General Radio

INSTRUCTION MANUAL

Type 1666 Dc Resistance Bridge

Contents

Type 1666 Dc Resistance Bridge

Concord, Massachusetts, U.S.A. 01742

Form 1666-0100A
July 1973
ID-0100

Warranty

We warrant that this product is free from defects in material and workmanship and, properly used, will perform in full accordance with applicable specifications. If, within a period of ten years after original shipment, it is found, after examination by us or our authorized representative, not to meet this standard, it will be repaired or, at our option, replaced as follows:

- No charge for parts, labor or transportation during the first three months after original shipment;
- No charge for parts or labor during the fourth through the twelfth month after original shipment for a product returned to a GR service facility;
- No charge for parts during the second year after original shipment for a product returned to a GR service facility;
- During the third through the tenth year after original shipment, and as long thereafter as parts are available, we will maintain our repair capability and it will be available at our then prevailing schedule of charges for a product returned to a GR service facility.

This warranty shall not apply to any product or part thereof which has been subject to accident, negligence, alteration, abuse or misuse; nor to any parts or components that have given normal service. This warranty is expressly in lieu of and excludes all other warranties expressed or implied, including the warranties of merchantability and fitness for a particular purpose, and all other obligations or liabilities on our part, including liability for consequential damages resulting from product failure or other causes. No person, firm or corporation is authorized to assume for us any other liability in connection with the sale of any product.

Specifications

Bridge Circuits: Kelvin and guarded Wheatstone in both resistance and conductance configurations.

Ranges: TOTAL MEASUREMENT RANGE, 1 μΩ to 1 TΩ. Resistance ranges, 1 μΩ to 1.1 MΩ in 7 ranges (1 μΩ is one count), conductance ranges, 1 p℧ to 1.1 ℧ in 7 ranges (1 p℧ is one count). RECOMMENDED RANGES; Wheatstone, 100 Ω to 1 TΩ; Kelvin, 1 μΩ to 10 kΩ.

Resolution: Six digits or 1,111,110 counts.

Accuracy (limit of error): DIRECT READING, ±(0.01% + 10 ppm of full scale). For low-value readings, when first and second digits are zero, ± (0.1% + 3 ppm of full scale). These limits apply from 20 to 25°C at < 75% RH, within 6 months of calibration. Error remains less than ±0.1% from 0 to 25°C at 95% RH and from 0 to 35° C at 85% RH. LONG TERM ACCURACY: Add 0.01% per year, if not recalibrated. COMPARISON ACCURACY: ±[2 + 0.001x(ppm difference)] ppm of full scale (decade values to 2 ppm where sensitivity is adequate and difference is small).

Sensitivity (with internal source): RESISTANCE: 2 μΩ at very low values; 10 ppm at 1 Ω; 5 ppm at 10 Ω; 1 ppm at 0.1, 1, 10, and 100 kΩ; 5 ppm at 1 MΩ. CONDUCTANCE: 2 p℧ at very low values, 5 ppm at 1 μ℧; 1 ppm at 10 and 100 μ℧, 1 and 10 m℧; 5 ppm at 100 m℧; 10 ppm at 1 ℧. An external source can be used for even better sensitivity.

Sources: INTERNAL: 6 V (set of 4 D cells), 0.01 W max for resistance bridge. EXTERNAL: Up to 30 V dc, 0.5 W max.

Detector: SENSITIVITY: Meter deflection ≈ 5 mm/μV. INPUT RESISTANCE: approx 20 kΩ. SHORT-CIRCUIT NOISE (slow position): Approx 0.1 μV pk-pk. DRIFT: Typically 0.5 μV/h. RESPONSE (slow/normal/fast, respectively): Low-level time constant, 4/2.5/0.7 s; high-level meter reversal, 1/0.5/0.3 s.

Guard (Wheatstone): No error with >5 MΩ to ground, either terminal.

Lead Error (Kelvin): Less than 2 μΩ additional with ≤0.1 Ω in any lead.

Supplied: Set of 4 leads with gold-plated copper alligator clips.

Available: 1440 Standard Resistors, for recalibration.

Power: Battery of 8 D cells (Burgess type 1200 or equivalent), i.e., 4 for internal bridge source and 4 for detector power.

Mechanical: Flip-Tilt case. DIMENSIONS (wxhxd): 15x12x8 in. (381x305x203 mm). WEIGHT: 21 lb (10 kg) net.

Description	Catalog Number
1666 DC Resistance Bridge, portable	**1666-9700**

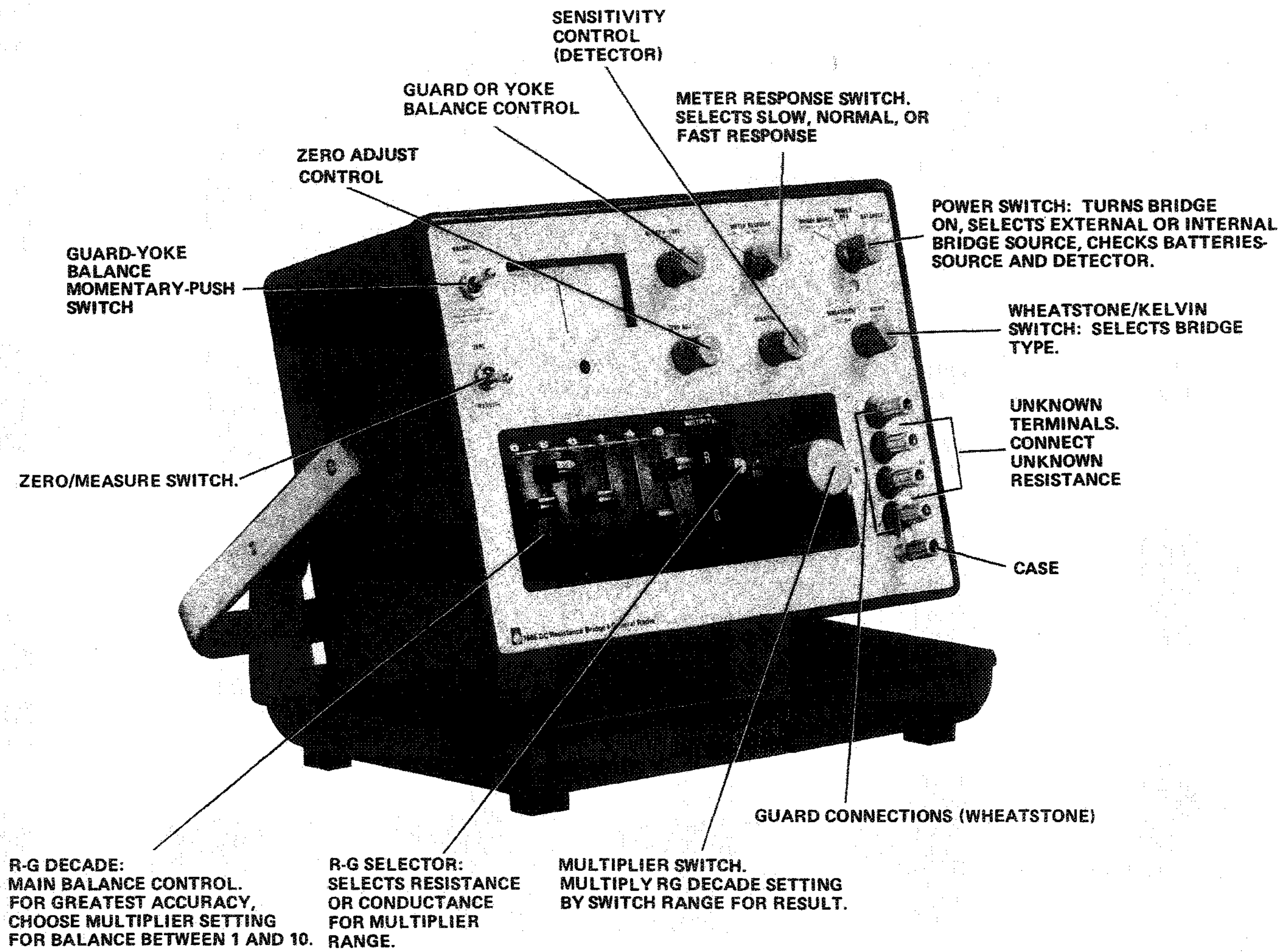


Figure 1-1. Type 1666 Dc Resistance Bridge.

Introduction—Section 1

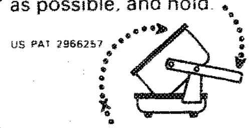
1.1 DESCRIPTION.

The Type 1666 D-c Resistance Bridge (Figure 1-1) is a self-contained resistance measuring system that includes Wheatstone and Kelvin bridges for the measurement of resistance and conductance. Features of this bridge include a basic .01% accuracy, convenient lever switches, visual null indications, complete portability, and a convenient carrying case.

1.2 OPENING AND TILTING THE CABINET.

The directions for opening the Type 1666 D-c Resistance Bridge are given on the panel at the rear of the instrument. Once open, the instrument can be tilted to any convenient angle. The angle should be chosen to give the most comfortable access to the controls and the best view of the meter.

Whether the instrument is open or closed, the cover forms a convenient storage place for the instruction manual and for any other test data that should be kept with the instrument.



1.3 POWER SUPPLY.

The 1666 is powered by 8 D cells: 4 cells are used to power the detector, and 4 are for power to the bridge (source). Tubes containing the batteries are marked to indicate the proper placement for polarity. With the instrument removed from its cabinet, the top tube is for the source; the bottom for the detector.

To install the batteries proceed as follows:

a. Open the instrument cabinet until the instrument and cover are at 90°.

b. Remove the 2 cabinet screws located on the rear of the cabinet.

c. Lift the instrument from its cabinet.

d. To remove either battery tube, push the tube in the direction of the arrow (toward the spring), until the opposite end is clear of the plus (+) terminal, and lift the tube out.

e. Insert 4 batteries in each tube, observing the correct polarity flat (negative) ends of the batteries towards the spring and place the battery tube in its holder.

f. Mount the instrument in its cabinet and install the cabinet screws.

