Model 1030
MR-compatible
Small Animal Monitoring
and Gating System

Operation Manual

SA Instruments, Inc.

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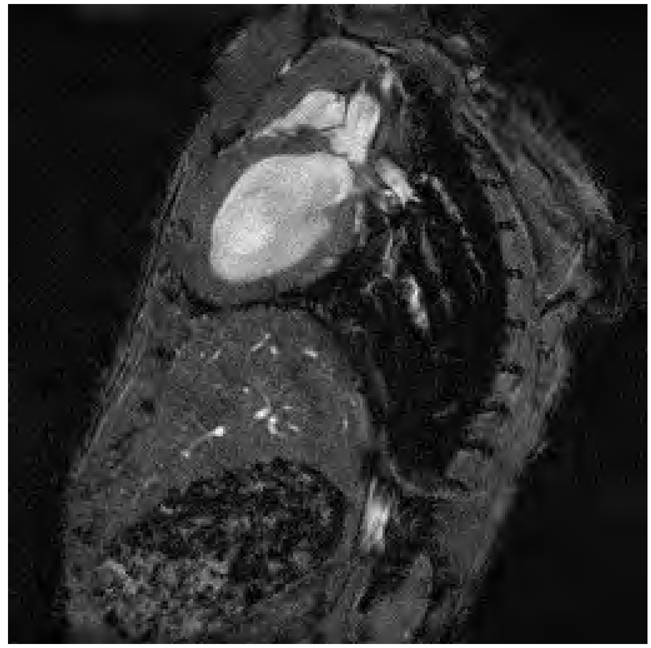

Mouse aortic root study

9.4T vertical field
ECG and respiratory gated
90 second image, without contrast

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Introduction

This Operation Manual accompanies the release of Revision 11.12 of the PC software for SA Instruments' small animal monitoring and gating systems including the Models 1030, 1025T and 1025.

Every major medical school in the world has at least one of SA Instruments monitoring and gating systems and many have several. We are grateful to all those medical researchers who have used SAI equipment and offered constructive comments allowing us to improve the performance and capabilities of our systems.

The Model 1030 monitoring and gating system measures and records physiological parameters of small animals. It currently measures ECG, respiration (two ways), temperature (two ways), pressure including invasive and minimally invasive blood pressure, oxygen saturation, end-tidal CO_2 and minimally inspired CO_2. For larger animals the 1030 system supports options for non-invasive blood pressure and CO2 with data acquisition modules positioned near the magnet. In addition, there are four user auxiliary input channels which can be used as a data interface for equipment such as a stimulator, ventilator, additional probes, the MR scanner, etc.

The system generates an output trigger or gate based on a user defined algorithm composed of nearly any combination of the measurements. It also provides flexible control for air and fluid heaters to regulate animal temperature and incorporates a MR-compatible ventilator to regulate and control animal respiration.

Chapters 2. 3, and 4 of the Operation Manual cover basic system operation. This information may be all that is needed for some users. Viewing and reformatting trend data for export to a spread sheet program is covered in Chapter 7. The SnapView program to view SnapShot data files is covered in Chapter 8. Many advanced features such as the advanced gating menu, time stamping and inversion timing are discussed in Chapter 15. A troubleshooting guide with useful tips is presented in Appendix C.

I encourage new users as well as those familiar with most of the system's capabilities to study the waveform examples in Appendix E. Valuable information on obtaining reliable triggers even when large artifacts are present in the ECG waveform can be found in Appendix C. The waveform examples and associated comments should help overcome most of the pitfalls present in monitoring and gating in MR.

Visit our web site www.i4sa.com for the latest information on software and hardware upgrades and extended system capabilities.

Please do not hesitate to contact us at service@i4sa.com or (631) 689-9408, if you have questions, comments or need additional information.

Ron Morris
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Chapter 1
System Overview

Mouse long axis, bright blood

4.7 T horizontal
ECG and respiratory gated

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Chapter 1
System Overview

Monitoring and gating

The Model 1030 monitoring and gating system was designed specifically to meet the physiological monitoring and gating needs for anesthetized mice, rats and larger animals in the high field MR environment. Both anesthesia and the local environment can adversely alter animal physiology. For that reason, research experiments often require measurement of physiologic parameters for heart rate, respiration rate, temperature, blood pressure, etc. It can also be necessary to control the temperature of the animal. For example, sedated mice can have heart and respiration rates depressed by more than a factor of two when exposed to a room temperature environment.

Motion artifacts in MR images can be eliminated or greatly reduced by employing gating techniques during the acquisition of the MR image data. By synchronizing MR data collection with the electrocardiogram, images can be obtained at specific times during the animal's cardiac cycle. These images, which are free of cardiac motion, can be viewed individually or in a cine time sequence to visualize heart movement.

Motion artifacts due to breathing can also be eliminated or reduced by synchronizing MR data collection with the respiratory cycle. Typically, the largest movement of the diaphragm and abdomen is during inspiration. Thus, selective acquisition of MR data during expiration can be effective in reducing breathing artifacts.

In some cases, it is advantageous to employ gating combinations to trigger MR data acquisition. For example, both cardiac and respiratory gating can be employed to selectively acquire cardiac data only during expiration. These acquisition techniques can produce anatomic images free of breathing, heart and/or blood flow artifacts.

System Components

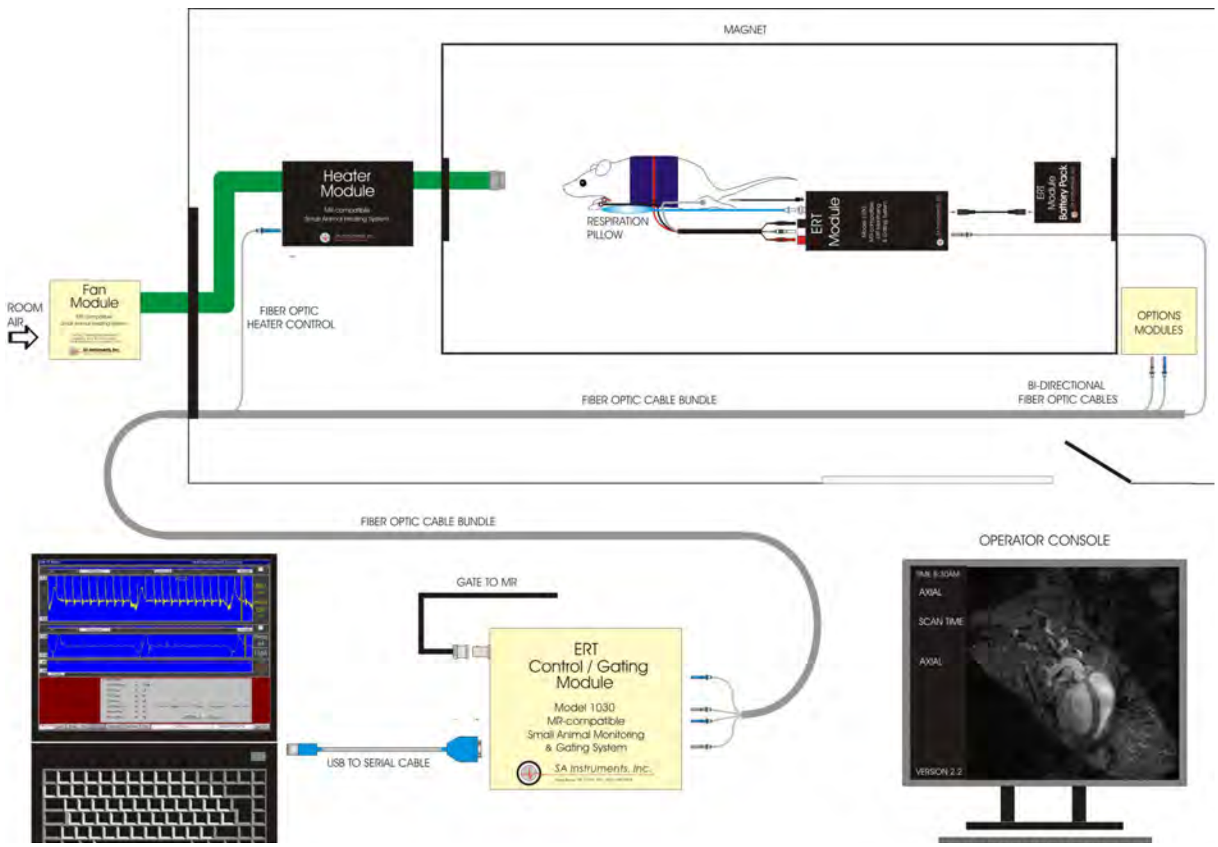
The Model 1030 monitoring and gating system consists of data acquisition modules located near the animal and a Control/Gating Module connected to a PC located near the operator console. The PC displays multiple waveforms, measured values, trends and gating pulses, which can be used to trigger MR data collection. The data acquisition modules are controlled by menu driven software from the PC. A SAII heater system, either air or water, can be used with the monitoring system to regulate the temperature of smaller animals in the magnet bore.

The in bore **ERT Module** measures ECG using three leads with needle or surface electrodes, respiration from a small pneumatic pillow sensor and/or from the movement of one ECG lead in the strong magnetic field and temperature with a small rectal thermister probe. Power is supplied by an external, rechargeable battery (refer to Chapter 4) or an isolated power supply (refer to Chapter 19). ECG, respiration and temperature measurements are transmitted out the magnet bore on an optical fiber to the ERT Control/Gating Module.

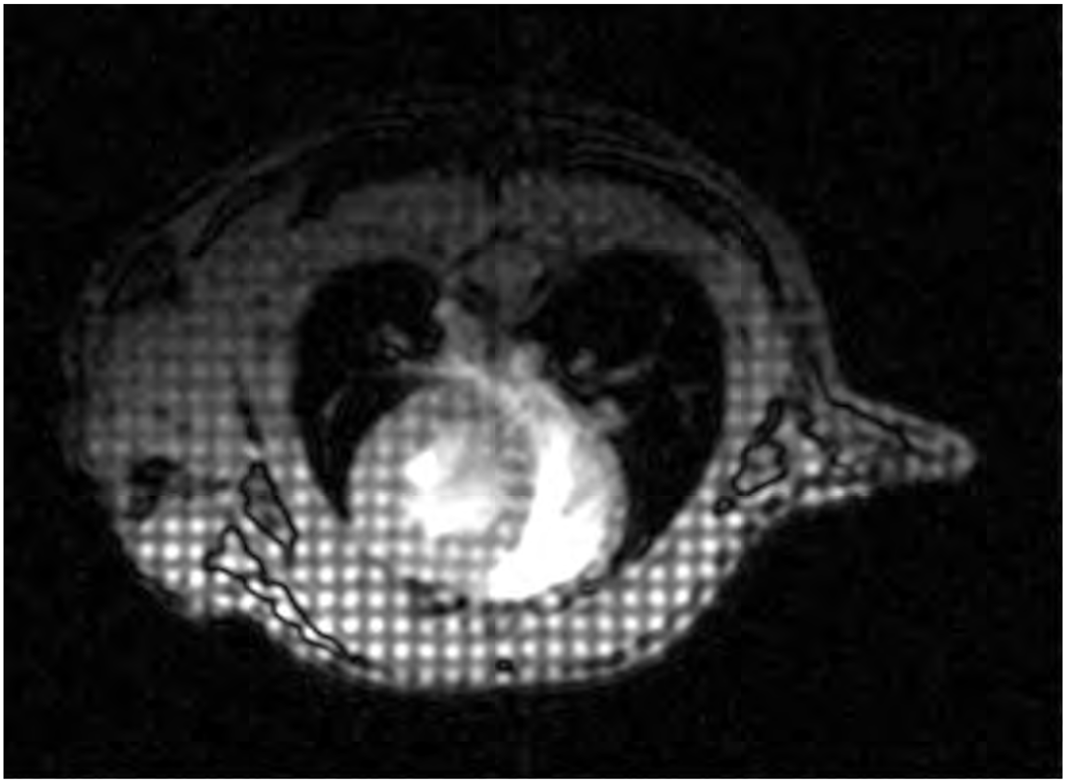
The **ERT Control/Gating Module** resides outside the RF shielded room near the MR operation console. It receives data from the ERT Module and any of several optional acquisition modules. The ERT Control/Gating Module sends data to the PC for display and receives user instructions from the PC to control measurement and gating functions. Gates from ECG, respiration and any of the available options are generated by the ERT Control/Gating Module's microprocessor and sent to the MR system. The delay from the R-wave peak to the MR system gate is user selectable as is the expiration gate delay and width. Two auxiliary gate input channels allow the user to synchronize gating to other external devices such as a ventilator and/or the scanner's imaging sequence. A fiber optic output provides control for the air Heater Module.

The **Air Heater System** supplies warm air in the magnet bore. A Fan Module located in the low fringe field of the magnet delivers cool room air to the Heater Module located near the magnet bore. The ERT Control/Gating Module, using the measured value of rectal temperature and a user defined set point, controls current to the heating element in the Heater Module to regulate the animal's temperature.

The following **options** are available for use with the Model 1030: invasive blood pressure (IBP) measuring systolic, diastolic and mean arterial pressure, pulse oximetry using fiber optic sensors to measure oxygen saturation (SpO2), heart rate and pulse distension, fiber optic temperature (FOT) to measure rectal or skin temperature, an ultra-miniature fiber optic pressure (FOP) system with fiber optic sensors to make minimally invasive pressure measurements, capnography measuring end-tidal and minimally inspired CO_2, a Fluid Heater System to control the animal's temperature and a ventilator to regulate respiration and to control the tidal gas volume delivered to the animal. All these options are covered in later chapters of this manual.


MAGNET
Heater Module
MR-compatible Small Animal Heating System
RESPIRATION PILLOW
ERT Module
ERT Module Battery Pack
ROOM AIR
Fan Module
FIBER OPTIC HEATER CONTROL
OPTIONS MODULES
BI-DIRECTIONAL FIBER OPTIC CABLES
FIBER OPTIC CABLE BUNDLE
FIBER OPTIC CABLE BUNDLE
OPERATOR CONSOLE
GATE TO MR
ERT Control / Gating Module
Model 1030
MR-compatible
Small Animal Monitoring
& Gating System
SA Instruments, Inc.
USB TO SERIAL CABLE
AXIAL
SCAN TIME
AXIAL
VERSION 2.2

Chapter 2
System Setup



Mouse short axis, bright blood, double tagged

4.7 T horizontal
ECG gated

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Installation of software

If the system was supplied with a PC, the software will already be installed. To start the monitoring system double click the PC-SAM icon on the desktop (refer to Chapter 3). To view and format trend data click the TrendMap icon on the desktop (refer to Chapter 7). To view saved SnapShot data files, click the PC-SAM icon on the desktop and select the SnapView option.

If the system was not supplied with a PC, install the software following the instructions in the readme file on the USB flash drive. Specification requirements for the PC are listed in Appendix A.

Windows can go to sleep and be difficult to awaken. Follow these instructions to disable hibernation on your PC:

> Windows XP: click Start>Settings>Control Panel>Power Options and open the hibernate tab. Clear the hibernate check box.
>
> Windows Vista or seven: click Start>Control Panel>Power Options and select “Power Management Off”.
>
> Windows 10: click Start>Power Options>enter Never for sleep on power.

Setting up the hardware

The Model 1030 has several optional functions. This manual assumes most functions are present with the system. Ignore those sections of the manual for options not present with your system. Refer to Appendix B for a list of major system components and accessories. Refer to Chapters 10 through 14 for instructions on setting up and testing the following options: IBP, Pulse Oximetry, Fiber Optic Temperature, Fiber Optic Pressure, Capnograph and Ventilator. Refer to Chapter 20 and 21 for instructions for the Dual and Single Pump Fluid Heater Systems. The ERT Module can be powered using a rechargeable 6 V battery (Chapter 4) or using an isolated 6 VDC power supply (Chapter 19). Instructions in this chapter assume power is provided from a battery.

1. Locate the two <u>simplex fiber optic cables</u> (25SFOC-23) and <u>fan air hose</u> (FAH-20), which is the longer of two heater hoses. If the MR scanner has a RF room, it will be necessary to install the fiber optic cables and air hose passing through wave guides. Follow the color code on the fiber optic cables connecting gray plugs to gray receptacles and blue plugs to blue receptacles. Note: the simplex fiber for the ERT Module will have a gray plug near the magnet while the fiber for the Heater Module will have a blue plug near the magnet.

2. Connect the <u>ERT Control/Gating Module</u> (720200) to the PC using the USB to <u>serial interface cable</u> (USB-21).

3. Power the ERT Control/Gating Module with the external 12 VDC power supply (PS-2-12-CG).

4. Connect the ERT Control/Gating Module to the ERT Module (110100) using the simplex fiber optic cable. Connect to the port on the ERT Control/Gating Module labeled “ECG” and to the ERT Module’s “Gray Fiber” port. Note no connection is made to the blue fiber port if it is present.

5. Connect the ERT Module Battery Pack (ERTBP3-108-PCC) to the ERT Module using the ERT Module Battery Pack Cable (BPC-210). A red light should be visible in the fiber optic port labeled “gray fiber”. The battery pack should be connected to the ERT battery charger when not in use. The ERT battery pack charger is internal to the ERT Control/Gating Module. An optional ERT Battery Pack Wall Charger (BPCG-210) is also available. It is not necessary to deep discharge the battery or to disconnect it from the charger after it is fully charged.

Caution: Do not operate the ERT Module and Battery Pack in gradient or RF fields. Refer to Chapter 4 for instructions on how to identify the position of gradient and RF coils within the magnet bore.

6. Position the Heater Module (76n100) near the magnet bore and connect it to AC power. Connect the fan air hose (FAH-20) (long tube) to the port on the Heater Module labeled “Fan”. Connect the warm air hose (WAH-5) (short tube) to the port on the Heater Module labeled “Warm Air”. Connect the simplex fiber optic cable to the fiber optic receptacle on the Heater Module and ERT Control/Gating Module labeled “Heater Control”.

7. Locate the Fan Module (77n100) in a low region of fringe field and connect to AC power and to the fan air hose. Note: In some situations, it may be desirable to locate the Heater Module outside the magnet room or to locate the Fan Module in the magnet room (refer to Chapter 6).

Warning: The Fan Module is magnetic and must be fix mounted if located in the magnet room.

8. To provide a trigger to the MR system, connect a BNC cable (not supplied) from the MR scanner’s gate input to the GATE connection on the ERT Control/Gating Module. Note the ERT Control/Gating Module is shipped from the factory with the gate output pulse configuration set to either “active low” or “TTL” based on your scanner’s gating signal requirements. The gate output pulse configuration can be changed (refer to Chapter 3).

Communication port assignment

Windows will automatically assign a communication port number for the serial or USB port which is being used for communication to and from the ERT Control/Gating Module. The assignment is made when the PC is turned on. The most common port assignments are “com1” for a serial connection and “com4” for a USB connection. However, other assignments are possible.

Follow these instructions to determine the com assignment:

Windows XP: click Start>Settings>Control Panel>System>Hardware tab>Device Manager>expand Ports (COM & LPT) and read the serial or USB assignment.

Windows Vista and seven: click Start>Control Panel>System>Device Manager>select continue in the permission window>expand Ports (COM & LPT) and read the serial or USB assignment.

Windows 10: Start>Device Manager> expand Ports (COM & LPT) and read the serial or USB assignment.

Setting the communication port in PC-SAM

To set the com port, double click the PC-SAM icon on the desktop. Click the button labeled “Click Here to Show Full Setup Screen”. The com port assignment should be set in the upper right-hand portion of the Full Setup Screen.

Testing the monitoring and gating system

The system can be tested using the Simulator (750100). Connect the Simulator to the ERT Module using the Simulator ECG leads (SEL-705) and the Simulator Temperature Cable (STC-105). The simulator generates an ECG waveform with respiration superimposed as well as a temperature reference.

Turning on the Simulator power should result in ECG and E-resp™ waveforms and a temperature reading on the PC display. The ECG waveform appears after the offset voltage reaches 2.5 V (refer to Chapter 3). Adjust the simulator amplitudes, if necessary, to obtain heart and respiration rate readings and indications of gate detection. Turning on the gradient switch superimposes spikes on the ECG waveform. The effect should be barely noticeable on the PC display. The simulator is powered by an internal 9V battery, which is not rechargeable (refer to Chapter 5).

Caution: The Simulator battery is magnetic and should not be extended into the magnet bore

Open the SYSTEM INFO window and observe the 50/60 Hertz notch filter setting for the ERT Module. Make certain the filter is set properly for your location (50 Hz in Europe, 60 Hz in US, etc.)   The ERT Module has a provision for the filter to be changed by the user (refer to Chapter 4).

Test the Respiration (P-resp) function of the ERT Module by connecting a Respiration Pillow Sensor (RS-301) to the pneumatic port on the ERT Module. Lightly touching the pillow sensor should produce waveform deflections on the PC's Resp display.

Testing the heater system

Activation of the Fan Module power switch should produce air flow to the Heater Module. Turn on the Heater Module power switch and observe a green LED indication. Connect the Simulator or a Rectal Temperature Probe (RTB-101) to the ERT Module and observe a temperature reading on the PC monitor display. Select a set point higher than the measured temperature by opening the heater window (refer to Chapter 6). A yellow LED should intermittently pulse on the Heater Module indicating power being delivered to the heating element. Within several seconds, warm air should be present.

Later chapters of the manual provide details on menu selections and settings. Refer to Appendix C for troubleshooting.

Step by step Instructions for monitoring and gating

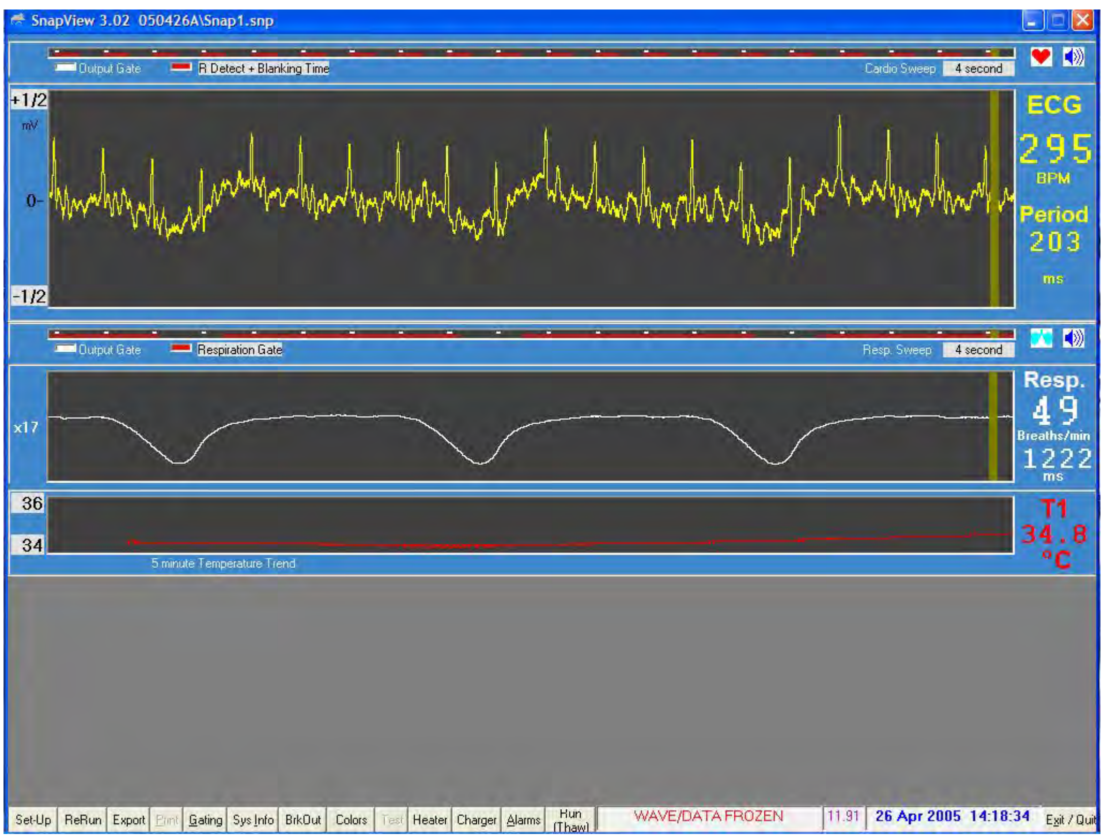
Click the PC-SAM icon on the desktop > select “Start Monitor with Selected Setup” to view the main monitor display screen. The “selected setup” should be “factory defaults” which includes ECG, respiration from the pillow sensor, temperature from the thermister probe and ECG gating. Refer to Chapter 3 to alter the monitor configuration.

Attach ECG electrodes, a pneumatic pillow respiration sensor and the thermister temperature probe to the animal following instructions in Chapter 4.

ECG and respiration waveforms along with temperature measurements should appear similar to those shown below. If your ECG waveform has negative rather than positive peaks, switch the electrodes at the red and white connectors on the ERT Module.

Note the presence of small red bars above the peaks of the ECG waveform which indicate R-wave detection. Longer red bars appear above the respiration waveform which coincide with the animal’s expiration. White dots appear at the same time in both the Cardio and Resp Sweep displays whenever a gate is sent from the ERT Control/Gating Module to the MR scanner.

The heart and respiration rates are displayed to the right of the waveforms measured in beats or breaths per minute. The period displayed below each rate is the time interval



in milliseconds for the cardiac or respiratory cycle. Refer to Chapter 3 for additional information regarding the main monitor display

Recommendations for daily operation

Connect the ERT Module Battery Pack to the charger at the end of the day. The battery pack can be left on the charger when not in use. It can not be over charged.

The ERT Control/Gating Module can be powered on all the time.

The IBP Module - a) if you have power in the magnet room, use the 12 V power supply provided. Make sure the power supply is not in a really strong fringe field. It will work in a strong field but will have a shortened lifetime. The module has an internal battery. You can leave the battery switch and power switch in the on position all the time. b) if you do not have power in the magnet room, then you need to operate the module on internal battery and charge the battery overnight. Refer to Chapter 10.

The power to the Heater and Fan Modules should be turned off when not in use.

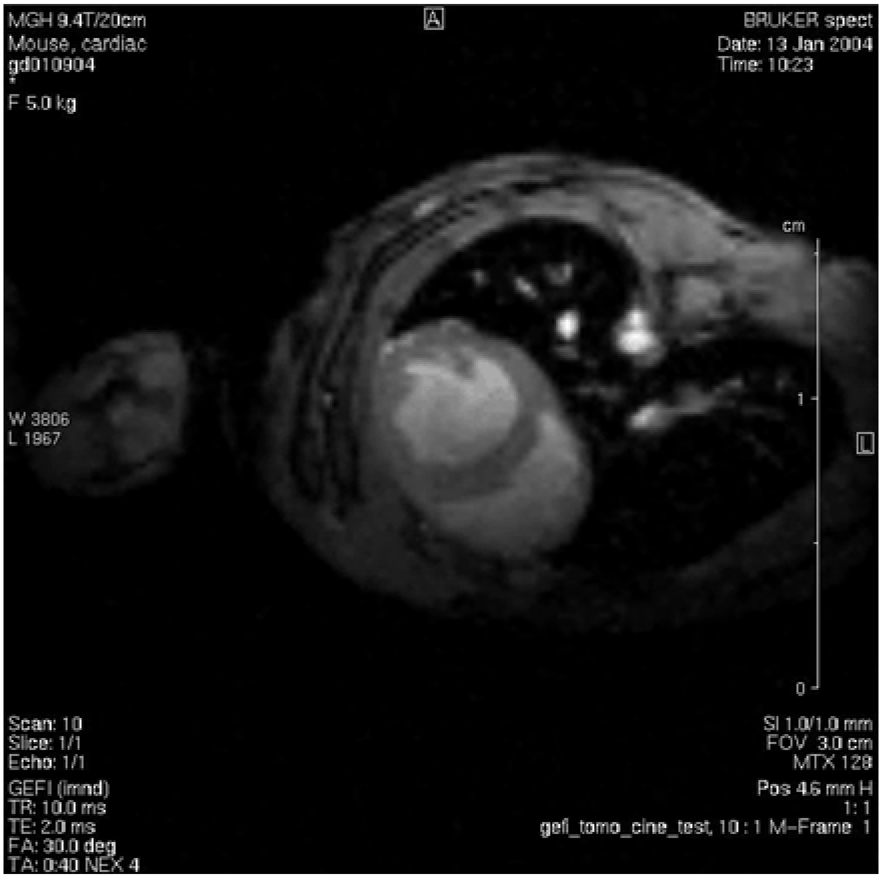
FO Temperature, FO Pressure and Pulse Oximeter Modules - We recommend unplugging the 12 V power at the end of the day. Turning off power turns off the light source for the temperature, pressure and oximetry probes.

Capnograph – turn off the main power switch when not in use.

Ventilator – turn of the main power and compressed gas supply when not in use.

Fluid Heater System – turn off the power to the Heater Module and Circulation Module when not in use.

Chapter 3
PC and ERT Control/Gating Module



Mouse short axis, bright blood

9.4 T horizontal
ECG and respiratory gated

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Chapter 3
PC and ERT Control/Gating Module

Overview

The ERT Control/Gating Module, located near the operator's console, is connected to a PC to provide operator control as well as display and storage of waveforms, computed gates, measured values and trends.

The optical signal received at the ERT Control/Gating Module from the ERT Module is demodulated and separated into ECG, respiration from the pneumatic pillow sensor and temperature components before being processed to detect the R-wave (primary) peak of the ECG waveform. Operator control of the QRS (R-wave) detection algorithm is affected from the PC by selecting threshold values for the QR (leading) and RS (trailing of opposite polarity) slew rates as well as ECG gate blanking time. Slew rate control allows reliable determination of the ECG R-wave peak with minimal delay. Gate blanking time is set to eliminate unwanted gates from secondary peaks and/or interference.

The respiration waveform from the pneumatic pillow sensor is automatically processed to detect inspiration. When the animal takes air into the lungs, the pillow sensor is compressed and the respiration waveform dips. The dip in the waveform is detected and an inspiration gate is generated. The inspiration gate is usually inverted to make an expiration gate. Both the beginning delay and maximum width of the gate are user controlled.

The E-Resp™ respiration waveform is extracted from digitized ECG measurements and processed to detect inspiration. Respiration gates (E-Resp™ gates) are determined either automatically or manually from the E-resp waveform. Gate position in the respiratory cycle can also be set by the user similar to P-resp or respiration gates.

Monitor display

The monitor display is user configurable from the MONITOR SETUP window. Double clicking the PC-sam icon on the PC desktop generates an option to enter the MONITOR SETUP window before starting the monitor.

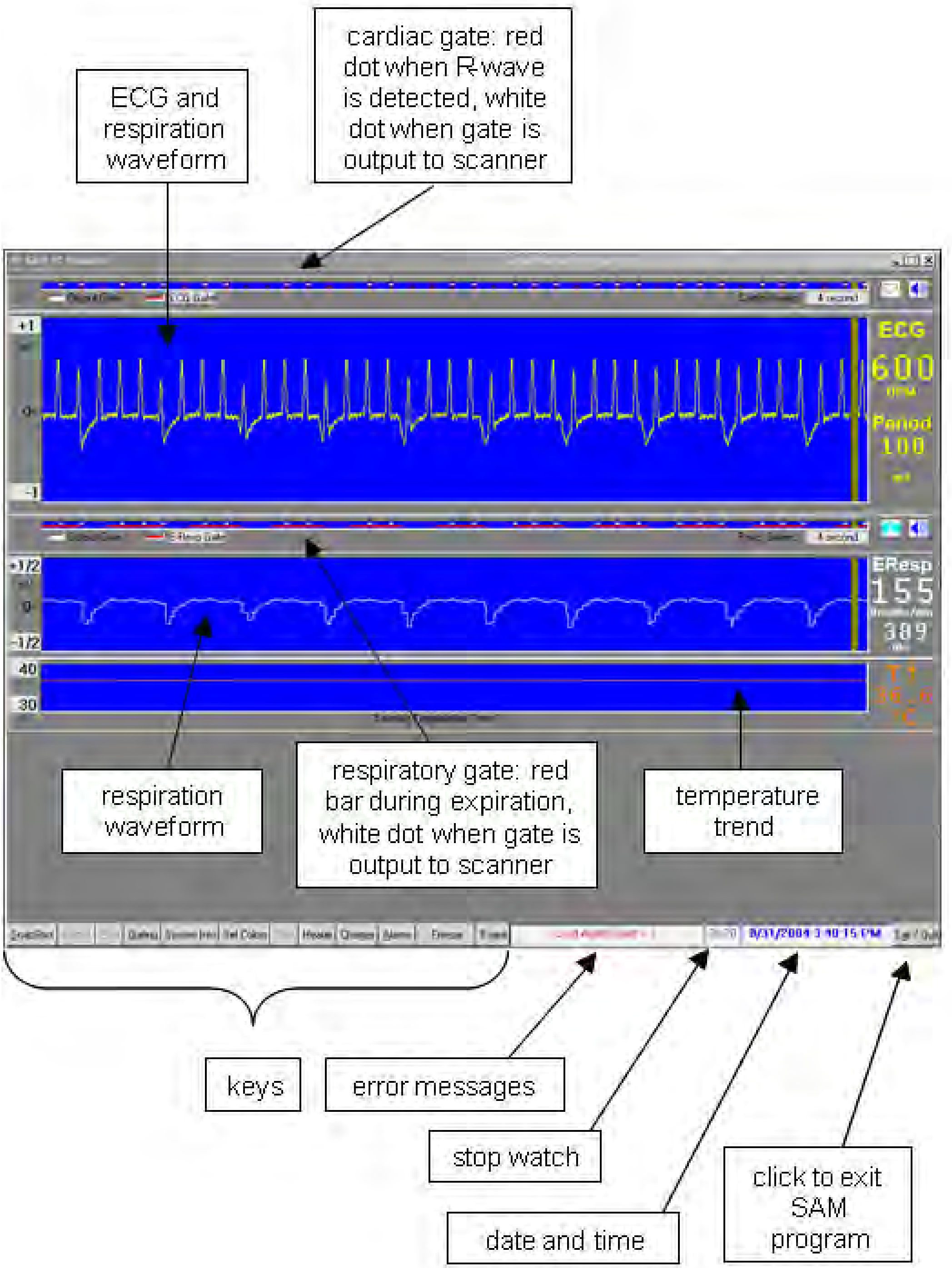
A typical monitor display configuration is shown on the next page. In this example, the parameters monitored are ECG, respiration and temperature. Detection of the R-wave (QRS complex) is indicated by the presence of a red dot on the cardio sweep display above the R-wave peak.

The respiration waveform dips during animal inspiration and exhibits only small changes in amplitude during expiration. Expiration is indicated by the presence of a red bar above the appropriate portion of the waveform.

White dots in the cardio sweep display are also shown in the respiration sweep display. They indicate times when gates have been sent to the scanner to initiate image data acquisition. In this case, the gating algorithm included both ECG and respiration, so red dots (R-waves) only generate white dots (gates) when they occur during animal expiration.

PC and ERT Control/Gating Module

Gates and waveforms sweep from left to right. The number of red dots (R-waves) determines the measured heart rate and the R to R period. Likewise, the number of red bars (expirations) generates the measured respiration rate and period.

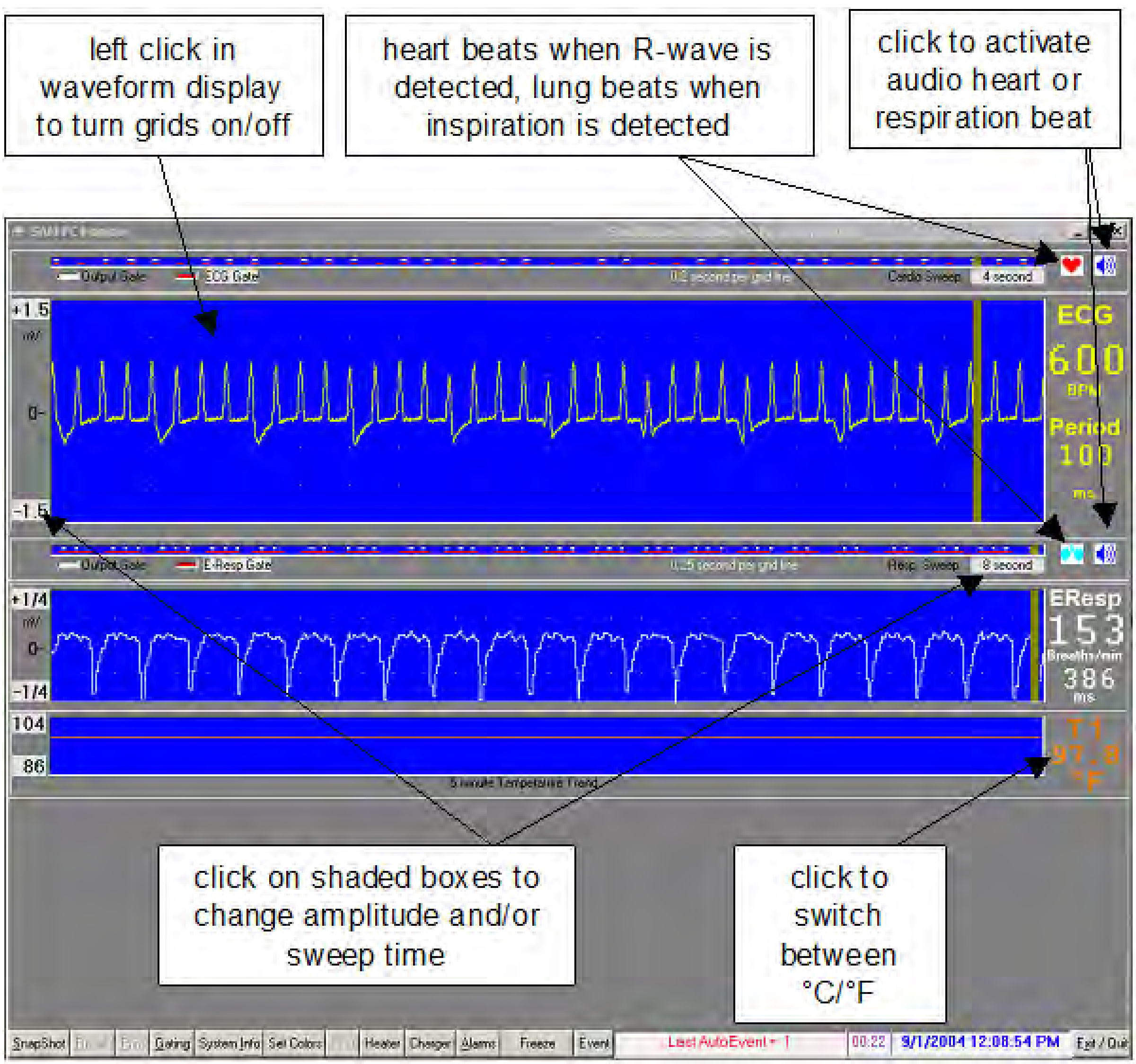


Temperature measurements are displayed in a 5-minute trend with the most recent measurement on the right of the display. Each new temperature measurement is displayed in digits as it is entered in the trend portion of the display.

Located along the bottom of the monitor display are several keys which perform special functions, display data or allow user entry of operating parameters. Each of the keys will be discussed in a later section of this chapter. In addition to the keys, there are regions for display of error messages, a stop watch and the date and time.

The stop watch displays in hours and minutes. A bar flashes to indicate the stop watch is running. Click on the stop watch display, to reset to zero.

Right click on the shaded waveform amplitude values to increase or left click to decrease the maximum and minimum values. Right click on the shaded sweep time



boxes to increase or left click to decrease the sweep time. Note the cardiac and respiratory sweep times are independent and can be set to different values.

Switch between ºC and ºF by clicking on the digits in the temperature display

Clicking on the speaker icon associated with the cardiac sweep activates an audible beep for each ECG R-wave. Likewise clicking on the speaker icon associated with the respiration sweep activates an audible beep for respiration. It is not intended for both the ECG and respiration audio indicators to be on at the same time.

Grids can be turned off and on by left clicking inside a waveform display. Note the time separation of the grid lines is displayed above the waveform.

Right or left clicking on the gray box next to the red indicator of the cardio or respiration sweep gate displays will sequentially change the gate displayed. For the cardiac sweep the most useful gates are ECG and R-detect + Blanking Time.

Labeling convention for respiration channels

Respiration waveforms, measured from ECG leads, and the associated gates are labeled as "E-Resp" or ''EResp". Respiration waveforms, measured from a pneumatic pillow, and the associated gates are labeled as "Resp" or "P-Resp". Waveforms and the associated gates for the User Spare Analog Channel are labeled "UserR" or "User Resp". Note that the "UserR" label can be changed in the User Spare Resp Setup menu. (Refer to Chapter 10).

User Input channels

Up to four user auxiliary input channels are available, two digital (on/off) and two analog. The digital channels are useful to synchronize gating with external equipment such as a ventilator and/or to time stamp physiological measurements with an event marker from the scanner (refer to Chapter 15). The analog channels allow user defined waveform information to be input for recording, display and gating.

The digital auxiliary channels are input through the ERT Control/Gating Module at "AUX" (TTL) and "AUX GATE IN" (fiber optic signal). They are digitized at 1800 samples/second.

The analog auxiliary channels are associated with the IBP Module. They are input at "User Resp" and "IBP3". User Resp is digitized at one half the IBP rate of 900 samples/second. Refer to Chapter 10 for connector pin specifications and Chapter 15 for setup features.

ERT Control/Gating Module input/output connections

Electrical connections:

Gate	output gate to trigger scanner
PC	Serial connection to PC
RESP GATE	output respiration gate to trigger scanner
Power	12 VDC input power connection
AUX	Aux gate input, a user TTL input gate channel

Fiber optic connections:

ERT	Input from the ERT Module
AUX GATE IN	fiber optic aux in, a user digital gate input channel
AUX GATE OUT	Gate or trigger pulse out
OPTION IN	Input from optional modules
OPTION OUT	Output to optional modules
HEATER CONTROL	control signal for Heater Module

Note: if optional modules (IBP, Pulse Oximetry, Fiber Optic Temperature, Fiber Optic Pressure, Capnograph and/or Ventilator) are in use then a duplex fiber optic cable should be connected to the OPTION IN and OPTION OUT ports and the options I/O switch set to “options in use”. Otherwise the options I/O switch should be set to “options not in use”.

Gate output pulse signal configuration

The ERT Control/Gating Module is shipped from the factory with the gate output pulse configured appropriate for the user’s anticipated scanner either TTL (H) or active low (L). The gate output pulse can be changed by removing the cover of the ERT Control/Gating Module. The switch is located inside a small access hole in the RF shield.

Scanners manufactured by Bruker require active low (L) while those manufactured by Varian require TTL (H). The switch position as set by the factory is indicated on the bottom of the module.

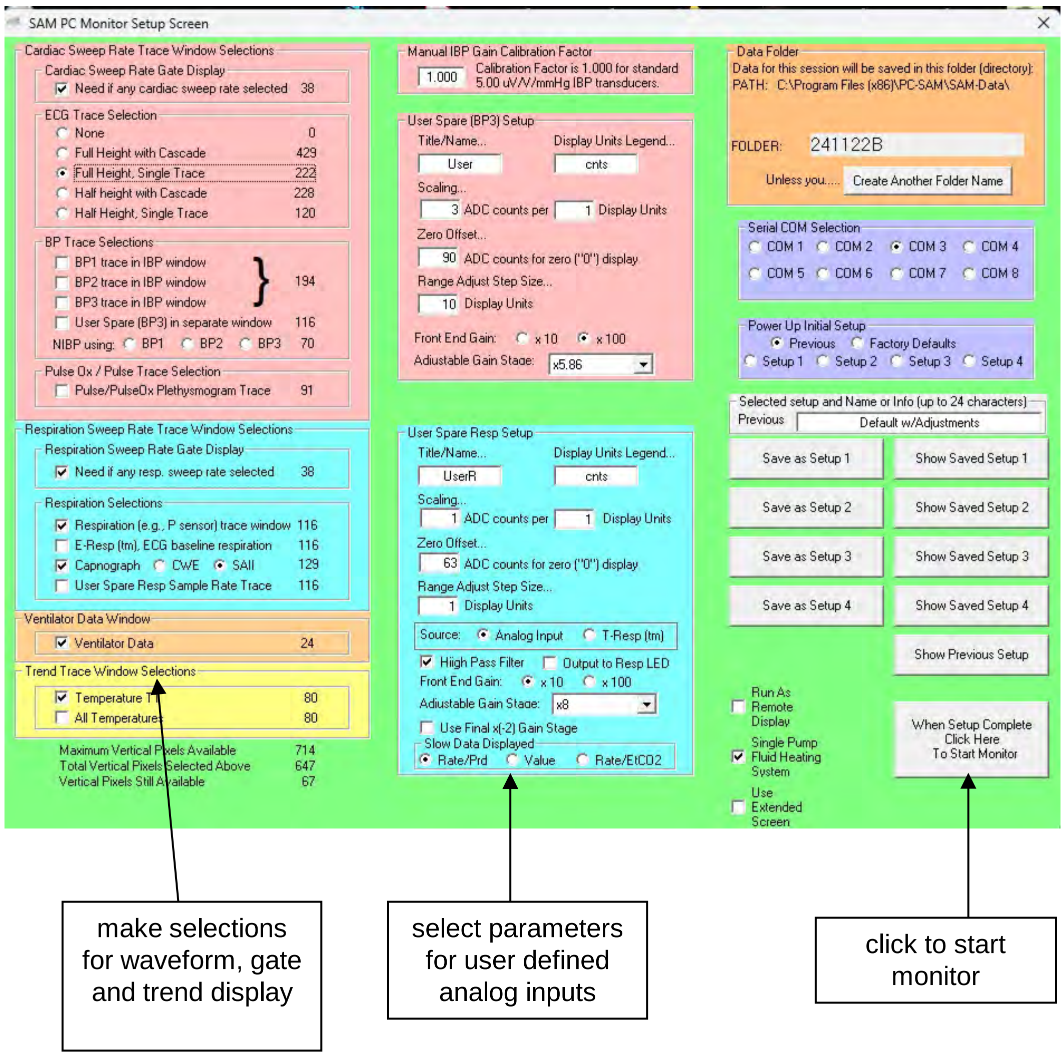
Altering monitor configuration

An option exists to open the MONITOR SETUP window after executing PC-sam. The SETUP window is shown on the next page.

The MONITOR SETUP window allows the user to do the following:

1. Define which waveforms, gates and trends to display
2. Setup user defined traces
3. Select the respiration channel signal source
4. Change the name for the data folder for the current session

5. Change the serial communication port
6. Select a default stored setup file at startup
7. Select an alternate stored setup for the current session.



The portion of the setup window for waveform, gate and trend selection includes sections for cardiac, respiration and temperature. The numbers to the right of the trace selections are the number of vertical pixels necessary for that portion of the display. The total number of pixels used can not exceed the number available for the PC's display. A calculation to determine the number of pixels still available is performed in the lower left corner of the display.

The portion of the setup window for user defined auxiliary waveforms allows selections for gain and labeling. These parameters can also be set in real time by right clicking the appropriate waveform from the main monitor display. (Refer to Chapter 15).

The data folder for storage of trend data defaults to a date encoded name of the form yymmdd(letter). The letter changes for each successive session during the day. The user can change the file name and storage location from the setup window.

Up to four user defined setup files allow different monitor configurations to be saved for easy retrieval. For example, setup files could be stored for different types of animals or different users or for different types of studies. In addition, Factory Defaults can be selected or the previously configured setup. In the later case, any changes made during the last monitoring session will be remembered and restored for the next monitoring session.

