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INTRODUCTION

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

Section 1 briefly describes the function of the Pulsed Doppler Displacement 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 Displacement theory, a discussion of transducers and their limitations, and provides a brief description of how the Pulsed Doppler Displacement Module works.

Section 3 provides information about additional equipment necessary to operate the Pulsed Doppler Displacement 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 the manual (the manuals for each module type have their own indexes).

The Appendix provides in-depth information pertaining to application of the Pulsed Doppler Displacement Module.

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1. PULSED DOPPLER DISPLACEMENT MODULE

1.1 FUNCTION

The Pulsed Doppler Displacement Module (DDM) uses bursts of high frequency sound traveling through layers of muscle to measure tissue displacement. A burst of sound is transmitted into the myocardium from a single epicardial transducer. The range gate is set to sample echoes returning from a fixed point in the mid-myocardium. The echoes are shifted in frequency by an amount proportional to the velocity of the structures passing through the sample window (Doppler shift). The frequency shifts are proportional to the velocity of the moving structures. The resulting velocity signals are integrated to form a displacement signal output.

The DDM cannot be calibrated in terms of absolute distance but can be calibrated in terms of displacement. The system is calibrated by integrating known frequency signals derived from the internal clock for 100 msec. These calibration frequencies have been calculated for integer displacements using the Doppler equation.

There are two versions of the DDM that measure displacements over different ranges. The 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**, thicker tissues require a lower f_c, and a lower PRF.

In addition to the analog voltage output, the DDM gives audio indications of the Doppler frequency shift through the System 6 Mainframe Chassis. Audio output may be monitored through the front panel speaker or from stereo headphones plugged into the backpanel.

1.2 SPECIFICATIONS

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

VERSION fc (MHz)	PRF (Hz)	PW (µs)	Muscle Thickness (mm)
20	31,250	0.4	1.5-10
10	15,625	0.8	1.5-20

Table 1 Pulse Rate and Pulse Width

PULSE REPETITION - FREQUENCY (PRF) The PRF is factory set at 31.25 or 15.6 KHz corresponding to ultrasonic frequency as shown in **Table 1**. These frequencies are derived from the mainframe timing and are synchronized with the Pulsed Doppler Flowmeter and Sonomicrometer.

TRANSMIT OUTPUT - 15V p-p RF burst into 50-ohm load from a transformer-coupled, balanced source isolated from 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 sample range is set by the multi-turn range control on the front panel and displayed on the front panel LED.

AUDIO BANDWIDTH - The Audio bandwidth is controlled by highpass and lowpass filters. These are four-pole active filters with a Butterworth response. The filter responses are shown below in **Table 2**

VERSION fc (MHz)	HIGH PASS (Hz)	LOW PASS (Hz)
20	200	6,600
10	100	3,300

Table 2 Nominal Audio Bandpass Filter Response

1.3 FRONT PANEL CONTROLS

NOTE: The number preceding each item corresponds to its location in Figures 1 & 2.

54 TRIGGER

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

55 GAIN

This recessed 10-turn pot controls the Displacement DC output voltage sensitivity (V/mm). (*** This option not available at present ***)

56 OFFSET

This recessed 10-turn pot controls the offset voltage of the Displacement output ("FLOW OUT"). This makes it possible to use the output with many types of chart recorders, tape recorders, or data acquisition systems.

57 RANGE

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

58 AUTO RESET RATE

This recessed 10-turn pot controls the auto-reset rate. The minimum rate is approximately one reset every 2 seconds.

59 RUN/CALIB (DISPLACEMENT)

This six-position switch selects RUN mode, ZERO or any of 4 calibration displacements (1, 2, 5 & 10mm). This switch selects one of 4 calibration frequencies which are then integrated for 100 ms to develop a displacement calibration output.

60 LED

The LED flashes each time the integrator is reset by any of the RESET modes.

61 RESET MODE

The RESET MODE selector determines which RESET mode is in use.

62 +/-

The POLARITY (+/-) switch determines the output voltage sense of the reset triggering signal for EKG, trigger, and gate modes. This control is used in conjunction with the level control to determine the reset point.