1.4 SYMBOLS, ABBREVIATIONS, DEFINITIONS.

The following symbols, abbreviations, and definitions are used in this instruction manual:

G	conductance, the inverse of resistance; $G = \frac{1}{R} = \frac{I}{E}$
G_X	unknown conductance
R	resistance, the ratio of voltage to current; $R = \frac{E}{I}$ (dc)
R_A	decade resistance
R_B	standard resistor
R_r	ratio arm resistance
R_X	unknown resistance
Ω	ohm, a unit of resistance
kΩ	kilohm, 1 kΩ = 1000 ohms
MΩ	megohm, 1 MΩ = 1×10^6 ohms
mΩ	milliohm, 1 mΩ = 1×10^{-3} ohm
℧	mho, a unit of conductance
⊥ (case symbol)	case
⏚	ground
m℧	millimho, 1 m℧ = 1×10^{-3} mho
μ℧	micromho, 1 μ℧ = 1×10^{-6} mho
n℧	nanomho, 1 n℧ = 1×10^{-9} mho
p℧	picomho, 1 p℧ = 1×10^{-12} mho

1.5 RESISTANCE DECADE READINGS.

The bridge balance contains 6 lever-type decades in series. Each decade has 11 digits (from 0 to 10). An X is used to indicate the 10, to avoid the extra decimal place. All but the very highest of readings can be obtained without using the X position (which is added mainly to facilitate the balancing procedure), so that it need not be used. However, a little practice in interpreting readings containing one or more X's will allow faster balancing, particularly with unknown values containing several zeroes. Some examples:

37123X = 371240
6842X4 = 684304
761XXX = 762110
769X4X = 76X050 = 770050
XXXXXX = 1111110

1.6 CONNECTIONS.

The bridge terminals (A,B,C and D) and the ground terminal are gold-plated copper binding posts that accept banana plugs, standard telephone tips, alligator clips, spade terminals and any wire size up to 11 AWG, as shown in Figure 1-2. Copper binding posts are used to minimize thermally induced voltages when connected to copper wire. The test lead set supplied has copper alligator clips for the same reason. The external source jacks accept standard banana plugs with 3/4-in. spacing.

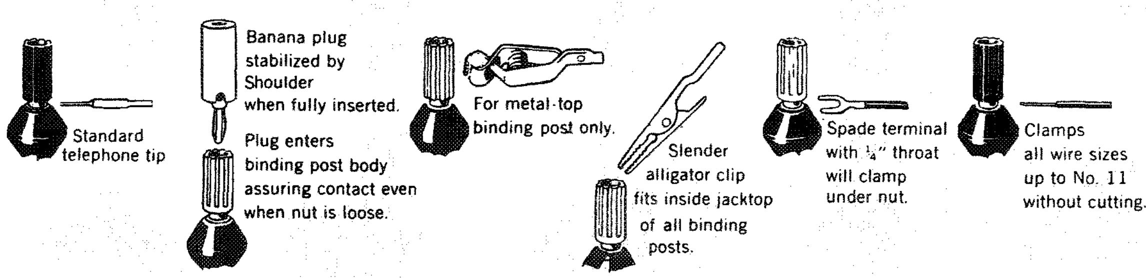


Figure 1-2. Methods of connection to the measurement terminals.

Basic Measurement Procedures—Section 2

2.1 SELECTION OF BRIDGE CIRCUIT

The 1666 Resistance Bridge incorporates 4 bridge circuits to span the range from 1 μΩ to 1 p℧ (1 TΩ) with low error introduction. Resistance or conductance measurements can be made with either the Wheatstone or Kelvin bridge circuits. While both bridges function over the entire range, limits are recommended to preserve accuracy. The bridge type used depends on the approximate value of the unknown. The Wheatstone bridge is not recommended below 100 Ω, since lead resistance can cause significant error introduction below this value. The recommended upper limit for Kelvin bridge use is 10 kΩ, since above this value the exposed leads are susceptible to capacitance transients (refer to para 3.3) and leakage resistance to the case, both of which degrade accuracy.

Measurements using the resistance bridges (either Kelvin or Wheatstone) can be made up to 1.1 MΩ. Above this value, conductance must be measured and the reciprocal of the reading made, to obtain the resistance value. Similarly, measurements using either conductance bridge can be made up to 1.1 mho (down to 0.9 Ω). Above this value, resistance must be measured and conductance obtained from the reciprocal of the reading. Between 0.9 Ω and 1.1 MΩ, either mode and bridge type can be used and readings made directly. Figure 2-1 summarizes the measurement mode and bridge type to be used for a given range i.e., Kelvin-Resistance (KR), Kelvin-Conductance (KG), Wheatstone-Resistance (WR), or Wheatstone-Conductance (WG).

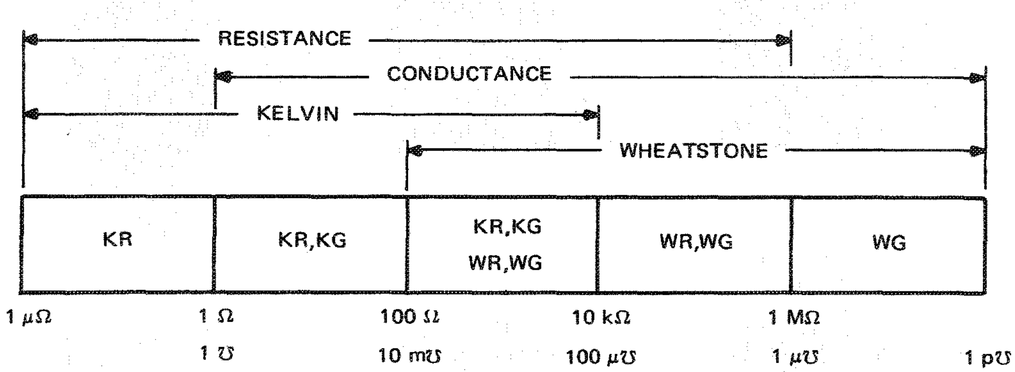


Figure 2-1. Selection of bridge circuit. 1666-2

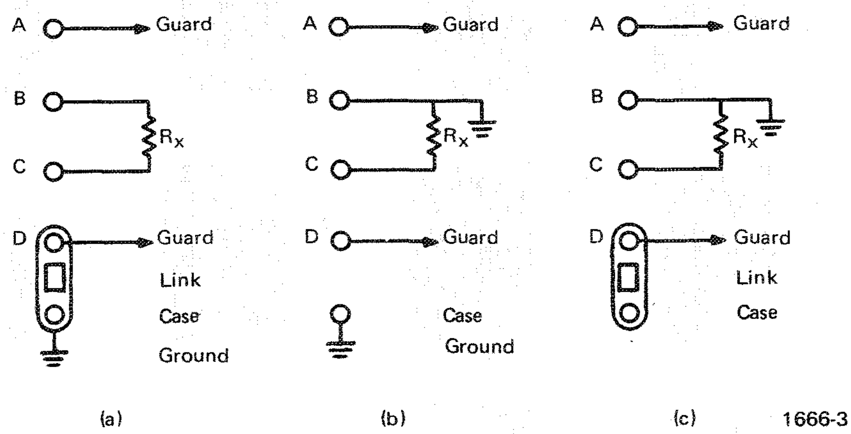


Figure 2-2. Wheatstone bridge connections.

2.2 WHEATSTONE BRIDGE MEASUREMENTS (100Ω – 1.1 MΩ).

2.2.1 Connections

Figure 2-2 illustrates the proper methods for connection of the unknown to the bridge for Wheatstone measurements for 2 and 3-terminals measurements (a), and 2 possible connections when a lead of the unknown must be grounded (b,c).

The unknown resistor is connected between terminals B and C using, either the lead set provided, or other suitable leads, or direct connection to the terminals. Terminals A and D are both guard and should be connected to any guard point required (refer to para 3.6). It is preferable to have the unknown ungrounded and the guard connected to the chassis with the link provided (Figure 2-2a).

The instrument chassis should be well grounded, especially for high-precision comparison measurements or very high resistance measurements, to avoid capacitive pick-up effects. (Refer to para 3.3.).

If one terminal of the unknown must be grounded, connect this terminal to bridge terminal B and either open the link and ground the case (Figure 2-2 b), or connect the link and unground the case (Figure 2-2 c). The former connection results in lower capacitive transients; however, the latter is less affected by leakage resistance errors.

2.2.2 Balance Procedure.

a. Turn the POWER switch to the SOURCE and then the DETECTOR BAT CHECK positions. Observe that the meter reading is in the indicated range in each case (refer to para 1.3 for battery replacement).

b. Turn the POWER switch to INTERNAL BRIDGE SOURCE (refer to para 2.5 for use of external source).

c. Set METER RESPONSE switch to FAST.

d. Set SENSITIVITY control at midrange (dot up).

e. Select for resistance or conductance measurement mode with the R-G switch, located near the RANGE SELECT dial.

f. Set the WHEATSTONE-KELVIN switch to WHEATSTONE.

g. If the approximate value of the unknown is known, turn the RANGE SELECT dial to the appropriate range. If not, set the ZERO-MEASURE switch to MEASURE, and the 2 left most digits (most significant) of the DECADE to XX and rotate the RANGE SELECT dial (clockwise for the R mode, or counterclockwise for G mode), until the meter deflection reverses.

h. Set the ZERO-MEASURE switch to ZERO and turn the ZERO ADJ control to indicate a reading of 0 on the meter.

i. Set the ZERO-MEASURE switch to MEASURE.

j. Adjust the DECADE digit switches, starting from the left, until the meter indicates 0. Fast balances can be made by increasing each decade digit until the meter deflection reverses, then "backing off" 1 digit step. If the meter reads to the left of 0, increase the decade setting; if it is to the right, decrease the setting.

NOTE

Increase SENSITIVITY, if present setting is inadequate for required accuracy.

k. Set ZERO-MEASURE switch to ZERO and re-adjust ZERO ADJ control, if necessary.

l. If step k resulted in a change, return to the MEASURE position and re-adjust the decade digit switches. If no guard connection is used, the resistance or conductance of the unknown is the decade reading multiplied by the RANGE setting.

m. For guarded connections, depress the BALANCE switch and simultaneously adjust the GUARD OR YOKE control for a zero meter reading. At low decade readings a balance may not be possible, but adjustment as far as possible towards balance should be made.

n. Release the BALANCE switch and re-adjust the decade setting. This setting is the 3-terminal resistance of the guarded unknown, unless the shunting resistors are below 5 MΩ (refer to para 4.2.1).

NOTE

For very low readings, greater accuracy is obtained if 1 is added to the least-significant digit, to account for zero resistance of the decade adjustment.

