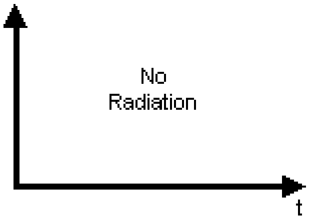
A cine camera, running on a selected speed, picks up the image from the Image Intensifier output screen.
The camera has a shutter, which opens when the film has a stillstand and can be exposed and closes when the film is transported.
Synchronously with this shutter the radiation is controlled via the electronic switch and the grid voltage.

Which camera phase does the left sketch show?
Click on your answer here.

The switch connects helix and cathode.

.





When the switch changes the cathode is on 2,5 kV refering to filament.
This voltage builds up an electric field between helix and cathode (green), which blocks the electron flow, so that the radiation production stops.
Now, the camera shutter is closed and the film can be transported forward for the next image.

Click here for a short camera run!

The grid voltage can also be used for reducing the focal spot size. In this case a lower voltage is supplied, which depends on the required size.
The higher the value the smaller the focus.
This mode is applied for enlargement diagnostics, which asks for finest focal spots to obtain an acceptable image resolution.

▼ ▲

.

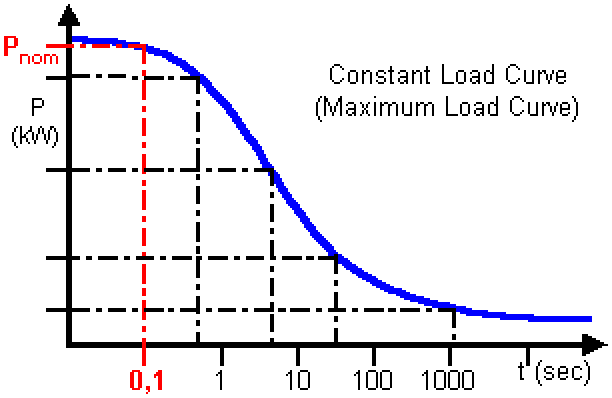
Tube Load

Less than 1% of the electrical energy supplied to the tube is converted into x-rays. The rest is heat which consequently must be dissipated from focal spot, anode, tube, and housing to avoid overloading.

Anode type and material, focal spot size, and anode speed fix the maximum output. But this maximum can only be applied to a given focus within a limited time. After then, the permissible focal spot temperature is reached, which depends on the melting point of the anode material.

According to international standards the **constant** nominal tube rating **P_{nom}**, the focal spot can safely withstand, can be supplied for just **0,1s** under the following conditions:

constant output, about 100 kV, and at least a 12-pulse voltage.

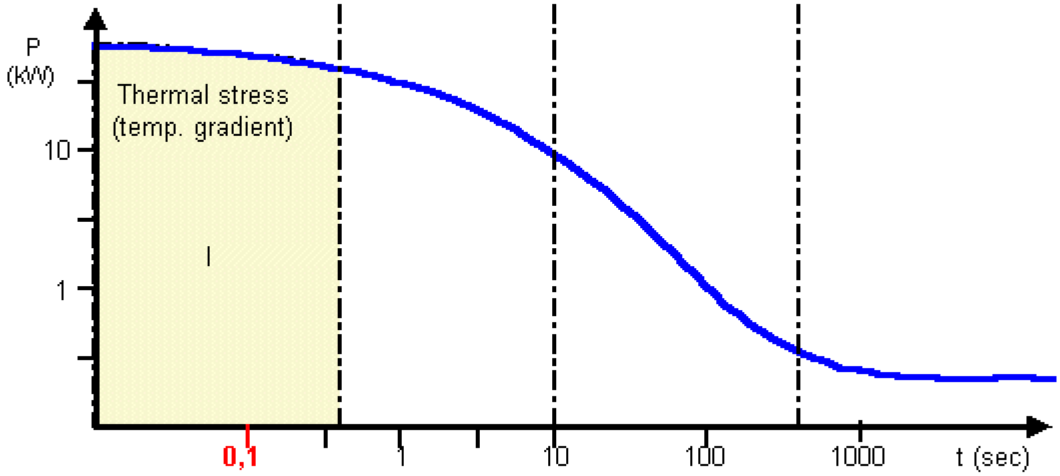


With a short exposure time the energy is transfered just to a small anode volume. The longer the time the larger is the volume heated up, that is, more energy is permitted. This is expressed in the **Constant** or **Maximum Load Curve** for a specific focal spot with the nominal output P_{nom}.

In order to expand the lower time range (mainly used for radiographies), the time base is logarithmically.

▼ ▲ more info?

.

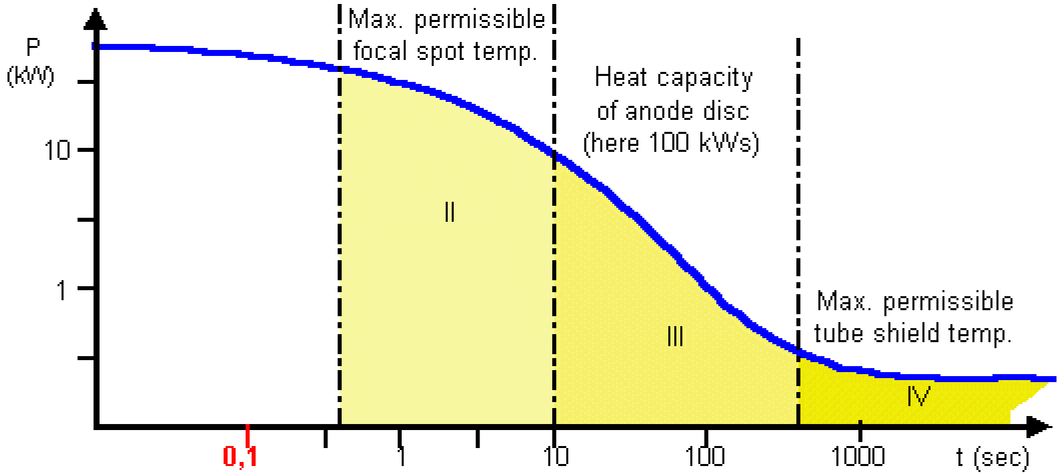


The **constant** (or maximum) **load curve** of a rotating-anode tube can be divided into four sections each determined by completely different physical processes. The changeover from one section to the other is continuous.

Section I :

Even when the load duration is short, the power should not be increased beyond a maximum value. The temperature drop from the focal area towards the surroundings, which is proportional to the power, determines the thermal stress. If the power is too high, the thermal stress becomes so great that the surface of the focal spot (path) is roughened (doserate reduction can occure).

.



Section II:

Here the maximum temperature of the focal spot determines the maximum load curve. In this

Section III:

With long operating times the heat imparted to the focal spot is distributed throughout the

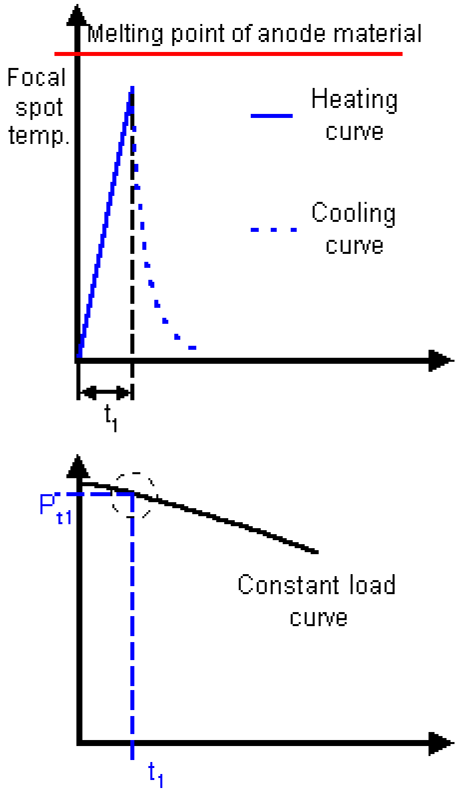
Section IV:

Low output does not build up high anode temperatures. The continous load, however, section the drop in the maximum permissible load is proportional to f(t) for both rotating and stationary tubes.

entire anode disc. Here the heat storage capacity of the disc determines the exposure duration for a given power.

must be restricted to about 300 W (without additional cooling), as otherwise the tube shield will become too hot.

.

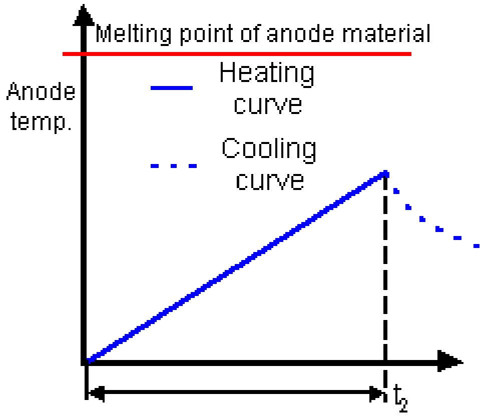


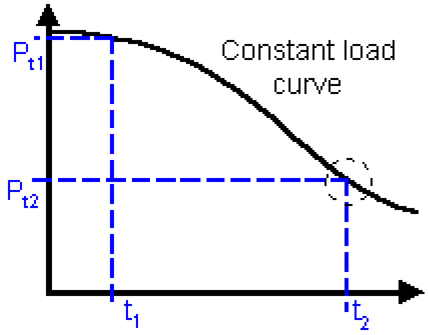
Short Time Exposure

In the first milliseconds (t_1 < 100 ms) only the anode surface is stressed which can not store very much energy and is therefore heated up quickly.
This limits the supplied electrical tube output per unit time and area.
The temperature rises exponentially during the exposure (on the left simplified by a straight line).
The final surface temperature should not even reach the melting point to avoid material evaporation.
The maximum temperature is achieved when a constant power line (P_{t1}) intersects the constant load curve. At this time t_1, the high tension supply must be terminated to protect the anode for being overloaded.
Since only the surface of the anode is effected, the supplied heat is distributed to the surrounding material which results in a rapid temperature drop - cooling curve.
The energy applied is the area within the blue dashed lines, that is $P_{t1} * \ t_1$.

more info?

.





Long Time Exposure

A load of several seconds (t_2) affects the anode in a quite different way.
Not alone the surface is here heated up but the whole anode.
Only a significantly reduced constant power P_{t2} can be applied for the time t_2 , according to the constant load curve. When the maximum anode temperature is reached (far below the melting point) the electron flow needs to be stopped.
Since the entire anode is involved the stored heat is given up via the vacuum and the glas envelope to the oil in the housing. This needs a much longer cooling time than with short time loads.
The transfered energy is of course much greater now.
The area of rectangle P_{t2} ; t_2 seems to be not very much larger as with the short time exposure P_{t1} ; t_1.
But look at the time scale on page 8 to 10. It is logarithmic, which doesn´t allow a simple comparison between the two areas.

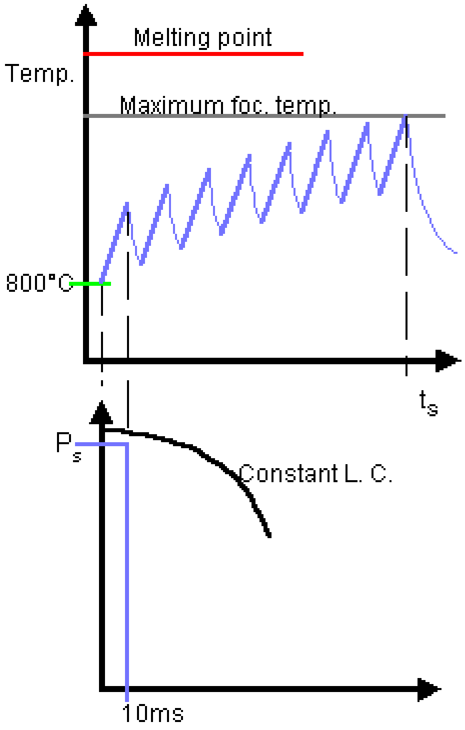
▼ ▲ more info?

.

Serial Radiography

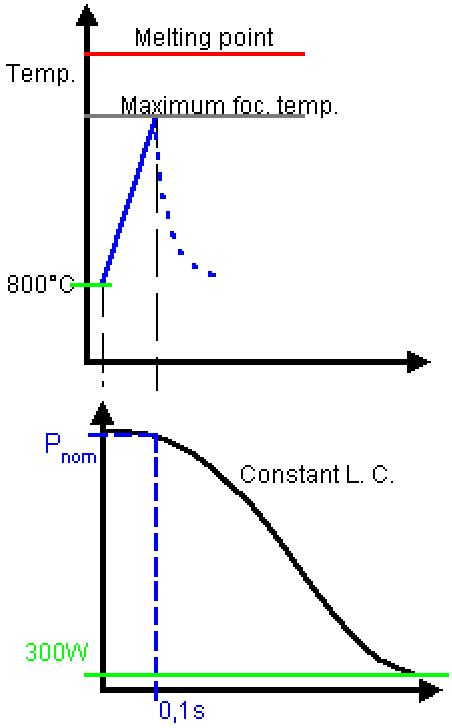
Angiography requires the serial radiography, that is, several short time loads (P_s) within a fixed serial time (t_s) .
This operating mode heats up not only the whole anode, but, depending on power; time per puls; and serial time, even the tube housing.
The serie must be terminated on t_s , because the maximum focus temperature is reached.
This is monitored by the generator.

Such operating mode is the biggest challenge for a x-ray tube and requires often additional measures for cooling.


Melting point
Temp.
Maximum foc. temp.
800°C
t_s
P_s
Constant L. C.
10ms

▼ ▲ more info?

.



Continuous Load

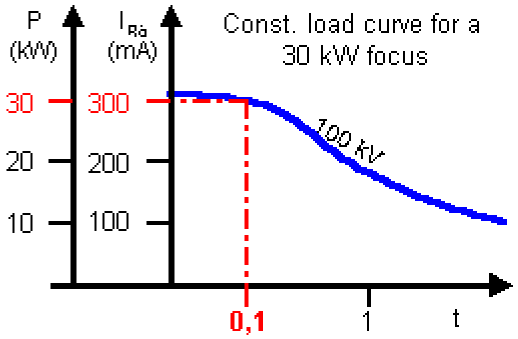
This mode is required for fluoroscopy.
The maximum applicable power is limited through the heat dissipation capability of the tube housing.
An equilibrium is reached when the outgoing energy per unit time is the same as the incoming.
This is achieved for most of our tube housings with about 300 W electrical power when no additional cooling devices are installed.
Under those conditions the anode reaches a final temperature of about 800 °C.
On this basis an exposure can be added with the power and time given in the constant load curve for each individual tube and focus type.
Two different nominal values for the focal power are therefore given in the data sheets:

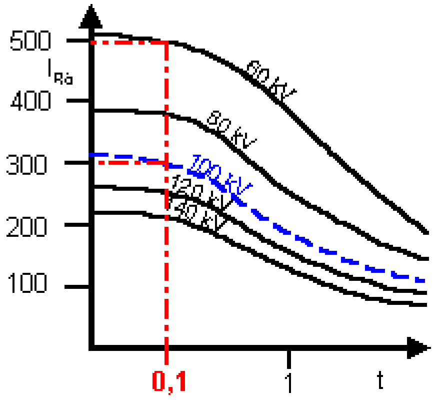
1. cold anode (no pre-load) **P_{nom}(0 W)**
2. hot anode **P_{nom}(300 W)**

It is conform to the IEC standard 613.
Tubes from different companies can correctly be compared only if they fulfil this standard.

▼ ▲ more info?

.

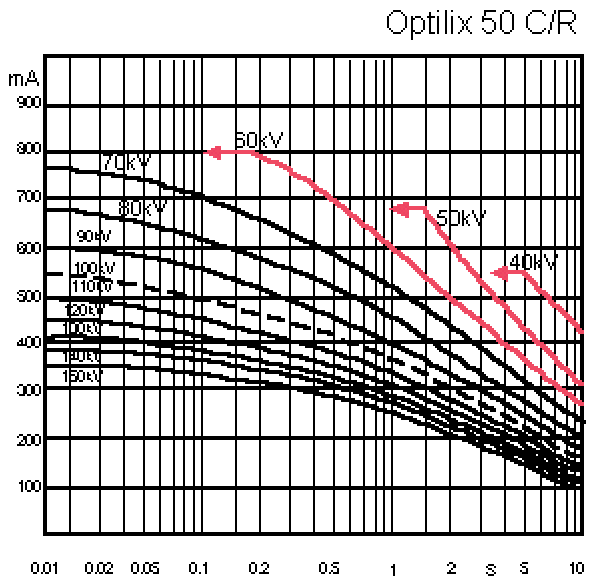




Tube ratings
Tube data sheets show the constant load curve in a different way as described on page 8-10.
The power P is splitted in kV and mA where the kV are the parameter for the charts and mA is used instead of P.
If we take the original load curve and assume that it is used for a 100 kV radiography, then P can easily be replaced by mA at the y-axis.
The time scale was reduced because the longest normal exposure has 5 seconds.
Next we draw separate curves for a certain selection of kV-values.
The result are the charts on the left.
At the line 0,1 s you find always the P_{nom} value when you multiply the kV value at the curve with the connected mA value.
Examples:
100 kV * 300 mA = 30 kW;
60 kV * 500 mA = 30 kW.

.

Original tube charts



About the designation "Optilix 50 C/R you find something in the next section 07 "Types and Designations".

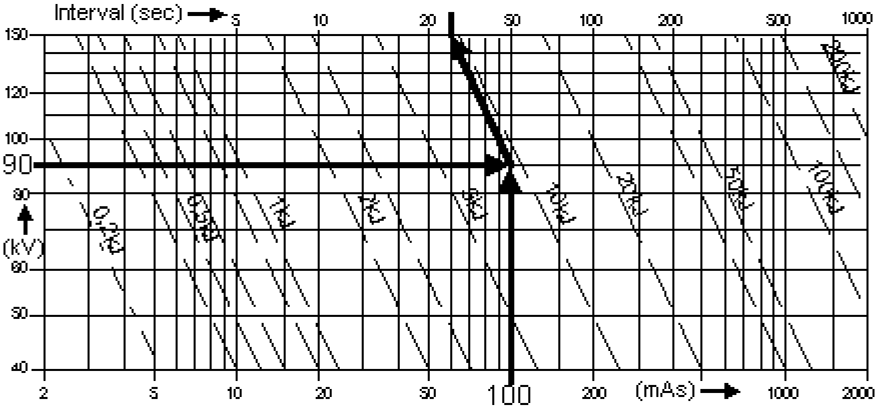
The charts on the left are for a 50kW focus. It shows interrupted curves (red) with low kV values (here < 70kV).
With such kV the tube doesn´t anymore allow the maximum tube current due to the space charge effect.
As a consequence, the maximum tube output is not achievable with such low high tension.

You may say: Then let´s increase the filament current!!
In that case I´d like to remind you of
1. page 04 back again **or**
2. section 2 - "Cathode, Helix", page 09.

.

Heating and Cooling of Anode

After energy was transfered to the anode, the heat needs to be distributed before the next load.
The duration of a required interval, to cool down the bombarded area, depends on the factors: *the previous load, tube/anode type, and extra cooling measures*.
The energy E_R per radiography can be calculated from the selected exposure values:
$E_R = U_R$[*kV*] * (I_R * t_R)[*mAs*]



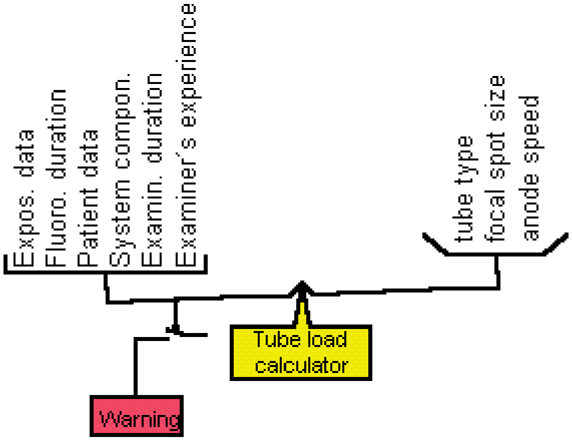
The left diagramm serves as a coarse orientation.

How to read?
Example:
Exposure with 90 kV, 100mAs requires an interval of about 30 sec.

The normal clinical activities let the anode enough cooling time, due to patient and cassette changes and new positioning of the object.

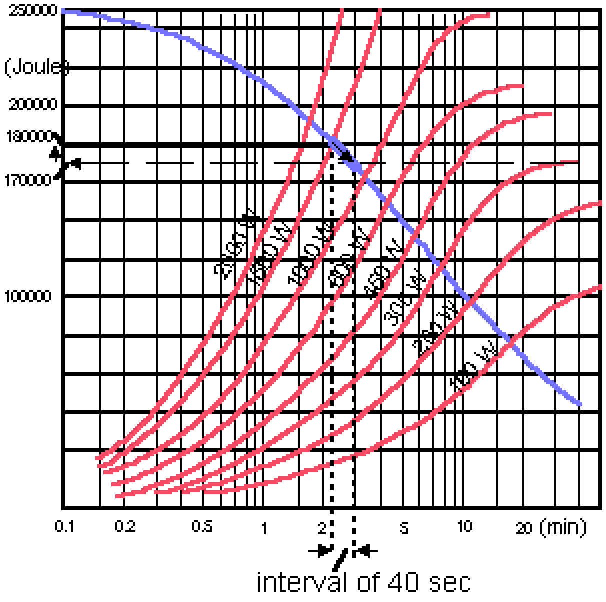
.

Much more load is put on the anode and tube when fluoro is used during the x-ray diagnostic procedures (e.g. gastro-intestinal diagnosis).
The final load, the tube has to bear, depends not only on the system components, but as well on the examination method and the doctor´s experience.
Since it is to complicated for the operating personel to watch the tube´s temperature, a built-in protection system must be established. It warns for possible tube overloads during more complex examinations.



More sophisticated generators are equipped with a so-called **Tube Load Calculator**. It reduces the exposure data for the next radiographies automatically, and warns the operator or even blocks the control circuit, when the tube load reaches certain levels.
It receives the inputs from the selected data and simulates the cooling, too.
For this reason, all data from the installed tubes must be available for the generator.

.



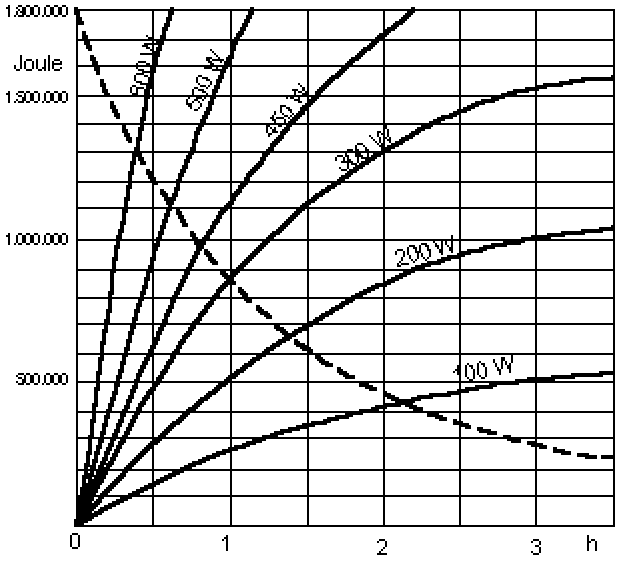
The diagram shows heating curves (red) and a cooling curve (blue) for a modern x-ray diagnostic tube used for general examinations.
The Y-axis refers to the applied energy. The maximum for this specific anode is 250.000J.

Heating and Cooling curves for the Anode

The heating curves are for different fluoro outputs and allow for loss in capacity of the anode, the cathode, and the stator *(each anode start needs between 1.500J and 4.000J, a fluoro rotation about 70 W)*.
A continuous fluoroscopy with 300 W over 30 min heats the anode to about 800°C, what refers to 170.000J.
On that basis an exposure can be added with the permitted load (according the constant load curve), for example 100 kV and 100 mAs.
The finally transfered energy is now 170.000J + (100kV * 100mAs) = 180.000J.
To take the same radiography again the anode needs an interval of about 40sec.

.

Heating and Cooling Curves for the Housing



In general, the housings have a heating capacity between 1.000.000 and 1.800.000 Joule (or 1.620.000 and 2.400.000 HU). The different values depend on whether a fan is installed to cool the housing or not.

HU - Heating Unit, is an american unit and replaces Joule (1 J = 1,35 HU)

With additional cooling measures like a fan the curves differ, of course.
Without fan the maximum capacity changes with the position of the tube assembly. The horizontal position allows higher values, because of the more efficient heat radiation..
The heating curves depend of course on the supplied fluoro output in Watt.

(For further information see the data sheets)

.

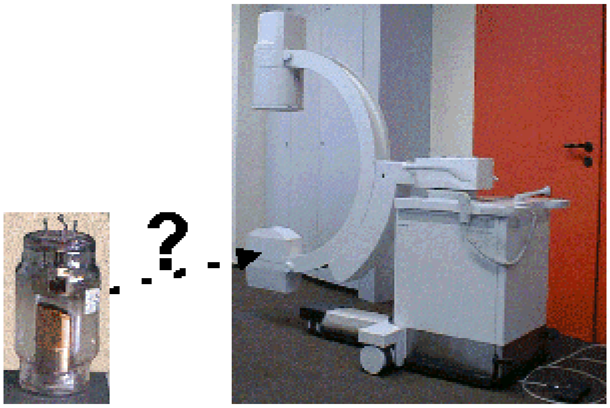
Electrical Values

End of Subchapter "Electrical Values"

.

Types and Designations

X-rays are utilized in several working fields, like material inspections, food sterilisation, science, and medical applications.
We confine us to the last and here as well only to the conventional x-ray diagnostics.
X-ray therapy and computed tomography (CT) do their one research and development on tubes.



The tube needs to fulfil the requirements of the examination method, that means, for dental purpose is a quite different tube required than in angiography.
And they are always subject of changes due to new laws and technologies, and demands from customers.

On the next pages we list the tubes with their features and the roentgen-system or examination method it is recommended for.
If necessary, you will find the legend for designations of tubes at the bottom of each page.

.

Different stationary anode tubes are installed in equipment for dental, orthopaedic and surgical examinations. Some of those units are mobil.
The tube output of course is restricted and the heat storage capacity relatively small.
The focal spot varies depending on application; and even bifocal tubes are available. The object examined and the desired image resolution decide the size of the installed focal spot.
During surgical operations, for example, fluoroscopy is mostly used to control the repositioning of bone fractions. That asks for small focuses.

Tube	**X-Ray System**	**Features**
SR 60/7	Dental units	focal spot 0,8; 60 kV; 7 mA; 5 kJ
SR 90/15		focal spot 1,8; 90 kV; 1,1 kW; 19 kJ
SR 110	Surgery	Focal spot 0,6; 110 kV; 1,2 kW; 37 kJ
SR 90/10/30		0,5/1,3; 106 kV; 2,7 kW; 37 kJ

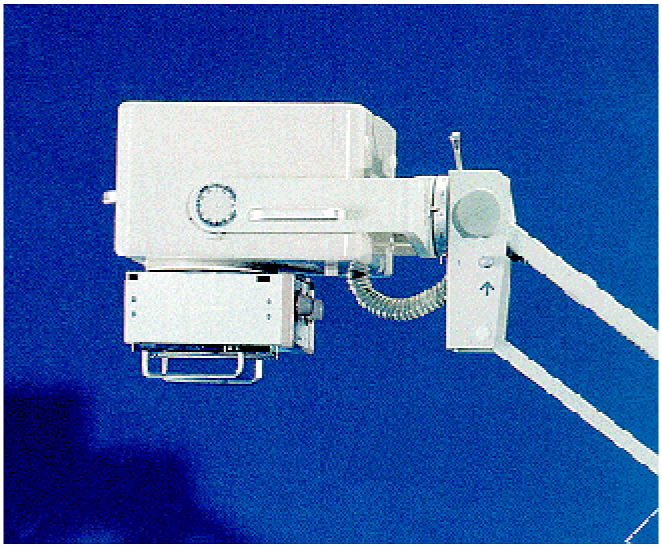
Legend: SR stands for **S**iemens **R**öhre(tube)

< Smallest x-ray tube:
6 cm lenght, stationary anode, for single tank head (e.g. in dental units)

.

Both units are equipped with a stationary anode tube but of different design and output.

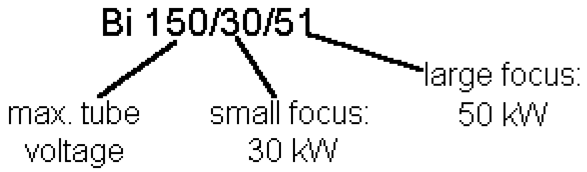
Siremobil for surgery, with single tank head "Sirephos".



Single tank head of a **Polymobil** unit, used for orthopaedy.

.

Types and Designations

X-Ray Tube	X-Ray System	Anode	Features
P 125/20/40	Replacement for old tubes; For general purpose with tables and UT-Fluoro units	Tungsten disk; heat capacity 80 kJ; anode diam. 85 mm	relatively large focal spots; for low stress; anode speed: 2.800 rpm
P 125/30/50		Tungsten; 100 kJ	
Bi 150/30/51		RTM disc, 190 kJ	
Bi 150/30/52 R		RTM disc; 250 kJ; anode speed 8.400 rpm	normal focal spot; stress relieved
Bi 125/20/40 R	For enlargement technique in skull diagnostics	RTM disk; 250 kJ; 8.400 rpm	relatively small focal spots
Legend: 		Normal anode diameter is 100 mm. P............Pantix; Bi - Biangulix; R............Rapid speed (8.400 rpm) 51..........RTM (compound disk: ....**R**henium-**T**ungsten-**M**olybdenum) 52..........stress relieved RTM disk	

.

Types and Designations

1...Mammography tube, metallic envelope, anode and window is molybdenum

2...Biangulix tube with RTM disk.

3...Polyphos tube with 60 mm RTMC anode

4...Optilix tube with RTMC disk

5...CT tube, anode without angle

.

Types and Designations

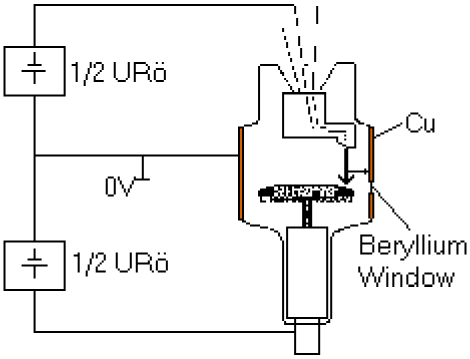
X-Ray Tube	**Used for***(recommended)*	**Anode**	**Features**
Opti 154/30/50 R	low-end fluoro units	RTM; 250 kJ	normal focal spot
Opti 150/30/50 C	UT units and ceiling stands	RTMC; 450 kJ (with graphite)	normal focal spot
Optitop 150/40/80 HC old: Opti 150/40/73 C or Opti 150/40/82 C	OT and UT units; ceiling stands and angiography	RTMC; 580 kJ (with graphite)	normal focal spot; stress relieved
Opti 150/12/50 C	enlargement technique	RTMC disk; 450 kJ	one very small focal spot: 0,3
Opti 110/12/50 HSG	enlargement technique and angiography	RTMC disk; 450 kJ	finest focal spot 0,1 with grid control
Legend:		C.............RTMC disk with ....Graphite(**C**arbon) HC..........**H**igh heat storage **C**apacit. HS...........**H**igh **S**peed: 17.000 rpm G.............grid controlled	

 Opti;Optitop....one focal track and rapid speed(8400rpm)	82/73......´2´ and ´3´ refers to stress ....relieved

.

The OT unit **Siregraph**
The tube is covered and equipped with a fan.

.

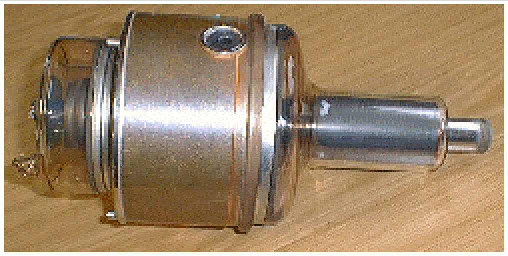


The **Megalix** tube has a copper center section. Its purpose is:
1. longer tube life, because ions which stem from metal atoms, evaporated from the filament or an overheated anode, produce a metallic layer on the glas envelope. This leads to arcing. The metal center, lying on a defined 0V potential, prevents that.
2. less extra focal radiation. Electrons which do not invade the focus area but rebound from it are again accelerated towards the anode but not in the focal spot. The radiation produced herewith is called **Extra-Focal-Radiation**, and harms the image to a certain extent. Those quanta cause a blur, because they do not leave the anode in the focal spot.
The metal center has only a small x-ray port very close to the anode. Therefore, the portion of extra focal radiation in the useful beam could be reduced from about 10% to 4%.
About 10% of the tube current flows towards the metal shield.

more info?

.

Types and Designations



Megalix

X-Ray Tube	Application*(recom.)*	Anode	Features
Mega 125/30/82 CM	Card-Angiography	RTMC; diam. 120 mm; 1000 kJ; 8400 rpm;	high loadability with rel. small focal spots
Mega 125/40/82 CM	General Angiography		
Mega 125/15/40/82 CM	General Angiography; for enlargement technique		3 focal spots; grid controlled
Megalix Cat 125/30/80 Megalix Cat 125/40/80	Angiography	like above but 1.130kJ	spiral groove bearing; direct oil cooling

Legend: Mega...Megalix (similar to Opti) but 1 MJ heat capacity due to its larger anode
M........**M**etal center (Copper)
Cat......**C**ontinuous **A**ccelerated **T**ube

.
.

Types and Designations

Other types of rotating anode tubes are used for **Mammography** and in **Single Tank Heads**.
Mammae radiographs need soft radiation produced with less than 50 kV.
The anodes are made from Molybdenum or Tungsten or a combination of both. Molybdenum produces soft characteristic radiation. The radiation passes a special filter, installed in the tube window, which filters out quanta with certain energies (for more detailed information look in chapter "Radiation Physics"). The special tube assembly has only one H.T. outlet for the anode cable; the cathode is connected to ground.

Tube	Anode	Features
P 49Mo	Molybdenum; 49 kV	focal spot sizes: 0,15 - 0,3; output: 0,6 - 4,7 kW; 100 - 120 kJ; 2800 rpm
P 49W	Tungsten; 49 kV	
P 40MoW	compound anode; 40 kV	

Legend: Mo.......Molybdenum
W........Tungsten

▼ ▲

.

Types and Designations

Single tank head means that the all high tension components, including the tube, are in one housing. That requires small x-ray envelopes and was applied already 1933 with the so-called Heliosphere. It had a stationary tube.
1980 came up a new technology which allowed smaller H.T. transformers for higher output, the **High Frequency Generators**. Now, it was possible to install even a rotating anode tube into a single tank head. The Polyphos was born, a stationary 30 or 50 kW generator. They are no more manufactured.
Two tubes were in use which differ when ordered for 50Hz or 60Hz line frequency.

Tube	Used for	Anode	Features
P 125/30 C	simple radiography units	RTMC disk;diam. 60 mm;110 kJ	focal spot sizes: 1,0 or 1,3; 2800 or 3300 rpm
P 125/30/50 CR	radiography units; UT and OT fluoro systems	RTMC disk;diam. 65	focal spot sizes: 0,5/1,0;

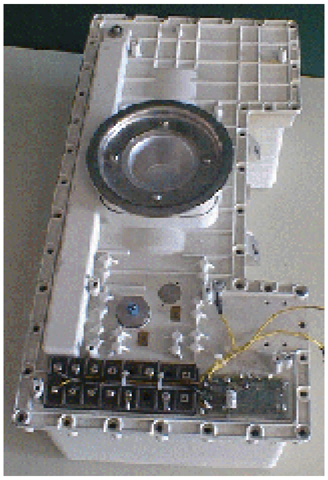
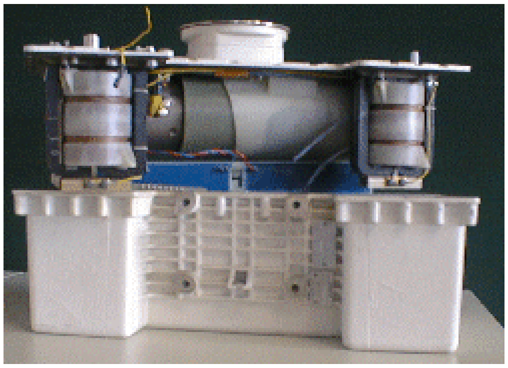
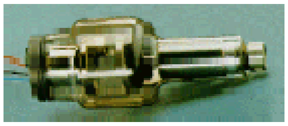
		mm;200 kJ	10000 rpm

Legend: C.......Graphite(carbon)
R........rapid rotation

▼ ▲

.

The X-Ray Tube **Types and Designations** 12/13

		
A closed Polyphos single tank head from top. In the middle is the x-ray window here covered with an Alu filter. On the bottom the terminals for electrical tube supply.	An open Polyphos single tank head. On the left and right side you see the HT transformers. They are so small due to the relatively high frequency of the HT supply.	The Polyphos tube P 125/30/50 CR

▼ ▲

.

The X-Ray Tube **Types and Designations** 13/13

End of Subchapter "Tube Types and Designations"

▲

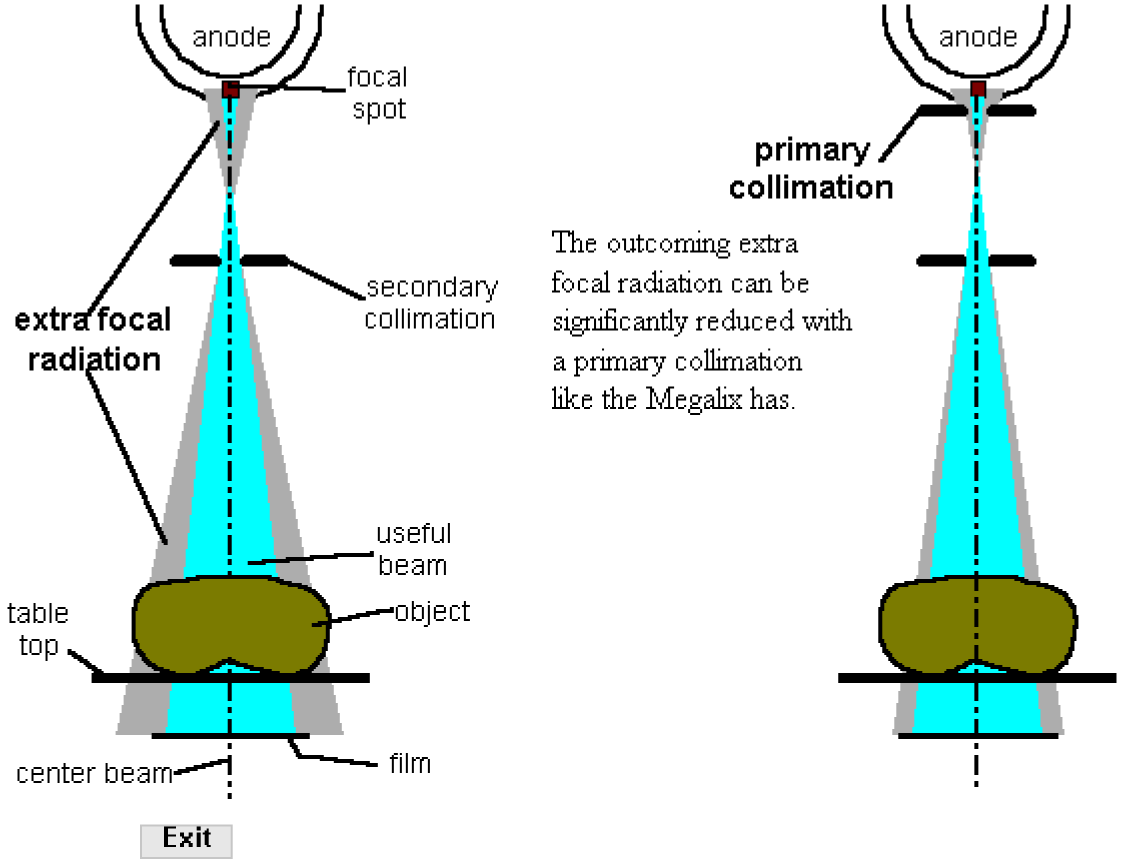
.

.

The X-Ray Tube

Extra Focal Radiation

1/



The outcoming extra focal radiation can be significantly reduced with a primary collimation like the Megalix has.

.

The X-Ray Tube

Tube Housing

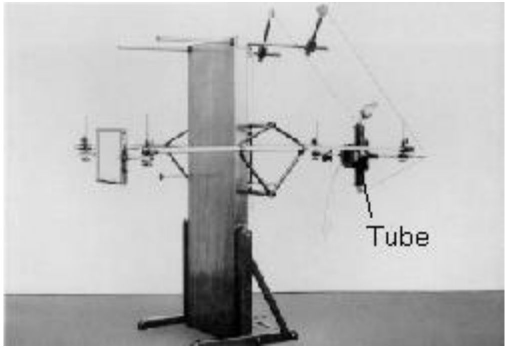
1/13

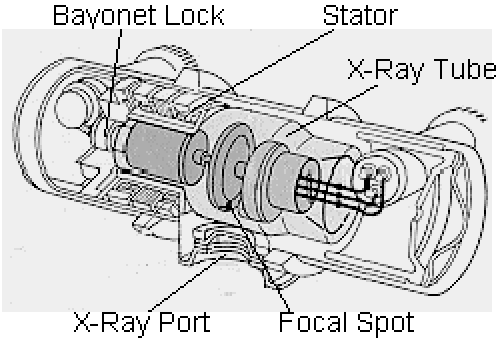
When professor W.C.Roentgen experimented with x-ray tubes he worked with open high tension circuits, that means, no cases for H.T. supply and tube.

The modern tube housing serves for
1. H.T. isolation;
2. mechanical safety;
3. electrical connection;
4. tube cooling and
5. radiation protection.

The rotating anode tube is fixed inside with a bayonet locking and sticks in the stator winding.
The focal spot is aligned with the center of the x-ray port.

Several different types of housings are produced to lodge various tube sizes. In this section you will find the description of their features and how they are designated.

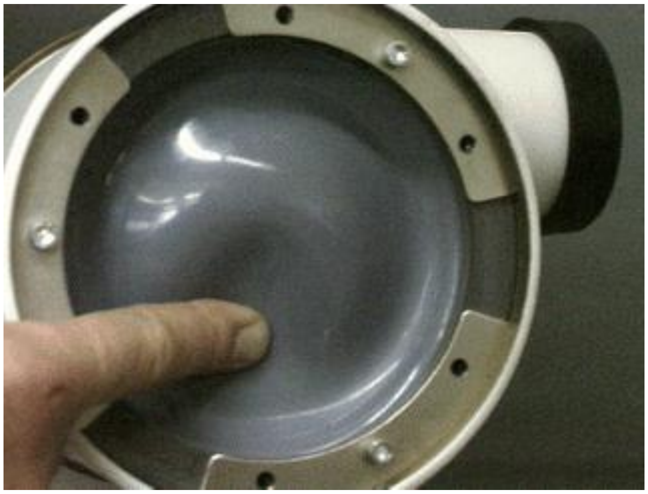




.

High Voltage Isolation
After assembling the tube unit, it is filled with a special isolating oil. During the further manufacturing process the open housing is then heated up in a vacuum to get rid of remaining air inside.
That ensures the high tension resistance.

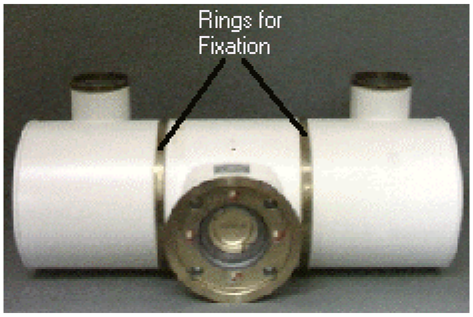
When the housing is heated up during normal operation the oil expands to a certain extend. This would put pressure on the glas envelope and perhaps destroy it. The cathode side of the housing has an expansion bellow to avoid that.



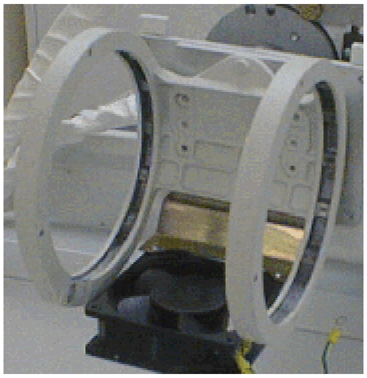
Expansion bellow on cathode side

.

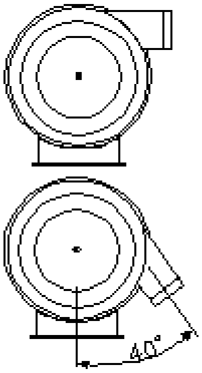
Tube Housing



Mechanical Safety
The housing protects the glas envelope against mechanical shocks.
It needs as well mechanical parts for the fixation on the roentgen system.
The two concentric rings at the housing are to install a ringlike clamp with the necessary fittings.

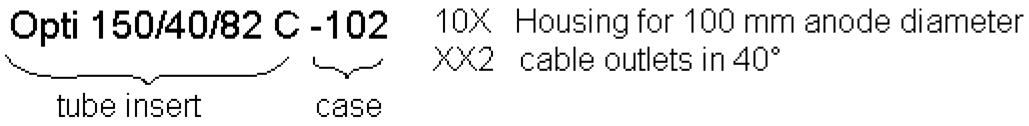


The clamp to mount the tube assembly on the x-ray system.



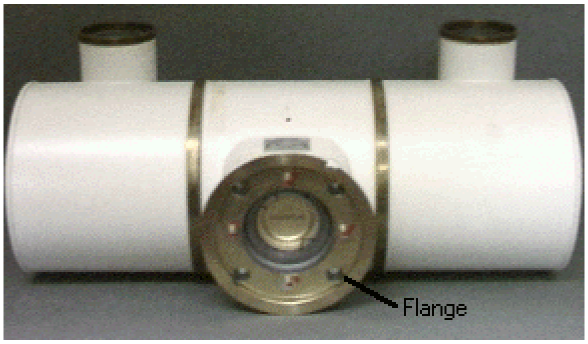
For special modifications in older UT systems housings with the horns in a 40° position to the x-ray window were used.

The designation for the tube housing is included in the general name for the tube assembly.
The first part refers to the tube insert the latter to the case.



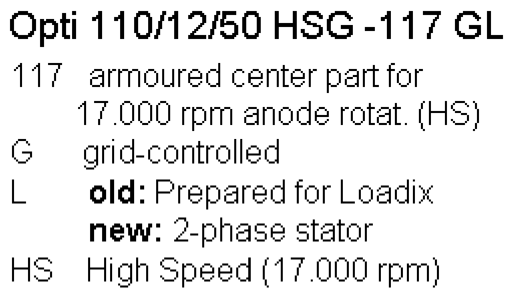
.

Tube Housing



Mechanical Safety
The flange at the window side of the tube is to fix the beam limiting device - the collimator.

The weakest part of the case is the x-ray window. The artifical material must be radiation resistant and mechanically stable to withstand shocks.
<   Housings which lodge tubes with high speed anodes (HS) at 17.000 rpm require special shields in the center and the window.
These armoured parts protect the case and window for being damaged when the anode


Opti 110/12/50 HSG -117 GL

117 armoured center part for 17.000 rpm anode rotat. (HS)
G grid-controlled
L **old:** Prepared for Loadix
new: 2-phase stator
HS High Speed (17.000 rpm)

possibly cracks under high load.

For more info about "G", "L" see pages 5-6.

.

The X-Ray Tube

Tube Housing

5/13

Electrical Connections

The tube assembly for rotating anodes needs several electrical supplies:

1. high tension (H.T.)
2. filament supply
3. stator voltage
4. grid voltage

The high voltage and the filament supply is fed via the H.T.-cables. The cable outlets jut normally out in 90° to the x-ray window. The horns are marked with ´+´and ´-´ for anode and cathode side.

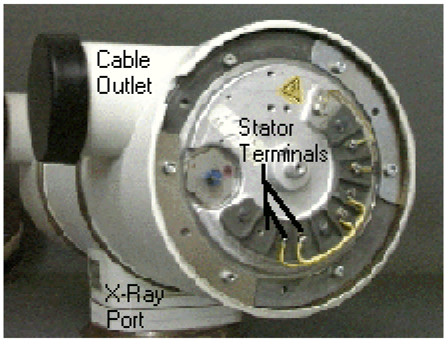
The standard anode and cathode HT-cables have 3 pins. Thus, they can easily be swapped if one became defective.

The grid-controlled tube has a 4-pin cathode cable to supply as well the grid voltage.

Inserting the H.T. cables requires certain precautions, because of

1. safety contact for the H.T. supply
2. proper H.T. isolation

(Follow the installation instruction)



< HT plugs; one covered

Rubber Caps >

Cover the outlets and H.T. plugs during transportation with rubber caps, for instance, to avoid damage. It ,otherwise, can later cause contact problems!

.

The X-Ray Tube

Tube Housing

6/13

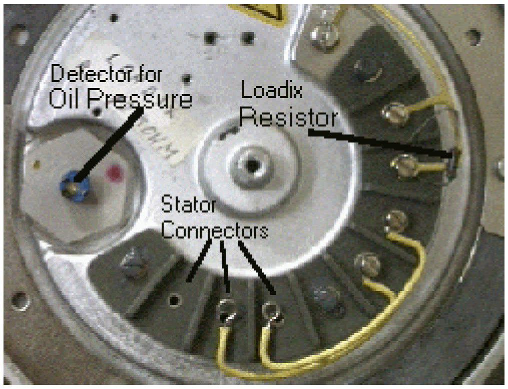
Monitoring devices are built into the housing for high

loadable tubes.
Detectors measure the oil pressure and oil temperature.

In old systems even the energy, already transfered to the anode, was detected (LOADIX). A photo diode measured the brightness of the anode to determine the absorbed energy. An individual resistor, fixed to the terminals, adapted this detector to an amplifier. **Do not replace!!** Since those tubes are still in operation they must be replaced when defective. So, housings for this purpose are further available.
A tube load calculator, built into the generator, takes over such monitoring today.

All the terminals are on the anode side, together with the stator connectors.

The stator cable is a specially shielded cable only for the motor supply.
Jumpers adapt the stator type to the supply.
Follow the installation instruction for correct connection.



Opti 110/12/50 HSG -117 GL

G..........grid controlled (4pin cathode plug)
L...........**old:** prepared for Loadix
new: 2-phase stator

Since the Loadix is no more available in modern tube assemblies the "L" designates a two phase stator instead of a three phase one.

Tube Housing

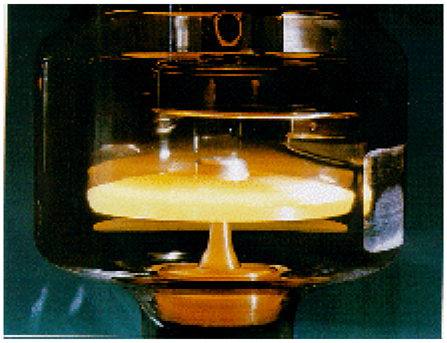
Cooling Tube and Housing

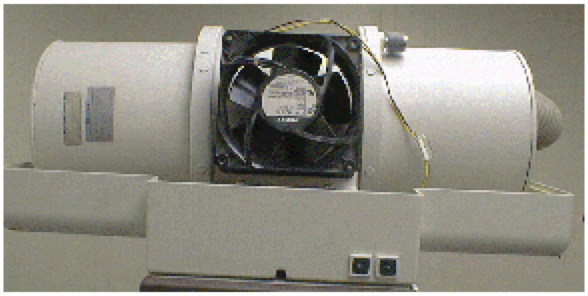
The oil serves as well as a cooling medium for the tube and the stator winding.
It transfers the heat from the glas envelope to the housing. But this effect occurs first when the anode is already hot, that is, after several heavy loads or long time fluoroscopy. Till then, only the anode alone has to bear the stress.

The normal tube assemblies have a heating storage capacity up to 1,8 MJ and a heat dissipation of about 400 W.
That is not enough for certain applications like angiography, serialography or DSA.
Additional cooling systems are necessary in this case.
Two possibilities are available:

1. a fan installed to the housing >

2. oil circulation *(next page)*

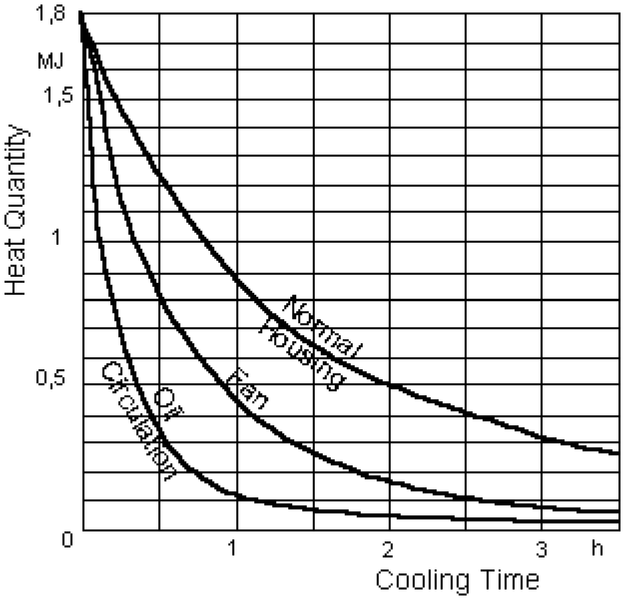




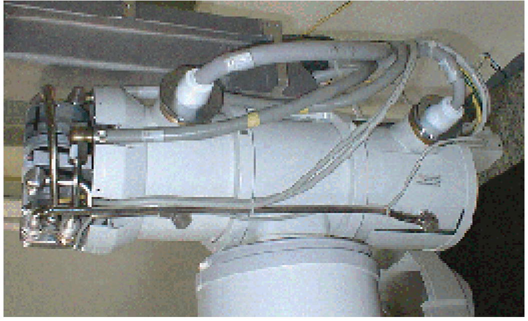
Tube Housing

Oil circulation requires pipeline connected to the housing. An external pump (left in bottom image) provides the circulation. The oil itself is cooled with water.
That allows long time loads of the tube assembly as they are quite common with card angiography.

On the right diagram you see the difference in the cooling characteristics of the housing when additional measures are applied.



Tube housing with oil circulation and water piping



Mega 125/30/82 CM -120 GLW

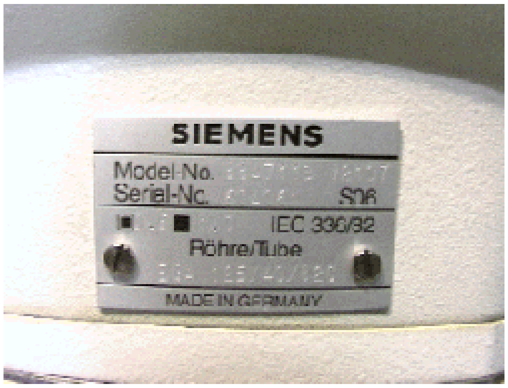
120..........120 mm anode diameter
W.............oil circulation with **w**ater cooling

.

Tube Housing

Tube Label and Focal Spot Marking

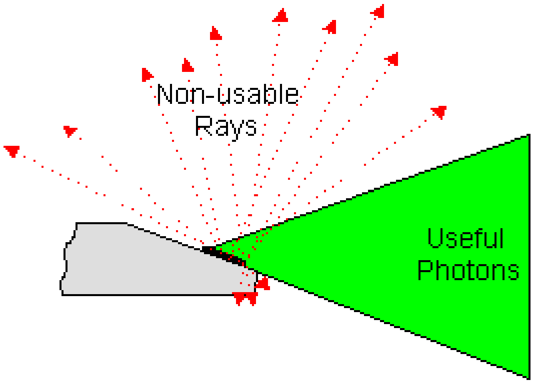
The tube label shows all necessary data like
- tube and housing type
- serial number
- focal sizes
It is somewhere fixed on the case.



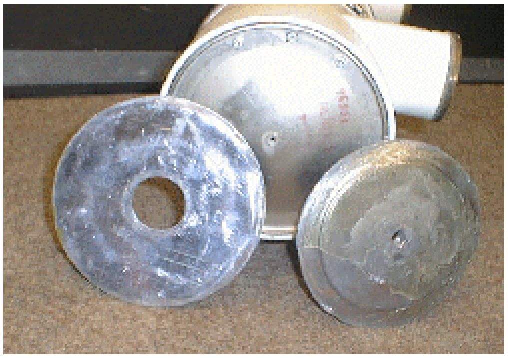
For the determination of the source-image distance you find a spot in front of the tube which marks the exact position of the focal spot.

.

Radiation protection
Since the produced radiation leaves the anode in all directions the housing needs to absorb the non usable quanta.
The housing material is brass or aluminium and the inside is covered with a lead layer.
Both caps, anode and cathode side, have lead plates, too.
The leakage radiation with Siemens tubes, measured after the complete assemblage, is far below the permitted value of 1 mSv/h in 1 m distance (according to IEC standards).



