LR-740

PICOAMP EXCITATION UNIT USER'S MANUAL

Linear Research Inc

LR-740-116

WITH LR-700PTC-466

2-1-05

LR-740
PICOAMP EXCITATION UNIT

USER'S GUIDE
VERSION 1.0

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SPECIFICATIONS
LR-740
PICOAMP EXCITATION UNIT

OVERVIEW
The LR-740 Picoamp Excitation Unit enables an LR-700 AC Resistance Bridge to measure a sensor with 6 new lower excitation currents. The new excitation currents are selectable from 1 picoamp to 300 picoamps in 1,3,10 steps.

A selected LR-700 excitation current is delivered to the input of the LR-740 current generator circuitry which then reduces it by 10^5 and delivers it as the new excitation current.

EXCITATION CURRENTS
1pA, 3pA, 10pA, 30pA, 100pA, and 300pA. Constant amplitude AC current to excite the sensor. The LR-700's variable Excitation Option allows each setting to be varied 5-100%.

Excitation picoamps	LR-700 Settings		Power @100KΩ
	Range	Excitation	
1	200Ω	20μV	10^{-19} W
3	200Ω	60μV	10^{-18}W
10	20Ω	20μV	10^{-17}W
30	20Ω	60μV	10^{-16}W
100	2Ω	20μV	10^{-15}W
300	2Ω	60μV	10^{-14}W

EXCITATION VOLTAGES
20nV,60nV, 200nV, 600nV, 2μV, 6μV RMS at full scale of resistance. The LR-700's Variable Excitation Option allows each setting to be varied 5-100%.

RANGES
Useful ranges of 0-20KΩ, 0-200KΩ, and 0-2MΩ.

SYSTEM NOISE PERFORMANCE
Tests made with a low noise sensor yields an outstanding resolution of 80pp10^6 for a 100KΩ sensor and 100 picoamps excitation. This spec is substantially better than other commercially available products.

DC CURRENT ELIMINATION
Eliminates the 0±100pA DC current that is generated by the LR-700's pre-amp.

LRI'S LOCK-BALANCE™ CIRCUITRY
Makes full use of LRI's proprietary Lock-Balance™ circuitry.

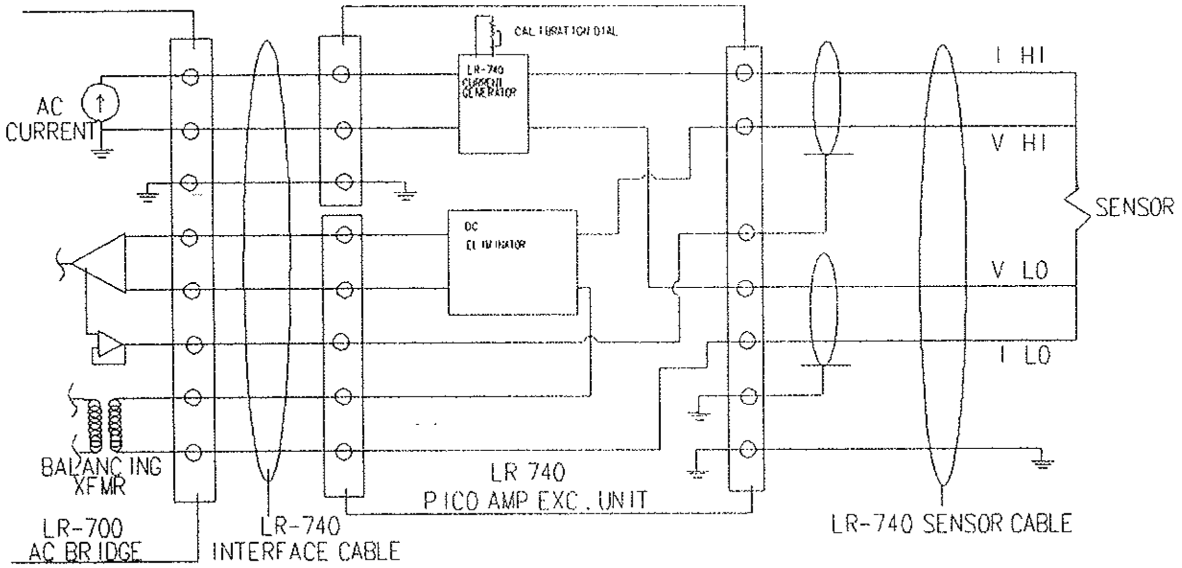
SPAN TRIM
Allows for elimination of span errors generated by variations in the combination of the LR-740/LR-700. The LR-700's calibration values are only accurate when this span trim is set correctly.

CABLES
A 0.5 meter interfacing cable is provided to connect to the LR-700. Uses the LR-700's Standard Sensor Cable.

OVERVIEW

The LR-740 Picocamp Excitation Unit enables an LR-700 AC Resistance Bridge to measure a sensor with 6 new lower excitation currents. The new excitation currents are selectable from 1 picoamp (pa) to 300pa in 1,3,10 steps.

Figure 1 shows a simplified schematic of the LR-700 and LR-740 setup. As shown, a selected LR-700 excitation current is delivered to the input of the LR-740 current generator circuitry which then generates an output current to the sensor.