SnapShot key

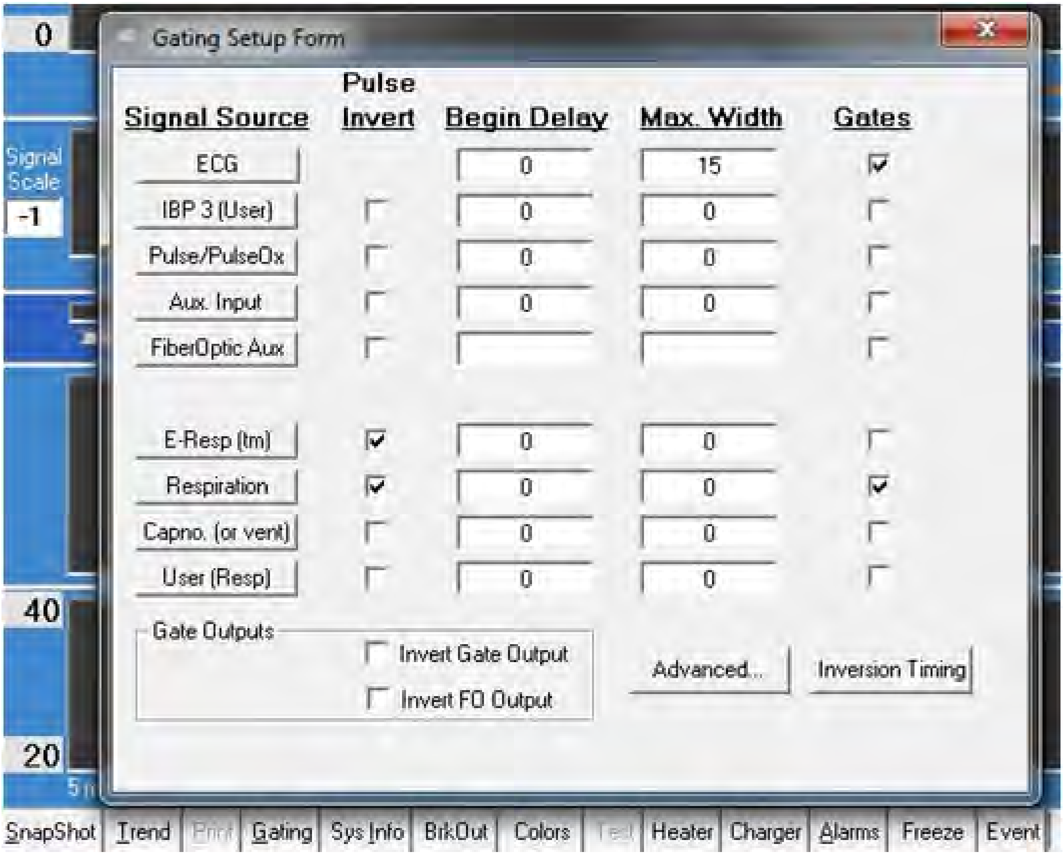
The SnapShot key in the lower left portion of PC-sam's main monitor display causes storage of the last 36 seconds of monitor data. All data transmitted to the PC during the last 36 seconds is stored not just displayed data. Parameter values set by the PC (e.g. slew rates for R-wave detection, blanking time, gating selections, etc.) are stored once, at the time the SnapShot key was clicked.

Data files can be viewed by selecting the SnapView option after launching PC-sam. Options exist to allow the entire file to be played back or to view the last few seconds of data. Most features available in PC-sam are also available in SnapView. For example, sweep rates and amplitudes can be adjusted while viewing the files and the keys are active to display windows with associated parameter values. (Refer to Chapter 8).

Trend key

The Trend key in the lower left portion of the monitor allows the current Trend file to be restarted or saved. When the saved selection is made a new Trend file is automatically started.

GATING SETUP window



Click the Gating key to open the GATING SETUP window. This window provides a means to include one or more signals in the gating algorithm. In the window above, both ECG and respiration gates must be satisfied for generation of an output gate (white dot).

Gate width and delay can be controlled for each signal source. Delay and width entries are in msec. A zero setting for Max Width is used to automatically determine the width from the gate detection software.

A check in the "Pulse Invert" column inverts the gate logic. For example, the E-Resp gate detection algorithm detects the dip in the waveform which occurs at inspiration. A check is placed in the Pulse Invert column to switch the gate to the expiration portion of the waveform. If desired, the expiration gate can be delayed in time or shortened in width.

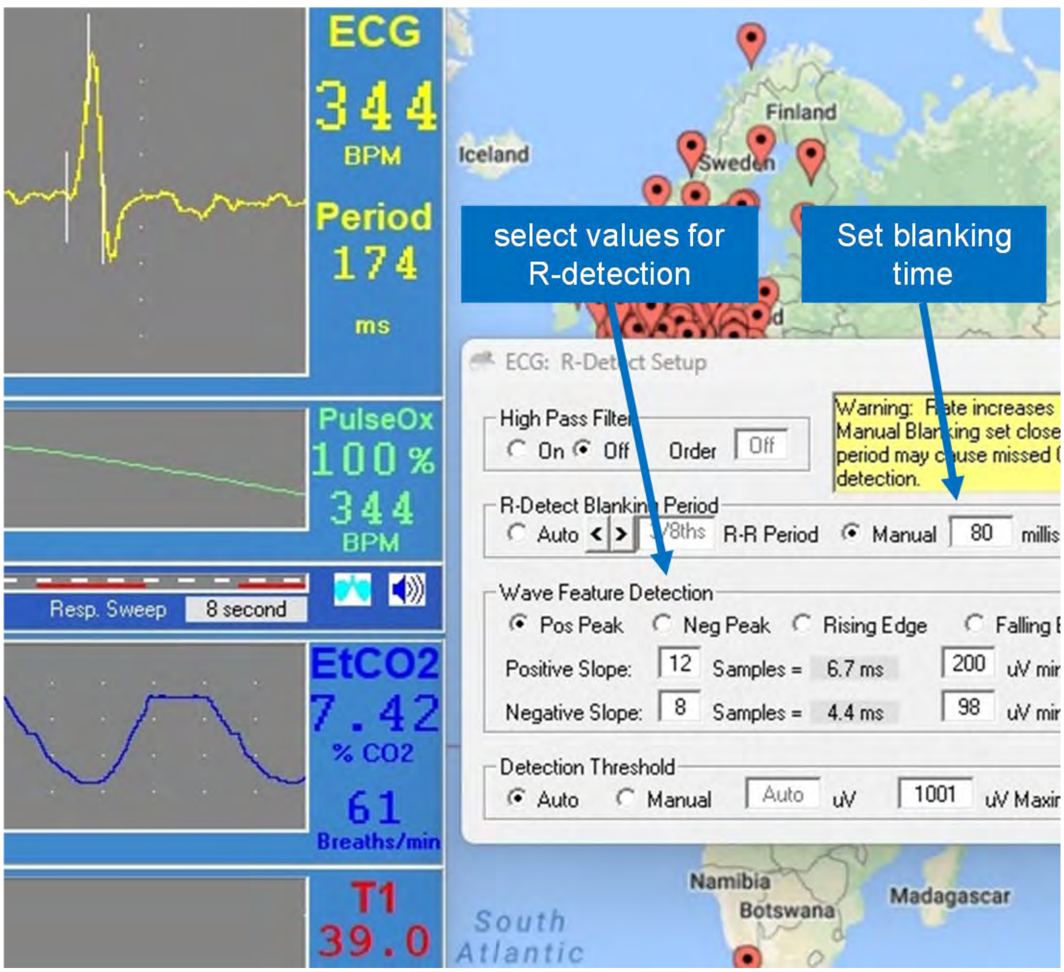
Clicking on either the Advanced or Inversion Timing keys expand the GATING SETUP window. (Refer to Chapter 15).

R-DETECT SETUP window

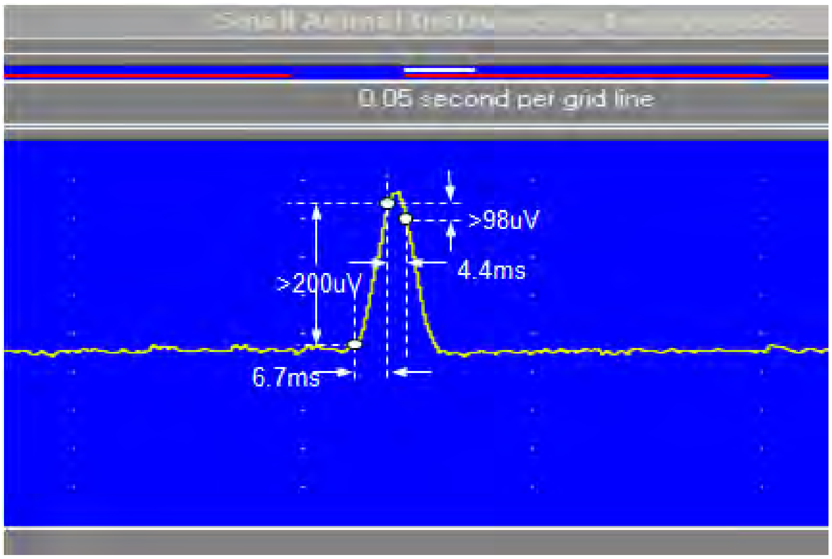
Click the ECG button in the GATING SETUP window or right click in the ECG waveform display to view the R-DETECT SETUP window.

The **high pass filter** removes low frequency components of the ECG waveform. It can be useful with large animals and low heart rates but is of little benefit for mice. The order number can be selected between 16 and 6. Order number 6 produces the strongest filter function. Use the high pass filter with low order numbers for large animals to reduce low frequency "T-wave" flow artifacts.

The **R-detect blanking period** or blanking time is a very useful feature. Once an R-wave has been detected, the software inhibits R-wave gate generation for the blanking time. This feature can be used to eliminate false triggers from gradient vibrations. In that case, the blanking time should be set to exceed the MR scanner acquisition time by about 10 msec.



The **R-detect algorithm** is based on 2 or 3 points and their positive and/or negative slew rates or slopes (amplitude/time). The waveform shown exhibits R-wave gate generation for factory defaults: positive peak with positive slope of 200µV/6.7ms and a negative slope of 98µV/4.4ms. The gate is generated at the end of the negative slope. In this example the R-wave is about 800µV in amplitude. The positive slope requirement is easily exceeded and the gate is generated as soon as the negative slope requirement is satisfied. Note that the mid point that satisfies the gate requirement is earlier in time than the R-wave peak. Thus, the delay of the scanner gate is less than the negative slope time (i.e. less than 4.4 msec)



Proper selection of parameters for R-wave detection are important in obtaining reliable results. This is especially true when the ECG waveform contains large contributions from blood flow, vibration or respiration.

Perform the following steps to determine optimum settings for ECG detection (note we assume a positive R-wave for this discussion, but the software works in a similar manner for a negative R-wave):

Select a wave feature to detect: Usually this is a positive going R-wave. Selecting positive peak will give more reliable detection than selecting a rising edge. The only reason to select a rising edge would be to obtain a gate occurring before the R-wave peak in time.

Pick the times for the slopes: There are a maximum of 31 sample points or about 17 ms. Different animals have different rise times for the R-wave. Select the largest time appropriate for the animal's rise time. For mice the rise time is about 7.5 ms. Because the gate is generated at the end of the fall time, the fall time is usually set to be less than the rise time.

Select the amplitude(s): Determine the peak amplitude of the R-wave: usually 500 µV to 1000 µV. In the case of mice with a rise and fall time selected of 6.7 and 4.4 ms respectively, we select rise & fall amplitudes of less than 6.7/7.5 = 90% and 4.4/7.5 = 60% of the peak amplitude. The system can be used to determine the amplitudes: set the amplitudes smaller than you expect, but large enough not to get false gates, then slowly increase one of the amplitudes until gates begin to be missed. Final setting of 30 - 50% of max works well with auto detection threshold and 60 – 80% for manual detection threshold.

The **auto detection threshold** is a proprietary additional detection criterion. To turn it off, select manual and set the threshold to the positive slope amplitude.

CHARGER window

The CHARGER window reports the current status of the IBP Module power, the IBP internal battery and the external charging battery (i.e. the ERT Battery Pack) if one is connected to the ERT Control/Gating Module's battery charger.

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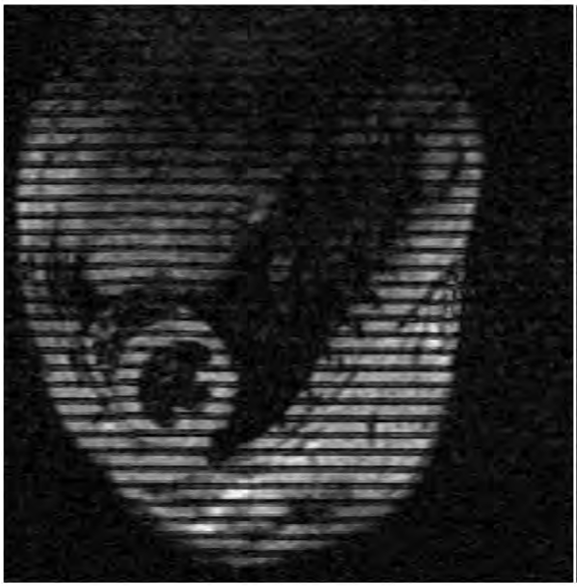
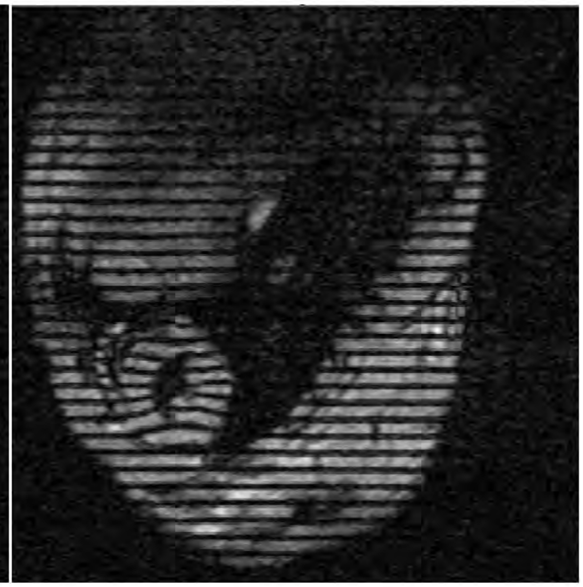
Chapter 4
ERT Module



diastole



systole

Mouse short axis, black blood, tagged

4.7 T horizontal
ECG and respiratory gated

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Brent A. French, Ph.D.
Zequan Yang, M.D., Ph.D.
Christopher M. Kramer, M.D

Overview

The animal's electrocardiograph (ECG) is obtained from two or three leads connected to sub-dermal needle electrodes, gold disk surface electrodes or pads. A respiration signal may be superimposed on the measured ECG waveform by closely coupling one of the active ECG lead wires to the animal's abdomen. This coupling is accomplished by attaching the ECG lead wire to a cradle configured to conform to the animal's abdomen. As the animal breaths, the lead wire moves in the strong static magnetic field creating a signal (E-resp™) that is superimposed on the ECG waveform. Another measurement of the animal's respiration can be made using a small pneumatic respiration pillow sensor. Temperature is measured using a temperature probe in the animal's rectum.

ERT Module signals are passed sequentially through an RF filter, amplifier and pulsed gradient filter before being combined and digitized. The digitized signal is transmitted out the magnet bore to the ERT Control/Gating Module using a long fiber optic cable.

ERT Modules have a gray fiber optic transmitter and in rare cases they can also have a blue fiber optic receiver. Under normal operation, only the gray transmitter is used and no connection is made to the blue receiver. Power is provided to the ERT Module by a Battery Pack or in some cases to an Isolated 6 VDC Power supply (refer to Chapter 19).

Positioning the ERT Module and Battery Pack

The ERT Module powered by the external battery pack is positioned in the magnet bore close to the animal. The ERT Module should be outside the imaging volume a few to several inches from the animal. The Battery pack should be further away from the imaging volume connected to the ERT Module with one of the available Battery pack Cables. Available cable lengths are 9", 15", 48" and 144". Contact SA Instruments if you need a length different than the one delivered with the system.

The ERT Module and Battery Pack are each enclosed in a copper RF shield. The RF shield absorbs all the energy of the RF field that they are exposed to and if the RF field is large they can get hot. For that reason neither the ERT Module or the Battery Pack should be positioned in or very near the RF coil.

Caution: Do not position the ERT Module or Battery Pack in or very near the RF coil or they may become hot.

The condition to position the ERT Module outside the RF coil is not very restrictive as the sensors for ECG, respiration and temperature are 9" long and sensor extensions can be used if necessary. By design the Battery Pack will be much further away from the RF coil and therefore of a lesser concern.

ERT Module

Special considerations for Bruker magnets: excerpts from the Bruker manual

The battery pack and ERT module of the animal monitoring device from SA Instruments must not be used within the gradient or RF field since they may overeat.

Locate the ERT Module at the rear of the animal cradle which does not extend into the gradient / RF field. For the battery pack, different lengths of cables are available in order to locate the battery pack at an appropriate distance.

Caution: Risk of burns or fire due to overheating of the battery pack.

The battery pack and ERT module of the animal monitoring device from SA Instruments Inc can be used within the static magnetic field. However, very fast switching gradients can heat the battery pack and ERT module due to eddy currents induced.

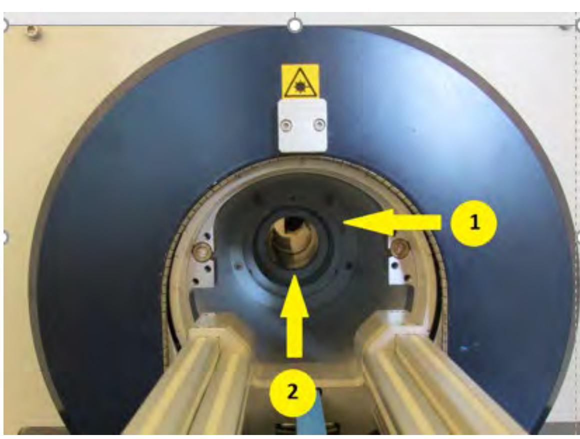
Locate the battery pack and ERT module such that it will not be within the gradient and RF coil (examples of gradient coils, see below).

Bruker recommends to validate the MR protocol in combination with the locations of the battery pack and ERT module initially prior to long term use. Run the protocol for 1-2 minutes, stop the scan and check surface temperatures of the battery pack and ERT module immediately. In case you detect a warming up of a module, position the module further outside and repeat the test. Otherwise, repeat the test with increased scan duration until a safe use of the modules can be guaranteed without noticeable warming up over the entire protocol duration.

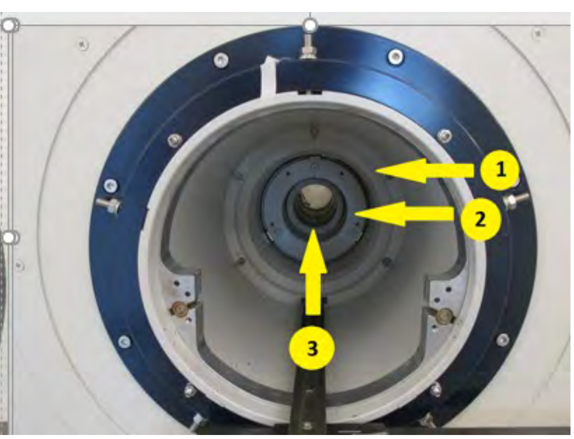
How to identify the location of the gradient or RF field?

At most instruments. You will identify the gradient coil looking into the magnet bore from the animal table side. The gradient coil itself will start at the rim where the diameter of the bore decreases. Some instruments use a smaller gradient coil within the larger one (gradient insert), so that you will detect two rims. Furthermore, inside the gradient coil, the RF coil is located.

Two examples are given below. In case you cannot identify the gradient or RF coil at your instrument, please contact the Bruker hotline.



1 Gradient Coil
2 RF Coil



1 Gradient Coil
2 Gradient Insert
3 RF Coil

Connecting the Battery Pack Cable

The Battery Pack Cable attaches to the ERT module and Battery Pack using small Lemo connectors. To make the connection, align the red dots and push the connector straight into the receptacle. To disconnect the cable, grasp the connector with the thumb and index finger near the red dot and pull straight back. Do not turn or twist the connector housing.

Attaching ECG electrodes

Active electrode placement (red and white) in mice is typically in or on the right front leg and left rear leg. For larger animals (rats and rabbits) it is best to avoid large electrode separation (due to detection of large blood flow artifacts). In the case of rats, the front legs work well, for rabbits a good location is under the front legs at the chest. In all cases the third black lead can be connected to one of the unused legs or any other convenient location on the animal. In cases where it is desirable to use only 2 ECG leads, the black lead can be eliminated using the 3-lead to 2-lead jumper cable.

Attachment of sub-dermal ECG needle electrodes

Make certain the needle does not enter the muscle, but rather is positioned between the muscle and skin. At least half the length of the needle should be inserted in the animal. Make certain the needle tip does not protrude. Secure the electrode with tape. If the needle electrodes are inserted in the muscle, a large offset voltage can occur. The offset voltage should be 2.5 +/- 1 V. It is displayed in the SYSTEM INFO window.

Attachment of electrode pads

Pad electrodes may be used by shaving the attachment site. Tape can be helpful in securing the electrode.

Attachment of gold surface electrodes

Surface electrodes may be used by shaving the attached site or by application to the animal's paws. Apply electrode gel to the cup of the electrode before taping to the animal's paw. Rubbing electrode gel in the pores of the paw before taping the electrode will improve the signal.

Positioning ECG lead wires

ECG lead wires should be twisted with each other and as short as possible. Excess wire should be wrapped in a loop and taped to collapse or eliminate the loop. Wrap excess wire around two or three fingers creating a loop, then pull the loop into a line and tape. The wire bundle should then be taped to the animal holder to eliminate movement from gradient vibration and/or air flow. Movement of the ECG lead wires will create artifacts in the ECG waveform.

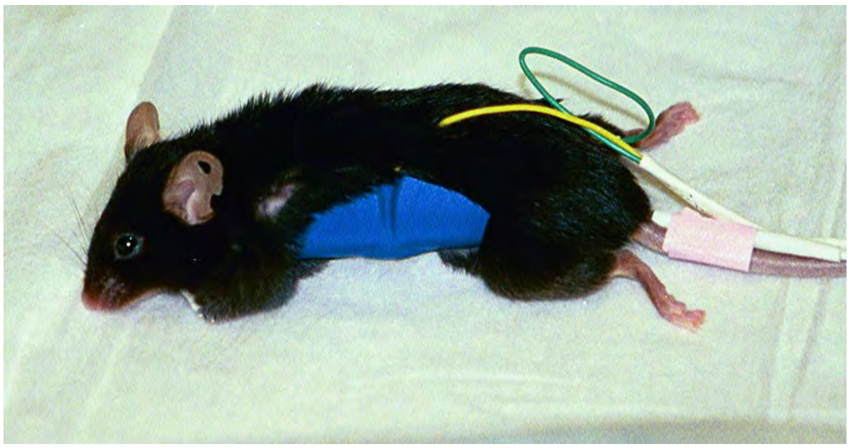
Caution: ECG lead wires should be twisted and unnecessary loops should be avoided. The lead wires should be taped to eliminate unwanted movement from gradient vibrations and/or air flow.

ECG lead wires can degrade tuning of the MR imaging coil. As a general rule, the lead wires should be routed as far away from the coil elements as practical

E-resp™ with a cradle

The cradle allows one of the active (red or white) ECG leads to be closely coupled to the abdomen of the animal. As the animal breaths, the lead moves in the strong magnetic field creating a respiration voltage signal superimposed on the ECG waveform.

For mice, the cradle can be positioned on the back or under the stomach. The photo below shows the cradle positioned under the mouse. The cradle can be used in different configurations by removing and reapplying the tape.

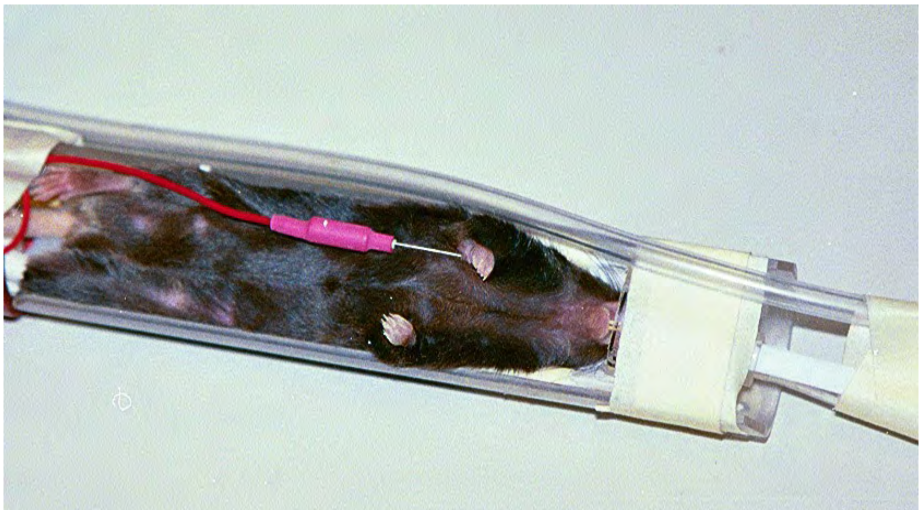


For rats, the lead does not need to extend around the entire cradle. The longer the length of wire attached to the cradle, the larger the respiration signal superimposed on the ECG waveform. At 4.7 T taping the lead on one half of the cradle gives a suitable signal. For higher field systems, less lead length coupled to the cradle maybe desirable.

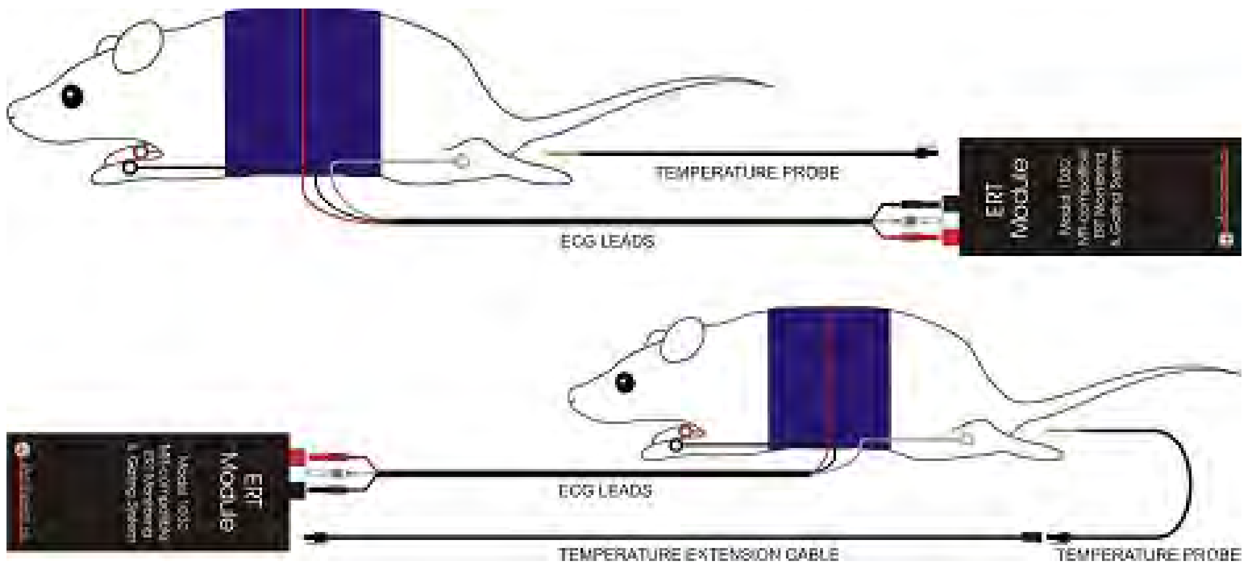
When a surface coil is used to image the liver or heart by positioning the coil under the animal's abdomen, an appropriate place for the E-resp™ cradle is around the spine. If a surface coil is used to image the spine, the cradle would be positioned from under the animal. When using a small whole-body coil, it may be necessary to connect the leads to both front legs or both rear legs keeping the lead wires out of the imaging coil.

E-resp™ without a cradle

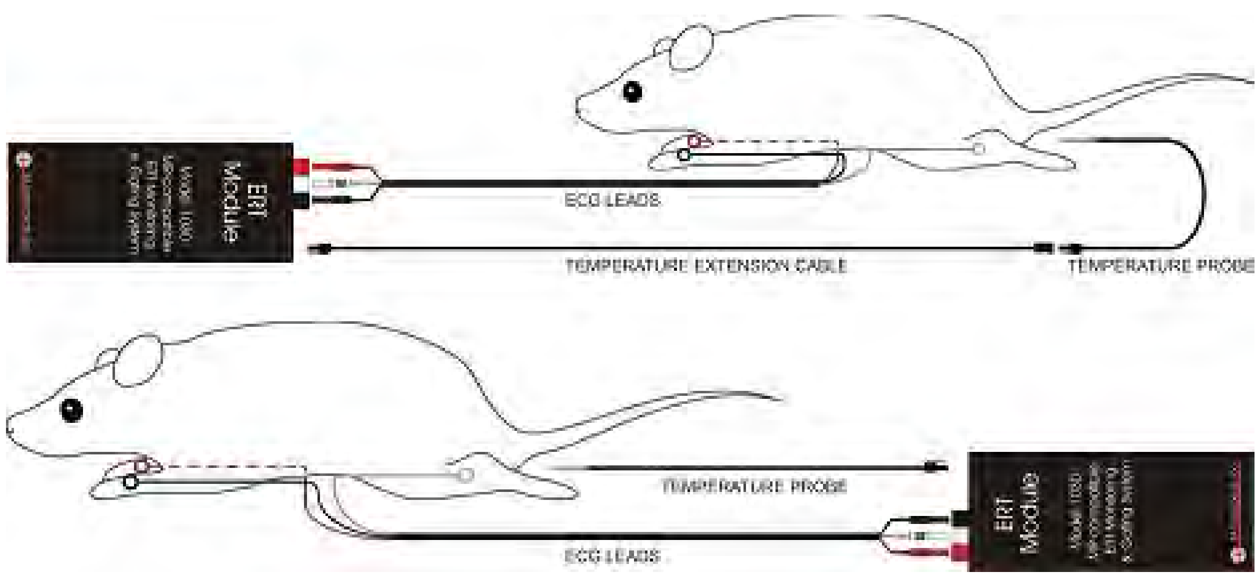
It is possible to obtain adequate coupling of an ECG lead wire to the animal's abdomen without the use of a cradle. The photo below shows a mouse without a cradle. In this case, an E-resp™ signal of 0.5 mVpp was obtained on a 9.4 T system.



With cradle



Without cradle



Attachment of the respiration pneumatic pillow sensor

Position the pneumatic pillow sensor near the animal's abdomen and secure it with tape as shown in the photograph. Attach the sensor's tube to the ERT Module at the Leur connection. It may be necessary to use one of the Respiration Extension Tubes to make the connection.

The respiration circuit incorporates an automatic gain stage that adjusts the amplitude of the respiration waveform within preset limits. After attaching the pillow, small respiratory signals may take a few seconds to gain up and produce respiration gates and a respiration rate.

The respiration waveform exhibits a negative peak during inspiration. The gating algorithm detects the negative peak and produces a respiration gate during the peak. To gate on expiration, check the "invert" box for respiration in the GATING SETUP window (refer to Chapter 3 and example waveforms in Appendix E).

Attaching the temperature probe

Use a lubricant or lubricated probe cover on the tip of the temperature probe before inserting it into the rectum. Secure the probe lead by taping it to the animal's tail. The temperature probe extension cable can be used when the ERT Module is near the animal's head. Clean the temperature probe with isopropyl alcohol.

Temperature probes are fragile and should be handled with care. The tip of the probe can be broken or cracked if the tip is bent. Problems with the temperature probe can occur if it develops a crack. Since the thermistor in the tip of the probe operates at 5 V and a break lets conductive fluid from the animal make contact with the thermistor wire, a small offset voltage can occur.

The offset voltage is displayed in the SYSTEM INFO window. It should be 2.5 V +/- 1.0 V for normal operation. If it goes close to 0 V or to 5 V the ECG will be flat lined by the software and a Lead Off error message will exist. An easy check to see if a large offset is due to the probe is to disconnect the probe from the ERT Module (no need to remove it from the animal). If disconnecting the probe removes the offset, the probe is at fault. In an emergency a faulty probe will work if placed in a plastic or rubber sleeve (e.g. a thermometer cover or finger from a rubber glove). The sleeve provides electrical isolation.

Positioning the thermistor temperature probe

The thermistor temperature probe will distort the magnetic field for a few mm around the tip creating a small signal void in the MR image. This artifact is normally only a problem when imaging near the rectum. In that case the probe can be used as a skin probe near the animal's head.

Under some conditions it is possible for the thermistor temperature probe to heat from interaction with the MR scanner's RF coil. Observation of the measured temperature will indicate if this happens. If a temperature rise is observed when the scanner begins to acquire data and the temperature decreases when the acquisition is complete, reposition the ECG/T Module, Battery Pack and cable. A position near the center line of the magnet bore is generally better than near the edge of the bore.

Charging the ERT Battery Pack

The ERT Battery Pack should be connected to the ERT battery charger when the system is not in use. The battery pack voltage is between 5.8 V and 6.5 V. A fully charged pack will operate for more than 30 hours when the battery is new. The battery pack voltage is displayed in the "System Info" window (refer to Chapter 3).

The ERT battery pack charger is internal to the ERT Control/Gating Module. An optional wall charger is also available. The battery pack will obtain a full charge in less than 5 hours. It is not necessary to deep discharge the battery or disconnect it from the charger after it is fully charged.

To obtain maximum battery life and performance:

- Recharge after each use
- Store in a charged state
- Store at room temperature or lower
- Recharge stored batteries every 9 months

ERT Battery Pack Protection Circuit

ERT Battery Packs have an internal protection circuit. The circuit opens to protect the battery if the battery voltage drops below a preset threshold. The circuit protects the battery from going into a deep discharge state. The circuit will activate in the event the battery is left connected to the ERT Module overnight.

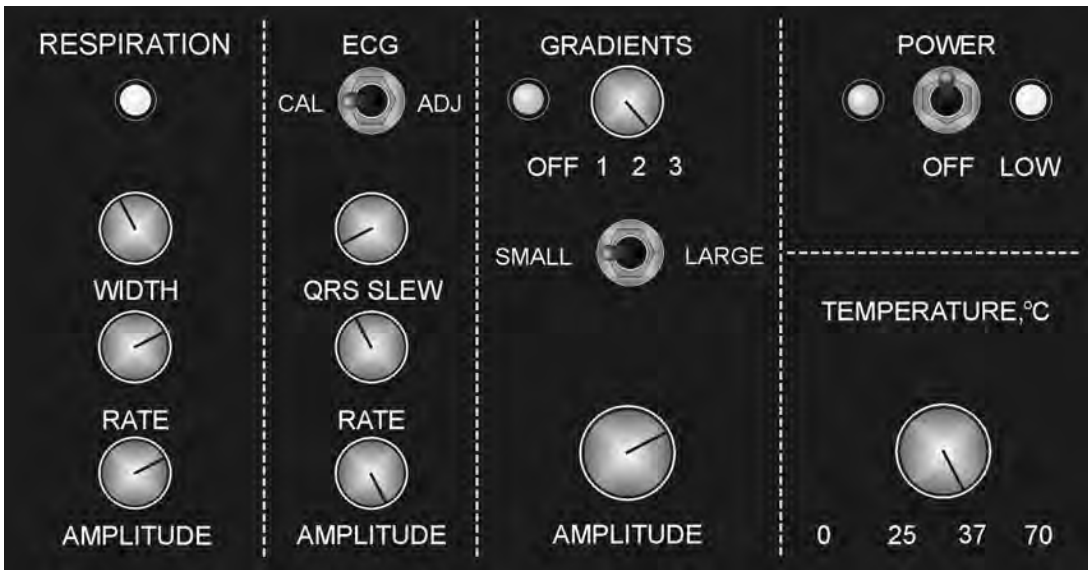
Setting the 50/60 Hz notch filter

The notch filter is selected for 50 or 60 Hz using a screw near the Battery Pack Cable connection. For 60 Hz remove the screw, for 50 Hz leave the screw in place. The filter setting is reported in PC-SAM's SYSYEM INFO window.

Chapter 5
Simulator

Overview

The simulator generates an ECG voltage waveform with respiration and gradient pulse interference superimposed. Connection to the ERT Module is from the simulator rear panel connections with simulator ECG leads to black, red and white labeled studs. The simulator also provides a reference temperature impedance. Connection to the ECG/Temperature module is from the rear panel with a simulator temperature cable to the labeled phono jack.



Simulator

Operation

The Simulator is powered by a 9V internal battery. The power switch on the front panel activates the ECG and Respiration waveform. Green LEDs flash with the heart QRS and with respiration. A yellow LED flashes when the internal battery is low. Separate controls are provided for ECG rate and amplitude and respiration rate and amplitude. In addition, the width of the respiration pulse can be controlled as can the slew rate for the rise and fall of the ECG waveform.

The Simulator controls allow settings as follows:

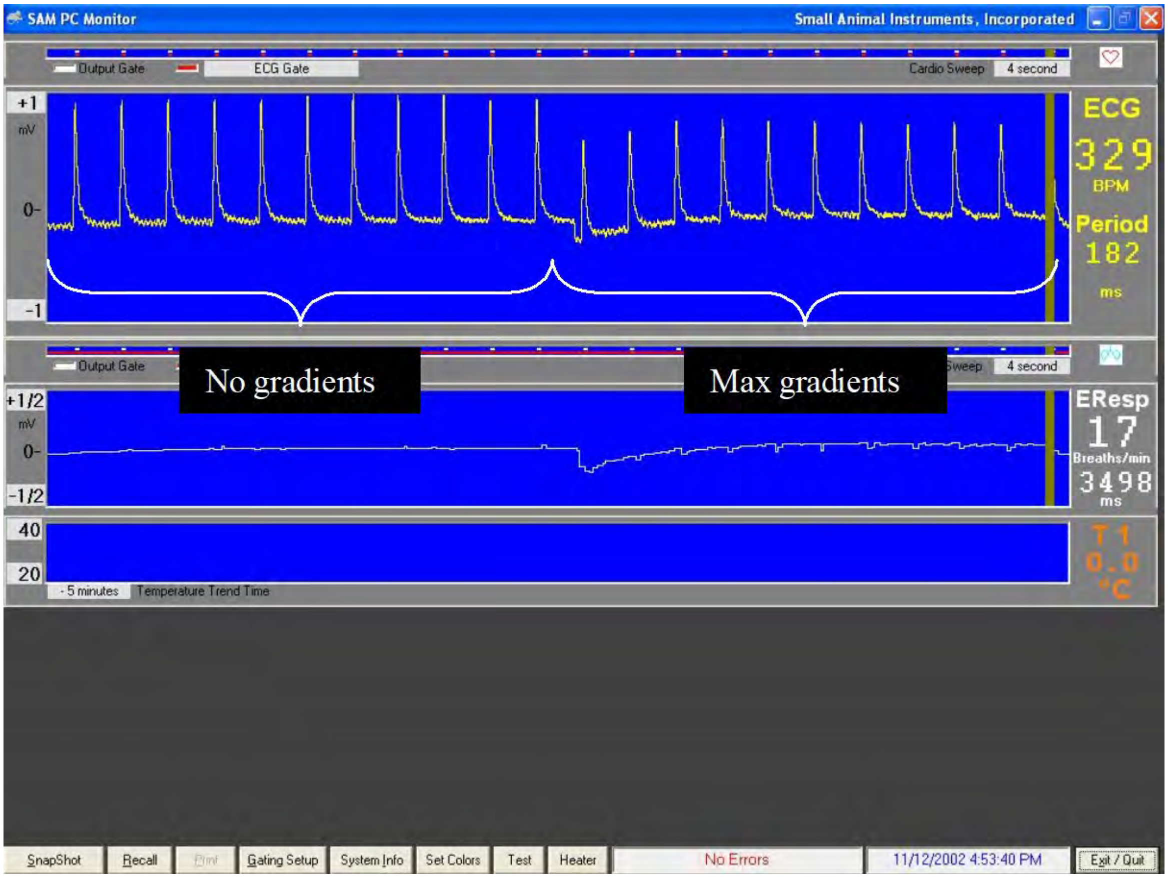
ECG rate:	30 - 700 beats per minute
ECG amplitude	0.25 - 2.5 mV
E-Resp rate	60 - 300 breaths per minute
E-Resp amplitude	0.0 - 0.50 mV
Temperature	0, 25, 37 and 70 °C

The ERT Module gives readings from the Simulator as follows:

0	3.0 ± 0.5
25	25.0 ± 0.2
37	37.0 ± 0.2
70	70.0 ± 0.5

Turning on the power switch to the gradients, superimposes gradient spikes on the ECG/respiration waveform. The gradient spike width and duty factor are controlled by a rotary switch with 3 positions while the spike amplitude is controlled by the amplitude knob and a small/large gradient switch.
The waveform shown on the next page was obtained with the switch at position 1 and maximum gradient amplitude. Note the lack of gradient interference on the ECG baseline, however the R-wave amplitude decreases by about 15% during maximum gradient activity.

The ECG CAL switch generates an 0.8 mV QRS complex at 200 beats per minute.



Battery replacement

The simulator is powered by a 9-volt battery. Replace the battery when the battery low indication illuminates. To replace the battery, remove two screws from the simulator case and remove the simulator top. Replace the screws to reattach the cover after replacing the battery.

Capnograph and ventilator option

Simulators can have, as an option, outputs to simulate a capnograph and a ventilator. In that case, in addition to ECG and temperature outputs the simulator will have the following connections and controls:

SYNC OUT	BNC	ventilator output for I/E ratio and respiration rate
SERIAL OUT	phono	ventilator output for tidal volume
CAP OUT	BNC	capnograph CO_2 waveform output
CAP AMPLITUDE	pot	single turn adjustment 0 – 10% CO_2
TIDAL VOLUME	pot	single turn adjustment 0 – 100 ml
CAL	switch	10% cal or normal
OUTPUT SCALE	switch	set CO_2 output scale to 0 – 1 V or 0 – 10 V

To use the simulator, connect the three outputs to the Capnograph/Ventilator Interface Module. Set the CAL switch to the normal position. Set the OUTPUT SCALE to agree with the input chosen on the Capnograph/Ventilator Interface Module.

The respiration rate is controlled from the respiration portion of the simulator. The respiration width control sets the I/E ratio. The other two parameters end-tidal CO_2 and tidal volume are set by the pots listed above.

Setting the CAL switch to the 10% CAL position will give a flat line at 10%.

Chapter 6
Air Heater System

Chapter 6
Air Heater System

Overview

The Air Heater System controls the temperature of small animals undergoing imaging procedures. Animal temperature is measured using a rectal thermistor or fiber optic probe. The software continuously processes temperature measurements and sends a control signal to the Heater Module. The control signal depends upon the measured temperature, the user selected set point and the control method. Mouse temperature variations of less than $\pm$0.1 ºC can typically be obtained during MR examination.

Heater components

The SAII Air Heater System consists of a Fan Module located in the low fringe field of the magnet and a Heater Module with “smart circuitry” located near the bore of the magnet. The Heater Module is RF shielded and non-magnetic. It is powered from 100, 115 or 230 VAC, 50 – 60 Hz. The Heater Module should be placed as close to the magnet bore as practical. It can be on the floor on a ladder or table or mounted in any convenient orientation. The optimum location will allow the 2 m air tube to supply warm air in the bore near the imaging volume. The Heater Module is controlled by the Control/Gating Module using a fiber optic cable connected to “Heater Control”. The fan and heater are connected to each other with a 7 m air hose.

If required, the Fan Module can be located inside the magnet room. In which case, the 7 m air hose can be shortened. To shorten the air hose, unscrew the cuff from one end and cut the hose with a knife.

> **Caution: The Fan Module contains small amounts of ferromagnetic components. It should be fix mounted if used in the RF shielded room or if it could inadvertently be moved into a region of large fringe magnetic field.**

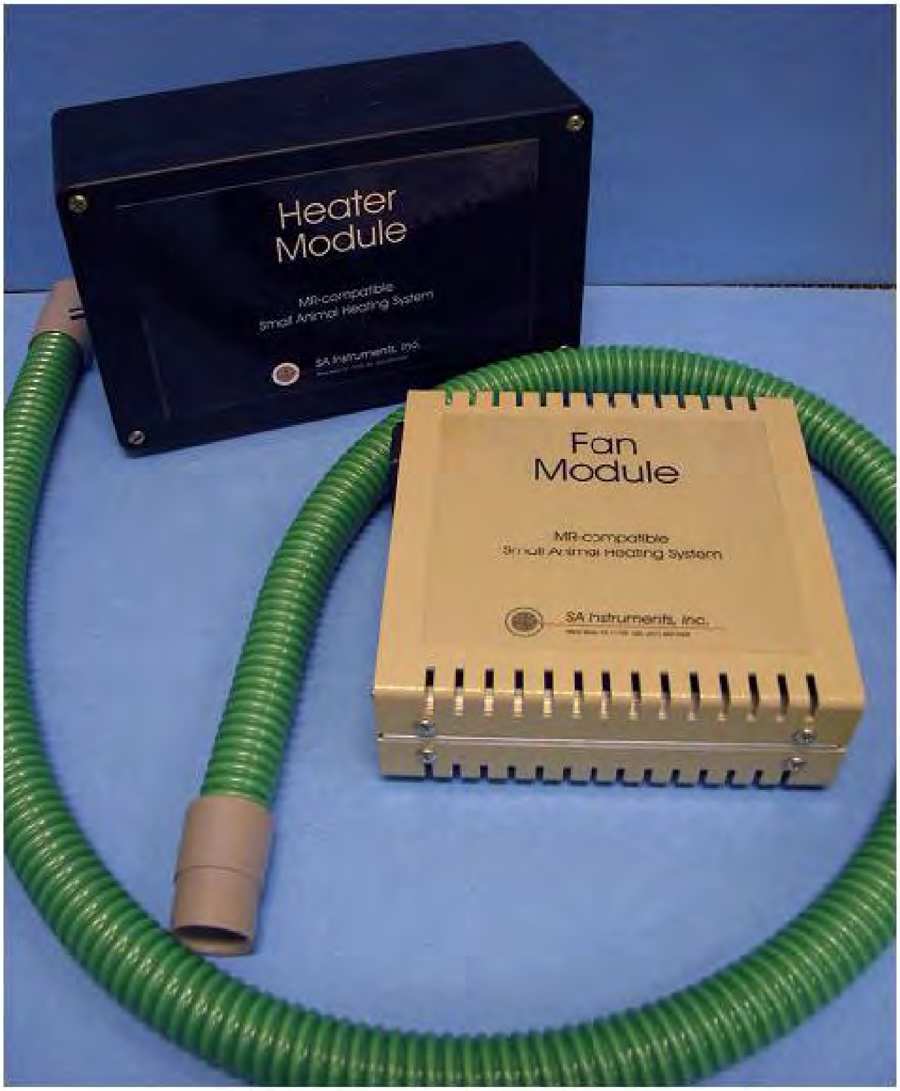
If power is not available in the magnet room, the Heater Module can be located outside the room with a longer air tube (up to 5 m) providing warm air to the bore. The longer tube will, however, somewhat degrade heater performance

It is important not to restrict the air flow coming from the Heater Module. Restricting the air flow by for example adapting smaller tubing can degrade system performance.

> **Caution: Do not restrict air flow from the Heater Module. Restricting air flow can reduce the amount of energy delivered into the bore and degrades performance.**

A Higher Output Fan Module is available as an option to increase the delivery of energy in cases where the setup necessarily restricts air flow. In that case contact SAII’s Customer Service.