2.3 KELVIN BRIDGE MEASUREMENTS (1μΩ – 10kΩ).

2.3.1 Connections.

The unknown is connected to all 4 bridge terminals as illustrated in Figure 2-3a, using either the lead set provided or other suitable leads. The instrument case terminal should be connected to bridge terminal D with the link provided, and these terminals connected to a good ground.

It should be noted that resistance in a 4-terminal measurement is from the junction of the leads A and B to the junction of leads C and D. Terminals A-D are from top-to-bottom on the instrument. Thus, if the component has two leads (Figure 2-3b) the resistance measured is that between the two inner connections. If the unknown has two binding posts the resistance of the connections may be avoided by making one connection to a wire through the hole and the other to the top of the binding post. The resistance then measured is that between the two lower (hole) connections (Figure 2-3c). If the unknown has four terminals, one lead should be used to connect to each bridge terminal (Figure 2-3 d). In general, connections to A and B are interchangable as are C and D.

2.3.2 Balance Procedure.

a. Perform steps a through e of para 2.2.2.

b. Set the WHEATSTONE-KELVIN switch to KELVIN.

c. Perform steps g through l of para 2.2.2.

d. If the measurement is on the lowest R or highest G ranges, perform steps m and n of para 2.2.2. (See also para 2.2.2 note.)

2.4 PRECISE COMPARISONS.

Because of the resolution and sensitivity of the 1666, highly accurate comparisons between resistors of nearly equal value can be made. The normal balance procedures are performed but additional care should be exercised, especially with the following:

1. The SENSITIVITY control is set fully cw.
2. The METER RESPONSE is set to NORMAL.
3. Balancing, is performed in both the ZERO and MEASURE functions.
4. The YOKE balance should be performed on the lowest Kelvin ranges, and the GUARD balance on the highest Wheatstone range, even if a guard is not used. Short heavy-gauge leads should be used for low resistance and conductance measurements. If the unknown has a very high resistance, the leads should be separated to avoid leakage between them.
5. The comparison should be made with as many possible high-order decade digits at the same settings (from left-to-right), since comparison measurements are independent of the accuracy of the unchanged decade digit settings. Therefore, it is good practice to avoid a setting of 10 (X) in the high-order digits. If for example, the value of one resistor is 1000.025 kΩ, and the other is 999.975 kΩ, it is preferable to make the first balance at 999.X25, so that the next balance changes only the last 3 digits. An error of 0.1% in the fourth highest-order decade results in the same measurement error as a 1 ppm error in the highest-order decade. If this procedure is followed, the error in resistance comparison should be less than 2 ppm + .001 (difference in ppm), assuming adequate sensitivity.

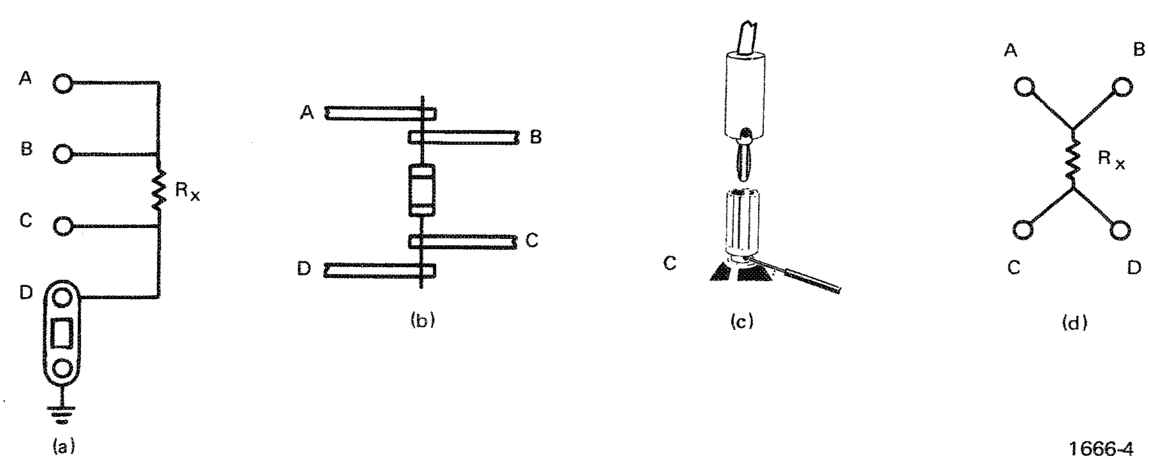


Figure 2-3. Kelvin bridge connections.

2.5 LIMIT TESTING.

The Type 1666 may be set up to provide a go-no-go indication useful for component testing. The panel meter is used as the indicator. Limit testing with the 1666 is useful when the limits are set no greater than 5% from the reference used. The setup procedure is as follows:

a. Balance the bridge using a standard resistor decade unit, or a resistor that is preferably within the desired tolerance.

b. Offset the instrument resistance decade by the desired tolerance if the tolerance is symmetrical, or by half the total allowable spread, if unsymmetrical.

c. Adjust the SENSITIVITY control for a 5-division meter deflection.

d. Set the decade to the center value (the nominal value, if the tolerance is symmetrical).

e. Connect each resistor to be tested to the bridge. If the meter deflection is less than 5 divisions the component is within limits.

When the unknown has a tolerance greater than approximately ±5%, the limits may be in error by more than 1% if the above method is used. A sure method is to set the decade so that the unknown components at both limits give the same extent of deflection.

Measurement Considerations – Section 3

3.1 POWER DISSIPATED IN UNKNOWN RESISTOR

The power dissipated in the unknown is a function of the open-circuit source voltage, the resistance of the source, the value of the unknown, the ratio arms, and the bridge circuit used. The actual power at null is determined by a measurement of the voltage across the unknown, or by the following formulas (which indicate the value at null).

Kelvin R: $$P_x = \frac{(E_b^2)\ (R_x)}{[R_x+R_r+R_g+R_gR_r/50\ \text{k}\Omega]^2}$$

Kelvin G: $$P_x = \frac{(E_b^2)\ (G_x)}{[1+G_x\,(R_r+R_g)\ +\ R_g/50\ \text{k}\Omega]^2}$$

Wheatstone R: $$P_x = \frac{(E_b^2)\ (R_x)}{[R_x+R_r+R_g+R_gR_r/8.33\ \text{k}\Omega]^2}$$

Wheatstone G: $$P_x = \frac{(E_b^2)\ (G_x)}{[1 + G_x(R_r+R_g) + R_g/8.33\ \text{k}\Omega]^2}$$

where:

E_b is the open-circuit source voltage (approximately 6 V internal)

R_x is the unknown resistor

R_r is the ratio-arm resistor

R_g is the bridge-source resistor (internal and external)

Table 3-1

RATIO ARM AND BRIDGE-SOURCE RESISTORS FOR EACH RANGE

Range	Multipliers	R_r	R_g*+
100 mΩ	100 m℧	1 Ω	62 Ω
1 Ω	10 m℧	10 Ω	182 Ω
10 Ω	1 m℧	100 Ω	492 Ω
100 Ω	100 μ℧	1000 Ω	882 Ω
1 kΩ	10 μ℧	10 kΩ	1.062 kΩ
10 kΩ	1 μ℧	100 kΩ	1.062 kΩ
100 kΩ	100 n℧	1 MΩ	1.062 kΩ

+This does not include the internal battery resistance, which increases with age.

*When an external source is used, subtract 62 Ω and add any external series resistance.

The values for R_r and R_g for each range are listed in Table 3-1. Note, when an external source is used, there is no source resistor in the lowest range, and an external resistor should be used to limit the power to 0.5 W (see para 3.1.2).

3.1.1 Internal Source.

The power dissipated by the unknown when the resistance bridges are used is limited by series resistance to less than 0.01 W, to avoid significant errors due to resistor heating. On the G bridge, however, the power dissipated by R_x may exceed .01 W on the lower ranges. The maximum

Table 3-2
POWER DISSIPATED IN UNKNOWN
(For Decade Setting Of 1/10 fs On G Bridge With Internal Source)

Multipliers	G_x	R_x	Power
100 m℧	100 m℧	10 Ω	.068 W
10 m℧	10 m℧	100 Ω	.042 W
1 m℧	1 m℧	1 kΩ	.014 W
100 μ℧	100 μ℧	10 kΩ	.0025 W
10 μ℧	10 μ℧	100 kΩ	290 μW
1 μ℧	1 μ℧	1 MΩ	30 μW
100 n℧	100 n℧	10 MΩ	3 μW

power is about 0.15 W when .016 ℧ (63 ohms) is measured on the lowest range. However, this is a setting below 1/10th full scale on the lowest decade readout and would normally not be used. The power for measurements on the G bridge at 1/10th full scale is given in Table 3-2. Power dissipation decreases at higher settings.

3.1.2 External Source.

The power dissipated in the unknown when an external source is used, can be calculated from the formulas given and from the constants in Table 3-1. Note that when an external source is used the R_g value of Table 3-1 should be reduced by 62 Ω and increased by any external resistance used. It is desirable to limit the applied power to 0.5 W or less.

3.2 THERMAL VOLTAGES.

A closed circuit consisting of conductors of different materials will have a current flowing in it, if the junctions of these conductors are not at the same temperature. This is the Siebeck effect. The voltage produced is approximately proportional to the temperature difference between the junctions and a constant that depends on the materials used. This constant is only a few μV/°C for combinations of various copper alloys, but can be much higher for some combinations of metals.

Because most resistors have leads of some alloy of copper, the 1666 Bridge has solid copper alloy binding posts and the lead set has copper alligator clips and banana pins to keep thermal voltages low. Gold plating is used to avoid corrosion; there is negligible thermal voltage, since the plating is so thin it can have only a small thermal gradient. The main cause for a thermal gradient is a result of body heat when the binding posts are tightened or the alligator clips handled. Also friction in plugging-in the banana pins of the lead set can result in a slight temperature change.

The effect of thermal voltages is greatest when the bridge voltage is low as it is when measuring low-valued resistors on the lowest range. A resistance change of 1 μΩ produces a 0.1 μV change in output voltage. Thus, small thermal voltages can cause appreciable errors. However, in most cases the temperature difference decreases quickly.

Thermal voltages affect the detector indication equally for both the MEASURE and ZERO functions. Therefore, a constant thermal voltage will give no error if the detector is zeroed. However, because the thermal voltage will usually disappear quickly, it is preferable to wait until the detector indicator is steady before making low ohm measurements.

