

Thermodilution Cardiac Output Computer Simulator



Clinical Cardiac Output Reference:

Measuring Cardiac Output: Intermittent Bolus Thermodilution Method
<http://ccn.aacnjournals.org/content/24/5/74.full.pdf>

13 Measuring Cardiac Output (youtube)
<https://www.youtube.com/watch?v=nAgmCoqAoPo>

Overview of the Thermodilution Cardiac Output Computer Simulator

In clinical practice cardiac output can be estimated with the thermodilution method. A catheter is inserted into the pulmonary artery. The catheter has a thermistor in the tip measuring the temperature of the blood. A second thermistor is inserted into a bag of saline to measure its temperature (the saline is the injectate). The injectate is typically room temperature or iced saline (0 degrees centigrade). On the cardiac output computer the user enters a “constant”. This is a number determined by the manufacturer that tells the computer the temperature of the injectate, and the volume of the injectate over a prescribed period of time. The constant is a number that the user looks up on a chart provided by the manufacturer. A typical injectate volume would be 10 ml, and a typical time would be 3 seconds. The user presses a “start measurement” button on the computer and delivers the injectate via syringe into the catheter and thus into the artery of the patient. The thermistor at the tip of the catheter measures the temperature differential of the blood/saline over time and performs a calculation estimating the cardiac output. Cardiac output typically run in the 3 to 8 liters per minute range. This process is very technique dependant so three measurements are done to get a good average.

Thermodilution Cardiac Output Computer Description

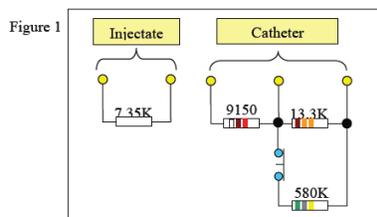
Cardiac output is measured by placing a catheter with a thermistor on the tip through the right ventricle into the pulmonary artery, injecting cold saline into the catheter, and integrating the resulting pulmonary artery temperature profile.

Testing a TDCOC is a matter of simulating an injectate temperature and blood temperature. These temperatures are measured using thermistors, therefore resistors can be used in their place.

For this example the injectate temperature is simulated by using a 7.35 K Ω resistor. This value resistor simulates a temperature of 0 degrees centigrade.

The catheter has two resistive values as shown in figure 1. The first having a value of 9.15 K Ω , and a second resistance of 13.0 K Ω . The 13.0K Ω resistor value is achieved by the combination of a 13.3K Ω resistor in parallel with a 580K Ω resistor. This simulates a catheter temperature of 38 degrees centigrade.

During the measuring time of the TDCOC, the 13 K Ω resistor needs to change to 13.3 K Ω in order to simulate a .5 degree centigrade change in blood temperature. This is accomplished by removing the parallel 580 K Ω resistance from a 13.3 K Ω resistance using a switch as shown in figure 1.



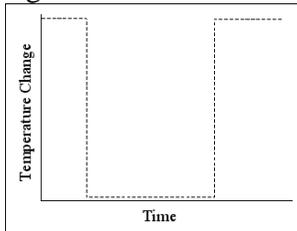
This change of .5 degrees centigrade for a 10 second period will simulate a cardiac output of roughly 4 liters per minute.

There are problems with this simple simulator that cause nuisance error messages as well as “unable to calculate” errors.

On some machines this type of simulator simply doesn't work.

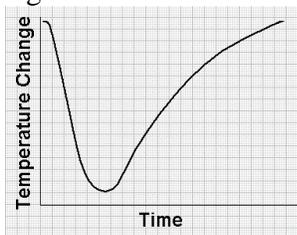
The TDCOC interprets the rapid change in temperature as a catheter fault, rather than the change that we desire. The output of the simple simulator is shown in figure 2.

Figure 2



A typical cardiac output graph is shown in figure 3 and is described by the Stewart-Hamilton equation.

