MODEL AVS-47B
AC RESISTANCE BRIDGE

2006-10-13

RELIABLE RESISTANCE THERMOMETRY AT ULTRALOW TEMPERATURES

New in the AVS-47B: *** Universal power supply for 90-250V mains**
*** Can be powered also from 12V AC safety voltage or from two 12V batteries**

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.

Five Reasons to use an Instrument dedicated to Cryogenic 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.

Why to choose the AVS-47B

The AVS-47B is a proven, reliable design with a good price/performance ratio. It offers the right features and sufficient accuracy for cryogenic thermometry. The long lifetime of our instruments (the AVS-47 was launched in 1994), three years warranty and our customer-friendly service policy after the warranty period, mean a low total cost of ownership.

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**.
- Seven resistance ranges from 0-2 Ω to 0-2 MΩ. Capable of handling 2*100 Ω **lead resistance** on the lowest 2 Ω range and more on higher ranges.
- 8 multiplexed 4-wire input channels.
- Less **ground loop** problems. Each channel can be individually grounded either to the cryostat or to the bridge.
- An active **capacitance compensation** circuit increases the allowed sensor capacitance up to 10 nanofarads on the 2 MΩ range. Effective RF filtering against sensor heating is possible.
- Seven excitation ranges
- Equivalent input noise voltage about 6 nV/sqrt(Hz), **virtually no noise current**.
- The **low-noise preamplifier** is located in a separate unit and can be mounted near to the cryostat with short leads to the sensors.
- Default value of the adjustable operating frequency is about 13.7 Hz. Portable between 50 and 60Hz countries without user actions.
- 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
- Mainly analog construction. Built without using fast digital electronics. **Very low RF emissions**.
- The Picobus **Primary Computer Interface** is supported by a few **LabView**™ Virtual Instruments. LV owners can connect the AVS-47B **easily 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 interface lines can be replaced by **optical fiber lines** (“Picolink” option, factory installation only).
- Operation is possible using two 12 V **batteries**.
- The **AVS-47B** can also be powered from a 11-14V AC voltage source (transformer).

About the AVS-47B Design

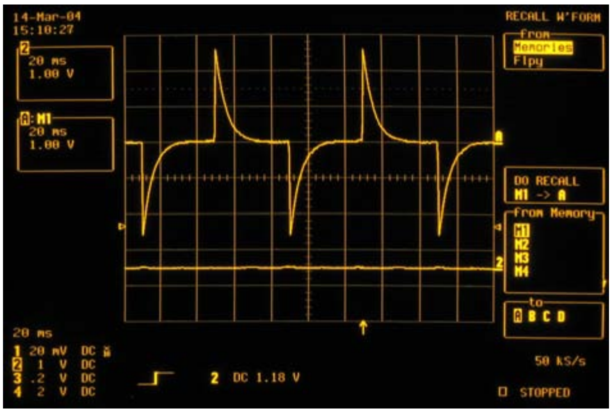
Input Stage is based on discrete FETs

The AVS-47B was designed to be a general-purpose precision tool for AC resistance measurements using ultralow excitation power. However, its main application is low-temperature thermometry using a variety of sensor types.
The resistance range encountered with cryogenic sensors is wide: Rhodium-Iron sensors start from below two ohms, Platinum wire resistors start from a decade higher. Thick-film resistors have typically a resistance of some kilo-ohms. The important Germanium resistors range from kilo-ohms to tens of kilo-ohms at the lowest temperatures. Various carbon resistors can go up to hundreds of kilo-ohms. All sensors that are useful at the lowest temperatures exhibit a middle to high resistance. This is why the input stage of the AVS-47B is built using discrete field-effect transistors, so optimizing its noise performance for work with dilution refrigerators at low and ultralow temperatures. A bipolar input would have been a better choice only if the sensor resistance is sure to stay below some hundred ohms. This is due to the high input noise current of bipolar devices.