Warning!
Nevertheless, wear protective closes when working close to the tube housing and the tube is radiating, and mind the x-ray window.



.

Further precautions to reduce the radiation risk are

1. a red lead cone in the x-ray port and,

2. the aluminium prefiltration of the useful beam.

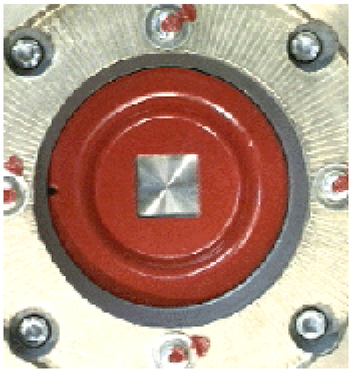
The two different cones which are available serve as the first limitation for the radiation beam.:

1. with a rectangular aperture for radiography units
2. a circular one for image intensifier inputs with fluoro systems

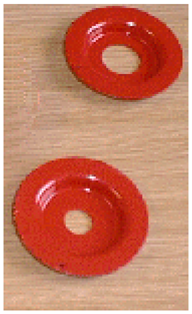
The tube assembly is generally delivered with an entire prefiltration of 2,5 mm Al equivalent.

That is, the glas envelope with about 0,7 mm, the case (oil and window) with about 0,8 mm, an Al cone with 0,5 mm and additional Al plates with 0,5 mm.

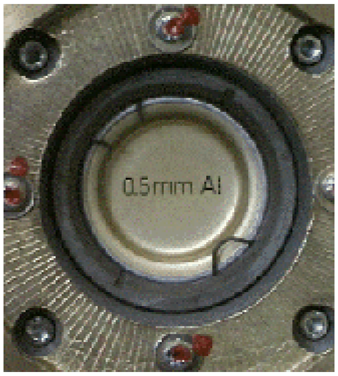
The tube envelopes and the housings carry lables which show their inherent filtration value.

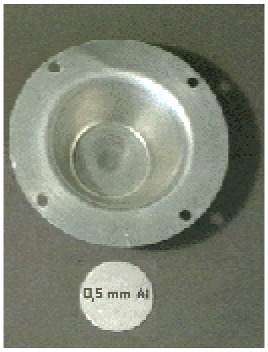


X-Ray window with lead cone



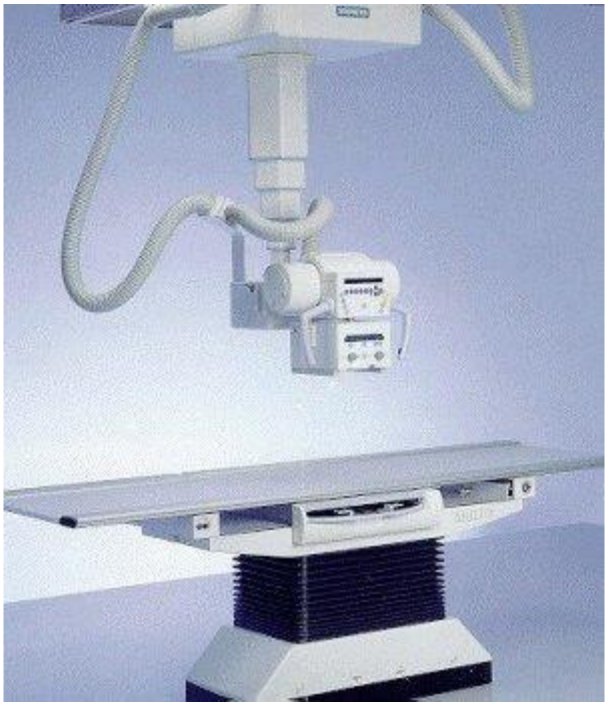
Lead cones with different circular apertures





.

Tube Housing



According to ICE standard, a minimum filtration of **2,5 mm Al equivalent** must be guaranteed for the tube assembly (including the collimator) if the system is ready for operation.
Additional filter can be selected with most collimators.

The 2,5 mm Al equivalent are not valid for mammography units.

.

Tube Housing

Here ends the chapter "The X-Ray Tube".
To test your gained knowledge a comprehensive test was prepared.
You will find it in the main menue "X-Ray Tube" as the last subchapter "Request"

End of Subchapter "Tube Housing"

.

Comprehensive Test

Questions	Answers
With multiple choice questions are as well more than one correct answer possible. Keep the explanations as brief as possible.	

.

Comprehensive Test

What is the biggest difference between stationary and rotating anodes?	o weight o rpm o focal size	o kW/0,1sec o radiation output o anode material
Which other anode material as tungsten do you know for the focal area in x-ray diagnostics?	Rhenium, Molybdenum	
Which material increases the heat storage capacity of Siemens anodes significantly?	Carbon(Graphite)	
What is the difference between a Pantix and a Biangulix anode?	Pantix has only one anode angle, Biangulix two (as the name says).	

Mark the advantages and disadvantages of the Biangulix anode.

Advantages
o smaller focal spots
o more heat st. capac.
o longer life time for
the focal tracks
o higher anode speed

Disadvantages
o more expensive
o focal displacement
between small and
large
o less kV maximum
o lower load /unit time

.

How many anode angles does an Optilix anode have, how many a Megalix with 3 focal spots?

Explain the terms
1. apparent focal spot
2. actual focal spot

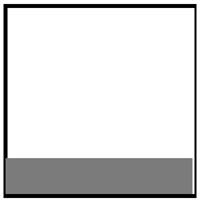
Which focal spot influences the image quality?

o apparent
o actual
o optical
o finest
o electronic

What advantage and disadvantage does a small focus have?

.

There is a complain from a customer:
he has got a linear shaddow on his lung image (35 x 35 cm) ranging from left to right on the bottom film side.
You had checked all alignments and found everything within the tolerance.
What solution do you have for him?
Roentgen-System: UT fluorotable with a
Bi 150/30/52 R
focal spots :0,6/1,0
anode angles : 10°/16°
The doctor used the small focus for a normal patient with about 22 cm object thickness.
Exposure data: 125 kV, 5 mAs



Comprehensive Test

Name the two applications in the roentgen diagnostics which need grid controlled tubes.	
What does the following designation for a tube assembly mean? Optitop 150/40/80 HC - 102 L	Optitop.....replacement for Optilix 150...........150 kV max 40/80.........small 40 kW/ large 80 kW focus H............... C...............graphite(carbon) 10X............case for 100 mm anode XX2...........HT outlets in 40° L................3-phase anode-stator
What are the important differences between the following both tubes: 1. Bi 150/30/51 2. Bi 150/30/52 R	o different power for the large focus o no.1 has higher anode speed o no.2 has higher anode speed o no.1 has smaller focal spots o no.2 has smaller focal spots o no.1 is stress reliefed o no.2 is stress reliefed

Comprehensive Test

A customer discusses with you about x-ray tubes. He asserts, that a tube from our competitor has a smaller nominal focus with the same maximum output. What should your reply be?	I´m quite sure that this specific focus was determined with a different standard. Siemens tubes comply with the IEC standard.
How is the tube current changed when the H.T. is constant?	With the filament current.

What limits the long time load (up to 10 sec) of a x-ray tube?	The heating storage capacity of the anode.
Which value/s is/are changed when a fan cools the housing?	o anode capacity o the max. short time load o prolongs the possible fluoro time o more power can be applied during fluoro

.

The X-Ray Tube **Comprehensive Test**

Till which max. exposure time can the nominal power of a focus be switched?	o 1 sec o 0,5 sec o 2 sec	o >5 sec o 0,1 sec o 10 ms
What limits the applicable short time power of a specific focus?	o max. tube voltage o max filament current o anode speed	o melting point of anode material o size of focal spot
You install a Optilix 150/30/50 C tube to an unknown x-ray generator. Which generator data do you need for a proper set-up?	o age of the generator o line frequency and voltage o type of starting device	o max. exposure time o form of H.T. o max. H.T. o max. filament current

.

The X-Ray Tube **Comprehensive Test**

How high must the minimum prefiltration with this x-ray system be?	Minimum 2,5 mm Al equivalent

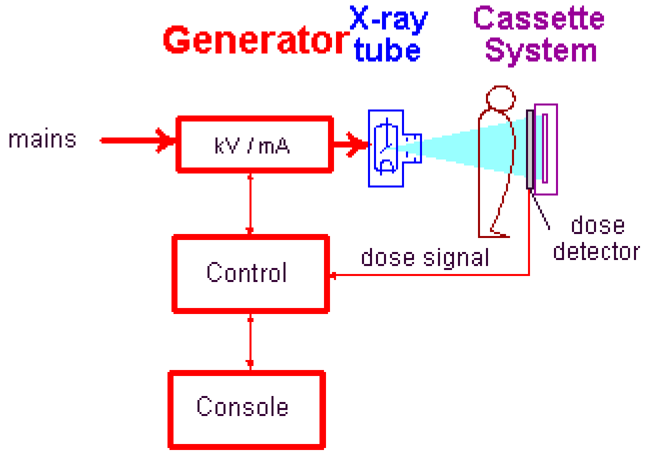
.

Generator **Principle** 1/4

Basic X-ray system

A basic X-ray system consists of:

- **generator**
- X-ray tube
- cassette system



The generator transfers the electrical power P (kW) to the X-ray tube.

The individual parameters **U** (kV) and **I** (mA) are defined at the generator`s console.
Start and stop of the exposure (time, **t**) are also defined at the console.

Normally the selection of the time **t** (s) and the current **I** (mA) are done in combination, i.e.electrical load **Q** (mAs).

If the cassette system is equiped with a dose detector, just kV-selection is necessary (1-point technique).
Then, exposure termination is done when the dose signal indicates, the required dose to blacken the film is reached.

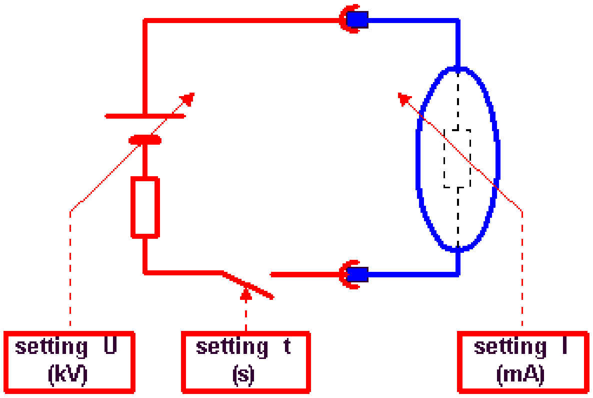
.

Basic function of the generator

Exact generation of the following preset parameter:

- high voltage **U** (**kV**)
- tube current **I** (**mA**)

- start and stop **t** (**s**)



The X-ray tube converts that supplied electrical energy to X-ray energy.
The characteristic of the generated radiation depends on the different level of the three energy parameters.This results in differences in image quality of the radiography.

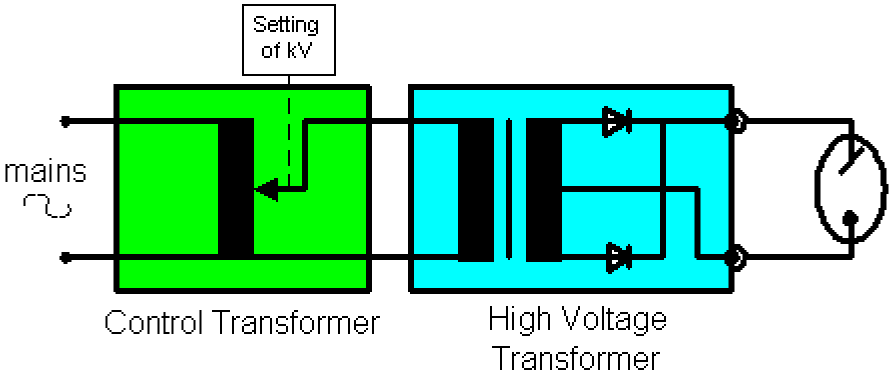
U ⇨ The level of energy of the generated X-ray quanta depends on the level of the supplied kV. The penetration of quanta through matter is as bigger as higher the level of energy of the quanta. more info?

I ⇨ The density of X-ray quanta (quanta per time unit) is as higher as higher the current passing the X-ray tube. more info?

t ⇨ A density of quanta while a specified time results in a quantity of quanta. This is necessary to expose a film or a target of a pickup tube of a TV-camera. more info?

.

Principle of an old X-ray generator



The main disadvantages of generators like that is, the high voltage transformer has to be very big because it is supplied with the mains we can see, that an increase of the frequency for example by the factor 100, results in the simultaneous reduction of the winding number frquency (50 or 60 Hz). If we consider the simplified transformer equation

$$\frac{u}{f \times n \times A} = \text{constant}$$

and core cross section by the same factor without a change in the denominator value. Another disadvantage is the necessity of a powerful control transformer.

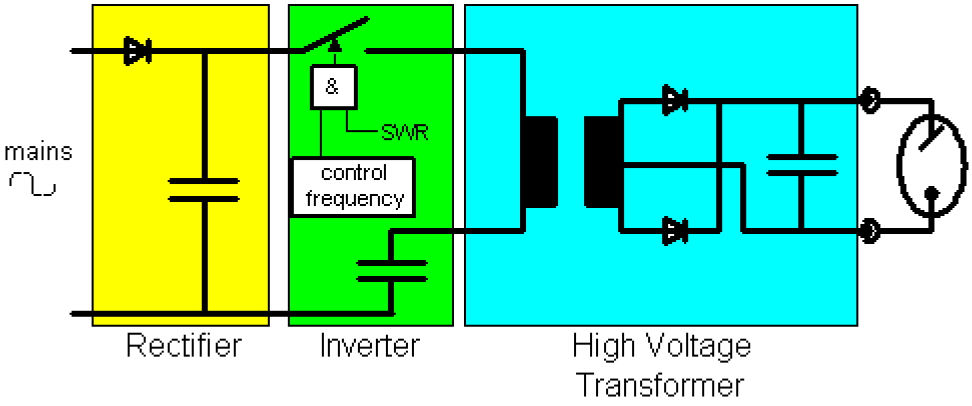
.

Generator

Principle

4/4

Principle of an modern X-ray generator



Modern X-ray generators supply the high voltage transformer with high frequency (e.g.,20kHz). The space requirement of this so called high frequency generators are therefore extremly reduced.To supply high voltage transformer with higher frequencies than the mains frequency, first the mains voltage has to be rectified. Then this rectified voltage is fed to an inverter. Here the DC-voltage is reconverted to AC but with a much higher frequency.This generated AC-voltage supplies the high voltage transformer.

At the secondary side of the transformer rectification and accumulation of the tube high voltage is done. For that a rectifier and a capacity is located there. The level of the high voltage depends on the control frequency of the inverter and the load of the X-ray tube. A regulation circuit maintain the constancy of the high voltage. The control signal "SWR" starts and stops the kV-generation and so the exposure of a image giving media (e.g.,film) due to radiation.

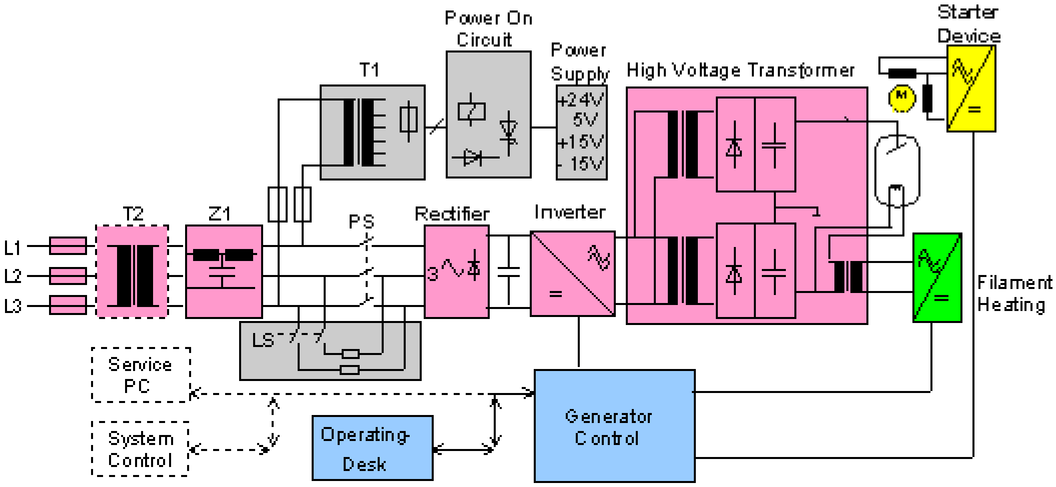
end of chapter "Principle"

.

Generator

Block Diagram

1/2



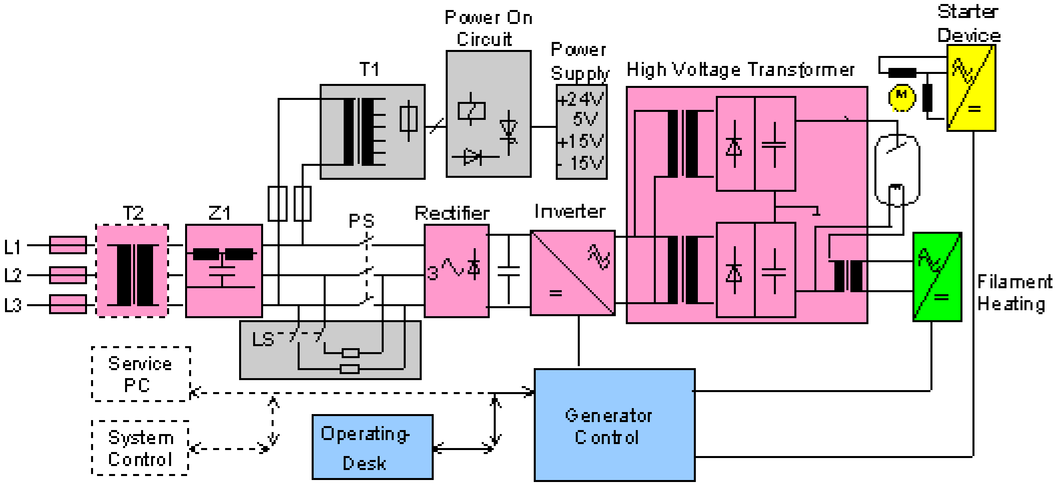
The block diagram shows the most important functions of the generator:

- power circuit
- filament circuit
- starter device
- generator control

- power on circuit and internal power supply

.

Generator — Block Diagram — 2/2



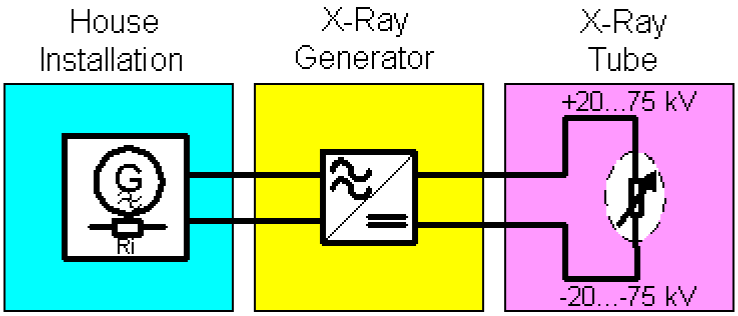
The task of the power circuit is to generate the high voltage for the X-ray tube.
The starter device drives the rotating anode.
The filament heating is responsible for the required emission of electrons in the X-ray tube.
To switch on the generator and to supply the electronic components with power this components are used.
Beside the control of the above functions, the "generator control" evaluates data from the operating desk, communicates with the system control (existing in complex X-ray systems) and supports

service with the service-PC.

end of chapter "Block Diagram"

Generator — Power Circuit 1/2

Here you can see, that an X-ray generator is basically just a voltage converter.

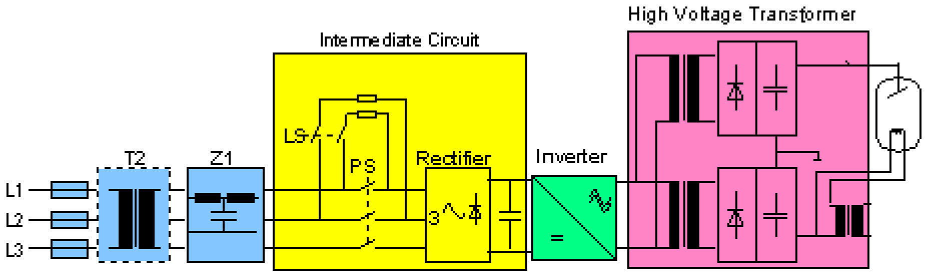


This converter has got the following tasks:

- transformation of the mains voltage to high voltage
- rectification of the high voltage to DC-voltage

- control a preset high voltage between 40 and 150 kV

Generator — Power Circuit 2/2



The power circuit consists of:

- Mains connection
- Intermediate Circuit
- Inverter
- HV-Transformer

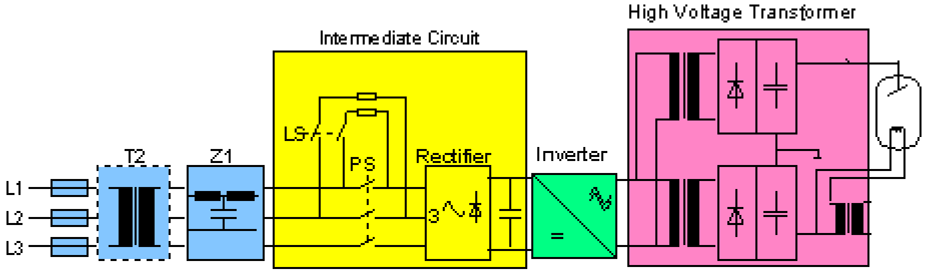
end of chapter "Power Circuit"

.

.

Generator

Mains Connection



The power circuit consist of:

- **Mains connection**
- Intermediate Circuit
- Inverter

- HV-Transformer

The Mains Connection comprises:

- internal resistance of the mains Ri
- input fuses
- pretransformer T2
  only for 480V

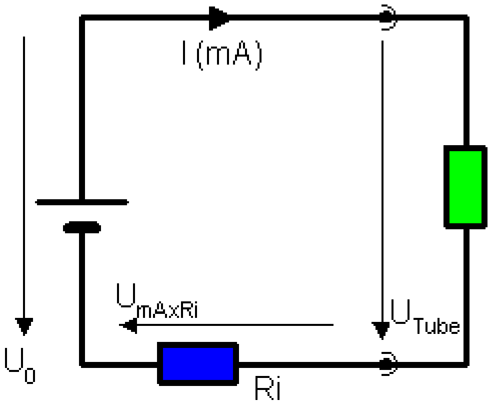
- mains filter Z1 (to suppress high frequencies which are generated in the inverter)

.

Generator

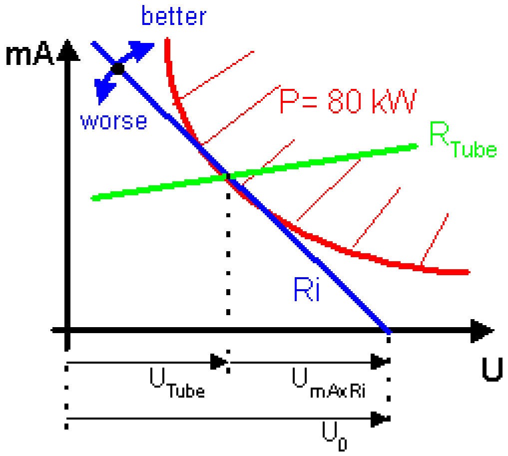
Mains Connection

Influence of the internal resistance



Ri:

Ri max



reached:

A too high internal resistance Ri (less steep) results in too much voltage dropping across Ri.
So the maximum focal spot load (e.g. 80 kW) could never be reached.

This resistance is based on the hospital installation.That is the cross-section of the supply cable, the resistance of the supply transformer,etc.

Consequence:

To start up an X-ray generator, first testing of the mains resistance is necessary.

For that measurement, a special mains resistance instrument is required.

See installation instruction!

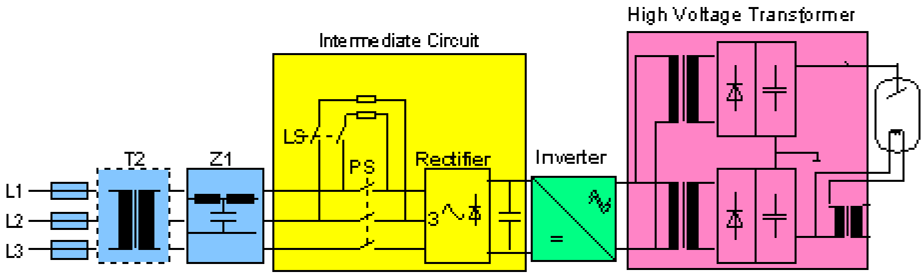
end of chapter "Mains Connection"

.

Generator

Intermediate Circuit

1/6

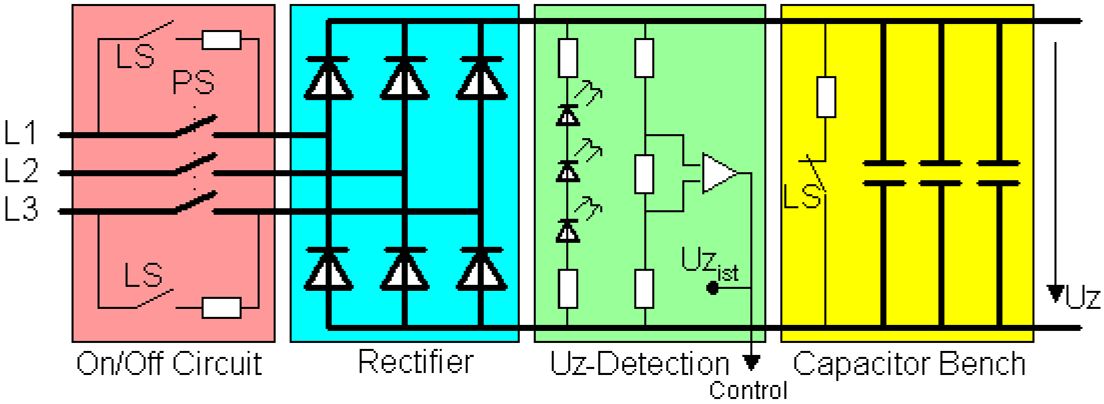


The power circuit consist of:

- Mains connection
- **Intermediate Circuit**
- Inverter
- HV-Transformer

.

Intermediate Circuit



Warning!
Uz is a voltage bigger than 500 V.

On/Off Circuit

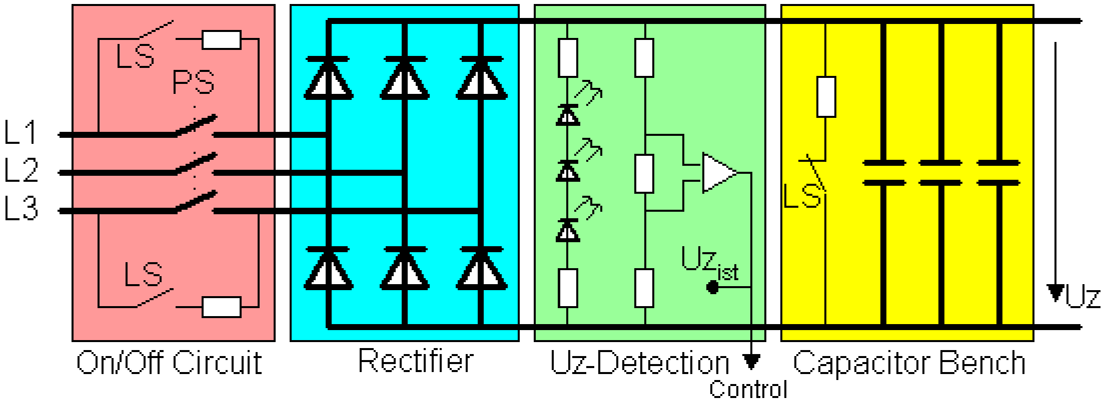
Due to the high charging currents, the power-up procedure is performed in two steps. In the first step, the intermediate-circuit capacitors are charged via the LS contactor. Following charging, the power-up damping circuit is by passed via the PS- (or SS) contactor.

The function of the contactors, charging process and the intermediate-circuit voltage are monitored by the "generator control". With a service switch (e.g.,POLYDOROS LX/SX; ZK on pcb D100) the charge of the capacitors could be prevented. This is necessary to measure at components in this circuits without any danger.

Rectifier

The rectifier is a three phase full wave rectifier based on diodes (normal standard diagnostic generators).

Intermediate Circuit



Warning!
Uz is a voltage bigger than 500 V.

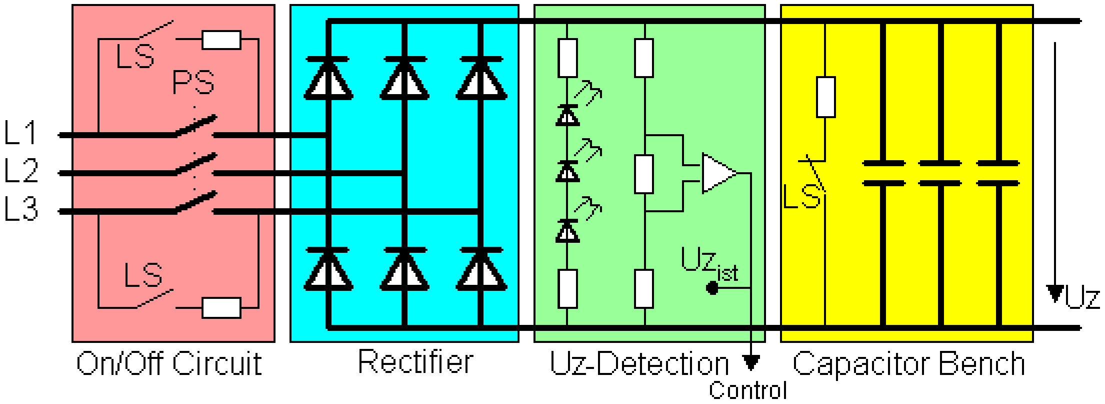
Uz-Detection

This is important because that voltage is still existing for more than two minutes after switching off (charge of the capacitors). **Do not touch before that LEDs are off!**

For two reasons a voltage divider detects the Uz .First to measure it in case of Service (MP Uzist) and secondly to transfer it to the "generator control" for monitoring. Furthermore some LEDs indicate a voltage bigger than 40V.

▼ ▲

.



Warning!
Uz is a voltage bigger than 500 V.

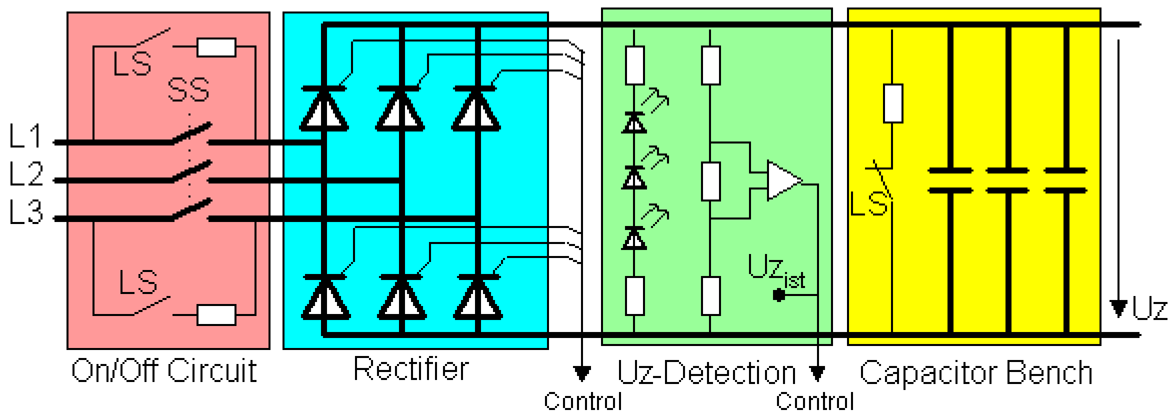
Capacitor Bench

Here the rectified voltage is charged up and smooothed to real DC-voltage. This voltage, Uz, is the supply for the following inverter. If the the system is switched off the closed LS-contact discharges the charge of the capacitors via the resistaance.

This is done to eleminate all dangerous charge of the capacitors and takes more than two minutes.

▼ ▲

.



Warning!
Uz is a voltage bigger than 500 V.

Controlled intermediate Circuit
The difference to the previous circuit is, that the rectifier consist of thyristors instead of diodes. So the Uz is controllable, that means variable. This is necessary for high quality X-ray generators.

To obtain in all working points of the X-ray tube (kV, kW) high inverter control frequencies reduction of Uz is necessary. The higher the inverter control frequency is the better the constancy of the generated high voltage. See chapter inverter!

Note!
In standby mode there is no generation of the dangerous Uz. This is a big advantage for servicing, but in all cases watch the LEDs!

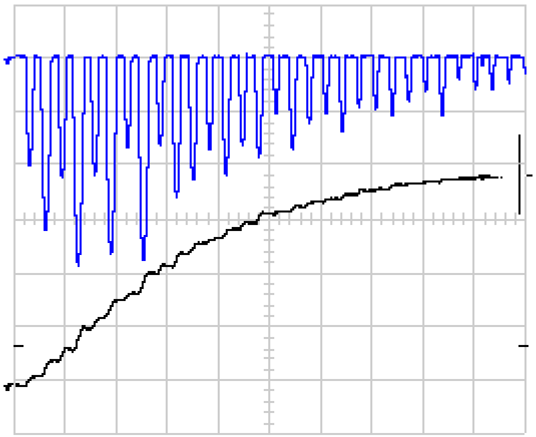
.

Intermediate Circuit

Here you can see the composition of Uz_{ist} during initialisation.

Beside the display of the Uz_{ist} also the charge current of the capacitors I_{Dist} are shown.This you can measure with a current converter.

Example of the POLYDOROS IS!



The generated Uz is aproximately 200 V. That indicates, this is a contollable rectifier. Otherwise we would have more than 500V.

uncontrolled rectifier:

- Uz_{ist} = 50 V / Div.
- I_{Dist} = 50 A / Div.

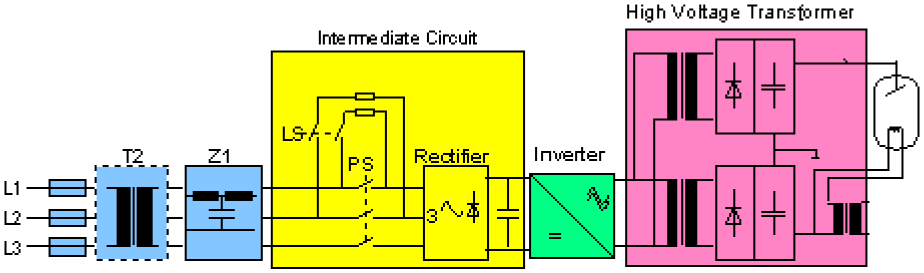
- t = 10 ms / Div.

example: mains voltage 400 V
Uz -> 400 V x **1.41 = 564 V**

end of chapter "Intermediate Circuit"

.

Generator **Inverter** 1/9



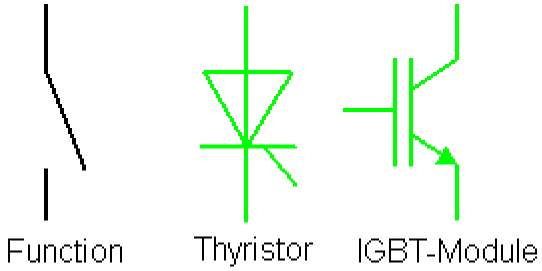
The power circuit consist of:

- Mains connection
- Intermediate Circuit
- **Inverter**
- HV-Transformer

.

Generator **Inverter** 2/9

There are two typs!
-with thyristors
-with IGBT-modules

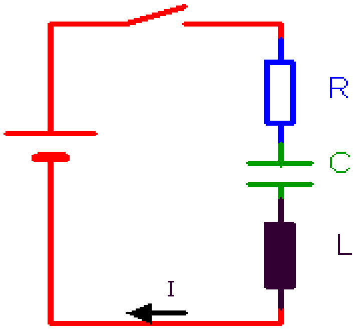


The task of the inverter is to convert the generated DC-voltage to AC-voltage with a much higher frequency than the mains frequency. For this conversion a switching device is required, the inverter.The switching elements have to be very powerful because the current to conduct could reach some 100 A.

IGBT = **I**nsulated **G**ate **B**ipol **T**ransistor

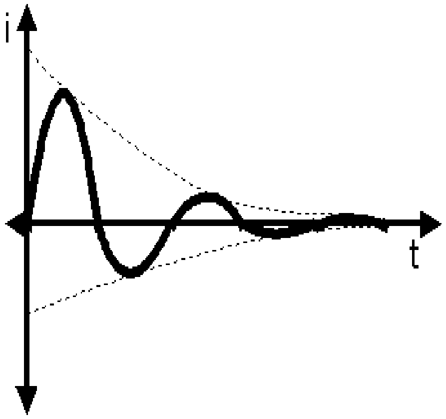
.

Principle of the Series Oscillator Inverter



If the switch is closed for a moment, the series oscillator starts to oscillate. In case of a single energy supply, the amplitude of the oscillation would drop to zero because of the effective losses (R), as illustrated.

It is therefore necessary to supply energy periodically.



In inverters of X-ray generators the load is so high (small R), that the second half periode is already very small.
That means, it is just used the first half periode (here positve) because only in this first swing the current is big enough. In fact, **the coil L** is the primary part of the high voltage transformer.
If we always use only the positive half periode, the transformer would run into the magnetical saturation.
Therfore we have to drive the current also in the other direction. For that we use four instead of one switch.

.

Inverter with thyristors

The task of the four thyristors is to conduct and to block the current across the oscillator.

Ignition pulses control always two thyristors conductive and that, first **V1 and V4** and then **V2 and V3**.

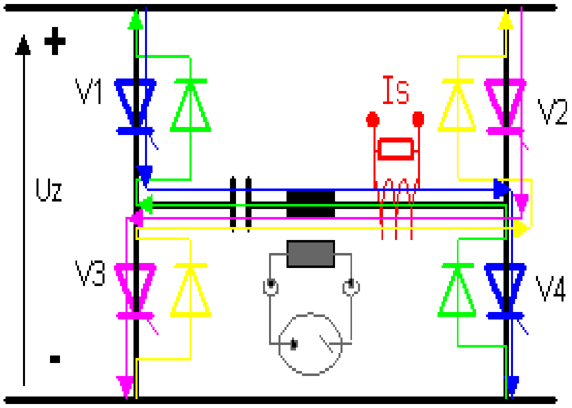
In this manner the current through the coil of the transformer changes the direction with all ignitions.

Every current swing through the coil is transfered to the secondary side of the transformer and contribute to the erection of the high voltage. The more often this is happening the higher the high voltage will be.

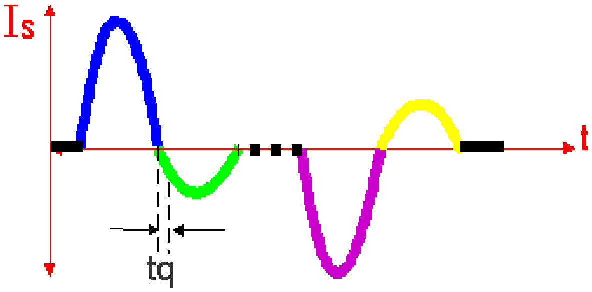
It is possible to measure the swing current at the **measureing point Is** (no danger because of the current converter).

.

If one pair of thyristors are conductive, the current will follow a sinus wave.
But just the first half amplitude could be conducted by the thyristors because they are able to conduct the current only in one direction.
However the back swing is very important and is accomplished via the antiparallel diodes.
Through the currentflow in the other direction the thyristors exstinguish.
If one of the thyristors does not extinguish and the next two tyristors are fired, a inverter short circuit will be created (V1 and V3 or V2 and V4 conductive at the same time).

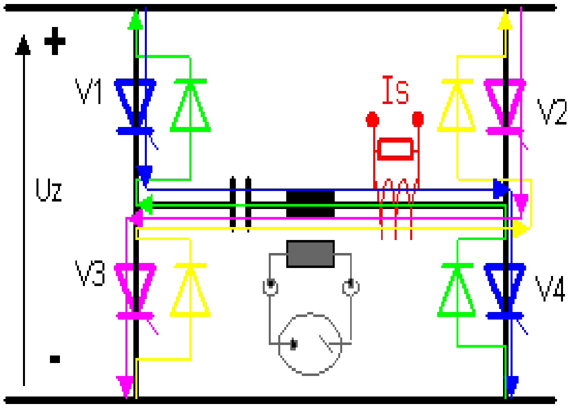


To evoid that, the back swing has to be there at least for some microseconds. This so called enable time tq is as shorter as better the quality of the thyristor.
The earliest moment of fireing the next pair of thyristors depends on this time. So the maximum control frequency $\mathbf{f}_{\mathbf{max}}$ of the inverter is defined.

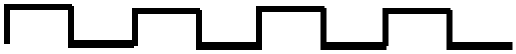


.

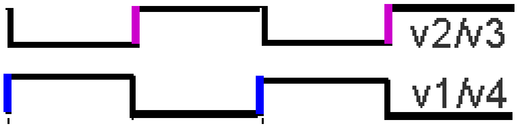
The **initial swing** of the **blue** (violett) part is caused by the charge current of the capacitor. With the current at its maximum, the inductance will become the source of the energy. The green (yellow) part is the start of the **back swing**. It is caused by the high charge of the capacitor. With the current at its maximum, the inductance will become the source of the energy.



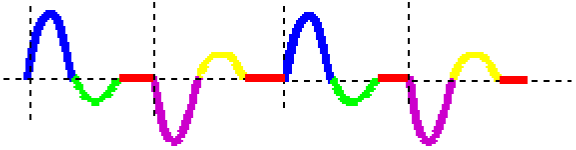
Here you can see the control frequency of the inverter.



To control the thyristors (positive pulse at the gate) this frequency has to devide by 2 and to invert for the two different pair of thyristors.



This is the result. The frequency could be encreased until the violett part almost reaches the blue part.



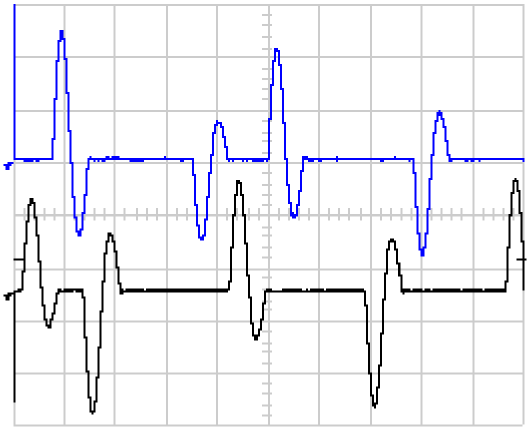
.

Modern powerful x-ray generators do have two inverters instead of one. That required, that also the high voltage transformer is subdivited into two sections. For a propper energy transfer the control of the two inverters have to be done alternating.

Here you can see the two inverter swing currents.

- Iswing =200 A/ Div. (Inverter 1)
- Iswing = 200 A / Div. (Inverter2)

- t = 100 us / Div.



Example from the POLYDOROS IS!
Test exposure after the start ramp:

- Large focus

- 77 kV
- 200 mA

.

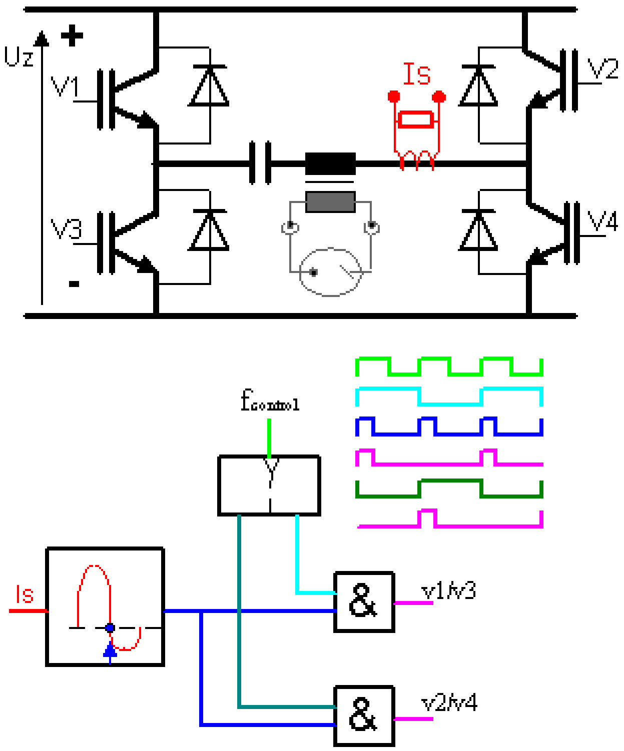
Inverter with IGBTs

Here we have also a series oscillator. That means the swing current and so the energy transfer to the high voltage transformer is similar to inverters with thyristors.

The only difference are the switching elements and their control.

Thyristors turn to be conductive with a short positive pulse at the gate. They stay conductive continously till the current level turns to zero at least for a short time. Then they block automatically.

IGBTs need to be controlled continously while the first amplitude of the oscillation. It is not enough to have just a short pulse at the gate. Furthermore, the control signal at the gate has to disapear in the zero crossing moment. For that, a special circuit to detect the zero crossing of the oscillation is required.



.

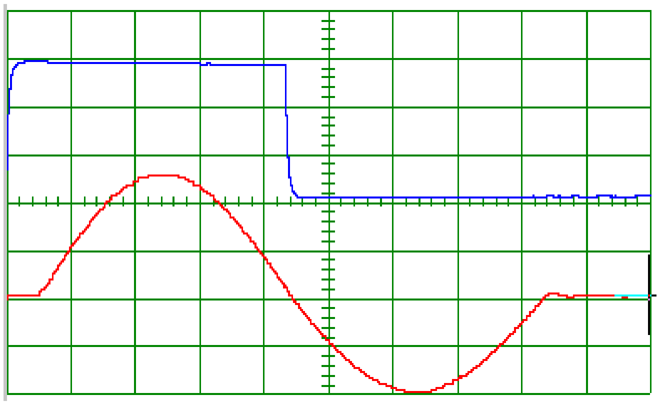
Service measurements

At some generators is is possible to perform a single swing (e.g. POLYDOROS LX/SX65/80).
For that the service program at the service PC has to be activated.

Pressing the certain key on the keyboard of the PC triggers a pair of IGBTs, the next press triggers the other pair of IGBTs.

Each pressing results in one current swing. If one of the IGBTs is defective and the other pair of IGBTs is triggered a current swing cannot be measured because of a inverter short circuit.
The inverter has to be exchanged.

OUTA is the signal to control one pair of IGBTs contactive. You see, that this is active only during the first amplitude.



Example from the POLYDOROS SX 65/80!
Single swing:

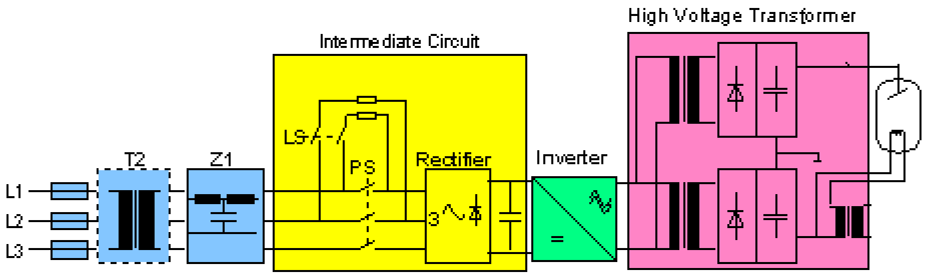
- OUTA =15 V/ Div.
- I_{swing} = 100 A / Div.
- t = 5 us / Div.

Note!
At this generator also the back swing current is high:

end of chapter "Inverter"

..

Generator High Voltage Transformer 1/5

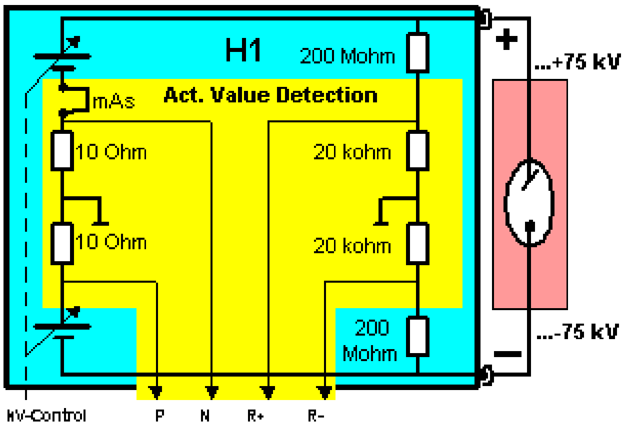


The power circuit consist of:

- Mains connection
- Intermediate Circuit
- Inverter
- **HV-Transformer**

.

Principle of the high voltage distribution

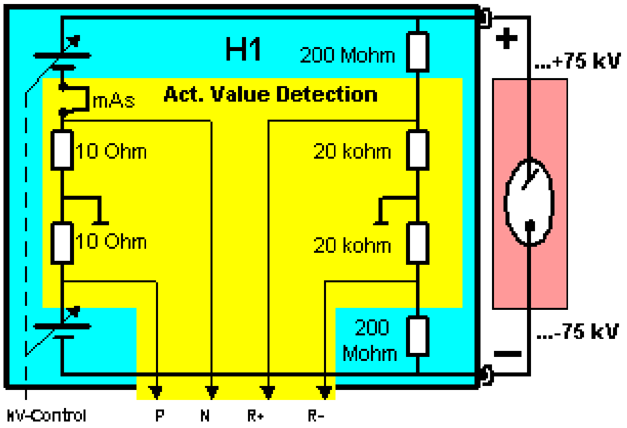


This drawing shows the high voltage situation at the secondary side of the **high voltage transformer** (**H1**).
The maximum voltage to generate is 150 kV.
To evoid insulation facilities and distances for that high voltage related to ground, two power suppplies are existing.
In reality the two battries are two sections of the high voltage transformer (see next page).
Both are generating the same high voltage, but with different polarity.

Between the two power supplies there is the ground level.
That is the resason wherefore we have ground symetry. So the insulation and distances have to dimension just for the maximum high voltage of 75 kV.

.

Principle of the high voltage distribution



Act.value detection

Tube current (mA) detection

Near the ground level between the two power supplies there are two small resistors. If there is the maximum tube current of aprox. 1000 mA, the voltage dropping comes up to 10 V. This is a level good to handle.

It is used for the following tasks:

- tube current control (mAact)
- radiography termination in mAs-mode
- monitoring

P -> mAact (positive level)
N -> mAact (negative level)
R+ -> (+)kVact (high voltage of the positive side)
R- -> (-)kVact (high voltage of the negative side)

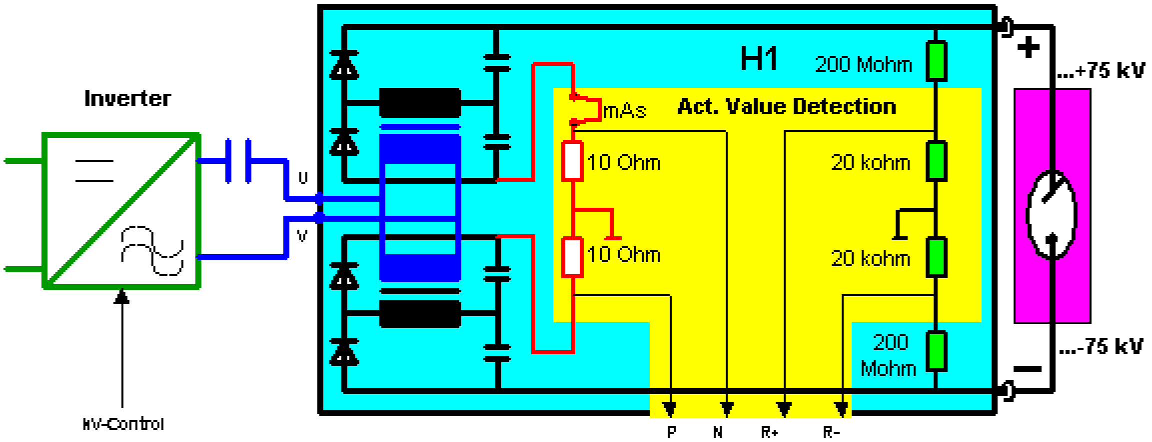
High voltage (kV) detection

Each high voltage side is detected separatly. For that there are two voltage divider 10000 : 1. That means, 1 V represants 10 kV.

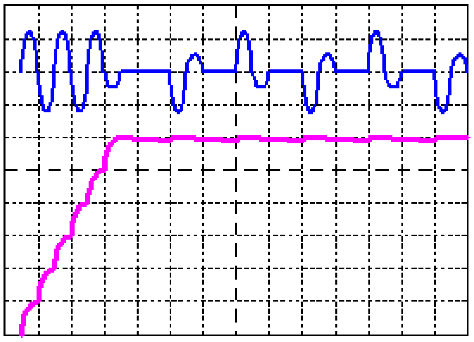
It is used for the following tasks:

- kV-control (kVact)
- monitoring

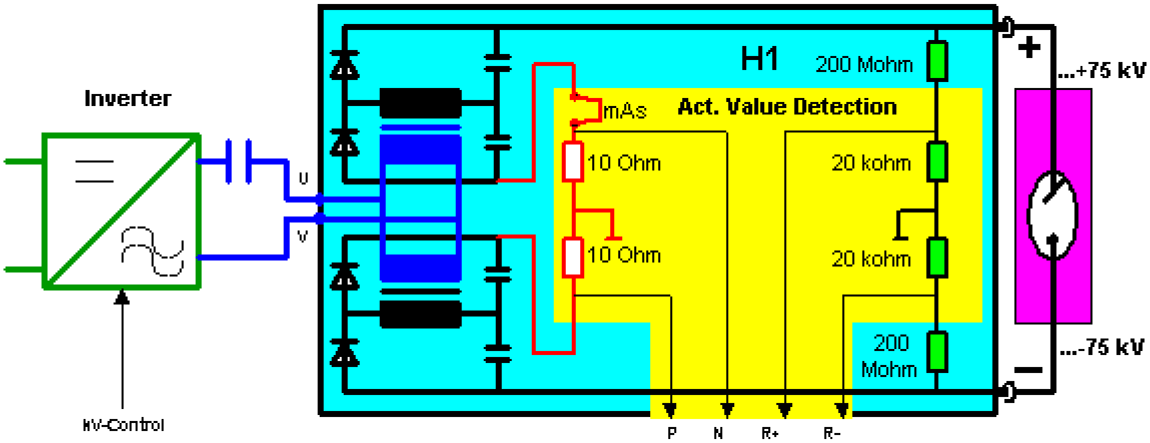
.

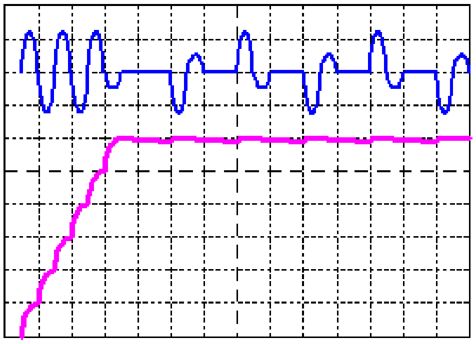


Two voltage-doubling circuits (Greinacher circuit) in series are used to generate the high voltage. The output d.c. voltage is four times the input a.c. voltage because of of the series connection of the two doubling circuits.
Each inverter swing does not generate the required voltage (see diagram beside), just a small portion of it. The capacitors in the doubler circuits accumulate these portions until the required high voltage (kV) is reached.
kV_{act} =10 kV / Div.
t = 10 us / Div.



.





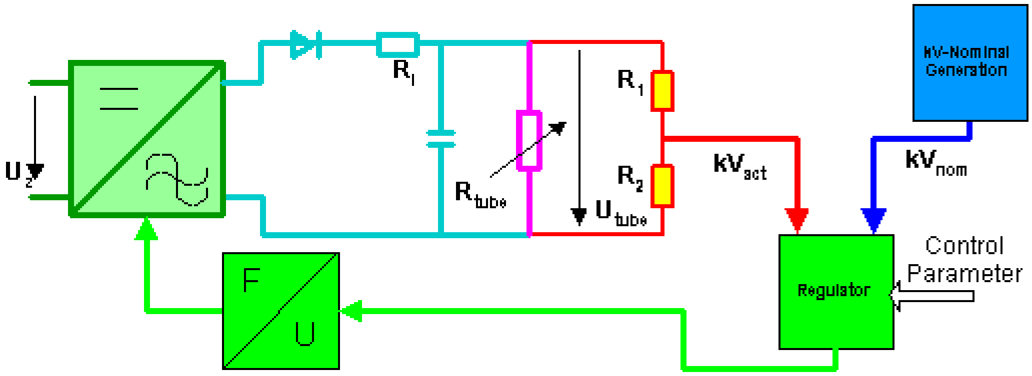
At initialisation to buid up the kV the inverter frequency is high. After that, there is just a swing if the kV drops down the reference value and compensate the consumption of energy of the X-ray tube. For the inverter frequency the kV-control circuit is responsable.

kV_{act} =10 kV / Div.
t = 10 us / Div.

end of chapter "High Voltage Transformer"

.