Figure 3



The Stewart-Hamilton Equation:

$$Q = (V(Tb-Ti)K1K2) / (Tb(t)dt)$$

Where:

Q = cardiac output

V = volume of injectate

Tb = blood temperature

Ti = injectate temperature

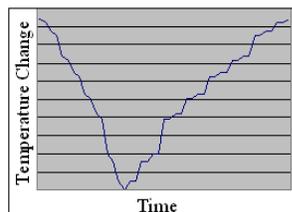
K1 = catheter constant

K2 = apparatus constant

Tb(t)dt = change in blood temperature over a given time.

This simulator more closely produces an expected change in temperature at the catheter tip as shown here in figure 4.

Figure 4



Thermodilution Cardiac Output Computer Block Diagram

The objective of the simulator is to produce a variable resistance. The change in resistance simulates the change in temperature that would be measured by the thermistor during a cardiac output measurement. The change in resistance is accomplished by using a resistor network. Different resistance values are selected by means of four analog switches. These analog switches are high speed, low power, solid state relays.

The analog switch is controlled by a four bit, digital, up/down, counter. The counter is driven by a variable speed clock and is controlled by two logic circuits.

One logic circuit is an up/down latch. The other is a start/stop latch.

When the start button is pressed, the up/down latch is set, causing the up/down counter to count up.

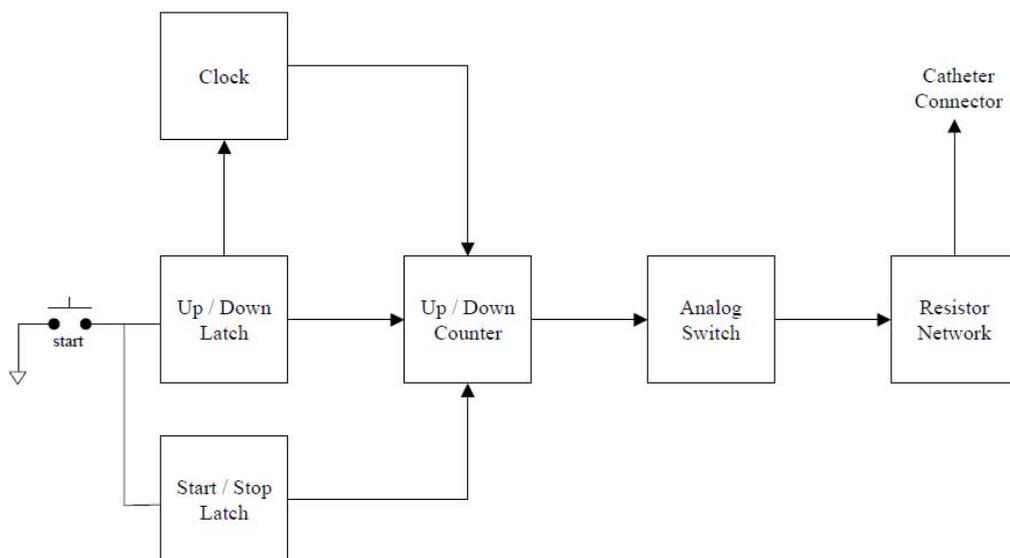
Another signal from the up/down latch is sent out to increase the frequency of the clock.

The start button also sets the start/stop latch which enables the up/down counter.

The up/down counter is now enabled and set to count up. It will increment one count for each clock pulse. When the up/down counter reaches its maximum count (of 15) the start/stop latch checks the output of the up/down latch. If this latch is set to count up, then the start/stop latch keeps the up/down counter enabled. With the count still at maximum (and after a short delay) the up/down latch changes state and causes the up/down counter to count down. The up/down latch sends a signal to decrease the frequency of the clock.

When the up/down counter reaches its minimum count (of 0) the start/stop latch checks the output of the up/down latch. If this latch is set to count down, then the start/stop latch disables the up/down counter.

This completes the cycle after the start button is pressed.

