



MPVS Ultra
Signal Conditioning
Hardware
User Guide

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I. Introduction

The MPVS *Ultra* simultaneously and continuously measures high-fidelity left ventricular pressure and volume from the intact beating hearts of large and small laboratory animals. The MPVS *Ultra* can be used on animals as small as transgenic mice and as large as full grown horses. Using the MPVS *Ultra*, cardiovascular pressure and volume signals can be plotted against each other in real time, generating the characteristic pressure-volume (P-V)

loops that are an excellent illustration of the cardiac cycle in normal or diseased conditions of the living heart.

With the MPVS *Ultra*, P-V loops may be captured during pharmacological, therapeutic and hemodynamic interventions, allowing comprehensive, beat-by-beat evaluation of the fundamental mechanical properties of the heart.

The MPVS *Ultra* supports the use of Millar's ultra-miniature P-V catheters for small animal studies and multi-segment P-V catheters for large animal studies. Both the small and large animal catheters couple a high-fidelity pressure sensor with volume electrodes spaced to match the longitudinal diameter of the left ventricle. The electrodes allow volume data to be acquired across a single segment of the left ventricle.

The MPVS *Ultra* has an internal 20 kHz fixed-frequency oscillator, which generates either a 20 μ A or 100 μ A RMS sine-wave current that creates an electric field within the left ventricle of the heart. The system measures a corresponding voltage that is proportional to the electric field. The system continuously measures this voltage across the receiving electrodes. The measured voltage changes during the cardiac cycle as the left ventricular blood volume rises (diastolic filling phase) and falls (systolic ejection phase).

The measured voltage decreases as volume increases (resistance of blood pool decreases, conductance of blood pool increases) and the measured voltage increases as volume decreases (resistance of blood increases, conductance of blood pool decreases). The system then converts measured voltages into ventricular conductance, which is proportional to the changes in ventricular volume as stated above.

The MPVS *Ultra* also measures high fidelity pressure signals using a Millar catheter. The solid-state pressure sensor uses the same technology found in Millar's extensive line of Mikro-Tip[®] catheter pressure transducers. The use of the pressure sensor located between the conductance/volume electrodes allows the simultaneous measurement of pressure and conductance/volume, enabling a researcher to obtain high quality P-V loops from the rapidly beating hearts of small animals. The MPVS *Ultra* system should ONLY be used with a Millar catheter.

II. Getting Started

Components and Contents

- MPVS *Ultra* Control Interface software
- PVAN *Ultra* analysis software
- MPVS *Ultra* unit
- MPVS *Ultra* P-V cable (CEC-10E or CEC-4E)
- Mikro-Tip® P-V Catheter
- Rho calibration cuvette (for measuring resistivity)
- BNC cables
- USB cable
- Optional: ECG cable (EPC-10UT, EPC-10A, EPC-4UT, EPC-4A)
- Optional: Thermodilution cable (SGC-10A, SGC-4A)
- Not included: Data acquisition system such as ADInstruments PowerLab 16/3 Data Acquisition Hardware with Chart DAQ software (v. 5.2 or higher)
- Not included: Computer with MS Windows operating system (XP or later) and MS Excel

Initial Setup

Typical Setup

Place the MPVS *Ultra* (and any related equipment) on a solid surface where the enclosure(s) will be protected from exposure to liquids and heat sources. Be sure that when the cables are connected they are not tight or sharply bent as this may damage the internal wires. The MPVS *Ultra* does not require ventilation, but most computers and data acquisition systems will. Position the equipment so that cables can easily be disconnected, especially the power cord, in case of an emergency. This system must be connected to an easily accessible wall outlet that remains accessible after installation so that the power cord can be disconnected in case of an emergency. Failure to operate the system according to the instructions provided in this manual may cause a hazardous condition that may lead to damage or personal injury.

Control Interface Installation

Install the MPVS Control Interface before connecting the system to your computer. Insert the disk into your computer. If the installation dialog does not automatically launch, run setup.exe from the CD or the software downloaded from the Millar web site. After installation is complete, store the disk and the serial number in a secure location for future use.

USB Control

The system is controlled by the MPVS *Ultra* Control Interface. A USB cable is included with the system. Connect the MPVS *Ultra* hardware to your computer before turning it on. The first time that a computer is connected to an MPVS *Ultra* system, software drivers will be installed; this installation will not be necessary after the first installation.

Power Input

The system has a universal power input, so it can accept 110V or 220V at 60Hz or 50Hz (47Hz minimum, 63Hz maximum). The system includes two power cords: one with a North American (NEMA) 5-15 plug and one with a European CEE (7)VII plug. If your region requires a different plug type, contact your distributor or see the Technical Support section for a source of power cords. See the Technical Specifications section for more specific information about the power requirements.

CAUTION – Reliable earth connection is required. This device is designed to be connected to protective earth through the power cord and the wall outlet. If your wall outlets do not have a grounding conductor, please contact an electrician for installation. Do not use groundless adapters.

The power switch is located on the back panel of the MPVS *Ultra*.

The green LED on the front panel will indicate whether the MPVS *Ultra* is turned on.

System Ground

For operator safety and signal noise reduction, an equipotential (earth ground) post is located on the rear panel. This terminal can be used to ground the subject and any sensitive equipment. Keep electrically noisy equipment such as lamps, heaters, and electrocautery generators as far from the system as possible. See the *Recommended Accessories* section for ordering information for equipotential cables specifically made for this type of terminal.

Data Acquisition

The system can be connected to any data acquisition system with sufficient voltage input channels to accept the desired number of signals. Users with an ADInstruments PowerLab system should refer to the *ADInstruments PowerLab setup* section for specific instructions. For users with other data acquisition systems, packages of BNC-to-BNC cables are available. See the *Recommended Accessories* section for ordering information.

Connect each channel of the MPVS *Ultra* to the data acquisition system. Millar recommends that the order of the channels be consistent with the order in which they are arranged on the front panel of the MPVS *Ultra*. (Channels on the front panel are numbered 1 through 11.) A user may choose not to connect certain outputs, but consistency from one study to the next is important to prevent problems in analyzing the data. Most users will not use the Cuvette Output and Cuvette Temperature signals available on the rear panel. (The Cuvette Temperature output can be used for a thermodilution measurement. See the “*Theory of Operation – Temperature Measurement*” section for details.)

Pressure-Volume Cable

The P-V cable connects the catheter to the system. The cable is available in two different lengths according to the users’ needs.

One end connects directly to the white low profile and gray circular connectors on the catheter and the other end plugs into the color-coded (black) pressure-volume channel receptacle on the front of the MPVS *Ultra*.

This cable carries the excitation signal from the MPVS *Ultra* to the catheter electrodes and returns the pick-up signal from the sensing electrodes. This cable also carries the excitation signal from the MPVS *Ultra* to the pressure sensor bridge as well as the pressure signal back to the MPVS *Ultra*. When the system is used to record the internal ECG (IECG), the signal is measured from the catheter through the P-V cable.

Rho Cuvette

The rho cuvette connects to the system through a cable connected to the front panel. The cuvette is packaged separately from the rest of the system. See the “*Normal Operation*” and “*Theory of Operation*” sections for more details on the cuvette. The Cuvette input can be used to connect a thermodilution sensor to the system. See “*Theory of Operation – Temperature Measurement*” for instructions. See “*Recommended Accessories*” for ordering information for the particular connector.

External ECG

The ECG cable will only be used by users who want to measure surface ECG. The Control Interface is used to select the input to the ECG channel. The ECG cable is available in different lengths and with different terminations according to user needs. See the “*Recommended Accessories*” section for ordering information.

P2 – Second Pressure Input

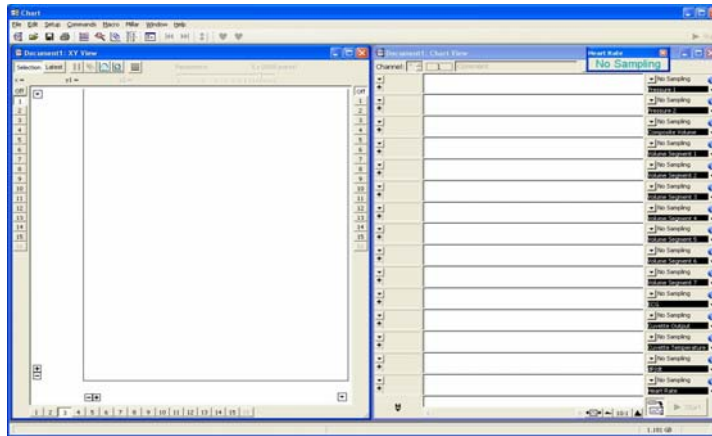
The system can measure two pressure signals simultaneously. If the user wishes to use a second transducer to measure pressure elsewhere in the body, the second transducer will be connected to the P2 input on the front panel. Use the Control Interface to select the input for the second pressure channel.

ADInstruments PowerLab Setup

As shown below, the MPVS *Ultra* connects easily to the ADInstruments PowerLab16/30 using the MPVS *Ultra* – PowerLab cable pack. The cable pack is a set of thirteen BNC-to-BNC cables specifically sized for connecting these two systems. Ten 9-inch cables are included for connecting the first ten channels on the MPVS *Ultra* to the first ten channels of the PowerLab system. A 1-foot cable is included to connect the ECG output to channel 11 of the PowerLab system. Two 3-foot cables are included for connecting the Cuvette Output and Cuvette Temperature signals to the PowerLab system.



The PVAN *Ultra* analysis software CD also includes an ADI Chart interface file that will save setup time by providing an interface to record data. A shortcut to the file `MPVS Ultra Interface.adiset` will be installed on your Desktop during a normal installation of the Control Interface. There will also be a shortcut in the Millar branch of the Start menu. The settings file itself will be installed in the same directory as the Control Interface.



Note that other ADI PowerLab hardware can be used instead of a PowerLab 16/30. Contact Millar to verify compatibility.

Tips for better performance

Steps can be taken to reduce signal noise. While the system meets CE requirements to withstand EMI (electromagnetic interference), noisy equipment such as lamps, heaters, and electrocautery equipment can add noise to the signal. The following suggestions can improve the signal-to-noise ratio.

Cable Length

Use the shortest cables and cords that will serve the purpose. Millar offers 4-foot input cables for users whose subjects will be located close to the hardware. BNC-to-BNC cables are available in shorter lengths for those who can use them. See the “*ADInstruments PowerLab Setup*” section for an example.

Cable Quality

Millar provides only high-quality shielded cables for input and output signals. If you acquire or build your own cables, be sure that the shield is a high-quality braid or foil shield. Be sure that the shield is connected to the ground pins indicated in the “*Theory of Operation*” section. Users who build their own interface cables assume all responsibility for harm, loss, or damage related to the use of such a cable.

Coiling Cables

For EMI purposes, the effective cable length will be reduced when a cable is coiled to take up excess length.

System Grounding

Grounding the subject can be beneficial, but in some cases, the signal can be affected if the animal is later ungrounded during the course of an experiment. If the animal is grounded, leave it grounded throughout the procedure.

