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INTRODUCTION

This manual describes the function, theory of operation, and operating procedures for the System 6 Pulsed Doppler Flow Velocity Module.

Section 1 briefly describes the function of the Pulsed Doppler Flow Module and its specifications. This section also describes and cross-references each control, indicator, or connector, to a number keyed to the panel illustrations.

Section 2 discusses the basic Pulsed Doppler Flow principle, and provides a brief description of how the Pulsed Doppler Flow Module works.

Section 3 provides information about additional equipment necessary to operate the Pulsed Doppler Flow Velocity Module. This section also describes how to connect the transducer and chart recorder, how to calibrate the system, and how to perform an end-to-end test to ensure the system is ready for data collection.

The Index provides easy access to information in the body of this manual (the manuals for each module type have their own indexes).

The Appendix provides in depth information pertaining to application of the Pulsed Doppler Flow Velocity Module.

1. PDFM MODULE

1.1 FUNCTION

The Pulsed Doppler Flowmeter uses bursts of high frequency sound traveling across a blood vessel to measure the bloodflow velocity in the vessel. The Flowmeter generates an analog output voltage proportional to the flow velocity.

The Pulsed Doppler blood Flowmeter (PDFM) module operates with a wide range of bloodflow transducer types including:

- Implanted flow cuff transducers
- Transcutaneous transducers
- Doppler velocity catheters

Three versions of the PDFM measure blood flow in three different vessel diameter ranges. The three versions are identical except for the ultrasonic frequencies (f_c) transmitted, the pulse repetition frequency (PRF), and the transmit burst pulse width (PW). As shown in **Table 1**, larger vessels require a lower f_c, and a lower PRF.

In addition to the analog voltage output, the PDFM gives both audio and visual indications of the Doppler frequency shift through the System 6 Mainframe Chassis. Audio output is available through a front panel speaker or from stereo headphones plugged into the back panel. The visual indication is a bi-directional LED bargraph display that indicates the Doppler frequency shift, indicating both amplitude and direction of flow.

1.2 SPECIFICATIONS

ULTRASONIC FREQUENCY - Factory set at 20, 10 or 5 MHz for different blood vessel diameters as shown in **Table 1**. The frequency is controlled by a ±.01% crystal TTL oscillator.

PULSE REPETITION FREQUENCY (PRF) - Factory set at 125, 62.5, or 31.25 KHz corresponding to ultrasonic frequency as shown in **Table 1**.

TRANSMIT OUTPUT - 15V p-p RF burst into 50-OHM load from a transformer-coupled, single-ended source with an isolated ground.

TRANSMIT PULSE BURST - The transmit burst is factory set at 8 cycles of RF but is internally switch-selectable for 1 to 8 cycles of RF frequency. Maximum transmit pulse widths are listed in **Table 1**.

SAMPLE RANGE - The maximum measuring range is a function of the PRF, the higher the PRF, the shorter the range. The maximum range is 5.5, 11, or 22 mm for 125, 62.5 and 31.25 KHz. The range is indicated on the Mainframe front panel LED digital display.

AUDIO BANDWIDTH - Four-pole Butterworth bandpass response:

HHIGH PASS:

1 100 Hz : 5 & 10 MHz

2 200 Hz : 20 MHz

LOW PASS: Corresponds to more than twice the velocity set on the SCALE switch. See **Table 2** for Audio filter response at the different scales for each version.

f_c (MHz)	PRF (KHz)	PW (µs)	Vessel dia. (mm)

20	125.0	0.4	1-4
10	62.5	0.8	4-10
5	31.25	1.6	10-22

Table 1 Pulse rate and pulse width

	NOMINAL LOWPASS FILTER CUTOFF FREQUENCY		
SCALE (cm/sec)	20 MHz VERSION	10 MHz VERSION	5 MHz VERSION
100	34 KHz	14 KHz	7 KHz
50	17 KHz	7 KHz	3.5 KHz
20	6.7 KHz	2.8 KHz	1.4 KHz

Table 2 Audio Filter Response

1.3 FRONT PANEL CONTROLS

NOTE: The number preceding each item corresponds to its location on the PULSED DOPPLER FLOWMETER MODULE FRONT AND REAR PANELS illustration.

41

TRIGGER
The TRIGGER sets the triggering level of the zero crossing discriminator. The normal position is full clockwise. The TRIGGER is a one-turn potentiometer.

42

RANGE
The RANGE determines the range at which bloodflow velocity is being sampled. The RANGE is a ten-turn potentiometer.

43

RUN/CALIB (FLOW)
This six-position switch selects RUN mode, "Zero" or any of 4 calibration "velocities". This switch selects frequencies corresponding to 100, 50, 20, 10 centimeters per second and zero or alternately known frequency steps.

44

DIR/NON
The DIR/NON selects DIRECTIONAL or NONDIRECTIONAL operation. When bloodflow is known to be non-directional, select NON (Example: Renal flow).

45

+/- SWITCH
The POLARITY (+/-) determines the output voltage sense, i.e. which flow direction generates a positive voltage output.

