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2006

AVS-47B
AC RESISTANCE BRIDGE
Instruction Manual

Serial Numbers: 1041A6B2C2D7E8F1-1060A6B2C2D7E8F1

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1. INTRODUCTION

Resistance thermometry is perhaps the most popular way to measure low temperatures. This is because of its simplicity: the resistance of a calibrated sensor depends on temperature in a known way. It is enough to measure the resistance in order to find the temperature.

A sensor, cooled down to a millikelvin temperature, is very sensitive to the $R*I^2$ heating caused by the measuring current. It is not very serious, if the current heats a room-temperature sensor by 0.01 °C. But if a resistor, cooled to 10 mK, is heated by another 10 mK, the error is 100%! One has to use a current low enough, so that sensor heating does not spoil the accuracy of the measurement. The thermal resistance between the sensor and its surroundings increases steeply as the temperature decreases - therefore a power as low as 10^{-15} watts may be required sometimes. A typical ohmmeter would use a 10 µA current for measuring a 100 kΩ resistor, which means a 10^{-5} watt heating power. Clearly, such ohmmeters are not suitable for low-temperature resistance thermometry

The current required for avoiding self-heating problems is too low for any ordinary ohmmeter. This is the first reason to rely on a cryogenic resistance bridge.

The voltage drop, generated by a sufficiently low current is so minuscule that it may be totally buried under thermal and contact voltages, not to speak about offset voltages of the measuring instrument. All cryogenic resistance bridges block the thermal and offset voltages by using alternating current for the measurement. This is the second reason.

Wire leads going from the room temperature down to the cryostat must not conduct heat to the cooled parts. The wires can be made of a material that is a poor heat conductor. Unfortunately, such a material is usually a poor electric conductor, too. Some sensors, especially Platinum wire and Rhodium-Iron sensors, exhibit a very low resistance, from ohms to tens of ohms at a low temperature. In order to prevent lead resistances and their changes from destroying the measurement accuracy, a 4-wire connection is necessary. The excitation current is fed to the sensor via two “current leads”, and the voltage drop is measured by using two additional “voltage leads”. The voltage leads do not carry any significant current, and therefore the voltage drop across the sensor can be measured accurately. While many commercial ohmmeters offer 4-wire measurement, only cryogenic resistance bridges offer it together with ultralow alternating current.

Random noise is a significant factor in low temperature thermometry, because the measuring power is extremely low, and therefore it is difficult to maintain a good signal-to-noise ratio. A cooled cryogenic sensor itself does not generate very much noise because of its low temperature, but most of the noise comes from the measuring apparatus. The fourth reason to use a specially designed instrument is the requirement for a low-noise input stage.

In addition to several resistance ranges, cryogenic bridges can use different currents on each measuring range. By selecting a suitable excitation current, the user can find the best trade-off between the sensor’s self-heating error and the obtainable signal-to-noise ratio. This is the fifth reason.

1.1 KEY FEATURES OF THE AVS-47B

- Stable circuitry is based on null indicators and passive attenuators rather than on the gain of an AC amplifier. The AVS-47B needs very little **re-calibration**
- The **low-noise input stage** is built using discrete field-effect transistors, which optimize the noise performance for work with dilution cryostats at low and ultralow temperatures
- The preamplifier is located in a separate unit and can be mounted **near to the cryostat** with short leads to the sensors
- Equivalent input noise voltage is about 6 nV/sqrt(Hz), **virtually no noise current**
- 8 multiplexed 4-wire input channels
- Seven resistance ranges from 0-2 Ω to 0-2 MΩ.
- Seven excitation ranges
- Sensors can be individually grounded either to the cryostat (grounded sensors) or to the bridge (floating sensors)
- An active **capacitance compensation** circuit allows effective RF filtering against sensor heating
- Operating frequency typically 13.7-13.8Hz, can be adjusted from 10 to 110Hz. Portable between 50 and 60Hz countries without adjustments.
- Any low frequency interference at the sensor is visible, because the **signal path is not filtered.**
- 4 1/2-digit output from 0 to 19999
- 2.5 readings/second
- Calibrated, **stepless** analog output 0..+2V
- All-analog signal path. **Very low RF emissions**.
- The **Picobus Primary Computer Interface** is supported by a set of **LabView**™ Virtual Instruments. LV owners can connect the AVS-47B **at no extra cost** to a serial port of their PC, obtaining optical isolation and complete control of both the AVS-47B and TS-530A. The **Picobus** lines can be filtered against RF.
- The optional **IEEE-488 Secondary Computer**

Interface unit **AVS47-IB** is located outside the bridge, providing additional functionality and physical distance from the noisy bus

- The Picobus lines between the AVS-47B and AVS47-IB can be replaced by **optical fiber lines** (“Picolink” option, factory installation only).
- The AVS-47B has a universal mains input voltage range from 90V to 260V (serial numbers starting from #861). This change makes the AVS-47B more convenient especially for OEMs, who no longer need to check or change the mains voltage setting before shipment to final user. The reduced power consumption means less heat generation inside the instrument.
- Operation of the standard model is possible using two 12 V batteries or other floating DC sources. Battery operation gives maximum security against mains-borne interference.
- Operation of the standard AVS-47B is also possible from 12V 50-60Hz sinusoidal AC voltage. Low voltage can be the solution, if self-made power wiring or RF filtering would be needed for an application, but safety regulations prohibit this.

1.2 WHO IS A “SERVICEMAN” ?

Some operations to the instrument, like changing the mains voltage setting, require that it be opened. There may be hazardous voltages inside the unit, which one can touch. Therefore, such operations are allowed only for a "qualified serviceman": “A person having appropriate technical training and experience necessary to be aware of hazards to which he is exposed in performing a task, and of measures to minimize the danger to him or other persons”. If you are not 100% sure, that you understand, which parts of the instrument may be dangerous to touch, please leave opening of the unit to a "qualified service-man".

2. WARRANTY

Picowatt warrants this product to be free from defects in materials and workmanship. Our liability under this warranty is limited to repairing or replacing any instrument or part thereof which, within three (3) years after the shipment to the original purchaser, proves defective. This warranty is void if the instrument has not been used according to the instruction manual, or if it has been used under exceptional environmental conditions (see below).

In need of warranty repair, the instrument must be returned to **Picowatt**, prepaid , and with a detailed description of the fault or misfunction following the instrument.

The instrument must always be returned complete with the preamplifier and the interconnection cable. This is because only then the calibration and performance of the AVS-47B can be checked and guaranteed.

The name, address and e-mail address of a person who is able to give supplementary information should be included whenever possible. **Picowatt** will take responsibility of charges for returning the instrument, if the repair was covered by warranty.

If no fault is found, or if there is a strong indication that the warranty is void, the purchaser is charged for all freight and shipping costs in addition to the repair. Therefore it is recommended that **Picowatt** be contacted prior to shipment, so that we can give instructions for additional tests or simple component replacements and unnecessary shipments may be avoided.

Caution: The AVS-47B is a delicate laboratory instrument. It has been designed only for the purpose of measuring the resistances of passive resistive networks. Using this instrument for any other purpose will void the warranty and may cause permanent damage to the instrument. By no means should the AVS-47B be used to measure internal resistances of power supplies, batteries, capacitors or any other devices which can supply energy to the bridge input. The AVS-47B has been designed to operate in a laboratory environment, which means normal living room atmosphere, temperature, humidity and purity of air. The unit does not tolerate continuous vibration or hard shocks.

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3. AVS-47B SPECIFICATIONS

RANGE: 0-2, 0-20, 0-200 Ω, 0-2, 0-20, 0-200 kΩ, 0-2 MΩ. Magnified difference mode can be used to implement ranges with ten times lower full scales: 0-200 mΩ...,etc. They are suitable for measuring changes.

EXCITATION: Nominal excitation voltages are 3, 10, 30, 100 and 300 µV, 1 mV, and 3 mV. The sensor is excited by a symmetrical square-wave shaped AC current, whose amplitude is equal to the excitation voltage divided by the middle-range resistance.

SENSOR CONNECTION: I+, V+,V- and I- leads. Each of the 8 input channels has its own short circuit piece that enables connection of the I- lead to the preamplifier ground. In that case, the sensor in the cryostat must be left floating in order to break ground loops. A sensor with its short-circuit piece inserted has its I- lead permanenly grounded regardless of whether the channel is selected or not.

If a short circuit piece is removed, the I- lead of that channel must be connected to cryostat ground by the user. Then any possible ground potential difference between the cryostat and the AVS-47B is arranged to appear as a common mode voltage which is rejected by the differential preamplifier.

It is possible to save one wire (and one RF filter) per channel by using the cable shield as the I- lead common to all sensors and by grounding the sensors to the cryostat. The cable jackets should always be grounded firmly to the cryostat and to the preamplifier in order to provide the best shielding against high frequency interference.

2-wire connection is possible by coupling together the corresponding (I+,V+) and (I-,V-) pins of the input connector plug.

EXCITATION FREQUENCY: The AVS-47B gets its operating frequency from a free-running oscillator, which can be adjusted to an arbitrary frequency in the range 10..110 Hz. Default is 13.7-13.8Hz, which is suitable for both 50 and 60Hz countries. Frequency selection is a compromise between 1/f noise, balancing speed, capacitive damping and beating with mains-borne interference. Detection of the bridge unbalance signal is inhibited during 1/4 cycle after each polarity change of the square wave excitation current. This reduces the non-linearizing effect produced by any possible capacitance shunting the resistive sensor.

INPUT CAPACITANCE: The input time constant (R_{SENSOR}*C) must not exceed 20 ms for the error to stay within a few digits at 13.7 Hz operation (10 nF on the 2 MΩ range or 100 nF on the 200 kΩ range). For higher operating frequencies, the time constant must be correspondingly shorter.

SENSOR LEAD RESISTANCE: The maximum permitted lead resistance depends on range and excitation. For example, the 2 Ω range (and the 0.2 Ω difference range) tolerates 100 Ω in both current leads at 3 mV excitation, and even more at lower excitations. Lead resistance can be estimated by switching the AVS-47B to measure the compliance voltage of the excitation source. The lead resistance error consists of offset shift and gain error. The total effect can be assumed to stay below +/- 5 digits for the maximum allowed lead resistances.

DIGITAL DISPLAY: 4 1/2-digit yellow LED display with parallel drive for minimum interference. Display and the status LEDs can be disabled in order to reduce power consumption during remotely controlled battery operation.

A/D CONVERSION RATE: The free-running, integrating A/D converter makes 2.5 conversions per second. Resolution is 4 1/2 digits, in other words -19999..0..+19999 .

DISPLAY SELECTOR: Display selector connects the front panel DVM to one of the following sources:

1. Sensor resistance (= ANALOG output).
2. Difference between the sensor resistance and the ΔR reference DAC (= DIFFERENCE output).
3. Output voltage from a 10-turn front panel potentiometer. Used for setting an arbitrary ΔR reference.
4. ΔR reference DAC output (= REFERENCE).
5. Excitation voltage. Used for estimating the current path lead resistance.
6. Temperature controller's set point voltage.
7. Temperature controller's heater output voltage (scaling depends on selected heater output range).
8. Temperature controller's heater output current (scaling depends on selected heater output range).

If the system has no temperature controller, inputs for items 6..8 are available for monitoring external voltages. They all have a calibrated gain of (0.01% ± 1 digit). These inputs can be accessed through the data connector to TS-530A.

ANALOG OUTPUT: Calibrated stepless high-resolution output that is obtained directly from the self-balancing loop. Filtered by 3rd order Bessel filter having an approximate bandwidth of 0.6Hz. Range 0..+2V, output impedance 100Ω.

DIFFERENCE OUTPUT: Difference ΔR between the Analog Output and the ΔR-reference DAC. Range from -2V to +2V. Output impedance 100Ω. The difference can be magnified by a factor of 10 in order to get a better resolution within a 10% sub-range. The origin of the sub-range is determined by the ΔR reference.

ΔR REFERENCE: The reference is determined by a 12-bit D/A converter. The possible reference values are spaced apart by 5 display units (for example 0120, 0125, 0130 etc.). Accuracy of the ΔR voltage is about +/- 200 microvolts (2 digits).

The reference can be set in four ways:

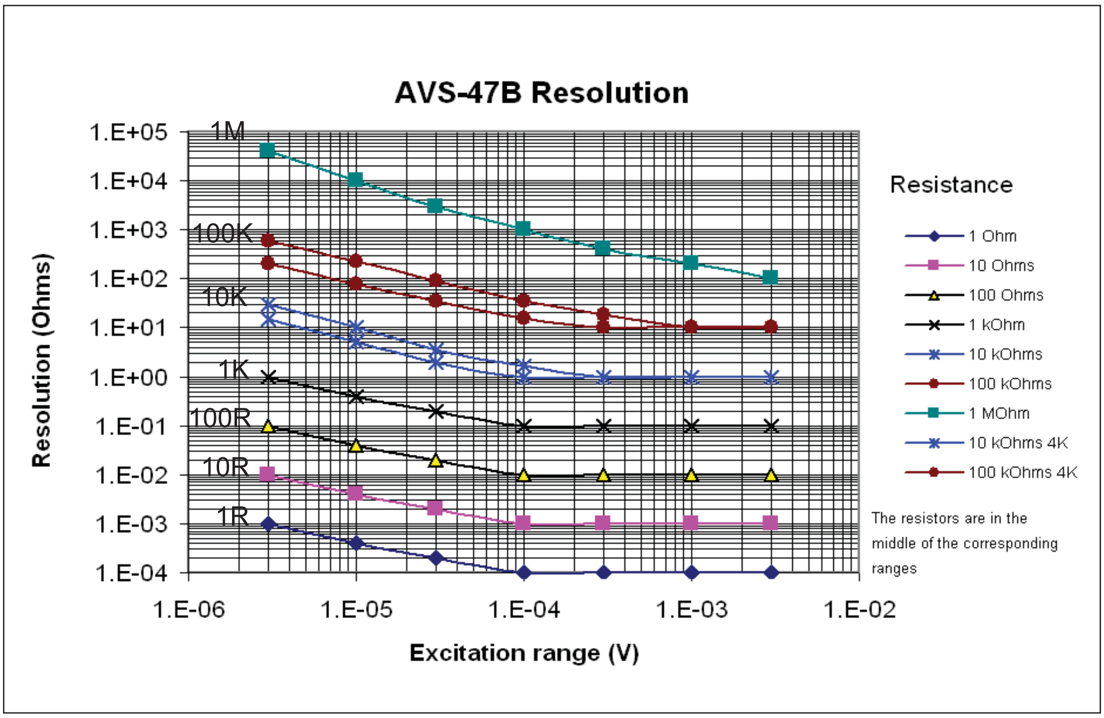
1. The displayed sensor value is taken as reference. The display value is rounded to the nearest number divisible by 5.
2. An arbitrary reference can be saved in memory by means of a 10-turn potentiometer. The display is used as an accurate potentiometer scale. The reference is rounded as above.
3. The reference can be set via the computer interface as an integer number. Minimum step is 500 μV.
4. It is also possible to bypass the set point memory and to use the potentiometer directly. This is the easiest way to null the DIFFERENCE output before a measurement.

RELAY OUTPUT: 0.5A relay switch is available for activating an alarm system or controlling an “on/off” heater. The relay can be configured to either open or close when the sensor value passes the deviation reference from low to high.

CALIBRATION ACCURACY: The basic calibration accuracy of all ranges is 0.0 1 % ± 1 digit at the highest excitation. Lower excitation ranges are calibrated to 0.01 -0.02% by taking sufficiently long averages.

RESOLUTION: The curves below show typical standard deviation of the display for seven different resistors at the room temperature. The lower parts of the 10kΩ and 100kΩ traces show the improvement that can be achieved by cooling these sensors to 4.2 K on these two ranges.

On high excitation ranges, the analog resolution (ANALOG OUT) may be better than the readout resolution.



Using the 10*ΔR mode for measuring changes smaller than 1/10 of the range gives a tenfold improvement in the digital readout resolution.

LINEARITY: Maximum linearity error for middle-point calibration is given by the table below. The input time constant is assumed to be less than 1 millisecond (cap.comp. disabled) or less than 10 ms (cap. comp. enabled)

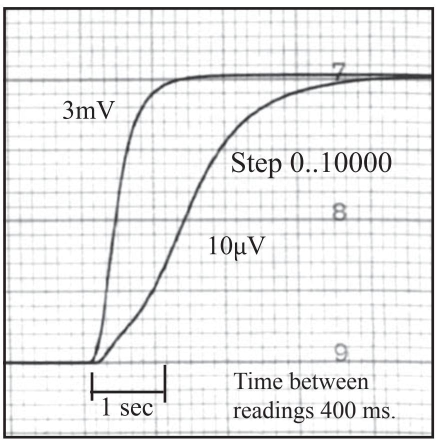
RANGE	ERROR AT F.S.
2Ω – 20 kΩ	± 1 dig
200 kΩ	± 2 dig
2 MΩ	± 20 dig

TEMPERATURE STABILITY: Typically, temperature coefficient is lower than 100 ppm/ºC and offset change less than 0.2 digits/ºC.