Grounding low-noise equipment, such as the MPVS *Ultra*, separately from high-noise equipment is advisable. High-noise equipment includes lamps, room lights, heaters, electrocautery (ESU/Bovie) equipment, power supplies, power cords and computers. If the equipment has a metal chassis, try grounding the chassis directly. Do not let power cords lie on top of signal cables. To avoid ground loops, connect the grounds of low-noise equipment with the shortest possible connector lengths, preferably using the chassis ground points such as the one found on the rear panel of the MPVS *Ultra*.

Normal Operation

After installation and the initial setup, the system is ready for use. The following sections are intended to guide preparation for a protocol. Some assumptions are made that may need to be modified to fit a particular user's preferences. Specific instructions are included in the "*Detailed Operation*" sections below.

Overview of a typical large animal procedure

1. Warm-up and calibration

Turn on the system, plug in the P-V and/or pressure transducer(s) and begin soaking them in body-temperature saline or deionized water according to the instructions in the IFU. A warm-up and pre-soak of 30 minutes or more is advisable. After the warm-up period, balance the pressure signals and calibrate all channels of the system that will be used in the procedure.

Place the cuvette under the animal or in a bath of body-temperature water to warm the plastic. This will minimize temperature effects on the resistivity (ρ) measurement.

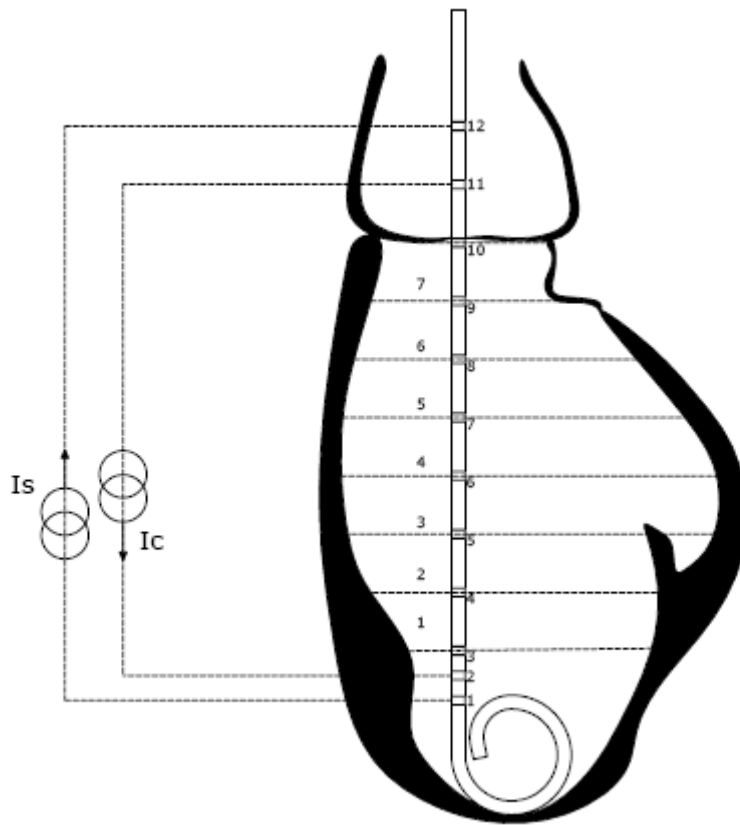
2. Prepare the animal

3. Resistivity

Perform this step before volume signal calibration if data will be recorded in volume units. Plug the cuvette cable into the MPVS *Ultra*. In the Control Interface **Rho Cuvette** tab, select the appropriate settings. Perform the following with as little delay as possible: Dry the cuvette's well with a gauze or swab. In a heparinized syringe, draw at least 0.5cc of blood. Fill the well. Click on **Measure** in the Control Interface. Additional information will appear. Click on **Load** to set the displayed resistivity as the value to be used in calibration and measurements.

4. Catheterize the subject

Monitor the data acquisition system output to determine proper placement of the transducer. See recommended catheter placement below.



5. Alpha correction

If stroke volume comparison for alpha correction will be used, this may be done at any point according to the protocol. If raw data will be recorded as volume units (ml or μl), alpha calculation should be performed before the final volume calibration. Recalibrate the volume signal channels now if alpha is used.

6. Record and export data as desired

Typical protocols may include baseline data, occlusion data, stimulus reaction data, and saline bolus data. Smaller animals should have saline bolus maneuvers performed at the end of the study in case the saline induces detrimental effects on the cardiovascular system.

7. Analyze the data in PVAN *Ultra*

If data were recorded in conductance units, PVAN will need resistivity (ρ), segment length and (if desired) alpha parameters.

Overview of a typical small animal procedure

1. Warm-up and calibration

Place the cuvette well in warm water or under the animal warming mat to warm the plastic. This will minimize temperature effects on the resistivity measurement.

Turn on the system, plug in the P-V and/or pressure transducer(s) and begin soaking them according to the instructions in the IFU. A warm-up and pre-soak of 30 minutes or more is advisable. After the warm-up period, balance the pressure signals and calibrate all channels of the system that will be used in the procedure.

2. Resistivity

Perform this step before volume signal calibration if data will be recorded in volume units. A representative animal is typically required due to the volume of blood removed. Plug the cuvette cable into the MPVS *Ultra*. In the Control Interface **Rho Cuvette** tab, select the appropriate settings. Perform the following with as little delay as possible. Dry the cuvette's well with a gauze or swab. In a heparinized syringe, draw about 0.3cc to 0.5cc of blood. Fill the well. Click on **Measure** in the Control Interface. Additional information will appear. Click on **Load** to set the displayed resistivity as the value to be used in calibration and measurements.

3. Prepare the animal

4. Catheterize the subject

Monitor the data acquisition system output to determine proper placement of the transducer.

5. Alpha correction

If stroke volume comparison for alpha correction will be used, this may be done at any point according to the protocol. If raw data will be recorded as volume units (μl), alpha calculation should be performed before the final volume calibration. Recalibrate the volume signal channel now if alpha is used.

6. Record and export data as desired

Typical protocols may include baseline data, occlusion data, stimulus reaction data, and saline bolus data. Smaller animals should have saline bolus maneuvers performed at the end of the study in case the saline induces detrimental effects on the cardiovascular system. The saline bolus is often lethal for a mouse.

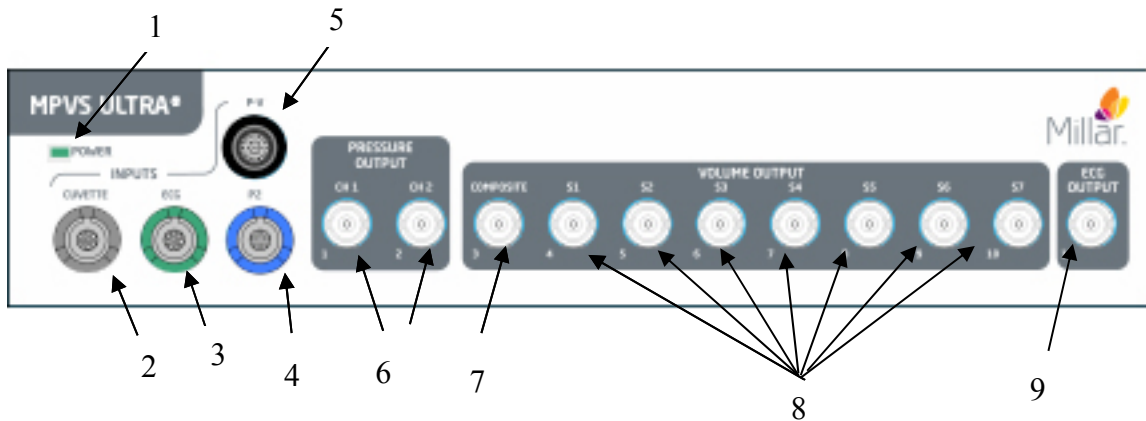
7. Analyze the data in PVAN *Ultra*

If data were recorded in conductance units, PVAN *Ultra* will need resistivity (ρ), segment length and (if desired) alpha parameters.

III. Detailed Operation

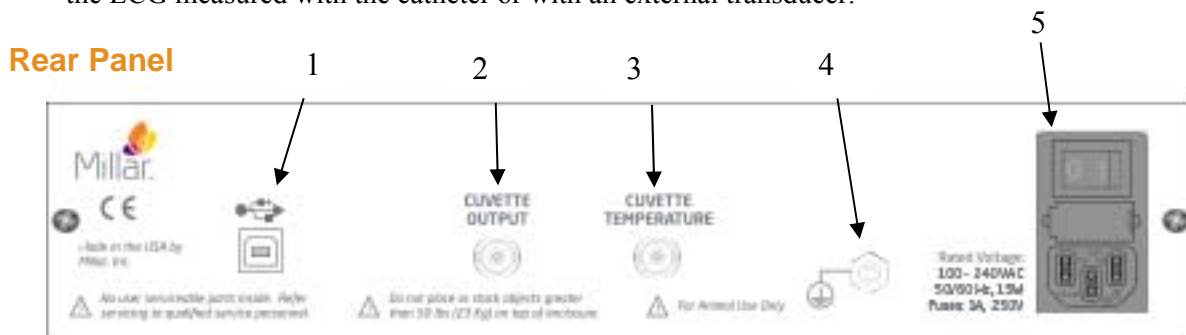
Hardware Connections

Front Panel



1. Lighted Power Indicator - The green indicator will be lit when the system is receiving power and turned on.
2. Cuvette Input – Rho Calibration Cuvette connects to the MPVS *Ultra* and provides resistivity value for volume calibration (color-coded gray)
3. ECG Input – External ECG electrodes can be connected to the MPVS *Ultra* (input color-coded green) and the signal can be displayed real-time
4. Pressure-Only Catheter Input (P2) – A second, pressure-only, Mikro-Tip[®] catheter can be connected to the MPVS *Ultra*. The input to the second pressure channel can be through the P2 connector (color-coded blue) or the P-V connector (color-coded black).
5. Pressure-Volume Catheter Input (P-V) – The MPVS *Ultra* connects to all of Millar's Pressure-Volume catheters including the *Ultra*-miniature single segment P-V catheters and the Multi-Segment P-V catheters with the appropriate cables. The system can accept inputs from P-V transducers with one or two pressure sensors. When connecting to a three-connector, dual-pressure P-V transducer, be sure to follow the labeling on the connectors to ensure that the pressure sensor inputs are not swapped.
6. Analog Pressure Outputs - The MPVS *Ultra* provides analog output for both pressure channels at individual BNC connectors. The pressure signals (P1 and P2) are scaled to 1V/100mmHg.
7. Analog Composite Volume Output – The MPVS *Ultra* provides an analog composite volume channel that outputs the analog sum of the individual volume segments. This signal is useful for viewing real-time P-V loops in the data acquisition software. The volume signal compliance can be altered with the gain adjust function in the MPVS *Ultra* Control Interface.
8. Analog Volume Segment Outputs – The MPVS *Ultra* provides an analog output for a maximum of seven volume segments which can be displayed in real-time on a computer through the data acquisition system. The pressure-volume analysis software PVAN *Ultra* will use these individual segments. The volume signal compliance can be altered with the gain adjust function in the MPVS *Ultra* Control Interface.