46 **DNR**

The audio filter in the PDFM module is followed by a dynamic noise reduction (DNR) circuit that significantly reduces high frequency audio noise during periods of low flow. The DNR circuit is a variable low pass filter that continuously adjusts its cutoff frequency in response to the frequency content of the input signal. Activating the DNR can improve the overall signal-to-noise ratio by up to 10 dB. Typical noise reduction is from 6 to 8 dB.

47 **FILTER**

The data FILTER selector switch selects the lowpass cutoff frequency applied to the phasic flow output signal. The available cutoff frequencies are 50, 25, and 12 Hz.

48 **PROBE**

The PROBE connector connects the flow probe to the RF transceiver inside the flow module. The impedance matching and isolation transformers are located inside the Flow module.

Mating connector: WIREPRO P/N 126-214-1000 (formerly AMPHENOL)
Triton P/N - 801228

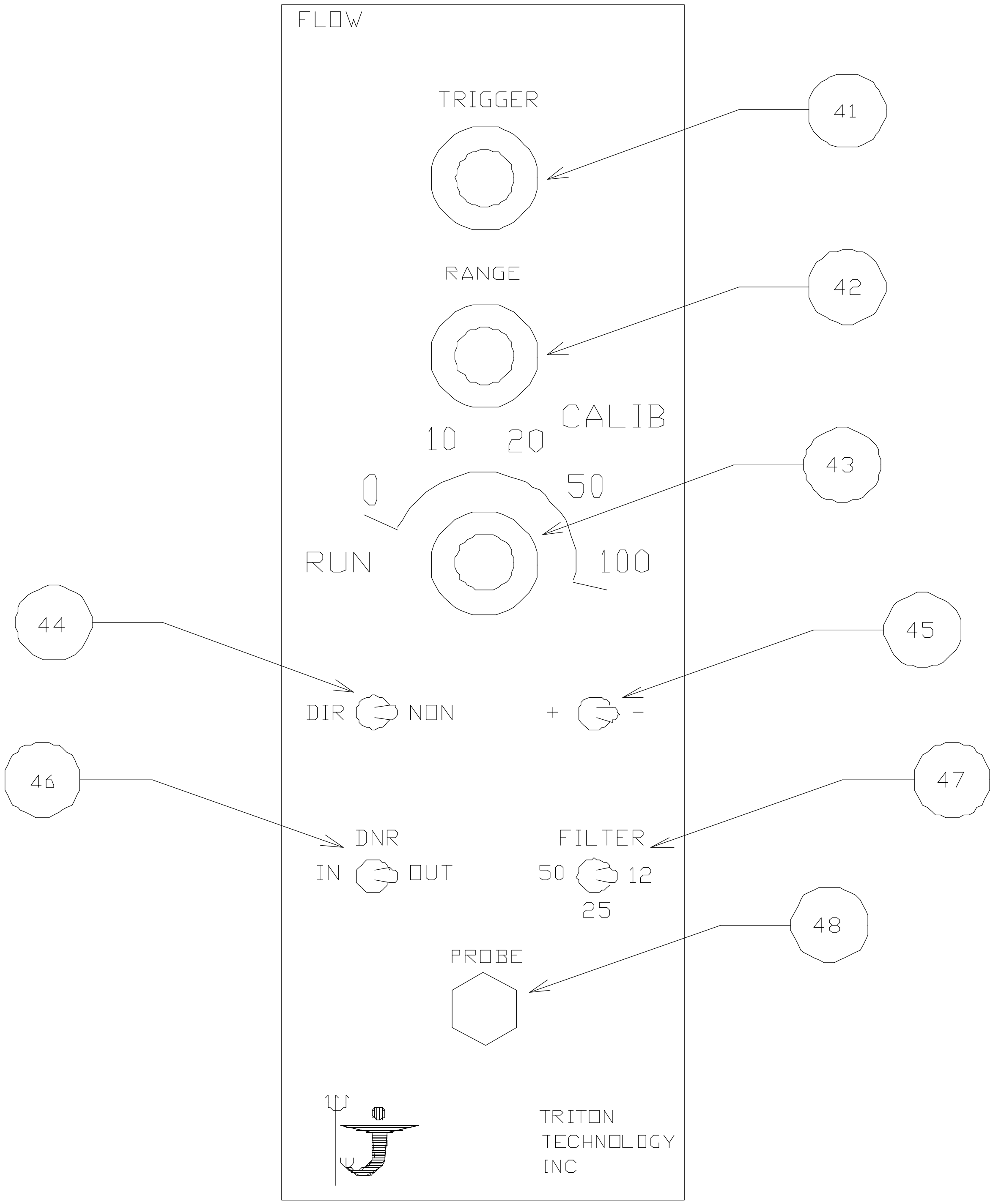


Figure 1 Flowmeter Module Front Panel

1.3 REAR PANEL OUTPUTS FOR PDFM MODULES

49 **"C" - FLOW OUT (PHONE)**
The FLOW OUT is a voltage proportional to the Doppler frequency shift or velocity of the bloodflow. As shown in **Table 1**, the DC output, in volts per KHz, is a function of the RF frequency. The FILTER switch on the PDFM module sets the frequency response of the phasic flow signal at flow out.

