LR-710

LOW RESISTANCE RANGE UNIT
USER'S MANUAL

Linear Research Inc

LR-710

LOW RANGE RESISTANCE UNIT

VERSION 2.0

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LR-710 OVERVIEW

The LR-710 Low Range Unit is a x10 Current Amplifier that can be used with the LR-700 to allow the system to measure lower full scale resistance ranges than the LR-700 can achieve on its own. The unit has two modes of operation. One is an LR-700 DIRECT mode that is transparent to the LR-700 Bridge and acts as if the low range unit is not there. It has a second LR-710 ACTIVE mode that magnifies the output current by 10 and delivers the x10 current to the sensor.

Although the current is increased by a factor of 10, the input voltage to the LR-700 cannot be changed, and so, the LR-700 still has its nominal full scale excitation voltage. For example, if the 60 microvolt excitation is selected, the x10 current amplification passing through your sensor must generate a full scale voltage coming in to the bridge of not more than 60 microvolts full scale.

The LR-710 Low Range Unit current booster may be used in conjunction with an LR-720 multiplexer to allow multiple sensors to be measured individually under selection of the IEEE-488, or by front panel selection from the LR-700.

The LR-710 is manually controlled. None of its controls can be affected by the LR-700 Bridge nor by either of the computer interfaces.

When using the LR-710 Low Range Unit in the LR-710 ACTIVE mode, you will need to interpret the readings presented on the front panel of the LR-700 or over the computer interface, to account for the x10 current amplification.

VOLTAGE SENSE LEADS

As shown in Figure 1, the block diagram of the LR-710, the voltage sense leads, V-HI/V-LO, pass directly through the LR-710 from the LR-700 to the sensor. Thus, the voltage span for all full scale LR-700 readings is as indicated on the LR-700 front panel by the selected excitation voltage.

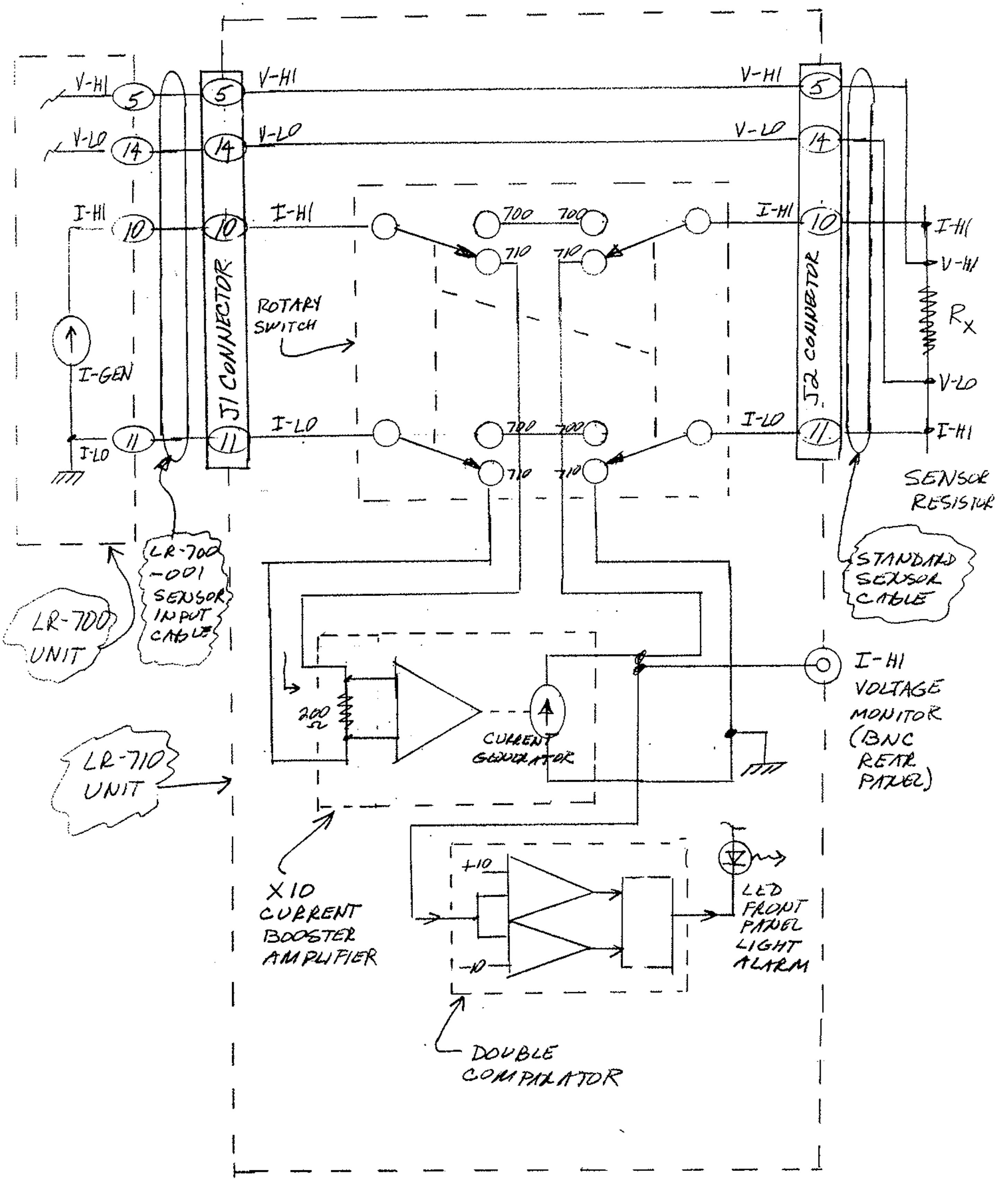


FIGURE 1

LR-710 BLOCK DIAGRAM

CURRENT EXCITATION

LR-700 DIRECT MODE

In the direct mode, the LR-710 front panel three position rotary switch is placed in the "LR-700 Direct" position. This allows the LR-710 unit to be fully transparent sending the LR-700 excitation current, arriving at J1, directly to the sensor via the LR-710's sensor output connector J2. This mode is labeled "700" in the block diagram.