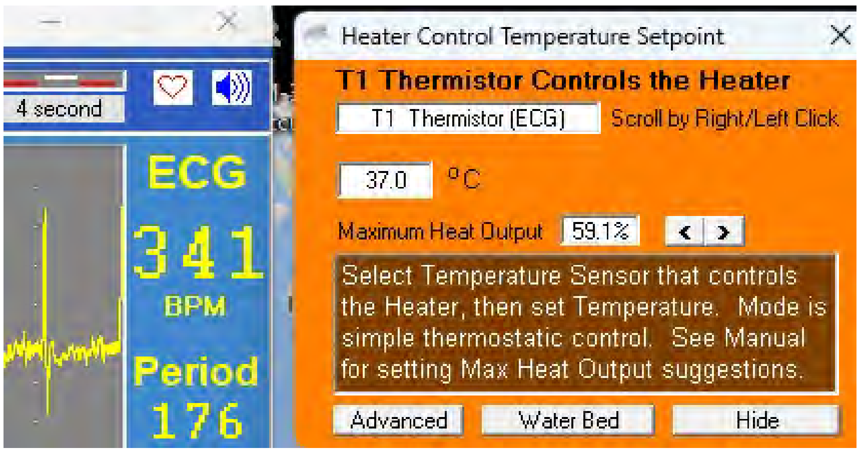
Air Heater System



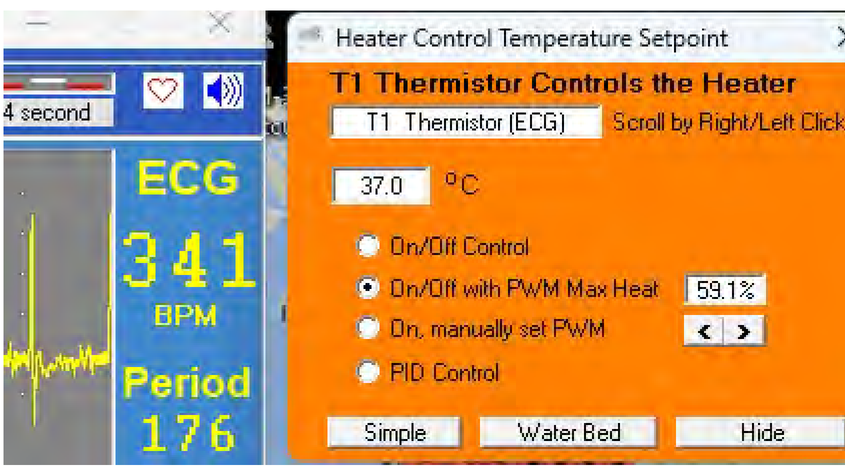
The hose cuff that connects to the warm air output of the Heater Module gets hot. To keep the cuff from melting, there is a copper ring positioned on the cuff as shown below.

Heater control

Clicking the Heater button at the bottom of the waveform display in PC-SAM opens the main HEATER window. The window can be used to select which temperature probe is to be used to control the heater (thermister or fiber optic), to enter the set point control value (usually around 37 ºC) and to set the maximum heat output (0 – 100%).



Clicking on the Advanced button opens the ADVANCED HEATER window shown below.



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PC-SAM software provides three methods for operating the heater: on/off control, on/off control with manual control of the duty factor and manual operation with manual control of the duty factor. The 4th option listed PID control is under development.

Selecting **on/off control** produces continuous light from the" Heater Control" port of either the ERT Control/Gating or Fiber Optic Temperature Module whenever the measured temperature is less than the user defined set point. Conversely the light from the "Heater Control" port is off whenever the measured temperature is greater than the set point. This method can be useful with external controllers and certain water bath heating systems. It will not provide control for the SAII Air Heater System.

Air Heater System

On/off control with manual control of the heater duty factor should be selected when using the SAII Air Heater System. Here, heater duty factor, PWM max heat and Maximum Heat Output all refer to the same setting.

When the mouse temperature is several degrees below the desired set point, the duty factor should be set near 100%. As the mouse temperature gets closer to the set point, reduce the duty factor (to near 50%) to prevent temperature overshoot. Once the measured temperature has reached the set point the system will turn on and off as required to hold the temperature at the set point.

Light used to control the heater is pulse width modulated (PWM). Selecting a small duty factor results in narrow light pulses which turns the heating element on for short time durations. A large PWM value results in wide light pulses and increased heat from the Heater Module.

Manual operation with manual control of the duty factor allows the Air Heater System to operate without regard for the measured temperature or the value of the set point. This method can be used to heat the local environment in the magnet bore before positioning the animal.

Heating the mouse

In the main HEATER window, select the temperature probe and set the set point. Position the tube from the Heater Module a few inches from the mouse. It may be necessary to insulate the environment around the animal from the magnet bore. Chilled water for gradient coil cooling may dramatically reduce the temperature of the bore. A plastic tube section, a plastic sandwich bag or foam can be used to funnel air from the heater around the animal. When using a plastic sandwich or larger bag, open both ends of the bag to allow air flow into and out of the bag.

Turn the Air Heater System on. Observe that the green power indicator is illuminated on the Heater Module. Also observe that the yellow heat indicator is intermittently flashing. If the heat indicator is not flashing check that the temperature measurement is lower than the set point (refer to Appendix C). Note that the control signal for the Heater Module will not be on if the temperature probe is not connected.

Set the duty factor based on the measured temperature of the mouse. If the mouse's temperature is more than 5 °C below the set point, use a duty factor of 100%. Observe the measured temperature of the mouse and decrease the duty factor to minimize overshoot. When the measured temperature reaches the set point, a duty factor of 50% or more should maintain the temperature within +/-0.1 °C.

Caution: The temperature at the end of the heater hose can be 55 °C or more. Do not position the hose closer than 4" to the mouse. Allow adequate air flow around the mouse.

The rectal probe can be used to check Air Heater System performance. Place the probe just inside the 2m warm air tube and set the set point high to 70 °C and the duty factor to 100%. The measured temperature on the monitor display should rapidly climb to 55 °C or more.

Chapter 7
Trends

Chapter 7
Trends

Overview

During operation, the Windows based PC-SAM software continuously logs data to a trend file located in a project folder. The data sample rate is once per second and more than 70 items are included in the recorded data point. The items include measured values of physiological functions (e.g. heart rate, temperature, etc) as well as status indicators of the hardware (e.g. battery voltage, offset voltage, etc.) The data file name and location are defined in the setup menu (refer to Chapter 3). The user has the option to save or discard the data when exiting the program.

To view data previously collected, execute the TrendMap program from the desktop. This program allows all or a subset of the data to be organized and output in a user defined format for import into a spread sheet program.

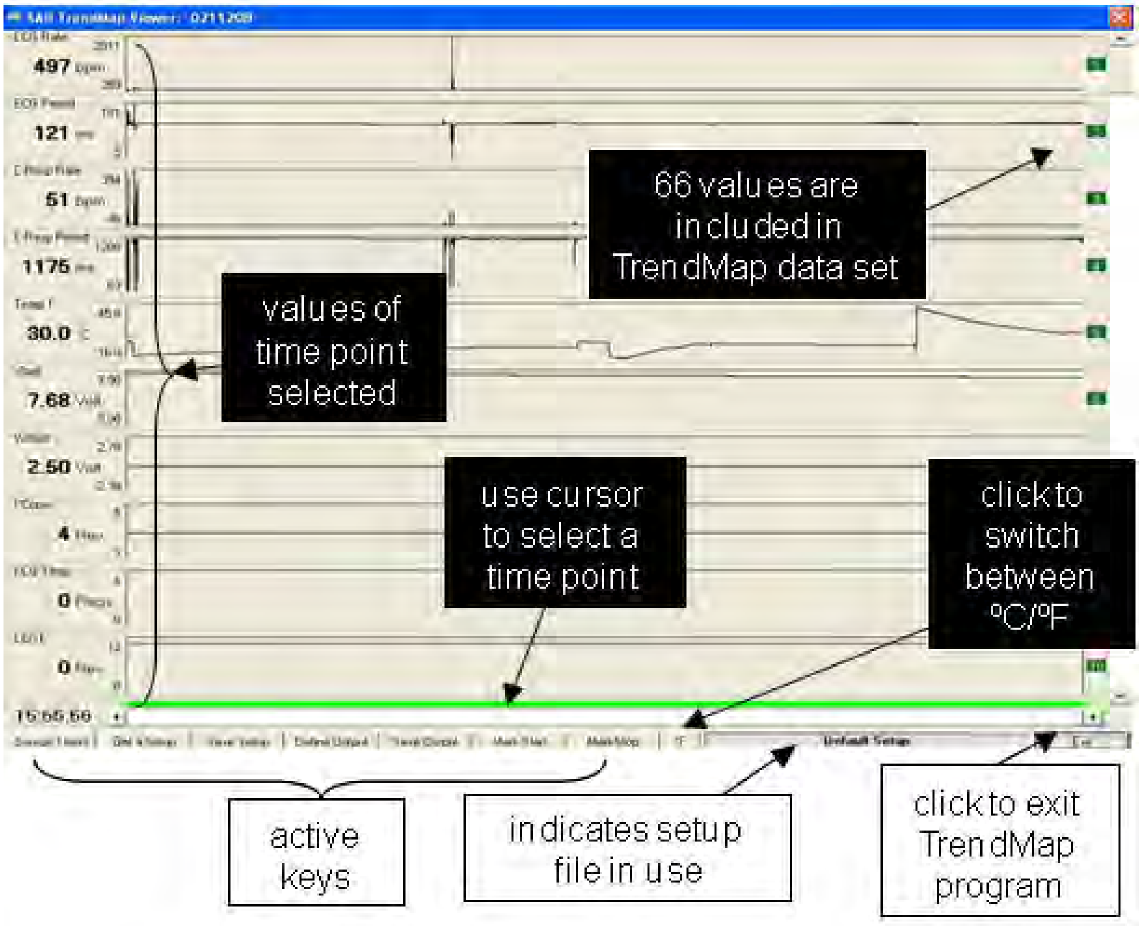
Provision exists to allow the user to configure the way the data is organized and viewed. Each new configuration can be saved as a setup file with the data set for recall later.

Events logged in PC-SAM are recorded in the trend file as item 64 and can be viewed with TrendMap. Also, AUX IN and Fiber Optic AUX IN are recorded in item 66.

TrendMap Viewer display

The TrendMap Viewer display is shown on the next page. More than 70 values are included in each TrendMap data set. A time cursor is displayed near the bottom and an item cursor is displayed on the right side of the display. Individual values are displayed on the left for the time point selected.

A subset of the trend data set is selected by the user for export. The exported data set is bound by a start and stop time and includes all trends up to one selected as the last to output. Commands exist to allow trend reordering before data is exported.



Several keys are located on the bottom of the display along with a message area. The following keys allow the data set to be retrieved, reconfigured and exported:

- Source Trend – opens a trend data file
- Get a Setup – opens a setup file for display of data
- Save a Setup – saves a setup file
- Define Output – specifies format for the exported data file
- Save Output – saves the exported data file
- Mark Start – selects the start time for data to be exported
- Mark Stop – selects the stop time for data to be exported
- ºC/ºF – toggle units for temperature measurements

In addition to the keys, a TREND ORDER ADJUSTMENT window is available to allow adjusting the order of trends in the data set. Click on any trend number on the right side of the TrendMap Viewer display to obtain the TREND ORDER ADJUSTMENT window.

A window for adjusting the displayed max/min of each trend data set is opened by clicking anywhere in the trend display

Source Trend key

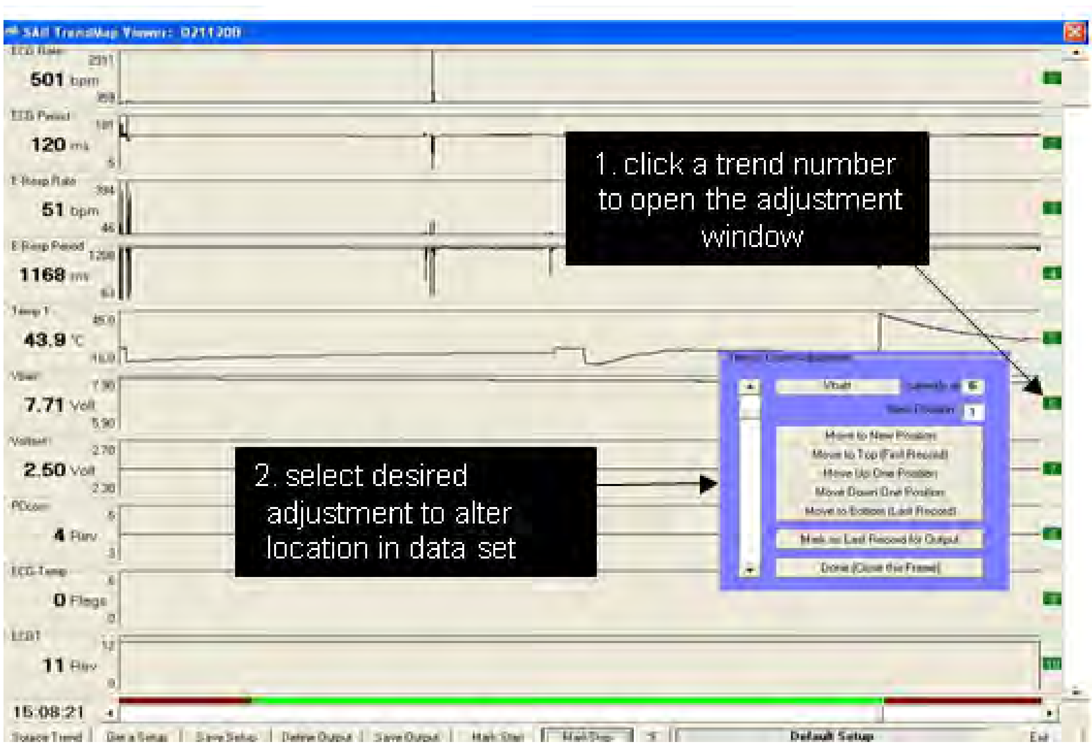
Clicking this key opens a window that allows selection of a trend data set. The window opens when TrendMap is executed or when the Source Trend key is clicked.

Get and Save Setup keys

These keys allow files which define the setup to be retrieved and saved. It can be useful after defining the order of trends in the data set (i.e. heart rate, temperature, respiration rate, time stamp events, etc.) and the output format to save the setup for future use.

TREND ORDER ADJUSTMENT window

Clicking any trend number opens the TREND ORDER ADJUSTMENT window. The scroll bar on the left of the window can select any trend location.



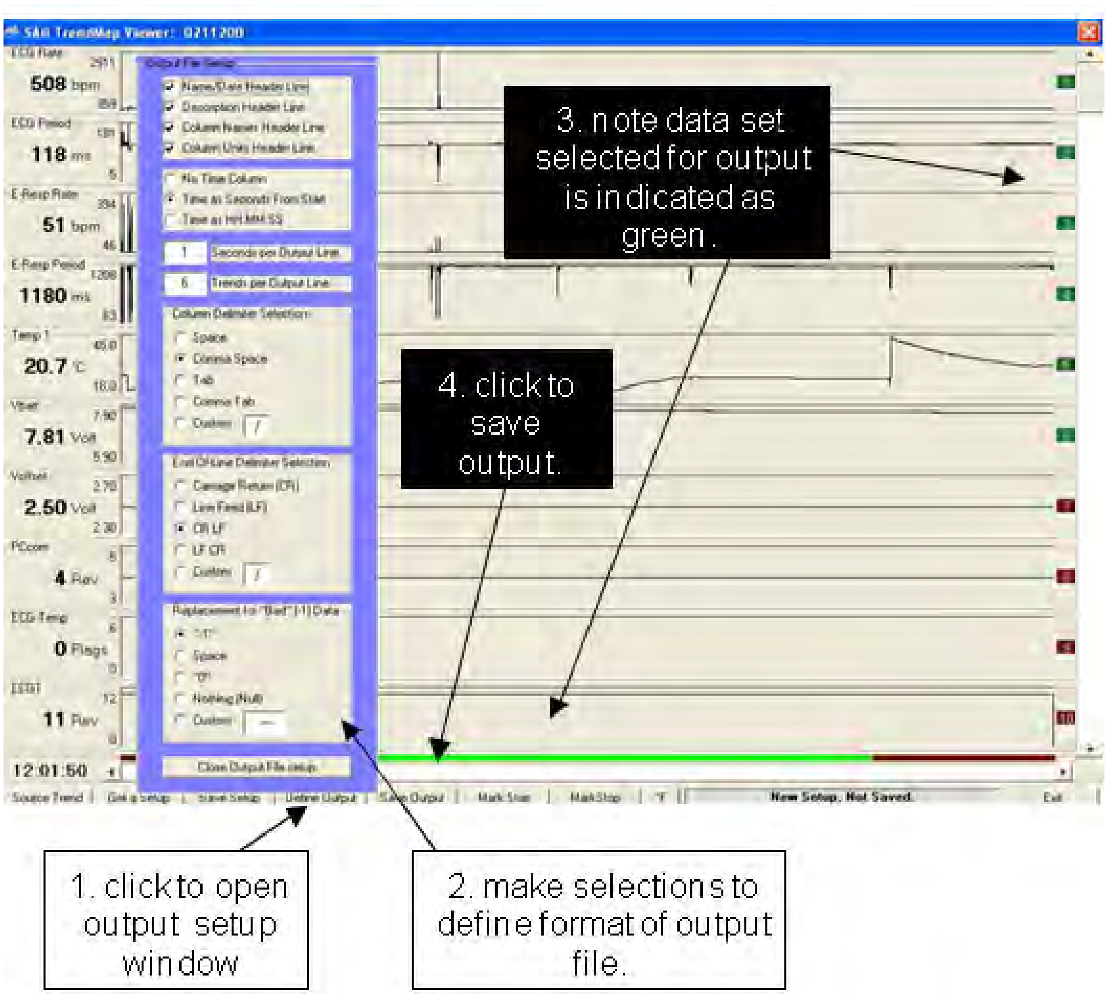
The trend selected is identified by name and current location number. Change the location of the selected trend by entering a new position number and clicking the Move to New Position key. Additional keys provide quick ways to move the trend up and down in the data set.

Clicking the “Mark as Last Record for Output” key defines the trends which will be included in the exported data set. The trends to be exported (number 1 through the last record) are indicated in green while all others are indicated in red.

Mark Start and Mark Stop keys

Mark Start and Mark Stop keys define the time portion of the exported data set. Select the beginning and end time points with the cursor as shown and click the keys.

Define Output key



The OUTPUT FILE SETUP window allows the following items to be defined for the exported data file:

Header information
Time column format
Seconds per output line
Trends per output line
Column and line delimiters
Number for bad data

The time exported can be as seconds from the start or actual time. Usually one second is output per line, but very large data sets may necessitate multiple seconds per output line. The number of trends per output line defaults automatically to the number selected for output. The most common choices for column and line delimiters are accommodated. Bad data which is set to “-1” in the trend file can be set to any other value.

Selecting events recorded in trend data

Events are recorded in the trend data file as item 64. An event selection key can be used to step through the events. A comment window displays comments entered for each event.

Trend data item list

The following table lists the items recorded in trend data.

Item #	Label	Unit	explanation
1	ECG rate	bpm	heart rate from ECG leads
2	Resp Rate	resp/m	respiration rate from the pneumatic pillow input
3	Temp 1	ºC or F	temperature from channel 1
4	SpO2	% Sat	oxygen saturation in % of hemoglobin
5	FOT1	ºC or F	temperature of fiber optic channel 1
6	BP3 Sys	mmHg	IBP channel 3 systolic pressure measurement
7	BP3 Dia	mmHg	IBP channel 3 diastolic pressure measurement
8	BP3 Mean	mmHg	IBP channel 3 mean pressure
9	EtCO2	mmHg	end tidal CO2 measurement
10	Insp CO2	mmHg	inspired CO2 measurement
11	FiO2	%	final inspired O2 measurement
12	E-resp rate	bpm	respiration rate from E-resp
13	ECG period	ms	R to R time interval from ECG leads
14	Resp Period	ms	respiration period from the pillow input
15	Ox Rate	bpm	heart rate from SpO2 waveform
16	Ox Period	ms	heart period from SpO2 waveform
17	BP3 rate	bpm	heart rate from IBP 3 measurement
18	BP3 period	ms	heart period from IBP3 measurement
19	CO2 rate	Resp/m	respiration rate from CO2 measurement
20	CO2 period	ms	respiration period from CO2 measurement
21	Vent period	ms	respiration period from the ventilator
22	Vent Insp time	ms	time of inspiration from the ventilator
23	Vent tidal vol	ml	tidal volume from the ventilator
24	E-resp period	ms	R to R time interval from E-resp
25	BP1 Sys	mmHg	IBP channel 1 systolic pressure measurement
26	BP1 Dia	mmHg	IBP channel 1 diastolic pressure measurement
27	BP1 Mean	mmHg	IBP channel 1 mean pressure
28	BP1 rate	bpm	heart rate from IBP 1 measurement
29	BP1 period	ms	heart period from IBP 1 measurement
30	BP2 Sys	mmHg	IBP channel 2 systolic pressure measurement
31	BP! Dia	mmHg	IBP channel 2 diastolic pressure measurement
32	BP2 Mean	mmHg	IBP channel 2 mean pressure
33	BP2 rate	bpm	heart rate from IBP 2 measurement
34	BP2 period	ms	heart period from IBP 2 measurement
35	FOT2	ºC or F	temperature of fiber optic channel 2
36	FOT3	ºC or F	temperature of fiber optic channel 3
37	FOT4	ºC or F	temperature of fiber optic channel 4
38	USER Rate	cpm	rate from USER Resp channel

Item #	Label	Unit	explanation
39	USER Period	ms	period from USER Resp channel
40	Pambient	mmHg	ambient barometric pressure
41	Temp; 2	ºC or F	temperature from channel 2
42	Event	text	users text message input
43	Vbatt	volts	battery voltage of ERT Battery Pack
44	Voffset	volts	offset voltage of ECG leads measurement
45	Chg Vplus	volts	Respiration Module's operating voltage
46	Chg Vbint	Volts	voltage for the Resp Module's internal battery
47	Chg Vbext	Volts	voltage for an external battery being charged
48	Chg Ipwm	mA	charging current for an external battery
49	Resp Gain	number	auto gain setting for the respiration channel
50	USER Gain	number	gain setting from USER Resp channel
51	Ox Monitor	level	auto gain level for oximeter measurement
52	ECGT	Rev #	ECGT software revision number
53	ETGate	Rev #	ETGate software revision number
54	PCcom	Rev #	PC com software revision number
55	RFcom	Rev #	RFcom software revision number
56	Resp	Rev #	respiration software revision number
57	Oximeter	Rev #	oximeter software revision number
58	FOT Rev	Rev #	Fiber Optic Temperature Module software rev
59	IBP	Rev #	IBP software revision number
60	Chg Rev	Rev #	battery charger software revision number
61	capnograph	Rev #	capnograph software revision number
62	Vent Rev	Rev #	ventilator software revision number
63	CVcom	Rev #	Capno/ventilator software revision number
64	POX Rev	Rev #	oximeter software revision number
65	FOT Rev	Rev #	fiber optic temp software revision number
66	ECG-Temp	flags	proprietary data for service
67	Resp	flags	proprietary data for service
68	Oximeter	flags	proprietary data for service
69	FOT Flags	flags	proprietary data for service
70	IBP	flags	proprietary data for service
71	Chg Flags	flags	proprietary data for service
72	Capno/vent	flags	proprietary data for service
73	Aux/FO in	flags	proprietary data for service
74	PCcom	flags	proprietary data for service
75	Number FOTs	number	number of fiber optic temperature channels
76	Plet signal	number	signal strength from the Oximeter Module

Note that as of the date of this manual, location 41 is not active. This locations has been reserved for future implementation of a second channel of thermister temperature.

Chapter 8
SnapView

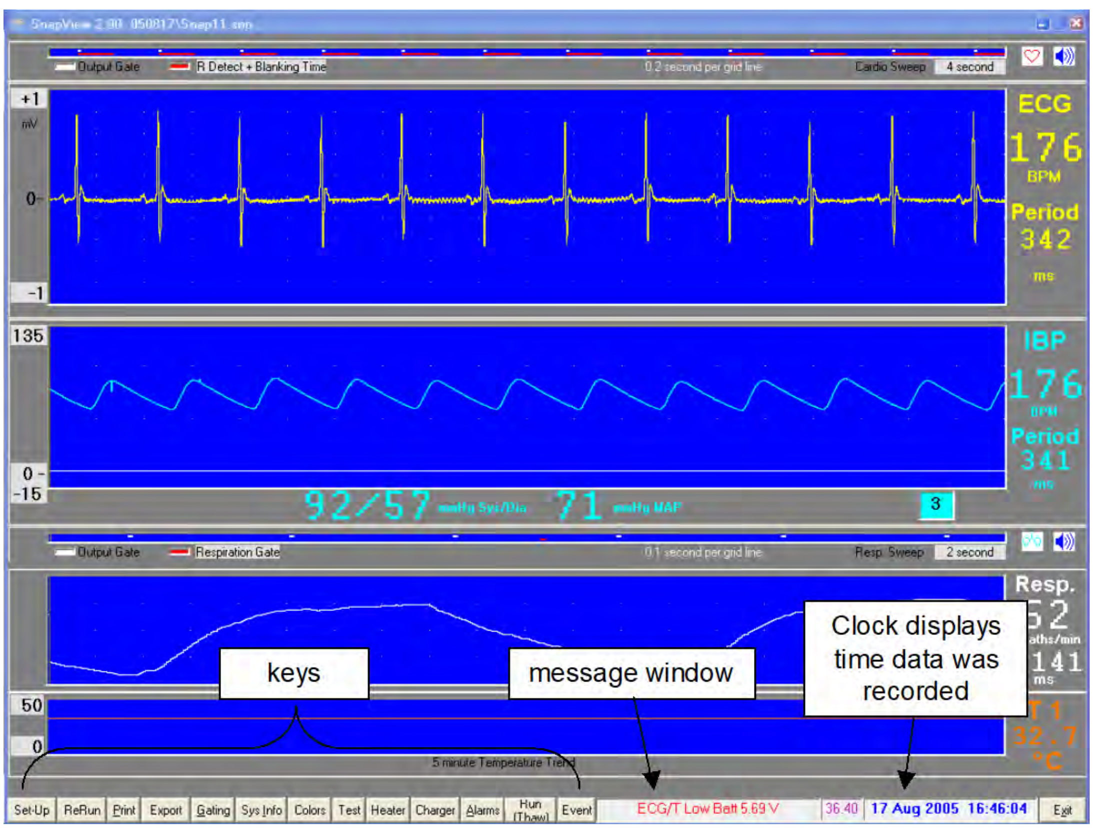
Overview

SnapShot data files record all measured data for a short time interval. The SnapShot key is located in the lower left portion of PC-SAM's main display. Clicking the key causes storage of the last 36 seconds of all measured data.

SnapShot data files are viewed with SnapView. SnapView is embedded in PC-SAM beginning with version 7. In this case, when PC-SAM is opened an option is available to execute SnapView. For earlier versions of PC-SAM, SnapView is executed by clicking on an icon on the desktop.

Most features available in PC-SAM are also available in SnapView. For example, sweep rates and amplitudes can be adjusted while viewing the files and the keys are active to display windows with associated parameter values.

SnapView display

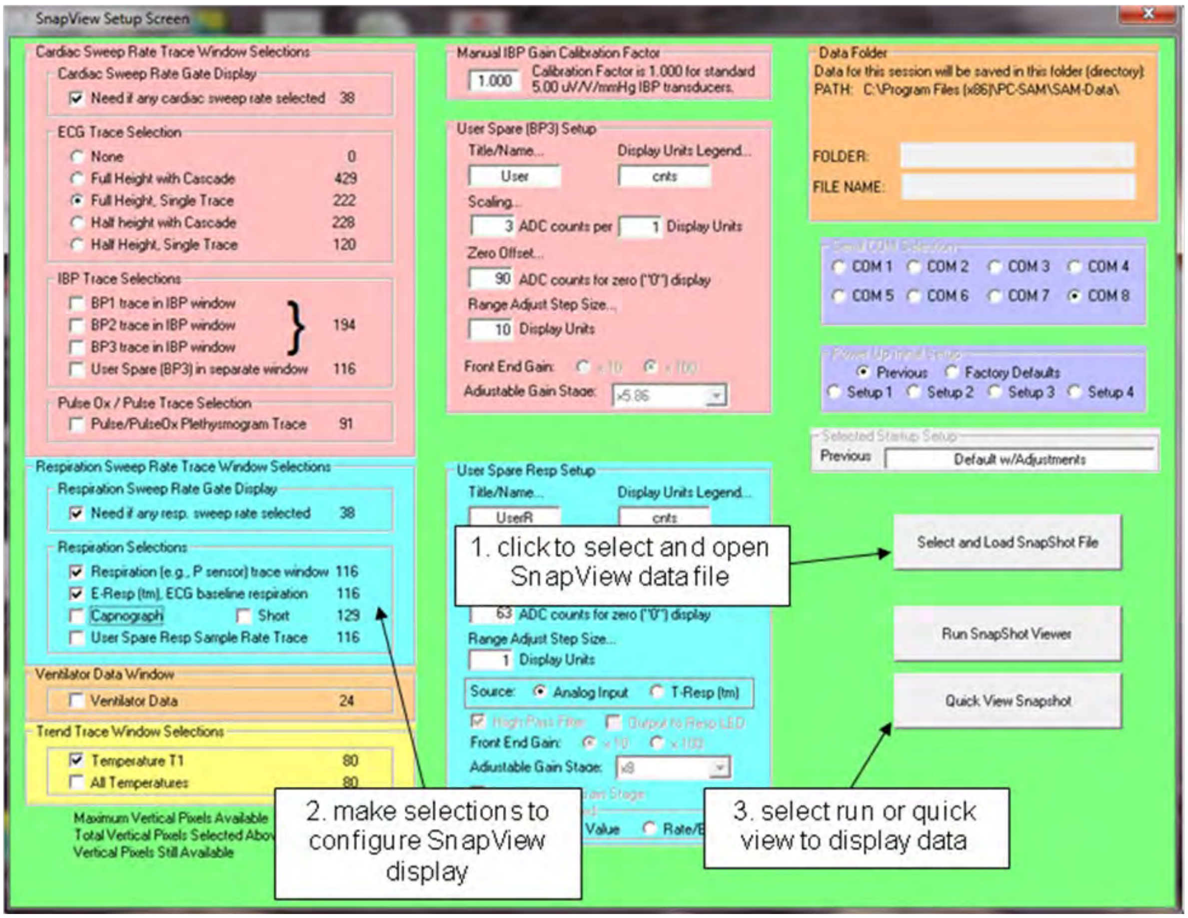


The SnapView main display is very similar to the monitor display of PC-SAM. Most keys perform the same function as in PC-SAM. The only differences are the Setup, ReRun, Print and Export keys.

SnapView

SETUP window

The SETUP window is displayed when SnapView is executed or when the Set-Up key is clicked. First select and open a SnapView data file, then make any desired changes to the display configuration before displaying SnapView data.



Two keys for data display are available: Run SnapShot Viewer and Quick View SnapShot. The Run key plays back the entire 36 second data set before freezing the display waveforms with the most recent data. The Quick View key plays back 1 second of data before freezing the display waveforms with the most recent data.

ReRun key

Click the ReRun key on the SnapView display to play back the 36 second data set.

Print key

The print key will print a frozen display. The desired printer should be selected as the default printer and the paper orientation should be set to landscape before running SnapView.

Export key

The Export key allow SnapView's raw data to be exported. This feature can be useful in the event wave shapes or features need to be analyzed offline.

Keying the EXPORT key opens an export setup window with preset parameters. The user can modify the parameters and make measurement selections before exporting the data to a .txt file. Up to 32766 lines of 19 items comma delimited can be exported to a .txt file. Each text line starts with a time sample number (0-32766) followed by a raw data count for the measurements selected.

If SnapView is at the end of displaying the data set and EXPORT is keyed, then the export routine is setup to dump the entire data set. The resulting file when opened and saved by Excel will be about 4.6 Mbytes.

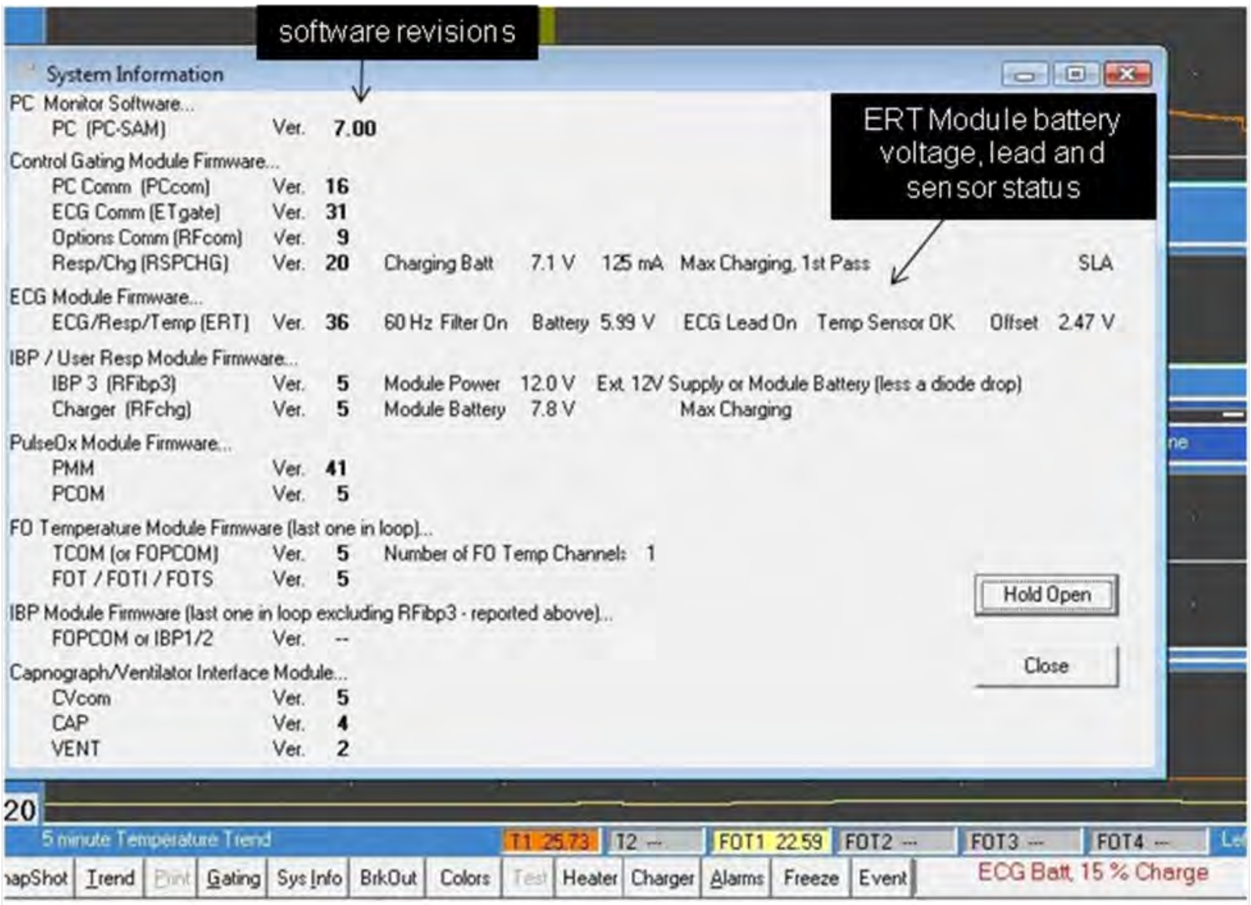
If SnapView is running (or FROZEN) and EXPORT is keyed the export parameters are setup to output data from the beginning of the data set up to the current (or frozen) time point. Note the time counter SS: HH (seconds: hundredths of seconds) displays the time of the data set from 0 to 36.4 seconds.

Chapter 9
Additional Features

Chapter 9 Additional Features

SYSTEM INFORMATION window

The SYSTEM INFORMATION window lists software revisions, current status for the ERT Module and other useful information. The window will automatically close after several seconds. Click the “Hold Open” button to keep the window visible.



ERT Module status includes the 50Hz/60Hz notch filter setting, battery voltage, ECG and temperature lead status and offset voltage.

The ERT Module operates on 5 VDC. But to display both positive and negative signals the zero point is offset to 2.5V. Any additional offset appears in this measurement and can affect the ECG. If the offset gets too close to zero or 5V, the software flat lines the ECG waveform and issues a lead off warning. The offset can deviate from 2.5V if needle electrodes are inserted in animal’s muscle or if the temperature probe is defective (refer to Chapter 4).

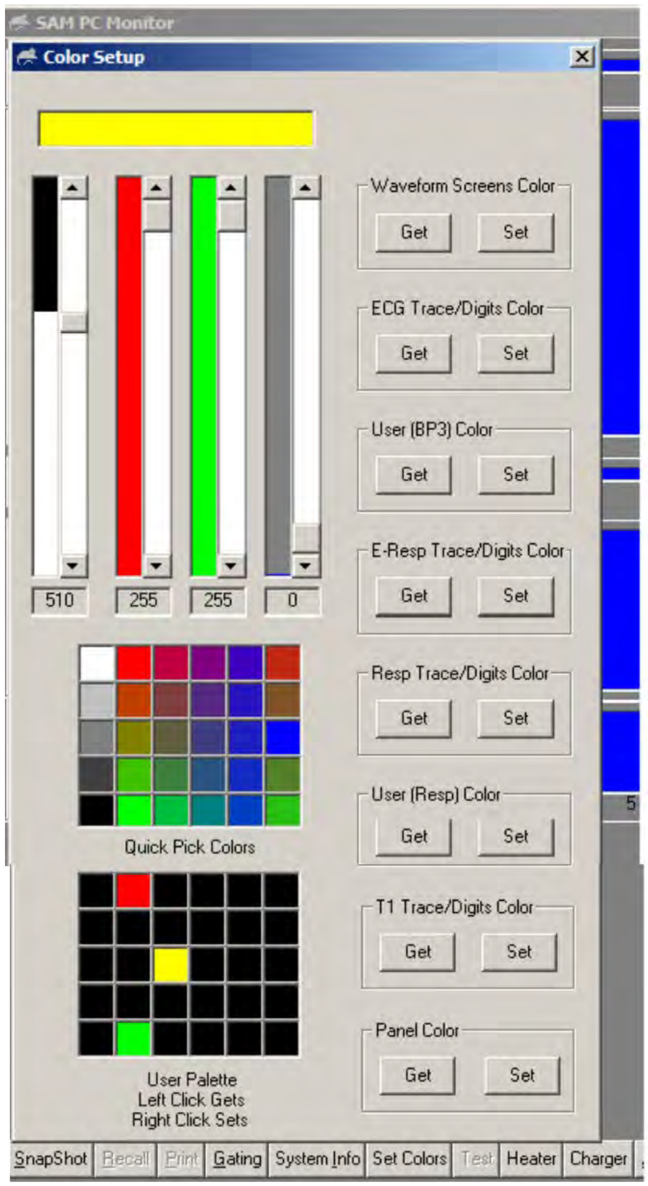
The IBP Module status includes the modules power source (12V or internal battery) and status of the internal battery charger.

Additional Features

SET COLORS window

The SET COLORS window allows selection of colors for regions of the display and for waveforms and digits.

The set button sets the current color for the region or waveform selected. Colors can be

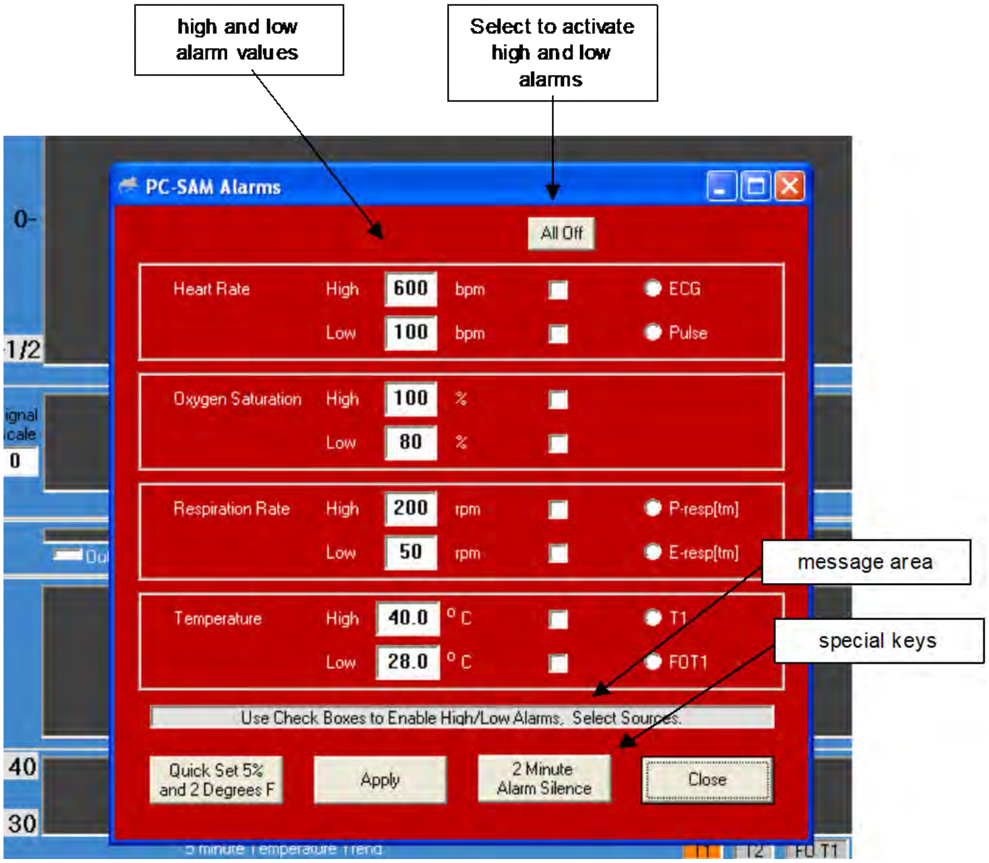


selected from Quick Pick or made from combinations of red, green and blue in the upper left of the window. Once colors have been constructed, they can be stored in the User Palette. Right click sets and left click gets.

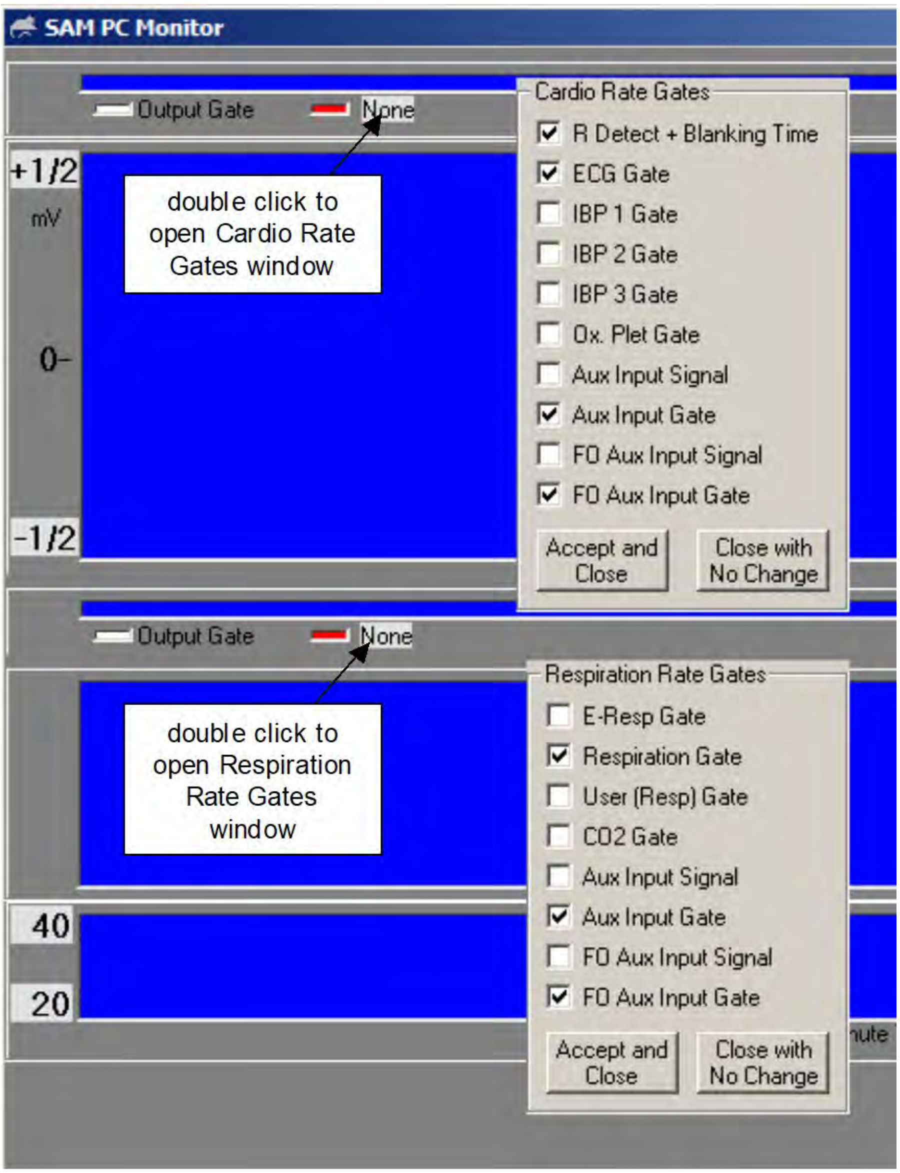
ALARMS window

The ALARMS window allows high and low alarm limits to be set for heart rate, oxygen saturation, respiration rate and/or temperature. A check mark next to an alarm limit followed by clicking the Apply key will activate the alarm. When the measured value meets or exceeds the limit, an audible alarm sounds.

The window has an area for messages and keys for Quick Set Alarms and Alarm Silence. The Quick Set key provides a convenient way to quickly set all alarm limits. Clicking the Quick Set key sets the high and low alarm limits 5% above and below the current measurement for heart rate, oxygen saturation and respiration rate and 2 ºF above and below the current temperature measurement.



Cardiac and respiratory sweep gates



Double clicking on the gray panel area of the cardio sweep display will open a window to allow other gates to be added to the selection list.

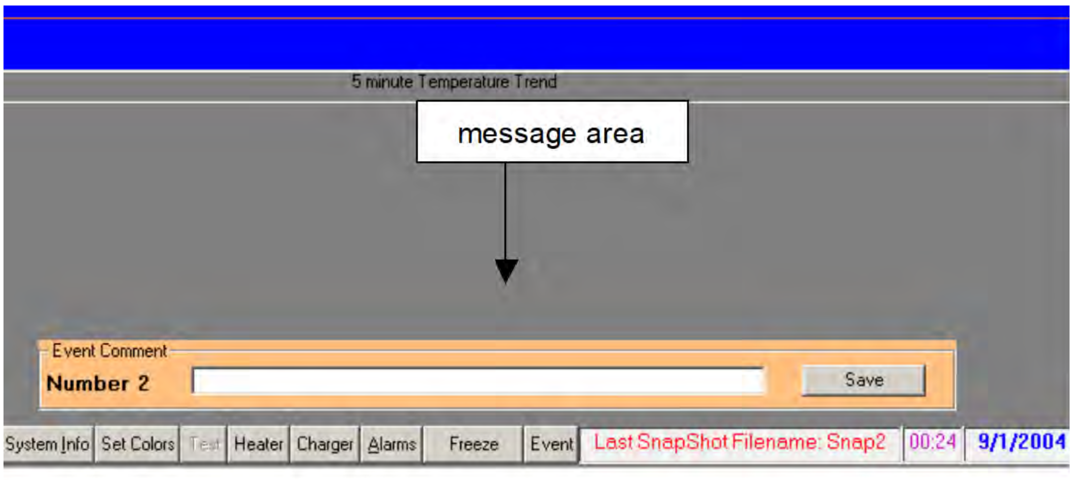
An indicator can be added to the ECG waveform to display timing of the selected cardio rate gate or the output gate by clicking on the colored box to the left of the cardio rate gate selection.

The respiration sweep display operates in a similar way to that on the cardio sweep display. Be certain the gate selected for display matches the waveform. For example, if E-Resp™ is the waveform displayed for respiration, the selected gate should be E-Resp gate not Resp gate or User Resp gate.