LR-740 SIMPLIFIED SCHEMATIC

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FIGURE 1

LRI'S LOCK-BALANCE™ CIRCUITRY

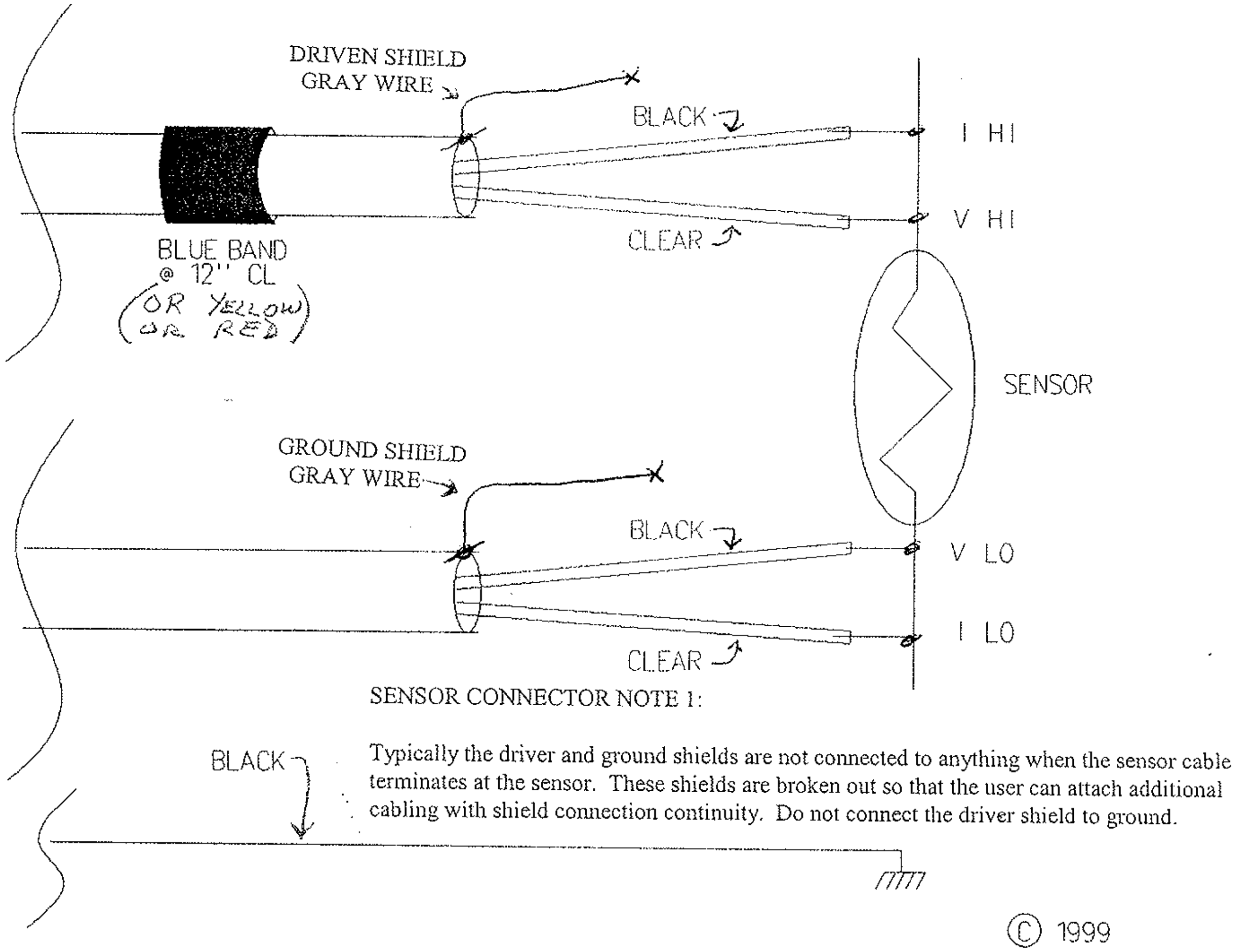
The LR-740 makes use of Linear Research Inc.'s proprietary analog Lock-Balance™ lock-in technique for front end balancing of the sensor's in-phase and quadrature AC signals directly at the sensor. The resultant null signal is then sent to DC elimination circuitry and then to the preamp for amplification. Thus, "loading" or paralleling of the sensor by the DC elimination circuit is avoided.

QUADRATURE CORRECTION

The LR-700 operates in a quadrature correction mode when measuring on the 20KΩ-2MΩ ranges. This mode balances the line capacitance reactance by changing the excitation current. Full details are shown in the LR-700 User's Manual (Chapter 4). However, since the LR-740 unit must operate on the LR-700's lower resistance ranges (200mΩ-200Ω) to generate the required lower currents, this feature is not in operation.

SENSOR CONNECTIONS

The following illustration, Figure 3, shows how to connect the LR-740 sensor cable to the sensor. Please note the color at each wire and which cable has a blue band.



SENSOR CONNECTOR NOTE 1:

Typically the driver and ground shields are not connected to anything when the sensor cable terminates at the sensor. These shields are broken out so that the user can attach additional cabling with shield connection continuity. Do not connect the driver shield to ground.

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LR-740 SENSOR CONNECTIONS

FIGURE 3

USING THE LR-740

Table 1 must be used to determine the correct settings of the LR-700. Once the sensor resistance (R_X) and either the sensor voltage (V_X) or sensor current (I_{EXC}) have been determined, Table 1 will show the correct settings of range and excitation to use in the LR-700 Bridge. For example, to measure a 100KΩ sensor using 30pa, the LR-700 should be set to 20Ω/60μV.

ELIMINATION OF DC CURRENTS

To eliminate DC current excitation of the sensor by the LR-700's preamp, DC elimination circuitry is placed between the sensor and the preamp. The LR-700's DC preamp input current can vary from ±50pa to ±100pa on either or both of the two preamp input lines, PA-HI and PA-LO. These DC currents are insignificant compared to the LR-700's lowest current range of 1,000pa. However, with the LR-740's lower AC current ranges down to 1pa, this DC current must be removed from the sensor to avoid sensor DC self heating. The DC elimination circuitry blocks the PA-HI DC current from flowing through the V-HI sensor resistor node and through the sensor while giving a DC current return path to ground for this current.

