INSTRUCTION MANUAL

for

RS101 LOOP ANTENNA SET

set includes:

12 cm (Radiating) Loop Antenna
Model: **AL-RS101-TX**

4 cm (Sensor) Loop Antenna
Model: **AL-RS101-RX**

1Ω (±1%), 10 Watt Precision Resistor Box
Model: **PR10-1E**

Table of Contents

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List of Figures

1.0 Introduction

This manual includes descriptions of product features; product specifications, safety precautions, operational instructions, antenna theory, measurement guidelines, warranty and product maintenance information.

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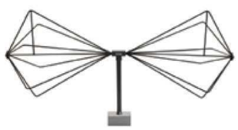
2.0 Products Available from Com-Power



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3.0 Product Information

3.1 Incoming Inspection

Please check the contents of the shipment against the package inventory in section 3.2 to ensure that you have received all applicable items.

3.2 Package Inventory

STANDARD ITEMS:

- ✓ **AL-RS101-TX** Loop Antenna
- ✓ **AL-RS101-RX** Loop Antenna
- ✓ **PR10-1E 1Ω (±1%),** 10 Watt Precision Resistor Box
- ✓ Teflon spacer attachment for mounting AL-RS101-RX Loop onto the AL-RS101-TX Loop.
- ✓ Non-metallic thumb screw to hold the Teflon spacer attachment in place.
- ✓ Calibration Data and Certificate

3.3 Product Features

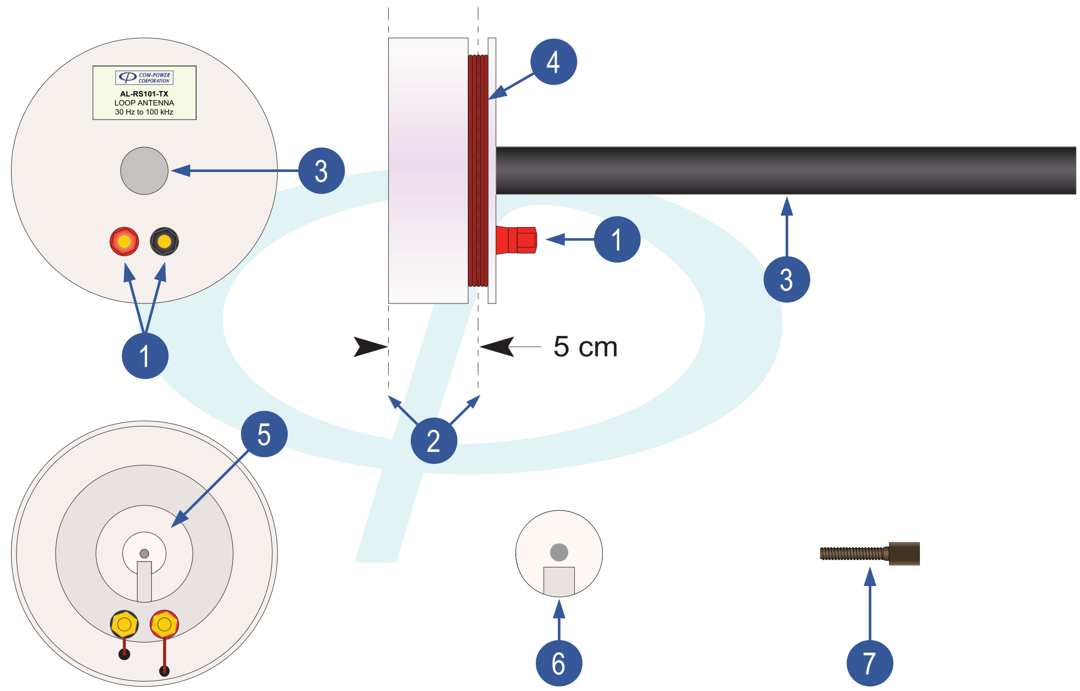

FIGURE 1 - *AL-RS101-TX Features*

1. **Antenna Input Port**
   Antenna input port terminals fitted with 4 mm banana jack binding posts.
2. **5 cm Spacing**
   The 5 cm spacing required for MIL-STD 461, RS101 is achieved when the front edge of the Teflon antenna structure is contacted against the surface of the equipment under test (EUT).
3. **Threaded Hole for Loop Mounting Pole**
   The black loop mounting pole screws into the threaded hole in the center of the loop coil assembly.
4. **Loop Coil**
   20 turns of 12 AWG enamel insulated wire
5. **AL-RS101-RX Mounting Position**
   During calibration, the AL-RS101-RX Loop Antenna is mounted into this location.
6. **AL-RS101-RX Mounting Teflon Spacer**
   Used to hold the AL-RS101-RX Loop Antenna into position when mounted onto the AL-RS101-TX Loop Antenna.
7. **AL-RS101-RX Mounting Thumb Screw**
   Locks the Teflon spacer in its position.

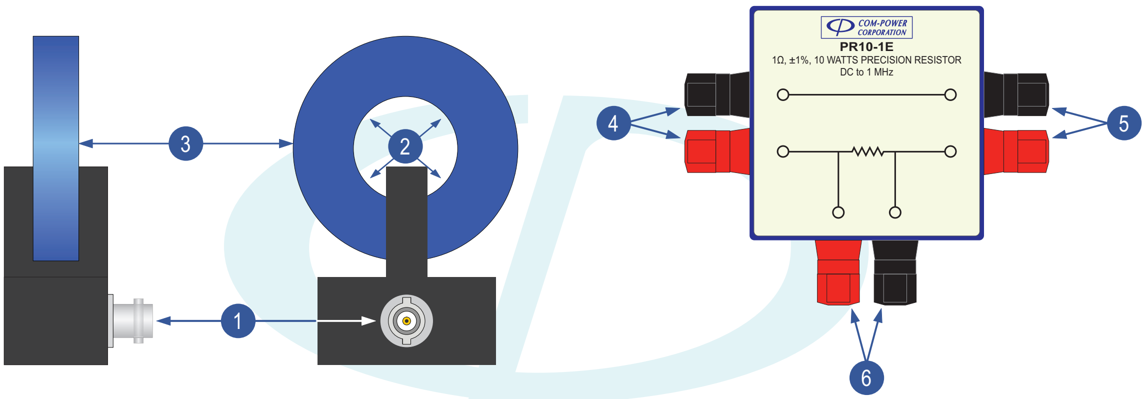

FIGURE 2 - *AL-RS101-RX Features*

1. **Antenna Output Port**
   Coaxial BNC female connector.
2. **Loop Coil**
   51 turns of 7 strand, 41 AWG Litz wire encapsulated within the electrostatic shield.
3. **Electrostatic Shield**
   Electrostatic shield for loop coil.
4. **Resistor Input Port**
   Connects to the source equipment.
5. **Resistor Output Port**
   Connects to the radiating (or transmitting) loop antenna (usually AL-RS101-TX)
6. **Voltage Monitor Port**
   Terminals for monitoring the voltage drop across the resistor.