FREEZE THAW key

The key freezes the waveform display. Pressing the key a second time restarts the waveform display.

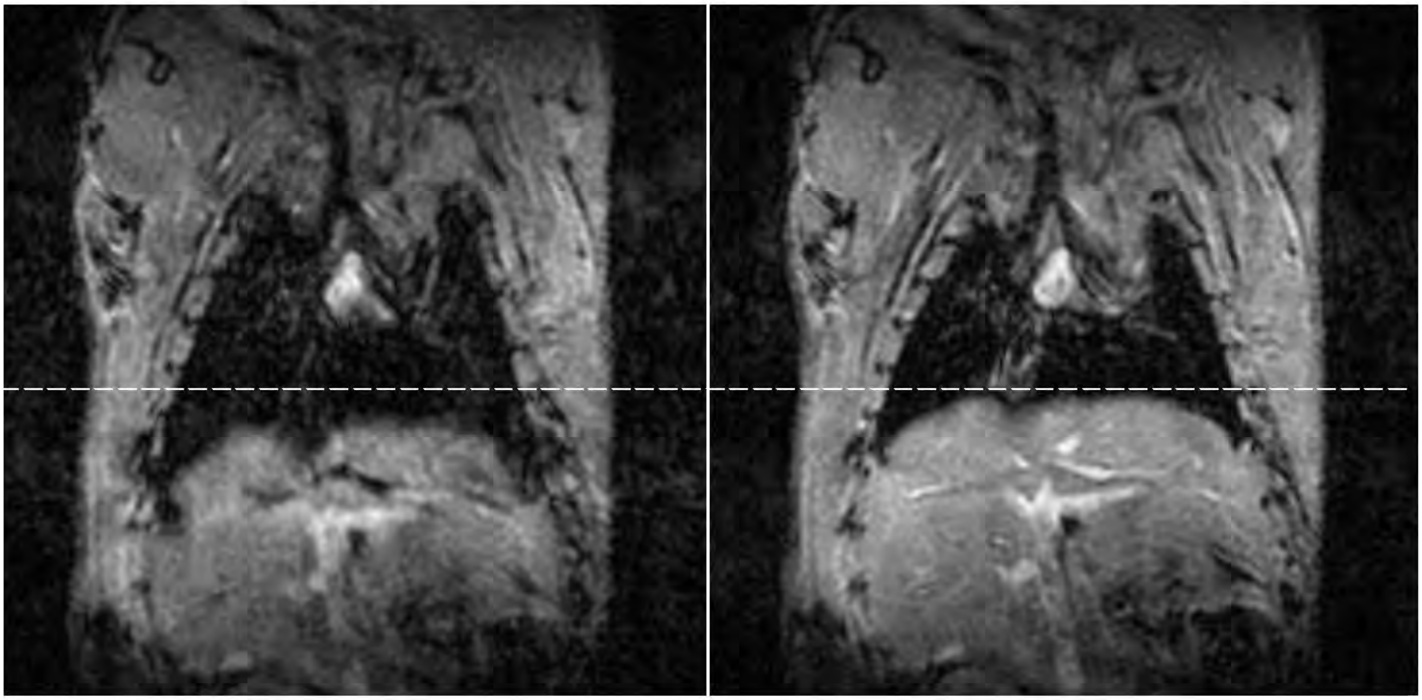
EVENT key



Pressing (left clicking) the event key causes an event to be logged in the trend file at the time the event key is pressed.

Each event is given a number in sequence beginning with one for each monitoring session. Upon pressing the Event key, a window opens and a comment can be entered and saved. The event number, time and comment are logged in the trend data and can be viewed with TrendMap.

Chapter 10
Invasive Blood Pressure



inspiration expiration

Mouse abdomen

4.7 T horizontal
ECG and respiratory gated

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Chapter 10
Invasive Blood Pressure

Overview

The IBP Module measures invasive blood pressure using a blood pressure transducer connected with tubing to an invasive line in the animal. System design accommodates up to three IBP channels with one channel designated as IBP3 incorporated in the IBP Module. The other two IBP channels (IBP1 & IBP2) are either incorporated into the IBP Module or they are battery-powered modules which daisy chain with simplex fiber optic cables from IBP3. The IBP Module has two auxiliary inputs to allow the user to input event markers or acquire, record, display and gate from user generated analog waveforms.

The module has bi-directional fiber optic communication to the ERT Control/Gating Module and is powered from a 12 VDC external supply or by internal battery.

Caution: the 12 VDC power supply is slightly magnetic and should be fix mounted in the magnet fringe field.

Fiber optic communication cable connections

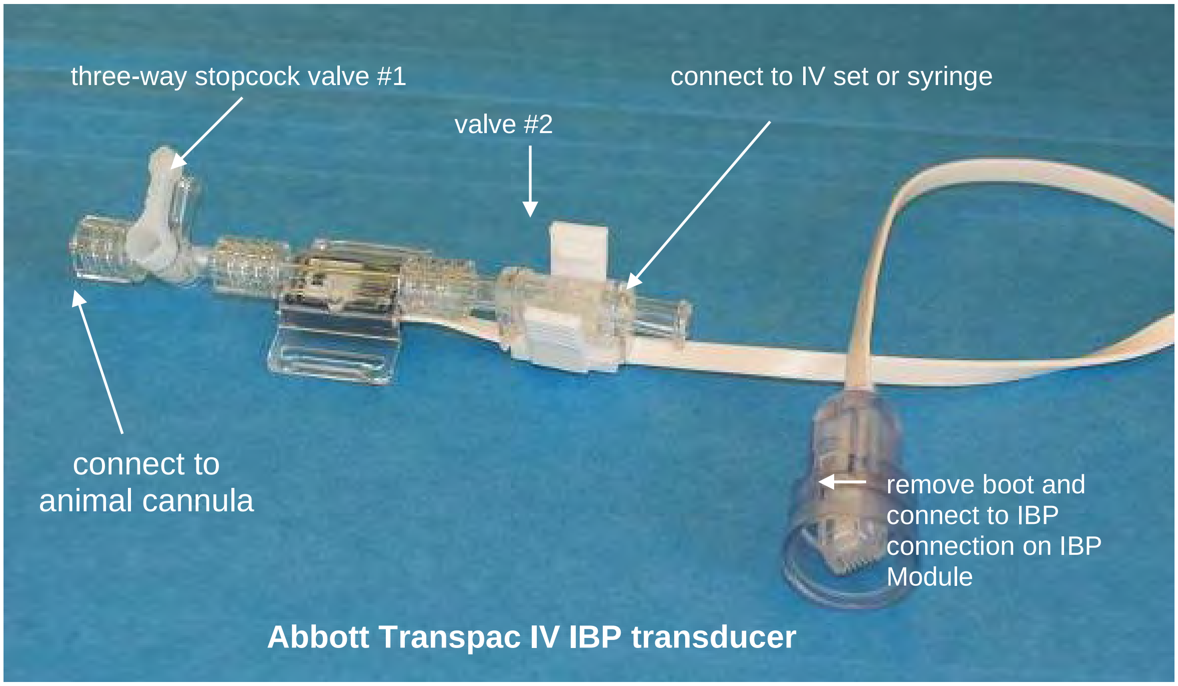
When the IBP Module is the only optional module, it connects to the ERT Control/Gating Module using a duplex fiber optic cable. The cable should be connected to the fiber optic ports labeled “option in” and “option out” and if an options I/O switch is present it should be set to “options in use”. When other optional modules are also present, the modules connect to form a data loop with one of the duplex fibers connecting to the 1st optional module and the other of the duplex fibers connecting to the last optional module. The modules are then connected to each other using short simplex fiber optic cables.

The fiber optic cables have blue and grey connectors. The driver and receiver ports are also blue and gray. The order of the modules in the data loop is not important. But, in all cases the color of the connector must match the color of the port
.

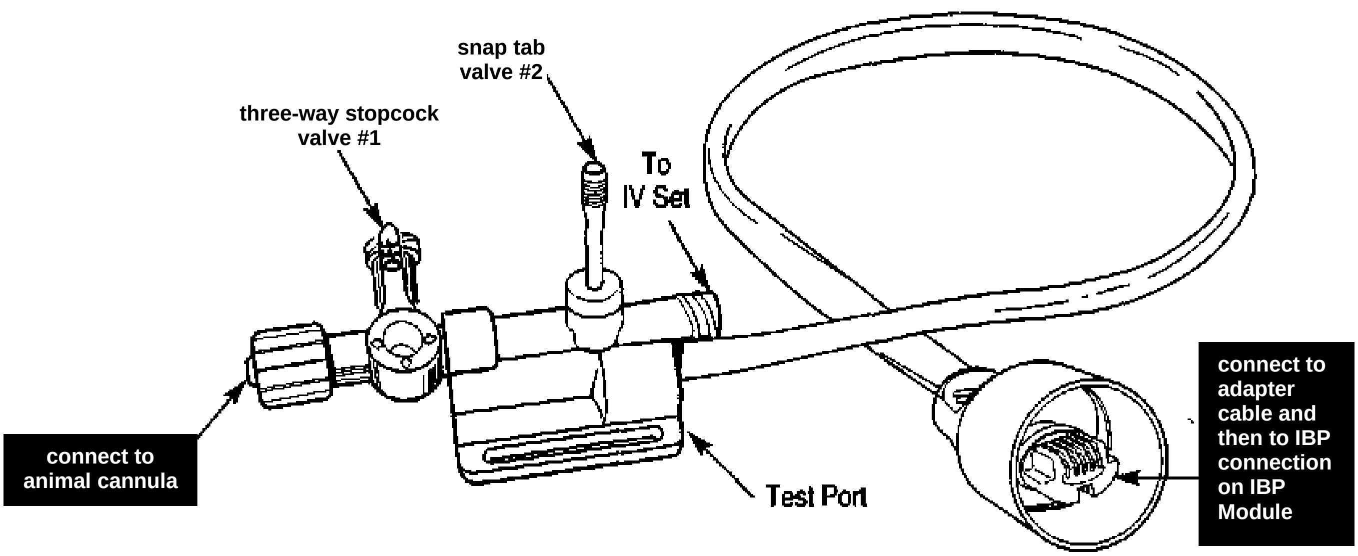
IBP transducers

The IBP Module is configured to operate using disposable invasive blood pressure transducers which meet the specification of 5µV/V/mmHg. The following IBP transducers meet this specification and can be used with the Model 1030.

Transducer name	Manufacturer contact information
Abbott Critical Care Systems Transpac IV	Hospira, Inc. Lake Forest, IL 60045 (877) 946-7747, www.hospira.com
Baxter Edwards TruWave	Baxter/Edwards Lifesciences, LLC One Edwards Way Irvine, CA 92614 (949) 250-2500, www.edwards.com
Utah Medical Deltran IV	Utah Medical Products, Inc. 7043 South 300 West Midvale, UT 84047 (801) 566-1200, www.utahmed.com
Becton Dickinson Gabarith PMSET 1DT-XX	Becton Dickinson 1 Becton Drive Franklin Lakes, NJ 07417 (201) 847-6800
Braun Exadyn-Combitrans	B. Braun Carl-Braun-Strasse 1 D-34212 Melsungen Germany +49 5661710



The Abbott Transpac IV transducer can be connected directly to the IBP Module at the IBP connection. If the transducer connector has a protective boot around it, remove the boot. The connection snaps into the receptacle and locks with the locking clip.



Invasive blood pressure transducers from other manufacturers can also be used with the system. However, an adapter cable will be required. Adapter cables can be obtained by contacting SAII Customer Service.

IBP transducers have an electrical connection (for the IBP Module), three fluid connections (for the animal, syringe and/or IV set) and two valves. A very small piezoelectric pressure sensor is located in the fluid pathway between the two valves. Pressure changes caused by the animal's blood in the tubing are converted to electrical signals by the transducer for display on the monitor.

Each manufacturer of IBP transducers provides detailed instructions for use. Please refer to those instructions for information in addition to that given below.

Transducer valves

IBP transducers have two valves: a three-position stopcock (valve #1) and a normally closed valve (valve #2).

The three-position stopcock valve makes a connection between two of the three ports while blocking the third. The stopcock lever can be rotated to select which port is blocked.

The second valve is a normally closed flow through valve. Action by the operator is required to open the valve. In the case of the Abbott Transpac IV, pressing the plastic tabs between the thumb and fore finger will open the valve. In the case of the Baxter Edwards TruWave transducer, pulling the snap tab opens the valve. Note the IBP transducer manufacturer's instructions should be followed in the event the port attached to valve #2 is to be connected to an IV set for fluid delivery to the animal.

Animal cannula

A cannula inserted in the animal's vessel will allow blood to enter the blood pressure

tubing. Cannulas can be constructed in a number of ways using needles, tubing and Leur connectors.

A simple cannula can be made using PE50 tubing and a Leur stub (Harvard Apparatus part number NP 72-4439 www.harvardapparatus.com). The Leur stub has a female Leur connection on one end and a short 22 gage metal stub on the other end. The metal stub can be inserted into one end of a length of PE50 tubing to fabricate the cannula.

When using the IBP function in the MR environment, make certain the tubing is no longer than necessary to extend from the animal in the bore to the IBP transducer location at the entrance of the bore, typically 1 to 1.5 m.

Flushing the IBP transducer and cannula

Before insertion of the cannula in the animal, the IBP transducer and cannula must be flushed and filled with heparinized saline. The tube and cannula must be completely filled with fluid (i.e. no air bubbles). Failure to eliminate entrapped air can result in inaccurate blood pressure readings due to the compressibility of air.

Flush the transducer and cannula by connecting a syringe or elevated IV bag to the port at valve #2. Opening valve #2 allows fluid to pass through and out the end of the cannula. Air bubbles can be eliminated by raising or lowering and tapping on the tubing. Note the three-way stopcock should be positioned to block the port with no connection (open to air).

Making blood pressure measurements

The following steps to make IBP measurements should be integrated with animal handling and aseptic protocols established for your facility:

Connect the transducer with cannula to the IBP port on the IBP Module. If necessary, use an adapter cable to make the connection. Select the IBP3 option in the monitor's SETUP MENU. A flat waveform should be present on the IBP portion of the monitor's display. The IBP waveform amplitude should change in response to pressure variations on the transducer.

Flush the transducer and cannula with heparinized saline solution. Remove all air bubbles.

When using the transducer in the MR environment, it should be constrained from moving in the magnet's fringe magnetic field. After positioning the IBP Module near the entrance to the magnet bore, tape the transducer to the canopy or bed near the entrance to the bore. Position the transducer at the level of the animal to maximize accuracy of Blood pressure measurements. Transducer offset changes with the magnetic field, so after securing the transducer it should be zeroed. Check to make certain air bubbles were not introduced.

Establish an invasive line in the animal by inserting the cannula according to the surgical protocol for your facility. Add additional heparinized saline if necessary to position the blood saline interface between the animal and the transducer. Repeat as necessary to keep blood from entering the transducer. A blood pressure waveform should be present on the monitor display.

Invasive Blood Pressure

Most IBP transducers provide a specified level of electrical isolation for the animal. However, if additional isolation is desired, the IBP Module can be operated on internal battery rather than mains power.

Zeroing the invasive pressure transducer

The transducer must be zeroed to ensure that accurate absolute pressure values are displayed. When the transducer is connected to the IBP Module, a yellow LED flashes to indicate zeroing is required. After securing the transducer in the magnet fringe field, follow these steps to zero the transducer:

1. Position the three-way stopcock valve to block the port connected to the animal cannula. This exposes the fluid in the transducer to atmospheric pressure.

2. Press the zero button on the IBP Module. The LED will turn off when the transducer is zeroed.

3. Position the three-way stopcock valve to block the port with no connection. This exposes the fluid in the transducer to the animal's blood pressure.

Calibrating the invasive pressure transducer

The IBP transducer can be calibrated using a manometer or other source of known pressure. The pressure source can be connected to the air port on the three-way stopcock valve. Some transducers (e.g. Baxter Edwards TruWave) provide a separate test port to allow verification of pressure readings without compromising sterility of the system. An IBP gain calibration factor is available in the PC=SAM SETUP WINDOW to allow for adjustment of the readings.

Charging the IBP Internal battery

The IBP Module has a built-in battery charger for the internal battery. The internal battery is charged when the module is connected to 12 VDC power. If line power is available near the magnet, the 12 VDC power supply can always be connected to the module. If line power is not available near the magnet, the module should be removed from the magnet and connected to the 12 VDC power supply for charging whenever the system is not in use. The battery will reach full charge in 2.5 hours.

The IBP Module's internal battery operates between 7.0 and 8.2 V. A fully charged battery will operate the Module for 6 hours. A low battery warning is displayed on the PC when the battery is low. The module will operate for approximately 1.5 hours following the first indication of low battery. The battery voltage is displayed in CHARGER window (refer to Chapter 3) and the SYSTEM INFO window (refer to Chapter 9).

Spare channels for auxiliary data

Auxiliary analog input capability allows the user to acquire, record, display and gate from user generated analog waveforms. The capability exists for two analog channels. One channel sampled at the rate for respiration and a second channel sampled at the rate for blood pressure. IBP sampling is 900 Hz. IBP sampling is twice the sampling rate for respiration.

The auxiliary channel sampled at the respiration rate is labeled “USER RESP”. The channel sampled at the IBP rate uses the IBP (IBP3) connection on the IBP Module. Parameters to adjust waveform gain, scaling, offset, polarity and labeling are set in the MONITOR SETUP SCREEN (refer to Chapter 3) or by clicking on the associated waveform display (refer to Chapter 9).

The connector pin outs for user RESP and USER IBP are listed below. (pin 1 is the right most pin when viewing the connector):

Pin 1 n/c
Pin 2 +5 VDC
Pin 3 Signal +
Pin 4 Signal –
Pin 5 ground
Pin 6 n/c

Chapter 11
Pulse Oximetry

Chapter 11
Pulse Oximetry

Overview

Pulse Oximetry allows noninvasive monitoring of arterial blood oxygen saturation. Fiber optic oximetry sensors are used to transmit pulses of red and infrared light through the animal's peripheral vascular region. Oxygen saturation is determined by measuring the differential absorption of the red and infrared light. In addition to oxygen saturation, the module measures the cardiac plethysmogram waveform, generates a plethysmogram gate, measures pulse distension and the animal's heart rate.

Oximeter components and connections

The Pulse Oximeter Module is located next to the magnet bore and near the IBP or other optional modules. The module receives and sends data to and from the ERT Control/Gating Module using fiber optic communication cables. It receives power from a dedicated 12V supply or from a daisy chain cable if other options are also in use.

Caution: the 12 VDC power supply is slightly magnetic and should be fix mounted in the magnet fringe field.

There is an option to power the module with an external battery pack. Contact SAII for information.

Pulse Oximetry

If the Oximeter Module is the only option in use, it connects to the ERT Control/Gating Module using a duplex fiber optic communication cable. The cable should be connected to the fiber optic ports labeled “option in” and “option out” and if an options I/O switch is present it should be set to “options in use”. When other optional modules are also present, the modules connect to form a data loop with one of the duplex fibers connecting to the 1st optional module and the other of the duplex fibers connecting to the last optional module. The modules are then connected to each other using short simplex fiber optic cables.

The fiber optic oximeter sensor attaches to the module using a Lemo connector. To make the connection, align the red dots and push the connector straight into the receptacle. To disconnect the sensor grasp the connector with the thumb and index finger near the red dot and pull straight back. Do not turn or twist the connector housing. With the module positioned near the entrance to the bore, the fiber optic sensor is long enough to extend into the bore and attach to the animal.

Display configuration

To add pulse oximetry to the monitor configuration, execute PC-SAM and select the option to “open the MONITOR SETUP window”. Select the Pulse Ox Plethysmogram Trace option on the left side of the window.

Changing sensor clips and forms

Fiber optic pulse oximetry sensors are constructed so the fibers can be detached from the clip or form that attaches to the animal. Small and large clips as well as mouse and rat tail/ankle forms and a reflectance form are available.

Each fiber has a collar. The collars have a grove on each side that lock into tracks on the clips and forms. Small and large clips are shown.

To attach a fiber to the clip, use the index finger to open the clip and position the fiber as shown. Grasp the collar with the thumb and index finger and insert the collar groves into the tracks of the clip. Use the index finger to push the collar to the end of the clip opening.

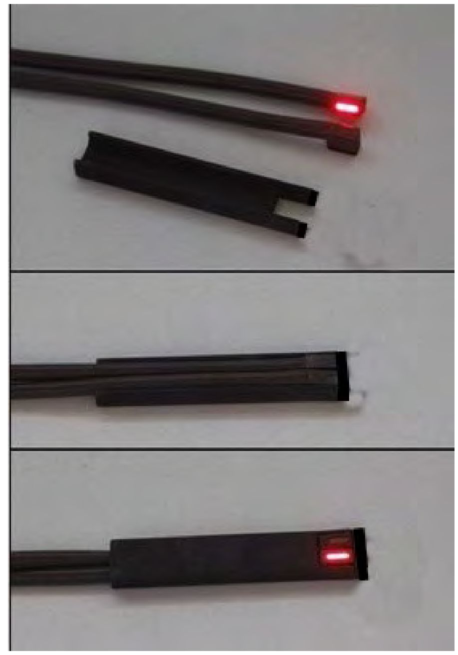
Push the fiber into the large grove along the length of the clip making sure the collar is in close proximity to the end of the clip.

To remove the fiber, grasp the fiber with the thumb and index finger as shown. Push the fiber to move the collar away from the clip. Then grasp the collar with the thumb and index finger and remove the collar from the clip.

Pulse Oximetry

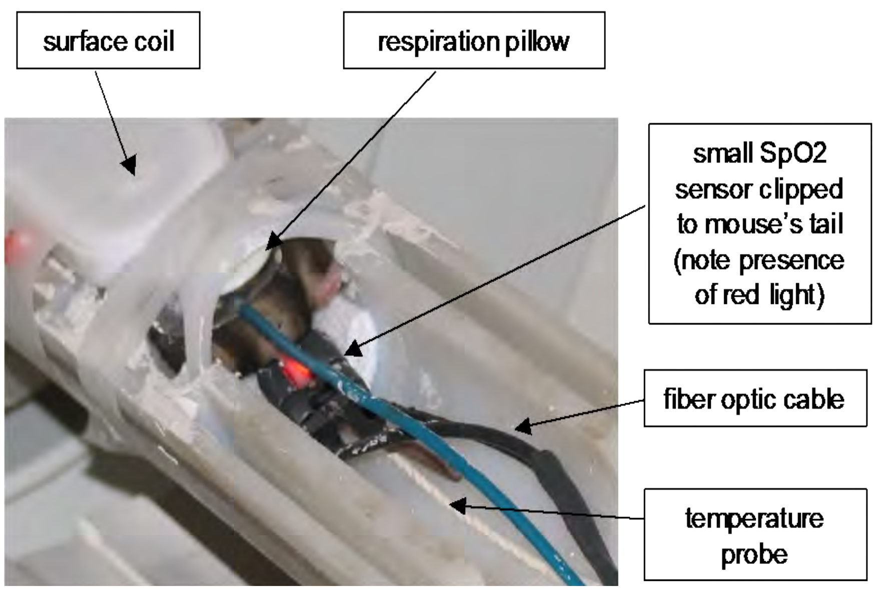
To attach the fibers to the reflectance form, hold the collars together side by side with the ends of the fibers pointed down.

Slide the two collars onto the tracks of the reflectance form making sure the groves in the collars engage the tracks on the form. Press the two fibers into the grove along the top of the form. .



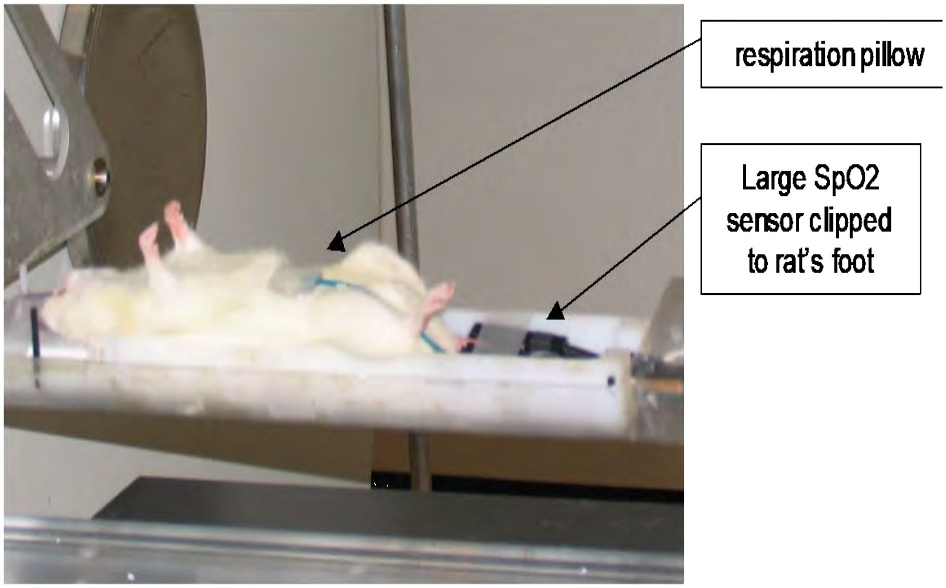
Attachment of fiber optic oximetry sensors

The clip-on sensors are typically attached to the rat foot or the shaved mouse thigh. For rabbits, the ear is often the location of choice



A black mouse is shown above prepared for MR with ECG, pulse ox, respiration and temperature sensors. The small pulse ox clip sensor is attached to the base of the tail.

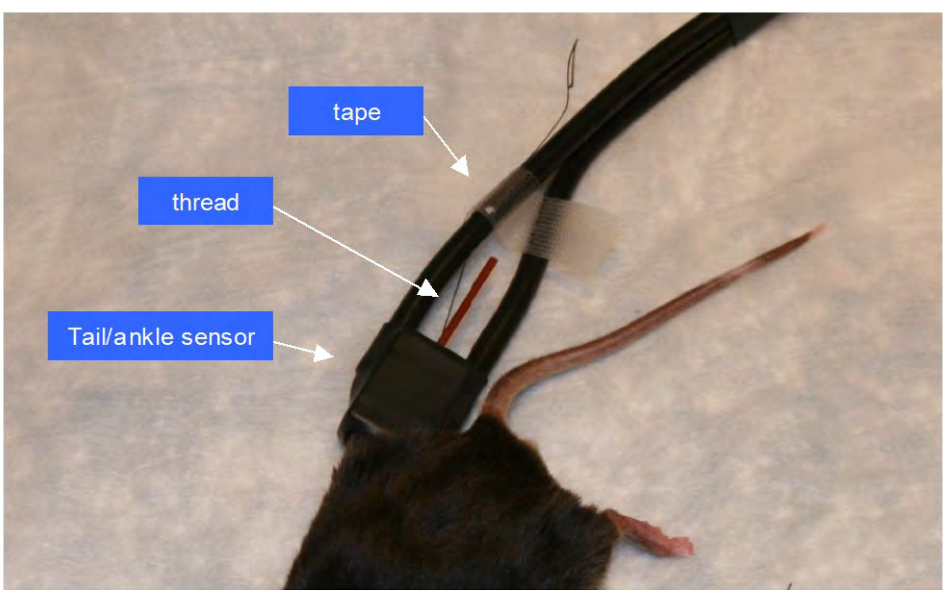
The clip sensor will work on the tail, but it can slip off. Better is to use the tail/ankle form on the mouse tail.



A white rat is shown above prepared for MR with pulse ox, respiration and temperature sensors. The large pulse ox clip sensor is attached to the rat's foot.

The clip on sensors can exert pressure on the attachment site which in turn can restrict blood flow. Restricted blood flow results in a reduction of the oximetry signal. An O-ring fitted over the clip of the sensor can be used to reduce the pressure.

The mouse tail/ankle fiber optic sensor is shown attached to the ankle of a black mouse.



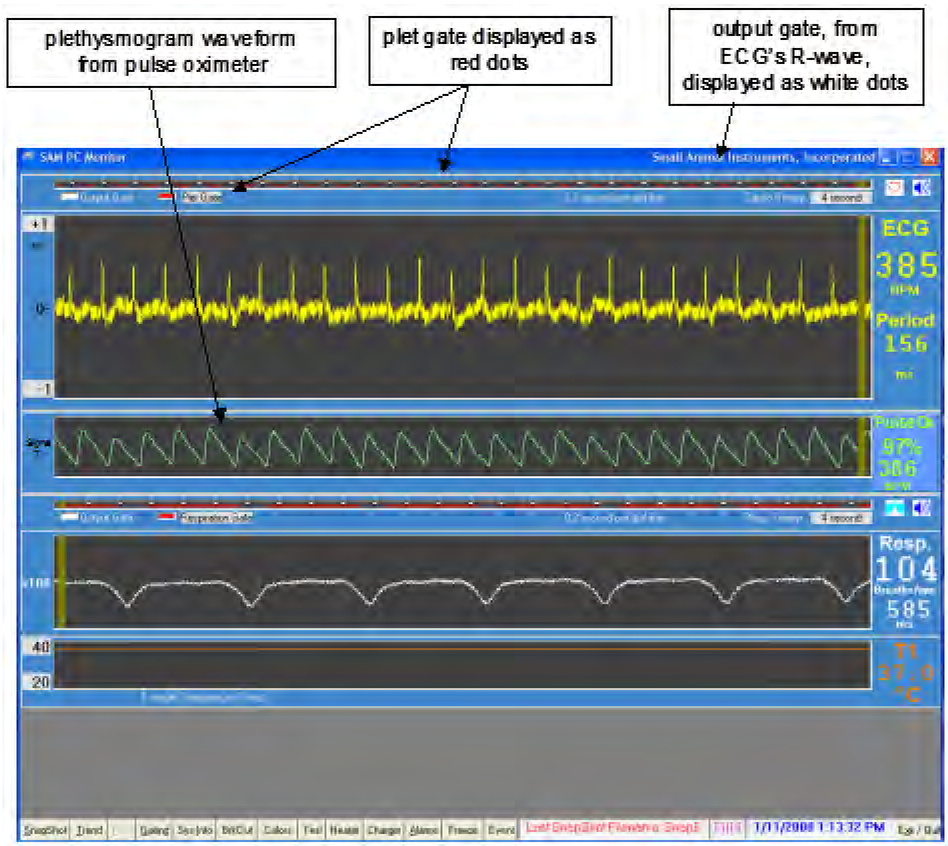
Pulse Oximetry

The sensor head holding the two fibers simply has a hole where the tail or ankle can be inserted. Note that the form does not apply pressure to the attachment site, so oximetry signals tend to be robust. In addition, the ankle and/or tail do not require shaving.

When attaching the sensor to the ankle, place a loop of thread around the mouse foot. Use the thread to pull the leg into the sensor form. Tape the thread to one of the fibers to keep the ankle in the sensor form.

PC-SAM main display

The PC-SAM main display is shown on the next page with ECG, pulse oximetry, respiration and temperature measurements. In this case, data was being collected for retrospective cardiac and respiratory gating of a black mouse in a 9.4T horizontal bore MR scanner. The animal's temperature was being regulated with a set point of 37 ºC. In the Gating window, ECG was selected so that a white dot in the Cardio Sweep display would indicate the detection of the R-wave. Plet Gate was selected to display as a red dot, by clicking on the label next to the red Cardio Sweep icon.



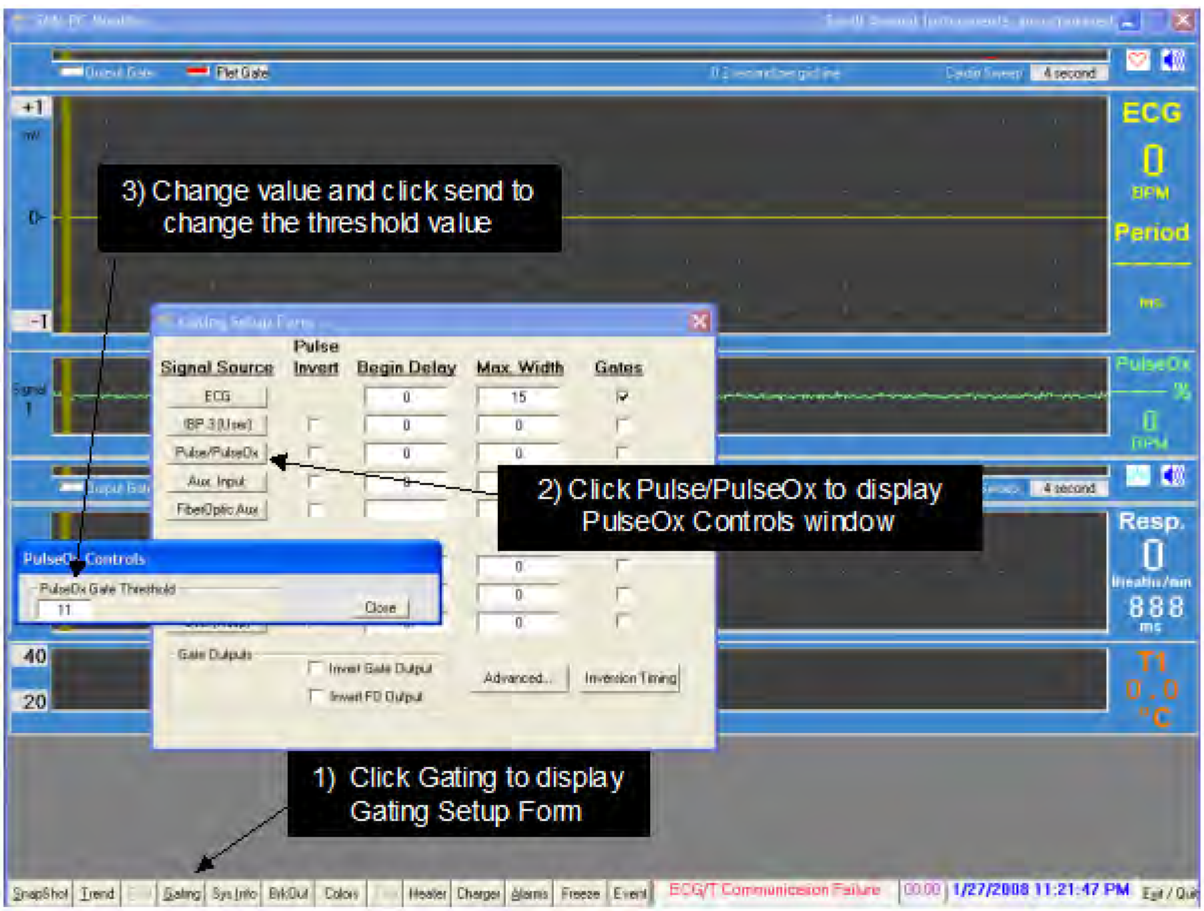
Note the following:

- There is a delay between the ECG and plet gates, because blood flows to a peripheral site after the heart beats.
- There is continuous presence of baseline interference in the ECG waveform, because the MR scanner is running continuously. i.e. not being triggered.
- The plethysmogram waveform has no interference from the MR scanner.
- There is a small modulation of the plethysmogram waveform from respiration.

Plethysmogram gate threshold

A threshold parameter is used to detect the plethysmogram gates for oximetry. In the current version of the software, the threshold's default value can be changed in real time by the user.

The figure below shows how to open the window that controls the pulse ox threshold. Factory default for the threshold is 11 counts. However, the best selection depends on the signal strength which is reported on the left side of the pleth waveform display. The higher the signal strength, the larger the optimum setting for the threshold. The



objective is to set the threshold so a gate is present above each peak in the pleth waveform with no extra gates.

For mice, the signal strength will be 4 or more and the best selection for the threshold is 11 to 20. For rats, the signal can be 6 or more and the threshold can increase to 20 to 40. For humans, the signal can be 10-15 with a threshold setting in excess of 75.

The standard plethysmogram detection algorithm is optimized for small signals and high heart rates. As a result, the standard algorithm does not give reliable results for humans and larger animals like pig and monkeys. There is an algorithm available that is optimized for large signal and low heart rates (contact SAII Customer Service).

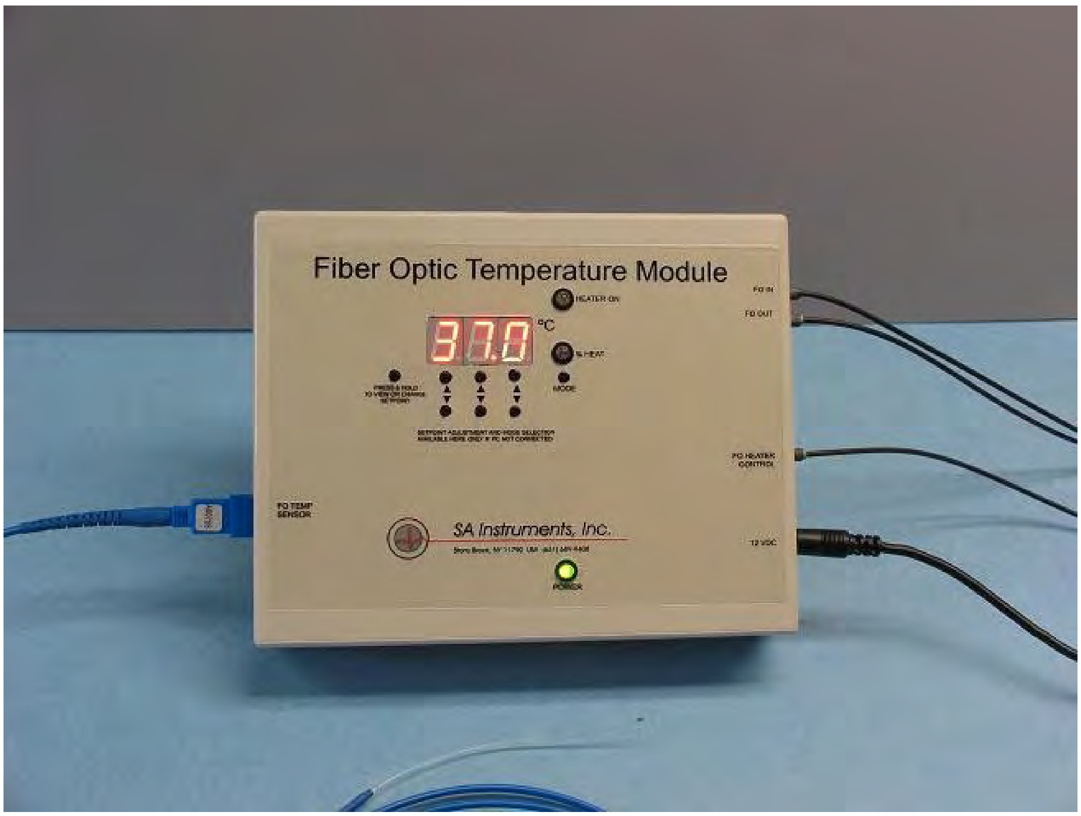
Chapter 12
Fiber Optic Temperature

Chapter 12
Fiber Optic Temperature

Overview

Fiber optic temperature probes provide an alternative method to thermister temperature probes for measuring temperature in the MR environment. Fiber optic probes are not affected by the strong RF and magnetic fields of the MR scanner. They cannot contribute to RF heating and they do not produce an artifact in MR images.

Components and connections



There are 2 configurations for the Fiber Optic Temperature Module. One is shown above with large LEDs and buttons. This configuration can operate as a module with PC-SAM or it can operate in standalone mode to control a Heater System. The other configuration has no LEDs or buttons and can only operate as a module with PC-SAM. Both configurations use the same fiber optic temperature sensors and connect to the ERT Control/Gating Module and other optional modules in the same way. Both configurations can have up to 4 channels of fiber optic temperature.

The Fiber Optic Temperature Module is located next to the magnet bore and near the IBP Module or other optional modules. One or more fiber optic temperature probes extend into the bore and attach to the animal. The module sends and receives data along with other optional modules to and from the ERT Control/Gating Module using fiber optic communication cables. It receives power from a dedicated 12 VDC external power supply or via a daisy chain cable from one of the other optional modules.

Caution: the 12 VDC power supply is slightly magnetic and should be fix mounted in the magnet fringe field.

There is an option to power the module with an external battery pack. Contact SAII for information.

When Fiber Optic Temperature is the only option in use, the module connects to the ERT Control/Gating Module using a duplex fiber optic communication cable. The cable should be connected to the fiber optic ports labeled “option in” and “option out” and if an options I/O switch is present it should be set to “options in use”. When other optional modules are also present, the modules connect to form a data loop with one of the duplex fibers connecting to the 1st optional module and the other of the duplex fibers connecting to the last optional module. The modules are then connected to each other using short simplex fiber optic cables.

The fiber optic cables have blue and grey connectors. The driver and receiver ports are also blue and gray. The order of the modules in the data loop is not important. But, in all cases the color of the connector must match the color of the port.

The temperature probe connects to the module by pushing the connector into the receptacle and turning to lock in place. To remove the probe press and twist the connector.

When controlling a Heater System with the Fiber Optic Temperature Module, connect a simplex fiber between the port labeled “FO Heater Control” and the Heater Module.

Display configuration

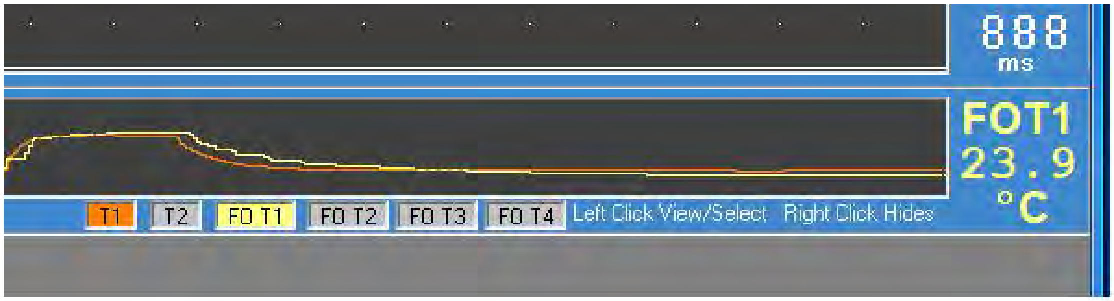
To add fiber optic temperature to the monitor configuration, execute PC-SAM and select the option to “open the MONITOR SETUP window”. Select the “all temperatures” box at the lower left-hand portion of the display.

Attaching, handling and cleaning fiber optic temperature probes

Use a lubricant or lubricated probe cover on the tip of the temperature probe before inserting it into the rectum. Secure the probe lead by taping it to the animal’s tail. Clean the temperature probe with isopropyl alcohol.

Temperature probes should be handled with care. The tip of the probe can be broken or cracked if the tip is bent. We recommend the fiber optic probe be suspended from a hook when not in use to minimize the possibility of damage.

PC-SAM's main display



When the "all temperatures" selection is made in the MONITOR SETUP window, a row of buttons appears below the temperature trend in PC-SAM's main display. These buttons allow the user to select which temperatures are displayed in the trend and which current temperature is displayed in the digital display to the right of the trend.

In the example above, both T1 and FOT1 have been selected and are present in the trend display. FOT1 was selected last, so that probe's current measurement is also displayed. The current measurement can be switched to T1 by left clicking on the T1 button. To remove a measurement set from the trend display right click on the corresponding button.

Heater control

The SA Instruments warm air Heater System can be controlled by the Fiber Optic Temperature module. The HEATER window can be used to select which temperature probe will be used to control the heater and to set the set point. Refer to Chapter 6 for a detailed explanation of the Heater System.

For the module with LEDs and buttons, the digital display on the Fiber Optic Temperature Module can display the current temperature, the set point or the PWM duty factor. Two buttons on the face of the module facilitate which value is displayed.

Chapter 13
Fiber Optic Pressure

Chapter 13
Fiber Optic Pressure

Overview

The Fiber Optic Pressure option for the Model 1030 provides the capability to continuously monitor physiological pressure using ultra-miniature, fiber optic pressure sensors. The ultra-miniature sensors are intended for use in small infusion needles, catheters and guide wires enabling minimally invasive physiology pressure measurements.

The pressure sensors can be used in locations like the aorta, left ventricle of the heart, ventricles of the brain and in the spinal canal. However, for many users, the most exciting application is to provide minimally invasive, continuous monitoring of blood pressure and heart rate by simply inserting the sensor tip into an artery

The ultra-miniature pressure sensor consists of a tiny silicon cavity attached to a relatively long fiber optic cable. White light is sent via the fiber to and from the cavity. Polarization interferometer processing electronics precisely computes the Fabry-Perot cavity length and determines the corresponding pressure reading. An internal manometer automatically corrects the reading for changes in atmospheric pressure.

Fiber optic pressure sensors are not affected by the strong RF and magnetic fields of the MR scanner. They can not contribute to RF heating and they do not produce an artifact in MR images.

The Fiber Optic Pressure Module is located next to the magnet bore. A fiber optic pressure sensor extends into the bore and attaches to the animal. The module receives and sends data along with other optional modules from and to the ERT Control/Gating Module using fiber optic communication cables. It receives power from a dedicated supply or a daisy chain power cable if other options are present.

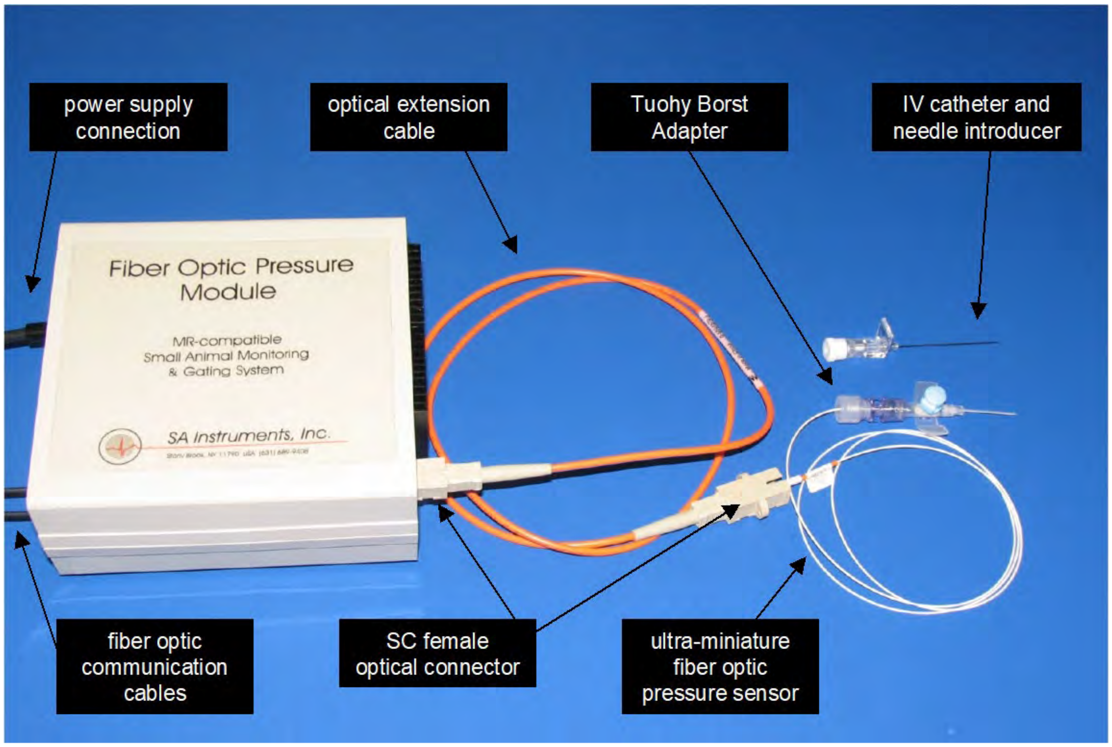
Caution: the 12 VDC power supply is slightly magnetic and should be fix mounted in the magnet fringe field.

Sensor and extension connections

The pressure sensor connects to the module using an optical extension cable. A 1 m extension is standard but other lengths are available. Special cleaning procedures for sensors and extension cables, detailed later in this chapter, provide for reliable long-term operation. We recommend leaving the extension cable connected to the module when disconnecting the pressure sensor.