The technique used here with the LR-740 works best with sensor contact resistance, and to a lesser extent, line resistance values much lower than actual sensor resistance. These DC currents go only through the sensor contact resistance associated with the V-LO/I-LO resistance path in the sensor and heat only this small, if any, path resistance. For thin film ceramic oxynitride type RTD's, the sensor contact resistance is, fortuitously, much less than 100mΩ and thus, associated DC heating should be negligible. The DC current also heats V-LO/I-LO line resistance in the cryostat that it flows through. Usually, this effect is also negligible in heating the sensor.

VIBRATION EFFECTS

Working with these low values of excitation currents, the sensor cable must be protected from mechanical vibration to reduce cable triboelectric noise current effects. Triboelectric noise is generated by a mechanical vibration stressing the dielectric insulation between the shield and conductors in a shielded cable, thereby causing a noise current to flow between shield(s) and/or conductor(s). The sensor cable and interface cable provided was specifically chosen for its low triboelectric noise. These cable are constructed of rubber/cotton insulation with a conductive rubber and copper braid shield instead of the more common PVC/polypropylene and aluminum foil cables. You must use the provided cables to get the maximum performance, i.e. lowest noise, of the system.

CAPACITANCE EFFECTS OF CABLE

The LR-740 sensor cable uses a common driven shield on the bundled I-HI, V-HI lines. This greatly reduces the effect of the LR-740 sensor cable capacitance that parallels the sensor. Line capacitances elsewhere, such as inside the cryostat, will still have a direct paralleling effect across the sensor.

The amount of capacitance of any feed through filters and the inside cryostat line capacitance will give capacitance reactance loading of the sensor.

When measuring large resistance sensors ($R \geq M\Omega$) with the LR-740, the effect of round trip line capacitance that is unprotected by a driven shield must be taken into account. The sensor resistance span error introduced by this line capacitance reactance is approx. the magnitude of the square of the ratio of (1)sensor resistance to (2)line capacitance reactive impedance. The LR-700's R and X readout are series equivalent components of the total parallel sensor impedance. The LR-700's circuitry performs a parallel to series conversion of this vector impedance. Thus, for a 1MΩ sensor in parallel with a 20MΩ of unprotected line capacitance impedance (c=300pf), series resistor readout error at the LR-700, due to this effect, is $(1/30)^2 \cong 1.1\%$. For a 100KΩ sensor with 30MΩ line capacitance, series resistor readout error, due to this effect, is reduced to $(1/300)^2 = 0.001\%$.

The LR-740 sensor cable uses a common driven shield on the bundled I-HI, V-HI lines. This greatly reduces the effect of the LR-740 cable capacitance that parallel the sensor. Capacitances inside the cryostat will still have a parallel effect.

The amount of capacitance of any feed through filters and the inside cryostat line capacitance must be added to sensor cable capacitance when considering capacitance reactance loading of the sensor.

CABLES

Figure 2, Cable Interfacing, shows the interfacing cable hook-up. The cable from the LR-740 to the sensor must be the LR-740-001 cable that is provided as shown in Figure 2. The standard shield and driven shield sensor cables provided with the LR-700 will not work with the LR-740.

Do not ground cable driven shield. Since the LR-740-001 cable has a driven shield covering I-HI and V-HI, this shield must not be grounded or connected to anything at the cryostat.