After self-calibration, the corresponding figures are 6 ppm/ºC and 0 digits/ºC (±1 digit).

AUTORANGING SPEED: There is a fixed delay of 1, 4 or 16 seconds between two successive autoranging operations. This delay prevents the bridge from oscillating between ranges. Speed is selected by a circuit-board jumper. Default is 1s.

SPEED OF BALANCE: Speed of balance depends on excitation range, being a little slower at low excitations. It takes about 5 seconds for the bridge to stabilize to ± 1 digit after a decade step, highest excitation. Analogue bandwidth is about 0.6 Hz at 3 mV excitation. Below are typical readings for a step change from 0 to 100 Ω on the 10 μV excitation range.



ADC readings, @3mV

```
 0.00
23.74
57.60
76.45
92.71
96.04
97.78
98.79
99.33
99.61
99.77
99.84
99.92
99.98
```

OPERATING TEMPERATURE: 15 ... 35ºC

MAINS VOLTAGE RANGE: 90V (100 mA)..260V (50 mA), 50-60Hz

BATTERY INPUT: Requires two 12V batteries or other floating voltage sources (each 11.5V ... 16.0 V) . Current consumption is about +550 / -150 mA (display enabled) and about +350 / -150 mA (display disabled). Input DIN socket PREH type 71206-040 and mating plug 71430-040.

SAFETY VOLTAGE INPUT: An alternative to the two DC voltage sources is a single floating 12V sinusoidal AC voltage (11.5-16.0V, 50-60Hz). The same DIN connector is used but wiring is different. The external transformer must be capable of giving 12V at 1.5A average load.

PRIMARY COMPUTER INTERFACE: Synchronous serial low-EMI interface uses a slow **“Picobus” protocol**. The primary interface can be connected to the **IEEE-488 (GPIB)** bus via the optional **AVS47-IB** secondary interface unit. **LabView™** owners can also connect it directly to a PC-type computer that has a free COM port.

Following items can be read and controlled via the primary interface: Input Source, Input Channel, Range, Excitation, Display Selector, ΔR Reference and Remote Control on/off.

If a **TS-530A** temperature controller is connected to the AVS-47B, its set point can be both read and programmed via the primary interface. The TS-530A PID parameters can be programmed but not read.

Following items are limited to be only read remotely: Result of the A/D conversion, Position of the “Ref Adj” Potentiometer, Excitation Compliance Voltage, TS-530A Heater Voltage and TS-530A Heater Current.

OPTIONS:

Model AVS47-IB Two-Stage Interface. Supports the IEEE-488 standard. Data sheet and a **LabView Driver** can be downloaded from our WEB site.

Picolink Optical Fibre Interface between the AVS-47B and the AVS47-IB. Can be installed only, if both an AVS-47B and an AVS47-IB are ordered at the same time.

WARRANTY: Three years.

4. UNPACKING

The shipment should contain following items:

1 pc AVS-47B main console unit
1 pc AVS-47B preamplifier unit
1 pc 5 meter cable for interconnecting the above units
1 pc 5 meter Picobus cable for the primary interface
1 pc mains power cord (Euro or US type)
1 pc spare fuse 1A slow action (T).
2 pcs 37-way input connectors with metallized shellos
1 pc 3-way plug for the relay output.
1 pc 4-way plug for external battery operation
1 pc instruction manual
1 pc Application Note for LabView VI:s

If you purchased also the AVS47-IB computer interface, the shipment further includes:

1 pc AVS47-IB secondary unit
1 pc mains power cord (Euro or US type)
1 pc 1A primary fuse slow action (T)
1 pc Instruction Manual
1 pc LabView Driver Manual
NOTE: The LabView Driver software must be downloaded from our WEB site www.picowatt.fi. The driver is no longer supplied on a 3.5" diskette.

If the bridge and the computer interface have the optional PICOLINK installed, then the shipment contains also

1 pc Picolink Optical Fibre Cable (5m)

5. INSTALLATION

The following section describes how to start to use the AVS-47B. It contains also a simple tutorial that makes you acquainted with the instrument. Even if you are familiar with our older models AVS-46 , AVS-47 or AVS-47A and feel, that it is waste of time to read this manual, you may want to glance through the text in order to see the differences and what is new.

5.1. MAINS VOLTAGE RANGE

Starting from serial number 861A6B2C2D7E8, the conventional iron transformer followed by diode rectifiers has been replaced by a commercial switching mode power supply whose input voltage range is from 90V to 260V. These bridges do not need any user action for selecting the mains voltage in any country. Older bridges need, and therefore please use an older operating manual with them.

The voltage range, instead of a voltage setting, is written on the identification label on the rear panel. If the label shows a voltage setting, then your AVS-47B is of older design and an older manual must be used with it. If the marking is unclear or if it has been changed by a previous user, the AVS-47B must be opened and the supply type and voltage setting must be verified from inside.

Opening the AVS-47B is allowed only for a qualified serviceman. See also page 4.

Instructions for a serviceman:

In order to check the type of the power supply in case of uncertainty, disconnect the power cord from the instrument and open the top cover. If there is a transformer on the circuit board in the right front corner of the the instrument, the supply is of old type and you must use an earlier manual for instructions how to check and -if necessary- change the voltage setting.

After having checked the type of the power supply and possibly changed the voltage setting, correct the markings on the rear panel identification label to correspond to the configuration.

5.2. FUSES

The AVS-47B has one primary and two secondary fuses. The primary fuse works between the mains power network and the switching power supply, whereas the secondary fuses are inserted between the transformer and the rest of the bridge. The secondary fuses protect the AVS-47B when it is operated from batteries.

Instructions for a serviceman:

The physical size of all fuses is 5 x 20 mm

Primary fuse: 1A-T (slow action)
Secondary fuses F401=1A-T, F402=0.5A-T

5.3. SET UP

Connect the preamplifier to the main unit of the AVS-47B using the symmetrical cable that has male 25-pin connectors in both ends. It is important to tighten the connector screws carefully, because this guarantees a low ground impedance between the preamplifier and the main console units. Do not use too much force, however.

Connect the power cord to a grounded outlet. Turn the AVS-47B on. Switch the input to ZERO, excitation to 3mV, and select the 200 Ω range. Let the unit stabilize for half an hour before doing measurements.

IN ORDER TO MAINTAIN THE INSTRUMENT'S ELECTRICAL SAFETY, CONNECT THE AVS-47B ONLY TO A GROUNDED MAINS POWER OUTLET.

5.4. SENSOR WIRING

The 8 input channels are wired as follows:

1	I+	channel	0
20	V+		0
2	V-		0
21	I-		0
3	I+		1
22	V+		1 . .

17,36,18,37,19 = CIRCUIT GROUND & ENCLOSURE

The sensors may share a common current return lead, or the I- leads can be separate for each channel. All four wires are switched in order to maintain true 4-wire connections to the sensors.

Because the I- leads are switched, you must use the "always-connected" ground pins for the cable shields. Refer to MEASURING WITH THE AVS-47B/SENSOR WIRING.

The current return leads (I- leads) are normally connected to the circuit ground of the preamplifier. This grounding scheme works if a sensor floats inside the cryostat. The I- lead can alternatively be connected to the cryostat body in order to get a better thermal contact or to reduce the number of sensor wires. Then the connection to preamplifier ground must be disabled. Refer to "SUGGESTIONS FOR GROUNDING" and "ABOUT RESISTANCE THERMOMETRY"

6. TUTORIAL

The purpose of this section is to get you familiar with the new instrument.

You need:

- one 47Ω and two 220Ω resistors
- a piece of wire
- a small screwdriver that fits into the trimmer holes
- soldering iron and tin plus tools like side cutters, pliers etc.
- a DC37P connector (supplied with the instrument).

Solder the ends of the two 220Ω resistors to pins 1 and 21 of the input plug (these act as "lead resistances"). Solder the 47Ω resistor between the free ends. Solder the voltage leads from the two ends of the 47Ω resistor to pins 20 and 2, corresponding to current feed pins 1 and 21.

Switch the power on. You can observe the **power-on state** of the AVS-47B: The input source is switched to zero, no range is connected (OPEN), excitation voltage is ZERO and the sensor resistance (R) is displayed. The purpose of this initial condition is to prevent the AVS-47B from heating the sensor in the case that there should be a power failure or an accidental reset.

If this happens in a real measurement, restore the original settings in the following order: first select the resistance range (if you don't remember it, choose the highest range by lifting the switch lever upwards), then the excitation, and finally release the input from "ZERO" to "MEASURE". This way, you avoid feeding a high current to the sensor.

The bridge will not stabilize properly in the power-on state, because there is neither range nor excitation connected. Therefore, move the range indicator (lift and release the switch lever) to 200Ω. Similarly, change the excitation range to 3 mV. After a couple of minutes' warm-up time the display should be very near to zero. Verify also that the magnifier switch is in the ΔR position (not 10xΔR), and that the mode is MANUAL. Then, do something else for the next 30 minutes (our suggestion is, of course, that you read this manual!). Never calibrate the bridge or use it for accurate measurements unless it has stabilized for at least a half an hour.

Use a small screwdriver and turn the OFFSET trimmer back and forth, so that you can see the effect on display. Adjust it to 0. Switch the INPUT then to CALIBRATE. The display should stabilize near to 100.00. Turn also the SCALE trimmer back and forth, and adjust the display to 100.00. These two steps comprise the "self-calibration" procedure. It takes into account most of the possible drift sources. It does not correct for differences between measuring ranges or excitation ranges. Such changes are, however, minor compared with changes that can be canceled using self calibration. You should conduct this simple procedure whenever the ambient temperature changes more than few degrees, or if the AVS-47B has not been used for a long time (summer holiday?).

Switch the input to “MEASURE”. The display shows something around 47 ohms. Change the range up and down. If you select the 20Ω range, AVS-47B will complain about overrange by blinking the display, and on the 2Ω range it complains also about excessive current lead resistance by lighting a red lamp. Leave the range to 200Ω.

Reduce the excitation, step by step and very slowly. Each step means ten times lower power dissipation in the sensor. At 300 or 100µV you start to see how the signal-to-noise ratio becomes worse. At 10µV the measurement is made with a dissipation lower than 1pW. On the lowest 3µV excitation range, the display is very noisy. Return back to 3mV.

Verify that the reference source switch is in the REF MEM position. The bridge is now measuring 47Ω on the 200Ω range. Lift the SET REF switch lever. The measured resistance value is now entered as the ΔR reference (or the new origin for the deviation scale). Shift the DISPLAY indicator to the REFERENCE position. You should see a display that is the original resistance value rounded to the nearest number that is divisible by five (± the accuracy of the analog circuits!!). The original reading is rounded, because the reference DAC has only 12 bits, whereas the 4 1/2 digit display corresponds to 14 bits.

Select the ΔR display. This is the difference between the original reading and the new reference. It should be almost zero, a couple of digits at most.

Shift the deviation magnifier switch to 10xΔR. Now the reading should become roughly ten times bigger (remember again: this is an analog instrument, and therefore the scale factor is not exact and offset is not zero!). Note how the position of the decimal point is changed: although the measuring range remains at 200Ω, the decimal point is shifted to a position where 19.999 is the maximum display. This reminds you about the fact that you have a tenfold sensitivity but only 10% of the original scale available. Switch back to ΔR from 10xΔR.

There are also other ways to determine the set point. Shift the display indicator to ADJ REF. Then dial the helipot until the reading is 20.00. Lift the SET REF switch. Then look at REFERENCE: it should be 20.00. Look at ΔR. The display should now be something like 27.00 (depending on the actual value of your 47Ω resistor).

If you just want to adjust ΔR to zero, you can also take the reference directly from the helipot, without using the memory. Set the reference source switch to REF POT and display ΔR Then adjust the potentiometer until the reading is zero. Return the display selector to the “R”-position.

> Because of loading, the potentiometer is not linear in the REF POT position. Do not rely on its 10-turn scale.

Set the MODE switch to AUTO. Short circuit your “sensor” with a piece of wire or similar. Once the display has fallen below 18.00, the AVS-47B changes range to 20Ω. If the “sensor” is kept short-circuited, the next change will take place after one second. Now open the short-circuit and the bridge will go back to the 200Ω range. Autoranging does not change the excitation.

As the last exercise, we determine the total lead resistance. Verify that you are using 3mV excitation and 200Ω range.

Shift the display indicator to EXC VOLT. The integer reading should be approximately 00048 (with the suggested resistor values). This means that the compliance voltage of the excitation source is 48 millivolts. The excitation current on this range is 3.3 mV/100Ω = 33µA. The total current path resistance is then 48 mV/33µA = 1454Ω. In order to find the lead resistance, we must first subtract the 47Ω sensor resistance 1454-47=1407Ω. We must also subtract the reference resistance, which is ten times the middle value of the range, 10*200Ω /2 = 1000Ω in this case, obtaining R_{LEADS} = 407Ω. Assuming that the lead resistances are evenly divided, we get 203Ω for each current lead.

You can expect to get only an estimate for the lead resistances this way. The AVS47-IB interface features a command that determines this **estimate** for you without need to do any calculations. But note that the lower is the excitation, the less accurate is the result.

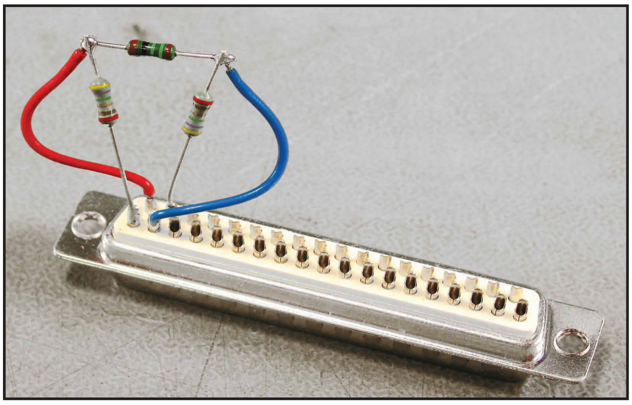


Fig. 6-1. Test plug for the tutorial lesson

7. SELF CALIBRATION

The AVS-47B contains very long chains of analog AC and DC amplifiers plus attenuators. The number of components that affect the stability and offset of the bridge is thus high, and with some bad luck, the worst-case drift can be significant. The vast majority of possible drift sources are common to all resistance and excitation ranges.

Self calibration is a procedure where a) the bridge input is connected to a zero reference so that the offset can be nulled, and b) the bridge is connected to measure its own resistance standard. During the latter phase, the display is adjusted to be exactly in the middle of the scale. After these steps, the accuracy of the AVS-47B on the 200Ω range and 3.3mV excitation is based on the accuracy of the resistance standard and on the linearity of the bridge.

Self calibration is made as follows:

1) Switch the input selector to ZERO, range to 200Ω and excitation to 3mV.

2) Let the bridge stabilize for at least half an hour.

3) Use a small screwdriver to adjust the OFFSET trimmer so that the display is zero.

4) Switch the input selector to CALIBRATE.

5) Adjust the SCALE trimmer so that display reads 100.00.

This procedure calibrates the scale and offset only on one resistance and excitation range. Usually there should be no need to recalibrate the lower excitation ranges, as these can be expected to follow the new calibration within a couple of bits.

You can check the calibration of the remaining higher excitation ranges by switching the excitation down (input switch in CALIBRATE). It is possible to go down to 300, or even to 100µV this way, but then the display becomes too noisy for checking it visually from the display. On the lowest ranges, one must count averages and therefore needs to interface the AVS-47B with a computer.

All excitation ranges, including the lowest ones are best checked and adjusted by using either

- The built-in averaging macro of the AVS47-IB computer interface. A simple GPIB communication software is needed on the PC for sending the necessary commands to the AVS-47B. Such software usually comes with the GPIB controller board
- our LabView Driver for the AVS47-IB together with the AVS47-IB interface box
- the Average.vi virtual instrument from the LabView VI package that supports direct interfacing with a PC.

The AVS47-IB has also a macro command for digital self-calibration. It does not calibrate the bridge, which requires a screwdriver, but it measures the scale factors and offsets on all seven excitation ranges. With this data, the interface box then automatically corrects all subsequent measurement results. Because digital self-calibration does not affect the analog output, it is not suitable in temperature control applications with the TS-530A.

> Digital calibration offered by the AVS47-IB does not calibrate the digital display of the AVS-47B. Use it only in a computer-included application.

7.1. CALIBRATING THE DEVIATION REFERENCE

Calibration of the deviation reference is required only if the reference produced by the SET REF command is unacceptable. Note that the reference is always rounded to the nearest value that is divisible by five (the steps are five, but the display may not end to exact 0 or 5 because of the limited accuracy of the analog circuits).

Select the R display and switch the input selector to ZERO. Lift the SET REF button. Select the REFERENCE display and adjust R401, if necessary, to get zero reading.