3.4 Product Specifications

	AL-RS101-TX	AL-RS101-RX
Frequency Range	**10 Hz to 100 kHz**	**10 Hz to 100 kHz**
Specifications	**MIL-STD-461,RS101**	**MIL-STD-461, RS101/RE101**
Loop Coil Diameter	**12 cm**	**4 cm**
Number of Turns ***(N)***	**20 turns**	**51 turns**
Wire Type	**12 AWG** *(enamel insulated)*	**7 Strand, 41 AWG Litz**
Loop Shielding	**N/A**	**Electrostatic Shield**
Resistance of Loop Coil ***(Rc)***	**40 mΩ** *(nominal)*	**4Ω** *(nominal)*
Inductance of Loop Coil ***(L)***	**90 µH** *(nominal)*	**180 µH** *(nominal)*
Maximum Input Current	**15 Amperes**	**N/A**
Connector(s)	**(2) Banana Jacks**	**Coaxial BNC** *(female)*
Weight	**2.2 lbs** *(1 kg)*	**0.26 lbs.** *(0.12 kg)*
Operating Temperature	**40°F to 104°F** *(5°C to 40°C)*	

All values are typical, unless specified.
All specifications are subject to change without notice.

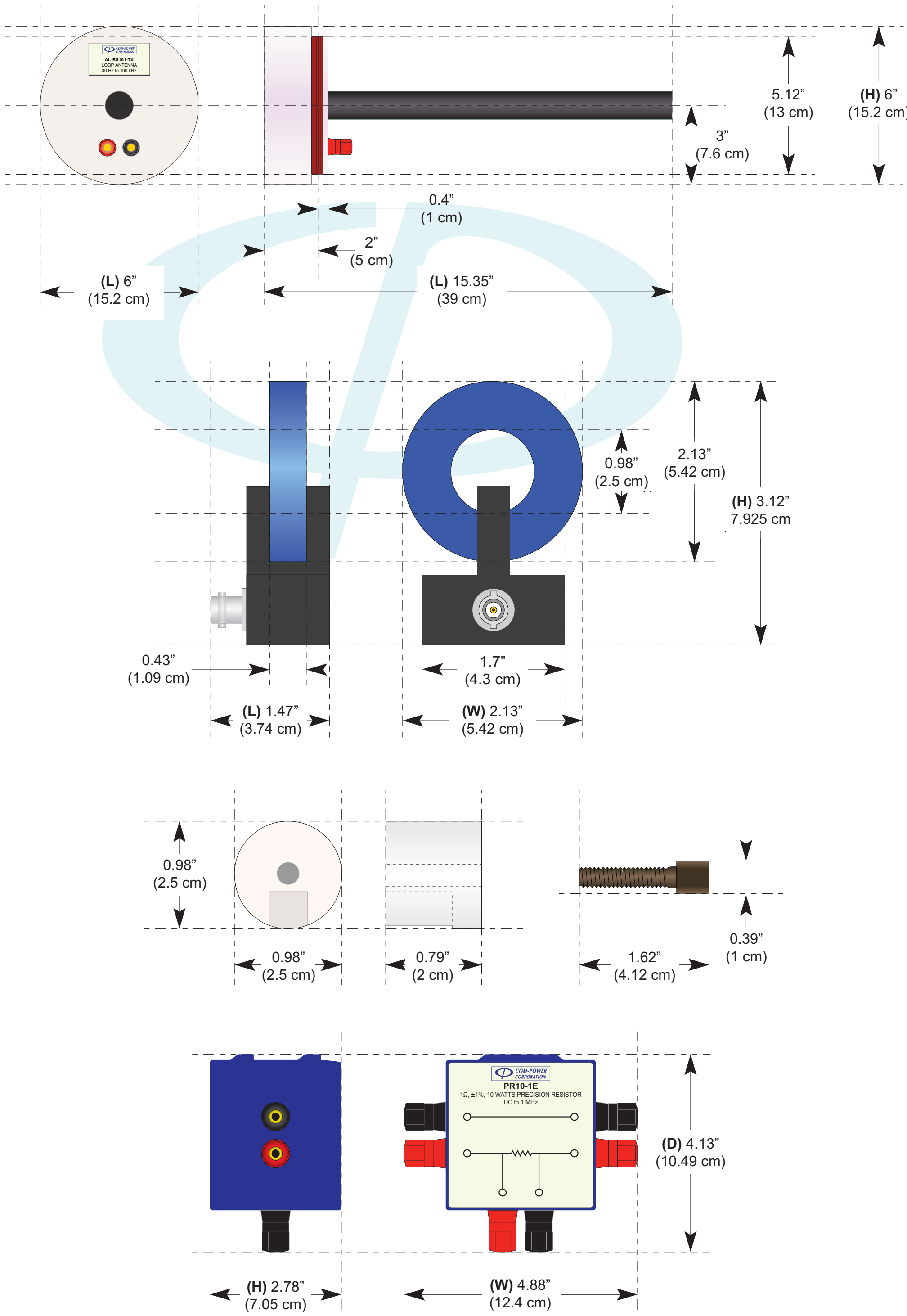

FIGURE 3 - *Dimensions of Loop Antennas and Accessories*

4.0 Using Your AL-RS101 Loop Antenna Set

The AL-RS101 Loop Antenna Set was designed specifically for MIL-STD-461, RS101, radiated susceptibility, magnetic field. Discussed in the following sections are general descriptions of each set component, as well as instructions for mounting the AL-RS101-RX antenna onto the AL-RS101-TX antenna.

Refer to MIL-STD-461 for procedures related to the performance of tests and general calibrations related to the RS101 test.

4.1 General Overview of Set Components

The AL-RS101 Loop Antenna Set consists of the following items:

1) **AL-RS101-TX Loop Antenna**

   Serves as the radiating, 12 cm diameter, 20 turn loop described in MIL-STD-461, RS101.

