OPERATING INSTRUCTIONS

TYPE 1633-A

INCREMENTAL INDUCTANCE BRIDGE

and

TYPE 1630-A

INDUCTANCE MEASURING ASSEMBLIES

1633-A

GENERAL RADIO COMPANY

A

READ COMPLETE INSTRUCTIONS BEFORE OPERATING BRIDGE

WARNING

The outputs of the ac and dc generators must be reduced to zero before connections are made to the UNKNOWN or to the GENERATOR terminals, and before the setting of the RANGE SELECTOR switch is changed. The leads to the unknown should always be connected and disconnected at the bridge terminals, not at the load.

CONDENSED OPERATING INSTRUCTIONS FOR TYPE 1633-A INCREMENTAL INDUCTANCE BRIDGE

(For more complete details, refer to the Operating Procedure in Section 2 of this book. The numbers following each heading on this page refer to the paragraphs in the book in which a detailed discussion of the particular subject can be found.)

I. CONNECT GENERATORS. (2.2)

a. Turn all generator outputs to zero.
b. Connect generators to front or rear GENERATOR terminals of the bridge.
c. Turn on SYSTEM POWER switch.
d. Reset overload circuits on generators, if necessary.

II. CONNECT UNKNOWN. (2.2.5)

a. Turn generator outputs to zero.
b. Open cover over UNKNOWN terminals (press button).
c. Connect unknown.
d. Close and lock cover (press button).

III. SET PANEL CONTROLS. (2.2.6)

a. R-Q switch -- to Q for high-Q coils.
-- to R for low-Q coils and resistors.
b. FREQUENCY switch -- to frequency of measurement.
c. RANGE SELECTOR switch -- to approximate value of unknown (MULTIPLIER windows).

IV. SET GENERATOR LEVELS. (2.2.7)

a. Do not exceed bridge rating indicated on panel, over RANGE SELECTOR switch position.
b. Set frequency of ac generator for maximum deflection of NULL indicator.
c. When Type 1308-A Audio Oscillator and Power Amplifier or Type 1266-A Adjustable AC Power Source is used, keep superimposed dc less than the ac switch setting.[1]
d. When Type 1265-A Adjustable DC Power Supply is used, keep superimposed ac less than the dc switch setting.[1]

V. BALANCE BRIDGE. (2.2.7)

a. Do not change RANGE SELECTOR setting or any connections while generator currents are flowing.
b. Balance bridge by means of two balancing controls (R and L dials).
c. Reduce setting of SENSITIVITY control slightly. Null should not change.
d. Multiply each dial reading by number in corresponding MULTIPLIER window to obtain value of unknown.
e. Turn all generator outputs to zero before changing or removing any connections.

(For other measurement problems, refer to paragraph 2.4. For use at frequencies other than those indicated on the FREQUENCY switch, refer to paragraph 2.3. Iron-core coils are discussed in paragraph 4.1 and special applications are described in Section 5.)

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[1]*These ratings are quite conservative; considerably more current can be used under most conditions, as noted in Section 7.*

OPERATING INSTRUCTIONS

TYPE 1633-A

INCREMENTAL INDUCTANCE BRIDGE

and

TYPE 1630-A

INDUCTANCE MEASURING ASSEMBLIES

Form 1633-0100-A
June, 1962

GENERAL RADIO COMPANY
WEST CONCORD, MASSACHUSETTS, USA

SPECIFICATIONS

	Frequency	Full-Scale Ranges						Smallest Division
		a	b	c	d	e	f	
L	50c, 60c, 100c, 120c	10 mh	100 mh	1 h	10 h	100 h	1000 h	20 μh
L	400c, 800c, 1 kc	1 mh	10 mh	100 mh	1 h	10 h	100 h	2 μh
L	10 kc, 15.75 kc	100 μh	1 mh	10 mh	100 mh	1 h	10 h	0.2 μh
R	all	10 Ω	100 Ω	1 kΩ	10 kΩ	100 kΩ	1 MΩ	10 mΩ
Q	all	∞ — 1 Direct Reading at Above Frequencies						Q = 1000
	Max rms volts	12.5	125	1250	1250	1250	1250	
	Max rms amp*	7	7	7	2	0.7	0.2	

*Maximum rms current = $\sqrt{I_{dc}^2 + I_{ac}^2}$

ACCURACY

Inductance: ±1% of reading or 0.1% of full scale, $\pm\left(\frac{2\pi}{100} \times \frac{f_{kc}}{Q_x}\right)$ %.

Resistance: ±2% of reading or 0.1% of full scale, $\pm \frac{Q_x f_{kc}}{2\pi}$ %.

$\frac{1}{Q}$: ±2% or 0.001.

Frequency Range: Direct readings at only one of nine specific frequencies with internal detector. External detectors can be used at any frequency between 20 cps and 20 kc.

INTERNAL DETECTOR

Frequency: Selective at any one of nine specific frequencies, accurate to ±1%, 50, 60, 100, 120, 400, and 800 cps, and 1, 10, and 15.75 kc.

Response to Second Harmonics: Approximately 60 db below fundamental.

GENERAL

Power Input: 105 to 125 (or 210 to 250) volts, 50 to 60 cps; power consumption, approximately 6 watts.

Accessories Supplied: One Type CAP-22 3-wire Power Cord and spare fuses.

Accessories Required: Generator to cover desired ranges of frequency and power, and a source of dc bias current (if desired).

Accessories Available: Type 1265-A Adjustable DC Power Supply (200 watts); Type 1266-A Adjustable AC Power Source (200 voltamperes).

Mounting: Relay-rack panel in aluminum cabinet. End frames are supplied with bench models.

Dimensions: Bench model, width 19, height 12¾, depth 10¼ inches (485 by 325 by 260 mm), over-all; rack model, panel 19 by 12¼ inches (485 by 315 mm); depth behind panel, 8¾ inches (225 mm).

Net Weight: 31 pounds (14.5 kg).

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*"The Use of Active Devices in Precision Bridges," H. P. Hall and R. G. Fulks, Electrical Engineering, May, 1962, p. 327.

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Figure 1-1. Panel view of Type 1633-A Incremental Inductance Bridge.

READ COMPLETE INSTRUCTIONS BEFORE OPERATING BRIDGE.

WARNING

It is possible to apply large values of current and voltage to an inductor through the Type 1633-A Incremental Inductance Bridge. These can be dangerous to both operator and equipment if the instructions are not followed.

When the current through an inductive circuit is suddenly interrupted, a voltage transient occurs across the open circuit. To avoid shock hazard to the operator and/or damage to the bridge, the outputs of the ac and dc generators must be reduced to zero before connections are made to the UNKNOWN or to the GENERATOR terminals, and before the setting of the RANGE SELECTOR switch is changed.

The bridge is equipped with several safety features that are intended to protect the equipment and to help the operator avoid mistakes. The UNKNOWN terminals are protected by a hinged safety cover which, when opened, effectively shorts the GENERATOR terminals of the bridge and discharges any energy stored in the inductor. The external generator should be fused or otherwise protected so that it will not be damaged by the effect of this short circuit.

The leads to the unknown should always be connected and disconnected at the bridge terminals, not at the load.

As an added protection, a red panel light indicates when the generator is connected to the UNKNOWN terminals.

SECTION **1**

INTRODUCTION

1.1 PURPOSE.

The Type 1633-A Incremental Inductance Bridge (Figure 1-1) is designed to measure inductors and resistors, both linear and nonlinear, over a wide range of ac and dc signal levels. Direct-reading measurements can be made over a broad frequency range.

1.2 DESCRIPTION.

1.2.1 GENERAL. The Type 1633-A Incremental Inductance Bridge includes a unique bridge circuit and a highly selective detector. It is direct reading in series inductance (L_S) and either series resistance (R_S) or storage factor (Q) at nine commonly used frequencies between 50 cps and 15.75 kc. It features single-knob controls for the measurement of L, R, or Q, and combines simplicity of operation with very high voltage- and current-handling capabilities. The signal losses in the bridge are small; thus the voltage and current through the unknown are nearly identical in both amplitude and waveform to the respective voltage and current applied at the GENERATOR terminals. In many instances measurements can be made while the inductor is actually operating in its circuit.

The bridge is designed primarily for the measurement of iron-core inductors such as transformers and chokes. It is also suitable for the measurement of other nonlinear devices, such as solid-state rectifiers and Zener diodes. The errors resulting from harmonics generated by nonlinear components are eliminated by the sharp tuning of the built-in null detector.

An oscilloscope connected to the CURRENT MONITOR panel terminals can be used conveniently to monitor the magnitude and waveform of the current through the unknown.

1.2.2 PANEL CONTROLS.

Name	Number*	Type	Function
Q-R SELECTOR	S1	2-position selector switch	Selects type of indication of loss component of unknown.
RANGE SELECTOR MAX RMS CURRENT MAX RMS VOLTAGE	S2	6-position selector switch	Selects resistance and inductance ranges. Also designates maximum allowable values of voltage and current for the selected bridge arm.
FREQUENCY	S3	9-position selector switch	Selects frequency at which bridge is direct reading and to which the detector is tuned.
R-Q	R106	Continuous rotary control with dial and vernier control	Adjusts bridge balance.
L	R102	Continuous rotary control with dial and vernier control	Adjusts bridge balance.
SENSITIVITY	R407, 408	Continuous rotary control	Adjusts sensitivity of detector.

**See schematic diagram on page 31.*

1.2.3 TERMINALS.

The following terminals are on the front panel of the Type 1633-A Incremental Inductance Bridge:

Name	Number	Type	Function
GENERATOR	J101, 102	Pair of Type 938 Binding Posts	Connection for external generator.
CURRENT MONITOR	J103, 104	Pair of Type 938 Binding Posts	Connection for external indicator, to monitor current in unknown impedance.
DETECTOR OUTPUT	J105, 100	Pair of Type 938 Binding Posts	Connection for external detector.
UNKNOWN	J107, 108	Pair of Type 938 Binding Posts, under safety cover.	Connection for unknown impedance.

The following terminals are located on the rear panel of the bridge:

Number	Type	Function
SO103	Four-point Jones-type socket	Connection for external generator
SO101 } SO102 }	Female power-line connectors	Line-voltage connections for external generators.
PL101	Male power-line connectors	Line-voltage connection for bridge.

1.3 SYMBOLS, ABBREVIATIONS, AND DEFINITIONS.

The following symbols, abbreviations, and definitions are used on the panel of the Type 1633-A Incremental Inductance Bridge and throughout these Operating Instructions:

C -- capacitance, ( )
C_s -- series capacitance
C_p -- parallel capacitance
L -- inductance ( )
L_s -- series inductance
L_p -- parallel inductance
R -- resistance, the real term of a complex impedance ( )
R_s -- series resistance
R_p -- parallel resistance
X -- reactance, the imaginary term of a complex impedance
Z -- impedance
Q -- storage factor $= \frac{X}{R} = \frac{1}{D}$
for inductors $\frac{\omega L_s}{R_s} = \frac{R_p}{\omega L_p}$
D -- dissipation factor $= \frac{R}{X} = \frac{1}{Q}$
ω -- angular frequency $= 2\pi f$
Ω -- ohm, a unit of resistance, reactance, or impedance
kΩ -- kilohm 1 kΩ = 1000 ohms
MΩ -- megohm 1 MΩ = 1×10^6 ohms
mΩ -- milliohm 1 mΩ = 0.001 ohm
μf (or μF) -- microfarad, a unit of capacitance
nf -- nanofarad, 1 nf = 0.001 μf
pf -- picofarad, 1 pf = 1 $\mu\mu$f = 1×10^{-6} μf
h (or H) -- henry, a unit of inductance
mh (or mH) -- millihenry, 1 mh = 0.001 h
μh -- microhenry, 1 μh = 1×10^{-6} h

1.4 SERIES AND PARALLEL COMPONENTS.

An impedance that is neither a pure resistance nor a pure reactance can be represented by either a series or a parallel combination of resistance and reactance. The value of resistance and reactance used in the equivalent circuit depends on whether a series or a parallel combination is used. Equivalent circuits are shown in Figure 1-2.

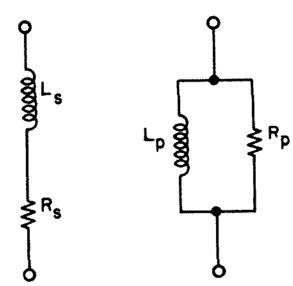


Figure 1-2. Equivalent circuits for a complex impedance.

The relationships between the circuit elements are:

$$Z = R_s + j\omega L_s = \frac{j\omega L_p R_p}{R_p + j\omega L_p} = \frac{R_p + jQ^2\omega L_p}{1 + Q^2}$$

$$Q = \frac{1}{D} = \frac{\omega L_s}{R_s} = \frac{R_p}{\omega L_p}$$

$$L_s = \frac{Q^2}{1 + Q^2} L_p = \frac{1}{1 + D^2} L_p$$

$$L_p = \frac{1 + Q^2}{Q^2} L_s = (1 + D^2) L_s$$

$$R_s = \frac{1}{1 + Q^2} R_p; \; R_p = (1 + Q^2) \; R_s$$

$$R_s = \frac{\omega L_s}{Q}; \; R_p = Q\omega L_p$$

The Type 1633-A Incremental Inductance Bridge measures L_s, R_s, and Q directly. Other forms of representation can be calculated from the above equations. A graphic representation of these relationships is located inside the back cover.

1.5 ACCESSORIES SUPPLIED.

One Type CAP-22 Power Cord is supplied with the bridge.

1.6 MOUNTING.

The instrument is available as either the Type 1633-AM, for bench mounting, or Type 1633-AR, for relay-rack mounting. The bench model is equipped with aluminum end frames (Type ZFRI-708-3), while the Type 1633-AR inclueds mounting brackets (Type ZSU-6-7). These brackets permit either cabinet or instrument to be withdrawn independently of the other. Instructions for installing the Type 1265-AR in a relay rack accompany these brackets.

1.7 TYPE 1630 INCREMENTAL INDUCTANCE MEASURING ASSEMBLIES.

The Type 1265-A Adjustable DC Power Supply, the Type 1266-A Adjustable AC Power Source, and the Type 1308-A Audio Oscillator and Power Amplifier have been designed primarily for use with the Type 1633-A Incremental Inductance Bridge. These units are available as two complete incremental-inductance measuring assemblies, Types 1630-AL and 1630-AV. The following table lists the instruments included in each assembly (see Figure 1-3):

Type 1630-AL Inductance Measuring Assembly

Type 1633-A Incremental Inductance Bridge
Type 1265-A Adjustable DC Power Supply
Type 1266-A Adjustable AC Power Source

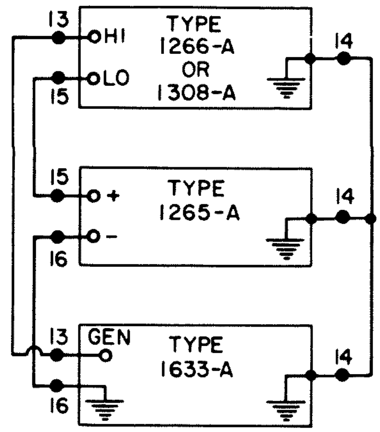


Figure 1-3. Block diagram of Type 1630 Inductance Measuring Assemblies showing interconnections.

Type 1630-AV Inductance Measuring Assembly

Type 1633-A Incremental Inductance Bridge
Type 1265-A Adjustable DC Power Supply
Type 1308-A Audio Oscillator and Power Amplifier

The Type 1265-A Adjustable DC Power Supply can be used as a source of either constant voltage or constant current. The output is continuously adjustable and is monitored by front-panel voltage and current meters. In addition to its use as an accessory for the Incremental Inductance Bridge, the Type 1265-A is useful as a general-purpose power supply. It is designed to carry large ac currents from the Type 1266-A, when these two power sources are connected in series.

The Type 1266-A Adjustable AC Power Source provides a power-line-frequency (50-60 cps) source of voltage and current for use with the Type 1633-A. The output is continuously adjustable and is monitored by front-panel voltage and current meters. The Type 1266-A is designed to carry large dc currents from the Type 1265-A when these two power sources are connected in series to form the bridge generator.

The Type 1308-A Audio Oscillator and Power Amplifier performs a function similar to that of the Type 1266-A, but the output frequency of the oscillator is continuously variable between 20 cps and 20 kc. In addition to its use as an ac bridge generator it is useful as a general-purpose power oscillator or power amplifier.

SECTION **2**

OPERATING PROCEDURE

NOTE: A condensed set of operating instructions is included inside the front cover of this book for ready reference.

2.1 INSTALLATION.

2.1.1 POWER CONNECTIONS. Connect the instrument to a suitable power source, as indicated on the plate near the power receptacle on the rear panel (115 or 230 volts, 50 - 400 cps). Two power receptacles for the generators are provided on the rear panel, so that power to all instruments can be controlled by the SYSTEM POWER switch on the front panel of the Type 1633-A. The current available at the receptacles is six amperes at 115 volts or three amperes at 230 volts, and is limited by the rating of the switch.

2.1.2 GROUNDING. To minimize the possibility of errors from power-line hum and of shock hazard when high-power sources are used, the instrument should be connected to a good ground. A three-wire power cord has been provided for this purpose, but any of the panel ground terminals can be used.

2.1.3 MOUNTING. The instrument can be operated in any position. Care should be taken to avoid using the bridge in the presence of large external fields of the same frequency as that used in the measurements.

2.2 USE AT FREQUENCIES INDICATED ON PANEL (INTERNAL DETECTOR).

2.2.1 GENERAL. The internal detector can be used at any one of the nine frequencies indicated on the panel FREQUENCY switch: 50, 60, 100, 120, 400, 800 cps, 1, 10, or 15.75 kc.

Install the bridge as noted in paragraph 2.1.

2.2.2 GENERATOR REQUIREMENTS. The bridge will operate with generator levels of 6 mv to 1250 volts and 0 to 7 amperes. A single generator usually will not cover this entire dynamic range. The generators of the Type 1630 Measuring Assemblies (paragraph 1.7) provide signal levels up to 200 volt-amperes ac and 200 watts dc over a wide range of impedances; they were designed specifically to complement the features of the bridge. However, other generators that satisfy the desired excitation requirements can be used. Any combination of ac and dc generators within the power ranges noted above the RANGE SELECTOR switch on the front panel can be connected to the GENERATOR terminals.

Two methods of superimposing ac and dc signals, in series or in parallel, are possible. With either method, each supply must be designed for use with the other and with the reactive load. In many instances, the unknown inductor or resistor can be measured under actual operating conditions, with its own power sources and circuit components (refer to paragraph 5.5).

2.2.3 RECOMMENDED GENERATORS. For general-purpose measurements, to 200 volt-amperes, ac and dc, the Type 1308-A Audio Oscillator and Power Amplifier, the Type 1266-A Adjustable AC Power Source and the Type 1265-A Adjustable DC Power Supply are recommended. For measurements at levels to one watt, with signal levels up to 100 volts (open circuit) or four amperes (short circuit), the Type 1311-A Audio Oscillator is suitable. At higher power levels, a General Radio Variac® Autotransformer and an isolation transformer can be used. The latter is necessary to avoid errors due to circulating ground currents.