	FLOW OUT GAIN (V/KHz)
20 MHz	0.25
10 MHz	0.50
5 MHz	1.00

Table 1 Flow Out DC GAIN Values

50 **"D" - FLOW MEAN OUT (PHONE)**
The MEAN FLOW OUT gain is the same as the FLOW OUT gain shown in **Table 1**. The MEAN filter has a 2-pole lowpass response with a 0.23 Hz cutoff frequency. The step input response rise time is approximately 3 seconds.

51 **"E" - RANGE OUT (PHONE)**
A voltage proportional to the RANGE is available at the rear panel for recording. The sensitivity is 0.1 V/mm, i.e., 5 mm = 0.5 V.

52 **"F","G" - LINE OUT (PHONE)**
A pair of LINE OUT connectors provide quadrature audio signals for recording or spectral analysis. The output signal level is approximately 300 mV.

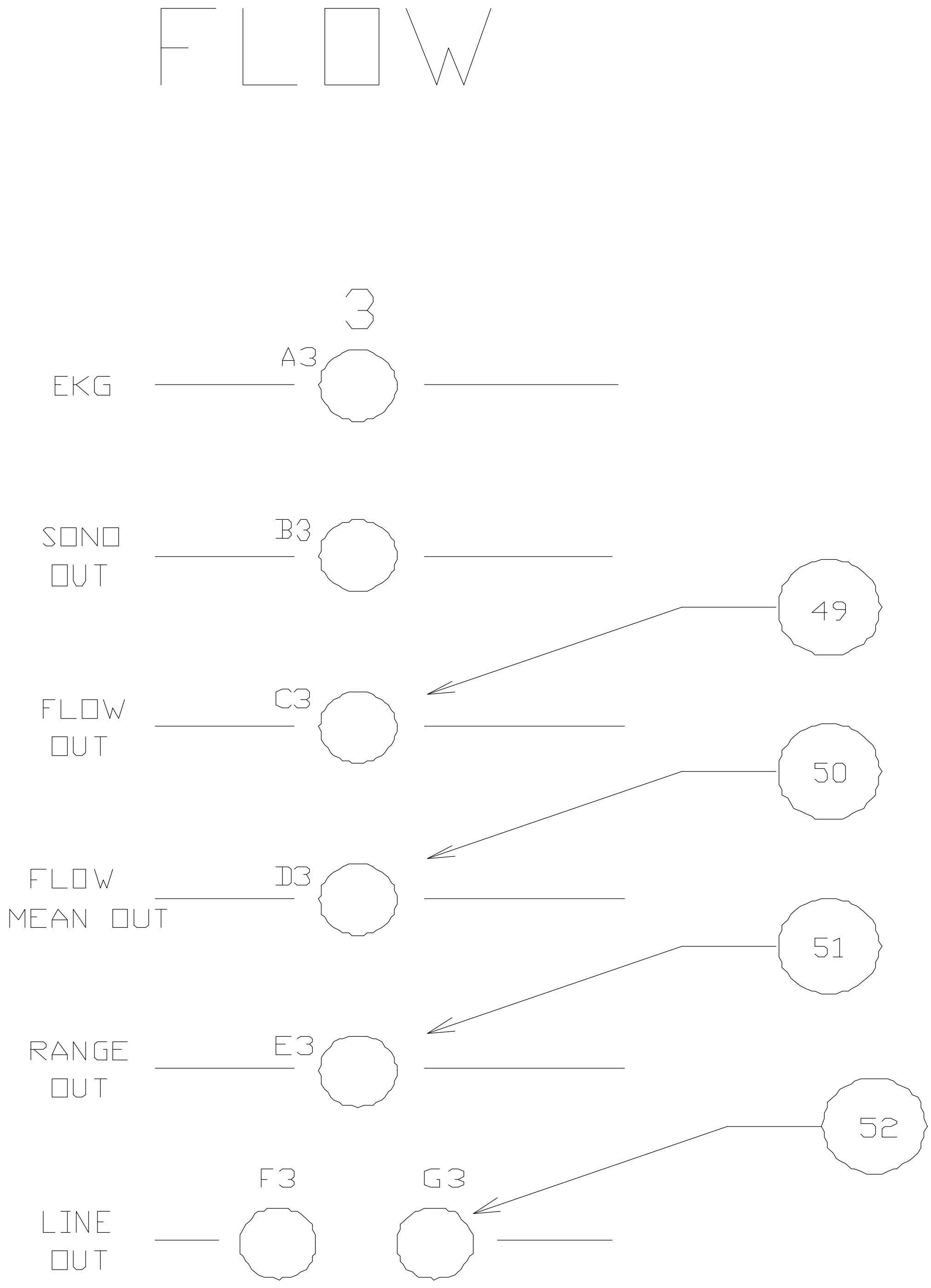
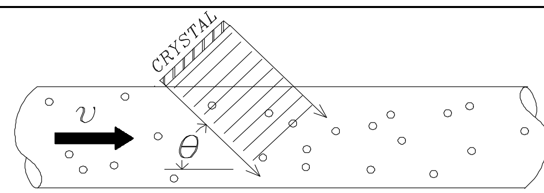