Input Capacitance

Any capacitance C across the sensor R_S attenuates the AC voltage drop that is to be measured. The magnitude of this effect depends on the R_SC time constant, and on the excitation frequency. The simplest solution is to specify a low maximum allowed capacitance - few hundred picofarads, for example - so that the bridge linearity is not compromised. This does not permit any RF filtering nor long sensor leads. In the second solution, which is useful with sine wave excitation, the bridge makes phase-sensitive detection in two perpendicular angles, 0 and 90 degrees. The sensor conductance vector can be divided into its resistive and capacitive components by calculation. This is a good method, but if the RC time constant is long, the result becomes very sensitive to a possible phase shift in the signal path.

The AVS-47B does not use any of the above principles, because it is based on square-wave excitation, and the effect of the input capacitance is different with square waves. The main effect of the capacitance is to slower the edges of the square signal. The preamplifier compares the voltage drop across the sensor against an ideal square from the feedback in order to generate a balancing signal. This comparison results in sharp spikes because the edges of the first voltage are not steep. In the AVS-46 and AVS-47, our previous bridge models, the effect of these spikes is eliminated by means of delaying the phase-sensitive detection until the spikes have died out. But if the R_SC time constant of the input is long, the available delay time does not suffice. Even worse, if the spikes are so large that they are clipped, the error increases drastically. Therefore, the upper limit for the R_SC time constant is 1 millisecond for the AVS-46 and AVS-47. This limit allowes use of normal low-cost sensor cables, but it is not long enough for effective RF filters.



The upper trace shows the bridge unbalance signal (AC OUT), when a 10 nF film capacitor was connected in parallel with a 1 MΩ resistor and the capacitance compensation was disabled. The AVS-47B measured 0.9850 MΩ. After the compensation was enabled, the bridge measured 1.0005 MΩ (lower trace). 3 mV excitation.

A new active shape-based capacitance compensation circuit has been added to the AVS-47 “A” and “B” versions. This circuit detects the difference between the ideal and the capacitively loaded waveforms. Then it generates short pulses that are used to charge the input capacitance quickly to such a voltage that the difference in shape disappears. With this option and delayed phase-sensitive detection, the AVS-47B can measure a 2 MΩ resistance in parallel with a 10 nF capacitor to a reasonable accuracy. It is now possible to have effective RF filters for preventing sensor heating without loss of bridge performance.

Especially ceramic capacitors – which are common in RF filters – may exhibit high and poorly specified resistive losses that may ruin the measurement. This is why we can say only "to a reasonable accuracy". Test your capacitors in parallel with the anticipated highest sensor value before using them in a filter.

The Operating Principle

The most prominent design features of the AVS-47B are its square-wave excitation and extensive use of analog electronics. The user benefits from these features in the form of a more affordable price and low emission of electromagnetic interference (EMI).

Basically, the AVS-47B consists of two similar feedback loops, A and B, and of series-connected reference resistor R_R and unknown resistor R_X. The purpose of loop A is to maintain an AC voltage drop V_{EXC} of a constant amplitude across the room-temperature R_R, which means that an AC current of constant amplitude flows through R_R to the cooled sensor R_X. This AC current generates a voltage drop, across the sensor, whose magnitude is $V_{EXC}*R_X/R_R$. The purpose of loop B is to measure this low AC voltage.

In practice, R_R is ten times higher on each range than the middle-range resistance. The purpose of this mismatch is to eliminate noise from the excitation and to prevent the warm R_R from injecting noise to the cooled sensor.

Square-wave Excitation

The excitation and all signals related to the measurement are symmetrical square waves. This makes the AVS-47B different from other resistance bridges on the market. Square waveform has some nice advantages: It can be generated simply and cheaply from two equal but opposite DC voltages by using a chopper, so that its amplitude is accurately proportional to the chopper's input voltages. One does not need expensive high-resolution DACs and fast digital intelligence, a fact that enables an almost purely analog – and therefore EMI safe – design. Square wave makes also possible cheap active compensation of the input capacitance with very good performance.