- Analog ECG Output – The MPVS *Ultra* provides an analog ECG channel that will output the ECG measured with the catheter or with an external transducer.



- USB Control** – The MPVS *Ultra* system is controlled by the MPVS *Ultra* Control Interface software through a USB connection. The system requires a computer with USB (v1.1) or later. A USB cable is included with the system. Connect the MPVS *Ultra* hardware to your computer before turning the computer on. The first time that a computer is connected to an MPVS *Ultra* system, software drivers will be installed; this installation won't be necessary after the first installation.
- Cuvette Output** – The system is designed to provide a numerical value for the resistivity measurement using the MPVS *Ultra* Control Interface. The analog voltage signal of this measurement is provided on this connection, but users typically will not use this signal. There is no straightforward conversion between voltage and resistivity.
- Cuvette Temperature** – The system is designed to provide a numerical value for the blood temperature using the MPVS *Ultra* Control Interface so that the user can choose to correct the resistivity measurement for temperature dependency. The analog voltage signal of this measurement is provided on this connection, but users typically will not use this signal in connection with blood sample temperature. With proper calibration, a user can choose use the temperature input pins on the front panel Cuvette input (see previous photo) to measure temperature with a thermodilution catheter. See “Theory of Operation –Temperature Measurement” for instructions. See “Recommended Accessories” for ordering information for the particular connector.
- Equipotential Point (Ground)** – The equipotential point or ground post provides a point at which the user can connect to the system's analog ground point. The equipotential point is connected to the ground wire of the power cord. Connecting the equipotential point to a common ground point with other equipment and possibly the subject may help reduce noise if signal noise is a problem. Note that the subject connections and the rho cuvette connections (all analog signal inputs) are isolated and therefore are not grounded to this point.
- Universal Power** – The system can be powered by 90VAC at 60Hz or 264VAC at 50 Hz. Use the power cord included with your system in North America or Europe. Power cords for other regions are available through your distributor or through the source listed in “Recommended Accessories”. See the Technical Specifications section for more specific information about the power requirements.

MPVS Ultra Control Interface

The Control Interface software allows the user to manage catheter configuration, calibrate all signals, and measure resistivity through an intuitive graphical user interface.

Single-Segment Mode

The MPVS Ultra is shipped from the manufacturer in Single Segment Mode. This mode only allows for the use of PV catheters with one volume segment such as the PVR-1045 and the SPR-838. A keycode must be entered in order to use the system in Multi-Segment Mode.

Registration

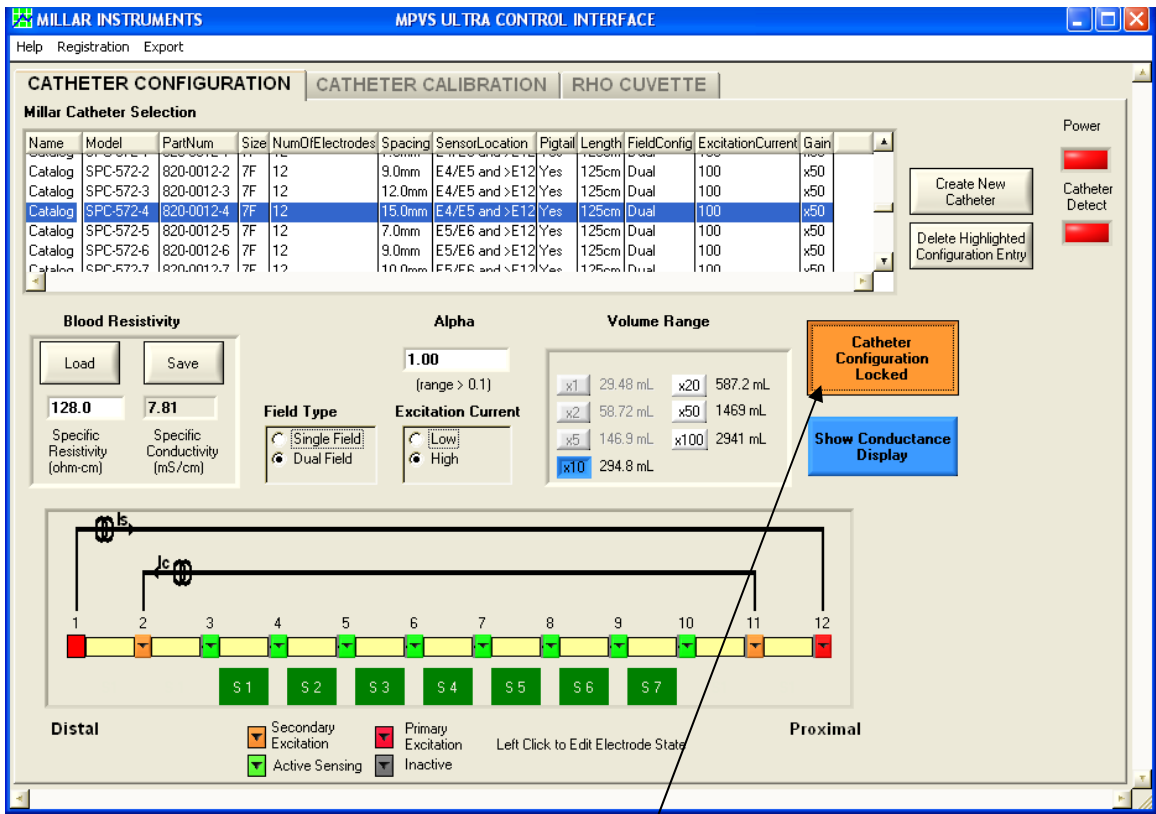
The Registration Menu allows the user to upgrade a MPVS Ultra Single Segment to the full Multi-Segment mode. If the user initially purchased the MPVS Ultra with Multi-Segment capabilities, a keycode will be supplied with the shipment. For information about upgrading a MPVS Ultra Single Segment unit for use with Multi-Segment PV catheters, please contact Customer Service.

Export

The Export menu allows the user to save the Catheter Configuration settings for later use in the PVAN Ultra analysis software. Saving the settings under a recognizable name and recording the name in the study notes allows the user to load the settings into PVAN *Ultra* without having to enter the setting manually.

Catheter Configuration tab

The Catheter Configuration screen allows the user to configure the hardware for operation with a specific catheter model by setting the appropriate electrode configuration, choosing the field configuration, excitation current and gain setting. The user can also enter blood resistivity and alpha for volume calibration.



(new screenshot)

Catheter Configuration Locked/Unlocked

This button unlocks and locks the controls on the Catheter Configuration tab in order to prevent inadvertent changes to the system settings which would affect the conductance/volume signal as it is being recorded. Click the button once to unlock the settings.

The catheter configuration must be unlocked before any of the controls on the Catheter Configuration tab can be adjusted.

The locking feature has a timeout feature which will relock the features after sixty seconds have passed with no configuration changes.

By default, the catheter configuration used when the program is opened will be the same as the configuration when the program was last closed.

Millar Catheter Selection

The Millar Catheter Selection table allows the user to load both standard and custom catheter configurations. This allows the user to configure the hardware for immediate use based on a known catheter model.

The Millar Catheter Selection table contains several descriptive fields described below. The table can be sorted by clicking on the desired field name. Click once to sort in ascending order. Click again to sort in descending order.

Name – The **Name** field is set to **Catalog** for standard catheter configurations. Users can select their own name when either editing a catalog catheter or creating their own catheter.

Model Number – This refers to the Millar model number of the catheter. Catheters modified using the **Create New Catheter** option retain the model from the catheter from which they were created. Custom catheters contain a user defined model.

Part Number – This refers to the Millar part number.

Size – Refers to the French size of the catheter. 3F = 1 mm diameter.

ElectrodeNumber – Refers to the number of electrodes on the catheter.

Spacing – Refers to the spacing between sensing electrodes. This spacing is used by the software when calculating volume from Baan's equation for calibrating in units of volume (μl or ml).

Sensor – Describes the location of the pressure sensor(s). The pressure sensor is located between the listed electrodes. If a pressure sensor is located proximal to all electrodes, its location will be described as ">E12" or ">E4" as appropriate.

Length – Refers to the length of the catheter from connector to tip.

FieldConfig – Refers to the excitation field configuration of the catheter – single field or dual field.

ExcitationCurrent – Refers to the excitation current set for this catheter configuration.

SegAmplifierGain – Refers to the chosen gain setting for this catheter configuration.

Blood Resistivity

This feature controls the resistivity used in Baan's equation for calculating the volume displayed on the gain and calibration controls within the **Control Interface**. The values can also be saved for use in *PVAN Ultra*. The *MPVS Ultra* system can measure resistivity using the rho cuvette (see information regarding the **Rho Cuvette** tab) or the user can enter a value for resistivity. Resistivity is used by the software when calculating volume from Baan's equation for calibrating in units of volume (μl or ml).

Click **Load** to recall information used in a previous study. Click **Save** to save the present value for later use. The interface allows the user to name the entry.

Unlock the catheter configuration and click **Load** to load settings from a previous study or the latest measurement from the rho cuvette.

Alpha (α)

Alpha is an electric field homogeneity factor that allows a user to scale volume measurements to match independent measurements. This is typically done to make the stroke volume measurement given by Baan's equation and the conductance method match the stroke volume measurement given by thermodilution, ultrasound or flow-probe measurements. Alpha is saved along with the present blood resistivity value and is used by the software when calculating volume from Baan's equation for calibrating in units of volume (μl or ml).

Graphical Electrode Configuration Control

When a catheter configuration is selected in the **Millar Catheter Selection** table, the display in the control will adjust to match the configuration. The user can then adjust the

electrode configuration; for example, choosing to use fewer electrodes when measuring a ventricle whose length does not justify the use of all available electrodes.

There are four electrode states which can be chosen by the user to configure the catheter to his specification.

1. Inactive – Inactive electrodes are grayed out. These electrodes are not used in generating or sensing the electric field.
2. Active Sensing – Active sensing electrodes are green. An active sensing electrode represents one edge of a volume sensing segment.
3. Primary Proximal – Primary electrodes are red. The primary proximal electrode designates the most proximal edge of the primary electric field. The user can choose to use any of electrodes 4 – 12 as the primary proximal electrode.
4. Secondary Proximal – Secondary electrodes are orange. The secondary proximal electrode designates the most proximal edge of the secondary electric field. The user can choose to use any of electrodes 5 – 11 as the secondary proximal electrode.

Configurations are limited according to the following rules:

1. Electrode 1 must be the primary distal excitation electrode. Only electrode 2 may be used for secondary distal excitation (but electrode 2 may be used for sensing in a single-field configuration). See the next section for a description of **Field Type**.
2. There can be no adjacent inactive electrodes.
3. All active sensing electrodes must be between excitation electrodes.
4. There must be at least two active sensing electrodes.