High Voltage Control



kVact - kVnom compare

The actual vlue **(kVact)** detected at R2 is used for the kV-control.
This value and the nominal value **(kVnom)** are compared in the regulator.
A control voltage is derived from the control difference.

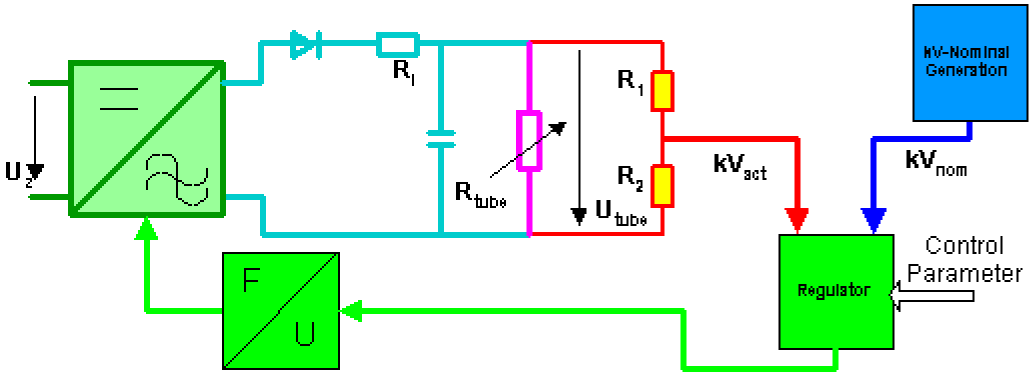
Regulator

For optimum control behave this control voltage is influenced by the regulating parameter.

These are set automaticly by the generator host and depends on the present working point of the X-ray tube.
That regulating parameter have to be taken, that any control deviation is compansated as fast as possible without any oscillation of the high voltage.
The result must be a high voltage d.c. very stable and constant.
The control voltage at the output of the regulator is transfered to the U/F-converter.

.

High Voltage Control



U/F - Converter

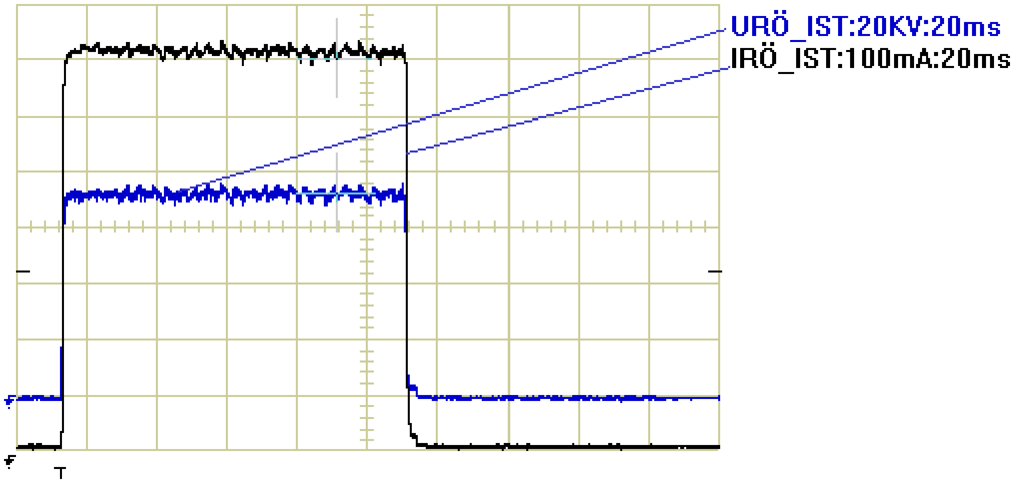
The control voltage at the output of the regulator is transfered to the U/F-converter.
That output frequency triggers the converter (inverter and high voltage transformer).

The higher the control frequency, the faster any control deviation is compansated.
The smaller the energy packages are, the better the accuracy of the high voltage. This is the reason because X-ray generator of the upper class are supplied with variable Uz.

Each trigger transfers a package of energy via the rectifier (diode) and the internal resistance (Ri) to the capacitor and charge it up. There are several energy transfers necessary to reach the required kV.

.

Generator **High Voltage Control** 3/5



Large Focus 73KV ; 710 mA

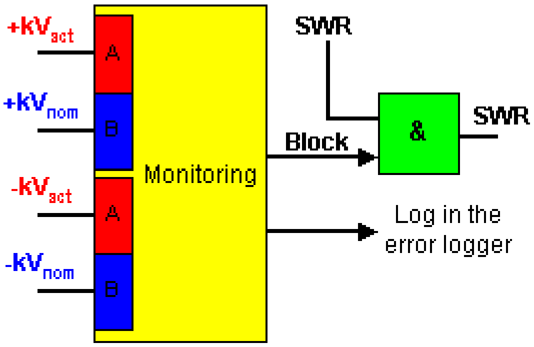
Control Example

The upper diagram shows the test exposure of the generator POLIDOROS IS with a high current.
You can see, that the kV reaches very fast the required value (< 1 ms). To see the start behave better, another time deflection would be necessary.
The accuracy and stability of the kV is ok too.

.

Generator **High Voltage Control** 4/5

kV-Monitoring



During radiation there is a constant monitoring of the kV. If there is detected a malfunction of the kV-generation the monitoring circuit reacts in the following way:

kVact > kVmax => Blocking and a log
kVact > kVnom => log
kVact < kVnom => log

Blocking Condition

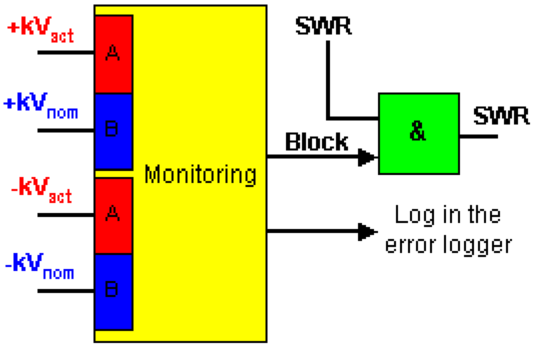
The kVmax-value for each high voltage side is aproximately 80 kV.

If this value is exceeded, immediately the kV-generation and so the radiation is terminated by blocking the control signal **SWR**. Additionally a message is given and logged into the error logger.

Tolerance Monitoring

In case of a difference, either kVact < kVnom or kVact > kVnom, there is normally not a blocking just a log in the error logger.
In some generators there is also a blocking if the difference is out of a certain tolerance window (not POLYDOROS IS).

Error Messages



To diagnos malfunction of the generator it is always good to examine the error logger.

........Example: POLYDOROS LX

.....**ERR 712** ....-> ....**+kVact > 80 kV**

The high voltage on the positive side exceeds the maximum value of 80 kV.
That is the reason for blocking!

Beside the error number it is also given a text about possible causes and remedies:

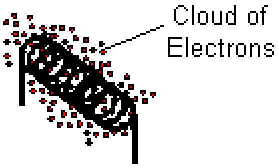
-tube assembly or high voltage cable defective
-high voltage generator defective
-kV-controller defective, replace pcb D100
-check flat ribbon cable between ...
etc.

end of chapter "High Voltage Control"

..

Filament

To obtain x-rays high-speed electrons are needed which bombard a target (anode). They are produced by heating-up a tungsten wire (filament) so that it emits electrons.
Helix is called the spiral wire. It is mainly made out of tungsten in x-ray tubes.



Generation of X-ray

X-ray radiation is created, if very fast accelerated electrons hit the anode .For that two parameter are necessary:
- free electrons, emitted by the filament heating - high voltage to accelerate the electrons

Tube Current (mA)

The flow of the electrons from the cathode to the anode is defined as tube current. Tube current while a certain time periode results linear in the amount of radiation quanta. That means doubbling the current doubles the dose.

..........mA$_{\text{soll}}$ = reference value
...........mA$_{\text{ist}}$ = actual value

Filament Current (I_H)

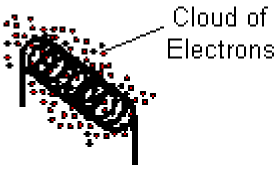
To get free electrons, they have to be emitted by a filament current. Filament current is therefore necessary to get tube current. There is not a linear relationship between the filament current and the tube current. Each X-ray tube has got a special characteristic in this context (more info in subchapter "Cathode and Helix" of chapter "The X-ray tube").

..........J_{Hsoll} = reference value
............J_{Hist} = actual value

.

Standby Heating (Preheating)

Specially in fluoroscopy systems physicians are watching live to the organs in fluoroscopy mode. If they see an important detail they want to make a radiography very fast. Normal rotating anodes need 0.5 sec. to reach the required revolution. This accelaration time is that time, in what the required electron emission has to be reached. For that the filament has to be heated. But a filament is a relatively slow device and unable to generate the necessary electron emission in that short time. To solve that time problem all filaments of the selected tube are preheated.
At standard tubes (filament diameter = 0.22mm) the two foci are preheated as followed:
......-small focus -> aprox. 3A



Because the reqired preheating of the large focus during fluoroscopy this standby heating has to be below the emission limit. Otherwise two geometrical focal spots would apear and unsharpness of the image would the result.

Maximum filament current (J_{Hmax})

The maximum filament current at standard tubes is aproximately 5A. This value should not be

......-large focus -> aprox. 2A

exeeded.

The small focus is used for fluoroscopy. Therefore the small focus heat current (J_H) is higher since a small amount of emitted electrons already is necessary.The standby heating current is the basis of the filament current during fluorscopy.

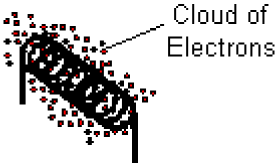
.

Filament Boosting Current (J_{push})

Although the filament is preheated the preptime is often not enough to reach the required emission.Therefore there is an encreased filament current (J_{push})during preptime.

............Jpush = JHsoll x Push factor

An aproximate value of the push factor is 1.1!



A selflearnig adjustment procedure automatically will find the necessary factor.

Exposure (main) Heating Current

If an exposure is triggerd, the system turns from standby heating to exposure heating. Now a lot of electrons have to be emitted. The level of the heating current depends on the type of the tube, the selected focus, the selected exposure parameter (kV, mA) and is defined by the J_{Hsoll}-value.

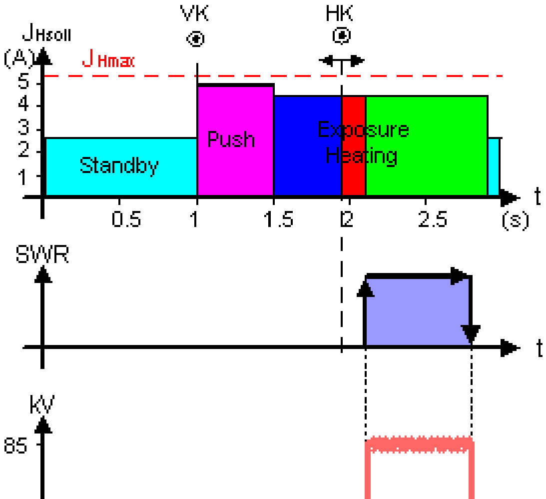
At standard tubes often it is a value between 4A and 5A.

Fluoroscopy Heating Current

Because the dose control the dose at the input screen of the image intensifier is constant although the size of the patient changes.This is obtained because of controlling the electrical power (kV, mA) transfered to the x-ray tube. I.e.,also the filament current changes. But because of the low power during fluoroscopy the filament current is low too. It is not so different as the standby heating current.

.

Example:



Standard tube, small focus (40kW)

During standby the filament is heated with about 2.8A. This indicates, that this focus is also used for fluoroscopy. The foci not used for fluoroscopy are set to preheating of aprox. 2A.

If a radiography is triggered and the precontact is given (VK), the push current is active. This is an encreased exposure heating and necessary to get enough electron emission after the preperation time (shortest time between VK and HK, e.g., 0.5sec).

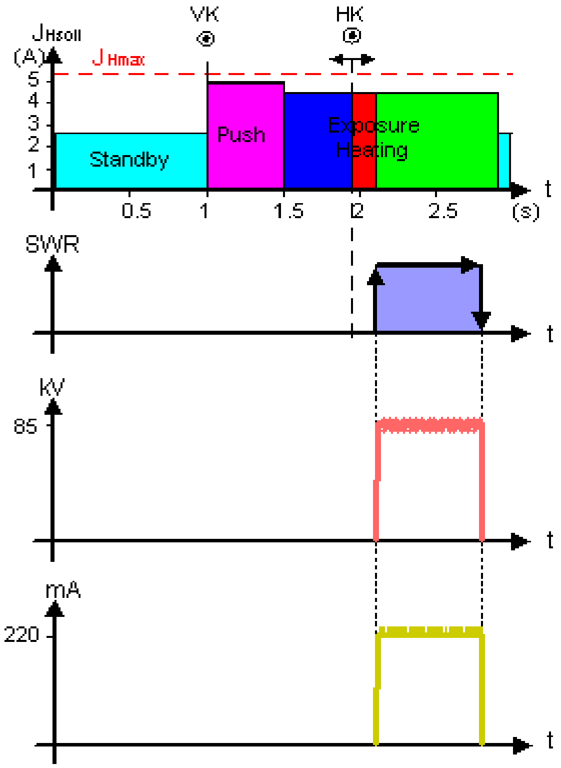
After the push time the exposure heating is active. The value depends on the selected exposure data (kV,mA).

.

Filament Circuit

Now the main contact is given (second contact of the hand switch). There is no change of the exposure heating. But the generator is prepared to generate high voltage and so radiation.

With a slight delay the control signal "SWR" switches on the high voltage (kV). The delay is system related and depends on e.g., the grid contact of a spot film device or of the TV-triggering of an angio system.
With high voltage tube current (mA) is generated.
Now the tube current control circuit is active. That means, if the generated tube current mA_{ist} does not correspond to the required tube current mA_{soll}, the present filament current J_H has to be corrected. An example for too low emission is shown on the next page.



.

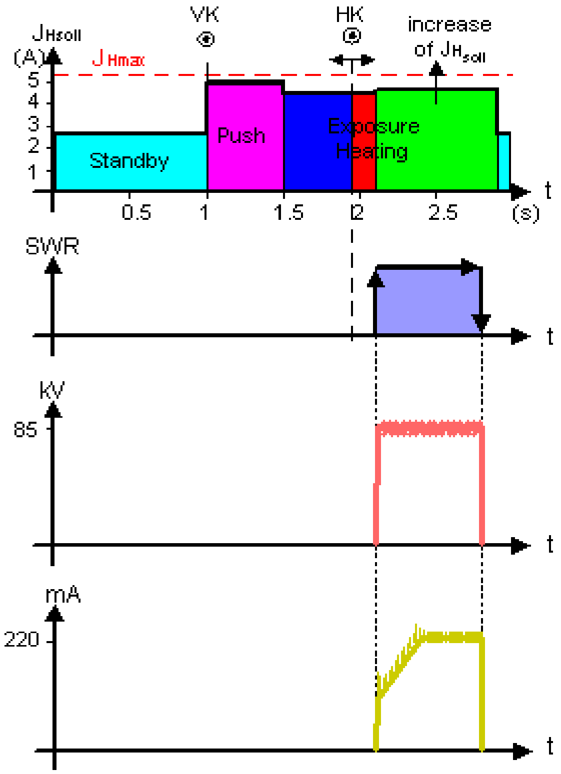
Tube current to low at initialisation (see picture)

Here in this example you can see, that the emission current at the beginning of the exposure (SWR on) is not enough. Therefore the exposure heating has to be encreased a bit. This is done through increase of JHsoll.

Tube current to high at initialisation

In case of having to much emission, the tube current wuold be to high at initialisation. JHsoll had to be decreased.

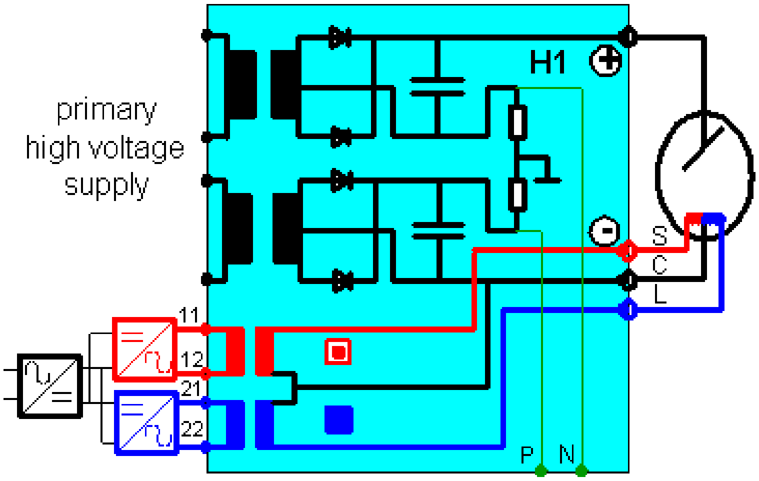
If just a single exposure was made, the generator switches back to standby heating after another short delay.



.

Filament Transformer

Standard X-ray tubes containing two foci. For the required filament current of both foci exist a separate transformer inside of the high voltage transformer tank H1. The required current is controlled via two extra inverters (small focus,large focus), which get their control signals from the filament and tube current controller (see next pages).



11; 12 -> filamament transformer connection small focus
21; 22 -> filament transformer connection large focus
P; N -> actual tube current (mAact)

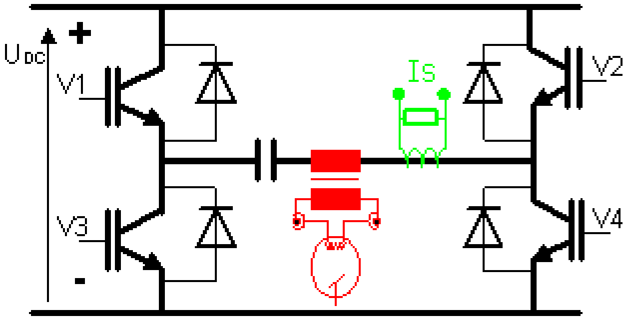
"mAact" is the actual value for the tube current control circuit.

.

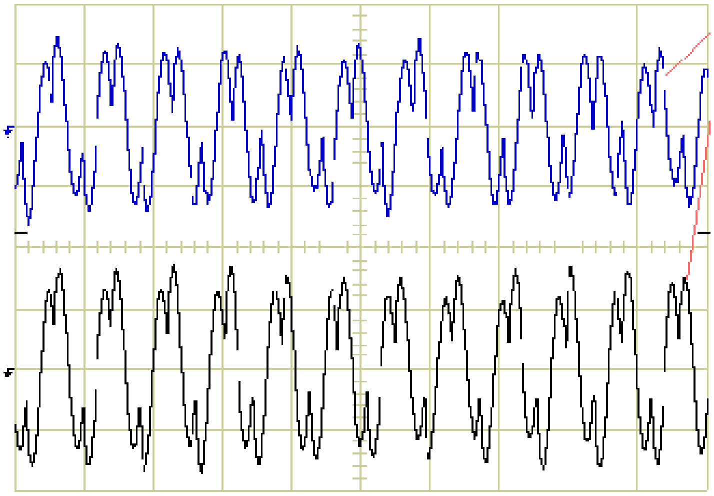
Filament Inverter

Basically there are two different types of filament inverters:

....**-series oscillator inverter**
.....(POLY DOROS IS)
....**-square wave inverter**
.....(POLYDOROS LX/SX)



Series Oscillator Inverter



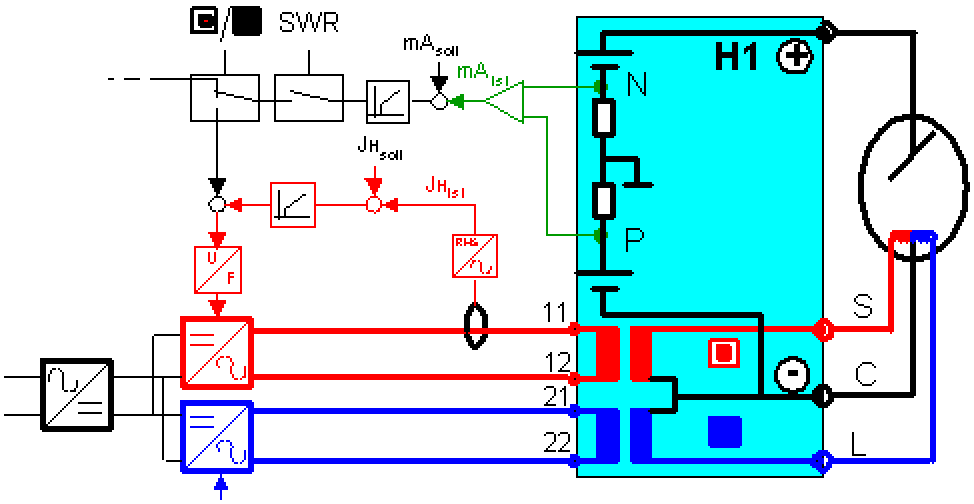
Principally it works like the high voltage inverter (see Inverter). Allways a pair of transistors are controlled conductive, either V1/V4 or V2/V3. This is done with the control frequency from the filament controller. **The higher this control frequency the higher the filament current**. Here you can see the swing current (Js) of both filaments.
t = 100 us

.

Filament Circuit

Filament Controller for series oscillator inverter

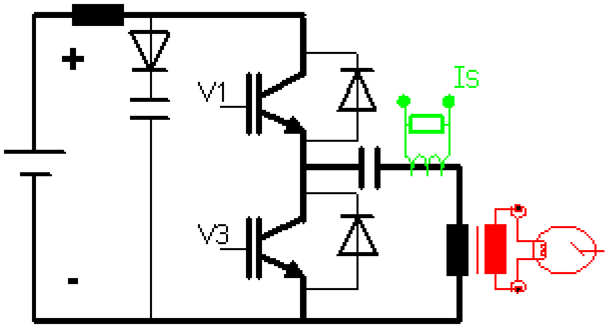
Only the control of the small focus is shown.



As long as the exposure is not triggered only the JHsoll is reponsable for the filament current. JHist, detected with a current converter, is compared with JHsoll and the difference signal is led to an U/F-converter after passing the controller.
The filament current is as higher as higher the output frequency of the U/F-converter is. This frequency controls the filament inverter. Here the DC-voltage is converted to AC and the AC-current is transformed via the transformer to the filament.
When exposure is triggered (SWR on) the input signal of the U/F-converter is influenced by the tube current (mA) control. The tube current control is activ during generation of radiation and only for the selected focus.

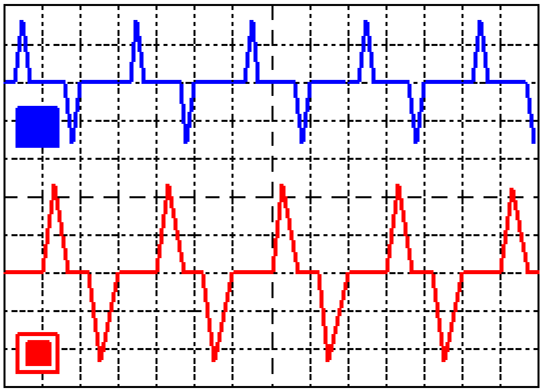
.

Square Wave Inverter



Alternately V1 or V2 is controlled conductive. This is done with a constant frequency of aprox. 20 kHz. The time of being conductive and so the level of the filament current depends on the output signal of the pulse width controller which is supplied from the filament controller.

The longer the conduction time the higher the filament current.



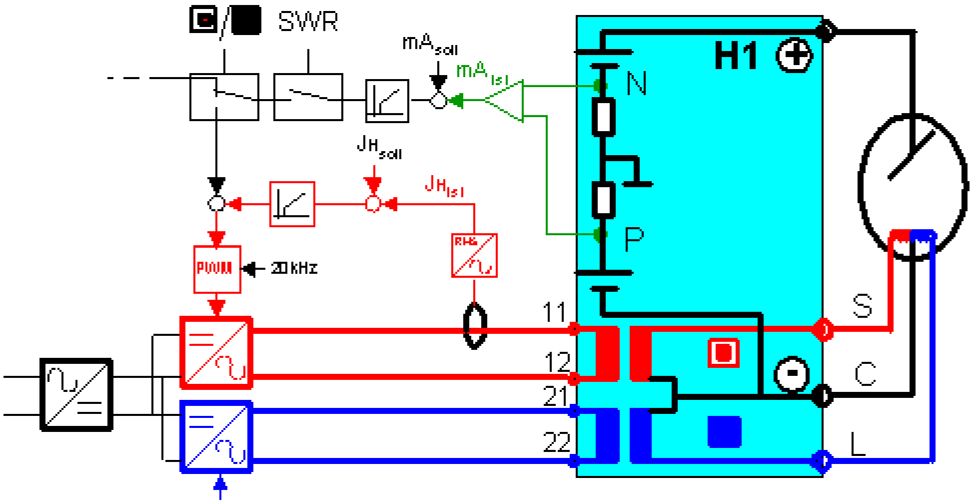
Here you can see the swing current (Js) during standby heating of both foci. The filament current of the small focus is a bit higher.

t = 20 us

.

Filament Controller for square wave inverter

Only the control of the small focus is shown.



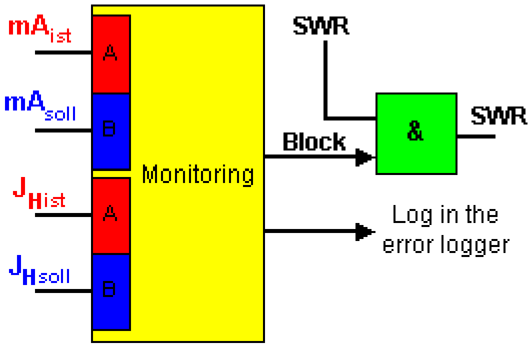
As long as the exposure is not triggered only the JHsoll is reponsable for the filament current. JHist, detected with a current converter, is compared with JHsoll and the difference signal is led to an pulse

width modulator (PWM) after passing the controller.
The output signal of the PWM controls the filament inverter. Here the DC-voltage is converted to AC and the AC-current is transformed via the transformer to the filament.
When exposure is triggered (SWR on) the input signal of the PWM is influenced by the tube current (mA) control. The tube current control is activ during generation of radiation and only for the selected focus.

.

Generator — Filament Circuit — 12/12

Monitoring e.g.: POLYDOROS IS C



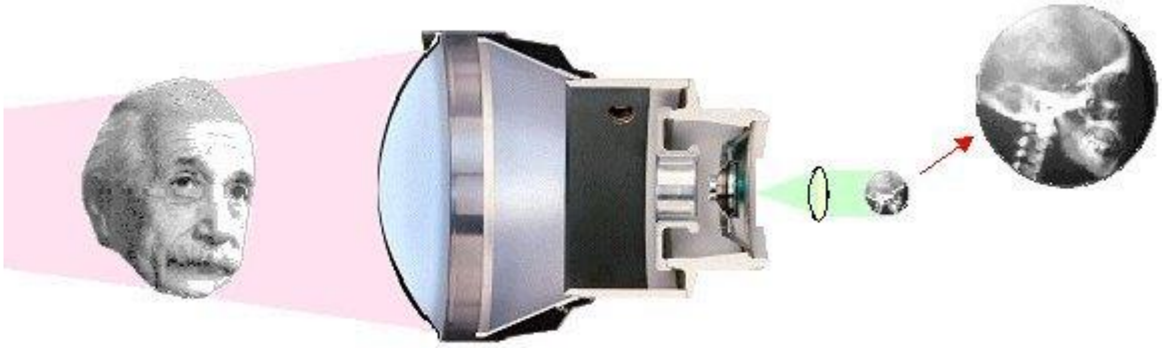
Fatal error:
ERROR W0026
"$I_{Hist} > I_{Hmax}$ for focus 2"
· Filament current max. value of focus 2 was exceeded
· If error occurs, radiation is interrupted

Tolerance monitoring:
ERROR L002F
"$mA_{ist} > 1.1 \cdot mA_{soll}$"
· The tube current is out of tolerance.
· no blocking, only messsage

ERROR L0030
"$mA_{ist} < 0.9 \cdot mAsoll$"
· The tube current is out of tolerance.
· no blocking, only messsage

end of chapter "Filament Circuit"

Image Intensifier — Introduction — 1/5



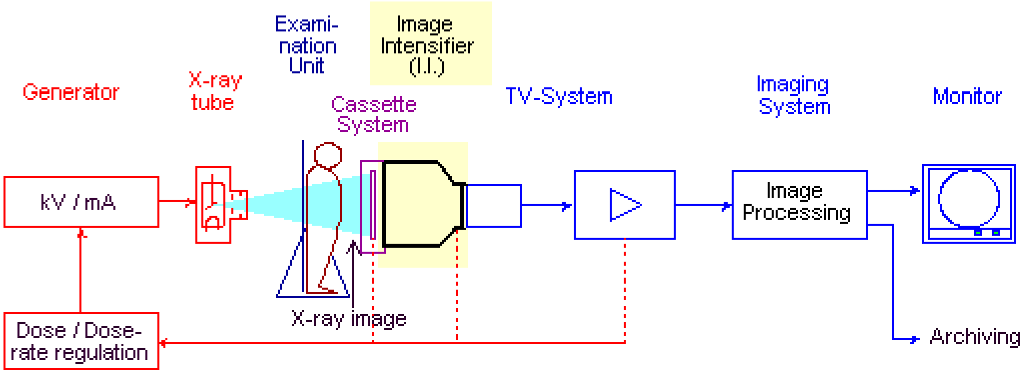
(cut view of an image intensifier)

- **Image Intensifiers (I.I.'s) are vacuum components**
- **They convert X-rays into visible light**

.

Image Intensifier **Introduction** 2/5

Blockdiagram of X-ray imaging chain



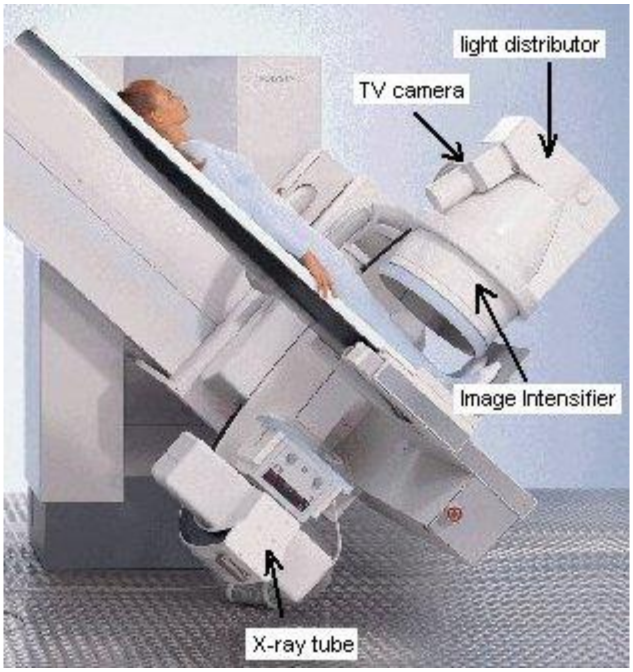
An **I**mage **I**ntensifier (**I.I.**) is a vacuum tube used to convert the X-ray image into a visible image.
This image can then be viewed via a television system at an image monitor.
On some systems the I.I. output image is additionally recorded photographically by Cine or Sircam Cameras.

Producing images from the image intensifier output means "indirect technique".

..

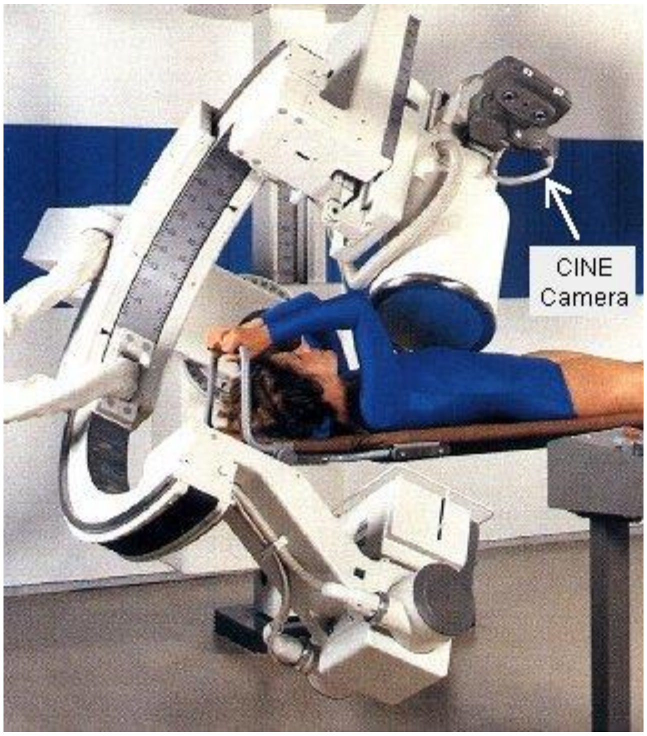
Image Intensifier **Introduction** 3/5

Example 1:
System with Image Intensifier and TV-camera (POLYSTAR T.O.P.)



..

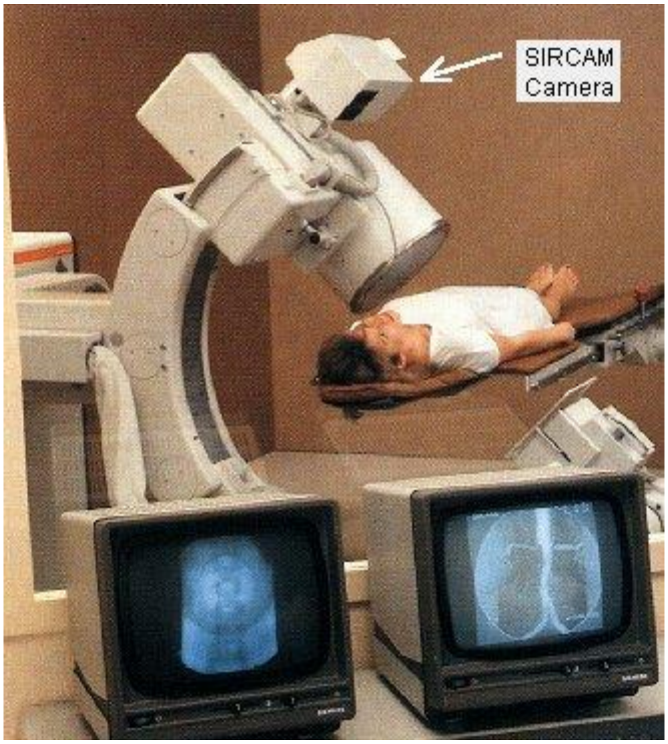
Example 2:
System with Image Intensifier, TV-camera and Cine camera (ANGIOSKOP C)



▼ ▲

..

Example 3:
System with Image Intensifier, TV-camera and SIRCAM camera (ANGIOSKOP D)



end of chapter "Introduction"

..

Image Intensifier **Construction** 1/3

The Image Intensifier (I.I.) consits of:
- the I.I. tube and
- the I.I. housing with
integrated I.I. power supply.

40 cm Image Intensifier tube

Image Intensifiers (housing with tube and power supply)

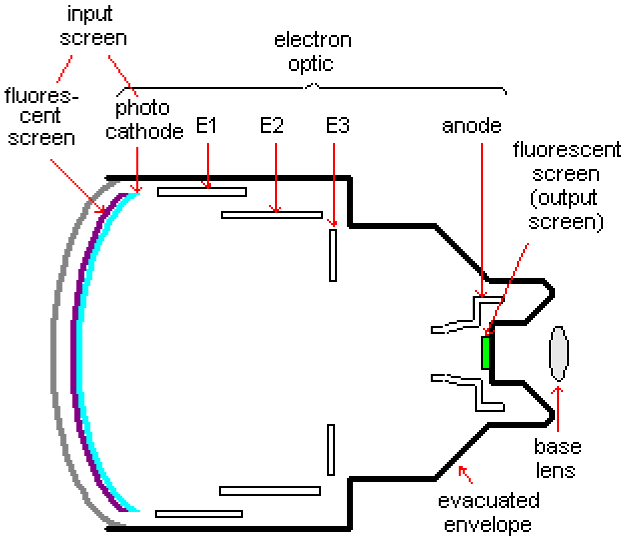
27 cm Image Intensifier tube

.

Image Intensifier Construction

The Image Intensifier tube comprises:

- **Evacuated envelope.**
  The material, e.g aluminum, glass, ceramic, depends on the type of I.I..
- **Input screen,**
  consisting of a fluorescent layer and a photo cathode.
  Here the X-ray quanta are converted into electrons.
- **Electron optic,**
  consisting of photo cathode (0 Volts), grids E1, E2, E3 and anode (25 kV).
  The electron optic accelerates the electrons towards the output screen.
  On the 40 cm I.I. the grids E1 and E2 are distributed into the grids E1a, E1b and E2a, E2b.
- **Output screen** (fluorescent screen),
  to convert the electrons into visible light.



- **Base lens,**
  to transfer the image from the output screen to a TV system, Cine camera or Sircam Camera.

.

Image Intensifier Construction

Example:
4th generation image intensifier (1976);
with aluminium input window; glass-metal
envelope; high contrast output window.

(cut view)

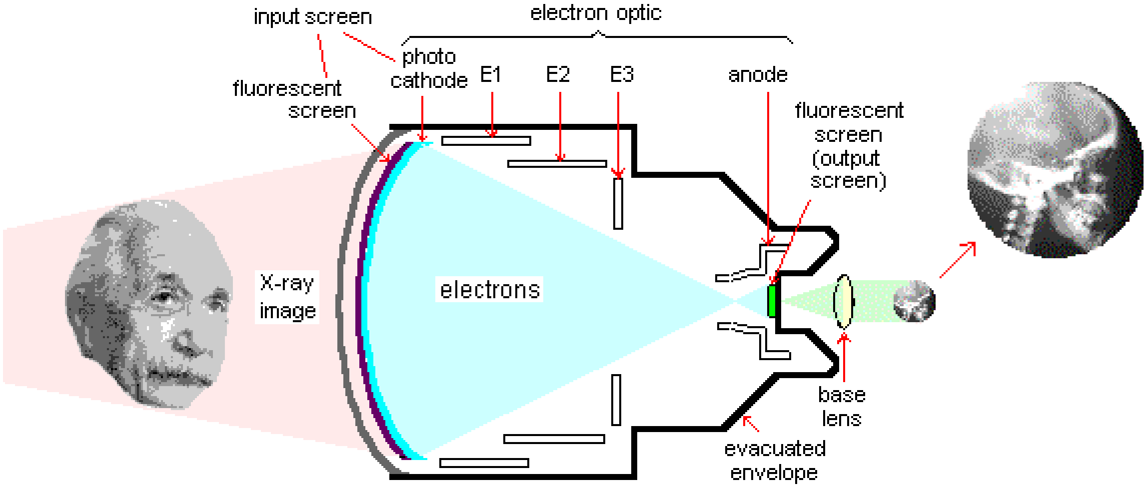
Example:
6th generation image intensifier
(1991);
metal-ceramic envelope;
Optilux HDR-series;
triple field 9" (23 cm) image intensifier.

(cut view)

end of chapter "Construction"

.

Image Intensifier **Function** 1/6

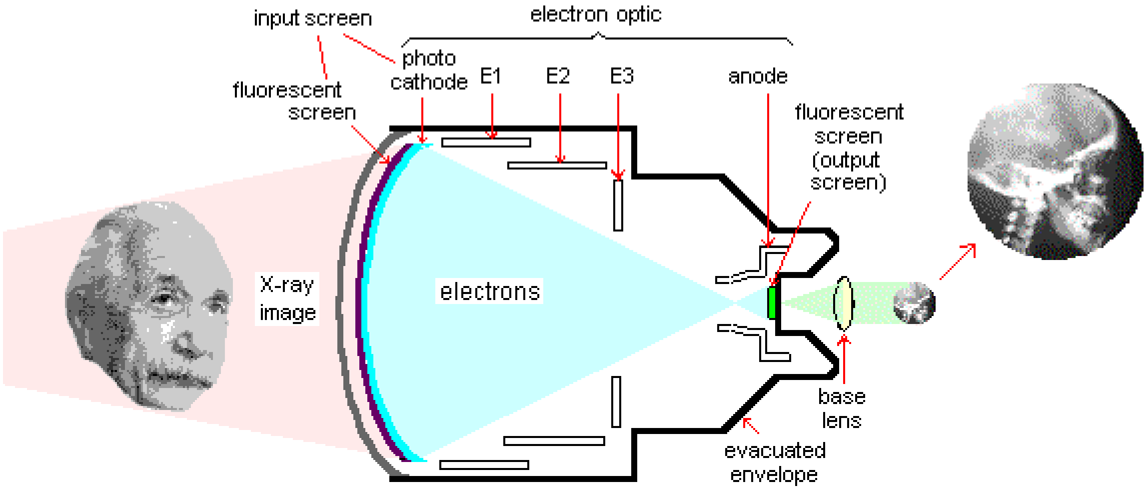


X-ray image:

The X-ray beam which leaves the X-ray tube, penetrates the object to be photographed and projects the X-ray image at the input of the Image Intensifier in the form of X-ray energy.

.

Image Intensifier Function

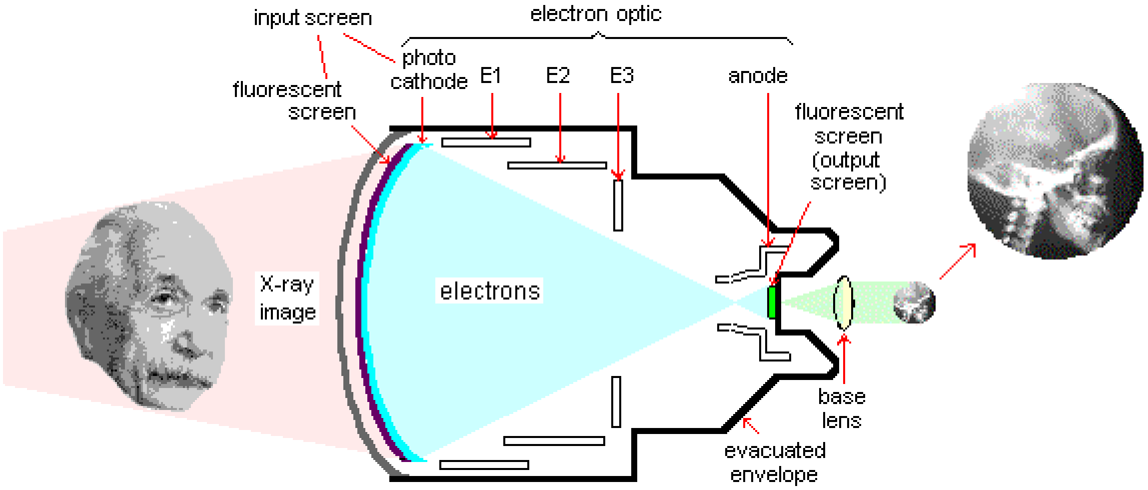


Input Screen:
The X-ray quanta first penetrate the envelope of the I.I. tube prior to striking the input phosphor (fluorescent screen).
In order to have a low absorption by the envelope, since 1973 aluminum is used instead of glass.

When the X-ray quanta reach the input screen, they excite the input phosphor, and light photons are emitted, which in turn excite the photo cathode to emit electrons.

.

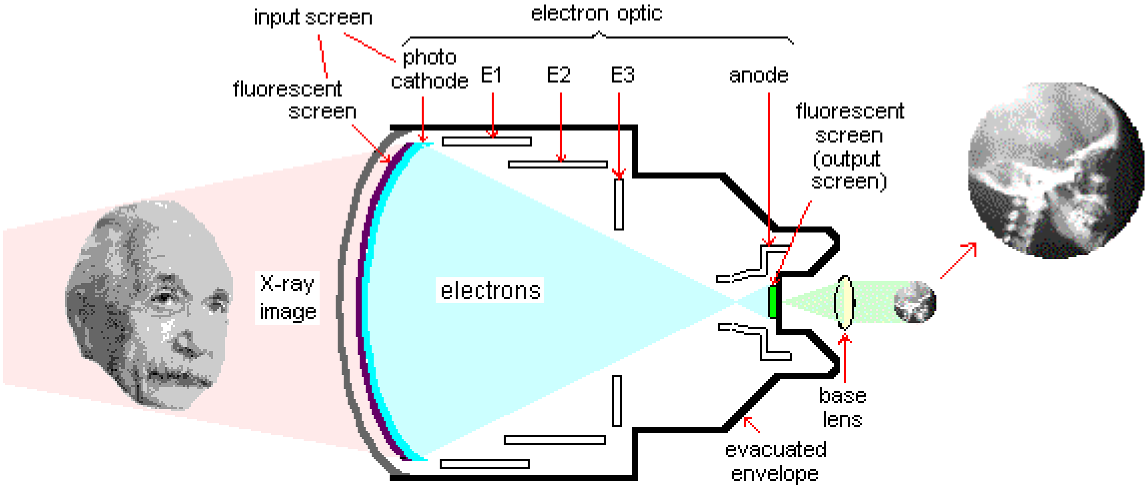
Image Intensifier Function



Electron optic:
The electrons are accelerated by the Electron Optic towards the output screen.
The photo cathode is on 0 Volts, the anode on a very high voltage, e.g. 30 KV
and the grids E1 to E3 voltages are in between.
On the 40 cm I.I. the grids E1 and E2 are distributed into the grids E1a, E1b and E2a, E2b.

The voltages on the grids determine the focus and the size of the
image to be projected onto the output screen.

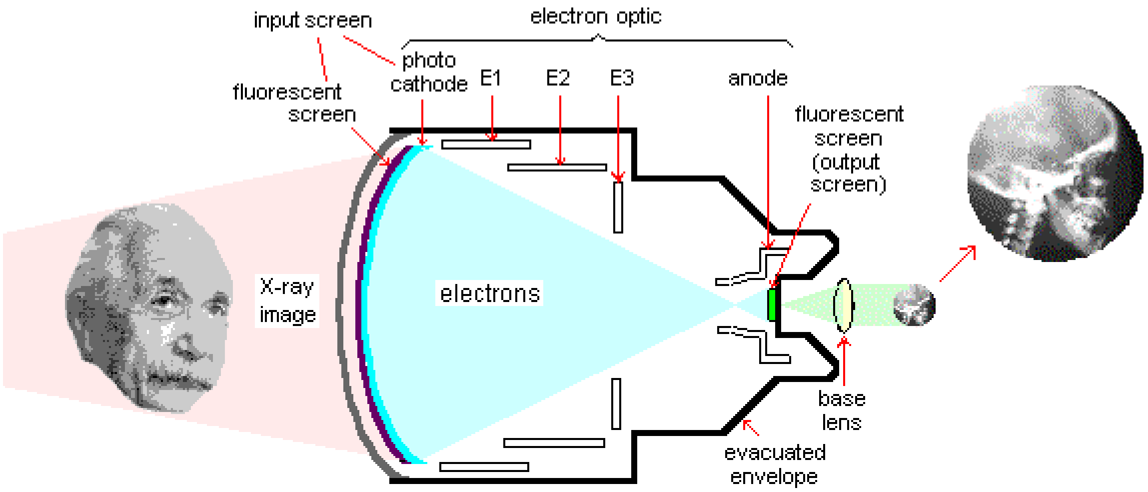
.



Zoom:
By changing the grid voltages the used image field of the I.I. input can be
switched to smaller diameters, designated as Zoom-Formats.
This smaller input field is still projected to the full size of the output screen.
Compared with the full field or "overview" of the I.I. input, now the middle section
of the object is displayed magnified.
This improves detail perceptibility and increases resolution.

Click here, to see the diagram above in Zoom mode

.



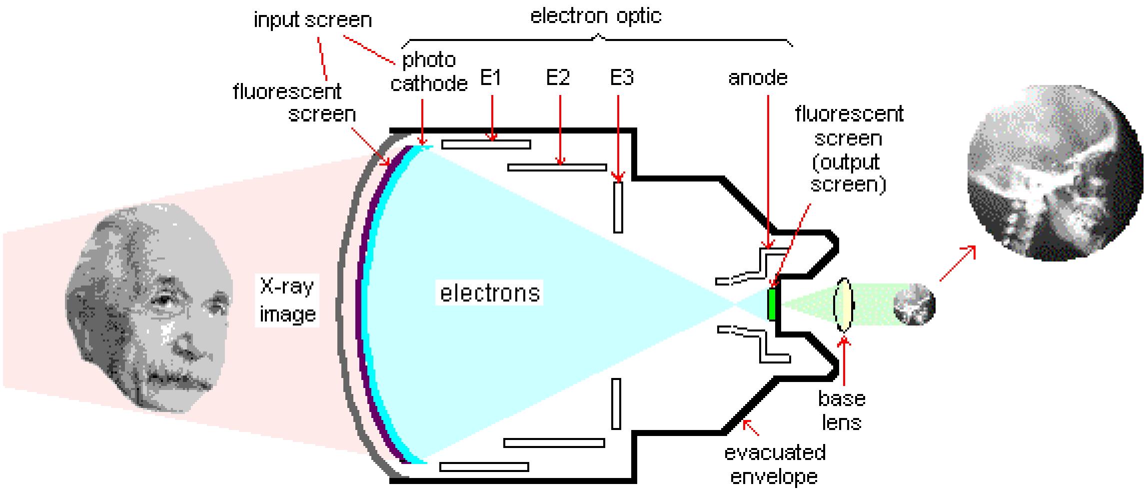
For a new Image Intensifier the I.I.-voltages are adjusted in the testfield and are recorded in a test certificate.

For checking purposes these voltages can later be measured on certain testpoints of the I.I. power supply.

▼ ▲

.

Function



Output screen, base lens:
On the output screen the electrons are converted to a visible image.
Compared with the light density of the fluorescent screen of the I.I. input, the light density at the output is much higher.
Gain factors of 20.000 are possible.

The I.I. output image is very small. It has a diameter of appr. 25 mm.

For further processing the image is tranferred via the base lens of the I.I. to a TV camera, CINE camera or SIRCAM camera.

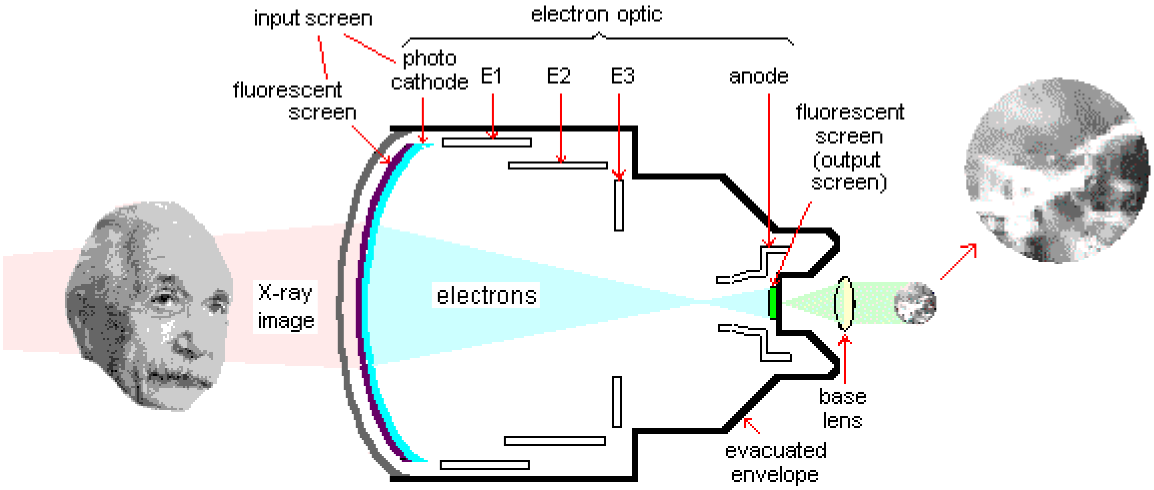
end of chapter "Function"

.

.

.

Function



Zoom

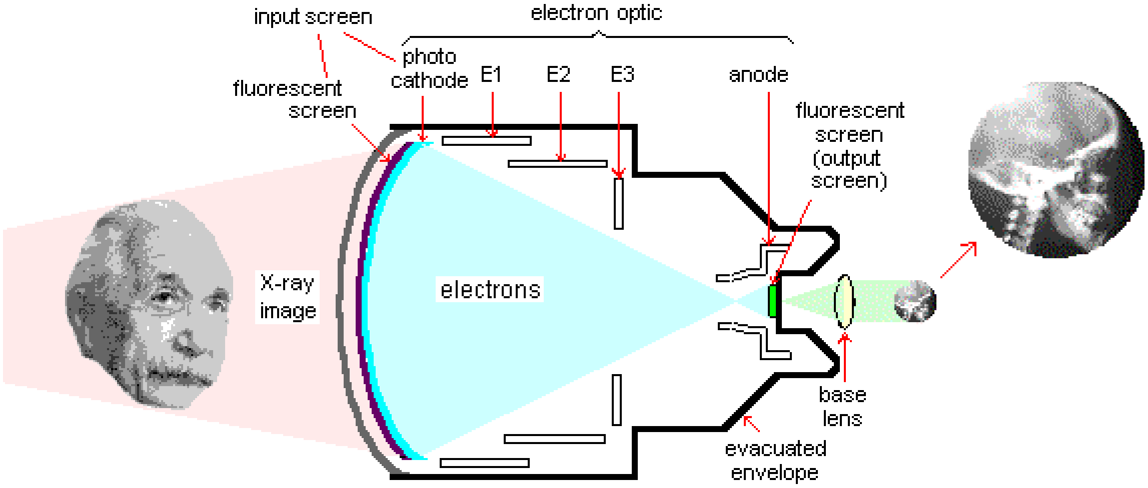
back

.

.

.

.



Gain / Conversion Factor (Gx):
The gain is definded by the quotient of output signal to input signal.

In case of an Image Intensifier it indicates how much greater the light intensity is at the output screen compared with that at the input screen.
Due to the acceleration of the electrons and to the ratio of the sizes of input- and output screens, gain factors of appr.. 20.000 are achieved.

.

As it is not possible to measure the light intensity at the input screen, the light intensity of an X-ray fluoroscopy screen is taken instead.

In order to have a distinctive and reproducable factor, another term is used to define the sensitivity.

This term is the **"Conversion Factor (Gx)"**.

The Conversion Factor is measured under ICRU-conditions and is the output density of the Image Intensifier divided by the input dose rate.

Gx = output luminous density ÷ dose rate at the Image Intensifier input

In the data sheets both the Conversion Factor and the Gain Factor are listed.
But the Gain Factor is not measured; it is the Conversion Factor multiplied by 100.

.

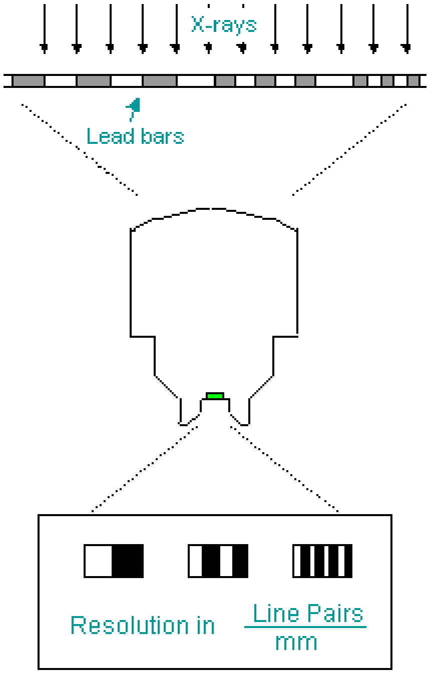
Resolution:

Resolution is the minimum distance between two details which the transmission system is still able to reproduce seperately.

Resolution depends on contrast, object properties, influence of noise signals and the property of the transfer medium, e.g. the Image Intensifier.

The unit of measurement for resolution is "Line Pairs per mm".

Each pair of light and dark bars makes up one cycle.
The cycles per mm are designated as **Spatial frequency**.



.

For resolution checks, special tests are avilable.
These tests can be mounted on the input side of the I.I. and under radiation the resolution can be determined.

Resolution Test (type)

Image at the monitor

.

Contrast:

Contrast is a measure of the intensity difference between different points in an image.

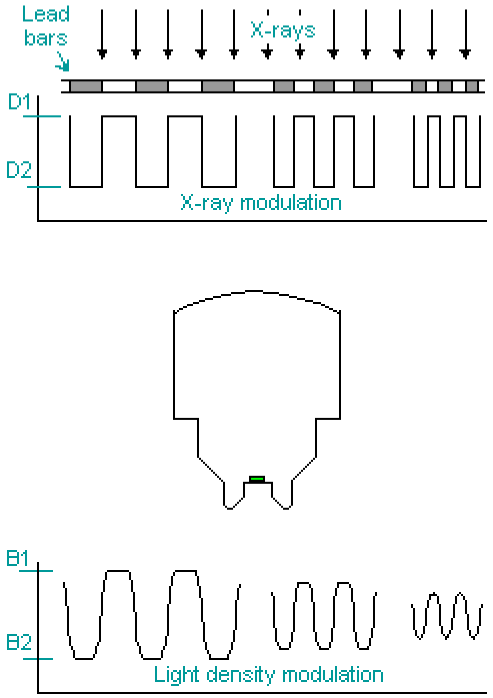
In the drawing, we see the Object Contrast in form of X-ray modulation, and on the I.I.-output the Picture Contrast in form of light density modulation.