2) **AL-RS101-RX Loop Antenna**

   Serves as the 4 cm, 51 turn, electrostatically shielded loop sensor described in MIL-STD-461, RS101.

3) **PR10-1E 1Ω (±1%), 10 Watt Precision Resistor Box**

   Serves as the Precision 1 ohm resistor described in SAE ARP958. It is placed in series with the drive line during antenna conversion factor calibration of the AL-RS101-RX Loop, and provides a means by which the drive current can be monitored.

   NOTE: Exercise caution not to exceed the 10 watt power rating of the resistor.

4) **Teflon Spacer Attachment**

   This spacer locks the RS101-RX Loop Antenna into its mounting position on the AL-RS101-TX Loop Antenna during antenna factor calibrations as well as during test level calibration according to MIL-STD-461, RS101.

5) **Non-metallic Thumb Screw**

   This screw is used to hold the Teflon Spacer Attachment into position over the AL-RS101-RX Loop Antenna.

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4.2 Mounting the AL-RS101-RX Loop onto AL-RS101-TX Loop

The AL-RS101-RX Loop Antenna can be mounted directly onto the AL-RS101-TX Loop Antenna. This mounting arrangement ensures that the following conditions are realized:

a) The separation distance between the loop coils is exactly 5 cm.

b) The respective loop coils are precisely aligned coaxially.

This mounting arrangement should be employed for all measurements of the magnetic field strength, or flux density of the field generated by the AL-RS101-TX, and measured with the AL-RS101-RX Loop at a 5 cm distance. These measurements are necessary during antenna factor calibration as per SAE ARP958 and during calibration of the field as described in MIL-STD-461.

Illustrated in Figure 4 is the method by which the AL-RS101-RX Loop Antenna is mounted onto the AL-RS101-TX Loop Antenna.

Illustrated in Figures 5 and 6 are diagrams of the calibration and test setups for MIL-STD-461, RS101, radiated susceptibility, magnetic fields.

