Model 1900

Precision Low-Noise Signal Transformer

Instruction Manual

216145-A-MNL-E

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This equipment uses and can radiate radio-frequency energy and, if not installed and used in accordance with this manual, may cause interference to radio communications. As temporarily permitted by regulation, operation of this equipment in a residential area may cause interference, in which case the user at his own facility will be required to take whatever measures may be required to correct the interference.

Company Names

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This product has been designed in conformance with the following IEC/EN standards:

EMC:	BS EN55011 (1991) Group 1, Class A (CSPIR 11:1990)	
	BS EN50082-1 (1992):	
		IEC 801-2:1991
		IEC 801-3:1994
		IEC 801-4:1988
Safety:	BS EN61010-1: 1993 (IEC 1010-1:1990+A1:1992)	

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Operating Instructions

Chapter 1

1.1 Description

The Model 1900 is a precision low-noise signal transformer designed to allow a low impedance source to be matched to the high impedance input of a preamplifier, lock-in amplifier, or other measuring instrument to give the lowest possible noise performance. It is especially suitable for use with signals in the frequency range from a few hertz to a few hundred hertz. Applications include measuring the very small voltages developed across near-superconducting samples when current is passed through them, as well as detection of signals from other low-impedance sources such as small pick-up coils.

1.2 Installation

Installation of the model 1900 is straightforward. The signal to be measured from the low-impedance source is applied to one of the two input connectors, depending on the transformer ratio required. The output is connected using the supplied low-noise double screened cable to the input connector of the following instrument. Note that if another cable is substituted for this then the length should not exceed one foot (30 cm) in order to maintain good high frequency performance.

It is important to note that the shells of the transformer’s input BNC connectors are isolated from the transformer case, and in order to retain the transformer's common-mode rejection, it is essential that this isolation be maintained. This can be achieved by ensuring that the input connector’s shell (i.e. the shield of the input coaxial cable) is not connected to the transformer case ground. However, the cable shields should be grounded at the source.

The transformer case is connected to the shell of the output connector. Thus the transformer case will assume the ground of the device that follows it.

1.3 Operation

As a passive device, operation of the model 1900 simply requires that the user allow for the effects of the transformer’s voltage gain, given by the selected turns ratio, and its frequency response to relate the signal measured at the input of the following instrument to the signal at the transformer input.

The circuit diagram of the model 1900 transformer is shown in figure 1-1.

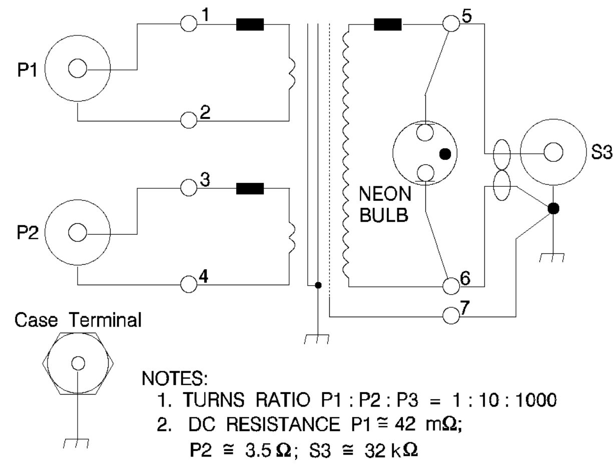

Figure 1-1, Model 1900 Circuit Diagram

It will be seen that there are two input connectors, P1 and P2, marked on the case of the transformer as **1** and **10** respectively, and an output connector, S3, marked as **1000**. Hence the unit offers two possible transformer turns ratios. When the signal is connected to the **1** input, with the output from the **1000** connector, the turns ratio is 1:1000, giving a voltage gain of ×1000. Similarly, when the signal is connected to the **10** input, with the output from the **1000** connector, the turns ratio is 1:100, giving a voltage gain of ×100. Only one of the inputs should be connected at a time, with the unused input left open.

The transformer is not of course lossless, so its frequency response also needs to be considered. The response depends both on the source impedance of the applied signal and on the selected turns ratio. Figure 1-2 shows the response for various combinations of these values.