3.3 CAPACITANCE TRANSIENTS.

When measuring high resistance values, currents due to capacitive coupling to exposed leads can cause large meter transients. These currents may be due to a fixed capacitance to a changing voltage or a changing capacitance to a fixed voltage.

These transients can usually be removed by: 1. grounding the bridge case with terminal D connected to the case terminal, 2. grounding the operator, 3. grounding nearby equipment, 4. using short leads.

In extreme cases such as when long leads must be used to connect high impedance resistors, the leads should be shielded, with the shields connected to the grounded bridge case.

3.4 A-C PICKUP.

The detector input filter and the selective a-c amplifier stages greatly attenuate the effect of power-line hum and other a-c pickup. The main effect of pickup is loss of sensitivity. The detector is relatively sensitive to pickup near the modulator frequency, about 750 Hz, or its harmonics. Pickup synchronous to the frequency will cause a constant bridge deflection.

The worst condition is pickup to the "C" terminal when high resistances are measured on the Wheatstone bridge. A 60-Hz voltage of 3 V, coupled to the "C" terminal by 100 pF, will make a .01% measurement of a 1 MΩ resistor difficult, because of the resulting loss of detector sensitivity.

Pickup can be removed by the same precautions used to avoid capacitance transients (See para 3.3.).

3.5 MEASUREMENTS UNDER HUMID CONDITIONS.

High humidity results in an increase in the conductivity of insulators and can even produce electrolytic voltages, if contaminating substances are present. The combination of humidity and high temperatures is particularly troublesome. While the 1666 bridge uses materials and components chosen for good operation at high humidity and uses internal guarding to reduce the effects of leakage currents, at very high humidity and high temperatures, the accuracy of the bridge is reduced, particularly when making high resistance measurements. While the best accuracy can be expected only over a low temperature range at low humidity, a 0.1% accuracy should be possible over the

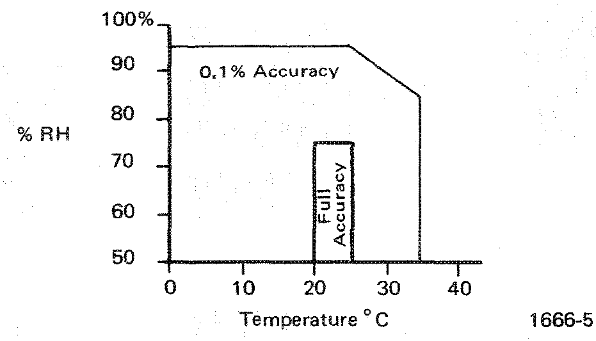


Figure 3-1. Bridge accuracy versus temperature/humidity.

ranges of humidity and temperature illustrated in Figure 3-1, as long as the bridge has not been exposed to excessive contamination.

Excessive humidity-temperature effects usually first appear as an inability to zero the instrument when the detector offset range, approximately ±100 μV, is not adequate to counteract the effects of leakage currents. Generally, if the bridge can be zeroed, the humidity effects are not serious.

Several precautions aid bridge operation at high humidity:

1. Connect the "D" terminal to the case terminal with the link provided.
2. Make sure external leads are not touching each other.
3. Set the first digit of the readout to zero.
4. Heat the bridge case slightly with a radiant lamp, or a contacting source of heat, to quickly reduce the internal relative humidity.

It is important to remember that the unknown resistance itself is subject to humidity effects, and leakage across it can produce what can appear as a bridge error.

3.6 RESISTIVITY MEASUREMENTS.

Resistivity measurements generally fall into 2 categories: measurements on low-resistance conductors and measurements on high-resistance insulators; however, there is also an in-between range of medium-resistivity materials, particularly semi-conductors. These categories require 3- or 4-terminal measurements, while in the middle range simple 2-terminal measurements are adequate. The 1666 bridge performs all of these types of measurements within its ranges and specifications.

The main difficulty with resistivity measurements is the conversion of resistance measurements into resistivity, since the conversion depends on the geometry of the specimen. This procedure has been standardized by the American Society For Testing Materials and a partial list of resistivity standards is given in Table 3-3. Refer to the ASTM Standards Index for a complete list of test configurations and dimensions.

Table 3-3

SOME ASTM RESISTIVITY STANDARDS

Title	Std	Vol.
DC Resistance or Conductance of Insulating Materials	D257	27,28 or 29
Resistivity of Electric Conductor Materials	B193	5,6 or 8
Resistivity of Semi-conductor Materials	F43	8
Resistivity of Silicon Slices with a Collinear Four Probe Array	F84	8
Specific Resistance of Electric Insulating Liquids	D1169	29

3.7 USE OF AN EXTERNAL SUPPLY.

An external supply is useful for increasing sensitivity when high resistance measurements are made. Sensitivity is proportional to the voltage supplied. A maximum of 100 V may be applied to the 1666, but it is desirable to limit the voltage to 30 V for safety reasons; 30 V is adequate for nearly all measurements. The input power should be limited to 0.5 W. Power limiting is most easily accomplished by insertion of a 0.5-W resistor of $0.5E^2$ Ω in series with the external source. Note that, with more power applied to the bridge, resistance changes increase because of power dissipation. For high resistance measurements (greater than 100 kΩ) the main bridge standard (50 kΩ) receives the most power. This is a maximum of 0.2 W, if 100 V is applied, and could result in a 20 ppm change in its value.

Sensitivity can be increased for low resistance measurements by using an external power supply that will provide more current capability than the 0.1 A furnished by the internal supply. The power applied should be limited to 0.5 W.

NOTE

Increased power to the bridge can result in error because of the power dissipation in the ratio arm. A dissipation of 0.5 W could cause an error of .04%.

Theory–Section 4

4.1 GENERAL.

The 1666 contains 4 bridge circuits: a guarded Wheatstone resistance bridge, a guarded Wheatstone conductance bridge, a Kelvin (Thomson) resistance bridge, and a Kelvin (Thomson) conductance bridge. The main circuit elements are common to all bridges, but are switched to the various configurations by the WHEATSTONE-KELVIN and R-G switches. The various bridge circuits are all variations of the Wheatstone Bridge.

4.2 WHEATSTONE BRIDGE.

Figure 4-1 illustrates the basic Wheatstone bridge. For this circuit the output voltage is zero or "at null" if $R_X/R_A = R_r/R_B$ or $R_X = R_A(R_r/R_B)$. In the resistance bridges, R_A is a decade resistor (55.5555 kΩ max.). The resistance of the decade is directly proportional to the value R_X. The value or R_r(the ratio arm) is changed with the range switch in in decade values from 1 Ω to 1 MΩ.

The above equation may also be expressed as $1/R_X = G_X = R_B/R_A R_r$ for conductance measurements. In the conductance bridges, R_B becomes the adjustable decade and the conductance of the unknown is then proportional to R_B and its digital readout.

The Wheatstone bridge has inherent advantages over other resistance measurement methods that have made it useful for over 100 years. Some advantages are:

1. The unknown is compared against precision resistors, which can be accurate and stable.
2. The null condition is independent of applied voltage and the source or detector impedance; these affect only the sensitivity.
3. The null point is independent of detector linearity.

4.2.1 Three-Terminal or "Guarded" Resistors.

When high-valued resistors are measured, the unknown is often part of a 3-terminal network, as shown in Figure 4-2. Here R_X is the value to be measured and R_P and R_Q are shunting resistances to a third (or guard) terminal G. While R_P and R_Q may be actual resistors, more often they are leakage resistances to shields or other circuit points. When measuring the resistivity of high-resistance material, they represent the resistance to the guard electrode (refer to paragraph 3.6.) They can also represent leakage resistance between the unknown terminals of the bridge and the bridge case.

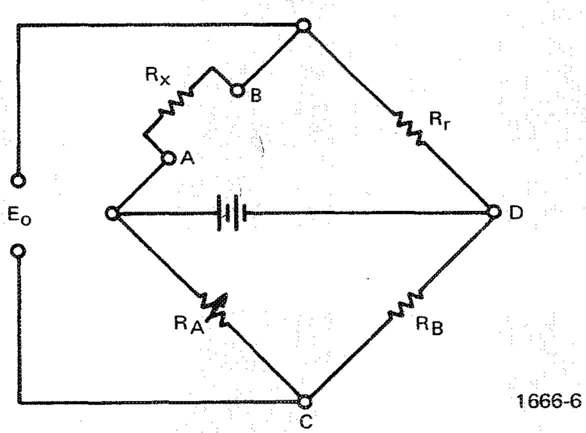


Figure 4-1. Basic Wheatstone bridge.

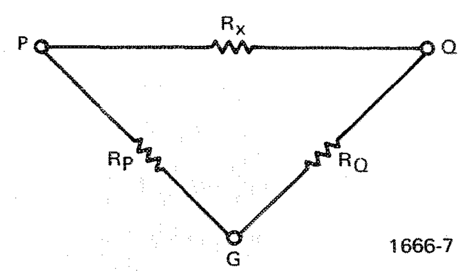
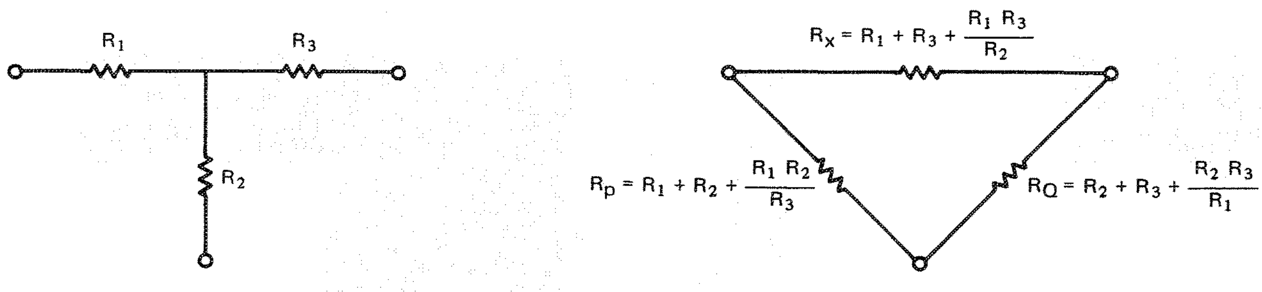


Figure 4-2. Three-terminal network.



(a) **Figure 4-3. Y-△ transformation.** (b) 1666-8

Most high-resistance standards are shielded, with the case as the guard terminal. Some very high-valued standards are actually T-networks, which can be converted to a Δ configuration by the Y-Δ transformation. This is illustrated in Figure 4-3. If R_2 is low, the effective value of R_X can be extremely large.