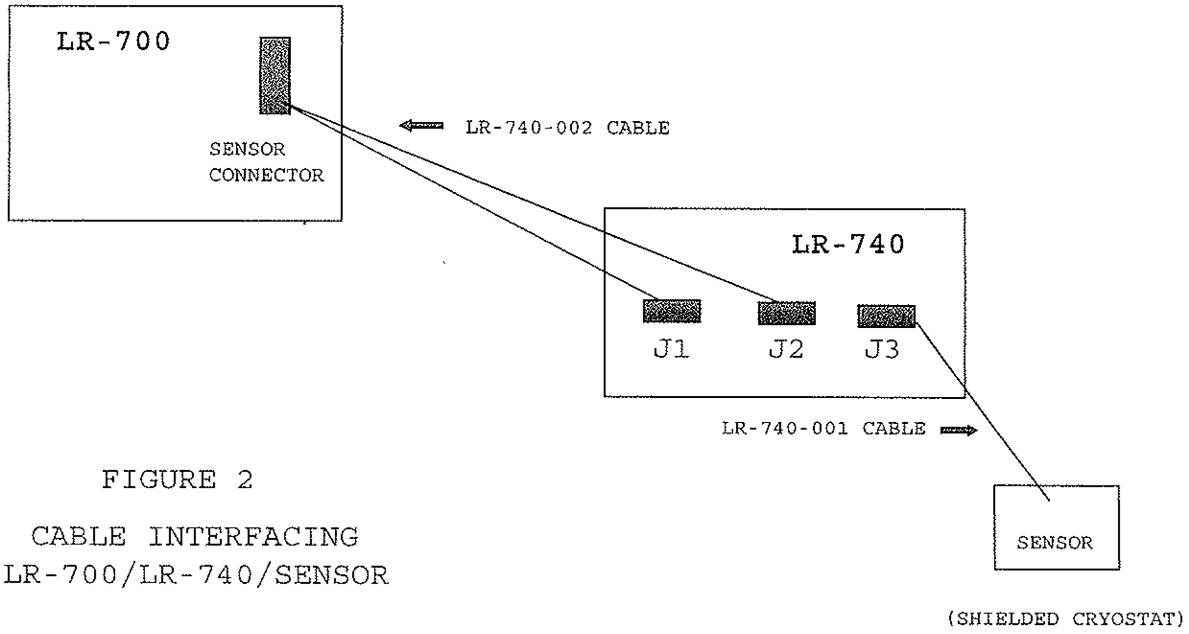
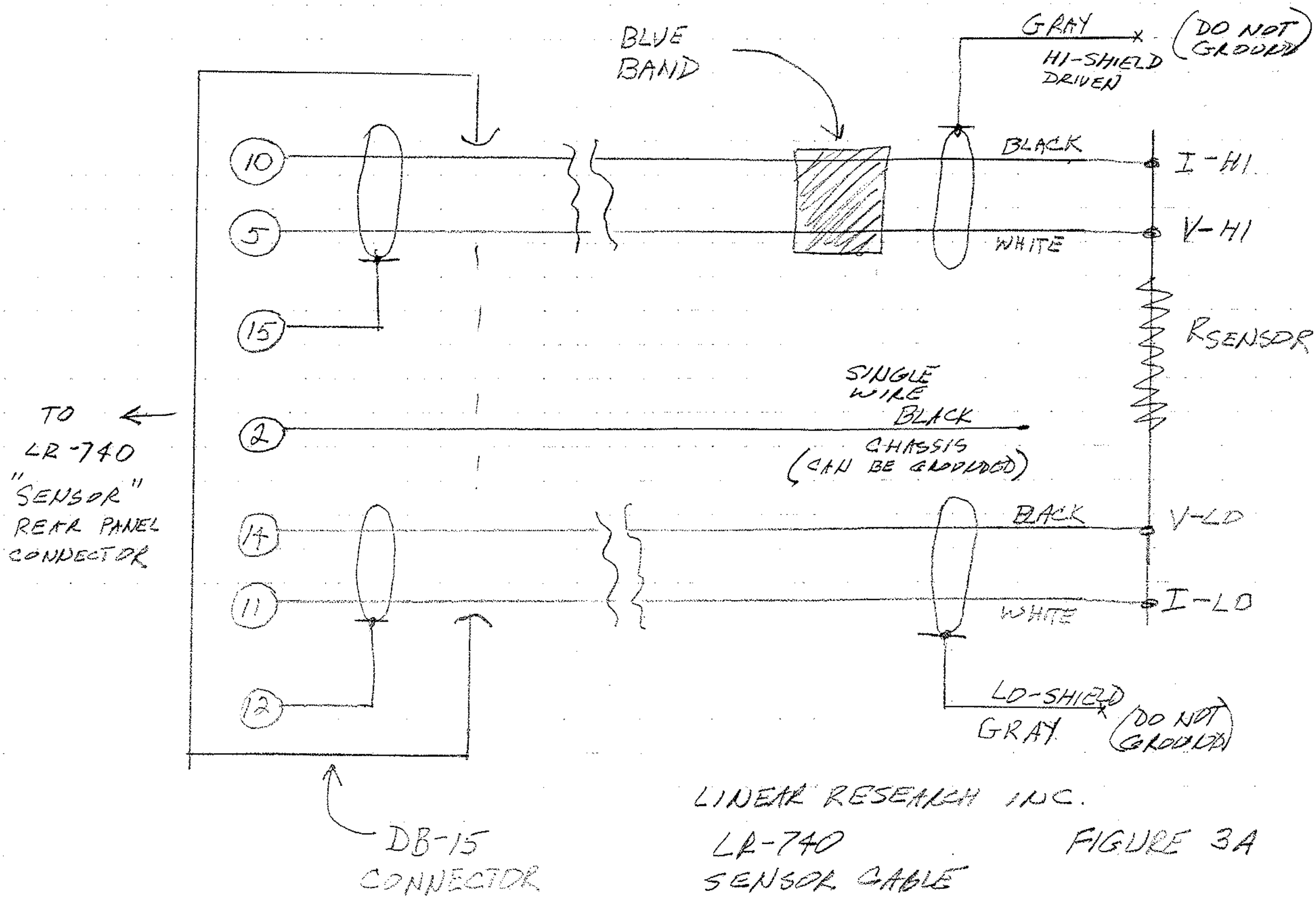


FIGURE 2

CABLE INTERFACING
LR-700/LR-740/SENSOR



LINEAR RESEARCH INC.

LR-740
SENSOR CABLE

FIGURE 3A

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R. ENTENMANN

TABLE 1. LR-700 SETTINGS FOR THE LOW EXCITATION CURRENT BOX UNIT

I_{EXC} Output	R_x	V_x	Actual Display Reading	Correct Interpretation of Display	Range LR-700	V_{EXC} LR-700	I_{EXC} LR-700
1pa	10KΩ	10nv	000.100Ω	00010.0KΩ	200Ω	20μv	100na
	100KΩ	100nv	001.000Ω	00100.0KΩ	*	*	*
	1MΩ	1μv	010.000Ω	01.0000MΩ	*	*	*
3pa	10KΩ	30nv	000.100Ω	00010.0KΩ	200Ω	60μ	300na
	100KΩ	300nv	001.000Ω	00100.0KΩ	*	*	*
	1MΩ	3μv	010.000Ω	01.0000MΩ	*	*	*
10pa	10KΩ	100nv	00.1000Ω	0010.00KΩ	20Ω	20μv	1μa
	100KΩ	1μv	01.0000Ω	0100.00KΩ	*	*	*
	1MΩ	10μv	10.0000Ω	1.00000MΩ	*	*	*
30pa	10KΩ	300nv	00.1000Ω	0010.00KΩ	20Ω	60μv	3μa
	100KΩ	3μv	01.0000Ω	0100.00KΩ	*	*	*
	1MΩ	30μv	10.0000Ω	1.00000MΩ	*	*	*
100pa	10KΩ	1μv	0100.00mΩ	010.000KΩ	2Ω	20μv	10μa
	100KΩ	10μv	1000.00mΩ	100.000KΩ	2Ω	20μv	*
	1MΩ	100μv	10.0000Ω	1.00000MΩ	20Ω	200μv	*
300pa	10KΩ	3μv	0100.00~~Ω~~mΩ	010.000KΩ	2Ω	60μv	30μa
	100KΩ	30μv	1000.00mΩ	100.000KΩ	2Ω	60μv	*
	1MΩ	300μv	10.0000Ω	1.00000MΩ	20Ω	600μv	*
1,000pa	10KΩ	10μv	100.000~~Ω~~mΩ	10.0000KΩ	200mΩ	20μv	100μa
	100KΩ	100μv	1000.00mΩ	100.000KΩ	2Ω	200μv	*
	1MΩ	1mv	10.0000Ω	1.00000MΩ	20Ω	2mv	*
Note 9 ›	10MΩ	10mv	100.000Ω	10.0000MΩ	200Ω	20mv	*