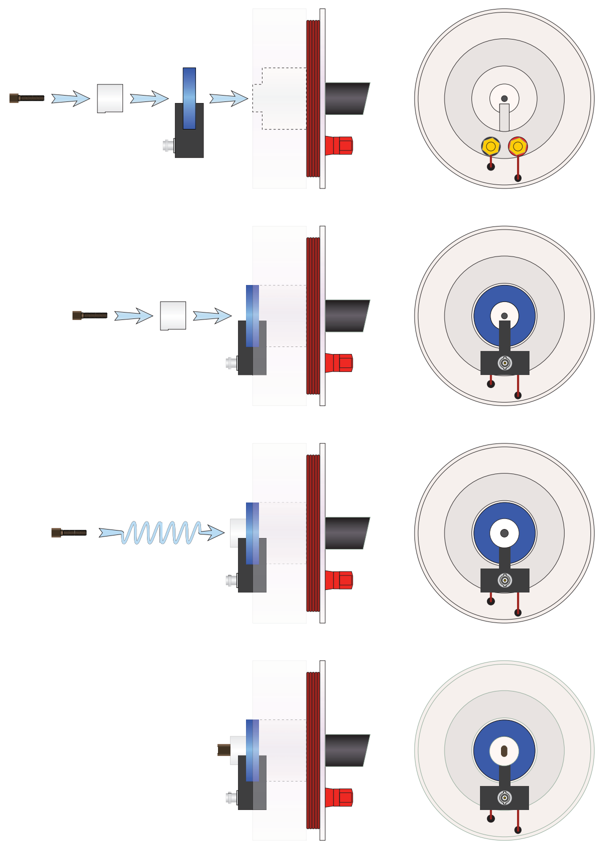

FIGURE 4 - *Mounting the AL-RS101-RX onto the AL-RS101-TX*

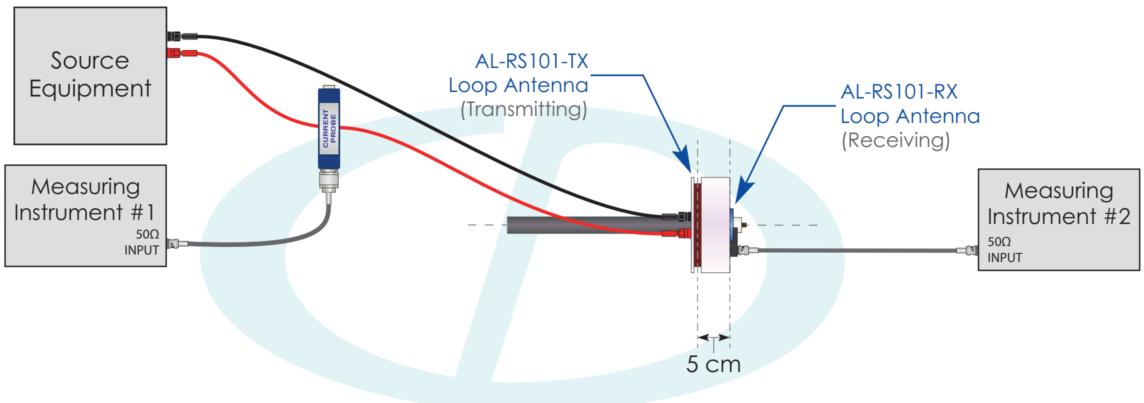

FIGURE 5 - *Setup Diagram for Test Level Calibration*

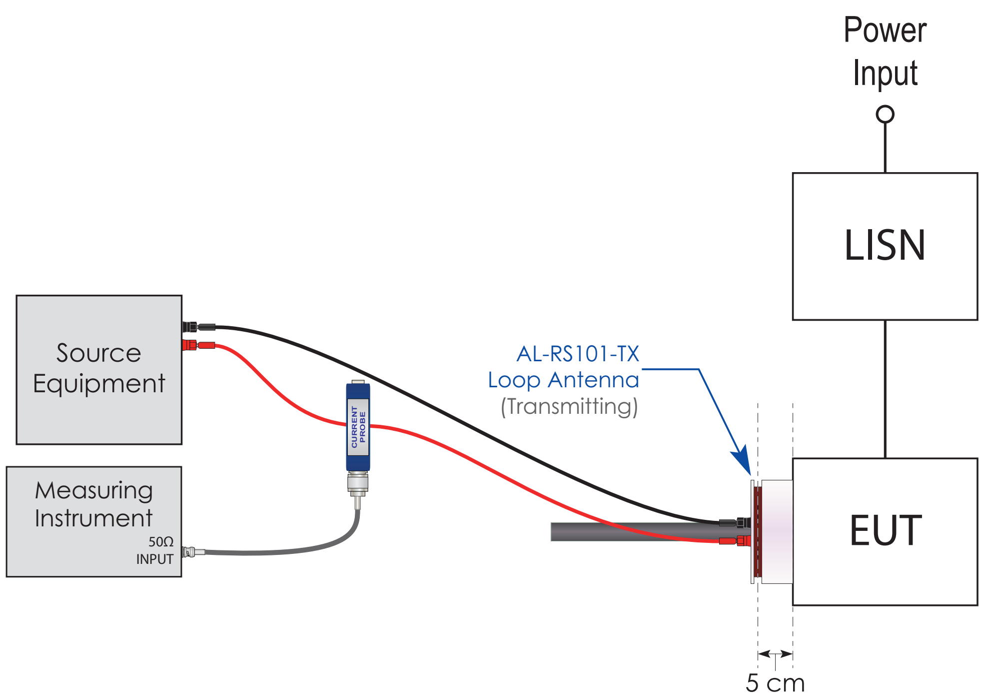

FIGURE 6 - *Test Setup Diagram*

4.3 Antenna Conversion Factors

Your AL-RS101-RX Loop Antenna is provided with two sets of antenna conversion factors. The input impedance of your measuring instrument determines which factor to use, as described below.

The 50 ohm antenna conversion factors are the most commonly applied. These are to be used when the AL-RS101-RX Loop Antenna is connected to a measuring instrument having a nominal input impedance of 50 ohms. These factors are provided over the frequency range of 10 Hz to 100 kHz, as shown in *Figure 7*. To find the factors for frequencies between those listed in the table, see section 4.3.1.

The 100 kΩ factors are used when the AL-RE101 Loop Antenna is connected to a measuring instrument with a high input impedance (greater than approximately 500 ohms). These factors are provided over the truncated frequency range of 10 Hz to 50 kHz, also as shown in *Figure 7*. The antenna should generally not be used above 50 kHz without a 50 ohm termination.

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Antenna Conversion Factors

Equipment:			Loop Antenna
Model:			AL-RS101-RX
Serial Number:			1031xxxx
Calibration Date:			any month, any day, any year
Frequency (Hz)	*Measured Antenna Conversion Factors* 50Ω (dBpT/µV)	*Theoretical Antenna Conversion Factor* 50Ω (dBpT/µV)	100kΩ (dBpT/µV)
10		108.57	107.90
20		102.55	101.88
30		99.03	98.36
50		94.59	93.92
70		91.67	91.00
100		88.57	87.90
200		82.55	81.88
300		79.03	78.36
500		74.59	73.92
700		71.67	71.00
1,000		68.57	67.90
2,000		62.56	61.88
3,000		59.04	58.36
5,000		54.64	53.92
7,000		51.76	51.00
10,000		48.76	47.90
20,000		43.25	41.88
30,000		40.47	38.36
50,000		37.81	33.92
70,000		36.65	31.00
100,000		35.88	

Calibration performed per: SAE ARP958, Rev D

Corrected Reading (dBpT) = Meter Reading (dBµV) + Antenna Conversion Factor (dBpT/µV)

FIGURE 7 - *Antenna Conversion Factors*

The antenna conversion factor (in dBpT/µV units) is to be added to the measured value (in dBµV) to obtain the corrected magnetic field strength value, or flux density (in dBpT).

Measured Value *(in dBµV)* + ***Antenna Conversion Factor*** *(in dBpT/µV)* = ***Magnetic Field Strength*** *(in dBpT)* **EQUATION (1)**

EXAMPLE CALCULATION #1:

A signal at ***500 Hz*** has a measured value of ***40 dBµV*** *(*or ***100 µV****)* on a measurement instrument having a nominal input impedance of 50Ω.

Using the table shown in Figure 7, the 50Ω antenna conversion factor at 500 Hz is 74.59 dBpT/µV; therefore:

40.0 *dBµV* + ***74.59*** *dBpT/µV* = ***114.59*** *dBpT*

The magnetic field strength, or flux density of the signal is 114.59 dBpT.

4.3.1 Interpolation of Antenna Conversion Factors

In order to find the antenna conversion factor **(ACF)** for frequencies between those listed in the table, *Equation (2)* may be used for interpolation:

$$ACF_X = ACF_1 + (ACF_2 - ACF_1)\left(\frac{\log(f_X/f_1)}{\log(f_2/f_1)}\right) \quad \textbf{EQUATION (2)}$$

where:

ACF_X = unknown antenna conversion factor at f_X
ACF_1 = antenna conversion factor at f_1
ACF_2 = antenna conversion factor at f_2
f_X = frequency at which antenna conversion factor is desired
f_1 = highest frequency < f_X on factor table
f_2 = lowest frequency > f_X on factor table

EXAMPLE CALCULATION #2:

In this example, the 50 ohm antenna conversion factor at **60 Hz** is calculated. Using the *Figure 7* table, the following values are known:

Frequency		Antenna Conversion Factor (50Ω)	
f_1	50 Hz	ACF_1	94.59 dBpT/µV
f_2	60 Hz	ACF_2	91.67 dBpT/µV

Using *Equation (2)*, the antenna conversion factor at 60 Hz is calculated as ACF_X:

$$ACF_X = 94.59 + (91.67 - 94.59)\left(\frac{\log(60/50)}{\log(70/50)}\right)$$

$$ACF_X = \mathbf{93.01}\ dBpT/\mu V$$

5.0 Antenna Theory

This section details the theoretical operation of the AL-RE101 loop antenna. *Equation (3)* through *Equation (7)* define the relationship between the average magnetic field strength (or magnetic flux density) within the area of the loop coil and the voltage present at the antenna terminals, in order to determine the antenna conversion factors. These equations consider the physical and electrical characteristics for the antenna, as shown in the following pages.

