

LR-400 000-1
Instruction Manual

INSTRUCTION MANUAL
LR-400
-----FOUR WIRE-----
AC RESISTANCE BRIDGE

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REMARKS:

Be sure to read the following sections of the LR-400 Instruction Manual.

1. Page 300-1 paragraph 3 (overload light).
2. Page 300-1 paragraph 4 (external DVM).
3. Page 300-1 paragraph 6, 7, & 8 (DPM).
4. Page 300-1 paragraph 9 (loading of the 2 VDC output).
5. Page 300-3A (set R/MI polarity switch & caution about missetting).
6. Page 600-1 (SQUID Readout description).
7. Page 700-1A preamp damage caution when working in the mutual inductance mode.

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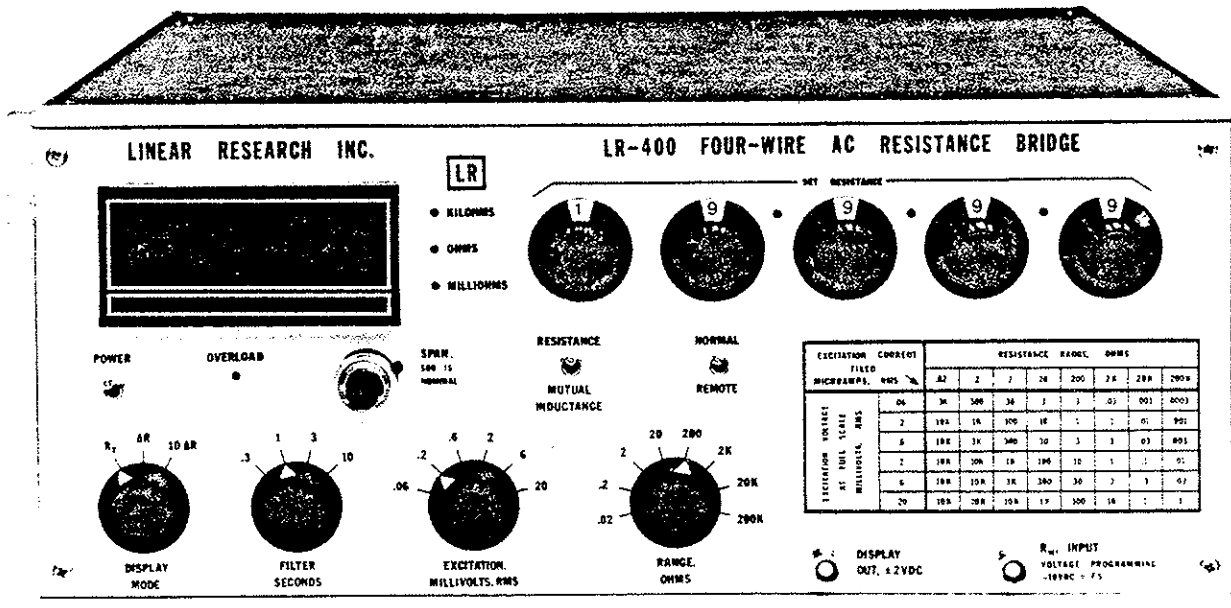
SECTION 100 LR-400 SPECIFICATIONS

LR-400

4-WIRE RESISTANCE / MUTUAL INDUCTANCE

BRIDGE SYSTEM

- LR-400 BRIDGE UNIT AND OPTIONS
- LR-HCA HIGH CURRENT ACCESSORY UNIT
FOR NANO-OHM RESOLUTION
- LR-4PC PERSONAL COMPUTER INTERFACE UNIT
- SUPERCONDUCTING SAMPLE MUTUAL INDUCTANCE
MEASURING TECHNIQUES



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LR-400 4-WIRE RESISTANCE/MUTUAL INDUCTANCE BRIDGE SYSTEM

MODEL LR-400
AUTO-BALANCE
FOUR-WIRE AC RESISTANCE BRIDGE

- * AC excitation for high sensitivity and elimination of thermal EMF errors.
- * Wide dynamic range: 0.02 ohms full scale to 200K ohms full scale.
- * 4 1/2 digit automatic resistance readout with RX, ΔR , and $10\Delta R$ modes.
- * 4 1/2 digit set resistance control (can be voltage programmed) for temperature control or resistance deviation measurements.
- * Sensor excitation power/sensitivity trade-off selection for all ranges.
- * Four wire platinum resistance thermometry with cryogenic temperature capability.
- * Four wire carbon and germanium resistor thermometry at cryogenic temperatures.
- * Four wire thermistor thermometry.
- * Low resistance measurements with low excitation currents.
- * Auto-balance mutual inductance bridge mode.

RESISTANCE RANGE

20 milliohms to 200,000 ohms full scale in 8 ranges. See LR-HCA Unit description for two additional lower ranges of 2 milliohms and 200 micro-ohms full scale, at 100 milliamps and 1 amp RMS.

EXCITATION VOLTAGE RANGE

Selectable from 60 microvolts to 20 millivolts full scale in 2-6-20 steps. Actual excitation voltage is proportional to sensor resistor (RX).

SENSOR EXCITATION CURRENT

Sensor excitation is supplied by a constant amplitude AC sinewave current generator. Frequency is 15.9 hertz. For any particular range control and excitation voltage control selected the actual value of excitation voltage (VX) appearing across the sensor resistor is directly proportional to the magnitude of the ohmic value of the

LR-400 4-WIRE RESISTANCE/MUTUAL INDUCTANCE BRIDGE SYSTEM

sensor resistor. (VX = 0 volts for RX = 0 ohms, VX = 100% excitation for RX = 100% of range).

Actual constant amplitude excitation current values are listed below for the six settings of the full scale excitation control. Voltage and current values shown are R.M.S. (peak to peak value = 2.83 Root Mean Square value).

RANGE	.06 mv	.2 mv	.6 mv	2 mv	6 mv	20 mv
02 ohm	3 ma	10 ma	10 ma	10 ma	10 ma	10ma
.2 ohm	300 ua	1 ma	3 ma	10 ma	10 ma	10ma
2 ohm	30 ua	100 ua	300 ua	1 ma	3 ma	10ma
20 ohm	3 ua	10 ua	30 ua	100 ua	300 ua	1 ma
200 ohm	.3 ua	1 ua	3 ua	10 ua	30 ua	100ua
2K ohm	.03 ua	.1 ua	.3 ua	1 ua	3 ua	10 ua
20K ohm	.003 ua	.01 ua	.03 ua	.1 ua	.3 ua	1 ua
200Kohm	.0003 ua	.001 ua	.003 ua	.01 ua	.03 ua	.1 ua

mv = millivolts ma = milliamps ua = microamps

For the convenience of the user the front panel of the LR-400 contains a table showing all of the above information.

DIGITAL READOUT

4 1/2 digits (19999 counts). Seven segment LED display. One part in 19,999 resolution. Kilohms, ohms, & milliohms LED annunciators. 5-1/2 digit resolving can be obtained by monitoring the front panel BNC ± 2 VDC analog output with an external digital voltmeter.

ACCURACY

$\pm 0.03\%$ typical, $\pm 0.1\%$ guaranteed for all range/excitation combinations when measured at the front panel BNC output with an external 5 1/2 digit digital voltmeter, ambient +25 degrees Celsius.

DRIFT (24 HOUR TEST)

Under typical laboratory ambient temperature conditions where Rset = RX, ΔR drift is typically better than 1 part in 20,000 full scale.

RESOLUTION

Digital Display: 1 digit (1 part in 19,999). Analog output: see strip-chart recordings, typically 1 part in 200,000 for 20 millivolt excitation on most ranges.

BRIDGE INPUT

Transformer coupled low noise input amplifier optimized for each range setting.

MODE

RX : Display reads value of RX.

ΔR : Display reads difference between RX and Rset and indicates polarity.

10 ΔR : Same as ΔR , but difference is amplified by a factor of 10.

ANALOG OUTPUTS

A front panel BNC output (± 2 VDC) gives a voltage equal to the digital display with output = +1.9999 VDC for a display of +19999.

A rear panel BNC output gives a voltage (± 10 VDC span) equal to the $10\Delta R$ value at all times. This can be used to drive the model LR-130 temperature controller or a chart recorder.

A rear panel BNC uncalibrated output gives a voltage (± 10 VDC span) equal to the quadrature component of the sensor resistor impedance, or when in mutual inductance mode proportional to the resistive losses.

SET RESISTANCE

4 1/2 dials, 1 part in 19,999 resolution on all ranges. A front panel BNC (Rset input) allows set resistance to be voltage programmed where "-10 VDC = full scale resistance" for all ranges. With the LR-4PC unit set resistance resolution is 1 part in 65,535, computer controlled.

LINEARITY

$\pm 0.025\%$ full scale for any range-excitation setting.

FILTER TIME CONSTANT

Selectable in steps of 0.3, 1, 3, & 10 seconds, allowing for "fast output response/noise resolution" trade off's.

LEAD RESISTANCE ERRORS including the error introduced by 16 feet of sensor cable capacitance:

.2 OHMS TO 20 OHMS RANGE

Lead resistance, any or all four leads, up to 10 ohms will introduce less than 2 parts in 10,000 error full scale.

200 OHM TO 20K OHM RANGE:

Lead resistance any or all leads up to 50% of RX will introduce less than 5 parts in 10,000 error full scale.

LR-400 4-WIRE RESISTANCE/MUTUA Instruction Manual

LEAD RESISTANCE INDUCED ZERO OFFSET ERROR

With RX = zero ohms on the 20 milliohm range the bridge will indicate an offset error in RX due to lead resistance (RL) that is less than: 1 micro-ohm/ohm (RL = 0 ohms to 100 ohms), 2 micro-ohm/ohm (RL = 100 ohm to 330 ohm).

DIMENSIONS

7 inches (178 mm) high, 17 inches (432 mm) wide, 17 inches (432 mm) deep. 19 inch rack mounting kit included.

NOISE RESOLUTION

Included herein are strip chart recordings showing the noise resolution/sensor power self-heating trade-off performance of the LR-400. Typical resolution is better than 10 parts per million for the 20 MV excitation setting on many ranges. Sensor resistors shown are at room temperature. Some improvement will occur when sensor resistors are at cryogenic temperatures due to their lower Johnson Noise.

INSTRUCTION MANUAL/CALIBRATION

The detailed instruction manual supplied with each LR-400 allows the user to adjust the span calibration of each of the 8 ranges as well as the ΔR span and zero offset. A detailed description of all circuits is also included.

DETAILED DESCRIPTION/BLOCK DIAGRAM

Upon request Linear Research will supply a description of the block diagram of the LR-400.

PARALLEL DIGITAL INTERFACE OPTION

Rear panel digital interface connector for full external programming of all front panel controls except set resistance and span trim. Set resistance can be programmed at the LR-400's analog input driven from your computer's digital to analog convertor or by our LR-4PC unit. 0/+5VDC Logic Input Levels. This non-standard interface requires some user design and hardware implementation to use. Not IEEE-488 or RS-232. See LR-4PC Personal Computer interface unit section for a complete system ready-to-run requiring no user design.

BCD DISPLAY OUTPUT OPTION

Rear panel connector with BCD logic output. Four output lines per digit. 0/+ 5VDC Logic Output Levels. Not IEEE-488 or RS-232. Requires some user design and hardware implementation to use. See LR-4PC Personal Computer interface unit section for complete system requiring no user design.

MUTUAL INDUCTANCE OPTION

Additional circuitry and front panel mode select switch allows the

unit to be operated as an auto-balance resistance bridge or as an auto-balance mutual inductance bridge with full scale ranges of 200 microhenries to 2000 henries in 8 ranges. Ideal for measuring Cerium Magnesium Nitrate samples for low temperature thermometry. Resolution is typically at least or better than 1 part in 20,000 on all mutual inductance ranges. With the LR-HCA unit two lower ranges of 20 and 2 microhenries full scale are available. See also superconducting sample mutual inductance measurements section.

SQUID READOUT OPTION (REMOTE FRONT-END BALANCING OPTION)

This option allows the LR-400 to self balance a squid system that is measuring in-phase and quadrature components of impedance. This option typically replaces the squid system's manually balanced precision low level AC impedance bridge and bi-phase null detector units at an appreciable savings in cost.

Carrier frequency is 15.9 hertz. The "hands-off" self balancing feature allows measurements to be made continuously. In addition the analog output of the LR-400 in this mode can be used to continuously drive a data acquisition system.

This option allows the user to place a user designed and built front end voltage balancing transformer in the cryogenic environment near the sensor resistor, mutual inductance sensor transformer, or SQUID area allowing for virtual elimination of the effect of the Johnson Noise of the room temperature regular balancing transformer-preamp in the LR-400. There is some minor interfacing design and hardware building required of the user when implementing this option.

**MODEL LR-HCA
HIGH CURRENT ACCESSORY UNIT**

This AC line powered self contained rack mountable unit is driven by the LR-400 unit and contains two high current excitation sources. Sources are 0.1 and 1.0 amps RMS at 15.9 hertz sinewave.

The user selects via the LR-HCA's front panel controls either an LR-400 generated excitation current (.0003 microamps to 10 milliamps) or the LR-HCA generated current.

The following two lower ranges are thus added to system performance:

- A. Two millionms full scale range.
 - 0.1 amp excitation current.
 - 0.1 micro-ohm resolution.

- B. 200 micro-ohm full scale range.
 - 1.0 amp excitation current.
 - 0.01 micro-ohm resolution.

All cables necessary for interfacing the LR-HCA to the LR-400 are included with this unit.

DIMENSIONS: 3.5 inches (89 mm) high, 19 inches (483 mm) wide, 14

inches (356 mm) deep. Rack mountable.

MODEL LR-4PC
PERSONAL COMPUTER INTERFACE FOR THE LR-400

The Model LR-4PC Personal Computer Interface will directly drive the LR-400's digital interface option, display output option, and analog set resistance/set mutual inductance input (set temperature).

Complete interfacing and control of all of the LR-400's controls from an IBM-PC Personal Computer or equivalent is thus achieved.

You can control the LR-400's range, excitation power, mode, filter time constant, and set resistance (set temperature) or mutual inductance, and also read the value of the digital panel meter, such as R_X , ΔR , and $10\Delta R$, with your IBM-PC/XT/AT, or equivalent, using standard computer languages such as Microsoft QUICK BASIC.

This is a complete working system and requires no user hardware design. The user, of course, must write his own BASIC software programs. The user simply plugs in the plug-in board, supplied with the LR-4PC, into his IBM Personal Computer (or equivalent) in one of the vacant slots. Two digital signal carrying cables supplied are connected from the LR-4PC to the LR-400 to control the digital interface and display output options.

The analog voltage set resistance signal is generated in the LR-4PC by a precision 16 binary bit digital to analog convertor under control of the IBM-PC.

The analog Rset signal is connected from the LR-4PC to a 9 pin rear panel connector on the LR-400 with a supplied shielded cable that eliminates ground loop noise.

The analog voltage set resistance signal output has the following characteristics:

A. Monotonic performance is ± 1 part in 65,535. Thus set temperature can be set with this resolution. This performance is sometimes referred to as differential linearity. It is the most important specification feature in any digital driven feedback system. This is especially true for set resistance temperature control systems where temperature is being "ramped" over small or large spans with staircase changes in set resistance. In a monotonic system such as ours, each successive ascending staircase step will be higher than the last step by a fixed one step size amount. In a non-monotonic system successive ascending steps may randomly be more or less than the last step by one or a few step sizes, even though the span linearity specification is fully met. Monotonicity for the LR-4PC is good over an ambient temperature range of 0/+70 degrees Celsius.

B. Span linearity is ± 1 part in 10,000 at 25 degrees Celsius. This is sometimes referred to as integral linearity, which is the maximum deviation from the best straight line through all output voltage

points.

C. Span end point drift over a 25C +15C temperature range is typically less than $\pm .03\%$

The LR-4PC is not an IEEE-488 or RS-232 Interface. The IEEE-488 interface is more noisy, with regard to radio frequency interference, and requires an IEEE-488 bus controller board in your computer.

DIMENSIONS: 3.5 inches (89 mm) high, 19 inches (483 mm) wide, 14 inches (356 mm) deep. Rack mountable.

WARRANTY/REPAIR

For all units described above Linear Research Inc. will repair the instrument for the first year, free of charge, parts and labor.

SUPERCONDUCTING SAMPLE MUTUAL INDUCTANCE MEASUREMENTS WITH THE LR-400
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The LR-400 is connected to the mutual inductance transformer as shown in figure 5. This figure shows separated current excitation and voltage sampling leads. Supplied for this measurement is our "split" sensor cable where the current excitation leads are separated slightly from the voltage balancing leads so there is no induced voltage in the voltage sampling leads due to the magnetic field set up by the current in the current excitation leads.

Figure 5 shows polarity with regard to the primary and secondaries of the transformers. Shown is the case of two transformers with individual primaries and the case of a single transformer with a single primary and dual secondaries. In both cases the outputs of the secondaries are connected so that induced voltages subtract, or buck each other, to give a null output voltage.

The sample is placed between the primary and one secondary. The other secondary is simply a "reference" secondary. Any changes in the flux exclusion or Meissner effect in the sample will then yield a change in mutual inductance, giving a DC output at the LR-400. The initial offset in mutual inductance when the sample is first placed into the coil, and when it is non-superconducting, can be set to zero by the LR-400's 4-1/2 digit set mutual inductance dials.

Users report good operation with a temperature controlled finger thermally isolated from liquid helium, but heat sunk eventually into liquid helium, and with the mutual inductance transformer coils wound directly outside of the finger area, such that the coils themselves are immersed in liquid helium. The sample is placed on the finger and the temperature is varied. Then the change in mutual inductance is measured as a function of temperature. Alternatively, the temperature can be held constant and a DC magnetic field, from a superconducting magnet can be applied to the sample, and the change

in mutual inductance as a function of DC magnetic field can then be measured.

In a typical example, shown in figure 1A & 1B, a non-magnetic, low susceptibility, tubular structure holds or incorporates the bobbins upon which the primary and secondary coils are wound. The usual order of magnitude of dimensions are: $A=B=C$, $D=0$ to $1.0A$, $E=2D$ to $4D$.

A cryogenic fluid, such as liquid helium or liquid nitrogen, surrounds and immerses all coils. This affords a reduction in the copper wire resistance of the coils compared to their room temperature resistance. The electrical Johnson noise of the coils is also reduced compared to the room temperature noise by the square root of the ratio of the cryogenic temperature to room temperature.

A payload structure, not shown, is inserted inside the tubular structure and is comprised of the following:

A non-magnetic low susceptibility outer shell holding inside a high thermal conductivity, low eddy current loss, temperature controlled mass which has attached a temperature sensor, an electrical resistive heater, and the superconducting sample. The temperature controlled mass must have a heat leak to the cryogenic fluid either by radiation or by conduction via a metallic tube, wire, or rod. The temperature controlled mass must be thermally isolated, usually by a vacuum, from the payload structure except for the heat leak. Provisions for electrical feed throughs must be included in the payload structure for electrical connections to the heater and the temperature sensor.

In figures 1 through 4: S1 = secondary number one, P1 = primary number one, etc. All have electric polarities as shown in figure 5. X = superconducting sample to be measured.

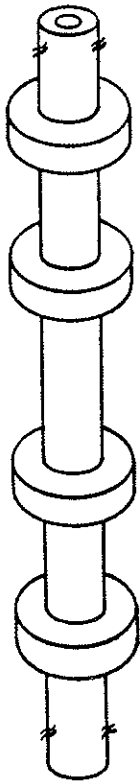


FIGURE 1A

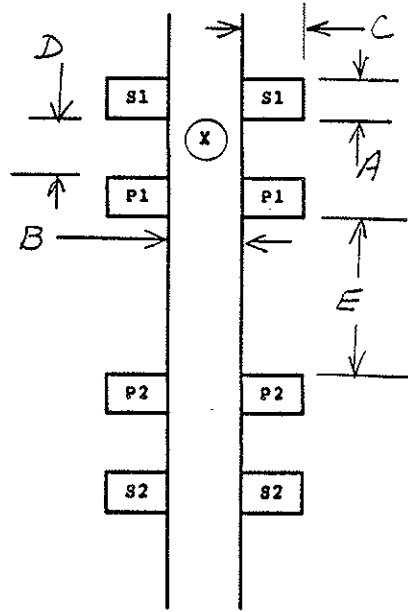


FIGURE 1B

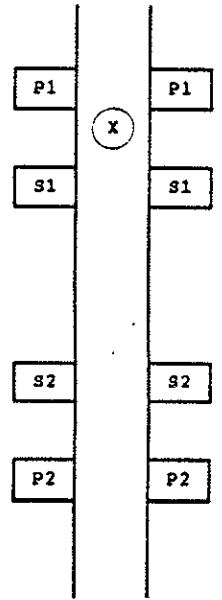


FIGURE 2

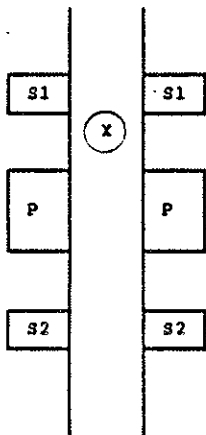


FIGURE 3

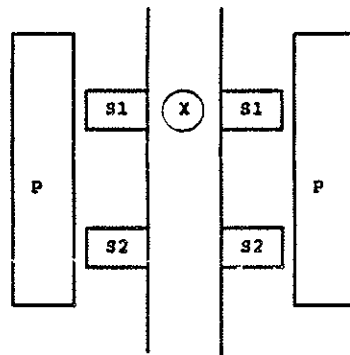
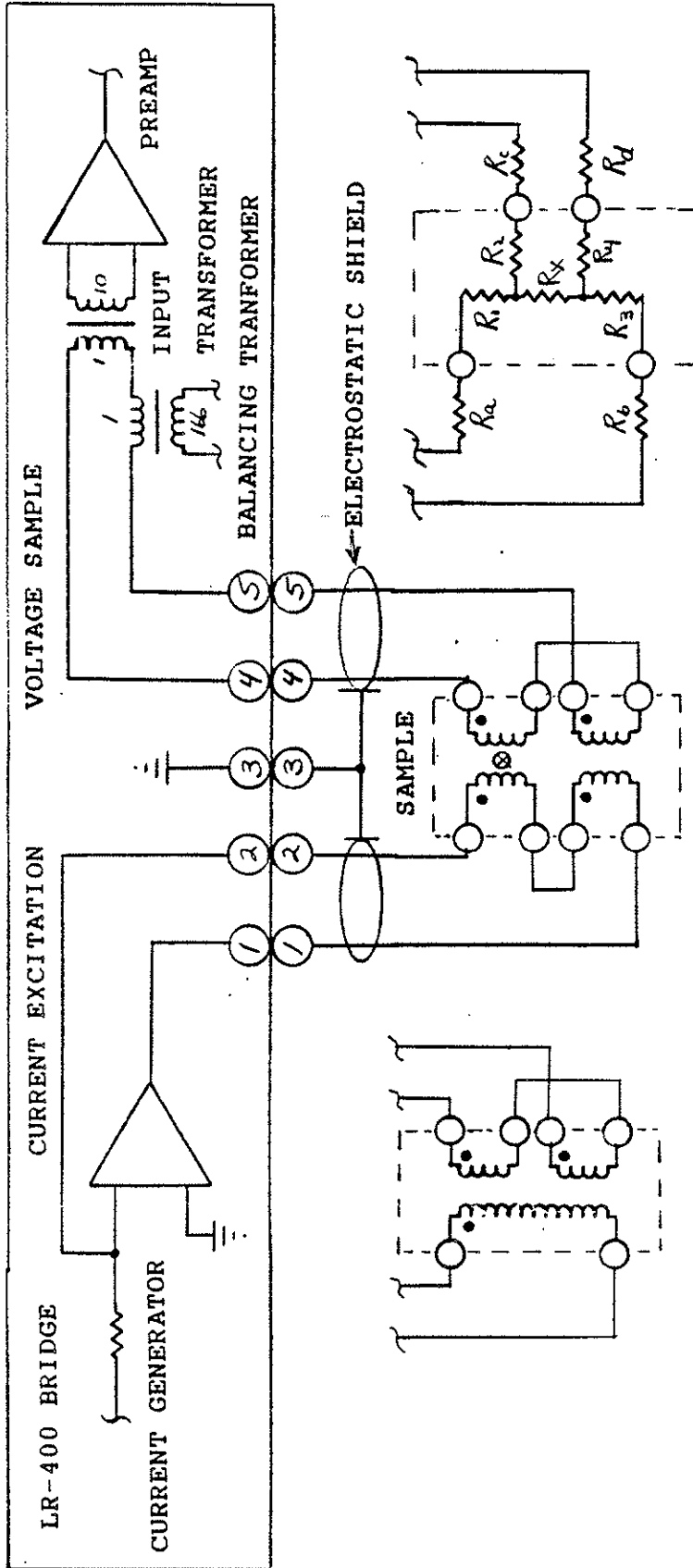


FIGURE 4



MUTUAL INDUCTANCE MEASUREMENT WITH 1 PRIMARY COIL

MUTUAL INDUCTANCE MEASUREMENT WITH 2 PRIMARY COILS

RESISTANCE MEASUREMENT SHOWING LINE & CONTACT RESISTANCE

R_a, R_b, R_c & R_d = CABLE LINE RESISTANCE

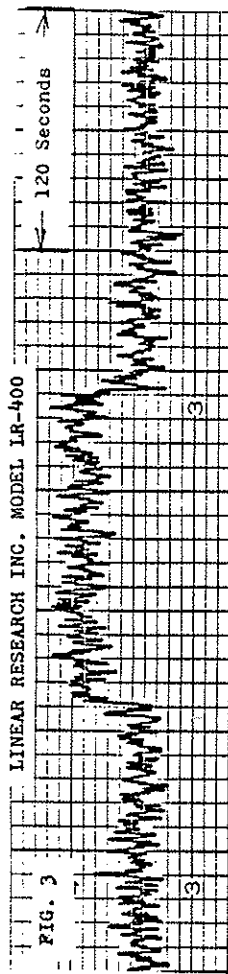
R_1, R_2, R_3 & R_4 = SENSOR CONTACT RESISTANCE

R_x = SENSOR RESISTOR BEING MEASURED

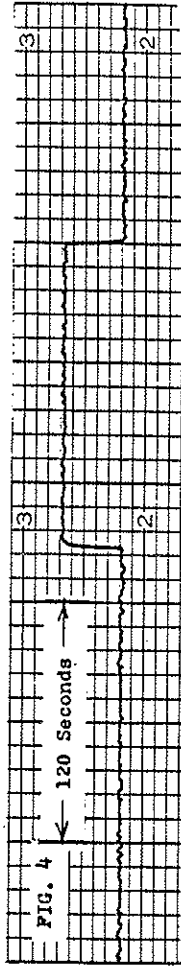
NOTES:

- 1) KEEP THE TWO SHIELDED CABLES SPACED APART FROM EACH OTHER THROUGHOUT THE CABLE RUN.

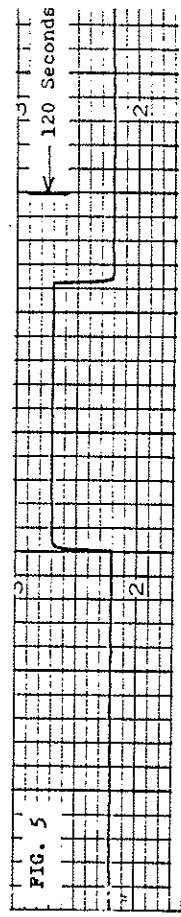
FIGURE 5	8-17-88
LR-400 SENSOR CONFIGURATIONS	
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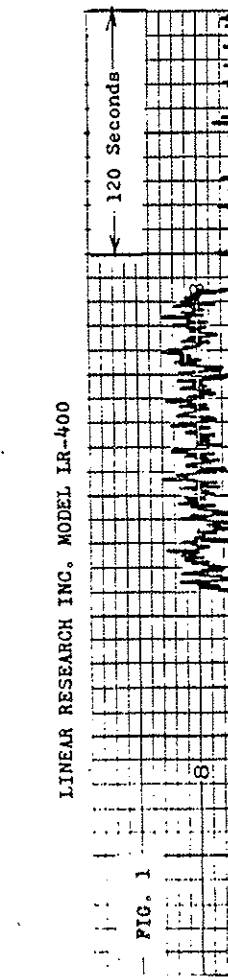
LR-400 Front Panel Settings
 Range 200 OHMS
 Excitation Voltage 0.2 MILLIVOLTS
 Time Constant 1 SECOND
 Set Resistance Dials 10000



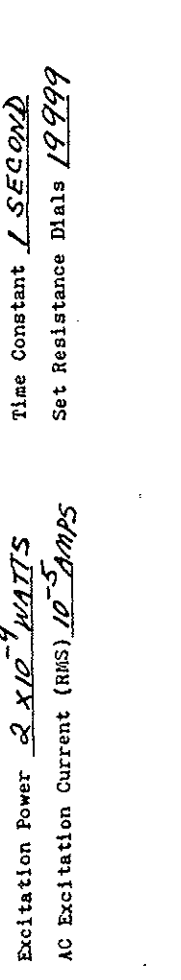
LR-400 Front Panel Settings
 Range 200 OHMS
 Excitation Voltage 2 MILLIVOLTS
 Time Constant 1 SECOND
 Set Resistance Dials 10000



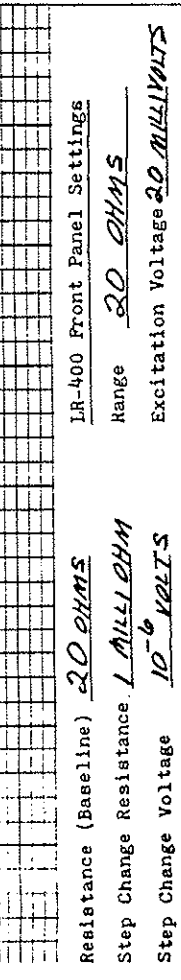
LR-400 Front Panel Settings
 Range 200 OHMS
 Excitation Voltage 20 MILLIVOLTS
 Time Constant 1 SECOND
 Set Resistance Dials 10000



LR-400 Front Panel Settings
 Range 20 OHMS
 Excitation Voltage 2 MILLIVOLTS
 Time Constant 1 SECOND
 Set Resistance Dials 19999



LR-400 Front Panel Settings
 Range 20 OHMS
 Excitation Voltage 20 MILLIVOLTS
 Time Constant 1 SECOND
 Set Resistance Dials 19999



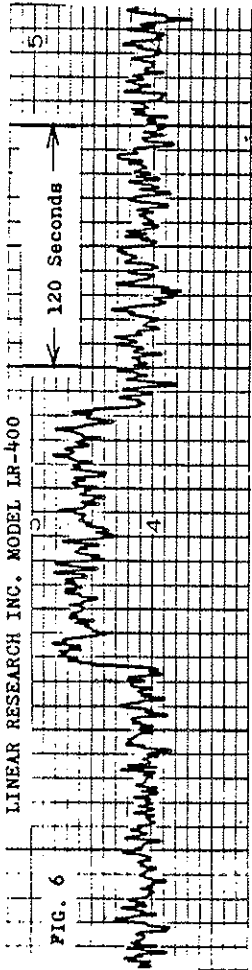
LR-400 Front Panel Settings
 Range 20 OHMS
 Excitation Voltage 1 MILLIOHM
 Time Constant 10⁻⁶ VOLTS
 Set Resistance Dials 10⁻³

Resistance (Baseline) 20 OHMS
 Step Change Resistance 1 MILLIOHM
 Step Change Voltage 10⁻⁸ VOLTS
 Excitation Power 2 X 10⁻⁹ WATTS
 AC Excitation Current (RMS) 10⁻⁵ AMPS

Resistance (Baseline) 100 OHMS
 Step Change Resistance .01 OHMS
 Step Change Voltage 10 X 10⁻⁹ VOLTS
 Excitation Power 10⁻¹⁰ WATTS
 AC Excitation Current (RMS) 10⁻⁶ AMPS

Resistance (Baseline) 100 OHMS
 Step Change Resistance .01 OHMS
 Step Change Voltage 100 X 10⁻⁹ VOLTS
 Excitation Power 10⁻⁸ WATTS
 AC Excitation Current (RMS) 10⁻⁵ AMPS

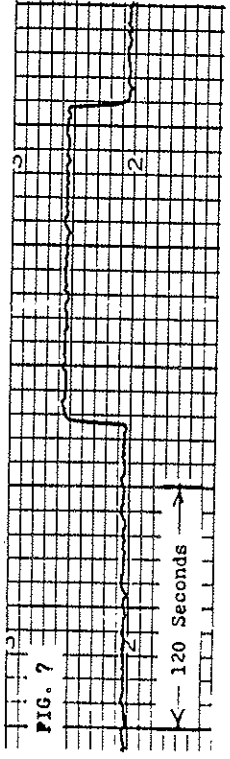
Resistance (Baseline) 100 OHMS
 Step Change Resistance .01 OHMS
 Step Change Voltage 1 X 10⁻⁹ VOLTS
 Excitation Power 10⁻⁶ WATTS
 AC Excitation Current (RMS) 10⁻⁴ AMPS



LINEAR RESEARCH INC. MODEL LR-400

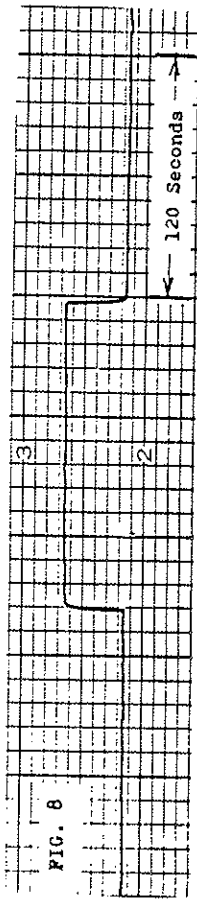
Resistance (Baseline) 1,000 OHMS
 Step Change Resistance 0.1 OHMS
 Step Change Voltage 10⁻⁸ VOLTS
 Excitation Power 10⁻¹¹ WATTS
 AC Excitation Current (RMS) 10⁻⁷ AMPS

LR-400 Front Panel Settings
 Range 2 K OHMS
 Excitation Voltage 0.2 MILLIVOLTS
 Time Constant 1 SECOND
 Set Resistance Dials 10000



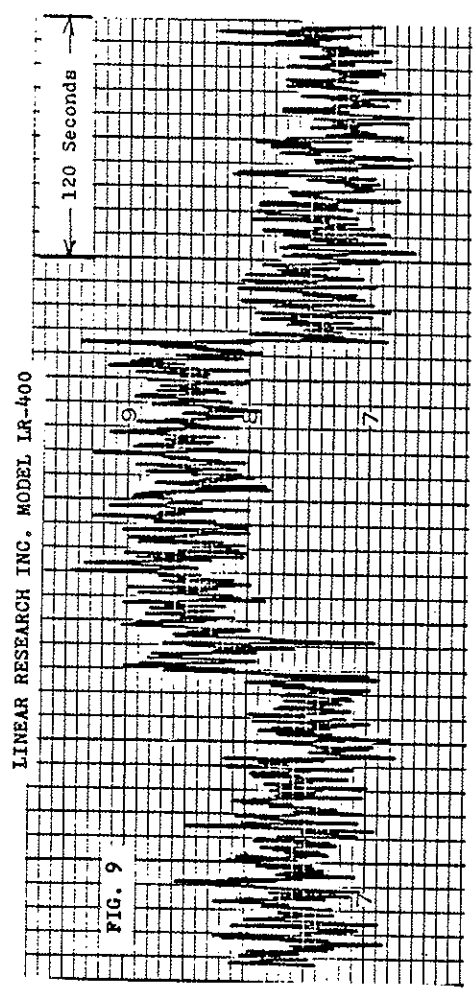
Resistance (Baseline) 10,000 OHMS
 Step Change Resistance 1 OHM
 Step Change Voltage 10⁻⁸ VOLTS
 Excitation Power 10⁻¹² WATTS
 AC Excitation Current (RMS) 10⁻⁸ AMPS

LR-400 Front Panel Settings
 Range 2 K OHMS
 Excitation Voltage 2 MILLIVOLTS
 Time Constant 1 SECOND
 Set Resistance Dials 10000