Select the R display and switch the input selector to CAL (resistance range = 200Ω). The display must be within 99.98....100.02. Enter this value to the reference memory. View the REFERENCE again and use trimmer R402 to make the display 100.00.

7.2. CALIBRATING THE ΔR DIFFERENCE AMPLIFIER

Calibration of the offset and two gains of this differential amplifier is not explained in this manual, as there should be very little need to do it.

Being an analog circuit, the difference ampllifier is assumed to retain its calibration only roughly. If you need the ΔRx10 function for accurate measurements, please obtain the short calibration instructions from **Picowatt**.

8. MEASURING WITH THE AVS-47B

8.1. MULTIPLEXER

The Input Multiplexer of the AVS-47B is a circuit board containing 16 double-pole, single-throw reed relays plus their drivers. The multiplexer is located inside the preamplifier unit, on the other side of the box than the preamplifier itself. The Multiplexer has a 37-pin female D-type connector for eight 4-wire sensor inputs.

The AVS-47B offers one 8-channel multiplexer unit as a standard feature. It is not possible to increase the number of input channels. This is because the multiplexer is located in the preamplifier box, which must remain reasonably small.

The input channel is changed by lifting or pressing the CHANNEL selector. The channel counter was made circular to ensure convenient scanning, i.e. it goes from 7 to 0 and from 0 to 7.

8.1.1. SENSOR WIRING

*	1	I+	channel 0
*	20	V+	channel 0
*	2	V-	channel 0
*	21	I-	channel 0
*	3	I+	channel 1
*	22	V+	channel 1
*	4	V-	channel 1
*	23	I-	channel 1
*	5	I+	channel 2
*	24	V+	channel 2
*	6	V-	channel 2
*	25	I-	channel 2
*	7	I+	channel 3
*	26	V+	channel 3
*	8	V-	channel 3
*	27	I-	channel 3
*	9	I+	channel 4
*	28	V+	channel 4
*	10	V-	channel 4
*	29	I-	channel 4
*	11	I+	channel 5
*	30	V+	channel 5
*	12	V-	channel 5
*	31	I-	channel 5
*	13	I+	channel 6
*	32	V+	channel 6
*	14	V-	channel 6
*	33	I-	channel 6
*	15	I+	channel 7
*	34	V+	channel 7
*	16	V-	channel 7
*	35	I-	channel 7
*	17	ground	
*	36	“	
*	18	“	
*	37	“	
*	19	“	

Use only the permanently connected ground pins for cable shields. If a grounding jumper JP1..JP8 on the multiplexer board is inserted, the I- (current return) lead of the corresponding channel is connected to the circuit ground of the preamplifier, but only when the appropriate channel is selected.

You can use one single wire as a common I- lead for some or all of your sensors. In that case, solder this wire to the I- pin of each of those channels. Although the sensors now have one common lead, they do not interact, because only one of them is measured at a time.

Reed relays have been used in the multiplexer because they provide the best combination of low leakage, high isolation resistance and low contact resistance. However, they are mechanical devices which have a limited (though long) lifetime. Therefore, if possible, do not leave the bridge scanning unnecessarily for extended periods of time (summer or Christmas holidays ?).

The bridge is not sensitive to contact resistances. But if the current-path contacts are in a very bad condition, they may become noisy and then the bridge performance will be seriously affected.

8.1.2. USING THE MULTIPLEXER

Be careful not to heat your sensors when changing from one channel to another. The preferred practice is to change the INPUT selector to ZERO, then select the new range, excitation and channel, and finally release the input again.

Driving the relay coils may produce small pulses that can heat the sensor. By switching the input to zero before changing range, you can limit the number of such pulses. The channels can be selected only sequentially in their numerical order. It is therefore possible, that the AVS-47B measures resistances that are too high or low for the selected range, or applies excessive excitation to a sensor, unless you keep the input selector at ZERO until you are done with all switching.

8.2. RANGE

8.2.1. MANUAL RANGING

You can change the range manually upwards until the bridge reaches the 2MΩ range. You can go downwards from the 2Ω range to the “open” range and then directly to 2MΩ. This arrangement lets you go from the initial “open” state to any range via 2 MΩ without danger of overheating, but eliminates the possibility of inadvertently measuring a high resistance on a 2Ω range.

8.2.2. AUTORANGING

Autoranging is useful, for example, during the cooldown of the cryostat, when the sensor resistance may increase by several orders of magnitude. In this case, it protects the bridge against a prolonged overrange condition.

The AVS-47B changes range upwards if the display exceeds 19999 until it reaches the 2MΩ range. Range is changed downwards if the display falls below 1800. The lowest range for autoranging is 2Ω, not the “open” range.

A fixed delay separates two successive autoranging operations. The purpose of this delay is to prevent the bridge from oscillating between ranges. Three jumper-selectable delays are available. When the AVS-47B is operated synchronized to the mains, these delays are approximately 1, 4 and 16 seconds, but they will be shorter if the free-running oscillator is used at a higher frequency. The bridge is shipped with the 1s delay selected.

If you use multiplexing together with autoranging, and the sensor resistance jumps much over one decade, the shortest delay may turn out to be insufficient. Move the short-circuit piece from JP101 to position JP102 or JP103 (circuit board AVS47E). The same operation may be necessary if your free-running excitation frequency is high and the delay is therefore correspondingly shorter.

Autoranging information is obtained from the A/D conversion result regardless of what is the quantity being measured. If you have autorange ON, and you display for example the excitation compliance voltage, which is small, the bridge will most probably shift the range downwards. Similarly, the bridge can easily go to an endless loop, if you use autoranging together with the 10xΔR display. **Therefore, autoranging should be used only together with the R-display**.

8.3. EXCITATION

An extremely low and selectable AC excitation current is perhaps the feature that most clearly makes cryogenic resistance bridges different from other resistance meters. There are basically two alternate ways to excite the sensor: either a constant voltage or a constant current.

Constant voltage is typically used in a conductance measurement. The resistance of a cryogenic sensor usually increases with decreasing temperature. With constant voltage excitation, the dissipation power decreases when temperature drops, which is convenient. The severe limitation is that the measuring range cannot include zero resistance, because conductance is infinite. A conductance bridge cannot be used for measuring low resistivity materials nor superconductive transitions.

Constant current is preferable in resistance measurements. A resistance bridge can be applied down to the superconductive state, but as a drawback, the power dissipation in the sensor increases linearly with the resistance. This increase can be cancelled by selecting a lower excitation range.

The AVS-47B is based on constant current excitation, although we talk often about the excitation voltage. The reason is explained below. Excitation current flows out from the I+ terminal to the sensor and returns to the I- terminal, which must be connected to ground, either to the cryostat body or internally to the preamplifier ground, but not both.

8.3.1. DISSIPATION POWER

The excitation current is supplied as a square-wave shaped AC current having a constant amplitude. To make matters more complicated, the excitation source is basically an AC *voltage source* with a low output impedance. The “excitation voltage” is applied to the series connection of the reference and unknown resistors. The voltage drop across the *reference resistor* is measured and compared with an accurate reference waveform. Depending on the comparison result, the excitation voltage is then adjusted by means of feedback. When the excitation voltage has been adjusted to V_{exc}, current through the reference resistor R_{ref} is V_{exc}/R_{ref}.

The dissipation power is defined as

$$P_d = (V_{exc} / R_{ref})^2 * R_{sensor}$$

The reference resistor is always 1/2 of the selected resistance range. For example, if the sensor’s value is 150kΩ (200kΩ range) and excitation voltage 10µV, the power dissipation is 1.5 femtowatts.

8.3.2. EXCITATION FREQUENCY

Default excitation frequency was 1/4 of the mains frequency for all AVS-47-series bridges with serial number lower than 861. It was also possible to take the excitation frequency from a free-running oscillator, a useful feature in cases, where the dominant interference comes from vibration caused by vacuum pumps etc. Such an interference can have a frequency, which is almost but not exactly a sub-harmonic of the power line, and then synchronisation to mains results in beating, which is difficult to filter off due to its low frequency.

Starting from serial number 861, the power supply of the AVS-47B was changed to use a switching mode unit with ultra wide input range. The bridge can now be operated all over the world without re-wiring the mains voltage. On the other hand, there is no longer any low-voltage AC available for taking synchronisation from mains, and the free-running oscillator is now the only possible source of excitation frequency.

1/4 of the mains frequency is 12.5 or 15Hz for 50 and 60 Hz lines, respectively. By default, the AVS-47B oscillator is adjusted to 13.7-13.8Hz , which gives a beating of over 1.5Hz for mains-borne interference regardless of the mains frequency.

If you want to try another frequency, adjust the oscillator as below. Use a frequency counter and a high-impedance probe (e.g. oscilloscope's x10 -probe) to determine the excitation frequency at test point marked “F”. This frequency can be adjusted from about 10 Hz to about 110 Hz by using trimmer R430. Some digital multimeters, like HP34401A, have also a very convenient frequency measurement capability, and this kind of low frequencies can be measured using ordinary DVM test leads.

The adjustment range has been divided into two parts, low and high, which are selected by having a jumper in JP401 or JP402, respectively.

Do not try to find the exact frequency of the interference, the simple RC oscillator is far too inaccurate for that. Instead, try to maximise the beating frequency and use averaging to reduce the bandwidth of your data. The AVS-47B has an internal 3rd order analog low-pass filter with 0.6Hz corner frequency. The AVS47-IB computer interface provides additional built-in averaging functions.

Please consider also another aspect when choosing a high operating frequency: The bridge becomes more sensitive to the nonlinearizing effect of input capacitance.

8.3.3. DC COMPONENT IN EXCITATION

The design of the excitation source guarantees that the maximum DC current that may flow to the sensor cannot be higher than the AC excitation current. The worst case is possible only on the 2Ω range when the 3 mV excitation is used and lead resistances are low. The likelihood of such a worst-case situation depends quite randomly on the difference of the base-emitter voltages of two buffer transistors.

At low temperatures, when the highest excitation cannot be used, the DC component and its heating effect are negligible.

8.3.4. NO AUTOMATIC CHANGE OF EXCITATION

The old Model AVS-46 could be programmed to change the excitation simultaneously with the range in the autoranging mode. This is not possible with the AVS-47B, but excitation can be changed only manually (or remotely in computer-controlled applications).

8.4. DISPLAY SELECTOR

One of the AVS-47B features is the display selector. There are 8 possible items that can be displayed. These are

0 R = Sensor resistance.
1 ΔR = Resistance deviation. This is the difference between the measured value and the deviation reference voltage.
2 ADJ REF = Reference potentiometer. This display indicates the position of the front panel 10-turn potentiometer, which is used for setting an arbitrary reference.
3 REFERENCE = The voltage that is currently being delivered by the reference memory circuit and is subtracted from R in order to get the deviation ΔR.
4 EXC VOLT = compliance voltage of the excitation source. By measuring this voltage, one can determine the approximate current path resistance.
5 530 HEAT V = temperature controller's heater output voltage.
6 530 HEAT I = temperature controller's heater output current.
7 530 SET PT = temperature controller's own set point voltage.

8.4.1. DECIMAL POINT

The decimal point has importance when items 0..3 are displayed, but it shall be ignored with items 4..7. This is because the scales for items 4-7 are very different from those related to the selected resistance range. The scaling is explained in the next paragraph.

Be careful with the magnifier switch. This switch moves the decimal point so that it corresponds to ten times lower ranges. It should be used only when displaying the magnified deviation in the 10xΔR mode. In order to avoid excessive hard-wired logic, the magnifier switch affects the decimal point also with other display modes, which is misleading.

8.4.2. INTERPRETING THE DISPLAY

Items 4 and 7 are quite straightforward, whereas some calculations and information about the TS-530A parameters are needed for interpreting items 5 and 6. These items are probably most useful in computer-controlled applications, where these calculations can be automated.

EXCITATION VOLTAGE (4) The least significant digit of the display corresponds to 1 mV. The reading is the compliance voltage of the excitation source. In order to determine the lead resistances, you must measure the sensor resistance and then item 4. Calculate the lead resistance as described in "Measuring Lead Resistances".

HEATER OUTPUT VOLTAGE (5) Let us denote the integer A/D conversion reading by ADC and temperature controller's power range by POW (0..7). Heater output voltage is then

$$V_H = - ADC * 3.162^{(POW-13)}$$

For example, if ADC=6821 and POW=7 (=1W), then V_H = 6.82 Volts, but if the same reading were obtained on the 0.1W power range, then the voltage would be 2.15 Volts.

HEATER OUTPUT CURRENT (6) Heater current is calculated in the same way as above

$$I_H = ADC * 3.162^{(POW-17)}$$

For example, if ADC=6821 and POW=7 (=1W), then the heater current is 0.068 Amperes. Note that you or your computer program needs to know the TS-530A power range setting for these calculations. (3.162 = sqrt(10)).

The actual heating power is the product of I_H and V_H.

The circuitry that enables reading of parameters from the TS-530A is not very accurate. Therefore one should use these values only for estimations and not for accurate measurements.

SET POINT (7) The least significant digit means 100µV. Multiply the integer ADC reading by this voltage. Because AVS-47B's A/D converter is limited to 19999, it cannot measure the temperature controller's full set point range, which goes up to 42000. However, this is not a limitation when the TS-530A is used with the AVS-47B.

8.4.3. MONITORING EXTERNAL VOLTAGES

Inputs for display items 5-7 are available in the rear panel ”TEMPERATURE CONTROLLER” data connector as follows:

pin	function
26	ground
5	item (7) = HEAT SP
25	item (6) = HEAT I
7	item (5) = HEAT V

All three inputs are calibrated to 0.02% (±19999 corresponds to ±1.9999V), and high input impedance. In applications without a temperature controller, you can connect one or all of these inputs to external sources and use the A/D converter of the AVS-47B to monitor them. This possibility can save you one external computer-interfaced DVM.

The absolute maximum input voltage range is -5V...+5V. These CMOS analog switch inputs have not been protected heavily. You can damage the internal circuits easily by feeding excessive voltages or currents to them. Please be very careful with electrostatic discharges: touch always some ground with your hand and with the connector just before plugging it into the “TEMPERATURE CONTROLLER” socket.

8.5. DEVIATION REFERENCE

The DEVIATION output together with the adjustable deviation reference serves for at least four purposes: you can center the pen if you are using a chart recorder, you can set a new origin for the measuring scale, you can implement a 0.2Ω measuring range with 10mΩ resolution and you can control the relay output with the deviation. There are four ways to set the deviation reference.

REFERENCE FROM SENSOR

You can take any value displayed in the R-mode as the new reference (or new origin for the ΔR output scale). Lift and release the SET REF front panel switch. The new reference can be viewed by shifting the display indicator to REFERENCE.

> You must take the reference from the original R-display, not from ΔR.

The AVS-47B’s digital display ranges up to 19999 whereas the 12-bit D/A converter used for the reference only ranges up to 4095. Therefore the displayed number is divided by five and rounded to the nearest integer.

The result of this rounding is that the reference can get only values that are divisible by five (or end either to 0 or 5, e.g. 120.00, 120.05, 120.10, etc.).

FROM HELIPOT VIA MEMORY

The reference may also be set in advance to any arbitrary value (within the rounding limitations described above).

Shift the display indicator to ADJ REF. Dial the 10-turn potentiometer so that the display indicates the desired reading, and lift the SET REF switch. Use the REFERENCE display to check the new reference.

The accuracy of the analog circuits is limited, and so there may be an error of couple of digits in the resulting reference voltage.

FROM THE COMPUTER

One can set the reference remotely either via the AVS47-IB computer interface option, when working with the GPIB bus, or directly from a controlling PC, if you use LabView and the VI package for the AVS-47B. In all our software, the remote reference ranges from 0 to 19999 for user convenience, and the necessary rounding is made either by the interface unit or by the programs.

The actual value of the reference can be read to the computer by remotely selecting the REFERENCE display and then reading the A/D converter.

DIRECTLY FROM THE HELIPOT

Sometimes you may wish to bypass the set point memory, e.g. if your intention is just to null the ΔR output before a measurement.

Set the reference source switch from the REF MEM position to the REF POT position. Then the potentiometer affects directly the ΔR without A/D conversion and memory storage. The memory will hold the last saved value, so that you can actually have two independent references. Which one is used, depends on the reference source switch position.

> The circuitry loads the helipot in the REF POT position. Therefore the potentiometer scale is not linear.

8.6. ANALOG OUTPUTS

The AVS-47B provides three analog outputs, which are wired to BNC connectors on the rear panel.

ANALOG

This is the most accurate output of the AVS-47B. It is the output of the self-balancing circuit, filtered by the 0.6 Hz 3^{RD} order low-pass filter. The self-calibration (and also the separate calibrations of the resistance and excitation ranges) affect this output. It is possible to use self-calibration for calibrating the ANALOG output when it is connected to an external (>5 digit) digital voltmeter. Then you can obtain a higher resolution than what is possible by using the AVS-47B's own A/D converter. This is true on the two highest excitation ranges only, then the decreasing S/N ratio starts to limit the attainable resolution.