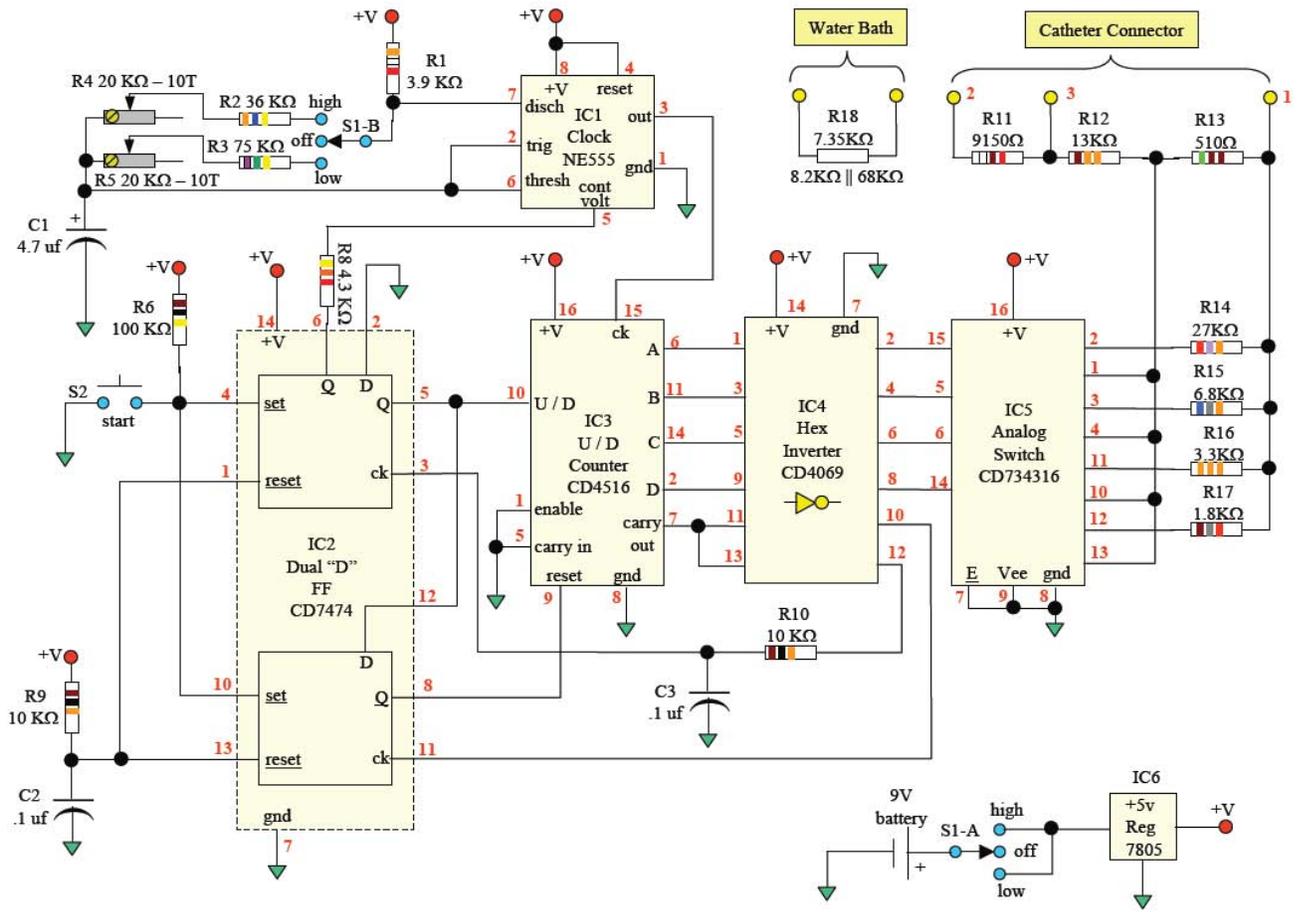


Theory of operation -Schematic

Starting with S1. This is the power switch as well as the high/low output. High being 6 liters per minute (LPM) and low is 3 LPM. It is a toggle switch (see revision note 1). The power source is a 9 volt battery regulated down to 5 volts by IC6. Once power is applied the “D” FF (IC2) starts running in the wrong mode. The RC combination of R9 and C2 time delays the reset of IC2. This does not work reliably (see revision note 2). The clock IC1 runs at a frequency determined by the position of the S1 switch and is adjustable by pots R4 and R5. Once the start button (S2) is pressed (see revision note 3) the dual FF (IC2) is set presenting a high on the up/down counter (IC3) to count up. The other half of IC2 remains in the reset state. The up/down counter is set to count up and will do so from the clock pulses received by the clock (IC1). Note IC3 is a binary up/down counter. The output of the up/down counter feeds a hex inverter IC4 for polarity correction and to drive the analog switch. The analog switch selects resistors (R14 through R17) to be put in parallel with the resistance of the catheter connector (R13). This change in resistance emulates a change in temperature on the catheter. The other two resistors on the catheter are used by the cardiac output computer to indicate that a catheter is present (R11 and R12). The cardiac output computer also needs to know the water bath temperature. This is done by R18 which is an 8.2 K-ohm resistor in parallel with a 68 K-ohm resistor. Once the up/down