While the value of R_X in Figure 4-2 may be determined by 3 separate 2-terminal measurements, it is more easily measured if the bridge circuit used is immune from the shunt loading of R_P and R_Q. There may be negligible errors with the conventional Wheatstone bridge if the guard point (Figure 4-2, point G) is tied to the bridge point C or D in Figure 4-1. If this is done, either R_P or R_Q shunts either R_r or R_A. The error is negligible only if the shunted resistor is sufficiently low.

4.2.2 The Guard Circuit.

If 2 bridge arms are added to the basic Wheatstone bridge, and their junction is used as a guard point, 3-terminal measurements can be made with 3-terminal resistors with no error. This addition to the bridge circuit is called a Wagner guard circuit. The bridge configuration is shown in Figure 4-4. The condition for zero error occurs if $R_X/R_r = R_A/R_B = R_a'/R_b$ where R_a' is the parallel combination of R_a and R_p. The amount of error depends on R_Q and the difference between R_A/R_B and R_a'/R_b, i.e.,

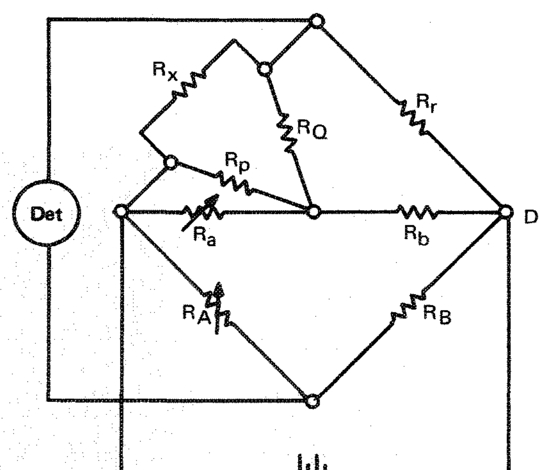
$$\% \text{ error} \simeq \frac{R_r}{R_Q}\left(\frac{R_A}{R_B} - \frac{R'_a}{R_b}\right)\frac{R_b}{R'_a + R_b}$$

In the 1666, R_a and R_A are ganged decades, so that $R_A/R_B \simeq R_a'/R_b$. This balance is not perfect because of bridge resistor tolerances and because of the effect of R_p on R_a'. Therefore, the GUARD-YOKE balance provides a slight adjustment on the R_a'/R_b ratio to make the error negligible.

4.2.3 Four-Terminal Measurements.

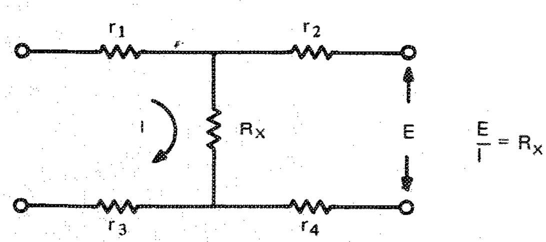
When a low-valued resistor is measured on a 2-terminal bridge, the resistance of the bridge terminals, the leads, and the contacts are added to the unknown measured. It is possible to correct for some of the resulting error by making a second measurement with the leads shorted and subtracting their measured resistance from the measurement of the unknown. However, this technique does not remove errors from differences in contact resistance for the 2 measurements.

In 4-terminal measurements, 4 leads are used to avoid the effect of lead and contact resistance. In the ideal case, this is a transfer-impedance measurement, where current is applied to 2 terminals of a network (Figure 4-5), and the resulting voltage is measured at two other terminals. The transfer of 4-terminal resistance is defined as the open-circuit output voltage divided by the input current. This ratio is R_X in Figure 4-5 and is completely independent of the resistance in each lead. This is the basis for 4-terminal bridges, although they are not quite as simple as this ideal case. In such bridges, the lead impedances have some effect that should be considered, even though it may be small.



1666-9

Figure 4-4. Wheatstone bridge with Wagner guard circuit.



1666-10

Figure 4-5. Illustration of Impedance Transfer.

Low-valued resistance standards generally have 4 terminals, so that any good 4-terminal measurement will give the same value independent of (external or internal) lead or contact resistance.

4.3 THE KELVIN BRIDGE

A 4-terminal resistor can be measured on a Wheatstone bridge having 4 terminals, as shown in Figure 4-6. Resistances r_1 and r_4 introduce no error (but may reduce sensitivity); however, r_2 and r_3 introduce errors of $-r_2/R_A \times 100\%$ and $-r_3/R_r \times 100\%$. This is preferable to the 2-terminal error $(r_2 + r_3)\, R_X \times 100\%$ only if R_r and R_A are $>> R_X$. Generally, the adjustable arm, R_A, is relatively large, so that r_2 causes only a small error. However, the ratio arm, R_r, is generally low-valued, when low resistances are measured, so that the error $r_3/R_r \times 100\%$ may be large.

The r_3 error is caused by having the voltage drop across r_3, e_g, added to the voltage across R_r. If the detector were connected to point B, this drop would add to that of the R_X arm, giving an error of $+r_3/R_X \times 100\%$. If voltage drop e_g could be divided between the R_X and R_r arms in the correct proportion, the error could be zero.

The Kelvin bridge, Figure 4-7, contains an additional pair of bridge arms, R_a and R_b, to divide e_g between the two sides of the bridge. The measured value of resistance is now (approx)

$$R_{meas} = R_X - \frac{r_2 R_r}{R_B} + \frac{r_4 R_b}{R_a + R_b}\left(\frac{R_a + r_3}{R_b} - \frac{R_A}{R_B}\right)$$

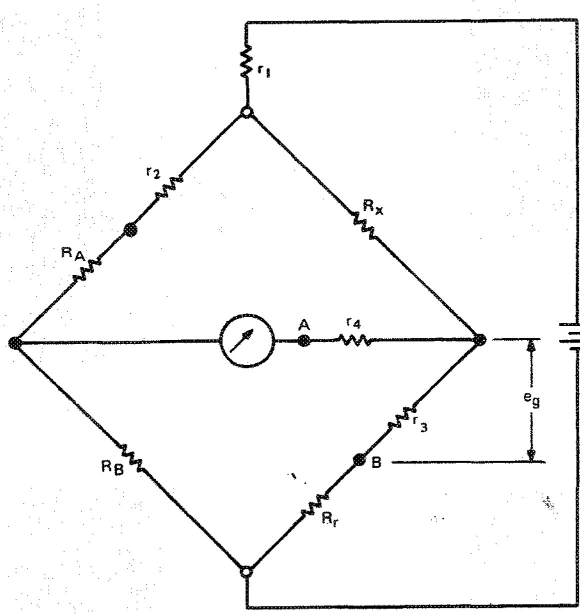
The percent of error due to first term is $r_2 R_r / R_X R_B \times 100\% = r_2/R_A \times 100\%$ and is the same for all ranges.

In the 1666, R_A is 50 kΩ at full setting, with least significant digits of .05 Ω per step. Thus, a lead resistance of, say, 0.1 Ω results in a measurement that is low by 2 steps of the last decade. Such an error is generally negligible, except for comparison measurements, in which case it can be made negligible if r_2 has approximately the same value for both measurements.

The last error term is made small by ganging R_a with R_A so that the ratio $R_a/R_b \simeq R_A/R_B$ and made even smaller by the YOKE adjustment that trims the R_a/R_b ratio. With no yoke adjustment, the value of $R_b/(R_a+R_b)\,[R_a+(r_3/R_B) - R_A/R_B]$ for the 1666 is typically less than .002 at full scale, and much less at lower settings, even if $r_3 = 1\ \Omega$. Therefore, a lead resistance, r_4, of 0.1 Ω generates an error of only 200 μΩ or .02% at full scale on the lowest R range. At low settings, it would be less than 10 μΩ. On higher bridge ranges this error is negligible except for precise comparisons.

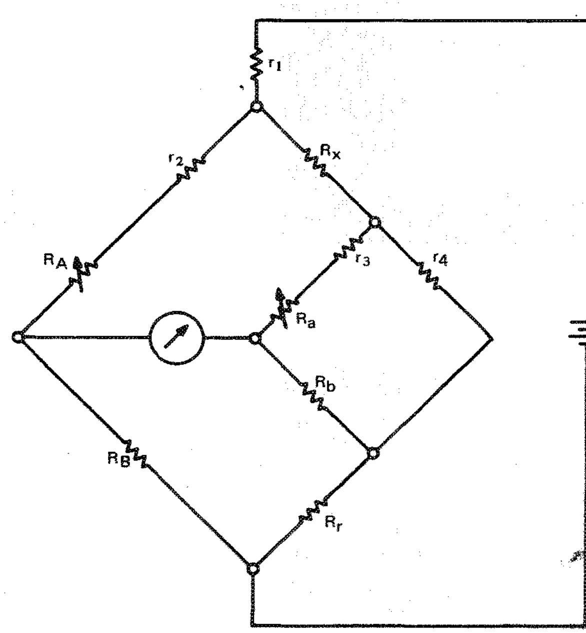
The yoke adjustment is made by increasing r_4 by 10 Ω and adjusting the yoke control to balance. This reduces the error by a factor of 100, making it negligible.

The yoke adjustment can modify R_b by about ±0.3% and add 0.2 Ω to R_a. Resistance cannot be subtracted from R_a to compensate for lead resistance (but the last decade of the adjustment does not add resistance in R_a, so it can be 0.1 Ω low). Therefore, yoke balances cannot be made at many low decade settings. However, if the lead resistances (r_3 and r_4) are 0.1 Ω or less, the resulting measurement error is 1 μΩ or less, if the best possible yoke balance is made (full cw).



1666-11

Figure 4-6. Basic Kelvin Bridge.



1666-12

Figure 4-7. Kelvin bridge with yoke adjustment.

4.4 THE BRIDGE SOURCE.

The bridge source consists of four 1.5 V-D cells in series with a series resistance of 62 Ω to limit the current to less than 0.1 A. On all but the lowest resistance range, additional resistance is placed in series with the source to limit the applied power. The source voltage is checked with a load of 200 Ω when the POWER switch is set to the SOURCE BAT CHECK position.

The polarity of the source is switched as the various bridges are selected to insure a right-hand meter deflection when the decade setting is too high.