Figure 2 Flowmeter Rear Panel *(located on mainframe)*

2. THEORY OF OPERATION

- **OPERATING PRINCIPLE**

The Pulsed Doppler Flowmeter uses short bursts of ultrasound projected diagonally across a blood vessel to measure blood flow velocity. The projected sound is scattered by the sub-wavelength particles in the blood, and the frequency of the scattered sound is altered by the interaction with the blood particles. The scattered sound, or return signal, is monitored between transmit bursts with the same transducer. The "Doppler effect" appears as a frequency shift of the return signal. As shown in **Figure** 3, the Doppler shift is proportional to the bloodflow velocity as well as to the angle between the sound beam, the axis of the particle (blood) flow, and inversely proportional to the velocity of sound. The frequency is shifted above or below the carrier frequency depending on the direction of the bloodflow. Flow traveling toward the transducer will shift the signal above the carrier frequency, and flow traveling away from the transducer will be below the carrier frequency.



$$df = \frac{2\ f\ v\ \cos(\theta)}{c}$$

df = Doppler frequency shift (Hz)

v = velocity (cm/sec)

f = ultrasonic frequency (Hz)

Ø = angle between beam and blood flow axis

c = sound velocity in blood (1.58×10^5 cm/sec)

Figure 3 Doppler Equation

- **FLOW VELOCITY theory of operation flow velocity**

The velocity of flow is determined by demodulating the Doppler shifted signal into an analog DC output voltage. This output voltage is a linear function of Doppler frequency shift.

- **FLOW DIRECTION**

The direction of flow is determined by detecting whether the return Doppler frequency is above or below the transmitted carrier. This is accomplished by mixing the received ultrasonic frequency signal with quadrature local oscillator signals. The resulting outputs are quadrature audio signals which are then processed to determine which audio signal leads the other in phase. This information determines whether the flow is moving toward or away from the crystal. The POLARITY switch is used to determine the output voltage sense for recording.

Converting quadrature audio signals to an analog DC voltage requires that the audio signals be converted to digital form for processing. This is accomplished with a zero-cross detector circuit. The resulting DC flow output can be monitored simultaneously at the rear panel in two forms: PHASIC flow voltage or time-averaged MEAN flow voltage. *Refer to SPECIFICATIONS (**page 3**) for audio filter frequencies.*

- **AUDIO BANDWIDTH theory of operation audio bandwidth**

The audio bandwidth is matched to the ultrasonic frequency (f_c), PRF, flow velocity, and transducer angle. The filter cutoff frequency corresponds to approximately twice the maximum velocity (100 cm/sec) set on the SCALE switch (i.e., the filter cutoff corresponds to a flow of more than

200 cm/sec). This provides at least a 2:1 peak-to-average velocity factor at full scale to prevent clipping on parabolic flow profiles. Special cutoff frequencies are available on request. Both the high and low pass filters are four-pole Butterworth response.

3. FIRST TIME START-UP AND OPERATION

3.1 EQUIPMENT REQUIRED

1 chart recorder

1 cup of milk or laundry starch solution

1 transducer extension cable (see Appendix A)

1 chart recorder cable
1 flow transducer

3.2 INITIAL SETUP

The initial setup ensures a standard starting point for operating the Pulsed Doppler Flow module (PDFM). The System 6 comes from the factory with the PDFM modules installed. However, you may wish to change module positions to suit your application, or add Flow modules at a later time.

NOTE: You should re-calibrate after changing the position of a module in the mainframe.

The following start-up procedure is meant to guide the new user through an initial setup, calibration and prepare for a flow monitoring session. For simplicity this procedure will assume that a 10 MHz system is being used with a chronically implanted cuff probe. The procedure for a Doppler velocity catheter or a transcutaneous probe are much the same. For in-depth information on alternate calibration schemes see Appendix B.

*******CAUTION*******

DO NOT REMOVE OR INSTALL MODULES WITH THE POWER ON

3.2.1 MAINFRAME REAR-PANEL SETUP

- These instructions ensure proper power-up.

1. Connect the power cable to the appropriate power mains.
2. Turn the SYSTEM 6 power switch on.
3. The LED power indicator light should light. If it doesn't, check the power cord, fuse, voltage selector, and mains receptacle. Contact Triton Technology if problem cannot be resolved.

3.2.2 MAINFRAME FRONT-PANEL SETUP

1. Set Mainframe Volume control to 1/4 cw position.
2. Rotate Mainframe FLOW CHANNEL selector to the desired channel.

3.2.3 PULSED DOPPLER FLOW MODULE FRONT-PANEL SETTINGS

- Set the selected Flowmeter module front panel controls as listed below in Table 1:

CONTROL	POSITION
TRIGGER	full cw
RANGE	center
RUN/CALIB	0
DIR/NON	DIR
POLARITY	+
DNR	IN
FILTER	25

Table 4 PDFM front-panel initial settings

3.3 CALIBRATION

Note: For in-depth information on alternate calibration schemes see Appendix B.