LR-710 HIGH CURRENT MODE

In the high current/low resistance mode, the rotary switch is placed in the "LR-710 ACTIVE" position. This delivers the LR-700's excitation current to the LR-710's x10 current amplifier. The amplified current is then sent to the LR-710's sensor output connector, J2. This mode is labeled "710" in the block diagram.

NO-EXCITATION MODE

The position at the front panel rotary switch is labelled "NO EXCITATION". This position was chosen to isolate the switch circuitry. Thus, the x10 current amplifier circuitry can not possibly interact, feedback, or damage the LR-700's circuitry during rotary switch position changes. This is a non-operating mode. The rotary switch, however, may be left in this mode indefinitely without damage to the units. For simplicity, this mode is not shown in the block diagram.

LR-710 CURRENT BOOSTER GENERATES 100ma AND 300ma

CURRENT BOOSTER

In the LR-710's x10 current booster circuitry, the LR-700's excitation current selected is delivered to the 200 ohm resistor shown. The resulting voltage drives the voltage to current power amplifier (x10 current booster). It has an amplifier transfer function admittance of 0.05 Siemens. Thus, an input current of 30ma rms yields a voltage at the 200Ω resistor of 6 volts rms which is then transferred into an output current of (6 volts rms) X (.05 Siemens) = 300ma rms.

COMPLIANCE VOLTAGE

The compliance voltage of the LR-710's x10 current booster output stage is about ±12 VDC. The current output stage goes into saturation and/or clipping if this compliance voltage limit is reached, and the measured value of sensor resistance will be invalid. Thus, to alert the user about this condition, a double comparator, to monitor the I-HI output line, is included that turns on a front panel LED when a conservative threshold of ±10 VDC is exceeded. This threshold will be reached when line resistance in the excitation current path is too large. See Figure 2 for maximum line resistance allowed when using the low ranges. A rear panel BNC connector test point, shown in the block diagram, is provided so that the I-HI's output voltage may be monitored, by an oscilloscope, to see how close the output signal approaches the ±10 VDC compliance voltage threshold. Monitoring the peak to peak voltage at this point, with a scope, gives an approximate value of round trip line resistance plus round trip sensor contact resistance in the current path.

MAXIMUM ROUND TRIP LINE RESISTANCE
ALLOWED IN THE I-HI/I-LO LEADS

LR-710 EXCITATION CURRENT	MAXIMUM I-HI PLUS I-LO LINE RESISTANCE ALLOWED
300ma	20 OHMS
100ma	60 OHMS

FIGURE 2

Notes:
1. Line resistance also includes I-HI and I-LO contact resistance at the sensor.
2. LRI sensor cables supplied with the units have about 1 ohm of round trip resistance for each I and V pair.

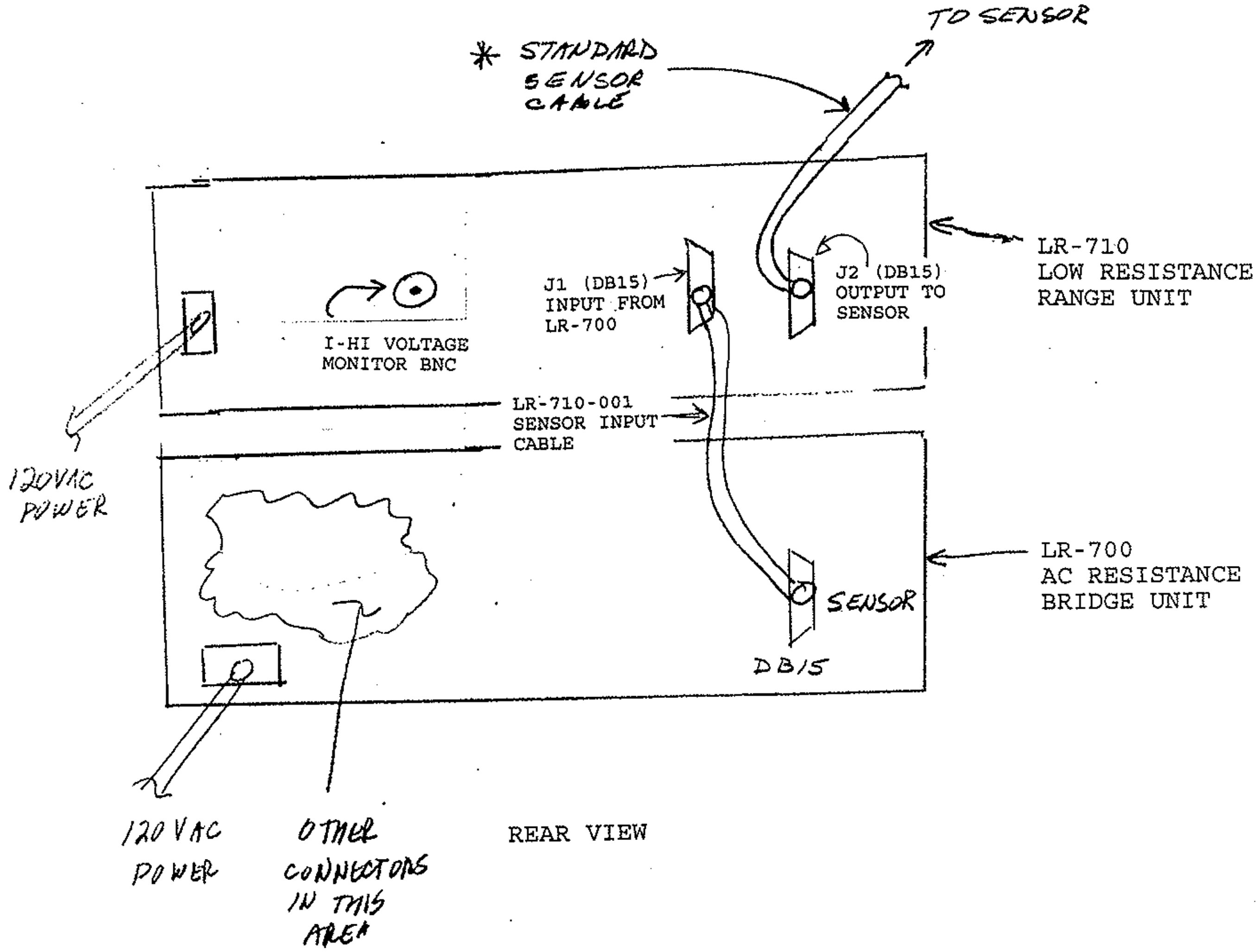
LR-700 READOUT IS 10 TIMES LARGER THAN ACTUAL VALUES