2.2.4 CONNECTING THE GENERATORS. TURN ALL GENERATOR OUTPUTS TO ZERO. Then connect them to the GENERATOR terminals of the bridge. Either the binding posts on the front panel or the multipoint connector on the rear panel can be used. A cap is provided to cover the front-panel GENERATOR terminals when the rear connector is used, to avoid possible shock hazard, since these terminals carry the full generator voltage.

2.2.5 CONNECTING THE UNKNOWN. Press the button below the UNKNOWN terminals to open the protective cover. Attach the leads of the inductor to be measured to the UNKNOWN terminals. The upper terminal is connected to the high GENERATOR terminal and has the higher voltage. The lower terminal is near ground potential. (Neither terminal of the unknown can be connected externally to the bridge ground; refer to paragraph 5.2.) Close the cover and lock it by again pressing the button. The DANGER warning light will now light.

2.2.6 SETTING THE PANEL CONTROLS.

2.2.6.1 Q-R SELECTOR Switch. Set the Q-R switch to either Q or R, as desired. If the resistance of the unknown is larger than the reactance (Q is less than 1), the R scale must be used $\left(Q = \frac{2\pi fL}{R}\right)$. If the Q of the unknown is greater than unity, either the R or the Q scale can be used. The Q scale provides greater resolution for high-Q inductors.

2.2.6.2 FREQUENCY Switch. Set the FREQUENCY switch to the frequency of measurement. For use at frequencies other than those indicated on the panel, refer to paragraph 2.3.

2.2.6.3 RANGE SELECTOR Switch. Set the RANGE SELECTOR switch to the approximate value of the unknown, as indicated in the MULTIPLIER windows. If the approximate value is not known, set the L control to mid-scale, apply a small amount of ac voltage, and adjust the RANGE SELECTOR switch until minimum reading of the NULL indicator is obtained.

2.2.7 BALANCING THE BRIDGE.

a. Turn on the generators. Do not exceed the voltage or current rating (ac or dc) indicated by the selected position of the RANGE SELECTOR control.

b. Tune the generator frequency for maximum deflection of the panel meter.

c. Adjust the R-Q and L controls until the bridge is balanced, as indicated by a null on the meter. When nonlinear unknowns are measured, it is possible for harmonics of the input signal to saturate the input stages of the null detector and cause errors. Therefore, the SENSITIVITY control of the detector should be advanced only as much as necessary for these measurements. When the balancing procedure has been completed, decrease the setting of the SENSITIVITY control slightly. If the pointer of the meter moves up scale, the original setting of the SENSITIVITY control was too high and the bridge must be rebalanced at a somewhat decreased setting. The null detector is designed to permit at least a 1% balance under the worst possible conditions, with the proper setting of the SENSITIVITY control.

To obtain the series inductance and resistance of the unknown, multiply each dial reading by the corresponding MULTIPLIER in the panel window. For example, if the L dial indicates 7 and the L MULTIPLIER window indicates 10 mh, the unknown has an inductance of 70 mh. The greatest accuracy is obtained when the RANGE SELECTOR switch is set so that, at balance, either the R or the L dial reads greater than 1.0. The value of Q is read directly, without the use of a multiplier.

CAUTION: Reduce the generator outputs to zero before changing connections or ranges, and make all connections and disconnections to the unknown at the UNKNOWN terminals on the panel, to reduce possible shock hazard.

2.2.8 ACCURACY.

At 1 kc or below, the accuracy of the L dial is ±1% of the reading, or ±0.1% of full scale, whichever is the greater. This corresponds to approximately ±1/16 inch at any point on the L scale. The accuracy of the R-Q dial is ±2% of the reading, or ±0.1% of full scale, whichever is the greater. This corresponds to approximately ±1/8 inch at any point of the R or Q scale. The effects of residual impedances are covered in paragraph 2.4.3.9.

At higher frequencies an additional error for L, $\left(\frac{2\pi}{100} \times \frac{f_{kc}}{Q_x}\right)$, may be important with low-Q coils. With high-Q coils, the error for R, $\left(\frac{1}{2\pi} Q_x f_{kc}\right)$, may be important.

2.2.9 CURRENT MONITOR TERMINALS.

The CURRENT MONITOR terminals are connected across R_b, Figure 2-1. The voltage across these terminals is proportional to the current through the unknown inductor, so that an oscilloscope or similar instrument can be used to monitor this current. The value of resistor R_b is a function of the RANGE SELECTOR switch setting, as given in Table 1.

The open-circuit voltage across the CURRENT MONITOR terminals is the difference between the voltage applied across the GENERATOR terminals and that applied across the UNKNOWN terminals. The voltage is small and is usually negligible if the impedance of the unknown is greater than 100 ohms and if the balance can be obtained above 1.0 on either the R or L scale.

2.2.10 DETECTOR OUTPUT TERMINALS.

The output signal of the internal tuned detector is available at the DETECTOR OUTPUT terminals, so that the signal can be monitored readily by an oscilloscope or other indicating device.

TABLE 1

VALUE OF RESISTOR R_b FOR EACH RANGE SELECTOR SWITCH SETTING.

RANGE SELECTOR SWITCH SETTING	R_b - OHMS (±1/4%)
a - c	0.9
d	9.0
e	90.0
f	900.0

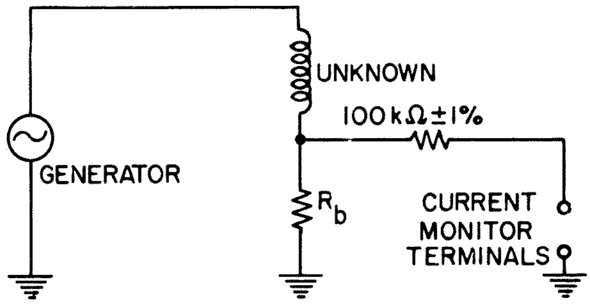


Figure 2-1. Connections to the CURRENT MONITOR panel terminals.

2.3 USE AT OTHER FREQUENCIES.

2.3.1 EXTERNAL DETECTOR. The bridge can be used at any frequency between 20 cps and 20 kc with an external detector such as the General Radio Type 1232-A Tuned Amplifier and Null Detector. To connect the external detector, remove the thumbscrews on the rear of the bridge and slide the instrument out of its cabinet about two inches. Locate the terminal strip behind the DETECTOR OUTPUT terminals. Change the metal link connecting terminals 68 and 67 to terminals 68 and 66. The output of the internal, low-noise preamplifier is now connected to the DETECTOR OUTPUT terminals, so that any external detector can be used. With this connection, careful shielding of these terminals and of the external detector leads from the generator potentials is essential to avoid errors.

2.3.2 SETTING THE CONTROLS. Set the FREQUENCY switch at some engraved value near the frequency of measurement. The 100 c, 1 kc, and 10 kc positions are generally the most convenient, since the readings of the Q dial must be multiplied by a factor involving the setting of the FREQUENCY switch.

$$Q = Q_o \times \frac{f}{f_o}, \text{ where}$$

Q = Q of unknown at frequency f;
Q_o = reading of Q dial at balance;
f = generator frequency;
f_o = setting of FREQUENCY switch.

With these modifications, the operation of the bridge is the same as that noted in paragraph 2.2.

For continued use at a frequency other than those indicated, a modification of the internal frequencies may be desirable (refer to paragraph 5.9).

2.4 POSSIBLE SOURCES OF ERROR.

2.4.1 GENERAL. Interaction between the bridge and other parts of the measurement assembly can produce certain problems. Particular care is necessary at high power levels. Some common sources of error that may be encountered are listed below. If other problems arise or a malfunction of the bridge is suspected, refer to the paragraphs on Service and Maintenance, Section 6.

2.4.2 BALANCE NOT OBTAINABLE.

2.4.2.1 Q Range is Exceeded. When L and Q are measured, the Q of the unknown may be less than unity. Make the balance in terms of L and R.

2.4.2.2 Measurement Frequency Higher than Resonant Frequency of Inductor. Above the frequency at which the inductor resonates with its stray capacitance, the impedance is capacitive. The balance will appear to be below zero on the L control. Use a lower frequency.

2.4.2.3 Low Sensitivity. This may be caused by:

a. Open safety cover over UNKNOWN terminals. With this cover open, the generator terminals are shorted. Close the cover before making measurements.

b. Low generator voltage. The bridge is useful over a very wide range of generator voltages. Typical values of the minimum signal for which a balance to a 1% precision can be obtained are listed below:

RANGE	50 - 60 cps	1 kc
a	25 mv	6
b	250 mv	60 mv
c - f	2500 mv	600 mv

c. Blown generator fuse. Replace the fuse (10 amperes) on the generator side of the rear panel of the bridge.

2.4.3 READING APPEARS IN ERROR.

2.4.3.1 Measurement Frequency Approaches Resonant Frequency of Inductor and Its Stray Capacitance. When the frequency of operation is within a factor of 10 below the resonant frequency of the inductor, the effective inductance will be higher than the low-frequency inductance. The following correction can be applied:

From the dial reading subtract $\left(\frac{f}{f_o}\right)^2 L_x$, where

f = frequency of measurement,
f_o = resonant frequency of inductor.

2.4.3.2 Current Induced in Bridge Circuit by Magnetic Field of Unknown Inductor. To check for this condition, change the physical orientation of the inductor with respect to the bridge.

2.4.3.3 Hum Pickup Due to Power Line. An error due to hum pickup may be encountered when measurements are made at the power-line frequency. To test for this condition, turn the generator output to zero after a balance has been made and short the generator terminals at the bridge. There should be negligible indication on the null detector. Hum signals present in the bridge due to internal sources will not cause an error if the balance can be made with the SENSITIVITY control less than 3/4 clockwise. At higher sensitivities, a small error, whose magnitude depends on the settings of the various controls, can occur if the generator signal level is very low (refer to paragraph 2.4.2.3). The test outlined above should be made if this error is suspected.

2.4.3.4 Bridge Measures Series Inductance; Parallel Inductance is Needed. In this case a correction is sometimes necessary. Refer to the chart inside the back cover, or to paragraph 1.4. When the Q of the unknown is greater than 10, the correction is less than 1%.

2.4.3.5 SENSITIVITY Control Set Too High. When components with unsymmetrical, nonlinear characteristics are measured (such as when a large dc bias current is applied to an iron-cored coil), large odd and even harmonics can be produced which mix to give a stray fundamental component if the signals are large enough to cause clipping in the detector circuits. To test for this problem, reduce the setting of the SENSITIVITY control after a balance has been obtained. The null should not change (refer to paragraph 2.2.7). The detector circuits are designed with sufficient dynamic range to allow at least a 1% balance under the worst possible conditions, with the proper setting of the SENSITIVITY control.

2.4.3.6 Ground Currents. If the bridge and the generator are connected with multiple ground leads, the potential drop in the leads can cause an error. Unless the generator current enters and leaves the bridge by either of the two sets of GENERATOR terminals provided, the magnetic field of the loop produced may induce stray currents in the bridge circuits. This problem is primarily important at high currents and high frequencies. To test for this, reduce the generator output to zero; then short the GENERATOR terminals at the bridge after a balance has been made and adjust the ac generator so that the current flowing in the generator circuit is the same as during the measurement. The null detector should show negligible deflection.

2.4.3.7 Results Not Repeatable. When ferromagnetic coils are measured, the inductance depends on the ac- and dc-signal levels and on the previous excitation history of the core. Also, results of a series of measurements made by progressively increasing the excitation

TABLE 2

APPROXIMATE VALUE OF EXTERNAL STRAY CAPACITANCE, C_b, FOR ONE-PERCENT INDUCTANCE ERROR.

RANGE SELECTOR SWITCH SETTING	FREQUENCY SWITCH SETTING		
	50 c to 120 c	400 c to 1 kc	10 kc to 15.75 kc
a	1 μf	0.1 μf	0.01 μf
b	1 μf	0.1 μf	0.01 μf
c	1 μf	0.1 μf	0.01 μf
d	0.1 μf	0.01 μf	1000 pf
e	0.01 μf	1000 pf	100 pf
f	1000 pf	100 pf	10 pf

will not necessarily be the same as those made by decreasing the excitation, because of the hysteresis effect (refer to paragraph 4.1.1). Effects of internal heating in the unknown should also be considered. Specifications of the value of inductance should include all of these factors.

2.4.3.8 External Stray Capacitance from Low UNKNOWN Terminal to Ground. This capacitance, C_b, shunts the ratio arm, R_b. The following corrections can be applied:

L— from the bridge reading subtract $R_xR_bC_b$.

R— to the bridge reading add $L_xR_bC_b\omega^2$.

(See Table 1 for value of R_b.)

Table 2 gives the approximate capacitance that will produce a one-percent error.

It may be helpful to reverse the connections to the unknown, since capacitance from the high UNKNOWN terminal to ground does not cause an error.

2.4.3.9 Effects of Lead Resistance and Inductance. When small inductances or resistances are measured, the impedance of the connecting leads and the bridge residual impedances can be important. To eliminate these factors:

a. Measure the unknown in the normal manner.

b. Without disturbing the connecting leads, connect a low-impedance, short circuit across the terminals of the unknown and measure the resistance and inductance of the leads. Subtract these values from those obtained in a, above.

The magnitude of the lead inductance can be estimated as 0.025 μh per inch of each lead, if the area of the loop formed is small. The residual impedances of the bridge at the terminals are approximately 0.2 μh and 1 mΩ.

SECTION **3**

PRINCIPLES OF OPERATION

3.1 GENERAL.

The characteristics of iron-cored coils are usually nonlinear. To measure the L or Q of such a coil, the direct current through the coil and the ac voltage across it must be specified, or the measured values are meaningless. Conventional inductance bridges are intended for the measurement of linear inductors, whose characteristics are practically independent of the ac voltage applied and do not, in general, carry any direct current. Although these bridges can be used to measure incremental inductance, their ratio arms are not designed to carry appreciable amounts of direct current. It is not usually convenient to apply a specified ac voltage across the unknown.

The Type 1633-A Incremental Inductance Bridge measures inductance without appreciably affecting the operating conditions. Since practically all of the voltage and current supplied by the generator is applied to the unknown, it is a simple procedure to set the appropriate levels. With this bridge, it is possible to measure the characteristics of the unknown under actual operating conditions.

A simplified schematic diagram showing the basic parts of the Type 1633-A is shown in Figure 3-1.

3.2 BRIDGE CIRCUIT.

The bridge circuit used in the Type 1633-A is unusual in that it contains three highly stable amplifiers that isolate certain parts of the circuit and perform functions that would be difficult to accomplish by other means.

The four arms usually associated with an impedance bridge are the unknown, and resistors R_a, R_b, and R_c, Figure 3-1. The current through an inductive unknown develops a voltage across R_b. (The value of R_b is usually small compared with the unknown impedance.) A fraction, α , of this voltage, determined by the setting of the L balance control, is present at the output of the L isolation amplifier and causes a current to flow in the standard capacitor, C (see Figure 3-2). This current is in phase with the generator voltage.

On the other side of the bridge, a divider formed by R_a and R_c presents a voltage, proportional to the generator voltage, to the high input impedance of the operational amplifier. The amplifier has a very constant transconductance, so that its output current is proportional to the input voltage and is opposite to it in phase. At balance, the current through the standard capacitor, C, is equal in magnitude and opposite in phase to the current from the amplifier. The net detector current, therefore, is zero and the meter indicates a null.

This circuit has several advantages over the more commonly used passive bridge circuits. Ordinarily, the current through the standard capacitor is changed by varying the capacitance. The convenience of single-knob operation usually is limited to the use of variable air capacitors of values up to a few thousand picofarads. For larger values, switched decades of capacitors must be employed. In the Type 1633-A Incremental Inductance Bridge, however, a single, large, fixed capacitor is used. The current through this capacitor is varied by changing the voltage developed across it. This is ac-

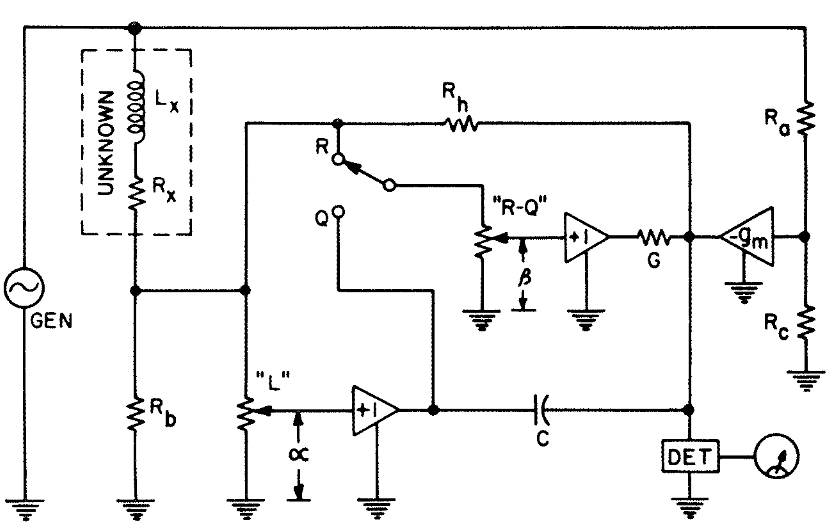


Figure 3-1. Elementary schematic diagram for Type 1633-A Incremental Inductance Bridge.

complished by adjustment of the L balance control. Thus the speed and convenience of single-knob control and the use of a large standard capacitor are both possible.

All resistors in the bridge circuit have fixed values and these are switched to achieve the wide range of inductance measurements. The resistor R_b can be made small and R_a very large, so that the impedance seen by the generator is very nearly equal to the impedance of the unknown. This is particularly important in measurements on nonlinear inductors, since a large voltage drop in R_b can cause the voltage waveform across the unknown inductance to differ considerably from the waveform of the signal applied to the GENERATOR terminals. Most of the power applied to these terminals is transferred to the unknown, so that very little is lost in the bridge elements.

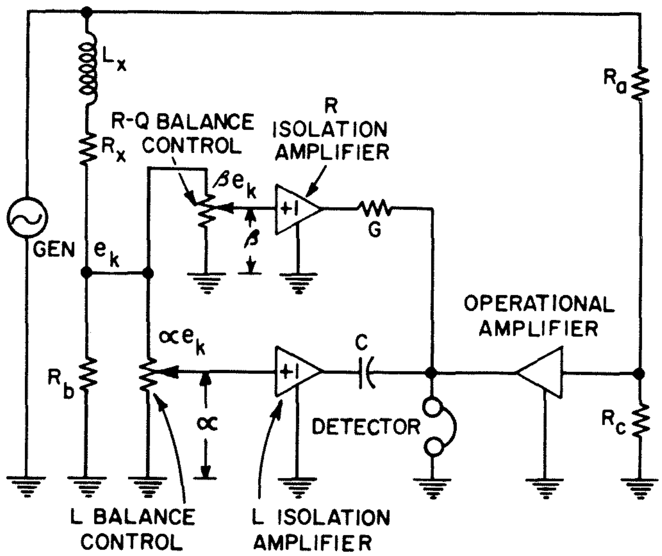


Figure 3-2. Simplified circuit for the R balance control.