The green boxes below the catheter graphic label the location of the segments that are being measured. The labels (S1-S7) correspond to the labels above the connectors on the front panel of the hardware. When an inactive electrode is located between two active electrodes, two segments are combined into one segment and two green boxes will have the same label. The output signal for the resulting double-length segment will be effectively the sum of the two segments. Be sure to account for this in processing the data.

The system can be configured for one to seven segments.

Field Type

The system can measure conductance with either single field or dual field excitation. This control determines which is used in the present study. The field configuration of catalog models is related to the electrode layout. Dual field catheters will have three closely spaced electrodes at one end (usually the tip) whereas single field catheters have evenly spaced electrodes. 12-electrode catheters are dual field catheters. Almost any catheter can be operated in dual- or single-field, but a minimum of six electrodes is required for dual-field excitation. See “*Theory of Operation – Dual Field Excitation*” for more information.

The graphical electrode configuration control will reflect the selected field type. The primary and secondary fields’ excitation currents are illustrated when **Dual Field** is selected. Only the primary field’s excitation current is illustrated when **Single Field** is selected.

Dual Field mode can only be used with high excitation current.

Excitation Current

Catalog models use 20 μ A for small animal models and 100 μ A for large animal models. Either excitation level can be used, regardless of catheter model, but the user is responsible for determining how much current can be used for smaller animals. Changing the current setting may require a change in gain setting. If the current is decreased, a larger gain setting may be required.

Segment Gain-Conductance Range/Segment Gain-Volume Range

The system is capable of measuring the conductance within the ventricle of animals ranging in size from transgenic mice to domestic livestock. Use the **Segment Gain Conductance (Volume) Range** control to make full use of the system's output range while keeping the system output from saturating. Choose **Conductance Display** (blue) or **Volume Display** (orange) by clicking on the button to the right of the **Segment Gain Conductance (Volume) Range** control. Smaller animals will be measured with lower gains (e.g., x1) while larger animals will be measured with higher gains (e.g., x100). Note the conductance or volume values to the right of the gain select buttons. The value shown is the maximum signal that should be measured across all active electrode segments. This setting affects the available calibration settings on the **Catheter Calibration** tab.

Show Volume Display/Show Conductance Display

This control will determine whether the guidance values in the **Segment Gain Conductance (Volume) Range** control are volume values or conductance values.

Create New Catheter

Use this button to create a new entry in the **Millar Catheter Selection** table. This is particularly useful if you regularly use a catheter in a configuration that doesn't match its "catalog" entry in the table. Users who purchase a Special model or any other model not listed on the table may need to add their catheter's configuration. The **Name** field can be used as a descriptive term such as the serial number of the catheter or the experimental group to which it applies (e.g. "50kg canine").

Before clicking on the **Create New Catheter** button, select an existing model that is similar to the new configuration as possible. Select the appropriate **Field Type**, **Excitation Current**, and **Segment Gain Conductance (Volume) Range**. Set the electrode settings on the graphical representation as appropriate. Click **Create New Catheter** and fill in the appropriate information. Click **OK**.

Delete Highlighted Configuration Entry

Use this button to delete non-catalog model catheters from the **Millar Catheter Selection** table. Catalog models cannot be deleted.

Power

This indicator will be green when the MPVS *Ultra* hardware is turned on and red when the hardware is turned off.

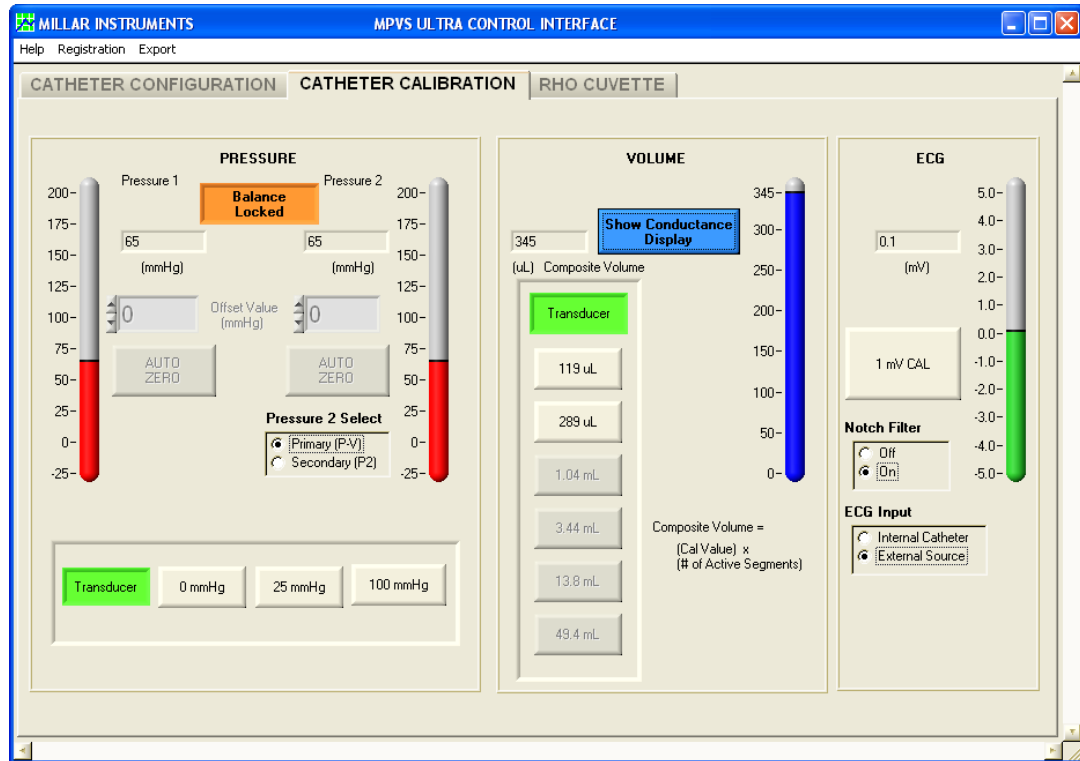
Catheter Detect

This indicator will be green when the catheter is successfully passing the primary excitation current through the selected electrodes. If the indicator is red, there may be a problem with the cable or the catheter. Check all connections and see the troubleshooting section. Current will not pass through the catheter when the catheter is not in a conductive

fluid such as blood or saline, so the catheter must be in a conductive fluid to use this feature.

Catheter Calibration Tab

The Catheter Calibration screen allows the user to electronically calibrate the pressure, volume, and ECG signals.



Pressure

Balance Locked/Unlocked Button

Use the Balance Locked/Unlocked button to unlock the balance controls.

The button automatically locks after 60 seconds of inactivity within the balance controls interface.

Pressure 1/Pressure 2

The Pressure 1 and Pressure 2 scales graphically display the currently measured pressure from -25 mmHg to 200 mmHg.

This number is also numerically displayed. The calculation of the pressure value is based upon the system's scale of $1V/100\text{mmHg}$. The system provides $5V$ excitation to transducers assumed to have a sensitivity of $5\mu V/V/\text{mmHg}$. (See "*Theory of Operation – Strain Gauge Pressure Transducers*.”) The system is designed to use Millar Mikro-Tip[®] pressure transducers with 1000 ohms input impedance and 1000 ohms output impedance. All Millar Mikro-Tip pressure transducers are factory-calibrated to meet these standards.

Offset Value (mmHg)

The user can manually adjust the pressure offset of each pressure channel. This is useful when an artificial offset is introduced into a system and requires correction.

To adjust the pressure offset, unlock the balance controls and use the offset arrows to manually adjust the offset up or down. The user can also type the desired value directly into the **Offset Value** fields. As noted in the procedural descriptions above and in the transducer IFUs, it is advisable to do this balance adjustment after soaking the catheter for 30 minutes. Ideally, the pressure sensor should be just below the surface of warm (body temperature) water and shielded from ambient light. See the troubleshooting section for tips on proper balancing techniques.

The range of the offset is -250 mmHg to 250 mmHg.

The balance control does not affect the electronic calibration outputs (0 mmHg, 25 mmHg, and 100 mmHg) described below.

Auto Zero

The user can quickly auto zero each pressure channel by applying a zero reference pressure to the catheter and then clicking **Auto Zero** under the desired channel. This sets the applied pressure as zero.

Pressure 2 Select

The MPVS *Ultra* provides two amplifiers for use with a pressure transducer.

Pressure 1 is always set to the P-V input connector on the MPVS *Ultra* front panel. This will typically be the pressure sensor located in the middle of the conductance electrodes. **Pressure 2 Select** allows the user to specify which input is used for the secondary pressure channel.

Primary (P-V) sets the second pressure input to the P-V input connector on the MPVS *Ultra* front panel. This is used when the user is using a dual sensor pressure volume catheter such as the SPR-562-1.

Secondary (P2) sets the second pressure input to the P2 input connector on the MPVS *Ultra* front panel. This is used when the user is using a separate single sensor pressure catheter.

Pressure Monitor and Calibration

Transducer – When the **Transducer** button is activated the system will read inputs from the pressure sensors. The **Transducer** button must be activated to view pressure waveforms.

0 mmHg – When the **0 mmHg** button is activated, the MPVS *Ultra* will output a zero volt signal to both pressure outputs.

25 mmHg – When the **25 mmHg** button is activated, the MPVS *Ultra* will output a 0.25 V signal to both pressure outputs.

100 mmHg – When the **100 mmHg** button is activated, the MPVS *Ultra* will output a 1.0 V signal to both pressure outputs.

Volume

Display Conductance/Volume Units

Use this button to change the display to conductance or volume units as desired. This button does not affect the output voltage.

Measured Volume

This display indicates the current composite volume as measured by the MPVS *Ultra*. The value displayed is based upon an analog summation of all active segments. This analog sum is the COMPOSITE output on the front panel.

The blue or orange scale is a graphical representation of the composite volume signal.

When the user opts to view units of volume (μl or ml), the calculation of this value takes into account segment length, rho and alpha chosen on the Catheter Configuration tab.

The output shown in the MPVS *Ultra* Control interface does not account for the volume attributed to parallel conductance of the myocardium. If desired, this correction can be made in the PVAN *Ultra* software or the user's acquisition software.

Transducer and Electronic Calibration Buttons

The active button is green. To measure a volume signal from the catheter, click the Transducer button.

In order to calibrate the data acquisition system from voltage to volume or conductance units, the system has six internal sets of resistors that are used as inputs of known conductance. Only two to three buttons are available at any given gain range. (Available buttons are beige; others are gray.) The available selections are designed to span the expected segmental conductance inputs for typical animals ranging from mice to domestic livestock. The gain setting on the Catheter Configuration tab controls the available input range in order to maximize the use of the available voltage output range. The indicated values on the buttons are the conductance or volume to be output by each segment, not the composite total.

The values indicated on the calibration buttons change according to the present configuration. When volume units are displayed, Baan's equation is used, so the present values of alpha, rho, and segment length are used, as noted in Measured Volume above.

Since the values on the buttons represent the per-segment conductance or volume, be sure to multiply by the number of active segments when entering the calibration value for the Composite Volume channel. The Composite Volume or Composite Conductance value is displayed by the software when one of the calibration buttons is pressed.