4.5 THE BRIDGE DETECTOR CIRCUITS.(Figure 6-4)

4.5.1 General.

Figure 4-8 is a block diagram of the detector circuits. Section 6 contains the schematic diagrams of these circuits. The detector consists of an input low-pass filter, an FET modulator-chopper, a tuned 3-stage ac amplifier, FET demodulator, an RC Wien-Bridge oscillator, and a meter response filter network. Refer to the detector specifications at the front of the manual. The following paragraphs describe the detector circuits.

4.5.2 Detector Power.

The detector is powered by four 1.5-V D cells in series. The voltage is checked when the POWER switch is set to the DETECTOR BAT CHECK position.

4.5.3 Input Filter.

The input filter is low-pass and consists of C1 and the bridge output resistance network. It reduces the effect of hum and other ac pick-up. Parallel-opposed diodes CR1 and CR2 limit the input voltage to prevent large dc overloads.

4.5.4 Modulator.

The FET modulator (Q1) modulates the filtered dc input signal from the bridge with a low-level sinewave (approx. 750 Hz) from the oscillator. The modulator output is fed to the amplifiers (para 4.5.6). There are internal adjustments (R40 and R51) for FET bias adjustment and to cancel the effect of capacitance across the FET. The modulator signal changes the resistance of the FET (Q1), so that the output of the divider formed by R1 and Q1 has an ac component when dc is applied to the input.

4.5.5 Zero Set.

The zero-adjust control (A-R2) inserts an in phase a-c signal of either polarity to compensate for input voltage offset of ±100 μV. A-R2 has an 11-turn range to provide high resolution.

4.5.6 Amplifier.

The Modulator output is applied to 3 cascaded high-gain, high-Q selective amplifiers (Q2-Q9), which reject noise that could otherwise overload the detector.

4.5.7 Sensitivity Control.

The sensitivity control (A-R3) is a logarithmic potentiometer that is located between amplifier stages 1 and 2. The control allows adjustment of the gain depending on the input conditions.

4.5.8 Demodulator.

The FET demodulator (Q14) converts the a-c amplifier output to dc. The oscillator output through Q13 and turns FET Q14 on and off to give synchronous detection.

4.5.9 Meter-Response Filters.

The meter-response filters consist of 2 cascaded R-C ladder sections, in which capacitor values are switched in for the different response-speed positions. Pairs of parallel-opposed diodes bridge (CR12, CR13) and load (CR2, CR6) this network. The loading pair of diodes prevents excessive output capacitor voltage and meter current. The bridging pair of diodes conducts only at high output levels and effectively by-passes the filter for large unbalances. Thus, the meter response is relatively slow for small unbalances, as it is desirable to reduce noise, but for large unbalances it provides for fast coarse adjustment.

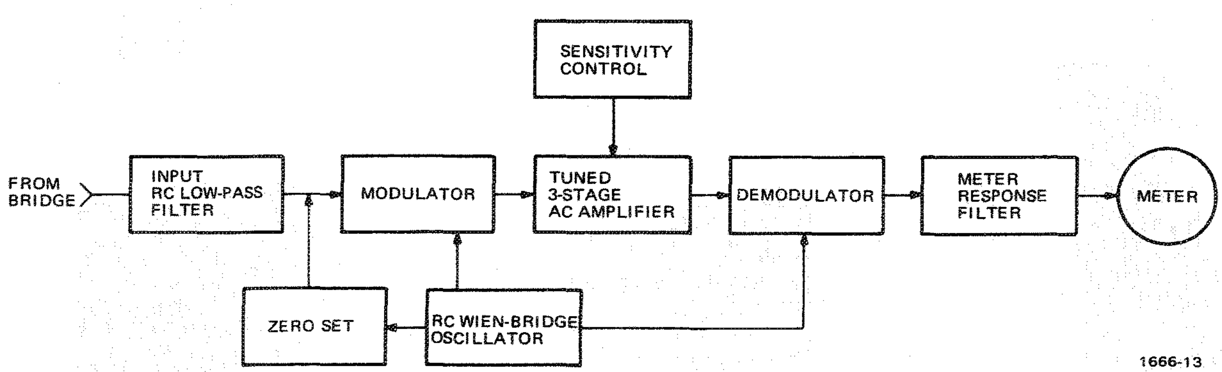


Figure 4-8. Block diagram of the 1666 detector circuits.

Service and Maintenance–Section 5

5.1 GR FIELD SERVICE.

The warranty attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible. If the difficulty cannot be eliminated by use of the following service instructions, please write or phone our Service Department (see last page of manual), giving full information of the trouble and of steps taken to remedy it. Be sure to mention the serial, ID, and type numbers of the instrument.

5.2 MINIMUM PERFORMANCE STANDARDS.

The 9 checks listed in Table 5-1 are given so that it can be determined that the instrument is in proper working condition (1) on receipt of a new bridge, (2) after a period of non-use, or (3) after repairs have been made to the bridge. If any specifications (Read Column) are not met, it is likely that 1 or more potentiometers are misadjusted. The calibration procedure should be performed until the misadjustment is corrected. Measurements should be made

Table 5-1
ACCURACY AND OPERATIONAL CHECKS

External Standard GR Cat. No.	Value	Parameter Switches*	Multiplier	Read**
1440-9601	1 Ω	KR	100 mΩ	R=X.00000±0.011%
1440-9611	10 Ω	KR	1 Ω	R=X.00000±0.011%
1440-9621	100 Ω	KR	10 Ω	R=X.00000±0.011%
1440-9631	1 kΩ	KR	100 Ω	R=X.00000±0.011%
1440-9631	1 kΩ	WR	100 Ω	R=X.00000±0.011%
1440-9631	1 kΩ	WG	100 μΩ	G=X.00000±0.011%
1440-9641	10 kΩ	WR	1 kΩ	R=X.00000±0.011%
1440-9651	100 kΩ	WR	10 kΩ	R=X.00000±0.011%
1440-9661	1 MΩ	WR	100 kΩ	R=X.00000±0.011$

* W = Wheatstone, K = Kelvin, R = Resistance, G = Conductance.
** Calibrated standards should be used and their corrections applied.

Table 5-2
RECOMMENDED TEST EQUIPMENT*

Name	Minimum Use Specification	Recommended Equipment**
Oscilloscope	Vertical Sensitivity: = 50 mV/cm Range: 100 kHz	Tektronix Model 503
Decade Resistor	6 decade, .1 Ω per step	GR Type 1433-F, G, or X
Frequency Meter Range:	Range: 735 Hz – 765 Hz	GR Type 1192 Counter
Standard Resistors	Value — Accuracy***	
	1 Ω — ±0.02%	GR Type 1440-9601
	10 Ω — ±0.01%	GR Type 1440-9611
	100 Ω — ±0.01%	GR Type 1440-9621
	1 kΩ — ±0.01%	GR Type 1440-9631
	10 kΩ — ±0.01%	GR Type 1440-9641
	100 kΩ — ±0.01%	GR Type 1440-9651
	1 MΩ — ±0.01%	GR Type 1440-9661
Microvolt Source	±2 μV dc	GR Type 1346 Audio-Frequency Microvoltmeter®
Cable Assy.	1666 – 4 Lead, Molded	GR Type 1666-2200 (supplied)

*Instruments recommended for minimum-performance standards and trouble analysis.
**Or equivalent.
***Calibrated to 30 ppm.

between 20°C and 25°C at less than 75% RH (see specifications). Table 5-2 lists the recommended test equipment for these checks plus the equipment needed for the calibration procedures given later. Refer to para 2.2 and 2.3 for the balancing procedures.

The proper method for connecting the bridge to a 1440 for a Kelvin connection using the lead set provided, is to connect lead A to one post of the 1440; lead B to the banana plug (bottom of the same post); and connect leads C and D in a similar manner with the other 1440 post and plug.

5.3 CALIBRATION CHECKS

5.3.1 Resistance Decade (R_A).

a. Connect a GR Type 1433-F, -G, or -X Decade Resistor to the 1666 Bridge as shown in Figure 5-1. Remove the 1433 ground link.

b. Perform Source and Detector BAT CHECKS.

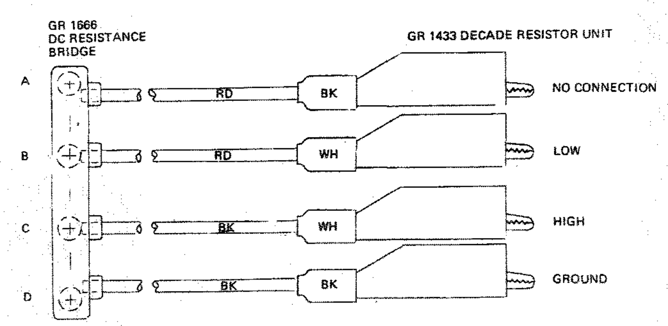


Figure 5-1. 1666/1433 Connections using Cable Assembly 1666-2200.

c. Set the 1666 controls as follows:
POWER – INTERNAL BRIDGE SOURCE
METER RESPONSE – FAST
SENSITIVITY – MIDRANGE
R/G – R
RANGE SELECT – x10 K
WHEATSTONE/KELVIN – WHEATSTONE
ZERO/MEASURE – ZERO
(adjust ZERO ADJ control to indicate reading of 0 on meter)
ZERO/MEASURE – MEASURE
1666 DECADE RESISTOR – X.00000

d. Adjust the 1433 for a balance as indicated by the 1666 front-panel meter. Record the 1433 reading.

e. Lower the most significant 1666 decade lever switch from X to 9 and raise the value of the 2nd most significant decade switch to X.

f. Rebalance the 1433. The difference should not be more than 2 Ω (20 ppm).

g. Repeat the procedure (lower the X to 9, raise the next most significant decade lever to X) for each decade lever switch. Each 1433 reading should not vary more than 2 Ω for the value initially recorded.

5.3.2 Sensitivity.

With a balance achieved during the decade-resistor calibration check in the previous paragraph, and no other changes made to the test setup, vary the right-hand-most 1666 decade lever-switch (LSD) 2 digits from its present setting. The meter should deflect approximately 1 division.

5.3.3 Meter Response.

Using the test setup described in para. 5.3.1, change the decade step that produces approximately a +5 to −5 meter movement at FAST (usually the 3rd decade from the right). Repeat the procedure with the METER RESPONSE set to NORMAL, and then SLOW. The NORMAL response should be observed as approximately half the speed of FAST, and SLOW should be approximately half the speed of NORMAL.