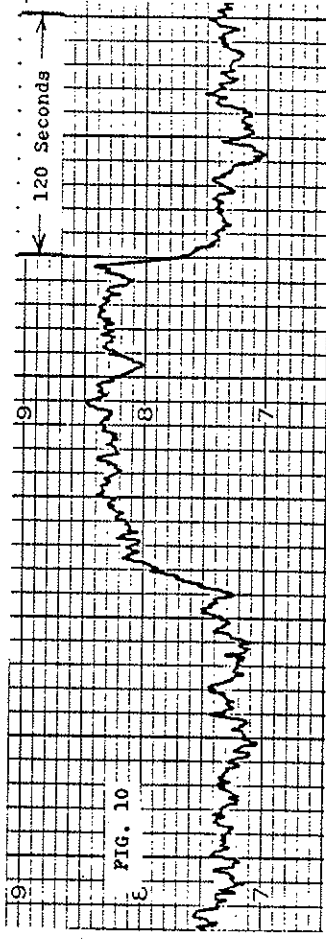
Resistance (Baseline) 1,000 OHMS
 Step Change Resistance 0.1 OHMS
 Step Change Voltage 10⁻⁶
 Excitation Power 10⁻⁷ WATTS
 AC Excitation Current (RMS) 10⁻⁵

LR-400 Front Panel Settings
 Range 2 K OHMS
 Excitation Voltage 20 MILLIVOLTS
 Time Constant 1 SECOND
 Set Resistance Dials 10000



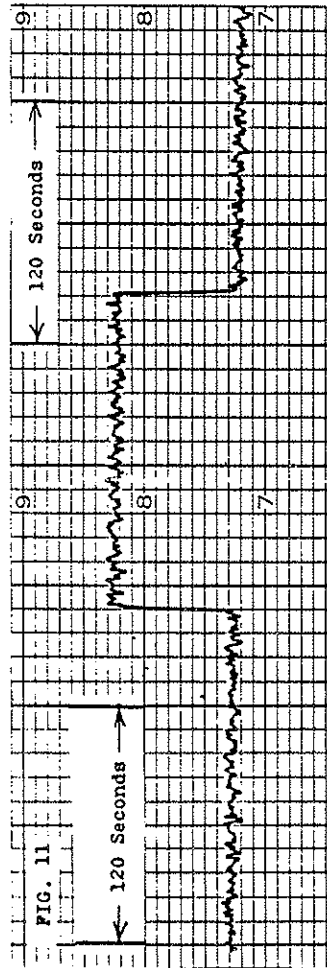
Resistance (Baseline) 10,000 OHMS
 Step Change Resistance 1 OHM
 Step Change Voltage 10⁻⁸ VOLTS
 Excitation Power 10⁻¹² WATTS
 AC Excitation Current (RMS) 10⁻⁸ AMPS

LR-400 Front Panel Settings
 Range 20 K OHMS
 Excitation Voltage 2 MILLIVOLTS
 Time Constant 1 SECOND
 Set Resistance Dials 10000



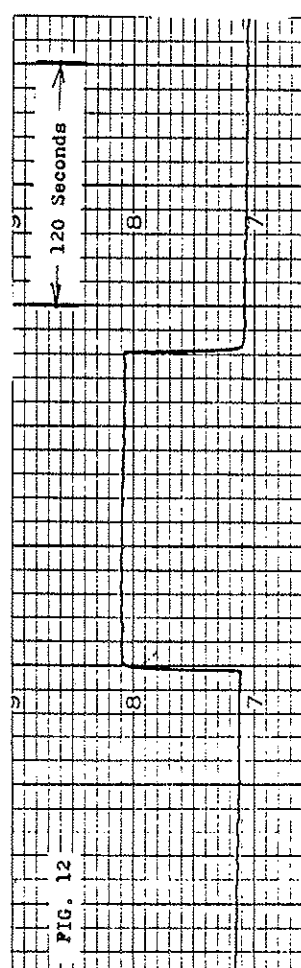
Resistance (Baseline) 10,000 OHMS
 Step Change Resistance 1 OHM
 Step Change Voltage 10⁻⁸ VOLTS
 Excitation Power 10⁻¹² WATTS
 AC Excitation Current (RMS) 10⁻⁸ AMPS

LR-400 Front Panel Settings
 Range 20 K OHMS
 Excitation Voltage 2 MILLIVOLTS
 Time Constant 10 SECONDS
 Set Resistance Dials 10000



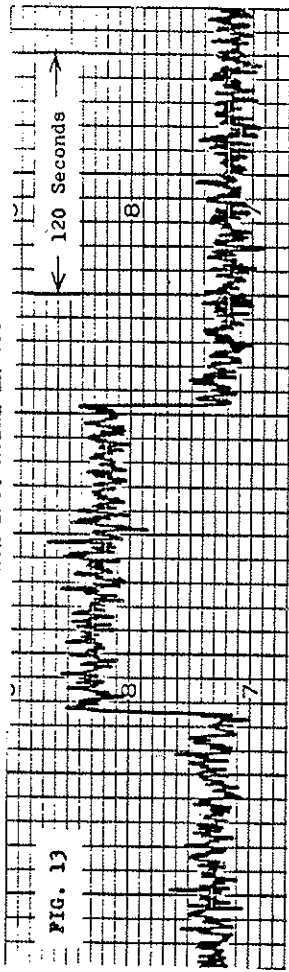
Resistance (Baseline) 10,000 OHMS
 Step Change Resistance 1 OHM
 Step Change Voltage 10^{-7} VOLTS
 Excitation Power 10^{-10} WATTS
 AC Excitation Current (RMS) 10^{-7} AMPS

LR-400 Front Panel Settings
 Range 20K OHMS
 Excitation Voltage 2 MILLIVOLTS
 Time Constant 1 SECOND
 Set Resistance Dials 10000



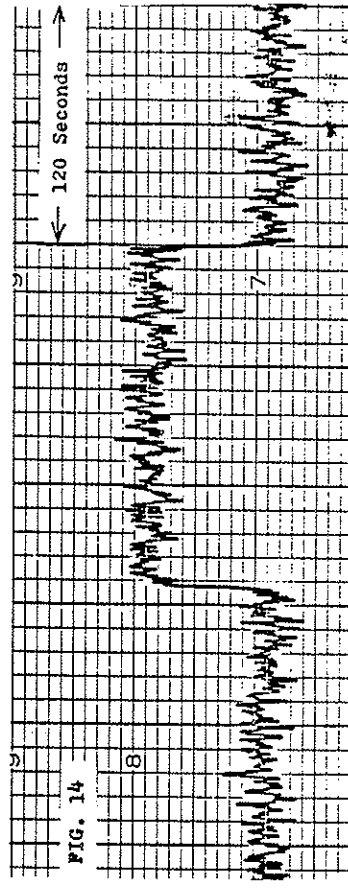
Resistance (Baseline) 10,000 OHMS
 Step Change Resistance 1 OHM
 Step Change Voltage 10^{-6} VOLTS
 Excitation Power 10^{-8} WATTS
 AC Excitation Current (RMS) 10^{-6} AMPS

LR-400 Front Panel Settings
 Range 20K OHMS
 Excitation Voltage 20 MILLIVOLTS
 Time Constant 1 SECOND
 Set Resistance Dials 10000



Resistance (Baseline) 201 OHMS
 Step Change Resistance 2×10^{-6} OHMS
 Step Change Voltage 2×10^{-8} VOLTS
 Excitation Power 10^{-6} WATTS
 AC Excitation Current (RMS) 10^{-8} AMPS

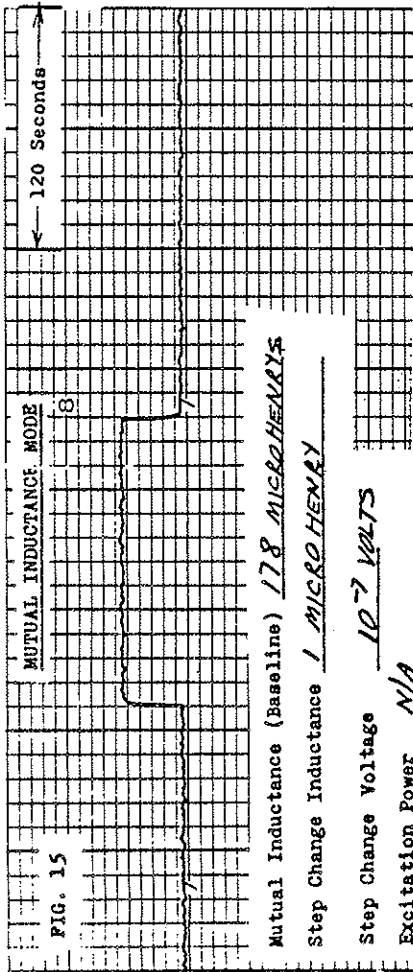
LR-400 Front Panel Settings
 Range 0.2 OHMS
 Excitation Voltage 20 MILLIVOLTS
 Time Constant 1 SECOND
 Set Resistance Dials 10000



Resistance (Baseline) 100,000 OHMS
 Step Change Resistance 20 OHMS
 Step Change Voltage 2×10^{-7} VOLTS
 Excitation Power 10^{-11} WATTS
 AC Excitation Current (RMS) 10^{-8}

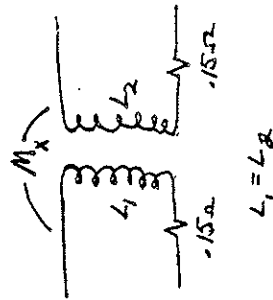
LR-400 Front Panel Settings
 Range 200 K OHMS
 Excitation Voltage 20 MILLIVOLTS
 Time Constant 1 SECOND
 Set Resistance Dials 10000

LINEAR RESEARCH INC. MODEL LR-400



Mutual Inductance (Baseline) 178 MICROHENRYS
 Step Change Inductance 1 MICROHENRY
 Step Change Voltage 10⁻⁷ VOLTS
 Excitation Power N/A
 AC Excitation Current (RMS) 10⁻³ AMPS

LR-400 Front Panel Settings
 Range 2 OHMS (2,000 MICROHENRYS)
 Excitation Voltage 0.2 MILLIVOLTS
 Time Constant 1 SECOND
 Set Resistance* Dials 01180
 (* MUTUAL INDUCTANCE)



Refer to Block Diagram, LR-400

Notice, in the upper left-hand corner, that the 10 volt reference is applied to the multiplier. Assume that the unit is in the resistance operating mode (as opposed to the mutual inductance mode). A digital sinewave is also applied to multiplier #1 from the digital sine/cosine generator, creating a fixed amplitude analog sinewave at the multiplier #1 output.

This sinewave is now fed to attenuator #1. The required value of attenuation is determined by the front panel resistance range and excitation settings. The sinewave output of attenuator #1 drives the current generator that generates a sinewave of current, I_{exc} . This current is fed via pins 1 & 2 of the sensor connector to the sensor resistor R_x at points I_{high} and I_{low} . The current, I_{exc} , fed into R_x is a true AC constant current, and thus is independent of the magnitude of line resistance between sensor pins 1 & 2 and the I_{high} and I_{low} points at R_x .

Across points V_{high} and V_{low} at R_x a sinewave voltage will be generated proportional to I_{exc} and R_x (and, unfortunately, any capacitive impedance, as well, that happens to be in the sensor cable). V_{RX} will be the voltage thus generated. It is sampled and sent back via pins 5 & 4 of the sensor connector to one side of the input of the preamp and to one side of the balance transformer.

Assume for the moment that an almost equal and opposite voltage ($V_{balance}$) is present at the secondary side of the voltage balancing transformer (i.e. $V_{RX} = V_{bal}$). Then the input to the preamp and, in this case the preamp transformer, is essentially a very low level voltage null signal. The input transformer at the preamp and the preamp itself will amplify this null signal by a gain of approximately 100. This amplified null signal is then fed to the tuned amplifier.

The tuned amplifier consists of five stages of tuned amplification, each has a center frequency of 15.9 hertz with an approximate gain per stage of 4, thus giving a total voltage gain for the 5 stages of approximately 1000. This tuned amplifier serves to reject undesirable 50 and 60 hertz power line pick-up and power line harmonics. The front panel controls the attenuator gain, shown connected between the first 2 stages and the last 3 stages of the tuned amplifier. This attenuator will attenuate the signal to yield an optimum net gain through the tuned amplifier for proper closed loop stability of the bridge. This attenuator's gain is fixed for any front panel setting.

The output of the tuned amplifier is fed, simultaneously, to the in-phase phase detector and the quadrature phase detector. The in-phase phase detector in the resistance mode is driven by a square wave in phase with the sinewave present at the output of the #1 multiplier (in-phase with the I_{exc} current). The quadrature phase detector is driven by a square wave 90 degrees out of phase with the I_{exc} current (a cosinewave). The DC components present at the output of these phase sensitive detectors are fed to high gain RC integrators.

The in-phase integrator generates a DC voltage essentially proportional to the resistive amplitude of $-\Delta R$. It is then fed to 3 op-amps. The first inverting op-amp with a gain of -1 combines this $-\Delta R$ with $-R_{set}$ yielding an output of R_x (the resistive component of R_x). Since $\Delta R = R_x - R_{set}$, by definition, then $R_x = R_{set} + \Delta R$. Remember that we are talking about DC voltages now, not 15.9 hertz sinewave voltages.

The second inverting op-amp with a gain of -1 yields an output of $+\Delta R$. The third inverting op-amp has a gain of -10 and yields an output proportional to $+10\Delta R$.

The $-R_{set}$ input mentioned above consists of the sum of an external $-R_{set}$ input at the front panel BNC combined with the $-R_{set}$ DC voltage generator that is controlled by the 5 fingertip operated R_{set} dials on the front panel. These three signals are sent to the solid state selector switch which connects the buffer output amplifier either to R_x , ΔR , or $10\Delta R$. It selects only one of the three and ignores the other two. The buffer amplifier output is sent to a 5 to 1 resistive attenuation network which then drives the display output BNC yielding a full scale span signal of ± 2 volts.

Meanwhile R_x , also called the in-phase feedback signal, is also sent to multiplier #2, the in-phase multiplier. The in-phase multiplier generates an analog sinewave of variable amplitude, proportional to the value of R_x (the in-phase feedback signal). If the in-phase feedback signal is zero, the sinewave output of multiplier #2 is zero. If the in-phase feedback signal is 10 volts (maximum span) then the sinewave output of multiplier #2 is a sinewave of large amplitude. This analog sinewave proportional to the resistive value of R_x is now fed to attenuator #2.

Let us now return to the quadrature phase detector. The quadrature phase detector drives the quadrature integrator. The variable DC output of this integrator is fed to the rear panel BNC as the quadrature output DC monitoring test point signal. If there were no quadrature error associated with the sensor resistor (that is, if there were no distributed capacitance across the sensor cable) this value of

quadrature output voltage would be zero. There is however, always a small amount of capacitance or phase shift present.

This quadrature integrator output signal, now called the quadrature feedback signal is also sent to multiplier #3, the quadrature multiplier. This is driven by a digital cosinewave. The quadrature multiplier generates an analog cosinewave output of variable amplitude depending upon the value of the input quadrature feedback signal. This is similar in amplitude operation to the in-phase multiplier just described. This analog cosinewave proportional to the quadrature value of Rx is now fed to attenuator #3. Attenuators 2 & 3 have gains determined by the setting of the front panel resistance and excitation ranges. These have been optimized for best closed loop response.

Attenuators 2 & 3 drive the summing amplifier. It then drives the primary of the voltage balancing step-down transformer.

The step-down ratio is 166 to 1. This transformer yields, at its secondary, the voltage balancing signal Vbal previously mentioned. Thus the Vbal voltage exactly balances the VRX voltage across the sensor yielding the previously mentioned null voltage at the pre-amplifier input transformer.

Essentially the value of the null signal will be as close to 0 as the DC gains of the in-phase and quadrature integrators will permit, ideally reaching 0 voltage for integrators with DC gains of infinity. The gains of these two integrators at close to DC are in fact greater than 100,000 and are relatively stable with time and temperature. Therefore any error that is present at the preamp will be a fairly stable error and the changes in this error will probably be less than a few parts per million.

Hence we have a theoretical stability of a few parts per million on the basis of the block diagram if we assume that all of the resistors, all of the attenuators, and all of the multipliers are stable with time and temperature. The voltage at the output of the integrators covers the span of ± 10 volts. This value is used because multipliers #1, #2, & #3 can handle a fairly large input voltage and the op-amps, working from a ± 15 volt power supply, can easily deliver ± 10 volts.

Elsewhere in the system the attenuators are of the CMOS integrated circuit type that can handle only a maximum analog signal of ± 8 volts. Accordingly, in this area, sinewaves and cosinewaves are restricted to less than ± 8 volts. Accordingly, in this area, sinewaves and cosinewaves are restricted to less than ± 8 volts. The philosophy has been to try to work with as high an amplitude of analog

voltage as possible within the bridge. It is only after the Rx, ΔR , and $10\Delta R$ selector and buffer amplifier that this signal is attenuated to a 2 volt level. The bridge delivers an output signal that can be easily monitored by an external digital voltmeter that reads 19,999 or 199,999 counts.

But inside the instrument, all DC feedback voltages are based on 10 volts DC equalling full scale for Rx. Thus the $10\Delta R$ BNC test point at the rear panel has a span of ± 10 volts, whereas the display output at the front panel, which is designed to drive an external digital voltmeter, has a ± 2 volt span. Thus when driving a temperature controller, the rear panel $10\Delta R$, ± 10 volt output should be used.

This is also reflected in the fact that the Rset input at the front BNC has a span of -10 volts, and the reference voltage to multiplier #1 is +10 volts. If you were monitoring the DC feedback points to multiplier #2, the in-phase multiplier or multiplier #3, the quadrature multiplier, these signals would have spans of ± 10 volts.

In the mutual inductance or "L" mode (instead of the resistance mode) multiplier #1 is driven by a digital cosinewave. Hence its output is an analog cosinewave. The primary of the unknown mutual inductance is now driven by a fixed amplitude constant AC cosine current source. The secondary of the mutual inductance will generate a sinewave analog voltage proportional to the value of mutual inductance, since $V_x = (I_{exc})(M)$.

Now since I_{exc} is at 90 degrees (a cosinewave) and M is a reactive impedance coupling at 90 degrees, we have two 90 degree phase shifts thus yielding a 180 degree phase shift which now can be processed by pins 5 & 4 of the Vhigh and the Vlow exactly as if this signal were generated by a resistive sensor. The previous discussion holds true in all respects for the operation of the instrument except now the Rx and the ΔR values become M_x and ΔM values, and the quadrature output is now an indication of the resistive losses in the mutual inductance.

Return now to the +10 volt reference source that drives multiplier #1. This +10 volt DC may be varied by the ten turn front panel helipot control called span. Nominal (factory calibration) setting for this control is 500. This can be varied from 000 to 999, thus yielding a change in excitation current of approximately $\pm 1\%$. Thus this acts as a front panel calibration control. For example, the bridge can be made to read exactly 1/2 full scale for a sensor resistor that is over or under 1/2 full scale by 1%.

The 4-1/2 dial set resistance DC generator will not be affected by the front panel span helipot and if it is set to 1/2 scale i.e: "10000", the ΔR and $10\Delta R$ should still read

zero. This is so because, although for simplicity not shown on the block diagram, the Rset DC generator is driven by the output of the +10 volt reference supply. And as the 10 volt reference supply is varied by the span control, so too is the span of the Rset DC generator varied. However, the Rset input from the front BNC will not yield a ΔR or $10\Delta R$ balance if the span is changed from 500, but will show a span error proportional to the deviation of the span setting.

For simplicity the block diagram shows the quadrature correction signal driving the V-balancing transformer. This is true for the mutual inductance mode and the resistance mode lower ranges of .02 through 200 ohms. This is so because sensor cable series inductance/resistance is the main problem for these ranges.

However, when the bridge is operating in the three highest ranges of 2K, 20K, and 200K ohms the quadrature correction is fed to the current generator, since sensor cable parallel distributed capacitance is the main problem for these ranges.

1. In temperature control applications the digital panel meter plays no part other than a voltage monitor. The R-set controls are very stable and offer excellent temperature stability. Changing the "mode" from "Rx" to " ΔR " or " $10\Delta R$ " will not upset the temperature controlled system and is very helpful if one wants to know the actual value of Rx when Rx is not equal to Rset (due to the the thermal system having not yet settled). The rear panel $10\Delta R$ BNC has a span of ± 10 volts. The front panel $10\Delta R$ output has a span of ± 2 VDC. Use the rear panel BNC for temperature control applications.

2. The LR-400 will work directly with Linear Research Model LR-130 Temperature Controllers that have variable DC gain controls (eg: all LR-130 units made after April 1980).

3. The overload light will go on due to open current excitation leads, high AC "IR" drop in the excitation leads, or overload in the quadrature balance circuit. Quadrature balance has the same span as does in-phase balance (eg: the bridge will balance a 20K ohm resistor in parallel with a capacitor whose reactive impedance at 16hz is 20K ohms. For more details see the 402 preamp board description.

4. For improved digital readout connect your stable 5-1/2 digit digital voltmeter to the front panel BNC "display out". Source resistance for this output is 4K ohms. The panel meter is also connected across this point. Your DVM should have $\gg 4K$ ohm input impedance. Most have 1,000Meg ohms on the 2VDC range. See paragraph 9 also.

5. The front panel "span" 10 turn helipot will vary the span of the bridge for all ranges. Thus the display & display out BNC can be made to read 1,0000 VDC on the 200 ohm range for an $R_x = 99.5$ ohms or $R_x = 100.5$ ohms.

6. Digital Panel Meter.

A six page manufacturer's spec sheet of the LR-400's digital panel meter is enclosed. ("Texmate Inc. RP-4500D 4-1/2 digit panel meter").

CAUTION - The digital panel meter (DPM) uses 120 VAC/60hz or 240 VAC/50hz as input power at its rear 15 pin connector. Do not plug this connector in backwards or into the "BCD out option" as this will destroy the panel meter.

7. The bridge itself is quite stable but the built in front panel digital panel meter might show some war-up drift (zero & span) ± 1 count noise.

8. To calibrate the span of the digital panel meter: Disconnect A.C. power cord. Remove red bezel by inserting a screwdriver into the slot under the meter bezel and gently pry upward and outward until the bezel comes away. The span

adjustment is the trimpot in the lower right hand corner. There is no zero adjustment for the DPM itself.

9. ± 2 VDC BNC output source impedance loading. An external device such as a strip chart recorder, DVM, etc. will load this output giving an apparent reduction in "span". If $R_{load} = 10\text{meg ohm}$ the reduction in span is 0.04%.

10. A separate Printed Circuit board extender card is included for troubleshooting.
CAUTION: Plugging printed circuit boards into the wrong slot may cause permanent damage to the boards. Each PC board is labelled with a number (eg: 402 through 407) and the mother board is also labelled with the corresponding number along side the correct connector. Turn power off when removing boards. Turn power on only when all boards are in slots.

11. AUTO-BALANCE MUTUAL INDUCTANCE. READOUT IS IN HENRYS.

MUTUAL INDUCTANCE IN HENRYS FULL SCALE	RESISTANCE RANGE FULL SCALE
200 micro henry	.02 ohm
2 milli henry	2 ohm
20 milli henry	2 ohm
200 milli henry	20 ohm
2 henry	200 ohm
20 henry	2k ohm
200 henry	20k ohm
2000 henry	200k ohm

For high "Q" mutual inductors, when first setting up a new system monitor sensor connector pin 2, the sensor excitation lead, for possible high frequency oscillations. To kill oscillations add a film capacitor across the excitation leads.

Connect the primary of the mutual inductor to sensor pins 1 & 2. Connect the secondary of the mutual inductor to sensor pins 4 & 5. If output polarity is "-" reverse 4 & 5 for a "+" output. Rset dials will work only with a "+" output.

12. The unit has 120 VAC (or 240 VAC) power present on the power supply connectors and at the digital panel meter. It is also present at the rear panel. Be careful.

13. BCD OUTPUT OPTION FOR DIGITAL PANEL METER.

The pin out for the rear panel 25 pin connector for the BCD output option is shown in the following digital panel meter digits out table.

A description of this option ("Texmate RP-4500 BCD parallel BCD output option") is in the DPM manufacturer's four page spec sheet that is herewith included.

SET RESISTANCE/SET MUTUAL INDUCTANCE POLARITY TOGGLE SWITCH

For LR-400 units that include the mutual inductance option a front panel polarity switch associated with the R-set dials is incorporated.

When operating in the resistance mode, this switch must always be set to plus.

When operating in the mutual inductance mode the switch may be set either to plus or minus. The minus setting, in this case, would be used to balance out a negative mutual inductance.

Missetting the toggle switch to minus in the resistance mode might result in error readings on the digital panel meter when Rx values are above midrange and the R-set dial setting is above midrange.

14. DIGITAL PANEL METER - DIGITS OUT TABLE

DB-25 25-PIN REAR PANEL CONNECTOR	15 PIN CARD EDGE CONNECTOR AT THE DIGITAL PANEL METER	NAME/FUNCTION.
1	4	10,000's
2	H	8,000's .
3	F	4,000's
4	6	2,000's .
5	7	1,000's
6	K	800's .
7	J	400's
8	8	200's .
9	9	100's
10	M	80's .
11	L	40's
12	10	20's .
13	11	10's
14	P	8's .
15	N	4's
16	12	2's .
17	13	1's
18	E	Digital Ground .
19	5	Over Range output
20	A	not data Ready output .
21	1	not Print command output
22	D	Polarity output .
23	15	not busy output
24	14	not hold output .
25	R	Output enable (internally grounded).

15. LOGIC CONTROL INPUT OPTION

A category list and pin-out list for the rear panel 25 pin connector for logic control inputs are shown in the following tables.

Apply zero V.D.C. to select the various operating features. Apply +5 V.D.C. to deselect all other lines. +5 V.D.C. must be referenced to ground, pin 25.

Do not make an illegal selection (eg: you cannot select both "1 sec" and "3 sec" at the same time). Also you must make one selection in each category but select only one feature from each category at any one time. Logic "low" (zero vdc) selects the features. Never apply logic "low" to all input lines continuously at once as this might overload the 016 CMOS analog switches inside the LR-400 and cause a device failure.

In the remote mode, when the rear panel DB-25 connector is disconnected, all input logic lines go to "high" and all features are deselected. This should cause no damage to the LR-400. However, when not operating in the remote mode keep the front panel toggle switch in the normal (not remote) position.

To enable the rear panel logic input option the front panel toggle switch must be in the "remote" position. A mating 25 line inside the LR-400 is an input to a 339 comparator device located on the 408 interface board. The loading is thus less than one microamp for each logic line.

16. LOGIC CONTROL INPUT OPTION CATEGORY LIST

Select one line only from each of three following categories of operating features. 0vdc = select, +5 vdc = non-select. No lines may be left open. Apply either 0vdc or +5 vdc to every line.

CATEGORY	FEATURE NAME	REMARKS
A (one line)	RES/MI	zero vdc = resistance mode. +5vdc = mutual inductance mode.
B (three lines)	Rx ΔR 10 ΔR	with mutual inductance mode selected: Rx -> Lx, ΔR -> ΔL and 10 ΔR -> 10 ΔL (L=inductance)
C (four lines)	.3s 1s 3s 10s	
D (six lines)	.06 mv .2 .6 2 mv 6 mv 20 mv	
E (eight lines)	.02 ohms .2 ohms 2 ohms 20 ohms 200 ohms 2K ohms 20K ohms 200K ohms	200 uh } 2 mh } with 20 mh } mutual 200 mh } inductance 2 h } selected 20 h } 200 h } 2000 h }

17. LOGIC CONTROL INPUTS CONNECTOR PIN-OUT TABLE

CATEGORY	DB-25 25 PIN CONNECTOR REAR PANEL	DESCRIPTION
A	1	Resistance/mutual inductance
B	2	Rx
	3	ΔR
	4	$10/\Delta R$
C	5	.3 sec
	6	1 sec
	7	3 sec
	8	10 sec
D	9	.06 mv
	10	.2 mv
	11	.6 mv
	12	2 mv
	13	6 mv
	14	20 mv
E	15	.02 ohms
	16	.2 ohms
	17	2 ohms
	18	20 ohms
	19	200 ohms
	20	2K ohms
	21	20K ohms
	22	200K ohms
-	23	not used (spare)
-	24	not used (spare)
-	25	ground (must be connected to user's power supply ground).

SECTION 400 PLUG-IN BOARD CIRCUIT DESCRIPTION.

<u>BOARD 402</u>	<u>PREAMP</u>	<u>.</u>
<u>BOARD 403</u>	<u>CURRENT GENERATOR</u>	<u>.</u>
<u>BOARD 404</u>	<u>PHASE DETECTOR AND I RANGE</u>	<u>.</u>
<u>BOARD 405</u>	<u>ATTENUATOR</u>	<u>.</u>
<u>BOARD 406</u>	<u>MULTIPLIER</u>	<u>.</u>
<u>BOARD 407</u>	<u>R-SET AND LED DRIVE</u>	<u>.</u>
<u>BOARD 408</u>	<u>INTERFACE</u>	<u>.</u>
<u>BOARD 102A</u>	<u>TUNED AMPLIFIER</u>	<u>.</u>

Board 402 Preamp

As shown on the 401 Mother Board Schematic in the section for the 402 preamp board, the input error signal ΔV , appearing between card edge pins 1 & 3 is derived from the following: The voltage V_X ($v-x$) generated across the sensor resistor due to the excitation current, $I_{excitation}$, ($I_{excitation}$) and an equal and, ideally, opposite polarity voltage $V_{balance}$ ($V_{balance}$) from T2, the voltage balancing step-down transformer.

This ΔV signal is fed to the 402 board, goes to field effect transistor pair Q3A/Q3B, for the 200 Kilohm range, or through a series of reed relays to T1 the input transformer for all other resistance ranges.

The relays connect the dual primaries of the input transformer T1 to a parallel mode for the lowest ranges .02 through 2K ohms and to a series mode for the higher ranges. This gives the lowest noise on the lowest ranges (input resistances of the primary windings are in parallel, minimizing Johnson voltage noise) and in the higher ranges 20K & 200K ohms it affords a larger input transformer inductance by placing the windings in series mutually coupled additive. This ladder case gives a high inductive reactance, thus minimizing the loading of Rx.

The secondary of this input transformer T1 couples the signal to field effect transistor pair, Q4A/Q4B, that act as high input impedance buffers. These drive push-pull differential amplifier, op-amp 21. Then op-amp 22 resolves this push-pull signal to a single-ended signal referenced to ground via 4 each 10K 1% resistors.

In the next stage, solid state switch 24, under control of logic, accounts for the fact that on the lower ranges the transformer voltage gain is twice as large as on the higher ranges because the primary windings are in parallel. Thus, in the lower ranges .02 through 2K, the signal is picked off at chip 24-11 (attenuated by 1/2). On the higher ranges, 20K & 200K, the signal is picked off at chip 24-8 (no attenuation).

Op-amp 23 acts as a buffer amplifier, sending its output signal via board pin 45 to the tuned amplifier board 102A. The logic controlling the reed relays that connect the input transformer primary windings in parallel or in series is via buffer chip 18. Input logic signals drive that device from board pins 37 & 38.

Device 19 and 20 are used to monitor overload conditions and turn on the front panel overload light emitting diode (LED). This overload can be due to either:

1. An excessive voltage present at the current sample, which

comes from the current generator board 403, caused by an overrange Rx or an open sensor lead, etc.

2. A quadrature overload signal from the phase detector board 404, caused by the quadrature integrator locking up, due to excessive resistance in mutual inductance mode, or the reversal of the sensor connector leads in the higher ranges of 2K, 20K, & 200K ohms, example:

correct: J1-1 to J1-4 at Rx top
 J1-2 to J1-5 at Rx bottom
wrong: J1-1 to J1-5 at Rx top
 J1-2 to J1-4 at Rx bottom

This is because quadrature correction feedback is via the Iexcitation channel and if in the "wrong" hook-up, as shown above, the net feedback is positive thus causing the quadrature integrator to eventually lock-up at the power supply rail. Also, when in the "wrong" hook-up, the front panel digital panel meter & B.C.D. output signal polarity will read negative instead of positive when measuring resistance.

3 .An overload condition on the dual input field effect transistor Q3 when the unit is operating on 200,000 ohm range. There are no trimpots or adjustable controls on this board. When troubleshooting this board note that chips 19 & 20 have their outputs in parallel so a fault in this area could be caused by either chip. Replace both if one is bad. Use an ohmmeter across the relay contacts K7 through K10 to check relay operation.

Take care if replacing the relays to be sure that new relays are installed with regard to proper pin-out polarity. (Labeling on relays when correctly installed will read upside down).

Board 403 Current Generator

As shown on the mother board schematic, the current generator board 403 accepts input sinewave signals (at board edge pins 24---38 from the I-range board 404, and logic inputs from the logic bus at board edge pins 33---34. Board 403 generates the excitation current used to excite the sensor resistor.

For the higher resistance ranges (200 ohms through 200 kilohms) the input signals are fed through precision high value current determining resistors (3.32 kilohms---33.2 meg ohms) by reed relays to the summing junction of the current generator op-amp chip 11 creating a precise and stable excitation current Iexcitation.

The relays K3 through K6 are selected by reed relay driver chip 17 depending upon the input range logic. The current generator op-amp configuration includes amplifiers 11, 12, 13, 14 & 15. Op-amp 11 is a field effect transistor op-amp buffer that is used to assure that the input to this amplifier configuration has a very low excitation error input current at the summing junction.

Op-amp 12 acts as the main voltage gain portion of the configuration in that it has high voltage gain at 15.9 hertz, whereas op-amps 13, 14, & 15 act as parallel unity voltage gain buffers that generate sufficient current for the 10 milliamps RMS (\pm 14.1 milliamps DC) current ranges.

Should the sensor connector lines from board pins 2 & 5 to the sensor resistor Rx be open, or an excessive sensor resistance or line resistance for that range be present, board pin 6 will experience an excessively high voltage signal. This signal is sent to the preamp at 402-40 as an overload sample signal to light the front panel overload LED.

For the four lower ranges (.02 ohms through 20 ohms) a slightly different set-up is used. Instead of a single resistor to determine the excitation current to the summing junction, the current is determined by a feed-back array. In the case of the 20 ohm range, the current determining resistor is 3.32 Kilohms, a resistance not large compared to the on resistance of reed relay K2 that connects to the main op-amp summing junction.

Thus we use op-amps 7, 8 & 9 to assure that the current is based only upon the 3.32K resistor itself and none of the external spurious resistances. Solid state switch 10 is used to assure that this current will be sent to power supply ground when the 20 ohm range is not selected (K1 open).

Similarly for the lowest three ranges of .02, .2, and 2 ohms the input signal at pin 38 is processed by the circuit composed of chips 1, 2, 3, 4, 5 & 6 and the 332 ohm resistor. This assures that the current into the summing junction of the main op-amp is determined solely by the 332 ohm resistor and not by any other spurious resistances such as the K1 on resistance.

In the upper part of the schematic the eight diode array is used as a voltage clamp. When the sensor resistor Rx is open, or very large the voltage present at the summing junction of the main op-amp chip 11 is clamped by these diodes and doesn't give large voltage swings that could possibly damage solid state switch 10.

There are no alignment controls on this board.

When troubleshooting this board use an ohmmeter across the relay contacts K1 through K6 to check relay operation. Take care if replacing the relays to be sure that new relays are installed with regard to proper pin-out polarity. (labelling on relays when correctly installed will read upside down).

Check also that the op-amps used in parallel to generate high excitation currents (op-amps 13, 14 & 15 and 2, 3, & 4) are not locked up at one of the power supplies rails or that their outputs have not shorted. If one is bad, or runs hot to the touch, replace all three. We want to be sure that the current is equally shared between the three op-amps that are connected in parallel.

Board 404 Phase Detector and I Range

There are two distinct portions or features on this board. On the right hand side of the 404 board schematic is feature 1, the I range (current range) section. Here the current excitation signal, at board edge pin 20, from the 405 attenuator board, is used to drive the circuits for calibrating all eight of the resistance ranges.