ECG Calibration

The ECG Calibration interface allows the user to generate a calibration signal for the ECG output, control the source of the signal, and enable or disable the notch filter.

Current Value

The numerical readout displays the current ECG signal measured by the MPVS *Ultra*.

ECG Scale

The ECG Scale graphically displays the current ECG signal measured by the MPVS *Ultra*.

1 mV Cal

This button outputs a one second 1 mV cal signal. The signal can be used to calibrate the user's data acquisition system or monitor. Note that since the ECG circuit has a high-pass filter to eliminate DC offset, the output signal will appear as an initial upward pulse and then a downward pulse. This is an ECG circuit's response to a square wave.

The ECG output is scaled at 2V / 1 mV.

Notch Filter

The MPVS *Ultra* contains a built-in notch filter on the ECG circuit to remove 50Hz and 60Hz noise. To turn this filter on, select "On" and to turn it off, select "Off".

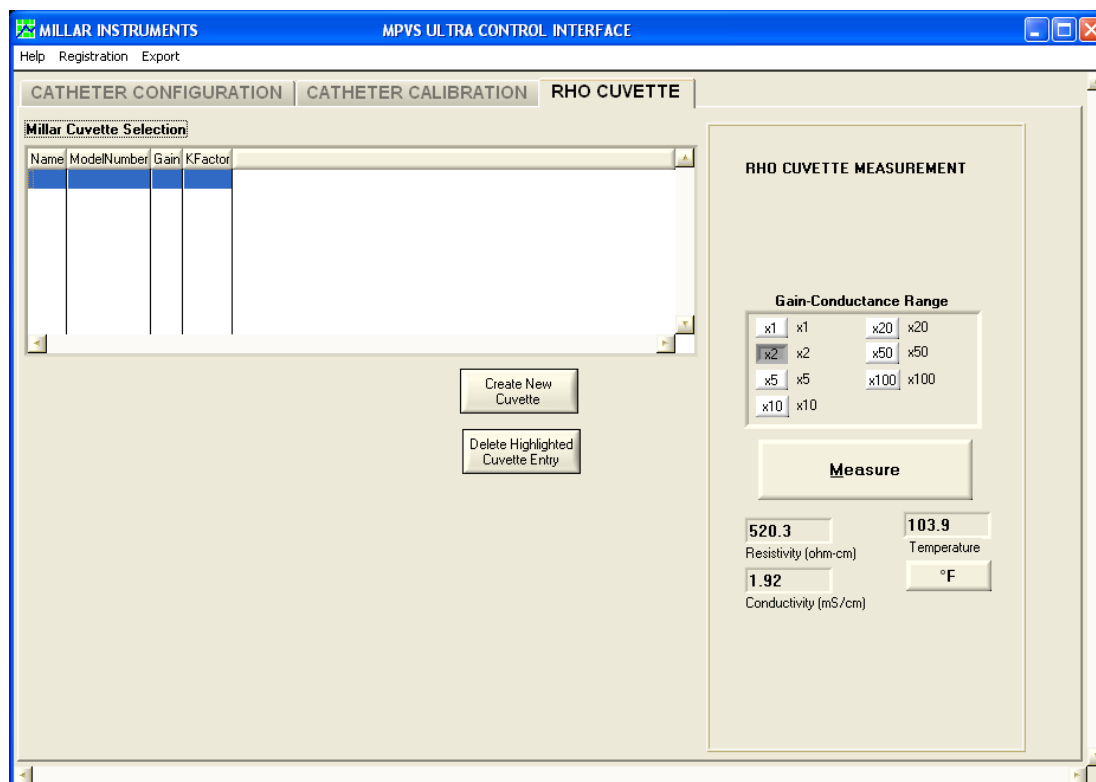
ECG Input

The ECG Input allows the user to choose the source of the ECG input signal.

The MPVS *Ultra* can record an internal ECG signal from the electrodes on the P-V catheter. To record this signal select Internal Catheter.

The MPVS *Ultra* can also be used as a bioamplifier for an external ECG source. To choose this option, select External Source. The input for this signal is the ECG connector on the front panel of the hardware.

Rho Cuvette Tab



Miller Cuvette Selection

This table contains the specifications for the catalog cuvettes built by Millar. Different entries can be added with different gains and K factors. The gain will typically be x2.

K Factor

The K factor is a calibration value that is specific to your system. While all of the parts of your MPVS *Ultra* system are made with precision, slight variations are inherent in the design. The K factor is used to reduce the error in the resistivity reading. Your system is delivered with a K factor. The K factor is entered when you create a new entry in the Millar Cuvette Selection table. It cannot be changed from the main interface shown above. The software will not accept a K factor value below 0.100.

Create New Cuvette

Use this feature to create an entry in the Millar Cuvette Selection table. This will allow you to use the K factor that is specific to your system. Before clicking the Create New Cuvette button, be sure that the gain in the Gain-Conductance Range field is correct. (Unless a need arises to do otherwise, use a gain of x1.) After clicking the Create New Cuvette button, enter a name for the cuvette configuration (for example, you may choose to use the lot number written on the cable). Enter the K factor for your system. (The gain cannot be changed in this view.) Click OK, then click on the new entry in the Millar Cuvette Selection table.

Delete Highlighted Cuvette Entry

Unwanted entries can be deleted from the table if desired. The catalog model entry cannot be deleted.

Gain Conductance Range

The MPVS *Ultra* provides seven gain settings which serve to optimize the accuracy of the resistivity reading for a particular fluid. Fluids used in most experiments will be best measured with a gain of x2.

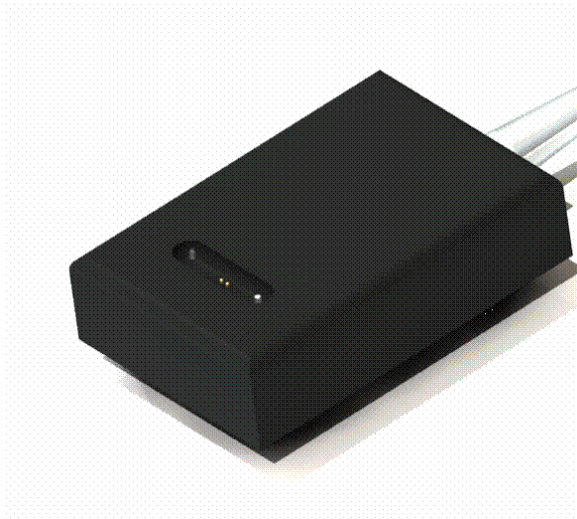
Export

Click the Export button to place the displayed resistivity value into the Blood Resistivity field on the Catheter Configuration tab. This will automatically unlock the catheter configuration.

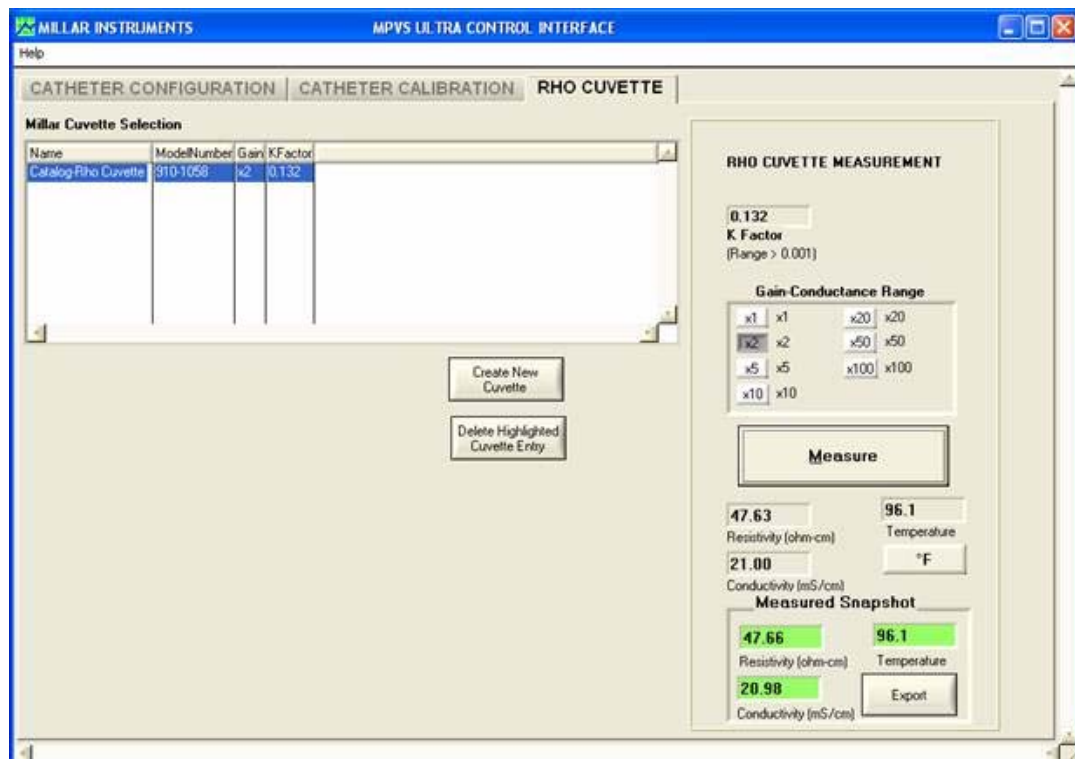
Millar recommends saving the file with a descriptive name to ease later identification.

Measuring the resistivity of a blood sample

1. Connect the cuvette (shown below) to the MPVS *Ultra*'s Cuvette input. Warm the cuvette to body temperature in order to minimize errors due to the change in the blood's temperature. The cuvette can be placed under the animal or a warming mat or it can be submerged in warm water. Do not submerge the cable and connector.



2. In the Millar Cuvette Selection field, select the appropriate configuration. By default, the software will use the configuration that was used most recently. The configuration includes both the gain and the K factor.
3. Select the desired units for temperature measurement (°F/°C).
4. With as little delay as possible, do steps 4-6. Place the cuvette on a flat surface and dry the well with a gauze or swab.
5. In a heparinized syringe, draw about 3cc to 5cc of blood. Place the tip of the needle at the bottom of the well and inject the blood into the well. Ideally, the surface of the blood should be level with the top surface of the cuvette.
6. Click on Measure in the Control Interface. The Measured Snapshot field will appear.



7. Click on **Load** to set the displayed resistivity as the value to be used in calibration and measurements. The loaded resistivity value affects the displayed reading and calibration values when displaying volume units. The resistivity value is not temperature corrected; the user is responsible for deciding whether and how to correct for temperature.
8. Save this value to your computer using a descriptive name so that the file can be identified at a later time (i.e., Sheep_1623_3-01-07).
9. Properly dispose of the blood sample and thoroughly clean the cuvette.

Cleaning the Cuvette

The cuvette should always be emptied and cleaned immediately after use to prevent blood from clotting within the cuvette.

Procedure for cleaning the cuvette

1. Properly dispose of the used blood sample.
2. Rinse the cuvette with warm water for several minutes.
3. Soak the cuvette in a beaker of enzymatic cleaner for 15 – 30 minutes.
4. Rinse the cuvette with warm water for several minutes.
5. Dry the cuvette completely using either a Kim Wipe or an air dryer.
6. Store the cuvette in its container.