3.3.1 CHART RECORDER SETUP

1. Turn the chart recorder power on, with the paper drive turned off.
2. Set the chart recorder to a DC gain level appropriate for a 5-volt deflection.
3. Short the chart recorder input leads and connect to ground.
4. Use the chart recorder position or offset control to position the pen at the bottom of the chart tracing.
5. Remove the short circuit and ground from the chart recorder cable input.
6. Insert phone jack end of chart recorder cable into FLOW OUT (Mainframe rear panel) of the selected Flow module.

3.3.2 CALIBRATE CHART RECORDER

- After performing the setup above, the chart recorder can be calibrated to a full-scale level appropriate for the expected maximum flow. In this example a full scale of "100" will be used.

1. Rotate RUN/CALIB switch to "100". Adjust the Mainframe VOLUME control for comfortable listening level.
2. The chart pen should deflect upward; if it does not, switch the polarity switch to "-".
3. If the pen has deflected beyond the top of the chart paper, the chart recorder gain must be decreased. Decrease the chart gain until the pen is at the desired chart line. Conversely, if the chart gain is too low, it will have to be increased until the pen is at the desired level for "100".
4. Rotate the CALIB switch back to "0" to ensure the pen returns to the correct "zero" level. If it does not, repeat Steps 3 and 4 until the "0" and "100" positions are correct. It may be necessary to run the chart recorder at slow speed to final check these levels.

5. Rotate the CALIB switch to "50". The pen should deflect to a position halfway between the "0" and "100" levels.

6. Set the CALIB switch to "0" and start the chart paper at slow speed. Slowly rotate the RUN/CALIB switch clockwise, forming a stair step on the chart recorder as shown in **Figure 4**.

7. Stop the chart recorder and return the RUN/CALIB switch to "0".

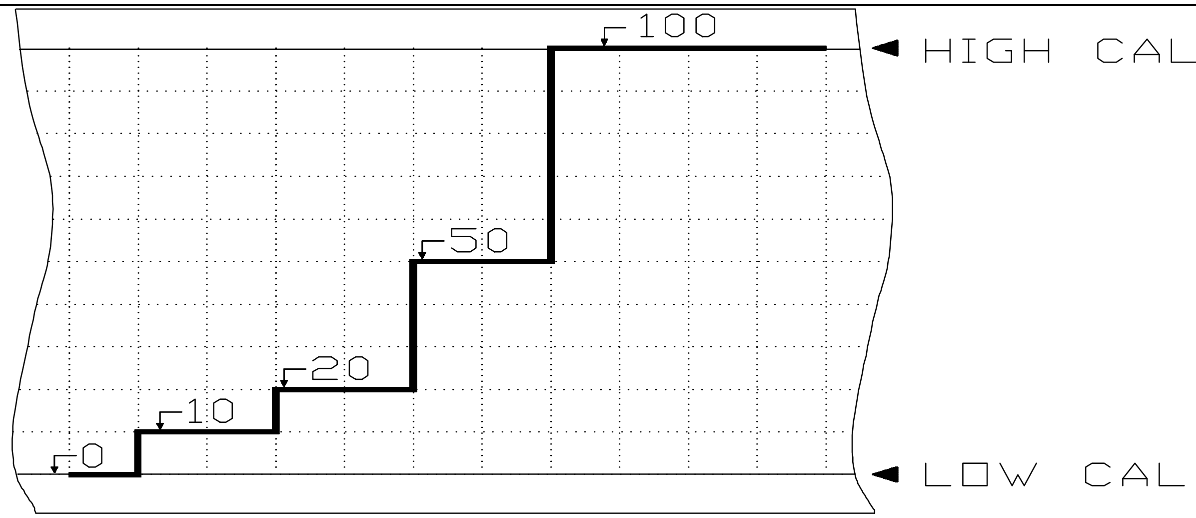


Figure 4 Chart recorder calibration

3.4 FINAL SETUP AND TEST

Now that the chart recorder is calibrated to the Doppler Flowmeter it may be configured for operation in the RUN mode as follows:

3.4.1 CONNECT TRANSDUCERS

- These instructions describe how to connect the appropriate flow probe to a module. **Figure 5** illustrates the transducer connections. transducers connections

  1. Make sure the RUN/CALIB is in CALIB mode.

  2. Prepare a flow probe for use with System 6 by attaching a connector. These are WIREPRO 126 Series, 4-Pin connectors, available from the manufacturer or Triton Technology[1]. Connect flow probe leads to Pins B and D.