63 RESET

The RESET button is used to reset the output to midrange at any time. The RESET button overrides all other reset modes.

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64 LEVEL

The LEVEL control is used to set the triggering level for the various RESET modes. This control is used in conjunction with the RESET POLARITY switch.

65 PROBE

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

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

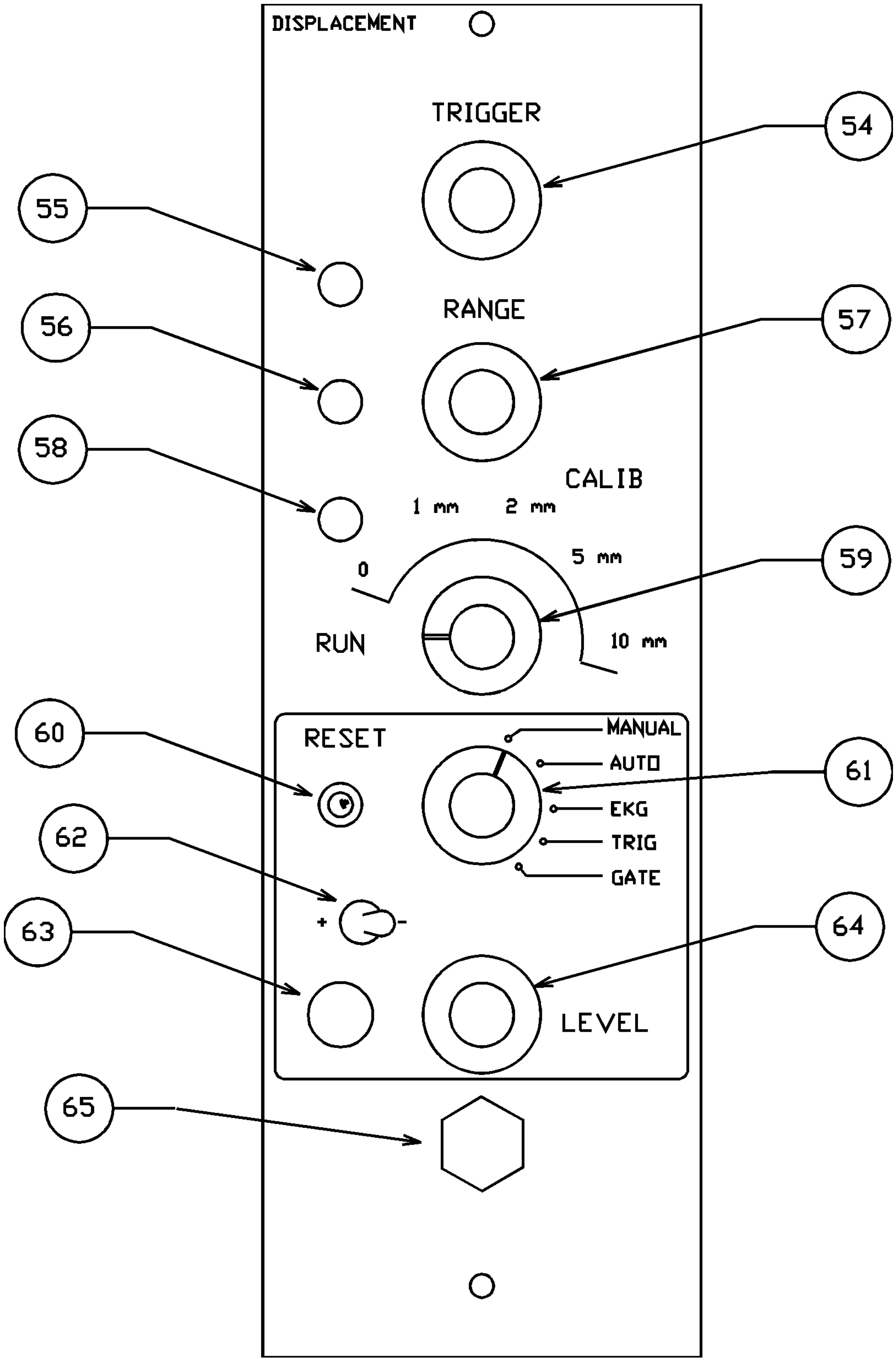


Figure 1 Doppler Displacement Module Front Panel

1.4 REAR PANEL FOR DOPPLER DISPLACEMENT MODULES

39 , 40 "A" & "B" - AUDIO SIGNAL OUT (PHONE)

The quadrature audio signals are provided for recording on a stereo tape recorder or for spectral analysis.