The optical sensor extension cable (FOP-OEX-1M) has a male SC connector on one end and a female SC adapter on the other end. The male SC connector connects to the Fiber Optic Pressure Module at the port labeled “sensor”. Align the keyway and insert the male connector to make the connection. Use the thumb and forefinger to grasp the male connector housing on either side of the keyway and pull to disconnect.

Fiber Optic Pressure



Two fiber optic pressure sensors are available with tip OD of 0.3 mm and 0.4 mm. They have a male SC connector that connects to the extension cable's female SC adapter.

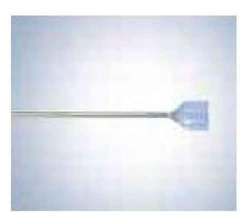
Fiber optic communication cable connections

When the Fiber Optic Pressure Module is the only optional module, it connects to the ERT Control/Gating Module using a duplex fiber optic cable. The cable should be connected to the fiber optic ports labeled "option in" and "option out" and if an options I/O switch is present it should be set to "options in use". When other optional modules are also present, the modules connect to form a data loop with one of the duplex fibers connecting to the 1st optional module and the other of the duplex fibers connecting to the last optional module. The modules are then connected to each other using short simplex fiber optic cables.

The order of the modules in the data loop is not important. But, in all cases the color of the fiber optic connector must match the color of the port

.

Handling and cleaning fiber optic pressure sensors



The sensors have a SC male connector on one end and a small pressure transducer on the other end. For the larger sensor (FOP-5-4) the diameter of the transducer is 0.4 mm and the diameter of the fiber optic cable without the jacket is 0.2 mm, so the transducer diameter is considerably larger than the fiber diameter as shown in the photograph. The smaller sensor (FOP-3-3) has a polyimide protective sheath covering the pressure transducer.

Cleaning the transducer end of the pressure sensor

The transducer is glued to the fiber, but it can be broken off if not handled carefully. The sensor can not be mechanically cleaned by for instance rubbing with a tissue soaked in alcohol. Instead the tip is cleaned by soaking in a solution of enzyme-active detergent.

Clean the tip of the fiber optic pressure sensor as follows:

1. Make a fresh solution of 1 gm of Tergazyme powered detergent in 100cc of warm water (<130 °F or 55 °C).
2. Soak the sensor tip for at least 10 minutes.
3. Rinse in water.
4. Dip in rubbing alcohol.
5. Store in the sensor storage case.

> **Caution: The transducer tip of the fiber optic pressure sensor is delicate. Refrain from applying mechanical pressure to the transducer tip. Do not attempt to clean the sensor with mechanical pressure.**

Cleaning the pressure sensor and extension cable SC male connectors

Clean the SC male connector ferrule end face before each use using the Fiber Optic Connector Cleaner included in the Cleaning Kit (FOP-CLNKIT). Clean the end face as follows:

1. Ensure a new cleaning surface by advancing cloth tape and tear off excess tape as required.
2. Softly press the connector end face on the clean cloth tape and drag it across the tape while rotating the connector.
3. Several connectors (<6) can be cleaned before advancing the tape.

> **Caution: The SC connector ferrule end face should be cleaned before each use. Failure to do so can result in permanent damage to the connector caused by hard particles trapped between the fiber optic end faces.**

Cleaning the SC female connectors

Clean the SC female connectors as follows:

1. Dip the tip of the cleaning stick included in the Cleaning Kit (FOP-CLNKIT) in alcohol.
2. Insert the tip of the cleaning stick in the SC female connector and rotate the stick.
3. Allow the SC connector to dry before inserting the SC male connector.

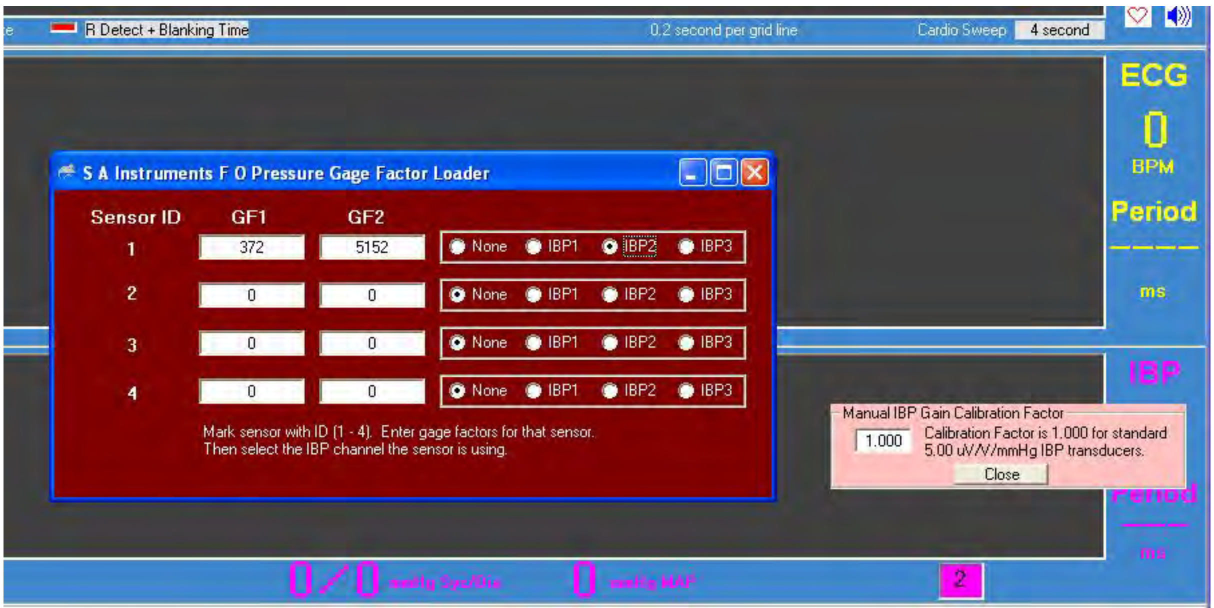
Fiber Optic Pressure

Display configuration

To add fiber optic pressure to the monitor configuration, execute PC-SAM and select the option to "open the MONITOR SETUP window". Select the BP2 box on the left-hand portion of the setup display.

Calibrating the fiber optic pressure sensor

Each fiber optic pressure sensor is factory calibrated. The calibration information unique to each sensor is contained in two gage factors. The gage factors are on a label next to the sensor's SC connector and on the sensor's storage case. The sensor gage factors need to be entered in PC-SAM where they are automatically sent to the Fiber Optic Pressure Module.



Right click on the IBP2 waveform display to open the GAGE FACTOR LOADER window. The window has space for gage factors for up to 4 pressure sensors. Click the IBP2 selection for the sensor ID currently in use. Within 2 to 3 seconds, the gage factors will automatically be sent to the Fiber Optic Pressure Module.

Gage Factors sent to the Fiber Optic Pressure Module by the PC are first written into the module's volatile memory. i.e. memory that will be erased when power is removed. The Module also has EEPROM memory which is non-volatile. The EEPROM memory is used to store calibration parameters so they can be automatically used when the module is first turned on.

The Fiber Optic Pressure Module has two indicator lights and two push button switches as shown in the photograph below. A green light is present when power is on. A yellow light labeled “pulse” can have three conditions as follows:

1. On continuous to indicate either no sensor connected or the gage factors in EEPROM memory are different than those currently being sent from the PC.
2. Flashing to indicate a zero is or maybe needed.
3. Off to indicate pressure measurements are being sent to the PC.

If the yellow light is on continuous and a pressure sensor is connected, press the “send Cal” button to store the new gage factors in EEPROM memory. The yellow light should then begin flashing to indicate a zero is necessary.

Zeroing the fiber optic pressure sensor

Before inserting the sensor into an animal, the sensor must be zeroed in air to ensure that accurate absolute pressure values are displayed. The module can zero the sensor when the yellow light is flashing. In that case, perform the zero calibration by pressing the button labeled “zero”. The yellow light should go out and the pressure reading on the PC should go to zero.

Small offsets may occur within the first 30 seconds of power up and/or when the Fiber Optic Pressure Module is in a very strong fringe field. Make certain the module has been powered on for at least 30 seconds before performing the zero. Then move the Fiber Optic Pressure Module into the location next to the bore where it will be located during the MR procedure. Observe if the zero value remained. If it did not, perform the zero again.

If power is inadvertently interrupted to the Fiber Optic Pressure Module during a procedure, the yellow light will flash for 15 seconds after power is restored. The flashing yellow light is a reminder that a zero may be needed. However, in this case, with the sensor in the animal, a new zero should not be performed. Instead the previous calibration parameters written to the EEPROM memory are automatically used to make the pressure measurement.

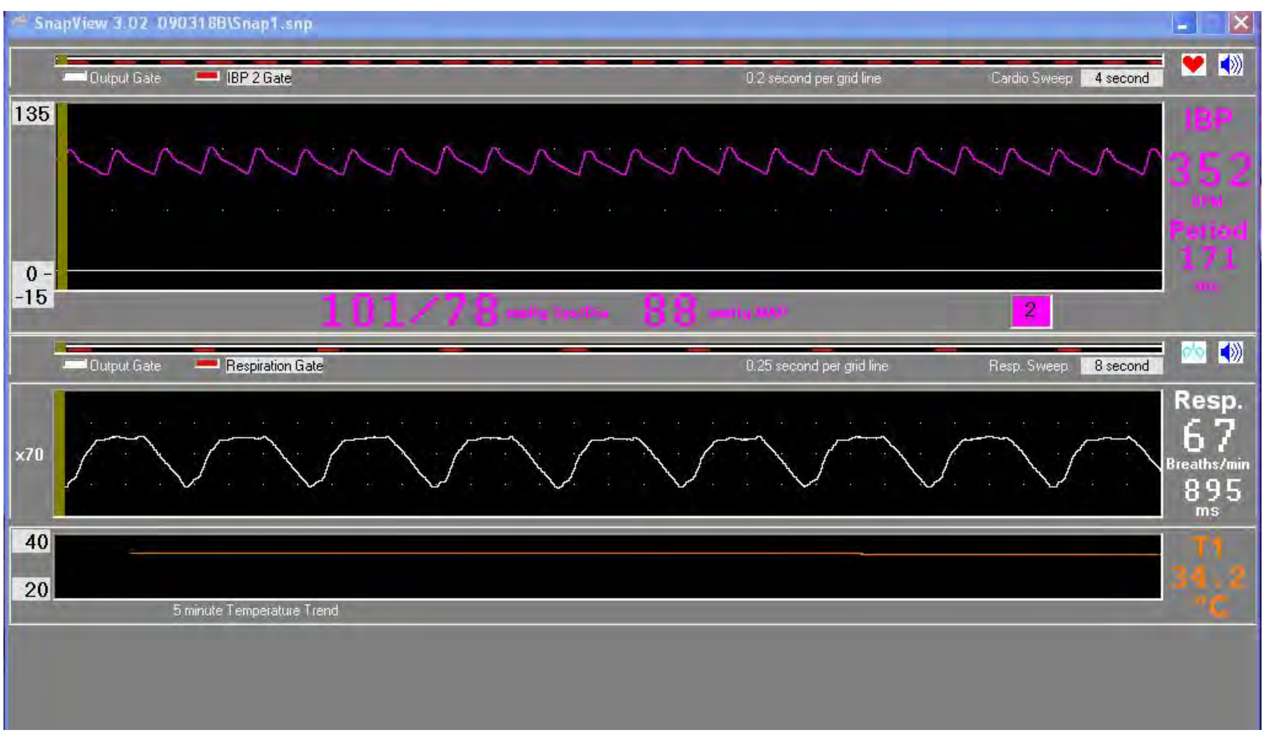
Inserting the fiber optic pressure sensor

The fiber optic sensor can be inserted at any location where a 22 gauge catheter can be inserted. One of the most common placements of the sensor is in the tail artery of a rat to make continuous real time blood pressure measurements.

In the case where the pressure sensor is inserted into a rat's tail artery, the tail is first heated, usually in warm water, and a catheter is inserted in the tail artery. The fiber optic sensor is carefully inserted through a Tuohy Borst Adapter and then into the catheter. The Tuohy Borst Adapter is connected to the catheter and then the adapter gland is tightened around the jacket of the sensor to form a seal. A catheter with a 2^{nd} port (IVC-22B) as shown on page 17-1 or a catheter without a 2^{nd} port (IVC-22A) but with a 3 way stop cock allows heparinized saline to periodically flush the transducer to eliminate clotting.

PC-SAM's main display

The IBP waveform obtained from the fiber optic pressure sensor in a rat's tail artery is shown below. Note the IBP2 gates are displayed in the Cardio Sweep display. The heart rate and peak to peak period are displayed to the right of the waveform. The systolic, diastolic and mean arterial pressures are computed and displayed below the waveform.



Procedure for making IBP measurements from the rat tail artery

Heat the rat tail using warm water. A second set of hands is recommended to compress the tail artery and prevent bleeding. Insert the 22 gauge Terumo Surflo-W cannula with injection port in the tail artery outside the MR under a bright light. Flush the port with Heparin and seal the port.

Position the rat in the animal cradle. Insert the pressure transducer into the Tuohy Borst adapter. Zero the pressure transducer. Compress the tail artery to prevent bleeding, open the cannula port and insert the fiber optic transducer. Seal the Tuohy Borst adapter around the fiber. Flush with Heparin every 30 minutes or as needed.

Chapter 14
Capnograph and Ventilator

Chapter 14
Capnograph and Ventilator

Overview

The microCapStar Capnograph provides accurate end-tidal or continuous measurement of expired CO_2 in animals as small as mice. It features very low sample flow requirements, rapid response time and long-term stability. The CO_2 waveform, respiration rate, end-tidal CO_2 and minimally inspired CO_2 are measured, displayed and recorded along with all other available physiological monitoring parameters. The CO_2 waveform, end-tidal CO_2 and minimally inspired CO_2 can be displayed in either mmHg, kPa or percent.

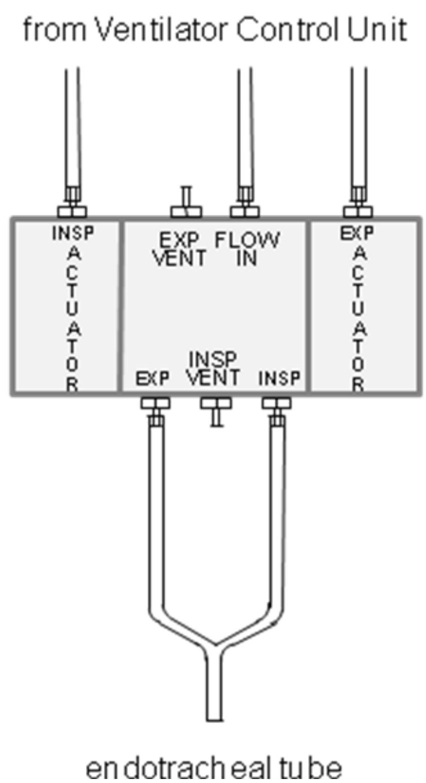
The MR-compatible Ventilator consists of a Ventilator Control Unit and a MR-compatible Valve Assembly. The valve assembly is positioned in the magnet bore close to the animal. The Ventilator Control Unit works on the flow-time principle. An inspiratory airflow is delivered to the animal for a known time resulting in a known air volume. This approach provides great flexibility. A wide range of volumes, breaths/minute and Inspiration/Expiration ratios are possible without additional hardware and using just three controls: respiration rate, percent inspiration and flow rate.

The Capnograph and Ventilator options can be used individually. However, in most cases they are used together. Ventilation requires intubating the animal. Once intubated it is easy to attach sample lines for the Capnograph.

Ventilator MR-compatible Valve Assembly

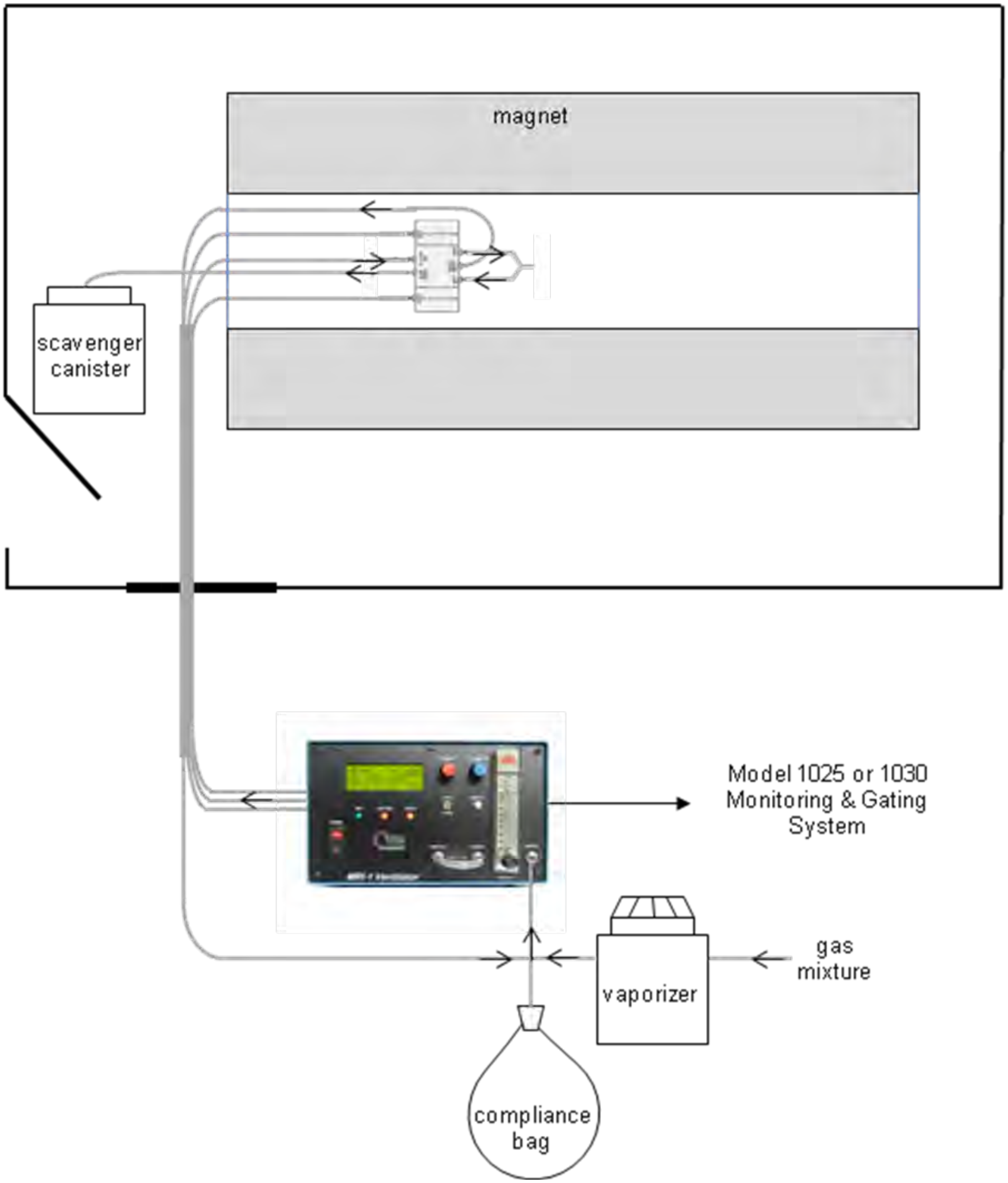
The MR-compatible Valve Assembly incorporates two high speed, miniature pneumatically activated, non-metallic valves to direct air between the animal and vent ports. Locating the valves close to the animal in the magnet bore improves performance by minimizing dead space and tubing compliance.

The MR-compatible Valve Assembly allows inspiratory air or anesthetic gas to be delivered to the animal during inspiration. During expiration, the valves switch to vent the inspiratory airflow and to allow the lungs to vent passively to the atmosphere. The valves allow inspiratory air to flow continuously preventing pressure transients that would result from starting and stopping the flow of air.



Ventilator setup in MR

The Ventilator Control Unit is positioned outside the magnet room. It is connected to the Valve Assembly using 23' (7 m) long pneumatic tubes.



Anesthesia connection in MR for rodents

The diagram above shows connections between the Control Unit and the Valve Assembly as well as connections to components of an anesthesia setup. The ventilator should be located near a waveguide and accessible to the operator. Long cables are provided to connect to the Capnograph/Ventilator Interface Module.

Ventilator operation

Refer to the MRI-1 Ventilator Instruction Manual for detailed instructions for connecting and using the ventilator.

Ventilator setup in MR for animals larger than rodents

The MRI-1 Ventilator has a maximum internal flow measuring capacity of 1100 ml/min which is appropriate for rodents. However larger animals require larger flow rates and larger MR-compatible pneumatic valves.

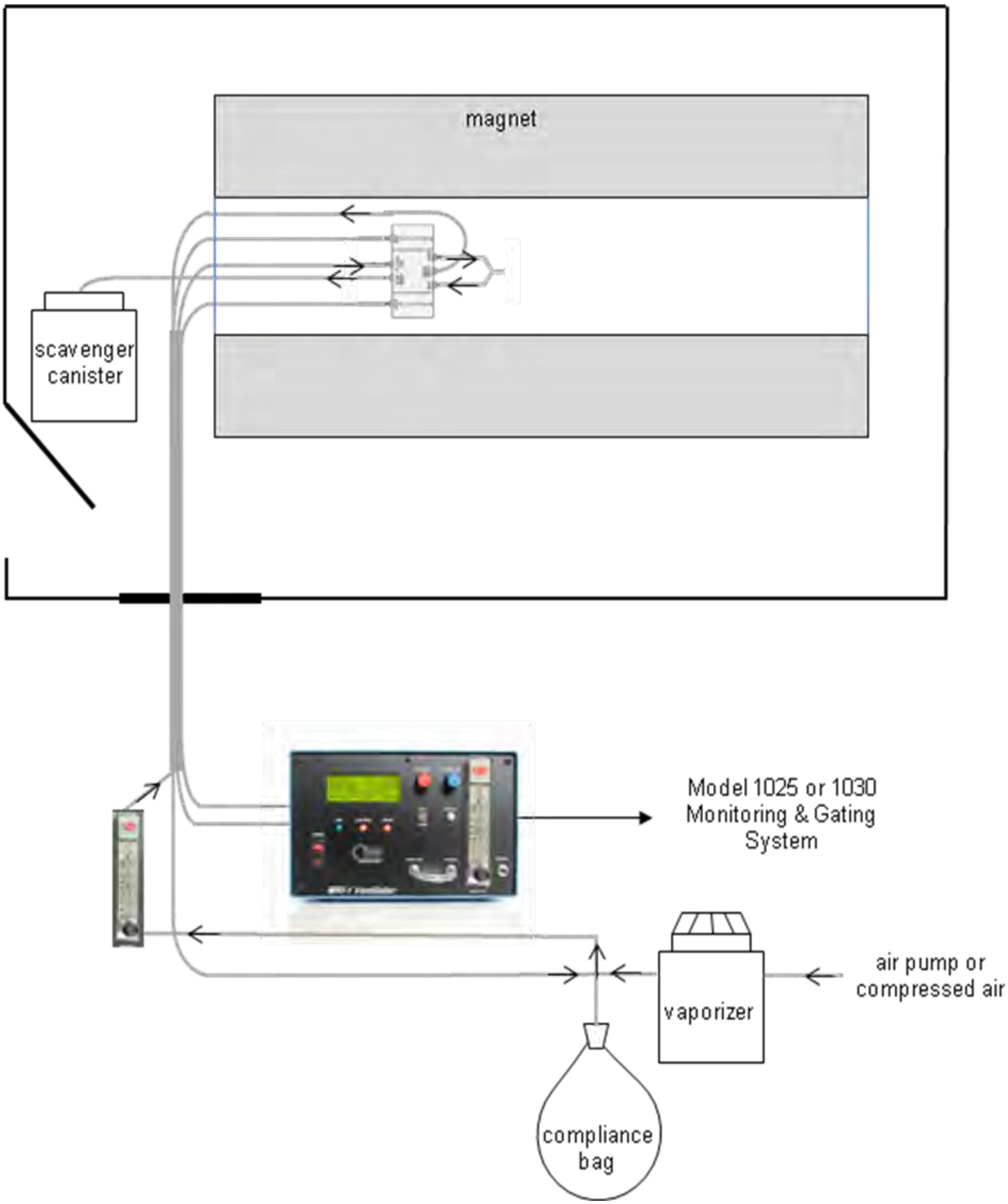
The diagram on the next page shows the setup in MR using the larger MR-compatible valves and a flow meter with larger flow rate capacity. In this case gas flowing to the valve does not pass through the ventilator but connects directly and the flow is controlled by the larger capacity flow meter.

In the larger animal setup, the respiration rate and I/E ratio are set by the ventilator and the flow rate which determines tidal volume is set by the larger capacity flow meter. The tidal volume can be calculated manually using the formulas in the MRI-1 Manual.

Alternatively, a proportional tidal volume can be determined automatically by setting the ventilator to pump room air through the ventilator flow meter at ½ or ¼ the flow of the larger capacity flow meter. This room air is not delivered to the MR-compatible valve or the animal, but it lets a proportional tidal volume be calculated and reported by the ventilator and by PC-SAM which is ½ or ¼ of the true tidal volume.

To pump room air through the ventilator flow meter, the ventilator front panel connection for “pump in” is open to room air, the rear panel connect to “Insp Flow Out” is open to room air and the front panel connections to “pump out” and “flow in” are connected to each other. Then the internal ventilator pump can deliver room air through the ventilator at a proportionally reduced flow rate set by the ventilator flow meter and the ventilator automatically calculates the proportionally reduced tidal volume

As an example, with a respiration rate of 20 BPM, an I/E ratio of 1/3 and a tidal volume of 30 ml the respiration interval is 3 sec and the inspiration time is 1 sec so the flow rate is 30 ml/sec or 1800 ml/min. This exceeds the capacity of the ventilator so the setup for large animals is necessary. If the ventilator flow meter is adjusted to read 900 ml/min then the proportional tidal volume reported by the ventilator and by PC-SAM will be 15 ml or ½ the true tidal volume.

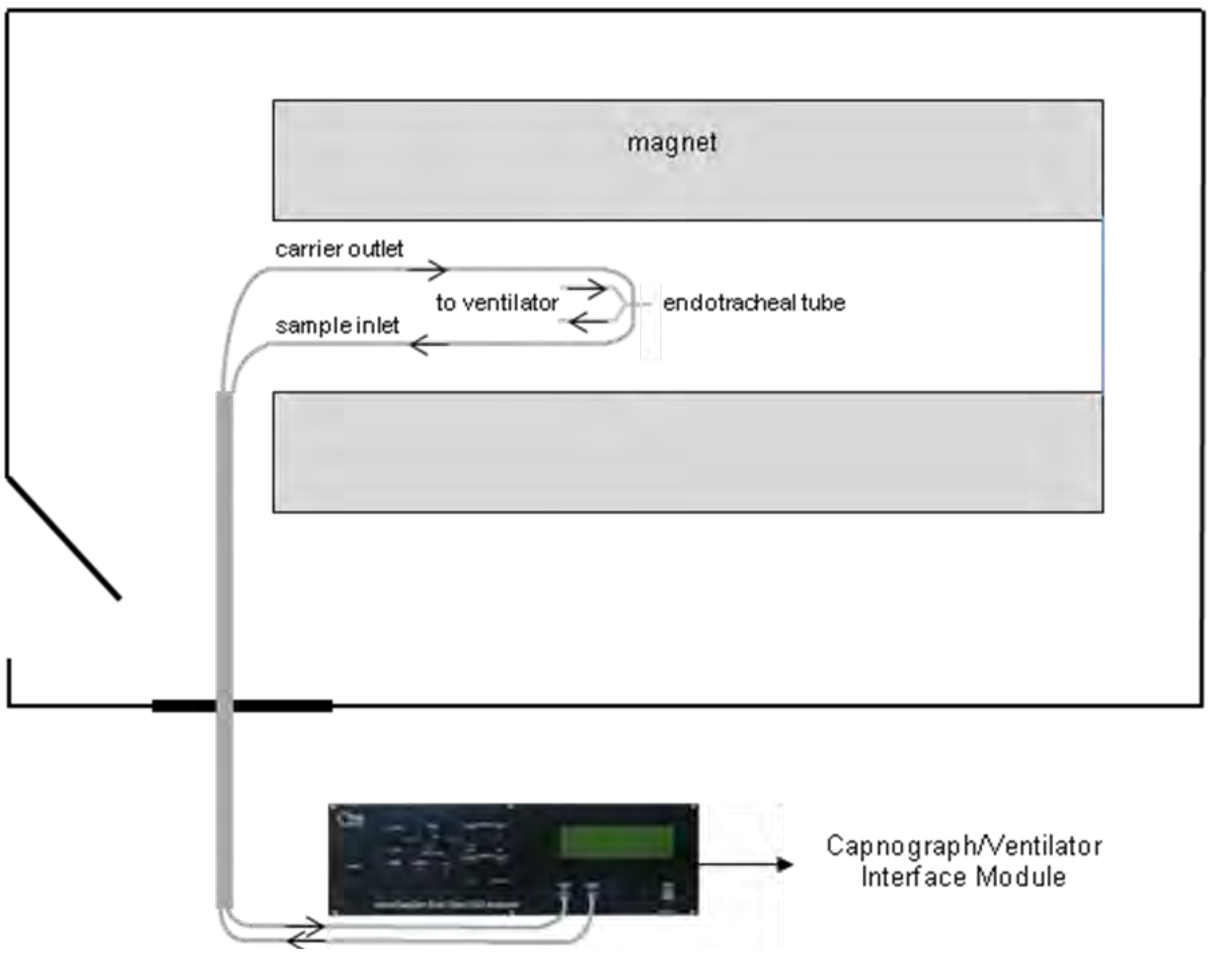


Anesthesia connection in MR for larger animals

microCapStar Capnograph

A miniature, infrared CO2 sensor with a temperature controlled sample cell prevents water condensation even during long measurement sessions. Low sample flow and rapid response is achieved with a carrier gas system where the high flow carrier gas quickly brings the low flow sample to the sample cell.

Capnograph setup in MR



The diagram above shows connections between the microCapStar and the animal. The measuring and control module is located outside the magnet room near a waveguide. A long tubing set is provided to connect to the animal in the magnet bore. Note: it is important to perform the CO2 calibration with the tubing set which will be used with the animal.

Capnograph and Ventilator

Capnograph operation

Refer to the MicroCapStar End-Tidal CO_2 Analyzer Instruction Manual for detailed instructions for connecting and using the capnograph.

Capnograph/Ventilator Interface Module

The Capnograph/Ventilator Interface Module sends capnograph and ventilator measurements to the ERT Control/Gating Module so they can be displayed and recorded using PC-SAM.

The Capnograph/Ventilator Interface Module should be located near the ERT Control/Gating Module. Unplug one of the fiber optic cables from OPTION IN or OPTION OUT, it does not matter which one, and connect it to the fiber optic port of the Capnograph/Ventilator Interface Module. Make sure you match the color of the cable with the color of the driver/receiver port. Use a short fiber optic cable to connect to the unused ports on the two modules.

There are two input connections for the ventilator:

> SYNC IN – which provides measurements for I/E ratio and respiration rate
> SERIAL IN – which provides tidal volume measurements

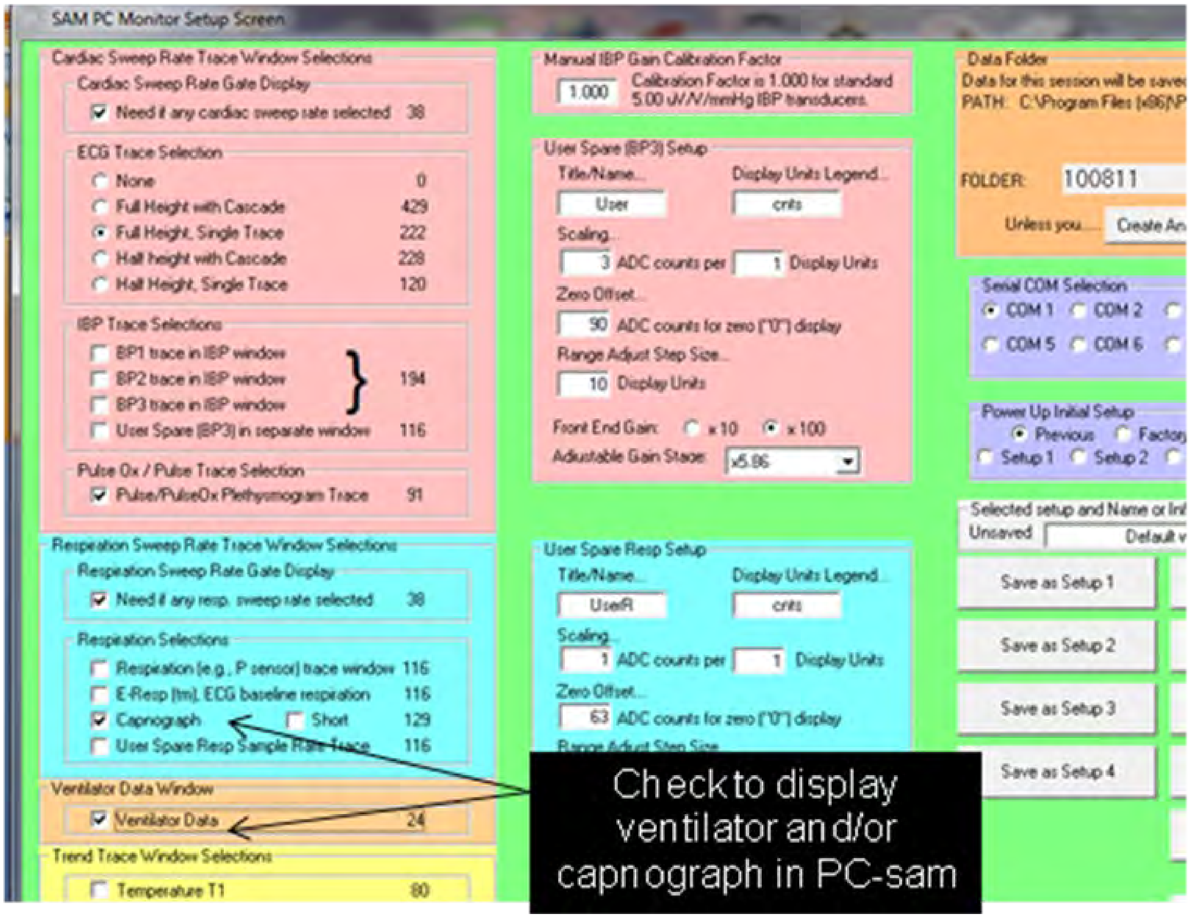
There are two inputs for the capnograph:

> 0-1V – which is used for capnographs having a 0-1V output range
> 0-10V – which is used for capnographs having a 0-10V output range. The microCapStar Capnograph uses this input.

The switch between the two capnograph inputs should be positioned to be closest to the input being used.

Display configuration

To add the capnograph and/or ventilator to the monitor configuration, execute PC-SAM and select the option to “open the MONITOR SETUP window”. Check the boxes indicated in the figure below to activate the capnograph and/or ventilator displays.



PC-SAM main display

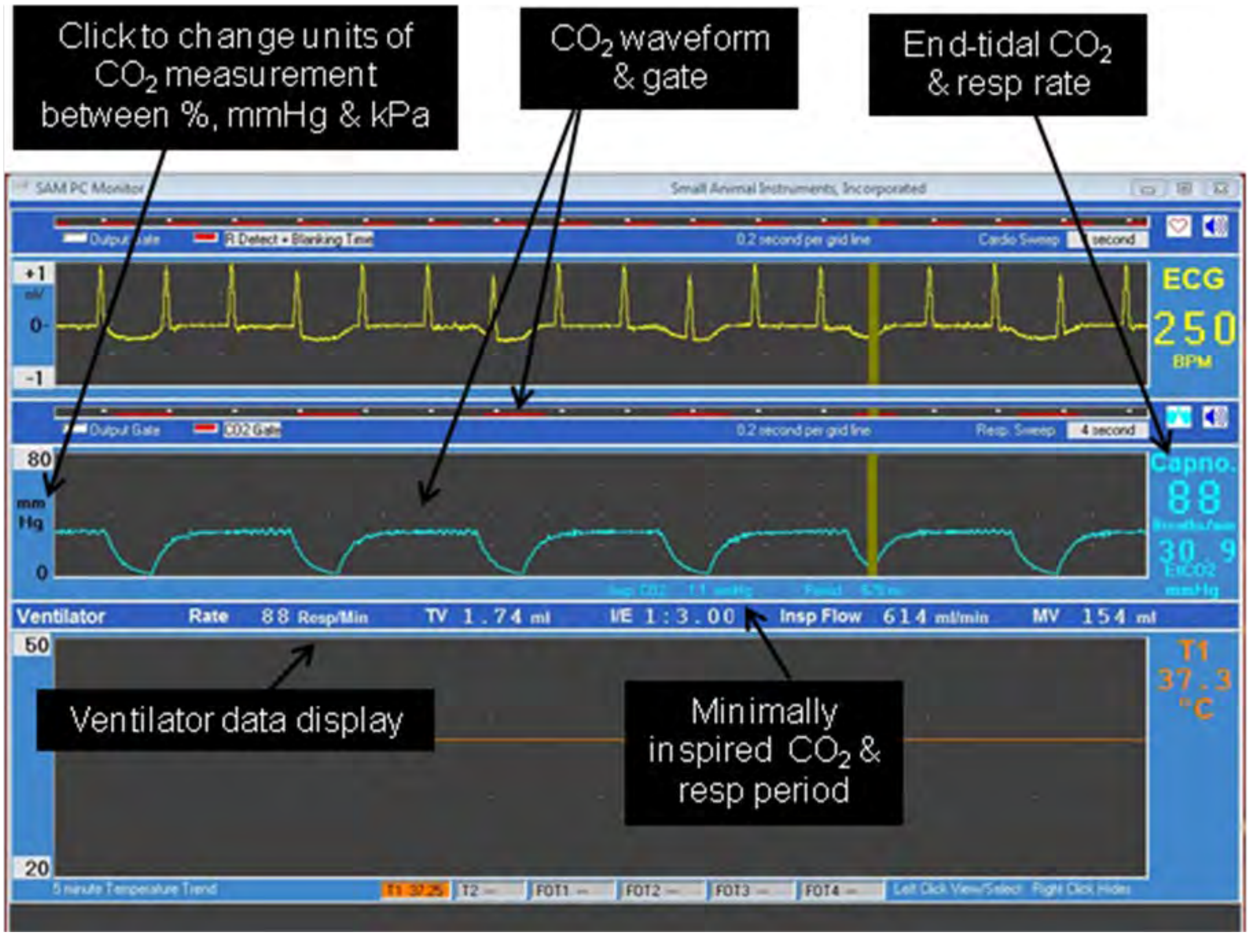
The PC-SAM main display is shown on the next page configured with ECG, capnograph, ventilator and temperature.

The CO_2 waveform from the capnograph is displayed along with the respiration rate, respiration period, CO_2 gate, end-tidal CO_2 and minimally inspired CO_2. The CO2 waveform can be displayed in %, mmHg or kPa. The microCapStar measures the CO2 as a % and sends the value to the Capnograph/Ventilator Interface Module where the current atmospheric pressure is measured and used to make the conversion to mmHg or kPa.

Note that the CO_2 gate is delayed by several seconds relative to the breathing of the animal. The delay is due to the long length of tubing. As a result, the CO_2 gate should not be used for respiratory gating. Instead use P-resp or E-resp. when performing respiratory gating.

Capnograph and Ventilator

Ventilator measurements are displayed below the capnograph display. Readings include respiration rate, tidal volume (TV), inspired to expired ratio (I/E), inspiratory flow and minute volume (MV).

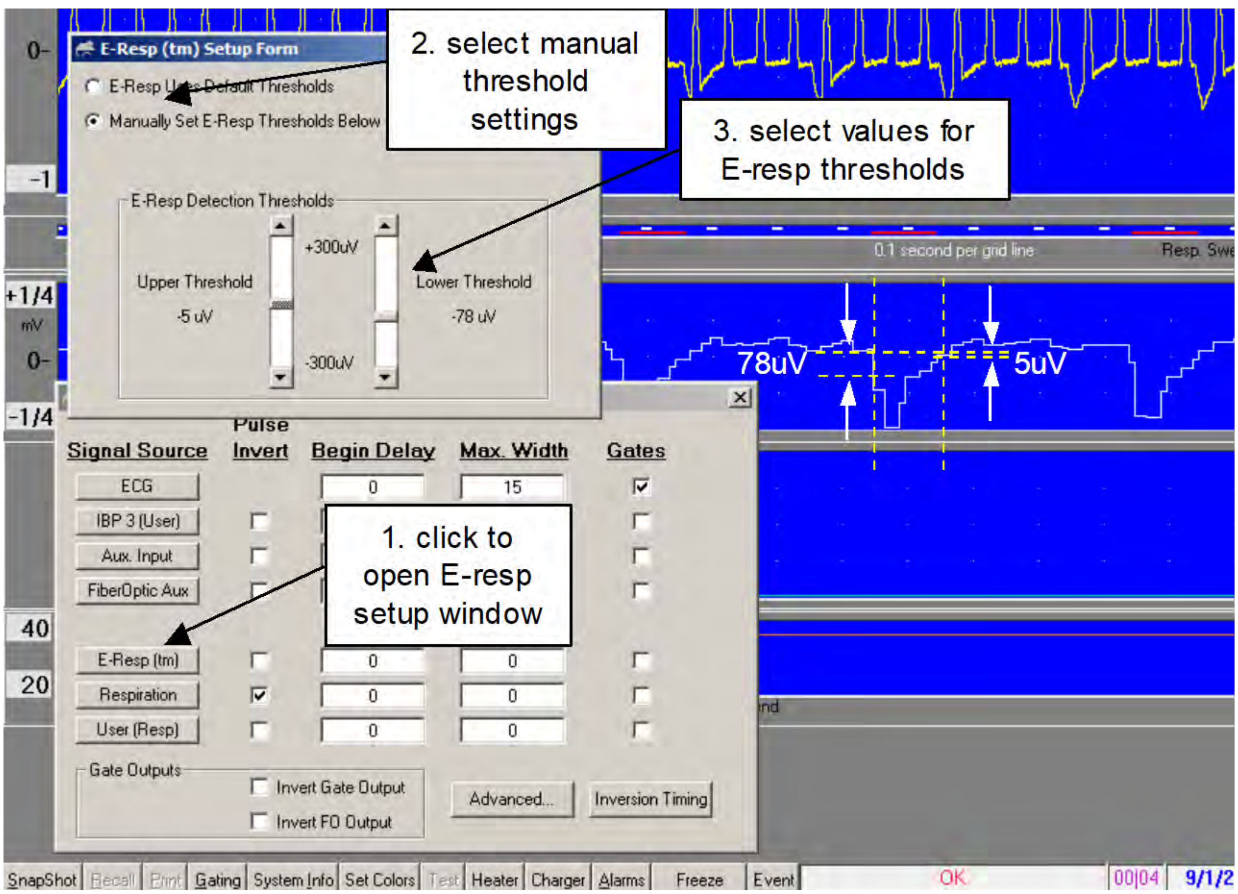


Chapter 15
Advanced Features

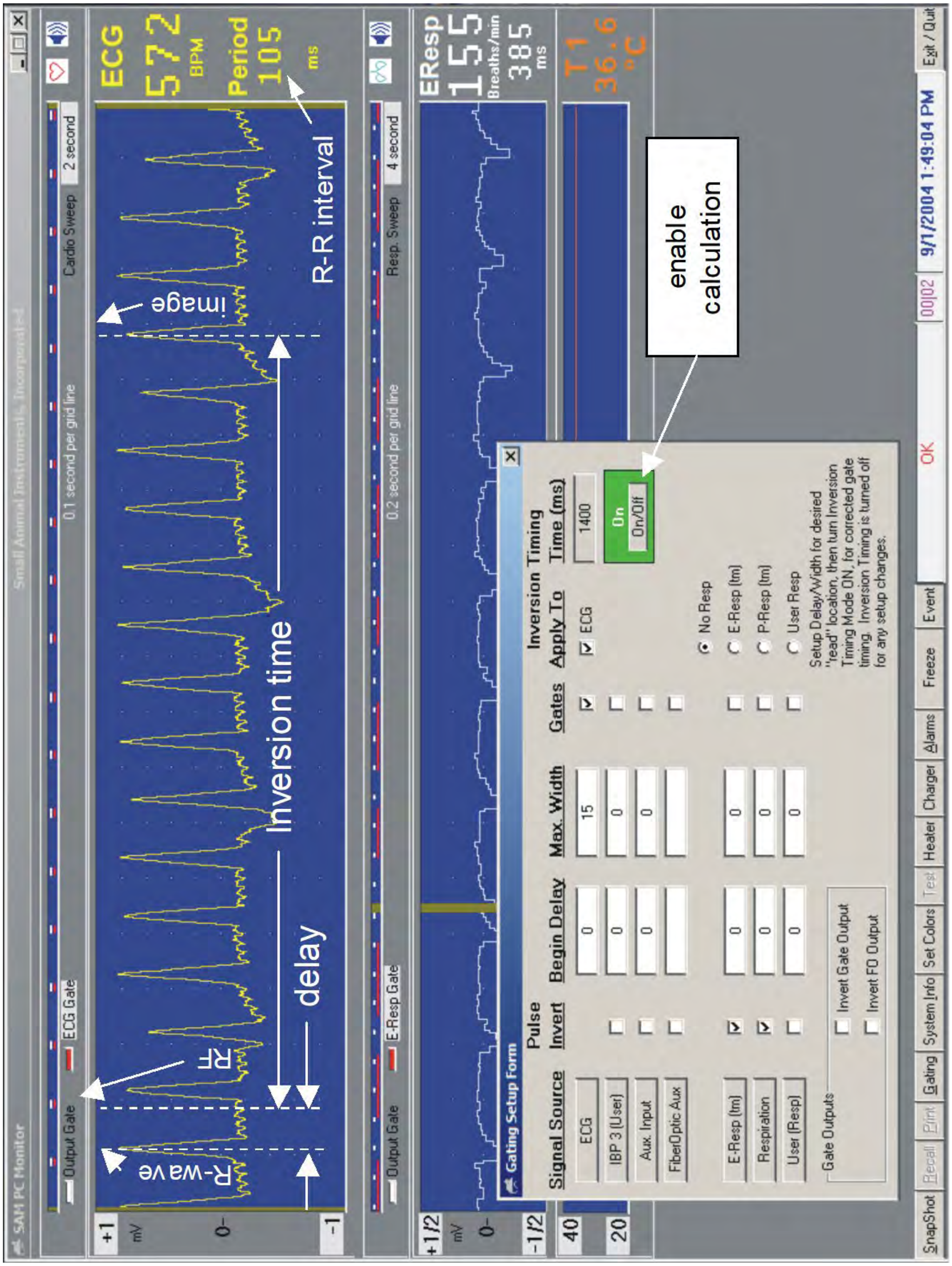
Manual E-Resp^{TM} thresholds

Respiration waveform gates are generated automatically for E-Resp^{TM}, P-Resp^{TM} and User Resp. However, in the case of the E-Resp^{TM} waveform, the option also exists to manually set the thresholds for gate generation. The E-RESP SETUP window can be opened by clicking on the E-Resp button in the GATING SETUP window.

For the example shown, the pulse invert check has been removed in the gating setup menu. This allows detection of the dip with manual thresholds. The gate starts when the waveform falls below the lower threshold of -78µV and ends when the waveform rises above the upper threshold of -5µV.



Once the manual thresholds are set to detect inspiration, the pulse invert box can be selected to switch the gate to expiration. Gate position can also be adjusted using Begin Delay and Max Width settings.