Conductivity, Resistivity, Temperature

The **Resistivity**, **Conductivity** and **Temperature** fields located directly under the **Measure** button dynamically display the measured values from the attached cuvette. Use the °F/°C button to select the displayed units of temperature.

IV. Theory of Operation

The Conductance Method

Single Segment Measurement

Researchers are able to estimate left-ventricular volume changes via the conductance method using the tiny electrodes built into the catheter tip.

A small constant-amplitude AC current is sent out through the distal electrode (E1) to the proximal electrode (E4). The current flow creates an electric field within the ventricle.

The voltage potentials (differences) between the two inner sensing electrodes (E2 and E3) are measured as the heart expands and contracts and the volume of the left ventricular blood pool changes. The operational theory of the impedance/conductance method for estimating left ventricular volume changes can be simplified in terms of Ohm's Law.

Ohm's Law

$$V = IR$$

$$G = \frac{1}{R}, \text{ therefore } R = \frac{1}{G}$$

$$V = \frac{I}{G}, \text{ therefore } G = \frac{I}{V}$$

$$\text{Volume} \propto G = \frac{I}{V}$$

V = voltage potential between E2 and E3

I = constant current

C = conductance (the inverse of resistance)

R = resistance of the left ventricular blood pool

During systole, the heart pumps blood out of the left ventricle and the resistance of the blood pool increases; therefore, the voltage potential between the inner two electrodes (E2 and E3) also increases.

During diastole, the left ventricle is filling with blood and the resistance of the blood pool decreases; therefore, the voltage potential between the inner two electrodes (E2 and E3) also decreases.

$$\text{Systole} = R \uparrow V \uparrow G \downarrow \text{ and Volume } \downarrow$$

$$\text{Diastole} = R \downarrow V \downarrow G \uparrow \text{ and Volume } \uparrow$$

A good analogy is to think of the blood-filled left ventricle as a wire that changes size during the cardiac cycle.

- A thick gauge wire (large diameter) will have a low resistance and a low voltage drop across it (diastole). The wire contains more volume because it has a larger diameter.
- A thin gauge wire (small diameter) will have a high resistance and a high voltage drop across it (systole). The wire contains less volume because it has a smaller diameter.

Multi-Segment vs. Single-Segment

Millar's multi-segment P-V catheters measure volume using the conductance technique described above. Unlike the single-segment catheter, a multi-segment catheter measures conductance over several electrode segments. The system then sums individual segments' signals to generate a total volume signal over the length of the catheter. In the MPVS *Ultra* system this summation is performed in PVAN *Ultra* when the user records data for individual segments. The composite volume channel is an analog sum of the voltages in the active channels.

Baan's Equation

The basis for calculating volume from conductance is Baan's equation. The general equation for volume measurement is given to be:

$$\text{Volume} = \frac{1}{\alpha} \rho L^2 (G - G_p)$$

where alpha (α) is the volume calibration factor, rho (ρ) is the resistivity of the blood, L is the segment length, G is the conductance and G_p is the parallel conductance of surrounding structure.

In a multi-segment measurement, G is actually a summation of the segmental conductance measurements.

Dual Field Excitation

The dual field method sends the primary excitation current through a selected primary excitation electrode (E5 through E11) located at the proximal end of the measurement area and through primary excitation electrode (E1) located at the distal end of the measurement area to generate an electrical field within the heart. In addition to the primary excitation current, a secondary excitation current of opposite polarity is sent through the next electrode, located distal to the selected primary excitation electrode at the proximal end of the measurement area and secondary excitation electrode (E2) at the distal end of the measurement area. This secondary excitation current creates a second electrical field which serves to expand the primary field to create a more uniform electrical field over the length of the measurement area. The change in conductance as the blood pool changes is then measured across each electrode segment and then summed for a total volume signal in the same manner as the single field configuration.

Dual field catheters can be quickly identified by the group of three closely spaced electrodes at either the proximal or distal end of the measurement area.

Field lines and equipotential planes

Ideally, when measuring the resistance of a uniform (homogeneous) material, the paths of the electrons are straight from one end of the sample to the other. Equipotential planes, which are perpendicular to the current flow, would be flat surfaces. The result would be a current density that is uniform throughout the sample, which means that every portion of the sample affects the measurement equally. This requires the current generated in the

sample to be injected evenly across the ends of the sample. However, the conductance catheter method requires the use of two very small areas to inject the current. Thus, the current density is much higher at these two points than at points half way between, where the electrons are able to spread out. The current density will also be higher near the axis of the current flow (the catheter) than in regions farther away since the electric field tends to decrease with the cube of the distance.

In a single field configuration, the path of the current through the blood is not straight. When graphed together, the electrons' paths resemble the shape of an American football, where the ends are narrow (the electrons must all pass through the electrodes) and the central portion is expanded (the like charges of the electrodes cause them to repel each other and spread out). Equipotential planes, drawn perpendicular to the electrical flow, are not flat, except at a point half way between the excitation electrodes. Equipotential planes closer to the electrodes tend to bow outward, away from the center plane. This effect is more pronounced farther from the catheter, so measurements of smaller diameter volumes can approximate a uniform field.

In a dual field configuration, the secondary current is injected to change the shape of the electrical field so that it is more uniform. The polarity of the secondary current is the opposite of that of the primary current and the amplitude is 30% of the primary current. This straightens the equipotential lines and makes the electric field more uniform, optimizing the electrical field to allow a more uniform measurement of volume in larger hearts.

Resistivity – Rho Cuvette

Resistivity is a material property whereas resistance (and therefore conductance) is a property of a sample or a structure. When measuring the conductance of the blood in the ventricle, the reading is based on the electrical current passing through blood, a material whose resistivity can change with temperature, hematocrit, and a number of other parameters. Resistivity is used in Baan's equation to relate conductance of the structure (the blood in the ventricle) to the volume of the structure.

The MPVS *Ultra* rho cuvette measures resistivity using Baan's equation, but in a form where the equation has been solved for resistivity. The volume of blood in the cuvette is known – it is that of a cylinder whose diameter is that of the well and whose length is the distance between the voltage sensing electrodes. The current passed through the sample is known since it is precisely calibrated during the manufacturing process. The voltage is readily measured by the MPVS *Ultra* hardware. The resistivity can then be computed from these known and measured values. (α is assumed to be 1.)

Effects of Temperature

The resistivity of blood is temperature dependent. The MPVS *Ultra* system does not adjust the reading to correct for temperature. Instead, the rho cuvette measures the temperature of the blood and the resistivity of the blood at the same time. (These are the values reported in the Control Interface.) The user can correct for temperature if desired. Peer-reviewed literature indicates that the resistivity of the blood varies by about 2% per degree C within a few degrees of body temperature. This relationship is not linear, so the user should attempt to make the measurement as quickly as possible after blood is drawn from the animal. It is advisable to keep the rho cuvette well at approximately body temperature before taking the measurement so that the well will not contribute to the cooling of the blood sample.

Resistivity – Dip Cuvette

The dip cuvette method used in the MPVS-300, MPVS-400, and MPCU-200 ARIA pressure-volume measurement systems was used as a way of relating measurements to volume in a more empirical manner. The dip cuvette contains wells into which blood is injected. The catheter is then dipped into each well so that the system is reading from a known volume in a material assumed to have the same resistivity as that in the subject's ventricle. Relating the resulting readings to the known volumes (typically through a linear regression) allows the user to calibrate measured voltages to volumes. This method is less direct than that employed by the MPVS *Ultra* system and is not practical for use with multi-segment P-V catheters.

IECG vs. ECG

The MPVS *Ultra* can measure the ECG signal from the PV (catheter) input or the ECG input. When the system measures ECG from the PV catheter, the signal is an internal ECG, or IECG. Since the electrodes are in the ventricle, the source of the R wave, the R wave will be much larger than the other aspects of the ECG signal. While this may not provide some of the information for a detailed ECG analysis, the signal-to-noise ratio will be reduced and the signal will be ideal for timing in PVAN *Ultra* calculations. The input to the IECG signal is the electrodes that are presently in use for the primary excitation field. This ensures that the spacing between the electrodes will be as wide as possible for a maximal signal.

When the system measures the ECG through the ECG connector, the signal will resemble a normal ECG signal.

Since the hardware only has one ECG amplifier circuit, the MPVS *Ultra* can only measure one signal at a time.

Strain Gauge Pressure Sensors and Catheter Tip Transducers

Strain Gauge Pressure Sensor

Millar Mikro-Tip pressure transducers use a microscopic pressure sensor embedded in the tip of a catheter to measure pressure directly at the source. The design offers superior size, accuracy, and frequency response. The pressure sensor contains a pair of strain-gauges on a very thin diaphragm. These gauges are resistors whose resistance changes as they are stretched. The gauges are stretched when pressure exerted on the diaphragm makes it bend. These resistors are in turn wired into a Wheatstone bridge circuit. When the resistors change resistance in response to pressure changes, the output voltage of the Wheatstone bridge changes. The voltage output of the circuit is amplified by the MPVS *Ultra*, whose output is factory calibrated to a 1V output for an input pressure of 100mmHg.

Care of Ultra-Miniature P-V Catheters

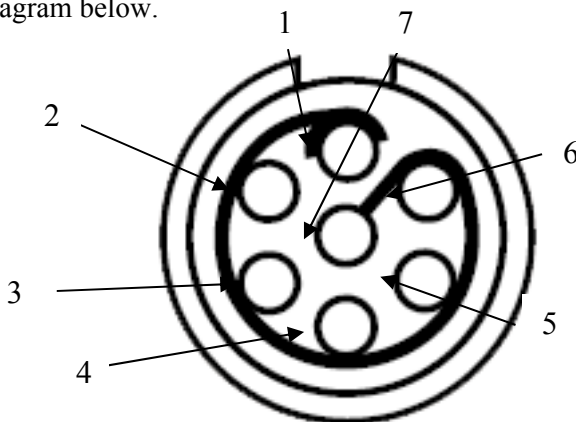
Proper Handling is Critical to Maximizing the Use-Life of Millar's Ultra-miniature P-V Catheters. Refer to the Troubleshooting, System Maintenance, and Specifications section of this document for important information.

Additional guidelines

Temperature Measurement

The system was designed assuming that the input to the temperature measurement circuit will be a thermistor with a standard J curve and a resistance of 10kohms at 25degreesC. This is the type of temperature sensor that is used in the rho cuvette. It is possible to use the temperature measurement circuit in the MPVS *Ultra* to measure temperature from another source. For example, a thermodilution catheter with an appropriate thermistor can be connected to the system. The output of the temperature measurement circuit is available on the rear panel of the MPVS *Ultra*. The user is responsible for calibrating the relationship between voltage and temperature.

When making a custom cable to connect a temperature measurement device to the Cuvette input, use the diagram below.