The formula of contrast is :
(maximum intensity - minimum intensity) ÷
(maximum intensity + minimum intensity).

Object Contrast : (D1-D2) ÷ (D1+D2)

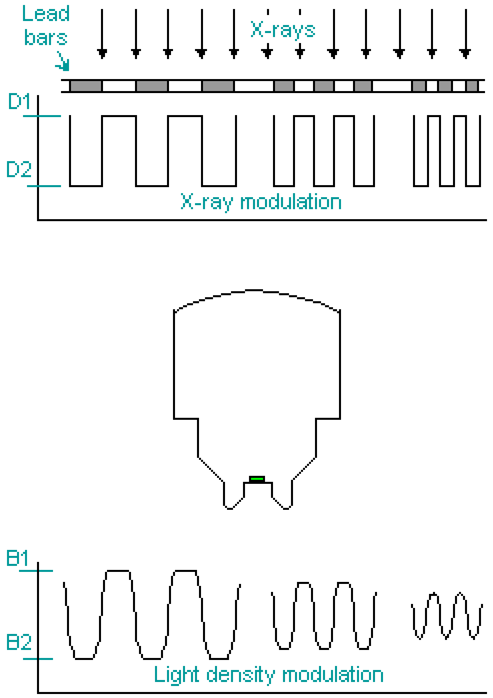
Picture Contrast : (B1-B2) ÷ (B1+B2)

The maximum contrast is 1.



.

In this drawing the contrast is below 1, because there is a constant portion, that raises the



modulation curves.
Such an effect can be caused for example by too high KV.

Klick here to see the modulation curves with maximum contrast.

A few factors that decrease contrast:

- Too high KV
- Ambient light
- Scattered radiation. Collimate to the object's size to reduce scattered radiation.
- Wrong setting of contrast and brightness at the image monitors
- Wrong setting of window pots (digital contrast and brightness settings)

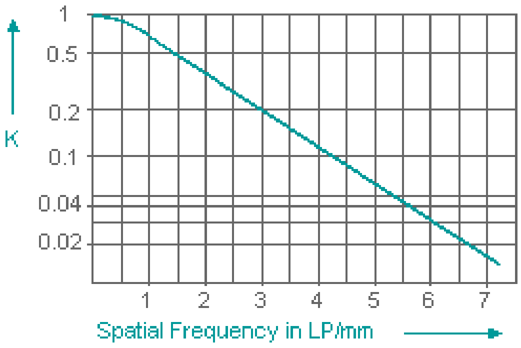
.

Image Intensifier **Data / Properties** 7/12

Modulation Transfer Function (MTF) :

The MTF is used to assess optical and electrical transmission components.
It shows the relationship between Relative Contrast (K) and Spatial Frequency.

While resolution indicates which image details are just visible, the MTF shows **how** the contrast varies in the transmission of variously large image details.



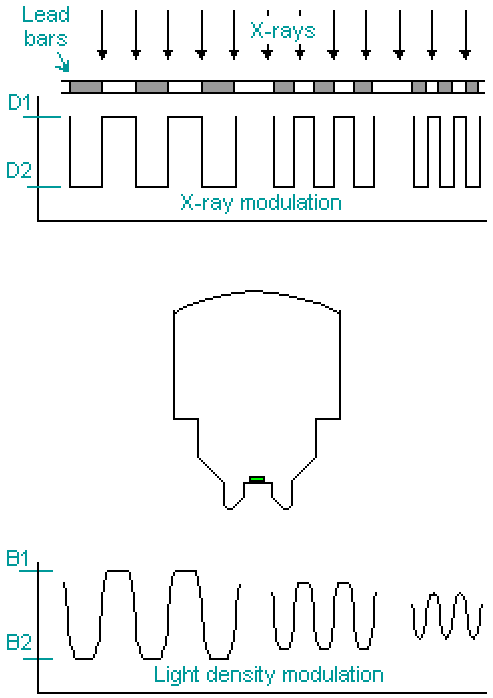


Image Intensifier

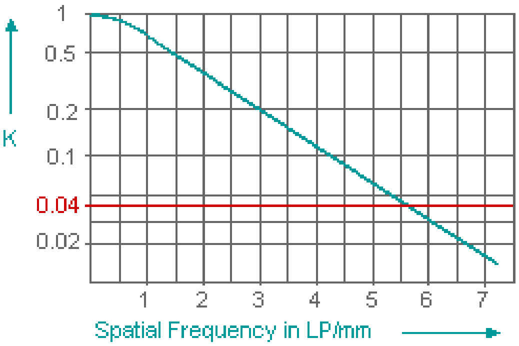
Data / Properties

Relative Contrast (K) =
Picture Contrast ÷ Object Contrast

Picture Contrast : (B1-B2) ÷ (B1+B2)

Object Contrast : (D1-D2) ÷ (D1+D2)

Experience has shown that the limit of resolution is at a spatial frequency at which the MTF has fallen to a value of K=0.04 corresponding to 4% of the maximum value.



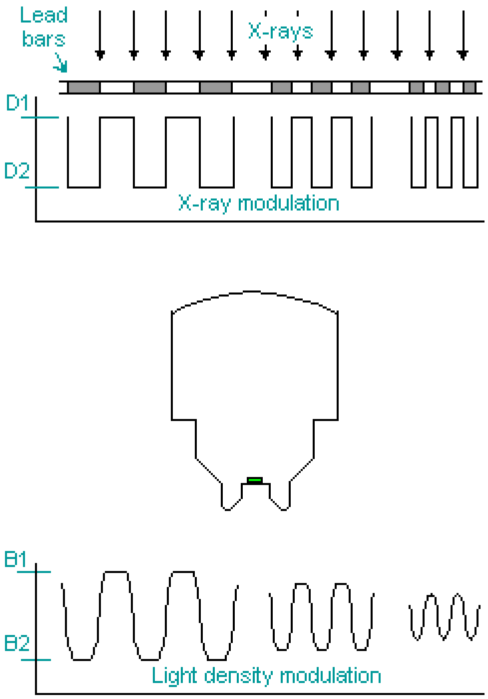
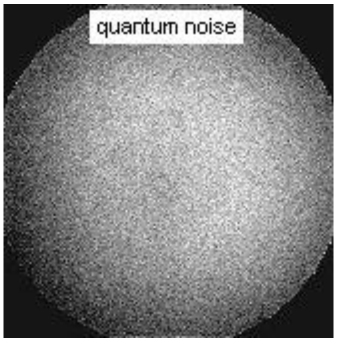


Image Intensifier

Data / Properties

Quantum Noise:

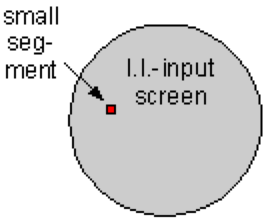


Quanta are the smallest indivisible quantities of energy contained in radiation.
Because of its quantum nature, X-ray radiation is subject to statistical fluctuations.

For further explanation let's have a look at a small segment of the I.I.-input.
Let's assume that right now 100 quanta hit this

segment.
This is equivalent to a certain light density at the I.I.-output.
If due to the statistical fluctuation now the amount of X-ray quanta change, e.g. 110 quanta, also the light density at the I.I.-output changes for that segment.

If we see now the entire Image Intensifier, the statistical fluctuations of quanta are visible as noise.



Dispersion = $\pm\sqrt{N}$

N = mean number of impinging quanta

Example: N = 100

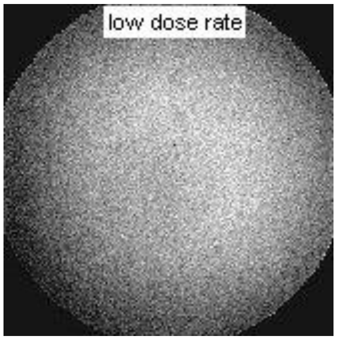
Dispersion = $\pm\sqrt{100} = \pm 10$

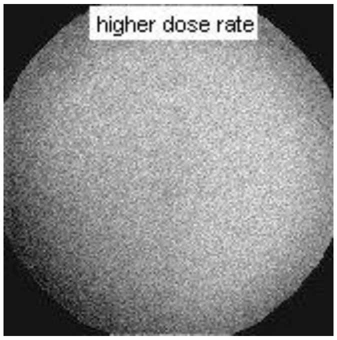
⟹ Statistical fluctuation is between 90 and 110

.

A higher dose rate increases the amount of X-ray quanta.
Therefore the statistical fluctuation is reduced.

Remember:
A higher dose rate reduces the quantum noise !



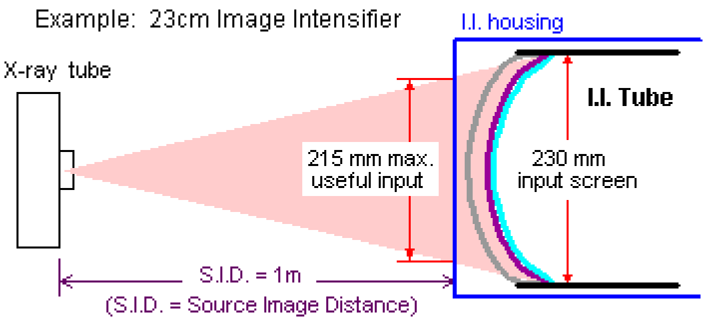


.

Nominal Diameter / Useful Diameter :

Example: OPTILUX 23 D-C

"23" indicates the **Nominal Diameter**.
This is the physical size of the input screen (230mm).



The **Useful Diameter** is smaller, because the input screen has a certain distance to the front of the I.I. housing.

The Useful Diameter explains the maximum object diameter which can be displayed in the housing input plane with a source to I.I. distance of 1m.

In the I.I. Data sheets both diameters are entered.

Designations for SIEMENS Image Intensifiers:

The general designation is "OPTILUX x y", where

- "OPTILUX" is the general SIEMENS name for Image Intensifiers
- "x" indicates the Nominal Diamater and how many formats can be selected
- "y" stands for the design, that means milestones in I.I. technology.

Examples:

- OPTILUX 40-4 HD :
  - The Nominal Diameter is 40 cm and 4 formats are possible
  (the full format or "overview" and the three zoom formats 28cm, 20cm, 14cm)
  - The technology is "HD" (**H**igh **D**ynamics)
- OPTILUX 23-3 HDR-E :
  - The Nominal Diameter is 23 cm and 3 formats are possible
  (the full format or "overview" and two zoom formats 17cm, 13cm)
  - The technology is "HDR-E" (**H**igh **D**ynamics high **R**esolution,
  Metal-**E**namel envelope)

end of chapter "Data / Properties"

.

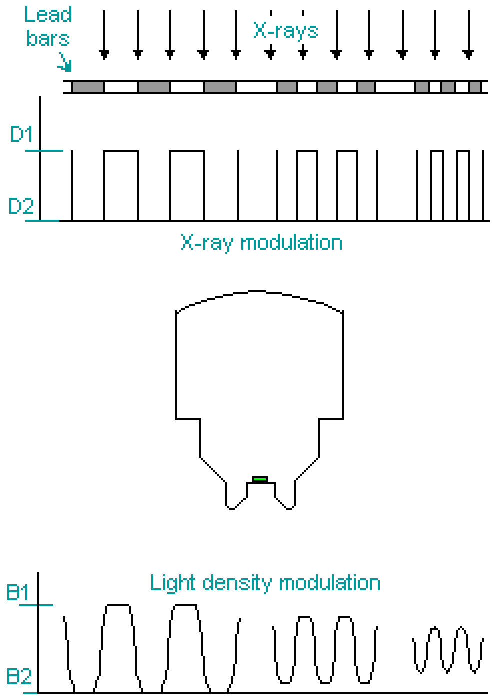
.

.

Data / Properties

Maximum contrast we have only for the lowest spatial frequency.

Due to the transfer characteristic of the I.I. the higher frequencies are displayed with a lower contrast.

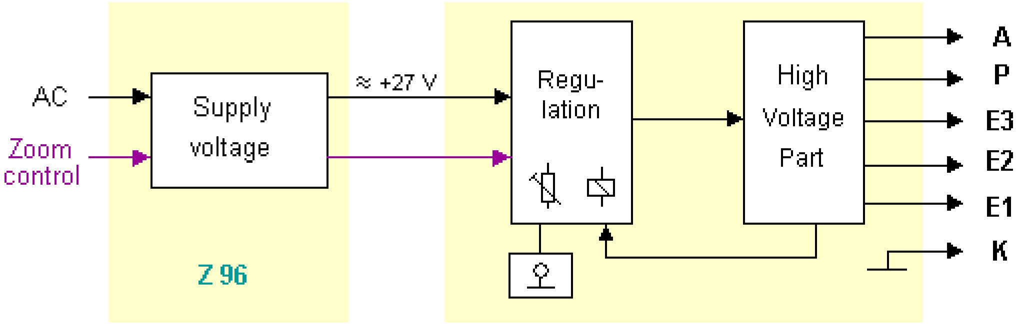


back

.

.

Image Intensifier I.I. Power supplies 1/



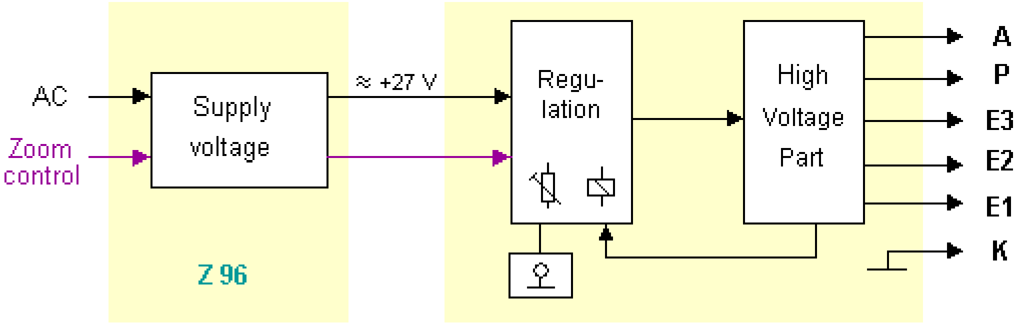
The following voltages are generated :

- A = Anode voltage, e.g. 30 KV
- P = Penning getter voltage, appr. 2.5 KV
- E3 = Grid E3 voltage, 2...15 KV
- E2 = Grid E2 voltage, 0...900 V
- E1 = Grid E1 voltage, 0....600 V
- K = Cathode voltage = 0 V

The values of E3, E2 and E1 depend on I.I.-t ype and the selected I.I.-format.
The voltages are entered in the I.I. test certificate.

.

Image Intensifier — I.I. Power supplies — 2/



Function:
The device Z96 is located in the cabinet and generates a supply voltage of appr. +27 Volts.
This voltage and also the zoom control signals are transferred to the regulation circuit and to the high voltage part.

Both circuits are mounted inside the I.I. housing.

under construction !

.

.

Image Intensifier

SIEMENS

Prüfprotokoll
Test certificate

Röntgenbildverstärkereinheit......
Image intensifier system

Bezeichnung/*Model* :...... **Sirecon 33-4**
Sachnr./*Model No.* : **Angio**
Typ/*Type*: **31 34 868**

Seriennr./*Serial No.* : **G 5382 01086**

Röhrentyp: **Optilux 33-4 HDR**
Tube type:

Modell-Nr.: **98 05 490 V 5071**
Model No.:

Seriennr.: **32950214**
Serial No.:

Konversionsfaktor : Gx= **39,0** $\frac{\mathrm{cd}\quad\mathrm{s}}{\mathrm{m}^2\quad\mu\mathrm{Gy}}$
Conversion factor :

End-Prüfanweisungs-Ausf.: **RV B2-AA 179 0015/001**
Main test instructions vers.:

Spannungs-versorgung: **Power Supply HV30-4**
Power supply :

Modell-Nr.: **16 54 768 X 2134**
Model No.:

Seriennr.: **95095086**
Serial No:

Schaltungsunterlagen: **X 2134 C**
Wiring references:

next page back

.

Spannungen / Voltages

Eingangsformat / *Input format*		33 cm	22 cm	17 cm	13 cm
Spannung an / *Voltage on*	K	0 V	0 V	0 V	0 V
	E1	137 V	174 V	120 V	1 V
	E2	388,2 V	240,7 V	331,4 V	614,0 V
	E3	3,650 KV	6,670 KV	9,900 KV	15,000 KV
Referenzspannung *reference voltage*	ME3	0,365 V	0,667 V	0,990 V	1,500 V
	A	30 KV	30 KV	30 KV	30 KV
Referenzspannung *reference voltage*	MA	3,000 V	3,000 V	3,000 V	3,000 V

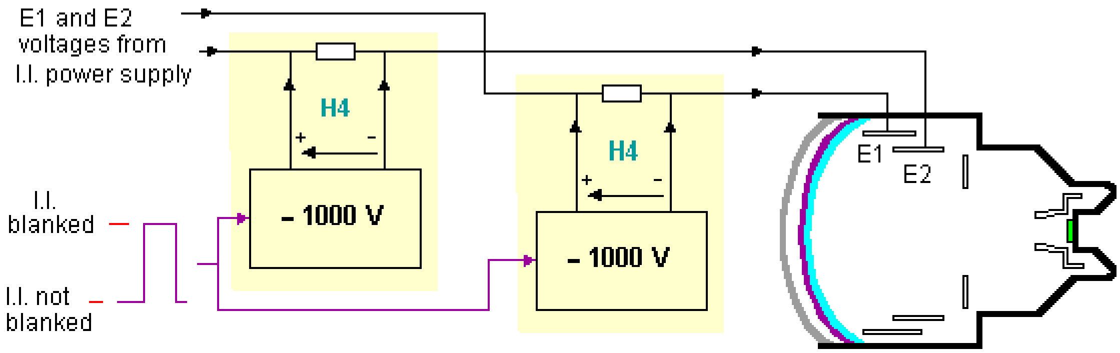
Bemerkung /
Remarks

previous page back

.

Image Intensifier

I.I. blanking



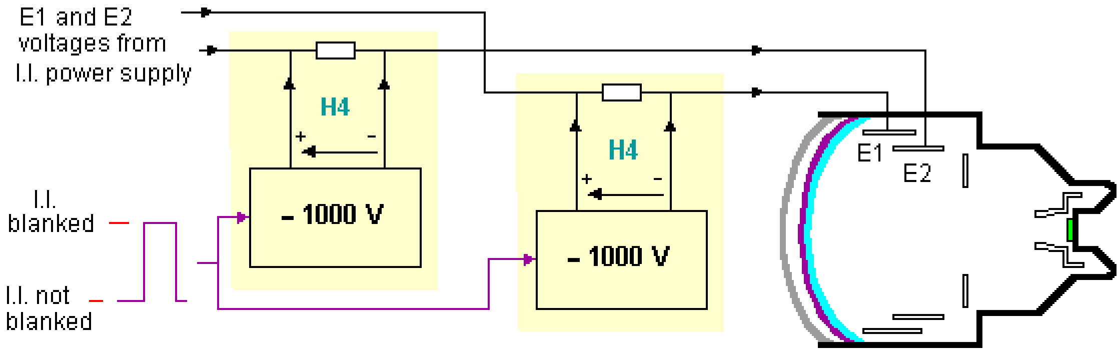
The I.I. blanking stages (H4) are needed in biplane systems.
They are located in the I.I. housing.

The I.I. blanking prevents that the scattered radiation from the active plane produces light at the I.I. output of the passive plane.
Otherwise the Pick-up tube or Cine Film of the passive plane would be pre-exposed.

Older systems have only one H4 connected to grid E2 voltage.

Image Intensifier

I.I. blanking



Function:
During the passive time, minus 1000 Volts are given to the grid voltages of E1 and E2.
This high negative voltage blocks the flow of electrons in the tube.
The H4 generates minus 1000 Volts only, when the incoming control pulse is on "high"-level.
With "low"-level the H4 is electronically switched off.
The control signal is derived from the radiation pulse and is for example generated in the ANGIOMATIC.
The ANGIOMATIC is a component in modern angiography systems and

regulates dose-/ dose rate and the TV-iris.

▲ *end of chapter "I.I. blanking"*

.

Image Intensifier — General Service Notes — 1/4

GX:

During longer operation time the GX-factor might decrease.
This results in a higher dose rate, because the regulation always tries
to regulate to the same brightness at the I.I. output
(to the same B-signal, if B-signal regulation).

When dose rate and TV-Iris Diaphragm have been readjusted, the
original image quality is reastablished.

This means, that a lower Gx-factor does not influence
the Contrast or Quantum Noise !

▼

.

Image Intensifier — General Service Notes — 2/4

Zoom:

Comparisons with full format:

- A smaller diameter of the image intensifier the used
- The image at the I.I. output is displayed magnified
- Detail perceptibility and resolution is increased
- Gx is lower, because the ratio between the used area of the I.I. input screen to the area of the I.I. output screen is decreased.
  This results in a higher dose rate.

  Remember: For dose regulation the brightness at the I.I. output is measured,
  and independent on the used I.I. format the regulation regulates
  to the same brightness.

  When the dose rate is higher, also the KV might go up.
  Too high KV reduce the contrast.

When the object is big or when wrong X-ray parameter are selected
(too high dose, too short exposure time e.t.c.), it can happen, that even
the maximum fluoroscopy or exposure data (KV, mA, time) are not sufficient enough
to reach the required dose at the I.I. input.

Images generated under that circumstances have a relative bad image quality,
because the contrast is bad due to the high KV
and the quantum noise is increased due to the reduced dose.

▼ ▲

.

Image Intensifier **General Service Notes** 3/4

Distortions:

On some systems the influence of the earth's magnetic field to the I.I. is so serious, that straight objects are displayed distorted in the output image.
Our Image Intensifiers have already a MU-metal shielding against magnetic fields, and there is no further remedy available.

Getter:

Prerequesite for a proper operation is a vacuum inside the I.I. tube.
If there are too many gas molekules inside, a so called "Ion Spot" is visible during radiation.

Therefore inside the Image Intensifier tubes there are divices so called Getters that are able to remove the residual gases.

Since 1984 the gettering is permanent activated ;
on older I.I.'s the gettering had to be activated with a service switch, or on the I.I. Mini Power Supply the getter cable had to be connected to the getter socket.

▼ ▲

.

Image Intensifier **General Service Notes** 4/4

Checking the I.I. :

All Image Intensifiers are optimally adjusted in the Image Intensifier test lab.
The exact voltages are recorded in the pertinent test certificate.

To check the Image Intensifier adjustment, it suffices to check the voltages according to the test certificate.

If voltages are out of tolerance or totally missing, the I.I. has no output image, or the size of the output image is wrong and/or the resolution is bad.

Also note, that the dose regulation will regulate to maximum KV and mA values, when the output of the I.I. is dark during radiation.

For the evalation of the sharpness, an Monokular is available, which can be mounted to the I.I. instead of the TV-camera.

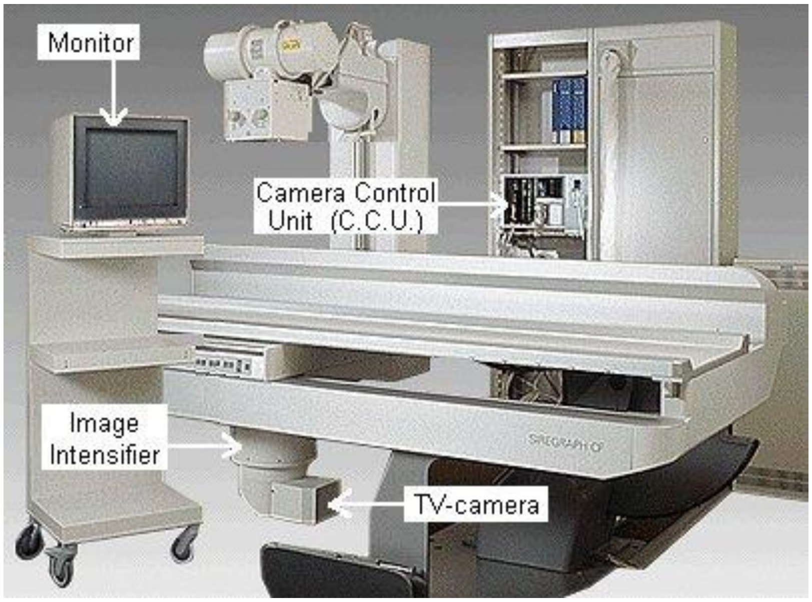
Unsharpness can be also caused by a wrong setting of the
Base-lens, the TV-lens or the Cine-lens.

end of chapter "General Service Notes"

.

.

Television Unit / Monitor — Introduction 1/10



The tasks of the **Television Unit (TV Unit)** are:

- Conversion of the I.I. output image into an electrical signal.
- Contrast optimization through gamma correction.
- Providing a standard output signal (BAS-signal) for **Monitor,** Imaging System, Video Tape Recorder and Hardcopy Camera.

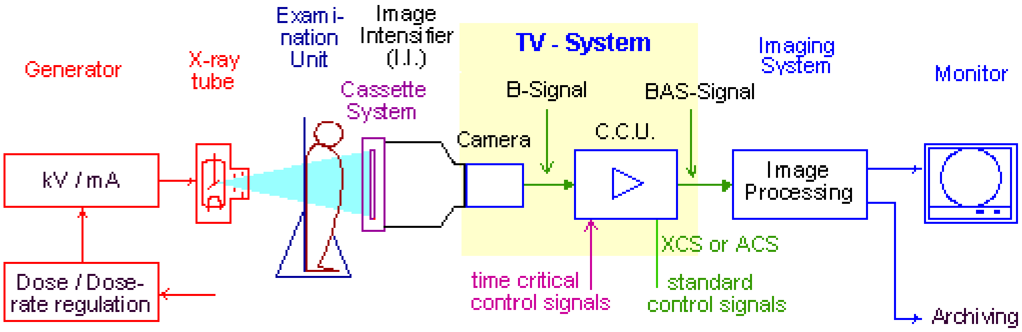
Most TV Units consist of a **TV-camera** and a **Camera Control Unit (C.C.U.).**

The designation of our TV-systems is **"VIDEOMED",**
and the monitors are named **"SIMOMED".**

Examples: TV-system "VIDEOMED S/SX", monitor "SIMOMED HM".

.

Television Unit / Monitor — Introduction 2/10



The electical signal on the camera output is the B-signal.
"B" is the abbreviation of the german word "Bild" which means "video".

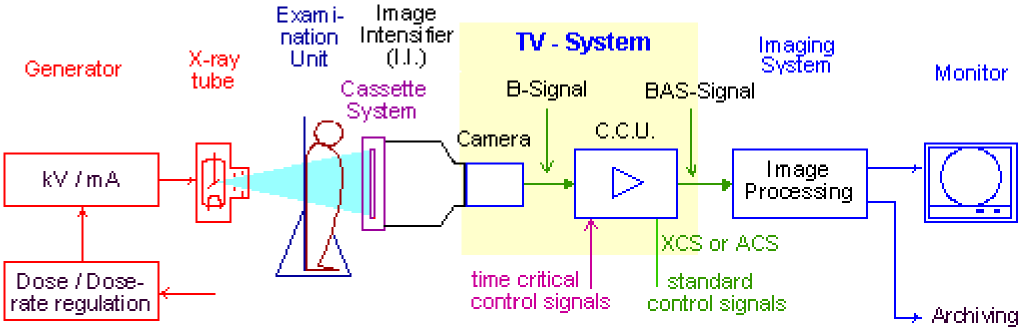
In the C.C.U. the B-signal is further processed to the BAS-signal.

The BAS-signal is used for :

- Display at an image monitor
- Further digital processing

- Archiving, e.g. archiving on Hardcopy Camera

.



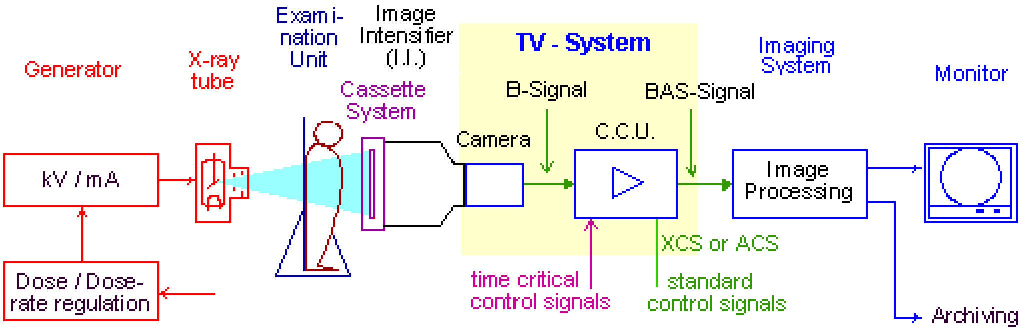
The BAS-signal is a composite signal and consists of:

- **"B" = Video Signal**
- **"A" = Blanking Signal** or short A-signal.
  "A" is the abbreviation of the german word "Austastung".
  Sometimes the Blanking Signal is also designated as
  pedestal, blanking offset or setup.
  The Blanking Signal is used to blank the retraces of the electron beam in the

monitor and to blank to area outside the medical image (postblanking circle).

- **"S" = Synchronizing Signal** or short Sync-signal or S-signal.
  This signal synchronizes the timing in the connected component, e. g. monitor, to the timing of the TV Camera.

.

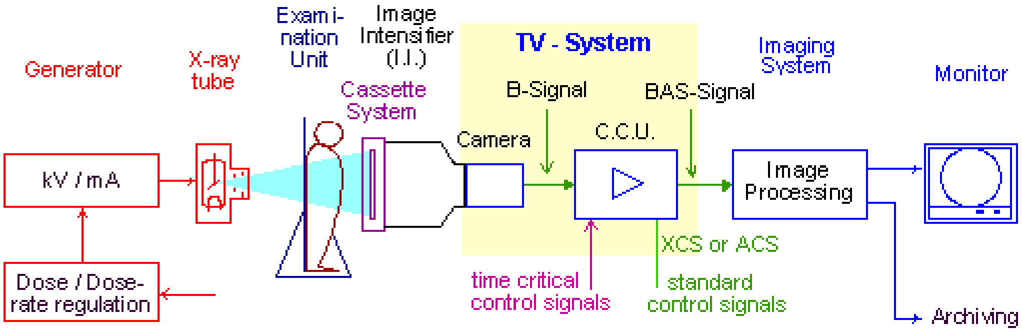


The operating modes of the TV Unit are determined by **standard control signals** via the XCS or ACS network and by **time critical signals** via direct connections.

A control signals via XCS or ACS is for example the "Fluoro on" signal.
This signals switches the TV System from standby mode (videochannel blocked) into the active mode (videochannel on) .

The "Beam Blank" signal is an example for a time critical signal.
It is needed for pulsed radiation to inhibit the read out of the target during the exposures.

.



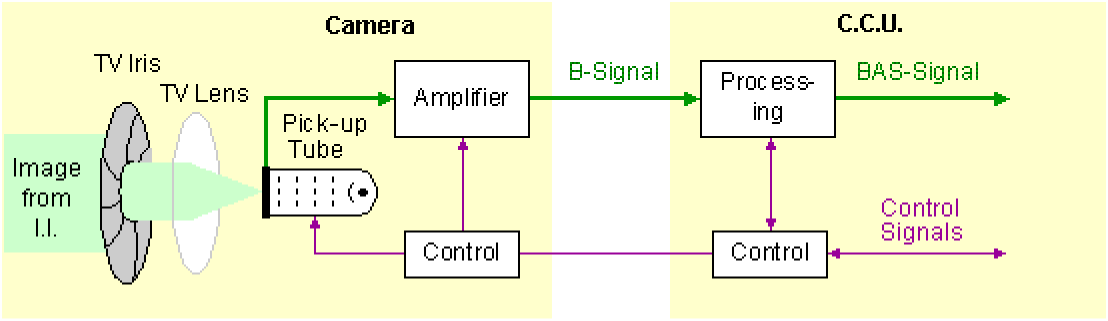
Two types of TV Systems are used:
1. TV Systems with **Pick-up Tubes**
2. TV Systems with **CCD Sensors**

Furthermore the TV Systems can be differentiated according to **resolution:**

- **Standard resolution units.**
  Here an image consists of 525 TV lines in 60 Hz systems,
  and 625 TV lines in 50 Hz systems.

- **High resolution units.**
  The range from 1023 to 2250 lines is possible.
  The line number depends on the system and the mains frequency.

.



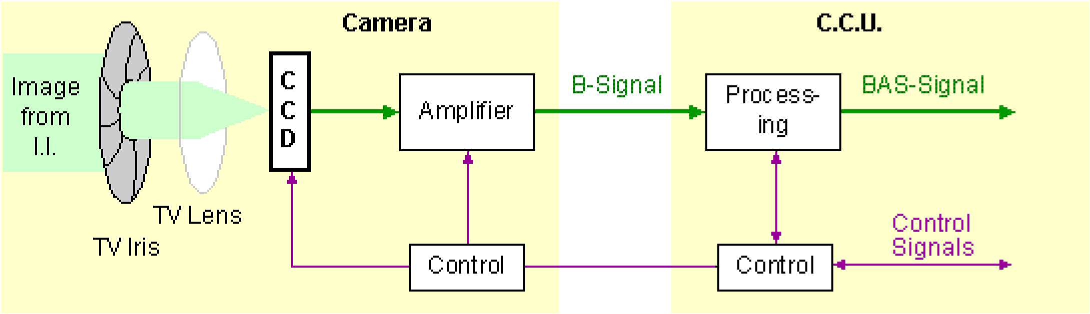
Simplified block diagram of a TV Unit with Pick-up Tube:

With the aid of a TV Lens the image from the I.I.output is sharply focused onto the light sensitive layer (Target) of the Pick-up Tube.
A motorized TV Iris or a TV Iris with a fixed aperture adapts the light intensity to the sensitivity of the tube.

The electrical signal is produced, when the target is read out by an electron beam.

Via the video amplifiers the signal is further processed to the BAS-signal.

.

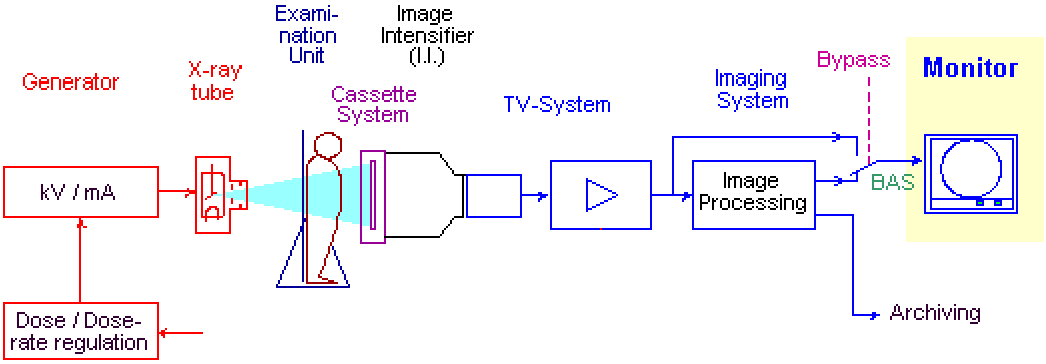


Simplified block diagram of a TV Unit with CCD-Sensor :

A CCD Sensor is a light sensitive semiconductor consisting of a capacitor matrix to convert the light into photo charge.
The electrical signal is produced by reading out the capacitor matrix sequentially with shift registers.
The output signal is analogue !

CCD-Sensors replace the Pick-up Tubes more and more.

.



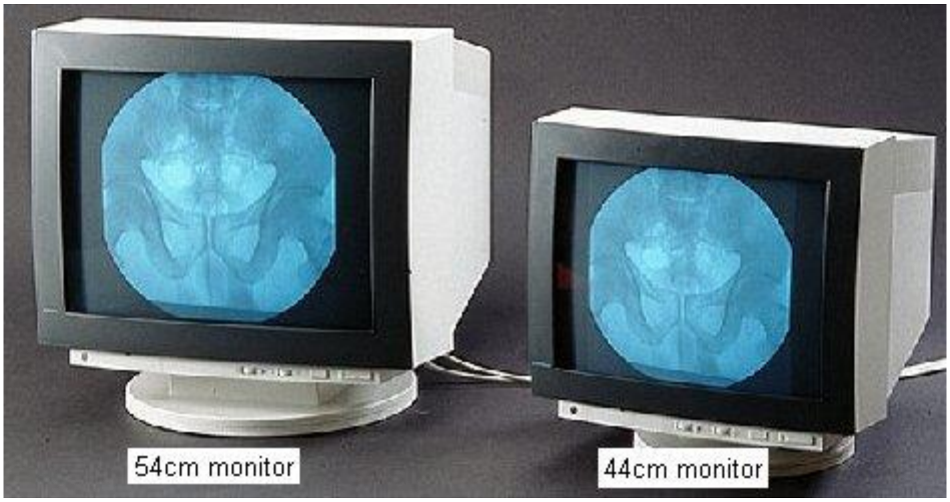
Monitor :

In systems with Image Processing the Image Monitor receives in normal cases the BAS-signal from the Imaging System.

If a malfunction occurs, the system switches to Bypass Mode and bypasses the Imaging System.
Then the monitor gets the BAS-signal from the TV-system.
In Bypass Mode or emergency mode only continous fluoroscopy is possible.

In systems without Image Processing the Monitor is connected directly to the TV-system.

Television Unit / Monitor **Introduction** 9/10



Example:
44 cm
and 54 cm
"SIMOMED H"
monitors.
"SIMOMED H"
is a high
resolution
monitor.

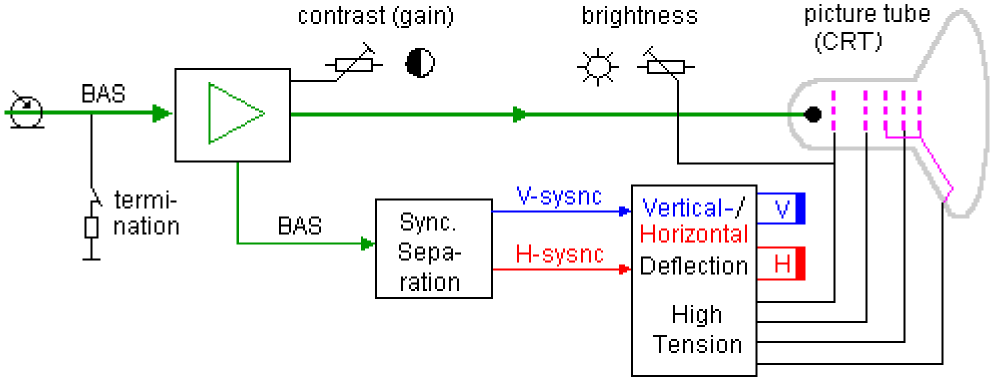
The **diameter of the picture tube** is 44 cm or 54 cm.
On older systems you may also find 38 cm monitors.

There are **two monitor versions:**

1. **Standard version** with 625 lines / 50 Hz and 525 lines / 60 Hz

2. **High resolution version** from 1023 up to 2497 lines and images frequencies from 50Hz up to 120 Hz.

Television Unit / Monitor **Introduction** 10/10



The simplified block diagram of the monitor shows the following circuits:

- **Video amplifier** with termination switch and termination resistor at the input.
- **Sync. Separation** for synchronizing the H- and V- deflection stages
- **H- and V- deflection stages**
- **High tension circuit**
- **Picture tube** (CRT = Cathode Ray Tube)

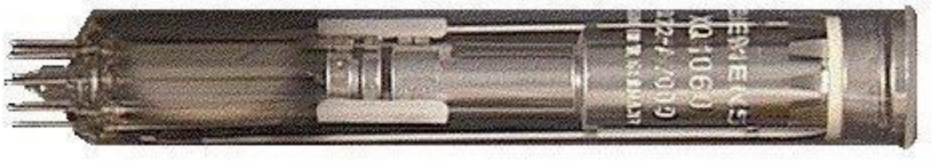
- Two adjustment possibilities for **Contrast** and **Brightness.**
  1. Setting the **limits** of Contrast and Brightness by the service engineer.
  2. Setting a certain **operating point** with potentiometers on the front panel.
  ....This setting is disabled, when the monitor is connected to an Imaging System,
  ....because in this case Contrast and Brightness are altered by *windowing*.

end of chapter "Introduction"

.

Introduction

tube with magnetic deflection



tube with static deflection

click here, to see a front view

back

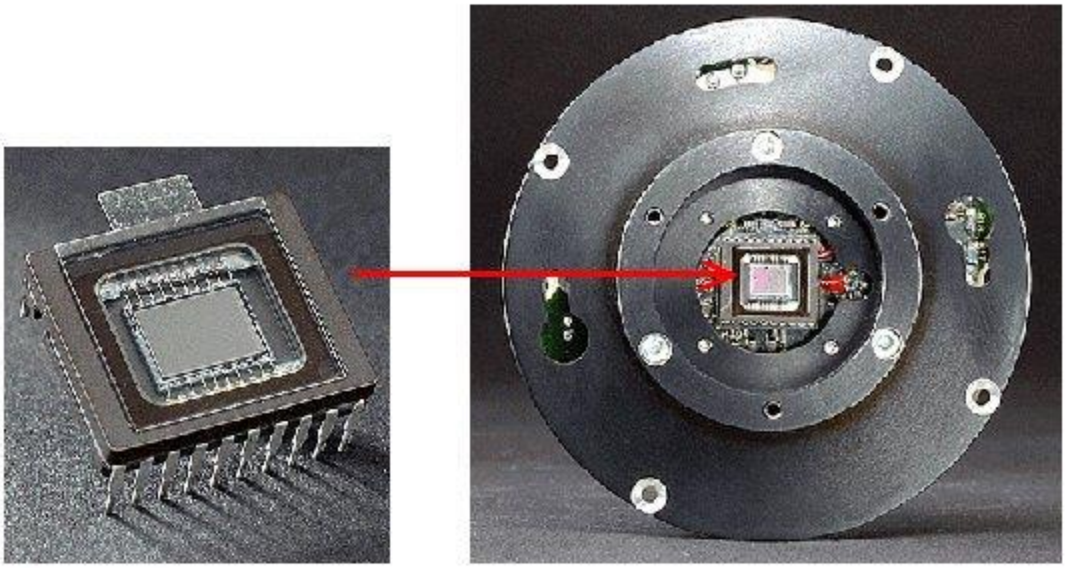
.

Introduction

back

.

Introduction

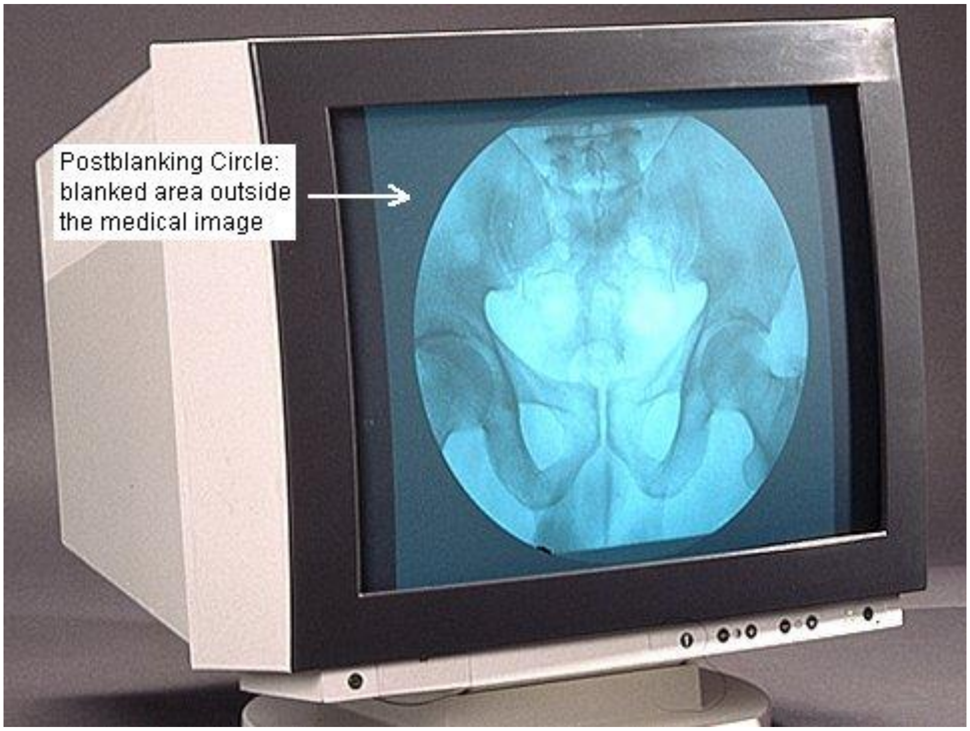

CCD Sensor

Camera Head with CCD Sensor

back

.

Introduction



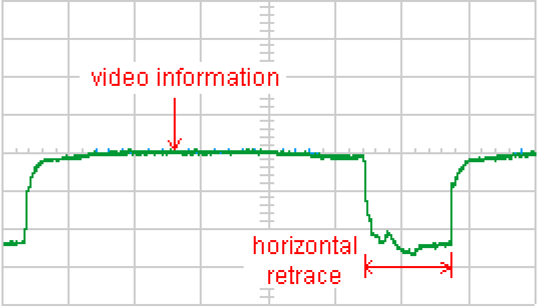
back

.

Introduction

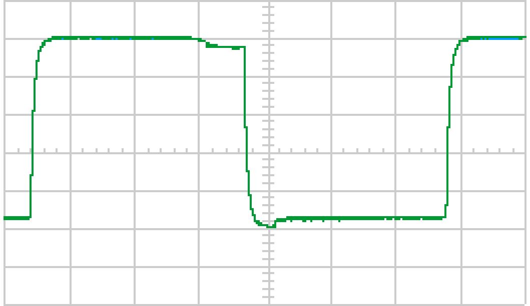
B-Signal

Fluoroscopy (no object)



50 mV/div, 10 µs/div

Test signal



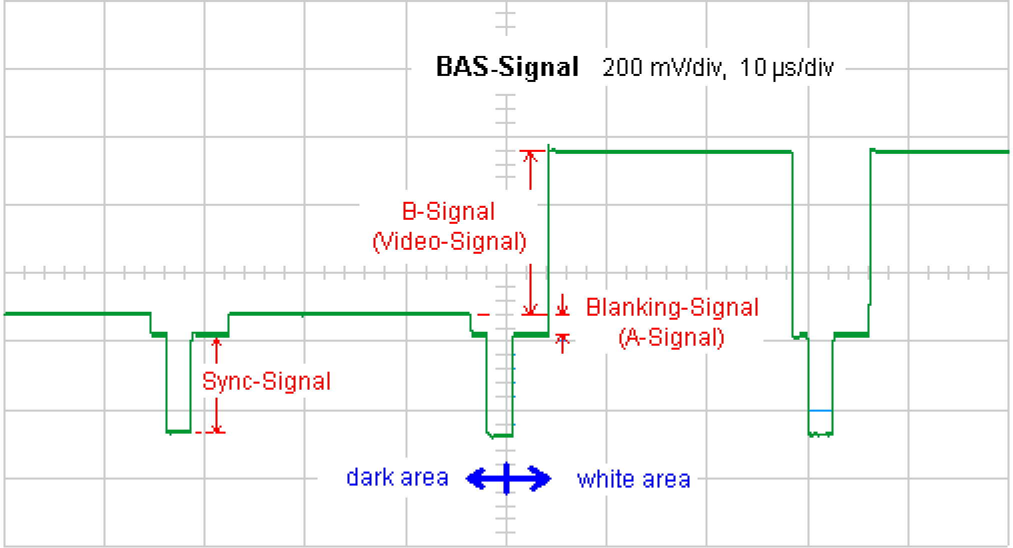
50 mV/div, 10 µs/div

click here, to see the test signal displayed on a monitor

back

.

Introduction

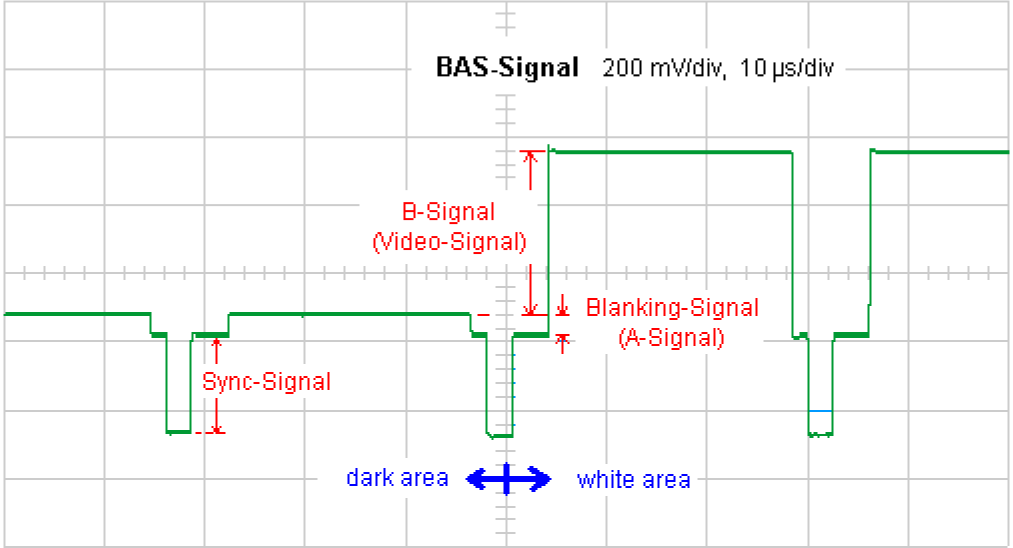


click here, to see the test signal displayed on a monitor

back

.

Introduction



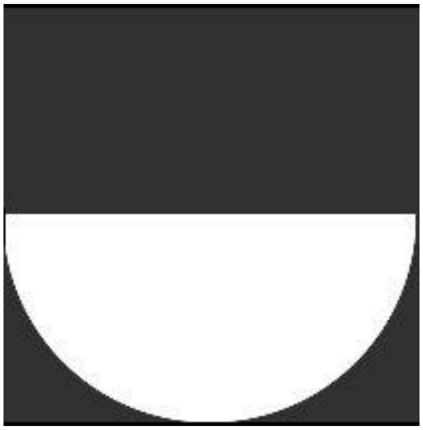
click here, to see the test signal displayed on a monitor

back

.

.

Introduction

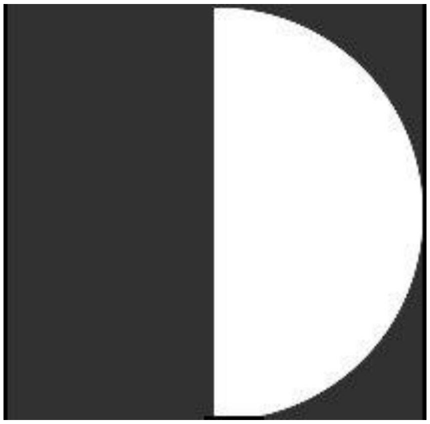


vertical
black and white
test signal

back

.

Introduction

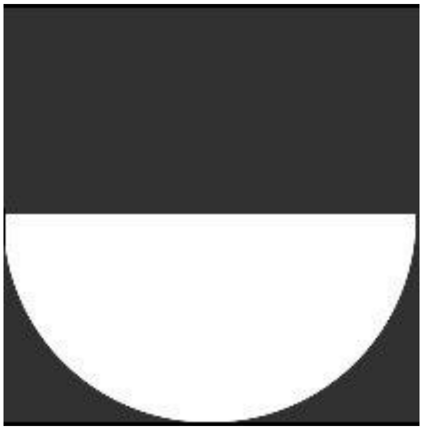


horizontal
black and white
test signal

back

.

Introduction

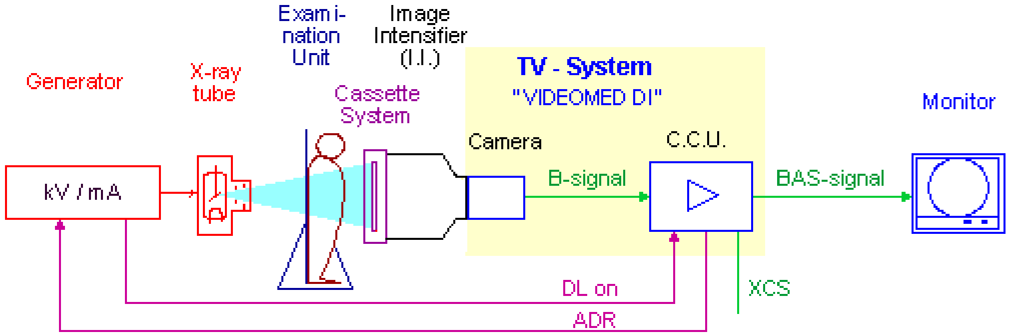


vertical
black and white
test signal

back

.

.



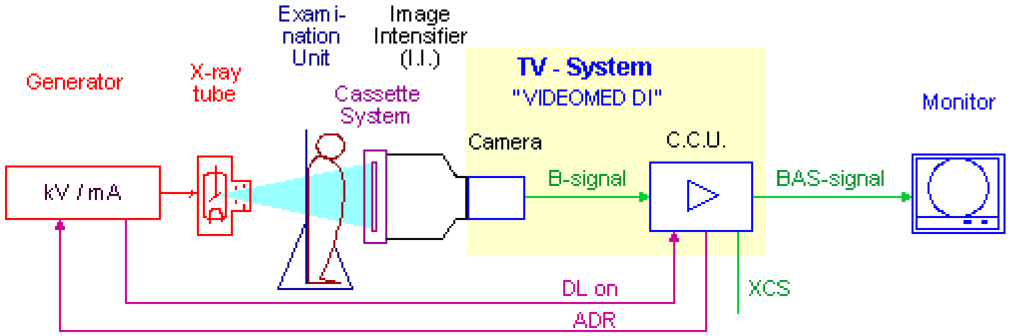
The following description is based on a system with **XCS network**
and the TV Unit **"VIDEOMED DI".**

VIDEOMED DI is a standard resolution TV System with CCD technology.
The standards are: 625 lines / 50 Hz and 525 lines / 60 Hz.

VIDEOMED DI is equipped with a memory and an image processing for
- Last Image Hold (LIH)
- Noise Reduction for fluoroscopy and
- Image Reversal

VIDEOMED DI also generates the actual value for the dose regulation.

.

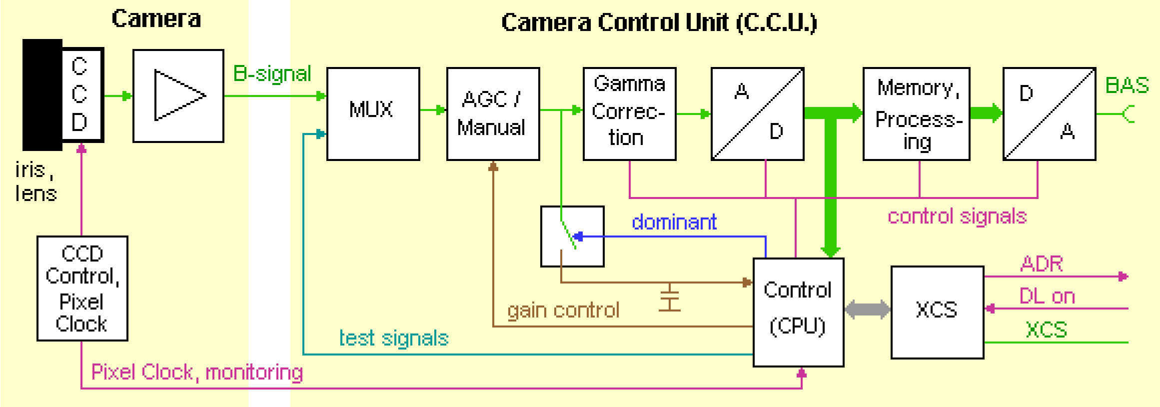


Input and Output signals:

- **"BAS-signal"** for the monitor.
- **Standard control signals** via XCS network to control the mode of the video channel e.g. gamma factor, noise reduction factor, dominant selection etc.
- Time critical signal **"DL on"** to control the image processing.

- Actual value **"ADR"** for the dose regulation.
  This DC voltage is derived from the B-signal.

.