The resistive component of the unknown can be measured by the adjustment of a second potentiometer that is calibrated in terms of the series resistance of the unknown. The potentiometer and a second isolation amplifier are used to control the current through the standard resistor, G, Figure 3-2. If the R potentiometer is connected across the output of the L isolation amplifier (as in Figure 3-3), the voltage at the standard resistor, G, depends upon the settings of both the R and the L potentiometers. A change in the setting of the R potentiometer changes the effective dissipation factor of the standard capacitor, so that the potentiometer dial can be calibrated in terms of the Q of the unknown inductor. The value of resistor G is changed by switching, to make the Q scale direct reading at any of nine different frequencies. This eliminates the multiplying factor that must be used with conventional bridge circuits when a frequency other than that at which the Q scale was calibrated is used.

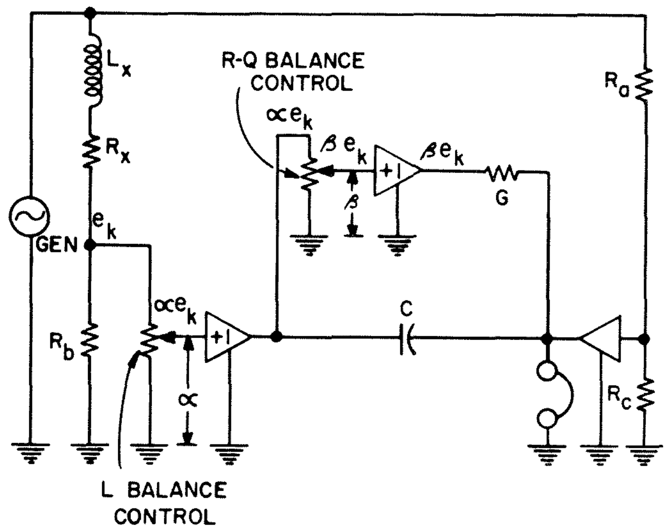


Figure 3-3. Simplified circuit for the Q balance control.

In the diagram of Figure 3-1, the following relationships are necessary for a balance:

$$L_x = \alpha C R_b R_h$$

$$R_x = \beta G R_b R_h$$

$$Q_x = \frac{\omega C}{\beta G}$$

if $$R_h = \frac{R_c + R_a}{gm R_c}$$

where β = fractional rotation of R-Q potentiometer.

The resistor R_h compensates for the small signal-voltage drop across R_b so that the calibrations of the L and R-Q dials are directly proportional to their respective rotations.

A bridge transformer is not necessary, since the generator and the detector have a common ground. This feature avoids the possibility of stray magnetic coupling, which is particularly troublesome with measurements in the presence of large magnetic fields.

3.3 ISOLATION AMPLIFIERS.

The primary purpose of these two identical amplifiers is to isolate the bridge standards from the voltage dividers. Figure 3-4 shows a simplified schematic diagram of these amplifiers.

Three transistors are included in a feedback circuit to provide a high input impedance (approximately 10 MΩ) and to prevent loading of the calibrated poten-

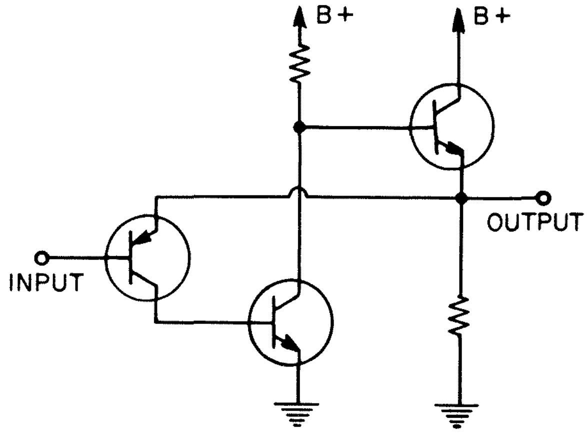


Figure 3-4. Simplified diagram of the isolation amplifier.

tiometers. The low output impedance (approximately 10 mΩ) is effectively in series with the standard capacitor and does not appreciably affect its dissipation factor. The voltage gain is very nearly unity and is very stable; thus the accuracy of the bridge is not appreciably affected.

3.4 OPERATIONAL AMPLIFIER.

This amplifier provides a current in the detector circuit that is proportional to the input voltage to the amplifier. Thus an extremely stable transconductance (g_m) is necessary. A simplified diagram of the amplifier circuit is shown in Figure 3-5. The mutual transconductance of this circuit is nearly equal to the reciprocal of the resistance of R_k (R308).

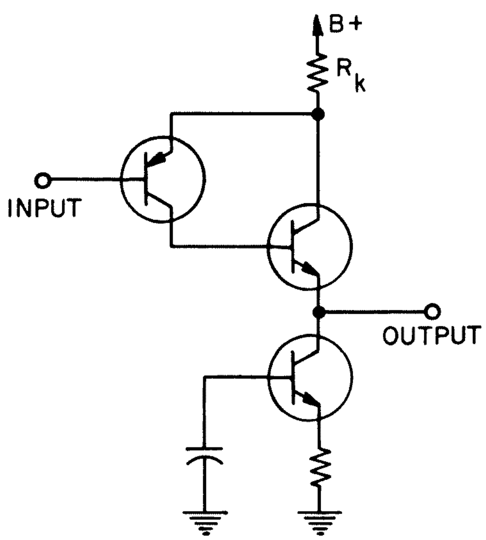


Figure 3-5. Simplified diagram of the operational amplifier.

3.5 STANDARDS.

The value of the standard capacitor, C, is determined by the setting of the FREQUENCY switch. The capacitance is changed by a factor of 10 at certain selected switch positions, to center each inductance range at or near the value most frequently encountered. This makes possible more inductance ranges over the broad frequency range. A mechanical mask over the L MULTIPLIER window indicates the correct multiplier for any combination of settings of the FREQUENCY and the RANGE SELECTOR switches. At low frequencies, General Radio polystyrene capacitors are used; a General Radio silvered-mica capacitor is used at 10 and 15.75 kc. The balance controls are General Radio precision, wire-wound potentiometers. Ratio arms R_a and R_c (Figure 3-1) are wire-wound General Radio units, except on the f range, where R_a is a 1-megohm, precision, film resistor. The power resistors of R_b are 50-watt, 1/4%, precision, wire-wound resistors.

3.6 INTERNAL DETECTOR.

The detector is a highly sensitive and selective transistor amplifier that enables measurements to be made over a wide range of generator voltages. The amplifier is tuned to any one of nine frequencies, selected by the panel FREQUENCY switch. Selectivity is obtained from two cascaded, active, RC filters (see Figure 3-6). The response of these filters to the second harmonic of the signal is approximately 60 db below the fundamental. High selectivity is necessary, since nonlinear impedances can generate harmonics that must be attenuated sharply in the detector to eliminate errors. The filter sections are slightly stagger-tuned so that the stability of the generator frequency is not critical. The amplifier drives the panel meter, to provide a visual ac null indication. The rectifier shaping circuits give a meter reading approximately proportional to the logarithm of the input signal, thus eliminating the necessity of frequent adjustments of the SENSITIVITY control. The ac output of the detector is available at the DETECTOR OUTPUT terminals on the front panel. The output of the low-noise preamplifier is also readily accessible (refer to paragraph 2.3), to facilitate measurements at some frequency other than those provided on the FREQUENCY switch.

3.7 COMPENSATION TECHNIQUES.

To achieve the required accuracy over the wide ranges involved, numerous components have been added to the circuit to compensate for the residual impedances in the bridge elements.

The following components compensate for the inductance of the ratio arm R_b, so that it appears resistive

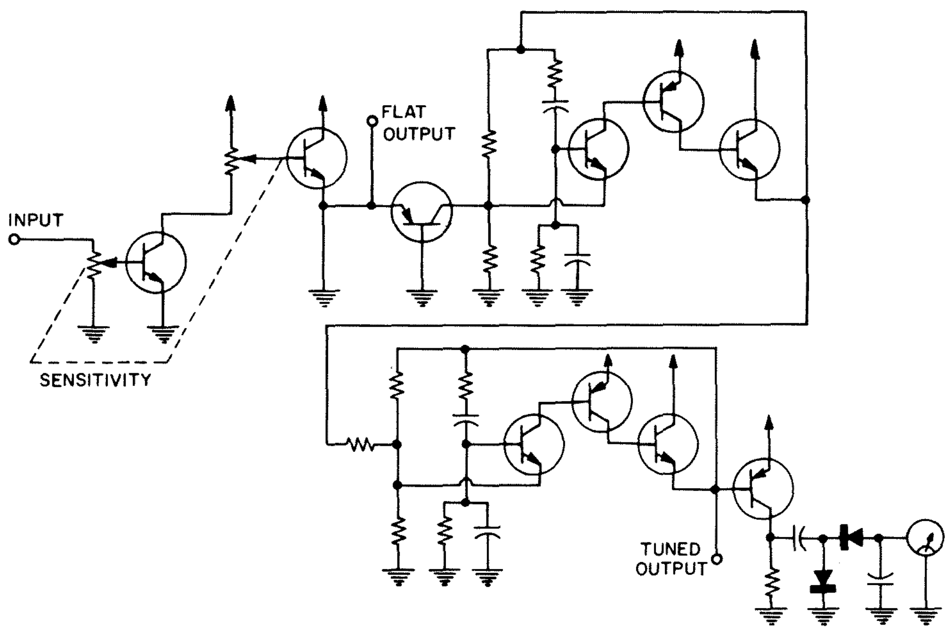


Figure 3-6. Simplified diagram of the internal detector.

over a wide frequency range: C1, C2, C3, C4, R4, R6, R8, and R10.

The following capacitors provide compensation for the lumped and distributed capacitances across R_a, to make the voltage-divider ratio independent of frequency: C5, C6, C7, C8, C9, C10, C17.

Capacitors C105 and C108 compensate for the stray capacitances in the voltage-divider potentiometers so that their input and output voltages are nearly in phase at all settings of the potentiometers.

Part of the current from the output of the isolation amplifier is coupled to the input circuit through capacitor C203 to neutralize the capacitive current from the arms of the L and R control potentiometers to ground.

3.8 PROTECTIVE DEVICES.

Because the bridge is designed to measure inductors in which the stored energy can be very large, a number of features have been incorporated in the instrument that are intended to protect the equipment and to alert the operator to possible danger. The most prominent among these is a hinged cover over the UNKNOWN terminals. A lock on this cover is mechanically connected to a switch that shorts the GENERATOR terminals to ground (through a 1-ohm, 50-watt resistor). Thus any current in the unknown inductor is discharged harmlessly, before the operator disconnects the unknown. To prevent damage to the generator due to this 1-ohm short circuit (in the event the generator has not been turned off before making connections), a 10-ampere fuse has been incorporated in the circuit. This fuse is available on the rear panel. A panel light under the UNKNOWN terminals indicates when the generator is not shorted.

It is not always possible to provide a protective device at the unknown end of any cables used to connect the unknown to the bridge. Therefore, <u>the unknown should always be connected or disconnected at the bridge terminals.</u>

The SYSTEM POWER switch controls the power to two receptacles on the rear panel of the instrument, so that the bridge and its generators can be conveniently controlled by the same switch. In this way the generators are also prevented from supplying power, in the event the bridge power and warning light are turned off.

If the generator connections are removed with current flowing in the circuit, the induced voltage transient is applied directly across the bridge. Thyrite varistors (R33, R34, and R35 on the wiring diagram, Figure 6-12) have been included to limit this voltage and to help prevent damage to the bridge.

SECTION **4**

APPLICATIONS

4.1 MEASUREMENTS OF IRON-CORED COILS.

4.1.1 GENERAL.

4.1.1.1 Definitions. A ferromagnetic core is composed of many small magnetic units, called domains, that are randomly oriented in a demagnetized sample, so that no net magnetization (B) exists. If a field (H) is applied to the core, the domains tend to line up with the field. When a sufficiently large magnetizing force is applied, substantially all the domains will be oriented in the direction of the field and no further increase in magnetization will result. This is called saturation. If the field is then decreased to zero, the domains will not necessarily redistribute themselves in a random fashion and therefore may leave a remanent magnetism. This effect is called hysteresis.

4.1.1.2 Demagnetizing. It is evident from the above that the particular state of a core depends on both the values of excitation and on the previous history of excitation. This last factor is particularly troublesome; to eliminate it, the core should first be demagnetized. An ac current of sufficient magnitude to saturate the core is applied to the coil; the current is then slowly reduced to zero (or the core is gradually removed from the field of the coil). The core is then said to be demagnetized, or brought to a symmetrically cyclically magnetized (SCM), or cyclic, condition. This procedure should be followed with any coil that has been subjected to a transient or to a direct current before an attempt is made to measure its inductance. Also, when a series of measurements is made with superposed dc in the coil, it should be made with increasing values of dc.

4.1.1.3 Commonly Used Parameters. The inductance of an iron-cored coil is proportional to the effective permeability (μ) of the core. Several different permeabilities are defined as follows:

a. Normal or DC Permeability $\left(\mu_{dc} = \frac{B}{H}\right)$

A dc field is applied and the resulting magnetization is measured.

b. Incremental Permeability $\left(\mu_{\Delta} = \frac{\Delta B}{\Delta H}\right.$ where ΔH approaches 0 and H_{dc} is not 0.$\left.\right)$

To measure μ_{Δ}, superpose a small ac field (proportional to the current in the coil) upon a dc field (H_{dc}). The resultant ac induction (proportional to the voltage across the coil) is then measured. To do this, measure the inductance of the coil with a small ac signal and a dc bias applied. In general, this inductance is a function of both the ac and dc signal levels.

c. AC Permeability $\left(\mu_{ac} = \frac{\Delta B}{\Delta H}\right.$ at frequency f_o, with $H_{dc} = 0.\left.\right)$

This value is obtained by measurement of the inductance of a coil with ac signals applied (no dc) on a bridge with a selective detector tuned to the frequency of measurement, f_o. In general, the ac permeability is a function of the signal level and differs from the normal or dc permeability if the core is nonlinear over the range of operation, since only the fundamental component of the waveform is used is the measurement.

d. Initial Permeability $\left(\mu_i = \frac{\Delta B}{\Delta H}\right.$ where ΔH approaches 0 and $H_{dc} = 0.\left.\right)$

If the signal level is decreased, the ac permeability generally decreases, and at low signal levels it is proportional to H_{ac}, plus a constant (see Figure 4-1). This constant is called the initial permeability. To determine it, measure the inductance of the coil at two small values of excitation and extrapolate to zero. (This is the most easily reproducible condition for measurements and is generally used when a high degree of accuracy is required. It is the condition under which all "standard" iron-dust-cored inductors are calibrated.)

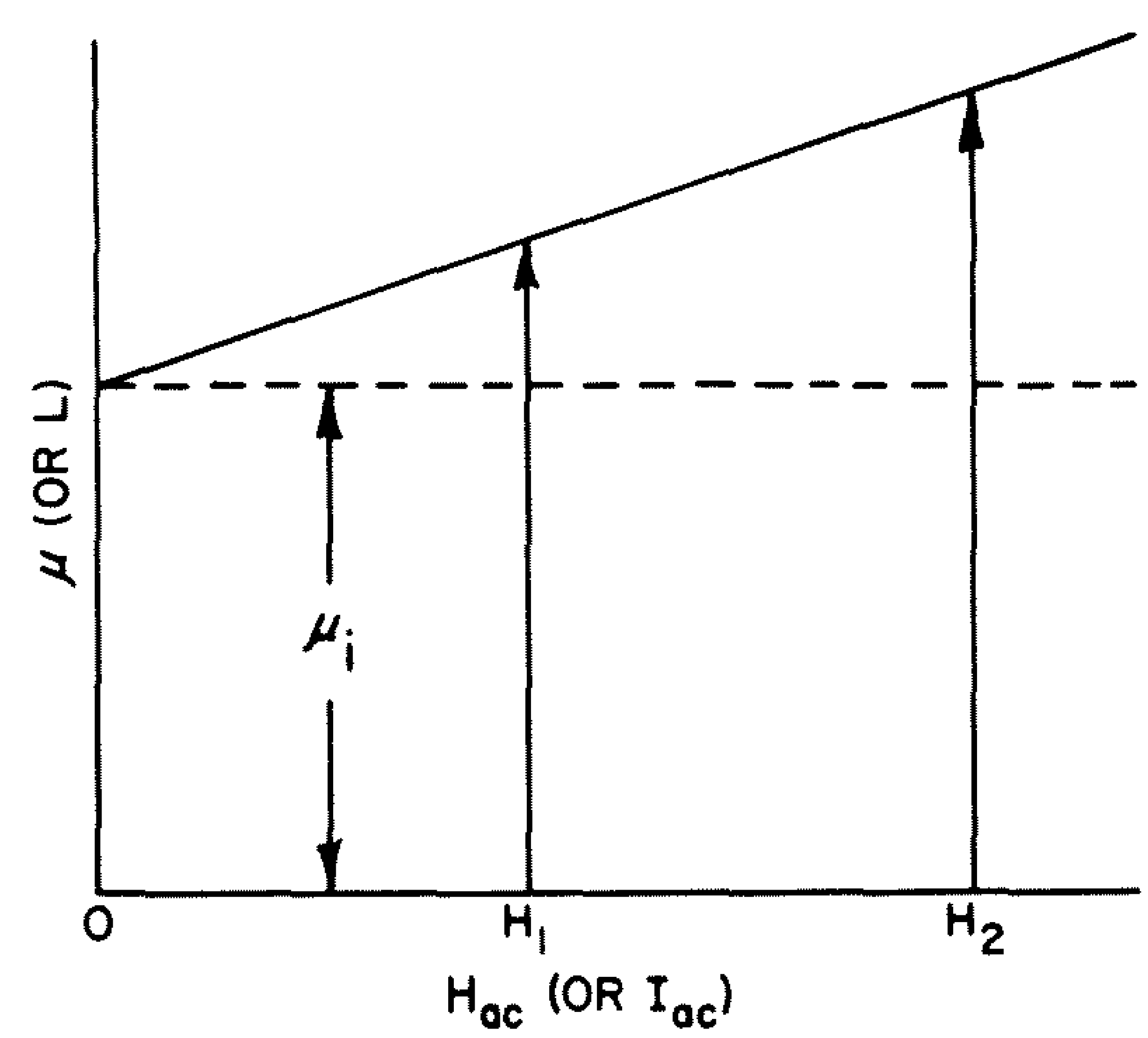


Figure 4-1. Determination of initial permeability.

4.1.1.4 Losses.

4.1.1.4.1 General. The equivalent circuit of an iron-cored coil at low frequencies is shown in Figure 4-2. Resistors R_c and R_e are nearly independent of frequency and represent, respectively, the ohmic loss in the copper and the eddy-current loss in the iron and in the copper.

4.1.1.4.2 Copper Loss. At low frequencies the resistance R_c is equal to the dc resistance of the winding. The dissipation factor corresponding to this resistance is

$$D_c = \frac{1}{Q_c} = \frac{R_c \text{ (series)}}{\omega L} = \frac{c}{f}, \text{ where c is a constant.}$$

D_c is inversely proportional to the frequency.