The input impedance of the DVM must be at least 10MΩ, because the internal resistance of this output is 100Ω (usually the DVMs have a very high input impedance on the 2 Volt input range). The cable to the DVM must have a shielding jacket.

After having calibrated the analog output, you may wish to use trimmer R107 on the "E" circuit board to calibrate also the AVS-47B's own A/D converter.

DEVIATION

The meaning of this output was already explained above (deviation reference). Output impedance is 100Ω, and range from -2V to +2V.

The 1xΔR mode serves for at least three purposes: it provides the zero-crossing output for driving the relay switch, so that this can be used while displaying the normal sensor resistance. It provides an error (or deviation) signal for driving a temperature controller, if a controller other than the TS-530A is used. (The TS-530A is connected to the ANALOG output, because it has its own set point voltage source). And finally, you can null the reading before a measurement, if you want to record changes.

The 10xΔR mode makes it possible to implement a 200mΩ measuring range. It can also be used to improve the resolution of the bridge within a 10% sub-range. This is, however, feasible only when using a high sensor excitation when a good signal-to-noise ratio can be achieved.

The differential amplifier is an analog circuit which is not capable of utmost accuracy or stability. The offset and scale factors (1 and 10) of this amplifier may drift with time and temperature. If you need to take ΔR readings with the best possible accuracy, check the offset (input = zero) and scale (input=200Ω for ΔR and 2kΩ for 10xΔR).

AC OUT

The AC OUT -output represents the signal across the sensor, amplified by the complete AC amplifier chain. It is available for trouble-shooting purposes.

It is a good idea to make yourself familiar with this output before starting to use the AVS-47B for real measurements. Connect an oscilloscope to it. Shift the INPUT selector between ZERO and CALIBRATE. You can see, how the bridge stabilizes. Shift the excitation range gradually downwards. Noise level becomes higher. When the bridge uses 3μV, switch again between ZERO and CALIBRATE. You can see how the noise is now dominant.

In contrast to the AVS-47, the AVS-47B has a special circuit for compensating the shunting effect of a possible high input capacitance. If you want to see, how it works, proceed as follows.

Solder a 1MΩ resistor across the input. Open the top cover of the AVS-47B and set the short-circuit piece on the small AVS47F- add-on circuit board so that it connects the two header pins (see the layout picture in the appendix). The compensation is now disabled.

Using the highest excitation range of 3mV, look at the AC signal. You may need to shield the resistor with your hands, touching some ground at the same time, otherwise mains hum can mix the signal. The signal might

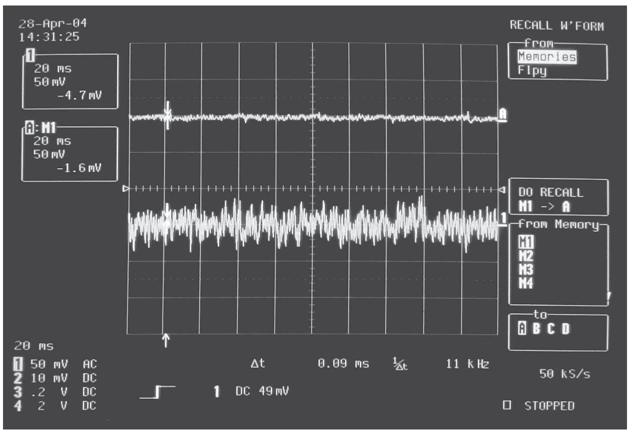


Fig. 8-1. This oscilloscope graph shows two typical waveforms as seen at the AC output. The upper trace was obtained using 100μV excitation and the lower using 10 μV excitation. The bridge was in the calibrate mode, and therefore the signal is free from any mains hum.

look like the upmost trace in the oscilloscope screenshot below.

Solder a 10nF film capacitor across your 1MΩ resistor. The sharp spikes in the output will grow in magnitude, and their decay times are longer. These spikes result from the comparison of the almost ideal reference square-wave and the capacitively shunted input waveform. As long as the decay time constant of these spikes remains well under 1ms, there should be no big error even without the compensation circuit, thanks to the delayed phase-sensitive detection. But the present 10ms time constant disturbs the bridge seriously and the readings are much too low (a factor of 10 in time constant is a factor of 22000 in exponential decay).

Enable automatic compensation by removing the short circuit piece on the AVS47F circuit board (insert

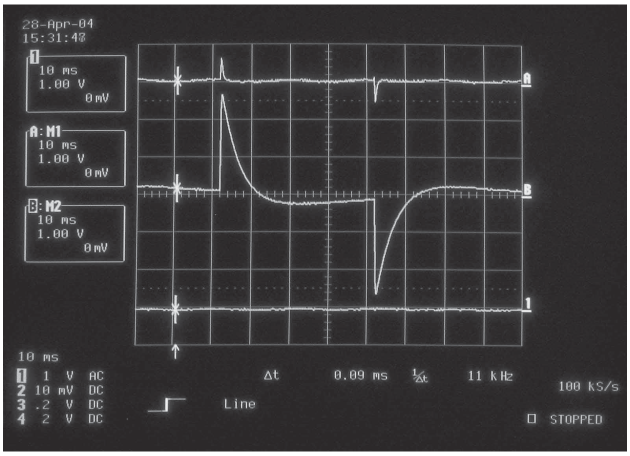


Fig. 8-2. Top trace: AC OUT from a 1MΩ resistor at 3mV excitation range. Middle trace: same as above, but 10nF capacitor was added across the resistor and the cap. comp. circuit was disabled. Bottom trace: compensation was enabled.

it to only one of the pins). The compensation works by charging the input capacitance rapidly to its correct voltage. The spikes disappear and the resistance reading is correct again.

Use the AC output for verifying that the signal you receive from the cryostat does not have an excessive 50/60 Hz component. **Please note that there is a potential problem when doing this:** When you connect an oscilloscope to the rear panel BNC, you may generate a new low-impedance ground path. The signal can then show something that was not there before you connected the scope, or you no longer see something that was there earlier. For maximum confidence, you can make a special cable and use the oscilloscope in the A-B mode. Connect one channel to the BNC jacket, the other one to the center pin and do not generate a new ground path via other connections.

There are two philosophies regarding filtering of the AC signal from the sensor within the instrument. The first (of the other manufacturers) is to block effectively all other signals than the carrier signal of the bridge. Even a large mains interference cannot then saturate the amplifiers nor the phase-sensitive detector. The problem is, that one has no way of knowing whether the sensor suffers from mains hum. The second philosophy (of ours) is to have no filtering at all. If you can see the interference (AC OUT), you can estimate its magnitude and whether any actions are needed to remove it. This is one reason, why we use the second philosophy (the other reason is, that square-wave excitation does not permit signal filtering).

The following table shows roughly the mains hum amplitude across the sensor, assuming that there is a 1Vpp signal at the AC output. Scale the interference according to what you actually see.

excitation (rms)	50/60Hz hum at sensor (rms)
3mV	1mV
1mV	300µV
300µV	140µV
100µV	50µV
30µV	18µV
10µV	5µV
3µV	5µV

Do not take the above figures too literally - they depend a lot on the gain of the preamplifier FET's. Anyway, a large mains hum at the AC output can mean, that the interference is heating the sensor more than the excitation current.

RELAY OUTPUT

The AVS-47B provides a relay output for applications that require an isolated switch. Examples of such applications are a robotic telephone or an alarm bell, which both may be used when the AVS-47B monitors cryostat temperature in the night. A completely different application is an “on/off” heater for a very simple temperature control system.

The 0.5 Ampere relay contacts are wired to pins 1 and 2 of a 3-way audio connector on the rear panel.

Opening/closing of the relay is controlled by the DEVIATION output signal, when this crosses zero.

A front panel indicator light shows when the relay contacts are closed.

A short-circuit piece is used to set the polarity of the switch : whether it either closes or opens when the DEVIATION changes its sign from negative to positive.

Locate jumpers JP201 and JP202 on the AVS47D circuit board, and change the short circuit piece to the adjacent position, if the polarity appears to be wrong for your application.

You can also disable the relay by removing the short-circuit piece completely, or by placing it horizontally.

Do not use the relay switch together with multiplexing.

8.7. TS-530A DATA CABLE

The AVS-47B and the TS-530A Temperature Controller are connected together by two cables: a coaxial for the analog input signal, and a 37-way ribbon data cable (only 9 wires are used). The data cable has a DC37P connector in both ends (the data cable for the older AVS-46 had one DC37P and one DC37S, one cannot mix them).

Pin assignments are as follows:

signal	AVS-47B	TS-530A
ground	20&2	20&2
heater set point	5	5
heater current	25	25
heater voltage	7	7
signal ground	26	26
serial data	16	16
serial strobe	35	35
serial clock	17	17

If possible, use the 30 cm ribbon cable that was supplied with the controller. A much longer cable can cause timing problems. Serial data, strobe and clock are digital signals of a one-direction, synchronous, serial data line that is required for controlling the TS-530A remotely.

8.8. POWER ON DEFAULT STATE

The power-on defaut state of the AVS-47B is as follows:

INPUT	ZERO
CHANNEL	0
RANGE	OPEN
EXCITATION	0
DISPLAY	R
REFERENCE	NOT DEFINED (random)
CONTROL MODE	LOCAL

This power-on state prevents the bridge from feeding an excessive current to the sensor (and heating it) in case of a power outage or other inadvertent reset.

Because no range is connected and the excitation is zero, the AVS-47B does not stabilize properly unless some range and a non-zero excitation are selected. The input should be kept at ZERO or CALIBRATE during stabilization, or any time when no other resistor is connected to it.

8.9. MEASURING LEAD RESISTANCES

The AVS-47B offers a convenient way to estimate the total resistance of the current-carrying leads to the sensor. This unique feature among resistance bridges may turn out useful in applications where reliable contacts to the sample material, like a non-metallic HT superconductor, cannot be guaranteed.

The method is based on measuring the compliance voltage of the excitation source. The display selector has the position “EXC VOLT” for this purpose.

Measure first the sensor resistance R_S. Then record the compliance voltage V_E. The excitation current to the sensor is the excitation voltage divided by the range-determining resistor. The actual excitation voltages are given below:

nominal V_E	actual V_E
3 mV	3.3 mV
1 mV	1.1 mV
300 µV	360 µV
100 µV	120 µV
30 µV	40 µV
10 µV	13.6 µV
3 µV	4.5 µV

The total current path resistance is calculated by dividing the compliance voltage V_C by the actual excitation current. This total resistance consists of the sensor, of the lead resistances and of the range-determining reference resistor (=the middle-range resistance R_R x 10).

In order to find the lead resistance, you have to subtract from the total resistance first the sensor resistance and then ten times the middle-range resistance (the factor 10 is due to the internal structure of the AVS-47B). An example of this calculation was given in the tutorial. As a formula, the lead resistance is:

$$R_L = (V_C * R_R)/V_E - 10*R_R - R_S$$

The AVS47-IB computer interface offers a macro command that makes these measurements and calculations automatically.

This method, based on the compliance voltage, is good for estimating R_L when it is large, and when a high excitation can be used.

If you are interested also in low lead resistances, or if you cannot increase excitation for this measurement, then you must make a switch that toggles between a true 4-wire mode and a 2-wire mode (connect the corresponding current and voltage terminal pins together in the 37-way input plug and use only the current leads to the sensor). Alternatively, sacrifice one channel by connecting it in parallel with the original channel, but using 2-wire configuration. The total resistance of the *current leads* is then the difference between the two readings. This method works also on low excitation ranges.

9. BATTERY OPERATION

The power supply of the AVS-47B is designed so that the bridge can be used from two 12 V batteries or other floating 12V voltage sources. Refer to specifications for current drain and voltage limits. Battery operation provides valuable means for trouble-shooting in case of EMI heating problems and despite the high power consumption, it can also turn out useful in applications where an AC voltage is just not available.

You need two separate (nominally) 12 Volt batteries or stabilized DC voltage sources which both must give at least 11.5 Volts. Below that, performance of the bridge may suffer. However, because battery voltage has no ripple, noise performance should remain unaffected.

Connect the two batteries in series. The middle point is wired to pin 2 of the 4-pole DIN plug. +12V goes to pin 1 and -12V to pin 3. There is no power switch for battery operation. Either provide your own switch, which must break both the +12V and -12V leads, or just pull the plug off. Do not use battery input without the center lead (0 V or GROUND).

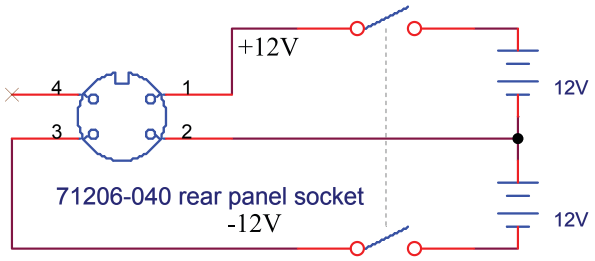


Fig. 9-1. Connecting external batteries to the rear panel DIN socket.

The power consumption is about 100 mA and about 550 mA from the negative and positive batteries, respectively. You can reduce the positive current by +150 mA by disabling the digital display, which you can perhaps do, if readings are taken through the computer interface. Locate the only jumper on the rear side of the display circuit board, and remove it from position “BLANK DISPLAY”. You can save additional +50 mA by disabling the status leds as well: Insert the short-circuit piece to position “BLANK STATUS LEDS”. This will blank all other status leds, except the REMOTE mode indicator and the state indicator of the relay switch.

With these measures, the power drain can be reduced to a minimum of about +350/-100 mA.

The front panel mains switch does not break currents that are taken from batteries. They need a separate external two-pole switch as shown by figure 9-1.

NOTE 1: Center pin No. 2 is internally connected to conducting parts of the enclosure (ground and safety ground).

NOTE 2: Simultaneous use of both the mains input and batteries as backups is allowed. However, if the battery voltages are higher than 12V, there may be more or less current drain from them. Measure the two currents after the battery voltages have settled to their normal values in order to avoid surprises.

NOTE 3: The battery input lines are not internally filtered against EMI, whereas the mains input socket contains an EMI filter.

10. SAFETY VOLTAGE OPERATION

Introduction of the switched mode power supply made it possible to use also a 12 Volt AC source (11..14V) for powering the AVS-47B. The 12V voltage can be touched without danger of electric hazard. Such a “power line” allows self-made wiring and RF filtering, because the safety regulations have been written for voltages higher than 42V (at least presently).

The average 12V AC current drain is less than 1A. However, using an oversized transformer is recommended, because of the half-wave rectification.

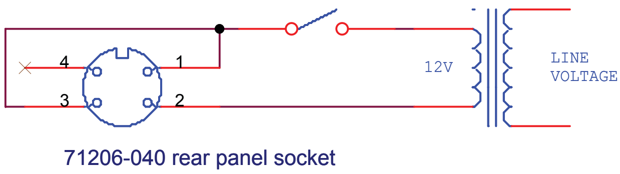


Fig.10-1. Connecting an external 11..14V AC source to the rear panel DIN socket.

As seen from figure 10-1, wiring is similar to battery input, except that pins 1 and 3 must be connected together outside the AVS-47B (inside the plug, for example).

The front panel mains switch does not break the current that is taken via the DIN connector. Use an external one-pole switch as shown by figure 10-1.

NOTE 1: Center pin No. 2 is internally connected to conducting parts of the enclosure (ground and safety ground).

NOTE 2: The low voltage input lines are not internally filtered against EMI, whereas the mains input socket contains an EMI filter.

11. SUGGESTIONS FOR GROUNDING

The best grounding practices for the AVS-47B may differ from those that are most suitable for other resistance bridge of another maker. This is a natural consequence of differences in their design. Therefore, please read the following discussion.

If the excitation current source of a resistance meter is a feedback loop that includes also the sensor resistor, one may not be allowed to ground the sensor. If a sensor in the cryostat has worked well with a resistance bridge from a manufacurer other than Picowatt, one can be almost sure that none of its four leads is connected to the cryostat body.

The excitation source of the AVS-47B is also a feedback loop. It adjusts the magnitude of the excitation current I_E, but the sensor resistor acts only as a load into which I_E is fed. The sensor itself is outside the loop. This arrangement has both benefits and drawbacks.

The AVS-47B allows grounding of the sensor to the cryostat. Depending on sensor mounting, this can improve the thermal contact between the sensor and the cryostat. It can also reduce the number of required sensor leads, because the cryostat body can be used as a current return lead common to all input channels. Grounding sensors to the cryostat can also be good if the sensor leads are filtered against RF when they enter the cryostat. Only the I+ and V+ wires need to be filtered in this configuration. Two filters less per channel can make a difference if space is at a premium.