49 "C" - DISPLACEMENT (PHONE)

The Displacement output is available from the "C" terminal, which is marked "FLOW OUT". The DC level may be reduced with the GAIN potentiometer.

50 "D" - EXT RESET IN (PHONE)

External signals may be used to reset the integrator. These may be either synchronous or non-synchronous with the heart rate. For example, an externally generated positive dP/dt signal may be used to reset the integrator at the beginning of each systole. This input is used for both the External Trigger mode and the External Gate mode.

51 "E" - RANGE OUT (PHONE)

A DC voltage proportional to the range gate is provided for recording. The voltage is calibrated at 0.1V/mm.

52 "G" - RESET INPUT MONITOR (PHONE)

The input monitor allows the user to monitor the selected reset signal for amplitude, polarity and quality. This output functions in all modes.

53 "F" - RESET TRIGGER MONITOR (PHONE)

The reset trigger pulse output is used to monitor the reset trigger timing relative to the reset input signal described above. This is accomplished by adjusting the "POLARITY" and "LEVEL" controls so that the "TRIGGER PULSE" output transitions from low to high at the desired trigger point.

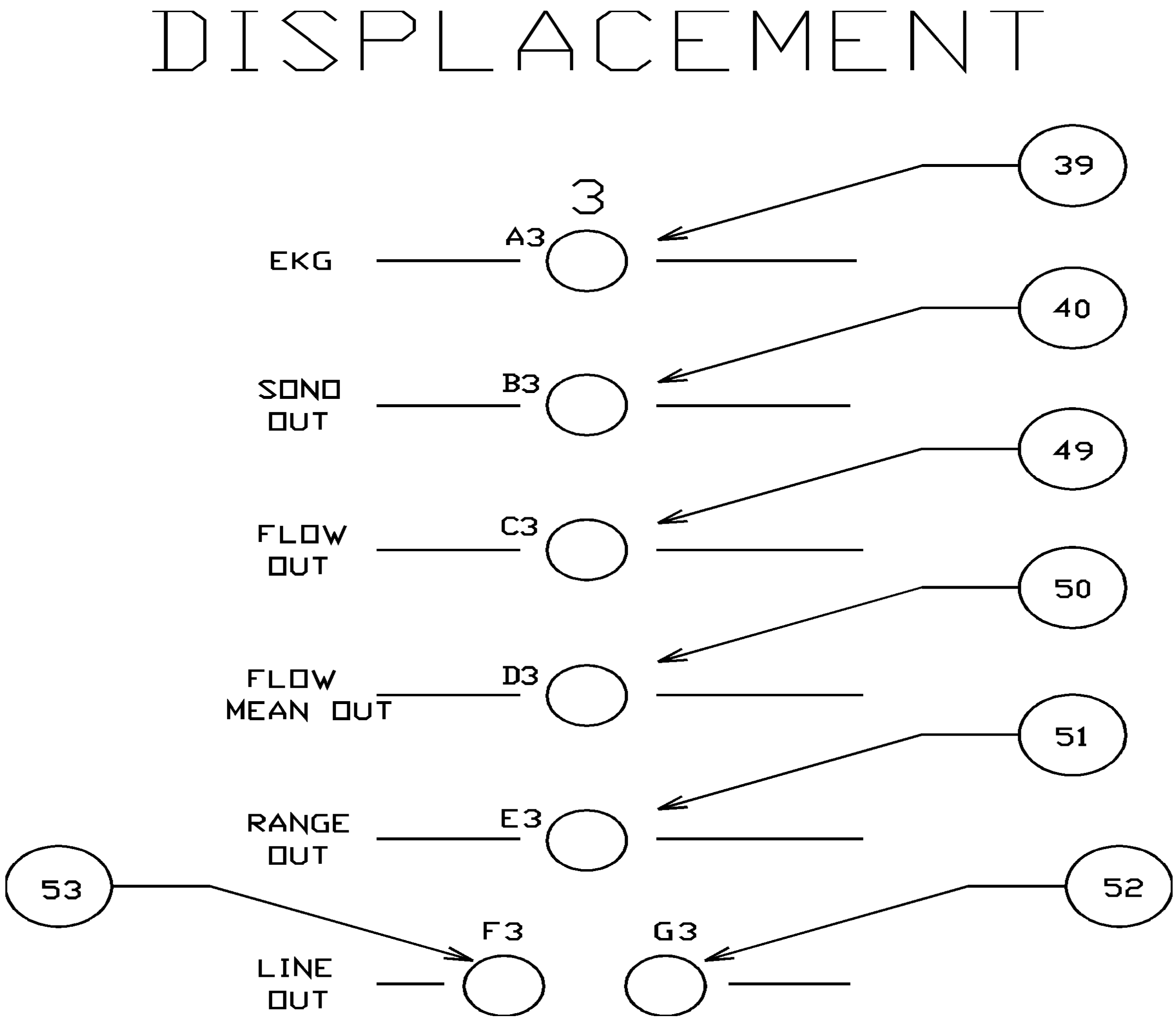
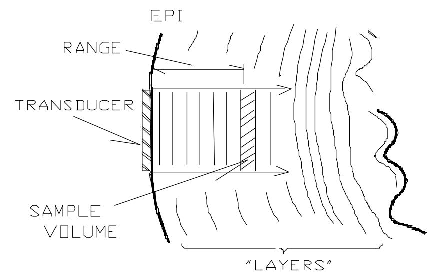