4.1.1.4.3 Eddy-Current Loss in Iron and Copper. The resistance R_e corresponds to a dissipation factor D_e.

$$D_e = \frac{1}{Q_e} = \frac{\omega L}{R_e \text{ (parallel)}} = ef, \text{ where e is a constant.}$$

D_e is directly proportional to the frequency.

4.1.1.4.4 Hysteresis Loss. The hysteresis loss is proportional to the area enclosed by the hysteresis loop and to the rate at which this loop is traversed (frequency). It is a function of signal level and increases with frequency. Thus no simple frequency-independent resistor can be used in Figure 4-2 to represent this component (shown in dotted lines).

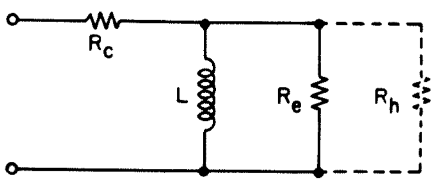


Figure 4-2. Equivalent circuit of an iron-cored coil at low frequencies.

The dissipation factor corresponding to this is

$$D_h = \frac{\omega L}{R_h \text{ (parallel)}} = h, \text{ where h is a constant.}$$

Thus D_h is independent of frequency.

4.1.1.4.5 Total Loss. The total dissipation factor (D) is the sum of the three separate dissipation factors.

$$D = \frac{1}{Q} = \frac{c}{f} + ef + h$$

where c, e, and h are constants related to the physical properties of the core. This function is plotted in Figure 4-3.

The minimum dissipation factor occurs at a frequency

$$f_{min} = \sqrt{c/e}$$

To separate the effects of these three components, a series of measurements can be made at several frequencies. When a curve of $D = \frac{1}{Q}$ for any coil has been found experimentally, numerical values for the three coefficients, c, h, and e, can be found by drawing 45° asymptotes to the curve. The intercepts of these lines with the 1-cycle axis are the values of c and e. The value of h is the difference between the observed minimum and twice the value of the two asymptotes at their crossing point.

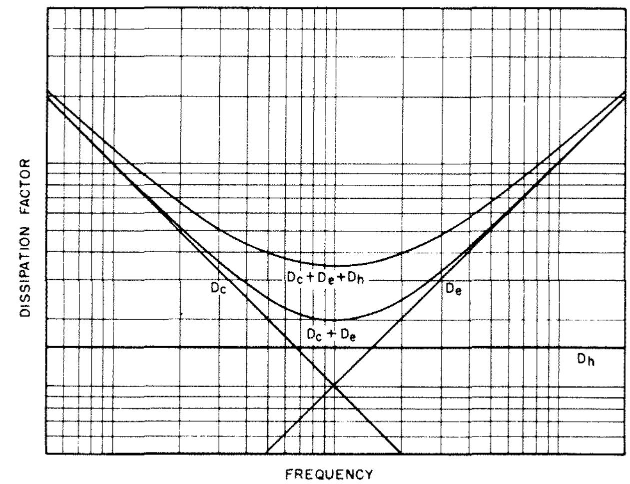


Figure 4-3. Curves showing relationships between dissipation factor and frequency. The three labeled straight lines are separate dissipation factor curves.

4.1.1.5 Inductance. The bridge measures series resistance and inductance (refer to paragraph 1.4). When the losses are primarily due to R_c, the simplified representation is valid. When the hysteresis and eddy-current losses are the most important, the measured values should be converted to parallel components. A chart is included inside the back cover of this book to facilitate this conversion.

The distributed capacitance of an inductor and of all the windings of a transformer is reflected to the winding under test and can affect the accuracy if measurements are made near the resonant frequency of the coil.

4.1.1.6 Summary. Since the permeability of core materials is very nonlinear, inductance measurements must be made under the same excitation conditions as the anticipated use. The specification of inductance must also include a statement of the dc and ac signal levels, the frequency, and any significant history of excitation.

If no history is given, the cyclic (SCM) condition is generally assumed. The Type 1633-A Incremental Inductance Bridge is designed for operation over the wide range of signal levels necessary for this type of measurement.

The bridge measures series components directly. If the parallel components are required, they can be calculated from the measured values. (See chart inside rear cover.)

4.1.1.7 References. For a more detailed discussion of magnetic properties and their measurements, several excellent references are available:

1. "Iron-Cored Coils for Use at Audio Frequencies," a reprint of a series of articles from the General Radio Experimenter, containing a detailed explanation of the behavior of iron-cored coils over wide frequency ranges. Included also is a discussion of the effect of the various physical parameters of a coil on the inductance and on the losses. The individual articles contained in the reprint are

"Losses in Audio-Frequency Coils" L. B. Arguimbau
"How Good is an Iron-Cored Coil?" P. K. McElroy
"Those Iron-Cored Coils Again" Parts I and II, P. K. McElroy.

2. "Alternating-Current Measurements of Magnetic Properties," by H. W. Lamson[1] (GR Reprint No. A-37).

This article contains a critical analysis of various procedures for determination of the permeability and core loss of ferromagnetic materials, together with a discussion of the limitations under which such observations are made and the interpretations which should be applied to the data obtained.

[1]*Proc. I. R. E., February 1948.*
[2]*Journal A. I. E. E., February 1927.*

3. "Iron-Cored Inductors Carrying DC," General Radio Drafting Department Standards.

This article describes a design procedure for obtaining maximum inductance with a given dc current, as originally described by C. R. Hanna[2] and extended by P. K. McElroy.

The above references are available without charge from General Radio, upon request.

4.1.2 TRANSFORMER MEASUREMENTS.

4.1.2.1 Equivalent Circuit. The normal low-frequency equivalent circuit of a transformer, referred to the primary terminals, is shown in Figure 4-4.

4.1.2.2 Leakage Inductance. To find the total leakage inductance, short-circuit the secondary and measure the primary impedance, ($Z_{po} = R_{po} + j\,\omega L_{po}$). The total leakage inductance is then

$$L_1 + L_2 \approx L_{po} - D^2_{(sec)}\, L_{(pri)}$$

where $D_{(sec)} = \dfrac{R_{(sec)}}{\omega L_{(sec)}}$, L_1 and L_2 = leakage inductance of the primary and secondary, respectively, and L_{po} = primary inductance with secondary short-circuited. The core has very little effect on the leakage; thus the measurement of L_{po} can be made at any signal level.

The second term in the above equation is usually not negligible unless the measurement is made at a high frequency, where $D_{(sec)}$ is very small.

On two-winding transformers, the leakage is generally assumed to be equally distributed between the primary and the secondary ($L_1 = L_2$).

4.1.2.3 Magnetizing Inductance. To determine the magnetizing inductance, measure the primary inductance with the secondary open-circuited and subtract L_1.

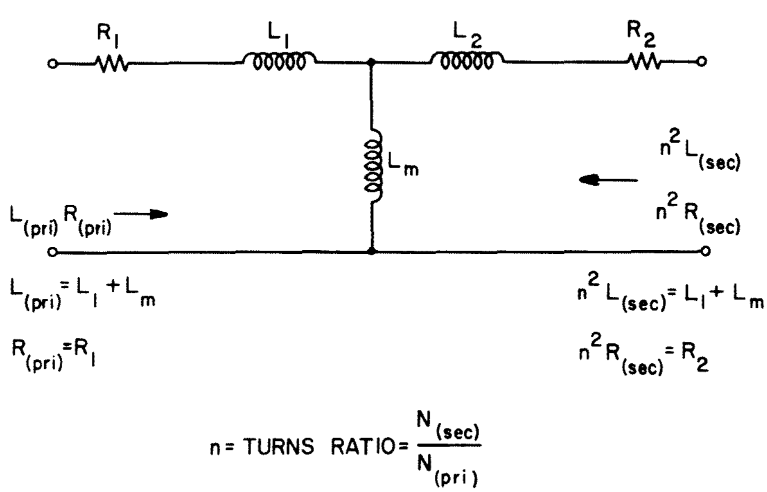


Figure 4-4. The equivalent circuit of a transformer at low frequencies.

4.1.3 INDUCTORS CARRYING DIRECT CURRENT. An air gap (g) is generally used in the core structure of an inductor carrying dc current. For a given coil and core, with a given value of direct current in the coil, there is an optimum size of the air gap that results in the maximum inductance of the coil, as indicated in Figure 4-5. A procedure for determination of the optimum design of such an inductor has been derived by C. R. Hanna (refer to paragraph 4.1.1.7). The empirical measurements required to design such coils can be made on the Type 1633-A Incremental Inductance Bridge. The inductance of the coil is measured with the desired ac voltage and dc bias current applied at the GENERATOR terminals.

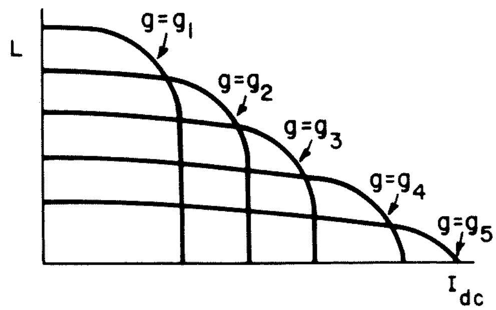


Figure 4-5. Use of optimum-size air gap in an inductor carrying a given value of direct current to produce maximum value of inductance of the coil.

4.2 AC RESISTANCE MEASUREMENTS.

4.2.1 GENERAL. Incremental ac resistance can be defined in a manner similar to incremental inductance. The value of resistance indicated by the bridge is the ratio of the fundamental component of voltage to the fundamental component of current.

In the following paragraphs are noted some of the reasons for the difference between the ac and dc resistances of a component.

4.2.1.1 Losses. Losses of other forms, such as core losses or reflected load losses, will cause the indicated series resistance of a coil to be higher than its dc resistance.

4.2.1.2 Skin and Proximity Effects. At higher frequencies, the magnetic field of a conductor (and of adjacent conductors) forces the current to be distributed nonuniformly throughout its cross section, thereby increasing its effective resistance. At high audio frequencies, these effects may be appreciable in coils, but they are negligible in most wire-wound resistors.

4.2.1.3 Lumped and Distributed Capacitances. The lumped and distributed capacitances across a resistor change its effective series resistance. These capacitances may be important with inductors and with resistors of values over several hundred ohms.

4.2.1.4 Nonlinearities. This term applies to any resistor whose value is a function of current or power. Thermistors, lamp bulbs, varistors, diodes, and many semiconductor elements are examples of this type.

4.2.2 SEMICONDUCTOR MEASUREMENTS. The incremental resistance of semiconductor circuit elements, such as the forward resistance of rectifiers or the dynamic resistance of Zener diodes, can be easily measured on the bridge over a wide range of dc bias currents. For these measurements, the ac-signal current is generally kept much smaller than the biasing direct current. Under these conditions, the bridge measures the slope of the volt-ampere characteristic at the bias point. The proper polarity of the bias source must be observed. The operating procedure is described in Section 2.

4.2.3 CAPACITIVE BALANCE. In the Type 1633-A Bridge, the L control provides a phase balance for inductive resistors. If the phase of the unknown resistor is capacitive, as it usually is with large-valued resistors, the L-control balance will appear to be below zero. An external capacitor (C_b) can be connected between the low unknown terminal and the GENERATOR ground terminal, to effect a capacitive balance. The L control can be used near zero for a fine phase balance. The value of the effective capacitance shunting the unknown resistor can be calculated from:

$$C_x \approx \frac{R_b}{R_x}\left[C_b - \frac{L_o}{R_b R_o}\right]$$

$$R_x \approx R_o + \omega^2 L_o R_b C_b$$

where L_o = inductance indicated on L control scale
R_o = resistance indicated on R control scale

Values of R_b are given in Table 1. Since the value of R_x depends upon the L control reading, the external capacitor C_b should be adjusted to give a balance with the L control near zero.

SECTION **5**

SPECIAL MEASUREMENTS

5.1 GENERAL.

A discussion of some of the more unusual measurements that can be made with the Type 1633-A is given in this section. They include:

- Grounded Unknowns
- Use at Higher Currents
- Three Terminal Measurements
- Use with Nonsinusoidal Waveforms
- Remote Measurements
- Measurement of Mutual Inductance
- Limit Testing
- Use at Other Frequencies
- Displaying AC Hysteresis Loops

5.2 GROUNDED UNKNOWNS.

Since neither UNKNOWN terminal of the Type 1633-A Bridge is grounded, special arrangements are necessary to measure grounded unknowns. In many cases, the external circuit can be rearranged to permit operation of the bridge in a normal manner. If this cannot be done, either of the two procedures described below can be used, but proper safety precautions should be observed. In either case, the ground connection in the three-wire power cord must be disconnected.

5.2.1 GROUNDING HIGH UNKNOWN TERMINAL.

CAUTION: This method places the bridge panel and controls at the full generator voltage above ground and should not be used with high voltages.

With this connection, the capacitance of the case to ground is placed across the generator; no error is produced.

5.2.2 GROUNDING LOW UNKNOWN TERMINAL.

In this case the bridge panel and controls are at a potential above ground determined by

$E = IR_b$ (ac and/or dc)

(See Table 1 for values of R_b.)

This voltage can be as high as 180 volts. The capacitance C_b from the case to ground can cause an error. Refer to paragraph 2.4.3.8.

5.3 USE WITH HIGHER CURRENTS.

The bridge can be used on the a, b, or c range with ac and/or dc currents up to 70 amperes by the addition of an external 0.1-ohm, 500-watt resistor (R_m, Figure 5-1). Connections to any other generators must be removed. Use only the a, b, or c range and multiply

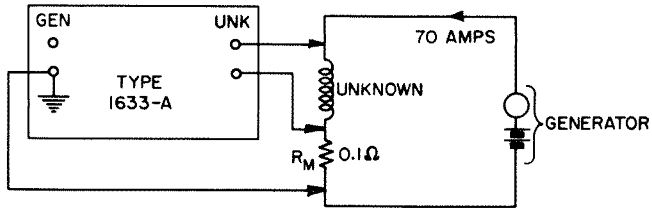


Figure 5-1. Circuit showing addition of 0.1-ohm resistor for measurements involving higher current values.

the L and R bridge readings by 0.1 (Q is direct reading). The maximum allowable rms generator voltage is indicated by the RANGE SELECTOR switch. The inductance L_m of the external resistor can cause an error. The following correction should be applied:

$$L_x = L_o + \left(\frac{R_o}{R_m}\right) L_m$$

$$R_x = R_o - \omega^2 \frac{L_m L_o}{R_m}$$

where L_o and R_o are the respective readings of the L and R dials.

An accessory unit, the General Radio Type 1633-P1 Range-Extension Unit, containing a suitable resistor and with the proper connections for this purpose, is available on special order.

5.4 THREE-TERMINAL MEASUREMENTS.

The bridge can be used to measure the transfer impedance of an inductive, three-terminal network, as in Figure 5-2. L_x and R_x (or Q) are measured directly. C_g causes no error. When C_b is large, it can cause a small error (refer to paragraph 2.4.3.8).

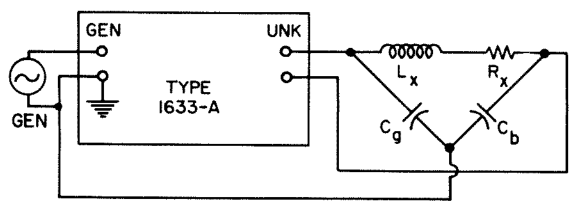


Figure 5-2. Diagram of connections for three-terminal measurements.

5.5 USE WITH NONSINUSOIDAL WAVEFORMS.

The Type 1633-A Bridge can be used with any generator of arbitrary waveform within the ratings of the bridge. The internal tuned detector can be used to measure the effective inductance at a harmonic of the generator signal, if desired. The SENSITIVITY control should be set only as high as needed to obtain a satisfactory balance. This avoids clipping on the other unbalanced components of the waveform (refer to paragraph 2.4.3.5).

It is often convenient to use as the generator the actual circuit in which the inductor is being used. The operation of the circuit will not be affected by the bridge to any appreciable extent, since the value of the resistance R_b, inserted in series with the unknown inductor, is usually much lower in impedance than the unknown. A typical power supply circuit and two possible methods for measurement of the filter choke under operating conditions are shown in Figure 5-3, a, b, and c.

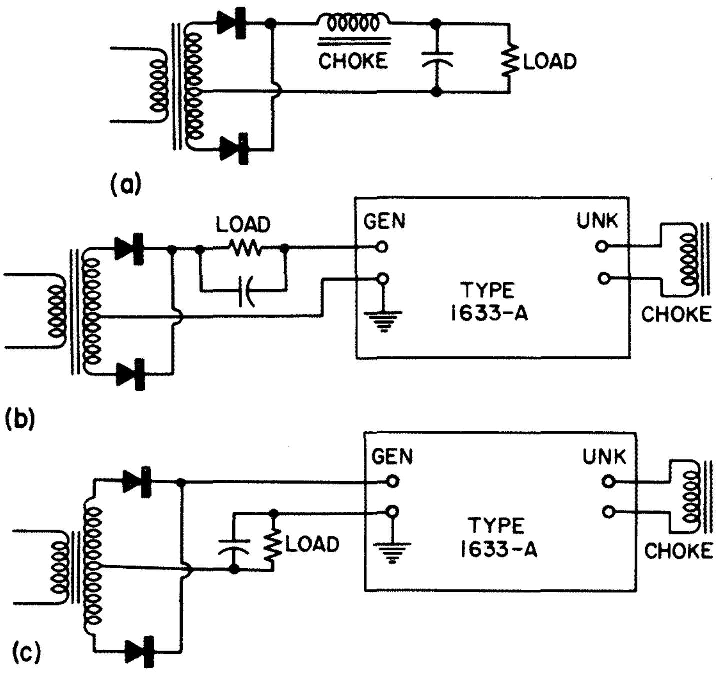


Figure 5-3. a, b, and c. A typical power supply circuit (a) and two possible methods for measurement of the filter choke (b and c).

5.6 REMOTE MEASUREMENTS.

A shielded cable can be used to connect the unknown inductor to the bridge terminals if the inductance and resistance of the leads are taken into account (see Figure 5-4). To measure this impedance, short-circuit the leads at the remote end, X. The lead from the lower UNKNOWN terminal can be shielded, but its capacitance to ground (C_b) can cause an error, as discussed in paragraph 2.4.3.8. The connecting leads should be capable of carrying the required current and they should be insulated for the required voltage.

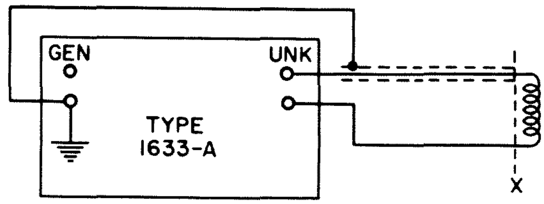


Figure 5-4. Use of a shielded cable to connect the unknown to the bridge.