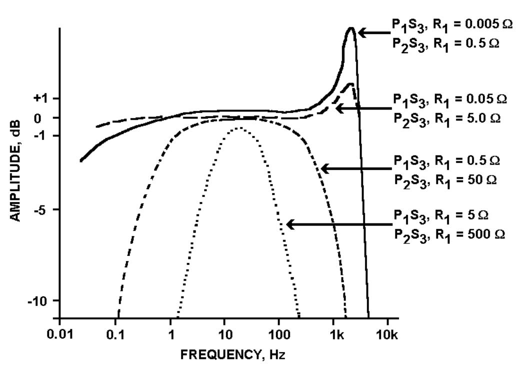

Figure 1-2, Model 1900 Typical Frequency Response

Hence, for example, with a source impedance of 0.5 Ω and a selected ratio of 1:1000 (P1:S3) a signal of 1 kHz would be subject to a transformer attenuation of about 5 dB. Hence the overall voltage gain of the transformer would be $1000 \times 10^{-5/20}$, or about 562. If a lock-in amplifier was used as the following measuring instrument and showed a measured voltage of say 50 nV, then the corresponding voltage at the transformer input would be about 89 pV.

It will be seen that operation at frequencies away from the optimum values gives significant attenuation, reducing the benefits gained by using the transformer.

Note from the circuit diagram that the transformer secondary is protected by a neon bulb. In normal operation this has no effect, but if for any reason the secondary voltage exceeds about 90 V (the breakdown voltage for the bulb) then the bulb will briefly conduct and prevent damage of the secondary winding due to insulation breakdown. Nevertheless, take care not to apply signals that could generate such voltages, since it is better to rely on good operating techniques than on the over-voltage protection that the bulb provides.

CAUTION: Avoid passing excessive DC current through the 1900's primary winding. Currents larger than 200 µA will permanently magnetize the core, making it necessary to degauss the transformer (see section 1-6) to restore normal performance. A magnetized core is usually noisy and microphonic. Do not measure the winding resistance with a multimeter set to the "ohms" ranges, since the test current used is usually sufficient to magnetize the core.

1.4 Noise and Source Resistance

1.4.01 Description

The noise performance of the model 1900 can be specified by its noise figure (*NF*), which indicates the amount of noise it adds to the transformed source, as follows:

$$NF(dB) = 20\log_{10}\left(\frac{Total\ Output\ Noise}{G \times E}\right) \qquad (1)$$

where

G is the transformer voltage gain (either 1000 or 100),
E is the source thermal noise

The source thermal noise, E, is in turn give by

$$E = \sqrt{(4kTBR)}\ \text{V rms} \qquad (2)$$

where
k = Boltzmann's constant = 1.38×10^{-23} joules/Kelvin
T = Absolute temperature in Kelvin
R = Source Resistance in ohms, and,
B = Equivalent Noise Bandwidth in hertz over which the measurement is made.

The total output noise may be converted to an equivalent input noise by dividing by the amplifier or transformer gain. The noise figure, expressed in these terms, becomes:

$$NF(dB) = 20\log_{10}\left(\frac{Total\ rms\ noise\ referred\ to\ input}{rms\ source\ thermal\ noise}\right) \qquad (3)$$

Each amplifier or transformer has its own characteristic set of noise figures, which vary as a function of frequency and source resistance. These figures are obtained experimentally and plotted graphically. The resulting noise figure contours allow the noise figure of the device for any source resistance and operating frequency to be quickly determined. The equivalent rms input noise can then be calculated by the formula:

$$\text{Input Noise (rms)} = \text{Source Thermal Noise} \times 10^{NF/20}$$

In using these equations, note that the Equivalent Noise Bandwidth must be specified. The ENBW is usually determined by the external circuitry and/or the amplifier or transformer bandwidth. Equivalent Noise Bandwidth is defined as the unattenuated bandwidth of an equivalent theoretical (but physically impossible) perfectly sharp-cornered filter that, with the same wideband input noise, yields the same rms output noise as the filter of interest.

Obtaining exact conversion factors to get from signal bandwidth to equivalent noise bandwidth is complex and depends on the specific roll-off characteristics of the system. Usually, however, actual or accurate figures are not important, and an approximation or even just an understanding of the situation will do. If the signal bandwidth is relatively wide and the roll-off fairly steep, the signal and equivalent noise bandwidth are nearly the same.