If sensor number n [0..7] (=its I- lead) is connected to cryostat, then the **corresponding channel must be detached from preamplifier ground** by removing its jumper (please note the numbering of the jumpers: JP1 corresponds to the last channel and JP8 corresponds to the first channel). This prevents a sensor from being connected, in addition to the cryostat, also to the preamplifier ground, which would enable ground currents in the I- lead.

The sensors can also **float inside the cryostat**. Then the corresponding **jumpers JPn must be inserted**, so that the I- lead of the currently selected sensor is grounded inside the preamplifier box. **This is the default configuration when the AVS-47B is shipped**.

A floating sensor is a more versatile choice than a grounded sensor, because the former can be measured with most resistance bridges. It can reduce mains hum if the problem is magnetic induction (which is usually almost equal in all four leads).

In need of an RF filter, all four leads to a floating sensor must be filtered.

Refer also to the chapter “ABOUT RESISTANCE THERMOMETRY”.

Those I- leads that are jumpered to preamplifier ground remain connected to ground regardless of whether the corresponding channel is selected or not.

12. ABOUT RESISTANCE THERMOMETRY

One of the most popular ways to measure low temperatures down to as low as 10mK is to use a resistor whose value depends on temperature. The following are just examples on what is available:

- Rhodium-Iron RhFe (T>1.5K)
- Ruthenium Oxide RuO_2 (T>50 mK)
- Germanium (T> 50mK)
- Carbon resistors (T>10 mK)

The temperature limits are only typical. Before any of these resistance sensors can be used for thermometry, its T vs. R dependence must be calibrated with the help of some other thermometer or against some physical phenomena. Because of this need of calibration, all ordinary resistance thermometers are "secondary" or "relative" thermometers . A "primary" or "absolute" thermometer, in turn, is based on some physical law in such a way that the temperature can be calculated from measurement results without a prior calibration.

Do not confuse the word "absolute" with absolute accuracy. An absolute thermometer may have a poor accuracy and it may be noisy, whereas a secondary thermometer can be very accurate, if it is accurately calibrated. *Some people have the enviable talent of remembering the absolute pitch of music tones, whereas we ordinary people can only say that one tone is higher or lower than the other, or we may be able to tell whether the harmony is correct or not. But remembering the pitch without comparing it to anything does not mean that the person remembers it exactly right. He may remember it approximately, to a varying degree of accuracy. On the other hand, someone having only a "relative" ear, may be very good in detecting the smallest deviations from a correct harmony.*

Secondary thermometers are usually cheaper, simpler and easier to use than absolute ones, which accounts for the popularity of resistance thermometry.

If the T-R dependence is linear (Fig.1) only two points are required for calibration. Unfortunately, all thermometers that are suitable for low temperature work are more or less nonlinear.

Calibration of a nonlinear sensor (Fig. 2) is more tedious. The number of required calibration points is the greater the wider is the temperature range to be calibrated and the steeper is the nonlinearity. If the sensor can be approximated using an equation of a standard form, it is enough to determine only the coefficients. A high order polynomial is very likely to behave badly between the calibration points, whereas a low order polynomial cannot be fitted to the many points. Any behaviour can be mapped using sufficiently small linear segments or splines.

Manufacturers like **LakeShore** sell their sensors both calibrated and uncalibrated. Uncalibrated sensors are cheaper but you must calibrate them at least at some interesting temperatures before they are useful. The cost of factory calibration, which is often significant, depends on the number of calibration points and on the temperature range. This is natural because it takes time for the calibration system to reach each new temperature.

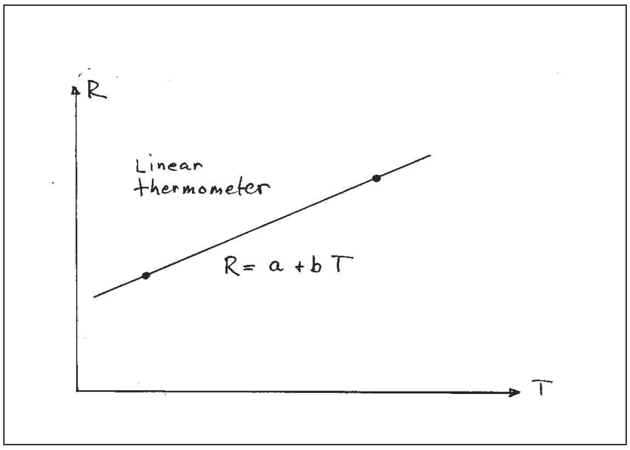


Fig 12-1. A linear secondary thermometer needs only two points for calibration.

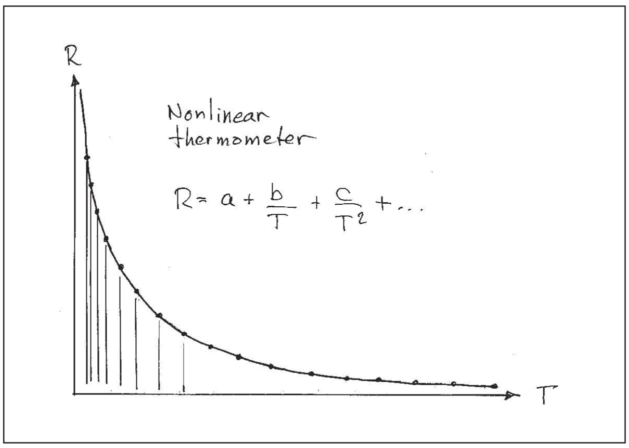


Fig. 12-2. A nonlinear secondary thermometer requires many points for calibration. The calibration points must be the closer to each other the steeper is the curve. Calibration at a low temperature takes time and is therefore expensive.

12.1. THE MEASUREMENT HEATS THE SENSOR

It is not possible to get information from a system without disturbing it, in other words, transferring energy either to it or from it. A resistor is measured by leading a current through it and by measuring the resulting voltage drop R = V/I. But at the same time, we heat the sensor by power $P = R * I^2$.

The sensor is never in perfect thermal contact with its environment, and therefore the power P raises the sensor's temperature above the surroundings (Fig. 12-3). But then it shows only its own temperature, not that of the cryostat, which we would like to know. The heat dissipation must be kept as low as possible in order to minimize the self-heating error. The thermal resistance between the sensor and the environment increases drastically as the temperature is lowered. At the same time, the self-heating error that we can allow is reduced. For example, the error due to a 1mK self-heating at 4.2K would be negligible whereas at 10mK it would be 10%. The thermal resistance, on the other hand, can be orders of magnitude higher at 10mK than at 4.2K. This means that the heating power must be very low indeed.

At 10mK one may want to heat by only 10^{-15} watts. In order to get some idea of this power, consider an electric pocket torch. One can hardly feel how it warms. Divide this power by ten millions, then again by ten millions, and finally by three! Suppose, that the sensor value is 100kΩ. Then the measuring current should be 100pA. This is less than the input bias current of any bipolar operational amplifier on the market. An ordinary Agilent 34401A multimeter uses 10μA for measuring 100kΩ. It would heat the sensor by 10^{10} times more than what we can afford. The 100pA excitation produces a voltage drop of 10μV across the sensor. As a comparison, an ordinary copper-to-tin/lead solder joint produces a thermal voltage of 5μV/°C. Two such joints in the sensor leads, thermally 1°C apart, would produce a 50% error in the measurement of the voltage drop.

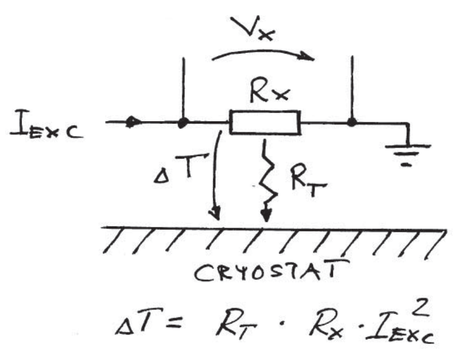


Fig. 12-3. The sensor may have a large thermal resistance to the cryostat

It is easy to realize that instruments like precision DVM's and current sources are not useful for measuring a low-temperature resistive sensor. This fact has created a (small) market for a dedicated instrument group called "Cryogenic Resistance Bridges".

12.2. THE FUNDAMENTAL TRADEOFF

No instrument can have an infinite resolution. In case of a cryogenic resistance bridge, which is based on the use of electronic amplifiers, the noise of those amplifiers sets the main limitation. Also the noise from the sensor itself can limit the resolution, especially if a high resistivity sensor is not cooled to cryostat temperatures.

Resolution is the smallest change in the signal that can be detected. It is often expressed as a number relative to the maximum signal. For example, if the maximum signal amplitude is 10 and the change to 9 is the smallest that we can detect, the resolution is 1/10 or 10%. If the maximum signal is 10000 and we can detect its change to 9999, the resolution is 0.01%. Cryogenic resistance bridges offer typical resolutions between

- less than 1% (high resistance, low excitation or high sensor temperature) and
- better than 0.01% (low to moderate resistance, sufficient excitation)

The resolution that can be achieved depends on the amplitude ratio of the signal and the noise. This ratio is called "signal-to-noise ratio (S/N)". The amount of noise is determined mainly by the amplifier of the bridge, and to a less extent by the cooled sensor. All amplifiers exhibit noise, the nature and amount of it depends on the construction of the amplifier and on its component selection. Amplifiers that use field-effect transistors (FETs), like the AVS-47B, are optimal with high-to-moderate resistance sensors, whereas bipolar-input amplifiers would be better with low resistivity sensors, like Pt-100 or RhFe.

You cannot do anything to the amount of noise, except trying to get a better amplifier. The amount of signal, on the contrary, depends on the amplitude of the excitation current. The S/N ratio, and the resolution, can thus be improved by increasing the measurement current. On the other hand, this increases the self-heating error of the sensor.

The ***fundamental tradeoff in resistance thermometry is between resolution and self-heating***. The optimum excitation current would be such that the uncertainty due to self-heating is about the same as the uncertainty due to noise. The uncertainty due to random noise can be reduced by averaging or by using more effective filtering, but it makes the measurement slower (there is no distinct frequency to deal with, because noise is random). So the fundamental tradeoff includes also a "sub-compromise" between resolution and speed. The self-heating error is seldom known, and it can be tedious and time-taking to measure it. This means that one is usually unable to really make a well-informed compromise. There are also other sources of error, and we will discuss them later.

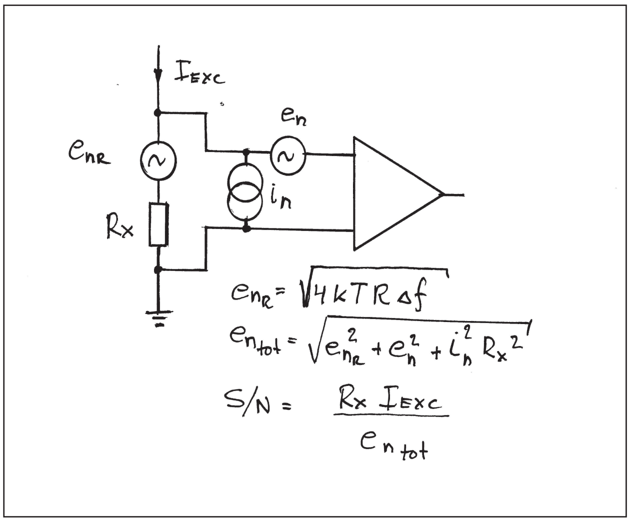


Fig. 12-4. A very simple noise model of the resistance measurement. If the resistance bridge uses a FET input, the noise current can usually be neglected.

12.3. WHAT IS A CRYOGENIC RESISTANCE BRIDGE

Difficulties relating to thermal voltages and contact potentials can be solved by using alternating current instead of direct current.

Turning to AC eliminates also various offset voltages in the measuring instrument.

The lead wires from an instrument to the sensor have a nonzero capacitance. The operating frequency must be very low so that the voltage drop across the sensor is not shunted by the capacitance. Typically, a frequency between 10 and 20 Hz is used.

It is necessary to use wires that do not conduct heat from the room temperature to the low-temperature sensor. Unfortunately, such wires have also a high electrical resistance. The only way to measure low-ohmic sensors reliably in the presence of high lead resistances is the so-called 4-wire method. The excitation current is lead to the sensor via two wires ("current leads") and the voltage drop is measured directly from the sensor using another two wires. These "voltage leads" do not carry any current, and so the lead resistances are excluded.

The measuring instrument must yield an acceptable accuracy and resolution regardless of the tiny measuring current and other complications.

As a conclusion, a cryogenic resistance bridge

- uses a low frequency alternating current for the measurement
- has separate current and voltage leads in a 4-wire configuration (Kelvin leads)
- gives useful resolution and accuracy even when the excitation is very low
- provides selectable excitation currents within a wide range

12.4. THE AVS-47B

The most dominant difference between various resistance bridge architectures is perhaps the waveform of the AC excitation current. Other manufacturers (Lake Shore and Stanford) use sine waves whereas **Picowatt** use square waves.

A spectrally pure sine wave has only one frequency component and it behaves almost ideally. At a low frequency, sine wave is not very sensitive to stray capacitance in the sensor leads (on the other hand, capacitive loading results in changes only in the amplitude and phase

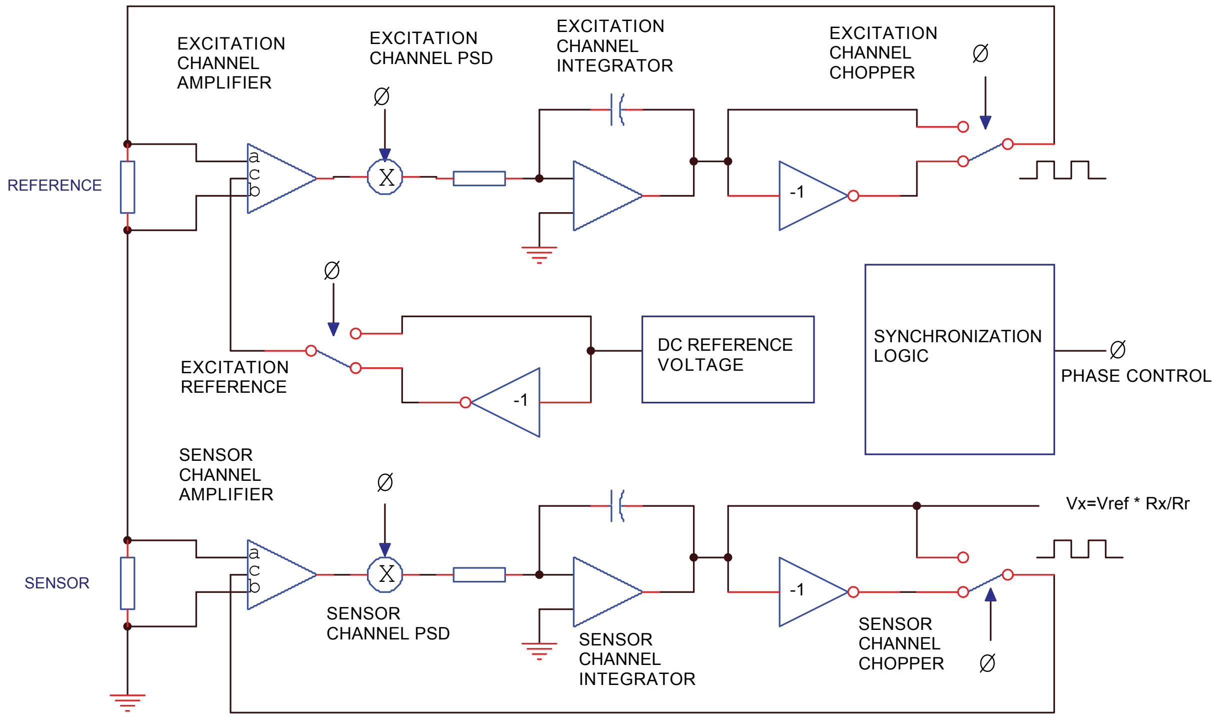


Fig 12-5. A simplified block diagram of the AVS-47B

of a sine wave, which are difficult to detect. In case of a square wave, the shape changes, too, which is easy to detect). A sine-wave resistance bridge can be modified for use as a mutual inductance bridge. A microprocessor with a reasonable speed is necessary for generating smooth sine waves. It means that the instrument must be very well shielded, so that it does not emit high frequency interference, which could heat the sensor.

Square wave signals are easily and cheaply generated in an analog instrument using choppers. Such a bridge can be used only for resistances, it cannot be used to measure mutual inductance, for example. Square wave excitation is very sensitive to stray capacitance in the sensor leads. Because capacitive loading changes the shape of the unbalance signal, it is easy to detect. Capacitive sensitivity is reduced in the AVS-47B by using a shape-based compensation circuit that charges the input capacitance quickly to its final voltage. In addition, a time delay after each edge in the excitation current allows all transients to decay off before the phase-sensitive detector is allowed to inspect the balance of the bridge.

Square waves can be generated and used without need of high speed digital electronics or intelligence. An analog instrument is inherently silent and safe to use for LT resistance thermometry. This is why **Picowatt** have always used square waves.