The 8 each ten turn mother board mounted potentiometers that are used for this calibration are shown inside a dashed line block. As shown on the mother board schematic, the output of the 405 attenuator board on 405 board pins 39 & 40 are used to drive the 8 range calibration ten turn pots on the mother board.

These pots are driven in parallel and their wiper arms are fed to 404 board pins 45, 44, 22, 21, 24, 25, 23 & 43. These signals are combined with the main current excitation signal from board pin 20 via the 1K and the 37K (36.5K) resistor networks selected by the range logic. These calibrated signals are then delivered through buffer op-amps as output signals that will drive the current generator board 403.

An interesting feature of this section of board 404 is that for the three lowest ranges of .02, .2 & 2 ohms, pin 42 delivers the signal for all 3 ranges. Hence op-amp 25 is configured for three different selectable voltage gains. The gain selected is determined by the bridge's resistance range and excitation range. The 11.7K, 1.17K, and 130 ohm resistors give the required gain and are selected by chip 20 and 21.

There are no adjustable controls to align in the I range section of the 404 board. Troubleshooting this section is straight forward. Check the outputs of all the op-amps to be sure that none of them are defective (locked-up at a supply rail voltage).

On the mother board schematic the phase detector section (which is feature 2 of board 404) is shown in block diagram outline separate from the I range section of board 404. The signal from the tuned amplifier coming in on board pin 1 is buffered with op-amp 1. Another amplifier, op-amp 2, gives an inverting unity gain signal which is used to drive both the in-phase (zero degree) and the quadrature (90 degree) phase detectors both on chip 4.

These phase detectors are driven in the proper phase by logic signals from the multiplier board coming in on pins 3 & 4. The quadrature, 90 degree, or co-sine, phase detector is used to drive integrator op-amp 3 which has an integrator

time constant of 0.33 seconds composed of a 330K resistor and a 1 microfarad capacitor.

The output of op-amp 3, board pin 2, is the quadrature feedback signal which is sent to the multiplier board to drive the quadrature multiplier. This signal is also sent to the rear panel quadrature output BNC which is a ± 10 volt monitoring point. This signal is also sent to the preamp board to be monitored as an overload LED drive signal.

The in-phase, zero degree, or sine, phase detector signal is sent to integrator op-amp 7 which has a time constant variable from 0.33 to 10 seconds. This time constant is determined by the 10 microfarad capacitor shown and one of the four resistors which have values ranging from 33K to 1 megohm. The two diodes shown force the time constant into the 0.3 second mode for large signal charges.

The front panel filter time constant switch determines which one of these resistors is selected. For clarity, the front panel filter time constant switch and the polarity of the signal from it are shown on the left hand side of the 404 schematic. Of course, what is not shown in this schematic area is that when the digital interface board is a selected option the filter time constant logic signals will pass through the 407 board.

In-phase integrator op-amp 7 has a zero voltage off-set trimpot control R7. The output of op-amp 7 is the $(-\Delta R)$ signal which drives op-amps 8, 9, and 10 to give signals for $(+RX)$, $(+\Delta R)$ and $(+10 \Delta R)$, respectively.

Op-amp 8 has two other inputs. One is the internal Rset (R-set) signal coming from the R-set board 407 which is derived from the front panel finger-tip operated R-set rotary switches. The other input is the external Rset signal coming in on pin 12 from the front panel R-set input BNC. The internal and the external Rset signals both have spans of 0 to -10 volts.

The output of op-amp 8 is also sent as a voltage feedback signal on board pin 10 to the Vbalance multiplier on the 406 multiplier board. These three signals are sent to device 12, which acts as a 1 pole 3 position solid state switch. This switch selects either the RX , ΔR , or $10\Delta R$ signal and feeds it to unity gain buffer 13. Chip 13's output signal span is ± 10 VDC. This ± 10 VDC is then reduced by resistor chip 16 to a ± 2 VDC signal. This ± 2 VDC signal is sent from board pin 13 to the front panel digital voltmeter. This signal is also sent to the front panel BNC output labelled "display out ± 2 VDC".

Op-amp 9, with a gain of minus 1 simply inverts the $(-\Delta R)$ signal. Trimpot R9 between the two 15K resistors will

allow this op-amp to have its gain trimmed to the nominal value.

Op-amp 10 has a gain of 10 determined by resistor chip network 14 and generates the (+10 ΔR) signal from the (- ΔR) signal. The trimpot labelled R10 serves to trim this gain to the nominal value of 10, this is described in the alignment procedure. The 10 ΔR signal is sent on board pin 9 to the rear panel 10 ΔR BNC output. Since this is a ± 10 volt signal it can be used to drive temperature controllers or other external apparatus with a full ± 10 volt span.

The ± 8 VDC logic signals for RX, ΔR , and 10 ΔR mode selection at board pins 14, 16, & 15, are coupled through diode and resistor networks to give the required 0 to +5 VDC voltage swing for driving chip 12.

The alignment procedure includes a procedure for adjusting the three trimpots R7, R9, & R10 mounted on the 404 board. For de-bugging this section of the board check the outputs of all op-amps to be sure they are not locked up at a power supply rail.

Board 405 Attenuator

As shown on the 401 mother board schematic, the 405 attenuator board accepts the three signal inputs from the 406 multiplier board, and under control of the logic bus, attenuates these signals as required to yield correct values of excitation current and balancing voltage.

Three attenuator circuits are present on the 405 board: the I_{exc} current excitation attenuator, the $V_{balance}$ attenuator, and the tuned amplifier attenuator. The tuned amplifier attenuator is used to maintain proper system gain under closed loop feedback stability.

The logic bus signals, shown in the upper left hand corner of the 405 schematic, are fed to chips 1, 2, and 3 which are tri-state hex buffers. Their function is to generate a pseudo-bus similar to the excitation logic bus. For logic buss signal notation: 6a means that "6 millivolts" has been selected on the front panel excitation rotary switch.

Note on the front panel chart of the LR-400 instrument that when operating on the .02 and 2 ohm ranges, the excitation current for certain excitation voltage selections reaches a maximum limiting value of 10 milliamps.

Now, if the current increased as it did on the 2 ohm range the chart for the .02 ohm range should read 3K, 10K, 30K, 100K, 300K and 1000K milliamps. But The LR-400 can not do that because the output current generator on the 403 board is not capable of delivering more than 10 milliamps RMS. Thus the function of the logic buss to pseudo-buss converter circuitry on this board must be to limit the maximum excitation current to 10 milliamps as per the excitation chart.

For instance, if we have selected 6 millivolts excitation and are on the .02 ohm range the input logic at board edge pin 7 and the range logic at pin 3 of the 405 board will give logic one (+8VDC) signals labelled 6A and .02. The logic one on the .02 signal, fed into pin 6 of chip 5, will activate the tri-state buffer chip 3. On chip 3 notice that output lines of 12 millivolts, 6 millivolts, 2 millivolts, and 600 millivolts will all be at logic zero, meaning that they will all be inhibited, thus allowing only the 200 microvolt (.2mv) logic line to be selected. This will determine the correct balancing voltage range and excitation attenuator setting.

In a similar fashion the other tri-state buffers, chips 1 & 2 make selections. Chip 2 makes the selection for the .2 ohm range and chip 1 for the 2 ohm through 200,000 ohm range. Note that when chip 1 is used the regular logic bus

sends signals directly to the pseudo bus (logic buss=pseudo buss) on this board.

The ten turn excitation alignment pots shown on the mother board are shown again on the schematic for board 405 for clarity. The 5 pots are driven in parallel from op-amps 22 & 40. The required excitation pot's wiper arm is selected via the solid state switches 6 & 7 by the pseudo logic bus signals for excitation. The signal from the wiper arm selected goes to buffer op-amp 20. These signals make a small percentage correction on the main I excitation signal input, at board pin 43.

On the lower ranges from 20 milliohms through 200 ohms the quadrature compensation is implemented by adding a compensating quadrature voltage in series with the in-phase balancing voltage. While the excitation current is held constant at its fixed in-phase value. Thus on the higher ranges adding capacitance across the sensor resistor will not affect the bridge resistance reading.

"Iexc sig in", the I-excitation signal, is buffered through op-amp 40, and combined with the signal from op-amp 20 in the summing op-amp 21, with the summing resistors in the R1 network and the 150K 1% resistor. Under conditions where the quadrature signal must be summed with the current attenuator and be used as a quadrature correction in the excitation current, the quadrature signal, board pin 35 via analog switch sections on chip 13, is channeled into the I excitation attenuator.

Analog switch 13 is under the logic control of the quad V/I logic signal coming in on pins 31 & 34. Quad V/I logic signal is fed through solid state switches 12 to drive analog switch 13. If quadrature signal is channeled to the I excitation attenuator it goes from analog switch 13 to op-amp 29 and then summed, through the R1 resistor network, with the other inputs to op-amp 21.

The quad signal is always under the control of the quad V/I logic which was derived from board 407, the Rset and LED drive board. The quadrature signal is sent to the I excitation channel for the 2000 ohm, 20,000 ohm and 200,000 ohm ranges.

For all the lower resistance ranges from .02 to 200 ohms and in the mutual inductance mode, the quadrature signal is sent to the Vbalance channel, once again by operation of the quad V/I logic on pins 31 & 34 and the solid state switches 12 & 13. The Vbalance attenuator receives its main signal from pins 36 & 37 labelled Vbalance signal in, these come from the 406 pin 37 multiplier board. Buffer op-amp 28 and inverting op-amp 32 allows the quad signal to reach the V-

balancing channel by combining in resistor network R2, with the Vbalance signal in via op-amp 25.

The excitation attenuator is driven from op-amp 21 and the magnitude of the signal is selected by solid state switches 7 & 8 and fed through buffer op-amp 24 out through pin 38 as the I excitation signal out. Op-amp 41 acts as an inverting buffer to drive the resistance range ten turn pots. In a similar fashion, the Vbalance attenuation network, receives its signal from op-amp 25 and is selected by solid state switches 9 and 10, to drive buffer op-amp 31 which drives inverting op-amp 26. Op-amp 26 drives board pin 42 which drives the Vbalance step down transformer. Buffer op-amp 27 isolates analog ground from high signal currents.

In a similar fashion, the tuned amplifier attenuator is driven by solid state switches 11 & 12 to send the input signal present on pin 24 through buffer 30 to output pin 26 once the signal is sent back to the output stages to the tuned amplifier.

On the 405 board there are no trim pots or alignment controls, of course the five ten-turn pots on the mother board show on the left hand side are used to set up the excitation ranges and that is covered in the alignment procedure. Note that there is not a 20MV ten turn excitation calibration pot.

When troubleshooting this board, check all the op-amps to be sure that none of their outputs are at the power supply rails. Some of the solid state switches are paralleled, such as switches 7 & 8 and switches 9 & 10. If you find trouble in that area, try replacing both switches at once.

The 503 buffers all have their outputs in parallel, one of which is selected in the 'on' condition and the other two are in the tri state high impedance 'off' state. If you have, or suspect, trouble with these chips replace all three at once.

Shorted attenuator switches might also give rise to clipping of some of the signals out, consequently, an oscilloscope can be used to monitor pins 38, 42, and 26 to be sure that the signals look like good sinewaves and are not clipped.

Board 406 Multiplier

As shown on the 401 mother board schematic the 406 multiplier board accepts three input signals: from the quadrature phase detector pin 29, from the in-phase phase detector pin 26 and from the 10 volt buffer voltage pin 30, board 406 generates sinewave signals proportional to the amplitude of these three variable DC analog input voltages.

Referring to the 406 board schematic in the upper left hand corner, a crystal oscillator of 4.1722 megahertz chip 1 is down counted by chips 2, 3, & 5 and then drives the programmable read only memory (PROM) chip 8. Chip 8 is programmed at Linear Research in an in-house proprietary manner to generate the digital sine and cosine drive for the 3 multipliers.

The dual one-shot chip 7 assures that the output of the PROM is properly held in octal registers 10, 20, & 30. A logic signal entering in the left side of the schematic on pins 35 & 6, whose logic state is dependent upon whether the instrument is in the resistance or the mutual inductance mode, allows multiplier chip 31 to receive either the digital sinewave signal or the digital cosine signal from the PROM.

Chip 31 originates the current excitation analog signal, I excitation, and in the resistance mode this chip will generate a sinewave analog signal. In the mutual inductance mode it will generate a cosine analog signal. This is because the balancing voltage V balance being a sinewave signal requires that the current excitation voltage be a cosine so that the induced voltage at the secondary of the unknown mutual inductance will be in phase with the balancing voltage.

Chip 9 is a logic array that assures that device 30 receives either the digital sinewave or the digital cosinewave drive. The diode resistor network, composed of the diode, the 39K resistor, and the 56K resistor assures that the signal present on pin 35, which nominally is $\pm 8\text{vdc}$, is converted to $0/+5\text{vdc}$ to drive chip 9 properly.

All the chips from the left hand side of schematic 406 to the center, work with a $0/+5\text{vdc}$ logic levels. These are chips 1, 2, 3, 5, 6, 7, 8, 9, 10, 20 and 30. The PROM chip 8, requires power supply voltages of $\pm 5\text{vdc}$, and $+12\text{vdc}$. In the bottom left hand corner of the 406 schematic, three terminal regulators 7805, 7812, & 7905 furnish these voltages from the $\pm 8\text{vdc}$ and $+15\text{vdc}$ power supply busses.

In the center of the 406 schematic, portions of buffer 6 send square wave logic signals to board pins 7 & 8 for driving the in-phase phase detector and the quadrature phase

detector on the 404 board. These square wave signals with logic levels of 0/+5vdc are exactly in phase respectively with the sinewave generator and the cosinewave generator.

The multiplying digital to analog converter chip 11, labelled Vbalance multiplier, receives its input analog signal from board pin 26. An analog sinewave is generated by chip 11, the amplitude of which is dependent upon the value of the DC analog signal at pin 26.

If this signal (pin 26) is +10 chip 11 will generate a sinewave of +10/-10 volt peak to peak amplitude. If this signal (pin 26) is 0 vdc, the sinewave will have 0 volt peak to peak amplitude. If it is -10 volts the sinewave will once again have a +10 /-10 volt peak to peak amplitude but be inverted by 180 degrees. Op-amps 12 & 13, in conjunction with the R12 network serve to generate this sinewave.

The sinewave at the output of device 13 has a number of staircase steps on it as a result of the logic drive from chip 8, the programmable read only memory device. These staircase steps are filtered by low pass filter op-amps 14 & 15. At the output of op-amp 15, a sinewave of maximum amplitude of +10/-10 volts peak to peak could be present.

R-13 attenuates the amplitude of this sinewave by about 50%. It is then buffered through op-amp 16 and sent out at pin 37 to the attenuator board 405. This signal at pin 37 was attenuated so as not to over load subsequent solid state switches of the 016 variety on the various other boards. The 016 CMOS solid state switch can only accept signal levels of ± 8 vdc maximum.

Op-amps 12 & 13 require zero offset trimpot controls.

In a similar fashion the quadrature MDAC chip 21 generates a cosinewave at the output of op-amp 23. Once again two trimpots are used here to zero the offsets in op-amps 22 & 23. This signal is then fed through a similar low pass filter (op-amps 24 & 25) as was done in the Vbalance multiplier to eliminate staircase steps. The signal is available at pin 38 as a quadrature signal output.

In the Iexcitation channel, the input signal at board pin 30 is fixed at approximately +10 vdc, derived from the Ref 01 10 vdc reference chip, chip 14, on the Rset and LED board 407, shown also on the mother board schematic. Since this signal will always give a high level output of either sinewave or cosinewave, depending only on resistive or mutual indicative mode no trimpot off-set controls need be used on op-amps 32 & 33. This signal is sent through similar low pass filters and attenuating networks, as in the other two channels, and thus it is available on pin 39 as the current generator signal output.

Setting The four trimpot controls for the quad multiplier channel and Vbalancing multiplier channel is described in the alignment procedure.

When troubleshooting this board, check the outputs of the three terminal regulators 7805, 7812, 7905 for proper voltages. Check the output of op-amps 13, 23 & 33 for analog sinewaves and cosinewaves and then check all other op-amps at their outputs to be sure that none are locked up at the power supply rails.

Board 407 R-set and LED Drive

This board has two separate sections. The first section is the DC analog circuitry that generates the R-set analog voltage from the 4 1/2 dial (actually 5 dials) finger tip front panel controls. This is shown in the upper half of the schematic. The second section shown in the lower half of the schematic has logic circuitry that generates the light emitting diode LED signals and the decimal point relay closures for the front panel digital panel meter.

In the LED drive section, on the lower left hand side of the schematic, the logic bus signals are entered through logic control chips 20, 22, 23, & 21. Signals called A, B, C, D, K, ohms, & M, are generated. These are a function of the particular resistance range selected and they are sent to hex buffer 25 to drive the six light emitting diodes on the front panel.

These LED's indicate kilohms, ohms, or milliohms and the decimal point location for the 4-1/2 R-set front panel dials. Two 1.8K resistors in parallel are used to generate the correct LED drive current. Relays K1 through K4 are used as switch closures to select the proper decimal point location in the front panel DPM.

Hex buffer 26 determines which relay is closed based on logic bus signals A, B, C, & D. These signals are also dependent upon whether or not the unit is operating in the ΔR or $10\Delta R$ mode. In the $10\Delta R$ mode the decimal point on the digital panel meter is shifted one place to the right. Board pin 23 receives the inverted $10\Delta R$ signal. $10\Delta R$ is fed to the logic control networks at chips 22 & 23 to generate the correct relay closure to shift the decimal point on the DPM.

Another feature of this board is the generation of the logic quadrature control signal to be used to feed the quadrature analog signal either to the current generator or to the Vbalancing transformer on board 405 as shown on the mother board schematic. The input at pin 26 is dependent upon whether the LR-400 is in the resistance mode, or in the mutual inductance/lower resistance mode ranges.

When the bridge is operating in the resistance mode and on the three highest ranges of 2K, 20K, and 200K ohms the quadrature correction is fed to the current generator, but in all other modes the quadrature correction is fed to the V-balancing transformer. Two sections of chip 23 and all of chip 24 perform this logic "or" selection function. The resulting logic output signal is fed to pin 25, labelled "I Mode Out". It is then sent to pin 34 on the 405 attenuator board.

There are no trim controls in this logic section of the board and when trouble shooting this section, check for relay closures with an ohmmeter. Use an oscilloscope for checking logic levels on the logic chips.

Now describing the R-set section of this board, note that the five front panel R-set switches are shown in an inset on the 407 board schematic for clarity. These five dials are also shown on the 401 mother board schematic inside the 407 R-set sub-block.

The most significant digit (MSD) can be set to 0 or 1 only. This most MSD Rset dial is labelled Rset 104. The next 2nd most significant digit is labelled Rset 103, etc., and the least significant digit (LSD) is labelled Rset 100.

Two different techniques are used. For the three most significant digit switches, since these require the highest degree of precision, buffer op-amps are used in a pseudo Kelvin-Varley circuit arrangement to pick off the three most significant digits. For the least significant two digits a simple summing amplifier with feed back around it is used.

These two DC signals are combined in op-amp 7 through a weighted summing resistor network chip 8 to give the required output voltage on board pin 12. This internal R-set signal has a span of 0/-10vdc and is sent to the phase detector board 404.

In the upper left hand corner of the schematic chip 14, generates a precision and stable +10 vdc. The front panel 10 turn span control can vary this voltage by a small percentage. This control is shown for clarity in the upper left portion of the 407 schematic connecting to board pins 2, 3 & 4. Pin 5 of the board sends this approximate 10 volt DC signal to the 406 multiplier board as the DC analog input for the I excitation multiplier.

This 10 volt signal is also sent to op-amps 1 & 2 to generate +12 VDC and +8 VDC so that the ten turn R-set span control pot shown on the inset between pins 6, 7 & 8, (mounted on the mother board) can vary the approximate +10 vdc output of chip 14 to generate the Rset span control DC reference voltage present at the output of op-amp 4. A 1K and 20K ohm summing resistor network at op-amp 4 perform this function.

This R-set DC voltage which is approximately +10 vdc is then sent to the Rset 104 switch, then voltages are picked off from this switch on its wiper arms and are sent to the Rset 103 switch through 2 buffers, op-amps 9 & 10, and in turn picked off from the wiper arms and sent to 2 more buffers, op-amps 11 & 12, to the Rset 102 power switch, the single

wiper arm of which is buffered through chip 13 and is fed back to the summing op-amp 7.

Meanwhile the very same R-set DC voltage at the output of op-amp 4 is inverted to -10 volts through op-amp 5 and sent to op-amp 6 to generate at the two least significant digits controlled by Rset 101 and Rset 100. R6 is the trimpot used to trim the two least significant digits to conform to the span of the three most significant digits. The R7 trimpot is used to trim the zero offset of op-amp 7.

The two trimpots R6 & R7 are the only controls present on this board. The method for adjusting these is described in the alignment procedure. Of course the Rset span control is on the mother board and it is also described in the alignment procedure.

When troubleshooting The Rset section of this board, a good place to start is with chip 14 the 10 volt reference, then check op-amps 1 & 2 for +12 and +8 volts, respectively, then op-amp 4 to be sure that you get approximately +10 vdc once again. Check Op-amp 5 for approximately -10 vdc. Check the output of op-amp 6 and vary the Rset 100, and Rset 101 controls for a voltage that steps between 0 and +10 vdc.

In a similar fashion the wiper arms of the 3 most significant Rset switches can be monitored at the teflon insulated stand-off terminal points and at the output of the buffer op-amps 9, 10, 11, 12 & 13 to see that signals of approximately 0 to +10 vdc are present as you change the settings of the various rotary switches. The output of op-amp 7 can be monitored to see that all the signals are combined, in this case the output at board pin 12 will be a 0 to -10 vdc signal.

Board R408 Interface

This board is present only when the digital excitation option has been ordered with the LR-400. When this board is not present, the logic bus pins on the bottom of this board's 100 pin connector are paralleled from one side of the connector to the other pin for pin. When this board is installed at the factory the parallel shorts are removed enabling the logic bus to feed into this board, and then the board sends out a new logic bus.

The 408 board sends out logic bus signals that either select the front panel or the rear panel as logic inputs. The lower right hand side of the 408 schematic shows the logic control input lines from the front panel. The lower left hand side shows the logic control input lines from the rear panel connector.

Since the logic levels for the rear panel connector are standard TTL 0/+5 vdc levels, (0vdc = true), these have to be fed to type 339 comparator devices. One comparator for each line chips 7, 8, 9, 10, 11 & 12. The output of these comparator gives the regular -8/+8 vdc logic signal that is used for the logic bus throughout the LR-400.

The rear panel logic signals labelled $\bar{\Delta}R$, 10 $\bar{\Delta}R$, Rx and R are inverted to allow these signals to conform to the front panel logic, since Rx, 10 $\bar{\Delta}R$ and $\bar{\Delta}R$ are barred (inverted) logic signals from the front panel.

An array of solid state switches 016 devices shown in the center of the schematic are used to either select the rear panel signals from either the 339 converters or from the front panel logic input signals. These 016 switches are controlled by the lines labelled R & F shown at the top central portion of the schematic. The R&F control line logic signals are generated by the front panel normal/remote switch shown for clarity on the 408 schematic at the lower right hand section entering the 408 board on pins 7 & 8.

The outputs of the interface board are shown just to the right of center on the 408 schematic as a vertical array of circles beginning with 9 bar at the bottom and ending with 37 bar at the top. These output signals are the logic bus used the mother board to drive all other plug-in boards.

There are no alignment controls on this board. When troubleshooting this board the most likely problem will be a shorted 016 switch section. Under this condition one bad 016 switch can short its control line to the power supply rail of +8/-8 vdc, thereby possibly damaging other 016 switches since half of the control lines are all connected in parallel. Consequently, if problems develop on this

board and one 016 switch fails, replace that, and if another switch seems to fail as well, it might be best to go through and replace all of the 016 devices on the board at one time.

Board 102A Tuned Amplifier

As show on the 401 mother board schematic the input to the tuned amplifier board comes from the output of the 402 preamp board. The input enters the tuned amplifier board on pins 2 & 1, the signal at pin 2, the signal ground at pin 1. The input signal is buffered by unity gain amplifier A1 and fed to amplifier A2 which acts as a differential to single-ended amplifier. A2 eliminates noise on the ground line since the grounds may differ from the pre-amp board to the tuned amp board.

The output of A2 is fed to a tuned amplifier stage consisting of op-amp A3 and associated circuitry. This amplifier stage array is tuned to a resonant frequency of 15.9 hertz. The frequency is determined by the two .27 microfarad capacitors and the 36.5K/30.1K plus 20K trimpot resistors. This amplifier stage has a trimpot frequency control R1 and a trimpot gain control R2. The tuned amplifier serves to reject power line pick-up, allowing only the 15.9 hertz carrier signal to pass through.

A second identical stage follows A3, stage A4. The signal is sent out on board edge pin 12 to the tuned amplifier attenuator located on the 405 attenuator board. After the required attenuation the signal is once again fed back to the 102A tuned amp board on pin 11. The signal then undergoes amplification by an additional 3 tuned amplifier stages, amplifiers A5, A7 & A8. They all function similarly to amplifier stage A3. The signal is fed out on board edge pin 7 to the phase detector board 404.

When troubleshooting this board check the output of all the op-amps to be sure that none are locked up at a power supply rail.

The alignment procedure describes how to set the trimpots on this board. Unlike many of the other controls in the LR-400, if the trimpots on this board are mis-set it could cause gross malfunctioning of the LR-400.

SECTION 500 LR-400 ALIGNMENT PROCEDURE

This procedure covers the alignment of all of the variable controls in the LR-400.

These controls consist of multi-turn printed circuit board mounted variable potentiometer trimpot types and mother board plate mounted ten turn potentiometer helipot type controls.

The controls are:

<u>DESIGNATION</u>	<u>NAME</u>	<u>DESCRIPTION</u>
406-R20	(Quadrature) multiplier zero offset 1st op-amp	These two trimpot controls "zero" the output of the quadrature sine wave multiplying digital to analog converter and the two associated op-amps such that when the D.C. input signal is 0vdc the analog sine wave output has a peak to peak amplitude of zero.
R406-21	(Quadrature) multiplier) zero offset 2nd op-amp	
406-R10	(in phase) multiplier 1st op amp	"in Phase" zero. Same technique as used in the "quadrature" multiplier above.
406-R11	(in phase) multiplier zero offset 2nd op-amp	
*	*	The following ten controls are trimpots
102A-R1A	Tuned amp #1 phase	Stage #1 phase adjusts band pass center frequency to exactly 15.9 hertz by adjusting the phase shift to zero degrees
102A-R1B	Tuned amp #1 amplitude	Stage #1 amplitude adjusts output amplitude to be four

		times larger than input amplitude hence gain=4
102A-R2A	T.A. stage #2 phase	Stage #2 phase (same as stage #1 above)
102A-R2B	T.A. stage #2 amplitude	Stage #2 amplitude (same as stage #1 above)
102A-R3A	T.A. stage #3 phase	Stage #3 phase (same as stage #1 above)
102A-R3B	T.A. stage #3 amplitude	Stage #3 amplitude (same as stage #1 above)
102A-R4A	T.A. stage #4 phase	Stage #4 phase (same as stage #1 above)
102A-R4B	T.A. stage #4 amplitude	Stage #4 amplitude (same as stage #1 above)
102A-R5A	T.A. stage #5 phase	Stage #5 phase (same as stage #1 above)
102A-R5B	T.A. Stage #5 amplitude	Stage #5 amplitude (same as stage #1 above)
407-R6	Zero/R-set	Trimpot control for setting R-set zero
407-R7	Span, R-set L.S.D.	Trimpot control. Two least significant digits of R-set dial span to match the three most significant R-set digits
404-R7	Rx Zero	Trimpot control. Rx zero for in-phase phase detector integrator

		amplifier. Establishes zero setting when Rx equals zero ohms
404-R2	ΔR Gain	Trimpot control. sets span of ΔR mode to match Rx mode.
404-R10	10 ΔR Gain	Trimpot control. Sets span of 10 ΔR mode to be 10 times ΔR & Rx modes.
.02	.02 ohm range	These 10 turn helipot type controls set the span for each resistance range. Note that excitation range controls are set on 2K ohm resistance range.
.2	.2 ohm range	
2	2 ohm range	
20	20 ohm range	
200	200 ohm range	
2K	2K ohm range	
20K	20K ohm range	
200K	200K ohm range	
.06 mv	.06 mv excitation	These 10 turn helipot type excitation controls set the span of the bridge on the 2K ohm resistance range for the various excitation ranges. All lesser excitation settings match the 20 mv excitation reading. There is no 20 mv excitation control. Once set while on the 2K ohm range, these settings are good (by bridge design) for all other resistance ranges.
.2 mv	.2 mv excitation	
.6 mv	.6 mv excitation	
2 mv	2 mv excitation	
6 mv	6 mv excitation	
R-set span	R-set span	This 10 turn helipot control sets the span of the 5 (4-1/2) R-set front panel dials.

406-R20 MULTIPLIER ZERO OFFSET TRIMPOTS
406-R21
406-R10
406-R11

To adjust the trimpots on the 406 board first remove the following plug-in boards: 402, 403, 404, 405. An oscilloscope is needed for this procedure and the test points will be monitored on the highest sensitivity setting. First adjust the R20 trimpot by monitoring the A22 op-amp output at R22 at any pin from 9 through 16. Adjust R20 for 0vdc. Next adjust R21. For R21 monitor the A23 op-amp output at the 6.8K ohm resistor at the end that is connected to A23-6. Adjust R21 for 0vdc.

The test points for adjusting R10 and R11 are similar to those for R20 and R21, respectively. For R10 it is any pin 9-16 of R12 and for R11 it is the end of the 6.8K ohm resistor at A13-6. First adjust R20 for 0vdc. Next adjust R21 for 0vdc.

102A-R1A TUNED AMP PHASE & AMPLITUDE TRIMPOTS
102A-R1B
102A-R2A
102A-R2B
102A-R3A
102A-R3B
102A-R4A
102A-R4B
102A-R5A
102A-R5B

To adjust the trimpots on the tuned amp board first remove all the plug-in boards except the 406 board. That is remove the following: 402, 403, 404, 405, 407, and 408 if present. An oscilloscope with an x-y mode is needed, as well as a 10Kohm helipot (test helipot).

On the tuned amp board, with a clip lead, connect the top of the left-hand most .27 microfarad capacitor (labelled test point A on figure 1) to pin 11 of the card edge connector of the tuned amp board 102A.

On the 406 board, with a clip lead, connect the top of the 10 megohm resistor next to A31 (same as 406-26 edge pin) to pin 15 of the ± 8 VDC power supply board card edge connector. The ± 8 vdc power supply board is mounted on the left side panel of the LR-400 housing. CAUTION! Take care not to connect the +8vdc point to ground, etc.

On the 406 board, connect R33-16 to the X input of the oscilloscope and to the "999" or maximum clockwise terminal of the test helipot. Connect the "000" or maximum counterclockwise terminal of the test helipot to the aluminum frame of the plug-in board cage assembly which is frame ground. Connect with a clip lead the wiper arm of the test helipot to the tuned amp board card edge connector A102 pin 2. Connect A102 pin 1 to frame ground. Test point A connects to the Y input of the oscilloscope.

Note that there are five stages on the board. For each stage there are two trim pots close together at the top of the board and below them are two .27 microfarad capacitors close together near the bottom of the board. This is shown in figure 1. The top ends of these capacitors are the test points. On the left is the "in" or "A" test point for the stage and the "out" or "B" test point is on the right.

To tune a stage, first monitor the "in" test point "A" and adjust the external test helipot so the signal amplitude is 20 millivolts peak to peak. Then monitor the "out" test point "B" and adjust the trim pots so the amplitude is 80 millivolts peak to peak and the oscilloscope trace is a straight line. For the trim pots, the left one sets the phase and the right one sets the amplitude.

Figure 2 shows the correct x-y oscilloscope waveforms. Note that the external helipot must be reset for each stage alignment. Stages 3, 4, & 5 are cascaded. Stages 1 & 2 are cascaded. The helipot wiper arm drives the buffer amplifier which drives stage 3. If test point B shows a continuous oscillation, decrease (turn ccw) the amplitude trim pot until the oscillation stops.

20mvpp input & 80mvpp output is arbitrarily chosen. The idea here is to get a gain of (-4) per stage. If necessary you could use a larger magnitude of voltage, (eg. 1vpp input & 4vpp output) but keep in mind that the last stage on the right hand side of the 102A board has back to back zener diodes limiting its output voltage to approximately 5 volts pp.

Set the front panel 'span' 10 turn pot at '500' and leave it there throughout this alignment procedure.

407-R6 Zero/R-set Trimpot
407-R7 Span/R-set Trimpot
R-set span helipot (preliminary adjustment)

When adjusting the two trim pots on the 407 Rset & LED drive board, with a digital volt meter, monitor pin 14 of device A15 as a test point on the 404 phase detector board. An adjustment of the mother board mounted "Rset" pot will also

be done at this time. With the Rset dials at 00000, adjust the R7 trimpot so the test point reads 0 volts $\pm .05\text{mv}$.

Next, with the Rset dials at 19900 and the adjust the mother board mounted "Rset" pot so the test point reads -9.9500 volts. This is a preliminary adjustment . The final adjustment is described later in this procedure.

Next with the Rset dials at 00099, adjust the R6 trimpot on the 407 board so the testpoint reads -49.5mv . Reset the Rset dials to 00000.

<u>404-R7</u>	<u>Rx zero</u>	<u>Trimpot</u>
<u>404-R2</u>	<u>ΔR span</u>	<u>Trimpot</u>
<u>404-R10</u>	<u>$10/\Delta R$ span</u>	<u>Trimpot</u>

When adjusting the three trimpots on the 404 phase detector board, with a digital voltmeter monitor pin 9 of device A16 as a test point on the 404 board. Also needed are the sensor cable and the following precision resistors: 2 each 1K ohm, 2 each 100 ohms, 1 or 2 each 0 ohms(short).

For adjusting the R7 "zero" trimpot, set the range to 2K ohms, the excitation to 20mv, the mode to $10/\Delta R$, and Rx to 0 ohms. Adjust R7 so the test point reads 0 $\pm 0.2\text{mv}$.

Next, adjust the R2 " ΔR op-amp gain" trimpot. With the 4 settings at range = 2K ohms, excitation = 20mv, mode = Rx, and Rx = 2K ohms, take a reading, then change the mode to ΔR . Adjust R2 so the test point is again at the same voltage as the initial reading.

Next, adjust the R10 " $10/\Delta R$ gain trim" trimpot. With the settings at range = 2K ohms, excitation = 20mv, Rx = 2Kohms, and mode = Rx, adjust the mother board mounted "2K range" pot so the test point is at 10.0000v. Change Rx to Rx=200 ohms and mode to mode= $10/\Delta R$. If necessary, wait two minutes or less for reading to steady. Adjust R10 so the test point again reads 10.0000v $\pm .001\text{v}$.

<u>.06 mv</u>	<u>Excitation Helipots</u>
<u>.2 mv</u>	
<u>.6 mv</u>	
<u>2 mv</u>	

Alignment of the excitation pots is done on the 2K range. Monitor the 10v test point, pin 9 of device A16 on the 404 board, with a digital voltmeter. With the settings at range = 2K ohms, excitation = 20 mv, mode = Rx, time constant (TC) = .35, and Rx = 2K, adjust the mother board mounted 10 turn pot for the 2K range so the test point is at 10.000v.

Change excitation to 6mv. Adjust the 6mv mother board mounted 10 turn pot so the reading is again 10.000v. Repeat

for the other excitation settings, resetting the time constant as necessary to steady the reading.

.02 ohm Range Helipot

.2 ohm

2 ohm

10 ohm

200 ohm

2K ohm

20K ohm

200K ohm

Make the final adjustment of the 2K range 10 turn pot. With excitation = 20mv, time constant = .35, and Rx = 1K, monitor the front panel "display out, $\pm 2\text{vdc}$ " test point and adjust the pot so the test point is at 1.000v. Tighten the lock nut.

Adjustments of the mother board mounted "range" 10 turn pots are made while monitoring the front panel "display out" test point. On each range, with excitation = 20mv, time constant = .3s, and Rx = 12 full range, adjust the corresponding pot so the test point is at 1.000v. Tighten the lock nut after making final adjustments.