Figure 2 Displacement Rear Panel

2. THEORY OF OPERATION

ς OPERATING PRINCIPLE

The Doppler Displacement Module uses short bursts of ultrasound projected into the myocardium to measure the velocity of structures in the wall. The projected sound is reflected by muscle structures of the myocardium, and the frequency of the reflected sound is altered by the interaction with these structures. The reflected sound, or return signal, is monitored after the transmit burst with the same transducer. Thus the "Doppler effect" appears as a frequency shift of the return signal. As shown in **Figure 3,** the Doppler shift is proportional to the velocity of muscle layers, and inversely proportional to the velocity of sound. The frequency is shifted above or below the carrier frequency depending on the direction of the myocardial tissue movement. Muscle layers traveling toward the transducer will shift the signal above the carrier frequency, and muscle layers traveling away from the transducer will be below the carrier frequency.



$$Doppler = \frac{2 f v}{c}$$

Figure 3 Doppler Equation

Doppler = Doppler frequency shift (Hz)
v = velocity (cm/sec)
f = ultrasonic frequency (Hz)
c = velocity of sound in tissue (1.58×10^5 cm/sec)

The resulting velocity is integrated with a 12-bit up-down counter. The counter output is converted to a DC output with a 12-bit digital to analog converter (DAC). The resulting signal passes through a 4-pole, 100 Hz active filter with a Butterworth response. This output voltage is proportional to the integral of the velocity signal, i.e. displacement. The integrator (counter) output drifts as a natural consequence of the integration process of signal plus noise.

Resetting the output signal each cardiac cycle will minimize any drift due to unequal counts between upward and downward integration. The counter can be reset in one of several ways: a manual button, automatic timed reset, EKG R-wave, pressure waveform or any other signal source. The reset trigger signal source may or may not be synchronous with the heart rate. The counter is reset to a binary level of 2048, which is half way between zero and 4096 (full scale). This makes guard bands of equal width on both sides of the reset level.