Pins 5 and 6 are the inputs to the thermistor. Do not connect to pins 1, 2, 3, or 4 since doing so may damage the resistivity measurement circuit. Pin 7 may be used to ground the shield of the cable. It is very important to note that all four front-panel inputs are isolated from the voltage outputs, power input, USB input and equipotential point. However, these four inputs are not isolated from each other. When using accessories not designed or provided by Millar, the user assumes all responsibility for damage, harm, or loss resulting from the use of these accessories.

Conductance, Conductivity, Resistance, Resistivity

It is important to note the differences and relationships among conductance, conductivity, resistance and resistivity.

Resistivity and conductivity are properties of materials and are subject to the condition of the material when it is measured. Just as with metals, the conductivity and resistivity of blood is temperature dependent. The resistivity value used in volume calculation should ideally be measured in blood that is representative of the study groups. At a minimum, be sure to take species into account as resistivity varies between species. There is a noticeable difference in the resistivity of blood and that of muscle. Size and shape do not affect resistivity and conductivity.

Conductance and resistance are properties of a sample or a structure. They will be affected by the resistivity (or conductivity) of the materials in the sample. Size and shape of a sample have a strong bearing on resistance and conductance.

Conductivity is the multiplicative inverse of resistivity.

Conductance is the multiplicative inverse of resistance. $G = 1/R$

Conductance and conductivity relate to how well a structure or material conducts electrical current.

Resistance and resistivity relate to how strongly a structure or material resists the flow of electrical current.

Further Reading

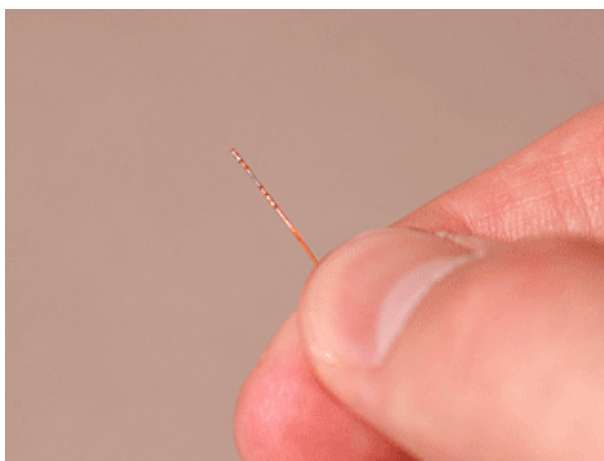
The Millar, Inc. web site, millar.com, lists published papers.

V. Troubleshooting, System Maintenance and Specifications

Refer to the MPVS *Ultra* training CD (001-1058) for more information.

Each catheter is delivered with Instructions for Use, complete with care and cleaning instructions.

Proper Handling is Critical to Maximizing the Use-Life of Millar's Ultra-miniature P-V Catheters



The Mikro-Tip[®] catheter is a robust yet delicate precision instrument.

Presoak the catheter tip for at least 30 minutes prior to use in saline or distilled water maintained at body temperature. Only soak the catheter tip. Do not submerge the catheter's electrical connectors, as doing so will damage the sensitive electronics housed inside!

The presoak helps prepare the pressure sensor diaphragm for the "wet" biological environment. Presoaking the catheter tip in body-temperature fluid also helps prevent pressure signal drift and negative pressure recordings. The presoak can be done by gently inserting the catheter tip into a beaker, dish, or through the tip of a syringe.

Do not, under any circumstances

Bend

Kink

Fold

Cut

Pinch

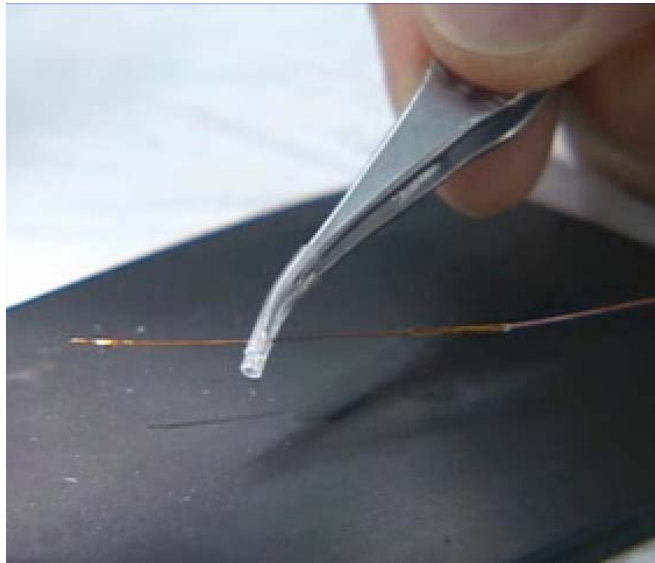
Crush

the Mikro-Tip[®] catheter, especially around the sensor/electrode area!

These actions could severely damage the catheter or render the catheter unusable and result in costly repair or replacement charges!

Additional guidelines

- Use of the Mikro-Tip[®] P-V catheter should be restricted to specialists who are familiar with, and have been trained to perform, the catheterization procedures for which the device is intended
- The Mikro-Tip[®] P-V catheter should be inspected for damage (cracking, kinks, etc.) prior to each use.
- Do not grip the Mikro-Tip[®] P-V catheter with forceps, tweezers, or fingers anywhere near the sensor/electrode area.
- Always grip the Mikro-Tip[®] P-V catheter proximal to the sensor/electrode area (E4). Never grip the catheter between the electrodes or between the electrodes and the pressure sensor case.
- When using metal forceps or tweezers to grip the Mikro-Tip[®] P-V catheter, slip some soft tubing over the tips of the metal instrument to cushion the interface between the instrument and the catheter body, as shown in the photo.



- Always be mindful of the location of the catheter tip.
- Do not set heavy objects or metal instruments on top of the Mikro-Tip[®] P-V catheter.
- Do not tighten sutures over the sensor/electrode area on the Mikro-Tip[®] P-V catheter.
- When using the carotid artery approach to insert the Mikro-Tip[®] P-V catheter into the left ventricle, advance the sensor/electrode area completely beyond the proximal suture before tightening the suture.
- When using the carotid artery approach to insert the Mikro-Tip[®] P-V catheter into the left ventricle, take care not to damage the catheter with the tips of any forceps or tweezers used to grip the artery when inserting the catheter.

- When using the open chest approach to insert the Mikro-Tip[®] P-V catheter into the left ventricle, do not push the catheter tip directly through the left ventricular wall. First, make an entry hole in the ventricular apex with a needle, and then insert the catheter through the hole.
- Never apply excessive force when inserting the Mikro-Tip[®] P-V catheter. The catheter may incur damage, and could puncture the left ventricular wall or damage the aortic valve.
- If resistance is encountered while inserting the Mikro-Tip[®] P-V catheter, pull back slightly and then try advancing again.
- When removing the Mikro-Tip[®] P-V catheter through the carotid artery, loosen the proximal suture before pulling the catheter out, to ensure the pressure sensor or electrodes do not catch on the suture and lift or tear away from the catheter.
- The Mikro-Tip[®] P-V catheter should be cleaned immediately after each use (see “*Cleaning*” section).
- The pressure sensor element on the Mikro-Tip[®] P-V catheter is sensitive to electrostatic discharge. Do not touch the sensor element while the catheter is disconnected from the monitoring equipment.
- The Mikro-Tip[®] P-V catheter should be thoroughly inspected under magnification after each use to determine its condition. Carefully examine the catheter for cuts, kinks, or creases.
- The active surface of the sensor and electrodes should be examined for film that has not been removed by cleaning. Any film may cause short-term baseline drift, and should be removed. Remove film by thoroughly soaking in Terg-A-Zyme[®], followed by persistent and gentle wiping along the sensor or electrodes with a moist tissue, gauze, or cotton-tipped swab. The connectors should undergo visual inspection for corrosion or bad contacts.

Hardware

The enclosure can be wiped with isopropyl alcohol (70%) on a damp cloth. Do not allow any liquids to enter the enclosure.

When connecting and disconnecting the system, check the following:

- Be sure that the enclosure is not cracked and that all of the screws are installed in the bottom and rear panels.
- Be sure that none of the cables (including the power cord) are frayed, cut, or cracked. All cables should connect firmly to the system.
- All except for the USB and power cords lock in place when properly connected.
- Be sure that none of the cables or cords are bent sharply as this may damage the internal wires.

If necessary, the fuses can be replaced by removing the drawer on the rear panel. It is located between the power switch and the power input connector. Use the fuse type indicated on the rear panel.

Other than the fuses, the MPVS *Ultra* has no user-serviceable parts. Do not open the enclosure or any cable connectors. Contact Millar or your distributor for service.

Cables

The cables can be wiped with isopropyl alcohol (70%).

Do not submerge the cables or cords.

When connecting and disconnecting the cables and cords:

- Be sure that none of the cables (including the power cord) are frayed, cut, or cracked. All cables should connect firmly to the system.
- All except for the USB and power cords lock in place when properly connected.
- Be sure that none of the cables or cords is bent sharply as this may damage the internal wires.

Technical Specifications

Pressure Transducer Characteristics	
Specification	Value
Transducer Sensitivity	5 μ V/V/mmHg, nominal
Bridge Excitation Resistance	1000 ohms, nominal 350 ohms, minimum
Transducer Bridge Load	5.0 V _{DC} , nominal
Signal Input Resistance	50 mega-ohms, nominal
Input connector for system	Five-pin Redel or ODU

Pressure Outputs	
Specification	Value
Sensitivity	1 V/100 mmHg, nominal.
Accuracy Error Band	0 – 200mmHg: $<\pm 1$ mmHg or 1 % of reading, whichever is greater 201 – 300mmHg: < 1.5 % of reading
Frequency Response	DC to 400 Hz (-3 dB)
Noise	< 0.3 mmHg peak-to-peak
Balance Adjustment Range	± 140 mmHg, nominal

Pressure Standby-Calibration Mode	
Specification	Value
Zero Offset	$<\pm 1$ mmHg
Calibration Steps	0, 25, and 100 mmHg
Calibration Accuracy	$<\pm 0.5$ mmHg

Volume/Conductance Outputs					
Specification	Value				
Sensitivity	Seven gain settings with the following maximal conductance inputs for single field (SF) and dual field (DF) configuration at 20 or 100 μ A excitation:				
	Gain	SF-100	SF-20	DF-100	Units
	1	-	3.33	-	mS/segment
	2	-	6.67	-	mS/segment
	5	-	16.7	-	mS/segment
	10	167	33.4	117	mS/segment
	20	333	66.6	233	mS/segment
	50	833	167	583	mS/segment
100	1667	333	1167	mS/segment	
Frequency Response	400 Hz				
Output Resistance	1690 ohms, nominal				
Output Voltage	± 10 V _{DC}				
Noise	≤ 75 mV _{PP}				
Input Connector	27-pin Alden Pulse-Lok® Pulse-Lok is a registered trademark of Amphenol Alden Products Company, Inc.				
Output Connectors	BNC connector Composite, S1, S2, S3, S4, S5, S6, S7				

Volume/Conductance Standby-Calibration Mode	
Specification	Value
Calibration Verification Steps	Single Field excitation mode: 1.14mS, 2.78mS, 10.1mS, 33.2mS, 133mS and 476mS. Dual Field excitation mode: 1.18mS, 2.82mS, 10.1mS, 33.2mS, 133mS and 476mS. Inputs are available at appropriate gain ranges.