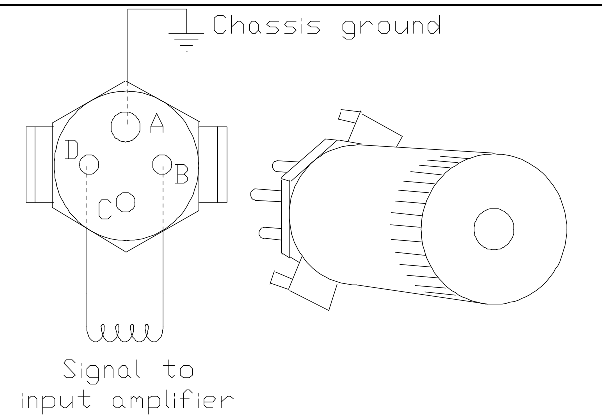


Figure 5 Transducer Connections

  3. As shown in **Figure** 5, the large pin (A) on the transducer plug is the guide pin and connects to chassis ground. This pin aligns with the large diameter socket on the jack labeled PROBE. The transducer plug has a rotating shell. Its metal ears *cam-lock* with the metal locking tabs on the PROBE jack. Push the transducer plug into PROBE and twist clockwise to lock in place. This prevents the plug from being accidentally pulled out.

Note: See Appendix A for a schematic of a typical transducer extension cable)

3.4.2 TRANSDUCER BENCH TEST transducers **bench test**

- This test ensures that the flowmeter, transducer, and chart recorder are working together as a velocity measuring system. It is usually easier to complete this task with two people. One person will move the flow transducer and the other will operate the equipment.

  1. The flowmeter should be connected to the chart recorder and the recorder should be calibrated to the expected flow range. The flowmeter RUN/CALIB switch should be set to "0". The transducer extension cable and an appropriate flow transducer should be connected to the flowmeter.

  2. Place the flow transducer in a cup of milk or laundry starch solution. Pre-made laundry starch solution works well and stays in solution for a long time.

  3. Move the chart recorder pen to center of the chart using the chart recorder offset control. Start the chart recorder paper drive at slow speed.

  4. With the transducer lying still in the solution, listen to the flow signal on the speaker at moderate volume level. The audio should have a low level of background "hiss". Switch

[1] WIREPRO P/N 126-214-1000, Triton P/N 801228

the DNR off and listen to the "hiss" level; it should be significantly higher. On weak signals the DNR will not improve the signal to noise ratio. Leave the DNR in the position that results in the lowest "hiss" level.

5. Move the flow probe to and fro in the solution such that the solution passes through the transducer lumen. The flow audio signal should have an almost musical sound, rising in pitch during peak flow and dropping in pitch for low flow. The flow display lights on the flowmeter front panel should rise and fall with the flow velocity. The flow display bars will indicate green bars for positive flow and red bars for negative flow.

6. The pen on the chart recorder should move above and below the centerline as the flow probe is moved. It may be necessary to increase the chart gain to properly view the flow trace. The chart can be re-calibrated using the RUN/CALIB switch.

7. Upon completion of this test turn the chart paper drive off and reposition the chart pen to the desired zero level. The chart can be re-calibrated to the expected flow level using the RUN/CALIB switch as before.

- This completes the verification test of the flow probe, flowmeter, and chart recorder.

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- *RANGE 5*
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- *TRIGGER 5*

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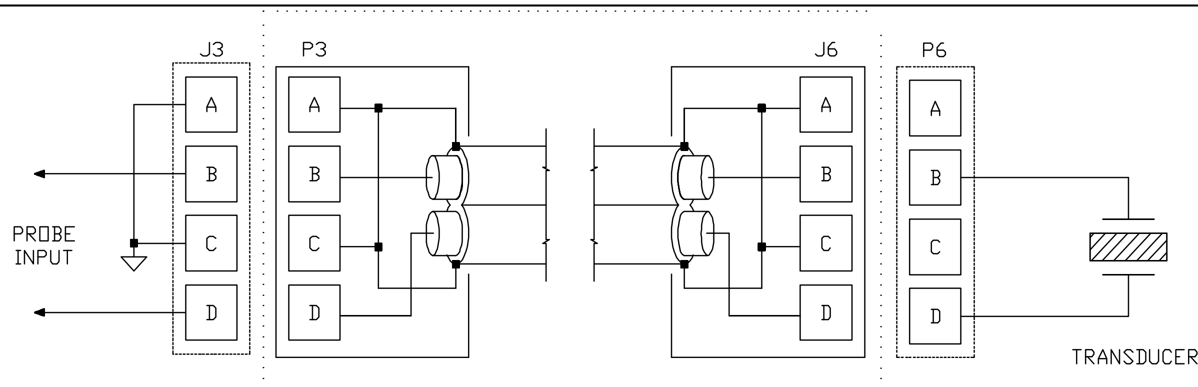
TRIGGER 5

APPENDIX A TRANSDUCER CABLE

The Pulsed Doppler Flowmeter requires lead wires from the front panel connector to the flow probe. For short distances (1 to 6 feet) these may simply be light gauge, twisted pair leads. The flowmeter input amplifier acts as a wideband video amplifier and the long leads act like an antenna, introducing unwanted external noise/interference. In addition, the Flow Module radiates high-energy bursts from unshielded leads, and may cause interference with other equipment.

For longer distances a shielded transducer cable can be fabricated. Twin RG-59 coax or ribbon coax can be used to fabricate this cable. The cable should be fabricated with a Wirepro Type 126 4-pin Plug at one end and a matching Type 126 Jack at the other end. This cable should use the Wirepro locking clips at each end in order to prevent the cables from pulling out of the panel or transducer connector.