TABLE 1 NOTES

1. LR-700 mode = ΔR.
2. Display reading column shows actual readout of R_x as listed in R_x column. Shown for R-set = zero.
3. "*" = same as above value.
4. R_x = value of sensor resistor.
5. V_x = actual voltage across sensor resistor R_x.
6. Range LR-700 column and V_{EXC} column are the required LR-700 front panel settings to achieve the listed I_{EXC} Box output.
7. I_{EXC} box column is the output current applied to the sensor R_x by the Low Excitation Current Box.
8. LR-700 has a 1,000pa I_{EXC} setting also. This is listed as 1na in the sensor current and power table on page 4-10 of the LR-700 Bridge User's Manual.
9. Last entry in Table under 1,000pa is a 10MΩ reactive range displayed in the LR-700's X, ΔX, X-set readout. Good for measuring total line capacitance reactance in a system. Use an open (R=∞Ω) sensor resistor and connect V-HI to I-HI and V-LO to I-LO. Possibly somewhat useful in measuring 10MΩ resistive sensors but quadrature error must be taken into account. For lower 10MΩ currents: 10pa, LR-700=200Ω/200μv; 30pa, LR-700=200Ω/600μv; 100pa, LR-700=200Ω/2mv.
10. μa = 10^{-6} amps, na = 10^{-9} amps, pa = 10^{-12} amps,
    mv = 10^{-3} volts, μv = 10^{-6} volts, nv = 10^{-9} volts,
    μf = 10^{-6} farads

SPAN ERRORS

Typically, LR-740 full scale span error differences should match each other to within 1% from range to range. The user might want to check his LR-700 to verify this difference as some LR-700 unit's circuitry combinations may be larger than 1%. The user can calibrate each range or leave the calibration dial set to one setting, if a 1% error is acceptable.

The LR-740 current generator circuitry includes a span calibration feature. This allows for elimination of span errors due to variations in the LR-740/LR-700 combination. The LR-700's calibration values stored in memory are not accurate when using the LR-740 unless the span is adjusted. To set the LR-740 span calibration control, the user first selects an LR-740 current range and measures a resistor of known value. The calibration dial is then set to yield a matching reading on the LR-700's display.

The 100pa range was calibrated for unit serial number 116 at LRI for a 100KΩ reference sensor with a resultant dial setting of 470.

INTERPRETING THE RESULTS

The LR-700 display, when using the LR-740, will indicate the correct mantissa value of the sensor. However, the order of magnitude in base 10 of the sensor's value, including the decimal point placement and the KΩ or MΩ annunciator suffixes, must be translated by the user. The correct interpretation is shown in Table 1, titled LR-700 Settings for the LR-740 Picoamp Excitation Unit.

For example, when using a 30pa excitation current to measure a 100KΩ sensor resistor, the LR-700 must be set to R-range = 20Ω and V_{EXC} = 60μv to generate within the LR-740 the required 30pa current. The LR-700 display will then read +01.0000Ω for a 100KΩ sensor resistor which must be interpreted by the user as +0100.00KΩ as shown in Table 1.

As an additional aid to the user, Tables 2-6 are included which show the voltage "weight" of each digit displayed. In the same 30pa excitation current measurement example range as above, if the R display reads +01.0100Ω, interpreted as a +0101.00KΩ sensor, the full scale range excitation voltage from Table 3 (20Ω), is 60μv maximum and actual sensor voltage is 03.0300μv. The weight of the following highlighted digit +01.0100Ω is 30nv.

TABLE 2, 20 MICROVOLTS FULL SCALE EXCITATION

LR-700 RESISTANCE RANGE	DISPLAY READING						
200mΩ	1	9	9	.9	9	9	mΩ
2Ω	1	.9	9	9	9	9	Ω
20Ω	1	9	.9	9	9	9	Ω
200Ω	1	9	9	.9	9	9	Ω
Least count weight of digit in volts RMS	10μV	1μV	100nV	10nV	1nV	0.1nV	

TABLE 3, 60 MICROVOLTS FULL SCALE EXCITATION

LR-700 RESISTANCE RANGE	DISPLAY READING						
2Ω	1	.9	9	9	9	9	Ω
20Ω	1	9	.9	9	9	9	Ω
Least count weight of digit in volts RMS	30μV	3μV	300nV	30nV	3nV	0.3nV	

TABLE 4, 200 MICROVOLTS FULL SCALE EXCITATION

LR-700 RESISTANCE RANGE	DISPLAY READING						
2Ω	1	.9	9	9	9	9	Ω
20Ω	1	9	.9	9	9	9	Ω
Least count weight of digit in volts RMS	100μV	10μV	1μV	100nV	10nV	1nV	

TABLE 5, 600 MICROVOLTS FULL SCALE EXCITATION

LR-700 RESISTANCE RANGE	DISPLAY READING						
20Ω	1	9	.9	9	9	9	Ω
Least count weight of digit in volts RMS	300μV	30μV	3μV	300nV	30nV	3nV	

TABLE 6, 2 MILLIVOLTS FULL SCALE EXCITATION

LR-700 RESISTANCE RANGE	DISPLAY READING						
20Ω	1	9	.9	9	9	9	Ω
Least count weight of digit in volts RMS	1mV	100μV	10μV	1μV	100nV	10nV	

Tables 2,3,4,5 and 6 above: mode = ΔR, Display Select = R

MEASURING CAPACITANCE SENSORS

The LR-740 allows the LR-700 AC Resistance Bridge to measure capacitors or capacitance temperature sensors. When measuring capacitors, it is important to keep in mind that the LR-700 measures resistance and reactance in ohms. Therefore, the display value will follow a $R_{equiv} = -1/2\pi fc = X_{measured} \cong -1/100C$ where $f=15.7$. For example, a 1nf capacitor will be measured as $X= -1/100.1\text{x}10^{-9} = -1/1\text{x}10^{-7} = -1 \text{ x } 10^{7} = -10\text{M}\Omega$.