SAM PC Monitor
Output Gate
ECG Gate
Cardio Sweep
2 second
0.1 second per grid line
R-wave
RF
delay
Inversion time
image
R-R interval
ECG
572
BPM
Period
105
ms
Output Gate
E-Resp Gate
Resp. Sweep
4 second
0.2 second per grid line
EResp
155
Breaths/min
385
ms
T1
36.6
°C
enable calculation
Gating Setup Form
Signal Source
Pulse Invert
Begin Delay
Max. Width
Gates
Inversion Timing
Apply To
Time (ms)
ECG
IBP 3 (User)
Aux. Input
FiberOptic Aux
E-Resp (tm)
Respiration
User (Resp)
1400
On
On/Off
No Resp
E-Resp (tm)
P-Resp (tm)
User Resp
Setup Delay/Width for desired "read" location, then turn Inversion Timing Mode ON, for corrected gate timing. Inversion Timing is turned off for any setup changes.
Gate Outputs
Invert Gate Output
Invert FO Output
OK
SnapShot
Recall
Print
Gating
System Info
Set Colors
Test
Heater
Charger
Alarms
Freeze
Event
9/1/2004 1:49:04 PM
Exit / Quit

Inversion timing

For certain imaging sequences, such as inversion recovery, the image data is acquired at a time later than the start of the pulse sequence. In those cases, it may be desirable to generate a delayed gate to make certain the image is acquired at a specific position in the cardiac and/or respiratory cycle.

Parameters for the inversion timing calculation are entered from an expanded GATING SETUP window implemented by clicking the Inversion Timing key in the GATING SETUP window.

Consider a pulse sequence which applies a RF pulse 1400ms before readout of the image data. If the detected R-wave peak generates a gate to initiate the pulse sequence and thus the RF pulse, the image data will be acquired 1400ms later at a position in the cardiac cycle which depends on the heart rate or R to R period. For the example shown on the preceding page, the image would occur 35ms after a later R-wave peak assuming the heart rate does not change.

To position the image at the beginning of the cardiac cycle (at the R-wave), we perform an inversion timing calculation where the calculated gate delay plus the inversion time is the first integer multiple of the R to R period. For the example shown where the inversion time is 1400ms and the R to R interval is 105ms, the smallest integer which when multiplied by the R to R interval exceeds the inversion time is 14. In this case the calculated delay is 70ms (70ms + 1400ms = 14*105). Since the calculation is made on the fly, the calculated delay will automatically change with animal heart rate to ensure the image data is collected at the same position in the cardiac cycle.

The inversion timing delay calculation can be applied to ECG, respiration or both. The Pulse Invert, Begin Delay and Max Width controls are active during the calculation. Make the desired changes to these parameters, input the inversion time and click the On/Off key. Within 2 seconds, the delayed gate should appear on the monitor display and be output from the ERT Control/Gating Module.

USER RESP SETUP window

Right click on the User Resp waveform to open the USER RESP (USER SPARE RESP) SETUP window.

The following items can be set from the USER RESP window:

1. Labels for both waveform and scale
2. Scaling,
3. Offset,
4. Scale adjust step size
5. High pass filter,
6. The flashing LED on the IBP Module
7. Signal gain

The waveform and scale labels are set in real time. They appear on the monitor display as they are being entered in the USER RESP window.

The analog to digital converter (ADC) has 1024 bits. The user can select the scaling and offset between the ADC scale and the displayed scale. The displayed max and min scaled values can be changed by right and left clicking the values on the monitor display. The step size for this adjustment is set in the Range Adjust Step Size box.

Application of the high pass filter can be useful to remove a DC offset. Selecting “Output to Resp LED” flashes the USER RESP Module’s LED for each User Resp gate.

Analog Input should be selected for the signal Source. The other option T-Resp™ which generates a respiration signal from a temperature sensor is under development and has not been released.

Three gain stages allow overall signal gain to be set between 80 and nearly 20,000 with the option to change signal polarity. The middle gain stage can also be set to AutoGain to automatically track a signal of varying amplitude.

The User Resp software can interpret the waveform in the following ways:

- As a respiration waveform displaying respiration rate and period
- As a slowly changing analog value, like temperature, displaying the value of the measurement
- As a capnograph waveform displaying the respiration rate and end-tidal CO2.

To make the selection for how to interpret and display the information, execute PC-SAM from the desktop and select the option to display the “full setup screen”, then make the selection at the bottom of the USER RESP SETUP window “Rate/Prd”. “value” or “Rate/EtCO2”. The corresponding measurements will be displayed to the right of the USER RESP waveform. The data will also be recorded in the Trend file.

User Resp gates are automatically generated for the User Resp waveform. The presence of gates generates values for User Resp respiration rate and period. The gates can be displayed on the respiratory sweep display and included in the algorithm for generation of output gates.

USER IBP SETUP window

Right click on the User IBP waveform to open the USER IBP SETUP window. The IBP connector on the IBP Module can be used as an IBP channel (IBP3) or as a user auxiliary analog input channel User IBP.

The following items can be set from the USER IBP window:

1. Labels for both waveform and scale
2. Scaling,
3. Offset,
4. Scale adjust step size
5. Signal gain

The waveform and scale labels are set in real time. They appear on the monitor display as they are being entered in the USER IBP window.

The analog to digital converter (ADC) has 1024 bits. The user can select the scaling and offset between the ADC scale and the displayed scale. The displayed max and min scaled values can be changed by right and left clicking the values on the monitor display.

The step size for this adjustment is set in the Range Adjust Step Size box.

Two gain stages allow overall signal gain to be set between 10 and nearly 5,000.

User IBP gates are automatically generated for the User IBP waveform. The presence of gates generates values for User IBP rate and period. The gates can be displayed on the respiratory sweep display and included in the algorithm for generation of output gates.

AUTO EVENT window for time stamping

Left click the Event key to manually log an event in the trend file. Right click the Event key to open the AUTO EVENTS window. The auto events feature allows pulses on the Auxiliary Input to be counted and automatically logged in the trend file. The Auxiliary Input can be either the AUX IN or the FO AUX IN on the ERT Control/Gating Module. A FORT Module can be used to convert an electrical (TTL) signal to an optical signal for input into the FO AUX port (refer to Chapter 3). The event can be triggered from either the rising or falling edge of the pulse.

When enabled, the Auto Event Counter will either increment or decrement from the Start Count value to the Stop Count value. If the window is closed it will reappear when the Current Count reaches the Stop Count. An audible alert can optionally be issued when the Current Count reaches the Stop Count. Options exist to hold, reset or continue counting when the Stop Count is reached. The Apply key sends entered data to the counter software. The Restore key restores the last applied entry.

Note the user can set the Start Count, Stop Count and Current Count to create a non-terminal state. To eliminate this condition, make certain the Current Count can either increment or decrement to the Stop Count value.

ADVANCED GATING SETUP window

The advanced gating menu includes the following additional features:

1. End Delay for the gate generated by each signal except ECG
2. Primary, begin, hold and end conditions for each signal gate included in the construction of the output gate
3. Gate count condition logic

End delay allows the gate to be delayed from its otherwise normal end position.

Primary, begin, hold and end are logical conditions applied to the gates generated for each signal which are included in generation of the output gate.

When using the complex gating control, separate criteria are used for beginning and ending the output gate signal. The beginning of the output gate occurs when all the gate signals checked under Begin are logic high. If a Primary gate is selected, the beginning of the output gate occurs when all the Begin gates are high AND there is a low to high transition of the Primary gate. The end of the output gate occurs when ANY of the Hold gates (gates checked under Hold) goes low, OR when ALL of the End gates go low.

The possibilities for using this gating control are limited only by imagination when one considers the flexibility provided by two external gate inputs and two user definable analog inputs. However, typically, only a few items would be checked, and the end condition would be defined by either Hold or End, but not both (a column with no checks has no effect).

The gate counting feature allows a preset number of gates based on the above criteria to be output, followed by a blockage of outputs until the Gate Count reset condition is met. As an example, it could be set up to reset on expiration and use only the first ECG gate for imaging

Auto Track

The auto track feature provides an automatic way to adjust the respiration gate when the animal’s respiration changes. The feature can be applied to E-Resp^{TM}, Resp or USER RESP. This feature is especially useful during long experiments when variations in either the animal’s sedation or temperature cause respiration to change.

In the GATING SETUP window click a respiration button to display the AUTO TRACK window. Make certain the waveform of interest is selected as E-Resp^{TM}, Resp or USER RESP. Either or both of the parameters Begin Delay and Max Width can be automatically tracked. Enter the desired percentage of the measured respiration rate for one or both parameters and check the Enabled box

Note that the Apply and Cancel keys control the values entered for the auto track parameters. Pressing the Cancel key will display the previous value while pressing Apply sends the value to the ERT Control/Gating Module. The background color in the value box indicates the status. White indicating the value has been sent to the ERT Control/Gating Module. If the enabled box is not checked it does not matter if the parameter value has been sent or not as it will not be used to determine the gate position or width.

For the example shown above Auto Track has been selected to apply to Respiration. The respiration gate has been defined to be during the expiration portion of the waveform by checking Pulse Invert. Begin Delay and Max Width have been set to 5 and 50% of the respiration interval or 15.5 and 155 msec respectively. When changes occur in the animal's respiration rate, the two parameters will automatically track according to the parameter settings.

Chapter 16
Signal Breakout Module

Chapter 16
Signal Breakout Module

Overview

Physiological measurements and gates from the MR-compatible Model 1030 Monitoring and Gating System can be acquired by another data acquisition system or a PC using the Signal Breakout Module.

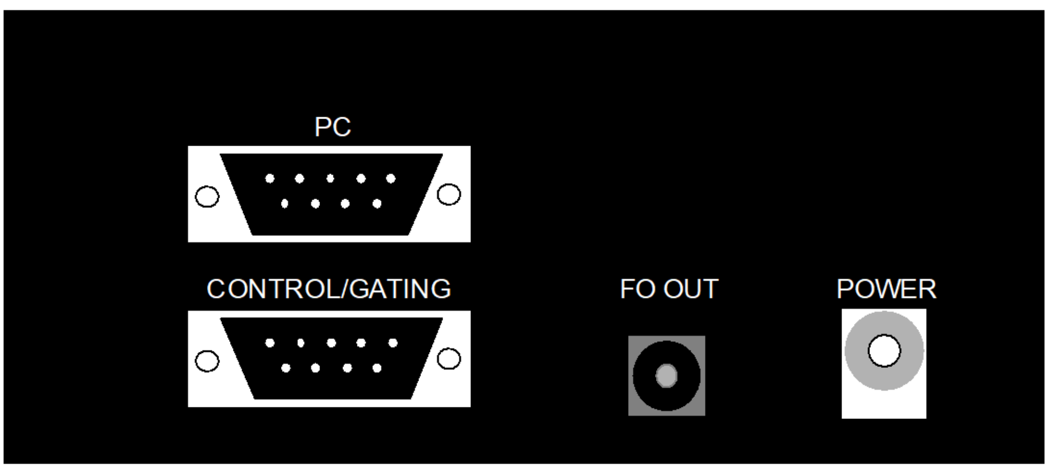
In order to maximize data transmission rate, SA Instrument's monitoring and gating systems send and receive densely packed data on the serial cable connecting between the ERT Control/Gating Module and the PC. The Signal Breakout Module can be connected in the serial line to unpack the data and allow users access to the real time physiological measurements.

Data available from the Signal Breakout Module includes slow data such as heart rate, respiration rate, temperature, etc. as well as fast data including gates and waveforms. The module includes 4 channels each with 3 outputs which are user configurable. i.e. units have the ability for the user to assign which physiological parameters are available on each output. Multiple modules can be used to allow more than 4 channels.

The Signal Breakout Module also provides capability for a second remote display through a fiber optic output connection. The packed data which is output on the fiber optic connection can be converted by a FORT Module to an electrical signal at a remote location for input on the serial or USB port of a second PC. This second PC has all the display capabilities of PC-SAM without the ability to control the system.

Input/output connections

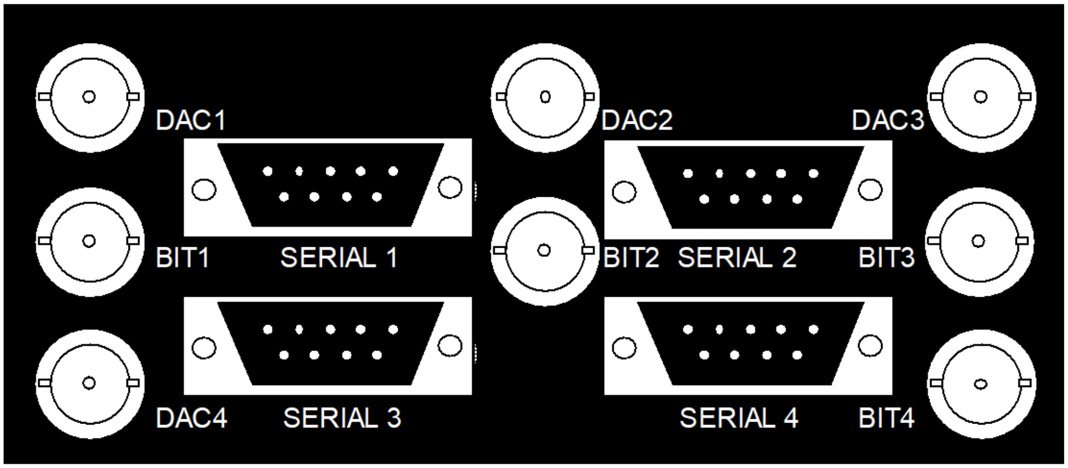
Power panel



PC	Serial I/O connection to PC
Control/Gating	Serial I/O connection to ERT Control/Gating Module
FO out	Fiber optic connection for remote display
Power	12 VDC input

Signal Breakout Module

Physiological measurement output panel



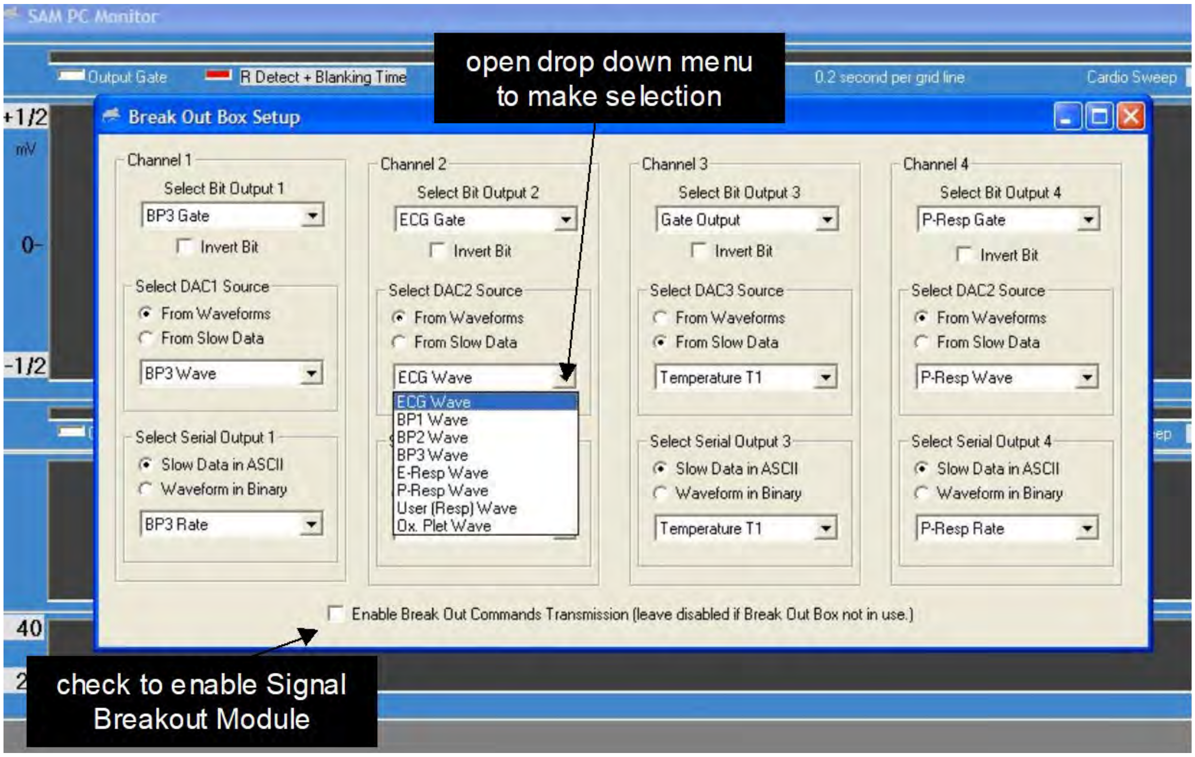
DAC1	Analog output 0 – 5 V channel 1
BIT1	Gate output 0 – 5 V channel 1
SERIAL 1	Serial output channel 1
DAC2	Analog output 0 – 5 V channel 2
BIT2	Gate output 0 – 5 V channel 2
SERIAL 2	Serial output channel 2
DAC3	Analog output 0 – 5 V channel 3
BIT3	Gate output 0 – 5 V channel 3
SERIAL 3	Serial output channel 3
DAC4	Analog output 0 – 5 V channel 4
BIT4	Gate output 0 – 5 V channel 4
SERIAL 4	Serial output channel 4

Setup and use

The Signal Breakout Module connects, using 9-pin D serial cables, to the PC and to the ERT Control/Gating Module. It gets power from the PC over the serial cable or from a dedicated 12 VDC power supply. or from the ERT Control/Gating Module using a daisy chain cable.

Clicking on the “BrkOut” key on the bottom of PC-SAM’s main display opens the BREAKOUT window, shown on the next page. The window has 4 independent channels with drop down menus to set bit (gate), DAC (analog) and serial outputs for each channel. The bit channels can be inverted. For the DAC and serial outputs, a selection between slow data or waveform data should be made before opening the drop-down menu.

Note the box at the bottom of the BREAKOUT window. This box must be checked to enable PC-SAM to send commands to the Signal Breakout Module.



Using multiple Signal Breakout Modules

More than one Signal Breakout Module can be used to output more than four parameters. Here are instructions for using two modules:

1. Connect the first module between the ERT Control/Gating Module and the PC. Configure the 4 channels using the Breakout window in PC-SAM. These settings are saved in EEPROM and will loaded on the next power up. You need to be sure the commands have made it to the Signal Breakout Module. Waiting ten seconds is probably adequate, but if you want to be sure, invert a gate bit from where you want it then invert it back. When you see it flip back all have been updated.

2. Connect the second module between the first module and the PC. This second module can now be configured using the Breakout window in PC-SAM. The commands from the PC do not pass through to the second module. Instead the second module settings are those previously stored in EEPROM.

3. If you want to change the setup for the second module, remove the first and reprogram,

Signal Breakout Module data formats

Waveform data

ECG	900 sps, 1024 count,	512 = 0	5 μV/count
IBP1/2/3	450 sps, 1024 count	90 = 0	3 counts/mmHg
Plet	450 sps, 127 count,	64 = 0	
P-resp	225 sps, 127 count	64 = 0	
E-resp	225 sps, 127 count	64 = 0	
USER resp	225 sps, 1024 count	512 = 0	
CO_2	225 sps, 1024 count	0 = 0	100 counts per 1% CO_2

Slow data

Temperatures	14 bits,	ºF = count/100 + 32; ºC = count/180
Rates	14 bits,	1 BPM/count
Blood pressures	10 bits,	90 counts = 0 mmHg, 3 mmHg/count

Analog output of slow data

Data is shifted to a 12 bit value to maximize use of the output range: 0 – 5 V for 0 – 4096 counts.

Capturing ASCII slow data from the serial output

ASCII values from any of the 4 serial output channels can be read and displayed on a PC using HyperTerminal as follows:

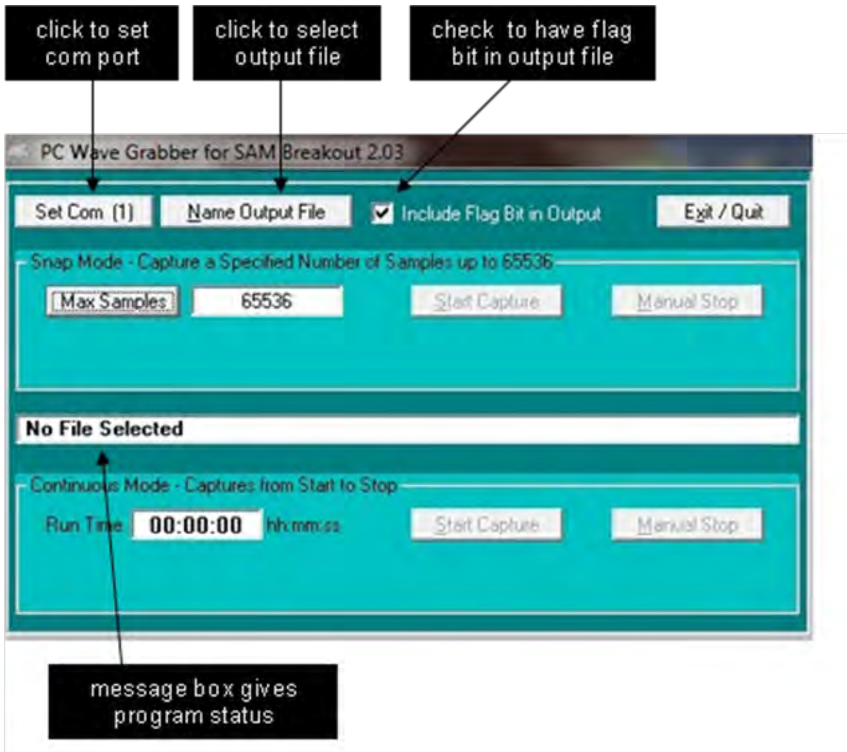
1. Make an appropriate selection for the connection com number.
2. Set the following port settings: 115200 Bits per second, 8 Data bits, Parity None, Stop bits 1, Flow control None.
3. Select File>Properties>Settings>ASCII Setup>ASCII Receiving. Make certain the following are not checked: “Append line feeds…” and “Force incoming data to 7-bit ASCII”. Check “Wrap lines that exceed terminal width”.

Capturing ASCII waveform data from the serial output

Waveform data streams from the serial port at a rate of 1800 8 bit bytes per second. Waveform data is digitized using a 10 bit A/D, so 2 bytes contain a single measurement. WaveGrab.exe can be used to capture the waveform data using a serial or USB PC port and write it as a text file with 900 samples per second. The text file can then be imported into a spread sheet program such as Excel.

To run the software, click on the WaveGrab icon on the desktop. The first time WaveGrab is executed on a PC an authorization code is required to activate the software. The PC’s ID code must be transmitted to SA instruments and then an authorization code for that PC can be entered to activate WaveGrab.

Once activated, you can set the com port, create a name for the text file, select either the number of samples to collect or run continuous and start or stop the capture process. Program status is displayed in a message box.



WaveGrab version 2.03 has the important option to include a flag bit in the output. It is sometimes of benefit to synch data from the MR scanner or another source with the ECG, respiration and other waveforms. In that case, a bit from the scanner or another source can be input to the Model 1030 at the AUX BNC connection of the ERT Control/Gating Module. In this case if you check to output the AUX GATE in the bit output and the waveform in the serial output of one channel using the BREAKOUT window and if the "include flag bit in the output" box is selected in the WaveGrab window then the flag/bit will be output with the waveform data (2 columns of data). This feature allows time stamping 2 or more waveforms so they can be synchronized for analysis.

The flag bit input at the AUX BNC should be a 5 V pulse >1 msec in duration. The bit can be displayed in PC-SAM by selecting AUX Input in the Cardio Sweep display.

Capturing digital waveform data from the serial output

A 2 byte packet is output at 900 packets per second from the serial port. For ECG each packet is a measured data point. For IBP & plet the sample rate is 450 samples/sec and 2 packets are output with the same value. For respiration the sample rate is 225 samples/sec and 4 packets are output with the same value.

The first byte output for the packet has bit 7 = 0 and low bits 0-6. The second byte has bit 7=1, bit 6=1 if data is deemed stale, bit 5 contains the status of the bit out, and high bits 0-4.

To decode the digital waveform data, do the following:
Read in byte by byte
If byte has bit 7 clear, save as low byte
If byte has bit 7 set and there was a previous stored low byte
Then the 2-byte packet is complete and can be decoded.

StaleFlag + HighByte and 64,	Stale flag is bit 6 of high byte
BitOut = HighByte and 32,	Bit output is bit 5 of high byte
IntVal=((HighByte and 31)*128)+LowByte	digital count decoded

Chapter 17
Fiber Optic Universal Gating Module

Chapter 17
Fiber Optic Universal Gating Module

Overview

The Fiber Optic Universal Gating Module can be used to supply a gate pulse to imaging systems. It is always used to supply the gate pulse for clinical imaging systems. The module gets an input from the fiber optic AUX GATE OUTPUT of the ERT Control/Gating Module. The fiber optic pulse is converted to both low level (2 mV) and high level (TTL) output pulses. The imager's ECG cable can be connected to ECG studs on the gating module to feed the low-level gate to the imaging system. Alternatively, the high-level gate can be obtained from the Module's BNC connection.

The module is non-magnetic and RF shielded so when it is being used with a MR system it can be located in the magnet room. Power is supplied from an internal 9 V battery. The module has both power on and low battery indicator lights.

Controls and connections

Fiber Optic Universal Gating Module

Input	fiber optic gate light pulse
Output	2 mV pulse on RA, LA, RL, LL studs TTL pulse on BNC connector
Power switch	activates the 9 V internal battery, the power on and low battery LEDs

Setup and use

When used with a clinical MR system, the Fiber Optic Universal Gating Module is positioned near the patient gantry. A simplex fiber optic cable is connected between the ERT Control/Gating Module's fiber optic AUX GATE output and the Universal Gating Module's fiber optic gate input. The ERT Control/Gating Module is located outside and the Universal Gating Module is located inside the RF shielded room. So, the simplex cable should pass through a wave guide installed in the room.

The optical gate signal is converted to an electrical signal by the Universal Gating Module. The electrical signal can be input to the clinical MR either by supplying the TTL signal to a gate input port (if available) or by supplying the 2 mV pulse to the scanner's clinical ECG cable. In either case, it maybe advantageous to change the gate width or invert the gate pulse using controls in PC-SAM's GATING window.

Clinical scanners typically use both analog and digital filters to remove gradient interference from their ECG input. These filters necessarily add delay to the time the gate is received by the scanner. This delay can be quite large, a few 10s of msec. So, if a TTL gate input is available, it is preferred over input from the clinical ECG cable.

Caution: the 9 V battery should only be replaced with a battery obtained from SAII. Many 9 V batteries are magnetic and may be attracted by the MR magnet.

Chapter 18
Micro-Imaging MR Systems

Chapter 18
Micro–Imaging MR Systems

Overview

Micro-imaging systems have a vertical bore with very limited space. A special "Micro-Imaging Kit" integrates the Model 1030 Monitoring and Gating System with these MR systems. The Micro-Imaging Kit effectively eliminates RF interference between the Micro-imaging MR system, the Model 1030's ERT Module and the external environment. The kit allows gated or ungated images free of RF artifact to be obtained while monitoring the physiological status of the mouse.

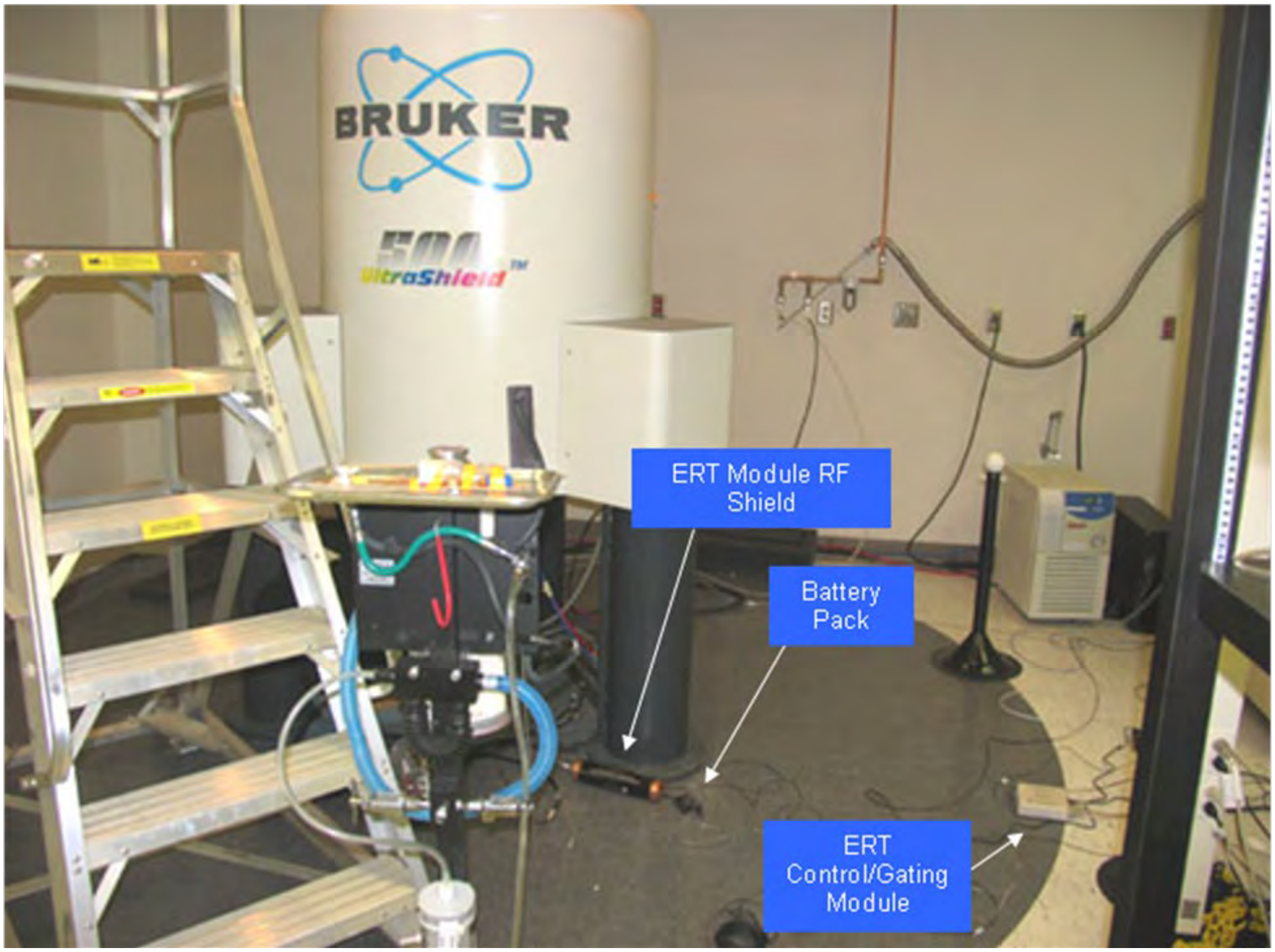
Micro-Imaging Kit

The Micro-Imaging Kit consists of an ERT Module RF Shield, a shielded Lemo cable and an assortment of in-bore sensor and sensor extension cables.

The ERT Module is placed inside the RF shield and connected to the Lemo cable, battery pack and fiber optic cable as shown in the picture above. The connection at the other end of the Lemo cable is connected to a Lemo receptacle mounted in the imaging probe. The battery pack shown in the photo above has recently been replace with a larger battery pack, but connections and function are not changed. The Iso 6 VDC power supply is also an option for powering the ERT Module with the Micro-Imaging Kit.

The ERT Module RF shield and shielded cable in effect place the ERT Module inside the magnet's RF shield allowing MR images to be free of RF induced interference from the external environment.

Micro-Imaging equipment setup



The equipment is implemented with the Micro-Imaging MR system as shown above.

The ERT Module inside the ERT Module RF Shield resides at any convenient location on the floor under the magnet. The Lemo cable connects the ERT Module RF shield to the MR probe which is inserted in the magnet.

Respiration measurements using the pneumatic pillow are made by connecting extension tubing to the ERT Module.

Bruker Micro 2.5 Mouse and Micro 2.5 AHS/RF Imaging Probes

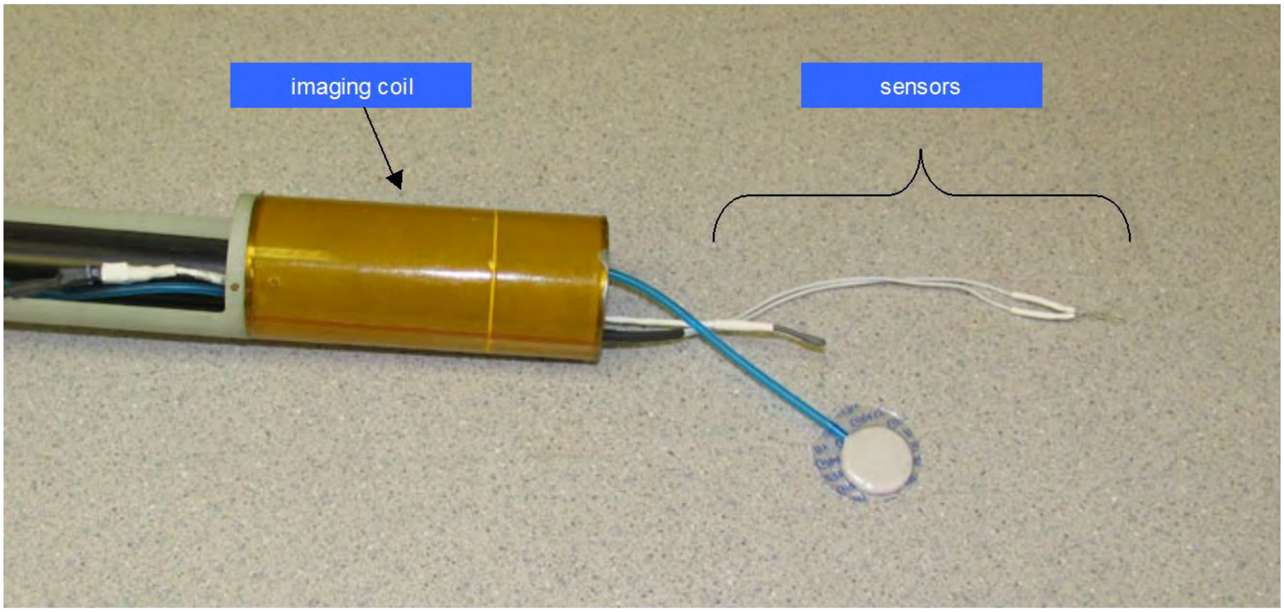
Bruker Micro 2.5 Mouse Probe

The Micro 2.5 Mouse probe is shown above with the Lemo and pneumatic respiration connectors mounted in the probe base.

Connections for ECG and temperature are made in the probe midsection. There are two or three ECG pins and a 3 pin Lemo receptacle in the midsection. If your probe has 2 ECG connections use the ERT 3-lead to 2 lead jumper cable (ERT3-2JMP) to connect the red and black ECG connections at the ERT Module. In this case the red and white connections are made to the ERT shield end cap and the black lead is not connected. A Lemo to Molex temperature extension cable (TPEC-110-10) connects to the Rectal Temperature probe (RTP-101-B). Two or three ECG pins connect to either Subdermal ECG Needle Electrodes (RMEC-703-19), Gold Disk Electrodes (EGD-705-619) or 3M Red Dot electrodes (E3M-103-3). The respiration pillow sensor (RS-302-14) connects to the Leur connection inside the probe body.

Moving the ERT Module RF Shield with the probe allows physiological measurements to be observed during animal setup. After connecting the sensors to the internal probe connections, they can be extended through the coil in preparation for attachment to the mouse.

The temperature probe, ECG needle electrodes and rectal temperature probe are shown below in the extended position for connection to the mouse outside the imaging coil.



After connecting the sensors to the mouse and inserting the mouse into the coil, excess cable should be taped to eliminate a loop and placed in the cavity in the midsection. Likewise, excess pneumatic tubing should be placed in the cavity in front of the Leur connection. Be careful not to kink the pneumatic tubing.

The same set of sensors and temperature extension cable can be used with the Micro 2.5 AHS/RF probe.

Bruker Mini 0.5 AHS/RF Imaging Probe

The Mini 0.5 AHS/RF probe has the same connections for physiological monitoring as the Micro 2.5 probes. However, the Mini 0.5 probe is longer requiring the use of ECG (ETLEC-703-3), temperature (TPEC-109-3) and respiration (RSET-1/4) extension cables.

Bruker Micro-Imaging Kit Components

The following parts are supplied with the Bruker Micro-Imaging Kit (BMIK-111):

Part number	Description
ERTS-110	ERT Module RF Shield
ERTCS-110	Cable, Shielded, Lemo 0B-1B, Micro-Imaging System
RMEC-703-19	Subdermal Needle Electrode set for mouse - 19”
EGD-705-619	Gold Disk Electrode set, 6mm – 19”
RS-302-14	Respiration Pillow Sensor – 14”
TPEC-110-10	Temperature Probe Extension Cable, Lemo – Molex – 10”
ETLEC-703-3	ECG Twisted Lead Extension set – 3”
RSET-1/4	Respiration Tubing Extension – 3”
TPEC-109-3	Temperature Probe Extension – 3”
ERT3-2JMP	ERT 3 lead to 2 lead jumper cable

Chapter 19
ERT 6 VDC Isolated Power Supply

Chapter 19
ERT 6 VDC Isolated Power Supply

Overview

A power supply option is available that can power the Model 1030's ERT Module in many MR installations. Most facilities that have a magnetically shielded magnet in a RF shielded room can use the ERT power supply in place of the ERT Module Battery Pack. Facilities that have a magnetically and internally RF shielded magnet can also use the power supply by installing the power supply interface kit.

The ERT power supply converts 12 VDC to 6 VDC with isolated grounds. It has a small isolation transformer that becomes saturated and stops working in a magnetic field larger than 100 gauss. The fringe field of a magnetically shielded MR magnet is usually less than 100 gauss 2 to 3 feet from the bore. Power is delivered to the ERT Module using a 12 foot RF shielded power supply cable.

System components and connections

The components of the ERT power supply option are shown in the picture below.

The connections are as follows:

input	12 VDC
output	6 VDC

ERT 6 VDC Isolated Power Supply

Connecting the power supply cable

The cable attaches to the ERT module and power supply using small Lemo connectors. To make the connection, align the red dots and push the connector straight into the receptacle. To disconnect the cable, grasp the connector with the thumb and index finger near the red dot and pull straight back. Do not turn or twist the connector housing.

System setup and test:

1. Connect the 12 VDC power supply to mains (100 – 230 VAC) and to the ERT Isolated 6 VDC power supply.

   Caution: the 12 VDC power supply is slightly magnetic and should be fix mounted in the magnet fringe field.

2. Connect the ERT power supply to the ERT Module using the RF shielded power supply cable.

3. Run PC-SAM and open the SYS INFO window. Observe the value reported for the ECG Module battery voltage. This is the voltage being supplied from the ERT power supply. The reported voltage should be greater than 6 volts when the ERT power supply is in a field < 100 gauss and 0 when in a stronger field. Move the ERT power supply module in the fringe field observing the reported voltage to determine a suitable location.

4. Compare MR images with and without the ERT Module to establish that images are not degraded by extending the power supply cable into the magnet bore.

Power Supply Interface Kit:

The power supply interface kit allows the ERT isolated 6 VDC power supply to work with magnetically and internally RF shielded magnets by extending the magnet's RF shielding to a region of low magnetic field. The kit consists of a "waveguide cap" or a "waveguide plug" and an ERT battery pack extension cable,

Magnets with an accessible waveguide can attach a "waveguide cap" with the receptacle end of the ERT extension cable fix mounted to the cap. The other end of the extension cable extends into the magnet bore to connect to the ERT Module. The long RF shielded cable connects between the isolated 6 VDC power supply and the receptacle in the waveguide cap. In a similar manner, magnets which do not have an accessible waveguide can install a small "waveguide plug" with the receptacle end of the extension cable fix mounted. Contact SA Instruments if you are interested in implementing this kit with your magnet.

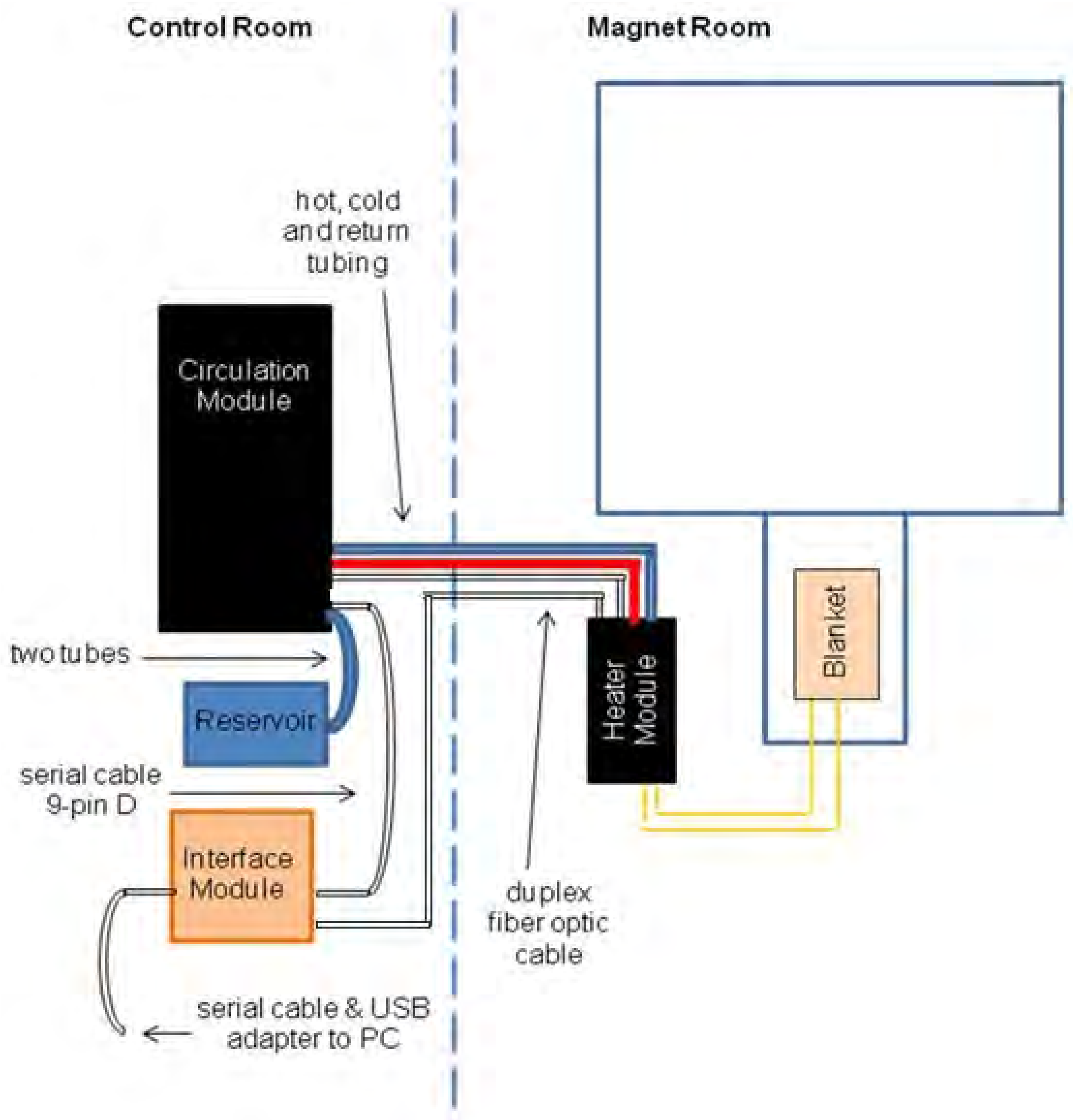
Chapter 20
Dual Pump Fluid Heater System

Chapter 20
Dual Pump Fluid Heater System

Overview

The MR-compatible Dual Pump Fluid Heater System is used to control the temperature of small animals undergoing imaging procedures. It is an option for any of the SA Instruments' Monitoring and Gating Systems. The heater system has been designed to control the temperature of the fluid flowing to the heating pad or the heating pad temperature or the body temperature of animals. The fluid is usually water, but optionally the fluid can be polyether. Polyether does not produce a signal in MR, however even though water does produce a MR signal, water does not create an artifact in the image.

The SAII Dual Pump Fluid Heater System consists of a Circulator Module located



outside the RF shielded magnet room and a Heater Module located near the bore of the magnet. The Heater Module is RF shielded and non-magnetic. It is powered from 100, 115 or 230 VAC 50 – 60 Hz.

The Heater Module should be placed as close to the magnet bore as practical. It can be on the SAII MR-compatible instrument stand, on a table or on the floor. The optimum location will allow the 2 m fluid tubes to connect to a heating pad in the bore near the imaging volume.

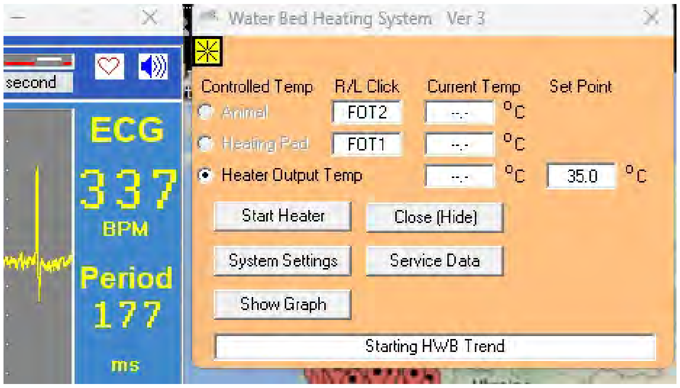
Hot, cold and return fluid tubes connect between the Circulator Module and the Heater Module. In addition, a duplex bi-directional fiber optic cable transmits data and commands between the Circulator Module and the Heater Module.

Operation

PC-SAM software provides user control of the system. The PC connects to the Circulator Module and to the monitoring system using two separate USB ports.

Clicking on the Heater button at the bottom of PC-SAM's main display followed by clicking on the water bed button opens the WBH USER INTERFACE window.

WBH USER INTERFACE window



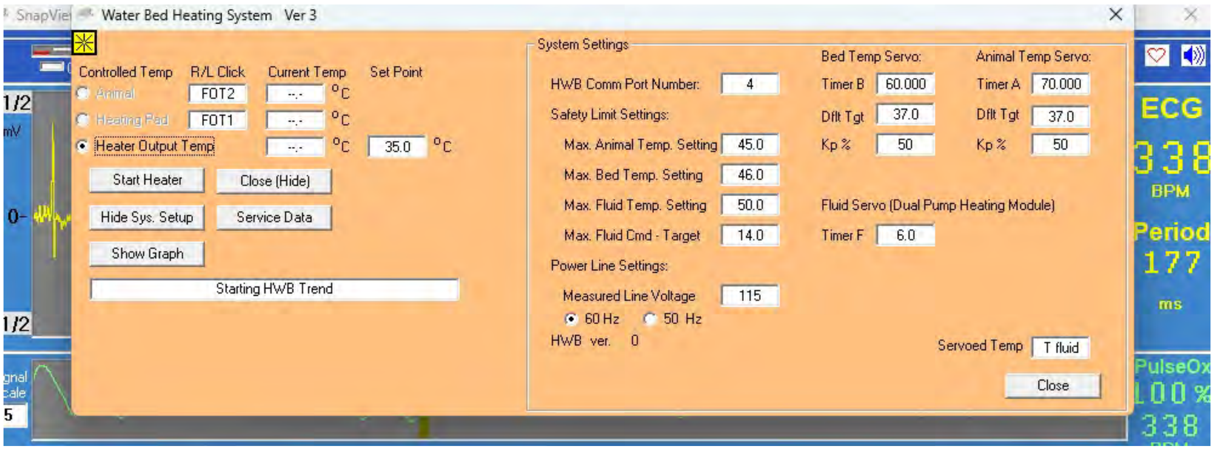
The message area on the bottom of the window gives system status and error messages. On the left of the window the user can select the method of control, the temperature probe for measuring the animal or heating pad and the temperature set point. Click in the box to change between available probes. Note the control selection is grayed out or made inactive if the probe selected does not have a valid temperature reading. Measured values are displayed for the temperature probes and for the heater output temperature, Tout, which is the temperature of the hot and cold fluid mixture,

The window has the following buttons:

- Start or stop the heater
- Display or hide Systems Settings window
- Show or hide graph which displays temperature trends
- Service data window

SYSTEM SETTINGS window

This window contains the communication port assignment, safety limit settings, power frequency setting, timer in seconds and controls for the bed and animal control systems. These controls are discussed in a later section of this chapter.