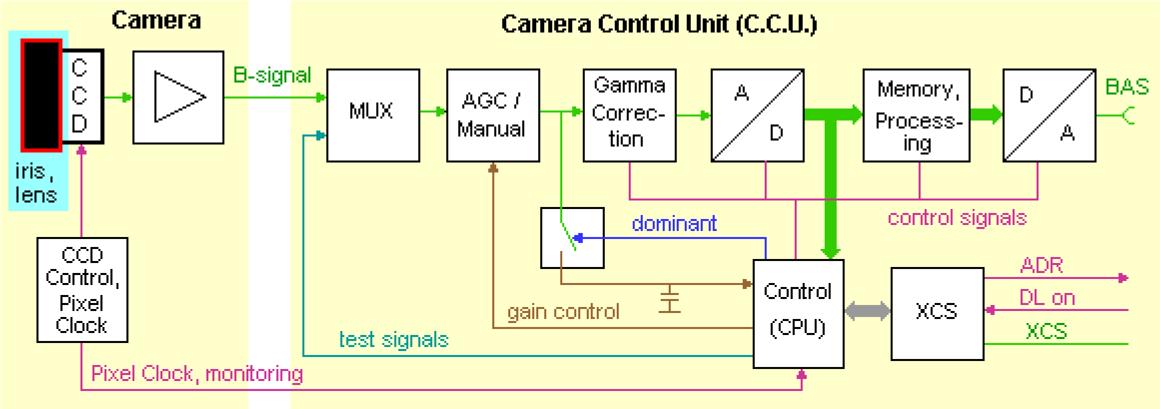
Overview block diagram VIDEOMED DI:

VIDEOMED DI consists of Camera and Camera Control Unit (C.C.U.).

A micro processor (CPU) is used, to control the different circuits
of VIDEOMED DI.

Since this micro processer is too slow for the TV timing,
all television synchronous clock, blanking and synchronizisation signals
are derived from the Pixel Clock.
The Pixel Clock is generated in the Camera.

.



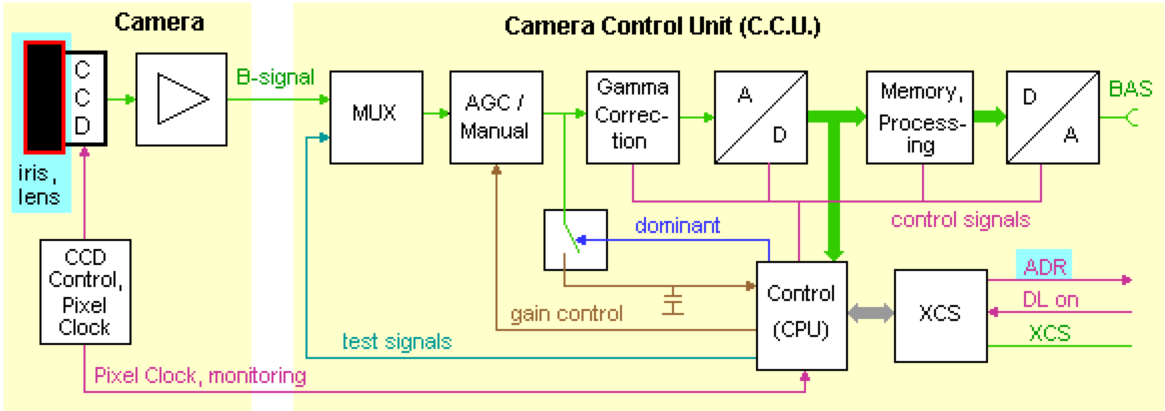
Iris Diaphragm:
The Iris Diaphragm or short "TV Iris" is used to adapt the amount of light to the sensitivity of the CCD Sensor.
A wrong adaptation results in a loss of image quality, for example poor contrast or saturation of the signal.

The basic adjustment of the TV Iris is:
Change the aperture of the TV Iris, until a defined amplitude of the B-signal is achieved, e.g. 155 mV.

.

Television Unit / Monitor

TV with CCD Sensor



In systems with VIDEOMED DI the B-signal is also used for the dose rate regulation.
This means, that a certain amplitude of the B-signal is equivalent to a certain dose rate,
e. g. 155 mV B-signal corresponds to a dose rate of 261 nG/s .

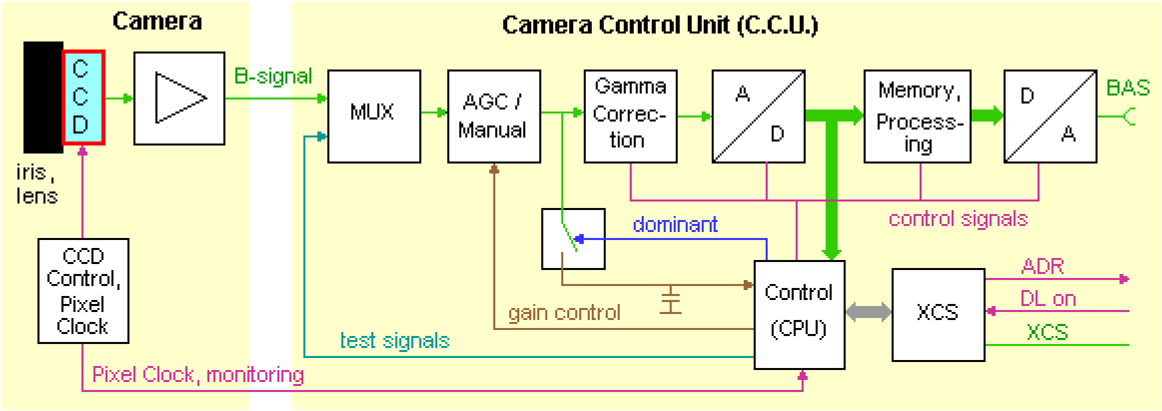
Therefore you will find the setting of the Iris for VIDEMED DI not under the "B-signal adjustment" but under the "dose rate" adjustment.

The "actual value" for the dose rate regulation is the signal "ADR".

.

Television Unit / Monitor

TV with CCD Sensor



CCD Sensor :
During radiation charges are stored in the individuals cells of the CCD sensor.
The extent of the charge depends on the incident light.
After read-out a voltage value is generated for each pixel.
The

Under construction !

more info ?

.

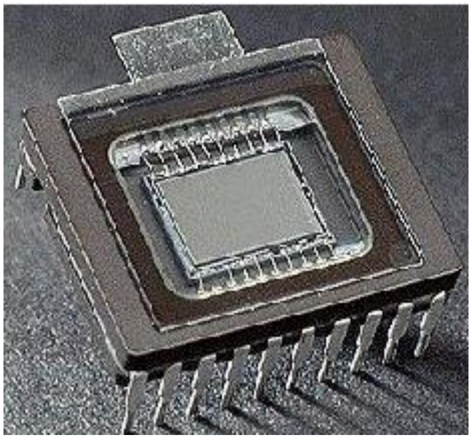
Controlled by a central process control, the data is forwarded electrically. Using a quartz controlled high frequency, this device supplies the necessary signals to control the CCD (cf. diagram).

The CCD sensor does not deliver the optically generated information as a full image, but in pixels as a serial electrical signal. This signal is processed and eventually displayed in a norm format.

Under construction !

.

.



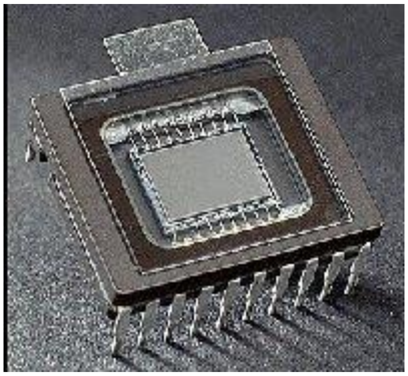
CCD Sensor

Camera head with CCD Sensor

back

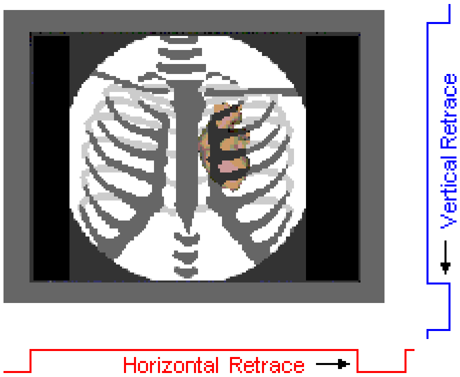
.

Television Unit / Monitor **Principle CCD Sensor** 1/4



The conversion from light into an electrical signal run

Under construction !

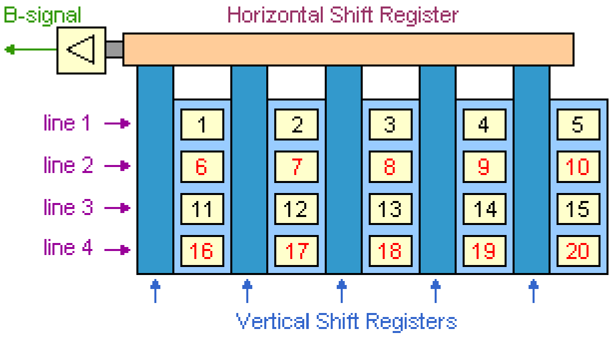


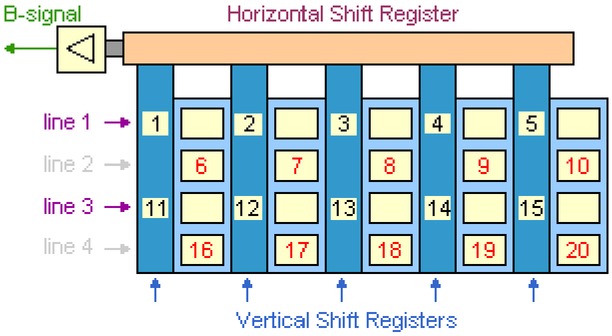
For a better understanding lets assume that the matrix of the CCD sensor is 5 x 4.

exit more info

.

Television Unit / Monitor **Principle CCD Sensor**

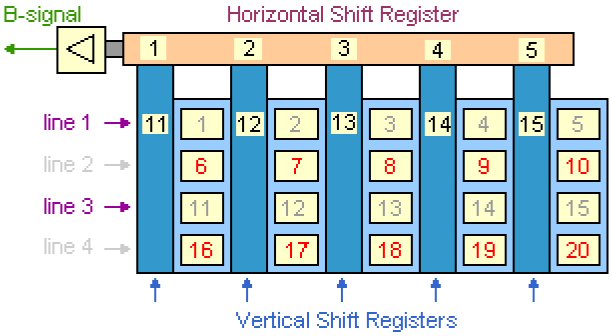


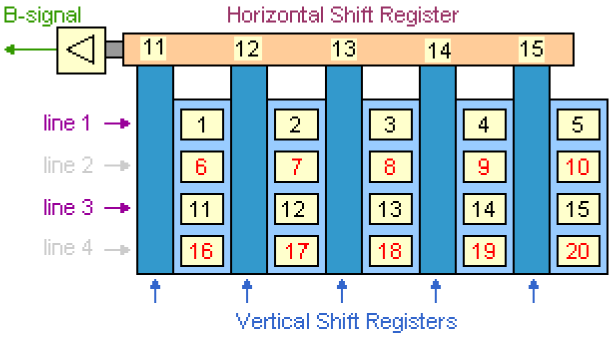


exit more info

.

Television Unit / Monitor **Principle CCD Sensor**

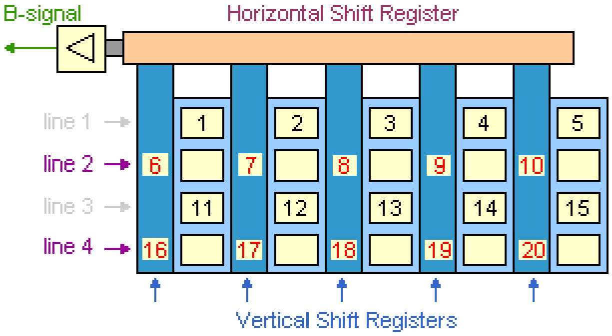




exit more info

.

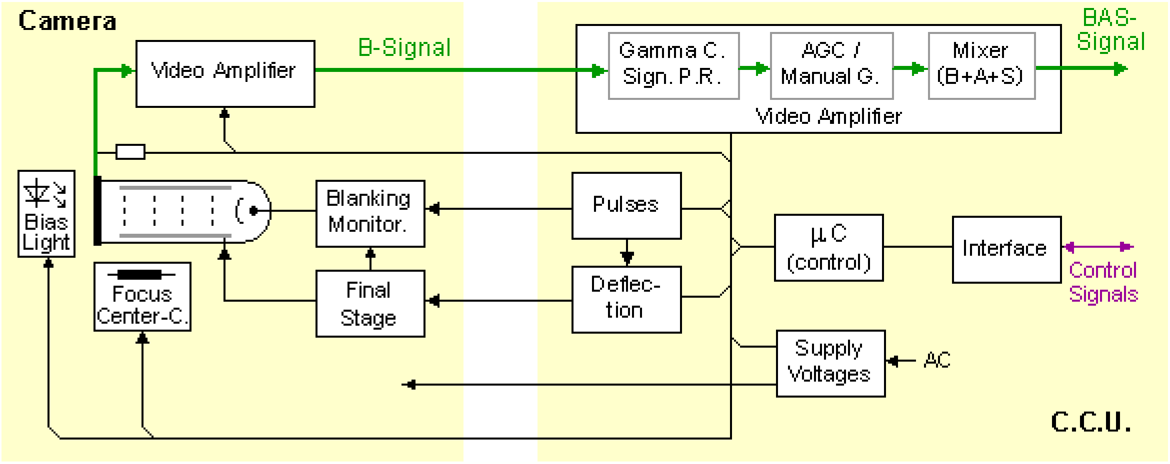
Television Unit / Monitor **Principle CCD Sensor** 4/4



end of more info (exit)

.

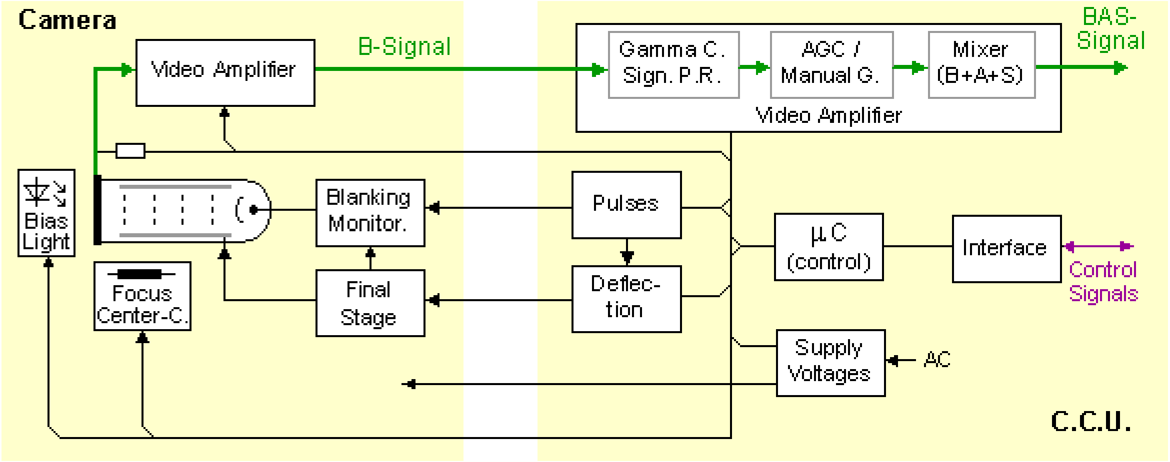
Television Unit **Block diagram** 1/16



This is a block diagram of the TV Unit **"VIDEOMED S/SX"**
with micro processor control and a Pick-up Tube with
static deflection.

On the following pages you will find a short explanation
of the different circuits.

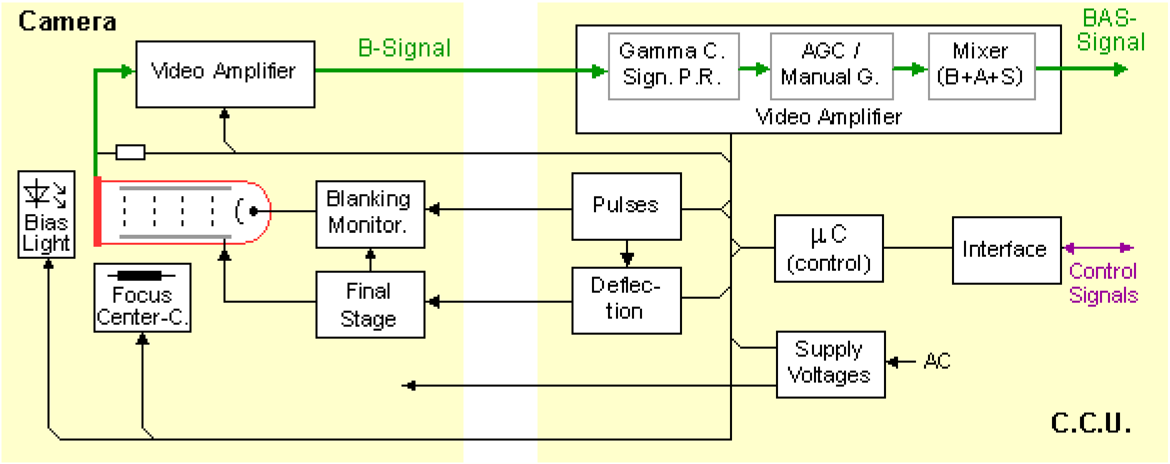
Due to the different design, the TV Units with CCD-Sensors are described
in a seperate chapter !



General:
The video signal is generated by scanning the light sensitive layer (Target)
of the Pick-up Tube with an electron beam.
In order to scan the whole surface of the Target, deflection stages move
the fine electron beam linewise from top to bottom.

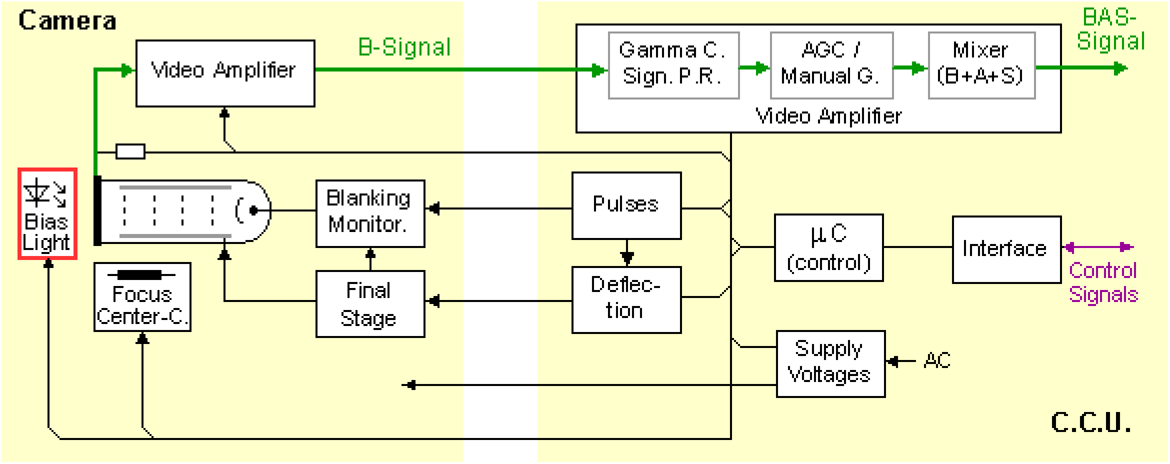
In the video amplifiers of Camera and C.C.U. the video signal is amplified, processed
for a certain image characteristic and A-Signal and Sync-Signal are added.

The timing is controlled by the pulse generator (block "Pulses" on C.C.U.).



- **Pick-up Tube:**
  It converts the image from the Image Intensifier into a video signal.
  For the TV Unit "VIDEOMED S/SX" a Pick-up Tube with
  static deflection is used.
  The inner metal coatings are the capacitor plates for the deflection.

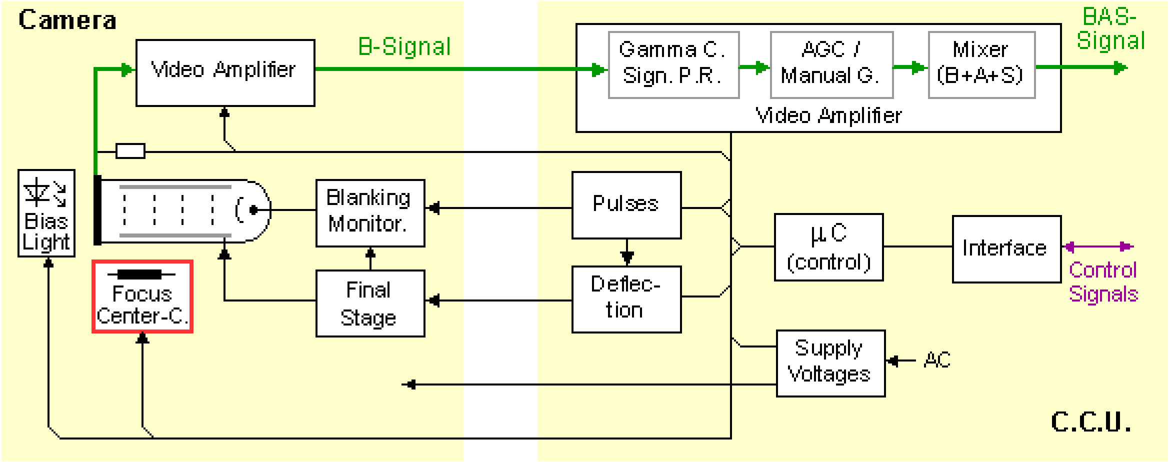
  All other TV Units with Pick-up Tubes have magnetic deflection.
  Here a coil system (yoke) is mounted outside the glass envelope.



- **Bias Light:**
  This is a continous or pulsed light for the Pick-up Tube generated by LEDs.
  The LEDs are mounted close to the TV Lens.
  The Bias Light shifts the operating point of the Pick-up Tube into the
  linear operating range.
  Otherwise the darker parts of the image would be displayed with poor contrast.
  The other task of the bias light is to decrease the inertia of the Pick-up Tube.

.

Television Unit **Block diagram** 5/16

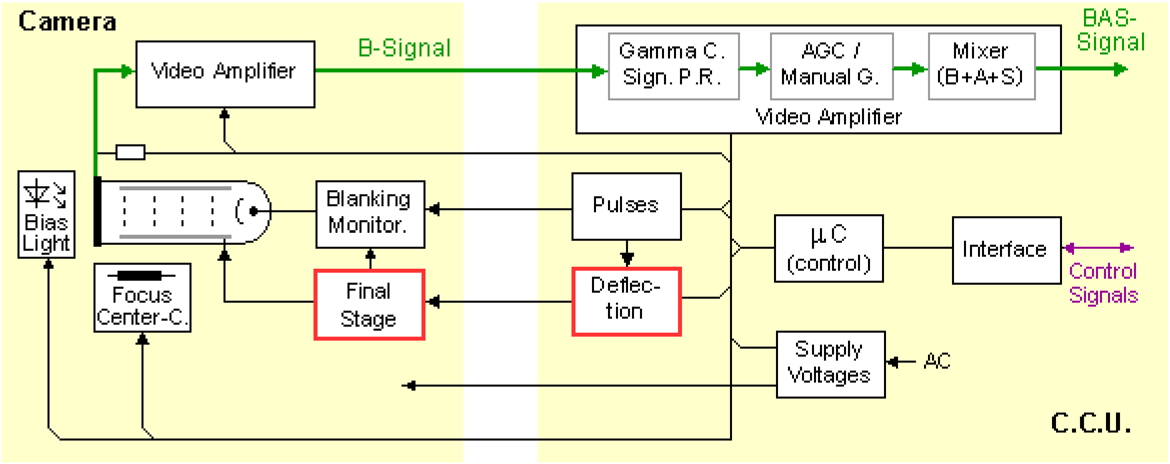


- **Focus:**
  For foccusing a DC- current is applied to the focussing coil.
  By changing the current, the sharpness or resolution can be adjusted.
  In contrast to the optical focus which is set with the TV lens, here the electrical focus is changed.

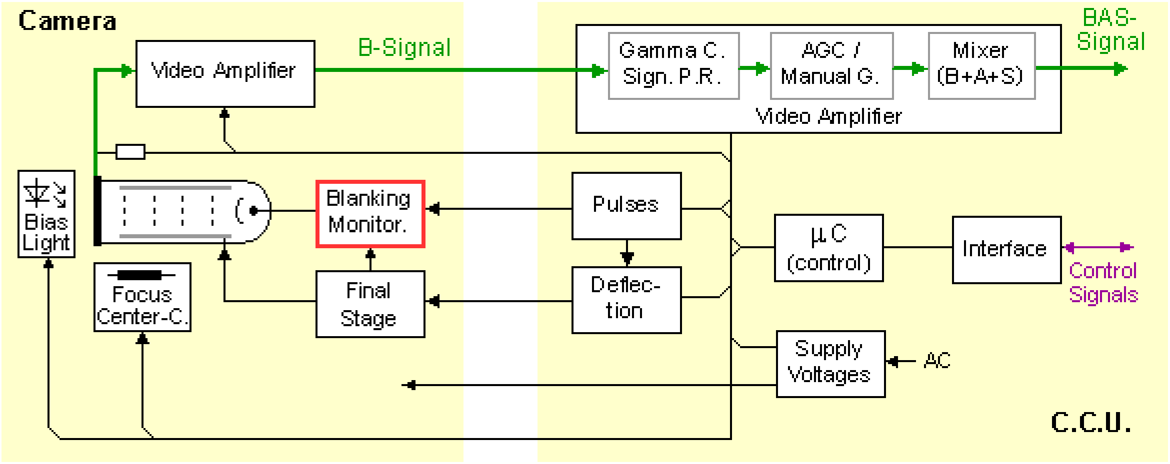
- **Centering Coils:**
  With the aid of the horizontal and vertical centering coils the inertia of the Pick-up Tube can be minimized.
  This guarantees also a sharp display for moving objects, e.g. cardiac studies.

.

Television Unit **Block diagram** 6/16

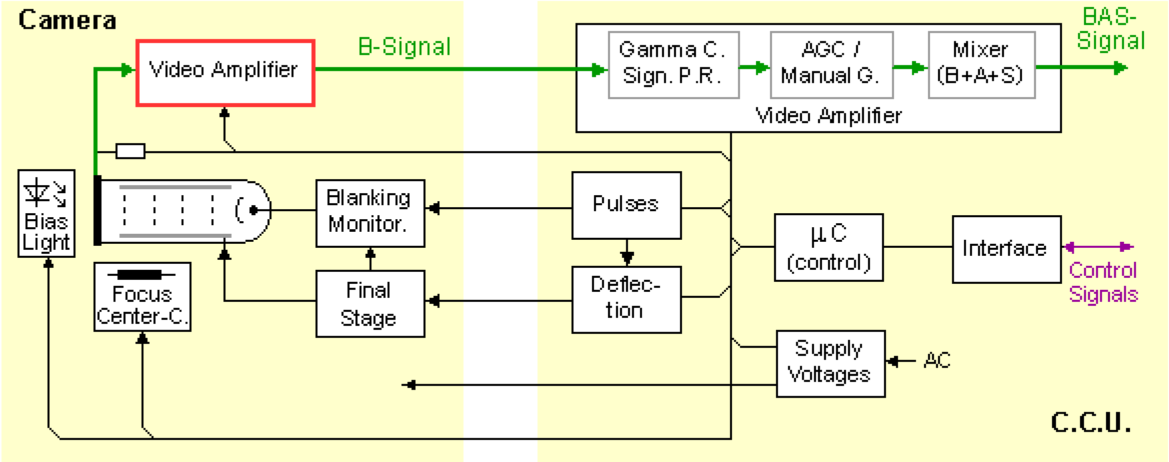


- **Final Stage (Camera) and Deflection (C.C.U.):**
  For the linewise deflection a Horizontal Deflection Stage and
  for moving the electron beam from top to bottom a Vertical Deflection Stage is required.
  The Deflection stage in the C.C.U. generates horizontal and vertical sawtooth signals and the final stage amplifies these to high levels.



- **Blanking / Monitoring:**
  The Monitoring Circuit prevents a burn-in into the Target of the Pick-up Tube, when a malfunction of a deflection stage occurs.
  In such cases the Monitoring Circuit blocks the beam current.

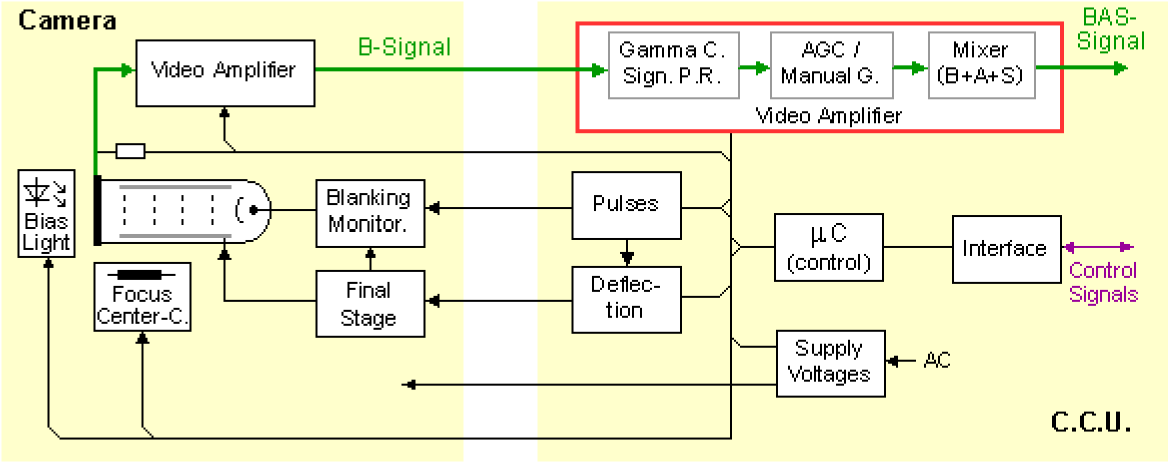
  Via the Blanking stage the vertical and horizontal retraces of the electron beam are blanked.



- **Video Amplifier Camera:**
  The video signal at the Target has a low amplitude and is very high ohmic.
  This requires an amplifier with a high input impedance and a certain gain.
  The output signal is the "B-Signal" which is fed via the camera cable
  to the C.C.U..
  Via the resistor the operating voltage for the Target is fed in.
  The operating voltage is designated as Plate Voltage.

  For service the Video Amplifier can be checked with a testsignal.

.



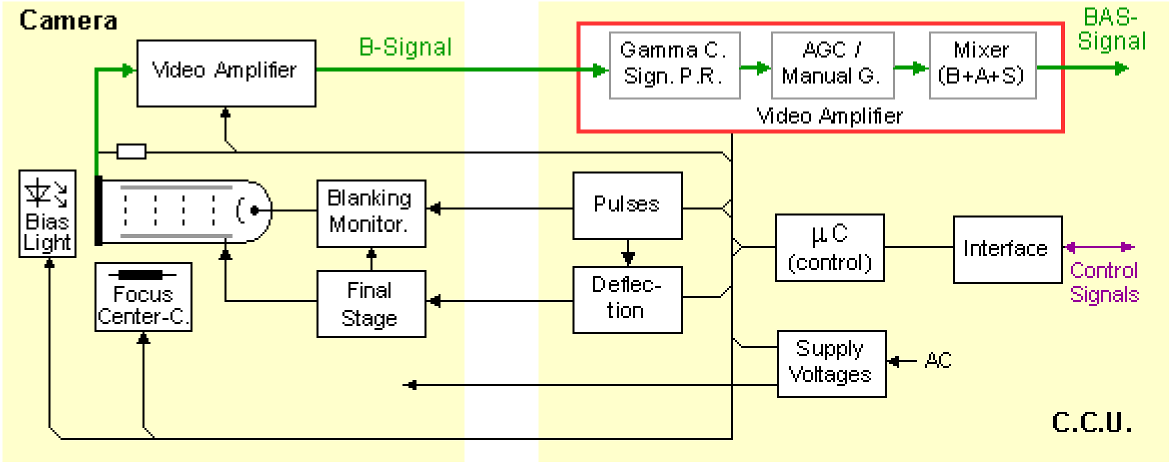
- **Video Amplifier C.C.U. :**
  The **Gamma Correction** stage is an amplifier with a nonlinear characteristic.
  The darker parts of the image (lower signal amplitudes) are displayed with a

high contrast, whereas the brighter parts are shown with a lower contrast.

For different examination methods different gamma curves are used.
This results in an image characteristic which is well suited to the specific medical application.

.

Television Unit **Block diagram** 10/16

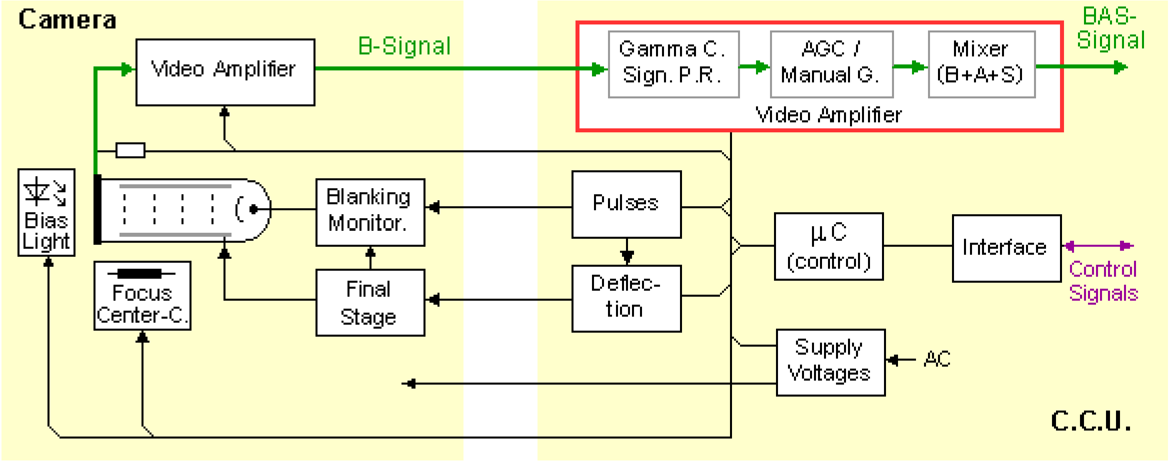


Signal Peak Reduction:
In this stage only the higher signal amplitudes upon a certain threshold are reduced.
This prevents blurring of the image when signals are too high.

AGC:
The **A**utomatic **G**ain **C**ontrol (AGC) is a regulation circuit that measures the video signal.
It keeps the average video level in the BAS-Signal nearly constant,
independent on the B-Sinal amplitude.

.

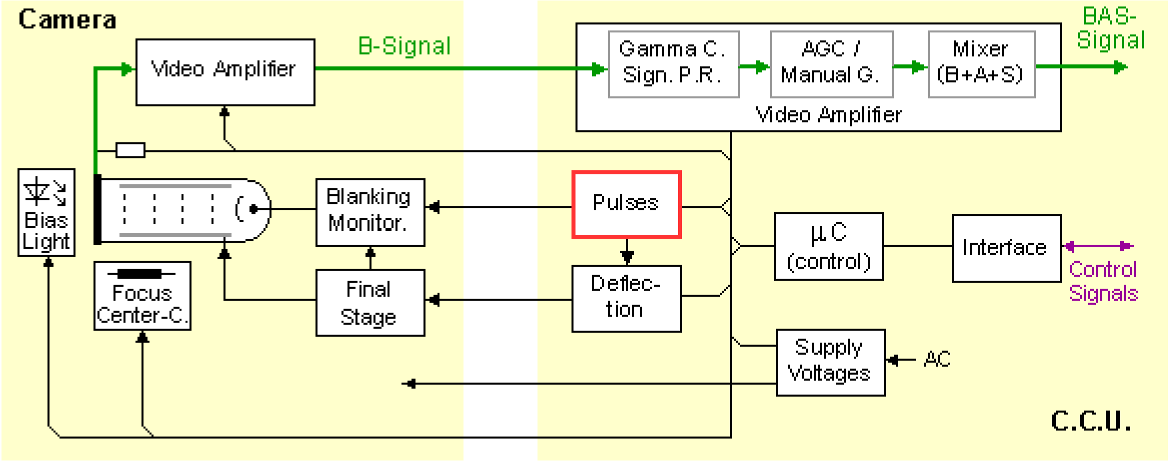
Television Unit **Block diagram** 11/16



Manual Gain:
For some examination methods, e.g. Digital Subtraction Angiography (DSA), a fixed gain factor (manual gain) has to be used instaed of AGC.

Mixer :
Here the blanking signal (A-signal) and the synchronizing pulses (S-signal) are added to the video signal (B-signal).
The result is a composite signal named "BAS-signal".

.



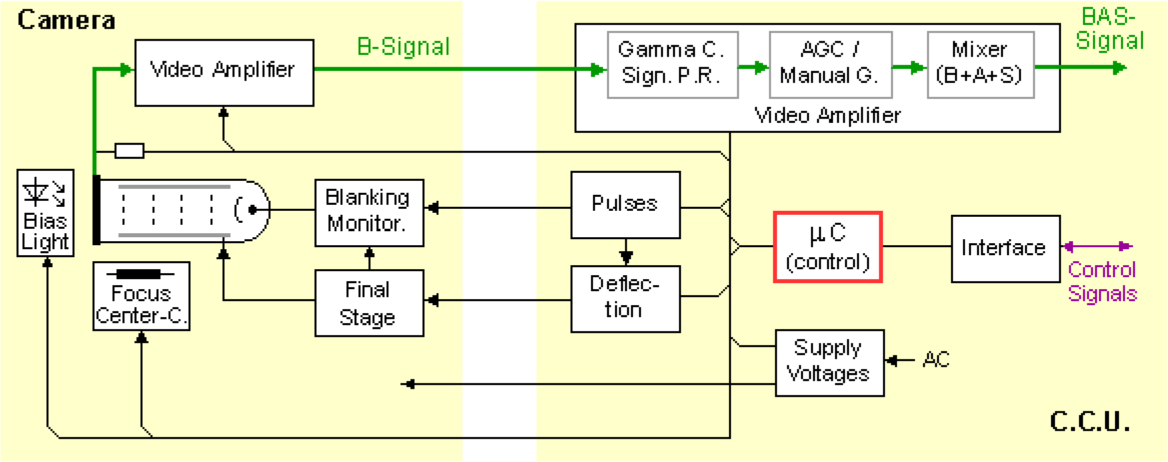
- **Pulses:**
  Various types of vertical or horizontal pulses are generated here.

  Examples:
  H-pulse: controls horizontal deflection,
  V-pulse: controls vertical deflection,
  A-signal: horizontal and vertical blanking pulses

S-signal: horizontal and vertical sync pulses

.

Television Unit **Block diagram** 13/16

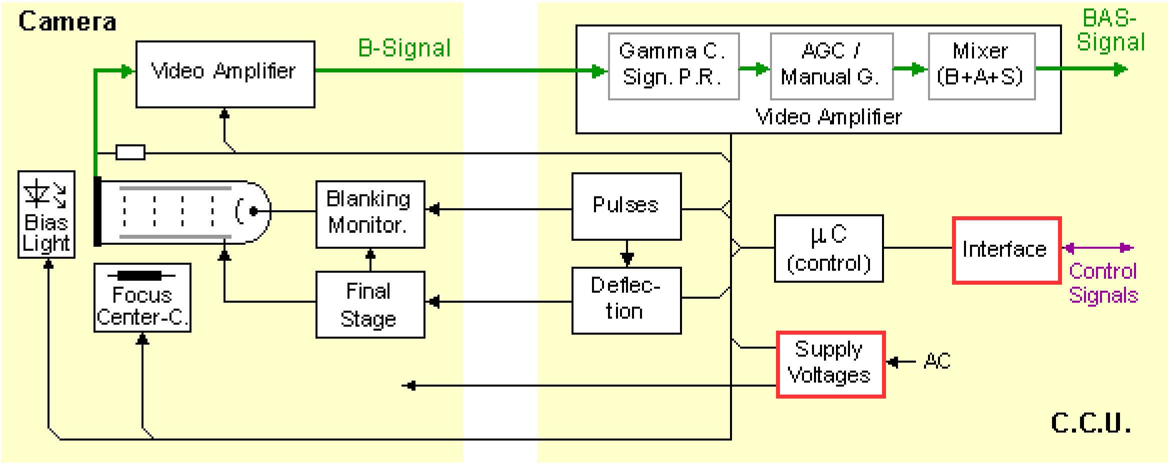


- **mC :**
  VIDEOMED S/SX is controlled by Micro Controllers (mC).
  Micro Controllers are chips with built in Micro Processor, RAM and I/O-ports.
  Earlier TV Units with Pick-up Tubes are not software controlled.

  The main advantages of software control are:
  - easier and flexible configuration
  - self adjustment of the TV Unit
  - monitoring of circuits and storing errors in case of malfunctions
  - test routines to test the different circuits.

.

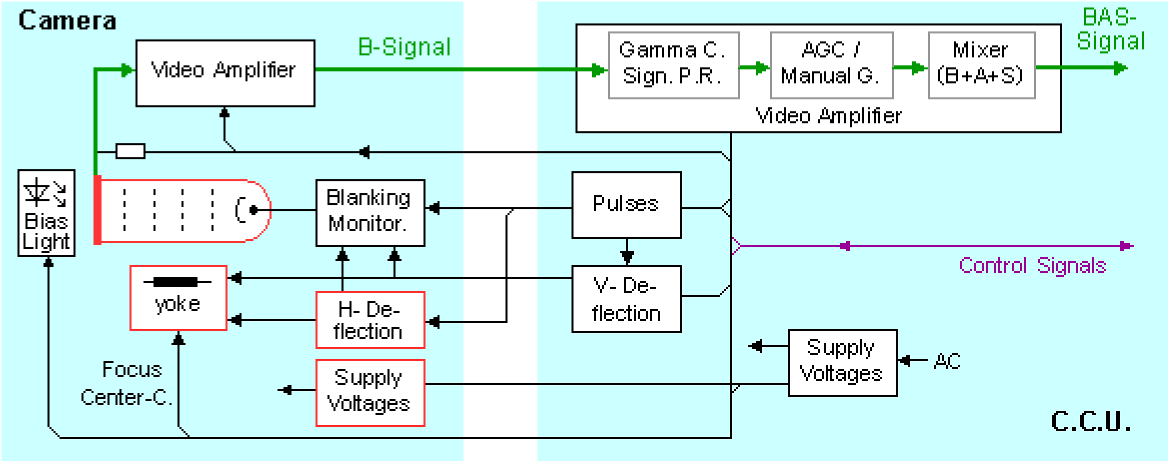
Television Unit **Block diagram** 14/16



- **Supply Voltages :**
  In this stage a lot of supply voltages are generated.
  They are in the range between 5V and 1000V.

- **Interface:**
  Control Signals from or to other components are transferred here,
  e.g. "Fluoro on" signal or "Exposure on" signal.
  Depending on the system wiring the signals are transferred softwarewise (ACS- or XCS- Network) or as hardware signals (KK-wiring).

.

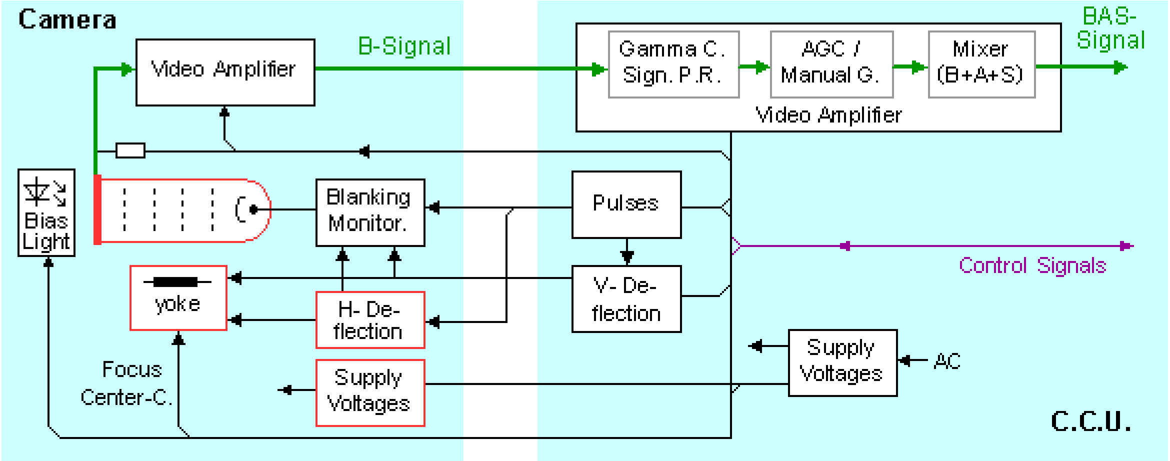


Now you see a block diagram of a TV Unit with Pick-up Tube that was sold before "VIDEOMED S/SX", e.g. **"VIDEOMED H1"**.

The main differences to VIDEOMED S/SX are:

- Pick-up Tube with magnetical deflection.
  This requires horizontal and vertical deflection coils.
  The coil system is designated as "yoke".

.



- Horizontal Deflection stage is located in the camera
- The higher voltages for the Pick-up Tube are generated in the camera
- No Micro Contoller --> no software control
- No extra interface for external control signal

end of chapter "Block diagram"

.

tube with magnetic deflection

tube with static deflection

click here, to see the tube with static deflection in another view

back

.

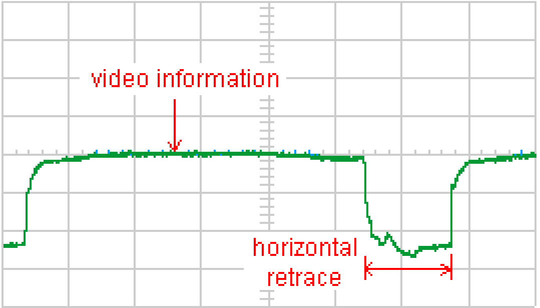
Block diagram

back

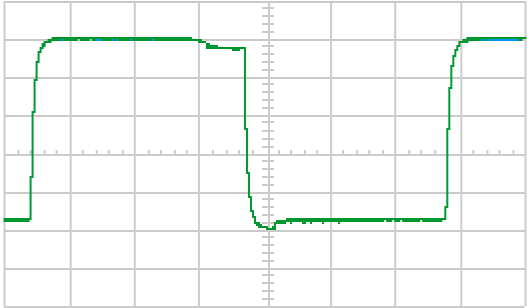
.

Block diagram

B-Signal



Fluoroscopy (no object)



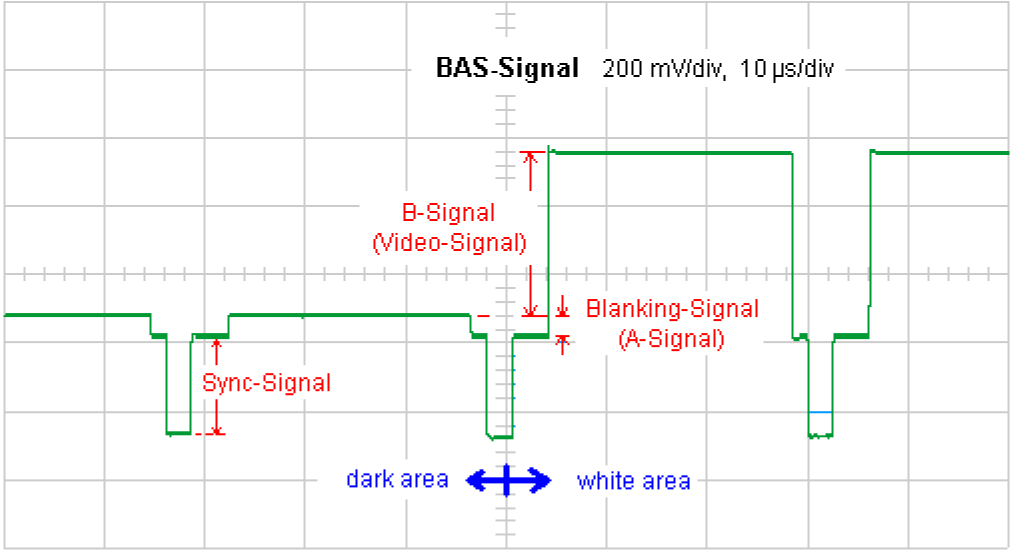
Test signal

click [here](), to see the test signal displayed on a monitor

[back]()

.

Block diagram

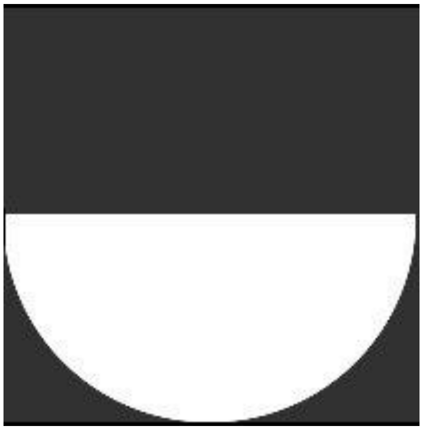


click [here](), to see the test signal displayed on a monitor

[back]()

.

Block diagram

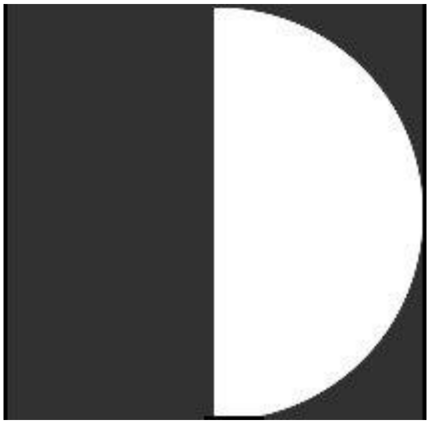


vertical
black and white
test signal

back

.

Block diagram

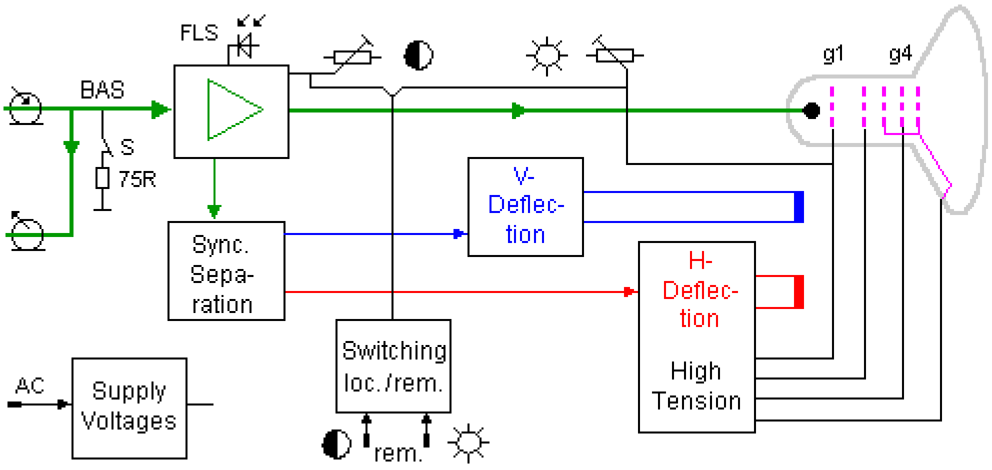


horizontal
black and white
test signal

back

.

.



under construction !

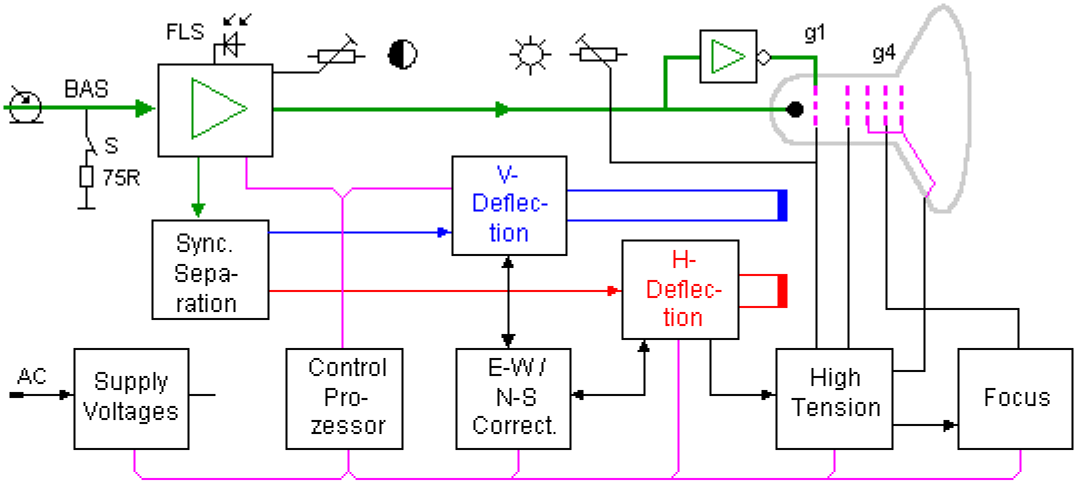
.

.

Television Unit / Monitor

High Resolution Version

1/



under construction !

.

Digital Image Processing

Introduction

1/5

Example:

Image monitors and
operating console of
Imaging System
FLUOROSPOT TOP

In most of the modern units an Imaging System for
Digital Image Processing is integrated.

With Imaging Systems various processing functions can be used
to improve the image quality.

New examination modes are possible,
e.g. Digital Subtraction Angiography (DSA).

The digital transfer of images allows the archival with Laser Cameras
and CD-ROMs and the processing on other imaging systems.

Digital Imaging improves the ordinary fluoroscopy image significantly
and it also contributes to dose saving.
In exposure mode, digital imaging replaces the ordinary screen-film
radiographs and the Cine and SIRCAM technology more and more.

Digital Image Processing Introduction

Fluoroscopy and Exposure in connection with a
Digital Imaging System are designated as:

- Digital Fluoroscopy
- Digital Radiography (DR)
  Digital Angiography (DA)

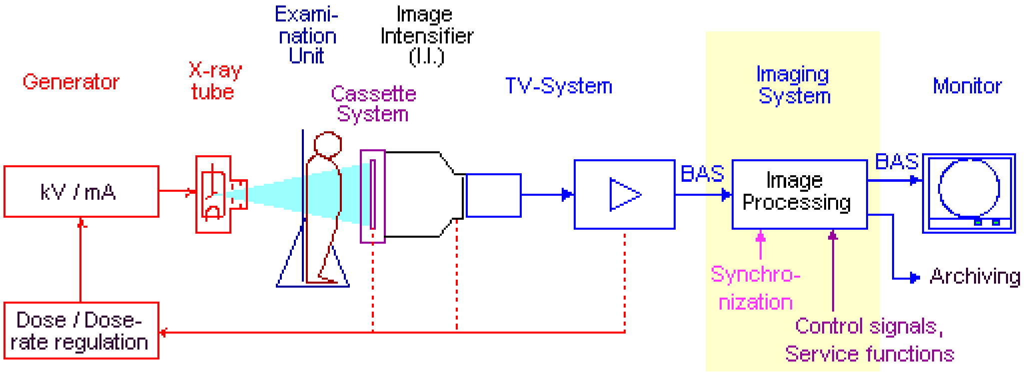
Digital Imaging Systems enable :

- Pulsed radiation (pulsed radiation is also possible in connection with Cine- or Sircam Cameras)
- New examination modes, e.g. Digital Subtraction Angiography (DSA)
- Image manipulations like edge enhancement, zooming, windowing (digital brightness and contrast control) etc.
  During the real time examination (Acquisition) the images are influenced depending on the paremeter settings of the current organ program.
  After the Acquisition the images can be further processed (Postprocessing).
- Archiving on Digital Hardcopy Cameras (Laser Cameras) or on CD-Rs.

- Transfer via a hospital`s network for archiving or postprocessing on other imaging systems.

.

Digital Image Processing Introduction



In the Imaging System the BAS-signal from the TV-system is converted into digital data and stored and manipulated.

The output signals of the Imaging System are:

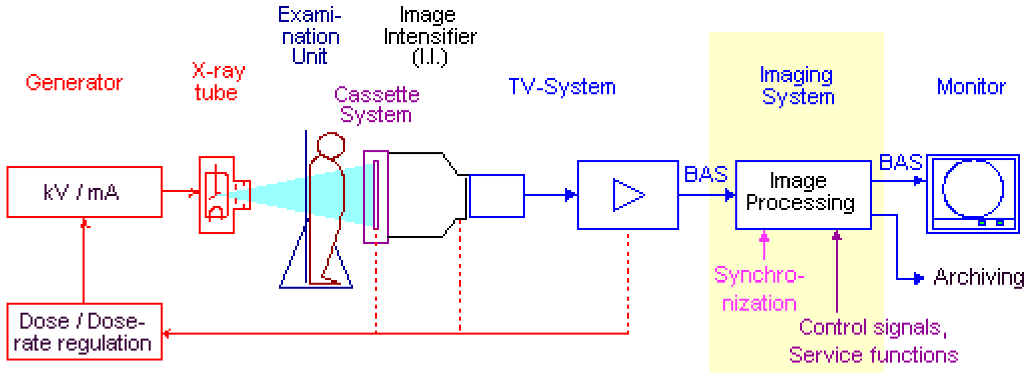
- The analog BAS-Signal

for the image monitor, for a video tape recorder (VCR)
or for an analog hardcopy

- The digital data
for archiving on digital harcopy camera and CD-ROM or for the transfer to other imaging systems for further processing.

.