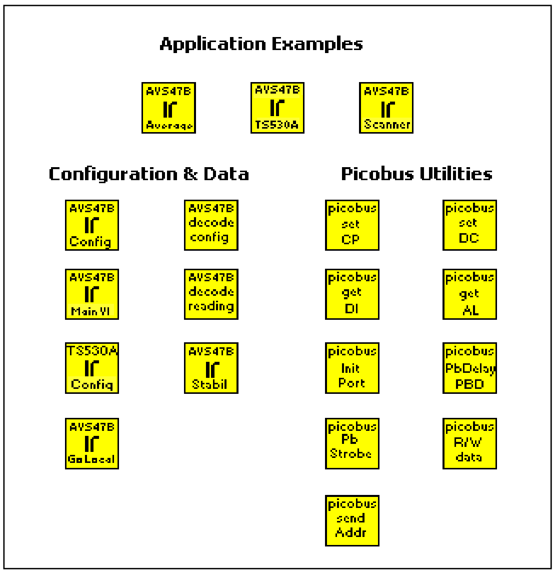
A square wave contains a spectrum of higher frequencies, and it is sometimes asked, whether these high frequencies can disturb other sensitive measurements inside the cryostat. Relative amplitudes of the frequency components of an ideal square wave go down like 1/n where n is the multiplier of the harmonic (F, 3*F, 5*F etc.). The excitation current of the AVS-47B does not produce an ideal square across the sensor because of the use of slow active components, so nothing of the spectrum is left beyond 100 kHz. Those components in the frequency spectrum that are high enough to disturb other devices either capacitively or via electromagnetic radiation, have vanishingly low amplitudes. Components, whose amplitudes are of any significance, have too low frequencies to propagate as electromagnetic waves, or for coupling through a stray capacitance of few picofarads.

EMI Considerations

Although cryogenic thermometry using a resistive sensor is simple in principle, it is often bothered by unwanted extra heating of the sensor. Extra heating is usually caused by radio frequency interference that in one way or another couples to the sensor. The foremost goal in the design of the AVS-47B was to minimize this danger. The following list shows, how this goal has influenced the design of the bridge:

- The AVS-47B is a digitally controllable analogue instrument that does not contain microprocessors or any other fast digital circuitry.
- All of the circuitry is grounded to the instrument case. No floating sections are allowed, except the output side of the primary computer interface. This is the best way to make the instrument immune against EMI and ESD (electrostatic discharges). Ground loop problems are prevented with the new "A"and "B" versions by selecting the best grounding scheme for each sensor.
- The preamplifier is located in a separate unit that can be placed in the immediate vicinity of the cryostat. The sensitive input leads can be short.

- The capacitance compensation circuit permits more effective RF filtering of the input lines than before.
- The optional IEEE-488 interface is located in a separate unit. It uses the low-speed Picobus protocol for communicating with the bridge.
- The Picobus cable from the bridge to the GPIB interface can be replaced by the optional Picolink optical fiber link.
- **The AVS-47B** can be operated from two 12 V batteries of from a 12V safety AC voltage. These options serve for isolating and filtering the input power.
- The digital display is directly driven, instead of being multiplexed.



A tree representation of VI:s for controlling the AVS-47B directly from PC.

Computer Interfacing

Primary Interface

All AVS-47 versions are equipped with a low-speed, low-EMI primary computer interface. The synchronous, serial **Picobus** protocol makes use of two handshaking inputs and two handshaking outputs of the controlling PC:s serial port. Picobus communications can be made as slow as desired, and therefore this protocol is suitable for EMI-critical applications, especially if the interface line must be filtered.

The proprietary Picobus requires direct manipulation of individual bits in the serial port's status and control registers. This difficulty has discouraged people from using Picobus without the help of the optional AVS47-IB protocol converter box. The **Picobus is now supported by a few LabView™ VI's**. They make interfacing very easy for users, who run LV7.1 or later on a PC that has a free standard serial port. These VI:s and a written manual can downloaded from our WEB site, and they support also the TS-530A.

The AVS-47B offers **optical isolation** between the primary interface and the controlling computer.

A LabView Application Example combines the AVS-47 and TS-530A into a single virtual instrument.