In the "LR-710 ACTIVE" mode, the full scale range of the LR-700/LR-710 combination is, as expected, changed by the x10 output current boost in the LR-710. <u>When using LR-710 low ranges, all readings of the LR-700 appear to be 10 times larger than the actual sensor range and the actual sensor resistance measured.</u> The LR-700's R, ΔR, 10ΔR, R-set, X, ΔX, 10ΔX, and X-set all read-out ten times larger than the actual sensor resistance. When using the computer interface, keep in mind that this factor of 10 must be accounted for when programming set resistance and receiving data.
EXAMPLE: When the LR-700 is set to 2mΩ/60μV (30mA) and 10ΔR=+000.078μΩ is the display (i.e. 78 nano ohms), the resistance being measure is actual +7.8 nano-ohms not +78 nano-ohms.

UNIT TO UNIT HOOK-UP INTERFACING

Figure 3A shows the unit to unit interface cabling setup for measuring a single sensor using the LR-700 Resistance Bridge driving the LR-710 Low Range Unit (LR-700/LR-710).

Figure 3B shows the unit to unit interface cabling setup for multiple sensors using the LR-720-8, 8 Sensor Multiplexer, driven by the LR-710 (LR-700/LR-710/LR-720). This set up can measure up to eight individual sensors under IEEE-488 control.

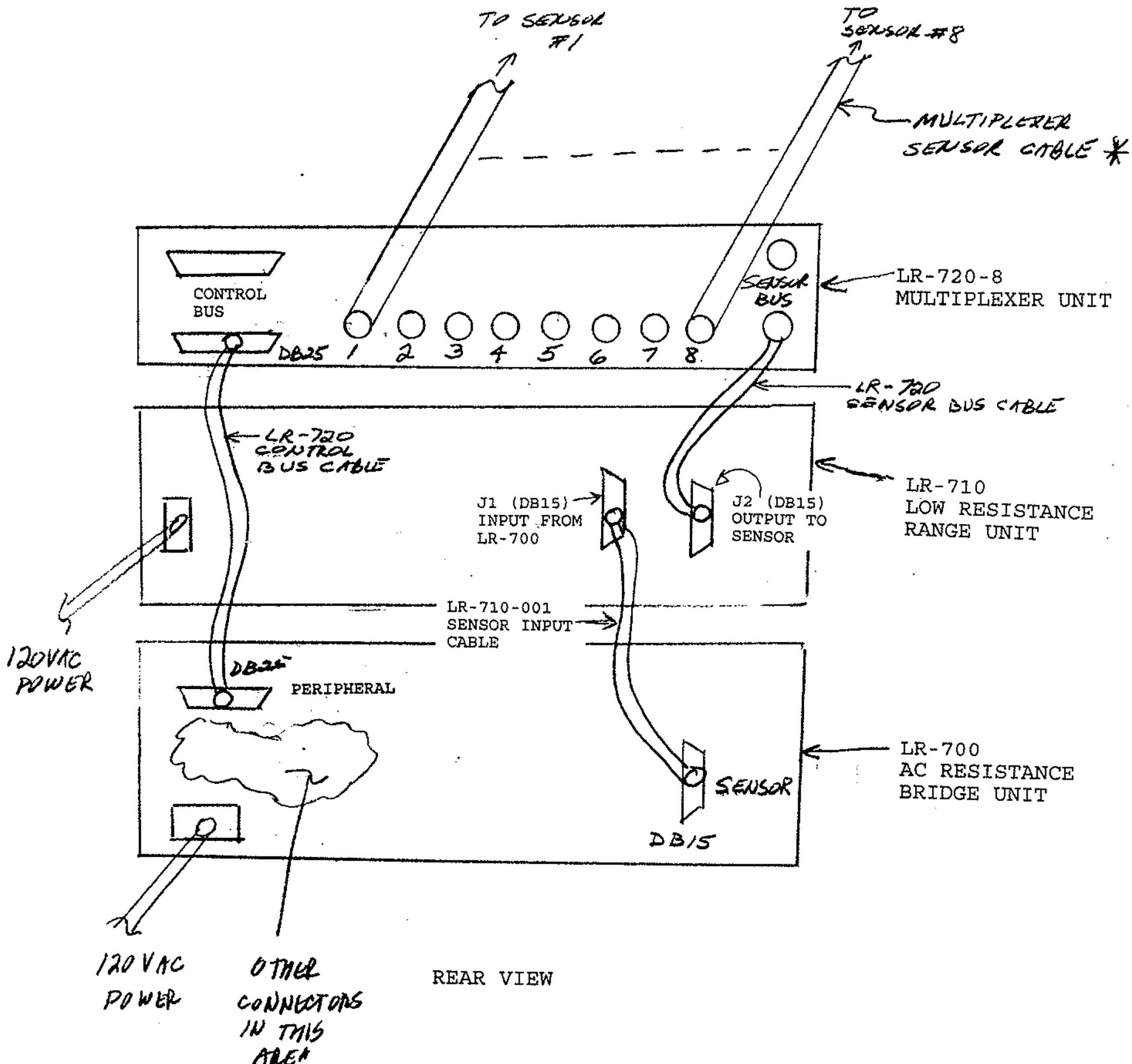


NOTES:

* SEE FIGURES 3.2 & 3.3 IN THE LR-700 USER'S MANUAL FOR STANDARD SENSOR CABLE SCHEMATIC.