Table 7, Capacitor Measurement Settings, shows the settings needed on the LR-700 to measure some common capacitor sensors.

Table 8, Capacitor Sensor Displays, shows how to interpret the display value when measuring a capacitor.

Table 9, Capacitive Measurement Resolution, shows the analog resolution and settling point resulting when using capacitive sensor to control temperature.

CAPACITOR MEASUREMENT SETTINGS			
Capacitance Sensor Cx	Range LR-700	V_{EXC} LR-700	I_{EXC} LR-740 Output
1nf	200Ω	20mv	1na
2nf	200Ω	20mv	1na
5nf	200Ω	20mv	1na
10nf	20Ω	6mv	3na
15nf	20Ω	6mv	3na
30nf	20Ω	6mv	3na
100nf	2Ω	600μV	3na
150nf	2Ω	600μV	3na

TABLE 7

CAPACITOR SENSOR DISPLAYS

Capacitance Sensor Cx	Capacitance Reactance of Cx	Vx	Actual Display Reading	Correct Interpretation of Display
1nf	10MΩ	10mV	-100.000Ω	-10.0000MΩ
2nf	5MΩ	5mV	-05.000Ω	-05.0000MΩ
5nf	2MΩ	2mV	-020.000Ω	-02.0000MΩ
10nf	1MΩ	3mV	-10.0000Ω	-1000.00MΩ
15nf	667KΩ	2mV	-06.6666Ω	-0.66666MΩ
30nf	333KΩ	1mV	-03.3333Ω	-0.33333MΩ
100nf	100KΩ	100μV	-1000.00mΩ	-100.000KΩ
150nf	66.7KΩ	66.7μV	-0666.66mΩ	-066.666KΩ

TABLE 8

CAPACITIVE MEASUREMENT RESOLUTION

CAPACITANCE SENSOR Cx	LR-740 ANALOG RESOLUTION 10ΔX OUTPUT BETTER THAN	LR-740 DIGITAL X-SET SETABILITY RESOLUTION EQUAL OR EXCEEDS
1nf	0.01pf	0.01pf
2nf	0.03pf	0.05pf
5nf	0.10pf	0.25pf
10nf	0.02pf	0. 1pf
15nf	0.03pf	0.25pf
30nf	0.06pf	1.00pf
100nf	0.3pf	1.2pf
150nf	0.6pf	2.5pf

Analog filter = 3 sec
Peak to peak resolution values are 5 times larger
Data measured with a strip chart recorder driven by the LR-700's 10ΔX analog output.
1nf = 10^{-9}farad

TABLE 9

TESTS MADE ON THE UNIT

In order to test the LR-740 at room temperature, and simulate a low temperature sensor's performance with bench top room temperature sensors, LRI used a 0.1μf capacitance, as a "noise free" 100KΩ reactive sensor impedance. The room temperature Johnson noise of a 100KΩ resistor is approx. 40nv per square root Hz given by the Johnson noise equation $e^2=4kTR\Delta f$. Using an analog time constant in the LR-700 of 3 seconds, the bandwidth is reduced from 1Hz to approx. 0.05Hz, which will give a Johnson voltage noise reduction proportional to the ratio of the square root of the bandwidth reduction. Thus, the Johnson voltage noise of a room temperature 100KΩ resistor associated with a 3 second time constant is approx. 9nv RMS. For a temperature of 4.2 Kelvin, the noise will be reduced further by the square root of the ratio of room temperature compared to 4.2 Kelvin which is approx. the square root of 70. Or, at 4.2 Kelvin, noise voltage for a 3 second time constant for a 100KΩ resistor is approx. 1nv RMS. To get a 100KΩ impedance at room temperature with it's Johnson noise approaching 1nv RMS for a 3 second time constant, LRI used a polystyrene dielectric capacitor with it's low equivalent series resistance for low room temperature Johnson noise.

Pure capacitance by itself generates no Johnson noise, only the capacitor's equivalent internal series resistance will generate Johnson noise. Polystyrene dielectric capacitors typically have dissipation constants (the ratio of their series resistance to their capacitance reactance at the operating frequency) of appreciably less than one part in 1,000. This gives an equivalent room temperature series resistance in the capacitor of less than 100K ÷ 1,000 = 100Ω. This 100Ω has Johnson voltage noise of approx. 0.3nv RMS for a 3 second bandwidth. Other type film dielectric capacitors have higher dissipation constants with higher series resistance and higher room temperature Johnson noise.

The LR-700 AC Bridge/LR-740 combination was tested using this technique of substituting room temperature capacitance sensors for low temperature resistors for noise resolution testing since, the LR-700 bridge alone, compared to other bridges commercially available, can balance both real and imaginary components at 16Hz. The LR-700 is also capable of setting both Rset and Xset offset features. The LR-700 can then see small ΔR and ΔX changes in the sensor impedance. This allows easy measurement of the noise resolution of the measuring system without a cryostat setup that would require stable temperatures, and/or stable resistors, at the low temperature.

RESOLUTION

The strip chart recording shows noise resolution results for the LR-740 unit excitating a 0.1μf (100KΩ reactive) polystyrene capacitor sensor at room temperature. This technique simulates a low Johnson noise 100KΩ resistance at low temperature. The excitation voltage across the sensor is 10μv. Sensor current is 100pa. LR-700 analog filter time constant, using the LR-700 filtered analog output option, is 3 seconds. Noise resolution shown for this sensor excitation current is 0.8nv RMS, or 80 parts per million of the 100KΩ sensor.