Digital Image Processing **Introduction** 5/5



The Synchronization Signal synchronizes the Analog to Digital Converter (ADC) and the Digital to Analog Converter (DAC) to the timing of the TV-system.

Control Signals, such as "Fluoroscopy on" and "Exposure on" control certain functions of the Imaging System.
Also status messages, e.g. the "OK-status" are transfered.

The Service Functions comprise error messages, diagnostics, download and configuration.

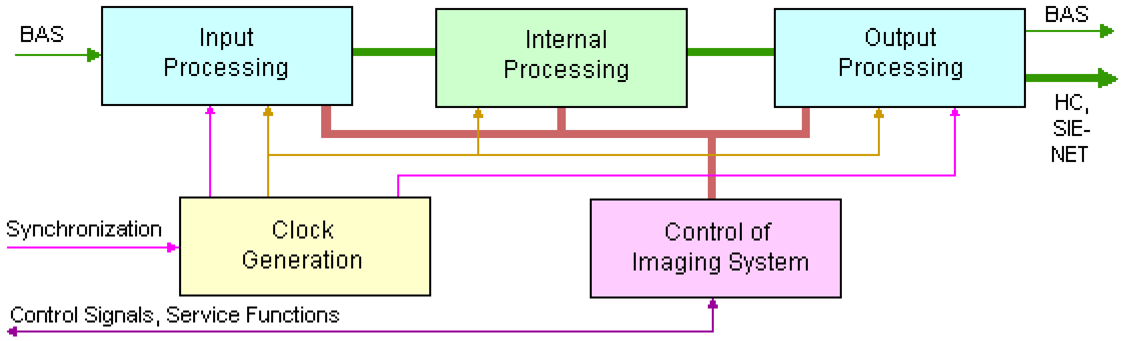
end of chapter "Introduction"

.

.

.

Digital Image Processing **Block Diagram** 1/2



General:

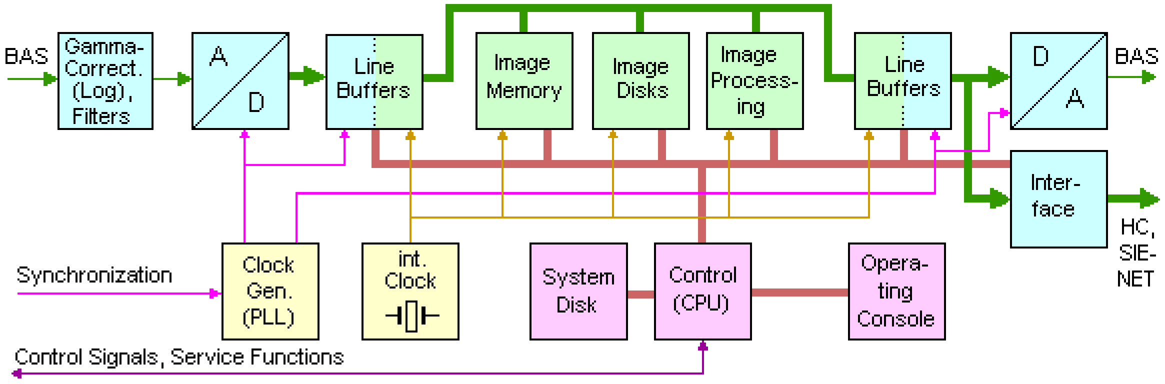
The blockdiagram of the Imaging System can be subdivided into:

- **Input Processing**
- **Internal Processing**
- **Output Processing**
- **Clock Generation**

- **Control of Imaging System**

.

Digital Image Processing **Block Diagram** 2/2



The circuits on the different stages are :

- **Input Processing:** Gamma Correction (Log), Filters, Analog to Digital Converter (DAC) and Line Buffers
- **Internal Processing:** Line Buffers, Image Memory Image Disks and Image Processing
- **Output Processing:** Line Buffers, Digital to Analog Converter (DAC) and Interface for the transfer to Hardcopy and SIENET

- **Control of Imaging System:** CPU board, System Disk and Operating Console

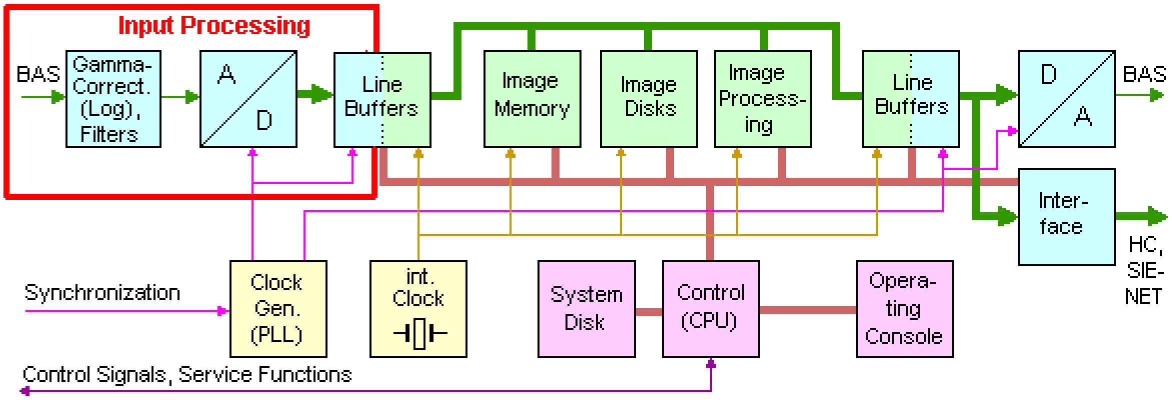
- **Clock Generation:** Clock Generator for the Input and Output Processing, and the clock generation for the Internal Processing

end of chapter "Block Diagram"

.

.

.

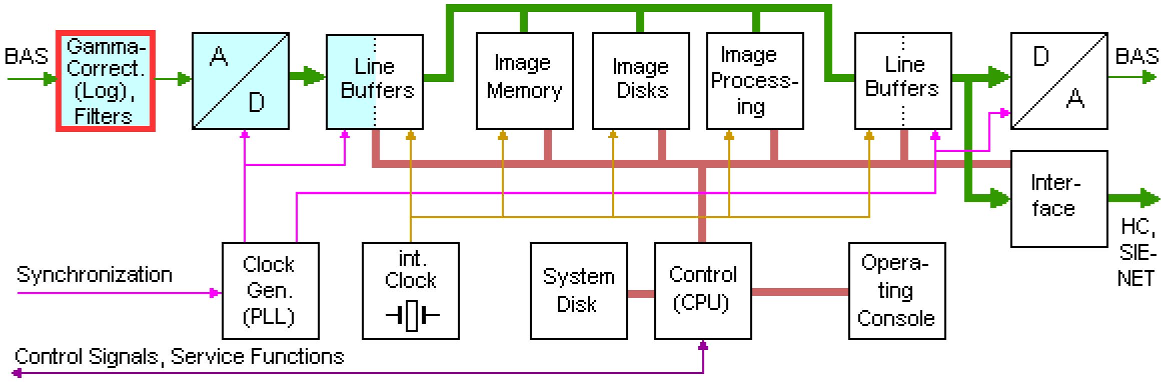


The **Input Processing** comprises:

- **Gamma Correction** (Log) for contrast optimization
- **Filters**, to reduce the bandwidth of the video signal
- **Analog to Digital Converter** (ADC)

- **Line Buffers** for the adaptation to the different timings

.



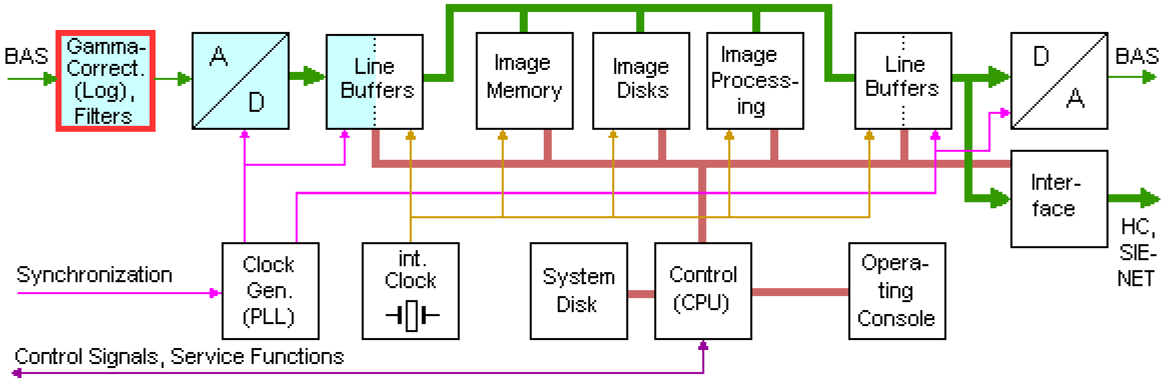
Gamma Correction (Log): This stage is an amplifier with a characteristic
that depends on the configured or adjusted gamma value.
For different examination methods different gamma curves are used.
This results in an image characteristic which is well suited to the specific medical application.
The gamma values are in the range between 1.0 and 0.2.

Examples:

- Gamma = 1.0. This is a linear (Lin) curve that does **no** correction to the video signal.
- Gamma = 0.45. This is a nonlinear curve for card applications.
- Gamma = 0.2. This is a logarithmic curve (Log) for Digital Subtraction Angiograpghy (DSA).

▼ ▲ more info ?

.

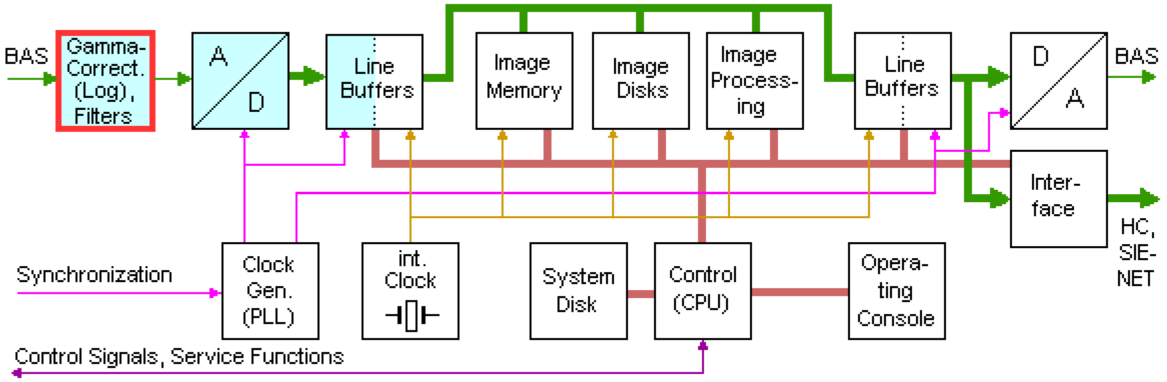


For DSA the logarithmation (Log curve) of the video signal is an essential step,
before images are subtracted.

With logarithmation the subtraction result, that means the display of the vessels,
is independend on the surrounding skin and bones.

Without logarithmation a vessel surrounded by thin skin only, would be displayed with more contrast than a vessel surrounded by a more dense or more thick background structure.

.



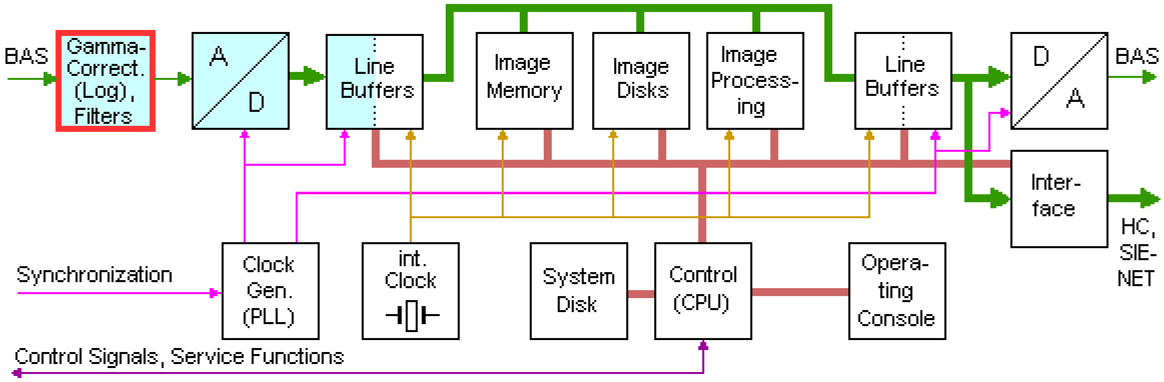
Depending on the system the Gamma Correction (Log) stage might be distributed into a separate gamma correction stage and a Lin / Log stage.
The Gamma Correction (Log) stage can be also found included in the internal digital processing of the Imaging System.

Examples:

- MULTISTAR TOP: Gamma Correction and Log stage are in theTV System (VIDEOMED S).
- COROSKOP TOP: Gamma Correction is in the TV System and in the Imaging System (e.g. HICOR) is the Lin / Log stage.

- SIRESKOP CX / DFR: Gamma Correction and Log stage are included in the internal digital processing of the Imaging System FLUOROSOPT COMPACT.

.

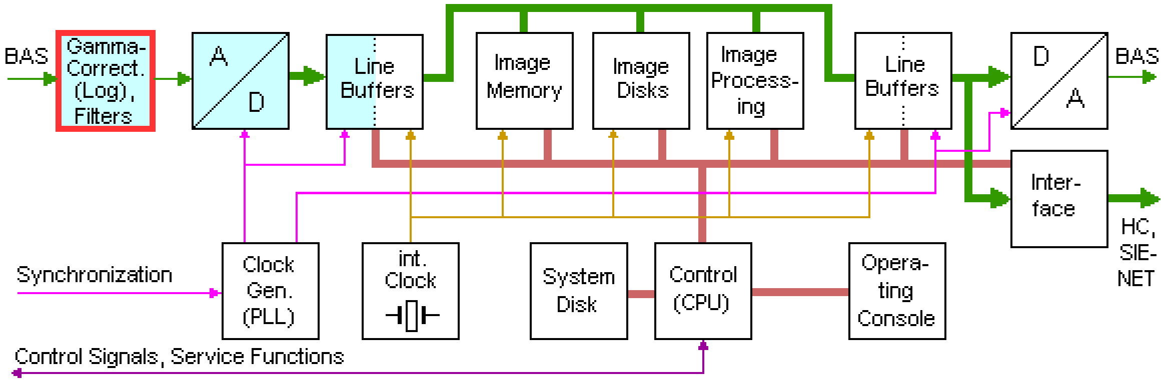


Filters:
The Filters reduce the bandwidth of the video signal.
The bandwidths of the filters depend on the ADC-clock and the scan mode of the TV system.

According to the conversion theorem the maximum bandwidth of the video signal is limited to the half ADC-Clock.

Example for Angio system MULTISTAR TOP:
- ADC-clock is appr. 43 MHz
- Maximum bandwidth for the video signal is 43 MHz ¸ 2 = appr. 22 MHz

.



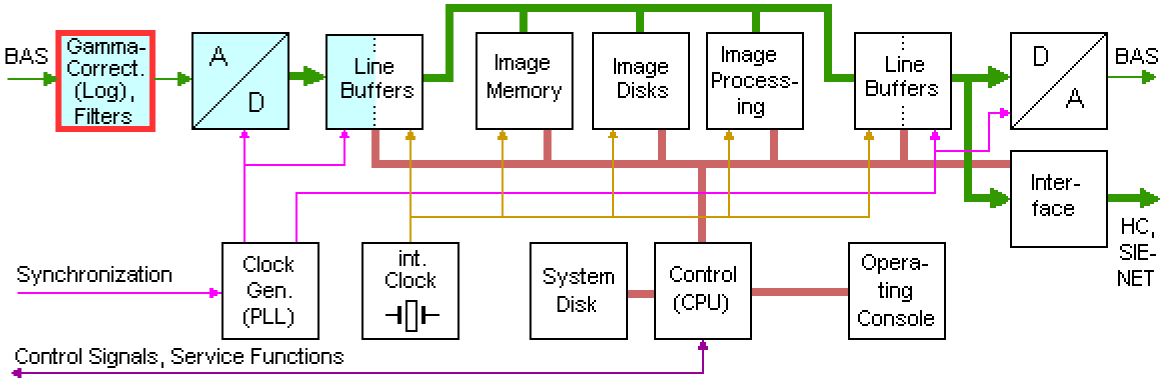
This filter of 22 MHz is used for the scan modes interlaced, noninterlaced and progressive.
These scan modes have the same horizontal timing, e.g. a period of 30 ms on the Angio System MULTISTAR TOP.

For the slow progressive scan modes
- Slow progressive factor 3 (SPS x 3 or SPS 100) and
- Slow progressive factor 5 (SPS x 5 or SPS 167)

..other filters can be used, because the TV-timing is 3 times or 5 times slower.

.

Digital Image Processing Input Processing

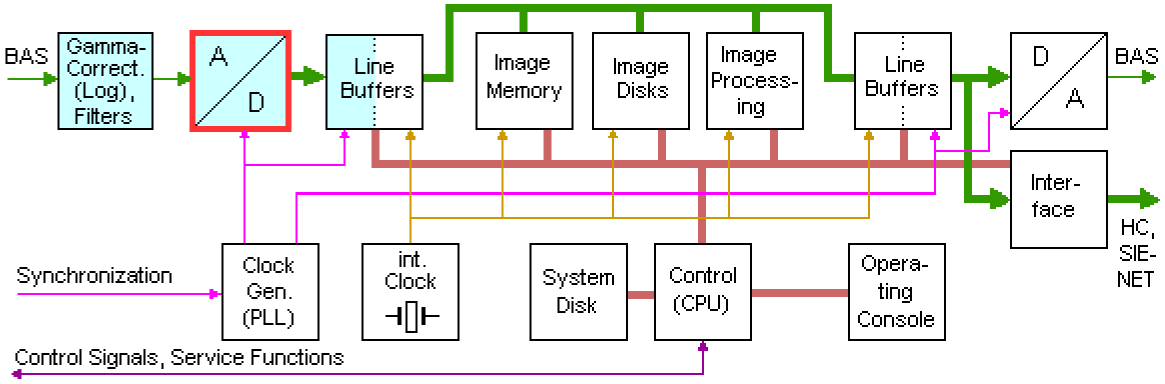


Example Angio System MULTISTAR TOP:
Bandwidth of the filter for SPS x 3 : 7 Mhz
Bandwidth of the filter for SPS x 5 : 4 Mhz

Conclusion:
Due to the lower bandwidths the acquisitions with slow progressive scan have a better signal to noise ratio (less noise) than acqusitions with interlaced, noninterlaced or progressive scan.

.

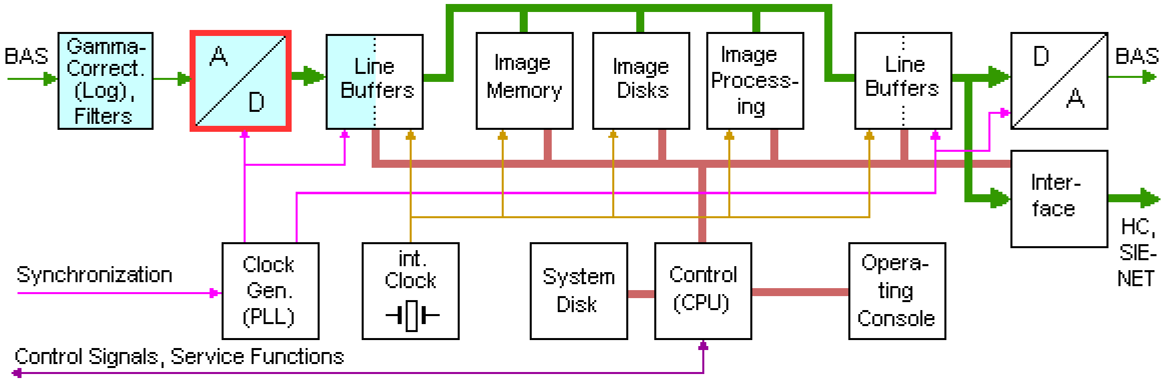
Digital Image Processing Input Processing



Analog to Digital Converter (A/D or ADC):
The function of an Analog to Digital Converter (ADC) is to convert the "Analog Video Signal" at it's input into "Digital Numeric Values", the so called "pixels".
Such a pixel is generated with every ADC-clock pulse by sampling the analog videoinformation.

The data depth of the digital data, that means the amount of bits per pixel define the range of possible gray steps.
Examples:
- 8 bit ADC: 256 gray values are possible (from 0 = black to 255 = white)
- 10 bit ADC: 1024 gray values are possible (from 0 = black to 1023 = white)

.



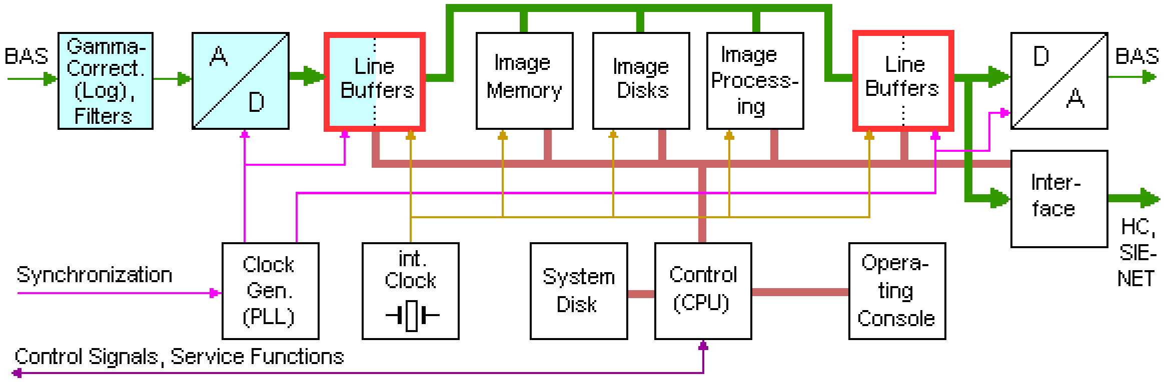
The digital image consists of a certain amount of pixel.
The number of pixel in horizontal and vertical direction is designated as matrix.

Example: A matrix of 512x512 means, that the digital image is constructed from 512 pixel in horizontal direction and 512 pixel in vertical direction.

Common matrix sizes are 512x512, 1024x1024 and 2048x2048.

The higher the matrix size, the higher is the resolution !
But higher matrix sizes require more technical expenditure especially for higher frame rates.

.

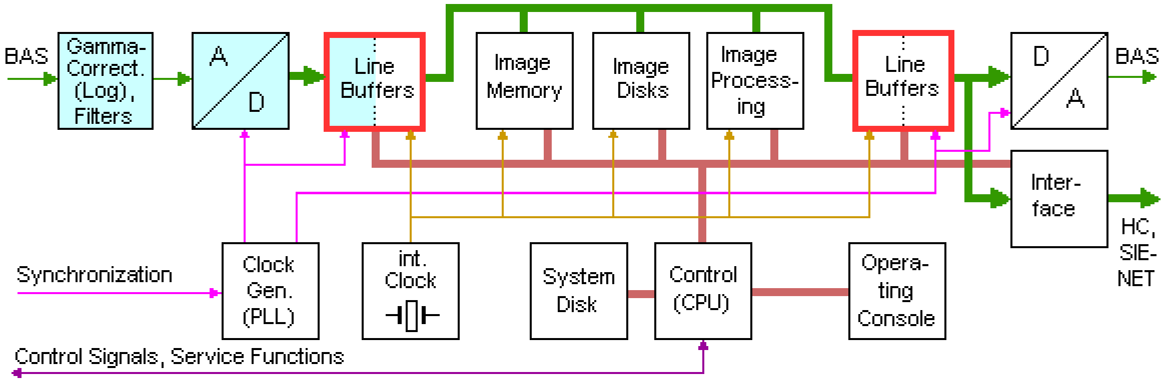


Line Buffers:
Modern Imaging Systems use for the timing the following principle:

- For the Input Processing (for the ADC) clock pulses that are sysnchronized with the TV-system.
  Example: 43 MHz clock for the ADC
- For the Internal Processing a constant clock.
  Example: 20 MHz clock, generated by a crystal oscillator

- For the Output Processing (for the DAC) clock pulses that give a certain scan mode for the display at the image monitor.
  Example: 120 MHz clock for the ADC resulting in a scan mode of 120 Hz and 2251 lines for high resolution and flicker free image display at the monitors.

.



The principle, to seperate into input-, internal- and output clock, allows different timing at the TV System and the monitors and makes the design of a system easier and more flexible.

The conversion of the digital data to the different clockrates is done with the aid of Line Buffers.

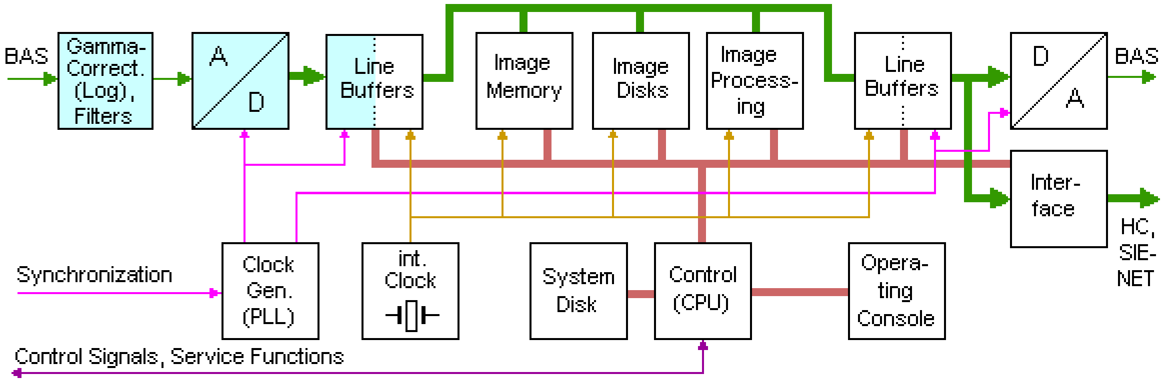
The pixel are written into the buffers with one clockrate (e.g. ADC clock) and read out with the other clockrate (e.g. internal processing clock).

The Line Buffers are located between Input Processing and Internal Processing, and between Internal Processing and Output Processing.

end of chapter "Input Processing"

.

.



Example for the calculation of the ADC-clock for the Angio System MULTISTAR TOP :

- TV-timing for interlaced, non interlaced and progressive scan :
  1125 lines / 60 Hz ق The horizontal period is 30 ms.
  The period of 30 ms consists of the matrix time of 24 ms and a time of 6 ms for the horizontal retrace.
- Matrix: 1024 ق in 24 ms 1024 clock pulses are required.
- Calculation: ADC clock = 1 ¸ (24 ms ¸ 1024) = 43 Mhz

An ADC-clock of 43 MHz is required.

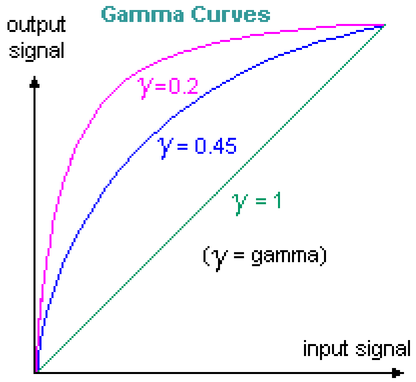
.

.

More Info

Gamma Correction

1/2



The advantage of gamma correction is the high contrast for the darker parts of the image, and the reduction of contrast for the higher signal amplitudes.

A steep curve improves the contrast for low input signals, but it also amplifies the noise (quantum noise, amplifier noise). Especially during fluoroscopy, where the doserate is relative low, the image is worsened by noise.
Therefore most digital systems have the capability to reduce noise (Noise reduction, Temporal Filter or Noise Integration).

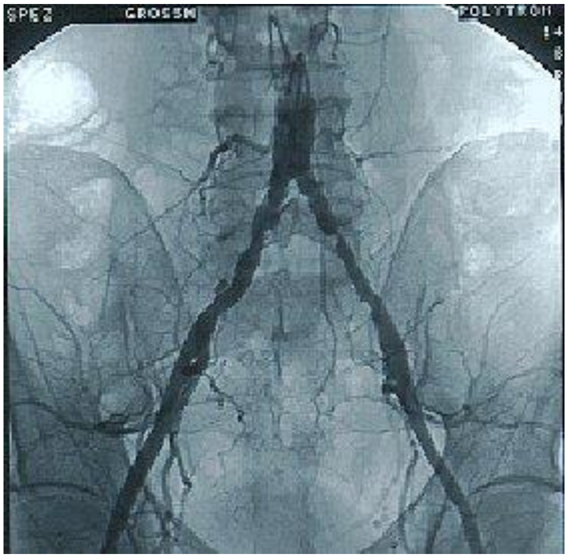
exit more info

More Info

Gamma Correction

2/2

without Gamma Correction



with Gamma Correction

Without Gamma Correction it is hard to see the details in the darker parts of the

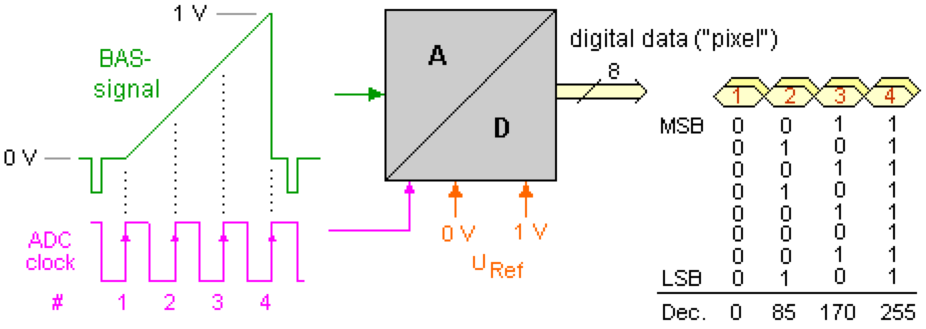
With Gamma Correction the contrast in the darker parts of the image is enhanced, image, and the higher signal amplitudes drive the videochannel into saturation (white areas in the image).

and the higher signal amplitudes are reduced, so that they can not overdrive the videochannel.

end of "more info"..... exit

.

Title 33/



	1	2	3	4
MSB	0	0	1	1
	0	1	0	1
	0	0	1	1
	0	1	0	1
	0	0	1	1
	0	0	0	1
	0	0	1	1
LSB	0	1	0	1
Dec.	0	85	170	255

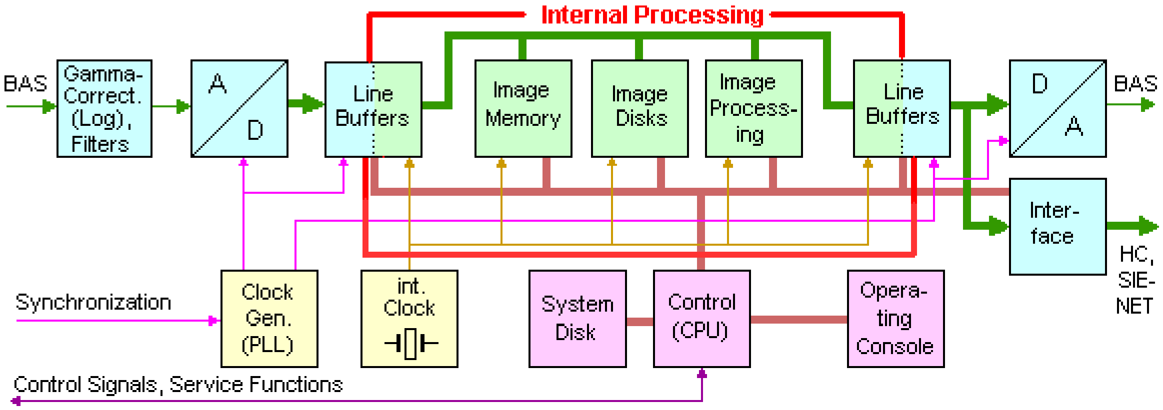
.

Title 34/

Generally the clock for the ADC depends on the matrix size and the
scan mode of the TV-system.

.

Digital Image Processing **Internal Processing** 1/



The Internal Processing consists of:

- **Line Buffers**
- **Image Memory**
- **Image Disks**

- **Image Processing**

.

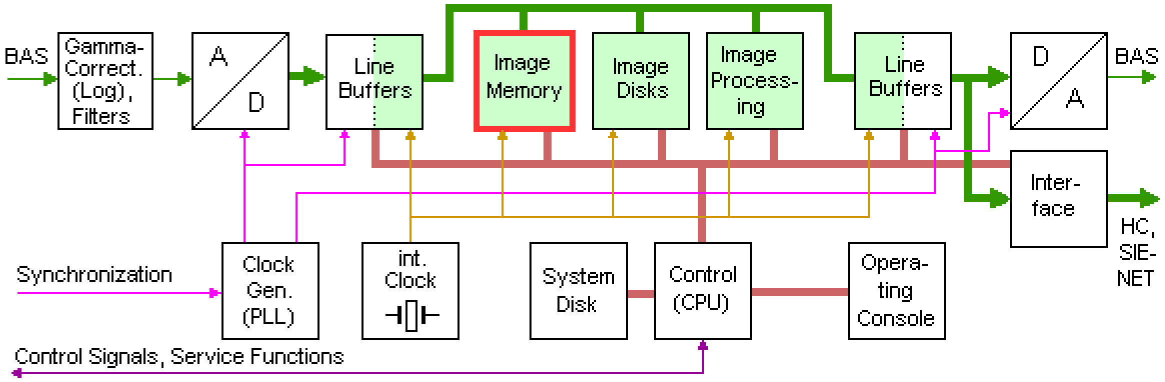


Image Memory:
RAM memory, where the digitized TV images are temporarily stored.
Almost every operating mode passes image data through the Image Memory before further processing.

In subtraction, for example, it holds the "Mask Frame" or at the end of fluoroscopy it stores the image for "LIH" (Last Image Hold).
In the Imaging System "HICOR" it stores temporarily the whole acquisition.

.

Internal Processing

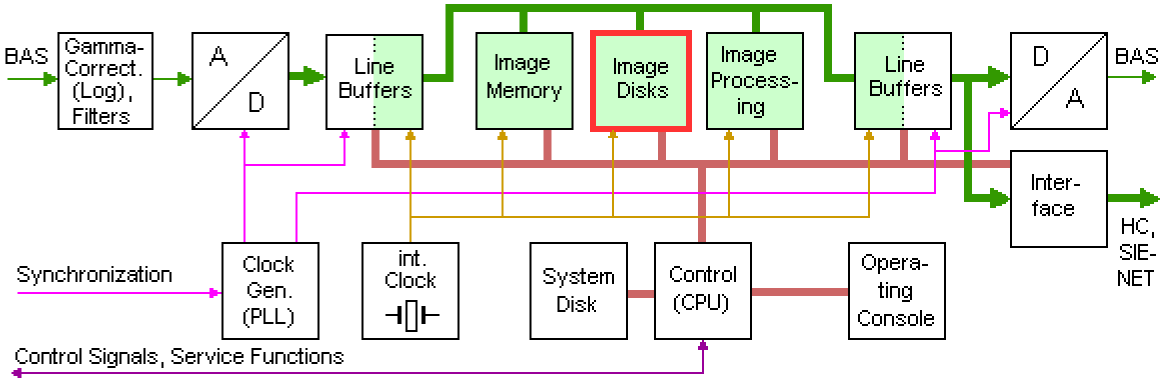


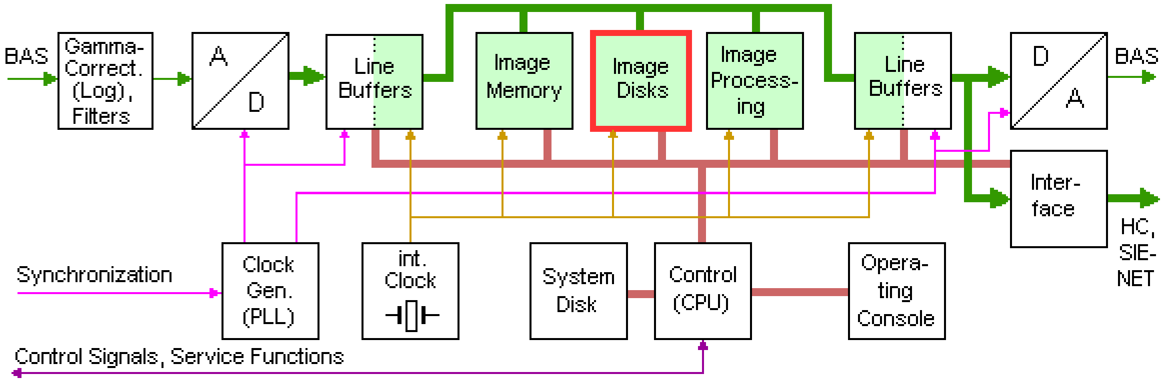
Image Disks :
During Acquisition the images are stored on the Image Disks.
So the images are available for postprocessing, for sending to a long time archiving device or via network (SIENET) to other imaging systems.

The Image Memory (RAMs) can not be used for this purpose, because with power off the data are lost.

The number of drives and their capacity depends on the system design and the options ordered by the customer.

.

Internal Processing



On most of our Imaging Systems the image data are compressed, before they are written onto the disks.
This data compression cuts down transfer times and increases the number of images that can be stored.

Example: Imaging System "POLYTRON TOP"
- max. 4 image disks
- max. 10.000 images with a matrix of 1024x1024 can be stored
- compression factor is appr. 1.6

On some systems the Image Disks, their control and the data compression are designated as "Mass Storage Device" (MSD).

.

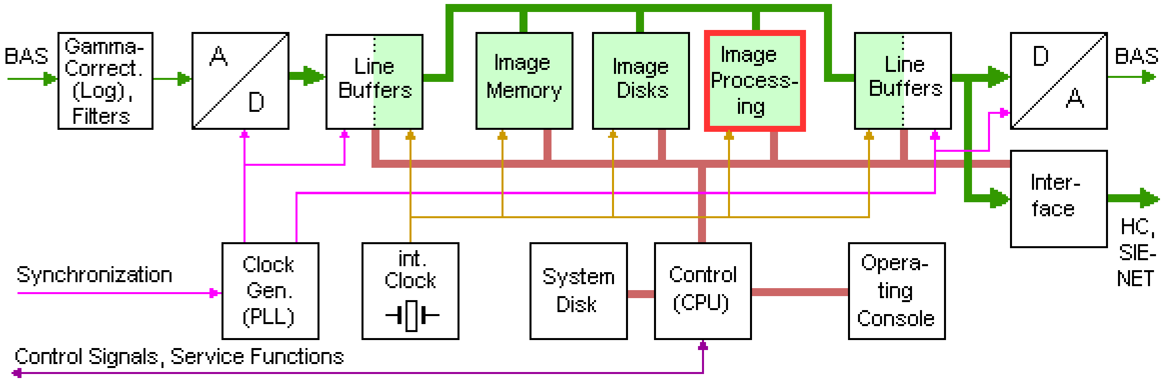


Image Processing :
Here the image manipulation takes place.

Examples :

- Windowing:
  By windowing the contrast and brightness of the displayed image can be adjusted (more info ?).
- Edge Enhancement or Spatial Filter:
  The Edge Enhancement function produces a sharper display,
  for example of vessel edges (see example).

.

- Noise reduction or Temporal Filter or Noise Integration (see example) :
  This function is especially needed for fluoroscopy, because the

quantum noise is relative high due to the low dose rate.
The degree of noise suppression is selectable by the operator.
High noise suppression factors reduces most of the noise, but the the display of motions, for example the display of the heartbeat, is unsharp.

- Zoom:
  Electronic magnification of a section of an image.
  It is displayed on the entire monitor (see example).
  With "Roaming" it is possible to move the section.
  In most systems the magnification factor is 2.
- Magnifying Glass:
  The Magnifying Glass function is used to enlarge a selectable section of the image (see example).
  In contrast to Zoom the section is superimposed on the normal image.
- Shutter:
  Parts of the image which do not contribute to the diagnosis can be eliminated by electronic collimation the so-called Shutter (see example).
  With "Roaming" it is possible to move a section of the entire image within the collimation.

- Roaming:
  With roaming an image segment can be moved or centered at the monitor.

▼ ▲

.

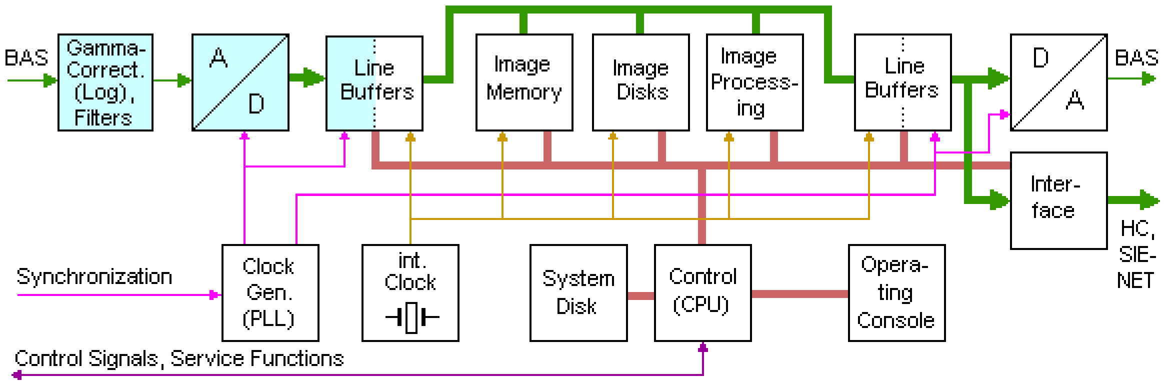
- Digital Subtraction Angiography (DSA):
  DSA is an X-ray diagnostic procedure for producing images, that only show the vessels.
  The background information e.g. bones and skin is not visible (more info ?).
- Pixelshift:
  When the object moves during a DSA examination in such a way, that Mask and Filled Image are slightly out of alignment, the vessels are displayed unsharp, and a background structure is visible.
  If the motion artefacts cannot be compensated by selecting a new mask, the Pixelshift function can be used to shift the Mask electonically into coincidence with the Filled Image.

- Inversion:

▼ ▲

under construction !

.



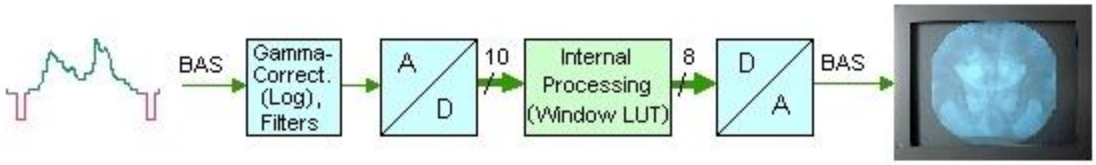
Example for the calculation of the ADC-clock for the Angio System MULTISTAR TOP :

- TV-timing for interlaced, non interlaced and progressive scan :
  1125 lines / 60 Hz ق The horizontal period is 30 ms.
  The period of 30 ms consists of the matrix time of 24 ms and a time of 6 ms for the horizontal retrace.
- Matrix: 1024 ق in 24 ms 1024 clock pulses are required.
- Calculation: ADC clock = 1 ¸ (24 ms ¸ 1024) = 43 Mhz

An ADC-clock of 43 MHz is required.

.

More Info **Windowing** 1/3

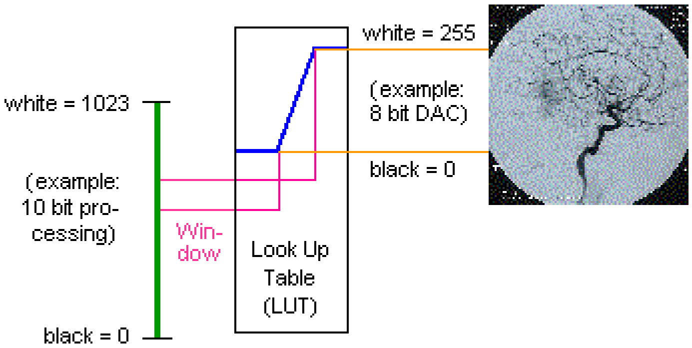


under construction !

exit more info

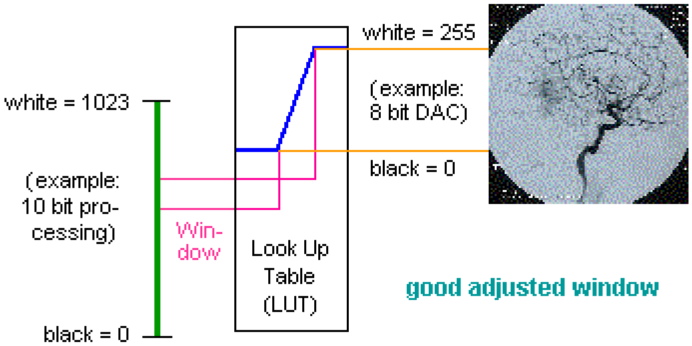
.

More Info **Windowing** 2/3

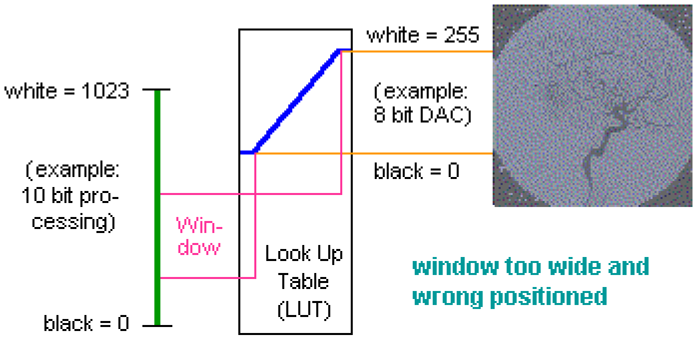


exit more info

More Info **Windowing** 3/3



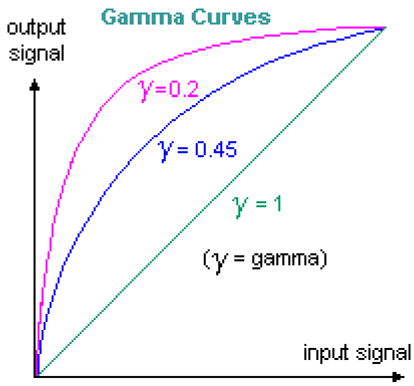
good adjusted window



window too wide and wrong positioned

end of "more info".....exit

More Info **Gamma Correction** 1/2



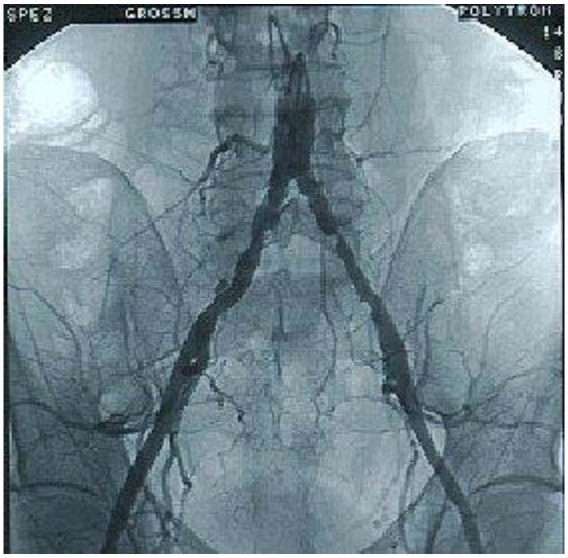
The advantage of gamma correction
is the high contrast for the darker parts
of the image, and the reduction of contrast
for the higher signal amplitudes.

A steep curve improves the contrast for low input signals,
but it also amplifies the noise (quantum noise, amplifier noise).
Especially during fluoroscopy, where the doserate is relative low,
the image is worsened by noise.
Therefore most digital systems have the capability to reduce noise
(Noise reduction, Temporal Filter or Noise Integration).

exit more info

without Gamma Correction

Without Gamma Correction it is hard to see the details in the darker parts of the image, and the higher signal amplitudes drive the videochannel into saturation



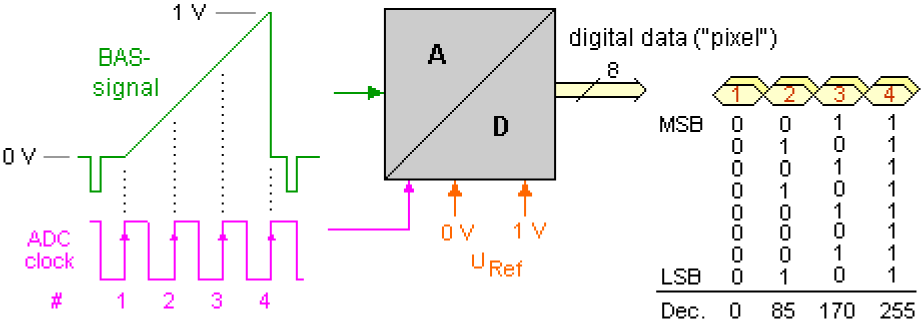
with Gamma Correction

With Gamma Correction the contrast in the darker parts of the image is enhanced,
and the higher signal amplitudes are reduced, so that they can not overdrive the videochannel.

(white areas in the image).

end of "more info".....exit

.

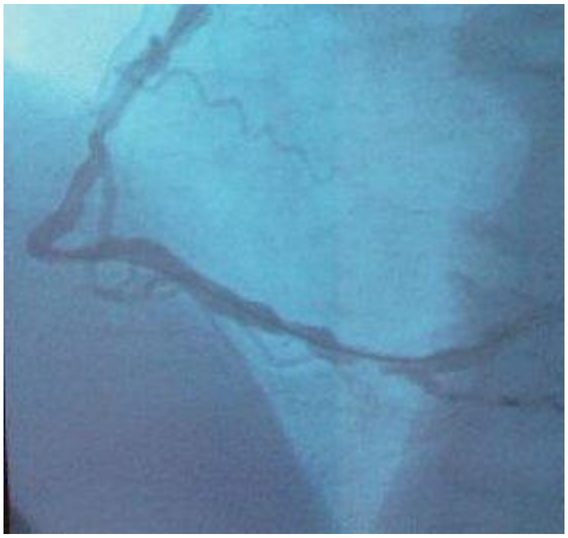


.

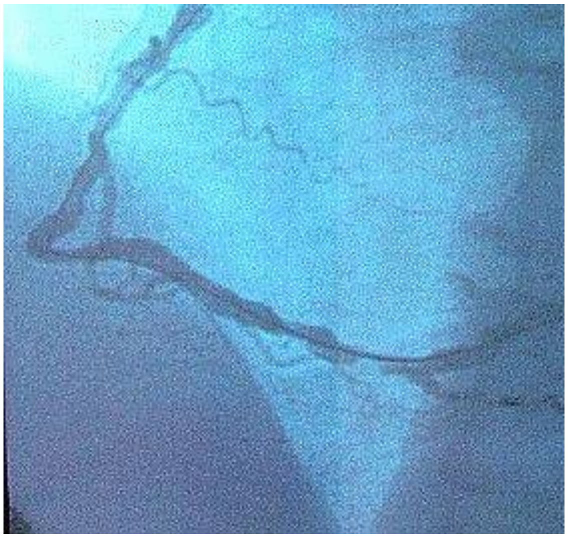
Generally the clock for the ADC depends on the
matrix size and the
scan mode of the TV-system.

.

Edge Enhancement



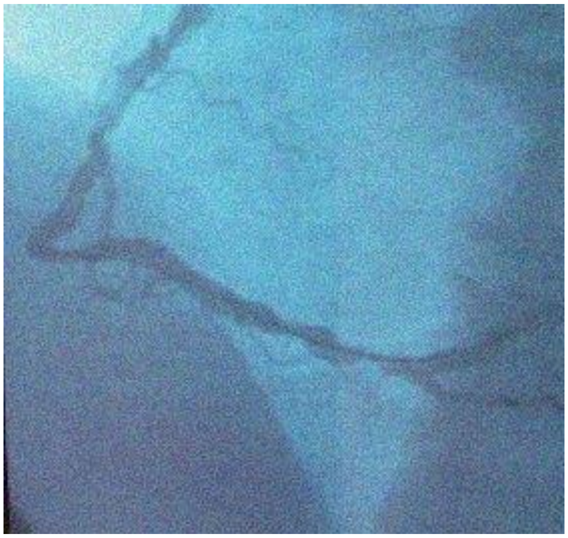
without Edge Enhancement



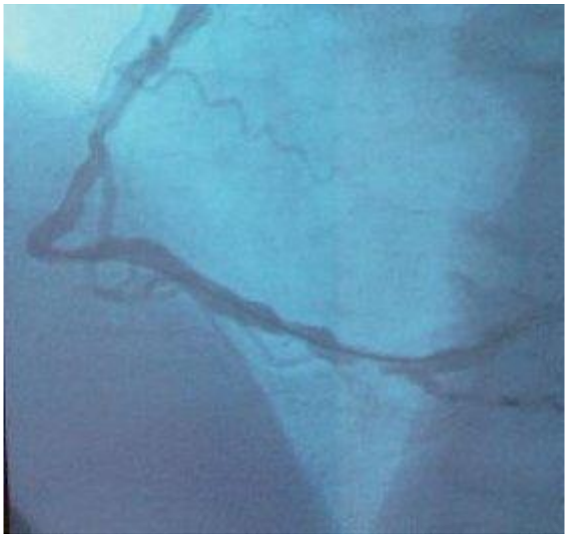
with Edge Enhancement

back

Noise reduction



without Noise Reduction

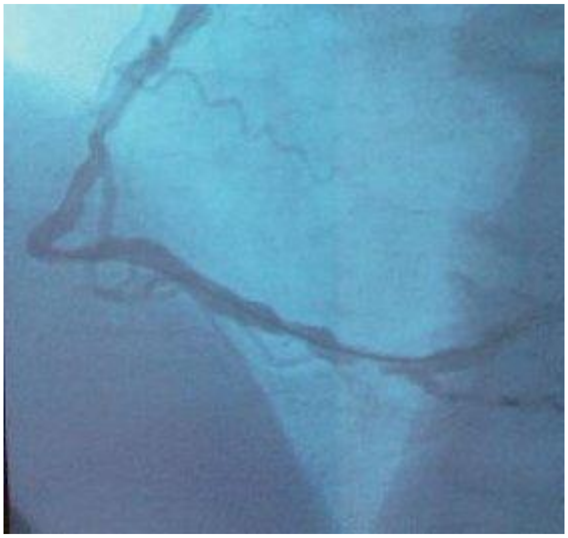


with Noise Reduction

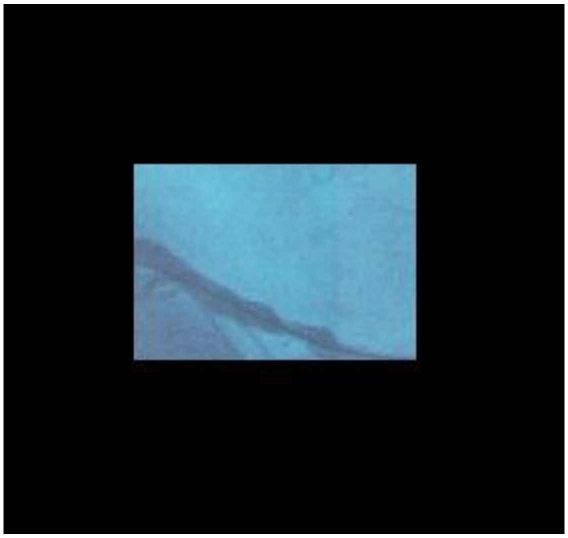
back

.

Shutter



without Shutter

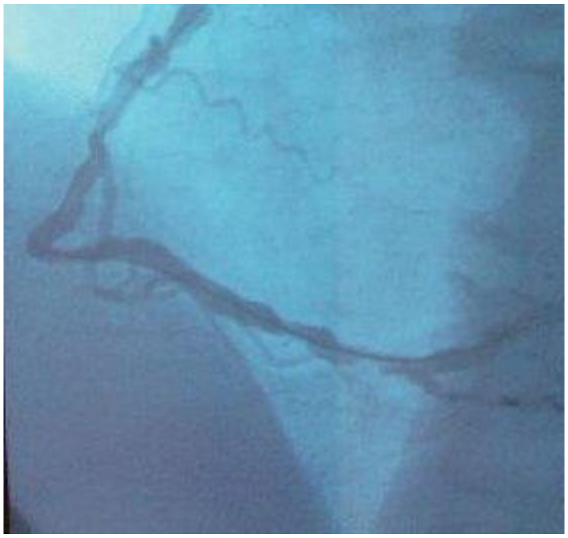


with Shutter

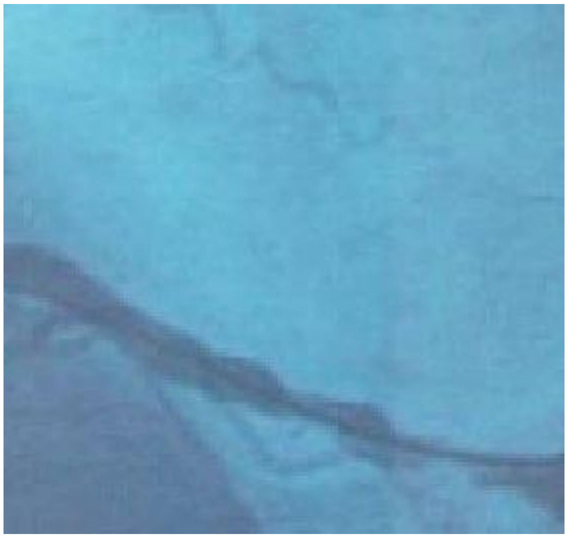
back

.