SERVICE DATA window

The Service Data window, not shown, allows many parameters to be viewed which are not useful to the user. However, the window does allow the user to see the two parameters which the control software is setting “flow command” and “PWM count” it also displays Tin, the Heater Module inlet fluid temperature and the mixed fluid temperature or Tout, which is also displayed in the HWB USER INTERFACE window.

The system adjusts the flow command to control the mixed water temperature or Tout on the set point. As the system adjusts the hot flow, the cold flow is changed to keep total flow constant.

The “PWM count” is proportional to the current delivered to the fluid heating element. PWM count is between 0 and 1024. PWM of 0 turns the heater off. PWM of 1024 delivers maximum current to the heating element.

GRAPH window

The graph window accumulates over time up to 8 WBH parameters including flow, PWM, several temperatures and set points. The display is a useful tool to record system performance and diagnose problems.

Dual Pump Fluid Heater System

Circulator Module input output connections

Electrical connections:

Interface Module	serial connection to the Interface Module that connects to the PC

Fluid connections:

HOT	fluid flow to Heater Module for hot
COLD	fluid flow to Heater Module for cold
RETURN	fluid flow from Heater Module
TO RESERVOIR	optical input from Heater Module
FROM RESERVOIR	optical output to Heater Module

Interface Module input output connections

Electrical connections:

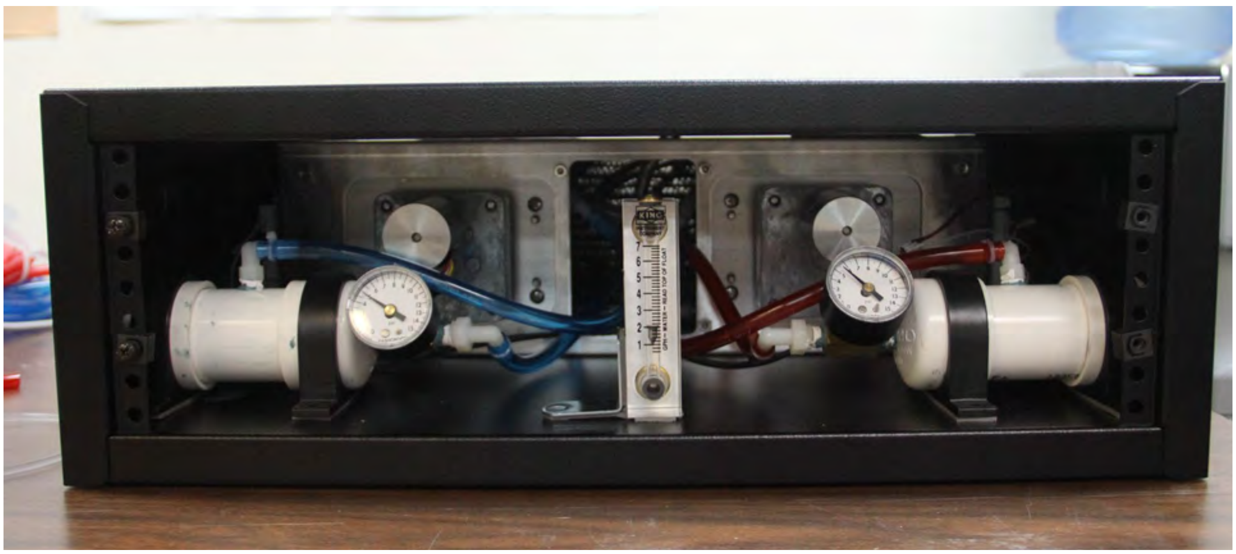
PC	serial and USB to serial adapter connection to the PC
Circulator Module	serial connection to the Circulator Module
Power	12 VDC power connection

Optical connections:

HEATER IN	fiber optic to the Heater Module
HEATER OUT	fiber optic from the Heater Module

Circulator Module flow meter and pressure gauges

The flow meter and pressure gauges are shown below. Flow is typically 2 GPH. The pressure of the hot and cold lines depends on the heating pad in use, but it should be 15 psi or less. The life of the roller pump tubing is pressure dependent. The tubing life is longer when operating at lower pressure.



Heater Module input output connections

Cold fluid end:

HOT	input for hot fluid
COLD	input for cold fluid
RETURN	output for fluid from the heating pad
FORT IN	optical input from Circulator Interface Module (gray)
FORT OUT	optical output to Circulator Interface Module (blue)

Warm fluid end:

AC power	input power for 100 – 120 VAC or 230 VAC
WARM	output for fluid to the heating pad
RETURN	input for fluid from the heating pad

Heating pads

Flexible, curved and flat heating pads are available for small animals. Flexible pads have the shape of an inverted U and can cover the animal' back and sides or chest and sides. The beds are usually inserted in a thin disposable plastic cover before use.

Flexible heating pads	ODxLxT mm:
mouse	38x 76x3
large mouse	48x102x4
rat	57x152x5

Curved heating pads	WxLxT mm:
mouse	30x 76x3
large mouse	35x102x4
rat	40x152x5

Flat heating pads	WxLxT mm:
mouse	30x 76x3
large mouse	35x102x4
rat	40x152x5

Heating blanket

The heating blanket for large animals is a 12" x 24" thin flexible polycarbonate sheet with tubing attached. Two tubes 10' long extend from the blanket and connect to the Heater Module without the need for fittings or connectors. This construction minimizes the risk of getting water in the bore of the magnet. A sheet is normally positioned between the animal and the heating blanket.

Dual Pump Fluid heater System setup in MR

The Circulator Module (880100) should be located outside the RF shielded magnet room. The Circulator Module has magnetic parts and is not RF shielded. The Heater Module (76x100) should be located inside the RF room near the bore of the magnet. The Heater Module is RF shielded and non-magnetic. It is powered from 100, 115 or 230 VAC, 50 – 60 Hz. Check to make sure your power matches the specification on the Heater Module label.

The Heater Module should be placed as close to the magnet bore as practical. It can be on the SAII MR-compatible instrument stand or on a table or on the floor. The optimum location will allow the 3 m fluid tubes to connect to a heating pad or blanket in the bore near the imaging volume.

Connections to the Circulator and Circulator Interface Modules

A duplex fiber optic cable (10DFOC-23) connects between the Interface Module and the Heater Module. The WBH hot, cold and return tube set (WBH3TS-10H/C/R) connects between the Circulator Module and the Heater Module. The standard tubing set is red for hot blue for cold and clear for return fluid. The tubing is 3/8” OD x ¼” ID 30’ long.

Run the tubing set and the duplex fiber optic cable through a waveguide into the magnet room. The Heater end of the tubing set has connections which reduce to 3/16” OD tubes.

Connect the red, blue and clear tubes to the Circulator Module at the connections labeled HOT, COLD and RETURN respectively. Make certain the 3 tube clamps are in the open position. Connect the tubes from the Reservoir to the Circulator Module. Use a small cable tie to secure each tube to the connector.

Caution: All cable ties need to be tight enough so that they will not turn with twisting motion. Use a cable tie tool to tighten the tie or use needle nose pliers to grasp the cable at the connector and twist to tighten. Cut excess cable when tight.

Connect the duplex fiber optic cable to the Circulator Interface Module. Make certain the color of the connector matches the color of the receptacle.

Connect a serial cable to a USB to serial adapter cable (USB-20) and to the Circulator Interface Module. Connect the USB connector to the USB port on the PC.

Connect the Circulator Interface Module to the WBH 12 VDC power supply (WBHPS-12).

Connect the Circulator and Circulator Interface Modules using a serial cable.

Connections to the Heater Module

Connect the 3/16” OD tubes to the Heater connections labeled HOT, COLD & RETURN by simply pushing them into the connectors. To remove the connection press in the small collar on the connector and gently pull the tube out. Make certain the 3 tube clamps are in the open position.

Strain relief the hot, cold and return tube set using a cable tie connected to the mount provided on the cold fluid end of the Heater Module..

Connect the duplex fiber optic cable to the Heater Module. Make certain the color of the connector matches the color of the receptacle.

Connect one end of the heater to bed tubing set (WBHHB-1) to the WARM and RETURN connections on the Heater Module.

Connect mains power.

Connections to the Heating pad

Connect the heater to bed tubing set to the heating pad or blanket of choice. Heating pads supplied by SA Instruments come with tubing that can be inserted in the ends of the push to connect fittings on the ends of the heater to bed tubing. Make certain the tube clamps (2) are in the open position.

Energize the Dual Pump Fluid heater System

Add cold fluid to the reservoir and follow these steps:

1. Connect the monitor’s USB cable to the PC,
2. Connect the Dual Pump Fluid heater System USB cable to the PC.
3. Launch PC-SAM from the icon on the desktop.
4. Click the button to display the monitor window.
5. Open the HEATER window
6. Click the Water Bed button to open the WBH User Interface
7. If the error message “Serial Port Setup Failed” is displayed in the message window, open the SYSTEMS SETTINGS window and set the com port. Follow the instructions in Chapter 2 to determine the com port assigned to the USB cable
8. Turn on power to the Circulator Module. The pumps should turn on.
9. Check connections to make sure there are no leaks.

Let the system run for about 30 minutes or until all the air is out. Add more fluid to the reservoir as needed. The system will hold about 3 liters of fluid.

If the fluid is water, add 2 or 3 teaspoons of chlorine.

When all the air is out of the system, the Circulator Module flow meter should read 2.0 +/- 0.5 gallons per hour and the two pressure gauges should have readings between 4 and 15 psi depending on the heating pad in use. If the flow is low refer to Appendix D.

Refer to Appendix D for maintenance instructions for the Dual Pump Fluid Heater System.

Controlling on heater output temperature

Click the option to control on the Heater Module output temperature. Set the target set point. Pick a value for the set point between 31 and 48 ºC. The temperature of the heating pad will typically be a few ºC below the Heater Module output temperature.

Turn on the Heater Module power switch and click “Start Heater” to turn on the Heater Module. The yellow HEAT LED should start to flash. Note that moving a window turns off the Heater Module in versions of PC-SAM earlier than 9.0906.

For a target temperature of 40 ºC the output fluid temperature should rise from room temperature and become stable around the target temperature within 5 minutes.

Turning off the Dual Pump Fluid heater System

Click the “Stop Heater” button to turn off the Heater Module. Let the pumps continue to run for 5 – 10 minutes to allow the temperature of the fluid in the Heater Module to cool down. The yellow HEAT LED on the Heater Module should go off as soon as the “Stop Heater” button is clicked, but the mixed fluid temperature will remain at the set point for a few minutes as the control system is changing the hot and cold pumps speeds. When the mixed fluid temperature (Tout) falls below the set point turn off the Heater and Circulator Modules.

> **Caution: Turn off the Heater Module and let the Circulator Module continue to run for a few minutes. If Circulator is stopped when the Heater Module is at a high temperature the heat chamber temperature can climb rapidly and may cause the fluid to boil.**

Controlling on heating pad temperature

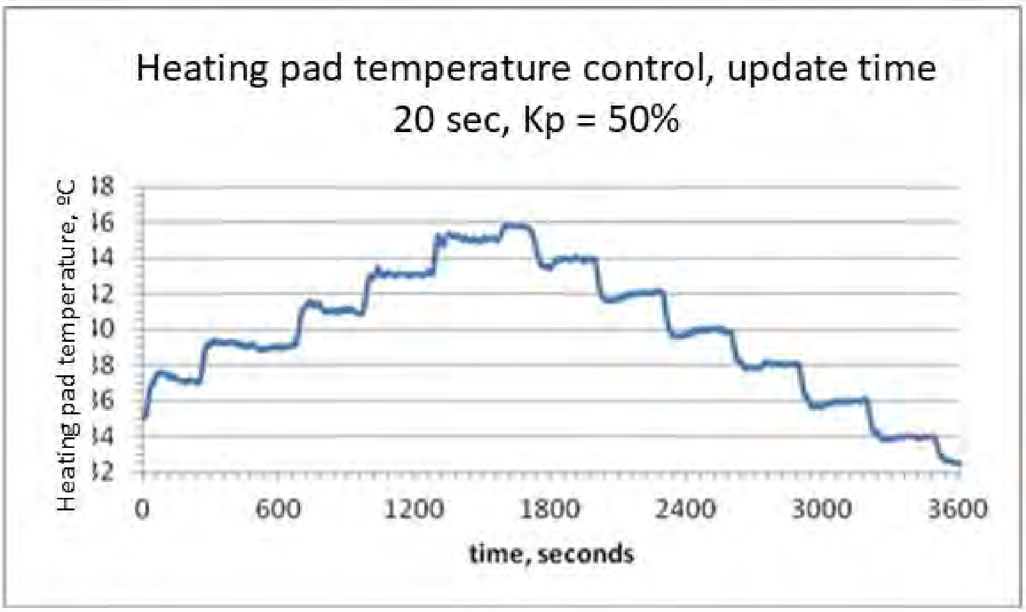
Controlling on heating pad temperature is performed by PC software using the same parameters for Single and Dual Pump Heating Systems.

The heating pad temperature control algorithm uses the values for Timer B and Kp listed in the Bed Temp Servo portion of the System Settings window. The algorithm is a simple PID control servo using just the proportional parameter. A new heating pad temperature (Tnew) is calculated every Timer B interval using the current heating pad temperature (T0), set point (Tsp) and Kp. as follows:

$$T_{new} = T0 + Kp*(Tsp – T0)$$

Turning off/on the Heater Module and/or updating the target setting resets the PI

We obtain good results as shown in the plot below with the proportional term set to 50% and an update time of 20 seconds. Here we have changed the bed temperature every few minutes. There is a few second delay followed by a rise of bed temperature over about 25 seconds followed by a small overshoot before settling at the set point value.



Controlling on animal temperature

Controlling on animal temperature is performed by PC software using the same parameters for Single and Dual Pump Heating Systems.

Controlling animal temperature uses the same control algorithm as used to control on the heating pad. In this case the timer is Timer A. We get good results with a 70 second timer and Kp = 50%.

An example of controlling on the animal temperature is detailed on page 21-6 and the graphs on page 21-7 of the following chapter.

Polyether as an alternate fluid

Perfluorinated, inert polyethers with no hydrogen in the molecular structure can be used in place of water to eliminate a fluid signal in MR images. These fluids have low viscosity and low water absorption. They are nonflammable, nontoxic and safe for the environment.

Polyether fluids are manufactured by Solvay Solexis, Inc. and distributed by the Kurt J Lesker Company www.lesker.com. Grade H110 with a boiling point of 110 ºC is recommended for use with the Dual Pump Fluid heater System.

Chapter 21
Single Pump Fluid Heater System

Chapter 21
Single Pump Fluid Heater System

Overview

The MR-compatible Single Pump Fluid Heater System is used to control the temperature of animals undergoing imaging procedures. It is an option for all SA Instruments' Monitoring and Gating Systems. The heating system has been designed to control the temperature of the fluid flowing to the heating pad or to control the heating pad temperature or the body temperature of animals.

The Single Pump Fluid Heater System, shown below, consists of a Circulation Module, a Heater Module and a Reservoir located in the magnet room. The Heater and Circulation Modules are RF shielded. The heater Module is non-magnetic. The Circulation Module contains a small amount of ferromagnetic material and is fix mounted to the Heater Module or the roll stand. The system is powered from 100, 115 or 230 VAC, 50 – 60 Hz.

Water is circulated through the closed loop system at constant flow (1.5 GPH) and low pressure (5 psi). PC software controls the temperature of the water being circulated through a heating pad or blanket covering the animal in the magnet bore. Control is based on a user defined set point for the water output temperature, the heating pad temperature or the animal temperature.

Single Pump Fluid Heater System

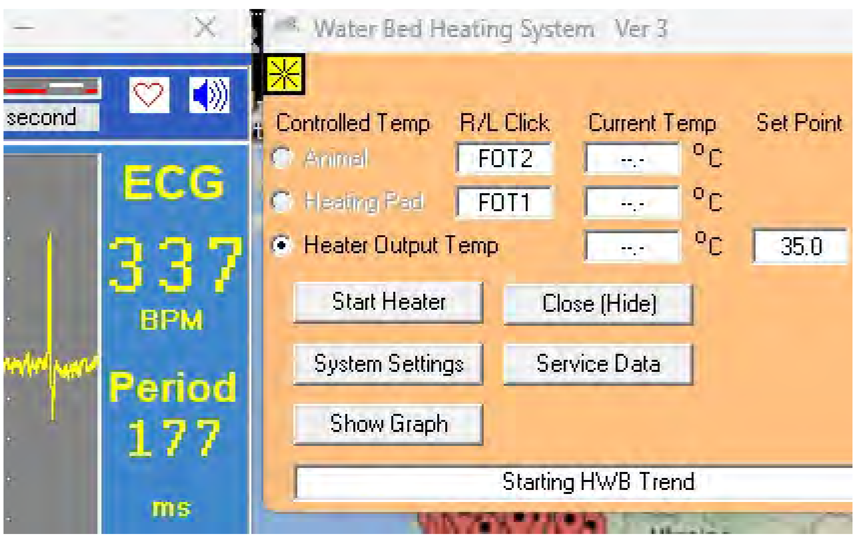
Operation

Make the selection in the "full setup" window to activate the Single Pump Fluid Heater System.

PC-SAM software provides user control of the heating system. The PC connects to the Heater Module through a FORT Module and to the Model 1030 Control/Gating Module using two separate USB ports.

Clicking on the Heater button at the bottom of PC-SAM's main display followed by clicking on the water bed button opens the WBH USER INTERFACE window.

WBH USER INTERFACE window



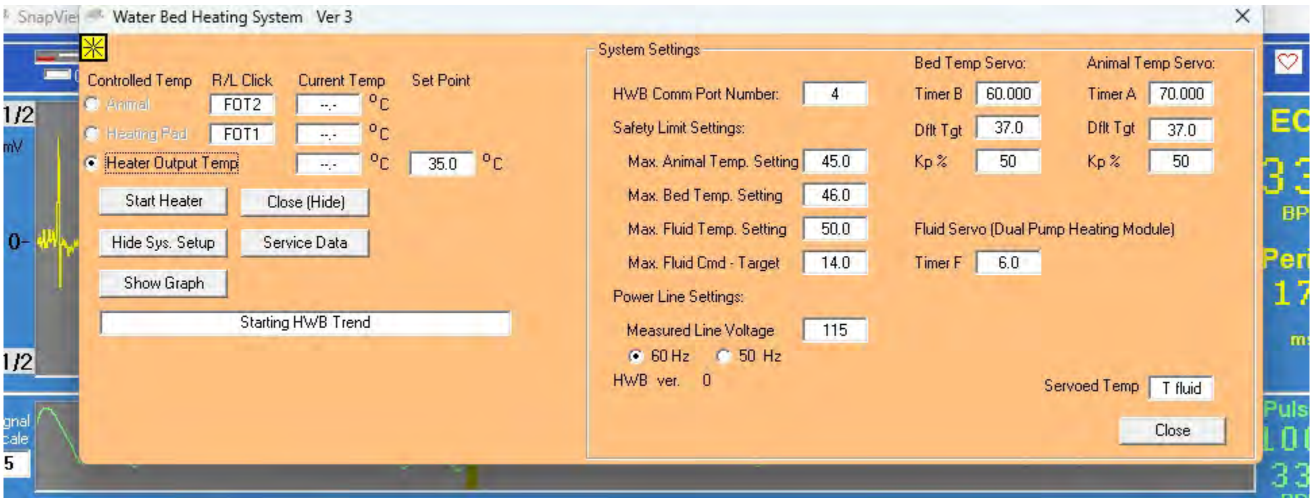
The message area at the bottom of the window gives system status and error messages. On the left of the window the user can select the method of control, the temperature probe in use for measuring the animal or heating pad and the temperature set point. Click in the box to change between available probes. Note the control selection is grayed out or made inactive if the probe selected does not have a valid temperature reading. Measured values for fluid output and temperature probes are displayed.

The window contains the following buttons:

Start or stop the heater
Display or hide Systems Settings window
Show or hide graph which displays temperature trends
Service data window

SYSTEM SETTINGS window

This window contains the communication port assignment, safety limit settings, power frequency setting, timer in seconds and controls for the heater output temperature and bed and animal control systems. These controls are discussed in a later section of this chapter.



SERVICE DATA window

The Service Data window allows many parameters to be viewed which are not useful to the user. However, the window does allow the user to see the parameter that the control software is setting “PWM count” which determines the current delivered to the heating element. The window also displays Tin and Tout. Tin is the fluid temperature entering the Heater Module which is also the Reservoir temperature. Tout is the fluid temperature exiting the Heater Module. This is the same temperature displayed in the WBH User Interface window.

PWM count is between 0 and 1024. PWM of 0 turns the heater off. PWM of 1024 delivers maximum current to the heating element.

GRAPH window

The graph window accumulates over time up to 8 WBH parameters including PWM, several temperatures and set points. The display is a useful tool to document system performance and to diagnose system problems.

Single Pump Fluid Heater System

Circulation Module input output connections

Electrical connections:

Power	12 VDC power connection

Fluid connections:

FROM RESERVOIR	cool fluid to Circulation Module
TO HEATER	cool fluid to Heater Module
FROM HEATER	warm fluid from Heater Module
TO RESERVOIR	cool fluid from Circulation Module

Heater Module input output connections

Cold fluid end:

FROM CIRCULATOR	cool fluid input
TO CIRCULATOR	warm output from the heating blanket
FROM FORT	optical input from FORT Module
TO FORT	optical output to FORT Module

Warm fluid end:

AC power	input power for 100 – 120 VAC or 230 VAC
WARM	output for fluid to the heating blanket
RETURN	input for fluid from the heating blanket

Heating pads

Flexible, curved and flat heating pads are available for small animals. Flexible pads have the shape of an inverted U and can cover the animal’ back and sides or chest and sides. The beds are usually inserted in a thin disposable plastic cover before use.

Flexible heating pads	ODxLxT mm:
mouse	38x 76x3
large mouse	48x102x4
rat	57x152x5

Curved heating pads	WxLxT mm:
mouse	30x 76x3
large mouse	35x102x4
rat	40x152x5

Flat heating pads	WxLxT mm:
mouse	30x 76x3
large mouse	35x102x4
rat	40x152x5

Heating blanket

The heating blanket for large animals is a 12” x 24” thin flexible polycarbonate sheet with tubing attached. Two tubes 10’ long extend from the blanket and connect to the Heater Module without the need for fittings or connectors. This construction minimizes the risk of getting water in the bore of the magnet. A sheet is normally positioned between the animal and the heating blanket.

System setup

If using the roll stand position the shelf (321966) on the base of the roll stand and secure it with cable ties. Position the Single Pump Circulation Module (880200), the Heater Module (76x200) and the Reservoir (321322) on the shelf as shown in the photo on page 21-1. Fittings for the tubes are at the back of the stand, while the power switches are at the front of the stand. Fix mount the Circulation Module to the shelf by attaching the shelf ring lug to a screw on the bottom and front of the Circulation Module.

If the roll stand is not being used, fix mount the Circulation Module to the Heater Module. Remove one of the screws from the Heater Module inlet power connector and reconnect securing the ring lug from the Circulation Module,

Connect the 3/8 OD tubing (SPFHSTS-10) as shown in the photo on page 21-1. Connect the heating blanket (FHS-BLANKET) or the heater to bed tube set (WBHHB-2) with one of the heating pads to the Heater Module at fittings labeled WARM and RETURN. Connect the Circulation Module to the 12 VDC power supply (SPCMPS-12)

Prime the pump by disconnecting the hose at the “hot” connection of the Heater Module and hold it over a cup or pail lower than the Reservoir. Apply 12 VDC power.to the Circulator Module. The pump should prime in just a few seconds.

Connect the duplex fiber optic cable to the Heater Module. Connect the other end of the duplex cable to the FORT Module (M92001) located near the PC and Control/Gating Module. Connect a USB to serial adapter cable (USB-21) to a USB port on the PC and to the FORT.

Single Pump Fluid Heater System

Control on Heater Module output fluid temperature

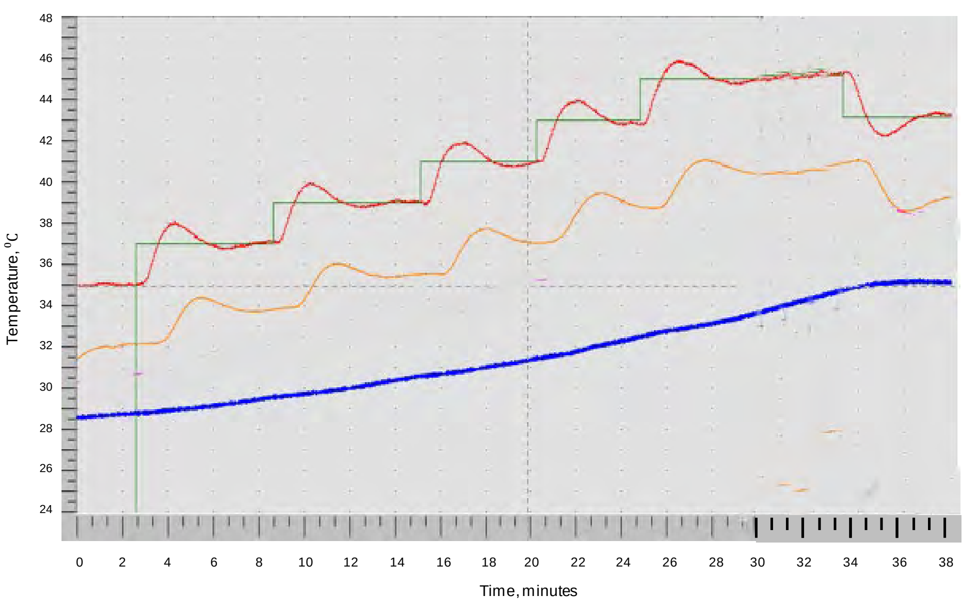
The simplest and a very effective way to regulate animal temperature is to control on the output fluid temperature. Power on the Heater and Circulation Modules. If the com port for the heater system has not been previously set, open the SYSTEM SETTINGS window and set the com. Select the option to control on output fluid temperature in the HWB USER INTERFACE window and enter a value for the set point. Click START HEATER. You should see the output temperature rapidly rise to the set point as in the graph on the next page.

Often it is necessary to run the system with the fluid output temperature at 40 ^{0}C or higher. If you set the target setpoint to 40 ^{0}C from a cold start the system will overshoot and trip the high temperature setpoint which turns the Heater Module off. To keep this from happening, first control at 35 ^{0}C, and then after a few minutes control at 40 ^{0}C.

In the graph below, the output temperature is red, the blanket temperature is yellow and the reservoir temperature is blue. The set point was changed in 2 ^{0}C increments from 35 ^{0}C to 45 ^{0}C and then decreased to 43 ^{0}C. For each new setting the output temperature reaches the set point in just under a minute. Then there is an overshoot of about 1 ^{0}C for almost 2 minutes. Finally, there is a very small decaying oscillation about the set point temperature.

Note that the blanket temperature is lower than the Heater Module output temperature by about 3 ^{0}C. But the difference will depend on the heat loss of each setup. The blanket temperature lags the Heater Module output temperature by about 40 seconds due to the flow rate and the length of tubing. The fiber optic temperature probe was positioned on the blanket at the middle of the tubing. That is the measurement was made at a position half of the total tubing length.

The PID control algorithm uses 4 parameters from the SYSTEM SETTINGS window PWM/c, Pfluid, Ifluid and Dfluid. Changing the flow or altering tubing length could make it necessary to calculate new parameters. If that is the case, contact SA Instruments.



Controlling on heating pad temperature

Controlling on heating pad temperature is performed by PC software using the same parameters for Single and Dual Pump Heating Systems.

The heating pad temperature control algorithm uses the values for Timer B and Kp listed in the Bed Temp Servo portion of the System Settings window. The algorithm is a simple PID control servo using just the proportional parameter. A new heating pad temperature (Tnew) is calculated every Timer B interval using the current heating pad temperature (T0), set point (Tsp) and Kp. as follows:

$$Tnew = T0 + Kp*(Tsp - T0)$$

We get good results with a 60 second timer and Kp = 50 %.

Controlling on animal temperature

Controlling on animal temperature is performed by PC software using the same parameters for Single and Dual Pump Heating Systems.

Controlling animal temperature uses the same control algorithm as used to control on the heating pad. In this case the timer is Timer A. We get good results with a 70 second timer and Kp = 50%.

Turning off the Fluid Heater System

Let the Circulation Module run for a few minutes after turning off power to the Heater Module, to allow hot water in the system to cool.

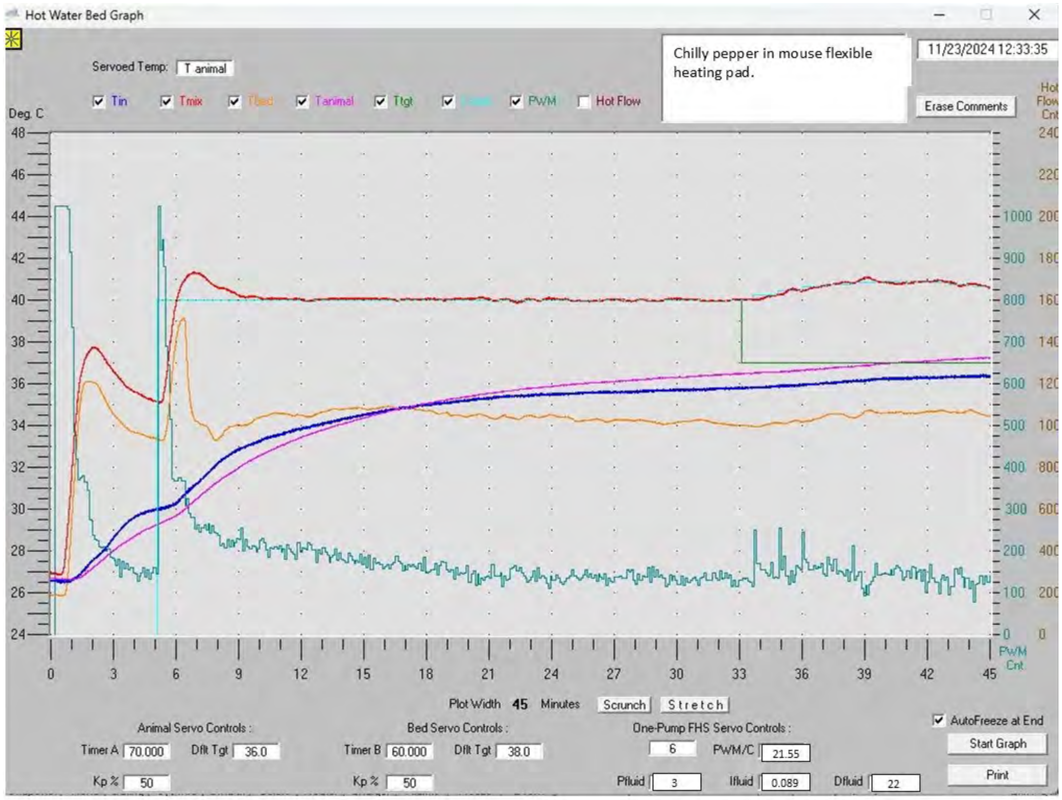
Example of Controlling on Animal

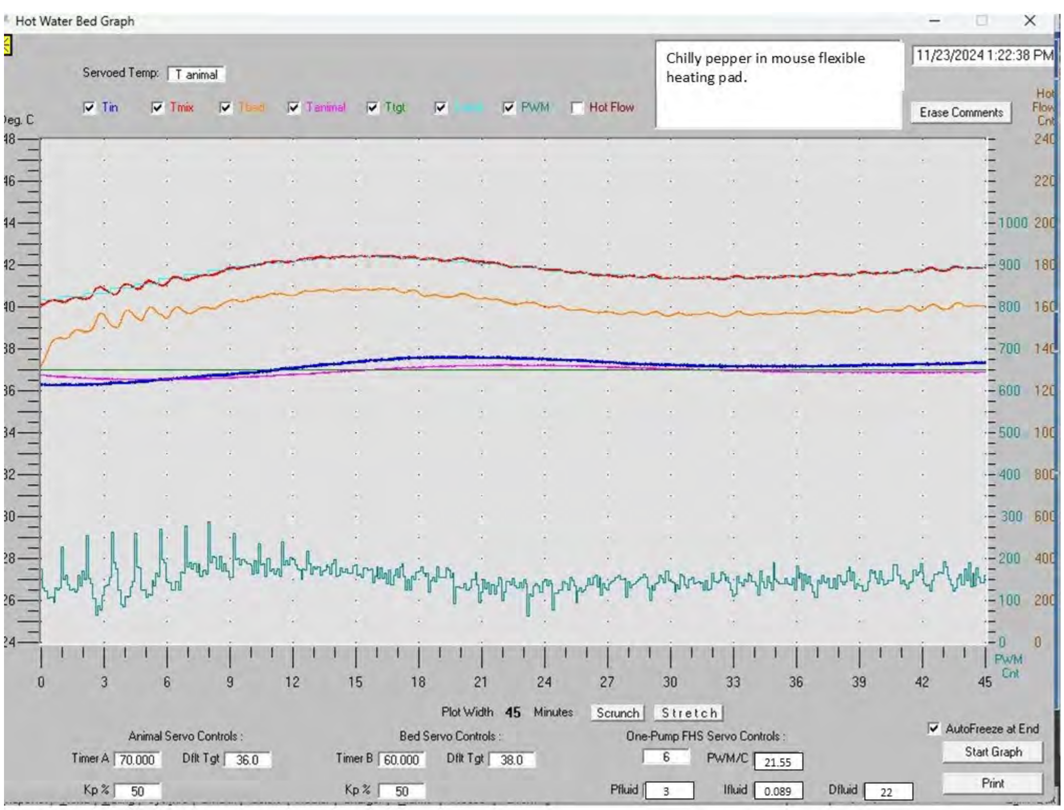
The graphs on the next page exhibit the Single Pump Fluid Heater System performance controlling first on output water at 35 ^{0}C, then at 40 ^{0}C and finally when the animal temperature gets near the 37 ^{0}C setpoint, control was switched to the animal temperature

In the graphs, the output water is in red, the heating pad temperature is in yellow, the animal temperature is pink, and the reservoir temperature is blue. The green trace is PWM which is proportional to the current in the heating element.

In the first graph at time 7 minutes, the temperature probe monitoring the heating pad came loose. It was attached to the heating pad for the 2nd graph.

Single Pump Fluid Heater System





Chapter 22
Capnograph for Large Animals

Capnograph for Large Animals

Available options

Animals with heart rates less than 300 BPM can be monitored using the SAII large animal non-invasive blood pressure (NIBP) and large animal Capnograph options for the Model 1030 Monitoring and Gating system.

The data acquisition modules for the large animal options are designed to operate close to the magnet bore in a fringe magnetic field of 100 gauss or less. They contain a small amount of ferromagnetic material so they should be fix mounted in the magnet's fringe field. An easy way to fix mount the modules is to attach them to the SAII MR-compatible roll stand.

> **Caution: The NIBP and Capnograph Modules for large animals must be fix mounted in a magnetic field less than 100 gauss**

Capnograph overview

The **Capnograph Module** provides continuous monitoring of respiratory carbon dioxide in animals with respiration rates less than or equal to 150 breaths per minute. It includes a CO_2 sensor, barometric pressure transducer, sampling flow control and a miniature vacuum pump. A microprocessor collects data from the sensor and calculates the following real-time parameters: CO_2 concentration, respiration rate, end-tidal CO_2, minimally inspired CO_2, inspiration and expiration times. The CO_2 waveform, end-tidal CO_2 and minimally inspired CO_2 can be displayed in mmHg, kPa or percent.

The module operates in a fringe magnetic field of 100 gauss or less. Most magnetically shielded MR magnets have a fringe field of 100 gauss 1 to 3 feet from the magnet bore. A red LED flashes when the module is in a magnetic field greater than 100 gauss.

Sensor connections

Capnograph for Large Animals

The Capnograph Module sensor panel is shown above. It includes the following:

- Gas sample input connection with moisture trap.
- Yellow LED that illuminates when respiration is detected.
- Red LED that flashes when the module is in a high magnetic field.

A gas sample line with a 24” length of Nafion™ tubing connected to a moisture trap at the gas sample input connection delivers respiratory gas to the module. Total tubing length can be 9’ or greater which allows the instrument stand to be 3’ or more from the magnet bore.

Caution: Do not connect the sample line directly to the gas sample input port. Connect the moisture trap to the gas input port then connect the sample line to the moisture trap.

Power panel

The Capnograph Module power panel is shown below. It includes the following:

- 12 VDC power connection with power switch and indicator LED.
- Fiber optic communication ports to connect to the Multi-parameter and Control/Gating Modules.
- Leur exhaust port which can be connected to a scavenger system
- Push button switches for calibration.

Sample gas flow

The water trap and Nafion tubing™ prevent water vapor from entering the IR bench but allow gas to pass. Sample gas flow rate is user selectable from 50 to 200 mL/min. A flow regulation system controls the flow rate and attempts to clear the sample line if it gets occluded.

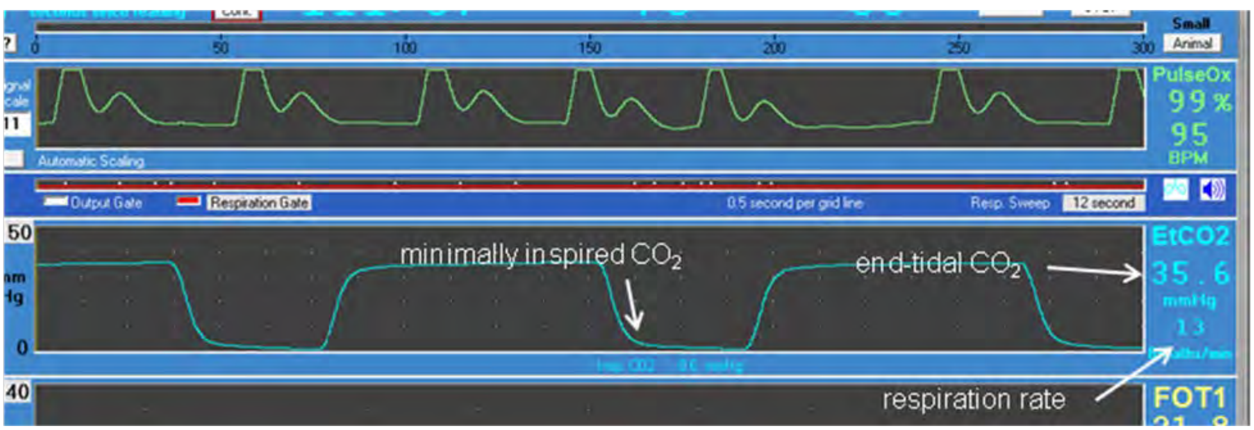
Caution: Not for Human use.

Caution: Do not use the Capnograph Module in the presence of flammable anesthetics; this could cause an explosion

The 12 VDC power should be switched off on the Capnograph Module at the end of the day.

PC-SAM main display

The capnograph display is shown below. The instantaneous carbon dioxide waveform is displayed along with end-tidal CO_2, respiration rate and minimally inspired CO_2. Click on the label to the left of the waveform to change between %, mmHg and kPa.



Moisture trap replacement

The moisture trap and Nafion™ tubing remove moisture from the gas sample. The moisture trap shown below has a green threaded connection that attaches to the gas sample input port and a Leur connection that attaches to the Nafion™ tubing. Note the direction of sample gas flow is from the patient into the monitor.

The Nafion™ tubing allows water vapor to pass through the tubing wall while blocking the passage of the gas sample. While the Nafion™ tubing does not retain moisture the moisture trap does. The moisture trap should be replaced when air flow is restricted. To test if the moisture trap is restricting air flow compare the sound of the pump to the sound with a new moisture trap. If the trap is restricting air flow the sound from the pump will increase as it works to maintain flow.

O_2 and N_2O compensation

The interfering effect of O_2 and N_2O results in inaccurate CO_2 readings. However the device has the ability to compensate for this error.

Right click on the CO_2 waveform to open the Capnograph Settings window. The % O_2 and N_2O can be entered to compensate for interfering gas being delivered to the patient. The atmospheric pressure reported by the module is displayed in this window.

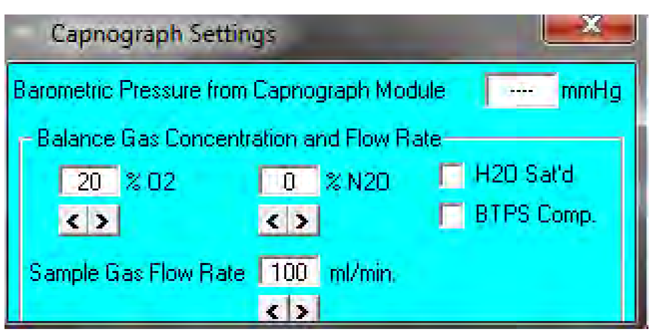
The sample gas flow can be set using the arrows at the bottom of the window. The setting can be between 50 and 200 mL/min in 10 mL/min steps.

Calibration

The module automatically performs 0% CO_2 calibrations in order to correct for changes in temperature, pressure and electronic component drift. When performing an automatic calibration a solenoid valve switches for a few seconds from the patient sample line to ambient air from the gas port above the calibration buttons. Automatic calibrations are performed at 1, 2, 5, 10 and 15 minutes after power up and every 30 minutes thereafter.

It is recommended to periodically perform a 5% CO_2 calibration. Perform the calibration monthly or whenever the measurement seems to be in doubt.

To perform the calibration power up the Module and wait for 20 minutes. Connect the calibration gas bottle with the regulator and tubing kit to the moisture trap in the gas



sample input. The tubing kit has a tee that is open to room air. The tee open to air protects the Capnograph Module from being over pressured. First press the 0% button to perform a room air cal. Then open slightly the regulator on the cal gas bottle. You should observe the CO_2 reading rise to near 5%. Press the 5% cal button wait 3 seconds and turn the gas regulator off.

Chapter 23
Non-Invasive Blood Pressure for Large Animals

Non-Invasive Blood Pressure for Large Animals

Available options

Animals with heart rates less than 300 BPM can be monitored using the SAII large animal non-invasive blood pressure (NIBP) and large animal Capnograph options for the Model 1030 Monitoring and Gating system.

The data acquisition modules for the large animal options are designed to operate close to the magnet bore in a fringe magnetic field of 100 gauss or less. They contain a small amount of ferromagnetic material so they should be fix mounted in the magnet's fringe field. An easy way to fix mount the modules is to attach them to the SAII MR-compatible roll stand.

Caution: The NIBP and Capnograph Modules for large animals must be fix mounted in a magnetic field less than 100 gauss

NIBP overview

The oscillometric method of blood pressure measurement is a non-invasive method that monitors the amplitude of cuff pressure changes during cuff deflation to determine arterial blood pressure. The cuff pressure is first elevated above the patient's systolic blood pressure level and the cuff begins to deflate at a certain rate. The initial rise in amplitude of these pressure fluctuations during cuff deflation corresponds closely to the systolic blood pressure. As the cuff is further deflated, these pressure fluctuations increase in amplitude until a peak is reached which is referred to as the mean arterial pressure (MAP). As cuff deflation continues, the diastolic pressure can be determined based upon the rapidly diminishing amplitude of the pressure fluctuations.

Each NIBP measurement cycle results in systolic, diastolic and mean arterial pressure readings as well as values for heart rate.

The NIBP Module incorporates the SunTech Medical ADVANTAGE OEM BP™ veterinary NIBP module. This module has been specifically designed for use with dogs and cats.

NIBP components and connections

The NIBP hose is black polypropylene with durometer of 85 Shore A (firm). The tubing is 9/32 OD, 5/32 ID and with length that varies depending on the magnet. It has a nylon CPC quick connect connector on one end and a nylon Leur connector on the other end.

The CPC quick connect connector mates with the NIBP connection on the NIBP Module. To make the connection align the connectors and twist clockwise to lock the connection.

NIBP cuffs come with a short length of tubing and a male Leur connector. To connect a cuff to the NIBP hose push the male Leur of the cuff into the female Leur of the hose.

Non-Invasive Blood Pressure for Large Animals

The following cuff sizes are provided:

Cuff size	Circumference range, cm
#1	3 - 6
#2	4 - 8
#3	6 - 11
#4	7 - 13
#5	8 - 15
#6	12 - 19
#7	17 - 25

Animal modes

There are two animal modes that are needed to handle the large variety of animal sizes within the dog and cat populations. These are Small and Large Animal modes.

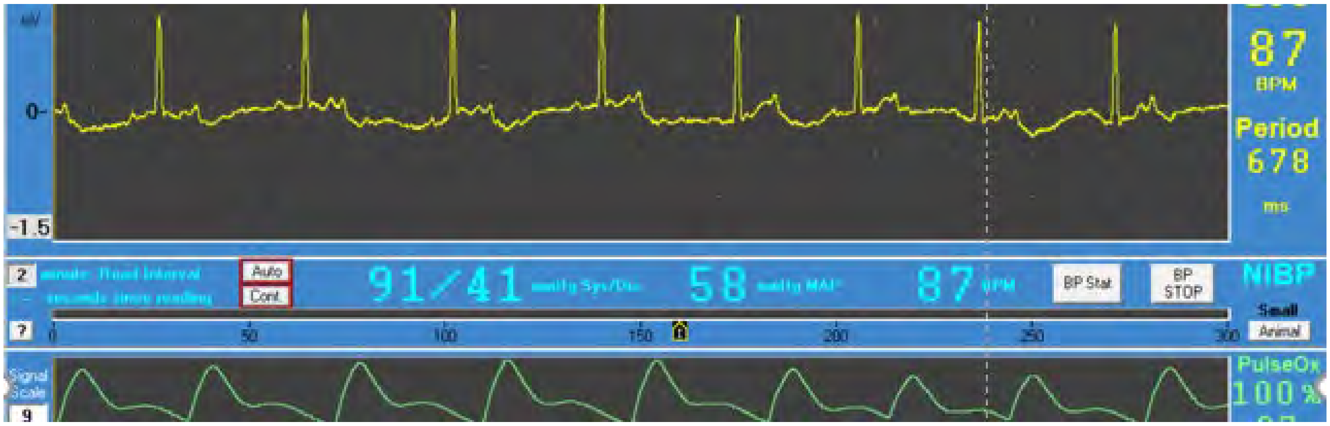
The *Small Animal Mode* has been developed to perform on smaller animals including cats and small dogs. Cats typically have very low oscillometric signal strength and are difficult patients for non-invasive blood pressure. The Small Animal Mode in the SunTech veterinary BP algorithm was specifically designed for this patient population and cuff placement plays a key role in obtaining BP measurements. This mode should be chosen when taking BP measurements on all cats up to a # 3 cuff. Also, dogs equal to or less than 8kg (~17.5 lb) should also have their blood pressures measured in this mode. Dogs or cats that require a #4 cuff or larger should use the Large Animal Mode. Animals that require a # 3 cuff usually can have their blood pressures measured with the Small Animal mode. If problems arise, then try the Large Animal mode.

The *Large Animal Mode* has been designed for animals requiring a #4 cuff or larger. This typically is dogs weighing more than 8kg (~17.5 lb). If a patient is using a #3 cuff in this mode and problems arise, then try the Small Animal mode or a larger cuff. For cats and dogs, the preferred position for all NIBP measurements is either left or right lateral recumbency. This will position the limbs fairly close to heart level.

PC-SAM main display

The NIBP system uses one of the data channels of the IBP system. The data channel is assigned in the Setup Screen available at the launch of PC-SAM. Once set, the channel is not changed during the study.