5.7 MEASUREMENT OF MUTUAL INDUCTANCE.

The bridge can be used to measure the mutual inductance between two coils if the internal lead connecting terminal 11 (Figure 5-5) to the high UNKNOWN terminal is removed from the latter and is connected as shown in Figure 5-5. The equivalent circuit of the mutual inductance under test and the connections are shown in Figure 5-6.

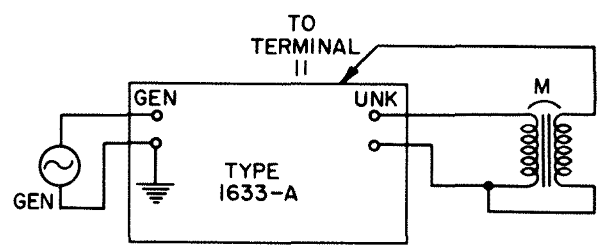


Figure 5-5. Connections for measurement of mutual inductance.

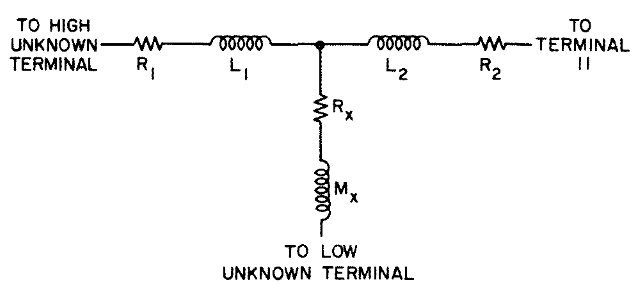


Figure 5-6. Equivalent circuit of mutual inductance.

The Type 1633-A Bridge measures the equivalent series mutual inductance (M_x) and resistance (R_x) or Q. These are usually converted to parallel components (see chart inside rear cover).

Under some conditions, the leakage inductance, L_2, and resistance, R_2, can cause a small error. The corrections are as follows:

$$M_x = L_o \left(1 + \frac{R_2}{R_k}\right) + L_2 \left(\frac{R_o + R_b}{R_k}\right)$$

$$R_x = R_o + R_2 \left(\frac{R_o + R_b}{R_k}\right) - \omega^2 \left(\frac{L_o L_2}{R_k}\right)$$

where L_o = inductance indicated by the L control
R_o = resistance indicated by the R control
R_k = an equivalent resistor in the bridge whose value depends upon the setting of the RANGE SELECTOR switch.

The value of R_k for each range is given in the following table:

RANGE	R_k
a	10 kilohms
b	100 kilohms
c	1 megohm
d	1 megohm
e	1 megohm
f	1 megohm

With high-Q coils, this error is usually negligible.

5.8 LIMIT TESTING.

The bridge can be set up to provide a "go no-go" indication that is very useful for component testing. With the panel meter used as the indicator, the procedure is as follows:

a. Connect one of the components to be measured (preferably one within limits) to the UNKNOWN terminals and balance the bridge.

b. Offset the L (or R) dial by the desired tolerance if the latter is symmetrical, or by half the allowable spread if the tolerance is unsymmetrical.

c. Adjust the SENSITIVITY control for a five-division meter deflection.

d. Set the L (or R) dial to the center value (the nominal value, if the tolerance is symmetrical).

e. The meter deflection will now be less than five divisions as each unknown component is connected to the bridge, if the component is within limits.

If the above method is used when the unknown has a tolerance greater than ±10%, the limits can be in error by more than 1%. To eliminate this error, set the L (or R) dial so that unknown components at both limits give the same meter deflection.

5.9 USE AT OTHER FREQUENCIES.

The bridge can be made direct reading in Q and its internal null detector can be tuned to any frequency between 20 cps and 20 kc if the values of five resistors are changed as follows:

One of the internal bridge standards, R_{18} to R_{24}, must be replaced by a new standard resistor whose value can be calculated from the data in Table 3. Mount the new resistor between the first and second sections of the FREQUENCY switch in place of the resistor supplied with the bridge. Its tolerance should be consistent with the required Q accuracy. The new frequency must be in the same range as the frequency for which the resistors are replaced (see Table 3).

Four resistors are used to determine the detector frequency. They are located inside the shield can, on the rear of the FREQUENCY switch. The nominal value of these resistors can be calculated from the following relation:

TABLE 3

FORMULAS FOR THE CALCULATION OF THE VALUE OF THE INTERNAL BRIDGE STANDARD.

DESIRED FREQUENCY	USE SWITCH POSITION	STANDARD RESISTANCE REQUIRED (OHMS)
20 - 200 cps	50, 60, 100, 120 c	$1353 \left(\frac{100}{f_{cps}}\right)$
200 - 2000 cps	400 c, 800 c, 1 kc	$1353 \left(\frac{1\ kc}{f_{kc}}\right)$
2 - 20 kc	10 kc, 15.75 kc	$1353 \left(\frac{10\ kc}{f_{kc}}\right)$

$$R = 7960\left(\frac{1\ \text{kc}}{f\ \text{kc}}\right)\ \text{ohms.}$$

To give a somewhat flatter response, resistors R453 to R469 are approximately 1% lower than the nominal values and resistors R435 to R451 are approximately 1% higher. The components should have a tolerance of ±1%.

5.10 DISPLAYING AC HYSTERESIS LOOPS.

The ac hysteresis loop of an iron core can be displayed by means of a resistor, a capacitor, and a differential oscilloscope while the inductance of the coil is being measured on the bridge. The connections are shown in Figure 5-7. The impedance of the resistor should be high compared with that of the unknown; the impedance of the capacitor should be comparable to that of the unknown at the frequency of measurement. If a secondary winding is available on the coil under test, the voltage across the secondary should be used (dotted lines in the figure) instead of the voltage across the UNKNOWN terminals.

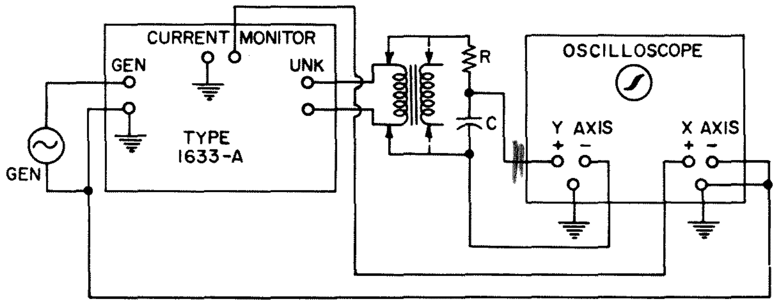


Figure 5-7. Method of displaying an ac hysteresis loop on an oscilloscope.

SECTION **6**

SERVICE AND MAINTENANCE

6.1 GENERAL.

The two-year warranty given with every General Radio instrument attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible.

When difficulties cannot be eliminated by the use of these service instructions, please write or phone our Service Department, giving full information of the trouble and of steps taken to remedy it. Be sure to mention the serial and type numbers of the instrument.

Before returning an instrument to General Radio for service, please write to our Service Department at West Concord or nearest district office (see back cover), requesting a Returned Material Tag. Use of this tag will ensure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid unnecessary delay.

If troubles other than those covered in paragraph 2.4 are encountered, the following suggestions may be helpful.

6.2 NOISY OR ERRATIC BALANCES.

When the Type 1633-A Incremental Inductance Bridge has been idle for an extended period, surface contamination of the wire-wound L or R-Q potentiometer may cause erratic behavior of the null indicator. To remedy this situation, rotate the controls back and forth several times.

6.3 BRIDGE ERROR AT LOW FREQUENCIES.

To locate a defective component, first determine which particular range or ranges are affected. The standards involved in each range are listed in Table 4.

6.4 BRIDGE WILL NOT BALANCE.

If no balance can be obtained, one or more of the internal amplifiers may not be functioning. A check of the following points should help to locate the difficulty. All voltages are dc, with reference to ground.

a. Power Supply. Voltage at terminal 43 (Figure 6-1) approx +30 volts.

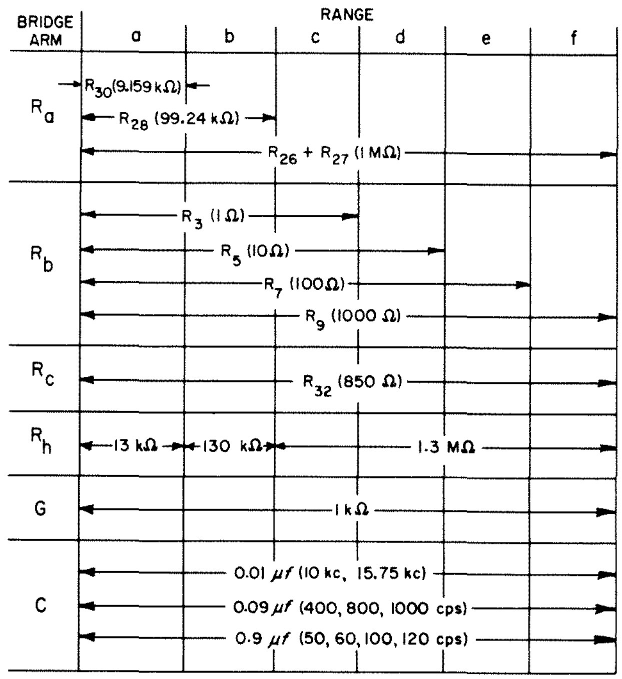
(1) No voltage —— check fuses.

(2) Voltage too high —— check regulator transistor Q501 or Q502, located behind rear panel.

b. Isolating Amplifiers. Voltage at terminal 70 (Figure 6-1) approx +18 volts on each amplifier board.

TABLE 4

BRIDGE STANDARDS IN USE FOR EACH SETTING OF THE RANGE SELECTOR SWITCH.



c. Operational Amplifier. Voltage at the case of capacitor C307 (Figure 6-1) approx +12 volts.

d. Detector.

(1) Test voltages (Figure 6-2):

At terminal 66 -- approximately +6 volts.

At terminal 68 -- approximately +22 volts.

(2) Noisy Detector:

The detector noise should be less than one meter division at 1 kc with the SENSITIVITY control fully clockwise. Excessive noise may be caused by transistor Q201 or Q301 (Figure 6-1), or Q400. These are located in sockets on the various amplifier circuit boards. To change Q400, take off the dress panel by removing panel knobs and screws. Transistor Q400 is located under the shield on which the SENSITIVITY control is mounted.

6.5 CALIBRATION PROCEDURE.

6.5.1 GENERAL. The calibration of the bridge depends primarily on passive standards and is not affected by changes in transistors or in operating conditions normally encountered in a laboratory. If, however, it is necessary to check or adjust the calibration, the procedure noted in the following paragraphs should be used.

6.5.2 STANDARDS. The following standards are required to check the calibrations of the bridge.

Resistors:

one, each of the following values: 1, 10, 50, 100, 160, 200, 500, 700, 1000, 10,000 and 100,000 ohms. The General Radio Type 1432-X Decade Resistor is recommended.

1/2-watt, composition-carbon resistors, of the following values, ±5%: 11, 56, 110, and 1100 ohms.

Air-core Inductors:

1 mh, GR Type 1432-E
5 mh, GR Type 1482-G
10 mh, GR Type 1482-H
20 mh, GR Type 1482-J
50 mh, GR Type 1482-K
100 mh, GR Type 1482-L

6.5.3 R-RANGE MULTIPLIERS. To check the bridge arms, measure the following standard resistors at 1 kc:

RANGE	STANDARD (OHMS)
a	1
b	10
c	100
d	1000
e	10,000
f	100,000

The General Radio Type 1432-X Decade Resistor is suitable. The lead resistance should be added to the values of the standards on the low-resistance ranges.

6.5.4 L-RANGE MULTIPLIERS. Measure a 10-mh, air-core inductor (General Radio Type 1482-H) on the following ranges, to check the standard capacitors:

RANGE	FREQUENCY
b	100 cps
c	1 kc
d	10 kc

6.5.5 Q-RANGE RESISTORS. Measure a standard air-core inductor at each engraved frequency, using first the R and then the Q scales. The readings should correspond.

$$Q = \frac{2\pi fL}{R}$$

6.5.6 SCALE CALIBRATIONS. Measure the standards listed below, at 1 kc on the c range, to check the calibration of the R-Q and L potentiometers. To make small changes, remove the dress panel and adjust the screws surrounding the shafts.

R STANDARD	L STANDARD
10 ohms	1 mh
50 ohms	5 mh
100 ohms	10 mh
160 ohms	20 mh
200 ohms	50 mh
500 ohms	100 mh
700 ohms	
1000 ohms	

6.5.7 HIGH-FREQUENCY ADJUSTMENTS. Several adjustments are provided in the bridge to compensate for the effects of stray reactances at high frequencies. Make the following tests at 10 kc, with the R-Q switch in the R position. Use the main controls to balance the bridge.

STANDARD (Composition-carbon resistors)	RANGE	OPERATION
a. Short circuit	b	Note the L dial reading[1].
b. 110 ohms	b	Set C5 so that the L dial reading is the same as in step a, above.
c. 56 ohms	b	Set R209 so that the L dial reading is the same as in a above.
d. 0 ohms	c	Note the L dial reading.
e. 1100 ohms	c	Set C8 so that the L dial reading is the same as in step d, above.
f. 0 ohms	a	Note the L dial reading.
g. 11 ohms	a	Set C10 so that the L dial reading is the same as in step f, above.

[1]*A balance made with the L control may give a slightly negative reading. This can be neglected, or a small inductor can be placed in series with the standard to bring the balance on scale.*

SECTION **7**

TYPE 1630 INDUCTANCE MEASURING ASSEMBLIES

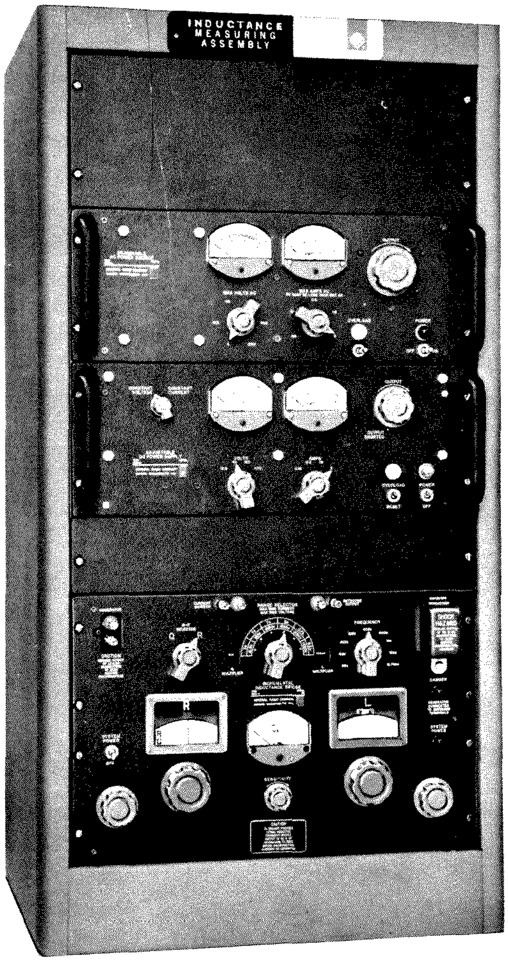


Figure 7-1. Type 1630 Inductance Measuring Assembly.

7.1 GENERAL.

Except where noted, the material in this section applies to both the Type 1630-AL (shown in Figure 1-3) and the Type 1630-AV Inductance Measuring Assemblies (refer to paragraph 1.7). These instructions should be used in conjunction with the Operating Instructions for the individual power sources.

7.2 OPERATING PROCEDURE.

The operating procedures for the Type 1630 Inductance Measuring Assemblies is covered in Section 3. Condensed instructions are included on the inside front cover of this book.

7.3 ALTERNATING CURRENT IN THE DC SUPPLY.

The value of the capacitor in the output of the Type 1265-A Adjustable DC Power Supply is a function of the settings of the range switches and is large enough to carry alternating current up to the amounts shown in Table 5. These figures apply for continuous operation at a room temperature of 70 F. They can be increased 25% for intermittent operation and should be reduced 1% per degree F for operation above 70 F. Note that all the capacitors are capable of carrying an alternating current greater than that indicated by the setting of the AMPS switch; on many ranges the corresponding capacitor can carry considerably more current.

Always use the lowest dc voltage range that gives the desired dc current, to permit the greatest ac current-carrying capacity.

When no direct current is used, the OUTPUT control of the Type 1265-A should be set to the OUTPUT SHORTED position. The instrument can then safely carry an alternating current of 5 amperes on any of the range switch positions.

7.4 MAXIMUM DIRECT CURRENT IN THE AC SUPPLIES.

The maximum value of direct current that can flow through the output of either the Type 1266-A or 1308-A is determined by the flux-density limit of the output and current transformers. The value of this direct current for each range switch setting is given in Table 6. This maximum allowable current is always at least equal to the rating of the MAX AMPS AC switch position and, in many cases, it is much greater. The resulting error in the reading of the ac ammeter is negligible. The output from the dc supply should be increased slowly, as a sudden increase can trigger the overload circuits of the ac supply.

7.5 METER READINGS.

In the Type 1630 Inductance Measuring Assemblies, the power supplies are connected in series. Therefore the current through each generator is equal to the current in the loop (see Figure 1-3). With the Type 1265-A, the dc ammeter is not affected by the alternating current. However, the ac ammeter of the Type 1266-A or 1308-A may be affected by a direct current larger than that indicated by Table 6.

The indication of the ac ammeter is proportional to the average value of the alternating current.

TABLE 5

CAPACITANCE AND CURRENT VS RANGE SWITCH SETTINGS FOR THE TYPE 1265-A ADJUSTABLE DC POWER SUPPLY.

AMPS SWITCH SETTING		VOLTS SWITCH SETTING: 12.5	40	125	400
5	Output Capacitor	8100 µf	8100 µf		
	Maximum Allowable Current 60-Cycle	5.6 amp	5.6 amp		
	Maximum Allowable Current 120-Cycle	7.0	7.0		
	Maximum Allowable Current 400-Cycle and above	9.8	9.8		
1.6	Output Capacitor	8100 µf	3100 µf	1100 µf	
	Maximum Allowable Current 60-Cycle	5.6 amp	3.6 amp	2.2 amp	
	Maximum Allowable Current 120-Cycle	7.0	4.5	3.2	
	Maximum Allowable Current 400-Cycle and above	9.8	6.3	4.5	
0.5	Output Capacitor	3100 µf	1100 µf	320 µf	80 µf
	Maximum Allowable Current 60-Cycle	3.6 amp	2.2 amp	2.2 amp	1.1 amp
	Maximum Allowable Current 120-Cycle	4.5	3.2	3.1	1.5
	Maximum Allowable Current 400-Cycle and above	6.3	4.5	4.4	2.2
0.16	Output Capacitor	1100 µf	320 µf	80 µf	50 µf
	Maximum Allowable Current 60-Cycle	2.2 amp	2.2 amp	1.1 amp	0.75 amp
	Maximum Allowable Current 120-Cycle	3.2	3.1	1.5	1.1
	Maximum Allowable Current 400-Cycle and above	4.5	4.4	2.2	1.5

TABLE 6

MAXIMUM ALLOWABLE DC IN AC SUPPLIES (TYPES 1266-A AND 1308-A).