R-set Span Helipot (Final Adjustment)

To make the final adjustment of the mother board mounted "Rset span" pot, with range = 2K, Rset = 10000, and Rx = 1K, monitor the front panel "display out" test point and, first, take a reading with mode = Rx. Then with mode = ΔR , adjust the "Rset span" pot so the test point is at 0.00mv. Tighten the lock nut.

SENSOR JIG

The technique that we use at Linear Research Inc. when connecting precision resistors to the sensor cable for alignment and/or testing of the LR-400 is as follows: Attach the resistors to individual dual banana plugs. Then use a jig consisting of an aluminum plate with 9 each insulated female banana binding post jacks mounted thereto. Five of the jacks are used to terminate the sensor cable tinned wire ends. Use one of the 5 jacks as the "shield" jack and connect it electrically to the aluminum plate.

The four remaining jacks are each in turn connected to the first four jacks that accepted the cable (connected by soldered leads underneath the plate). These second four jacks are used for mounting the dual banana plugs holding the sensor resistors in either the two wire or four wire resistance mode. In the two wire mode use two "shorting" dual banana plugs.

To electrostatically shield the sensor resistor from power line voltage pick-up, enclose the entire jig array inside an aluminum chassis box. Use a loose cover plate to allow the cable to enter the box. Be sure to electrically connect (ground) the chassis box to the aluminum jig plate.

RECOMMENDED COMPONENTS FOR THE SENSOR JIG:**1. 2-wire resistors (1K ohms through 200K ohms)**

Vishay Resistive Systems
63 Lincoln Highway
Malvern, PA 19355
215-644-1300
Part # VR Series .01%

2. 4-Wire Resistors (10 milliohms through 100 ohms)

Electro Scientific Industries
13900 N.W Science Park Drive
Portland, Oregon 97229
503-641-4141
Part # RF4R .01%

3. Dual Banana Plugs

ITT Pomona Eletronics
1500 East 9th Street
Pamona, CA 91769
714-623-6751
Part # MDP-2

4. Binding Post Jacks

E. F. Johnson Co.
Part #111-0102

FIGURE 1. 102A TUNED AMP BOARD TRIMPOT LOCATIONS

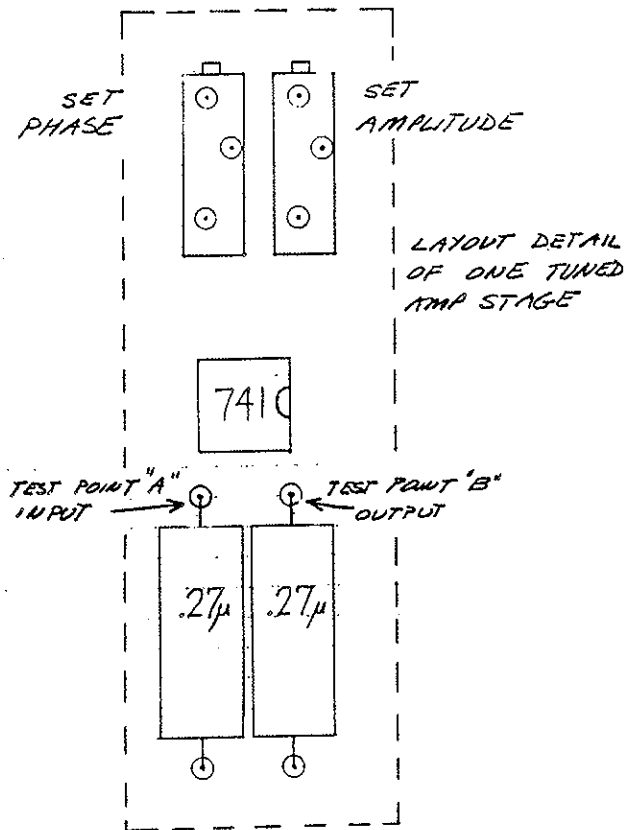
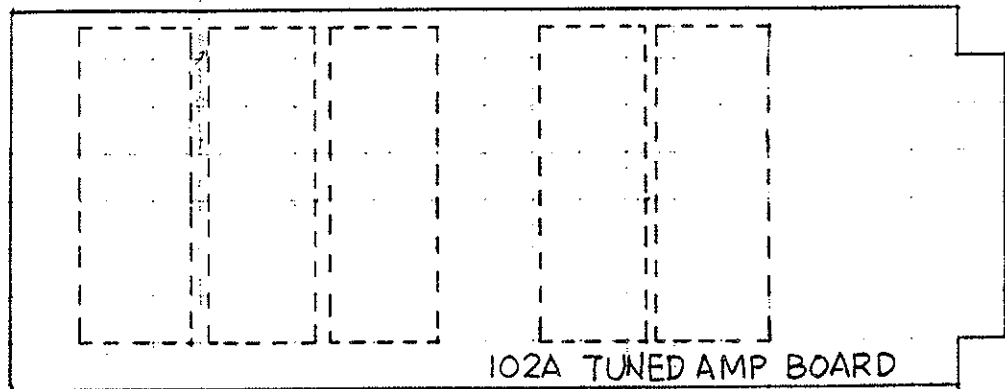
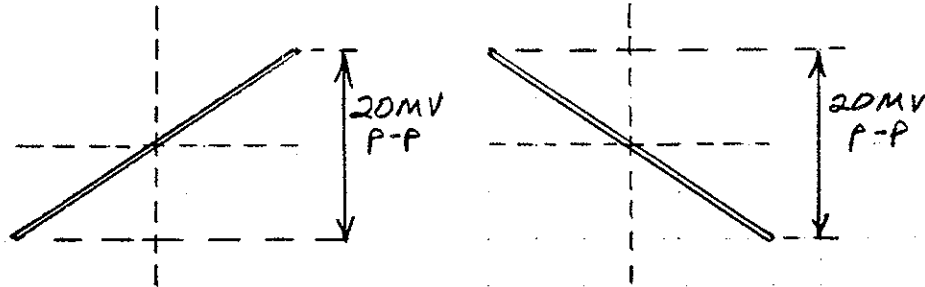


FIGURE 2. X-Y OSCILLOSCOPE WAVEFORMS FOR 102A BOARD.

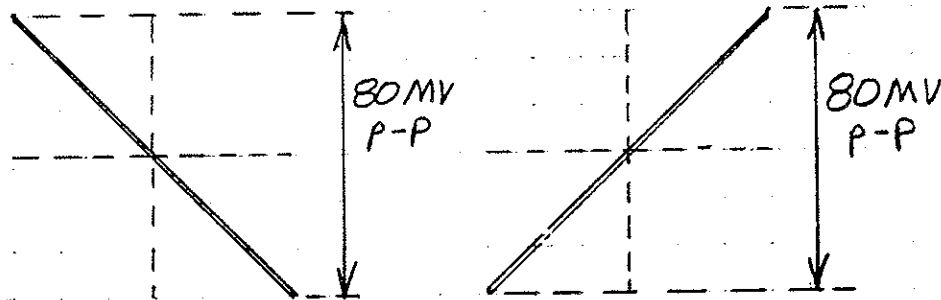
CORRECT WAVEFORMS.

Two waveforms are shown since there is a 180 degree phase shift per stage.

INPUTS, TEST POINT A.



OUTPUTS, TEST POINT B

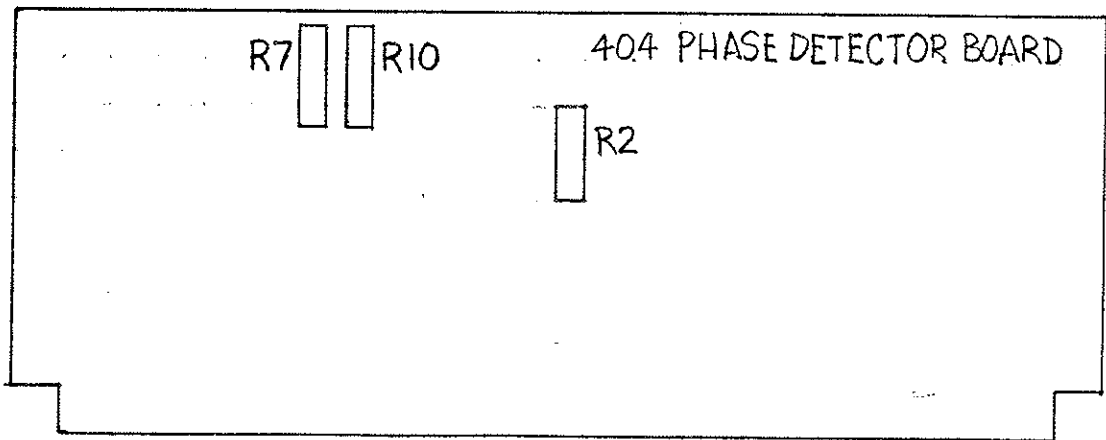
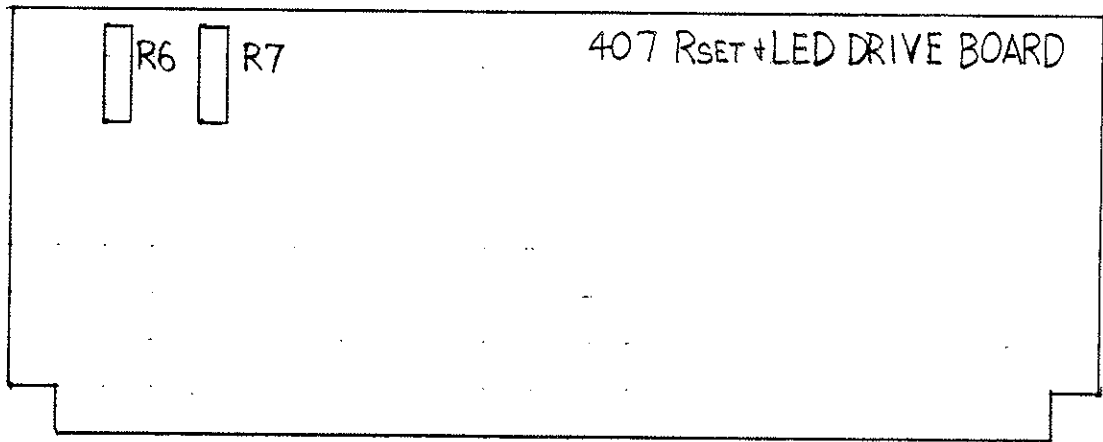
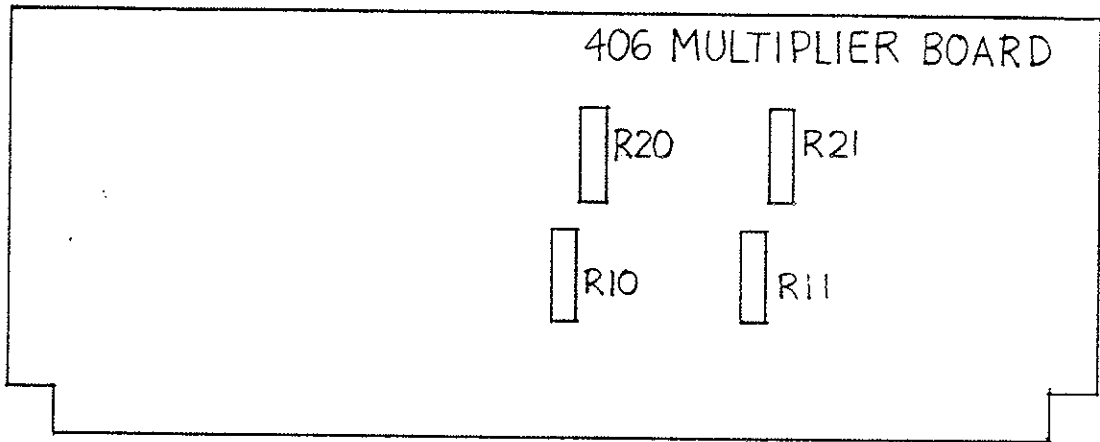
WAVEFORMS THAT STILL NEED ADJUSTMENTS.

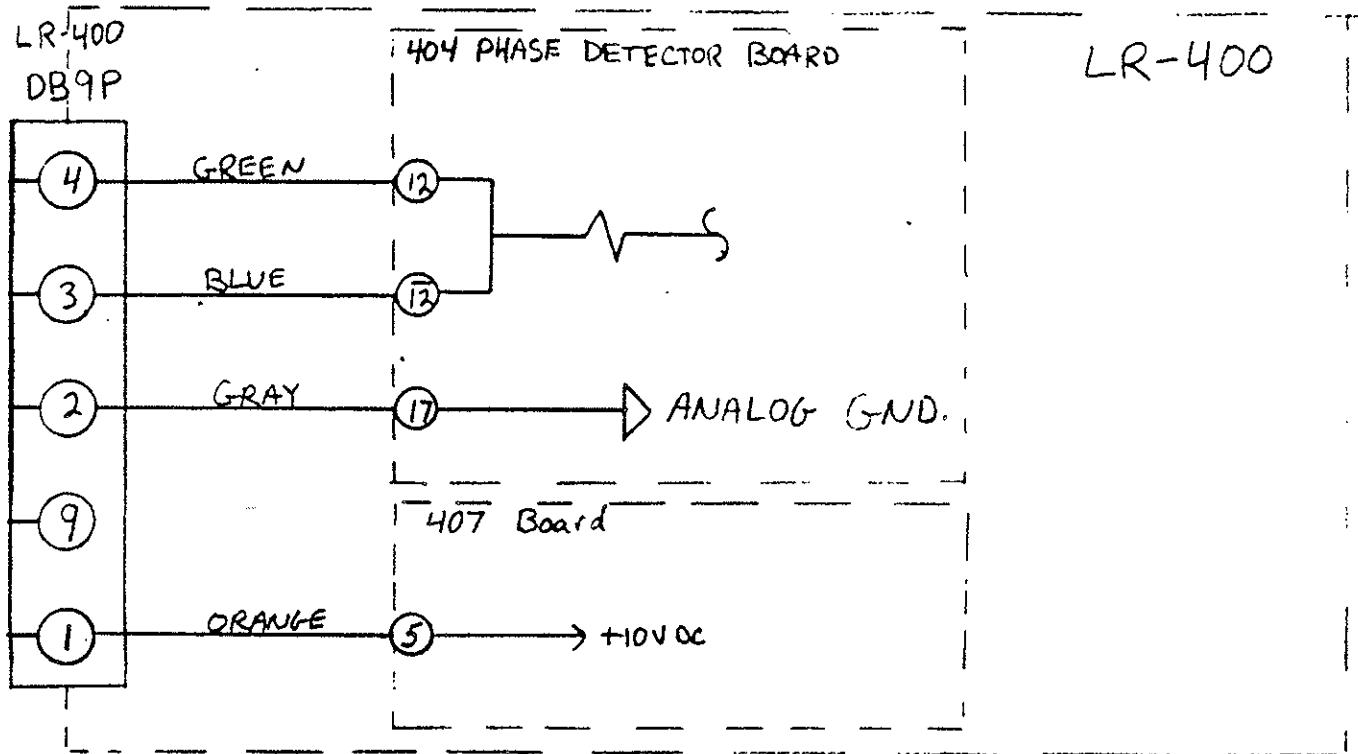
PHASE GROSSLY UNADJUSTED

PHASE SLIGHTLY UNADJUSTED



FIGURE 3. 404, 406, & 407 BOARD TRIMPOT LOCATIONS.





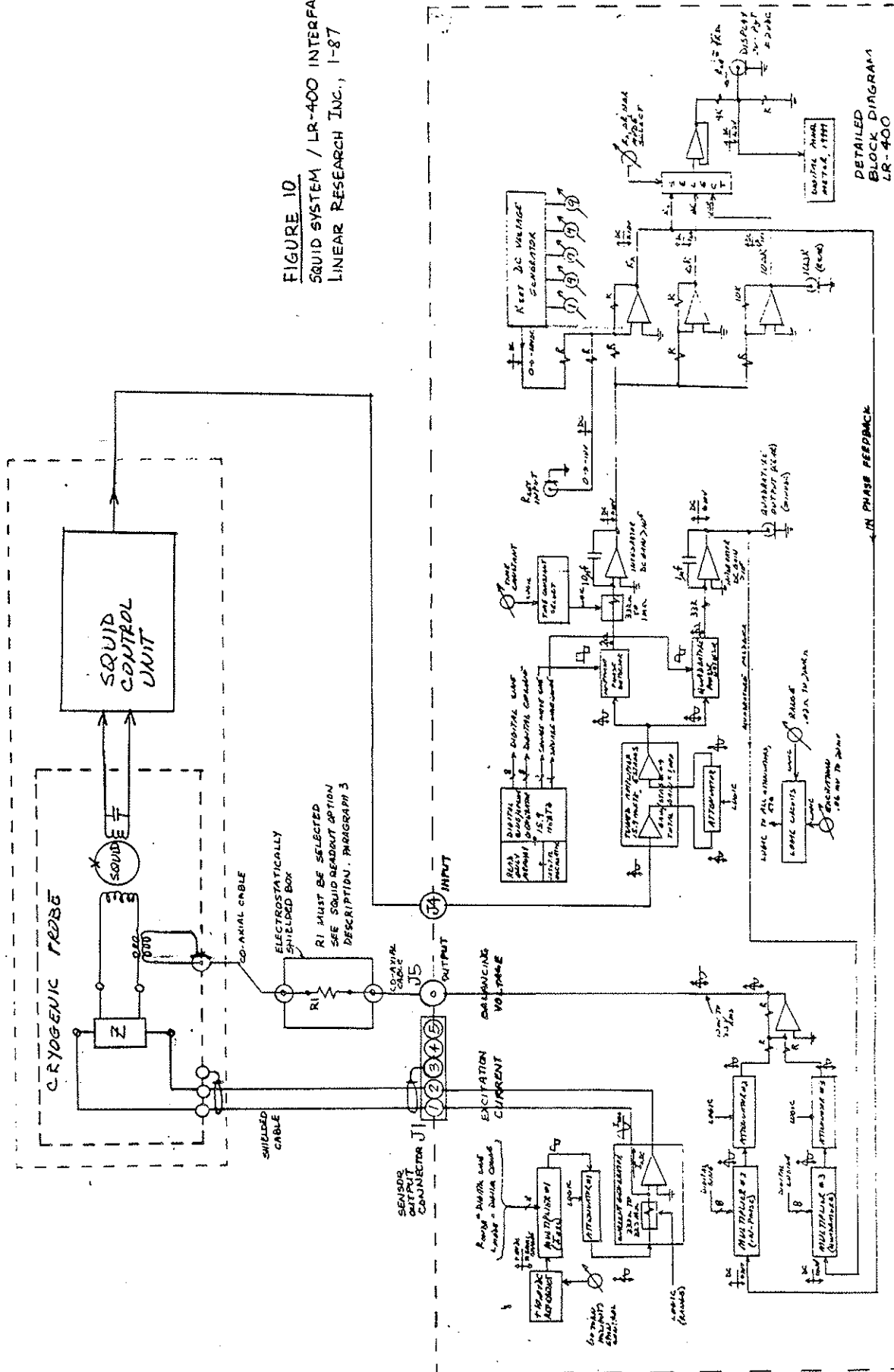
SCHEMATIC
SHOWING 9 PIN REAR
PANEL HOOK-UP FOR
LR-4PC ANALOG SET
RESISTANCE INPUT

7/17/87

SQUID READOUT OPTION DESCRIPTION

1. Figures 100A, 100B, and 100C, schematically show the changes made to the LR-400 to implement this option.
2. Figures 10 and 11 show a typical hook-up of the cryogenic probe and squid control unit to the LR-400. In Figure 10 the balancing voltage is picked off at J5, the high level output. In Figure 11 the balancing voltage is picked off at pins 4 and 5 at J1, the low level output (balancing voltage here is 166 times lower than the high level output). We recommend using J5 the high level output.
3. The 16 hertz sinewave excitation current is sent from the LR-400 via pins 1 and 2 of rear panel connector J1 to excite an impedance Z in the squid cryogenic probe. Z can have both resistive and reactive components. The balancing voltage at J5 is applied to the transformer in the squid probe via resistor R1. Thus the balancing voltage is turned into a current by R1, and delivers a voltage at the secondary of the cryogenic probe transformer, that almost exactly balances, both in phase and in quadrature, the voltage that was created across impedance Z by the excitation current. The resulting vanishingly small error voltage is then amplified by the squid and the squid control unit and outputs a 16 hertz amplified sinewave error signal back to the LR-400 at connector J4.
4. The user must select resistor R1 to scale the current into the cryogenic probe transformer to allow the system to be in range for proper balancing. R1 must be electrostatically shielded from power line pick-up and radio frequency interference. A small tightly sealed aluminum box (not supplied by Linear Research Inc.) should be used to hold R1. The value of R1 will depend upon the turns ratio of the transformer in the cryogenic probe and the order of magnitude of the voltage across impedance Z in the cryogenic probe. It will also depend upon the magnitude of the excitation current at pins 1 & 2 being delivered from the LR-400. The balancing voltage output at J5 is capable of delivering a current of 3 milliamps RMS. The low level output can deliver more current.
5. Remember that stability in the closed loop will also be affected by the gain setting in the squid control unit and the current excitation range and balancing voltage range settings on the front panel of the LR-400.

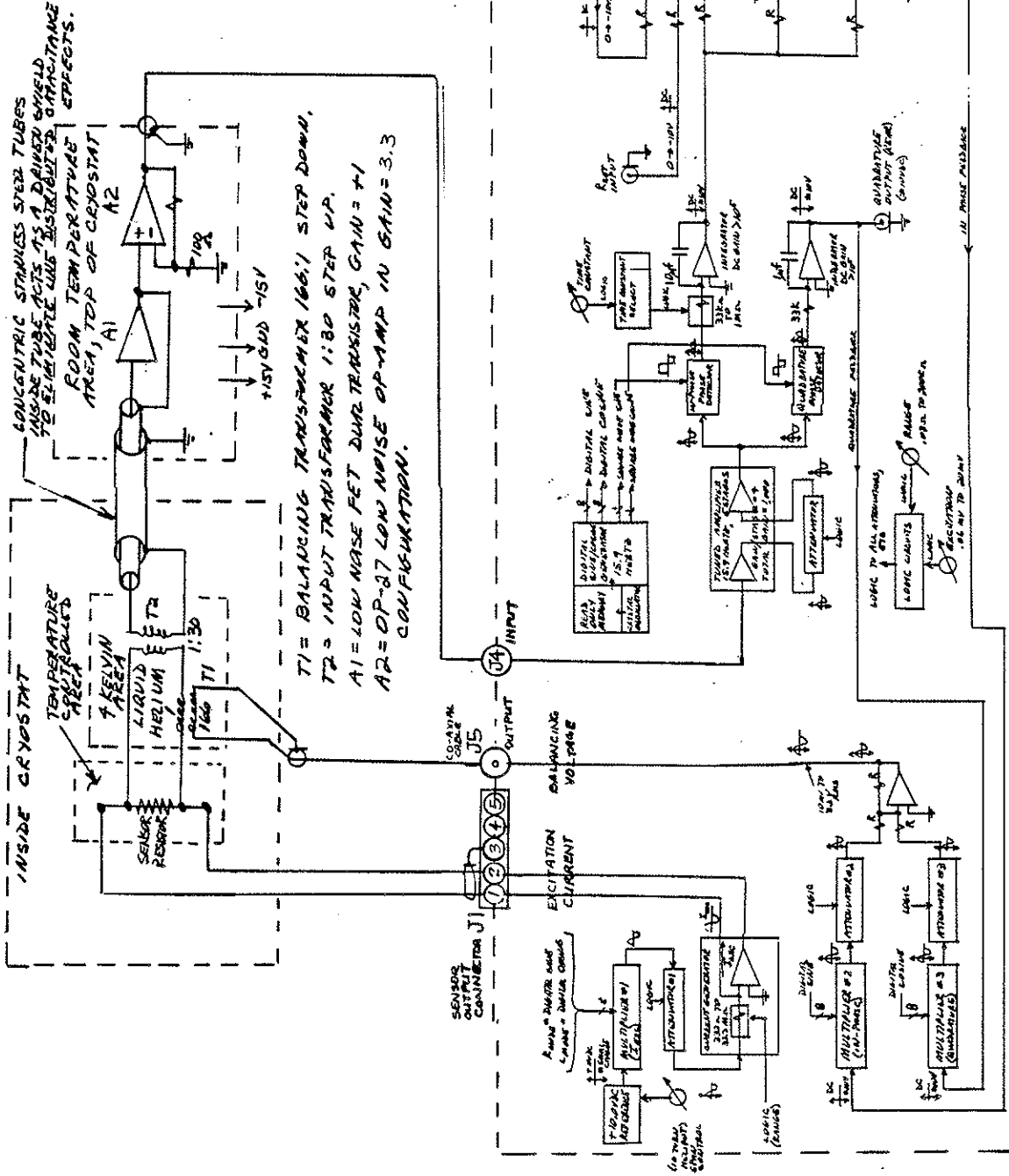
FIGURE 10
SQUID SYSTEM / LR-400 INTERFACING
LINEAR RESEARCH INC., 1-87



DETAILED
BLOCK DIAGRAM
LR-400

FIGURE 10A
SRUID OPTION/LR-400
INTERFACING
LINEAR RESEARCH INC.

SET-UP FOR LOW NOISE
MEASUREMENT OF A
SENSOR RESISTOR



DETAILS BLOCK DIAGRAM
LR-400

FIGURE 10 B
SQUID OPTION / LR-400
LINEAR RESEARCH INC.
SET-UP FOR LOW NOISE
MUTUAL INDUCTANCE
MEASUREMENTS WITH
DUAL SECONDARY MUTUAL
INDUCTANCE TRANSDUCERS

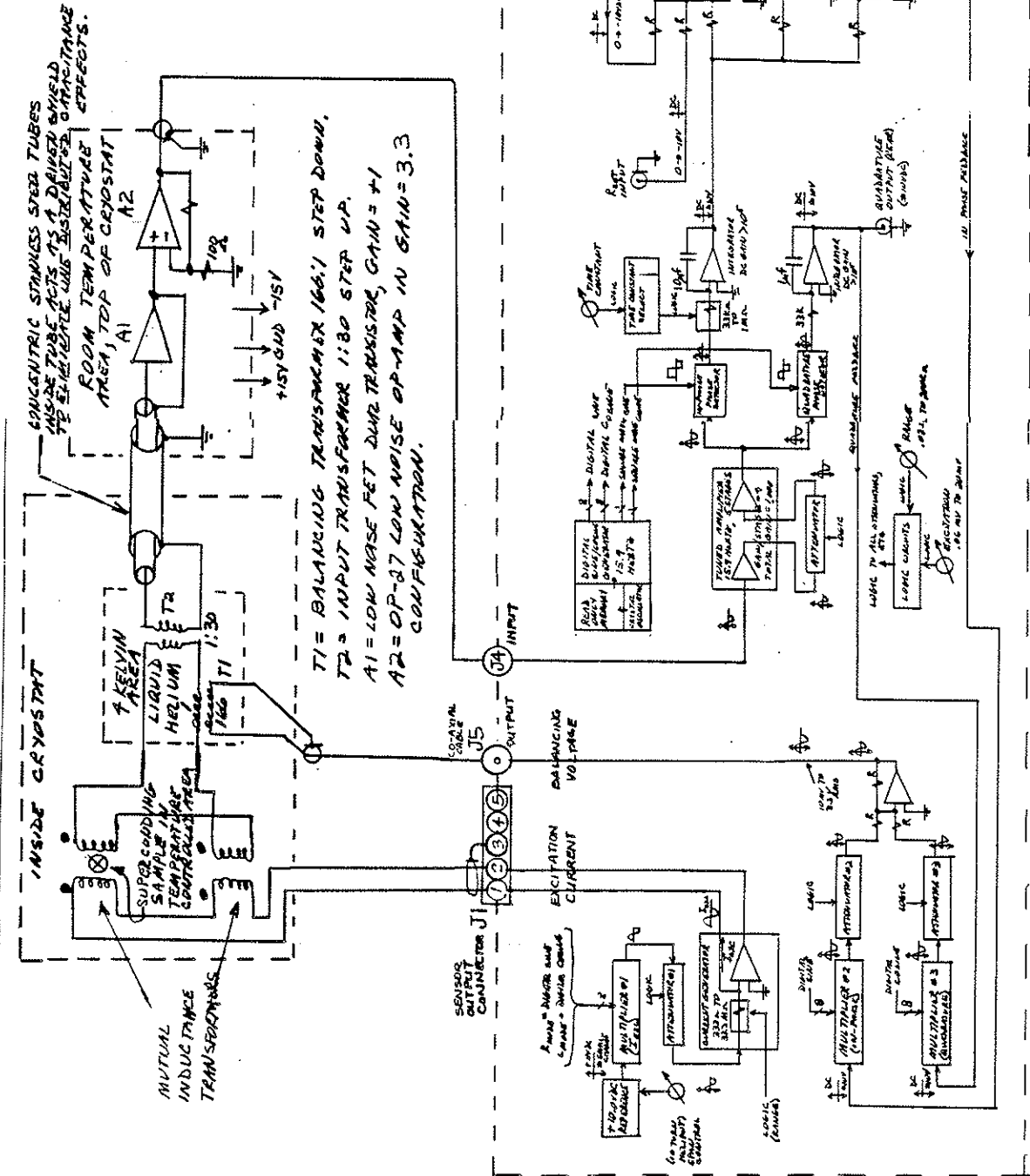
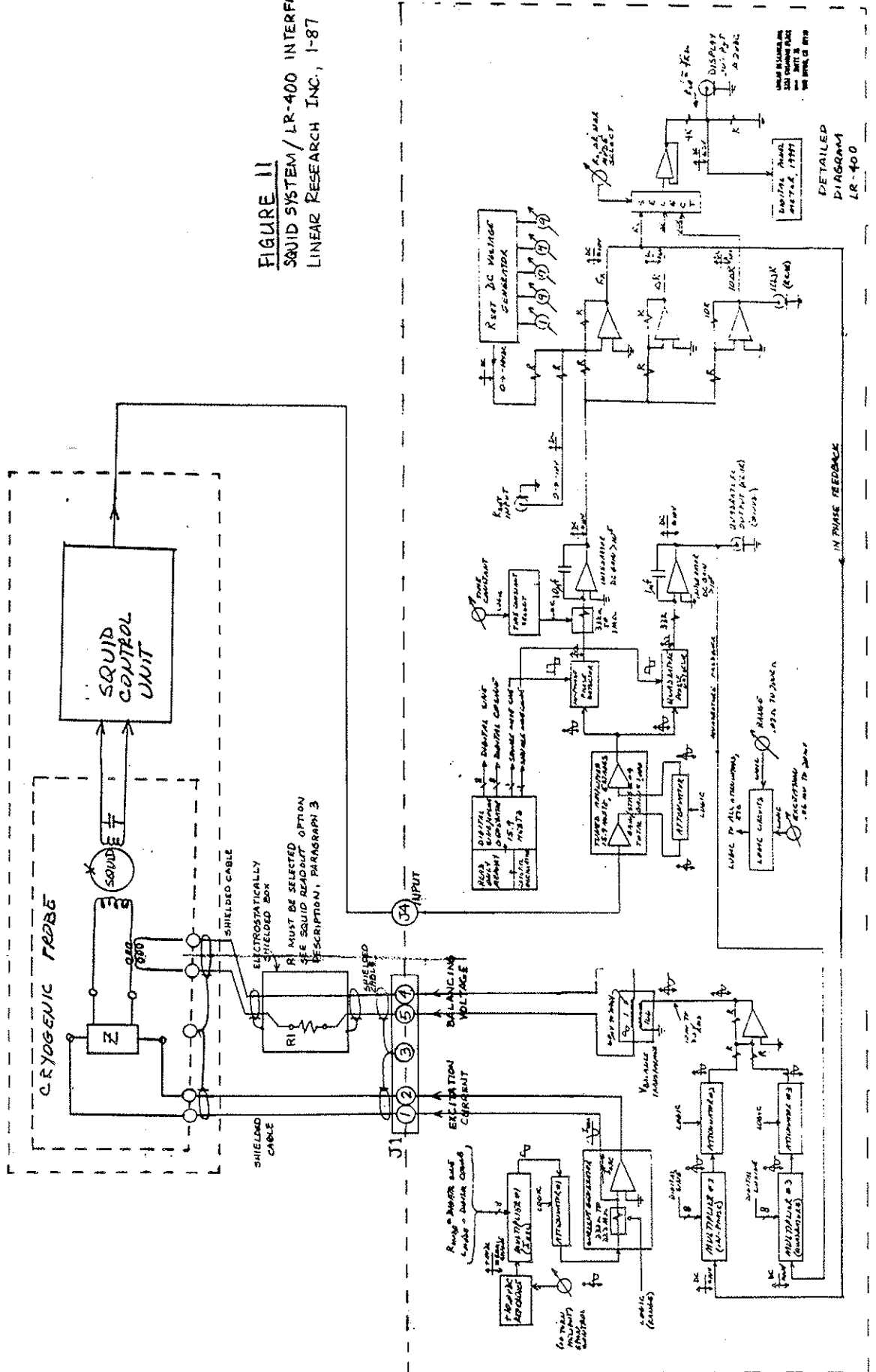


FIGURE 11
SQUID SYSTEM/LR-400 INTERFACING
LINEAR RESEARCH INC., 1-87



DETAILED
DIAGRAM
LR-400

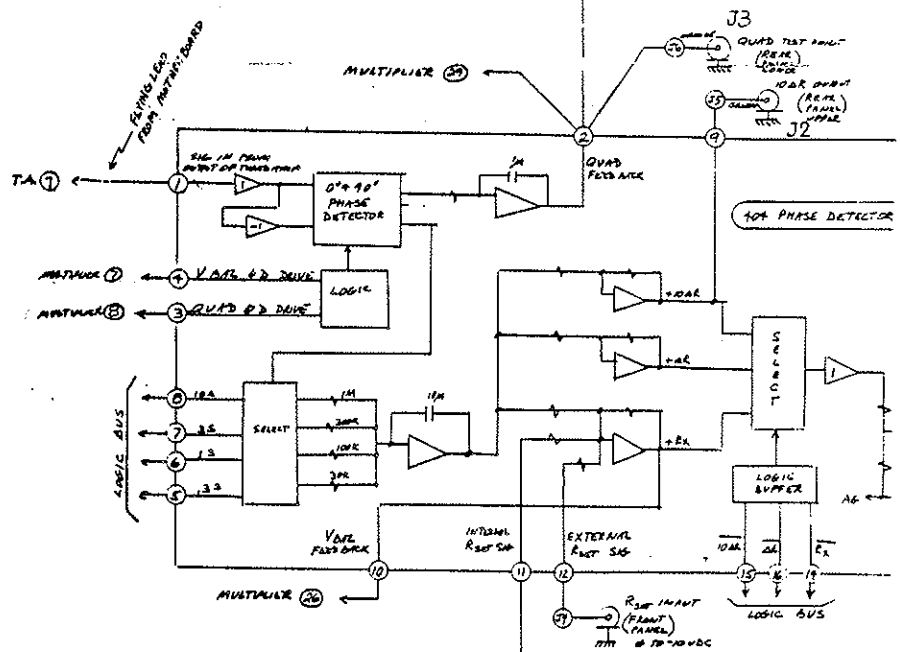
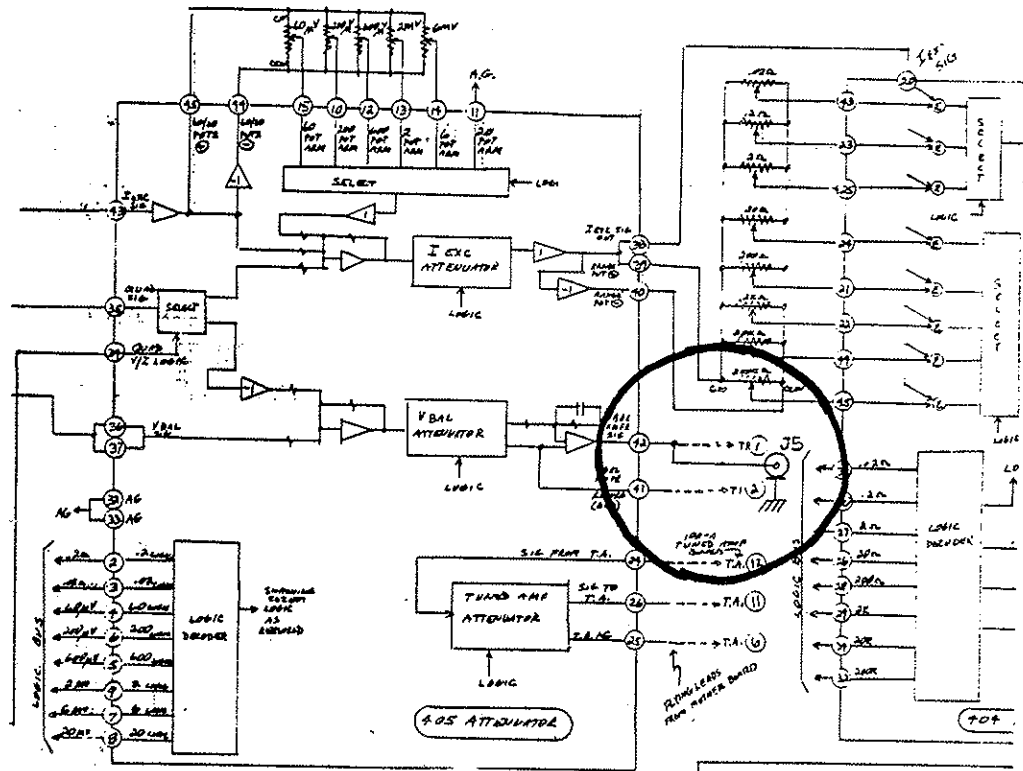