I-HI = CLEAR } BLACK BANDS ON CABLE
I-LO = BLACK }
V-HI = CLEAR
V-LO = BLACK
BLACK WIRE = CHASSIS

FIGURE 3A
UNIT TO UNIT INTERFACE CABLING
SINGLE SENSOR (LR-700/LR-710)



NOTES:

SEE ALSO FIGURE 3.14
LR-720 MULTIPLEXER
HOOK-UP IN THE LR-700
USER'S MANUAL

* SENSOR CABLE ENDS:

I-HI = CLEAR } BLACK BANDS
I-LO = BLACK } ON CABLE

V-HI = CLEAR
V-LO = BLACK
BLACK WIRE = CHASSIS

FIGURE 3B
UNIT TO UNIT INTERFACE CABLING
MULTIPLE SENSORS (LR-700/LR-710/LR-720-8)

REQUIRED LR-700 SETTINGS FOR LOW RESISTANCE OPERATION

Figure 4, shows the required LR-700 settings of resistance range and excitation voltage to achieve the actual LR-710 low resistance ranges.

For nano-ohms sensors, the 200μΩ/300ma and 200μΩ/100ma actual ranges will no doubt be the most useful, but the other actual ranges achievable are also listed for possible use (i.e. 2mΩ, 20mΩ, and 200mΩ).

REQUIRED LR-700 SETTINGS TO ACHIEVE
LR-710 ACTUAL LOW RESISTANCE RANGES

LR-710 LOW RANGES			
EXCITATION CURRENT	ACTUAL RANGE	REQUIRED LR-700 SETTINGS	
		RANGE	EXCITATION
300ma	200μΩ	2mΩ	60μV
	2mΩ	20mΩ	600μV
	20mΩ	200mΩ	6mV
100ma	200μΩ	2mΩ	20μV
	2mΩ	20mΩ	200μV
	20mΩ	200mΩ	2mV
	200mΩ	2Ω	20mV
All LR-700 display readings read 10 10 times larger than actual values			

FIGURE 4

SPAN CALIBRATION FOR THE LR-710 LOW RESISTANCE RANGES

The LR-710 unit has a front panel ten turn control with a locking three digit dial labeled "SPAN CALIBRATION". This is used to calibrate the full scale span of the seven actual low range/excitation combinations. This control accomplishes span variation by slightly changing the gain of the x10 current amplifier.

Figure 5 shows the calibration dial settings for the LR-710's low resistance ranges for your unit.

Changing the span dial from 000 to 999 counts (1,000 counts total) will change the LR-710's span by 1.8% total (18 parts in 1,000) of full scale.

Expected span error, if you leave the dial permanently set to the 200μΩ/300ma value listed below, this will yield a maximum error of less than 1pp 1,000 when in any other low resistance range listed.

The span calibration dial has no effect upon the zero calibration setting of the system. Zero calibration is stored in the LR-700 micro-controller's memory and can only be changed at LRI.

CALIBRATION DIAL SETTINGS
LR-710 LOW RESISTANCE RANGES

LR-710 SPAN CALIBRATION		
EXCITATION CURRENT	ACTUAL RANGE	LR-710 SPAN CALIBRATION DIAL SETTING
300ma	200μΩ	
	2mΩ	
	20mΩ	
100ma	200μΩ	
	2mΩ	
	20mΩ	
	200mΩ	

FIGURE 5

COMMON MODE REJECTION OF SENSOR LINE OR CONTACT RESISTANCE

Figure 6 shows common mode zero offset errors due to line resistance. Figure 7 shows common mode span errors (including the effect of zero offset) due to line resistance. Readings are with digital filter = 30 seconds, and R-set = X-set = zero.

Large values of the 10ΔX (quadrature) readings shown for the multiplexer configuration (LR-700/LR-710/LR-720-8) are believed to be due to the large loop area of I-HI/I-LO and V-HI/V-LO printed circuit traces in the multiplexer unit's circuit board, and cannot be reduced. The current excitation circuit trace loop couples (magnetically transformer action) a quadrature signal into the voltage balancing input leads, giving rise to the relatively large 10ΔX readings shown.

To minimize this quadrature (10ΔX) coupling effect inside your experimental cryostat Dewar, if possible, twist together the I-HI and I-LO lines and also twist together the V-HI and V-LO lines. try to keep as much spacing as possible between the I and V pairs.

COMMON MODE ZERO OFFSET ERRORS DUE TO LINE RESISTANCE

LR-710 ACTUAL RANGE	LINE RESISTANCE ADDED IN EACH OF THE 4 LINES	MEASURED CHANGE IN 10ΔR READING (TYPICAL)	I-HI VOLTAGE MONITOR TEST POINT
200μΩ 300ma	3 OHMS	LESS THAN 1 NANO-OHMS	APPROX. 6 VOLTS pp
200μΩ 100ma	9Ω IN EACH OF THE 4 LINES (18Ω TOTAL IN I LINES)	-5 NANO-OHMS	APPROX. 19 VOLTS pp

SENSOR = TRUE ZERO

FIGURE 6

As shown above, equivalent common mode rejection ratio for line resistance is better than 180db (greater than 1 part in 10^9).