The NIBP portion of PC-SAM's main display includes systolic, diastolic, mean arterial pressure and heart rate readings as well as the elapsed time since the measurement currently being displayed. The cuff pressure is displayed in real time in a manometer bargraph at the bottom of the NIBP display



Control of NIBP measurements is facilitated using the following buttons:

BP Stat – to immediately initiate a measurement
BP Stop – to stop the NIBP measurement
Auto – starts auto cycling measurements (button turns from red to green)
Cont – starts continuous measurements for 6 minutes or until BP Stop.

To the left on the NIBP display is a box where the time interval between successive NIBP measurements can be entered. The time interval can be 1 to 99 minutes. After entering a new value hit the enter key. The color of the box will change to indicate the new value was accepted. Regardless of the interval setting, the minimum interval between successive measurements will be the inflation time plus the deflation time plus 10 seconds. The NIBP measurement typically takes between 20 and 60 seconds. After three successive unsuccessful measurement cycles PC-SAM software turns auto off. This routinely occurs at the end of a study when the NIBP cuff is removed from the patient.

The legend above the “Animal” button shows the active mode. Clicking the button toggles the mode between Small and Large Animal.

Before initiation of a measurement, a small icon is present on the manometer bargraph indicating initial inflation pressure. The default pressure is 160 mmHg for both animal modes. The initial inflation pressure can be changed by clicking and dragging the icon to a new pressure value. After completion of the initial NIBP cycle the icon disappears and the inflation pressure for the next cycle is set to the measured systolic pressure plus 30 mmHg.

Click on the “?” to the left of the manometer to open a window with a description of the NIBP measurement and also the “Signal Quality” which gives a relative measurement of the quality of the last measurement. Numbers typically are between 10 and 100 with larger numbers indicating a stronger signal.

Cuff selection and placement

It is important to select the cuff size that is appropriate to the diameter of the patient's limb or tail. Use the *Range Lines* on the inside of the cuff to determine the correct size cuff or use the width of the cuff. The cuff width should be approximately 40% of the limb circumference.

It is better to use a cuff that is slightly too big than one that is slightly too small. The cuff should never extend over a joint. Wrap the cuff around the limb making sure that the *Artery Marker* is reasonably close to the artery. It may become necessary to shave the animal fur if there is trouble obtaining BP measurements. The cuff should fit snug to the patient's limb for maximum oscillometric signal quality.

Ensure that the air hose from the monitor to the cuff is not compressed, crimped or damaged.

The cuff should be at heart level for proper measurement accuracy. When the cuff is below heart level, measurement results may be higher and when the cuff is above heart level, measurement results may be lower than comparative results obtained at heart level.

Please remember that using a cuff that is the wrong size may give false and misleading results.

Appendix A
Specifications

ERT:

ECG	Range:	40 - 900 BPM
	Accuracy:	±1%
	Input range:	-2.50 mV to 2.5mV
	Input Impedance:	>10 MΩ @ 10 Hz
	CMRR:	100 dB @ 60 Hz
Resp	Range	15 - 300 bpm
	Accuracy	1 count
	Sensor	pneumatic pillow and/or ECG lead
Temp	Probe type	thermister, rectal
	Tip OD, mm	1.0 and 2.5
	Range	3 – 70 ºC
	Accuracy	+/-0.26 ºC, 32-42 ºC
Module	Power - battery	Rechargeable
	Battery life:	>30 hours
	Time to full charge	<5 hours
	ERT module size: hxwxd cm	2.1x5.1x15.0
	Battery Pack size: hxwxd cm	11.2x6.2x3.1

ERT Control/Gating:

Gating	R-wave to gate delay	selectable - 0 to 600 ms
	Expiration gate width and delay	selectable - 1 ms step size
Temp	Heater control	fiber optic PWM
	Size: hxwxd cm	3.8x13.3x12.5
Module	Auxiliary inputs	2 TTL
	Power	12 VDC

Air Heater System:

Heater	Heater control	fiber optic PWM
	power	100/115/ 230 VAC
	Size: hxwxd cm	16.4x8.9x26.0
Fan	power	100/115 /230 VAC
	Size: hxwxd cm	6.4x18.0x18.4

Dual Pump Fluid Heater System:

Heater	Heater control	mixed fluid temperature 35 – 45 ºC ±0.1 ºC
	power	100/115/ 230 VAC
	Size: hxwxd cm	16.4x8.9x26.0
Circulation	power	12 VDC, 2.0 A
	Size: hxwxd cm	19x54x33

Specifications

Single Pump Fluid Heater System:

Heater	Heater control	output fluid temperature 35 – 45 ºC ±0.1 ºC
	power	100/115/ 230 VAC
	Size: hxwxd cm	16.4x8.9x26.0
Circulation	power	12 VDC, 2.0 A
	Size: hxwxd cm	10x22.5x20

IBP:

IBP	Display range	0 – 300 mmHg
	Channels	up to 3
Module	Auxiliary inputs	2 analog 0 - 5 V
	Power	12 VDC & battery
	Battery life:	>6 hours
	Time to full charge	<3 hours
	Size: hxwxd cm	4.2x15.8x15.0

Pulse Oximetry:

Rate	Range	40 - 700 BPM
	Accuracy	±1%
	Probe type	fiber optic
SpO_2	Range	0 – 100 %
	Resolution	1 count
Module	Power	12 VDC
	Size: hxwxd cm	3.8x13.3x12.5

Fiber Optic Temperature:

Temp	Probe type	fiber optic, rectal
	Tip OD, mm	1.0 and 3.0
	Range	20 – 60 ºC
	Accuracy	+/-0.2 ºC
Module	Power	12 VDC
	Number of channels	1 to 4
	Heater control	fiber optic PWM
	Size: hxwxd cm	4.8x15.6x19.7

Fiber Optic Pressure:

Pressure	Probe type	fiber optic
	Tip OD, mm	0.3 and 0.4
	Range	0 – 300 mmHg
	Accuracy	1 count
Module	Power	12 VDC
	Number of channels	1 or 2
	Size: hxwxd cm	3.8x13.3x12.5

Capnograph:

CO_2	Analysis method	single beam IR
	Measurement range end-tidal	0 – 9.9%
	Accuracy end-tidal	0.15%
	Measurement range mmHg	0 – 76.0
	Accuracy mmHg	1.1 mmHg
	Sample flow	5 – 20 ml/min
Resp	Rate	5 – 200 bpm
	Pneumatic tube length	8 m
Module	Capnometer size hxwxd cm	13x49x41
	Capnometer weight	10 lbs
	Interface size hxwxd cm	3.8x13.3x12.5
	Power	100/115/230 VAC

Ventilator:

Resp	Rate	5 – 150 bpm
	Inspiratory flow	50 – 1000 ml/min
	Percent inspiration	10 – 90%
	Tidal volume	0.1 – 30 ml
Valve	type	pneumatic
	Actuation pressure	25 – 50 psi
	Assembly size hxwxd cm	1.0x5.4x2.4
	Pneumatic tube length	8 m
Module	Control unit size hxwxd cm	23x14x23
	Control unit weight	6 lbs
	Power	100/115/230 VAC

PC requirements:

Software:	Windows	any including 11
Hardware:		>1 GHz processor
		USB port
		Display resolution 1360 x 768 pixels or greater

Part No.	Description
M1030OP-rev	**Operation Manual, Model 1030 SAM & Gating System**
M1030PCS-rev	**PC-SAM Software USB drive**
1030-CASE	**Storage Case Model 1030 System**
110100-xx-rev	**ERT Module**
ERTBP3-103A-PCC	ERT Module Battery Pack
BPC-210-L	ERT Module Battery Pack Cable, L is the length in inches
BPCG-210	ERT Battery Pack Wall Charger with European adapter
25SFOC-23	Simplex Fiber Optic Cable, 25 m
RMEC-703-4	3 Lead ECG Needle Electrode Set for Mouse
RMEC-703-6	3 Lead ECG Needle Electrode Set for Rat
RMEC-703-10	3 Lead ECG Needle Electrode Set for Rabbit
EGD-705-612	3 Lead Gold Disk Electrode set, 6 mm
EGD-703-1012	3 Lead Gold Disk Electrode set, 10 mm
ETLEC-703-36	3 Lead ECG Twisted Lead Extension Cable 36” Long
E3M-103-3	ECG 3M Red Dot neonatal electrodes 3/pack
EGEL-103	Electrode Gel
ETLEC-103-36	ECG twisted lead set 36”
RC-107-SM	E-resp Cradle-Small Mouse
RC-107-LM	E-resp Cradle Large Mouse
RC-107-RAT	E-resp Cradle-Rat
RS-301	Respiration Pillow Sensor
RSET-303-9	Respiration Extension Tubing, 9” long
RSET-3	Respiration Extension Tubing, 36” long
RTP-101-B	Rectal Temperature Probe for mouse & rat – 3 mm OD tip 7" long
RTP-102-B	Rectal Temperature Probe for mouse & rat – 1 mm OD tip 7" long
RTP-103-B	Rectal Temperature Probe for rabbit – 4 mm OD tip 7” long
TPEC-109-7	Temperature Probe Extension Cable - 7"
TPEC-109-12	Temperature Probe Extension Cable - 12"
TPEC-109-36	Temperature Probe Extension Cable - 36"
TPC-200	Temperature probe covers
720200-rev	**ERT Control/Gating Module**
USB-21	Prolific USB to Serial Adapter Cable
PS-2-12	Power Supply, 12V
PSLC-2-E	Line Cord 230 VAC Europe
PSLC-2	Line Cord 115 VAC
25DFOC-23	Duplex Fiber Optic Cable, 25 m

Appendix B: System Components and Accessories

Part No.	Description
1FTSFOC-23	Simplex Fiber Optic Cable, 1' long
731100-rev	**IBP Module**
IBPX-A	IBP Transducer Abbott Transpac IV
750100-rev	**Simulator**
SEL-705	Simulator ECG Leads
STC-105	Simulator Temperature Cable
M9001	**MR-compatible Small Animal Air Heater System**
761100-rev	Air Heater Module 115 VAC
760100-rev	Air Heater Module 230 VAC
771100-rev	Fan Module 115 VAC
770100-rev	Fan Module 230 VAC
FAH-20	Fan Air Hose 7 m
WAH-5	Warm Air Hose 1.5 m
CUF-2	Cuff, Heater Hose
HOS-x	Heater Hose (x feet long)
M9002	**Dual Pump Fluid Heater System**
763100	WBH Heater Module 115 VAC
762100	WBH Heater Module 230 VAC
880100	Circulation Module
660100	WBH Circulator Interface Module
WBH3TS-10	WBH hot, cold & return tube set – 10m
WBHHB-2	WBH heater to bed tube set – 2m
WBHPS-12	WBH power supply, 12 VDC
FWB-M	Flat heating pad mouse
FWB-LM	Flat heating pad large mouse
FWB-R	Flat heating pad rat
CWB-M	Curved heating pad mouse
CWB-LM	Curved heating pad large mouse
CWB-R	Curved heating pad rat
SWB-M	Flexible heating pad mouse
SWB-LM	Flexible heating pad large mouse
SWB-R	Flexible heating pad rat
WBC-M	Cover flat & curved heating pad mouse
WBC-LM	Cover flat & curved heating pad large mouse
WBC-R	Cover flat & curved heating pad rat
WBCS-M	Cover flexible heating pad mouse
WBCS-LM	Cover flexible heating pad large mouse
WBCS-R	Cover flexible heating pad rat
WBH-FILTER	Circulation Module water filter

Part No.	Description
WBH-RPT-12	Circulation Module roller pump tubing 3/8” OD x 12” long
M92001	**FORT Module (fiber optic receive/transmit conversion)**
880200	**Single Pump Circulator Module**
UGM-100	**Universal Gating Module**
15SFOC-23	Simplex Fiber Optic Cable, 15 m
810100	**Fiber Optic Temperature Module**
FOTS-2	Fiber Optic Temperature Sensor, 2’ long, 1 mm tip OD
WBH-RPT-12	Circulation Module roller pump tubing 3/8” OD x 12” long
M92001	**FORT Module (fiber optic receive/transmit conversion)**
UGM-100	**Universal Gating Module**
15SFOC-23	Simplex Fiber Optic Cable, 15 m
810100	**Fiber Optic Temperature Module**
FOTS-2	Fiber Optic Temperature Sensor, 2’ long, 1 mm tip OD
FOTS-5	Fiber Optic Temperature Sensor, 5’ long, 1 mm tip OD
FOTS-9	Fiber Optic Temperature Sensor, 9’ long, 1 mm tip OD
FOTE-10	Fiber Optic Temperature Sensor Extension Cable, 10’ long
580100	**Pulse Oximeter Module**
530100	Fiber Optic Pulse Ox Sensor, 6’ with clip & form kit
DCPC-2	Daisy Chain Power Cable for 2 modules
430100	**Signal Breakout Module**
830100	**Fiber Optic Pressure Module**
FOP-3-3	Fiber Optic Pressure Sensor, 3’ long, 0.3 mm OD
FOP-5-4	Fiber Optic Pressure Sensor, 5’ long, 0.4 mm OD
OEC-1M-B	Fiber Optic Pressure Extension Cable, 3’ long
OEC-3M-B	Fiber Optic Pressure Extension Cable, 10’ long
260100	**Capnograph/Ventilator Interface Module**
635xxx	**NIBP Module for Large Animals**
CUFF-3-6	Blood Pressure Cuff 3 – 6 cm circumference
CUFF-4-8	Blood Pressure Cuff 4 – 8 cm circumference
CUFF-6-11	Blood Pressure Cuff 6– 11 cm circumference
CUFF-7-13	Blood Pressure Cuff 7 – 13 cm circumference
CUFF-8-15	Blood Pressure Cuff 8 – 15 cm circumference
CUFF-12-19	Blood Pressure Cuff 12 – 19 cm circumference
CUFF-17-25	Blood Pressure Cuff 17 – 25 cm circumference
NIBP-BLKH-108	NIBP hose 9’
635300	**Capnograph Module for Large Animals**
CMW-TRAP	Water Trap
NSLT-CO2-84	Nasal CO2 Sample Line Tube with Male Luer Connector 7ft
SLET-48	Sample Line Extension Tubing 4ft (1.2 meter)
SLET-96	Sample Line Extension Tubing 8ft (2.4 meter)

Appendix B: System Components and Accessories

SA-ADAPTER	Straight Airway Adapter
CAL-CO2-5%	Calibration Gas - Carbon Dioxide 5%
C-VALVE	Control Valve
CV-TUB-20	Control Valve Tubing Assembly

Appendix C
Troubleshooting

Problem	Possible Cause	Corrective Action	See
No waveform on display. Trace frozen & communication error.	Wrong com port selected.	Select the correct com port in PC-SAM setup menu.	2-3 3-6
No waveform on display. Trace frozen & no communication error.	No power to the ERT Control/Gating Module or communication problem.	Check the power and serial connections	2-1 2-2
Sweeping waveform but no ECG signal.	No communication to the ERT Module.	Check power to the ERT Module & fiber optic cable connections. Look for red light in the fiber optic driver.	2-2
Sweeping waveform but no ECG signal.	Lead off.	Check lead attachment.	4-2
Sweeping waveform but no ECG signal.	Offset voltage too large.	Check offset voltage in system info window. Check for faulty temp probe by disconnecting the probe from the ERT Module & check for needles in muscle.	9-1 4-7
ECG waveform but no heart rate display.	R-detect parameters incorrect.	Set correct values.	3-9
Excessive artifacts on ECG without scanning'	Movement of leads in magnet bore.	Check for vibration or air flow. Tape leads and/or ERT module.	4-1
Excessive artifacts on ECG while scanning'	Movement of leads or module in magnet bore.	Check for vibration. Tape leads & ERT module to restrain motion.	4-1

Problem	Possible Cause	Corrective Action	See
Air Heater system has cold air blowing from the heater tube.	Wrong set point.	Check that the set point is greater than the measured temperature.	6-3
Air Heater system has cold air blowing from the heater tube.	Power is not on.	Check power to the Heater Module. A green LED indicates power. Check AC connection.	6-1
Air Heater system has cold air blowing from the heater tube.	Control signal not present.	Power indication OK, but Heat LED not flashing. Check the fiber optic connection to the Heater Module. Red light should be present in the end of the fiber to turn on the heater element. Check the temperature probe, set point and connections at the ERT Control/Gating Module. Select "On/Off with PWM Max Heat" in HEATER window.	6-1 6-3
No gate detected by MR scanner.	Improper gating setup selection.	Check for the presence of trigger output to the scanner (white dots in Cardio Sweep display). If trigger is not present, check selections in Gating Setup menu.	3-2 3-8
No gate detected by MR scanner.	Improper switch setting on ERT Control/Gating Module.	Check for the presence of trigger output to the scanner (white dots in Cardio Sweep display). If trigger indication is present, check gate output pulse signal characteristic switch setting is appropriate for the MR scanner.	3-2 3-5

Problem	Possible Cause	Corrective Action	See
Fluid Heater System has no flow	Power is not on.	Check power to the Heater and Circulation Modules. Green LEDs indicates power is on.	20-8
Fluid Heater mixed water temperature (Tout) is not being updated.	Fiber optic connection problem.	Check fiber optic cables for a red light in the blue fiber at the Circulator and Heater Modules.	20-7 20-8
Fluid Heater bed is not hot.	Control signal not present	Power indication OK, but Heat LED not flashing on the WBH Heater Module. Check the set point for the mixed water temperature.	20-8

Troubleshooting

ERT communication error

This error means the ERT Control/Gating Module is not receiving valid data from the ERT Module. It can occur for one of the following reasons:

1. battery is discharged
2. faulty connection of the Battery Pack Cable at the Battery Pack or at the Module
3. fiber optic signal is not getting to the ERT Control/Gating Module

The **Battery Pack voltage** can be checked with a digital volt meter or by connecting it to the ERT Control/Gating Module's internal battery charger. If connecting to the ERT Control/Gating Module, open the CHARGER window and read the voltage on the last line. A fully charged battery will be > 6.5V it will stop operating the module when it is less than 5.8 V. We issue the low voltage error message when the battery's voltage reached 6.0 V.

If the battery is OK, **test the ERT Module's Battery Pack and cable** by holding the ERT Module and Battery Pack with one hand so that the Battery Pack connections are visible. Connect the Battery Pack Cable with the other hand and observe a red light in the module's fiber optic port. Gently move the cable at each connection. Any interruption of light from the fiber optic port would indicate a potential short in the cable or connections.

Check the fiber optic signal by observing the red light at the fiber optic driver on the ERT Module. Connect the fiber optic cable to the module and observe red light on the other end of the fiber. Connect the fiber to the ERT Control/Gating Module at the port labeled ECG. If the communication error persists, check for lint or blockage inside the ECG port on the ERT Control/Gating Module and or try another fiber optic cable.

Check communication between the PC and ERT Control/Gating Module

With the system running and with red bars for "R-detect + blanking time" open the R-detect setup window (right click on the ECG waveform display) and change the wave feature detection from "positive peak" to "negative peak". Within 2 seconds the red bars should disappear. Switch back to "positive peak" and in 2 seconds or less the red bars should again be displayed.

Determine if other features of the system are working? When pressing on the pillow, do you get red bars indicating inspiration (when the signal dips)? If you click the invert pulse box for respiration in the GATING SETUP window does the red bar switch to the expiration portion of the waveform (flat portion between the dips)? Since the ECG and respiration detection is performed by the ERT Control/Gating Module, a response 1 to 2 seconds to changes in parameters from the PC is a test that communication is working.

No heat from air heater

If the Heater Module is not generating heat and the yellow “heat” light does not flash, check the following settings:

1. The heater set point is large (70 ^{o}C)
2. The measured temperature displayed on the PC is less than the set point
3. The heater window has "on/off with PWM max heat" checked
4. The max heat value is large (100%).

Then check to see if there is a red light in the Heater Control fiber optic connection on the ERT Control/Gating Module. If the above are all true, and there is no red light, the problem must be a communication problem between the PC and ERT Control/Gating Module. The problem has nothing to do with the Heater Module. It is confined to the PC, the ERT Control/Gating Module and the cable between the two units.

If there is a red light, then check the following:

1. Power is applied to the Heater Module. If the green light is not on, check the switch and/or internal fuse.
2. Red light is present on the fiber optic cable connected to heater control.
3. The heater control fiber is seated in the connector (should snap in place).
4. Check inside the fiber optic connector for lint.

If still the yellow light does not flash, contact SAII’s Customer Service.

Low heat from air heater

If the yellow heat LED is flashing, but the temperature from the Heater Module is low, follow these instructions.

Using the 1.5 m tube from the Heater Module and the 7 m tube between the Fan and Heater, the temperature at the end (or just inside the end) of the outlet of the 1.5 m tube should be 55 ^{o}C. The ERT module can be used to measure the temperature.

You can pretty well tell what the control electronics in the Heater Module is doing by observation of the yellow heat LED. When the system is first turned on and with the Fan Module off (with set point very high and duty cycle to 100%) The yellow LED should flash continuously until the temperature just inside of the heater (inside the hole labeled Warm Air) rises to a standby level of about 40 ^{o}C. Once the temperature reaches the standby level, the yellow LED should only flash occasionally to maintain that temperature. When the fan is turned on, the processor senses a difference in temperature between the thermisters located at the inlet and outlet of the Heater Module. In this case the processor allows the outlet temperature to rise to approximately 85 ^{o}C correspondingly the temperature at the end of the 1.5 m tube is about 55 ^{o}C. When that temperature is reached the yellow LED will flash only when current is required to maintain the temperature.

Look inside the holes of the Heater Module. You will see a thermister at each end. The thermisters should stand erect and not be bent against the heat chamber. If the Heater

Module was dropped during shipment, the heat chamber may be damaged. You might start with a cold system and without the Fan and then with the FAN to try to understand what is not working.

You can only get very low temperature if one of the following occurs:

1. Wrong voltage,
2. Fan not on or the processor thinks it is not on
3. Heat chamber housing cracked and leaking

Make certain the air hoses are connected properly. i.e. that the fan is not connected to the "Warm Air" port on the Heater Module.

Gating Setup when large artifacts are present in the ECG waveform

The most common artifact in the ECG waveform is generated by vibrations of the ECG leads due to activation of the pulsed gradients during MR system data acquisition. When the MR scanner acquires imaging data, pulsed gradients are activated which generates acoustic noise, movement of the gradient insert and corresponding movement of the ECG leads. Vibration or movement of the ECG leads in the presence of the strong static magnetic field creates artifacts on the ECG waveform.

Many factors contribute to the size and extent of vibration artifacts on the ECG waveform. High field strength, long lead length, leads that are not taped and close coupling of the animal to the gradient insert all make vibration artifacts more extensive. However, in many cases it is not necessary to minimize the effects of vibration. It is usually possible to create accurate and reliable triggers even with the presence of large artifacts on the ECG waveform.

Follow these steps to generate accurate gating when large artifacts are present:

1. When the scanner is not acquiring data, check that each R-wave is detected and that no false gates are generated. i.e make certain a red dot (ECG gate) is present for each R-wave and that there are no extra red dots in the Cardio Sweep display. If this is not the case, adjust the R-detect parameters according to Chapter 3 of the Operation Manual.

2. Set the blanking time to 90% of the R-R interval. Note the R-R interval is displayed below the heart rate. Right clicking the ECG display will open the R-DETECT SETUP window.

3. Run a gated scan with the total slice acquisition time at least 20 msec less than the animal's R-R interval. It maybe useful to initially run a single slice scan to observe the effect of gradient vibrations on the ECG waveform. As you increase the number of slices, you will observe an increase in the width of the artifact following the trigger generated by the R-wave. Note that 5 to 10 msec are required for the vibrations to damp after the pulsed gradients are turned off. If the total slice acquisition time is too long, a false trigger will be generated at the end of the blanking time.

As an example, consider the case of a cine field echo sequence run on an animal with a heart rate of 600 beats per minute (R-R interval of 100msec). Setting the blanking time to 90 msec will accommodate an arrhythmia rate of up to 10%. If the single slice acquisition time is 10 msec, then 8 slices can be acquired each at a different phase in the cardiac cycle. Note that if 9 slices are attempted, false gates will occur, as the vibrations ring down after the end of the blanking time, and the images will not be accurately gated.

microCapStar Capnograph - lack of response or abnormally low readings

Usually these problems with the capnograph are due to a leak or interference in the sample tubing system. Follow these steps to help identify and clear the problem:

1. Check that the CO2 sensor is working – with the module warmed up, set the mode switch to FAST, disconnect the CARRIER OUT tube from the front panel and sample your breathing. If you see a large response to CO2 (10% or more) the sensor is working.

2. Check for leaks – occlude the sample flow by putting a finger over the distal Y sample inlet (the connection that normally connects to the animal's trach tube). After about 10 seconds you should see "Check sample flow" error message.

    a) If you see the message proceed to step 3

    b) If you do not see the message or the air pumps sound very loud, there is a leak somewhere in the sampling circuit. Check the external sample tubing and connections and replace if necessary.

3. No leaks detected, but incorrect readings – with the mode switch set to FAST, check CO2 ZERO. Adjust CAL LOW clockwise a few turns to see if the reading becomes positive. Sample your breath and adjust CAL HIGH; to give approximately 4.5% CO2 reading. (Refer to page 7 of the microCapStar Instruction Manual). Check the sample flow being drawn into the distal Y inlet. Follow instructions on page 9 of the Instruction Manual to adjust the flow. Note: If the sample flow rate is changed, the instrument must be re-calibrated before accurate readings can be obtained.

PC-SAM data files as diagnostic tools

Both SnapShot and Trend data files are extremely useful in troubleshooting. SnapShot files give a 36 second recording of all measured data while Trend data files continuously record system measurements once per second.

Trend data files are collected automatically in the background while PC-SAM is running. Each Trend file has an associated Events file. SnapShot data files are collected every time the SnapShot key is pressed. The SnapShot key is in the lower left of PC-SAM's main display. When the SnapShot key is pressed, the previous 36 seconds of all measured data are stored on the disk drive.

The factory default location for these files is

c;/ProgramFiles/PC-SAM/SAM-Data/
If the SAM-Data folder is not visible click on “compatibility files” at the top of the window.
If all else fails navigate to c:/users/SAII (or your user name)/AppData /Local/VirtualStore/ProgramFiles(x86)/PC-SAM/SAM-Data

Folders in SAM-Data are date encoded in the format yymmdd. If PC-SAM is opened more than once in a day a letter is appended to the folder name. Trend files have a “.trd” extension. Event files have a “.evt” extension. SnapShot files have a “’snp” extension.

These data files are not large. They can easily be attached to an e-mail. It can be very useful to send these data files with a description of your problem to service@i4sa.com.

Clean the monitor's surfaces or probes with a soft cotton cloth moistened in a mild soap solution. If disinfection is required, wipe the surface with alcohol, sodium hypochloride or glutaraldehyde (Cidex, Metrucude, etc.). Follow the instructions provided by the manufacturer.

Charge the ERT Battery Pack when the system is not in use. The battery pack can be left attached to the charger after it is fully charged. There is no requirement to deep discharge the battery before charging.

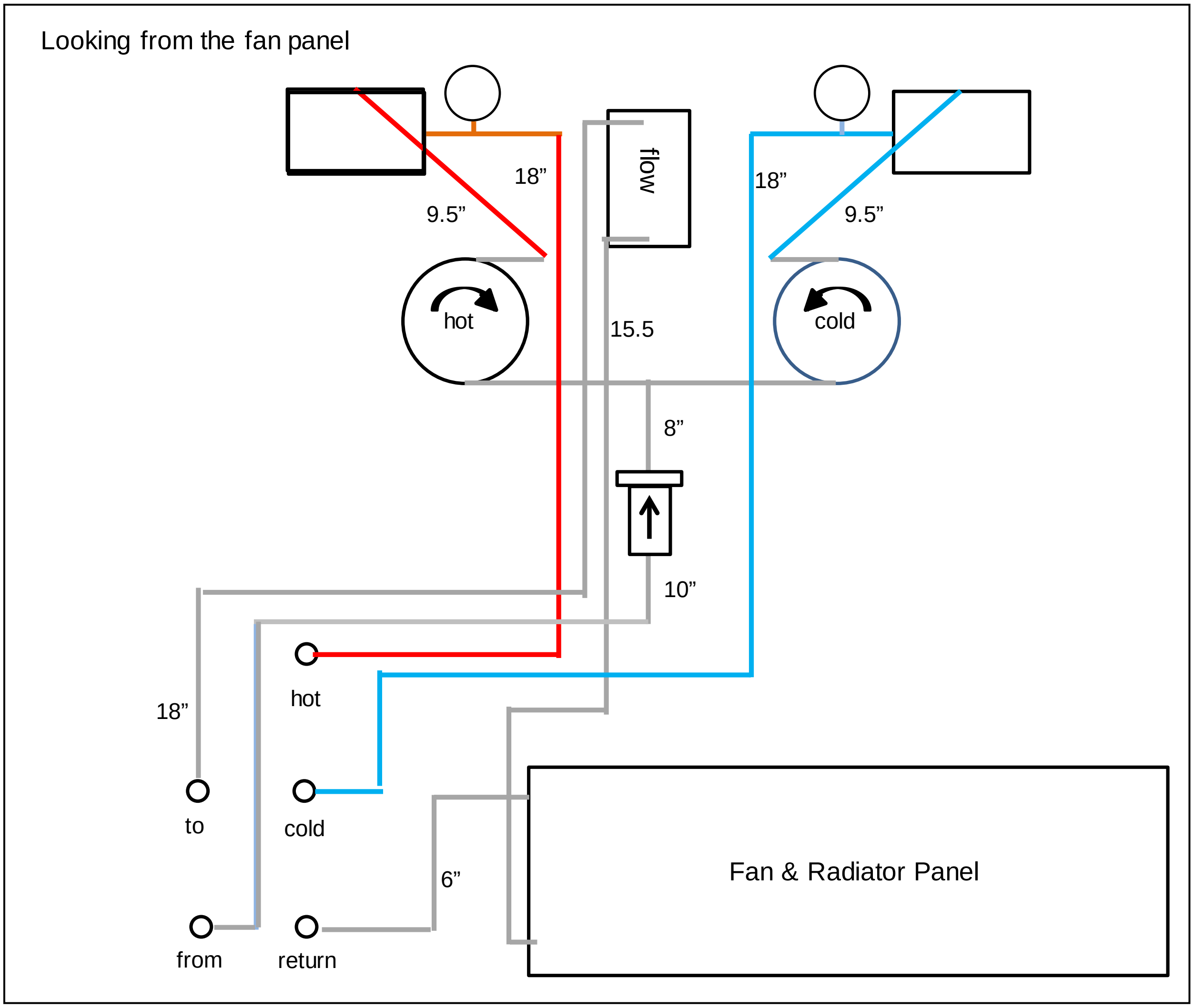
Charge the battery in the IBP Module when the system is not in use. The charger is internal to the module. The internal charger automatically charges the internal battery when the IBP Module is connected to 12 VDC power.

The water, water filter and roller pump tubing in the Dual Pump Fluid Heater System should be changed annually or as needed. The lifetime of the roller pump tubing depends on the operating pressure of the system. Higher pressure reduces the lifetime of the tubing. For a pressure of 10 – 12 psi the tubing will normally last 500 hours. A maintenance record should be maintained and keep in the envelope on the side of the Circulation Module.

Refer to the pictures below of the Circulation Module with the Fan Panel removed.

When removing tubes from the Heater Module, clamps can be useful on the 3/8" OD tubing. Plugs can also be used on the Heater Module ports.

The diagram on the next page shows how the components of the Circulation Module are connected.



To replace the filter cut the cable ties and remove the tubing. When installing the new filter note the direction of flow and attach new cable ties.

The roller pump tubing is accessible from the front of the Circulation Module. Remove the clear plastic cover over the roller assembly and the bracket that holds the tubing in position. Unscrew the tension adjustment nuts to remove pressure on the tubing. Disconnect the clear tube from the fitting at each end. Connect new tubing and reassemble. Use cable ties to lock tubing to the fittings. Note special roller pump tubing is required (WBH-RPT-12).

To adjust the roller pump tension tighten the adjustment nuts completely and then back off 2 full turns. Once the system has water flowing minor adjustment can be made if necessary, by observing the effect on water flow.

Appendix E
Example Waveforms

This appendix presents the following waveform examples collected in the MR environment:

1. Mouse outside the MR magnet
2. Mouse with E-Resp™ cradle in 7.0 T
3. Mouse with E-Resp™ cradle in 7.0 T, ECG and respiratory gated spin echo sequence

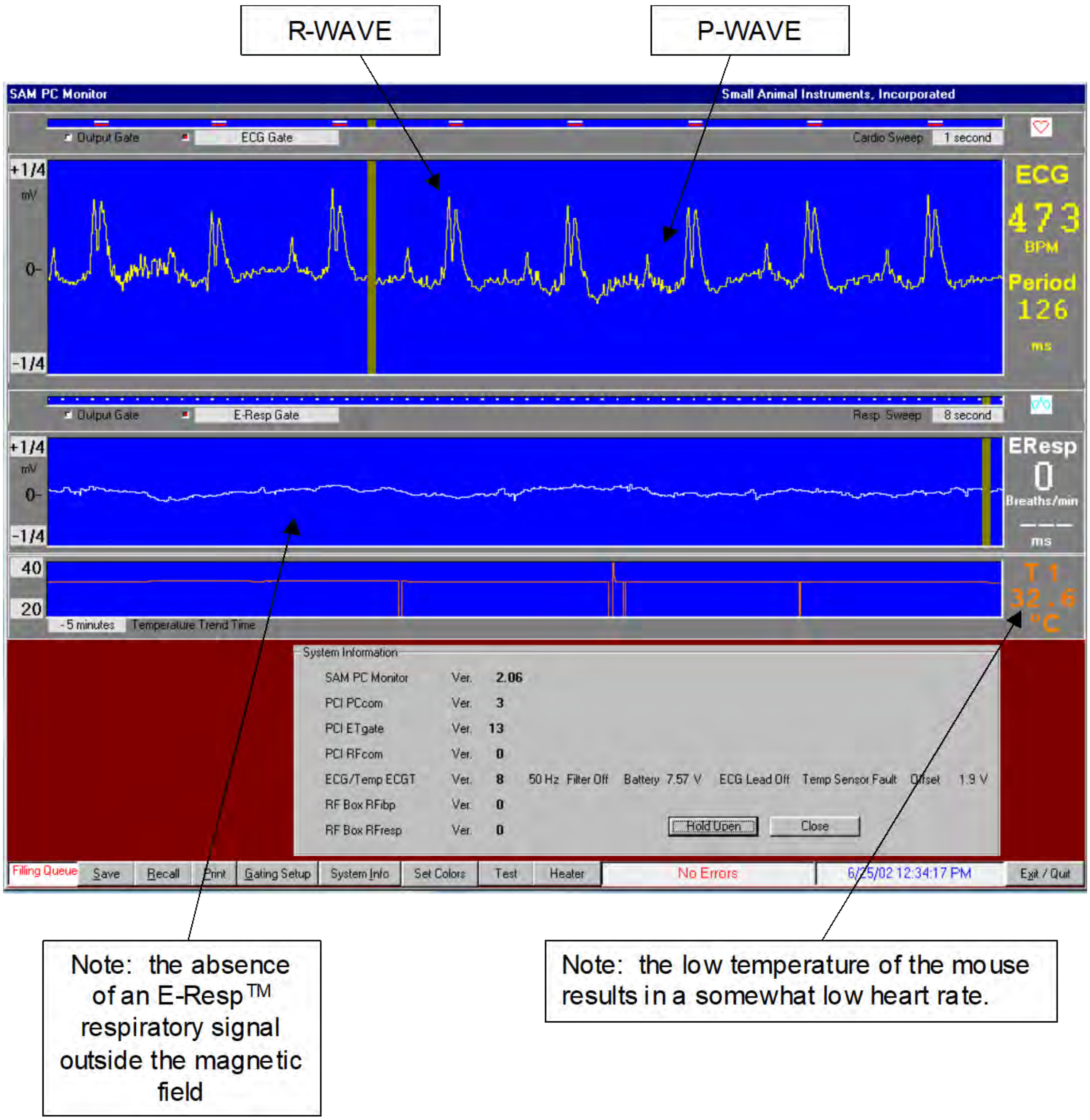
Examples 1 and 2 exhibit how important temperature is on the physiology of the mouse and the effect of the strong static magnetic field on the ECG waveform.

Examples 1 and 2 were acquired with the same mouse and the same preparation. Example 2 was acquired thirty minutes after example 1. In that length of time the temperature of the mouse, which was not being regulated, dropped nearly 5 ^{o}C. With the drop in temperature the heart rate also decreased from 473 to 302 BPM.

Comparison of the ECG waveforms shows the signal contributions from flowing blood and from respiration. In this case we increased the respiration signal by intentionally coupling one of the ECG leads to the mouse's abdomen using an E-Resp™ cradle.

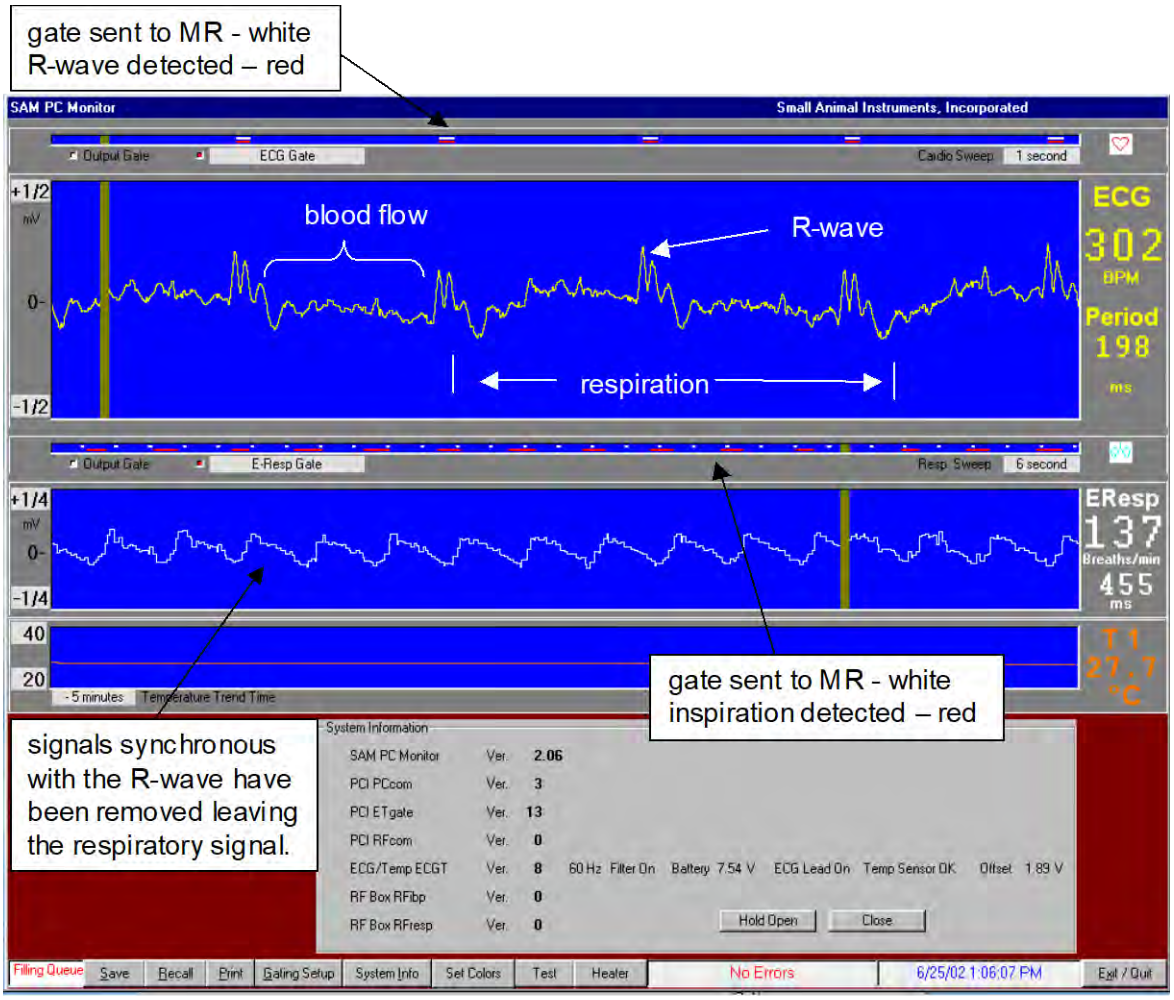
Example 3 shows us how to interpret scanner operation by observing the ECG waveform. Gradient interference is observed after each gate and we can clearly see the data acquisition time intervals for each slice in the sequence.

Mouse outside the MR magnet



The ECG waveform was obtained with sub-dermal right arm and left leg electrodes. The measured waveform does not contain signal contributions from respiration or blood flow outside the magnet.

Mouse with E-Resp™ cradle in 7.0 T field



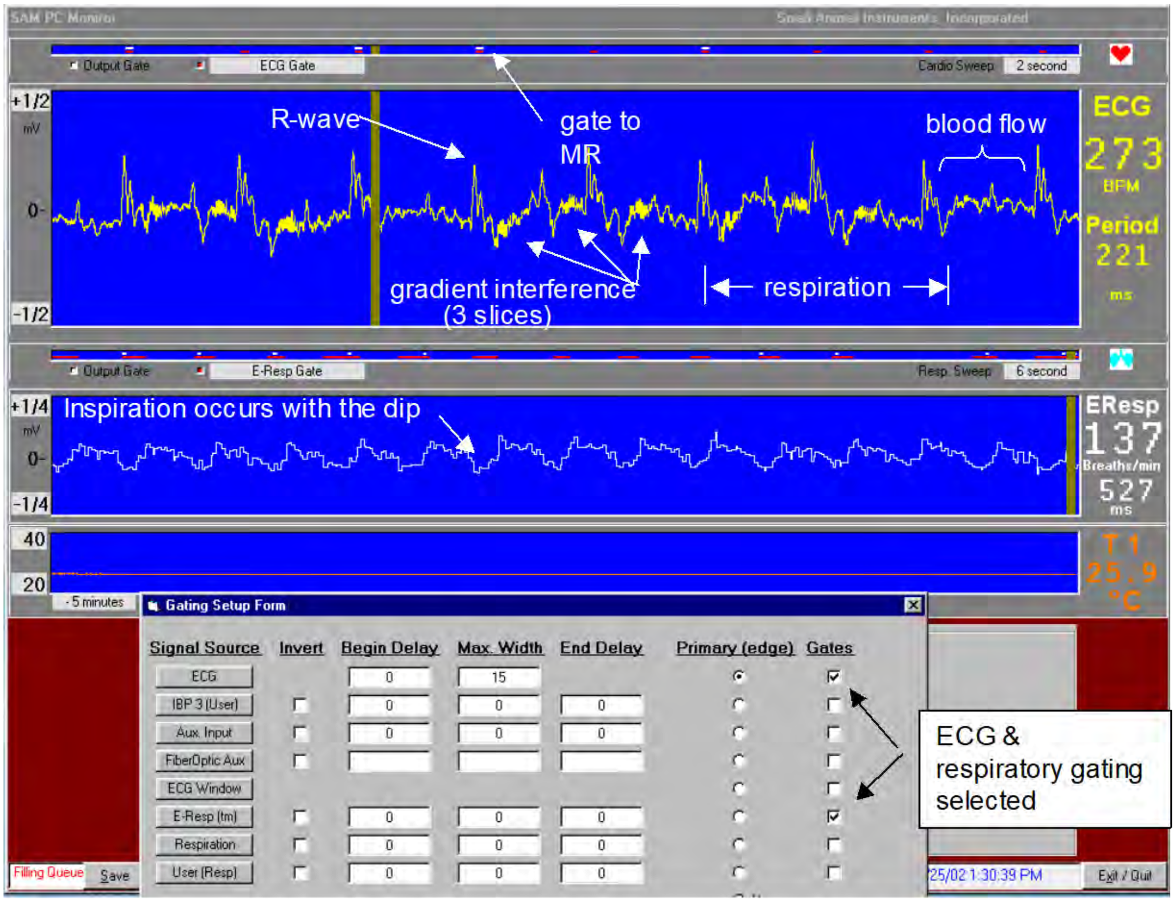
The measured ECG waveform has signals superimposed from respiration and blood flow. After the heart contracts (after the R-wave), flowing blood, which is ionic or charged, moving in the strong static magnetic field creates a signal synchronous with the R-wave (i.e. it is reproducible each heart beat).

The R-wave and other signals synchronous with the R-wave are removed from the measured ECG waveform to give the E-Resp™ waveform. Note because the sweeps are different, respiration in the ECG waveform appears compressed in the respiratory waveform.

Output gates are generated for each R-wave because ECG was selected as the only condition for the gating algorithm.

Example Waveforms

Mouse with E-Resp™ cradle in 7.0 T MR
ECG & respiratory gated spin echo sequence



This example, which does not show the best way to make gated images, is a good example of observing MR scanner operation from interference in the ECG waveform.

The measured ECG waveform has signals superimposed from respiration, blood flow and pulsed magnetic field gradients.

A gate for the MR scanner is generated by the first R-wave after detection of inspiration. The gate initiates MR scanner data acquisition for three images (slices). The gradient interference for a single slice lasts about 50 msec and the acquisition time between images is 130 msec. It is easy to conclude, from gradient interference present in the ECG waveform, that three images are being acquired during the respiratory cycle but not during the same cardiac cycle.

Note sometimes R-waves do not fall inside (coincide with) the inspiration window and therefore gates are not sent to the MR scanner.

Warranty Period

This product is warranted to be free from defects in material and workmanship for the following periods, commencing from the date of first use by the original end user:

- Labor - one (1) year
- Parts - one (1) year except accessories which are warranted for ninety (90) days

What is covered and what is not covered

Except as specified below, this warranty covers all defects in materials and workmanship in this product.

Accessories include batteries, ECG electrodes, respiration cradles, respiration pillows, extension cables and temperature probes.

The following are not covered by the warranty:

1. Personal Computer (the PC manufacturer's warranty applies).
2. Software or hardware upgrades.
3. Damage to or deterioration of the external cases
4. Any module which has been altered or on which the serial number has been defaced, modified or removed.
5. Damage, deterioration or malfunction resulting from:
    A. Accident, misuse, abuse or neglect;
    B. Failure to follow instructions supplied with the product;
    C. Shipment of the product (claims should be presented to the carrier);
    D. Repair or attempted repair by anyone not authorized by SA Instruments, Inc. to repair this product;
    E. Causes other than product defects, including lack of technical skill, competence or experience of the user.

Who may enforce the warranty

This warranty may be enforced by the original purchaser or to the present owner if the warranty has been properly transferred (contact SA Instruments, Inc.).

What we will pay for

We will pay all labor and material expenses for items covered by the warranty. Payment of shipping and insurance charges are discussed in the next section.

Warranty, service and support

How to obtain warranty service

1. If your system needs service during the warranty period, contact SA Instrument's Service Department at service@i4sa.com or (631) 689-9408. A service representative will provide technical support and help in diagnosing the failure.
2. In the event your system or part of your system needs to be returned for repair, the service representative will identify the closest repair facility and assign a return material authorization number (RMA). Defective components should be shipped freight and insurance prepaid to the repair facility. If necessary, repairs are covered by the warranty, return ground shipment and insurance will be paid by SA Instruments, Inc. Let the service representative know if you require overnight shipment.
3. In the event estimated repair time is deemed to be excessive by SA Instruments, loaner equipment may be provided.

Limitation of liability and exclusion of implied warranties

Warranty terms:

1. SA Instrument's liability for any defective product is limited to repair or replacement of the product, at SA Instrument's option. No one is authorized to assume any greater liability on SA Instrument's behalf. SA Instruments, Inc. shall not be liable for damage to other products caused by any defects in SA Instrument's products, damages arising out to loss of use, loss of revenue or profits, or any other damages, whether incidental, consequential or otherwise.
2. All implied warranties or conditions, including but not limited to warranties or conditions of merchantability and fitness for a particular purpose, hereby are excluded.