Secondary Interface

The optional model AVS47-IB interface for IEEE-488 is located in a separate mains-powered unit, which is connected to the AVS-47B via the Picobus. The bridge can be kept far from the noisy GPIB bus. If the AVS47-IB is placed outside the cryostat room, the Picobus lines can be filtered at the point where they enter the shielded space.

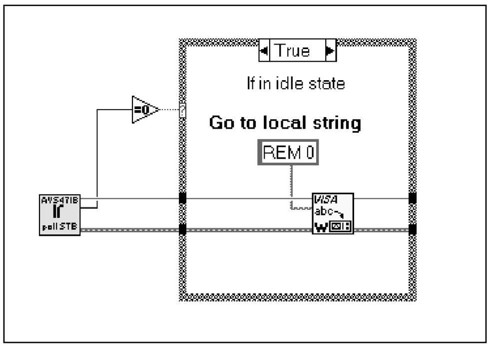
AVS47-IB is based on a small embedded computer. It offers, in addition to the basic low level commands for managing the AVS-47B, also many high level macro commands like averaging, scanning, digital filtering and even digital self-calibration for obtaining the best accuracy. The AVS47-IB can buffer data in order to reduce the host computer's workload. Scheduled measurements at pre-set intervals, and printing the results on a printer, are also possible with this interface.

Description and a PDF manual for the AVS47-IB can be downloaded from our WEB site.

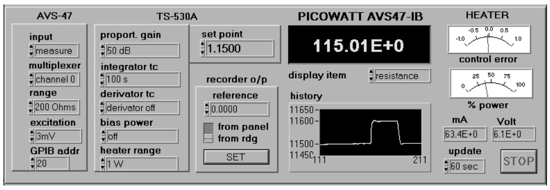
The AVS47-IB is built in a separate, mains powered unit which can be kept far from the bridge.

LabView™ Driver

A full-featured LabView™ Driver is available for managing the AVS-47B resistance bridge, the AVS47-IB computer interface and the TS-530A temperature controller. Two application examples are included. Both the driver and its PDF manual can be freely downloaded from our WEB site.



A LabView™ Driver and its PDF manual can be downloaded from our WEB site. A single driver covers the AVS-47B, the TS-530A and the AVS47-IB interface box.



In this LabView™ application example, the resistance bridge and the temperature controller have been combined into one single instrument.

AVS-47B and Temperature Control

The AVS-47B has a calibrated **stepless** analogue output which is obtained directly from the self-balancing loop. This output is suitable for high-resolution temperature control. Picowatt offers a precision PID (Proportional-Integrate-Derivate) temperature controller TS-530A, which is also based on analogue electronics. The TS-530A has been designed mainly for dilution refrigerator temperatures. Its maximum heating power is 1 watt into a 100 Ω heater.

The TS-530A receives its programming data from the AVS-47B, so that both instruments are handled together via one single computer interface. Both devices have similar 19-inch enclosures, which can be laid on top of each other.

The TS-530A is also a reliable analogue design. It can be controlled remotely via the AVS-47A.

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: 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 individual 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. If a short circuit piece is removed, the I- lead of that channel must be connected to cryostat ground. 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 in order to provide the best shielding against high frequency interference.

EXCITATION FREQUENCY: The operating frequency of the AVS-47B can be adjusted in the range 10..110 Hz. Default excitation frequency of about 13.7 Hz is suitable for both 50 and 60 Hz power systems. 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 a filter or cable capacitance in the input circuitry.

The free-running oscillator can be re-adjusted if the measurement suffers from an interference that is near to the default excitation frequency.

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 mains-synchronized 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 with 4 1/2 digits (0..19999) resolution.

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

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

If the system has no temperature controller, inputs for items 5..7 are available for monitoring external voltages. They all have a calibrated gain of (0.01% ±1 digit) and a very high input impedance. These inputs can be accessed via a rear panel DC37S connector.

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 0.6 Hz. Range 0..+2V, output impedance 100 Ω.