The DDM has internal reset trigger circuitry which makes it possible to change both the **TRIGGER** level and **POLARITY** of the reset point. The circuit, shown schematically in **Figure 4**, is configured so that the operator can monitor the selected **RESET** signal. This is available on the backpanel at output "F" of the channel in use. Simultaneously, the **TRIGGER/GATE** signal output may be monitored at backpanel output "G" as shown in **Figure 4**. The user may put these two signals on adjacent channels of a chart recorder or alternately on a two-channel oscilloscope. The **TRIGGER** level and **POLARITY** controls are adjusted to make the **RESET** pulse go from low to high at the appropriate reset time. This might be the "R" wave of the EKG, the raising edge of the left ventricular pressure or the peak of positive dP/dt.

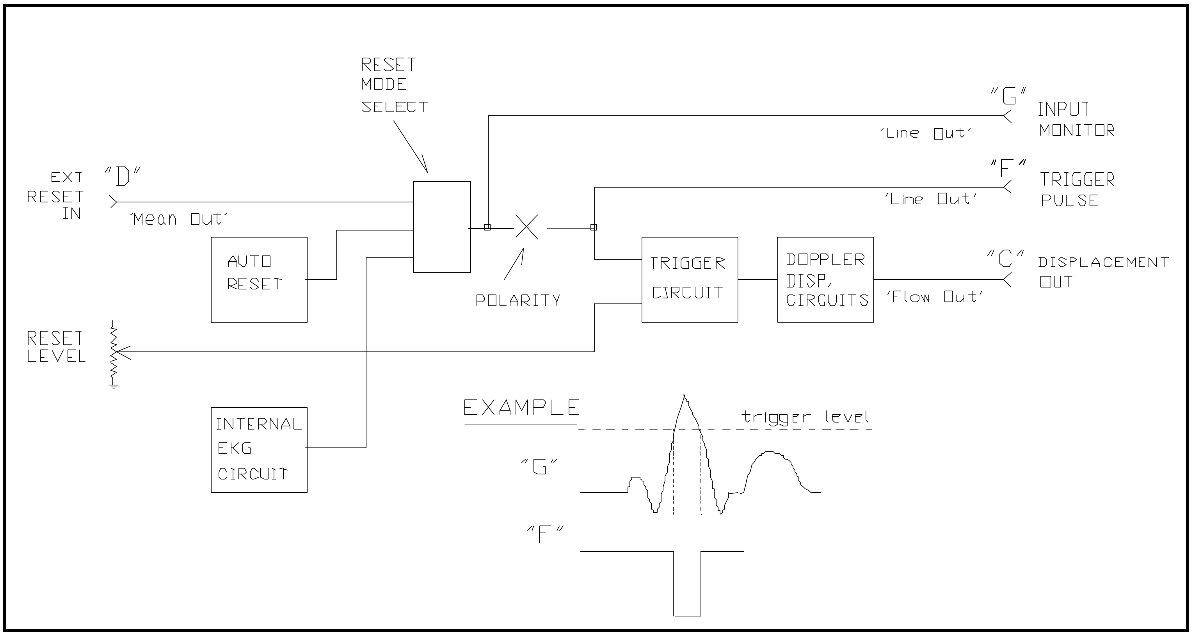


Figure 4 External Trigger Diagram

As previously stated, several **RESET** options may be selected. The options include a **MANUAL** overriding reset activated by a front panel button. The second option is an **AUTOMATIC** which resets the output at a fixed time interval between approximately 2 to 5 seconds. The rate is adjusted by a recessed front panel potentiometer.

The DDM includes an internal electrogram amplifier, which amplifies and filters the electrogram from the epicardial transducer for use as a reset signal source. This mode is entered by selecting the **EKG** reset mode switch position. The **LEVEL** and **POLARITY** controls are utilized to achieve proper triggering.

There are also two additional external **RESET** modes available: **TRIGGER** and **GATE**. External signals may be supplied to the DDM via the backpanel "D" input. This input is marked "MEAN OUT" (its Pulsed Doppler flowmeter function). Typical external signals are left ventricular pressure, dP/dt or an externally derived EKG. Any of these signals will work in the **TRIG** (triggered) mode. They will cause the DDM to momentarily reset to the zero level.