1.4.02 Example

This section considers a hypothetical measurement problem and determines the noise performance that might be obtained using the model 1900 transformer.

Suppose one intended to operate a ***SIGNAL RECOVERY*** model 5113 low-noise preamplifier in conjunction with an experiment that presents a source impedance of 50 Ω and suppose it is known that the information required from the experiment is below 3 kHz. Since the source thermal noise contributing to the total noise is dependent on bandwidth, the amplifier bandwidth is minimized by setting the 5113’s low-pass filter control to 3 kHz and the high-pass control to "DC", with DC coupling. If the equivalent noise bandwidth is approximated sufficiently by the signal 3 dB bandwidth as set by the model 5113’s controls, then the source thermal noise *E* at 290 K (17°C) will be given, using equation 2 above:

$$E = \sqrt{(4 \times 1.38 \times 10^{-23} \times 2.9 \times 10^{2} \times 50 \times 3 \times 10^{3})}$$

$$E = 49.0 \text{ nV rms}$$

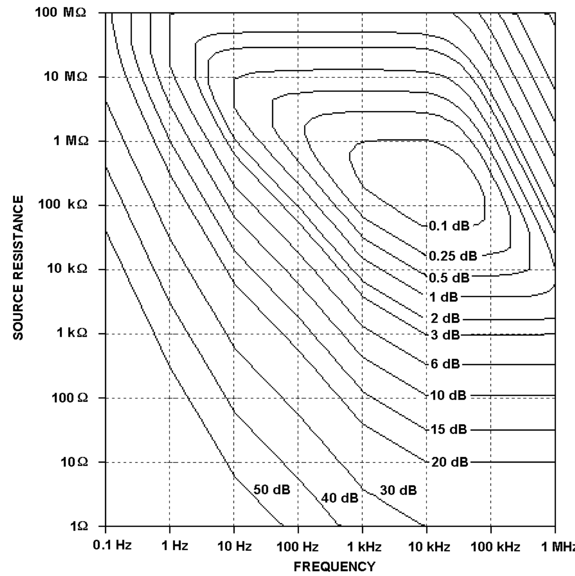

Figure 1-3, Model 5113 Noise Figure Contours

From the noise figure contours for the model 5113 , shown in figure 1-3, the noise figure at a center frequency of 1500 Hz and a source resistance of 50 Ω is about 20 dB. Solving for the total equivalent input noise, one gets:

Input Noise (V rms) = $49.0 \times 10^{-9} \times 10^{20/20}$

Input Noise (V rms) = 490 nV

Hence the 20 dB noise figure increases the equivalent noise voltage by a factor of ten (490 nV/49 nV = 10).

The noise performance can be greatly improved by using the model 1900 transformer. The source resistance as presented to the model 5113 will be increased by the square of the transformer turns ratio, to a region where the noise performance of the preamplifier is much better since the noise figure is smaller.

Referring to the model 5113 noise figure contours, note that the preamplifier is nearly noiseless at for source resistances in the range 100 kΩ to 1 MΩ. The required transformer turns ratio to match the 50 Ω source impedance to this range is therefore $\sqrt{(100 \times 10^3/ 50)} = 45$ to $\sqrt{(1 \times 10^6/ 50)} = 140$. Hence by interposing a transformer of say a 1:100 turns ratio between the source and the preamplifier, a preamplifier noise figure of near zero is obtained.

The thermal noise at the input of the preamplifier will simply be the source thermal noise multiplied by the turns ratio. Without the transformer, the amplifier added noise (20 dB) causes a factor of ten degradation in the signal-to-noise ratio. With the transformer, this degradation does not take place; both the signal and noise are increased by the turns ratio, but the additional noise contributed by the amplifier is reduced to a negligible level.

Note that the noise contributed by the transformer is not included in the preceding analysis, nor are the effects the transformer might have on bandwidth. In addition, it is seldom convenient to obtain a transformer having exactly the required turns ratio. Nevertheless the 1:100 ratio available with the model 1900 allows a very substantial improvement to be achieved.