Zoom



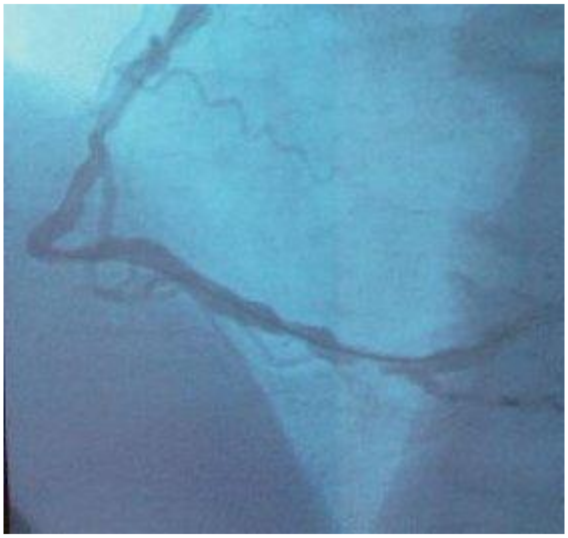
"normal" image



zoomed image

back

Magnifying Glass



"normal" image

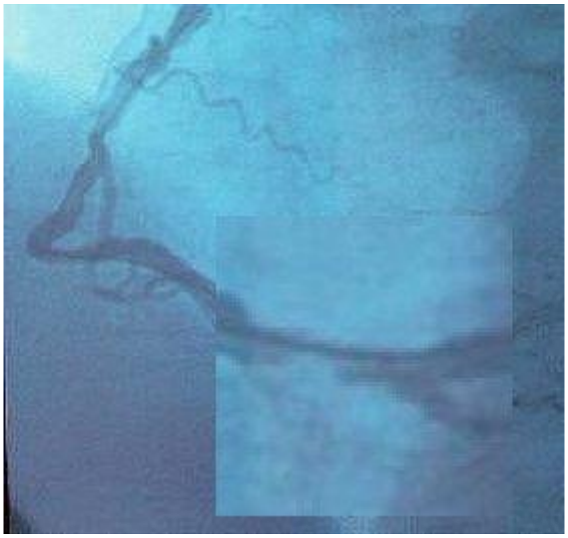


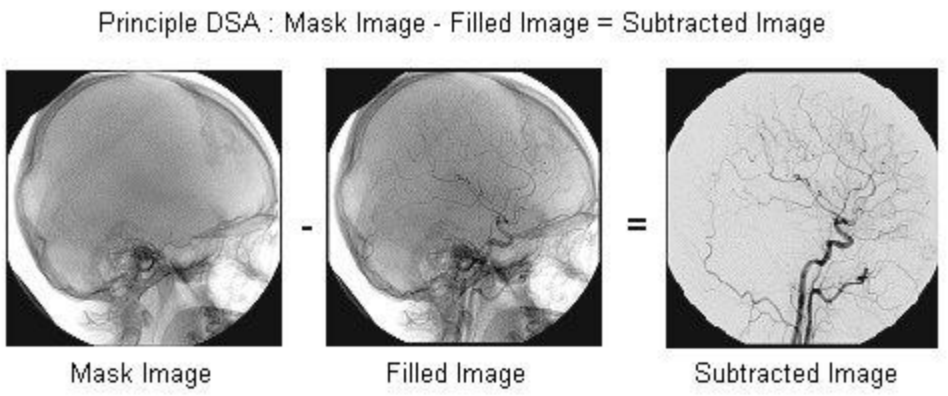
image with Magnifying Glass

back

.

.

More Info **DSA** 1/4



Principally the examination runs as follows:

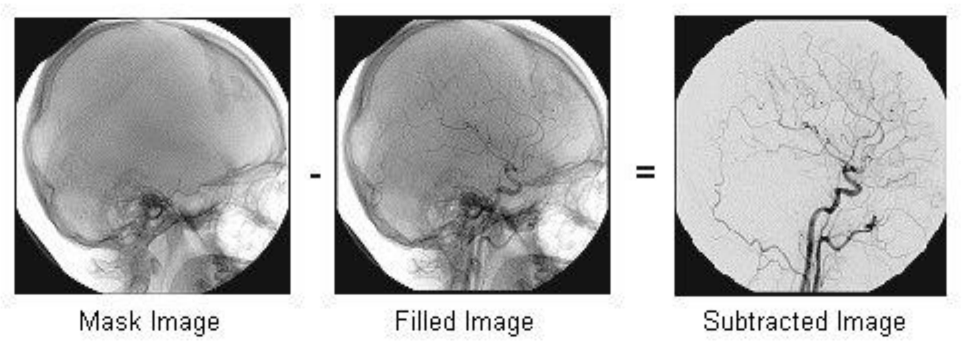
- The exposure switch is pressed and the radiation starts.
- Right at the beginning of the examination the "Mask Image"
  is stored into the Image Memory.
  This image does not show the vessels, because the contrast medium
  has not yet reached the target area.
  Depending on the system, the Mask Image is manually or automatically set.

exit more info

.

.

More Info **DSA** 2/4



- Then the Subtraction starts.
  All consecutive images are subtracted from the Mask.
  As soon as the contrast medium reaches the target area, the vessels become visible in the Subtracted Images.
  Depending on the system, the image with the highest contrast is automatically detected and stored or can be stored manually.
  This stored image is designated as "Filled Image".
- The scene ends with the release of the exposure switch.

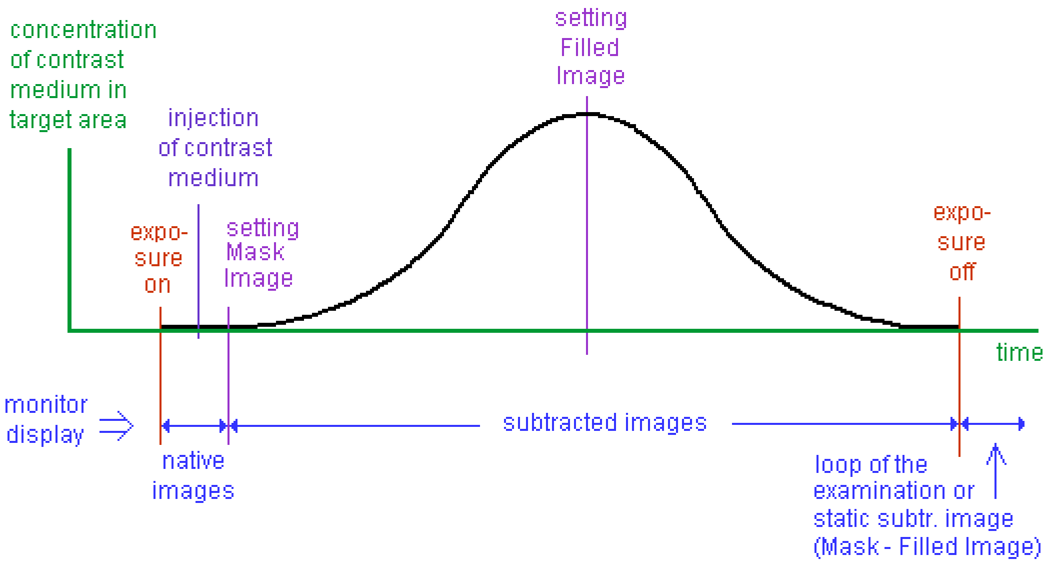
- In Postprocessing variuos functions are available to improve the display, e.g. Windowing, Zooming, Edge Enhancement (Filter) e.t.c.
  It is also possible to select another Mask Image or Filled Image, because all images of the scene are recorded on the image disks as native (non subtracted) images.

▼ ▲ exit more info

.

More Info **DSA** 3/4

The illustration below shows the events and the display mode of a DSA sequence



During the examination (Acquisition) the images are stored as native images on the image disks.
These images are then available for postprocessing, archiving and can be sent via a network to other imaging systems.

exit more info

.

Benefits of DSA :

- Immediate image evaluation and diagnosis
- Dynamic display of blood flow with the possibility of repeating (playing back) a dynamic process at any time
- Better detail contrast resulting in
  a reduction of the amount and concentration of contrast media (CM).
  Thus thinner catheters can be used which reduces invasivness
  (less post-examination bleeding).
- Possibility of enhancing the display through image postprocessing

Two types of CM -injection are used:

- Intra arterial (IA)
  - with injection into the main artery, e.g. the aorta, for survey radiography
  - or with injection into the vessel of interest for selective display.

- Intravenous (IV).

end of "more info"..... exit

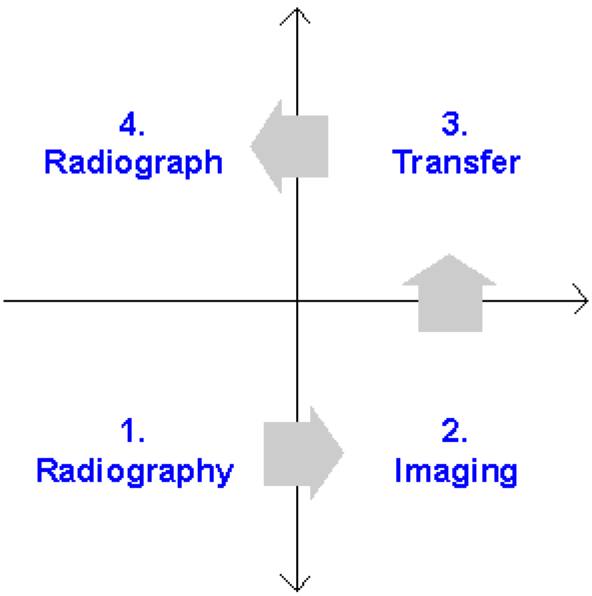
Basics

There are a lot of aspects and test-procedures defining image quality on the scientific level. A practical definition, however, is following:
Image quality is good when the customer sees what he is looking for right away.

It requires four steps to get an radiograph:

1. **Radiography**
   Using radiation, an X-ray image is produced.
2. **Imaging**
   Here, the invisible X-ray image is converted into a visible one.
3. **Transfer**
   The visible image is processed for optimum display, and must be stored in some way since the exposure produces a flash of light only.

4. **Radiograph**
   The image is presented to the radiographer for evaluation.



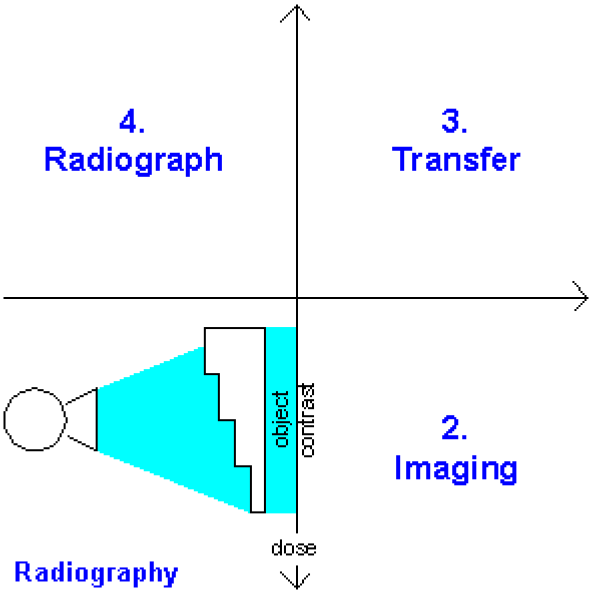
.

Radiography

This is the first step in the sequence and laying the **base for the final result**. Any quality loss here cannot be compensated later.

As a consequence, The **service engineer** must make sure that everything is correct concerning the X-ray system. The **radiographer or radiologist** is responsible for optimum realization of the examination itself.

In the end, we get an X-ray image represented by a **variation of dose levels**. The ratio of minimum to maximum dose identifys the **object contrast**.



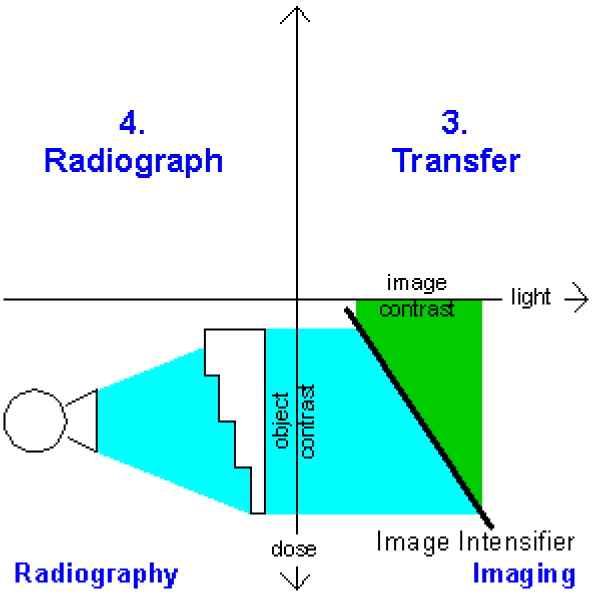
.

Imaging

Here, the **conversion** into a visible image takes place. At this stage, basically any of the imaging systems - film-screen cassettes, *reusable screens* or *flat-panel detectors* - can be used. In our example the **image intensifier** does the job; so we deal with an indirect exposure or DFR-system.

All the systems have one in common: They have a **given characteristic** of conversion which cannot be controlled. That means, besides of testing, little can be done here by the service engineer to improve the performance.

At the output of this stage one gets a flash of an image with the **intensity** depending on the input dose and the TV-iris set, and the **image contrast** slightly reduced by the image intensifier.



.

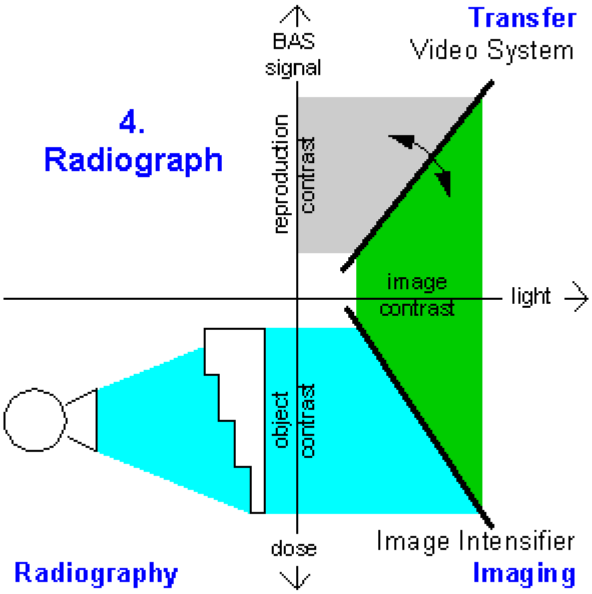
Transfer

This stage plays a decisive role in **image quality** because the overall transfer characteristic is variable and is used to match the image contrast of the input to the **reproduction contrast** of the output..

First, the transient image is picked up and **stored in memory**. As mentioned ealier, quite an amonut of **analog signal processing** takes place already during this procedure.

Secondly, the image is **processed digitally** enhancing **anatomical details** for easy assessment.

Finally, the image is converted to a standard **analog video signal** for monitor input. At this stage, pre-selected windowing parameters are

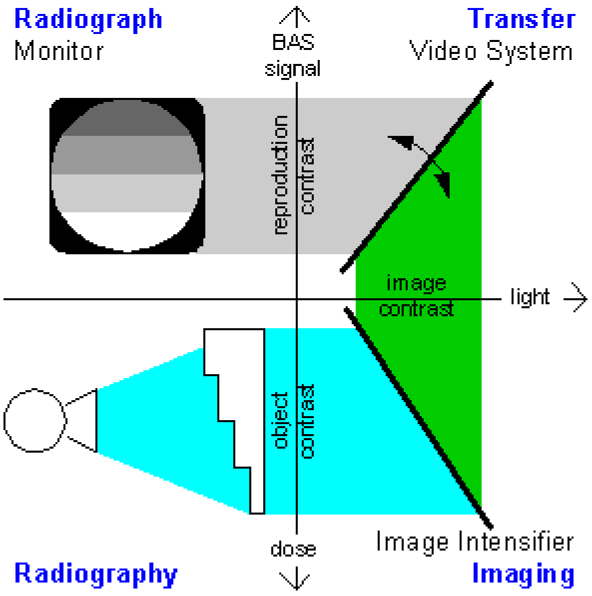


applyed providing **brightness and contrast** desired.

Apparently, this transfer stage is used to meet both technical and examination related requirements.

.

Radiograph



This is the final result, displayed at the monitor.

For the ease of assessment, it is important to utilize the **full range of luminance** from black to white and place the "important information" in the range of the **brightness evaluated best**. For the system, important information is placed inside the dominant selected

There apply some restrictions to the range of luminance, however: The darkest portions of the image must never be pitch black, they must have some transparency. An white must not be glaring white reducing the visual contrast.

Since the **visual contrast** impression depends very much upon the level of the background light, it is advised to keep the **room-light** allways at the same, dim level.

.

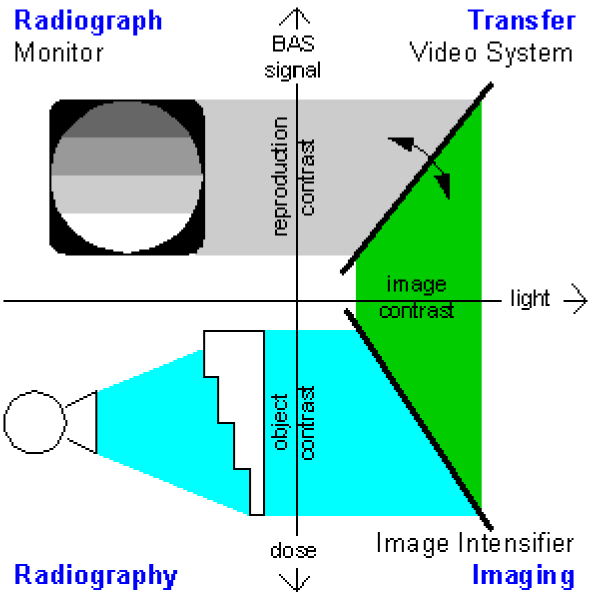
Conclusion

For optimum performance, it is quite important that **all four stages are tuned to each other**. Else information may be hidden from view or even be completely lost.

Optimization of image quality allways includes the complete X-ray imaging chain.

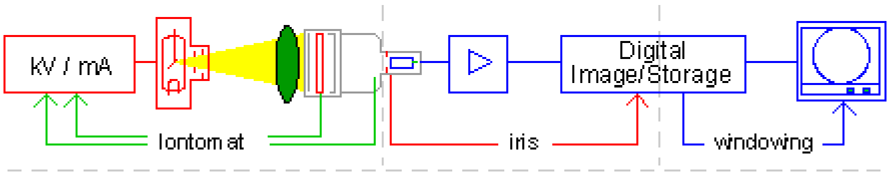
While some stages need more adjustment than others, all the four stages have to be **tested**. During installation and start-up the system has been tested and the results entered into a **test certificate**. All subsequent tests are compared to this test certificate.

With allmost every installation, an adaptation to the **customers needs** is required. This is never done by altering system parameters, but by adapting the **organ programs** accordingly.



.

The DFR System



Transferring the four stage model to the system hardware means:

Radiography
Includes the **generator** and the **Iontomat** controlling the dose (rate) by measuring the light output of the II. The dose levels are kept as low as possible with the quantum noise at an acceptable level for the examination at hand.

Imaging
This is the **image intensifier** in combination with the **iris control** providing a constant light level regardless of the dose selected.

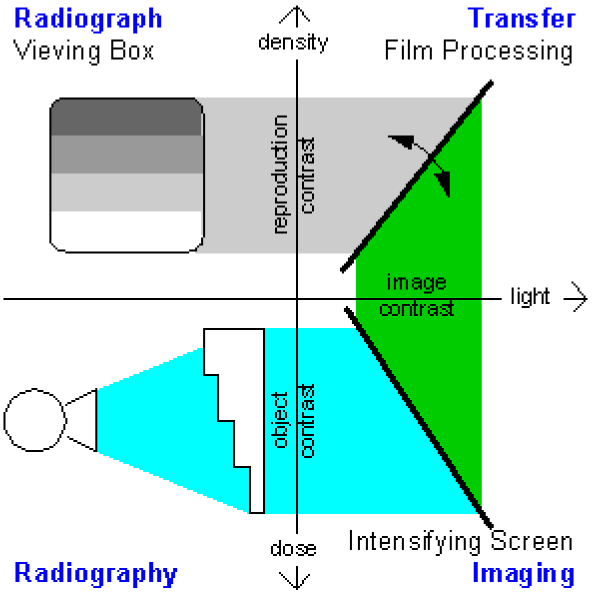
Transfer
This is the signal input from **camera** via analog **amplifiers** and **A/D** converter into memory. This part is influenced by the iris setting. The signal output from memory via **D/A** converter to the monitor is controlled by **windowing**.

Radiograph
With DFR, the "radiograph" is an image presented on a **monitor** rather than a film on a viewing box.
For consitency, the contrast an brightness controls on the monitor are factroy set and should not be touched by the user.

.

Direct Technique

The four step concept from radiography to radiograph applys to all X-ray imaging systems as is demonstrated with the film-screen combination in direct technique:



Converting radiation into light, the **intensifying screen** serves as imaging system. And again, the transfer characteristics cannot be influenced.

As with indirect technique, the transfer stage plays the important part of matching the image contrast to the **reproduction contrast**. Setting the correct average gradient, the vital information is presented in the optimum **range of densities**.

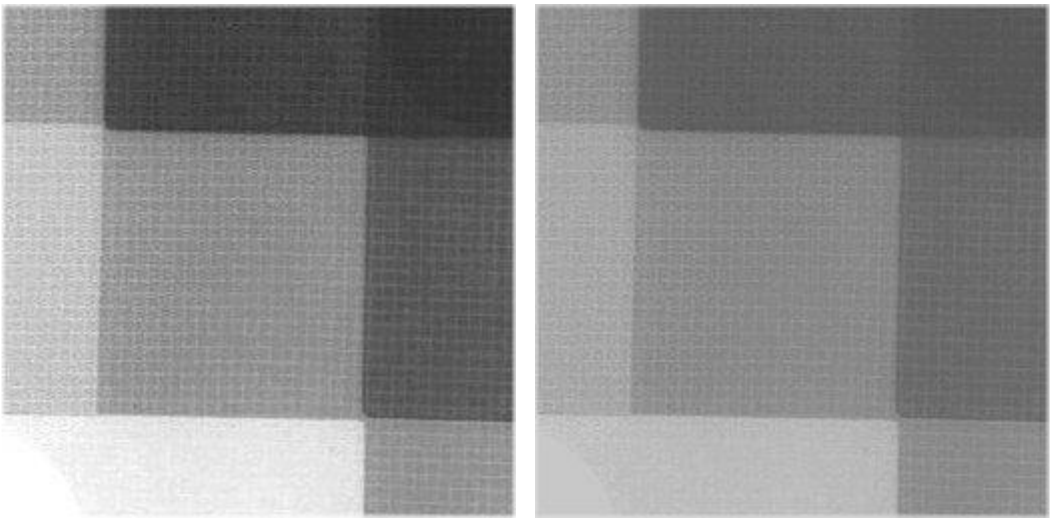
Unfortunately, film-processing is not integral part of our X-ray imaging system. Keeping **constant processing conditions** is the resposibility of the hospital staff. Therefore, a close cooperation between X-ray engineer and hospital staff is asked for.

End of introduction to "Image Quality"

.

.

Contrast



Of all image quality parameters, contrast has the biggest impact. Both X-ray images have identical information; they only differ in the gray scale used.
The left, high contrast image utilizes the full gray scale from **black to white**.

The low contrast image on the right is identifiyed by having **neither black nor white** image portions.
High contrast, obviously, makes the image evaluation easier. Especially, if one is interested in the center-part of the object (test device) only.

Information on the test-device

.

Contrast

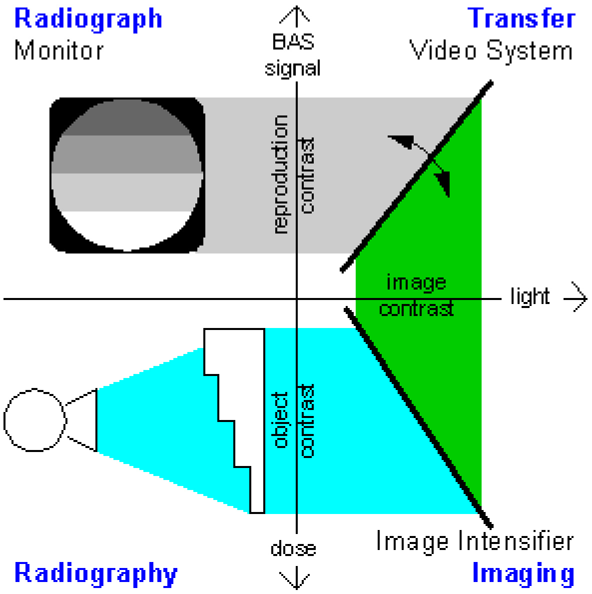
Contrast effects the image quality on film and monitor likewise

In a **DFR-system**, the conversion from the image contrast received from the image intensifier to the **reproduction contrast** displayed on the monitor is achieved by analog and digital signal porcessing (gamma correction and look-up tables). **Windowing** is used for the final adaptadtion to the customers taste.

A steep transfer curve, small window, increases, and a flat curve, wide window, decreases the contrast. For various kinds of examinations, slightly different window settings can be programmed to compensate different image contrast.

Additionally, the **average brightness**, that is the brightness inside the dominant, can also be

DFR-System



be altered by windowing

▼ ▲

.

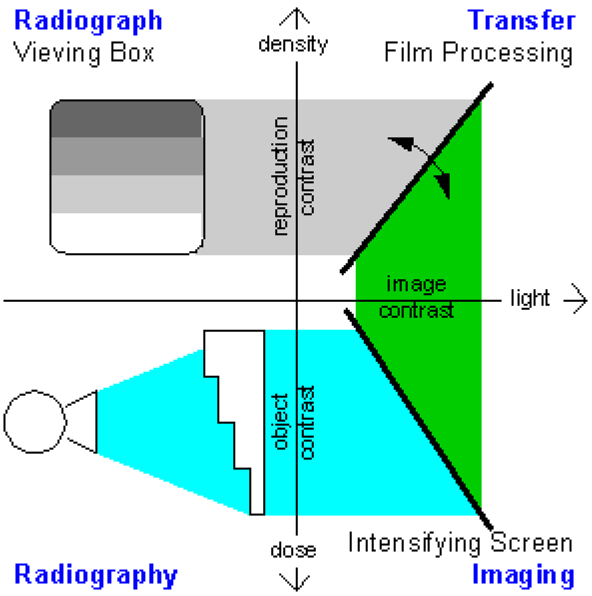
Contrast

In **direct technique**, variations in contrast are mainly the result of **different image contrast**.

A **thorax** radiograph, for instance, covers the wide contrast range from the radio-lucent lung over the heart to the spinal column as a solid absorber. On the other hand, a **gall bladder** inside the trunk, even filled with contrast medium, is hardly to distinguish from the surrounding tissue. In this case, appropriate **exposure kV** compensate for the different contrast to a certain degree.

Theoretically, varying image contrast could be compensated by changing the "steepness" of **film processing** providing allways the same range of densities. In practice however, we have to stick to a compromise average gradient, and keep processing conditions as **constant** as possible.

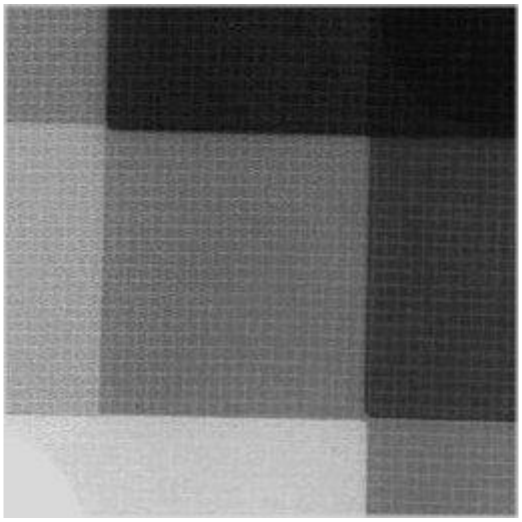
Film-Screen Combination

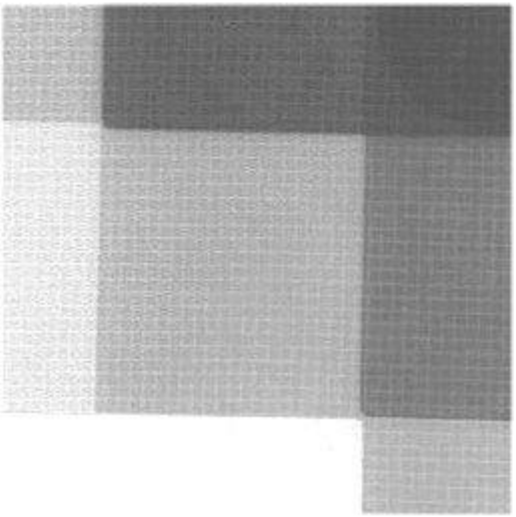


▼ ▲

.

Over- and Under- Exposure





The unexperienced observer may confuse contrast with **incorrect exposure**. However, in our example both radiographs have the same contrast.
The image on the left is over-exposed. Since there is no white area on the film, the film has been exposed far too much and information is **lost in the black** parts of the film.
The right, underexposed film has got too little light, and information is **lost in the white** area.
Keep in mind that over- and under-exposure just look inverted on film and on monitor!

more info?

.

Scattered Radiation

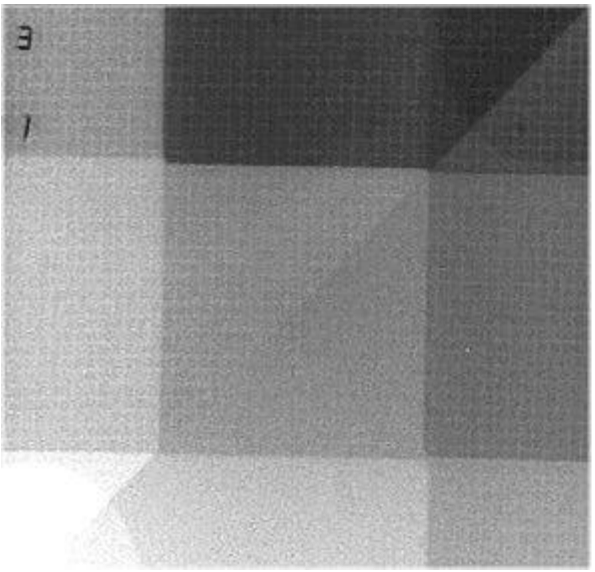
Another attack on contrast is scattered radiation. As one may recall, scattered radiation is **undirected radiation**, caused by interaction between primary radiation from the X-ray tube and the absorber, the patient.

The split-image shows the result with the anti-scatter grid in place on the the upper part, and with the grid removed on the lower part.

Scattered radiation causes an even **fog layer** all over the image **reducing** the contrast and **wiping out** low-contrast details.

Scattered radiation increases with the **amount of absorber** in the radiation beam. Therefore, the radiation field should allways be as small as possible.

place



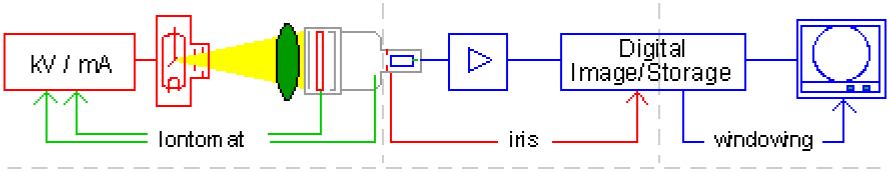
Only when examining **babys**, it is recommended to remove the grid for reduction of absorbed dose.

End of "IQ-Properties, Contrast"

.

Image Quality **IQ-Properties** 1/1

Exposure Adjustment



The adjustment of exposure differs between direct technique and DFR-systems.

Direct Technique

- With film-screen combinations, **film processing** is adjusted first (see chapter "Cassettes, Screens").
- Next, the Iontomat is set for **density** 1.0 above fog level using 20cm of water at 80kV.
- Finally, exposures are taken with 60kV and 120kV, and the **kV response** is corrected to obtain identical density over the full range of kV.

Indirect Technique

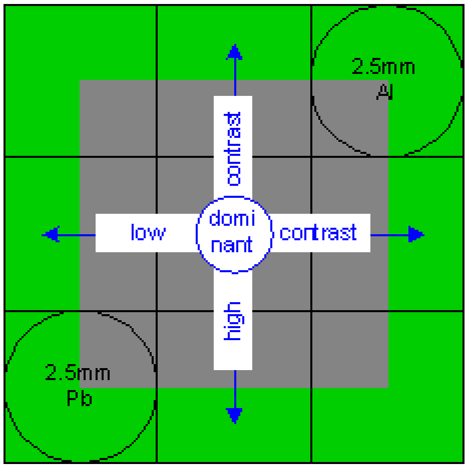
- First, the **Iontomat is calibrated**, then the various **dose levels are programmed**.
- After basic setting of the **iris in fluoroscopy**, the iris **correction** values are set for the **exposure modes**. For this, th BAS-signal is measured under standard window settings.
- Finally, the **organ programs** are optimized in close cooperation with the radiologist,

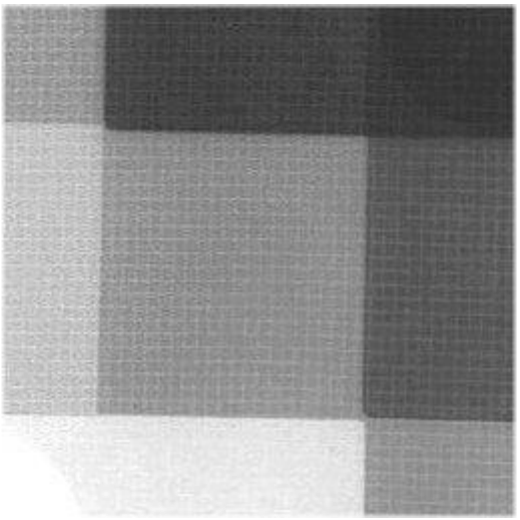
exit info End of more info on "Contrast"

.

Image Quality **IQ-Properties** 1/1

Test Device





For the demonstration of image quality properties, a specially designed aluminum step wedge has been used representing the high contrast of a thorax. Originally, the demonstration was aimed to optimize image quality for cardiac examinations, and the results we see are, therefore, from cine film. They can be applyed in general, however.

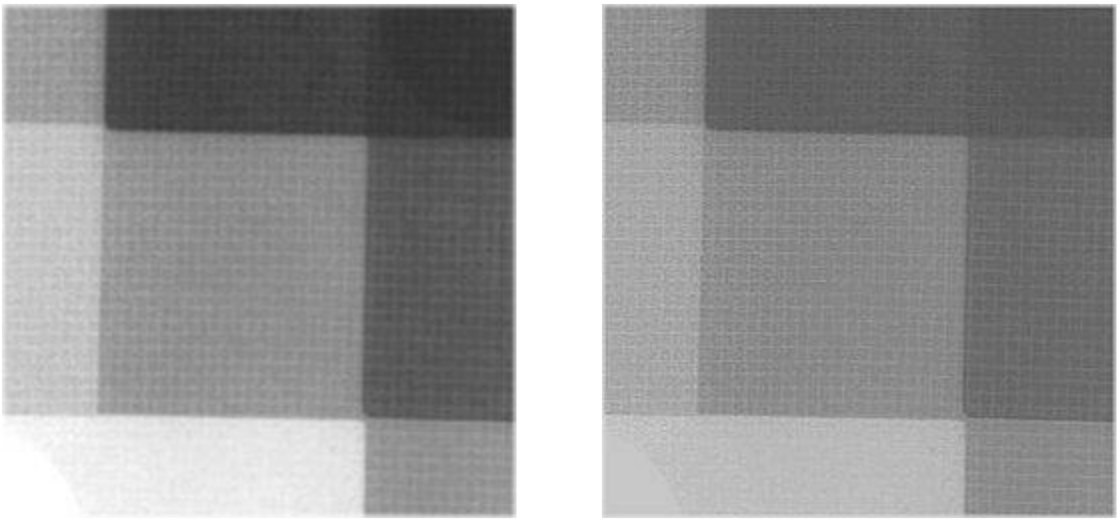
Starting from the center field, there are fields representing high and low contrast, while the mashed wire simulates small vessels filled with contrast medium.
The circles with lead and aluminum represent an extreme contrast we normally don't encounter in patients. The section marked gray, is what the images show.

back

.

.

Resolution



Resolution has a **rather subtle influence** on image quality and is often confused with contrast as is demonstrated with the two images.

At the first glance, the left, high contrast image looks sharper, and only a close inspection shows that the grid-structure of the low-contrast image on the right is much sharper.

On radiographs, anatomical details with well defined edges are rather seldom. The assessment of resolution is, therefore, **seeing fine structures** or not seeing them. A job which requires a lot of experience.

So, resolution can be tested best using technical tests.

.

Resolution

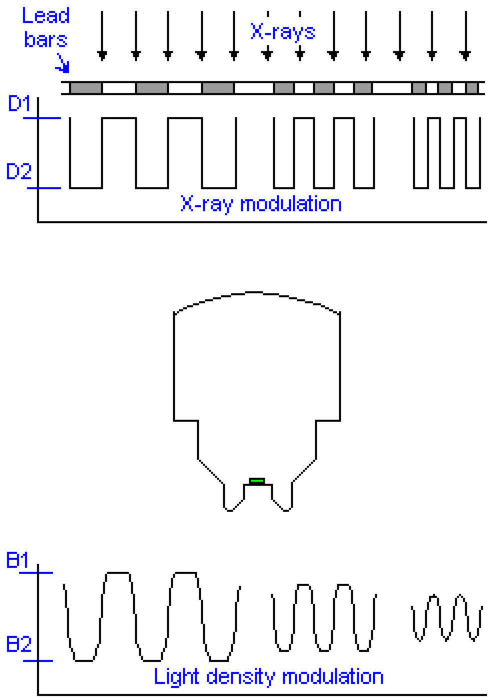
For measurement of resolution, fine lead stripes are used, arranged as "**line-pairs per mm**". The X-ray modulation measured behind this test has sharp transitions behind lead bar and radio-lucent field. This "**square-wave signal**" is **input** to the image intensifier.

Inside the image intensifier, numerous conversions take place **degrading** the signal ramps and deforming it into a **trapezoid** at the **output**.

Now, with the **resolution increasing**, the signal cannot reach minimum and maximum any longer, and the amplitude decreases. With increasing resolution, the **contrast decreases** and makes it difficult to see fine details.

What has been demonstrated with the image intensifier is basically true for all signal transfer systems. This method of testing signal transfer by comparing frequency against signal strength is called **Modulation Transfer Function** (MTF).

Transfer characteristic of an II



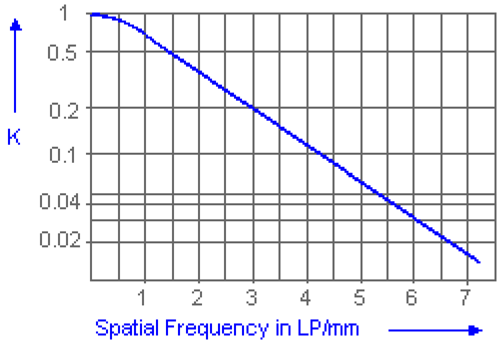
.

Resolution

The **MTF** shows the relation of contrast and resolution of a given image intensifier and zoom

Modulation Transfer Function of an II

format. With low resolution, less than 0.5Lp/mm, 100% of contrast are obtained.



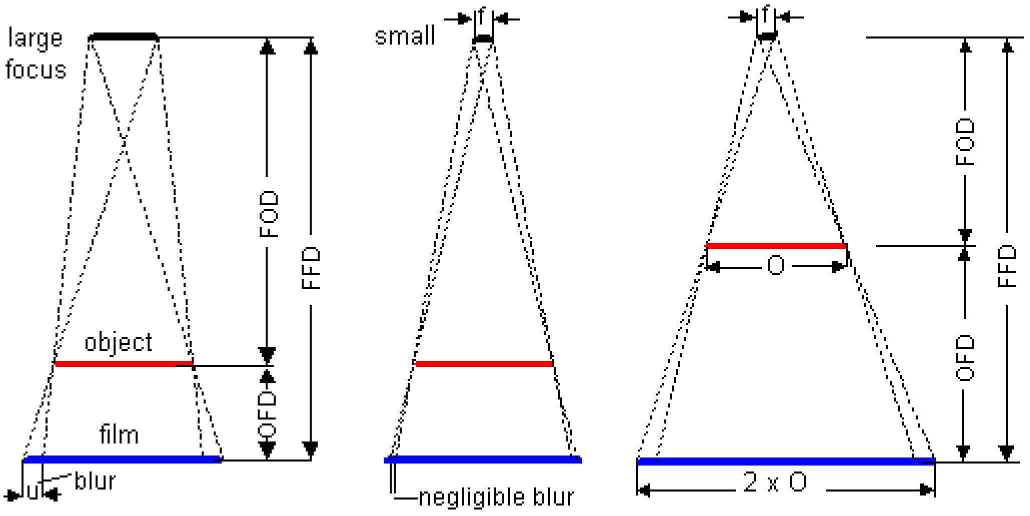
Increasing the resolution results in a significant drop in contrast: 50% at 1.4Lp/mm and 10% at 4.2Lp/mm. The **limit of resolution** is reached at 4% of contrast which is said to be the limit of human contrast perception. This value is used for system evaluation. In daily use, however, the contrast at 1 and 2 Lp/mm tells more about the system performance.

The MTF curve shown is taken from the output of the image intensifier directly. Every **additional optical and electrical device** reduces the resolution even more.

In a TV-system, the linie structure primarily restricts the resolution, while in digital systems the resolution is determined by the pixel size.

Image Quality **IQ-Properties** 4/4

Resolution



The resolution of a radiograph is also limited by the systems geometrical conditions as demonstrated above .A **large focal spot** (1.2mm) in combination with a magnification factor FFD/FOD (Film-Focus Distance, Film-Object Distance) causes a certain amount of blur degrading the resolution. The **small focal spot** (0.6mm) provide better resolution.
An increase in OFD (Object-Focus Distance) increases the **geometric magnification** and the amount of blurr likewise.
If geometric magnification is chosen for examination of small details it has to be

same geometrical conditions in combination with a

combined with a micro-focus (<0.4mm).

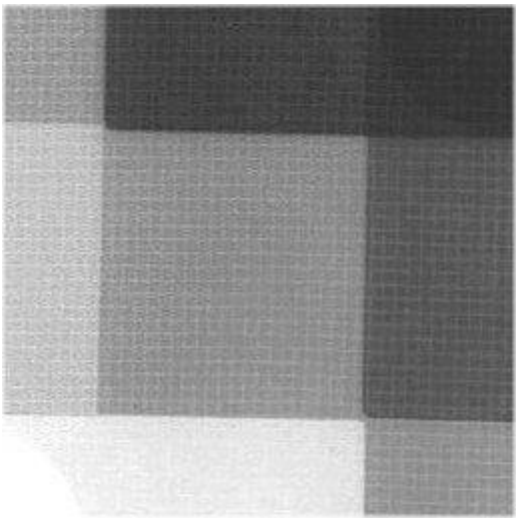
End of "IQ-Properties, Resolution"

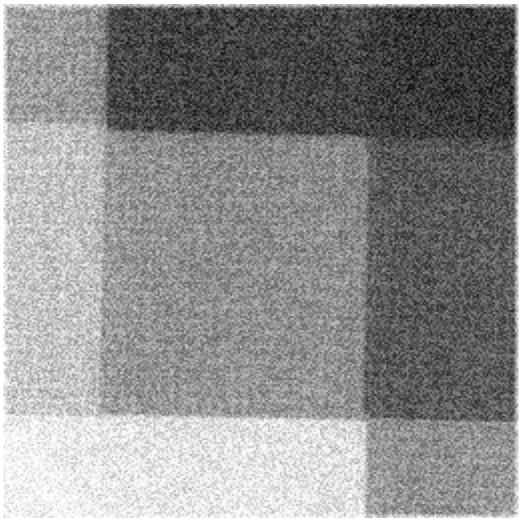
.

.

Image Quality **IQ-Properties** 1/2

Noise





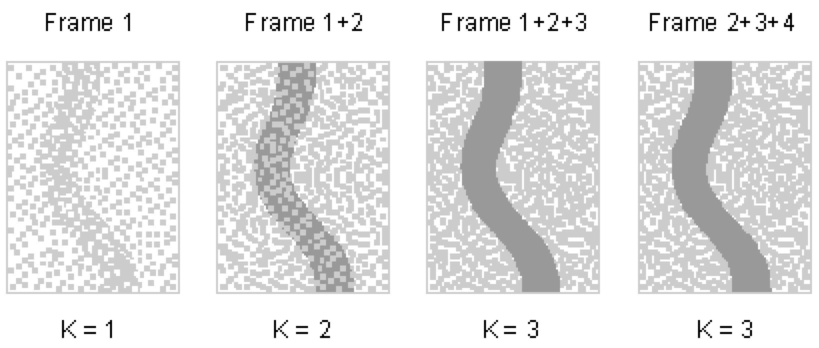
A certain amount of electronic noise is inherent to all imaging systems. In an X-ray imaging system, however, **quantum noise** or quantum mottle dominates.
This is due to the fact that inside the image receiver individual X-ray quants are integrated over a certain time period, referred to as **dose per frame**.

A **high dose** per farme results in a **homogeneous** image with details easily accessible (left) while a **low dose** per frame causes a **noisy** image with reduced resolution. Since radiation is dangerous, a suitable compromise has to be found for every **kind of examination**.

.

Image Quality **IQ-Properties** 2/2

Noise



In **fluoroscopy**, we operate at a **low dose rate**. And as every single image has integrated too little X-ray photons to be perfect, the image has a high amount of "quantum noise".
Based on the fact that two successive images mainly differ in the noise pattern, this noise can be reduced by **digitally integrating** images.

The images above demonstrate the integration effect of one, two and three images, referred to as K-factor. With K = 3, the last three frames are kept in image memory while earlier frames are discarded.
The disadvantage of integration shows up at fast moving objects which are blurred or smeared.

End of "IQ-Properties, Noise"

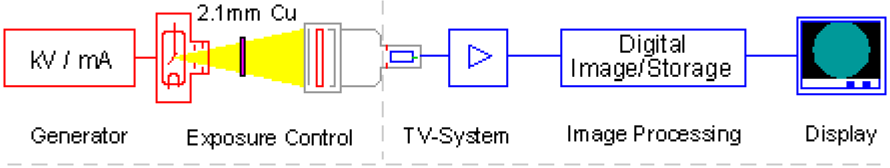
.

.

Image Quality

IQ-Tests

Overview



For testing purpose, the X-ray imaging chain can be split up into **two functional units:**

- **Image production**
  This means production of radiation (generator), image formation (image intensifier) and control of radiation (Iontomat).
- **Image processing**
  The image is picked up by the TV-system and transferred to the digital image processing unit Fluorospot, serving also as archiving medium. Gamma correction and gain along with noise reduction and edge enhancement are performed for optimum display on

The proper function of these functional units can be tested by means of two comprehensive tests:

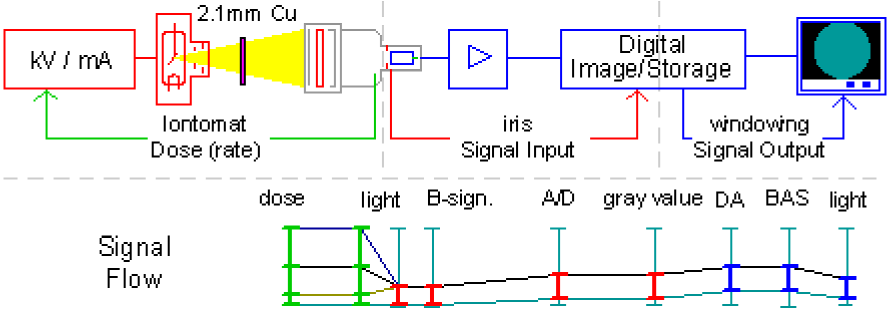
- The radiation part is tested performing the **Indirect Dose Test** using the 2.1mm Cu-filter.
- The image processing is tested by means of the **Signal Dynamic Test** using the Dynamic Test instead of the 2.1mm Cu-filter in combination with evaluation software.

In any case, the resulting data is to be compared with the entries in the **Image Quality Test Certificate**.

the Monitor.

.

Adjustment

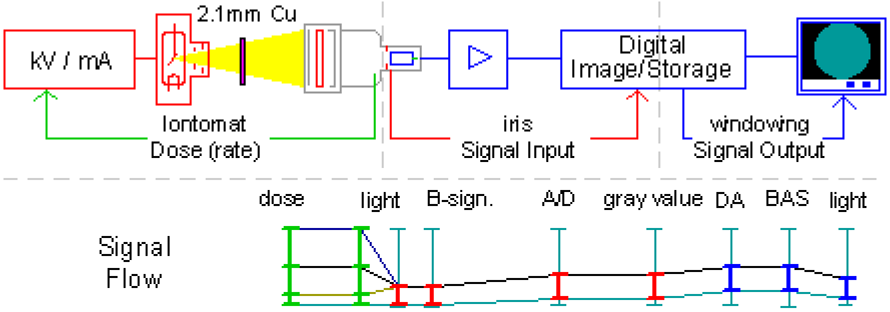


During **system adjustment**, the dose(rate) levels of all operation modes and image intensifier formats are configured.
During exposure, the light at the II output is measured and the **Iontomat** serves for the correct amount of dose resulting in various light levels.
The TV-camera providing the signal input, however, requires a fixed light level for optimum performance which is provided by the **iris control**.

Based on this light level, all signal processing is carried out on set parameters. The analog video amplifier is set to be well within the range of the A/D converter.
After digital signal processing, **windowing** is used to provide contrast and brightness as desired.
Notice the pedestal added to the signal making the black image portions brighter against the black image frame.

.

Basic Test



According to our image quality assurance system, a full **Basic Test** is carried out after complete sysem adjustment, and the results are entered into the **Basic Test Certificate**.

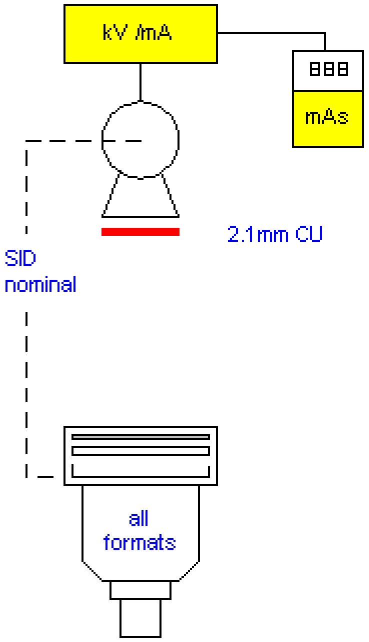
The follow-up tests are intended to check the **system constancy** regularly.
For this, two simple tests procedures have been developed:

The test comprises all **major adjustments** and **component tests** plus additional **system tests**. So, the Basic Test Certificate serves as a reference for all future service calls.

1. The **Indirect Dose Test** is used to test the performance of generator, image intensifier and dose regulation.
2. The **Dynamic Signal Test** is used to test the performance of the iris and analog and digital signal processing.

.

Indirect Dose Test



Test Conditions

Following the standardized test conditions:

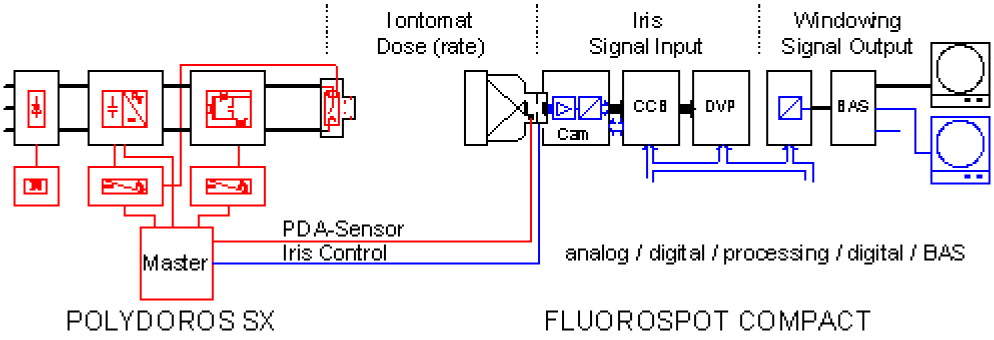
- **SID**
  - 115 cm with over table units
  - 100 cm with C-arm units and
  - max. with under table units
- **Absorber** 2.1mm CU-filter
  Only the single sheet precision type of filter must be used.
  ART Nr. 9900598 XE999
- **II-Formats**
  - all formats in fluoro mode
  - DFR-mode according the the test certificate

The resulting **kV/mA** combination depends upon the II-size and fluoro mode selected. Any change in radiation quality, drift of the Iontomat or aging of the image intensifier is reflected by a change in kV/mA combination. In DFR mode, the exposure data are set by the test program selected while the resulting **mAs** are measured.

The readings are compared to the test results recorded in the **Basic Test Certificate**.

.

Additional Tests



If the test fails, additional tests have to prove the source of trouble. The block diagram helps in orientation.

X-ray Tube

For testing the tube output, the **Dose Yield Test** is used. This test is based on the given relation between electrical input to the X-Ray tube and dose output. The tube output is effected by additional filtration.

Image Intensifier

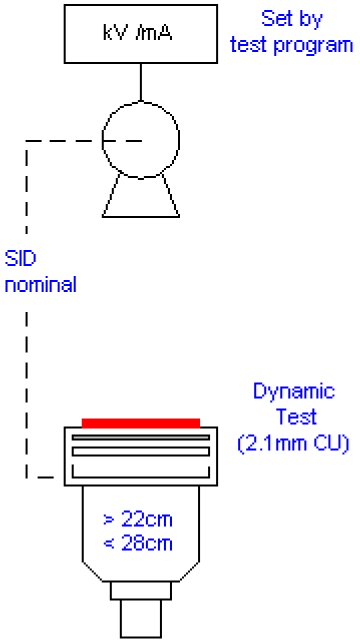
Image intensifiers are known to loose gain when used. The amount of wear depends very much on the light intensity at the output screen.

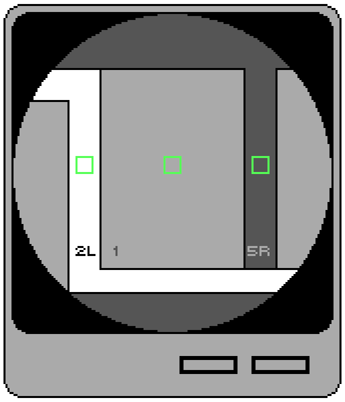
Iontomat

The Iontomat keeps a constant light level at the II output. That does not mean, however, that the dose is constant since the II has a non linear kV response and is loosing gain.
A gradual increase in dose within several month is verified by **dose measurement** and must be compensated by recalibration of the PDA-sensor.

.

Signal Dynamic Test





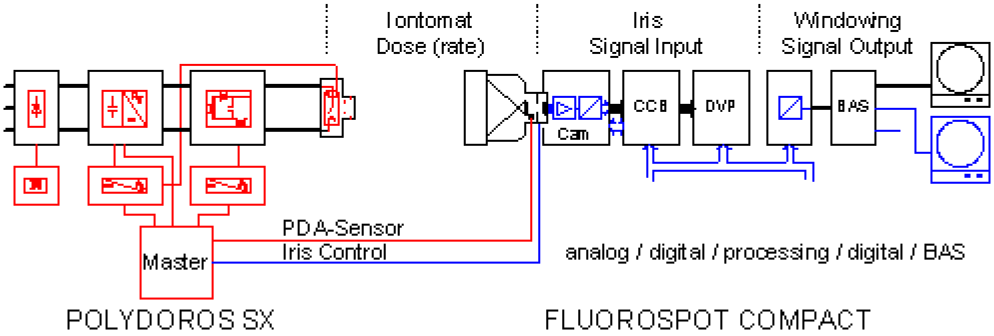
For testing the constancy of the **image processing** part, a software feature of the **Fluorospot** is used. With this, the gray levels of the digital image can be measured in a region of interest. These results are compared to the entries of the Basic Test Certificate.
The 2.1mm CU filter is replaced by the **Dynamic Test** plate for this test providing three differently absorbing areas reflecting the dynamic performance of the imaging system.