Let us try to explain the operation of the AVS-47B briefly and superficially with the aid of a block diagram (Fig. 12-5). The bridge relies on two three-input preamplifiers, one for the excitation and one for the unbalance signal. These preamplifiers work so that if the difference “a-b” is equal to the feedback signal “c”, the output is zero. The long chain starts by converting a precision DC reference voltage into an attenuated square wave. The bridge includes three attenuators with a seven selectable attenuation factors, and two amplifiers with seven gain steps, but they all have been omitted for clarity.

The reference square is fed to the “c” input of the excitation preamplifier. If the difference “a-b” does not correspond to input at “c” , a square wave output is obtained from the amplifier. This signal is rectified using a phase-sensitive detector that is synchronized to the excitation, and the rectified signal is accumulated in an analog integrator. The integrator’s voltage is chopped - again in phase with the excitation - in order to produce a square wave which is applied to the “hot” end of the reference resistor R_R.

A current flows through the series connection of R_R and R_X, where R_X is the sensor. This current creates a voltage drop across the reference R_R, which is the previously mentioned difference “a-b”. As long as “a-b” is not equal to “c”, the integrator slews either up or down, increasing or decreasing the excitation current, until a-b=c (Fig. 6). Then nothing more is accumulated in the integrator because the amplifier gives zero output. As a result, the excitation current has now the value $I_{EXC}=V_{REF}/R_R$.

I_{EXC} is a constant AC current whose magnitude is independent of the sensor resistance.

The excitation current produces a voltage drop of $V_X=I_{EXC}*R_X$ across the sensor. It is the difference "a-b" for the signal amplifier. Just like the excitation channel, also the signal channel has a phase-sensitive detector followed by an integrator, and the integrator voltage is chopped to produce a square-wave feedback voltage. As long as the feedback "c" deviates from "a-b", the integrator slews either up or down until the loop is in balance and the output of the signal-channel preamplifier is zero. Then "c"="a-b" $=V_X= I_{EXC}*R_X = V_{REF}*R_X/R_R$. In other words, the signal integrator voltage is directly proportional to the sensor divided by the reference resistor. Selecting V_X = 1Volt results in a simple calibration where V_X is 1V if the sensor is equal to the reference, 100 kΩ, for example.

This is the operating principle of the AVS-47B, simplified and briefly. The practical instrument further contains adjustable attenuators and amplifiers and logic for synchronization and autoranging.

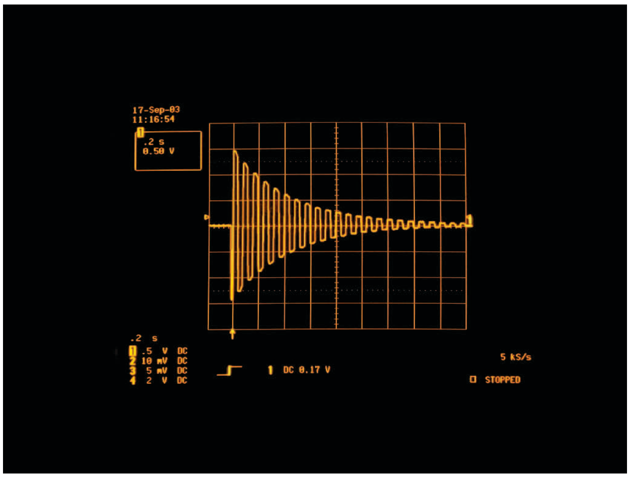


Fig 12-6. This is how the signal at the AC output looks like when the AVS-47B settles after a step change in the sensor resistance.

12.5. COMPARING OPERATION WITH THE SPECIFICATIONS

It was said in the beginning that resistance thermometry is popular because it is easy, but everything is relative. At least first-time users of a resistance bridge are almost sure to encounter problems. It is only after a long experience that one can tell at a glance whether everything is working well or if something is wrong.

If you are unsure, connect an oscilloscope to the AVS-47B and check that the signal looks sound. Fig. 12-7 shows a sound but noisy signal with very little mains hum. Fig.12-8 has the same noise but it has also a large mains hum (so large, that it heats the sensor about four times more than the excitation current on the 10µV excitation range). Fig. 12-9 is still the same measurement, but now there is so much more mains hum that the signal is clipped. This is a serious situation which must be fixed. Fig. 12-10 is a high-excitation measurement of a 1MΩ resistor but there is too much capacitance in the sensor cables (because of RF filters, for example. In addition, somebody has disabled the active compensation circuit!). If the signal is not OK, you should try to eliminate the sources of interference as much as you can. We will talk about two most common problems a little later. Even if the signal looks good, you should compare the readings from your cooled sensors with the resolution specifications of the AVS-47B (see Fig. 12-11).

Those resolution curves are given for room-temperature resistors. Results from a low-temperature sensor should not be much worse – in fact they should be better, because the thermal noise is lower. For example, suppose that you are measuring a cooled 100 kΩ sensor using 10µV excitation setting. The specified RMS resolution for such a sensor at 300K is 300Ω. If your result is better than this, you can be quite satisfied.

The resolution graphs show RMS values, not peak-to-peak values. But what is the meaning of the word "resolution" ?.

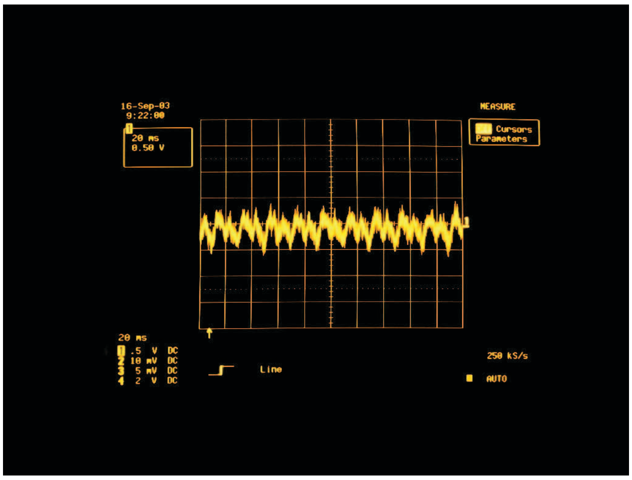


Fig 12-7. This trace was obtained by measuring a 100kΩ resistor at room temperature and using 10µV excitation (excitation power 10^{-15}W). This trace looks normal and there is very little 50Hz in addition to noise.

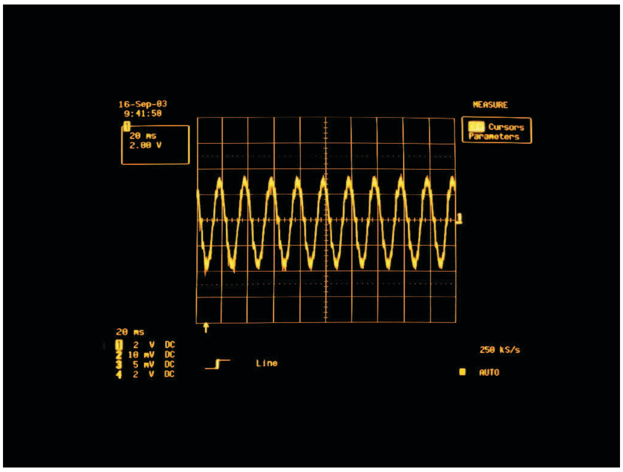


Fig 12- 8. More 50Hz was added by purpose to the previous measurement. Something should be done to reduce the mains interference, because now it heats the sensor more than the 10µV/100kΩ = 100pA excitation current.

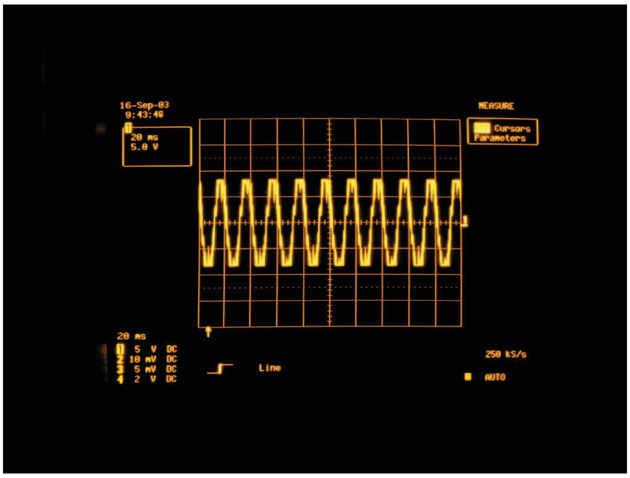


Fig. 12-9. If the amplitude of the 50Hz inteference is still increased, the signal is clipped. Clipping is seldom perfectly symmetrical and therefore a large error results.

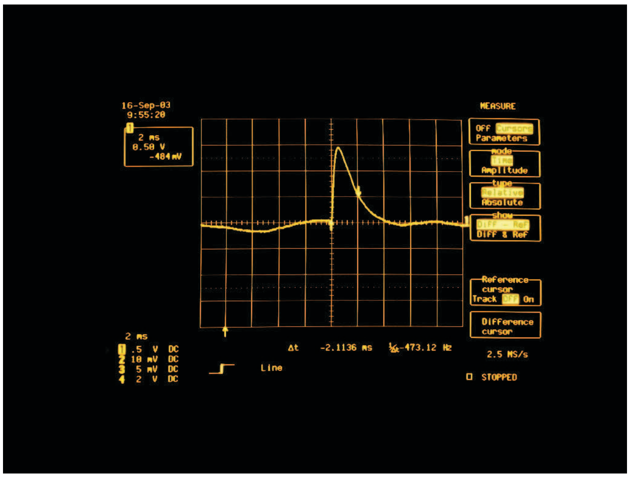


Fig. 12-10. If you see a trace like this, the RC time constant of the input is high (sensor resistance times the input capacitance), and the active capacitance compensation circuit has been disabled or it is not working. R is 1MΩ and C is 2nF in this figure. The high capacitance comes probably from RF filters in the cryostat. Time constant is approximately the time for the peak to decay to 1/3 of its maximum value. It should be less than 1 millisecond, if automatic compensation is not used. The overload LED blinks and warns you.

12.6. RESOLUTION, ACCURACY AND PRECISION

Manufacturers use these three words extensively in data sheets and manuals. When speaking of measuring instruments, they are used in a different way than what is common in physics textbooks. You may have heard expressions like “resolution can be improved by filtering” or “the accuracy of the instrument is X “ or “this is a precision instrument, handle it with care”. These words are used quite wildly, and one might feel confused if one cannot be sure about what the writer or speaker actually means. We try to give some definitions, but there are so many different opinions about them, that some readers are sure to disagree with us.

Resolution is the smallest change in the measured quantity that can be detected, or resolved, with a reasonable certainty. There are two different ways to specify the meaning of the expression “detected with a reasonable certainty”.

- The **RMS (root mean square) resolution** is the standard deviation of a **large number** of measurements. There is a likelihood of 68% that a new result is not farther than +/- STD away from its infinite average value.
- The **peak-to-peak resolution** is the difference between such maximum and minimum limits, that the result **hardly never** exceeds these limits **during a reasonable time**.

Physical measurements obey usually the Gaussian distribution law, because the result depends on a large number of individual factors. For such a result, there is a rule of thumb that the **RMS resolution is the peak-to-peak resolution divided by five**. It is astonishing, how well this applies to the AVS-47B.

Resolution describes the random variation of the results, but it does not say anything about how good or bad the average might be.

Resolution can be improved by averaging. If **S** is the standard deviation of a single A/D conversion, then the standard deviation of n averaged conversions is **S** /sqrt(n). In order to improve the resolution by a factor of 10, one must make 100 conversions, which will last 100 times longer.

The random fluctuation in a result can be made arbitrarily small by repeating the measurement sufficiently many times. After an infinite time, the average would no longer fluctuate, but still the result would not be the true value of the measured quantity. A practical measurement contains things like error in the zero value (offset), error in the scale factor, nonlinearity and possibly a digitizing error (if there are too few digits in the A/D converter). The ambient temperature is a typical factor that can change the initially adjusted offset and scale errors, aging of the instrument is another one.

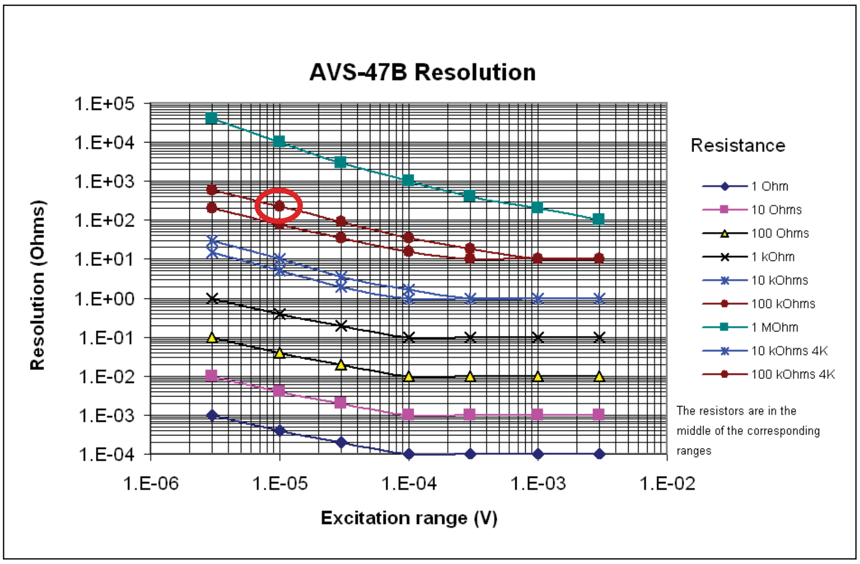


Fig. 12-11. The resolution curves from the AVS-47B data sheet. Expect an RMS resolution of about 300Ω when measuring a 100 kΩ resistor at the room temperature on the 10mV excitation. Cooling the sensor improves the resolution a little on the 200kΩ and 20kΩ ranges.

Accuracy is the maximum deviation of an average of infinite number of samples from the true value of the measured quantity. Accuracy of an instrument consists usually from at least two numbers, a zero offset and a percentage of the reading. Assume, for example, that an instrument has a full range of 20 000. Then the expression "Accuracy: 0.001% FS +/- 0.05% of reading" means that if you measure a true zero, you should be prepared to read something between -0.2 and +0.2 (calculate as 0.001%*20000). If you measure a true value of 10000 with this instrument, you should be prepared to have the infinite **average** somewhere between 10000 - 0.2 - 5 and 10000 + 0.2 + 5 (calculate as +/-0.001%*20000 +/- 0.05%*10000).

Accuracy tells, how good would be the infinite average, but it does not say anything about how much time is needed in order to get reasonably close to such an average.

If all error sources, like a 10-degree change in laboratory temperature and 10 years aging are included, accuracy readings may look poor. This is why various data sheets use expressions like "after self-calibration", which excludes the temperature drift, or "Calibration cycle: 1 year", which eliminates effects due to aging by forcing the user to send the instrument to factory for calibration each year. This is a tedious and costly way to get good-looking accuracy figures.

Precision does not seem to have any commonly accepted definition. Our simple suggestion is the following: **Precision is the worst-case combination of accuracy and resolution**. So defined, **"precision"** tells the maximum deviation from the true value that you should expect, if you make only one single measurement.
One physics textbook used "precision" instead of what we just called "resolution". Another "University Physics" book described precision as the number of displayed digits. The third book that we looked talked about "precisely correct results". The LabView software from National Instruments uses the term "precision" to describe how a number is displayed, whereas the number's "accuracy" depends on its internal representation in the program. In physics, pure numbers 100 and 100.000 cannot be different. However, these two numbers give a very different impression of how well we know the magnitude of a physical quantity.

Our above definition is in accordance with the common sense that a **"precision instrument"** has both good resolution and good accuracy (in addition to having enough digits in its readout).

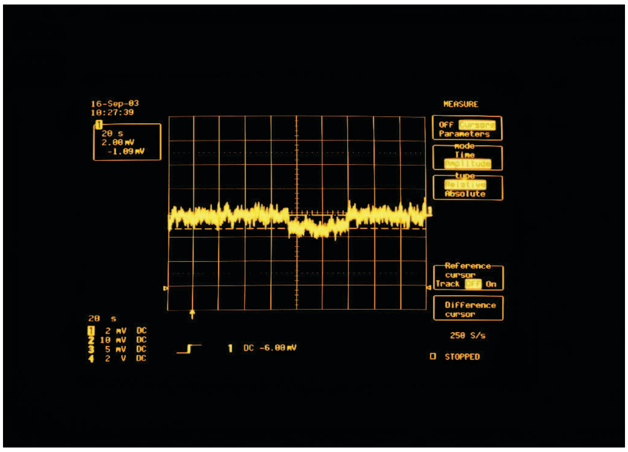


Fig. 12-12. A resistance of 10.010kΩ was measured using 30μV excitation. The value was temporarily reduced to 10.000kΩ. Measurement with cursors shows that the center lines differ by 1mV, , which is equal to 10 digits, or 10Ω. At least in our opinion, this change has been detected visually with a "reasonable certainty". The AVS-47B resolution curves give an RMS value of 3Ω (or 15Ω peak-to-peak) for this measurement. Using the RMS criterion, even a third part of this change would be detectable, whereas using the P-P criterion, this change is not quite enough.