counter (IC3) reaches its maximum count of 15, a carry out signal is generated. It is polarity corrected by the inverter (IC4) and clocks half of the dual “D” FF. This changes the state of the FF causing the up/down counter to count down. There is a race condition that could occur so a time delay (R10 and C3) provide the delay to prevent premature reset of IC2 allowing the circuit to count down rather than terminate. It also changes the state of the second half of the FF (IC2) to reset the up/down counter so it can start counting from 0 again. The third thing that occurs is that the first half of the “D” FF sends a signal to the clock (on the control voltage input of IC1) to slow the clock down. In looking at the cardiac output curve you will notice that the first half of the waveform has a high slope and the second half has a lower slope. This is done by changing of the clock speed. Once the cycle is complete and the up/down counter (IC3) reaches its maximum count of 15 another carry out signal is presented to the “D” FF which puts the “D” FF back to its original state (waiting for another “start” signal).

Revision notes

- 1- I would not use this toggle switch because it can be bumped easily and keep the circuit until the battery goes dead. A 3 position slide switch or locking toggle switch [Digikey PN 360-3001-ND](#) would be better.
- 2- The power on reset needs to be longer. Increase the value of the capacitor or resistor to get a longer time delay.
- 3- The start button in the parts list is a momentary N.O. switch with a wimpy actuator. Get a bigger button.