As with all comprehensive tests: If the tolerances are exceeded the components involved have to be tested / adjusted individually.

.

Additional Tests Fluorospot Compact

System Diagram



In contrary to the generator where closed loop circuits serve for constant conditions, the imaging chain is strictly based upon set parameters. Additionally, all adjustments can be done without radiation, based on test signals only.

So, if the gray values are incorrect check the two systems:

- **Internal signal processing**
  For this, the Fluorospot Compact software provides a number of tests.

more info on Fluorospot TOP

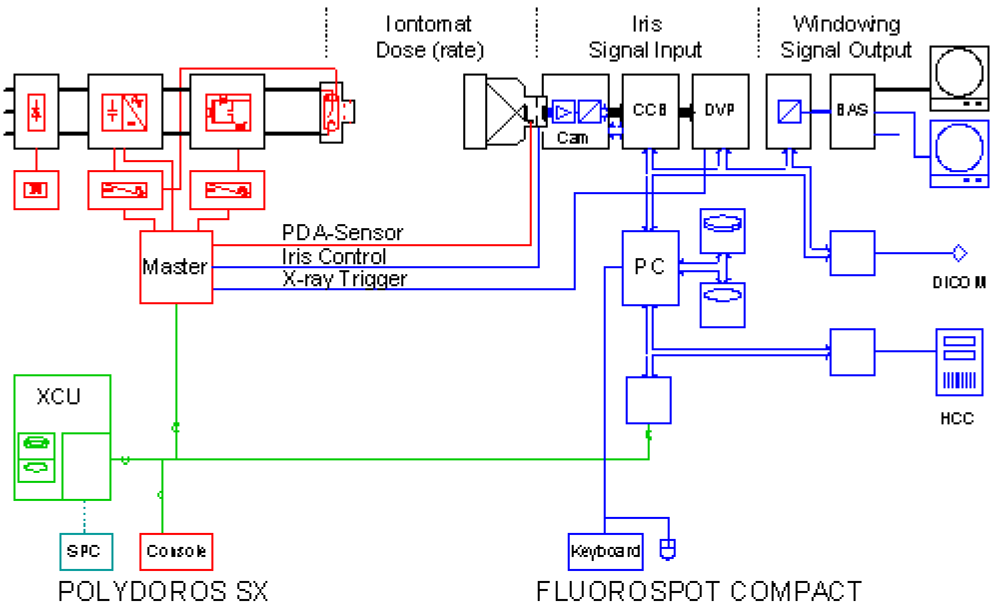
- **Iris control**
  Since the iris is part of the generator, the basic setting is part of the generator service software while the iris correction for the various operation modes is programmed in the XCS service software main manue.

Finally, the **monitor** has to be set for optimum performance using a test pattern, and the controls should be locked.

End of the paragraph "IQ-Tests"

.

Fluorospot Compact System



The FLC is a **CCD-chip** based TVsystem with digital image processing features. The system controller is a PC running under Windows NT and is connected to the XCU via an XCS interface.

The **camera head** includes an analog video amplifier and an A/D converter.

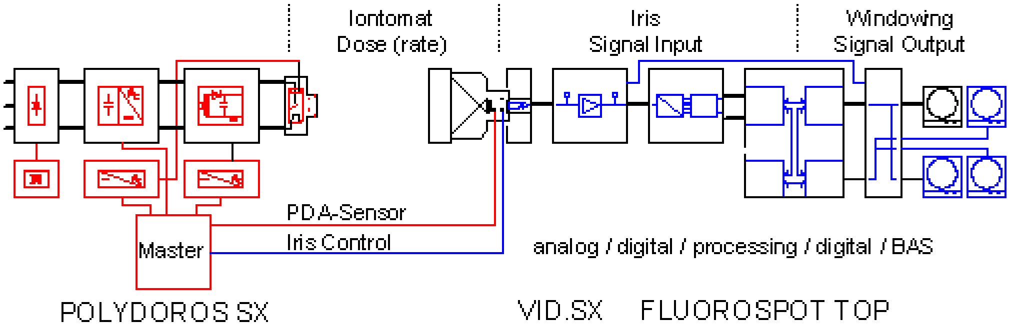
Image processing takes place on the CCB and DVP boards.

The **images** are stored in PC-RAM and output to an SVGA board diriving the **BAS converter** providing a standardized signal.

Additionally, the image can be output to a hard compy camera or to a network.

back

Additional Tests Fluorospot TOP



As part of an X-Ray imaging system, all Fluorospots are identical as is the generator part with dose regulation and iris setting. The imaging hardware, however is completely different.The operating and service software however provides similar functions.

The **Videomed SX**, despite of being an analog doesn't require adjustments. It is controlled by the organ programs only.

The **monitors**, again, are adjusted to set minimum and maximum brightness. Since the maximum brightness is set rather moderate,

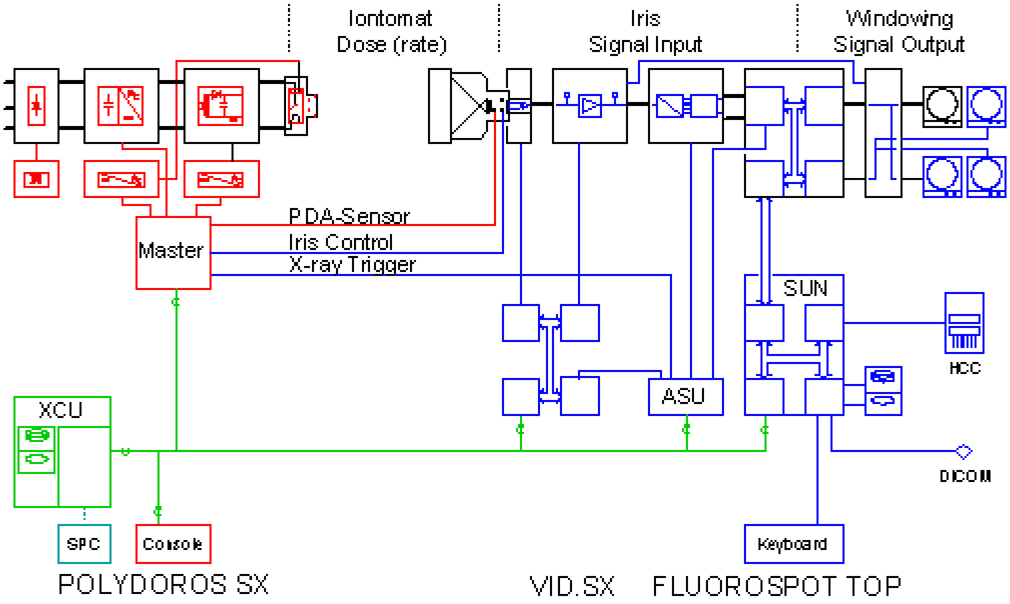
system, provides good constancy due to self adjustments during startup. The various modes of gamma correction and gain are selected by the system controller (XCU) according to the configuration.
The **digital imaging part**, including the A/D and D/A conversion, has proven to be stable and there is no forced wear of CRT.

As mentioned before, the generator is set to various dose levels, resulting in a wide range of light levels in front of the pickup tube. On the other hand, the gamma correction and gain of the Videomed SX are optimized for one light level only. The adaptation is handled by the **TV-iris control**.

exit info

.

Fluorospot Top System



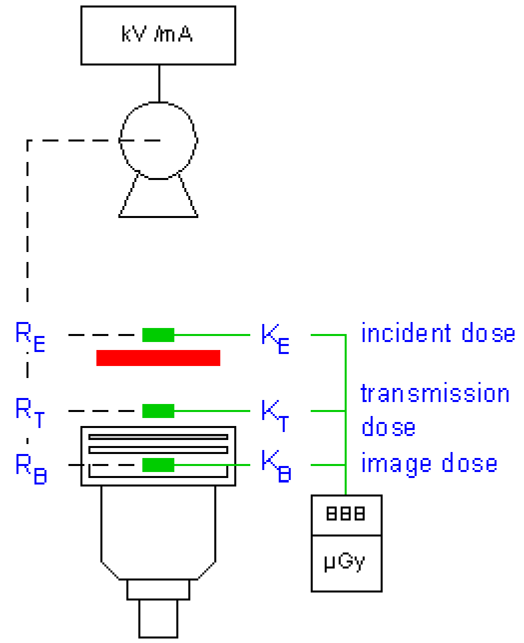
The FLT is composed of four mayor components:
First, the TV-system **Videomed SX**, featuring a pick-up tube and pure analog signal processing.
Next the **A/D converter DVS** including noise reduction generation an optimum digital image.

Image processing is done by a UNIX based **SUN-workstation**. Th
monitor via an A/D converter or to the hard copy camera or to a ne
Imaging is synchronized by **ASU** while the System operation is co

exit info

.

Dose Terms



In general, dose measurement is a rather tricky business, and a lot of damge to image quality has been done based on false measurement. To prevent theis, standardized procedures have been introduced.

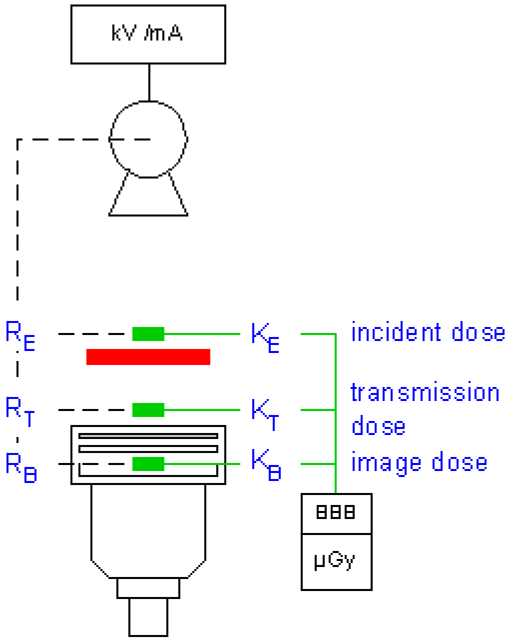
First of all, one has to clarify the **kind of radiation** to be measured. That determines the **location** of the measurement along with the **test conditions** and the possible application of **correction factors**.
In diagnostic X-ray imaging we measure three different kinds of radiation:

Incident Dose

In our documents identified by the term K_E.
The incident dose is measured in front of an absorber with nothing inbetween the tube and the detector. Assuming that the air doesn't absorb radiation, the intensity of the radiation decreases with the distance according to the inverse-square law. So, the distance (R_E) from the detector to the focal spot has to be recorded. Due to the missing absorber, we have to consider high radiation intensity here. In medical application, the incident dose is equivalent to the **skin dose**.

.

Dose Terms



Transmission dose (K_T)

The dose is measured behind an absorber and directly on the table top or in front of the spotfilm device respectively and is the **system dose** in radiation protection. The absorber has a beam hardening effect which must be compensated by a correction factor related to the detector characteristics.

With the absorber close to the detector, scattered radiation has to be considered falsifying the measurement, esepecially, when water is used as absorber.

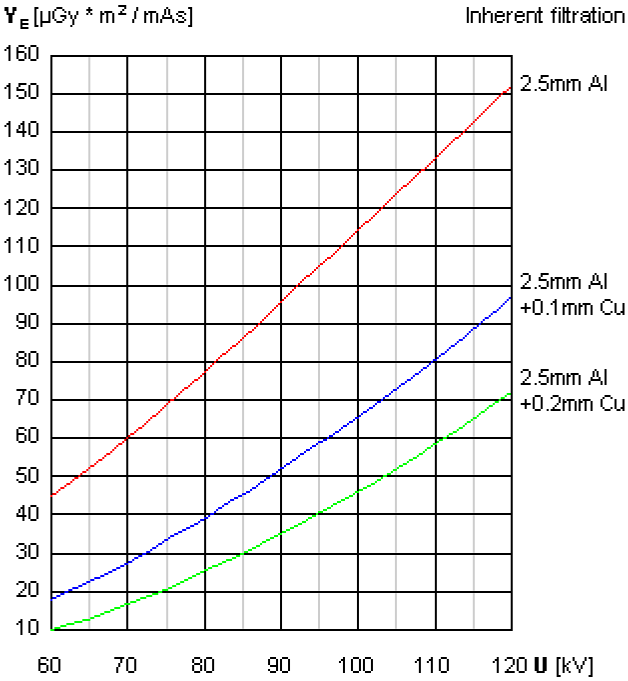
While the measurement location for transmission dose is rather convenient, the test conditions are somewhat problematic. To get reproducable test conditions, we allways use copper filter directly attached to the collimator and the standard SID.

Image receiver dose (K_B)

This is the dose measured in the image receiver plane and is directly related to image quality by controlling the **quantum noise**. Measuring behind the anti scatter grid, the influence of scattered radiation can be neglected.

▼ ▲ *End of the paragraph "Dose Terms"* 13

.



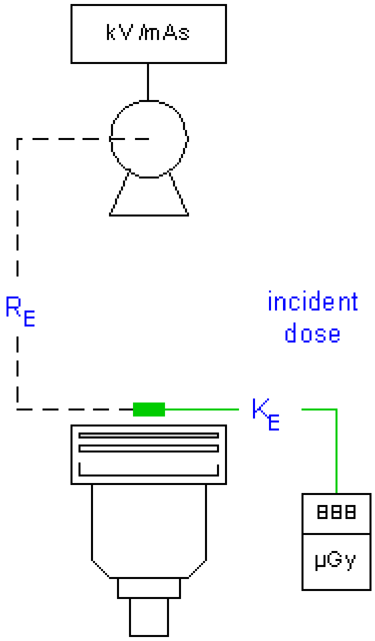
The table shows the relation between tube voltage, filtration and amount of radiation generated. That is, the dose per mAs at 1.0m distance. For varying distances between focal spot and place of measurement the inverse square law has to be considered (R_E^2).

This information is used for the calculation of **skin dose** K_E.

Exposure	$K_E = \frac{Y_E*Q}{R_E^2}$
	$[\mu Gy] = \frac{[\mu Gy*m^2/mAs]*[mAs]}{[m^2]}$
Fluoroscopy	$K_E = \frac{Y_E* I * t}{R_E^2}$
	$[\mu Gy] = \frac{[\mu Gy*m^2/mAs]*[mA]*[sec]}{[m^2]}$

.

Dose Yield



The dose yield test is a rather comprehensive test since it is based on the correct setting of kV, mAs and filtration.

For a quick system check you may even use a pen dosimeter readily availabe in every hospital.

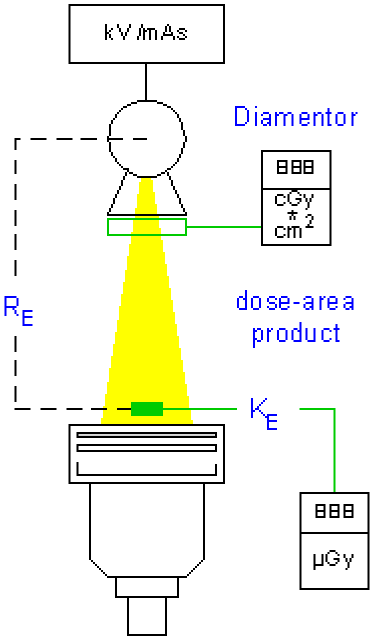
Make the following test setup:

- No additional filtration
- RE = 1m
- kV = 70
- mAs = 10
- Read-out: 600µGy ± 30%

According to the table on the previous page, the dose yield is 60µGy per mAs under the given conditions.

End of the paragraph "Dose Yield"

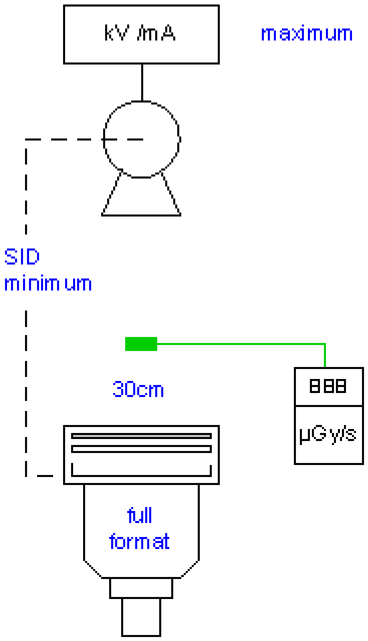
Skin Dose



In **radiation protection**, the skin dose is a key parameter. Additionally, the introduction of DFR has shown a negative side effect: The "low dose requirement" of image intensifiers in combination with no need to changing film cassettes has led to an increase of exposures per examination and, in some cases, led to a higher amount of absorbed dose compared to standard procedures.
So, with interventional DFR-systems, monitoring of the skin dose has become obligatory.

The technical equivalent to the skin dose is the **area dose product**, where the intensitiy of the radiation in combination with the area covered is measured indicating the total amount of radiation entering the patient.
The area dose product is measured directly at the collimator using a **Diamentor**. Here, the intensity is high and the field is small. Measured on the table top, the dose rate is low while the area covered is large. The product of dose rate and field size is allways the same regardless of the distance to the focal spot.

Skin Dose



In **fluoroscopy**, international standards require not to exceed a skin dose rate of

- 10 R/min or
- 1450 µGy/s

To verify this, a standard test procedure has been introduced:

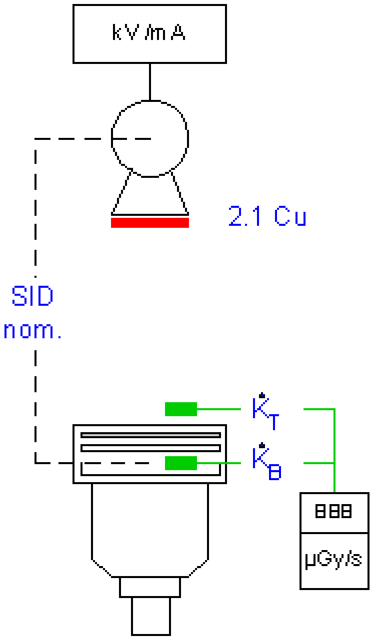
Under worst conditions, minimum SID and maximum tube output, the dose rate is measured in front of a virtual 30 cm-patient.

Special fluoro modes, indicated by a beeper, may overpass this limit.

End of the paragraph "Skin Dose"

.

Dose Rate



In fluoroscopy, the correct **image receiver dose rate** is the key element for image quality as well as for radiation protection.
Since in DFR-technique (image intensifier) all modes are controlled by the same hardware, testing one fluoro mode only represents the condition of the entire dose control system.

The test conditions are shown here.

- For correct measurement, the **detector** must be placed close to the II input and next to the dominant of the PDA (Photo Diode Array).
- **Radiation quality** should be 70 to 80kV and filtration of 2.1mm Cu.
- **SID** shold be the focussing distance of the grid.

If the II input isn't accessible the **transmission dose rate** has to be measured instead, and the result has to be corrected by the **attenuation factor** of the grid (C-arms) or the spotfilm device (universal units).

.

Image Quality — IQ-Tests — 15/15

Dose Rate

Dose levels related to the II-field size

Format		40	33	30	**27**	22	17	14
Zoom factor		0.5	0.65	0.7	**1.0**	1.5	2.5	3.7
Fluoro dose rate	[nGy/s]	87	113	120	**174**	255	440	650
	[µR/s]	10	13	14	20	30	50	75
Exposure dose 100	[nGy]	435	565	610	**870**	1270	2190	3220
	[µR]	50	65	70	100	150	250	370

Always keep in mind that **dose (rate) levels are programmed** (rather than "adjusted") and set by the system's dose control according to the

- doserate **calibration** and
- the **zoom dose factors** programmed.

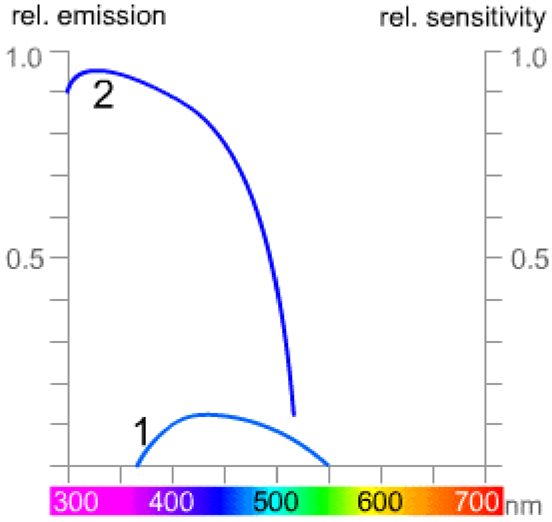
All nominal dose values are given for the 27cm format and calculated to the format selected according the the zoom dose factors:

The **zoom factor** describes the ratio of the various **input areas** to the reference format 27cm.
Notice the variation in dose (rate) levels when switching to another zoom format. Working with a small format allways increases the dose, and along with it reduces the amount of quantum noise which is a wanted affect. However, at the same time, the patient's absorbed dose increases!

End of the chapter "IQ-Tests"

.

Intensifying Screens — Film-Screen-Systems — 1/3

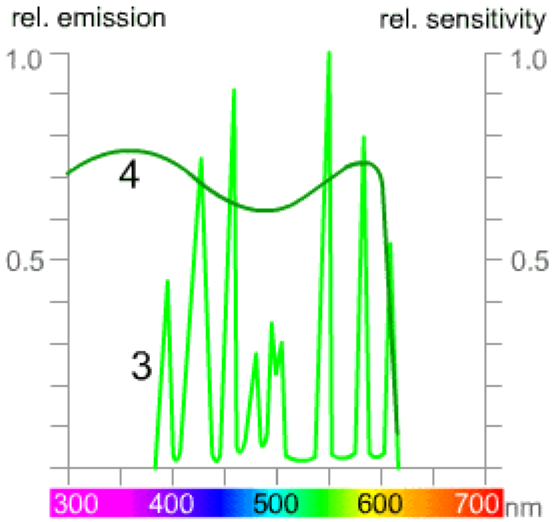


X-rays are in principle able to expose film emulsion, but with low efficiency. When the radiation is used to stimulate crystals to fluoresce and this light is used to expose film, this results in considerably improved efficiency. For many years, **calcium tungstate** was used as the luminescent substance. *Curve 1* shows the characteristic emission with its maximum in the blue range.

Film emulsion is normally sensitive to violet and blue light. The sensitivity curve of this type of **unsensitized film** is shown in *Curve 2*. It comes very close the emission curve of the calcium tungstate screens shown in the graph. This type of Film is known as a "blue system".

In combination with this film, green and red darkroom lights are safe.

.



In recent years, the so-called "**rare earth screens**" have appeared on the market. Rare earths are luminescent substances which produce considerably more light for the same dose. Screens can therefore be produced which have the same resolution at a considerably lower dose.
A typical spectral characteristic can be seen in *Curve 3*.
Compared with calcium tungstate, pronounced peaks can be seen which are characteristic for the luminescent substances involved. A prominent feature is also the emission in the green range.

In order to utilize this light, the film emulsion must be made color-sensitive as in *Curve 4*. This **orthochromatic film** curve extends into the green range. This combination is referred to as a "green system" and offers considerably more sensitivity over a blue system.

This film requires a strictly filtered red darkroom light.

.

Film-screen-systems are classified according to their sensitivity. For this, 1000µGy is divided by the system's nominal dose (the dose required to produce density 1.0 above fog).

So, a system of class 400 accordingly requires a dose of 2.5µGy in order to achieve the net density 1.0 and a resolution better than 2.4 Line pairs per mm.

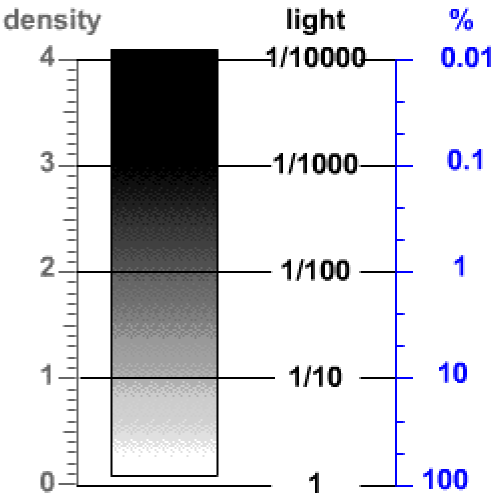
type of intensifying screen	sensitivity class	nominal dose µGy	limit of resolution lp/mm
detail	200	5	2.8
universal	400	2.5	2.4
high speed	800	1.25	2.2

The table shows the relationships between screen class and the required minimum resolution according to DIN.

End of chapter

.

Optical Density **Film-Screen-Systems** 1/5



Density

The film density, the ability to **absorb light**, is caused by tiny silver grains held inside the film emulsion. For this, the transparent radiograph has to be evaluated on a **viewing box**.

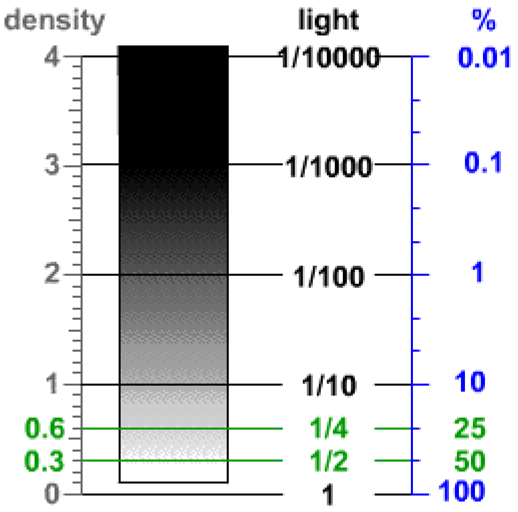
The density scale is calibrated to the light output of the light box. Here, we get the **maximum** possible light level, **density 0**.

If only **1/10** of the light passes the film, we have got **density 1.0**.

Density 2.0 means **1/100** of the light penetrating the film.

.

Optical Density **Film-Screen-Systems** 2/5



Logarithmic Characteristic

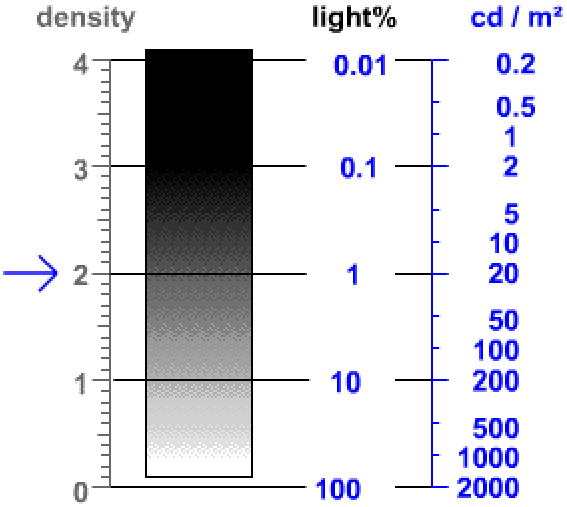
The scale seems to be rather coarse. However, it is adapted to the sensitivity characteristic of the **human eyesight**.

So, the density scale is of logarithmic nature and still it looks pretty linear.

An increase by **density 0.3**, that is factor 2 decimal, causes the light output to drop to one half.

.

Optical Density **Film-Screen-Systems**



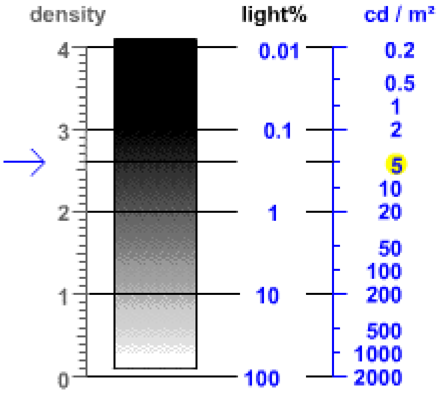
Viewing box

The output of a light source is measured in **cd/m²** (candela per square meter) which is based on a **linear** scale.

For reliable assessment, the radiograph should provide 20 cd/m² in the diagnostic area (at around density 2.0).
For this, the viewing box has to provide **2000 cd/m²**.

.

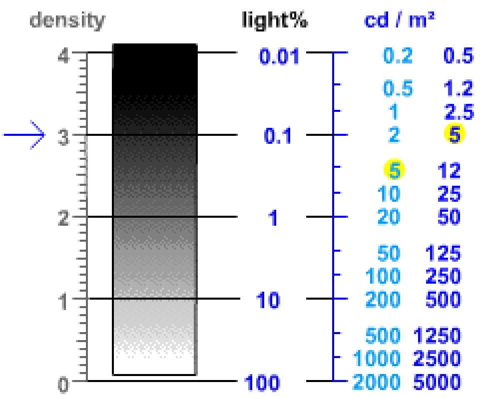
Optical Density **Film-Screen-Systems**



Maximum Density

Density 3 is not visible normally, and with modern radiographic films, the density is limited to about 3.5.

Under normal viewing conditions, that is room light switched on and the collimating shades of the viewing box not used, the maximum useful density is at **around 2.6**. Which provides 5 cd/m².

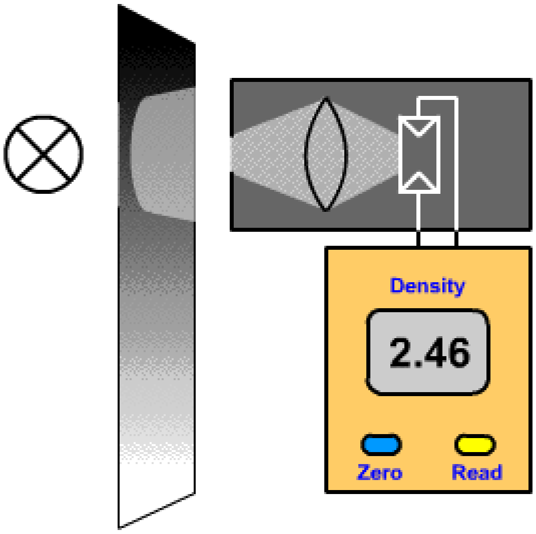


For pushing up the limit to **density 3.0**, the viewing box has to provide 5000 cd/m², and the shades collimated to the film format.

For assessment of high densities as with mammography, a small light box capable of 10000 cd/m² should be available.

.

Optical Density **Film-Screen-Systems** 5/5



Densitometer

Light pick-up
The light emitted by the lamp and passing the film is projected onto the photo cell.

Zeroing
Without film in place, the display is set to zero during measurement.

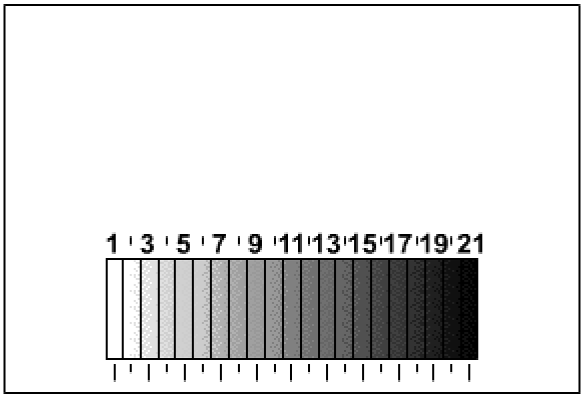
Density measurement
The film is put in place and a measurement is started. Don't release the measurement button before the readout is stable.

In general, measurement of densities above 4 is rather inaccurate since the light level is extremely low (1/10000 of the original), and ambient light may influence the measurement.

End of Chapter

.

Exposure **Film-Screen-Systems** 1/3



Test Film

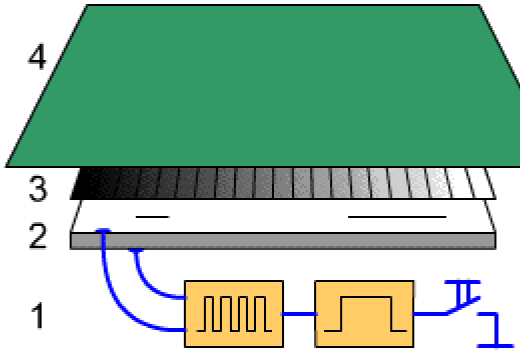
For evaluation of film processing, a **density wedge** is exposed to the film under examination.

This wedge represents **standardized** increments of **exposure** to the film. So it is possible to assess the **characteristics** of both film and processing.

Additionally the **constancy** of processing can be tested using this film.

The instrument used for exposure is called **sensitometer**.

.



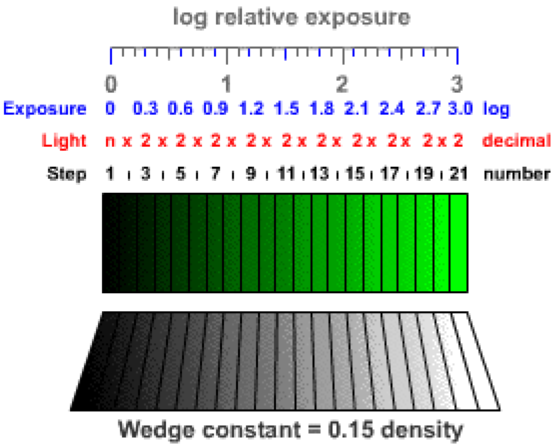
Sensitometer

Density wedge
Attenuated by a **precisely shaded** density wedge (3), the X-ray film (4) is exposed.

Light source
An electro-luminescent plate (2) is used for exposure. Here, **luminescent crystals** are stimulated by AC voltage (1).

For simulation of different light sources, the luminescent plate can emit both green or blue light. This is achieved by stimulating the crystals with different frequencies.
Since the absence of blue screens the **green light** is used in general.

.



Exposure Scale

The **wedge constant** is **0.15** according to international standards. So, the density is decreased by 0.15 per step.

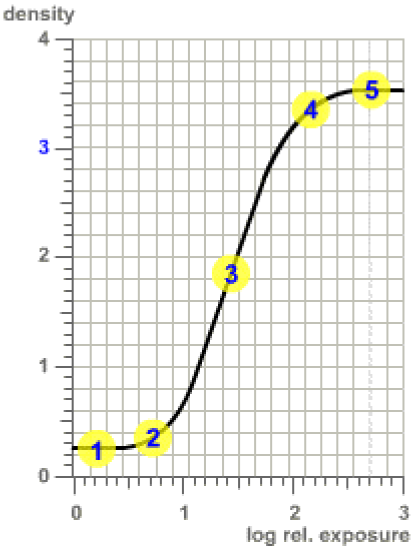
21 step range of exposure
The 21 steps represent an exposure range of **1:1000**.
The amount of exposure is adjustable (relative) to match both film and processing sensitivity. Only in Germany, the light output is standardized.

Graduation
Two steps represent twice the amount of exposure.

log exposure scale
Due to the logarithmic nature of density, the exposure the scale is sensitive at low light levels while covering a wide range at the same time.

End of Chapter

.



Sensitometric Paper
The 21 steps of the wedge are related to the exposure scale. The densities of a test wedge are measured and entered in the paper. This is the characteristic curve of film plus processing. If either is changed, so is the curve.

.

Sensitometry

The assessment of film properties is called sensitometry. For this, a film has to be exposed by means of a sensitometer and processed under controlled conditions. In the end we get a **test wedge** to start with.

The Characteristic Curve

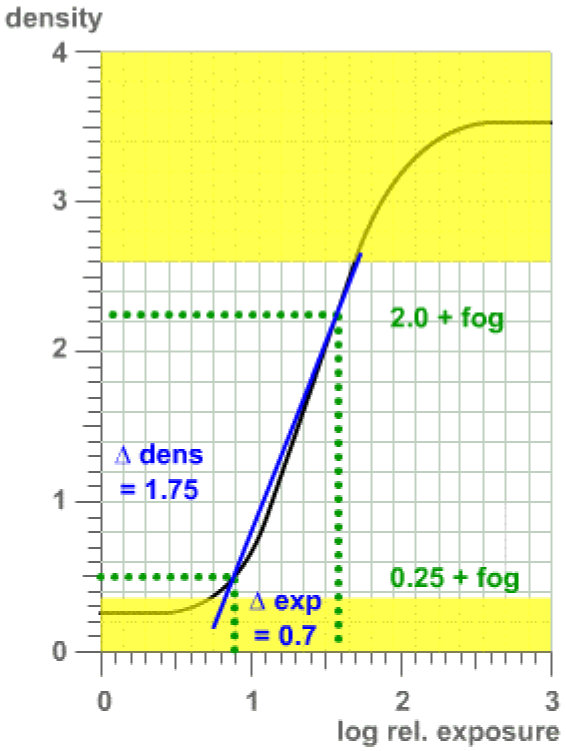
1 Fog
The result of faulty crystals, aging, and used-up developer.

2 Toe
The soft transition from white to gray.

3 Straight part
Dominating the image contrast.

4 Shoulder
Soft end of the gray scale.

5 Maximum density
given by the amount of silver grains



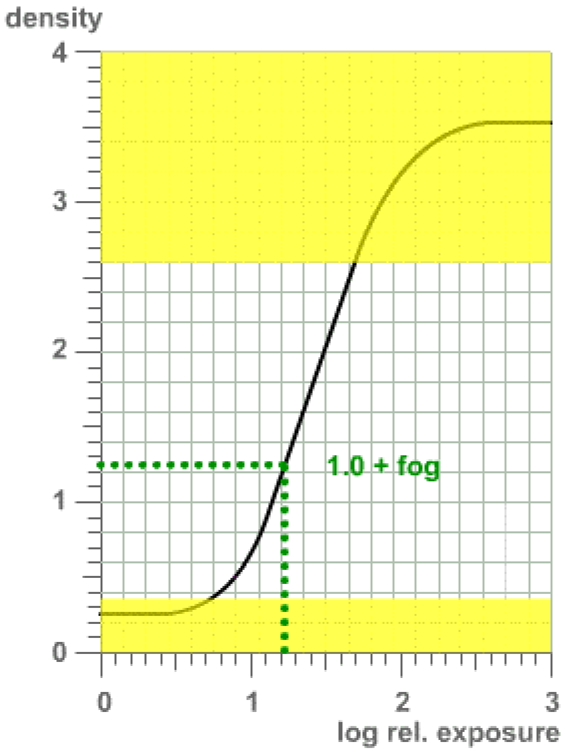
$$\frac{\Delta \text{ densities}}{\Delta \text{ exposure}} = G \qquad \frac{1{,}75}{0.7} = 2.5$$

Limits of Evaluation
Of all the curve, only a part carries information ready for visual assessment.
All densities above 2.6 are regarded as just black.
And at the low end, information must stand 0.1 above fog to become visible.

Average Gradient
So, the vital part of the characteristic curve is a slightly bent straight line with a flat gradient at the toe and a steep one in the straight part.
For simplicity, a compromise is found: the average gradient. A straight line intersecting two points of the curve.

The lower evaluation point is located at density 0.25 above fog.
The upper point of evaluation at density 2.0 above fog. For calculating the average gradient:Δ of densities is divided by Δ of exposure.

This is the **contrast gain** adapting the low X-ray contrast to the wide range of useful densities.



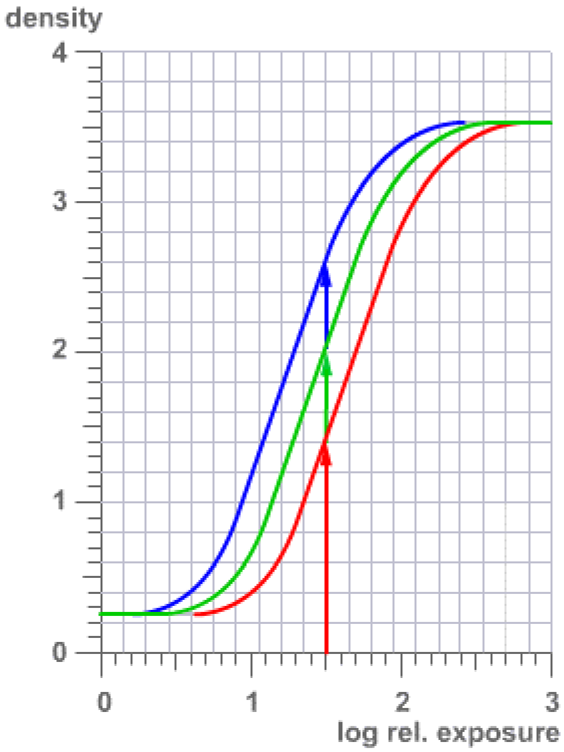
Sensitivity

This is the amount of exposure required to get density 1.0 above fog level.

Altering processing conditions like chemistry or temperature or processing speed, or switching to a different brand of film, all alters the characteristic curve and thus the speed.
And. with a given amount of dose, the radiograph will definitely look different!

▼ ▲

.



Caution

Since the **light output** of sensitometers may be **set differently**, the resulting sensitivity value differs accordingly.

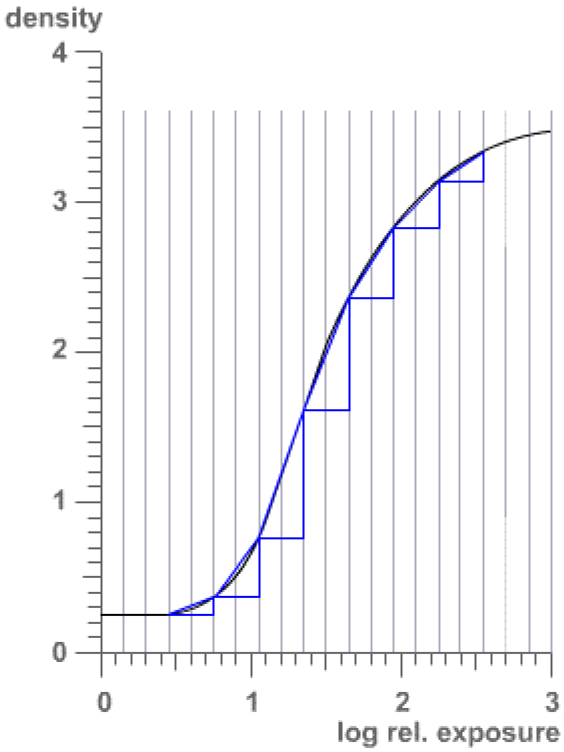
In the graph, the blue sensitometer has the longest exposure time and the red one the shortest. Notice that only the position, the sensitivity, changes while the curve is not affected.

To overcome these problems, all sensitometers used in Germany must be calibrated to a standard light output.

End of Chapter

.

.

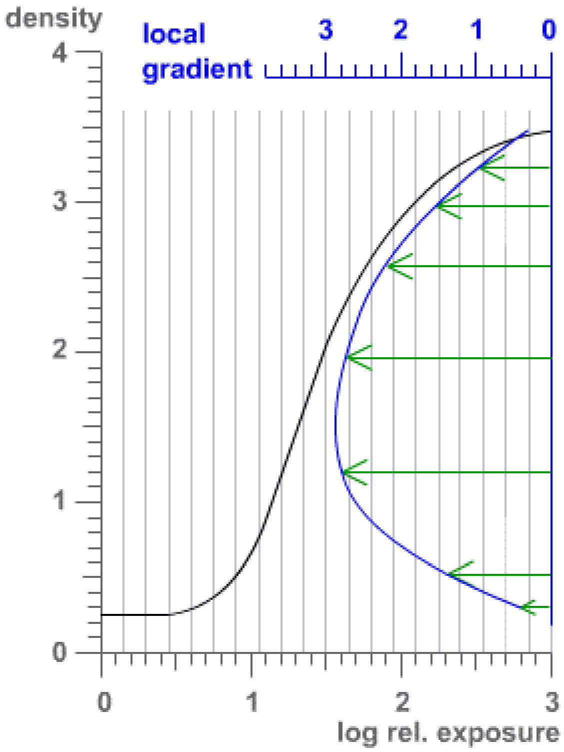


Local Gradient

The average gradient is suited perfectly to describe film processing in general. The characteristic curve, however, treats the gray scale in a very specific way.

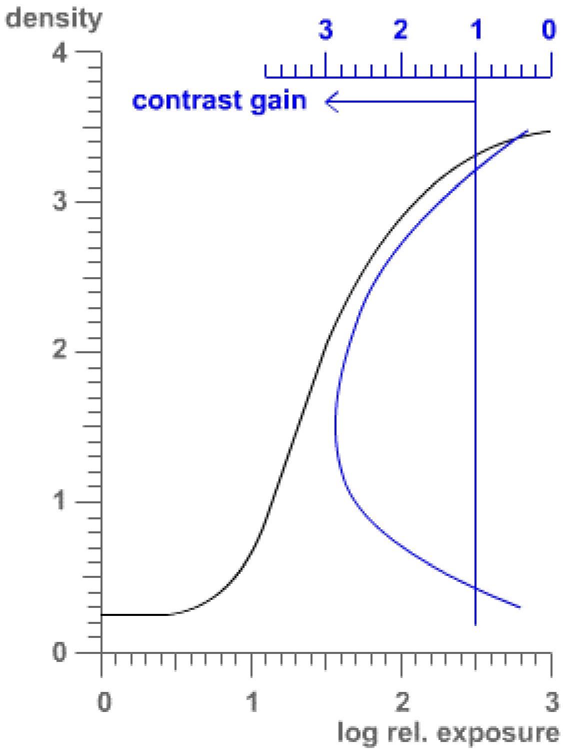
This is shown by the individual local gradients. For this, the characteristic curve is split up into individual sections of 0.3 increase in exposure and the local gradient is calculated.

.



Entering these values into the local gradient scale, we get a curve describing the variations in local gradient with respect to the density.

.



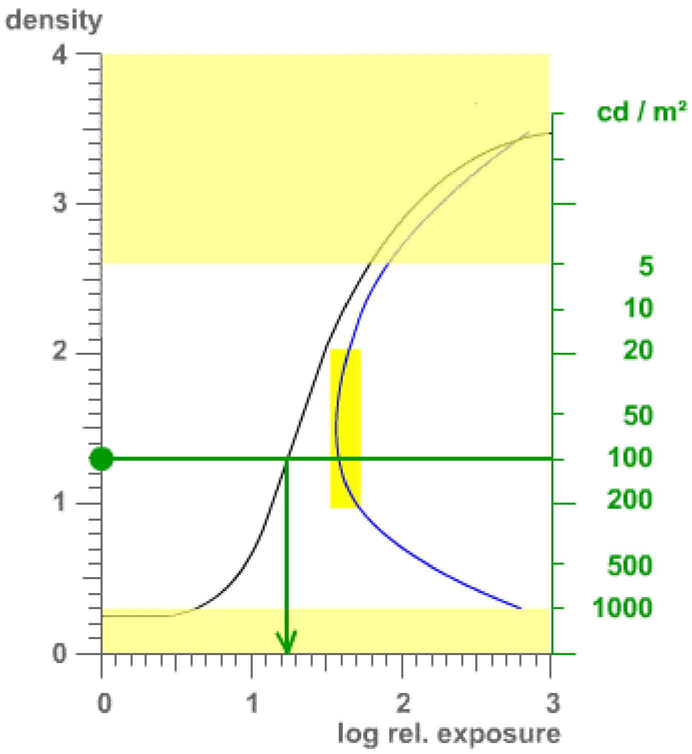
Contrast gain

The local gradient indicates the gain of image information in relation to areas of density.

Values larger than 1 indicate gain while lower values mean attenuation.

With optimum film processing, the range of maximum gain lies well inside the diagnostic range of densities.

.



Useful range of densities
The range in which to place the image information is set by the lower and upper limits of evaluation.

Average density
By experience, the average density is set to density 1.0 above fog; that is density 1.3.

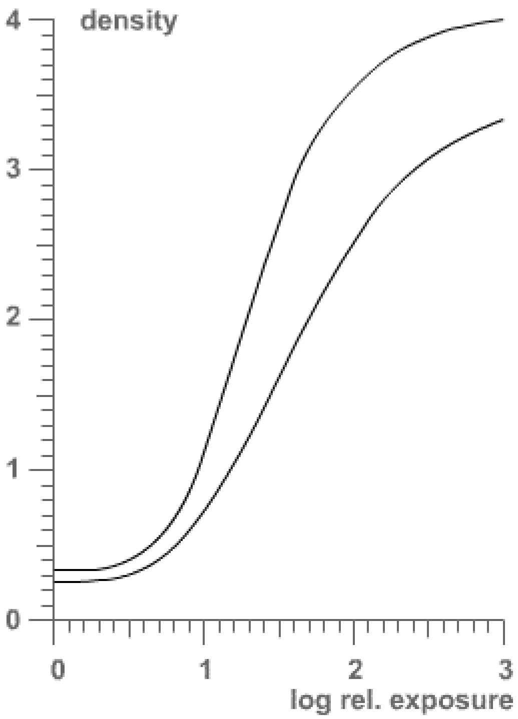
Average exposure
The automatic exposure timer is set to this density using an absorber of 20cm of water together with the film-screen combination and film processing given.

Optimum image contrast
The scope of exposure is log1.2 (1:16). This is the range of image contrast that can be utilized.

Given correct adaptation, a contrasty image is produced with all densities easily accessible.

End of Chapter

.



Film Processing
Due to its chemical nature, film processing is affected by temperature, immersion time and dilution.

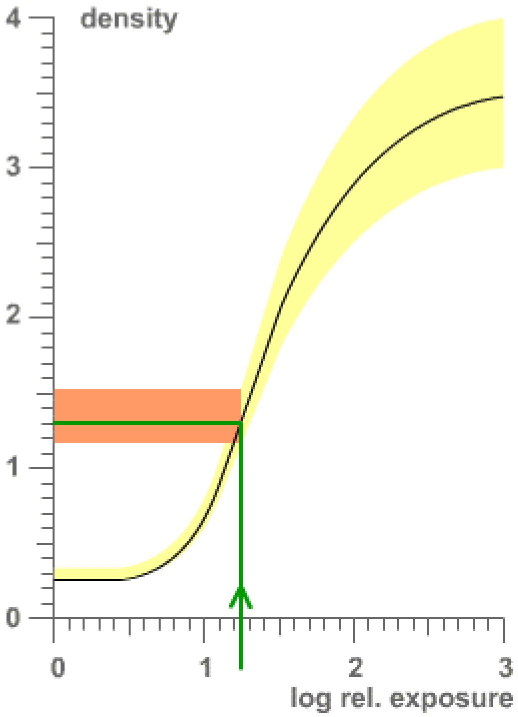
Temperature
Rising the temperature makes the characteristic curve rising as well. Maximum temperature is reached when the fog level starts rising. The minimum temperature is affected by the room temperature mainly. Else, cooling of the developer would be required.

Immersion time
Has the same effect as temperature, and is fixed with simple processors.

Dilution
One should not deviate from the manufacturers recommendations, as the developer tends to become chemically unstable.

▼ more Info

.



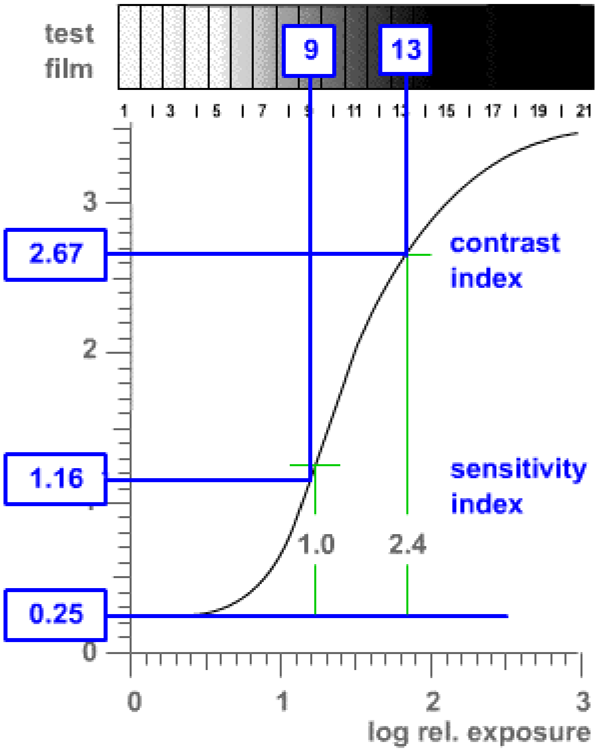
Imaging System

We always must consider processing as part of the imaging system. Therefore it has to match the X-ray imaging chain perfectly.

Calibration
First, film processing is tuned to the **average gradient** desired. Next, the density is set by programming the amount of **exposure**, the Iontomat.

Fluctuations
in film processing are due to chemical alterations.
In order not to sacrifice the diagnosis, the density must be kept rather stable. For this, **daily tests** of film processing are required

.



Reference Values

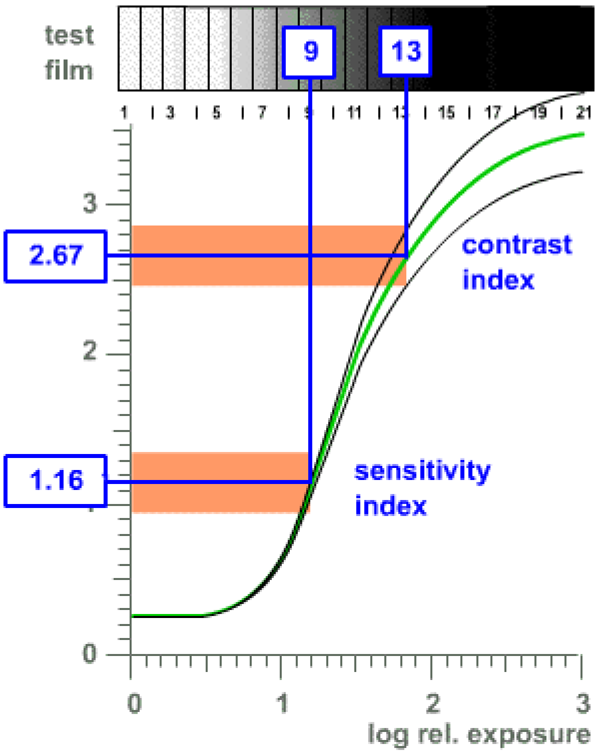
For testing the constancy, the measurement of only three key values is sufficient:

Fog
Measured far of the wedge. The density should not exceed 0.3.

Sensitivity index
Density of the step closest to 1.0 above fog. Maximum d = 1.35.

Contrast index
Density of the step closest to 2.4 above fog.

.



Tolerances

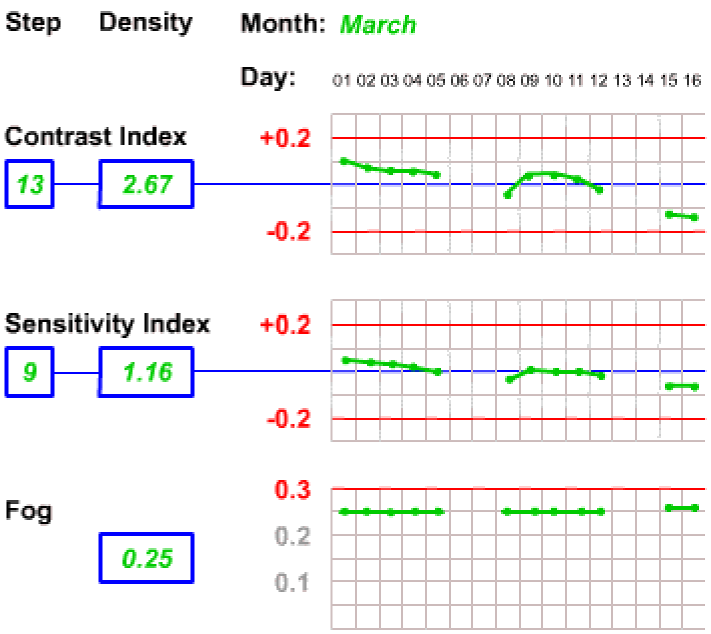
The admissible tolerances of +-0.2 are shown here.

Fresh developer
A newly prepared developer shows increased activity.

Used up developer
at the end of its usefulness with low activity and rising fog.

The contrast index
acts as an alarm before density deviations become visible in the diagnostic range.

.



Daily constancy tests

The reference values are transferred into a test protocol. A film pack has to be put aside for these tests only.

The results of the daily tests are entered as deviations from the reference values.

When exceeding the tolerances, the cause has to be found and rectified.

End of chapter

.

Processor

1. Stage: Development
Here, the silver halogenides exposed to light are converted into solid, metallic silver grains. In this procedure, the **developer** looses some of its activity. Additionally, it even ages when not used due to contact with oxygen. Therefore, it has to be replenished regularly.

Replenishment is controlled by film feeding. The correct amount of replenishment has to be established by trail and error and long term monitoring (constancy tests).
Aging is detected by a drop of the average gradient in combination with an slight increase of fog.
If the **visual inspection** shows a coffee-black developer instead of light to dark amber color, the developer is oxygenated and must be completely flushed befor new chemistry is prepared.

2. Stage: Fixation
All the silver halogenides not converted are washed out during this procedure. As the concentration of silver halogenices increases, the fixer looses activity. Again, replenishment deals with this problem.
For **testing** the fixer, a film - exposed or not doesn't matter - is inserted into the fixer tank bypassing development. After half of the normal fixing time, the film must have turned from milky to transparent. Else fresh fixer is required.

3. Stage: Rinsing
Rinsing is important for film **archiving**. During this procedure, all chemistry is removed from the emulsion. Make sure there is ample flow for of fresh water during film processing.

4. Stage: Drying
When heated up for drying, the emulsion is hardened making it somewhat **resistant** against scratches.

end Info