12.7. NOISE OR INTERFERENCE

It is common to use the word "noise" for almost everything that disturbs a measurement. In our opinion, this is not correct. We think that there are both noise and interference, and that these are different things.

Noise is completely random, so that there is no way of predicting a quantity's future value from its previous history or from anything else. A resistance bridge has to deal with thermal noise in resistors and with noise coming from its amplifiers. All this noise is random. Amplifier noise can be reduced to some extent by using money and by sacrificing some other desirable features, but thermal noise cannot be eliminated. For example, the thermal noise voltage generated by resistor R is sqrt(4*k*T*R*bandwidth), where k is the Boltzmann constant. It is not possible to make a resistor that is less noisy, but it **is** possible to make a worse one by using bad materials. Anyway, the uncertainty due to noise can be reduced by filtering or averaging but this makes the measurement slower. Reducing the noise bandwidth (=filtering or averaging) is almost everything that you can do with random noise.

Interference, in turn, **is predictable**, at least in principle. Interference may look random, but it is always an effect of one or more -but always a finite number of - causes. If these causes, or sources, were known, and if they could be measured, it would be possible - again in principle - to construct compensating circuits for canceling each individual interference in our instrument.

When we developed the AVS-46, our older bridge model, we were puzzled by a non-expected amount of noise in the preamplifier. Sitting in front of an oscilloscope for hours, we tried to discover, what we had done wrong. The noise did not look normal: its amplitude behaved somehow differently than what we had seen previously. Then we got an idea to try to listen the noise instead of looking it with the scope. We connected some old earphones to the signal - and to our surprise, it was a short-wave broadcast from London!

We have heard that radio amateurs have tried a special compensation method when they want to hear a weak broadcast that is behind a much stronger station. They receive the interfering strong station separately, using a second, cheaper receiver for that. They invert the audio signal, scale it suitably and adjust its phase. Then this correction is fed to the first receiver, where it is subtracted from the original signal. Only the weaker station remains audible. However, it would have been impractical to build a compensating circuit, so we voted to redesign the circuit board.

12.8. TWO COMMON PROBLEMS, LF AND RF INTERFERENCE

Most users of resistance thermometry, except those who have born lucky, will have either low or high frequency interference or both in their new installation.

Low frequency interference occurs at the main frequency and its near harmonics. We will use a term that dates back to tube amplifiers, and call it “mains hum”. It is easy to detect using an oscilloscope and often it can be reduced. **Mains hum can disturb the instrument. Usually it does not heat the sensor, unless it is very strong**.

High frequency or radio frequency interference can occur almost anywhere within the radio frequency spectrum, starting from long waves up to the gigahertz range. RF may be very difficult to detect, because **it does not disturb the low-bandwidth instrument. Instead, it heats the sensor, which does not cool down as expected.** High frequency interference can often be reduced but seldom totally eliminated. The remaining RF interference level, not the lowest available excitation power, is likely to determine the lowest temperature where you can use resistance thermometry.

12.9. MAINS HUM

Mains hum, if there is any, can be seen by connecting an oscilloscope to the AC output of the AVS-47B (see Fig.8). A word of caution: The oscilloscope provides a new ground path in the system and it may either create new or remove existing line interference. 50/60Hz is not a radio frequency, it can couple to the input circuit capacitively, via magnetic induction or because of a ground potential difference, but not as an electromagnetic wave.

Capacitive coupling from the external world to the input is avoided simply by shielding every single millimeter of the lead wires going from the AVS-47B preamplifier to the cryostat. Inside the metal cryostat, shielding needs not be as good.

Magnetic induction is avoided by moving all mains power cords away from the sensor leads. A power cord, running adjacent to an input cable, can induce an EMF of tens or even hundreds of microvolts. Keep all four wires of a sensor adjacent and close to each other. Better still, twist the leads in order to reduce the magnetic pickup area. It may not be possible to eliminate all sources of 50/60Hz magnetic fields, and then it is of utmost importance to take care that the same voltage is induced to all four sensor leads.

Do not route the sensor leads through the stray magnetic field of a demagnetization cryostat. Even though the field itself is stable, the wires may vibrate because of vacuum pumps or other electrical motors. Such a vibration may induce an interference that has an almost, but not exact, mains frequency or its multiple. When rectified in the phase-sensitive detector, it causes beating that is too slow for efficient filtering.

If your main problem is magnetic induction, use twisted wires and let the sensor float inside the cryostat - this ensures the best symmetry so that no potential difference appears across the sensor.

If the sensor resistance is high, inevitable unsymmetries and stray capacitances in the input circuitry can convert some part of the common mode interference into normal mode. Nothing can be done to prevent this from happening, except keeping the induction as low as possible.

The **ground potentials** between the cryostat and the preamplifier are often different, because the AVS-47B is connected to the mains safety ground which is usually not exactly the same as the cryostat ground. This 50/60Hz potential difference can couple to the input in a few ways. Which one of these is dominant, depends on how the sensor is connected, what is the resistance level and how large is the input capacitance (are there RF filters or not, for example). The shields of the sensor input cables must be wired so that they connect the cryostat ground to the AVS-47B (usually they do - never leave any ends of the shields unconnected). Take also care, that the enclosure of the bridge is isolated from the instumentation rack. On the other hand, you should perhaps fix the preamplifier box to the cryostat using metal brackets. This eliminates the potential difference between the preamp and the cryostat.

One way to elimate ground currents is to supply the 115/230V power to the AVS-47B via an isolation transformer. They are not expensive. Another possibility is to use 12V 50/60Hz safety voltage.

It is usually best not have a ground path between the AVS-47B and the AVS47-IB computer interface (or computer in case of direct connection). There are optical isolators for the Picobus signal lines inside the AVS-47B, and the shield of the Picobus cable is connected only to the AVS47-IB ground. This arrangement guarantees that no ground current can flow between the AVS-47B and the interface box.

If the AVS47-IB box is located outside the shielded room, then the Picobus cable can become a radiating antenna inside the cryostat room. The best alternative is perhaps to connect the cable shield to the conducting wall of the shielded room. If this cannot be done, then one can connect the cable shield also to the AVS-47B ground. There are two SHIELD connectors marked with GND and FLOAT inside the resistance bridge. Move the short cable from FLOAT (default) to GND for grounding the cable. This can help with radiated EMI, but may give rise to ground currents...

The final resort is to equip the AVS-47B + AVS47-IB system with the optional Picolink optical fibre connection. It provides an EMI safe solution without ground path problems.

If the system has also a TS-530A temperature controller, take its power from the same isolation transformer. The heater must float with respect to ground.

Note that you cannot isolate everything: the AVS-47B must remain grounded, preferably only at one point (often the main box is grounded to the instrumentation rack, but fixing the preamp to the cryostat body and have the main box floating can be better). Letting the complete system float makes it extremely sensitive to all possible interference as well as to electrostatic discharges (ESD).

If using an isolation transformer is not possible, or if it did not reduce the mains hum sufficiently (because of presence of magnetic induction, for example), you can experiment with the two alternative sensor input configurations.

- The AVS-47B comes with jumpers JP1...JP8 inserted on the multiplexer board inside the preamplifier box. These connect the I- leads of the corresponding sensors to the circuit ground of the preamplifier regardless of whether the sensor is selected or not. **Those sensors, whose I- lead jumpers are inserted must not be connected to the cryostat ground**. Floating connection works well when the sensor resistance is rather low and if input capacitance is low.
- Alternatively, you may want to connect the I- lead of a sensor to the cryostat. This can improve the thermal contact between the sensor and the experimental space, and it can be a better configuration if the sensor leads are filtered against RF (high input capacitance). Only the I+ and V+ leads of a grounded sensor need to be filtered. One can also reduce the number of wires by using one single current return lead, if the sensors are connected to the cryostat. **Jumpers of channels that are grounded to the cryostat must be removed**.

Mains hum can affect the measurement at least in four ways:

1) It can heat the sensor.
2) It can saturate the amplifiers, resulting in a large error.
3) It can add a large low-frequency beat to the signal, which can be removed only by effective filtering which in turn slows down the measurement.

Finally, if you have a large mains hum that saturates the amplifiers, and you have no possibility to improve the wiring just now, switch to the next higher resistance range and select ten times higher excitation voltage. This reduces the hum amplitude in the signal (but not across the sensor), while the excitation power in the sensor remains unchanged. Because of the higher range, the readings have, of course, one digit less, and therefore you have also less digital resolution.

When you connect an oscilloscope to the AC output for monitoring the signal coming from the sensor, trigger it from the line. This alternative is available in most modern oscilloscopes. It may happen that you see something, which looks like a mains interference but moves slowly on the screen. Such interference is probably caused by cables that vibrate because of the vacuum pumps or other electric motors. The vibration spectrum that they cause will not consist of exact harmonics of the mains, because the rotor of an induction motor must follow the rotating magnetic field with a little lower angular velocity so that induction can take place.

12.10. RF INTERFERENCE

Because the AVS-47B is a low-frequency instrument, one cannot detect the possible existence of a high frequency interference by connecting an oscilloscope to the bridge. The amplitude level of the disturbance is usually so low that you cannot see it by connecting the scope directly to the input, either. Oscilloscopes are not sensitive enough, whereas spectrum analyzers have sufficient sensitivy but too low input impedance of 50Ω.

The effect of an RF interference is not to disturb the resistance bridge, but to heat the sensor. **Adopt the habit of testing a new layout by moving the sensor cables to different positions, routing them another way or twisting or untwisting them just for seeing what happens to the reading**. If these actions change the reading, the measurement suffers from heating caused either by RF or by magnetic induction at 50/60Hz. Eliminate the latter possibility by having an oscilloscope connected to the AC output or the bridge. If you ever wonder, why you cannot measure the expected low temperature, make this quick check.

The first thing against RF interference is of course shielding, but this may not solve the problem completely. One thinks usually, that a coaxial cable shields the signal almost perfectly. This is not true, if a high-frequency (ground) current flows in the cable jackets, like in Fig. 12-13.

If a sensor cable has a nonzero length, the jacket has also a nonzero impedance, and so the RF current produces a voltage drop between the ends of the cable shield. There is a typical distributed capacitance of 100 pF/meter from the shield to the center wire. This capacitance connects a part of the RF voltage difference to the center wire, which goes to the sensor. Because of the distributed inductance and capacitance of the cable and because wavelengths can be longer or shorter than the cables, the behaviour seems to be very difficult to predict, and a similar case seems hard to find in electronics books.

The best way to fight against RF interference is to keep the sensor cables very short and to fix the preamplifier box to the cryostat. If this is not enough, you should try to filter the sensor leads. Filtering is, however, not a perfect solution, because also it has drawbacks. Assuming the simple RC or LC configurations, you must make some compromises:

- High capacitance values can make the input sensitive to mains hum pickup, if the resistance level is high.
- Very high filter inductance or capacitance may prevent the capacitance compensation feature to work properly, resulting in nonlinearity.
- High filter resistances (over some kΩ) at the room temperature produce thermal noise degrading the noise performance of the bridge.
- A danger with LC filters is, that the input circuit starts to resonate at some high frequency. When checking for a resonance with a scope and signal generator (cryostat is warm, signal is injected via a high resistance), remember that the sensor value and also the Q-value of the circuit can be much lower when the parts are warm.

In any case, the Q-value of the filter must be low. This cannot be accomplished by selecting highly dissipative capacitors, because their losses nonlinearize the bridge at high sensor resistance levels. It is safest to use simple RC low-pass filters. Keep the resistors between 100Ω and 1kΩ. Thanks to the new capacitance compensation circuit, the AVS-47B allows use of ten times higher capacitors than the AVS-47, so that a reasonably low cut-off frequency is possible also with RC filters.

Values for an RC filter could be, for example, 100Ω and 10nF. Do not use 10nF ceramic capacitors, because they have probably too high resistive losses. Instead, select a film capacitor (polystyrene and polypropylene are perhaps the best). They do not work well at high frequencies, connect therefore **small** (<100pF) ceramic capacitors in parallel with them.

An LC filter with component values as large as L=10mH and C=10nF is acceptable even at 1 MΩ sensor level. The above remark about capacitors applies also here, and the capacitance compensation must be enabled.

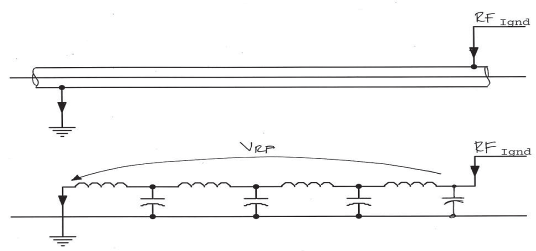


Fig. 12-13. An attempt to explain how an RF interference can penetrate to the cryostat even though all cables are well shielded. An RF ground current flowing in the shielding jacket couples to the center wire through the distributed capacitance.

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DECLARATION OF CONFORMITY

Manufacturer's name: RV-Elektroniikka Oy Picowatt

Manufacturer's address: Veromiehentie 14
FIN-01510 VANTAA
Finland

declares that

Product Name: Model AVS-47B
AC Resistance Bridge

with options: no options

conforms to the following Product Specifications:

EN 50 081-1: Generic emission standard, Part 1: Residential, commercial and light industry.

EN 50 082-1: Generic immunity standard, Part 1: Residential, commercial and light industry.

EN 61 010-1: Safety requirements for electrical equipment for measurement, con trol and laboratory use.

Additional information: The intended use of this product is resistance thermometry at low temperatures using ultralow sensor excitation current. Therefore, immunity against radiated RF fields has been deemed irrelevant, and conformity to EN 50 081-1 in this respect has not been verified.