MAX AMPS AC SETTING	MAX VOLTS AC SETTING: 4	12.5	40	125	400	1250
5	10	10	5			
1.6	10	10	5	1.6		
0.5	5	5	5	1.6	0.5	
0.16	1.6	1.6	1.6	1.6	0.5	0.16
0.05	0.5	0.5	0.5	0.5	0.5	0.16
0.016*	0.16	0.16	0.16	0.16	0.16	0.16

*Type 1308-A only.

TABLE 7

APPROXIMATE INDUCTANCE REQUIRED TO PRODUCE SERIES RESONANCE.

TYPE 1265-A OUTPUT CAPACITOR	FREQUENCY SWITCH SETTING (TYPE 1633-A)								
	50 c	60 c	100 c	120 c	400 c	800 c	1 kc	10 kc	15.75 kc
8100 μf	1.3	870	310	220	20	4.9	3.1	0.031	0.013
3100 μf	3.3	2.3	820	570	51	13	8.2	0.082	0.033
1100 μf	9.2	6.4	2.3	1600	150	36	23	0.23	0.093
320 μf	32	22	8.0	5.5	500	125	80	0.8	0.32
80 μf	130	120	32	22	2.0	500	320	3.2	1.3
50 μf	200	140	51	35	3.2	800	510	5.1	2.0

mh ◄—— ——► μh

Each panel voltmeter indicates the voltage across its own power supply. This voltage differs from that across the Type 1633-A Bridge by the voltage drop in the other supply. The ac voltage drop in the dc supply is usually small; it can easily be calculated from the value of the capacitance, given in Table 5, and the alternating current. This ac voltage drop should be subtracted vectorially from the voltmeter reading, to obtain the true bridge voltage.

The voltage across the unknown differs from the voltage applied to the bridge by the amount of the voltage drop in the current-sampling resistor, R_b (see Figure 3-4). This voltage drop (IR_b) is easily calculated (see Table 1). It should be noted that the bridge voltage is the vector sum of the voltage drops in the unknown inductor and in resistor R_b.

7.6 POSSIBLE RESONANCE OF DC SUPPLY CAPACITOR WITH INDUCTOR UNDER TEST.

It is possible for the output capacitor of the Type 1265-A to resonate with the inductor under test, thus causing considerable increase in the alternating current. In practice, this resonance condition is rarely encountered, particularly if the lowest dc output voltage range that gives the required direct current is used.

Table 7 gives the inductance required for resonance as a function of the frequency and the capacitance. These are approximate values, due to the wide positive tolerances of the capacitors.

When resonance occurs, the voltmeter on the ac supply may read considerably less than the actual voltage on the unknown inductor. An additional voltmeter, connected across the GENERATOR terminals, can be used to measure the actual voltage.

This resonance effect is important only when the Q of the unknown is near or greater than unity. An inductive resistor, whose inductance may be low enough to produce resonance, will, however, have too low a value of Q to produce a noticeable voltage increase.

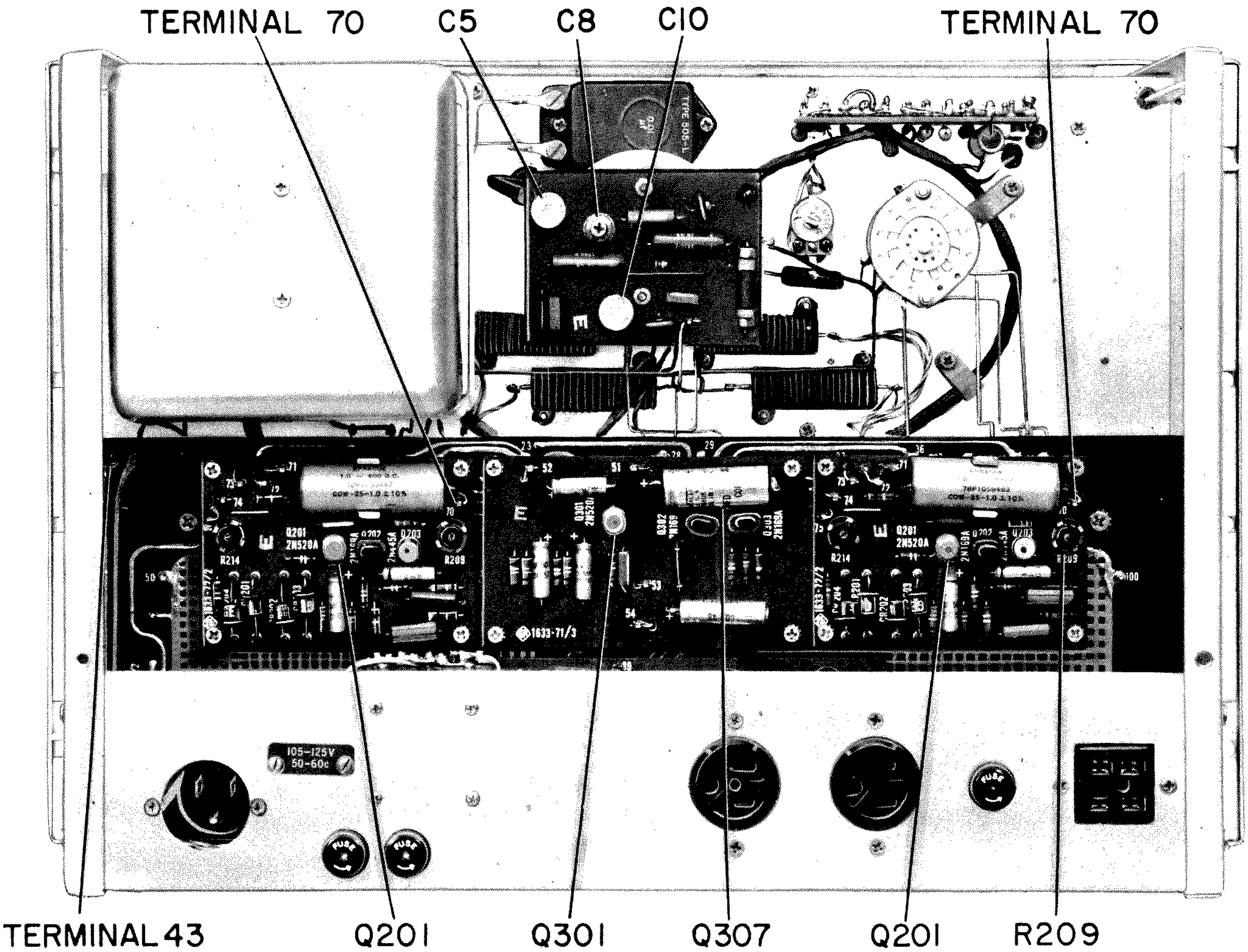


Figure 6-1. Rear interior view.

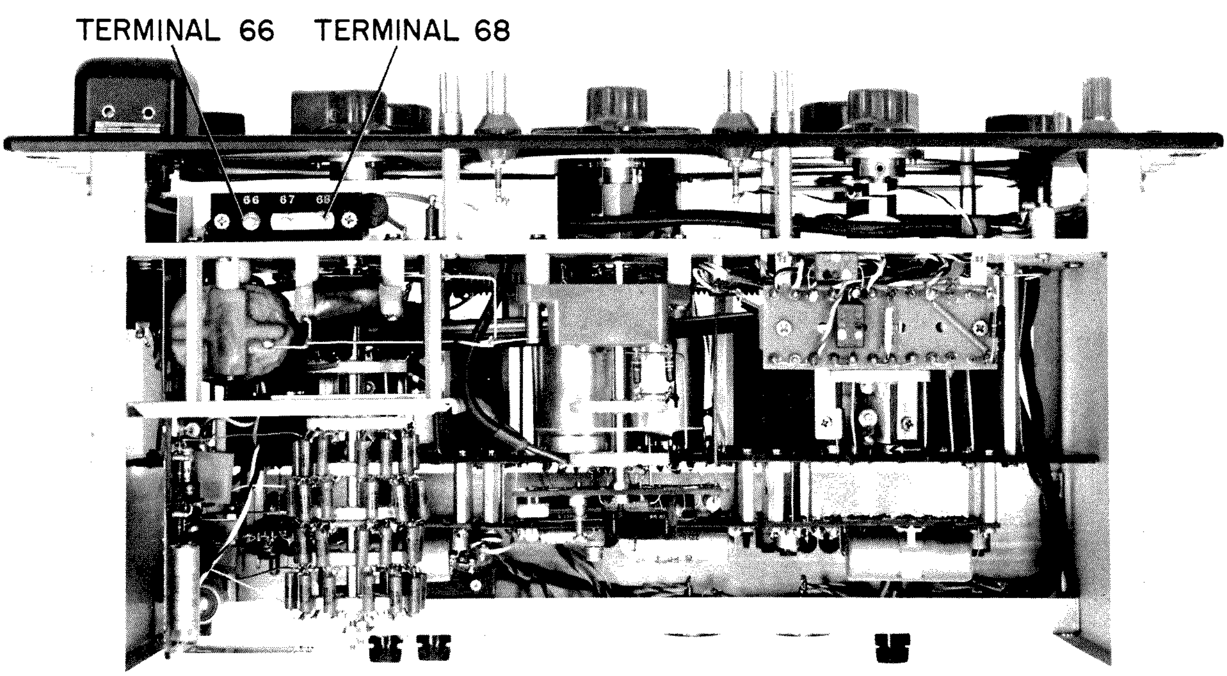


Figure 6.2. Top interior view.

RESISTORS

R201	1k	±5%	1/2w	REC-20BF(102B)
R202	68k	±5%	1/2w	REC-20BF(683B)
R203	68k	±5%	1/2w	REC-20BF(683B)
R204	330k	±5%	1/2w	REC-20BF(334B)
R205	750Ω	±5%	1/2w	REC-20BF(751B)
R206	22k	±5%	1/2w	REC-20BF(223B)
R207	2.2k	±5%	1/2w	REC-20BF(222B)
R209	100Ω	±20%		POSC-22(101D)
R210	1k	±5%	1/2w	REC-20BF(102B)
R211	120k	±5%	1/2w	REC-20BF(124B)
R212	22k	±5%	1/2w	REC-20BF(223B)
R213	2.2k	±5%	1/2w	REC-20BF(222B)
R214	1k	±20%		POSC-22(102D)

CAPACITORS

C201	1μf	±10%	400dcwv	COW-25(105C)
C202	0.001μf	±10%	300dcwv	COM-20B(102C)
C203	220pf	±10%	500dcwv	COM-15B(221C)
C204	5μf		50dcwv	COE-57
C205	0.001μf	±10%	300dcwv	COM-20B(102C)
C206	10μf		25dcwv	COE-56

RECTIFIERS

CR201	2RE-1001
CR202	2RE-1001
CR203	2RE-1001
CR204	2RE-1001

TRANSISTORS

Q201	2N520A, BR
Q202	TR-23/2N520A*
Q203	TR-31/2N445A*

*Selected for H_{fe} between 80 and 125.

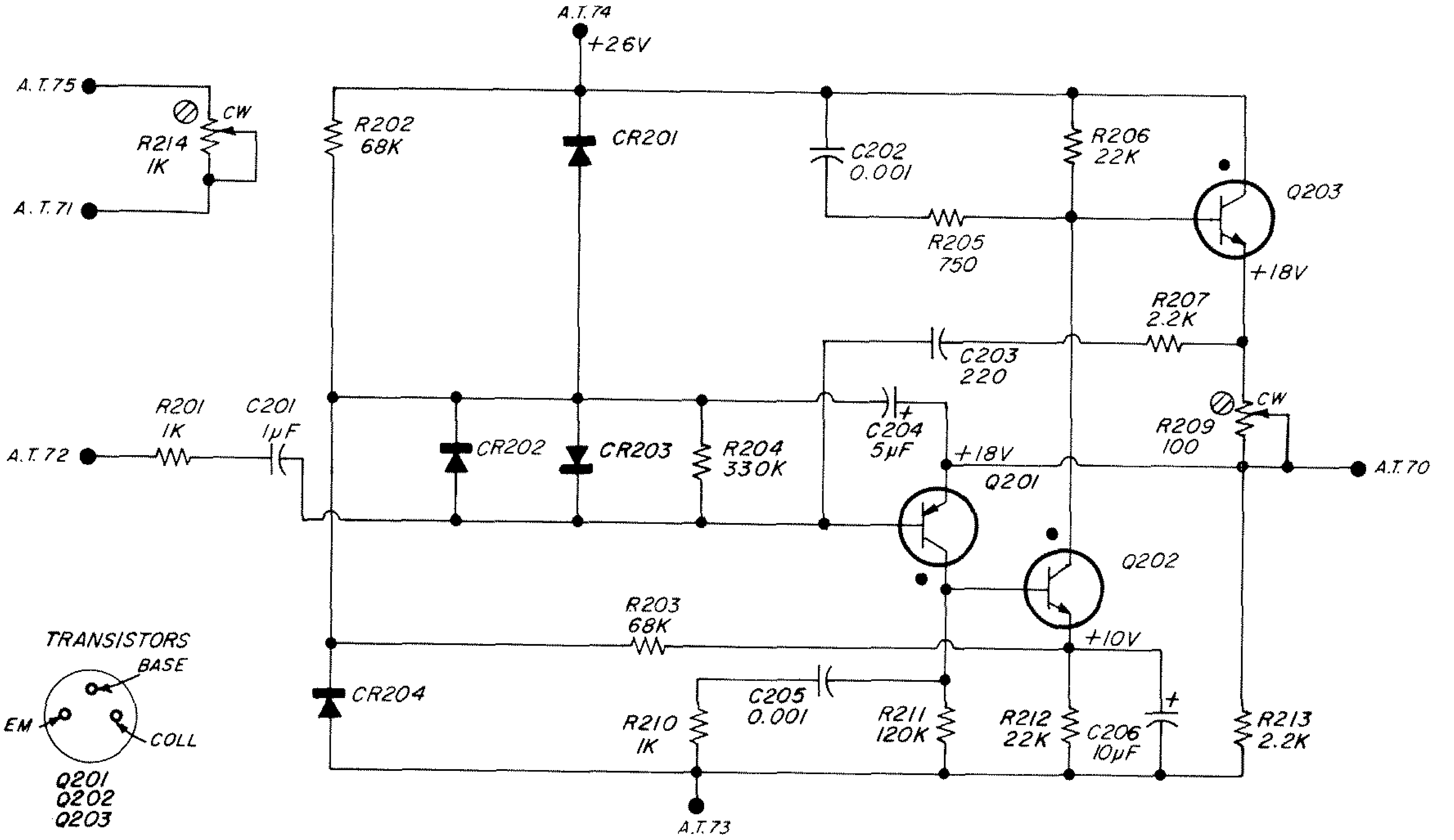


Figure 6-3. Schematic diagram of isolating amplifier.

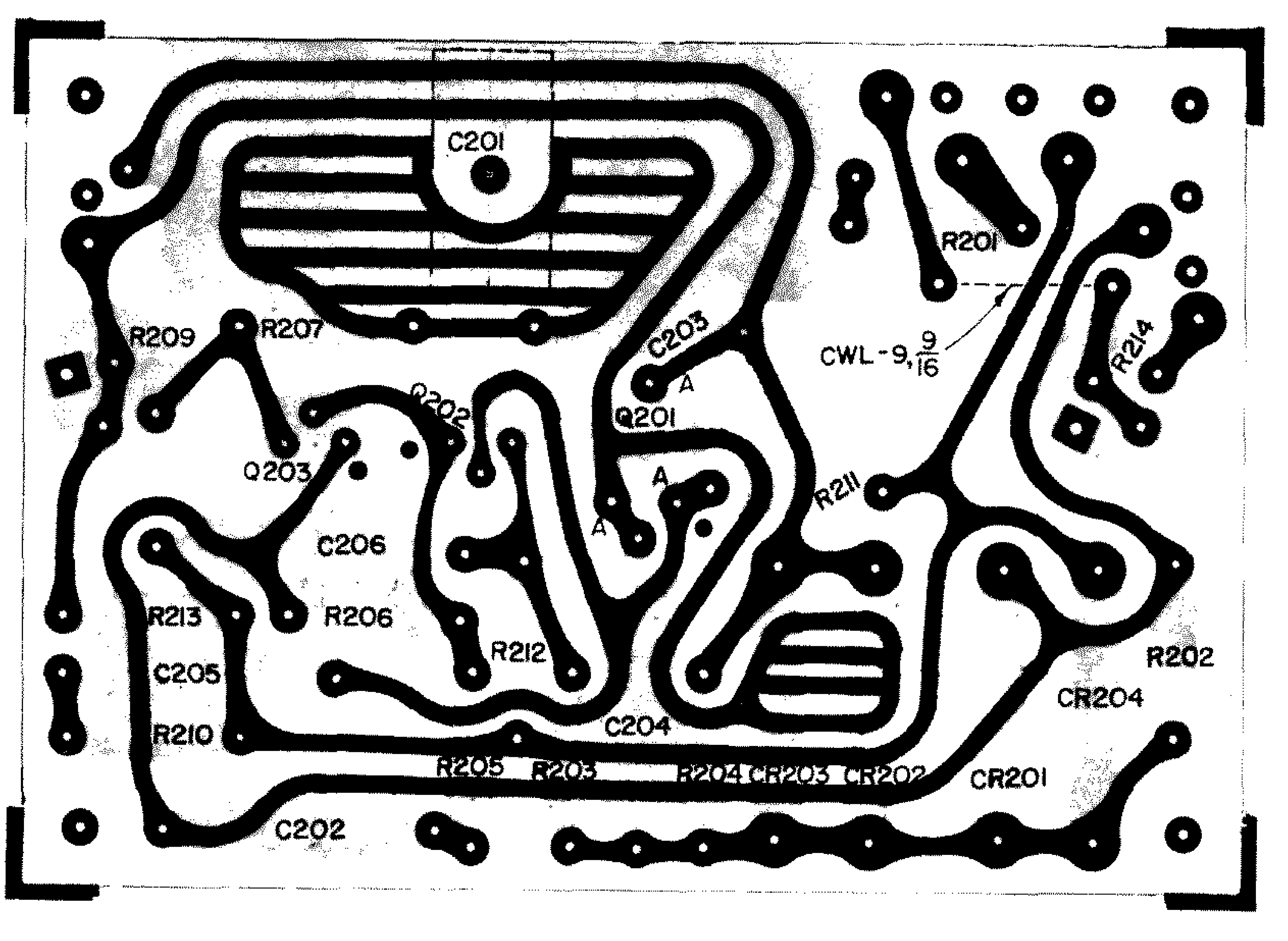


Figure 6-4. Etched board layout of isolating amplifier.