5.1 Open Circuit Antenna Terminal Voltage vs Flux Density

Equation (3) below defines the relationship between open circuit loop terminal voltage, number of turns in the coil, area of the coil, the frequency and the average flux density within the area of the coil:

$$e_{i(V)} = 2\pi NAfB_{(T)} \text{ (Volts)}$$

EQUATION (3)

where:

$e_{i(V)}$ = *open-circuit loop terminal voltage (in Volts)*
N = *number of turns in loop coil* = ***51 turns***
A = *area of coil* = ***0.001257 meters²***
= πr^2, *where* r = *coil radius* = *0.02 meters*
f = *frequency (in Hz)*
$B_{(T)}$ = *magnetic flux density (in Tesla)*

Equation (3) is resolved below by substituting the actual number of turns ***(N)*** and coil area ***(A)*** for the AL-RE101 Loop Antenna; and to provide the resultant quantity in microvolts (rather than volts).

$$e_{i(V)} = 2\pi NAfB_{(T)} \text{ (Volts)}$$

*substituting known constants (**number of turns** and **coil area**)...*

$$e_{i(V)} = 2\pi \times [51] \times [0.001257] \times fB_{(T)} \text{ (Volts)}$$

$$e_{i(V)} = [0.4028] \times fB_{(T)} \text{ (Volts)}$$

*converting **Volt/Tesla** units to more convenient **µV/pT** units...*

$$e_{i(\mu V)} = 10^{-6} \times [0.4028] \times fB_{(pT)} \text{ (µV)}$$

EQUATION (4)

where:

$e_{i(\mu V)}$ = *open-circuit loop terminal voltage (in microvolts)*
f = *frequency (in Hz)*
$B_{(pT)}$ = *magnetic flux density (in picotesla)*

EXAMPLE CALCULATION #3

In the following example, *Equation (4)* is solved for the magnetic flux density ***(B)*** assuming a frequency ***(ƒ)*** of ***500 Hz***, with the AL-RS101-RX Loop Antenna connected to a high impedance oscilloscope input. The measured amplitude ***(e_i)*** is ***108 µV, or 40.67 dBµV***.

$$e_{i(\mu V)} = 10^{-6} \times [0.4028] \times f B_{(pT)} \quad (\mu V)$$

as voltage is the known quantity, the formula is rearranged to solve for flux density...

$$B_{(pT)} = \frac{e_{i(\mu V)}}{10^{-6} \times [0.4028] \times f} \quad (pT)$$

*substituting known variables (**voltage** and **frequency**)...*

$$B_{(pT)} = \frac{[108]}{10^{-6} \times [0.4028] \times [500]} \quad (pT)$$

$$B_{(pT)} = 536{,}251 \text{ pT}$$

*converting **linear** result into **logarithmic** units...*

$$B_{(pT)} = 114.59 \text{ dBpT} \quad (20*\log[pT])$$

NOTE: The same result can be determined using Equation (1) and the 100 kΩ antenna conversion factor given in Figure 4.

EQUATION (1)

Measured Value (in dBµV)	+	Antenna Conversion Factor (in dBpT/µV)	=	Magnetic Field Strength (in dBpT)
[40.67] dBµV	+	[73.92] dBpT/µV	=	114.59 dBpT

5.2 Determination of Antenna Conversion Factors

The basic formulae for determining the antenna conversion factors for the antenna are given in *Equation (5)* and *Equation (6)*. Considered in these equations are the frequency and resistance, inductance, area and number of turns of the loop coil:

$$ACF = 20Log\left(\left|\frac{B_{(pT)}}{V_{L(\mu V)}}\right|\right) \text{ (dBpT/µV)}$$

EQUATION (5)

$$\left|\frac{B_{(pT)}}{V_{L(\mu V)}}\right| = 10^6 \frac{\sqrt{\left(1+\frac{R_C}{R_L}\right)^2 + \left(\frac{2\pi f L}{R_L}\right)^2}}{2\pi f A N} \text{ [pT/µV]}$$

EQUATION (6)

where:

- ACF = *antenna conversion factor* (in pT/µV)
- $B_{(pT)}$ = *magnetic flux density* (in pT)
- $V_{L(\mu V)}$ = *voltage across* R_L (in µV)
- R_C = *loop coil resistance* = **4Ω**
- R_L = *load resistance* [or input impedance of measurement instrument] (in ohms)
- f = *frequency* (in Hz)
- L = *loop coil inductance* = **0.00018 H**
- A = *area of coil* = **0.001257 meters²**
  = πr^2, where r = coil radius = 0.02 meters
- N = *number of turns in loop coil* = **51 turns**

The derivation of *Equation (6)* is given in section 5.2.1.

In the formulae below, *Equation (6)* is reformulated to integrate the actual resistance **(R_C)**, inductance **(L)**, number of turns **(N)** and coil area **(A)** for the AL-RS101-RX Loop Antenna; in *Equation (7)*:

rearranging equation (6) to separate **2πL** *from* ***f***...

$$\left|\frac{B_{(pT)}}{V_{L(\mu V)}}\right| = 10^6 \frac{\sqrt{\left(1+\frac{R_C}{R_L}\right)^2 + (2\pi L)^2\left(\frac{f}{R_L}\right)^2}}{2\pi f A N} \text{ (pT/µV)}$$

substituting known constants (coil resistance (R_C), coil inductance (L), number of turns (N) and coil area (A))...

$$\left|\frac{B_{(pT)}}{V_{L(\mu V)}}\right| = 10^6 \frac{\sqrt{\left(1+\frac{[4]}{R_L}\right)^2 + (2\pi \times [0.00018])^2\left(\frac{f}{R_L}\right)^2}}{2\pi \times f \times [0.001257] \times [51]} \text{ (pT/µV)}$$

equation (7) is determined...

$$\left|\frac{B_{(pT)}}{V_{L(\mu V)}}\right| = 10^6 \frac{\sqrt{\left(1+\frac{[4]}{R_L}\right)^2 + [1.279\text{x}10^{-6}]\left(\frac{f}{R_L}\right)^2}}{f \times [0.4028]} \text{ (pT/µV)}$$

EQUATION (7)

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EXAMPLE CALCULATION #4:

In the following example, the antenna conversion factor ***(ACF)*** is calculated using *Equation (5)* and *Equation (7)*. For the purposes of this example, the frequency ***(f)*** is assumed to be ***500 Hz***, and the measuring instrument termination or load resistance ***(R_L)*** is ***50 ohms***:

$$\left|\frac{B_{(pT)}}{V_{L(\mu V)}}\right| = 10^6 \frac{\sqrt{\left(1+\frac{[4]}{[50]}\right)^2 + [1.279x10^{-6}]\left(\frac{[500]}{[50]}\right)^2}}{[500] \times [0.4028]} \ (pT/\mu V)$$

$$\left|\frac{B_{(pT)}}{V_{L(\mu V)}}\right| = [5362.76] \ (pT/\mu V)$$

$$ACF = 20Log\left(\left|\frac{B_{(pT)}}{V_{L(\mu V)}}\right|\right) \ (dBpT/\mu V)$$

$$ACF = 20Log([5362.76]) \ (dBpT/\mu V)$$

$$ACF = 74.59 \ dBpT/\mu V$$

EXAMPLE CALCULATION #5:

In this example, *Equation (7)* is solved for magnetic flux density ***($B_{(pT)}$)*** assuming a frequency ***(f)*** of ***500 Hz***, with the AL-RS101-RX Loop Antenna connected directly to a spectrum analyzer having an input impedance ***(R_L)*** of **50 ohms**, which indicates a measured amplitude ***($V_{L(\mu V)}$)*** of ***100 µV***, or ***40 dBµV***:

$$\left|\frac{B_{(pT)}}{[100]}\right| = 10^6 \frac{\sqrt{\left(1+\frac{[4]}{[50]}\right)^2 + [1.279x10^{-6}]\left(\frac{[500]}{[50]}\right)^2}}{[500] \times [0.4028]} \ (pT/\mu V)$$

$$\frac{B_{(pT)}}{[100]} = [5362.76] \ (pT/\mu V)$$

$$B_{(pT)} = [100] \times [5362.76] \ (pT)$$

$$B_{(pT)} = 536{,}276 \ pT$$

$$B_{(pT)} = 114.59 \ dBpT \quad (20log[pT])$$

NOTE: For this example, the same result can be determined using Equation (1) and the 50Ω antenna conversion factor given in Figure 4.

Measured Value (in dBµV)	+	Antenna Conversion Factor (in dBpT/µV)	=	EQUATION (1) Magnetic Field Strength (in dBpT)
[40.0] dBµV	+	[74.59] dBpT/µV	=	114.59 dBpT

5.2.1 Derivation of Antenna Conversion Factor Equation

The formulae below demonstrates the derivation of *Equation (6)* for determination of the loop antenna conversion factors (ACF).

Equation (6a) was introduced earlier as *Equation (3)*. It is borrowed from basic magnetic loop theory, and establishes the relationship between the physical parameters of the loop antenna, the magnetic flux density present within the loop coil, and the open circuit voltage developed across the loop terminals.

$$e_{i(V)} = 2\pi N A f B_{(T)} \text{ (Volts)}$$ **EQUATION (6a)**

where:

$e_{i(V)}$ = open-circuit loop terminal voltage (in Volts)
N = number of turns in loop coil = **51 turns**
A = area of coil = **0.001257 meters²**
= πr^2, where r = coil radius = 0.02 meters
f = frequency (in Hz)
$B_{(T)}$ = magnetic flux density (in Tesla)

During actual measurements, the antenna terminals are terminated by the input impedance of the measuring instrument **(R_L)**. The measured voltage **(V_L)** is proportional to the impedance of the loop coil **(R_C) + (jX_C)** and **(R_L)**. This relationship is demonstrated in *Equation (6b)*, and then rearranged in *Equation (6c)* and *Equation (6d)*.

$$\frac{e_{i(V)}}{R_L + R_C + jX_C} = \frac{V_{L(V)}}{R_L}$$ **EQUATION (6b)**

where:

$e_{i(V)}$ = open-circuit loop terminal voltage (in Volts)
R_L = load resistance [or input impedance of measurement instrument] (in ohms)
R_C = loop coil resistance = **4Ω**
jX_C = loop coil reactance ($2\pi f L$) (in ohms)
L = inductance of the loop coil = **0.00018 H**
$V_{L(V)}$ = voltage across R_L (in Volts)

$$\frac{e_{i(V)}}{V_{L(V)}} = 1 + \frac{R_C}{R_L} + j\frac{X_C}{R_L}$$ **EQUATION (6c)**

$$\left|\frac{e_{i(V)}}{V_{L(V)}}\right| = \sqrt{\left(1 + \frac{R_C}{R_L}\right)^2 + \left(\frac{X_C}{R_L}\right)^2}$$ **EQUATION (6d)**

In *Equation (6e)*, *Equation (6a)* is integrated to substitute for **(e_i)** in order to solve for **(|B/VL|)**

$$\left|\frac{B_{(T)}}{V_{L(V)}}\right| = \frac{\sqrt{\left(1+\frac{R_C}{R_L}\right)^2 + \left(\frac{X_C}{R_L}\right)^2}}{2\pi f A N} \quad \text{(Tesla per Volt [T/V])}$$

EQUATION (6e)

And finally, in *Equation (6f)*, we multiply by 10^6 in order to convert the units from Tesla/Volt into pT/µV.

$$\left|\frac{B_{(pT)}}{V_{L(\mu V)}}\right| = 10^6 \frac{\sqrt{\left(1+\frac{R_C}{R_L}\right)^2 + \left(\frac{X_C}{R_L}\right)^2}}{2\pi f A N} \quad \text{[pT/µV]}$$

EQUATION (6f)

6.0 Calibration

The only item which requires calibration in the AL-RS101 Loop Antenna Set is the AL-RS101-RX Loop Antenna. The standard SAE ARP958 Rev. D is the applicable calibration standard for this Loop Antenna.

Your AL-RS101 Loop Antenna has been individually calibrated with NIST traceability, and the appropriate data and certificate has been provided. Periodic re-calibration of the AL-RS101-RX is recommended. Calibration intervals is left to your discretion, but should be chosen based on the frequency with which it is used, and/or as allowed for by your internal quality control system (if applicable). Com-Power offers NIST traceable calibration services. Recognized ISO 17025 accredited calibrations are also available.

The following sections describe the basic process for determining/verifying the antenna conversion factors for the antenna.

6.1 Calibration Equipment

During calibration, the current flowing through the transmitting loop must be monitored.

The recommended method for monitoring the current is to measure the voltage drop across a precision 1 ohm resistor placed in series with the drive line of the transmit loop. The supplied **PR10-1E 1Ω (±1%), 10 Watt Precision Resistor Box** is used for this purpose.

Alternatively, a current probe placed around the drive line to the transmitting loop can also be used to monitor the current.

Typical measurement setups for the respective calibration methods are illustrated in *Figure 8* and *Figure 9*.