The **GATE** mode causes the DDM output to be held in the reset mode as long as the external input signal is above the trigger level. For example, if the left ventricular pressure (LVP) is used as an input, the output would be clamped at zero the entire time the pressure is above a set level, i.e. the duration of systole.

3. FIRST-TIME START-UP AND OPERATION

3.1 EQUIPMENT REQUIRED

1 chart recorder
1 cup of milk or liquid laundry starch solution
1 epicardial displacement transducer
1 transducer extension cable (optional - see Appendix B)
1 chart recorder cable

3.2 INITIAL SETUP

The initial setup ensures a standard starting point for operating the DDM (Doppler Displacement Module). The System 6 usually comes from the factory with the DDM modules installed. However, you may wish to change module positions to suit your application, or add other Displacement 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 displacement monitoring session. For simplicity this procedure will assume that a 10 MHz system is being used with an epicardial patch transducer.

*******CAUTION*******
DO NOT REMOVE OR INSTALL MODULES WITH THE POWER ON

3.2.1 MAINFRAME REAR-PANEL SETUP

ς 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. The DDM sample range will be displayed on the Flow Range Display.

3.2.3 DOPPLER DISPLACEMENT MODULE FRONT PANEL SETTINGS

ς Set the selected Displacement Module front panel controls as listed below in **Table 3**:

CONTROL	POSITION
TRIGGER	FULL CW
RANGE	CENTER RANGE
RUN/CALIB	0
RESET SELECT	AUTO
RESET POLARITY	+
RESET LEVEL	CENTER RANGE

Table 3 DDM Front-Panel Initial Settings

3.3 CALIBRATION

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 middle 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 Displacement Module.

3.3.2 CALIBRATE CHART RECORDER

ς After performing the setup, the chart recorder can be calibrated to a full-scale level appropriate for the expected maximum displacement. In this example a full scale displacement of "10mm" will be used.

1. Rotate RUN/CALIB switch to "10mm". Adjust the Mainframe VOLUME control for comfortable listening level.

2. The chart pen should deflect up and down around the center of the chart.

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 "10mm".

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 "10mm" 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 "5mm". The pen should deflect to a position halfway between the "0" and "10mm" 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 5**.

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

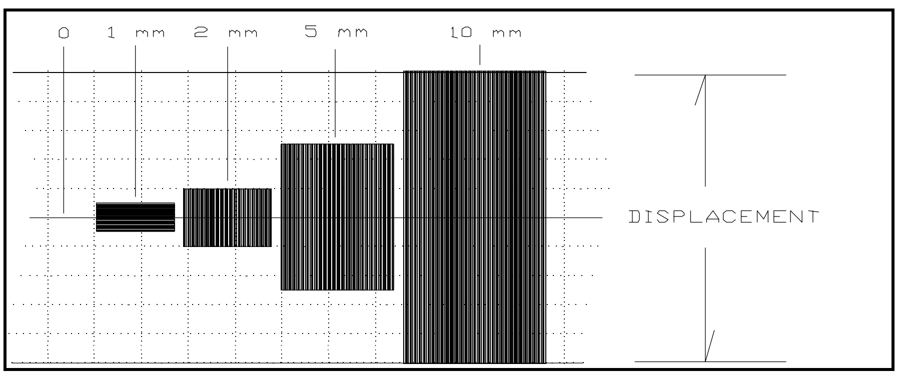


Figure 5 Chart recorder calibration

3.4 FINAL SETUP AND TEST

The Doppler Displacement Module may now be configured for operation in the RUN mode as follows:

3.4.1 CONNECT TRANSDUCERS

ς These instructions describe how to connect the appropriate flow probe to a module. **Figure 6** illustrates the transducer connections .

1. Make sure the RUN/CALIB switch 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 P/N 126-214-1000, avail-able from the manufacturer or Triton Technology P/N 801228. Connect flow probe leads to Pins B and D.