COMMON MODE RESISTANCE SPAN ERRORS DUE TO LINE RESISTANCE

LR-710 ACTUAL RANGE	LINE RESISTANCE ADDED IN EACH OF THE 4 LINES	MEASURED CHANGE IN 10ΔR READING (TYPICAL)	I-HI VOLTAGE MONITOR TEST POINT
200μΩ 300ma	3 OHMS	-1 NANO-OHMS	APPROX. 6 VOLTS pp

SENSOR = 10 MICRO-OHMS
R-SET = R

FIGURE 7

Note that the 10μΩ sensor's resistance is 5% of the full scale span of the 200μΩ range.

ZERO OFFSET CORRECTION OF USERS SENSOR CONFIGURATION

Figure 8 shows zero offset readings measured with a true zero sensor. A zero offset reading of +7.8 nano-ohms is shown with a true zero ohm sensor at the end of the standard sensor cable supplied. This table also shows offset value from 2.3 to 8.5 nano-ohms measured with the multiplexer. Accordingly, the user must measure his setup's true-zero offset readings before proceeding with a live sensor if valid true-zero reading corrections of his sensor are important. If only relative changes in zero ohm sensors are required, the set-up's true-zero offset readings can be ignored.

Zero correction can be done by placing a true-zero configuration in place of the live sensor. This must be done in the actual experimental sensor space in the exact place that a live sensor will reside and not at the top of the Dewar. Record this true-zero reading and then connect all live sensors to the sensor leads. Then, subtract the true zero reading above, recorded from the actual experimental live sensor's reading, to get the true corrected reading.

Under IEEE-488 control, zero offset correction can be done by holding the measured true-zero reading in the computer memory and doing a software subtraction. When using the multiplexer, with up to 8 sensors each, <u>all</u> such active sensor ports with their individual sensor cables must first have their experimental space sensors replaced with true-zero sensors and then pre-measured.

All true-zero readings thus measured should be stable with time and temperature as long as the cable lead-ins down into the Dewar remain mechanically unchanged.

TYPICAL ZERO OFFSET READINGS WITH A TRUE ZERO SENSOR

EXCITATION CURRENT	ACTUAL RANGE	LR-700/LR-710		LR-700/LR-710/LR-720-8	
		10ΔR	10ΔX	10ΔR	10ΔX
300ma	200μΩ	+78	+67	-23	+017273
	2mΩ	+69	+38	-85	+017131
	20mΩ	+04	+07	-04	+1726
100ma	200μΩ	+04	+08	-05	+1719
	2mΩ	-02	+00	-02	+173
	20mΩ	-02	+00	-03	+172
	200mΩ	-02	+00	-02	+017

FIGURE 8

1. The LR-720-8 multiplexer used sensor port number 01.
2. Shown above are the least significant digits on the LR-700's 10ΔR or 10ΔX display without decimal points or ohm range suffixes. For the 200μΩ/300ma true range above, the "+78" shown means +7.8 nano-ohms true resistance. Suffixes, then, for the ranges are: 200μΩ = x.x nano-ohms, 2mΩ = xx nano-ohms, 20mΩ = 0.0xx micro-ohms, and 200mΩ = 0.xx micro-ohms. "xx" represents the appropriate digits shown in the above table.
3. Note the low values of 10ΔX for the LR-700/LR-710 configuration.
4. Large values of 10ΔX in the LR-720-8 configuration are discussed in the text.