6.1.1 Source Equipment

The following subsections describe the type of equipment that will be needed in order to perform calibration of the AL-RS101-RX Loop Antenna.

As the current flowing through the transmitting loop antenna is monitored during the calibration, the type of source equipment has no real restriction; only that it be able to supply the desired current.

It is desirable from an efficiency standpoint that the output impedance of the source be as low as possible. The greater the output impedance of the source, the greater the power required to generate the same current.

Some typical examples of signal sources are given below.

- Signal (or function) generator with a power amplifier, such as the Com-Power ARI-300K Audio Power Amplifier.
- Signal (or function) generator with power amplifier and output transformer.
- Signal (or function) generator with transformer
- Signal (or function) generator with current amplifier
- Power sweep generator
- Network analyzer
- Spectrum Analyzer with tracking generator

6.1.2 Measuring Instrument(s)

Any properly functioning, calibrated measuring instrument, or combination of measuring instruments, having the proper input impedance and operational specifications/capabilities for the measurement functions for which it will be employed may be used for the calibration. Typical types of instruments include oscilloscopes, spectrum analyzers, EMI receivers, true rms volt meters, digital multimeters, etc.

6.1.3 Transmitting Loop Antenna

The Com-Power AL-RS101-TX Loop Antenna is the ideal antenna to use as the transmitting loop during the calibration. Other transmitting loops may also be used; however, the calibration-related calculations provided in section 6.2 apply only to calibrations performed using the AL-RS101-TX Loop Antenna.

6.1.4 Precision 1-ohm Series Resistor

This is the **PR10-1E 1Ω (±1%), 10 Watt Precision Resistor Box** included with the AL-RS101 Loop Antenna Set.

(This item is not needed if a current probe is used to monitor the loop current.)

6.1.5 RF Current Probe

Any properly functioning, calibrated current probe having appropriate operational specifications/capabilities for the measurement functions for which it will be employed may be used for the calibration.

(This item is not needed if the loop current is monitored using a precision 1-ohm resistor.)

6.2 Calibration Methodology

The calibration of the AL-RS101-RX antenna is performed by generating a known magnetic field using the AL-RS101-TX Antenna. The calibration is performed with a separation distance of 5 cm between the perpendicular loop antennas, with the centers of the loops aligned along the same axis (coaxially), as shown in *Figure 8* and *Figure 9*.

The SAE ARP958 standard suggests that the calibration be performed with one ampere of current flowing through the loop coil. However, most conventional signal sources are not capable of supplying the loop with one ampere of current without amplification or transformation. Introducing power amplifiers or step down transformers into the setup can distort the signal waveform, thereby complicating the measurement process and increasing measurement uncertainty. ***Therefore, it is recommended that the calibration be performed at a reduced current level, such as 100 mA; so that no amplification or transformation is necessary, and a higher level of measurement accuracy is maintained.***

The flux density of the generated field is calculated using *Equation (8)*:

$$B_{(T)} = \frac{\mu I N r^2}{2\,(r^2 + d^2)^{(3/2)}} \quad \text{(Tesla)}$$

EQUATION (8)

where:

$B_{(T)}$ = magnetic flux density (in Tesla)
$B_{(pT)}$ = magnetic flux density (in picotesla)
μ = permeability of air = $4\pi \times 10^{-7}$ H/m = $\mathbf{1.25664 \times 10^{-6}}$ H/m
I = current through loop coil = **0.1** Amps
N = number of turns in loop coil = **20** turns
r = radius of the loop coil = **0.06** meters
d = separation distance between the Tx and Rx loops = **0.05** meters

$$B_{(T)} = \frac{[1.25664 \times 10^{-6}] \times [0.1] \times [20] \times [0.06]^2}{2\,([0.06]^2 + [0.05]^2)^{(3/2)}} \quad \text{(Tesla)}$$

$$B_{(T)} = \frac{[1.25664 \times 10^{-6}] \times [0.1] \times [20] \times [0.0036]}{2\,([0.0036] + [0.0025])^{(3/2)}} \quad \text{(Tesla)}$$

$$B_{(T)} = \mathbf{9.4955 \times 10^{-6}} \text{ Tesla}$$

$$B_{(pT)} = \mathbf{9.4955 \times 10^{6}} \text{ pT} \quad ([\text{Tesla}] \times 10^{12})$$

$$B_{(pT)} = \mathbf{139.55} \text{ dBpT [for 100 mA Loop Current]} \quad (20\text{Log}[\text{pT}])$$

The difference between the calculated flux density *(in dBpT)* and the measured value *(in dBµV)* on the measuring instrument connected to the AL-RS101-RX Loop Antenna is the measured antenna conversion factor . As long as the measured factor at each calibration frequency is within **±2 dB** of the respective theoretical factor, then the antenna meets the calibration requirements.

Magnetic Flux Density *(in dBpT)* [**139.55** dBpT for 100 mA loop current]	—	***Measured Value from AL-RS101-RX Antenna*** *(in dBµV)*	=	***Measured Antenna Conversion Factor*** *(in dBpT/µV)*	≅	***Theoretical Antenna Conversion Factor*** *(in dBpT/µV)* (± 2 dB)	**EQUATION (9)**

EXAMPLE CALCULATION #6

Using the test arrangement illustrated in either *Figure 8* or *Figure 9*, the measured value on Measuring Instrument #2 *(connected to the AL-RE101-RX Loop Antenna)* at ***30 Hz*** is ***40.52 dBμV*** while 100 mA of current is flowing through the transmit loop coil.

The theoretical, 50 ohm antenna conversion factor for the AL-RS101-RX Loop Antenna (calculated using Equation (5) and Equation (7), and as given in the table shown in *Figure 7* at ***30 Hz*** is ***99.03 dBpT/μV***.

$$\underset{\text{dBpT [for 100 mA loop current]}}{139.55} - \underset{\text{dB}\mu\text{V}}{40.52} = \underset{\text{dBpT}/\mu\text{V}}{99.03} \cong \underset{\text{dBpT}/\mu\text{V} \ (\pm 2\ \text{dB})}{99.03}$$

In this example, the measured antenna conversion factor is within ±2 dB of the theoretical antenna conversion factor at 30 Hz. Therefore, the antenna meets the calibration requirement at 30 Hz.

6.3 Calibration Process

Step 1) Configure the equipment as shown in either *Figure 8* or *Figure 9*, depending on the method employed for monitoring the loop current.