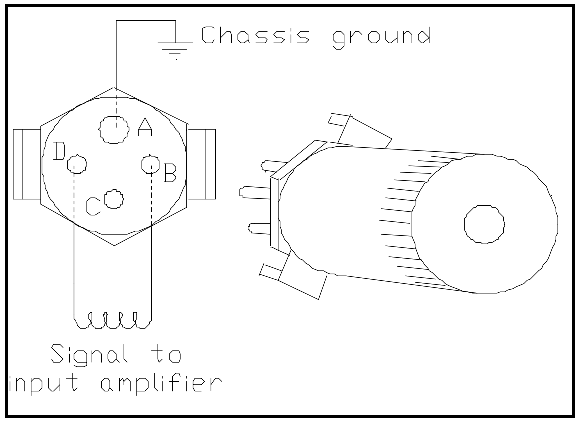


Figure 6 Transducer Connections

3. As shown in **Figure 6**, 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.

3.4.2 TRANSDUCER BENCH TEST

This test ensures that the Displacement Module, 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 displacement transducer while the other will operate the equipment.

1. The DDM should be connected to the chart recorder and the recorder should be calibrated to the expected displacement range. The DDM RUN/CALIB switch should be set to "0". The transducer should be connected to the DDM either directly or via the optional customer-supplied extension cable.

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

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

4. Hold the transducer still in solution while listening to the displacement signal on the speaker (at a moderate volume level). The audio should have a low level of background "hiss".

5. Move the transducer back and forth in the solution. The audio signal should be a low frequency sound rising and falling in pitch as the transducer moves through the solution.

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

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7. It should also be possible to obtain displacement signals by placing the transducer on the upper arm. Flexing the biceps should produce displacement signals on the chart recorder.

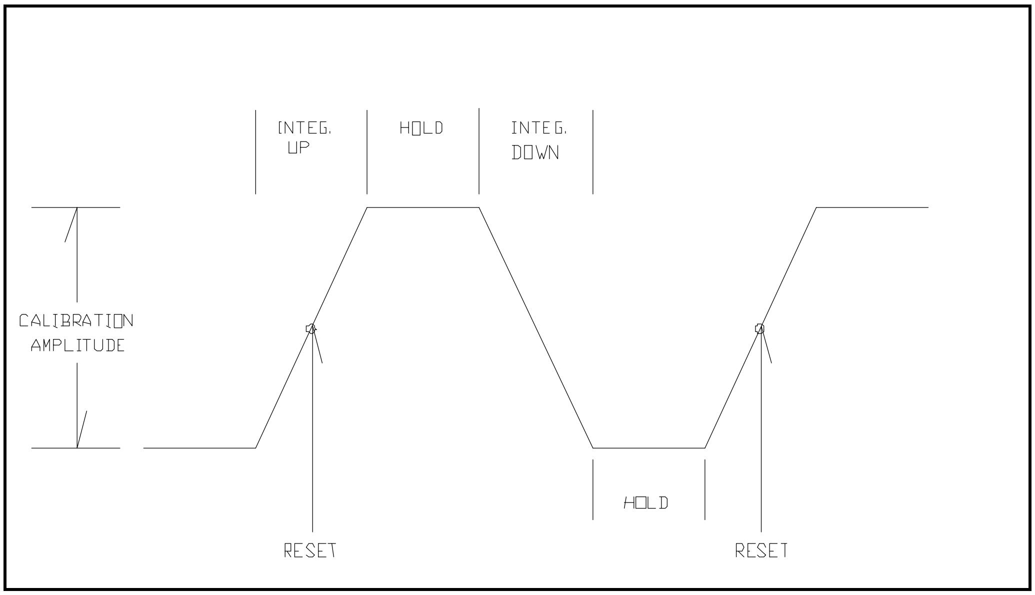
This completes the verification test of the Displacement probe, Displacement Module and chart recorder.

4. APPENDIX

APPENDIX A: DISPLACEMENT CALIBRATION

The Pulsed Doppler Displacement Module is calibrated by integrating a known frequency signal for a fixed period of time. Since frequency is proportional to velocity, this corresponds to integrating velocity to measure displacement. The displacement signal cannot be calibrated in absolute dimensions. The displacement calibration is used in conjunction with the RANGE control and range display to describe the tissue displacements vs range.