FIGURE 100A
SQUID READOUT OPTION
MODIFICATIONS TO THE LR-400
LINEAR RESEARCH INC., 1-87

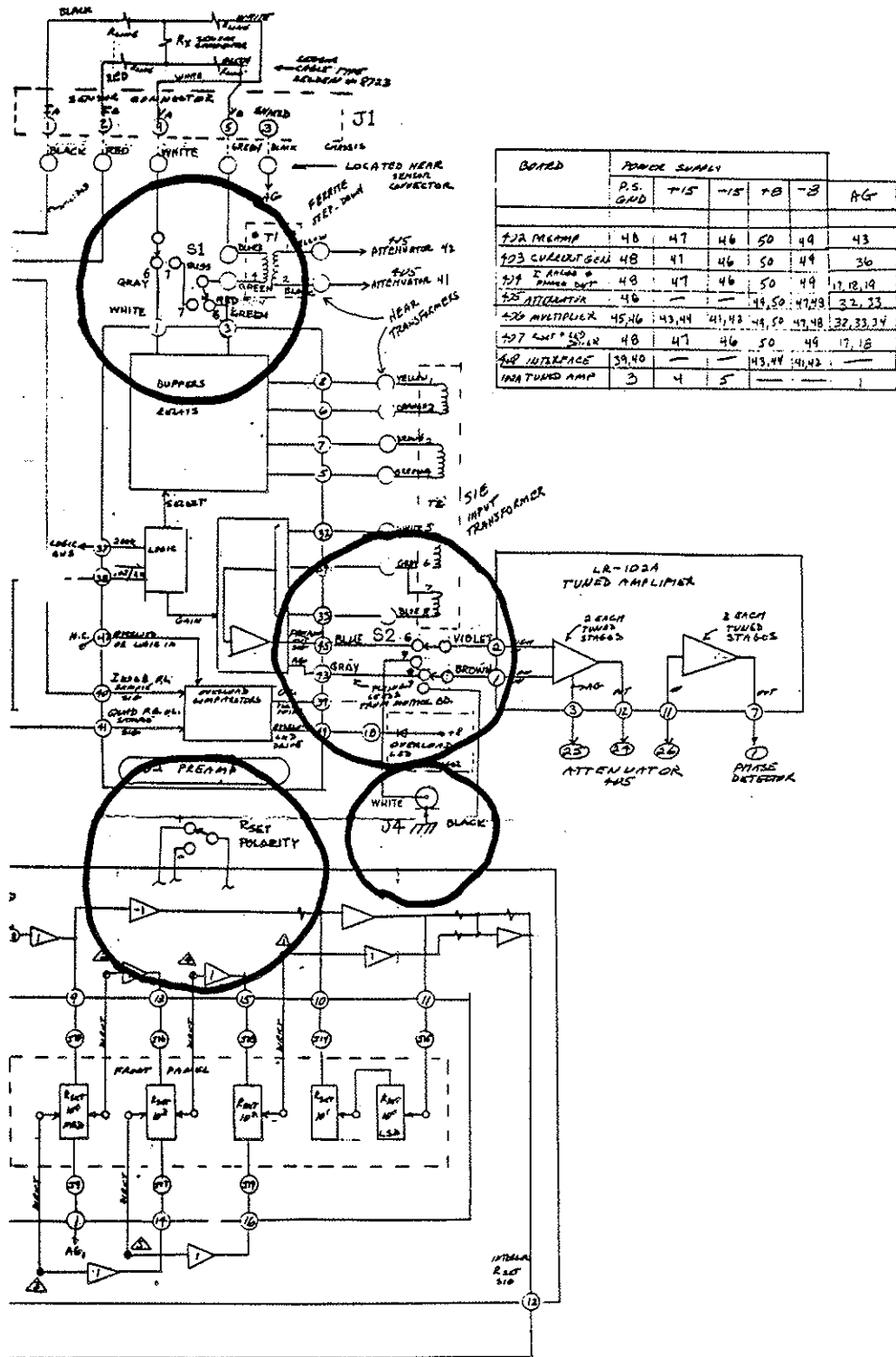
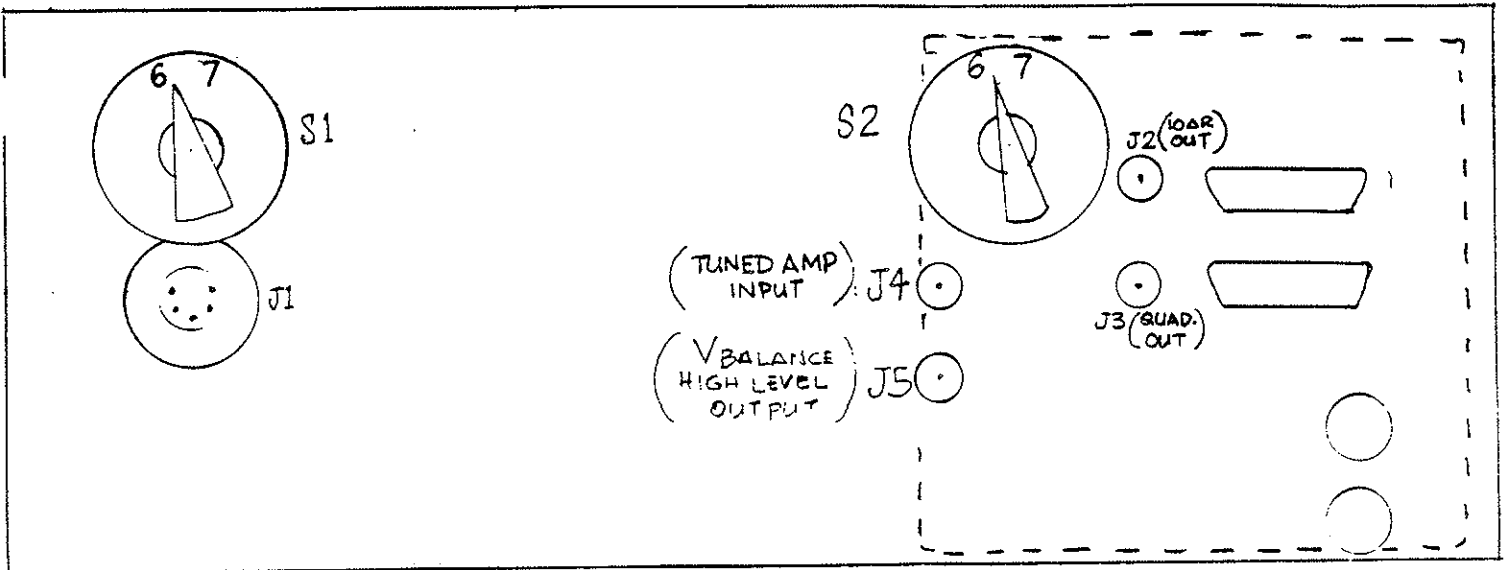


FIGURE 100B
SQUID READOUT OPTION
MODIFICATIONS TO THE LR-400
LINEAR RESEARCH INC., 1-87



LR 400 REAR PANEL
SHOWING "SQUID" OPTION

ITEM	POSITION	REMARKS
S1	6	NORMAL
	7	SQUID: ^(LOW LEVEL OUTPUT TO SQUID) OUTPUT OF V BALANCE STEPDOWN TRANSFORMER AVAILABLE <u>DIRECTLY</u> ON PINS 4+5 OF SENSOR OUTPUT CONNECTOR, J1
S2	6	NORMAL
	7	SQUID: ^(INPUT FROM SQUID) J4 ACTS AS A DIRECT AND ONLY INPUT TO THE TUNED AMPLIFIER BOARD, LR-102A, PIN 2
J5	6/7	^(HIGH LEVEL OUTPUT TO SQUID) CONNECTED TO OUTPUT OF A-26 ON 405 ATTENUATOR BOARD, OUTPUT PIN 42. DRIVER OF V BALANCE STEP DOWN TRANSFORMER CONNECTED AT ALL TIMES

FIGURE 1

LR-400 REAR PANEL SQUID CONTROLS
LINEAR RESEARCH INC., 1-87

CAUTION! CAUTION! CAUTION!

When operating the LR-400 unit in the mutual inductance mode follow this procedure.

Do not connect or disconnect the current excitation sensor leads or voltage sampling sensor leads to a mutual inductance sensor transformer while the LR-400 is turned on (has its power connected). The danger is that if a current excitation lead is mechanically opened or disconnected while conducting current then a large transient voltage will be generated at the point of disconnect. This instantaneous current can have an amplitude of up to 14 milliamps peak. Current will try to continue to flow through an inductor. Thus, depending upon the value of the primary inductance, leakage resistance, distributing capacitance etc., this current discontinuity might generate a high voltage transient. This transient might couple into the preamp section of the LR-400 via the mutual inductance secondary and the voltage sampling leads. This might damage permanently the dual field effect transistor on the 402 preamp board device Q3A and Q3B.

Thus be sure to turn the LR-400 power toggle switch to "off" before changing or opening leads to a mutual inductance sensor transformer.

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LR-400 FOUR WIRE AC RESISTANCE BRIDGE.

TECHNIQUE FOR MAKING MEASUREMENTS WITH MUTUAL INDUCTANCE TRANSFORMERS:

1. The LR-400 should be connected to the sensor mutual inductance transformer(s) as shown in figure 200.
2. Figure 200 shows separate shielded current excitation and voltage sampling leads. The cable normally supplied for resistance measurements has both the current excitation and the voltage sampling lines cabled in one bundle and it will work well enough for mutual inductance measurements. But for highest performance we recommend our "split" cable where the current excitation leads are separate from the balancing voltage section. These two should be separated by approximately two or three inches so that there is no induced voltage in the voltage sampling cable due to the magnetic field set up by the current in the current excitation leads.
3. Note in figure 200 the polarity with regard to the primary of the transformers and with regard to the secondary of these transformers. Note the case of two transformers with individual primaries and the case of a single transformer with a single primary and dual secondaries. In both cases the outputs of the secondaries are connected so that the voltages subtract or buck each other to give a null output voltage.

When working with a new mutual inductance transformer and a new set-up use the following procedure:

Turn off the LR-400 and connect the sensor cable to the sensor transformer.

Set the resistance/mutual inductance front panel toggle switch to mutual inductance.

Turn off the LR-400 and connect the sensor cable to the sensor transformer.

Set the display mode to RX (Display actually reads Mx).

Set the filter time constant to .3 seconds.

Set the excitation millivolts to 20 millivolts.

Set the range to 200K ohms (2,000 Henrys).

Turn on the instrument and note whether you get an on-scale reading of the front panel digital voltmeter.

The digital panel meter is in overload when it displays a +1 followed by all blanks. If DPM is in an overload condition, then check to be sure that (1), you do not have any open or short in the leads connecting the transformer to the sensor, (2), that the sensor wires are hooked up exactly as shown in

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figure 200, and (3), that the secondaries are used in the bucking mode and not in the additive mode.

Once you get an on-scale reading between (± 19999 and all zeros) then you should next reduce the range in ohms (Henrys) from the 200K (2,000 Henrys) setting downward until you get a mid-scale reading on the digital panel meter. Select the highest range that does not give you an overload indication and that will put you in to some reasonable span of the panel meter, not close to "00000" but not real close to "19999", preferably midscale or above.

Note the reading on the panel meter. For example: If the reading is -12.438 on the 20 ohm (200 millihenry) range then set the LR-400 set resistance dials and polarity toggle switch to the same value namely, "(minus) 12438". Set the display mode front panel control to ΔM (ΔR). You should now get an on-scale reading on the digital panel meter that is reasonable close to zero. If it is a few digits off then you may bring it as close to zero as possible by making a change in the least count of the set mutual inductance (set resistance) dials.

You are ready now to begin your experiment. Connect a strip chart recording to the LR-400 using either the display out BNC on the front panel or the dedicated $10\Delta R$ output on the rear panel to drive the stripchart recording. Go to a reasonable time period on the strip chart recorder of say one inch per ten minutes. Your strip chart recorder should have variable sensitivity, with at least a sensitivity of 10 millivolts/full span. Make an experimental change to induce a change in the mutual inductance. This is usually done by placing the sample of interest in the center of one of the transformers for a few minutes and then removing it. Watch the strip chart recording and note the change. If you anticipate a fairly small change a larger sample of known large value can be used to "calibrate" the system and then you can look for a smaller change. You also can make use of either the display out front panel BNC or the $10\Delta R$ output. You can feed these to a 5-1/2 digit digital voltmeter that has data acquisition capability that can interface with a computer or you can even use the digital voltmeter front panel display. Keep in mind that the digital panel meter supplied with the LR-400 might have a plus or minus one least count jitter (noise) in its display that is usually noisier than the display output front panel analog signal or the $10\Delta R$ signal at the rear of the LR-400. That is why you might want to go to a less noisy, more expensive digital panel meter or strip chart recorder.

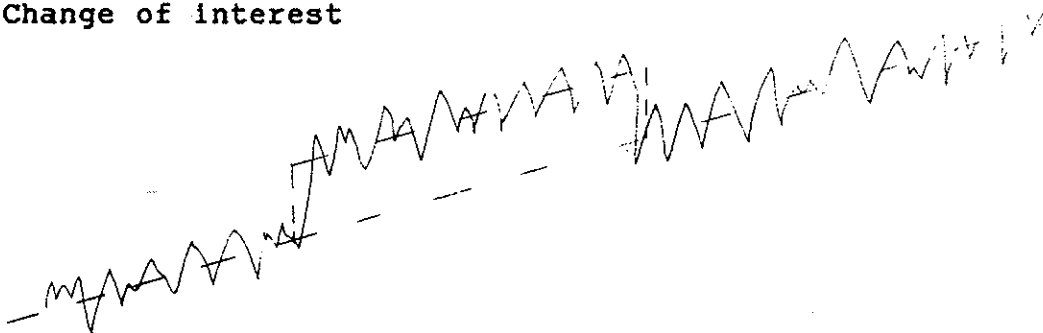
The technique of using the strip chart recording allows you to see changes induced by your target when it is inserted into the transformer even though the entire system may be drifting in a linear fashion. This drift, for example,

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might be because your temperature controlled system that should be holding the transformers at an ideal constant temperature is not stable, but has a long term drift, etc. The transformers themselves may give a net drift in mutual inductance because of mechanical stress in the windings yielding a small but constant motion. If this drift is a constant change with time and not a random fluctuation the strip chart recording will show a constant slope or ramp. If this ramp is small enough to keep the trace on scale on the strip chart recorder you can then insert and remove the sample to yield a step function change in this ramp.

Change of interest



Thus the strip chart recording affords more useful information in resolving small signals than does monitoring the digital panel meter on the front panel of the LR-400 or with an external digital panel meter where you just have a display. Of course if your external meter can interface with a computer then you can average the base line line in the computer using computer averaging software.

The LR-400 instruction manual, page 300-3, shows the full scale range in Henrys for the corresponding full scale range in resistance. We did not have space on the front panel of the LR-400 to place the mutual inductance range values alongside the ohm values. If you are going to be using this often then you certainly could make a photocopy reduction of this chart and tape it onto the front panel of the LR-400. Note that in the example given above where the MX reading was "12.438" on the 20 ohm (200 millihenry) range, this is equivalent to 124.38 millihenrys.

When initially designing your transformer(s) it is helpful to make individual measurements on individual windings of the transformer. For instance, with regard to figure 200 you could have connected the current excitation leads to points A and B and the voltage sampling leads to points E and F, and not connect anything to C, D, G, and H. This will give you the mutual inductance across one transformer, primary to secondary. Another interesting feature would be to measure just the self inductance of the primary, or of just the secondary. So you can also measure the AC resistance of the primary and of the secondary individually

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by changing the front panel mutual inductance resistance/mutual inductance toggle switch to resistance. In this case you would connect current excitation leads to A and B and voltage sampling leads to A and B to give you the self inductance of the primary. To get the self inductance of the secondary you would connect excitation current leads to E and F and voltage sampling leads to E and F. An ideal transformer would have a unity coupling coefficient so that when you measure the self inductance of the primary, assuming a one to one transformer turns ratio, compared to the self inductance of the secondary you then compare that to the mutual inductance, then the mutual inductance should be equal to the self inductance of the primary or secondary. Let the coefficient of coupling = K . Then $K =$

Where the coefficient of coupling will range from zero to one.

When measuring mutual inductance transformers using this technique the total resistance or inductance of the primary in AC ohms must not be so large that the compliance voltage of the output stage of the current generator in the LR-400 is in saturation. There is 20 millivolts of excitation voltage across the unknown impedance at full scale of range when the excitation control is set to 20 millivolts RMS. If the bridge is on the 20 ohm range this means that the AC current excitation is 1 milliamp (see front panel chart). Now if the total resistance or inductance of the primaries yields a voltage due to excitation current large enough to saturate the output of the current generator (two to three volts RMS) this requires a resistive or a total primary self inductance of approximately two orders of magnitude larger than the full scale range value, which in this case be 2000 ohms resistive and/or 20 henrys. Usually if you are approaching this limit the overload light, located under the digital panel meter, will turn on. Of course the overload light will turn on if you have an open lead to the primary, because then the current source will drive an infinite impedance.

SPLIT-LEAD CABLE "CABLE-MI-2"

The special mutual inductance "split-lead" sensor cable described in this section, and shown in figure 200, is available from Linear Research Inc. as Part Number "Cable-MI-2". This cable is nominally 10 feet long (3 meters long) but is available in longer lengths as required.

Domestic USA price as of 7-87 is \$ 50.00 FOB San Diego.

Cable-MI-2 may be substituted for the regular LR-400 cable on new orders of the LR-400 at no extra cost.

SUPERCONDUCTING SAMPLE MUTUAL INDUCTANCE MEASUREMENTS
WITH THE LR-400

The LR-400 is connected to the mutual inductance transformer as shown in figure 200. The figure shows separated current excitation and voltage sampling leads. Supplied for this measurement is our special "split" cable where the current excitation leads are separated from the voltage balancing leads by approximately 2 to 3 centimeters so there is no induced voltage in the voltage sampling cable due to the magnetic field set up by the current in the current excitation leads.

Figure 200 shows the polarity with regard to the primary of the transformers and with regard to the secondary of these transformers. Shown is the case of two transformers with individual primaries and the case of a single transformer with a single primary and dual secondaries. In both cases the outputs of the secondaries are connected so that the voltages subtract, or buck each other, to give a null output voltage.

The sample is placed between the primary and one secondary. The other secondary is simply a "reference" secondary. Any changes in the flux exclusion or Meissner effect in the sample will then yield a change in mutual inductance, giving a DC output at the LR-400. The initial offset in mutual inductance when the sample is first placed into the coil, and when it is non-superconducting, can be set to zero by the LR-400's 4-1/2 digit set mutual inductance dials.

Users report good operation with a temperature controlled finger thermally isolated from liquid helium, but heat sunk eventually into liquid helium, and with the mutual inductance transformer coils wound directly outside of the finger area, such that the coils themselves are immersed in liquid helium. The sample is placed on the finger and the temperature is varied. Then the change in mutual inductance is measured as a function of temperature. Alternatively, the temperature can be held constant and a DC magnetic field, from say a superconducting magnet can be applied to the sample, and the change in mutual inductance as a function of DC magnetic field can then be measured.

At the present time we do not make the mutual inductance transformers but we are thinking very seriously about making these so if there is a difficult problem for you to do the coil winding, or make the bobbin, please contact us with the appropriate inner and outer dimensions etc. and we can quote the cost for making the mutual inductance transformer.

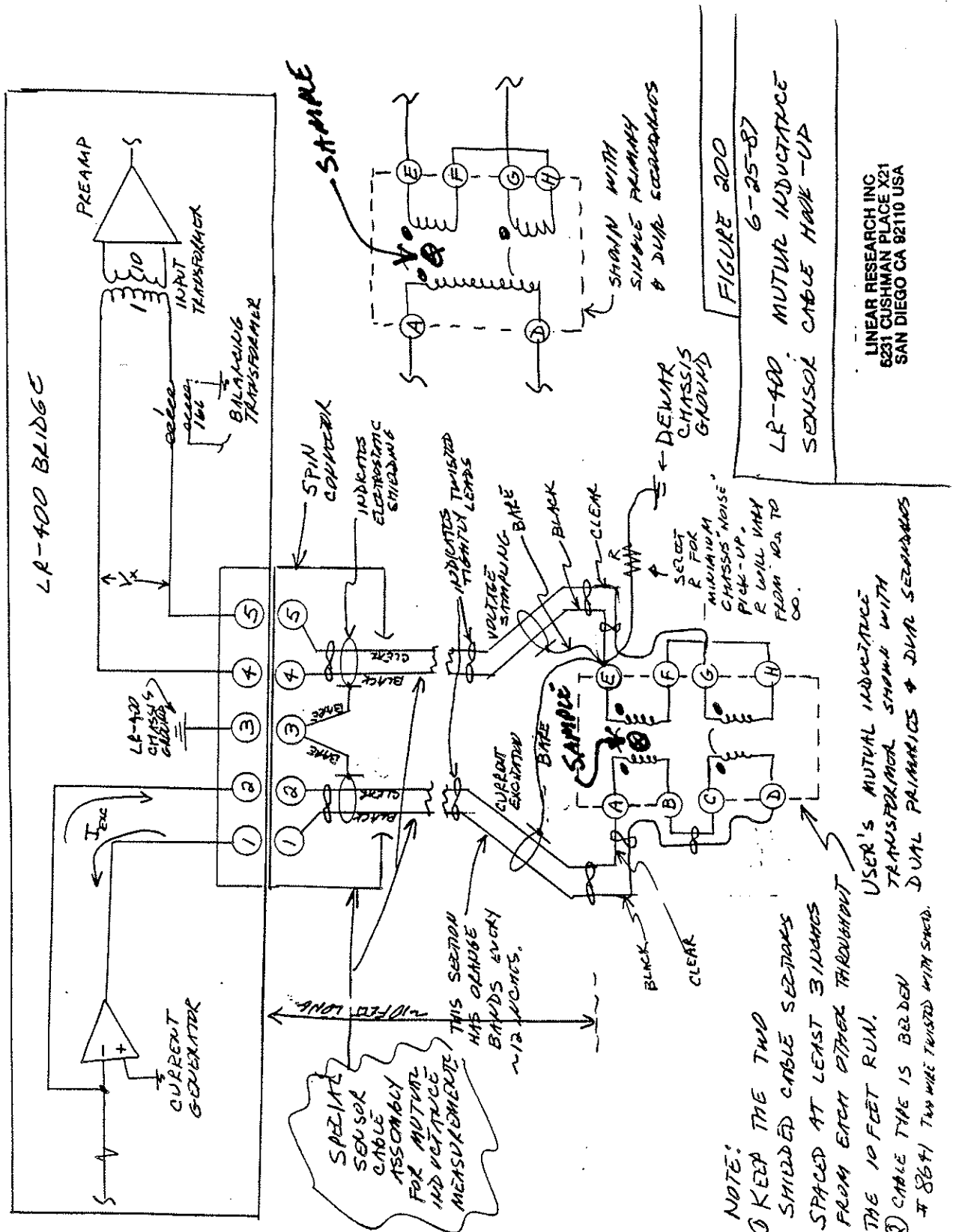


FIGURE 200

LR-400 MUTUAL INDUCTANCE
SENSOR CABLE MAKE-UP

LINEAR RESEARCH INC.
6231 CUSHMAN PLACE X21
SAN DIEGO CA 92110 USA

- NOTE:
- ① KEEP THE TWO SHIELDED CABLE SECTIONS SPACED AT LEAST 3 INCHES FROM EACH OTHER THROUGHOUT THE 10 FEET RUN.
 - ② CABLE TYPE IS Belden # 8641 TWO WIRE TWISTED WITH SHIELD.
- USER'S MUTUAL INDUCTANCE TRANSFORMER SHOULD BE WITH DUAL PRIMARYS & DUAL SECONDARIES

In a typical example, shown in figure 1A & 1B, a non-magnetic, low susceptibility, tubular structure holds or incorporates the bobbins upon which the primary and secondary coils are wound. The usual order of magnitude of dimensions are: $A=B=C$, $D=0$ to $1.0A$, $E=2D$ to $4D$.

A cryogenic fluid, such as liquid helium or liquid nitrogen, surrounds and immerses all coils. This affords a reduction in the copper wire resistance of the coils compared to their room temperature resistance. The electrical Johnson noise of the coils is also reduced compared to the room temperature noise by the square root of the ratio of the cryogenic temperature to room temperature.

A payload structure, not shown, is inserted inside the tubular structure and is comprised of the following:
A non-magnetic low susceptibility outer shell holding inside a high thermal conductivity temperature controlled mass which has attached a temperature sensor, an electrical resistive heater, and the superconducting sample. The temperature controlled mass must have a heat leak to the cryogenic fluid either by radiation or by conduction via a metallic tube, wire, or rod. The temperature controlled mass must be thermally isolated, usually by a vacuum, from the payload structure except for the heat leak. Provisions for electrical feed throughs must be included in the payload structure for electrical connections to the heater and the temperature sensor.

In figures 1 through 4: S1 = secondary number one, P1 = primary number one, etc. All have electric polarities as shown in figure 200. (X) = superconducting sample to be measured.

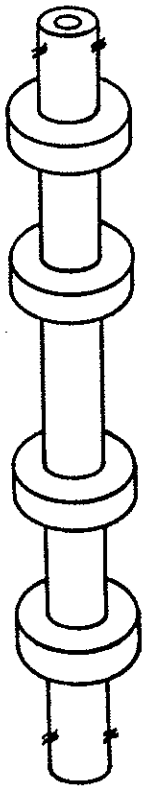


FIGURE 1A

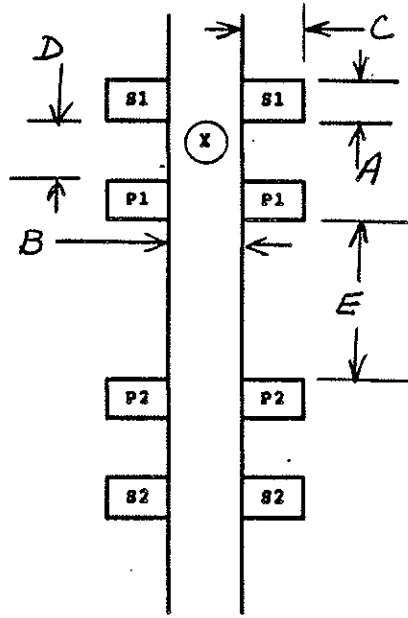


FIGURE 1B

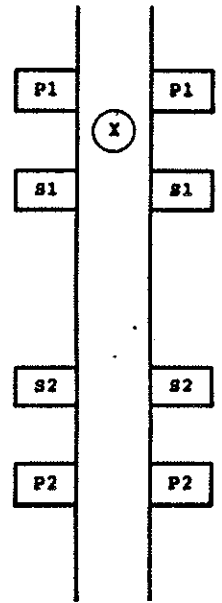


FIGURE 2

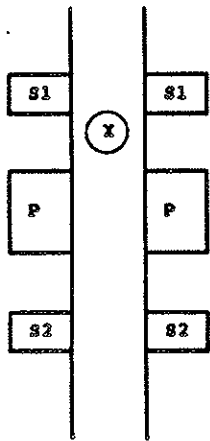


FIGURE 3

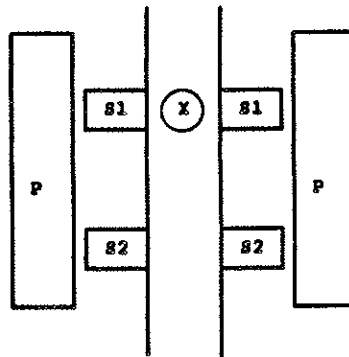
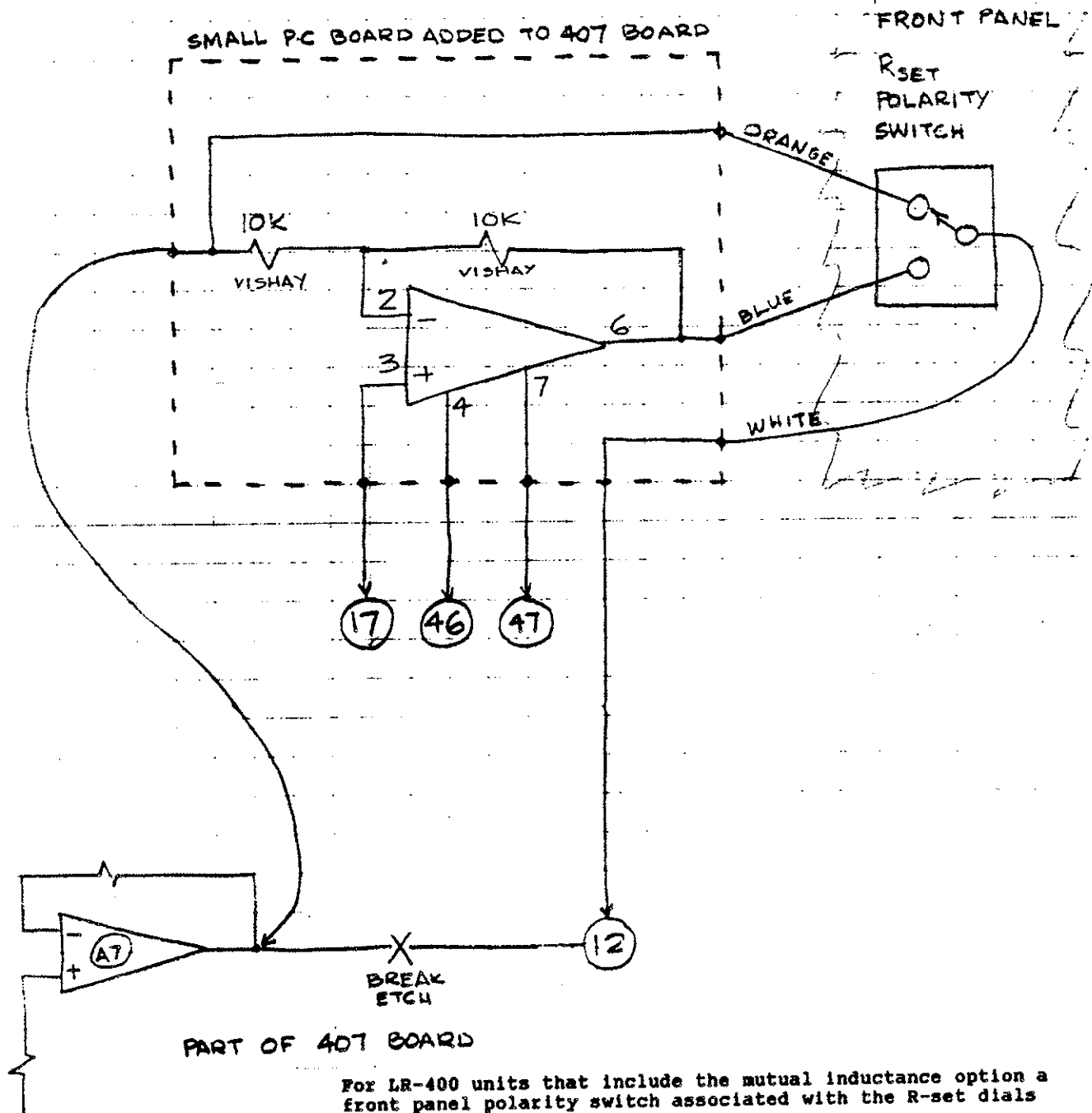


FIGURE 4

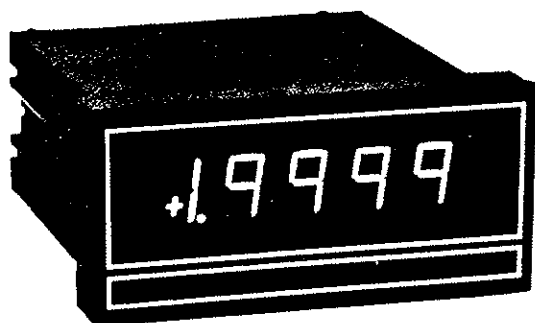
SET RESISTANCE/SET MUTUAL INDUCTANCE POLARITY TOGGLE SWITCH



For LR-400 units that include the mutual inductance option a front panel polarity switch associated with the R-set dials is incorporated. When operating in the resistance mode, this switch must always be set to plus.

When operating in the mutual inductance mode the switch may be set either to plus or minus. The minus setting, in this case, would be used to balance out a negative mutual inductance.

Missetting the toggle switch to minus in the resistance mode might result in error readings on the digital panel meter when Rx values are above midrange and the R-set dial setting is above midrange.



EXMATE INC

RP-4500D 4 1/2 DIGIT PANEL METER

**A HIGH ACCURACY DIFFERENTIAL INPUT AC POWERED METER WITH
CRYSTAL CONTROLLED 120dB NORMAL MODE NOISE REJECTION**

DESCRIPTION

The Texmate Model RP-4500D is an ultra stable, super accurate 4 1/2 digit panel meter featuring a 200KHz crystal clock. As a result of this feature, the meter provides an exceptionally high normal mode and common mode rejection. The meter measures bipolar true differential and single-ended DC voltages over five user programmable ranges from $\pm 1.9999V$ to $\pm 1200.0V$ full scale. Resolution is $100\mu V$ over ± 19999 counts, and errors due to zero drift are virtually eliminated by means of autozeroing. The meter has a multiplex BCD output capability and as an option a parallel BCD output can be provided. Other user programmable modes of operation include an ohmmeter, current meter, ratiometric voltmeter, and special scaling with offset capability.

The differential input capability of the RP-4500D has a wide common mode voltage range of $-3V$ to $+7VDC$ and a high common mode DC voltage rejection ratio of 80dB. Common mode signals are those which are present equally on both input terminals but do not develop a differential voltage between them. This capability is particularly useful for making accurate measurements of very small signals in the presence of much larger common mode signals. Because of its noise immunity, the RP-4500D is ideal for measuring various balanced transducers and bridge inputs.

The 120dB normal mode rejection of the RP-4500D at multiples of 50/60Hz means that almost any AC mains noise present on the input signal will be rejected.

In addition to standard run/hold and display blanking options, the RP-4500D features specially prepared internal mounting holes and solder pads to enable user designed input signal conditioning and control. These auxiliary pads provide access to all the key operating and control circuitry of the meter including regulated $+5VDC$ and $\pm 12VDC$ output (see page 3 for details).