RESISTORS

R301	220k	±5%	1/2w	REC-20BF(224B)
R302	100k	±5%	1/2w	REC-20BF(104B)
R303	100k	±5%	1/2w	REC-20BF(104B)
R304	100k	±5%	1/2w	REC-20BF(104B)
R305	82k	±5%	1/2w	REC-20BF(823B)
R306	68k	±5%	1/2w	REC-20BF(683B)
R307	750Ω	±5%	1/2w	REC-20BF(751B)
R308	1.124k	±0.25%		ZREPR-6S(11240BB)
R309	1.2k	±5%	1/2w	REC-20BF(122B)

CAPACITORS

C301	5μf		50dcwv	COE-57
C302	25μf		50dcwv	COE-48
C303	5μf		50dcwv	COE-57
C304	10μf		25dcwv	COE-56
C306	68pf	±10%	500dcwv	COM-15B(680C)
C307	200μf		12dcwv	COE-6

TRANSISTORS

Q301	TR-23/2N520A*
Q302	TR-21/2N338
Q303	TR-21/2N338

*Selected for H_{fe} between 80 and 125.

RESISTORS

R501	100Ω	±10%	1w	REC-30BF(101C)
R502	1.5k	±5%	1/2w	REC-20BF(152B)
R503	1k	±5%	1/2w	REC-20BF(102B)
R504	1k	±5%	1/2w	REC-20BF(102B)
R505	1k	±20%		POSC-22(102D)

CAPACITORS

C501	50μf	50dcwv	COE-34
C502	50μf	50dcwv	COE-34
C503	10μf	25dcwv	COE-56
C504	60μf	25dcwv	COE-47

RECTIFIERS

CR501	2RE-1001
CR502	2RE-1001
CR503	2REZ-1017

TRANSISTORS

Q501	TR-3/2N176
Q502	TR-4/2N1304

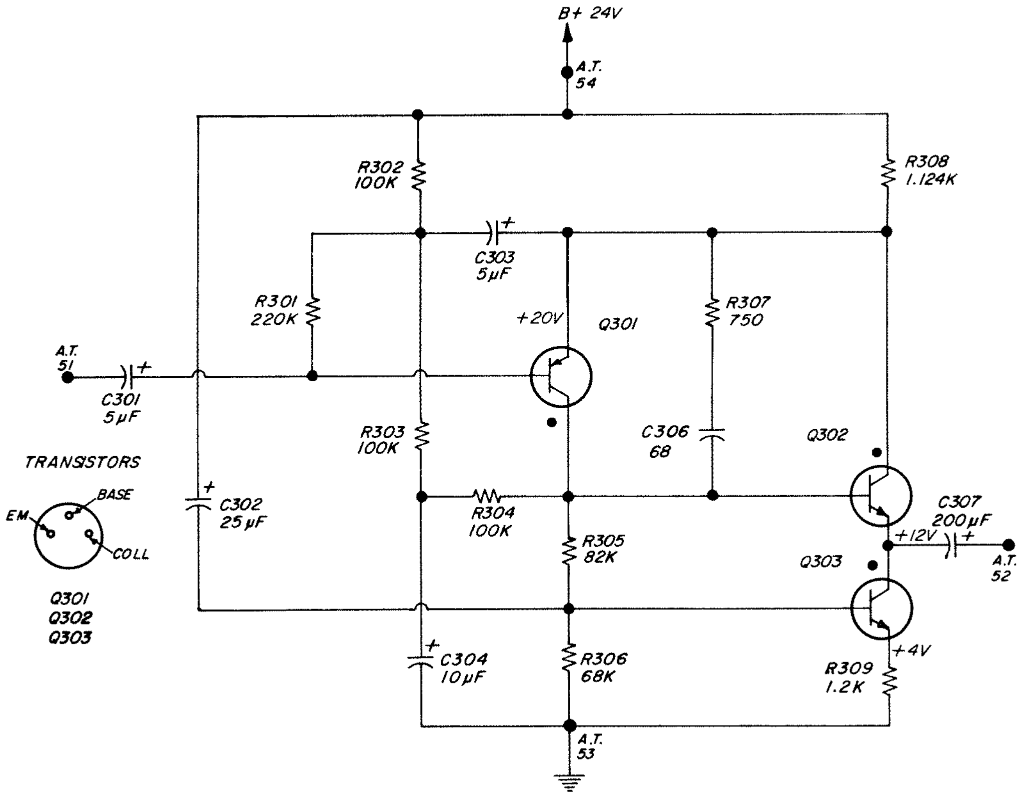


Figure 6-5. Schematic diagram of operational amplifier.

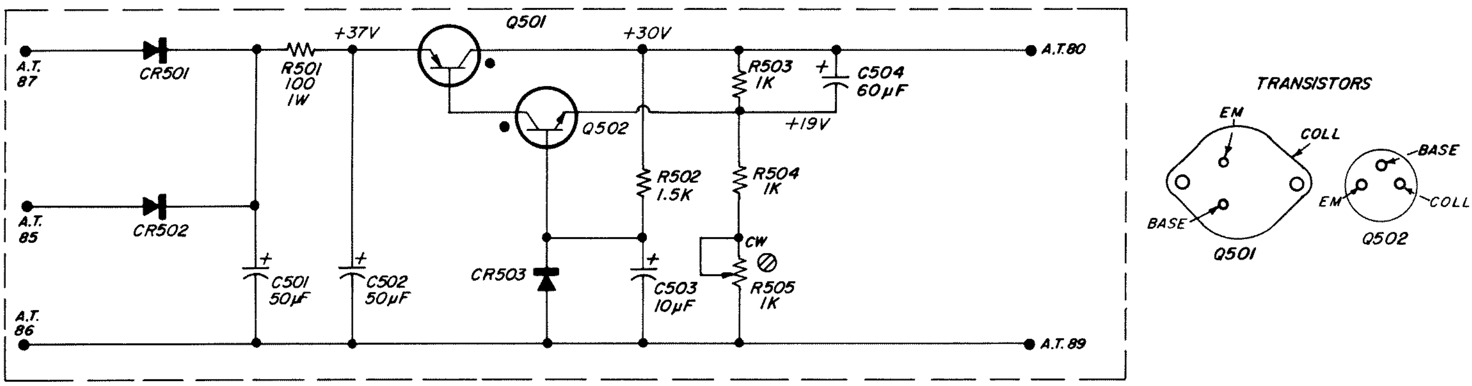


Figure 6-7. Schematic diagram of power supply.

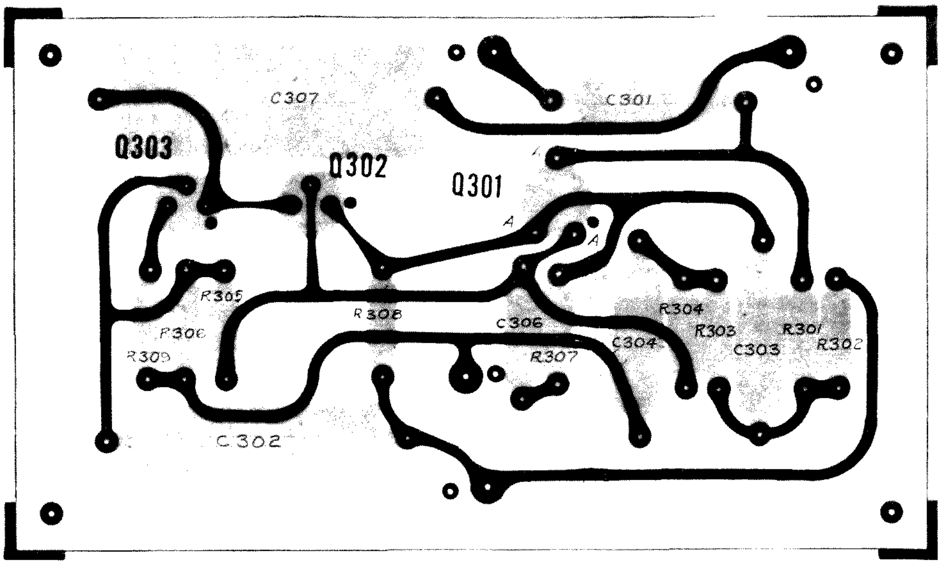


Figure 6-6. Etched board layout of operational amplifier.

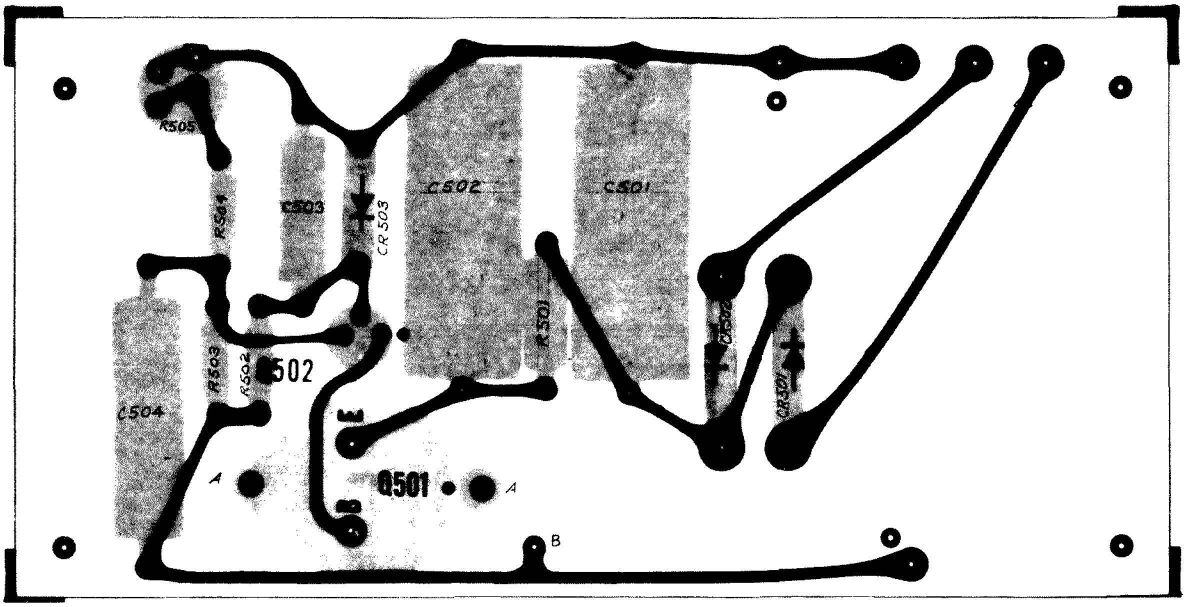


Figure 6-8. Etched board layout of power supply.

RESISTORS

R400	47k	±5%	1/2w	REC-20BF(473B)	R437	137k	±1%	1/4w	REF-65(1373A)
R401	100k	±5%	1/2w	REC-20BF(104B)	R438	137k	±1%	1/4w	REF-65(1373A)
R402	39k	±5%	1/2w	REC-20BF(393B)	R439	81.6k	±1%	1/4w	REF-65(8162A)
R403	47k	±5%	1/2w	REC-20BF(473B)	R440	81.6k	±1%	1/4w	REF-65(8162A)
R404	47k	±5%	1/2w	REC-20BF(473B)	R441	67.3k	±1%	1/4w	REF-65(6732A)
R405	15k	±5%	1/2w	REC-20BF(153B)	R442	67.3k	±1%	1/4w	REF-65(6732A)
R406	100k	±5%	1/2w	REC-20BF(104B)	R443	20.0k	±1%	1/4w	REF-65(203A)
R407	100k			1633-41	R444	20.0k	±1%	1/4w	REF-65(203A)
R408	1M			1663-41	R445	10.1k	±1%	1/4w	REF-65(1012A)
R409	180k	±5%	1/2w	REC-20BF(184B)	R446	10.1k	±1%	1/4w	REF-65(1012A)
R410	47k	±5%	1/2w	REC-20BF(473B)	R447	8.06k	±1%	1/4w	REF-65(8061A)
R411	75k	±5%	1/2w	REC-20BF(753B)	R448	8.06k	±1%	1/4w	REF-65(8061A)
R412	180k	±5%	1/2w	REC-20BF(184B)	R449	806Ω	±1%	1/4w	REF-65(8060A)
R413	150k	±5%	1/2w	REC-20BF(154B)	R450	806Ω	±1%	1/4w	REF-65(8060A)
R414	1.47k	±1%	1/4w	REF-65(1471A)	R451	511Ω	±1%	1/4w	REF-65(5110A)
R415	741Ω	±1%	1/4w	REF-65(7410A)	R452	511Ω	±1%	1/4w	REF-65(5110A)
R416	6.8k	±5%	1/2w	REC-20BF(682B)	R453	160k	±1%	1/4w	REF-65(1603A)
R417	330Ω	±5%	1/2w	REC-20BF(331B)	R454	160k	±1%	1/4w	REF-65(1603A)
R418	12k	±5%	1/2w	REC-20BF(123B)	R455	132k	±1%	1/4w	REF-65(1323A)
R419	30k	±5%	1/2w	REC-20BF(303B)	R456	132k	±1%	1/4w	REF-65(1323A)
R420	150k	±5%	1/2w	REC-20BF(154B)	R457	78.7k	±1%	1/4w	REF-65(7872A)
R421	1.47k	±1%	1/4w	REF-65(1471A)	R458	78.7k	±1%	1/4w	REF-65(7872A)
R422	759Ω	±1%	1/4w	REF-65(7590A)	R459	65.7k	±1%	1/4w	REF-65(6572A)
R423	6.8k	±5%	1/2w	REC-20BF(682B)	R460	65.7k	±1%	1/4w	REF-65(6572A)
R424	330Ω	±5%	1/2w	REC-20BF(331B)	R461	19.6k	±1%	1/4w	REF-65(1962A)
R425	12k	±5%	1/2w	REC-20BF(123B)	R462	19.6k	±1%	1/4w	REF-65(1962A)
R426	10k	±5%	1/2w	REC-20BF(103B)	R463	9.88k	±1%	1/4w	REF-65(9881A)
R427	1k	±5%	1/2w	REC-20BF(102B)	R464	9.88k	±1%	1/4w	REF-65(9881A)
R428	2.4k	±5%	1/2w	REC-20BF(242B)	R465	7.87k	±1%	1/4w	REF-65(7871A)
R429	4.7k	±5%	1/2w	REC-20BF(472B)	R466	7.87k	±1%	1/4w	REF-65(7871A)
R430	150Ω	±5%	1/2w	REC-20BF(151B)	R467	787Ω	±1%	1/4w	REF-65(7870A)
R431	220Ω	±5%	1/2w	REC-20BF(221B)	R468	787Ω	±1%	1/4w	REF-65(7870A)
R432	680Ω	±5%	1/2w	REC-20BF(681B)	R471	4.7k	±5%	1/2w	REC-20BF(472B)
R433	10M	±5%	1/2w	REC-20BF(106B)	R469	499Ω	±1%	1/4w	REF-65(4990A)
R434	10M	±5%	1/2w	REC-20BF(106B)	R470	499Ω	±1%	1/4w	REF-65(4990A)
R435	164k	±1%	1/4w	REF-65(1643A)	R475	10k	±5%	1/2w	REC-20BF(103B)
R436	164k	±1%	1/4w	REF-65(1643A)	R476	10k	±5%	1/2w	REC-20BF(103B)

CAPACITORS

C400	10μf		25dcwv	COE-56
C401	15μf		15dcwv	COE-55
C402	5μf		50dcwv	COE-57
C403	5μf		50dcwv	COE-57
C404	15μf		15dcwv	COE-55
C405	10μf		25dcwv	COE-56
C406	15μf		15dcwv	COE-55
C407	10μf		25dcwv	COE-56
C408	.02μf	±1%	300dcwv	COM-1F(203A)
C409	.001μf	±10%	500dcwv	COM-22B(102C)
C410	10μf		25dcwv	COE-56
C411	10μf		25dcwv	COE-56
C412	.02μf	±1%	300dcwv	COM-1F(203A)
C413	.02μf	±1%	300dcwv	COM-1F(203A)
C414	.001μf	±10%	500dcwv	COM-22B(102C)
C415	10μf		25dcwv	COE-56
C416	.02μf	+1%	300dcwv	COM-1F(203A)
C417	10μf		25dcwv	COE-56
C418	50μf		50dcwv	COE-34
C419	25μf		50dcwv	COE-48
C420	40μf		6dcwv	COE-54

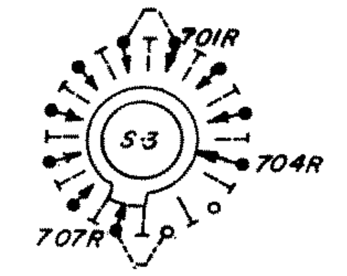
RECTIFIERS

CR401	2RE-1001
CR402	2RE-1001
CR403	2RE-1001
CR404	2RED-1008
CR405	2RED-1008

TRANSISTORS

Q400	TR-23/2N520A*
Q401	TR-21/2N338
Q402	TR-23/2N520A*
Q403	TR-21/2N338
Q404	TR-31/2N445A*
Q405	TR-31/2N445A*
Q406	TR-21/2N338
Q407	TR-31/2N445A*
Q408	TR-31/2N445A*
Q409	TR-23/2N520A*

*Selected for H_{fe} between 80 and 125.



NOTES:

RESISTORS 1/2 WATT UNLESS OTHERWISE SPECIFIED
RESISTANCE IN OHMS UNLESS OTHERWISE SPECIFIED
K=1000 OHMS M=1 MEGOHM
CAPACITANCE VALUES ONE AND OVER IN PICOFARADS,
LESS THAN ONE IN MICROFARADS, UNLESS OTHERWISE SPECIFIED
○ KNOB CONTROL

Figure 6-9. Schematic diagram of preamplifier and main detector.