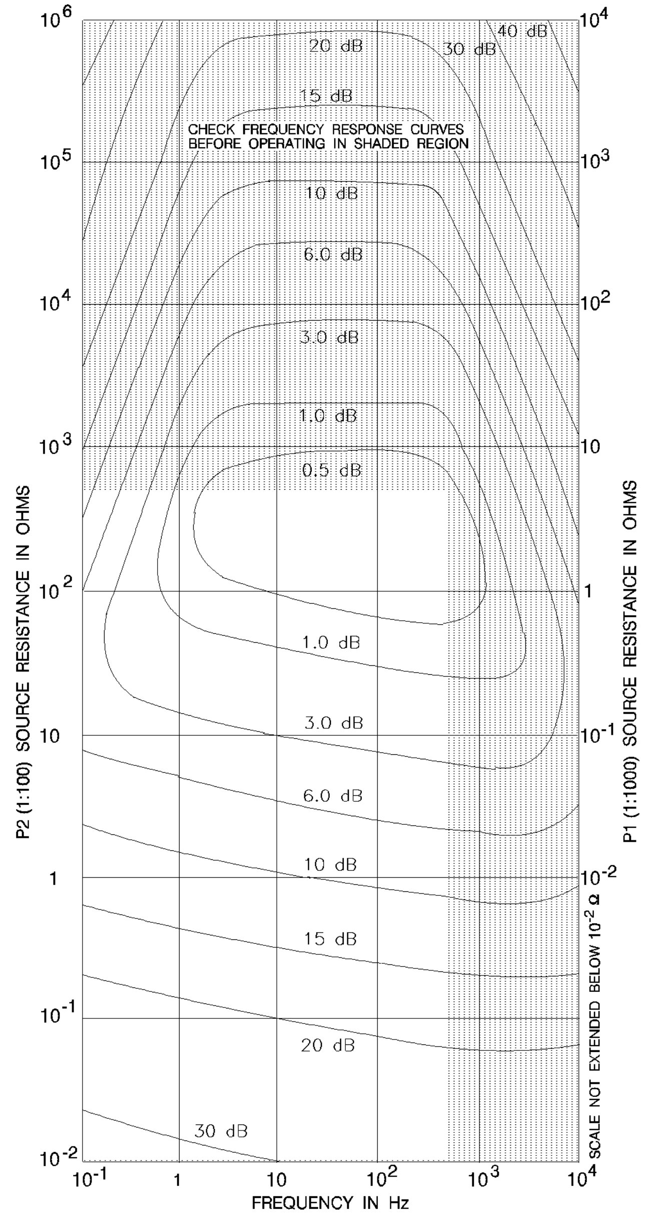

Figure 1-4, Model 1900 Noise Figure Contours

The model 1900 Noise Figure Contours, shown in figure 1-4, indicate that the transformer exhibits a reasonably uniform 1 dB noise figure over the bandwidth of interest (3 kHz) when working from a source resistance of 50 Ω.

However, because the bandwidth of the model 1900 is 1 kHz under the measurement conditions (see figure 1-2) instead of the 3 kHz set by the model 5113's passband, the rms thermal noise will be reduced from 49 nV to 28 nV. If the signal amplitude is not reduced, this noise bandwidth reduction itself increases the signal-to-noise ratio. However, it is unfair to attribute this improvement to the transformer, since completely independent of transformer considerations, the bandwidth could (and should) be reduced using filters so that only the band of frequencies containing the information is passed. In this particular case, the transformer, in addition to optimizing the source resistance, conveniently fills the filter requirement as well. In any case, the transformer causes a reduction in noise figure from 20 dB to 1 dB, and the amplifier, instead of causing a tenfold increase in the noise, adds only a 12% increase (1 dB) to it.

1.5 Phase Shift

Experimental measurements of phase shift versus frequency have been made for the model 1900. The measurements were made with a dual-phase lock-in amplifier using the following test setup.

1) The internal oscillator output of the lock-in amplifier was applied to a 500 Ω / 3 Ω voltage divider, yielding a signal source resistance of 2.7 Ω

2) The output of the divider was applied to the primary of the transformer under test.

3) The secondary of the transformer was connected to the input of the lock-in amplifier which was set to voltage mode operation.

4) The lock-in amplifier was set to internal reference mode and R-θ display.

At frequencies above 50 Hz, reflection of the high impedance input to the primary circuit can cause some measurement error with this setup. Nevertheless, this setup configuration was selected because it closely simulates typical operating conditions.