In order to make the calibration more usable, the integrator is designed to integrate up for one tenth of a second, hold for one tenth of a second, integrate down for a tenth, hold for a tenth and repeat the process over and over. The integrator is reset to zero each cycle, preventing the output from drifting. The result is an alternating trapezoidal signal, the peak-to-peak amplitude of which is equal to the displacement value shown on the front panel **RUN/CALIB** switch. Figure A-1 shows how the waveform appears on the chart recorder. The module can be calibrated in 1mm, 2mm, 5mm,and 10mm displacement levels. Refer to **Figure 5** of the text.



The frequencies for the calibrator are derived from the 60MHz mainframe system clock. The RUN/CALIB switch selects the frequency for the calibrator to integrate. The calibration frequencies are calculated from the Doppler equation as follows:

$$\textit{Calibration Frequency} = \frac{2 f \upsilon \cos\theta}{c} = \frac{2 f \upsilon}{c}$$

where:

f = operating frequency

υ = tissue velocity (mm/sec)

θ = angle of sound to motion = 0 degrees

c = velocity of sound = (1.58×10^6 mm/sec)

The velocity can be expressed in terms of millimeters of tissue displacement per second. The integration and hold times are also derived from the calibrator timing circuits and thus are very accurate and stable. **Table A1** gives the calibration frequencies for the 10MHz and 20MHz Displacement Modules. These signals are integrated for one tenth of a second to develop the displacement calibration signal.

FREQ	1 mm	2 mm	5 mm	10 mm
10 MHz	127 Hz	253 Hz	633 Hz	1266 Hz
20 MHz	253 Hz	506 Hz	1266 Hz	2532 Hz

Table A1 Calibration Frequencies

The Displacement calibrations are based on a velocity of sound of 1.58 x 10^6 mm per second. The system may be calibrated for other sound velocities. Please contact Triton for further information.

Example: 10MHz operating frequency, 10mm Calibration Frequency

Using $\text{Calibration Frequency} = \frac{2fu}{c}$

$$1266 = \frac{(2)(10^7)(v)}{(1.58)(10^6)}$$

Therefore, v = 100 mm/sec

and, in 100ms the displacement = 10mm

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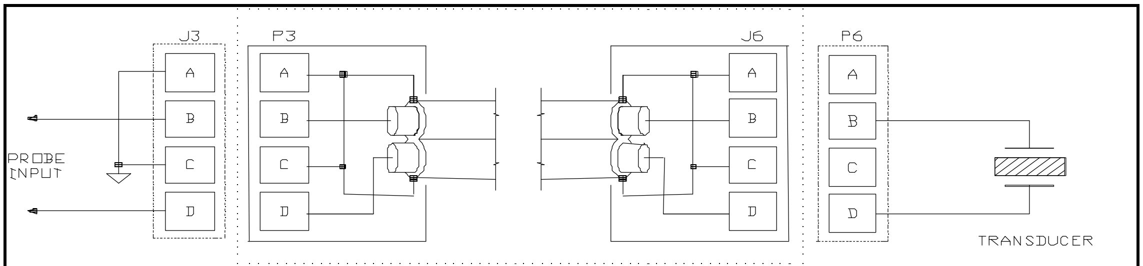
APPENDIX B: TRANSDUCER EXTENSION CABLE

The Doppler Displacement Module (DDM) requires lead wires from the front panel connector to the displacement transducer. For short distances (1 to 6 feet) these may simply be light gauge, twisted pair leads. The DDM input amplifier is extremely sensitive and long leads act like an antenna, introducing unwanted external noise/interference. In addition, the DDM radiates high-energy bursts from unshielded leads, and may cause interference with other equipment.

For longer distances a shielded transducer cable can be fabricated using twin RG-59 coax or ribbon coax. The cable should be fabricated using the diagram below:



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 7 DDM Transducer Cable Assembly