5.4 TROUBLE ANALYSIS. Figures 6-2, 6-3

5.4.1 Preliminary Checks.

If satisfactory measurements are difficult or impossible to obtain, make the following external checks first:

1. Is the unknown connected correctly?
2. Are the panel controls set correctly?
3. Are the batteries correctly in place and are both battery checks successful?

5.4.2 Measurement Errors.

Measurement errors due to faulty or misadjusted bridge-circuit components can be located by means of the resistance checks of Table 5-1.

Symptoms and Probable Remedies

1. When measurements on a particular range are in error, the ratio arm R_R, which consists of a potentiometer and fixed resistors in a series-parallel combination (refer to switch assembly AS4-AS8 schematic diagram Figure 6-5) is in error. Perform the calibration procedures for these adjustments (R101, R103, R105, R107, R109, R110 and R111) before replacing any ratio-arm resistors.
2. When all measurements are in error, adjustment of R112 (the standard arm adjustable resistor) should be performed. See para 5.5.7. Verify the value of R161 if the adjustment of R112 is out of range.
3. If the measurements are still in error perform the decade check (para 5.3.1).

5.4.3 No Meter Indication.

No meter indication, or a low meter indication may be due to weak or dead batteries, no oscillator output, poor detector sensitivity, faulty meter-response filter, or a faulty meter. If the batteries are not at fault, perform the detector calibration procedures to aid in fault isolation, and the procedure in para 5.4.4.

5.4.4 No Meter Deflection With A Large D-c Input (1 V) Applied.

a. Observe: TP 2 should be approximately 3.0 V ac pk-to-pk. If it is not, check Q15 and Q16.

b. Observe: TP 3 should be a squarewave with a lower value of approximately −0.5 V and an upper value of approximately +1.5 V.

1. If the signal drops to a relatively large negative voltage check the gate drive of Q14 (approx. ±3 V squarewave), and Q13 input (±0.4 V squarewave).
2. If the signal is correct, check the meter leads, CR6 and CR7, and the meter (BRIDGE SOURCE) switch. Continue if no signal.

c. No signal at TP 3.

1. Check AT4 for a 3 V ac pk-pk (approx.) signal.
2. If the signal is present at AT4 but not at AT6, insure that the SENSITIVITY control is set fully cw.
3. Check amplifier stages Q5 to Q12 (see para 5.5.6). Continue if there is no signal.

d. No Signal At AT4 (TP1).

1. Check that the signal at AT2 is approximately 200 mV ac pk-pk.
2. If the signal is present, then check Q2, Q3, and Q4. Continue if there is no signal.

e. No Signal At AT2

1. Check the gate drive of Q1 for a 1.0 V ac pk-pk (approx.) signal.
2. If the signal is absent check Q1.
3. Continue if there is still no signal.

f. No Signal At Q1 Gate.

1. Observe whether there is a signal at AT12 of 1.0 V ac pk-pk (approx.)
2. If the signal is not present, check the circuit between the oscillator and AT12.

5.5 CALIBRATION PROCEDURES.

5.5.1 General.

The few internal adjustments are factory set and normally do not require readjustment. Procedures for readjustment are included here but should be used only when the operator is reasonably certain that readjustment is necessary.

5.5.2 Equipment Required.

The equipment necessary to perform the following calibration procedures is listed in Table 5-2.

5.5.3 Etched-Board Access.

For access to the bridge board shown in Figure 5-2 perform the following:

a. Open the instrument cabinet until the instrument and cover are at 90°.

b. Remove the 2 cabinet screws located on the rear of the cabinet.

c. Lift the instrument from the cabinet and place it on either side.

d. Locate and remove the two interior and board retaining screws, as shown in Figure 5-2 on each side.

e. The back plate holding the battery tubes is now free to swing up and away from the interior. Both sides of the

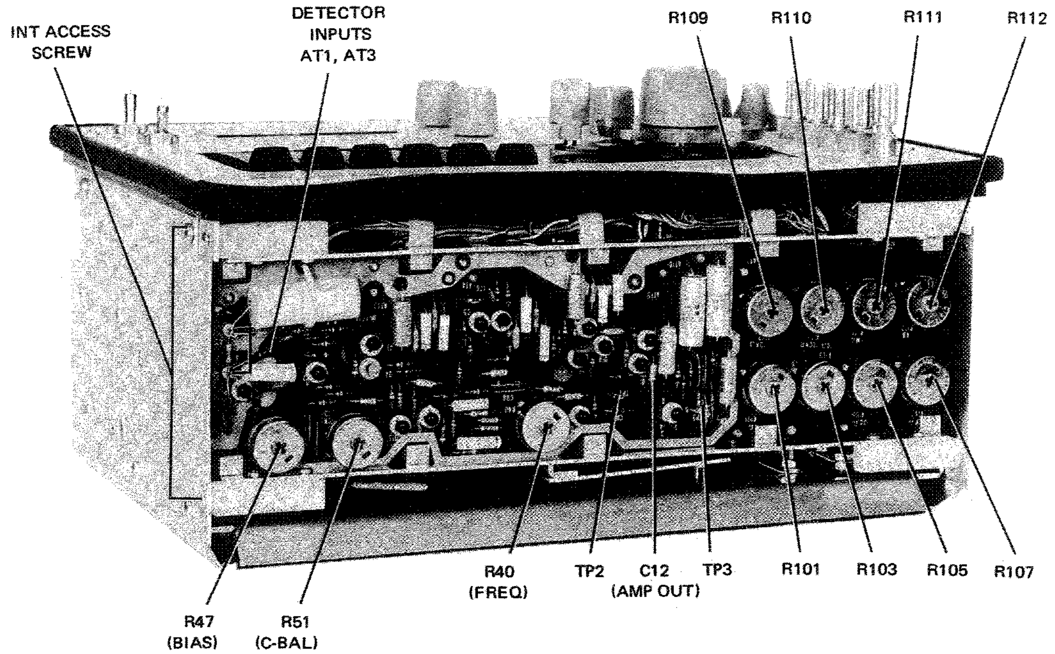


Figure 5-2. 1666 Bridge board adjustments (1666-4700)

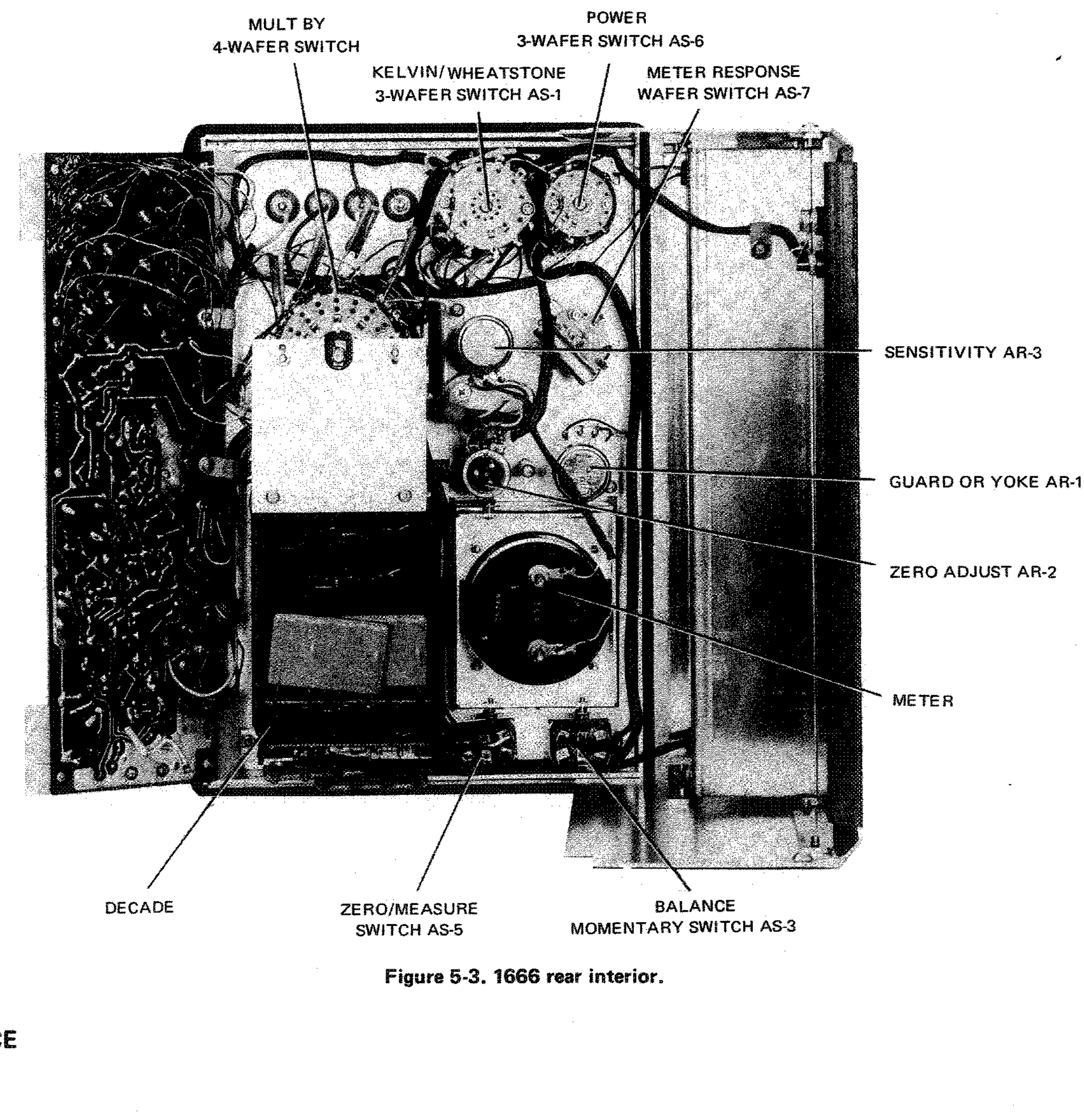


Figure 5-3. 1666 rear interior.

bridge board are now accessible for the calibration procedures.