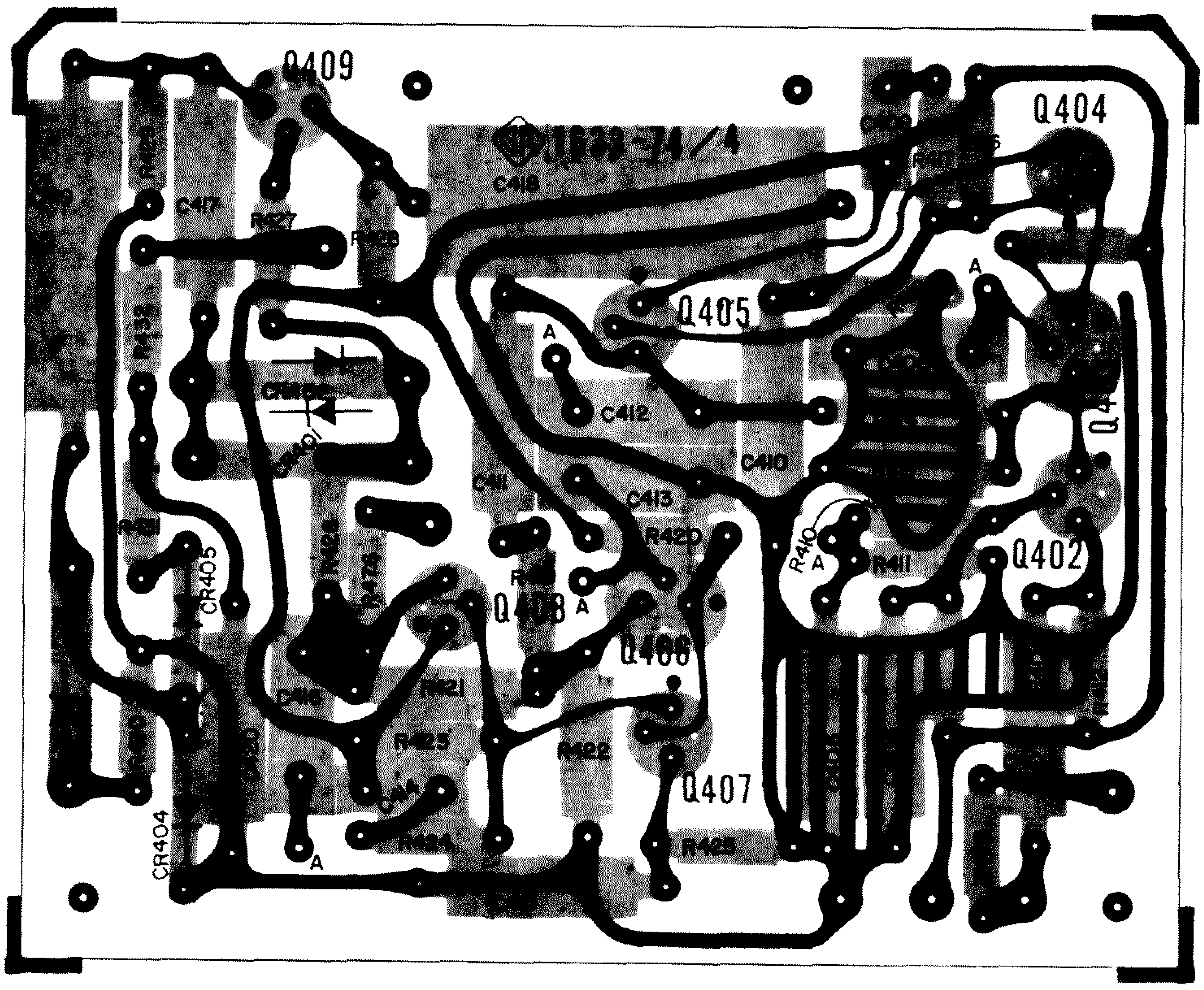


Figure 6-10. Etched board layout of main detector.

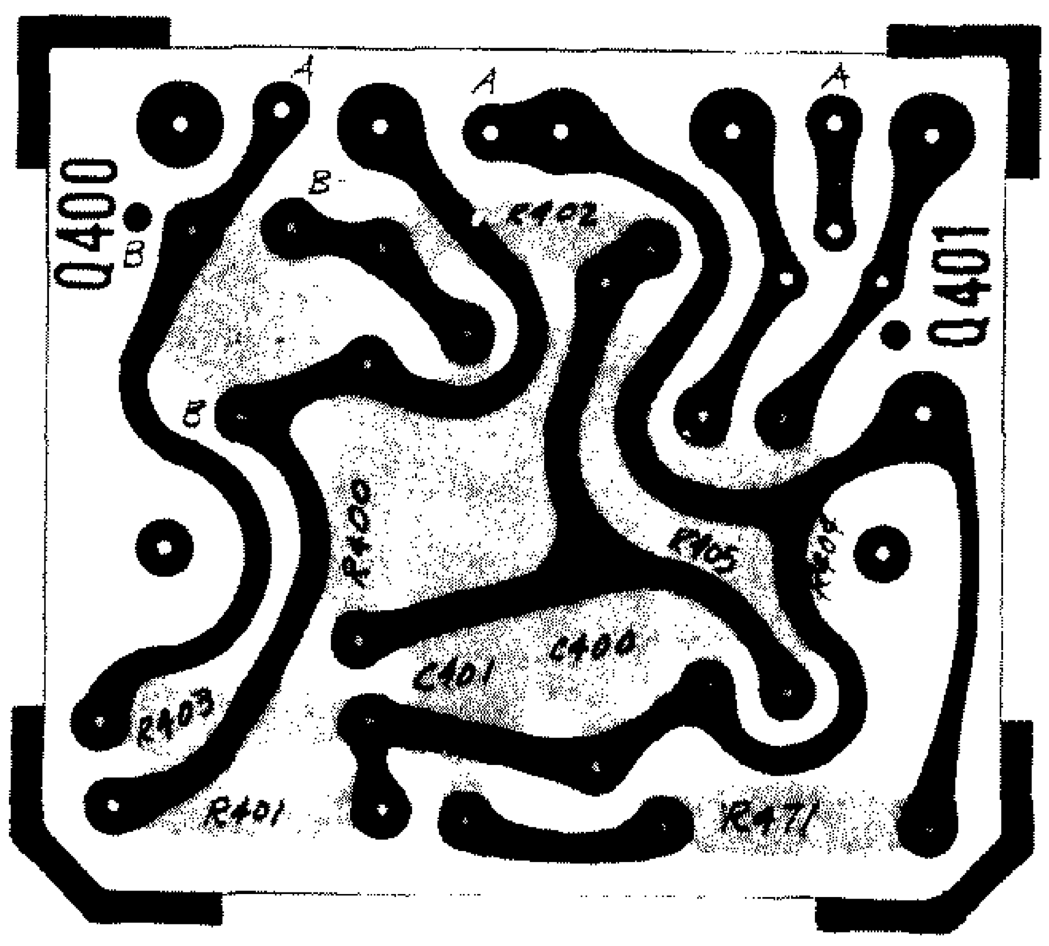


Figure 6-11. Etched board layout of preamplifier.

RESISTORS

R1	100k	±1%	1/2w	REF-70(104A)
R2	91K	±5%	1/2w	REC-20BF(913B)
R3	1k	±0.25%	50w	REPR-50(102BB)
R4	1k	±5%	1/2w	REC-20BF(102B)
R5	100Ω	±0.25%	50w	REPR-50(101BB)
R6	100Ω	±5%	1/2w	REC-20BF(101B)
R7	10Ω	±0.25%	50w	REPR-50(100BB)
R8	10Ω	±5%	1/2w	REC-20BF(100B)
R9	1Ω	±0.25%	50w	REPR-50-2(010BB)
R10	1Ω	±10%	1/2w	REW-3C(010C)
R11	13.09k	±0.25%		ZREPR-7S(13091BB)
R13	130k	±5%	1/2w	REC-20BF(134B)
R15	1.3k	±5%	1/2w	REC-20BF(135B)
R17	1Ω	±10%	55w	REPO-22P(010C)
R18	2.606k	±0.25%		ZREPR-6S(26060BB)
R19	2.255k	±0.25%		ZREPR-6S(22550BB)
R20	1.353k	±0.25%		ZREPR-6S(13530BB)
R21	1.127k	±0.25%		ZREPR-6S(11270BB)
R22	3.382k	±0.25%		ZREPR-6S(33820BB)
R23	1.691k	±0.25%		ZREPR-6S(16910BB)
R24	858.9k	±0.25%		ZREPR-6S(08589BB)
R25	1k	±0.25%		ZREPR-6S(102BB)
R26	500k	±1/4%,100	1w	REF-6-4(504BB) Weston
R27	500k	±1/4%,100	1w	REF-6-4(504BB) Weston
R28	99.24k	±0.25%		REPR-23(99241BB)
R30	9.159k	±0.25%		ZREPR-7S(91590BB)
R32	850Ω	±0.25%		ZREPR-6S(851BB)
R33				REU-13
R34				REU-8-2
R35				REU-8
R36	6.8Ω	±10%	1/2w	REW-3C(068C)
R37	6.8Ω	±10%	1/2w	REW-3C(068C)
R38	20k	±5%	5w	REPO-43(203B)
R39	56Ω	±5%	2w	REC-41BF(560B)
R101	470Ω	±5%	1/2w	REC-20BF(471B)
R102				433-409
R103	1k	±5%	1/2w	REC-20BF(102B)
R104	1k	±5%	1/2w	REC-20BF(102B)
R105	470Ω	±5%	1/2w	REC-20BF(471B)
R106				433-410
R107	1k	±5%	1/2w	REC-20BF(102B)
R108	1.5k	±5%	1/2w	REC-20BF(152B)
R109	1k	±5%	1/2w	REC-20BF(102B)
R110	4.7k	±5%	1/2w	REC-20BF(472B)

RECTIFIERS

CR101	2RE-1001
CR102	2RE-1001

FUSES

115v:

F101	.1 Amp	FUF-1
F102	.1 Amp	FUF-1
F103	10 Amp	FUF-1

230v:

F101	1/16 Amp	FUF-1
F102	1/16 Amp	FUF-1
F103	10 Amp	FUF-1

JACKS

J101	BP-5R	J105	BP-10, 1-5/16
J102	BP-5	J106	BP-10, 11/16
J103	BP-10, 11/16	J107	BP-5R
J104	BP-10, 1-5/16	J108	BP-5R

MISCELLANEOUS

M401	METER	MEDS-126
P101	PILOT LAMP	2LAP-6
P102	PILOT LAMP	2LAP-6
PL101	PLUG	CDPP-10-2-2
SO101	SOCKET	ZCDPR-14
SO102	SOCKET	ZCDPR-14
SO103	SOCKET	CDMS-11-4
S1	SWITCH	SWRW-233
S2	SWITCH	SWRW-234
S3	SWITCH	SWRW-235
S101	SWITCH	SWT-17
S102	SWITCH	1633-42
T501	TRANSFORMER	745-421

CAPACITORS

C1	7-45pf			COT-12
C2*				COM-20B
C3*				COW-17
C3A*				COW-17
C4	0.47µf	±10%	100dcwv	COW-17(474C)
C5	1.5-7pf			COT-29
C6*				COM-22
C7	4.7pf	±10%	500dcwv	COC-1(047C)
C8	Special			
C9	33pf	±10%	500dcwv	COM-22B(330C)
C10	8-50pf			COT-29-4
C11	0.01µf	±0.25%		0505-4412(103BB)
C12	.09µf		50dcwv	ZCOP-8(903)
C13	0.9µf			ZCOP-9-1(904)
C14	.01µf	±20%	500dcwv	COC-62(103)
C15	.022µf	±20%	500dcwv	COC-63(223)
C16	.01µf	±20%	500dcwv	COC-62(103)
C17	560pf	±10%	500dcwv	COM-22B(561C)
C101A	90µf		300dcwv	COE-52
C101B	30µf		300dcwv	COE-52
C101C	30µf		300dcwv	COE-52
C102A	90µf		300dcwv	COE-52
C102B	30µf		300dcwv	COE-52
C102C	30µf		300dcwv	COE-52
C103A	800µf		25dcwv	COE-9
C103B	400µf		25dcwv	COE-9
C103C	400µf		25dcwv	COE-9
C104A	800µf		25dcwv	COE-9
C104B	400µf		25dcwv	COE-9
C104C	400µf		25dcwv	COE-9
C105	30pf	±10%	500dcwv	COM-15B(300C)
C106A	800µf		25dcwv	COE-9
C106B	400µf		25dcwv	COE-9
C106C	400µf		25dcwv	COE-9
C108	30pf	±10%	500dcwv	COM-15B(300C)
C109A	800µf		25dcwv	COE-9
C109B	400µf		25dcwv	COE-9
C109C	400µf		25dcwv	COE-9

*Adjustable at calibration.

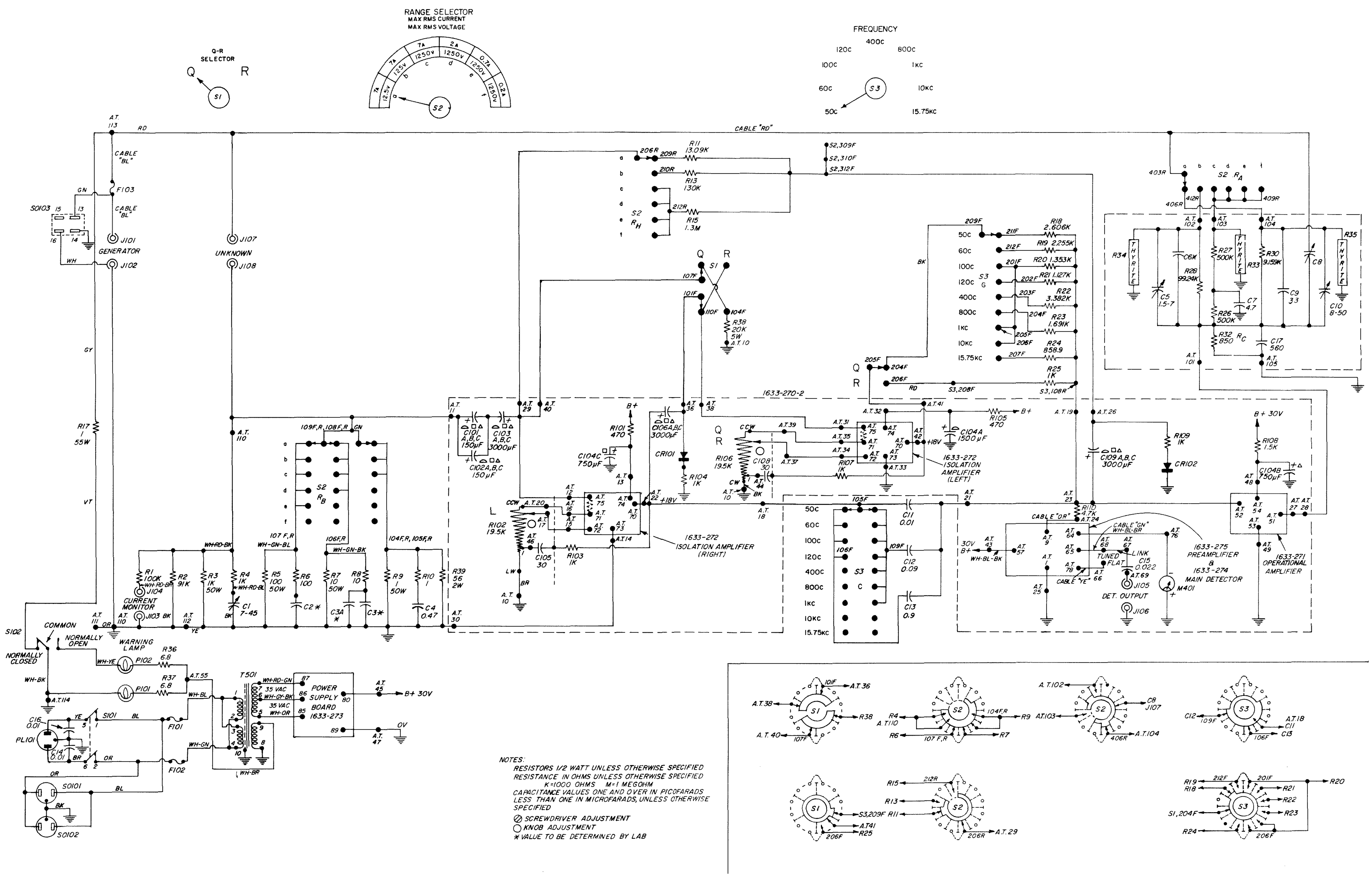


Figure 6-12. Schematic diagram of Type 1633-A Incremental Inductance Bridge.

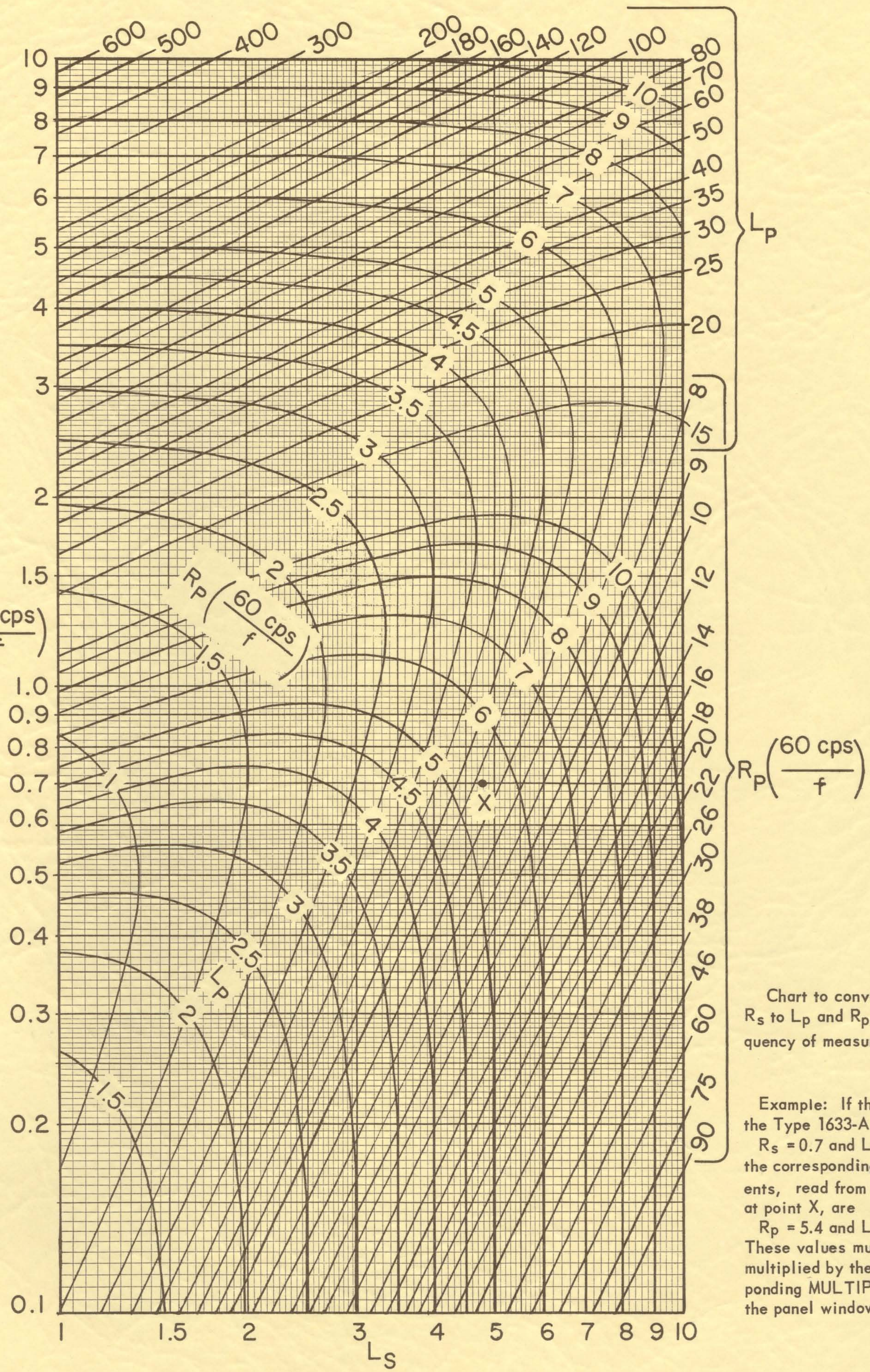


Chart to convert L_S and R_S to L_P and R_P. f = frequency of measurements.

Example: If the dials of the Type 1633-A indicate
$R_S = 0.7$ and $L_S = 4.8$
the corresponding components, read from the chart at point X, are
$R_P = 5.4$ and $L_P = 5.5$
These values must be multiplied by the corresponding MULTIPLIER in the panel window.

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