Thermo-dilution Cardiac Output Computer Simulator Schematic

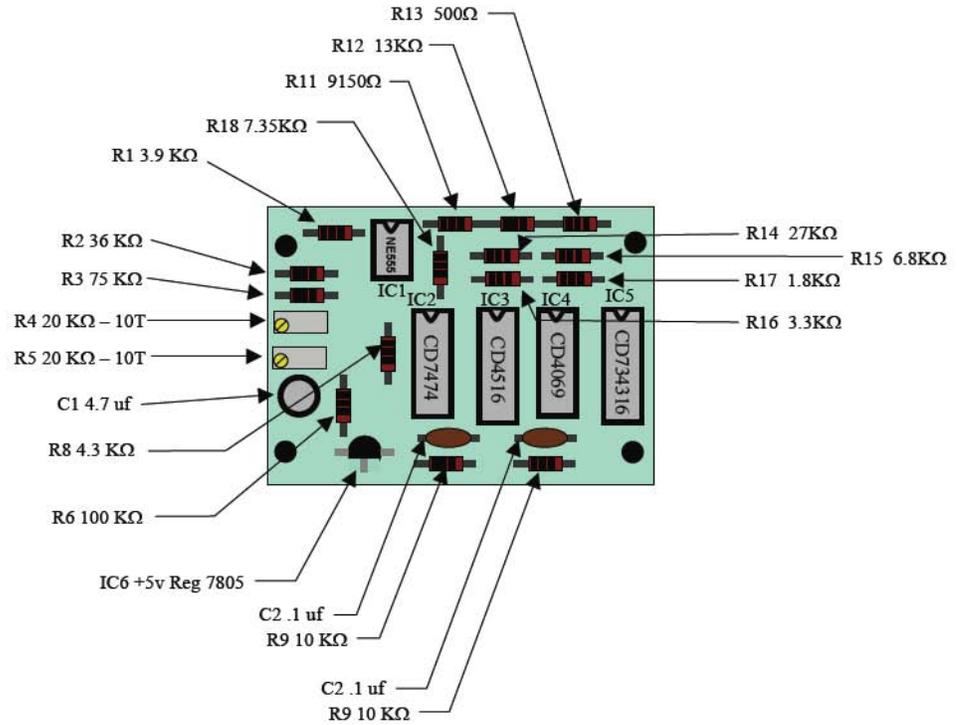
Parts List

There are two critical parts that are not designated in this parts list. That is because every Cardiac Output Computer has specific connectors. You will need to research the connectors that meet your needs. Making pigtailed from a wiring diagram or pinging out a cable that you have is the best way to connect your simulator to the TDCOC. Scrounge around your biomed shop for scrapped equipment and recycle connectors. The rest of the parts are common and easily obtainable. The source (Digikey Corp) and part numbers are here.

TDCOC Simulator parts list

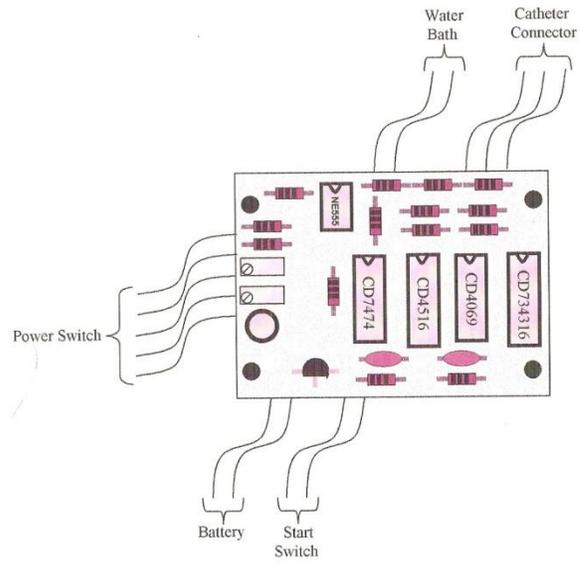
designation	qty	description	Digi Key PN	2014 cost	ext cost
C1	1	4.7 uf capacitor 50V	493-1102-ND	\$0.23	\$0.23
C2,C3	2	.1 uf capacitor 50V	399-4151-ND	\$0.30	\$0.60
IC1	1	NE555P timer	296-1411-5-ND	\$0.49	\$0.49
IC2	1	CD74HC74E dual "D" flip flop	296-12819-5-ND	\$0.70	\$0.70
IC3	1	CD4516BE up/down counter	296-2075-5-ND	\$0.60	\$0.60
IC4	1	CD4069UBE hex inverter	296-3518-5-ND	\$0.52	\$0.52
IC5	1	CD74HCT4316E analog switch	296-2124-5-ND	\$0.89	\$0.89
IC6	1	ua78L05 +5V voltage regulator	296-11119-5-ND	\$0.61	\$0.61
R1	1	3.9KΩ resistor			
R11	1	9150Ω resistor			
R12	1	13.0KΩ resistor			
R13	1	500 Ω resistor			
R14	1	27KΩ resistor			
R15	1	15KΩ resistor			
R16	1	3.3KΩ resistor			
R17	1	1.8KΩ resistor			
R18	1	7.35KΩ resistor			
R18 note		R18 = 8.2 KΩ in parallel with 68KΩ			
R2	1	36KΩ resistor			
R3	1	75KΩ resistor			
R4, R5	2	20KΩ potentiometer	3296W-1-203LF	\$2.41	\$4.82
R6	1	100KΩ resistor			
R8	1	4.3KΩ resistor			
R9, R10	2	10KΩ resistor			
S1 *	1	toggle switch DP3T center off	EG2425-ND	\$5.08	\$5.08
S2 *	1	pushbutton switch NO	CKN4054-ND	\$7.12	\$7.12
	1	9V battery			
	1	9V battery clip			
	1	case	SR232B-ND	\$6.43	\$6.43
*	1	circ board	V1046-ND	\$25.30	\$25.30
	1	pigtail connector injectate temp			
	1	pigtail connector catheter			
TOTAL					\$53.39
note *		find better or less expensive part			