SPECIFICATIONS

Input Configuration:	True differential and single-ended
Full Scale Ranges:	$\pm 1.9999VDC$ (standard) $\pm 19.999VDC$ $\pm 199.99VDC$ $\pm 1200.0VDC$
Input Impedance:	Exceeds $1000M\Omega$ on 200mV and 2V ranges; $10M\Omega$ on all other ranges
Input Protection:	$\pm 60VDC$ or 40 VAC maximum on 200mV and 2V ranges; $\pm 1200VDC$ or 850VAC on all other ranges
Normal Mode Rejection:	120dB at multiples of 50/60 Hz
Common Mode Rejection:	80dB at DC; greater than 120dB at 50/60 Hz
Common Mode Voltage:	-3 to $+7V$
Accuracy:	$\pm(0.01\%$ of reading + 1 digit)
Maximum Resolution:	$100\mu V$, over ± 19999 counts
Temperature Coefficient:	5PPM/°C in ratiometric operation; 50PPM/°C using internal reference with 200mV and 2V ranges
Zero Stability:	Autozeroed; $1\mu V/°C$ Typ
Conversion Rate:	2.5 readings per second, controlled by precision 200KHz Quartz Crystal Clock, or user controllable from 1 to 12 reading per second by external clock
Digital Output:	Multiplexed BCD (standard) Tri-State parallel BCD (optional)
Display:	0.56" LED
Polarity:	Automatically displays both "+" and "-". Polarity symbols may be blanked
Decimal:	User programmable to 4 positions
Overload Indication:	When input exceeds full scale on any range being used, most significant "1" digit and polarity symbol is displayed with all other digits blank
Power Requirements:	110V or 220V, $\pm 5\%$ at 50Hz; 117V or 230V, $\pm 5\%$ at 60Hz and 400Hz
Warmup Time:	3 minutes to specified accuracy
Operating Temperature:	$-10°C$ to $+50°C$

ORDERING INFORMATION

STANDARD 4 1/2 DIGIT PANEL METER (2V Range)

RP-4500D w/Tri-State Parallel BCD Output

Retrofit Parallel BCD Board for RP-4500D

ACCESSORIES: Edge Connector (30 pins solder tabs)

OPTIONS: Factory Installed 20V Range

Factory Installed 200V Range

Factory Installed 1200V Range

Factory Installed Offset Voltage Capability

Factory Installed Special Scaling (Specify input

signal, the span, and digital reading required e.g.

4 to 20mA input to display 0 to 19999, e.g. 0 to 2V

input to display -20 to 15000)

Order Part No.

RP-4500D

RP-4500D8CD

RP-4500D8CDD

CN-L15

VFA-0020V

VFA-0200V

VFA-1200V

VO-50K

VS-4.5

RANGE CHANGE KITS: (matched resistors for user installation)

20V Range

200V Range

1200V Range

Order Part No.

VKA-0020V

VKA-0200V

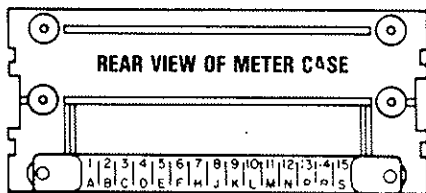
VKA-1200V

EVALUATORS KIT: (selected components to evaluate most circuit applications - includes 50K Ω offset pot)

RP-4500D KIT

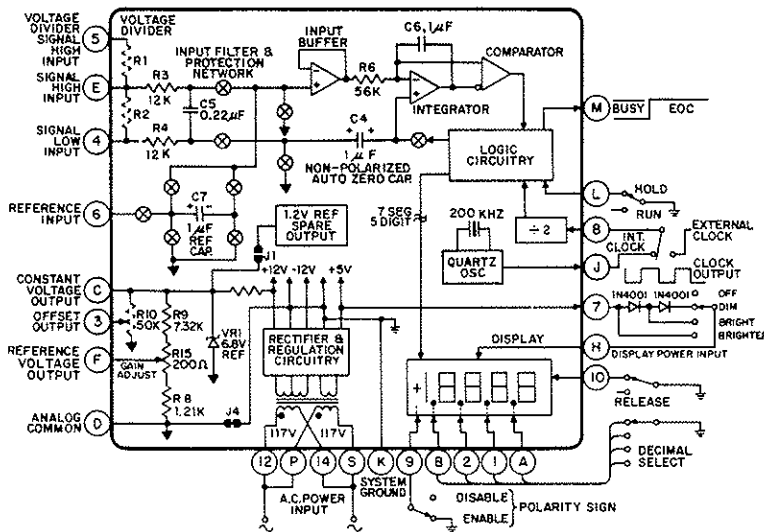
CONNECTOR PINOUTS

The Texmate Model RP-4500D interconnects by means of a standard PC board edge connector having two rows of 15 pins each, spaced on 0.156" centers. Connectors are available from Texmate, or from almost any connector manufacturer.



A- Decimal Select (1XXX.X)	1- Decimal Select (1XX.XX)
B- Decimal Select (1.XXXX)	2- Decimal Select (1X.XXX)
C- Constant Voltage Output	3- Offset Voltage Output
D- Analog Common	4- Signal Low Input
E- Signal High Input	5- Voltage Divider Signal High Input
F- Reference Voltage Output	6- Reference Input
H- Display Power Input	7- +5VDC Power Output
J- Clock Output	8- Clock Input
K- System Ground	9- Polarity Enable
L- Run/Hold	10- Display Test
M- Integration Busy Out	11- No Connection
N- No Connection	12- AC Power Input
P- 117/230V Select	13- No Connection
R- No Connection	14- 117/230V Select
S- AC Power Input	15- No Connection

The diagram values indicated for this mode of operation. Variations from the standard for use in special applications will be found under the heading Typical Application Circuits & Connection Instructions.



PIN DESCRIPTIONS

Pins A, B, 1 and 2 — Decimal Select: Decimal points may be displayed as required by connecting appropriate pin to System Ground Pin K.

Pin C — Constant Voltage Output: Pin C may be used as a primary reference Voltage Source of +6.9V referred to Analog Common Pin D. A temperature coefficient of 50PPM/°C is typical. The maximum usable load without component change is limited to 500µA.

Pin D — Analog Common: Signal return common for differential inputs, ratiometric inputs, external reference inputs. For single-ended inputs, Pin D and Pin 4 should be joined at the grounded side of the input signal source. **CAUTION:** Analog Common Pin D is not isolated and is internally connected to System Ground Pin K.

Pin E — Signal High Input: Signal high input of A to D converter. Maximum over-voltage protection is ±60VDC or 40VAC.

Pin F — Reference Voltage Output: Internal precision voltage reference. Standard output is 1.0000V, adjustable by ±5% with R15 potentiometer. Usable voltages from 0.05V to 5.0V for special high impedance scaling can be obtained by changing the value of internal dividing resistors R8 and R9.

Pin H — Display Power Input: Power input for LED display drive. For normal operation, connect Pin H to +5VDC Power Output Pin 7. The display may be dimmed or blanked by reducing or removing the voltage between Pin H and Pin 7. The power supply to the A to D converter and logic circuits is independent to that of the display. Thus, even with the display blanked, the remainder of the meter continues to function normally.

Pin J — Clock Output: A quartz crystal controlled oscillator provides a stable clock signal output of 200KHz.

Pin K — System Ground: All digital signals, decimal points, display test, and run/hold circuits should be returned to this ground point. Pin K is internally connected to Analog Common Pin D.

Pin L — Run/Hold: If Pin L is left open (or connected to +5VDC Power Output Pin 7 for logic control purposes) the meter will operate in a free-running mode. Under control of the internal 200KHz quartz crystal clock, readings will be updated every 400mS (2.5 per sec). If Pin L is connected to System Ground Pin K (logic low), the meter will latch up and continuously display the reading. If Pin L is released from Pin K (Pin L then goes logic high) for more than 2000 clock pulses (>10mS at 200KHz) and returned to Pin K (logic low), the meter will complete one conversion, update, and then hold the new reading. For all practical purposes, a manually actuated pushbutton switch will provide sufficient timing for "press-to-update" operation.

Pin M — Integration Period Busy Output: CMOS logic output (normally high) goes low and remains low during the period of the conversion cycle when the input signal is being integrated. Actual integration is performed for 20,000 clock pulses. De-integration then occurs for 0 to 40,000 clock pulses (each count display = 2 clock pulses), depending on signal magnitude. Pin M goes to logic high throughout Autozero Phase and during Hold Status.

Pins N, R, 11, 13, and 15 — No Connection: The PCB pads which would nor-

mally correspond to these pins do not exist on the PCB.

Pin P — 117/230V Select: Connect Pin P to AC Power Input Pin 12 for 117V operation. Connect Pin P to 117/230V Select Pin 14 for 230V operation.

Pin S — AC Power Input: Connect one side of 117 or 230V AC power input to Pin S.

Pin 3 — Offset Voltage Output: Pin 3 is the center tap of R10 potentiometer which when installed will provide an offset voltage output which is variable from 0 to +6.9V and may be used for signal offset or scaling purposes.

Pin 4 — Signal Low Input: Signal low input of A to D converter. Maximum over-voltage protection is ±60VDC or 40VAC.

Pin 5 — Voltage Divider Signal High Input: Signal high input for voltages that require attenuation or scaling. Dividing resistors R1 and R2 may be mounted internally for voltages up to 1200V max. Matched dividing resistors for 20V (1/10), 200V (1/100) and 1200V (1/1000) ranges are available from Texmate. Shunt resistors for current measurements up to 200mA may be internally mounted in the R1 position. The current loop is then applied to Pin 5 and returned through Signal High Input Pin E.

Pin 6 — Reference Input: Reference voltage input for A to D converter. Normally supplied from Reference Voltage Output Pin F. An external reference source referred to Analog Common Pin D may be used instead. Pin 6 may be used as an input for ratiometric measurements. Minimum usable voltage is 0.05VDC and the maximum voltage is 5.0VDC. (Signal Input Voltage ÷ Reference Input Voltage) × 10000 = Reading Displayed. Maximum signal voltage is 5V. Higher voltages must be scaled down through voltage divider. Reference input voltage must remain stable during measurement period.

Pin 7 — +5VDC Power Output: Regulated +5VDC ±3% power output to enable the display and logic circuitry. In addition, up to 25mA may be used to power external circuitry.

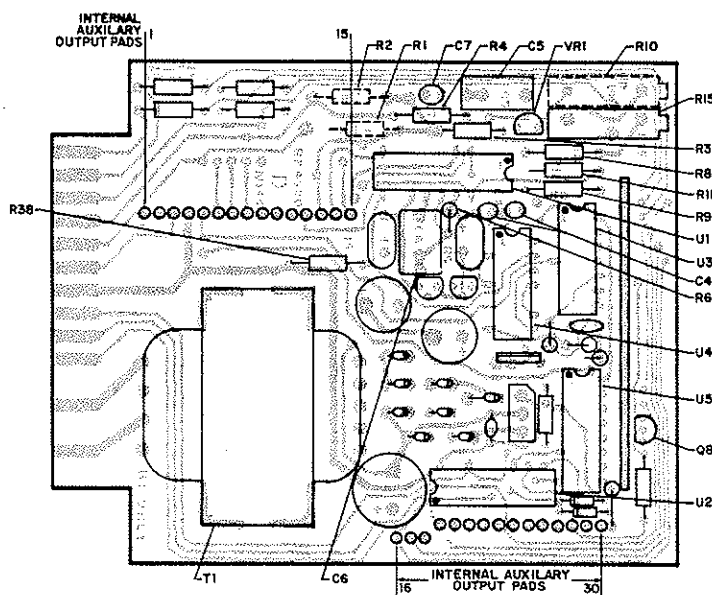
Pin 8 — Clock Input: Normally Pin 8 is connected to Clock Output Pin J which provides a 200KHz clock input for optimum rejection from 50/60Hz noise. An external clock source may be used if desired (+5V referred to power ground at 50% duty cycle). The minimum recommended frequency is 10KHz, and the maximum is 1MHz (12.5 readings per second). For inputs below 100KHz or above 300KHz, the integrator time constant and some component values have to be changed.

Pin 9 — Polarity Enable: Connect Pin 9 to System Ground Pin K to enable the constant minus bar for normal polarity indication. To blank both positive and negative polarity indication it is necessary, in addition to opening Pin 9, to cut J4D, which is located on the display board rearside. **NOTE:** To blank polarity for most positive signal input unipolar applications, open Pin 9 and reverse the signal input leads.

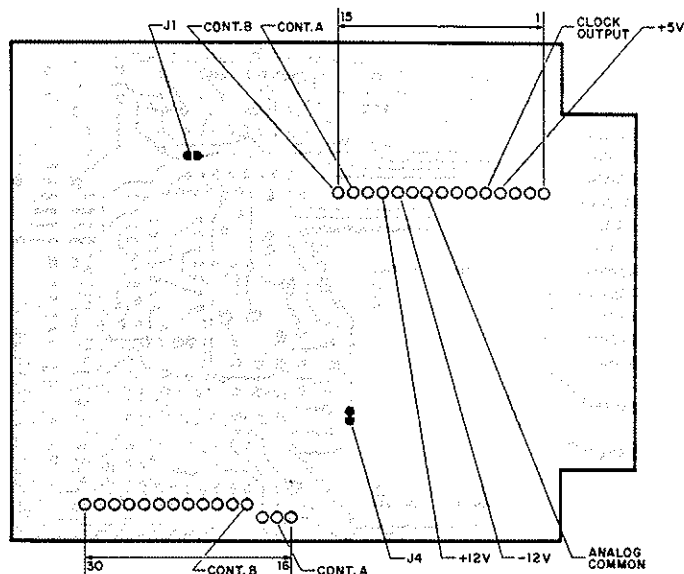
Pin 10 — Display Test: All display segments will operate when Pin10 is connected to System Ground Pin K.

Pin 12 — AC Power Input: Connect one side of 117 or 230V AC power input to Pin 12.

Pin 14 — 117/230V Select: Connect Pin 14 to AC Power Input Pin S for 117V operation. Connect Pin 14 to 117/230V Select Pin P for 230V operation.



COMPONENT SIDE



BOTTOM SIDE

SOLDER PADS USED FOR SPECIAL APPLICATIONS

AUXILIARY SOLDER PAD/PINOUTS

The RP-4500D has two rows of auxiliary solder pads located internally on the PC Board that provide access to the multiplexed BCD output and the key operating circuitry. They are laid out to facilitate the mounting of Texmate or user designed signal conditioning and digital output modules.

NOTE: The RP-4500D is available with an optional board that converts the MUX BCD to a buffered Tri-State parallel BCD output. Alternatively, the parallel BCD output board may be separately purchased and retrofitted by the user. For details see the RP-4500BCD application sheet. To order, see order information, page 1.

- | | |
|--------------------------------------|-----------------------------|
| 1— Voltage Divider Signal High Input | 9— Analog Common |
| 2— Reference Voltage Output | 10— System Ground |
| 3— Reference Input | 11— -12VDC Output |
| 4— +5VDC Output | 12— +12VDC Output |
| 5— Clock Output | 13— Signal High Input |
| 6— Constant Voltage Output | 14— Control A |
| 7— Signal Low Input | 15— Control B |
| 8— Offset Voltage Output | 16— Integration Busy Output |

- | | |
|--------------------------|--------------------------|
| 17— Control A | 24— D5 Digit Drive (MSD) |
| 18— Run/Hold | 25— B1 BCD Output |
| 19— Control B | 26— System Ground |
| 20— D1 Digit Drive (LSD) | 27— B8 BCD Output |
| 21— D2 Digit Drive | 28— B4 BCD Output |
| 22— D3 Digit Drive | 29— B2 BCD Output |
| 23— D4 Digit Drive | 30— +5VDC Output |

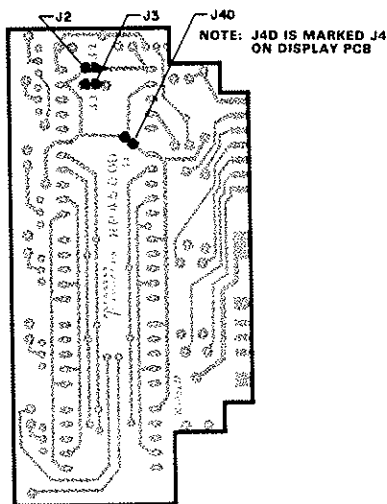
AUXILIARY SOLDER PAD/PIN DESCRIPTIONS

- Pad 1 — Voltage Divider Signal High Input:** Same as pin description Pin 5.
Pad 2 — Reference Voltage Output: Same as pin description Pin F.
Pad 3 — Reference Input: Same as pin description Pin C.
Pad 4 — +5VDC Output: Same as pin description Pin 7.
Pad 5 — Clock Output: Same as pin description Pin J.
Pad 6 — Constant Voltage Output: Same as pin description Pin C.
Pad 7 — Signal Low Input: Same as pin description Pin 4.
Pad 8 — Offset Voltage Output: Same as pin description Pin 3.
Pad 9 — Analog Common: Same as pin description Pin D.
Pad 10 — System Ground: Same as pin description Pin K.
Pad 11 — -12VDC Output: Auxiliary power output -12VDC at 20mA max. for input signal processing module.
Pad 12 — +12VDC Output: Auxiliary power output +12VDC at 20mA max. for input signal processing module.
Pad 13 — Signal High Input: Same as pin description Pin E.
Pin 14 — Control A: Pin 14 is normally logic low (zero volts); it goes to logic high "1" at the beginning of the integration period. If the input signal is negative Pin 14 will return to logic "0" at the end of the integration period; if the input signal is positive, however, Pin 14 will not return to logic "0" until either zero-crossover occurs or the end of the deintegration period is reached. See Timing Diagram.
Pin 15 — Control B: Pin 15 is normally logic low (zero volts); it goes to logic high

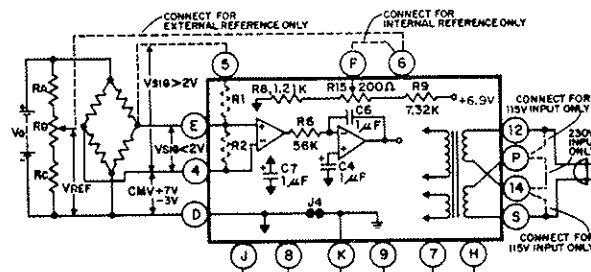
- "1" at the beginning of the integration period. If the input signal is positive Pin 15 will return to logic "0" at the end of the integration period; if the input signal is negative, however, Pin 15 will not return to logic "0" until either zero-crossover occurs or the end of the deintegration period is reached. See Timing Diagram.
Pad 16 — Integration Busy Output: Same as pin description Pin M.
Pad 17 — Control A: Same as Pin 14.
Pad 18 — Run/Hold: Same as pin description Pin L.
Pad 19 — Control B: Same as Pin 15.
Pad 20, 21, 22, 23 and 24 — Digit Drive D1 to D5: The digit drives are a negative true logic that goes to logic low for 40 clock pulses minus one clock pulse delay while waiting for validation of BCD data. The scan sequence is D1 (LSD), D2, D3, D4 and D5 (MSD). The scan is continuous unless an overrange condition occurs which will leave only D5 scanning and all other 4 digits blank. As D1 to D5 are open-collector output, pull-up resistors are required.
Pad 25, 27, 28 and 29 — BCD Output B1 to B8: The BCD output bits (B1, B2, B4, B8) are positive true logic that occur one clock pulse earlier than the Digit Drive. As B1 to B8 are open-collector output, pull-up resistors are required. The polarity signs and most significant digit "±1" have a special BCD format. +1XXXX = 0111 and -1XXXX = 1111; +0XXXX = 0101 and -0XXXX = 1101.
Pad 26 — System Ground: Same as pin description Pin K.
Pad 30 — +5VDC Output: Same as pin description Pin 7.

TYPICAL APPLICATION CIRCUITS & CONNECTION INSTRUCTIONS

The RP-4500D may be used in a wide variety of configurations. The following circuits illustrate some of the possibilities and demonstrate the exceptional versatility of Texmate products. Components called for in the applications which are not part of the standard meter may be supplied by the user or in some cases purchased from Texmate. The circuit diagrams explain the basic pinout connections required for each application. Unless otherwise specified, the diagrams will show the component values and solder junctions that would normally be installed on a standard 2V range meter. For those applications which have alternative ranges and/or input configurations, the required component values and any modifications are described in the text. **NOTE:** Use of these application circuits is entirely at the risk and responsibility of the user and any user modification of the meter may, at the discretion of Texmate, void the warranty. (See rear page for user's responsibility and warranty details.) The following legend applies to all application circuits: 1) optional component positions are shown in dotted lines; 2) internal solder junctions are shown by \bullet for a closed junction or \circ for an open junction; 3) Calibration voltages as measured by an external user supplied voltmeter are shown by \odot .

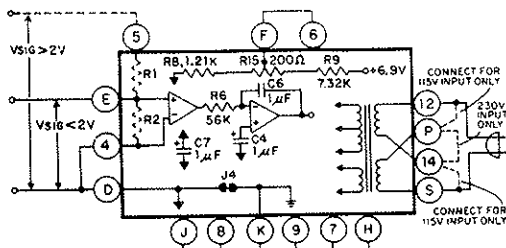


DISPLAY BOARD REAR/SOLDER SIDE



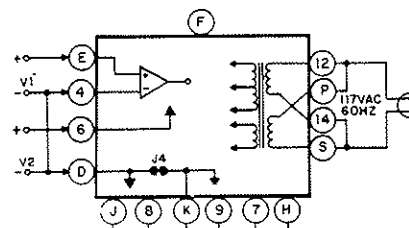
DIFFERENTIAL METER 2V, >2V RANGE, OR EXT. REF.

2V Range: 1) Connect up the circuit as shown; 2) Apply Signal Hi to Pin E and Signal Lo to Pin 4.



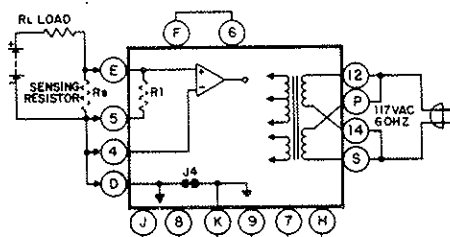
SINGLE-ENDED METER 2V, >2V RANGE

2V Range: 1) Connect up the circuit as shown; 2) Apply Signal Hi to Pin E and Signal Lo to Pins 4, D. >2V Range: 1) Install R1 and R2 as specified under section titled Useful Tables; 2) Apply Signal Hi to Pin 5 and Signal Lo to Pins 4, D.



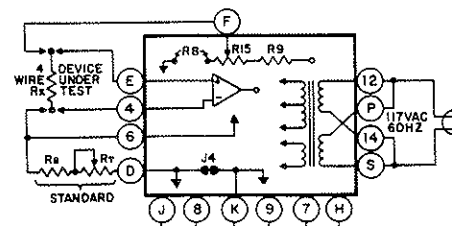
RATIO-METRIC VOLTMETER

Reading = $(V_1 + V_2) \times 10,000$ where $-2V < V_1 < +2.8V$ and $+100mV < V_2 < +5V$. If $50mV < V_2 < 500mV$, change C6 from $1\mu F$ to $0.1\mu F$.



SINGLE-ENDED CURRENT METER

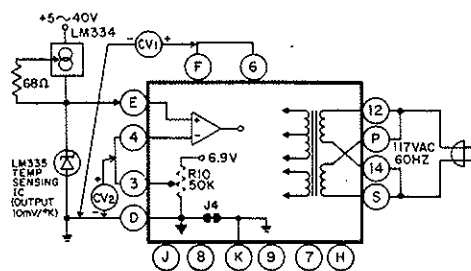
1) Connect meter as shown; 2) Install R_S . **NOTE:** R_S must be externally mounted when current is greater than 200mA. Standard values for R_S are specified under section titled Useful Tables. For all other ranges, R_S may be internally mounted in the R1 position.



DIFFERENTIAL RATIO-METRIC OHM METER

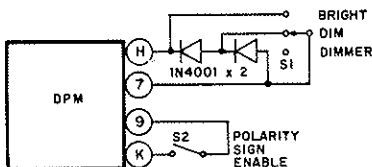
1) Remove (open circuit) R8; 2) $(R_S + R_T) \times 2 = \text{Full Scale Value}$; 3) Reading = $R_x \div (R_S + R_T) \times 10,000$; 4) Change C6 from $1\mu F$ to $0.1\mu F$ for 200 Ω range; 5) Remove C5 for 20M Ω range.

TYPICAL APPLICATION CIRCUITS & CONNECTION INSTRUCTIONS

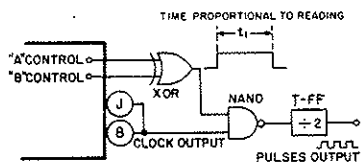


OFFSET CAPABILITY FOR THERMOMETER OPERATION

1) Install R10 Potentiometer of 50KΩ; 2) For -55°C to $+150^{\circ}\text{C}$ adjust CV1 = 1.000V and CV2 = 2.732V; 3) For -58°F to $+200^{\circ}\text{F}$ change R9 to 13.7KΩ and adjust CV1 = 0.555V and CV2 = 2.554V.

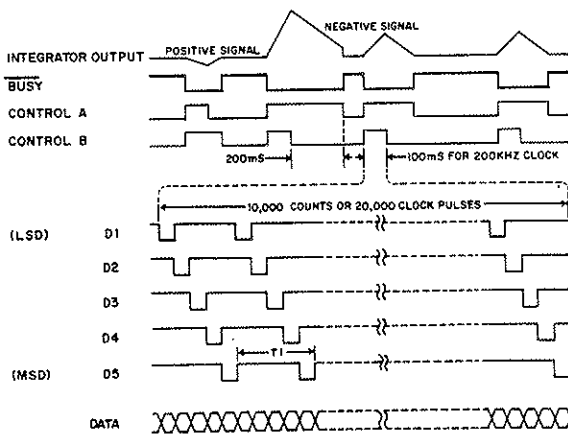


DISPLAY BRIGHTNESS CONTROL

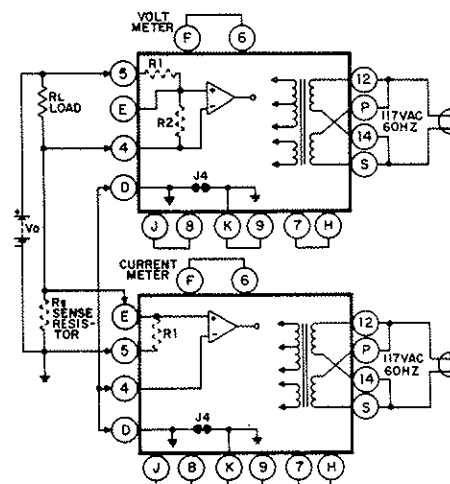


INTERFACE FOR PRESET COUNTER/CONTROLLER

Displayed reading is equal to the number of pulses during time t_1 . (See Component Layout Bottom Side illustration for location of "A" and "B" Controls.)

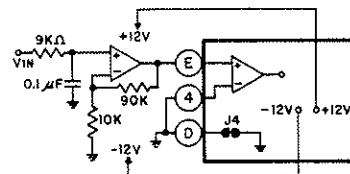


TIMING DIAGRAM



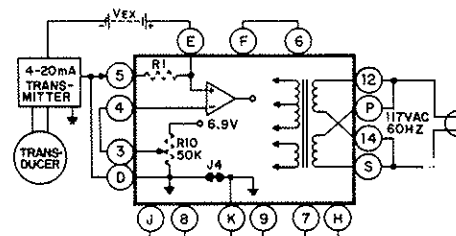
SIMULTANEOUS VOLTAGE AND CURRENT MEASUREMENT

1) Install R1, R2 and R3 as specified under section titled Useful Tables. NOTE: R3 must be located in low side of the current loop and Signal Low Input Pin 4 of Voltmeter must not be grounded.



AUXILIARY POWER OUTPUT

$\pm 12\text{V}$ output for external OPAMP circuitry 20mA max. (See Component Layout Bottom Side illustration above for correct solder pads.)



4 TO 20mA RECEIVER

1) Install 125Ω resistor in R1 position. 2) Install R10 potentiometer using any value between a minimum of 20KΩ and a maximum of 100KΩ.

USEFUL TABLES

CALIB. PROCEDURE

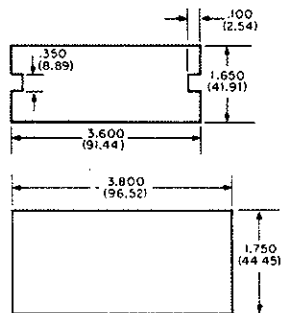
VOLTAGE RANGE CHANGE				CURRENT RANGE CHANGE (*)			RESISTANCE RANGE CHANGE		
F.S. In	R1	R2	Resol	F.S. In	R _S	Resol	F.S. In	R _S + R _T	Resol
2V	omit	omit	100μV	20A	0.1Ω	1mA	200Ω	100Ω	10mΩ
20V	9MΩ	1MΩ	1mV	2A	1Ω	100μA	2KΩ	1KΩ	100mΩ
200V	10MΩ	100KΩ	10mV	200mA	10Ω	10μA	20KΩ	10KΩ	1Ω
1200V	10MΩ	10KΩ	100mV	20mA	100Ω	1μA	200KΩ	100KΩ	10Ω
				2mA	1KΩ	100nA	2MΩ	1MΩ	100Ω
				200μA	10KΩ	10nA	20MΩ	10MΩ	1KΩ
				20μA	100KΩ	1nA			

Apply power to the meter. Then with a precision DC reference source, apply +1.9000 VDC between the Signal High Input Pin E and the Signal Low Input Pin 4. Adjust R15 potentiometer (behind front panel filter on right side as viewed from front) until the display reads +1.9000V. **Note:** The voltage applied in this case is for a +1.9999V F.S. meter. For other ranges, the voltage applied should be similarly proportionate to the particular full scale voltage.

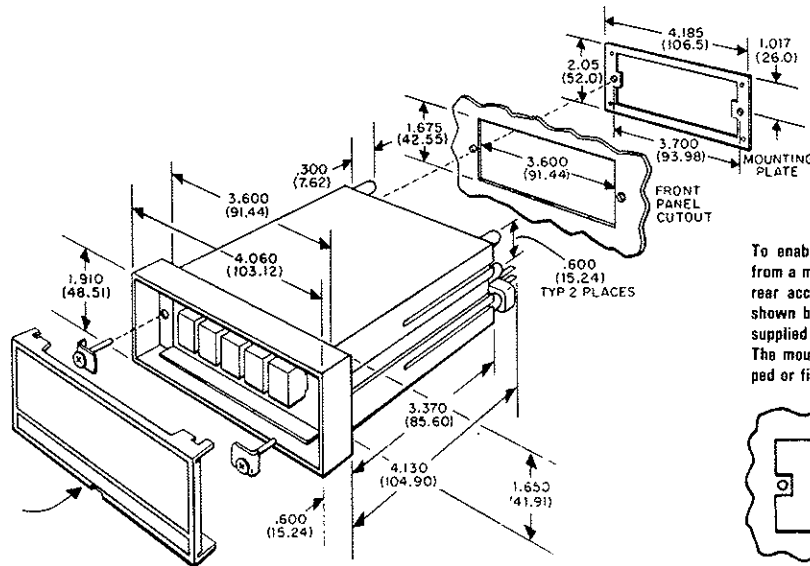
(*) For full scale current inputs greater than 200mA, R_S must be located external to the meter, and a 4-wire type connection should be used. For full scale currents of 200mA or less, R_S may be located on the meter's PCB in the R1 position.

DIMENSIONS AND CUTOUTS

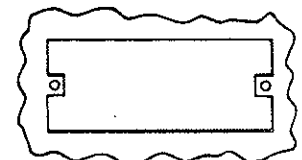
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To enable removal of the panel meter from a mounting panel without requiring rear access, make the panel cutout as shown below, using the mounting plate supplied with the meter as a template. The mounting holes should then be tapped or fitted with threaded studs.



WARRANTY

Texmate warrants that its products are free from defects in material and workmanship under normal use and service for a period of one year from date of shipment. Texmate's obligations under this warranty are limited to replacement or repairing, at its option, at its factory, any of the products which shall within the applicable period after shipment be returned to Texmate's facility, transportation charges prepaid, and which are after examination disclosed to the satisfaction of Texmate to be thus defective. The warranty shall not apply to any equipment which shall have been repaired or altered except by Texmate, or which shall have been subjected to misuse, negligence, or accident. In no case shall Texmate's liability exceed the original purchase price. The aforementioned provisions do not extend the original warranty period of any product which has either been repaired or replaced by Texmate, Inc.

USER'S RESPONSIBILITY

We are pleased to offer suggestions on the use of our various products either by way of printed matter or through direct contact with our sales/application engineering staff. However since we have no control over the use of our products once they are shipped, **NO WARRANTY WHETHER OF MERCHANTABILITY, FITNESS FOR**

PURPOSE, OR OTHERWISE is made beyond the repair, replacement or refund of purchase price at the sole discretion of Texmate. Users shall determine the suitability of the product for the intended application before using and the users assume all risk and liability whatsoever in connection therewith regardless of any of our suggestions or statements as to application or construction. In no event shall Texmate's liability in law or otherwise be in excess of the purchase price of the product.

SERVICE POLICY

Either during or after the warranty period, and as a result of noncatastrophic failures resulting from misuse, negligence, accident, or improper application or installation, Texmate will repair any of their instruments for a flat charge.

Product Price Range	Repair Charge
\$ 20 to \$ 70	\$20.00
\$ 71 to \$150	\$35.00
\$151 to \$300	\$45.00

For repairs that do not meet these conditions an individual quotation can be provided.

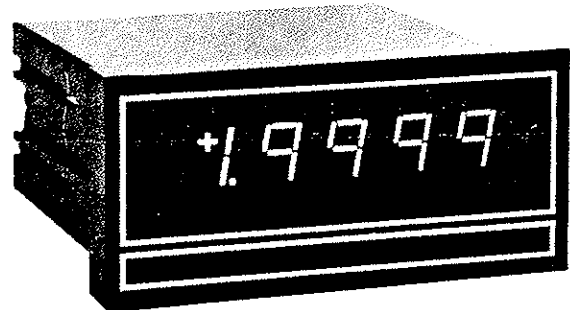
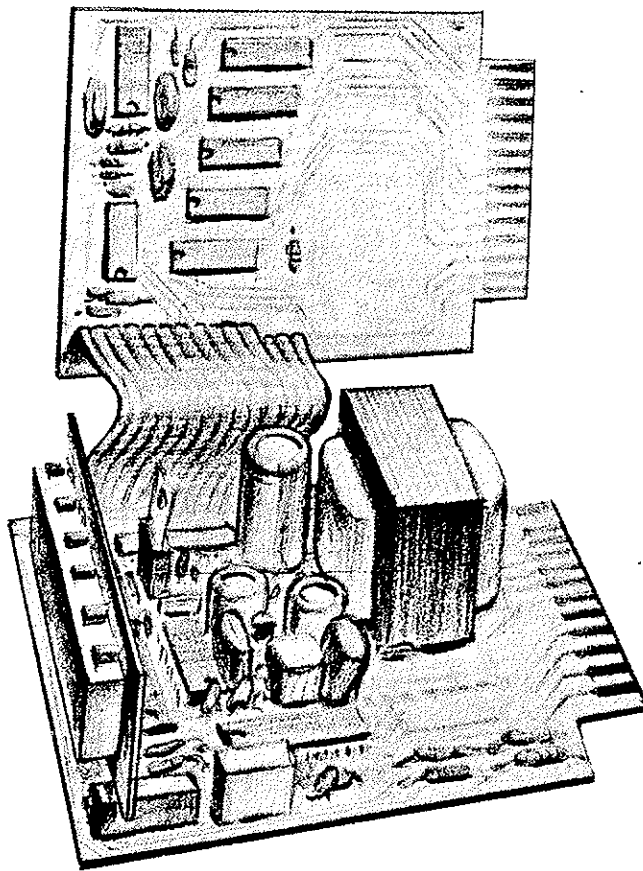


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TEXMATE INC

RP-4500BCD PARALLEL BCD OUTPUT OPTION



**4½ DIGIT TRI-STATE BUFFERED PARALLEL BCD
OUTPUT OPTION FOR THE RP-4500D PANEL METER.
ALSO AVAILABLE AS A FIELD RETROFIT MODULE.**

DESCRIPTION

The Parallel BCD Output Module for use with Texmate's Model RP-4500D Digital Panel Meter is designed to further increase the versatility of the meter. It consists of an additional PC board mounted in the case with the meter and connected to it with a multiconductor ribbon cable.