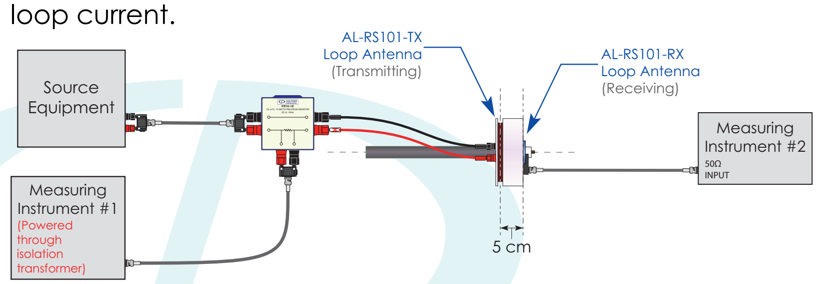

FIGURE 8 - *Typical Measurement Setup for Calibration (1Ω Resistor Method)*

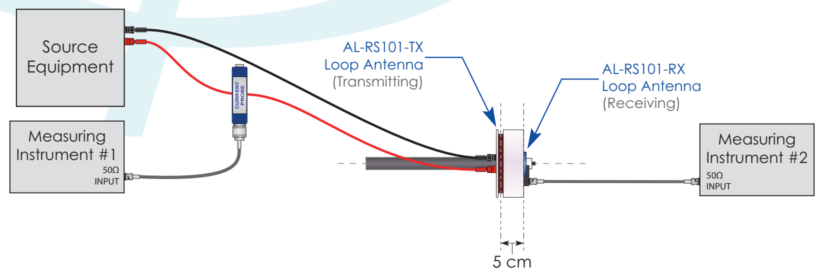

FIGURE 9 - *Typical Measurement Setup for Calibration (Current Probe Method)*

Step 2) Set the source equipment frequency to 10 Hz.

Step 3) Adjust the amplitude of the source equipment until the measured value on Measuring Instrument #1 indicates that the desired current level is reached (*i.e. 100 mA*).

Step 4) Record the voltage value *[in dBµV]* measured on Measuring Instrument #2 connected to the AL-RS101-RX Loop Antenna.

Step 5) Subtract the voltage value *[in dBµV]* measured in Step 4 from the flux density value *[in dBpT]* calculated using Equation 8 for the loop current value reached in Step 3. ***The resultant value is the measured antenna conversion factor.***

Magnetic Flux Density *(in dBpT)* [**139.55** for for 100 mA loop current] − ***Measured Value from AL-RS101-RX Antenna*** *(in dBµV)* = ***Measured Antenna Conversion Factor*** *(in dBpT/µV)* ≅ ***Theoretical Antenna Conversion Factor*** *(in dBpT/µV)* (± 2 dB)

If the measured antenna conversion factor is within ±2 dB of the theoretical antenna conversion factor calculated using Equations 5 and 7, or given in the *Figure 7* table for the present frequency, the antenna meets the calibration requirements for the present frequency.

Step 6) Repeat Step 3 through Step 5 for each calibration frequency.

6.4 Interpretation of Standards (Measured vs Theoretical Factor)

Section 4.3.11.2 of the MIL-STD-461G standard states the following:

"Factors for test antennas shall be determined in accordance with SAE ARP958".

Section 6 of the SAE ARP958 Rev. D (1999-03) standard contains the calibration procedures, associated calculations and theoretical antenna conversion factor tables for the three (3) loop antennas specified by MIL-STD-461 for the RE101 and RS101 tests.

Below are (2) excerpts from the above-referenced ***SAE ARP958*** standard:

(1) " 6.1 Operating Theory:

This test method is not meant to experimentally determine the magnetic fields. In most cases, for a controlled situation like this, they can be more accurately calculated than measured. This method is to set up a standard by which it can be determined that the antennas are functioning correctly. Thus, a failure such as a cold solder joint, broken wire, etc. can be detected."

And, from section 6.2 (Calibration):

(2) " The loop antenna shall be considered to be calibrated when the levels have been compared to the values of Table 1 and found to be within ±2 dB of those values."

Based on the above, it could be interpreted that the purpose of calibration is NOT to determine the actual antenna conversion factors; but only to validate that the antenna is functioning correctly, and that the theoretical factors are to be used in practice, rather than the measured factors.

Or, it could also be interpreted that the factors determined through calibration measurements are to be used in practice, as long as they are within ±2 dB of the theoretical factors.

Com-Power provides the AL-RE101 Loop Antenna individually calibrated as per the procedures described in the SAE ARP958 standard. The acceptance criteria employed dictates that the antenna conversion factors determined during the calibration shall be within ±2 dB of the calculated, theoretical factors.

Both sets of factors are provided; and it is left to the discretion of the user whether the theoretical, calculated factors, or the factors determined through calibration measurements are used in practice.

7.0 Warranty

Com-Power warrants to its Customers that the products it manufactures will be free from defects in materials and workmanship for a period of three (3) years. This warranty shall not apply to:

- Transport damages during shipment from your plant.
- Damages due to poor packaging.
- Products operated outside their specifications.
- Products Improperly maintained or modified.
- Consumable items such as fuses, power cords, cables, etc.
- Normal wear
- Calibration
- Products shipped outside the United States without the prior knowlege of Com-Power.

In addition, Com-Power shall not be obliged to provide service under this warranty to repair damage resulting from attempts to install, repair, service or modify the instrument by personnel other than Com-Power service representatives.

Under no circumstances does Com-Power recognize or assume liability for any loss, damage or expense arising, either directly or indirectly, from the use or handling of this product, or any inability to use this product separately or in combination with any other equipment.

When requesting warranty services, it is recommended that the original packaging material be used for shipping. Damage due to improper packaging will void warranty.

In the case of repair or complaint, Please visit our website www.com-power.com and fill out the service request form (http://com-power.com/repairservicereq.asp). Our technical assistance personnel will contact you with an RMA number. The RMA number should be displayed in a prominent location on the packaging and on the product, along with a description of the problem, and your contact information.

8.0 Maintenance

This product contains no user serviceable parts. If the unit does not operate or needs calibration, please contact Com-Power Corporation. Any modifications or repairs performed on the unit by someone other than an authorized factory trained technician will void warranty.

The exterior surface may be cleaned with mild detergent and then be wiped with a dry, clean, lint-free cloth. Use care to avoid liquids or other foreign objects entering the chassis.

9.0 Typical Performance Data