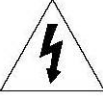



Temperature Measurement	
Specification	Value
Range	24 – 43 °C (75 – 110 °F)
Accuracy of analog output	± 0.36 °F (± 0.2 °C) over 32.2-40.6 °C (90-105 °F)
Input type	J curve thermistor, 10k-ohm at 25°C, beta = 3890

ECG	
Specification	Value
Gain	2000 X
Frequency Response	Band pass filter from 0.5Hz to 35Hz (-3dB attenuation) Software enabled/disabled 60Hz notch filter
Source	Software selectable between external leads connected through front panel receptacle and primary conductance excitation electrodes (for IECG).

Power	
Specification	Value
Input (Universal)	100 – 240V _{AC} , 50 – 60 Hz, 15W
Connector type	EN60320/C13
Ground terminal resistance to power cord ground pin, 7-ft cord	<1 ohm

Enclosure	
Specification	Value
Ingress protection	IP-20
Dimensions	12 3/8" x 11 3/4" x 2 7/8" (width x length x height) 31.4cm x 29.7cm x 7.3cm (width x length x height)
Weight	5.6 pounds (2.54kg)

Environmental Conditions	
Specification	Value
Location	Indoor Use
Altitude	Up to 2000m
Operating Temperature	10 – 40 °C (50 – 104 °F)* * ±3% over 1mS to 1000mS range
Storage Temperature	-20 – 70 °C (-4 – 158 °F)
Mains Supply Voltage Fluctuations	Power supply voltages may vary by up to 10% of the nominal voltage (110V _{AC} or 220V _{AC}). Transient overvoltages are allowable.

Explanation of Symbols	
Symbol	Explanation
	Protective Conductor Terminal (This terminal is connected to earth ground through the power cord.)
	Equipotential point (The output circuitry of the MPVS <i>Ultra</i> uses this terminal as a ground point. This point is also connected to earth ground.)
	Caution, risk of electric shock. (Do not open the MPVS <i>Ultra</i> enclosure. There are high voltages inside. There are no user-serviceable parts inside.)
	Caution, risk of danger, see note.
	On (System power)
	Off (System power)

Technical Support

Technical Support

The Purchaser is entitled to free technical support for any Millar product. Millar's technical support staff can provide help and advice concerning installation, operation, particular uses and problems with Millar products. Millar's technical support staff will not provide experimental protocols or procedural instructions for conducting experiments. However, information of this type may be provided in the supplied product documentation, or be found on the Millar web site.

Technical support can be provided to the Purchaser via the following options:

Phone 1-800-669-2343 or 832-667-7000

8:00AM – 5:00PM, Central Time, M-F

Fax 713-714-8497
24 hours a day, 7 days a week
Email info@millar.com
24 hours a day, 7 days a week
Web millar.com
Mail Millar, Inc.
6001-A Gulf Freeway
Houston, Texas 77023
USA

On-site installation and training for Millar products can be provided for an additional charge. Please contact Millar's customer service department for further details.

Recommended accessories

Power cords

Requirements

The system has been qualified with power cords whose maximum length is 2.5m (8' 2"). The input connector on the MPVS *Ultra* rear panel is a standard EN60320/C14, so a power cord with a standard EN60320/C13 connector is required.

Millar supplied cords

Millar can provide replacements for the cords that were shipped with the system. Use these part numbers when ordering

850-5105 North American cord with NEMA 5-15 plug, 2m (6' 7") long

850-5118 European cord with CEE (7)VII plug, 2.5m long

850-5117 North American hospital grade power cord, 2.5m (8' 2") long (not included with the system, but available as a replacement component)

Distributor

Your distributor may be able to provide you with a power cord.

Manufacturers

Feller www.feller-at.com

Interpower Corporation www.interpower.com

Fuses

The system requires two fuses which can be replaced by removing the tray in the power input module on the rear panel of the system. The parts are available from Millar. Reference Millar part number 241-0180.

The fuse requirements are 1A, 250V.

Fuses are also available from most electronics distributors. An example is Bel Fuse, Inc., part number 5ST1-R, www.belfuse.com

Cables and Connectors

ECG cable – unterminated

Millar offers ECG cables with tinned-wire terminations so that a user can attach any style of ECG connector desired.

850-5123 10-foot ECG cable with tinned-wire terminations

ECG input connector

Users may construct their own ECG cable. The required connector is available from the manufacturer and some distributors.

Strain Relief Lemo/Redel part number 1B.054,DV

Connector Lemo/Redel part number PAG.M08Gl.AC65GZ

Equipotential cable

The ground post on the rear panel is compliant with the DIN 42801 standard. Multi-Contact offers products that are designed to connect to this type of connector. www.multicontact.com

BNC Cables

Standard BNC cables are required for connecting to the outputs of the MPVS *Ultra*. BNC cable quality is important for ensuring clean signals, so be sure to use coax cables with a braided copper shield. Millar offers high-quality BNC cables in three lengths. Most electronics distributors offer BNC cables as well.

249-71183-foot BNC cable

850-51261-foot BNC cable

850-51259-inch BNC cable

880-0169 MPVS *Ultra* cable pack, 10-foot

880-0170 MPVS *Ultra* cable pack, 4-foot

880-0171 BNC cable pack, 13 × 3-foot

880-0172 BNC cable pack, PowerLab User

Connector for temperature input

In order to connect to the Cuvette input for temperature recording, use one of the following connectors. They are available from the manufacturer and some electronics distributors.

ODU, www.odu-usa.com or www.odu.de

Connector, part number S21M07-P07MFG0-657S

Strain relief, part number 701023207965050

Redel, www.lemo.com

Connector, part number PAGM07GLAC65GZ
Strain relief, part number GMA.1B.054.DG

Rho Cuvette

910-1060Rho Cuvette

Warranty

Warranty Agreement

Extent

This Agreement is between Millar, Inc. (“Millar”) and the purchaser (“the Purchaser”) of any Millar product – software, hardware, catheters, cables and/or accessories – and covers all obligations and liabilities on the part of Millar, the Purchaser, and other users of the product. The purchaser (or any user) accepts the terms of this Agreement by using the product. Any changes to this Agreement must be recorded in writing and have Millar’s and the Purchaser’s consent.

Copyright and Trademarks

Millar develops proprietary sensor technology, catheters, signal conditioning hardware and computer software including Mikro-Tip[®] catheter transducers and PVAN software. All Millar software, hardware, and documentation are protected by copyright, and may not be reproduced or copied in any way, nor may products be derived from or based on it. Millar retains the exclusive ownership of the trademarks represented by its company name, logo, and product names.

Responsibilities

The Purchaser and any others using any Millar product agree to use it in a sensible manner for purposes for which it is suited, and agree to take responsibility for their actions and the results of their actions.

If problems arise with a Millar product, Millar will make all reasonable efforts to fix them. This service may incur a charge, depending on the nature of the problem, and is subject to the other conditions cited in this Agreement.

General Limitations

Millar products are produced to high standards, and should perform substantially as described in the supplied documentation. There is a limited hardware warranty, and technical support is provided for all products.

Nevertheless, since Millar products could be affected by external factors (for instance, an environment filled with electronic noise or the computer system on which the products are run), absolute performance and reliability cannot be guaranteed. No warranty, either express or implied or statutory; other than contained in this Agreement, is made in respect to Millar products. The Purchaser therefore assumes all risks as to the performance and reliability of the products, and the results gained using them. Millar is not responsible for any problems with the computer system not directly related to Millar products.

Millar neither assumes nor authorizes any person to assume on its behalf any liability in connection with the sale, installation, service, or use of its products. Millar shall not be held responsible for special, consequential, or punitive damages of any kind arising out of sale, installation, service, or use of its products.

Millar Limited Hardware Warranty

Millar warrants that at the time of sale to the original Purchaser, the MPVS Ultra series hardware shall be free from defects in materials and workmanship for a period of one (1) year from its date of shipment to the original purchaser. If there is such a defect, Millar will, at no charge and at its option, either repair or replace the equipment as appropriate.

Millar's limited warranty does not cover damage to the product from alterations, misuse, abuse, negligence, or accident.

There are no user-serviceable parts inside the cabinet and the Purchaser should make no attempts to service the hardware. There is no need for the Purchaser to open the cabinet for inspection or maintenance, and doing so within the warranty period will void the warranty.

This warranty applies only to the hardware specified in this document and used under normal operating conditions and within specification. It does not cover hardware modified in anyway, subjected to unusual physical, electrical, or environmental stress, used with incorrectly wired or substandard connectors or cables, or with the original identification marks altered.

Since factors beyond Millar's control may directly affect the product and the results obtained from its use, Millar or its agents or employees shall not be liable for any incidental or consequential loss, damage, or expense arising directly or indirectly from the use of this product.

The user shall determine the suitability for use of these devices for research purposes only. Therefore, the user accepts these devices subject to all the terms hereof. Furthermore, Millar does not warrant that equipment is suitable for any specific purpose, other than that explicitly stated by Millar.

Millar hereby excludes all warranties not herein stated, whether express or implied by operation of law or course of dealing or trade usage or otherwise, including but not limited to any implied warranties of fitness or merchantability.

Products Supplied But Not Manufactured by Millar

Millar-supplied products of a third party manufacturer, i.e. data acquisition systems, amplifiers, computers, monitors, and printers including associated cables, probes, accessories, etc. are not warranted by Millar. These items are covered by the original manufacturer's warranties. Please contact the manufacturer directly if you encounter a defect with a third-party product. If a fault arises, Millar will help assist in determining which products may be the source of the problem encountered.

Note: If your problem involves computer hardware, back up data from the hard-disk drives(s) and any other storage device(s) in the product and remove any storage media, such as diskettes or CDs.

Warranty Service

To obtain service under the terms of this warranty, the Purchaser must notify Millar or the nearest authorized Millar distributor of the defect before the warranty period expires. The Purchaser must contact Millar or the nearest authorized Millar Distributor to obtain an RMA (Returned Materials Authorization) number and an address to which the Purchaser must ship the defective product at their own expense. The product should be packed safely (preferably in its original packaging) and have the RMA number prominently displayed on the return packaging, preferably beneath the address or shipping label. Millar will make all reasonable efforts to evaluate the product and provide service as necessary within a reasonable amount of time upon receipt of the returned product. Millar will pay the return shipping costs in the event the product is to be sent back to the Purchaser.

Technical Support

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8:00AM – 5:00PM, Central Time, M-F

Fax: 713-714-8497

24 hours a day, 7 days a week

Email: info@millar.com

24 hours a day, 7 days a week

Web: millar.com

On-site installation and training for Millar products can be provided for an additional charge. Please contact Millar's customer service department for further details.

Jurisdiction

This Agreement shall be governed by the laws of Texas in the United States of America, and any proceedings concerning it shall be heard and resolved in a Texas court of law.