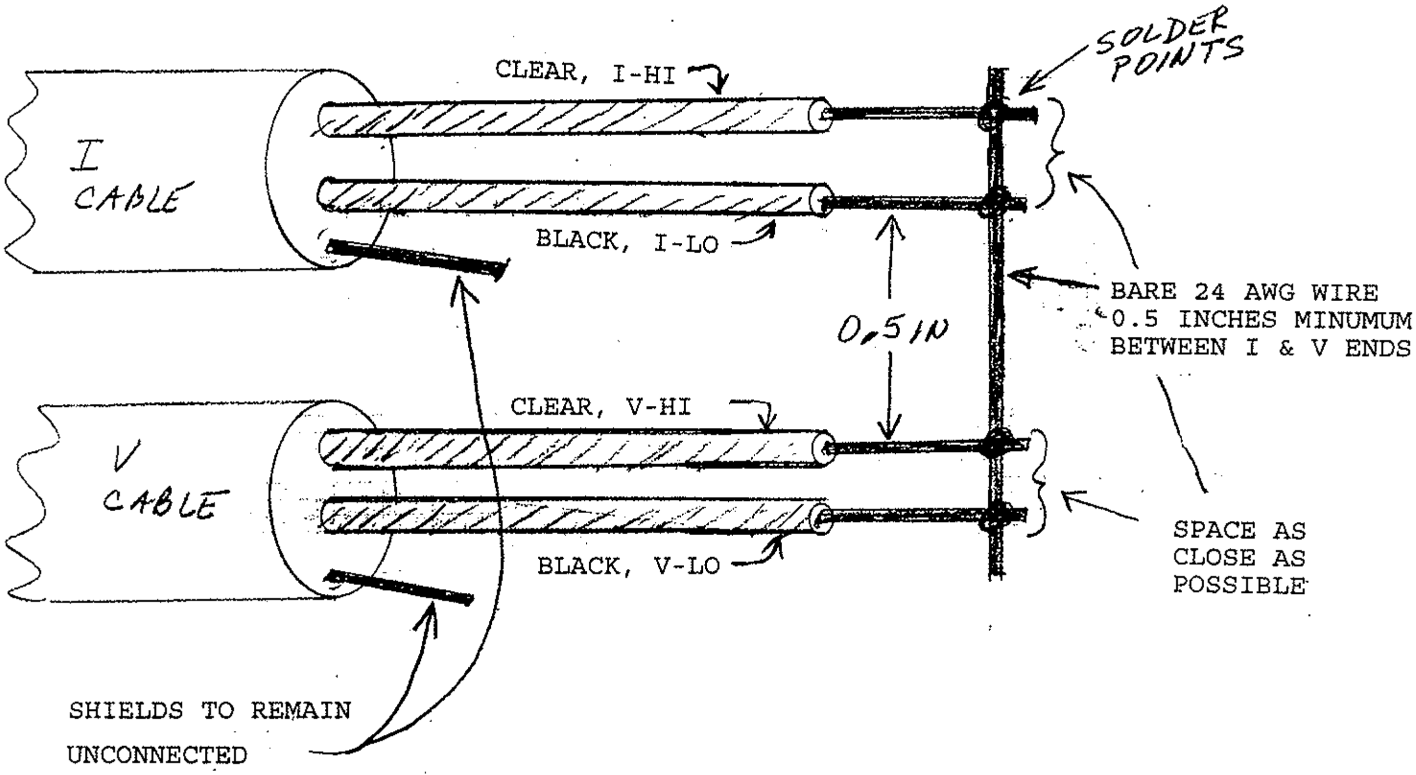
TRUE ZERO SENSOR

Figure 9 shows the true-zero ohm sensor used in bench-top operation at the end of the sensor cable. The operator should use a similar technique in the experimental low temperature area for zero offset correction.

To make the true-zero simulated sensor: (1) complete the current path with a short: (2) place a short across the V leads; (3) connect the V leads to I common mode sensor voltage so that there is a ground return path for the pre-amp; and (4) solder it as shown in Figure 9.

The sensor then is built in a way that doesn't couple <u>any</u> differential voltage generated by the I leads into the V leads. The V-LO to V-HI differential voltage is always zero, as would be the case with a true zero sensor.

FIGURE 9
TRUE - ZERO OHM SENSOR SIMULATION



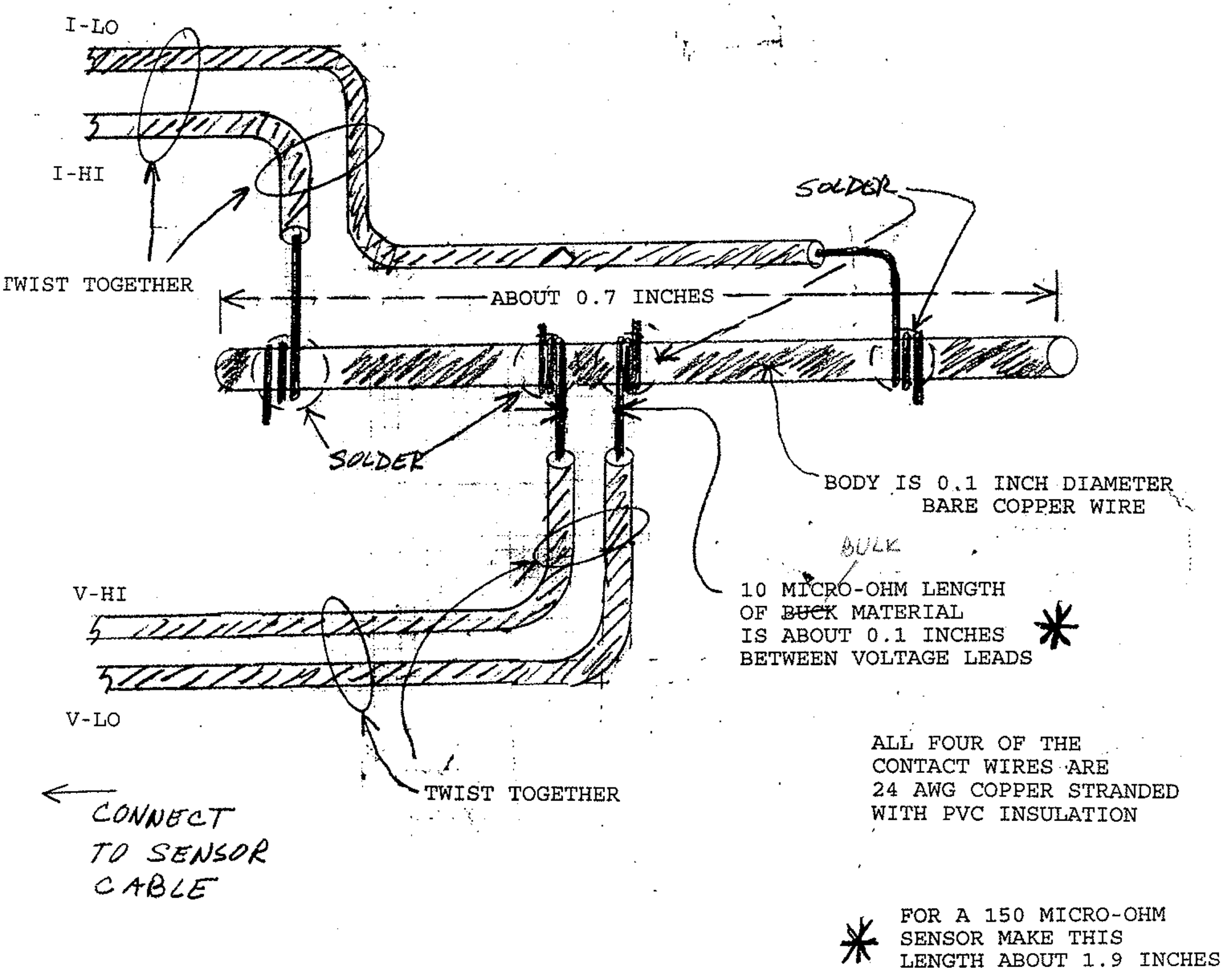
10 MICRO-OHM SENSOR

Figure 10 shows a 10$\mu\Omega$ sensor. This 10$\mu\Omega$ 4- wire sensor was made with a 0.1 inch diameter copper wire body with I and V leads of 24AWG copper wire wrapped around the body. It was placed at the bottom of the Dewar and then the Dewar was filled with ice cubes. Finally, the Dewar was fully filled with pre-chilled ice water.