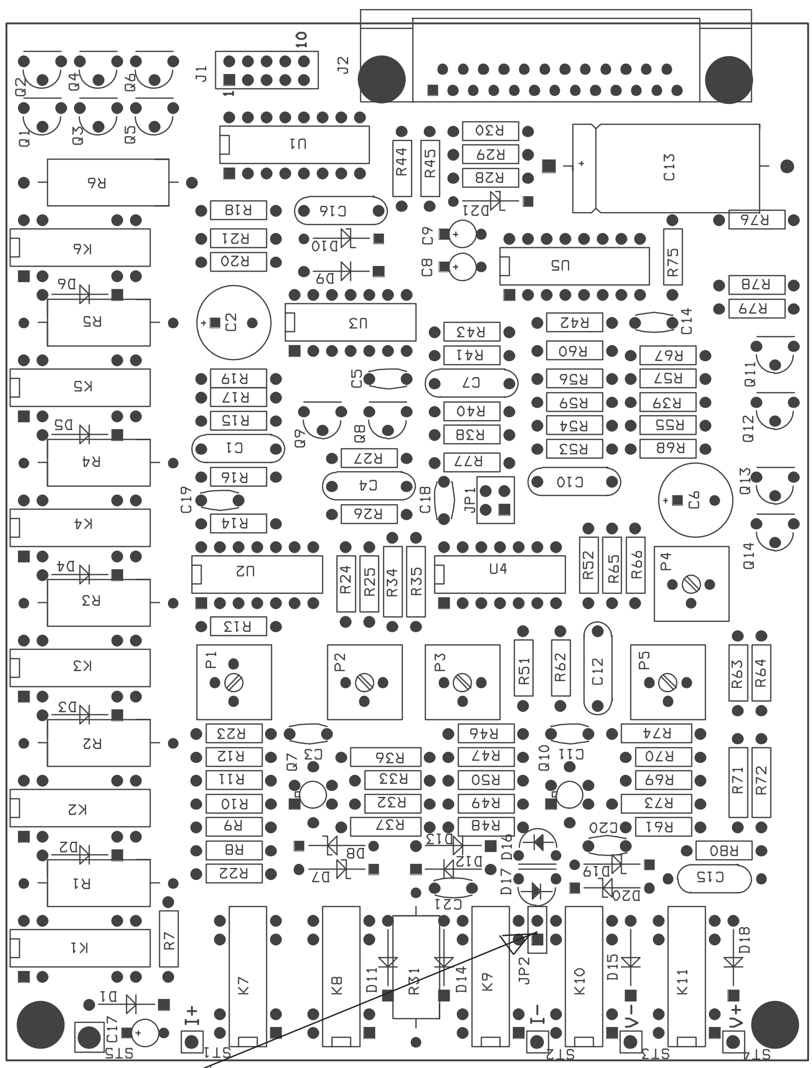
Vantaa, June 26, 2006

RV-Elektroniikka Oy

Reijo Voutilainen
President

APPENDIX

COMPONENT LAYOUT FIGURES

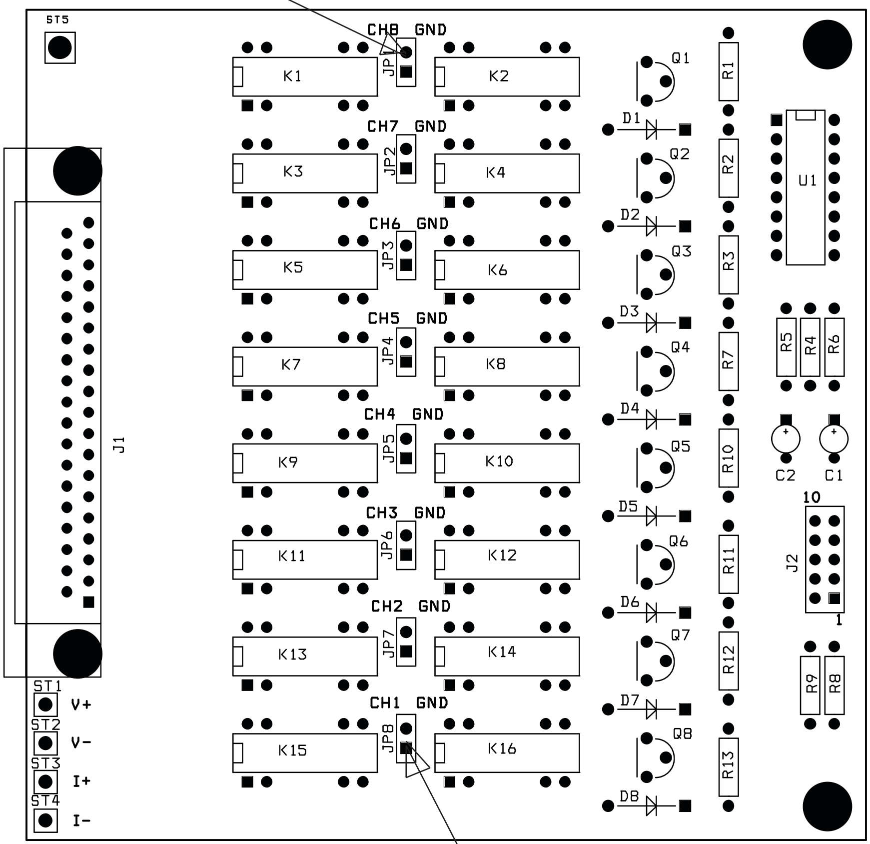


AVS47A6 preamplifier component layout

Insert this jumper and remove all JP1...JP8 jumpers on the multiplexer board, if you want to make the grounding same as with the AVS-47(A).

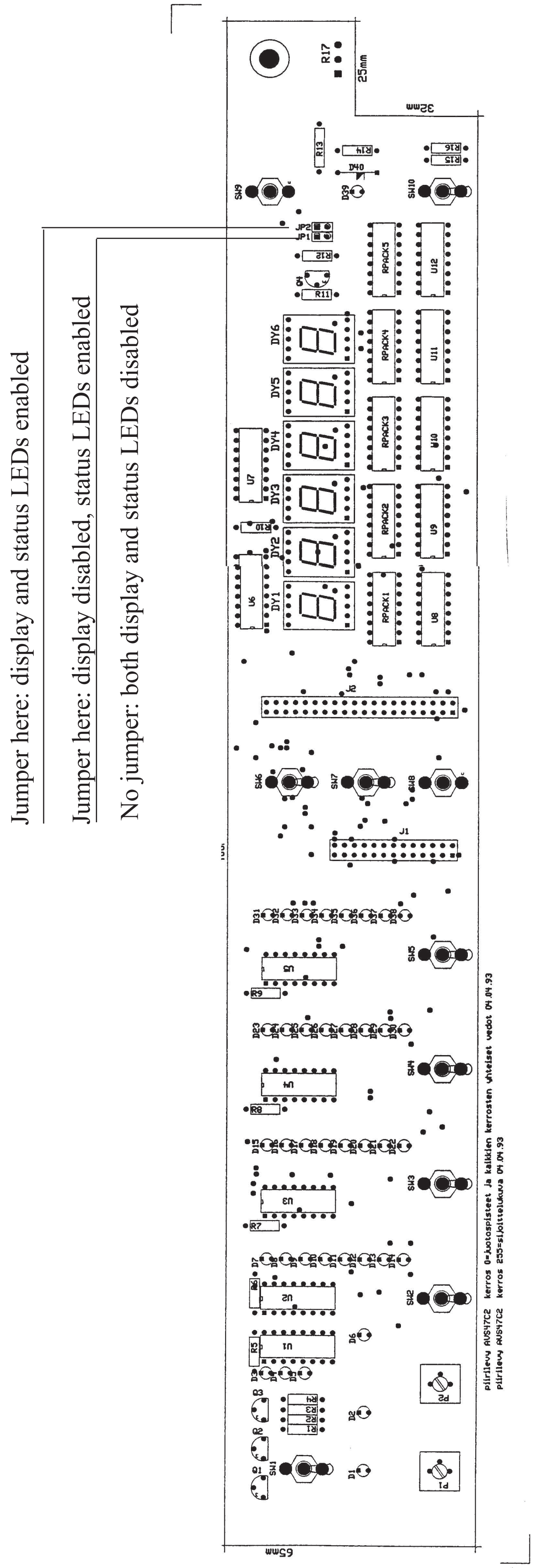
- If JP2 exists and the 8 jumpers on MUX board are removed, each sensor's -I lead is connected to preamplifier ground when that channel is selected, not otherwise
- If JP2 is off, grounding of each channel is determined by jumpers on the MUX board:
  - If JPn for CHn exists, the -I lead of that channel is permanently, all the time, connected to preamplifier ground
  - If JPm for CHm does not exist, the sensor floats and the user must connect the -I lead to the cryostat in order to provide a single grounding point for that sensor.

This short-circuit piece is for the last channel

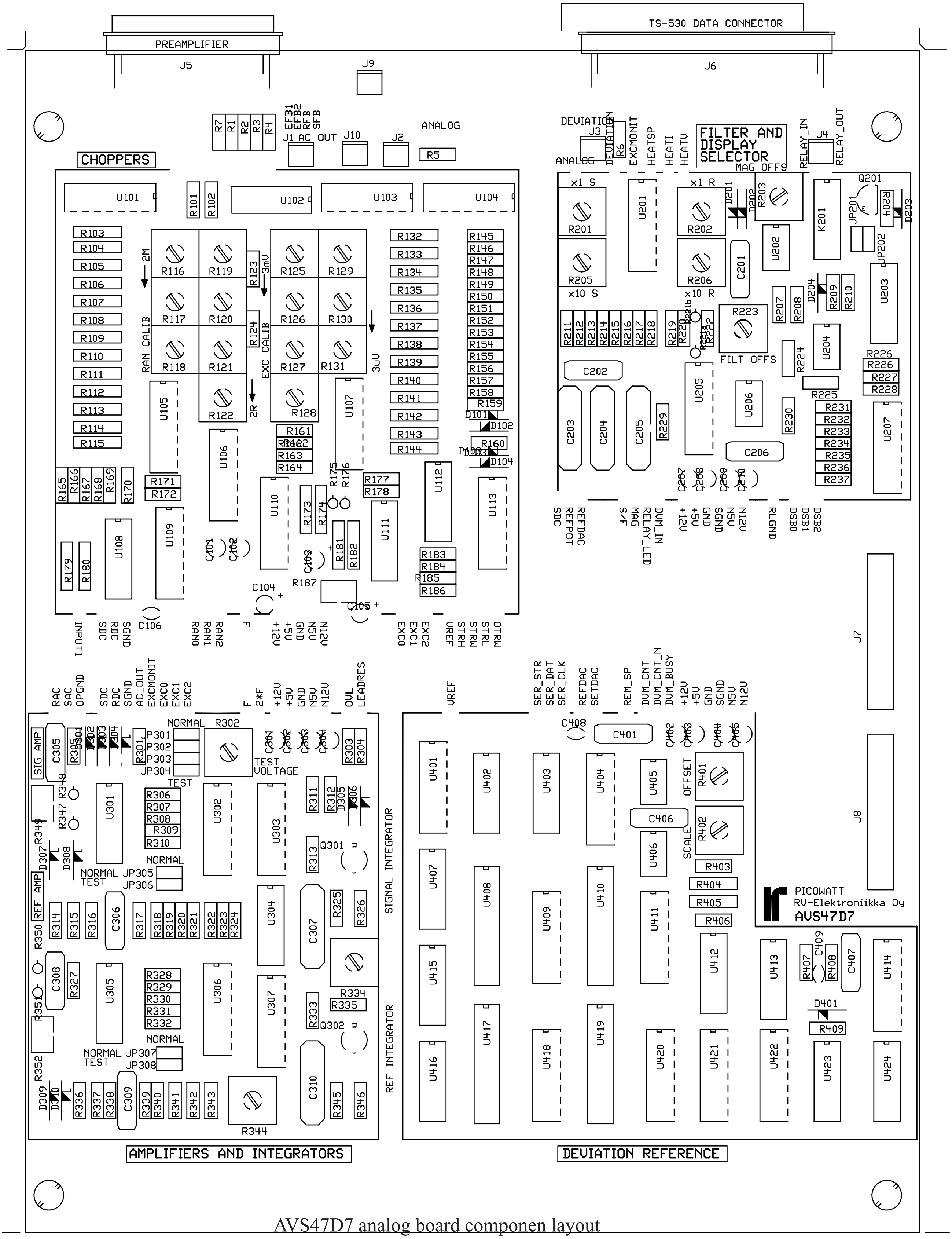


AVS47B2 multiplexer component layout

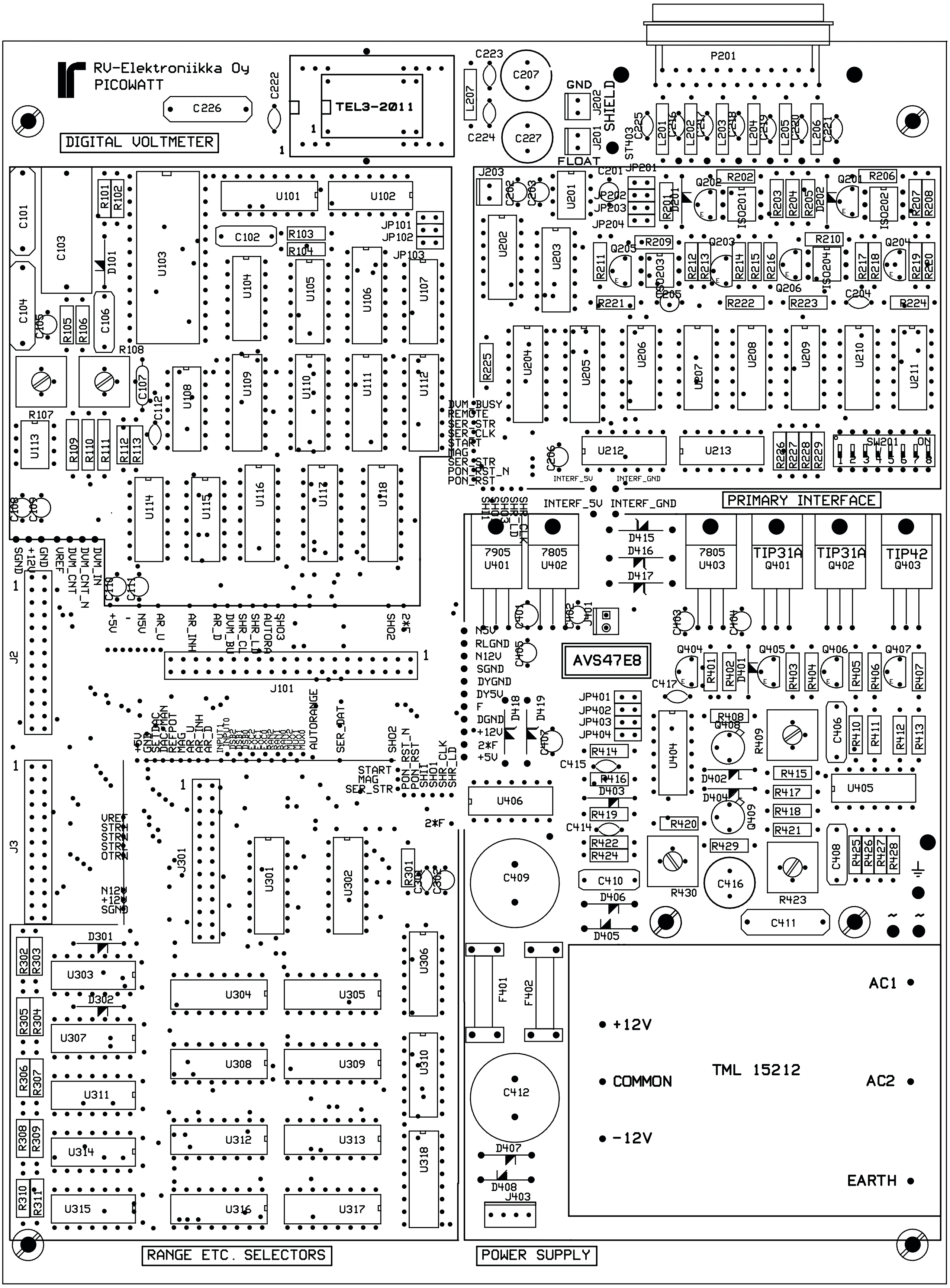
This short-circuit piece is for the first channel



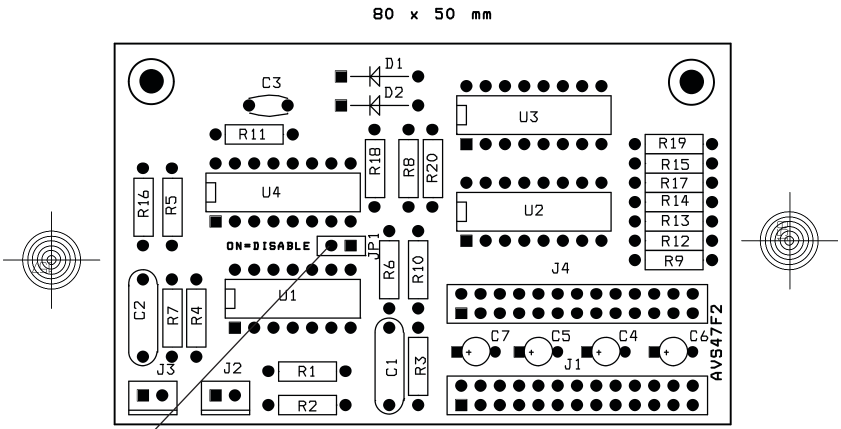
AVS47C3 display board component layout



AVS47D7 analog board componen layout



AVS47E8 digital board component layout



AVS47F2 capacitance compensation board
component layout

Compensation is disabled when header pins are shorted

REVISION HISTORY

AVS-47

The initial version. Many features were new or they were improved if compared with the previous AVS-46.

AVS-47A (2004)

With each of the 8 possible sensors, the I- lead can be grounded either to the cryostat or to the preamplifier. The former (grounded sensor) can give better thermal contact between the sensor and the cryostat, it is better for RF filtering and it can reduce the number of required feedthroughs. The latter (floating sensor) is better for eliminating ground currents.

An active shape-based capacitance compensation circuit allows at least ten times longer input time constant than before, which means that RF filters can be made more effective.

AVS-47B (2006)

The previous versions suffered from difficulties in obtaining complete galvanic isolation if the bridge was interfaced directly with a computer. Also the software routines that we could offer for this purpose were very old and written mainly for DOS.

The AVS-47B is equipped with a new DCDC converter that provides isolated power for the Picobus. This enables full isolation between the AVS-47B and the external computer (or AVS47-IB) without any user actions.

Direct interfacing is made easier by offering a set of Virtual Instruments (VIs) for LabView. LabView owners can now connect the AVS-47B to the COM port of their PC-type computer using the Picobus cable. The set of VIs enables full remote control of both the AVS-47B and the TS-530A, but they do not offer all the higher-level commands that are available with the optional AVS47-IB GPIB interface.

AVS-47B (2008, starting from s/n 861)

The conventional iron transformer followed by diode rectifiers is replaced by a switching mode power supply. It has a wide input range from 90 to 260 Volts, allowing use all over the world without need to check or change the voltage setting.

Better efficiency means cooler parts and less heat generation inside the instrument. Excitation frequency is changed from 12.5/15Hz (50/60Hz mains) to 13.7-13.8Hz which is taken from an internal clock.

The new power supply makes it possible to opearte the instrument, in addition to two 12V DC sources (like batteries), also from an external 12V 50/60Hz AC source (transformer). Such a low voltage allows one to have self-made wiring and RF filtering, whereas when working with normal line voltage, safety regulations may prohibit this.