The Parallel BCD module incorporates CMOS circuitry with Tri-State output, capable of two low power TTL loads.

The unit may be used to drive remote displays, digital printers, digital comparators, or provide data for digital processor applications.

NOTE: This instruction sheet only provides information on the parallel BCD output module. For information on the RP-4500D Digital Panel Meter see the RP-4500D instruction sheet.

SPECIFICATIONS

System Voltage:	5VDC $\pm 2\%$
Data Output:	Parallel Binary-Coded-Decimal (BCD) ± 19999 Counts Max.
BCD Logic Level:	Buffered CMOS Tri-State Output Logic 1: 4.6V at 1mA Logic 0: 0.4V at 1mA Logic X: High impedance 300nA max.
Polarity Output:	Logic 1 for positive. Logic 0 for negative.
Spare Data Latch:	2 bits spare latch available for decimal points and overrange output.
Data Input:	Multiplexed BCD CMOS input.
Control Output:	Data ready, print command, overrange, control A, control B, run/hold, clear, busy, and output select.
Operating Temp:	-10 °C to 50 °C.
Power Consumption:	2mA typical at no output load.

ORDERING INFORMATION

STANDARD RP-4500D 4½ DIGIT PANEL METER WITH PARALLEL BCD OUTPUT OPTION (2V Range)
PARALLEL BCD OUTPUT MODULE WITH CONNECTING CABLE
 For user Retrofit to RP-4500D
ACCESSORIES: Edge Connector (30 pins solder tabs)
OPTIONS: Factory installed 200mV Range
 Factory installed 20V Range
 Factory installed 200V Range
 Factory installed 1200V Range
 Factory installed Special Scaling (Specify input signal, the span, the digital reading required, e.g. 4 to 20mA input to display 0 to 19999, a.g. 0 to 2V input to display -20 to 15000)

Order Part No.
 RP-4500BCD
 RP-4500BCDD0
 CN-L15
 VD-200MVF1
 VFA-0020V
 VFA-0200V
 VFA-1200V
 VS-4.5

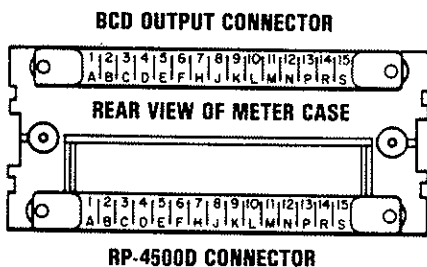
RANGE CHANGE KITS: (match resistors for user installation)
 200mV Range
 20V Range
 200V Range
 1200V Range

EVALUATORS KIT: (Selected components to evaluate most circuit applications)

Order Part No.
 VD-200MV
 VKA-0020V
 VKA-0200V
 VKA-1200V
 RP-4500DKIT

CONNECTOR PINOUTS

The Texmate Model RP-4500BCD interconnects by means of a standard PC board edge connector having two rows of 15 pins each, on 0.156" centers. Connectors are available from Texmate, or from almost any connector manufacturer.

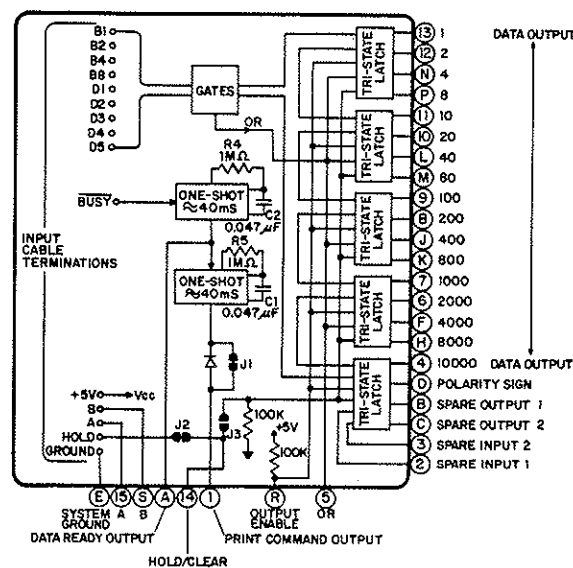


BCD OUTPUT CONNECTOR PINOUTS

A— Data Ready Output	1— Print Command Output
B— Spare Output 1	2— Spare Input 1
C— Spare Output 2	3— Spare Input 2
D— Polarity Sign Output	4— 10000 Data Output
E— System Ground	5— Overrange Output
F— 4000 Data Output	6— 2000 Data Output
H— 8000 Data Output	7— 1000 Data Output
J— 400 Data Output	8— 200 Data Output
K— 800 Data Output	9— 100 Data Output
L— 40 Data Output	10— 20 Data Output
M— 80 Data Output	11— 10 Data Output
N— 4 Data Output	12— 2 Data Output
P— 8 Data Output	13— 1 Data Output
R— Output Enable	14— Hold/Clear Input
S— Control B	15— Control A

NOTE: For RP-4500D connector pinouts see the RP-4500D instruction sheet.

The diagram below depicts the function of the parallel BCD output circuit in standard form. Components R5 and C1 can be changed to obtain different pulse-width on the print command output. The function of the Analog to Digital Converter and the general uses of the DPM are shown on RP-4500D instruction sheet.



RP-4500BCDO INTERNAL INPUT CABLE TERMINATION

16— Integration Busy Input	21— D2 Digit Drive	26— System Ground
17— Control A	22— D3 Digit Drive	27— B8 BCD Input
18— Run/Hold	23— D4 Digit Drive	28— B4 BCD Input
19— Control B	24— D5 Digit Drive (MSD)	29— B2 BCD Input
20— D1 Digit Drive (LSD)	25— B1 BCD Input	30— +5VDC Input

PIN DESCRIPTIONS

Pin A — Data Ready Output: Pin A remains at logic "0" during the period that valid data is available. Pin A goes high (logic "1") for approximately 20mS after the integrator output crosses zero. During this period of change the output data is considered invalid.

Pin B and C — Spare Outputs: Pin B and Pin C are spare Tri-state latched outputs that can be addressed by the spare inputs provided on Pin 2 and Pin 3.

Pin D — Polarity Sign Output: Pin D is a latched Tri-state output. Its output data is updated after every conversion cycle. Pin D goes to a Tri-state condition if Output Enable Pin R is either left open or applied to logic "1".

Pin E — System Ground: Pin E is the common for all digital signals.

Pins F, H, J, K, L, M, N, P, 4, 6, 7, 8, 9, 10, 11, 12, and 13 — Data Outputs: These pins are latched Tri-state outputs. Data is updated after every conversion cycle. They go to a Tri-state condition if Output Enable Pin R is either left open or applied to logic "1".

Pin R — Output Enable: For single meter applications, apply logic "0" (or connect to System Ground Pin E) to enable all data outputs. For multiple meter applications using a single data retriever such as a printer, apply logic "1" to Pin R in order to produce a floating output (Tri-state) at the Data Output Pins F, H, J, K, L, M, N, P, 4, 6, 7, 8, 9, 10, 11, 12, and 13.

Pin S — Control B: Pin S is normally logic "0" (zero volts); it goes to logic "1" at the beginning of the integration period. If the input signal is positive Pin S will return to logic "0" at the end of the integration period; if the input signal is

negative, however, Pin S will not return to logic "0" until either zero-crossover occurs or the end of the deintegration period is reached. See Timing Diagram.

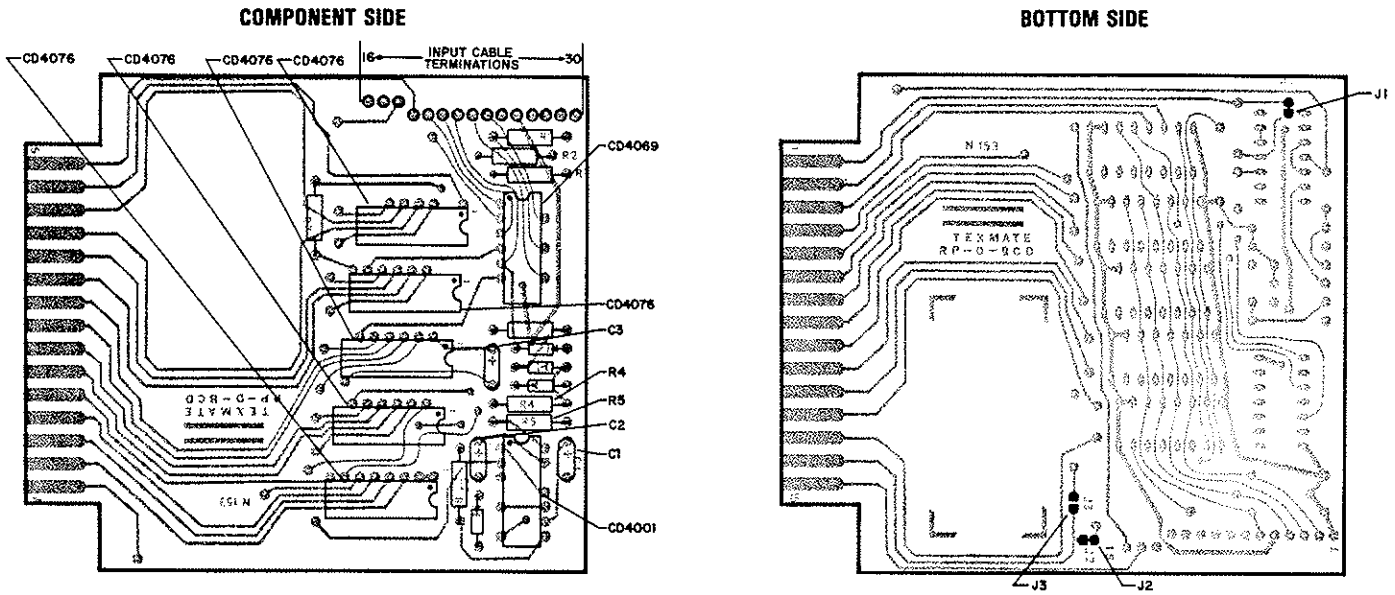
Pin 1 — Print Command Output: Pin 1 is normally at logic "1" and goes to logic "0" for approximately 20mS to activate a printer, and then returns to logic "1".

Pins 2 and 3 — Spare Inputs: Any required digital information (2 bits), such as decimal point positions, overrange/underrange can be transmitted to the data bus through Pin B and Pin C by using these two latches.

Pin 5 — Overrange Output: This pin can only be used with a CMOS input load, due to the high output impedance. However, if required, it can be buffered by joining Pin 5 to Spare Input Pin 1 and utilizing the output from Spare Output Pin B. Pin 5 is normally logic "0" and goes to logic "1" when overrange.

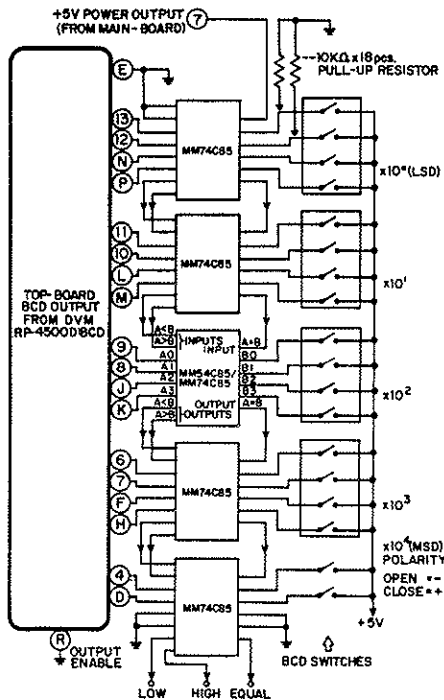
Pin 14 — Hold/Clear Input: Pin 14 normally serves as a Run/Hold Input which has identical functions as Pin L of RP-4500D digital panel meter. By opening J2 and closing J3, Pin 14 becomes a Clear Input to all the BCD Data Latches; then applying logic "1" to this pin will clear all data outputs to zero, and applying logic "0" or an open circuit will enable normal operation.

Pin 15 — Control A: Pin 15 is normally logic "0" (zero volts); it goes to logic "1" at the beginning of the integration period. If the input signal is negative Pin 15 will return to logic "0" at the end of the integration period; if the input signal is positive, however, Pin 15 will not return to logic "0" until either zero-crossover occurs or the end of the deintegration period is reached. See Timing Diagram.

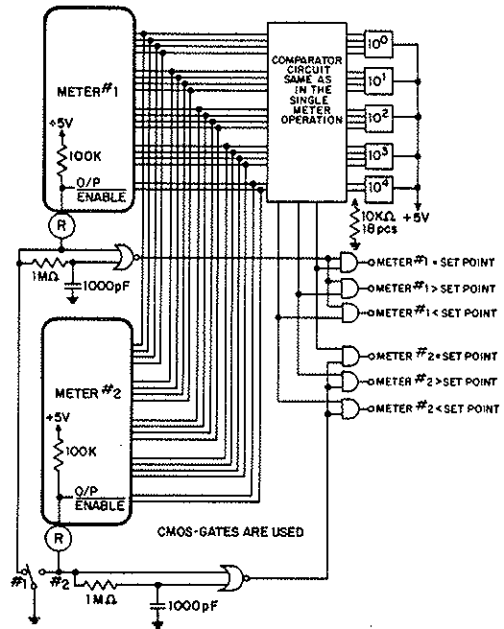


TYPICAL APPLICATION CIRCUITS & CONNECTION INSTRUCTIONS

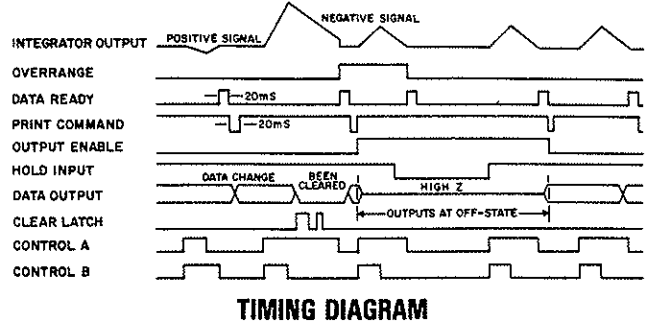
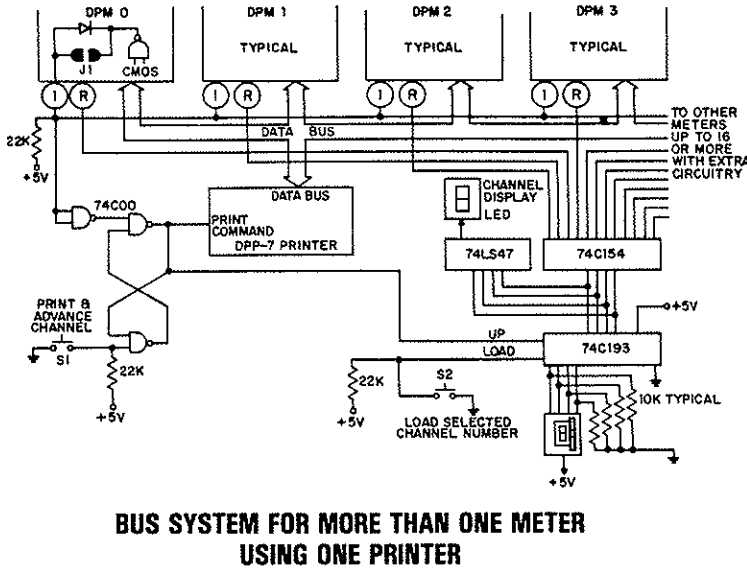
The RP-4500BCD may be used in a wide variety of configurations. The following circuits illustrate some of the possibilities and demonstrate the exceptional versatility of Texmate products. Components called for in the applications which are not part of the standard meter may be supplied by the user or obtained from Texmate. For some applications, standard components and solder junction modes may have to be changed as specified in the application. The following legend applies to all application circuits: 1) optional components to be user installed are shown in dotted lines; 2) internal solder junctions are shown by for a closed junction or for an open junction.



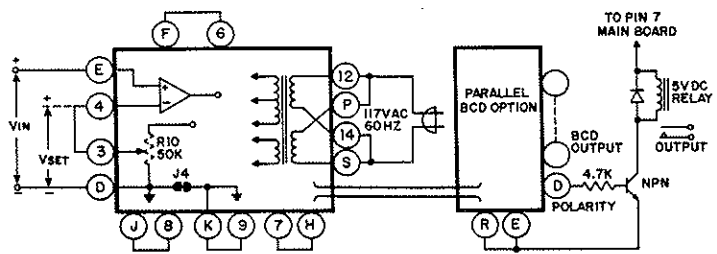
**THUMBWHEEL SWITCH DIGITAL COMPARATOR
 WITH HIGH, LOW, EQUAL OUTPUT**



**MORE THAN ONE METER COMPARED
 TO ONE SETPOINT**

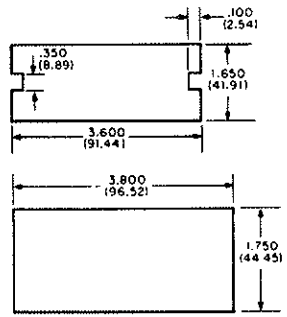


TIMING DIAGRAM



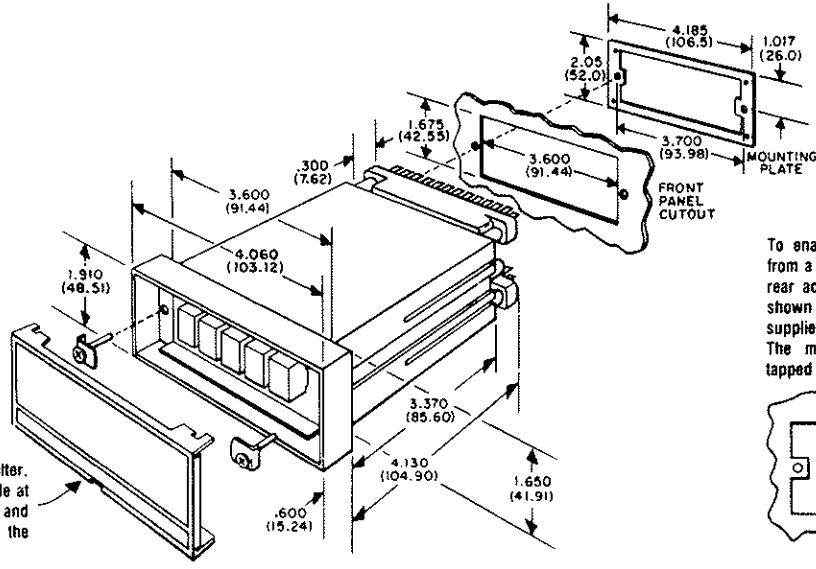
SUPER LOW OFFSET (<10µV) ANALOG COMPARATOR

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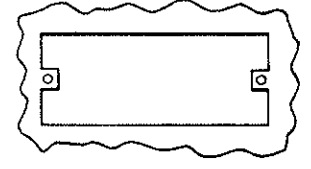


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DIMENSIONS AND CUTOUTS



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LR-400 HIGH T_c

SUPERCONDUCTIVITY MEASUREMENTS

* Y1-BA2-CU3-OX TESTING

* MUTUAL INDUCTANCE FLUX EXCLUSION TECHNIQUE

* MUTUAL INDUCTANCE TRANSFORMER CONSTRUCTIC

* SUB MICRO-OHM AC RESISTANCE TECHNIQUES

LR-400
Instruction Manual

900-1

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LINEAR RESEARCH INC. 5231 CUSHMAN PLACE, SUITE 21
SAN DIEGO, CA 92110 USA.
PHONE: 619-299-0719 FAX: 619-299-0129

HIGH TEMPERATURE SUPERCONDUCTIVITY MEASUREMENTS USING THE LR-400 BRIDGE. JANUARY 1989.

All measurements were made with a standard LR-400 Bridge with the mutual inductance option installed. Standard bridge frequency was 15.9 Hertz sine wave derived from a stable crystal oscillator. A single channel X-time strip chart recorder with 2 millivolts D.C. full span sensitivity was also used. The superconducting sample used in all tests was a 2.5 gram Y1-BA2-CU3-OX disk of diameter = 0.5 inches, thickness = 0.15 inches made by Superconductive Components Inc. of Columbus, Ohio.

1. AC RESISTANCE

With four lead contact surface resistance of less than one ohm, and bridge excitation current of 10 milliamps RMS, the bulk superconductive sample AC resistance was measured and found to be 0±0.10 micro-ohms. Bulk resistivity was then calculated, considering the volume, geometry, and placement of the voltage sampling leads, to be 0.12-0.05 x 10⁻⁷ ohm-cm. We used a strip chart recorder with the LR-400 set to its 10 second filter time constant. Figures 1A & 1B show the recording. Figure 2b shows a method of simulating an ideal zero resistance by closing switch S1. Figure 3 shows the physical contact connection method.

The contact method used in measuring the AC resistance superconducting sample used four standard gold-plated wire-wrapped socket pins, removed from a standard 16 pin dual-in-line wire-wrap integrated circuit socket, laid against one face of the sample. The sample and the pins were sandwiched between two 0.5 inch square, 0.25 inch thick polyvinylchloride (PVC) blocks. All were then clamped together with two small steel "C" clamps. The entire assembly was immersed in liquid nitrogen (LN2). The gold-plated wire wrap pins and the four sensor cable leads (PVC insulated stranded #24 AWG hook-up wire) were soldered beforehand to a small 0.7 inch long by .4 inch wide universal type printed circuit board piece at right angles. Contact AC resistance including the 70 inch round trip lead resistance for the current excitation lead pair, was measured on the 2 ohm range of the LR-400, as 866 milliohms @ 10 ma, 764 milliohms @ 1 ma, and 690 milliohms @ 100 micro-amps.

2. MUTUAL INDUCTANCE

We constructed and used a concentric mutual inductance primary-double secondary transformer with the following physical characteristics (see figure 4):

A. Primary:

Length = 6.5 inches. Inner coil diameter = 1.13 inches with 2,500 turns of #32 AWG copper magnet wire. The winding was hand fed for equal turns distribution and was multilayer. DC resistance at room temperature = 132 ohms.

With 10 milliamps RMS excitation current the calculated excitation peak magnetic field strength inside the primary coil was 0.27 millitesla.

B. Secondary:

Length = 1.0 inch, inner diameter = 0.85 inches. Spacing between secondaries = 1.5 inches.

3,000 turns of #34 AWG copper magnet wire hand fed for equal turns distribution.

DC resistance at room temperature of each secondary = 184 ohms. Total for both secondaries 368 ohms.

LR-400 measurements at room temperature yielded:

Inductive reactance of primary = 2.9 ohms @ 16 Hz.

Inductive reactance of each secondary = 21.47 ohms @ 16Hz.

Primary and secondaries were wound on individual PVC concentric plastic tube forms which were immersed directly in LN2. The LN2 was held by a 4 inch inner diameter 304 type stainless steel-walled 2 liter vacuum dewar.

The primary at room temperature oscillated at a frequency of 140 kilohertz when the transformer was initially connected to the LR-400 current excitation leads. This high level oscillation was monitored with an oscilloscope's 10 megohm probe with the probe ground connected to the LR-400 chassis (do not connect scope ground to the I-low lead). This oscillation was expected, and is usually the case, when using a high turns primary winding. The oscillation was eliminated by placing an ordinary 0.1 microfarad mylar dielectric 100 volt capacitor in parallel with the primary at room temperature at the top of the LN2 dewar (at first a 100pf capacitor was tried, then a 300pf, then a .001mf, etc.). The absence of oscillations was then verified with the primary immersed in LN2. The capacitive reactance of the 0.1 uF capacitor at 16 hertz is 100,000 ohms and thus has no appreciable effect on the 16 hertz excitation current phase shift performance of the transformer. No capacitors were attached to the secondaries.

After killing the oscillation the primary 16 hertz voltage as measured with an oscilloscope was 3.3 volts peak to peak (P-P) which was consistent with the 10 ma RMS excitation current. The induced voltage in each secondary as measured with an oscilloscope was 55 mv p-p.

Balancing or nulling the net secondary output voltage was done by physically moving the secondary coil form up and down along the transformer's axis inside the primary coil form, at room temperature with no sample present, until the LR-400 gave a null

LR-400

Instruction Manual

900-2

Full test results with the 10 ma RMS primary were:

SAMPLE	LR-400 READINGS		RESISTANCE	LR-400 RANGE
	MI	MODE		
Inside Upper Coil	+119.88 milliohm		-32.XX milliohms	0.2 ohm/2mv
Inside Lower Coil	-119.84 milliohm		+32.43 milliohms	
Sample Removed (ZERO)	00.003 milliohm *		00.030 milliohm	0.02ohm/20mv

xx = These two digits of data inadvertently not recorded

* Definitive zero data shown on strip chart recording Figure 6.

Signal to noise ratio is defined as the ratio of output mutual inductance signal due to the introduction of a superconducting sample into the center of one of the secondary coils as compared to the "long term" noise or "drift" of the LR-400 mutual inductance voltage sampling signal when no sample was present.

For this sample the signal to drift noise ratio was then calculated as 59,940 to 1. This is equivalent to a 43 microgram superconducting sample resolution with a one to one signal to noise ratio assuming linear volume scaling.

The LR-400 bridge input noise is considerably lower than the 20 nanovolts secondary drift noise measured. Bridge input noise in the mutual inductance mode is the same as in the resistance mode and is not larger than the noise shown in Figure 2 (2 nanovolts RMS p-p with a 10 second LR-400 time constant). The drift noise measured is apparently due to mechanical instabilities in the primary and secondary coil forms. More rigid type coil forms of possibly 304 stainless steel attached concentrically to each other with 304 stainless steel mounting brackets should yield an appreciable reduction (improvement) in drift noise. Figure 5 indicates reasonably low MI and R readings for 304 stainless steel. With both secondaries wound on a 304 coil form even these first order effects should cancel. The drift of our transformer at room temperature exhibited a constant drift or ramp in its output signal believed to be due to either temperature gradients in the coil forms or long-term mechanical stress do to the "springiness" of the copper magnet wire windings constantly squeezing the PVC coil forms. PVC coil forms appear to be more flexible at room temperature than at 77 Kelvin.

Using the LR-400 in conjunction with our Model LR-HCA High Current Accessory unit a 100:1 improvement in the AC resistance resolution should be possible by using its 1 amp RMS excitation

or as close to zero output as possible. The coil forms were then bonded to each other at their upper and lower ends with 0.3 inch long thin PVC epoxy dipped pegs that were cut from PVC tubes to lock-in this coarse null.

This physical coarse null was close enough to yield an on range signal on the 200 microvolt RMS scale. (LR-400 settings = 0.2 MV/.02 ohms). A good coarse null is very important since it enables the LR-400's R-set fine null to be made on the most sensitive ranges yielding greatest resolution for small volume samples. When the transformer was immersed in LN2 the null shifted slightly as expected but remained on scale. With the transformer in LN2, the Rx (actually mutual inductance X) reading was "-05.117" milliohms (about 20% of full scale range). Accordingly to "zero-out" this offset the R-set dials (acting as set mutual inductance) were set to "-05.117" as a fine null which gave a zero reading on ΔR . Thereafter measurements were made in the ΔR (actually delta mutual inductance) mode. The LR-400 was also operated in the resistance or quadrature mode (having first noted R-set = zero with no sample present since transformer coupling resistive losses are almost always negligible) to individually read the resistive quadrature signals. Alternatively, the rear panel quadrature output could be used to simultaneously measure quadrature resistive losses while measuring the front panel MI output.

The physical induced secondary null worked because of the end-effects of the magnetic field fall-off at the ends of the 6.5 inch long primary. For an "infinite length" primary this technique will not work. In this case one winds sufficient turns of a tertiary coil directly over the mid-point of the primary. This physically accessible coil allows for easily adding or removing turns as required. This tertiary winding is electrically connected (adding or subtracting) in series with the secondaries to achieve the coarse null.

Long term drift referenced to bridge input on the 20 milliohm scale (where 200 microvolts RMS is equivalent to full scale) was measured as 20 nanovolts RMS peak to peak. Over a "long term" period of 40 minutes. See figure 6.

The superconducting disk sample was inserted axially into the upper secondary. The sample was tightly attached with nylon string to the end of a .375 inch diameter, 18 inch long, nylon rod. Insertion into the upper secondary coil gave an output mutual inductance reading of +119.88 milliohms on the 200 milliohms scale (LR-400 settings = 0.20 ohms/2 MV) equivalent to +1.1988 millivolts RMS at bridge input.

current since it is 100 times larger than the 10 ma RMS maximum value of the LR-400's current generator. Careful attention has been paid in the design of the LR-HCA High Current Accessory unit so that the effect of high contact resistance at the four lead sample surface interface can be minimized. Measurements should be able to be made such that a common mode voltage at the voltage sampling leads, due to the interface current excitation contact resistance of up to 10 volts peak to peak (10 ohms total per contact pair @ 1 amp RMS), can be rejected. Thus nanovolt measurements can be made of the actual bulk resistance on the LR-400's 20 milliohm range which would read-out as 200 micro-ohms full scale with 10 nano-ohms of resolution.

The LR-HCA's 1 amp output could also be used to excite the primary of a mutual inductance transformer as was done in figure 5. With the 1 amp excitation current a single layer winding uniformly spaced could be used. Whereas with the LR-400 by itself a multilayer winding was required to achieve sufficient AC magnetic field strength with the 10 ma excitation to give reasonably high signal to noise resolution.

It is anticipated that various standard and "built to order" sizes of mutual inductance transformers will soon be commercially available from Linear Research Inc.

FIGURE 1A

4-Wire AC resistance measurement of superconducting sample. Sample assembly in LN₂.
 A = 1 least count (1 micro-ohm) momentary change of R-set dials for calibration.
 B = External laboratory electrical interference.
 Note that envelope of average value of short term (3-5 minutes) noise is less than 2 nanovolts RMS peak to peak.
 LR-400 setting:

Range = 20 milliohms.
 Excitation current = 10 ma RMS.
 Full scale range bridge input voltage = 200 micro volts RMS.

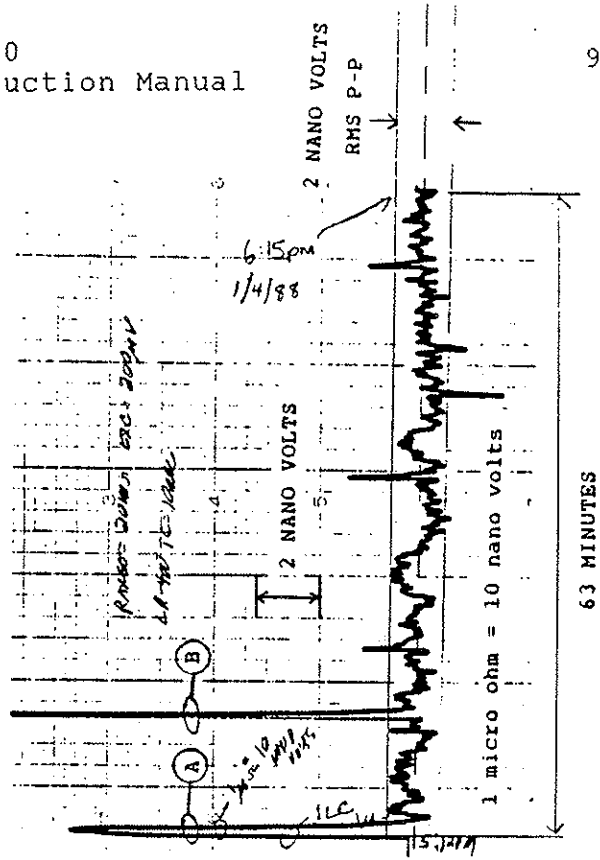


Figure 1B

4-Wire AC resistance measurement of sample. Sample assembly in LN2.
 A = S1 shorted (see figure 2).
 B = S1 open (see figure 2).
 C = 1 micro-ohm momentary change in R-set dials for calibration.

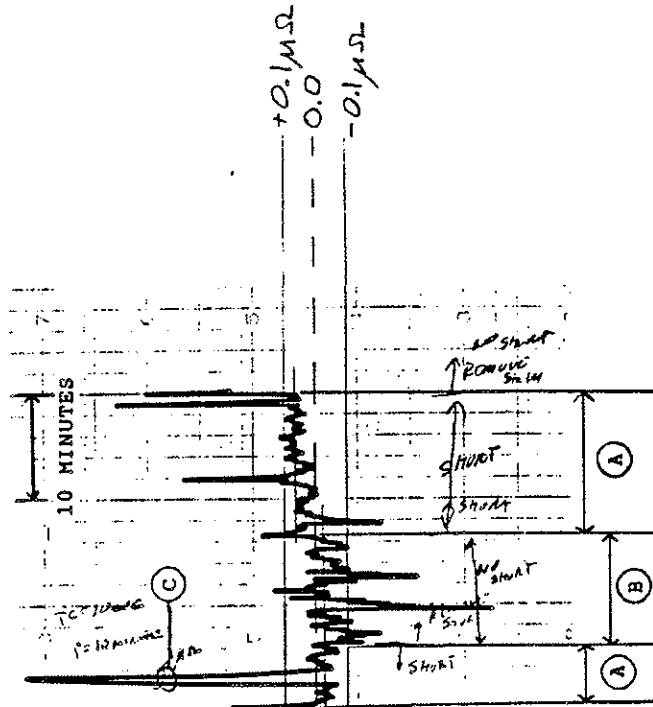
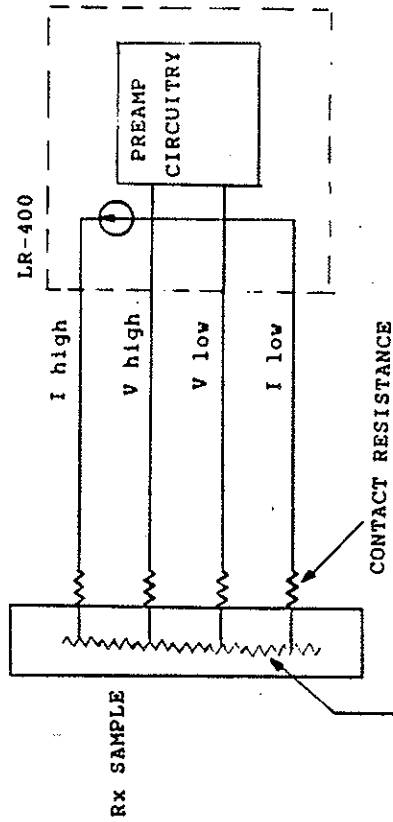


FIGURE 2A

Schematic of 4-wire AC resistance sample measurement.
 SUPERCONDUCTING SAMPLE



BULK AC RESISTANCE

FIGURE 2B

Schematic of technique to simulate a dead short at Rx by setting to zero the Vhigh-Vlow sample signal. Sample at LN2, 10 ohm resistors and S1 at room temperature.
 Vsample = 0 volts for S1 closed.

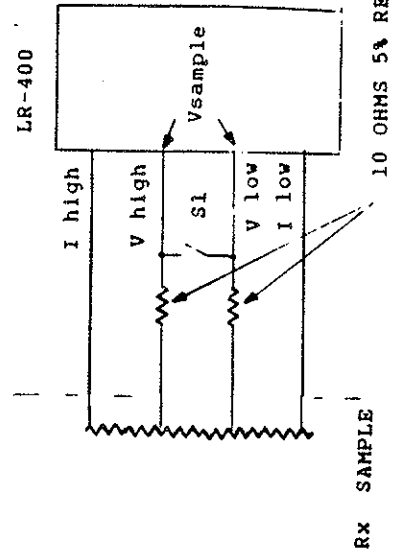


FIGURE 4
Primary & secondary coil forms.