The sensor was immersed in a constant temperature ice water bath to hold its resistance at a fixed value. The bath was held in a 2 liter stainless steel "thermos bottle" type Dewar.

10 micro-ohms is the lowest resistance value for a 4-wire non-superconductor sensor that can be physically constructed by LRI. Keep in mind that sensor excitation frequency is 16 Hertz sinewave with a resultant skin effect penetration depth of approximately 0.16 inches. Thus, sensor dimensions pertaining to thickness (as opposed to length) should be kept below this penetration depth, or skin effect value, if the user builds his own reference/test sensors.

FIGURE 10
TEN MICRO-OHM 4-WIRE SENSOR



NOISE RESOLUTION RECORDING

Figure 12 shows the 10μΩ short time noise performance with a 10μΩ sensor in an ice bath with the LR-700/LR-710 set-up on the 200μΩ/300ma range. Performance with the multiplexer should be the same. As in Figure 11, the recorder was driven by the LR-700's DAC output. Mode = 10ΔR, Digital filter = 60 seconds, R-set = +009328 (i.e. 9.328μΩ). Note, as expected, for an R-set step change of 10 nano-ohms, the system responded with a straight line ramp function and settled exactly in 60 seconds. This response is an improvement compared to an R-C type analog 60 second filter function that would take hundreds of seconds to settle.

Note: Short time peak to peak noise shown is about one nano-ohm.

ZERO DRIFT RECORDING

Figure 11 shows the true-zero long-time sensor drift of the LR-700/LR-710/LR-720-8 multiplexer set up with: Sensor = true zero, R-set = X-set = zero, Mode = 10ΔR, Actual Range =200μΩ/300ma, and Digital Filter = 30 seconds. The LR-700's digital to analog output (DAC output) directly drove the strip chart recorder. This figure shows that the change in output, when measuring a true-zero sensor, has a trend line change of less than 1 nano-ohm in 16 hours. Peak to peak noise is about one nano-ohm. Note however, that the LR-700 system will typically readout a finite offset value of between 0±10 nano-ohms for a true-zero sensor, as was shown in Figure 8.

SPAN DRIFT RECORDING

Figure 13 shows a 24 hour span drift test for the 10μΩ sensor with the LR-700/LR-710 configuration on the 200μΩ/300ma range. Digital filter = 60 sec. The LR-700/LR-710/LR-720 multiplexer configuration should give similar results.

The 24 hour span drift value shown of 7.8 nano-ohms in the 9,320 nano-ohm sensor is one part in 1,195. If one assumes that the ice bath temperature was not constant but warmed up by 209 milli-Celsius in 24 hours (8.7mC/hr), and if one considers the sensor's copper temperature coefficient of 4pp 1,000 of resistance per Celsius, then the foregoing would account entirely for the span drift's magnitude and direction of increase as shown in Figure 13.