The measurement results are given in table 1-1 below

	Turns Ratio	
Frequency	**10:1000**	**1:1000**
5 Hz	-3.0°	26°
10 Hz	-3.0°	9.4°
20 Hz	-2.0°	-2.6°
50 Hz	-1.2°	-21.1°
100 Hz	-1.4°	-39.7°
200 Hz	-2.8°	-59.9°
500 Hz	-8.0°	-77.3°
1 kHz	-16.9°	
2 kHz	-43.2°	
5 kHz	-137.8°	

Table 1-1, Phase Shift vs. Frequency and Turns Ratio for Model 1900 Transformer

1.6 Degaussing

All transformer cores saturate, if the magnetizing current is made high enough. A typical B-H curve is illustrated in figure 1-5A.

B, the core flux, increases linearly with the magnetizing force (H) over a wide range. (H is the product of the number of turns times the applied current). Once saturation is reached, further increases in H do not result in further increases in B. Since the voltage induced in the secondary of a transformer is proportional to dB/dt, the secondary voltage will be distorted in the saturated region. A permanently magnetized core saturates at a lower level of H, and so reduces the maximum signal current that can be transformed without distortion.

Figure 1-5 graphically illustrates core, saturation and the resulting distortion. Note that the B-H characteristic is actually a loop; curves #1 and #2 are only representative "center lines" of the corresponding loops. In practice, the loops are usually "squarish ovals", with different degrees of squareness for different core materials. The shape of the loop has much to do with distortion, but this is not of interest in this discussion, only the general situation of the loops with respect to saturation.

A magnetized transformer is usually noisy and microphonic compared to its performance when not magnetized. This noise is the most objectionable characteristic of a magnetized transformer because it affects low level signals. The distortion of high level signals described above is not usually an operating problem because the signal is seldom so large. But high level distortion is useful in determining the condition of the core and in monitoring the degaussing process.

Notice from figure 1-5A that as long as the core is not magnetized, the transformer works on a loop around center line #1 and the signal can be of maximum amplitude. If the core becomes permanently magnetized, the transformer works on a loop around center-line #2 (or equivalent for opposite polarity), and, if the same maximum signal current is applied, the core becomes saturated at one of the signal peaks.

Figures 1-5B, C and D also shows a primary signal current, with core magnetization, and the corresponding induced secondary voltage for a magnetized-core transformer with a large signal input. Note that the permanently magnetized core saturates sooner for one polarity of signal and later for the other polarity.