Figure A1 is a schematic showing the connections for fabricating the cables. (See **Figure** 5 on page 13 for a pictorial view of typical transducer connection)



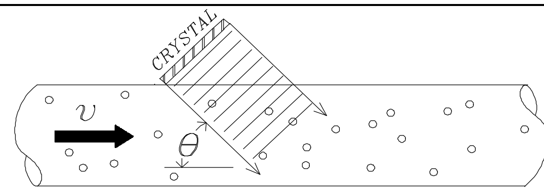
REFERENCE	PART NUMBER	MFGR.	DESCRIPTION
P3, P6	126-1429	WIREPRO	4-PIN MALE
J3, J6	126-214-1000	WIREPRO	4-PIN FEMALE
CABLE alternate:	9555 9K50004	BELDEN BELDEN	DUAL 75-OHM COAX QUAD 75-OHM COAX

Figure A1 Flowmeter transducer cable assembly

APPENDIX B CALIBRATION FACTORS

As shown in **Figure B6**, the Doppler shift is a function of the blood flow velocity, the RF operating frequency, the velocity of sound in the blood and the transducer geometry. The Pulsed Doppler Flowmeter has internal controls which allow the calibration levels to be set to the correct value for almost any transducer angle. The normal factory setting for the calibration is for a 45° transducer. Upon request, the calibration will be set for use with a catheter (0°) or any other angle between 0° and 87°.

The calibration values are derived directly from the quartz crystal oscillator which provides the timing for the entire system. Thus, each calibration frequency is an accurate, repeatable value which is used to drive the entire demodulation circuit, providing a true *end to end* calibration.



$$df = \frac{2\ f\ v\ \cos(\theta)}{c}$$

df = Doppler frequency shift (Hz)
v = velocity (cm/sec)
f = ultrasonic frequency (Hz)
Ø = angle between beam and blood flow axis
c = sound velocity in blood ($1.58\text{x}10^5$cm/sec)

Figure B6 Doppler Equation

NOTE: Although the front panel calibration markings are in units of velocity (cm/sec), they actually represent discrete calibration frequencies.

Tables B3, B4, and B5 at the end of this appendix show calibration frequencies as a function of RF frequency, transducer angle and calibration setting. These tables assume that the velocity of sound in blood is 1.58 mm/µsec.

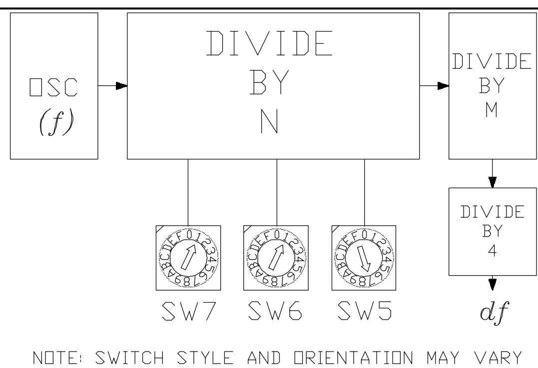


Figure B7 Calibration timing chain

Figure B7 shows the programmable counter used for calibration. Switches 7, 6, and 5 are set to the values shown in **Table B1** to achieve the desired calibration frequencies. In addition to the *angle* calibration, there are two alternate *frequency* calibrations -- *FREQ-A* and *FREQ-B*. These allow the user to calibrate flow waveforms in terms of frequency shift. The frequencies for FREQ-A and FREQ-B are shown in **Tables B3, B4, and B5** also.

Occasionally, a flowmeter set for a certain angle transducer will be used with a transducer of a different angle. If this is done, the calibration will be incorrect by a fixed ratio. If, for example, a flowmeter set for 45° is used with a 0° catheter, the calibration will be incorrect by an amount proportional to the ratio of the cosines. **Table B2** shows the true calibration value vs. the indicated calibration when using a flowmeter internally set for 45° and used with transducers of various common angles.

ANGLE	N-1	SW7	SW6	SW5
0°	197	0	C	5
45°	**279**	**1**	**1**	**7**
60°	395	1	8	B
"FREQ-A"	499	1	F	3
"FREQ-B"	249	0	F	9

Table B1 Calibration switch settings

	ACTUAL FLOW RATE (cm/sec)			
Angle of Transducer in use	100 cm/sec selected	50 cm/sec selected	20 cm/sec selected	10 cm/sec selected
60°	141.4	70.7	28.3	14.14
55°	123.3	61.6	24.7	12.3
45°	**100.0**	**50.0**	**20.0**	**10.0**
0°	70.7	34.4	13.8	6.9

Table B2 True calibration vs. indicated calibration when flowmeter is set for 45°.
(Note that the actual and selected flow rates match at 45°.)

If transducers with angles other than the ones in **Table B1** are to be used regularly with the Model 100, or if it is necessary to modify the calibration frequencies to agree with actual timed volume flow calibrations, follow the directions in the following paragraphs to determine proper settings for SW7, SW6, and SW5.