PCB parts layout



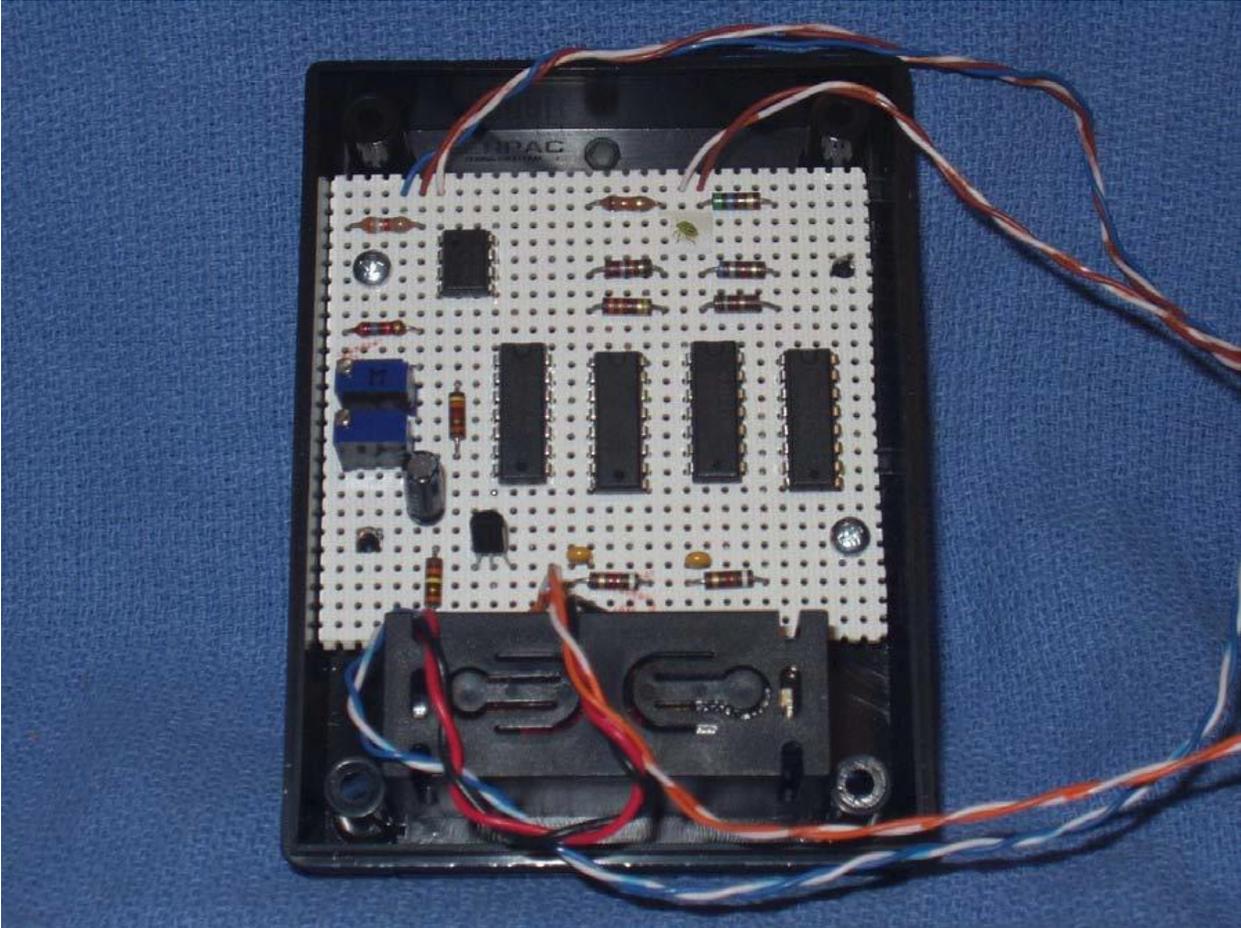
Thermo-dilution Cardiac Output Computer Simulator PCB Parts Layout