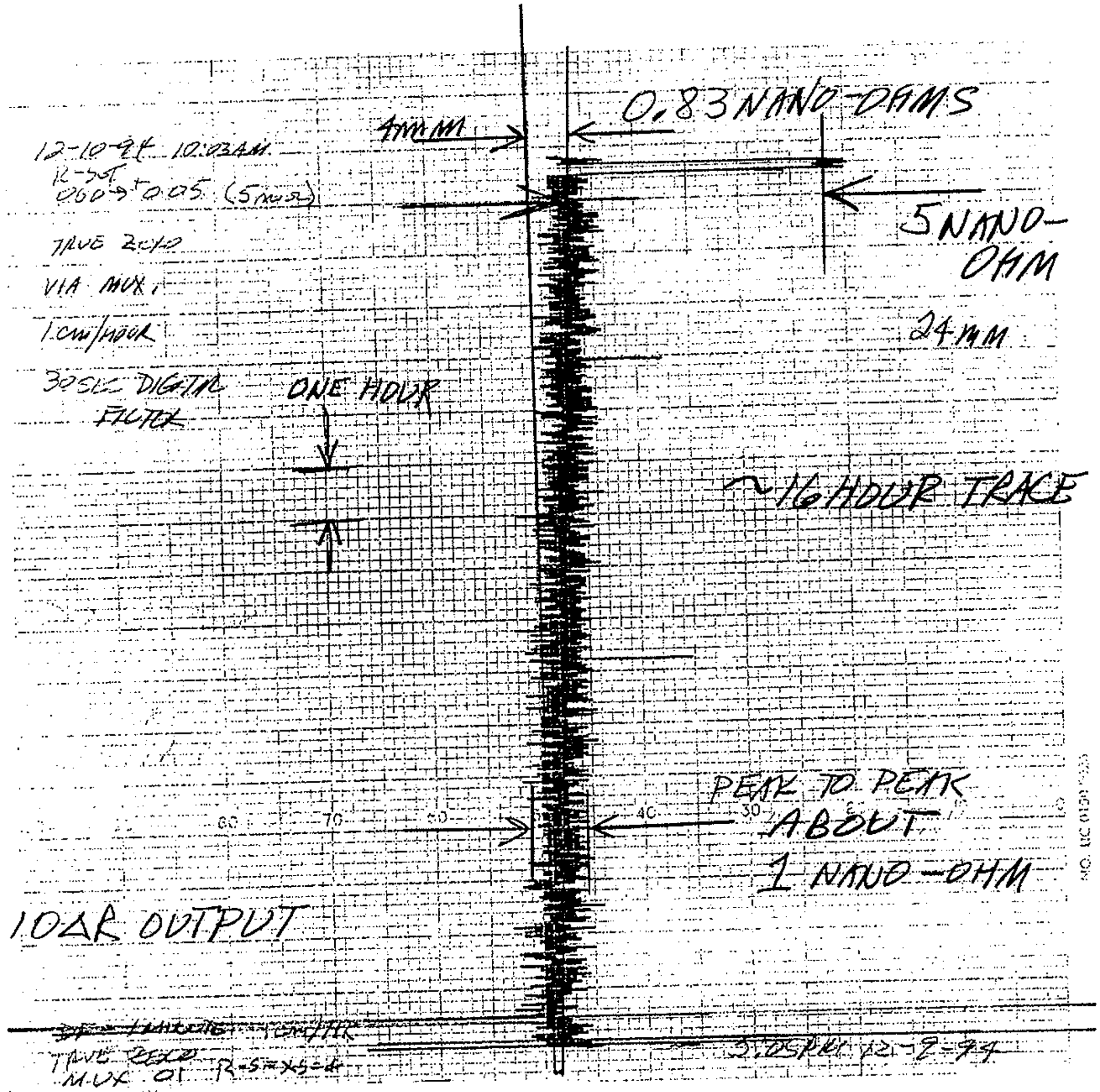


FIGURE 11
LONG TIME TRUE-ZERO SENSOR DRIFT

LR-700/LR-710/LR-720-8
200$\mu\Omega$/300ma RANGE
30 SEC DIGITAL FILTER

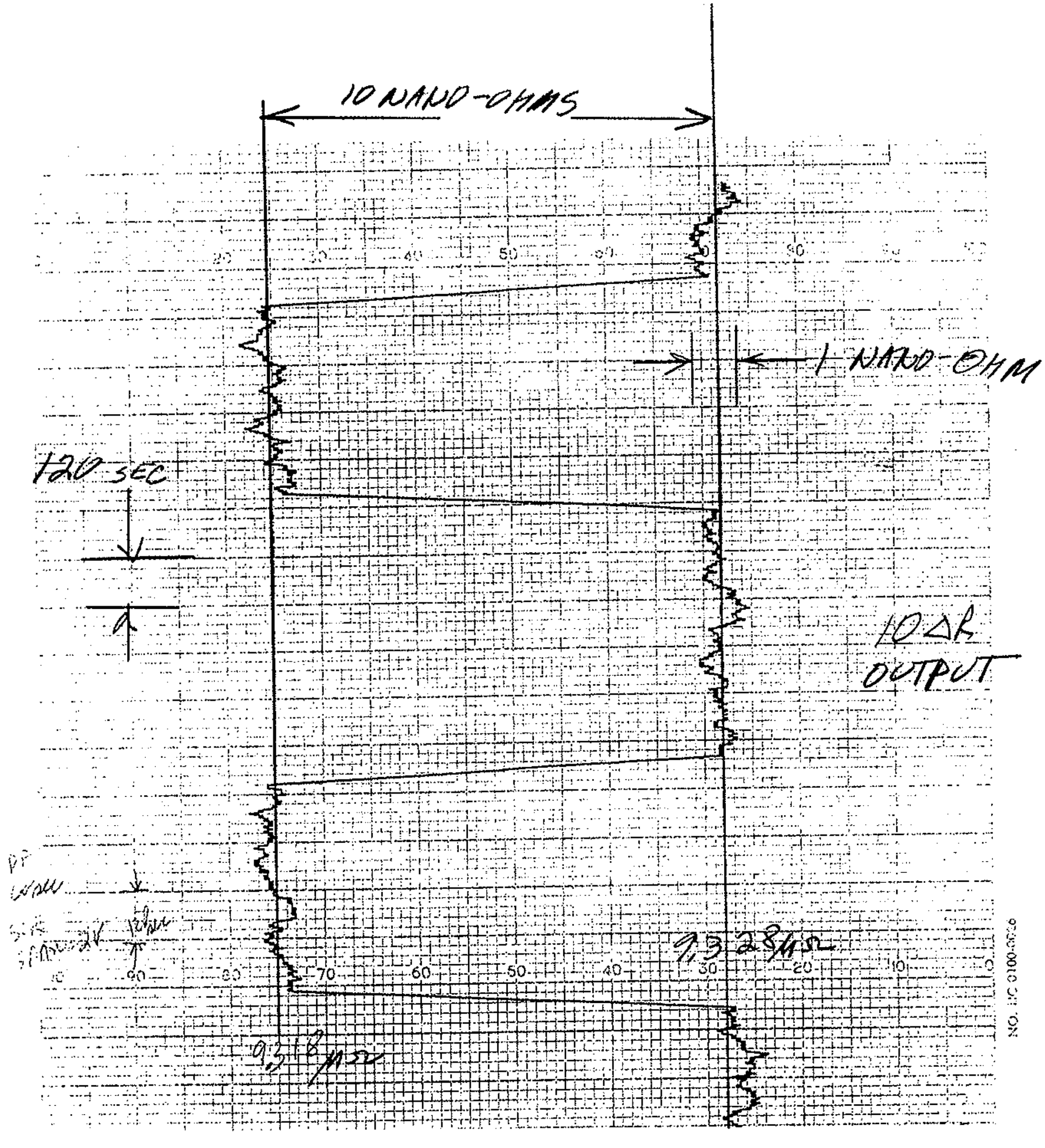


FIGURE 12
10 MICRO-OHM SHORT TIME
NOISE PERFORMANCE

200μΩ/300ma TRUE RANGE
R-SET = 9.318μΩ
DIGITAL FILTER = 60 SEC

FIGURE 13
24 HOUR SPAN DRIFT FOR A
10 MICRO-OHM SENSOR

LR-700/LR-710
200μΩ/300 ma RANGE
60 SEC DIGITAL FILTER