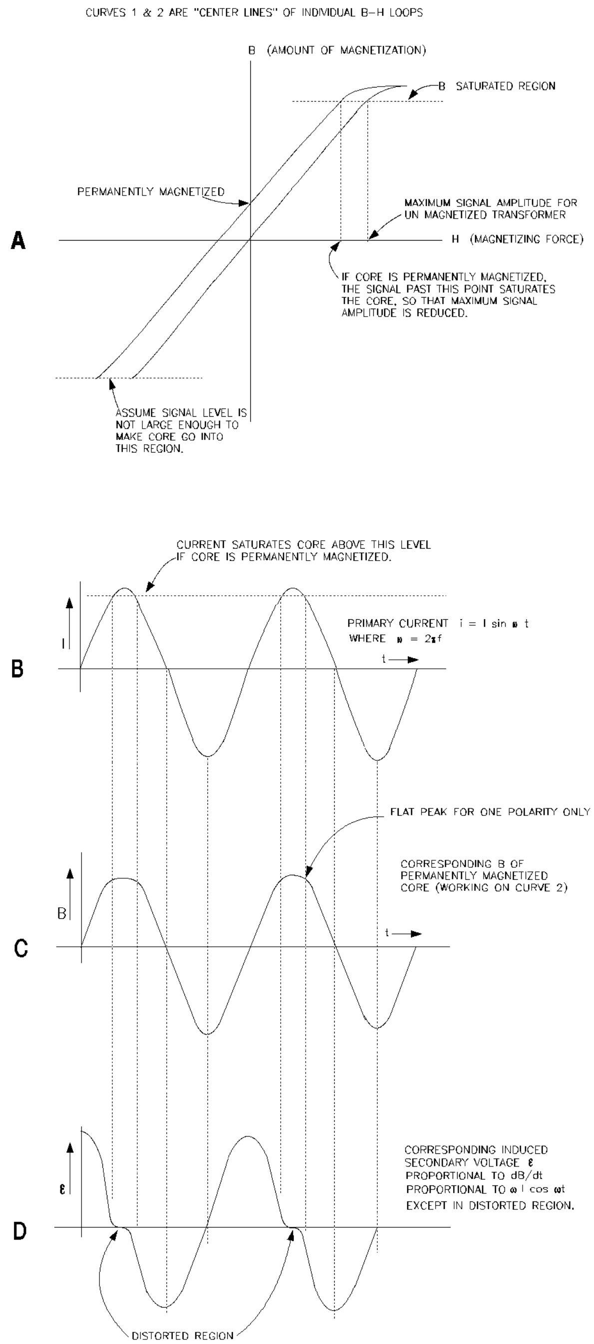

Figure 1-5, Typical Transformer B-H Curves

To demagnetize (degauss) the transformer, it is necessary to pass a relatively large AC current through the primary, then to very slowly decrease this current. The secondary should be left open. The degaussing current is initially large enough to magnetize the core in the direction of each corresponding polarity excursion of this current, and overrides the initial magnetization. The object is to decrease the current slowly so that each successive magnetization is slightly less than the preceding one of opposite polarity. As the current is decreased the core is progressively less magnetized until it is no longer magnetized at all. Figures 1-6A, B, and C illustrate the secondary waveforms as the transformer becomes demagnetized.

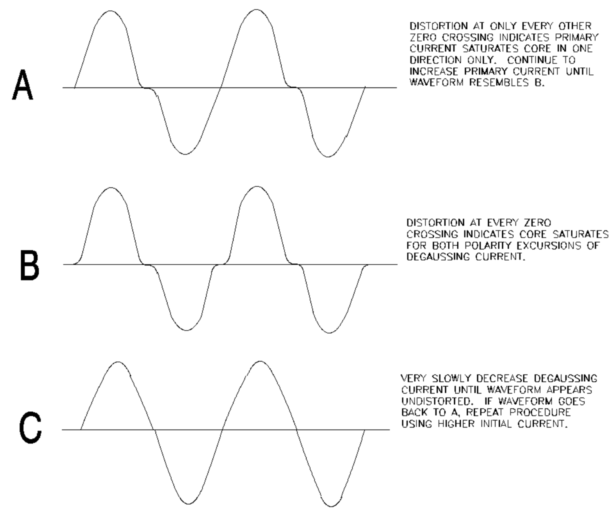

Figure 1-6, Degaussing Waveforms

CAUTION: Use a low frequency degaussing current, 1 Hz or so, to avoid inducing an excessively high secondary voltage. Even though the model 1900's secondary is protected by a neon lamp, it is better to be careful.

Specifications

Appendix **A**

General

Precision signal transformer with adjustable turns ratio mounted in a mu-metal case. Signal input and output connections via BNC connectors

Electrical

Voltage Gain	1:100 or 1:1000 selected by front-panel BNC connector
Frequency Response	See Figure 1-2
Noise	See Figure 1-4
Mounting	Free-standing fully shielded metal case

Mechanical

Dimensions (excluding connectors)	
	3" wide × 5.8" long × 3" high (76 mm wide × 147 mm long × 76 mm high)
Shipping Weight	5lbs (2.3 kg)

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B. We will need the following information, a copy of which should also be attached to any equipment which is returned for service.

1. Model number and serial number of instrument
2. Your name (instrument user)
3. Your address
4. Address to which the instrument should be returned
5. Your telephone number and extension
6. Symptoms (in detail, including control settings)
7. Your purchase order number for repair charges (does not apply to repairs in warranty)
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C. If you experience any difficulties in obtaining service please contact:

SIGNAL RECOVERY Service
AMETEK Advanced Measurement Technology, Inc
801 South Illinois Avenue
Oak Ridge
TN 37831-2011, USA

Phone: +1 865 483 2121
Fax: +1 865 483 0396
E-mail: service@signalrecovery.com

or

SIGNAL RECOVERY Service
AMETEK Advanced Measurement Technology
Astro House
Brants Bridge,
Bracknell
RG12 9HW, UNITED KINGDOM

Phone: +44 (0)1344 477900
Fax: +44 (0)1344 477901
E-mail: service@signalrecovery.com