PCB wiring diagram

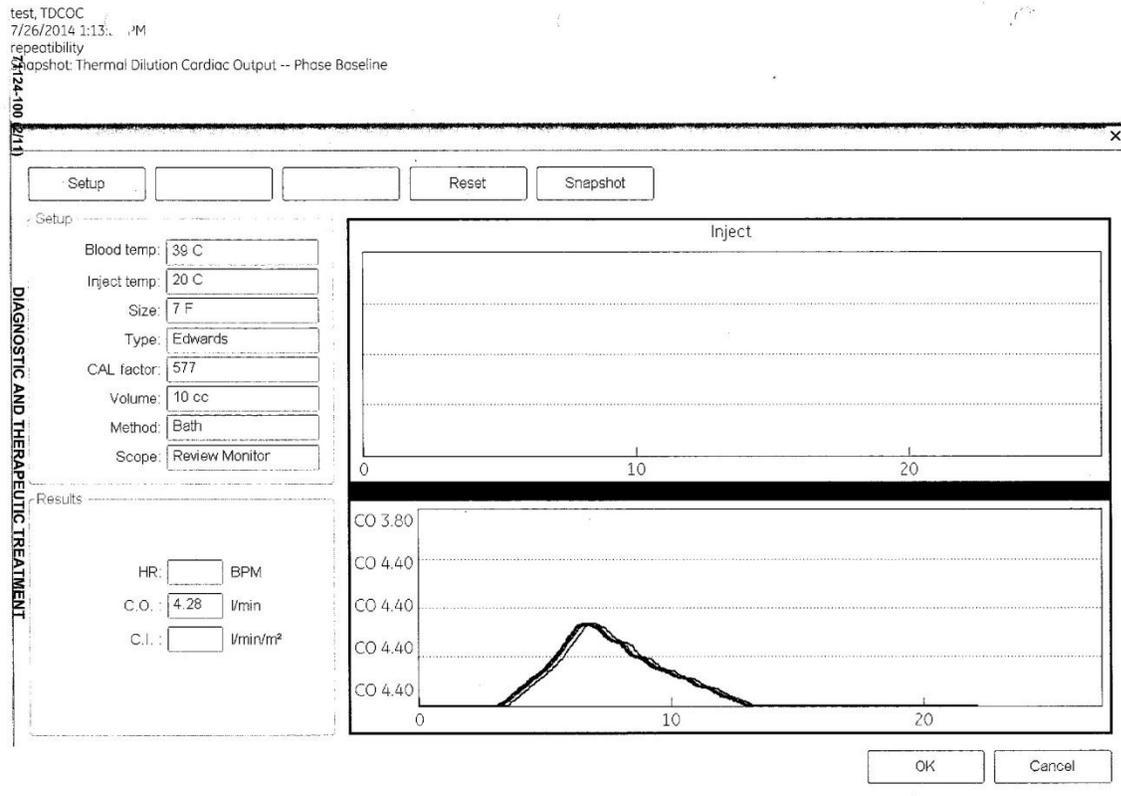


Thermo-dilution Cardiac Output Computer Simulator

TDCOC Simulator Assembly



Example of TDCOC waveform



Final notes

The simulator described here is just to verify that a cardiac output computer is working. It is by no means a calibrator. It is mostly intended for those of us that like to tinker with electronics. Attached are the schematic, parts list, example of the output waveform, and pictures of the simulator.

I should talk about calibration. It is empirical – meaning you make adjustments to the 2 potentiometers for the high and low cardiac output values and then call it good. We are looking for consistency, not absolute numbers. The electronics don't vary too much so you should be OK.

My hope is that others will have fun building, using, and improving this simulator.

Best Regards,

Barry