DIFFERENCE OUTPUT: Difference ΔR between the Analog Output and the ΔR-reference DAC. Range from -2V to +2V. Output impedance 100 ohms. The difference can be magnified by a factor of 10 in order to get a better resolution for resistance changes 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. Valid range is 0..4000 corresponding to 0.. +2 Volts in steps of 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.

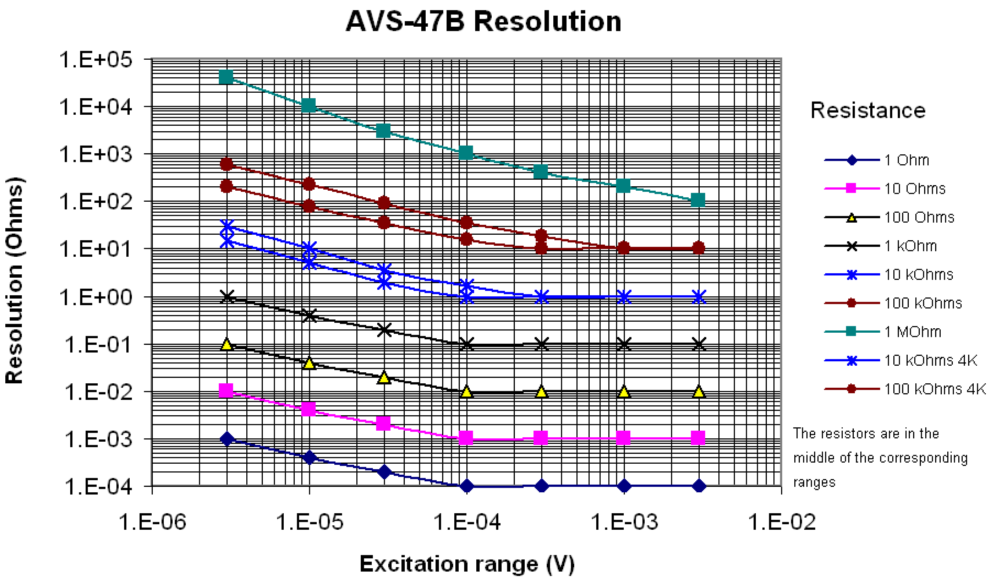
RELAY OUTPUT: 0.5A relay switch is available for activating an alarm system or controlling an “on/off” heater. The relay can be configured to either open or close when the sensor value passes the deviation reference.

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 10 kΩ and 100 kΩ traces show the improvement that can be achieved by cooling these sensors to 4.2 K.

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 ms (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).

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.

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

Time difference between readings is 2.5 s.

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.

OPERATING TEMPERATURE: 15 ... 35ºC

MAINS VOLTAGE: 90V (100mA)...250V (50mA) 50-60Hz.

SAFETY VOLTAGE OPERATION: Output from an 11..14V (rms) transformer is connected between pins (2) and (1&3) of the 4-way DIN connector. The transformer should be capable of delivering at least 1.5A. Front panel mains switch is inoperable.

BATTERY INPUT: Two 12V batteries are required. Current consumption is about +550 / -150 mA (display enabled) and about +350 / -150 mA (display disabled). The display and/or status LEDs can be blanked to reduce battery drain. Batteries can be used for trouble shooting or to guarantee uninterruptible operation. The batteries are connected in series. Center node is connected to pin (2), positive to pin (1) and negative to pin (3) of the 4-way DIN connector at the rear panel. Front panel mains switch is inoperable.

PRIMARY COMPUTER INTERFACE: Synchronous serial low-EMI interface uses a slow **"Picobus" protocol**. The primary interface can be connected to the IEEE-488 bus via the optional AVS47-IB secondary interface unit. It can also be connected directly to a PC-type computer. The computer's operating system must allow direct access to the PC hardware, as Picobus is based on using the handshake signals of the computer's COM1: or COM2: port in a non-standard manner.

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-488.2 standard. Data sheet can be downloaded from our WEB site.

Picolink Optical Fibre Interface between the AVS-47B and the AVS47-IB.

WARRANTY: Three years.

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