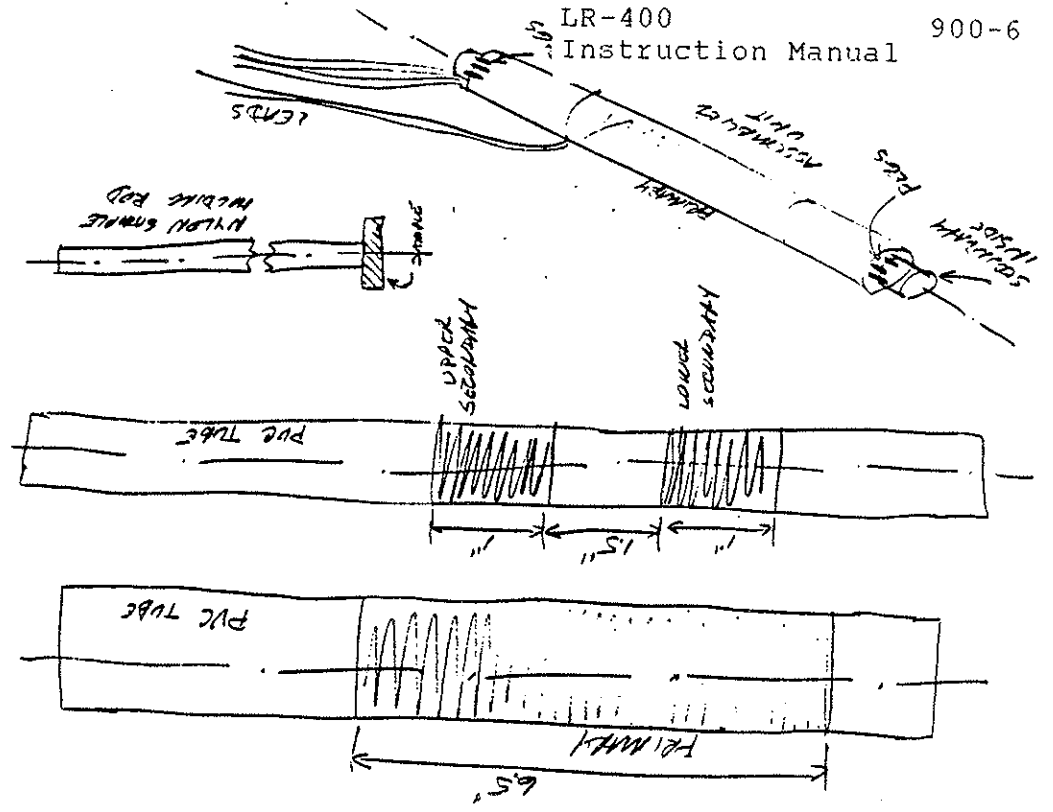


FIGURE 3
Sample holder assembly for 4-contact direct AC resistance measurements.

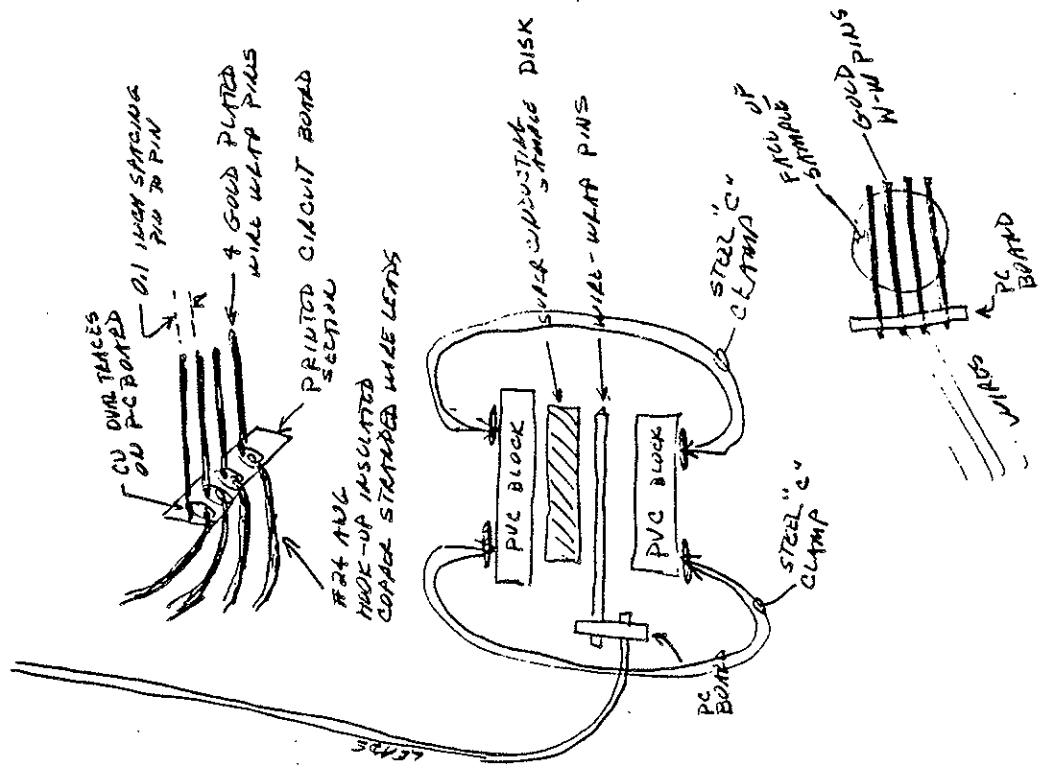


FIGURE 5

Testing of various samples with an earlier one amp primary mutual inductance transformer at room temperature. With 6.5 inch long primary. With 28 turns/inch single layer #20 AWG copper magnet wire. Excitation current = 1 amp RMS. RGC = 732 milliohms. XL = 24.9 milliohms @ 16 Hz.

SAMPLE	LR-400 READING		LR-400 RANGE SETTINGS	
	MUTUAL INDUCTANCE MODE	RESISTANCE MODE		
Standard Steel ball bearing 0.25 inches diameter	+03.800 ohms upper coil -03.800 ohms lower coil	-00.044 ohms +00.044 ohms	20mv 20 ohms	
0.2 inch OD copper tubing 1.5 inches long	+0.0000 ohms upper coil -0.0000 ohms lower coil	-0.0041 ohms +0.0043 ohms	2mv 2 ohms	
0.5x0.5" by 1.7 inch long aluminum bar	-0.0128 ohms upper coil +0.0125 ohms lower coil	+0.8200 ohms -0.8200 ohms	2 mv 2 ohms	
0.7" O.D. by 1.1 inch long copper tube	-0.0154 ohms upper coil +0.0154 ohms lower coil	+1.1900 ohms -1.1900 ohms	2mv 2 ohms	
304 stainless steel tube 0.3 inch OD, 0.030" wall, 6.2 inch long inserted part way in upper coil for maximum signal	+0.0460 ohms upper coil ----- -----	+0.0065 ohms ----- -----	2mv 2 ohms	
Superconducting disk 0.5" diam. X 0.15" thick	-04.295 ohms upper coil +04.314 ohms lower coil	+0.518 ohms -00.549 ohms	20mv 20 ohms	

FIGURE 5 (continued).

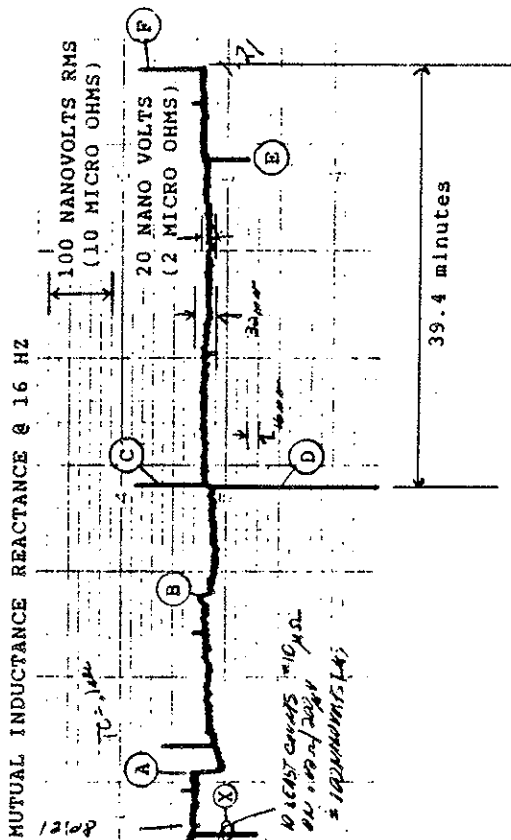
NOTES:

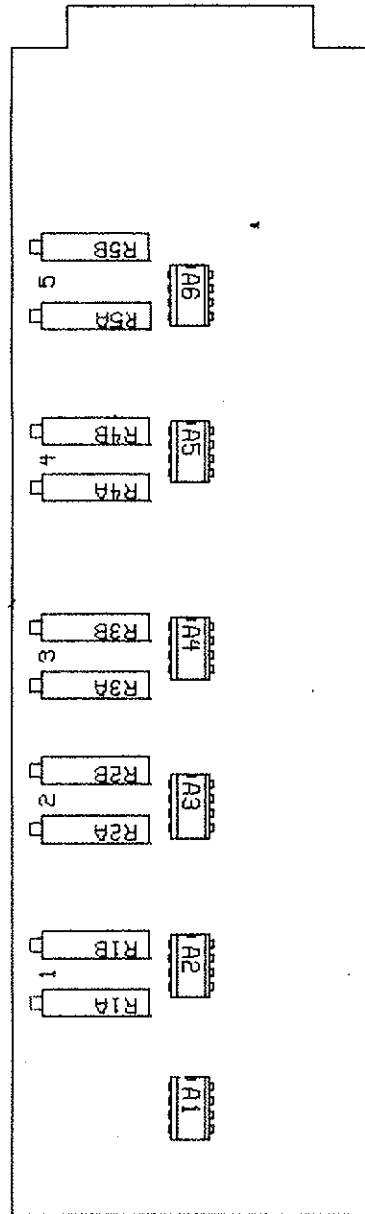
1. Consider the change of polarity in the MI signal for the steel ball versus the SC sample when inserted into the upper secondary. A "+" sign indicates flux concentrated at the steel ball and a "-" sign indicates flux excluded by the SC sample.
2. As expected there is a polarity change for all samples when moved from the upper to the lower secondary coil.
3. OD = outer diameter, SC = superconductor, " = inches.
4. All samples were at room temperature except for the SC sample.
5. Superconducting sample was first cooled in LN2 then quickly removed and inserted into the room temperature mutual inductance transformer. In about 30 seconds the SC sample warmed and the SC transition to the normal state could be observed with MI and R readings both going to "0000".

FIGURE 6

Zero output of mutual inductance transformer secondaries. No sample transformer in LM2. This shows that for 40 minutes peak to peak noise was about 20 nanovolts RMS referred to the output of the secondaries (or the input of the bridge).

A, B, & C believed to be mechanical instabilities in the coil forms. D, E, & F external laboratory electrical interference. "X" was a 10 micro-ohm momentary dial change of R-set for calibration.

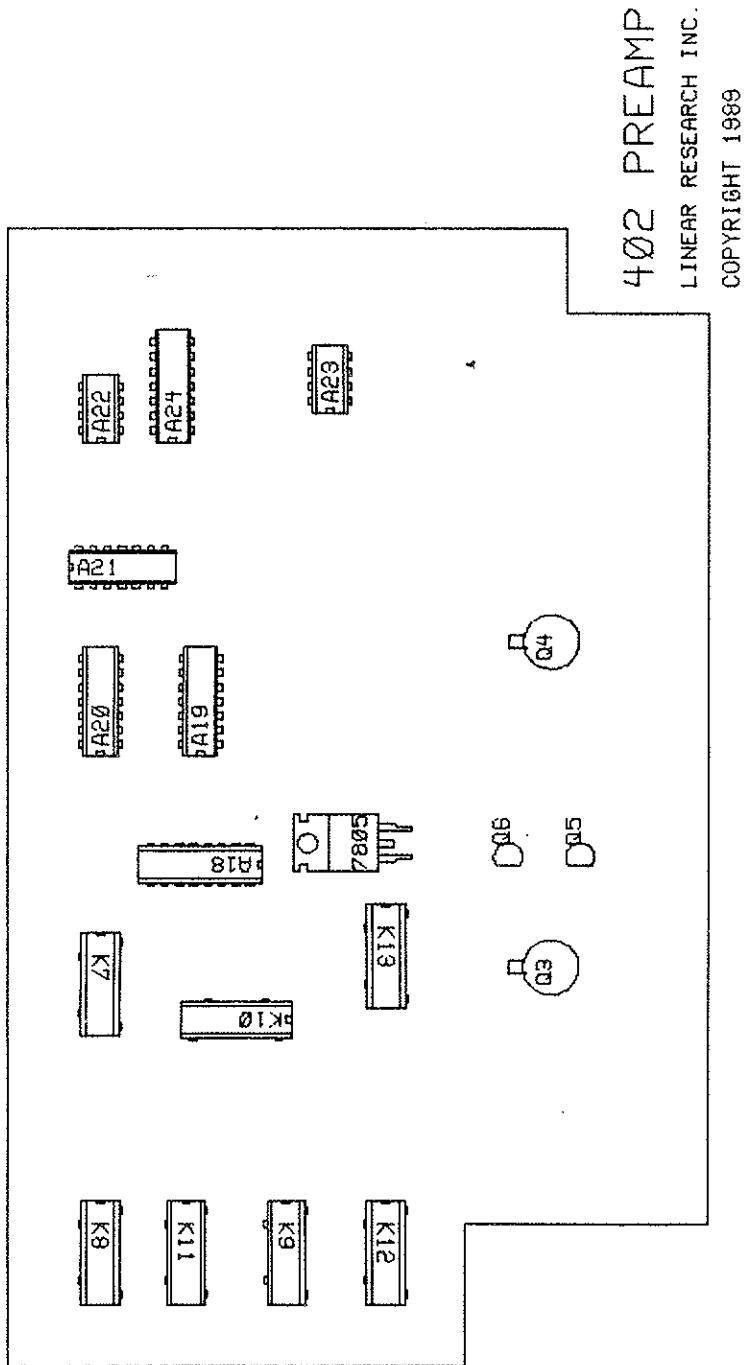




102A TUNED AMPLIFIER
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LR-102A TUNED AMP PARTS LIST	
Device	Generic Part #
A1	OP-07
A2	OP-07
A3	OP-07
A4	OP-07
A5	OP-07
A6	OP-07
R1A	20K 3/4" TRIMPOT
R1B	20K 3/4" TRIMPOT
R2A	20K 3/4" TRIMPOT
R2B	20K 3/4" TRIMPOT
R3A	20K 3/4" TRIMPOT
R3B	20K 3/4" TRIMPOT
R4A	20K 3/4" TRIMPOT
R4B	20K 3/4" TRIMPOT
R5A	20K 3/4" TRIMPOT
R5B	20K 3/4" TRIMPOT

102A
 TUNED AMP



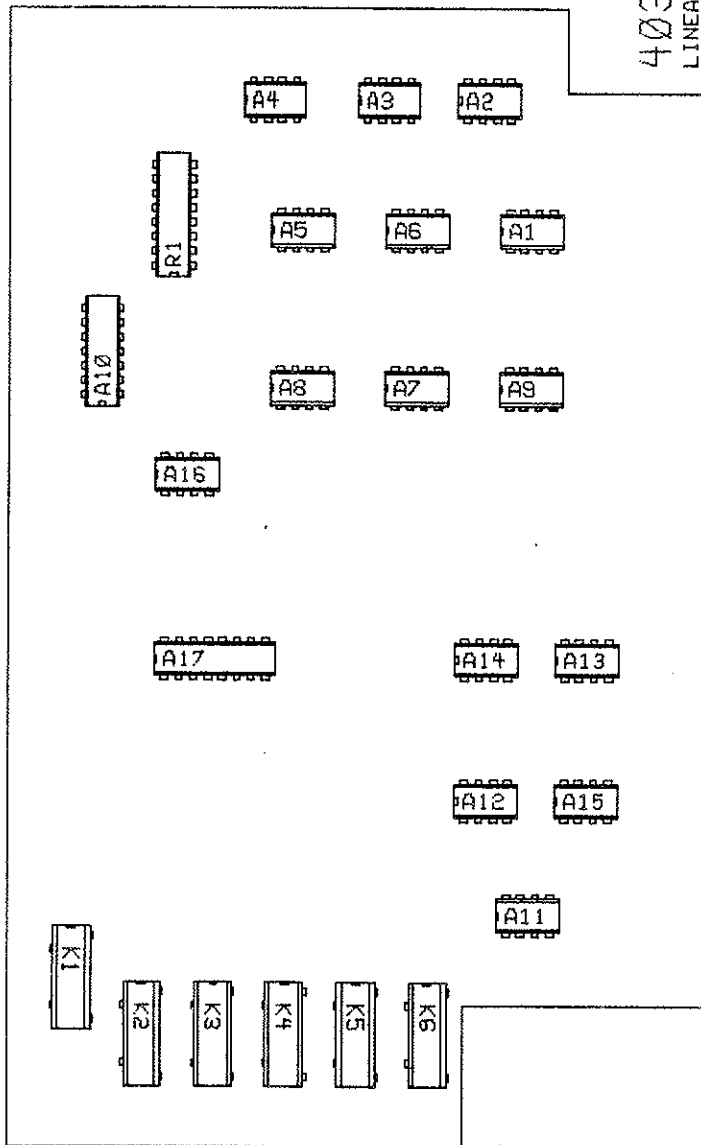
402 PREAMP
 LINEAR RESEARCH INC.
 COPYRIGHT 1989

LR-402 PREAMP PARTS LIST	
Device	Generic Part #
A18	4049
A19	LM339
A20	LM339
A21	OP-227
A22	OP-07
A23	OP-07
A24	4016
Q3	2N6485
Q4	2N6485
Q5	2N2222
Q6	2N2222
K7	REED RELAY 1A
K8	REED RELAY 1A
K9	REED RELAY 1A
K10	REED RELAY 1A
K11	REED RELAY 1A
K12	REED RELAY 1A
K13	REED RELAY 1A

402
 PREAMP

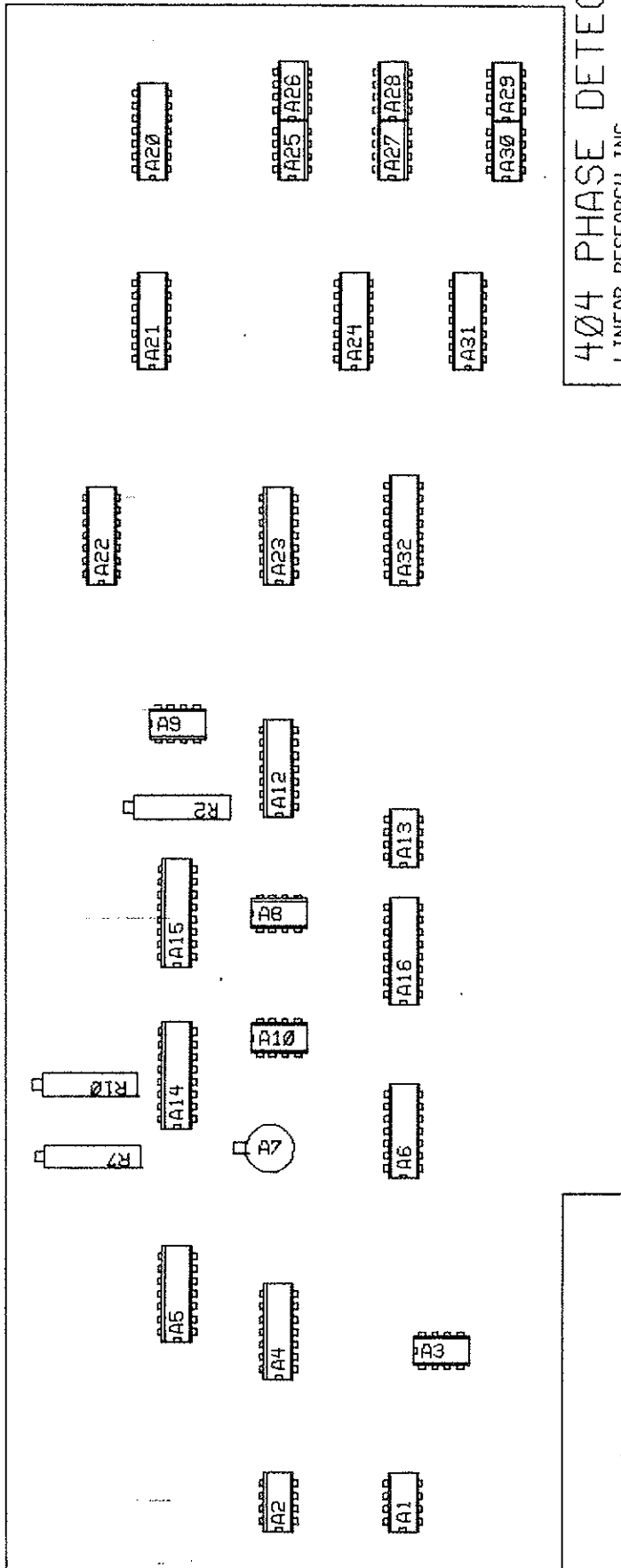
403 CURRENT GEN.
LINEAR RESEARCH INC.

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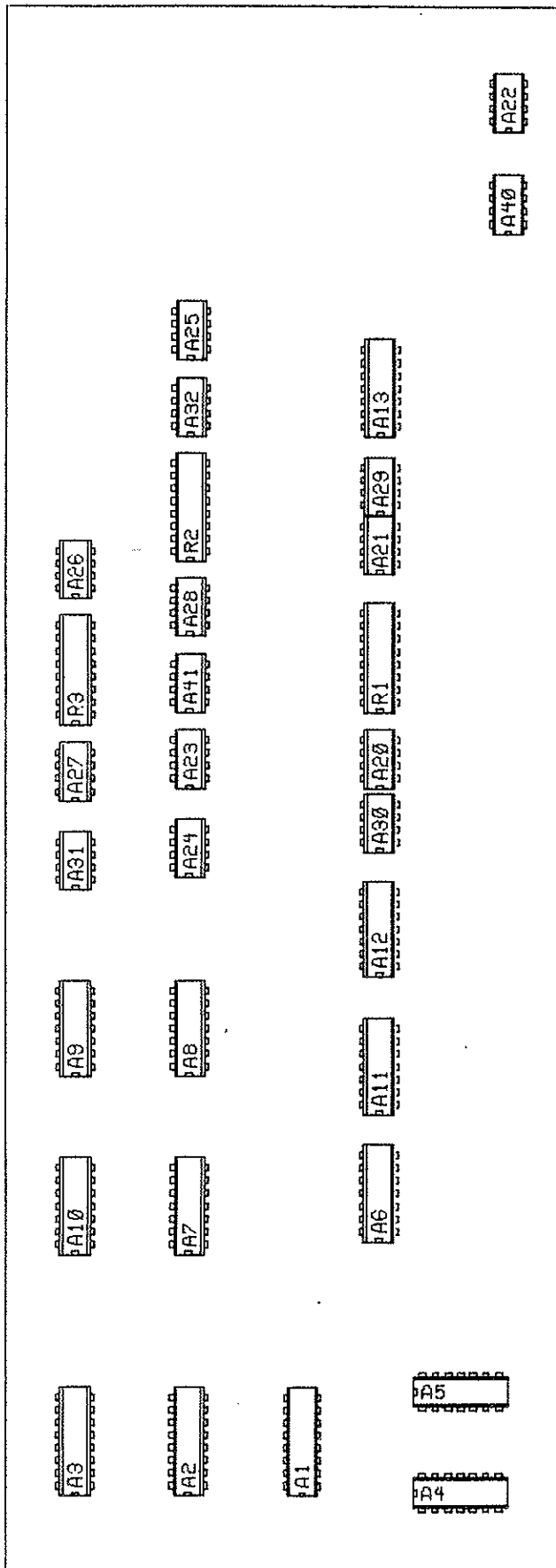
LR-403 CURRENT GENERATOR PARTS LIST	
Device	Generic Part #
A1	748
A2	741
A3	741
A4	741
A5	741
A6	741
A7	741
A8	741
A9	748
A10	4016
A11	LF 441
A12	748
A13	741
A14	741
A15	741
A16	741
A17	4049
K1	REED RELAY TYPE 1A
K2	REED RELAY TYPE 1A
K3	REED RELAY TYPE 1A
K4	REED RELAY TYPE 1A
K5	REED RELAY TYPE 1A
K6	REED RELAY TYPE 1A
R1	10K R-NETWORK

403
CURRENT GENERATOR



LR-404 PHASE DETECTOR PARTS LIST	
Device	Generic Part #
A1	OP-07
A2	OP-07
A3	LF-441
A4	4016
A5	LM 339
A6	4016
A7	AD 542
A8	OP-07
A9	OP-07
A10	OP-07
A12	DG 201
A13	OP-07
A14	10K R-NETWORK
A15	10K R-NETWORK
A16	10K R-NETWORK
A20	4016
A21	4016
A22	4016
A23	4016
A24	4016
A25	OP-07
A26	741
A27	741
A28	741
A29	741
A30	741
A31	4011
A32	4049
R2	20K 3/4" TRIMPOT
R7	20K 3/4" TRIMPOT
R10	20K 3/4" TRIMPOT

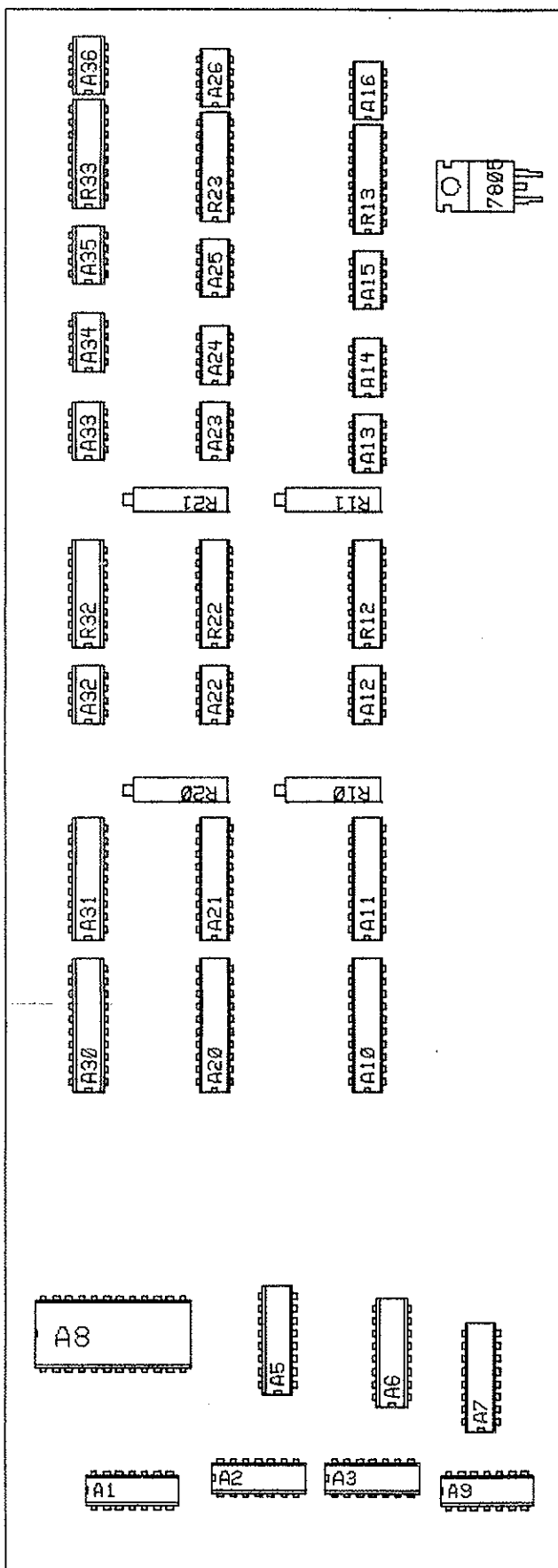
NOTES:
 A12 plug in sub-assembly comprises:
 A. DG201 Device.
 B. 1 each 4.7K, 1/4W, 5% resistor soldered in series to pins 2,6,&11.
 C. A16 pin plug-in connector holding A&B.



405 ATTENUATOR
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LR-405 ATTENUATOR PARTS LIST	
Device	Generic Part #
A1	4503
A2	4503
A3	4503
A4	4075
A5	4016
A6	4016
A7	4016
A8	4016
A9	4016
A10	4016
A11	4016
A12	4016
A13	4016
A20	741
A21	741
A22	741
A23	741
A24	OP-07
A25	741
A26	741
A27	741
A28	741
A29	741
A30	741
A31	741
A32	741
A40	741
A41	741
R1	10K R-NETWORK
R2	10K R-NETWORK
R3	10K R-NETWORK

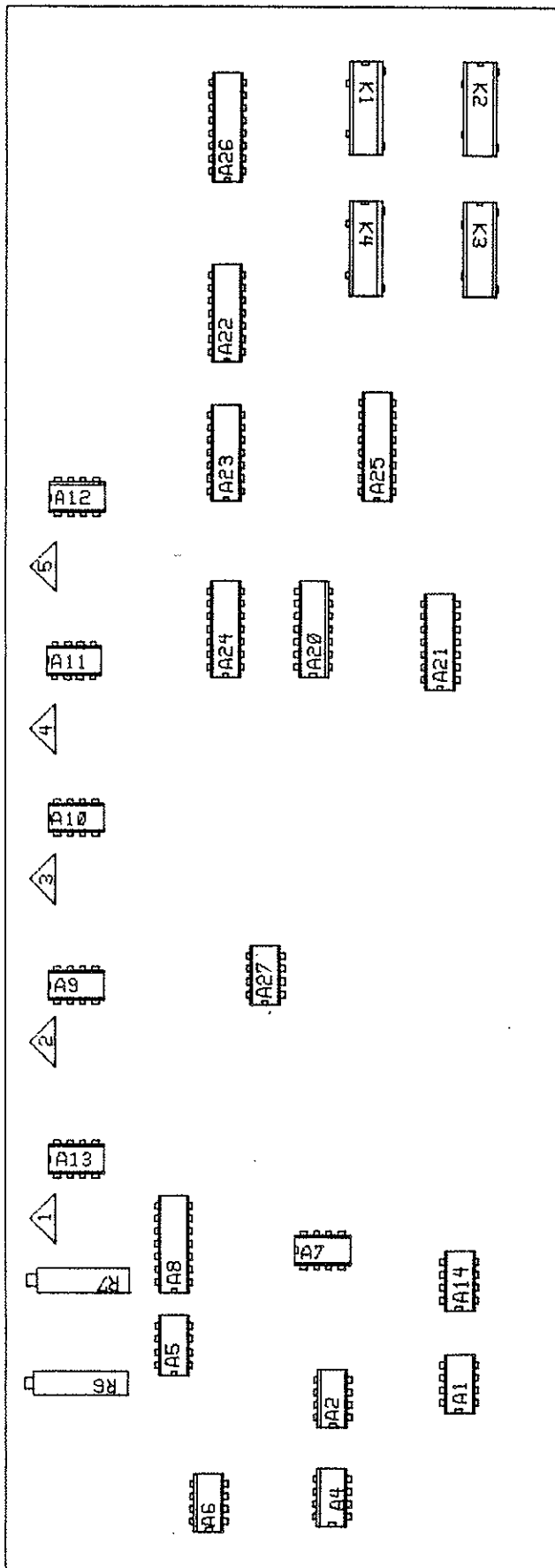
405
ATTENUATOR



406 MULTIPLIER
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LR-406 MULTIPLIER PARTS LIST	
Device	Generic Part #
A1	LSO4
A2	LS-93
A3	LS-93
A5	4040
A6	4049
A7	4528
A8	27C32 PROM
A9	4011
A10	HCT 374
A11	PM 7541
A12	OP-07
A13	OP-07
A14	741
A15	741
A16	741
A20	HCT 374
A21	PM 7541
A22	741
A23	741
A24	741
A25	741
A26	741
A30	HCT 374
A31	PM 7541
A32	741
A33	741
A34	741
A35	741
A36	741
R10	20K 3/4" TRIMPOT
R11	20K 3/4" TRIMPOT
R20	20K 3/4" TRIMPOT
R21	20K 3/4" TRIMPOT
R30	20K 3/4" TRIMPOT
R31	20K 3/4" TRIMPOT
R12	10K R NETWORK
R13	10K R NETWORK
R22	10K R NETWORK
R23	10K R NETWORK
R32	10K R NETWORK
R33	10K R NETWORK

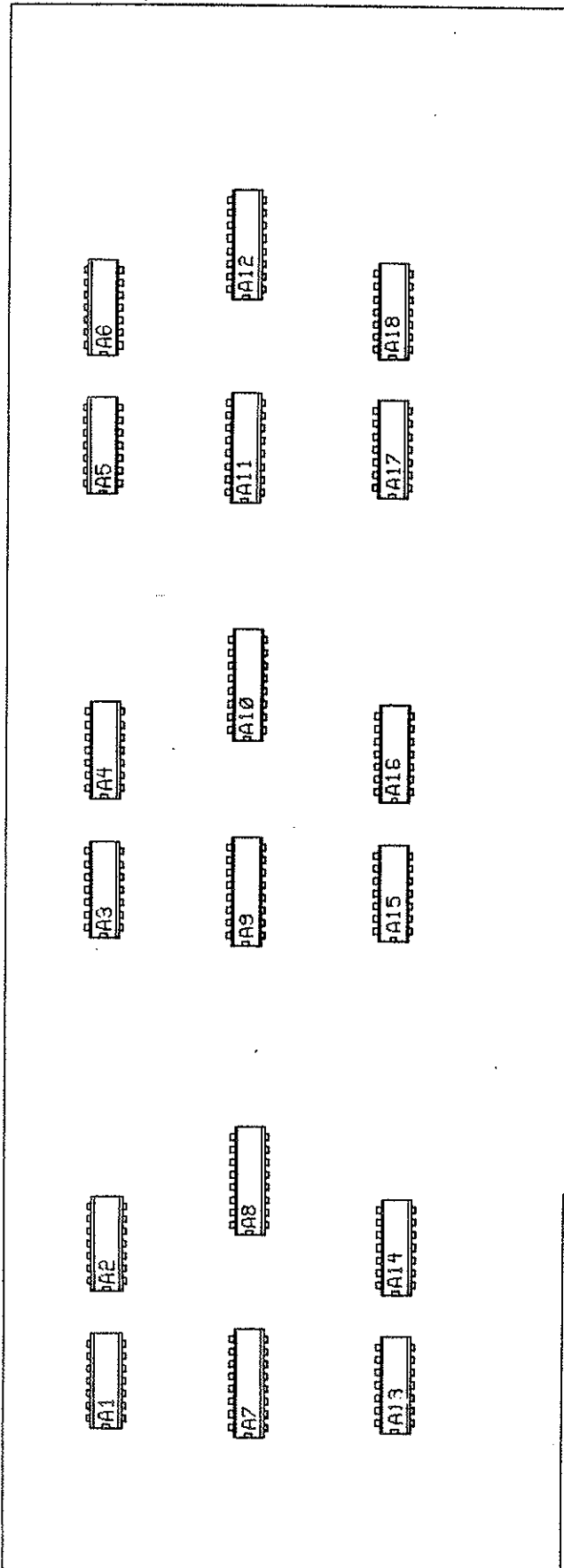
406
MULTIPLIER



407 RSET & LED
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LR-407 R SET PARTS LIST	
Device	Generic Part #
A1	741
A2	741
A4	741
A5	741
A6	741
A7	OP-07
A8	10K R-NETWORK
A9	OP-07
A10	OP-07
A11	OP-07
A12	OP-07
A13	OP-07
A14	REF-01
A20	4075
A21	4075
A22	4016
A23	4016
A24	4016
A25	4049
A26	4049
A27	OP-07
K1	REED RELAY 1A
K2	REED RELAY 1A
K3	REED RELAY 1A
K4	REED RELAY 1A
R6	20K 3/4" TRIMPOT
R7	20K 3/4" TRIMPOT

407
R-SET & LED



408 INTERFACE
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LR-408 INTERFACE PARTS LIST	
Device	Generic Part #
A1	4016
A2	4016
A3	4016
A4	4016
A5	4016
A6	4016
A7	LM 339
A8	LM 339
A9	LM 339
A10	LM 339
A11	LM 339
A12	LM 339
A13	4016
A14	4016
A15	4016
A16	4016
A17	4016
A18	4016

408
INTERFACE