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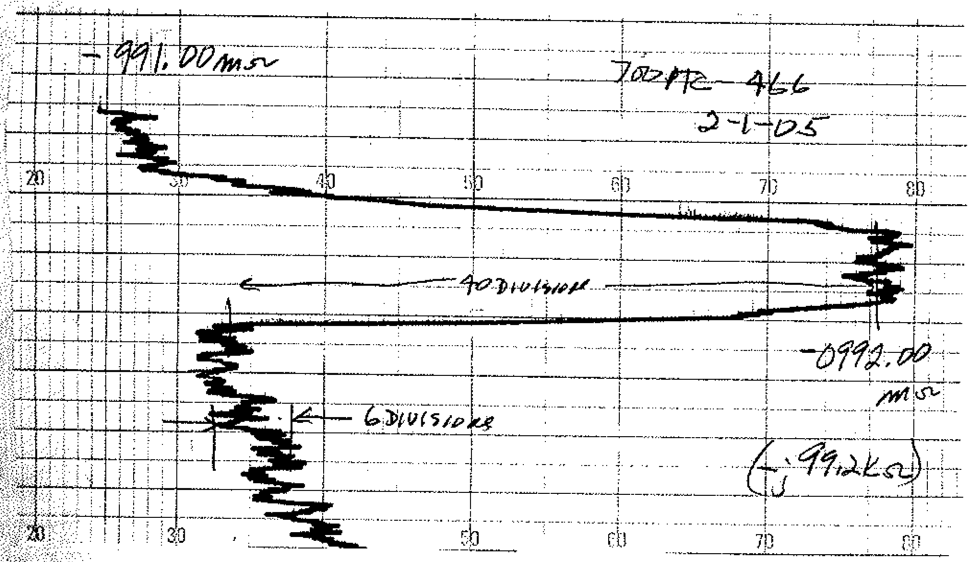
40 DIV = 100Ω

6 DIV = $\frac{6}{40} \times 100 = \frac{600}{40} = 15\Omega$ pp

pp → RMS: $\frac{15\Omega}{5} = 3\Omega$ RMS



$2\Omega / 20\mu V / \Delta R$ $Z_X = 0.1\mu$

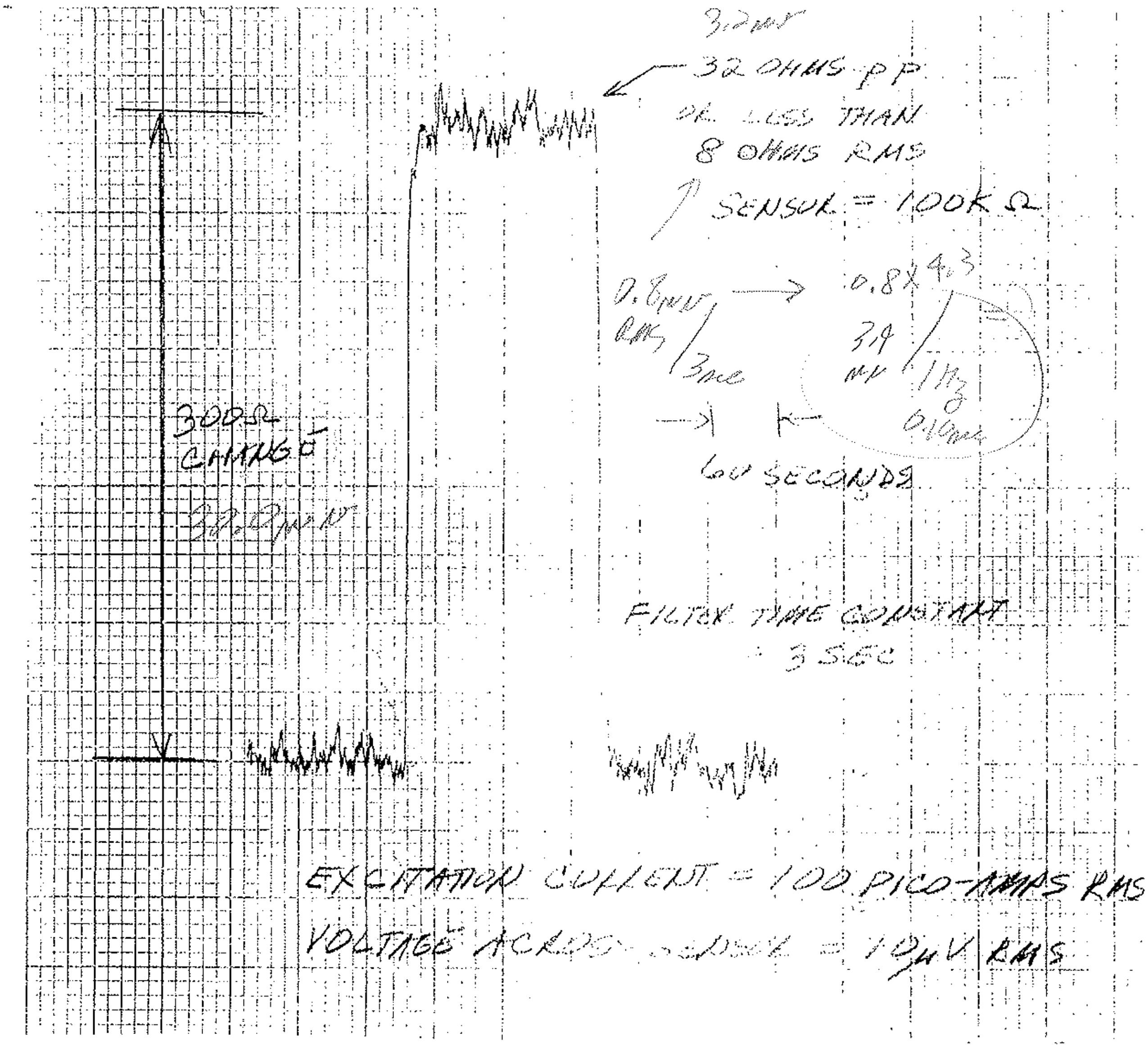
ΔX OUTPUT
TO STRIPCHART
RECORDER

$R_s = R$

SCR GAIN/FILTER
= 1k/x3/10sec

Sample Recording

The following recording was made using a .1μf polystyrene capacitor to simulate a low noise 100KΩ resistor. Range is 200KΩ, excitation voltage is 20μV full scale. Excitation current is 100 picoamps RMS. RMS noise shown is 80pp10^6 or 8Ω out of 100KΩ.