Determining N for Other Angles

The calibration frequency is a function of the assumed velocity of sound and the discreet divisors available from the counter. The calibration values do not agree exactly with the calculated frequency, but are within a fraction of a percent. The calibration frequency is set by placing the proper divisor (N) in the counter switches. For example, if a 0° transducer is used with a 20 MHz system, the Doppler shift for 100 cm/sec may be determined from the Doppler equation *(shown in Figure B6)* as:

$$df = \frac{2\,(20\text{x}10^6)\ \ (100)\ \ \cos(0^\circ)}{1.58\,\text{x}\,10^5}$$

$$\boxed{df = 25{,}316\ \text{Hz}}$$

For the calibrator to approximate this calibration frequency, the oscillator clock frequency must be divided by N, M, and the quadrature generator's factor of 4 as shown in **Figure B7**. The value of M is "1" for 100 cm/sec, "2" for 50 cm/sec, "5" for 20 cm/sec and "10" for 10 cm/sec. Thus, by following the divider chain with the Doppler frequency shift (*df*) known to be 25,316 Hz for 100 cm/sec, N is:

$$df = f \div N \div M \div 4$$

$$N = f \div M \div df \div 4$$

$$N = 20{,}000{,}000 \div 1 \div 25{,}316 \div 4$$

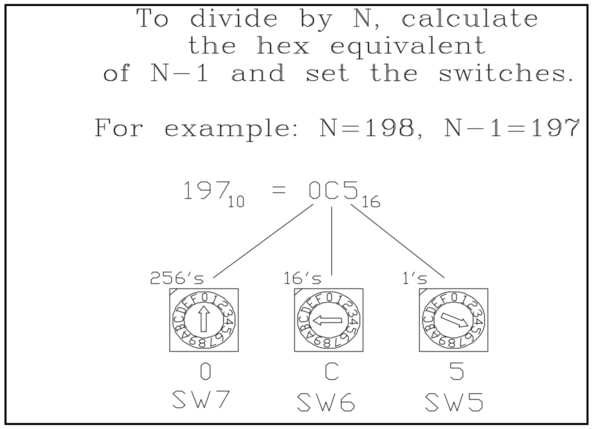
$$N = 198$$

But the divider circuit divides by N-1; therefore, 197 must be programmed in order to divide by 198.

The divider circuit uses binary counters and requires the desired number, 197, to be converted to a hexadecimal number. SW7 steps in multiples of 256, SW6 in multiples of 16 and SW5 in steps of unity. N-1 must be converted from base 10 to base 16:

$$(N\text{-}1) = 197_{10} = 0C5_{16}$$

The calibrator output frequency will be 20 MHz divided by (4 x 198), which equals 25,253 Hz. The error would be 25,316 divided by 25,253, or about 0.25%.



NOTE: Optionally, the dividers can be set to give even-numbered frequency steps for calibrating chart recorder waveforms in 'frequency steps'. Two such options are given in the tables below as FREQ-A and FREQ-B.

For a 0° transducer and 20 MHz carrier, the divisor (N) is equal to 198. At 20 MHz, the N value for other angles may be determined by dividing 198 by the cosine of the desired angle. For example, for 45° the cosine is 0.707107, and N will be 198 divided by 0.707, or 280.

The tables above assume that the velocity of sound in blood is 0.158 cm/µsec. The tables can be recalculated for any other velocity value by using the Doppler shift equation.

CALIBRATION FREQUENCIES

XDCR ANGLE	100 cm/sec cal frequency (Hz)	50 cm/sec cal frequency (Hz)	20 cm/sec cal frequency (Hz)	10 cm/sec cal frequency (Hz)
0°	25,253	12,626	5,051	2,525
45°	17,856	8,928	3,571	1,786
60°	12,626	6,313	2,525	1,263
"A"	10,000	5,000	2,000	1,000
"B"	20,000	10,000	4,000	2,000

Table B3 20 MHz Calibration Frequencies

XDCR ANGLE	100 cm/sec cal frequency (Hz)	50 cm/sec cal frequency (Hz)	20 cm/sec cal frequency (Hz)	10 cm/sec cal frequency (Hz)
0°	12,626	6,313	2,525	1,263
45°	8,928	4,464	1,786	893
60°	6,313	3,157	1,263	631
"A"	5,000	2,500	1,000	500
"B"	10,000	5,000	2,000	1,000

Table B4 10 MHz Calibration Frequencies

XDCR ANGLE	100 cm/sec cal frequency (Hz)	50 cm/sec cal frequency (Hz)	20 cm/sec cal frequency (Hz)	10 cm/sec cal frequency (Hz)
0°	6,313	3,157	1,263	631
45°	4,464	2,232	893	446
60°	3,157	1,578	631	316
"A"	2,500	1,250	500	250
"B"	5,000	2,500	1,000	500

Table B5 5 MHz Calibration Frequencies

The tables above assume that the velocity of sound in blood is 0.158 cm/µsec. The tables can be recalculated for any other velocity value by using the Doppler shift equation.