199 999

10 M. 100,032 = 10μV 30.0mv

1M 100μ 10μ 1μ 0.1μ

STRIP CHART NOISE RECORDINGS

Figures A & B show the possible noise improvement when the resistive sensor is at a sufficiently lower temperature to reduce the sensor's Johnson Noise.

The 0.1μf (100kΩ reactive impedance) simulates such a noise free resistor on the 200kΩ range/100 picoamp excitation/20μv range. The improvement factor shown is 62.4Ω RMS noise versus 5.16Ω RMS noise, a 12 to 1 improvement. This is equivalent to reducing the resistor sensor temperature by a factor of 144 (the square of 12) that is from 300 Kelvin to 2 Kelvin. Note that as a rule of thumb RMS noise is 1/5 the magnitude of peak to peak noise.

To achieve the results in Figure A the sensor cable must be held dead still and not subject to mechanical shock or vibration. For example if the user had walked around within six feet of the bench top where this test was made, then sufficient vibration would have been induced in the sensor cable to override the low value of noise shown in Figure A.

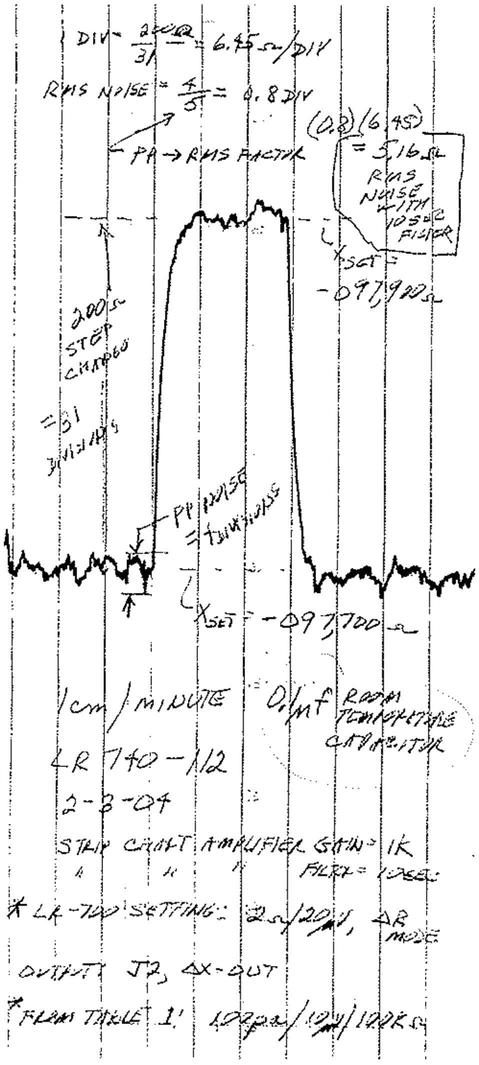


FIGURE A

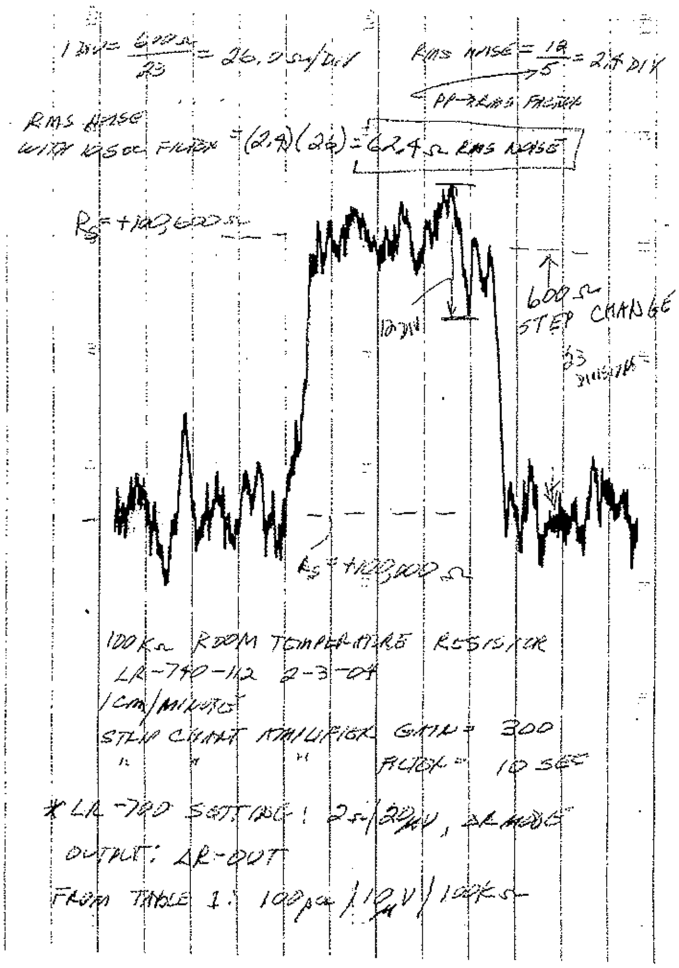


FIGURE B