5.5.4 Oscillator, Sensitivity Controls — Initial Setup.(Fig. 5-2)

a. Set the POWER control to INTERNAL BRIDGE SOURCE. Turn the ZERO ADJ control 5 1/2 turns to center (11-turn potentiometer); SENSITIVITY control to MID-RANGE. Additionally set the 1666 to WHEATSTONE, R, MULT BY 100KΩ, FAST.

b. Prepare the oscilloscope as follows:
Sensitivity — 50 mV/cm
Input — AC
Sweep Time/cm — 0.2 ms
Trigger — External

c. Ground the oscilloscope to the bridge board; place the sync on TP2 and connect the signal probe to C13 (high).

d. Prepare the AF Microvolter as follows:
OUTPUT — OFF
METER FULL SCALE — ±10 Vdc.
FULL SCALE OUTPUT VOLTAGE — 10 μV

e. Connect the Microvolter OUTPUT (high) to the bridge board anchor terminal AT1; the low output connects to AT3. Use a short shielded lead.

f. Adjust the counter for frequency measurement of approximately 750 Hz, and adjust the gate time to 1. Connect the counter input to TP2 and the shield strap to bridge board ground.

5.5.5 Oscillator Adjustment. (Figure 5-2)

a. Turn the bridge-board BIAS R47 for maximum sinewave amplitude.

b. Adjust the bridge front-panel SENSITIVITY control (approx. center of potentiometer) to produce an undistorted sinewave.

c. Adjust bridge-board FREQ R40 for a maximum amplitude on the oscilloscope. (This tunes the oscillator to the 3-stage amplifier.)

d. Observe with the frequency meter that the frequency is between 735 Hz and 765 Hz. If the frequency is outside of this range, one or more of the 3 amplifier stages is out of tolerance (refer to para 5.5.6).

e. Adjust C-BAL R51 for minimum amplitude on the oscilloscope.

5.5.6 Sensitivity Adjustment. (Figures 5-2, 6-2)

a. Connect oscilloscope probe to TP3.

b. Increase 1666 front-panel SENSITIVITY control to maximum cw. The waveform described in para 5.5.5 is obtained by the proper adjustment of the C-BAL control and the front-panel ZERO ADJ control. The ZERO ADJ control should be approximately ±1 turn from the center position.

c. Rotate the ZERO ADJ control and the front-panel meter must move in the same direction (to the right for a cw turn).

d. Turn on the Microvolter and adjust the level for 1 μV output.

e. Move the METER FULL SCALE control +10 Vdc to −10 Vdc. The front-panel meter should move approximately 4 divisions (±2 divisions).

f. If the sensitivity is not enough, readjust BIAS R47 in small increments, rezero, and check with the Microvolter. If the sensitivity is still low readjust the C-BAL, R51, in the same manner.

g. Check the gain of the amplifier (TP2) for a 3 V ac pk-pk (approx.) signal when there is a 0.1 Vdc input. If TP2 is low, check the first stage (Q1 in particular). If it is satisfactory continue with step h.

h. Check at the junction of C7 and C8 for a 4 V ac pk-pk (approx.) signal, when there is 1 mV dc input. If the junction voltage is low check the second stage. If it is satisfactory continue with step i.

i. Check the junction voltage at C13 and R29 for a 4 V ac pk-pk (approx.) signal when there is a 10 μV dc input. If the junction voltage is low check the third stage.

j. Readjust R47 (step f) as necessary.

5.5.7 Bridge Adjustments.

Standard Arm

a. Set the 1666 front-panel controls as follows:
BRIDGE SOURCE — Internal
WHEATSTONE/KELVIN — WHEATSTONE
R/G — R
SENSITIVITY — 1/3 cw
ZERO/MEASURE — MEASURE (perform zero adjust first.)
MULT BY — 100 Ω
METER RESPONSE — FAST
DECADE — 999X00

b. Set R107 and R112 to mid-range.

c. Plug into the 1666 unknown terminals a GR Type 1440 1-kΩ resistor, and adjust R107 for null on the meter.

d. Set the R/G Switch to G and adjust R112 for a null on the meter. The two operations interact with each other.

e. Repeat the R107 and R112 adjustment procedures in sequence with increasing sensitivity, until the SENSITIVITY control is at maximum cw, and the change in R107 and R112 is reduced to 1 division. Convergence is simplified if underadjustment is performed i.e., adjustment less than required for null.

f. Set the R/G Switch to R, and adjust the 1666 decade to the calibrated value of the 1440 Standard Resistor.

g. Readjust R107 for a zero meter deflection.

h. Set the R/G Switch to G and read the value (reciprocal of R). It should be within 10 ppm. A final adjustment of R112 and possible re-adjustment of R107 may be necessary.

Ratio Arm.

a. Set the 1666 front-panel controls as follows:
BRIDGE SOURCE — Internal

WHEATSTONE/KELVIN – KELVIN
R/G – R
SENSITIVITY – as required
ZERO/MEASURE – MEASURE (perform zero adjust first)
METER RESPONSE – FAST
MULT BY – 100 mΩ

b. Connect a 1-Ω GR Type 1440 Standard Resistor to the 1666 Bridge with the lead set for 4-terminal measurements.

c. Set the decade to the calibrated value of the standard resistor, and adjust R101 to meter null.

d. Perform the YOKE adjustment (para 2.3.2), and repeat the R101 adjustment, if necessary.

e. Adjust the remaining bridge board potentiometers (range resistors) as listed in Table 5-3, using the procedure described in the last paragraph, except that the YOKE adjustment is not required above 1 Ω.

5.6 KNOB REMOVAL.

If it should be necessary to remove any knobs on the front-panel to replace one that has been damaged, or to replace the associated control, proceed as follows:

a. Grasp the knob firmly with the fingers close in to the panel (or MULT BY dial if applicable), and pull the knob straight away from the panel.

CAUTION

Do not pull on the dial to remove a dial/knob assembly. Always remove the knob first. To avoid damage to the knob and other parts of the control, do not pry the knob loose with a screwdriver or similar flat tool, and do not attempt to twist the knob from the dial.

b. Observe the position of the setscrew in the bushing, with respect to any panel markings (or at the full ccw position of a continuous control).

c. Release the setscrew and pull the bushing off the shaft.

Table 5-3
RATIO ARM RESISTOR ADJUSTMENTS

Standard	Mult By	R Adjust	Bridge Type
1 Ω	100 mΩ	R101	K
10 Ω	1 Ω	R103	K
100 Ω	10 Ω	R105	K
1 kΩ	100 Ω	R107*	W
10 kΩ	1 kΩ	R109	W
100 kΩ	10 kΩ	R110	W
1 MΩ	100 kΩ	R111	W

*This adjustment was made previously in para 5.5.7, but can be readjusted here. However, any re-adjustment of R112 will require the procedure of all the ratio-arm adjustments to be repeated.

Table 5-4
NOMINAL TRANSISTOR VOLTAGES*

	Emitter	Base	Collector	Number	Junction Voltages
Q1	Source/OV	Gate/OV	Drain/OV	E101	R6, R8/1.43
Q2	0.9	1.4	5.1	2N4250	R15, R18/2.1
Q3	0.9	1.4	6.0	2N4250	R23, R25/3.2
Q4	6.0	5.1	2.8	2N3903	R41, R42/4.0
Q5	1.2	1.7	5.4	2N3905	R43, R59/4.2
Q6	1.2	1.7	6.0	2N3905	
Q7	6.0	5.4	3.0	2N3903	
Q8	2.43	2.8	5.4	2N3905	
Q9	2.43	2.8	6.0	2N3905	
Q10	6.0	5.4	3.9	2N3903	
Q11	3.2	3.9	5.8	2N3905	
Q12	3.2	3.9	0	2N3903	
Q13	0	0.35	3.4	2N3905	
Q14	Source/0	Gate/3.4	Drain/3.5	E113	
Q15	5.4	4.7	3.2	2N3903	
Q16	5.4	4.7	3.2	2N3903	

*All measurements are in negative dc. volts with respect to ground.

Parts Lists and Diagrams – Section 6

NOTE

Electrical parts information in this section is presented in such a way that all the data for a part-numbered subassembly is visible in a single opening of the manual. Thus the parts list appears on left-hand pages, while the etched circuit and schematic diagrams (tip out) are on the right-hand pages.

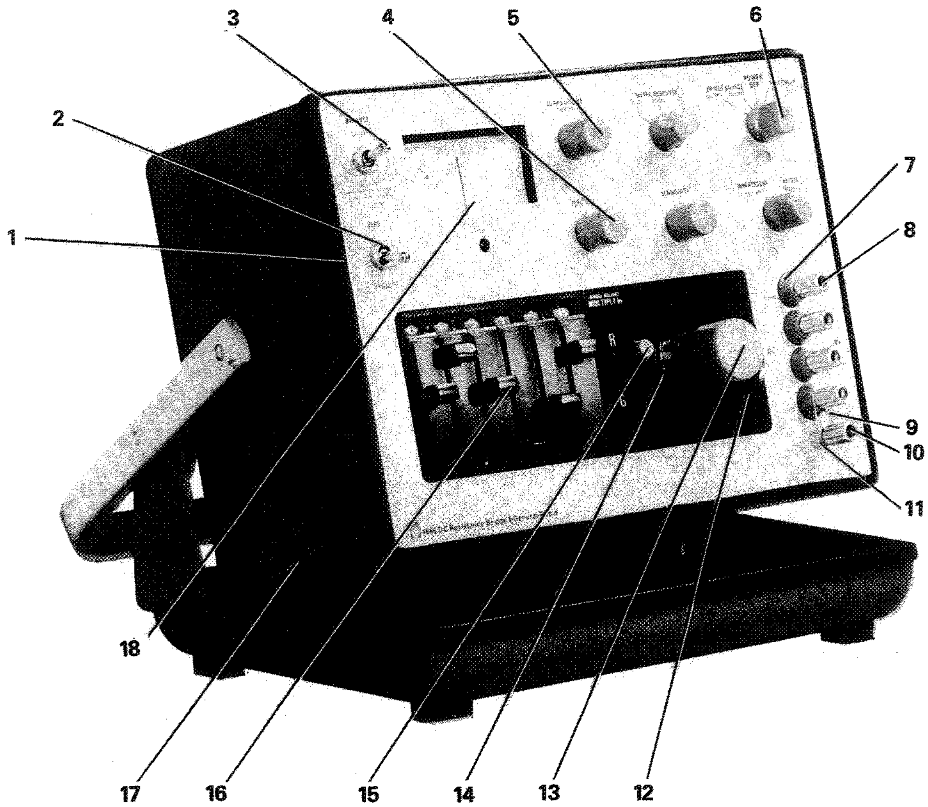


Figure 6-1. Replaceable mechanical Parts.

MECHANICAL PARTS LIST

Fig Ref	Qnt	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
1.	1	Panel gasket	5331-3606	24655	5331-3606	
2.	1	Switch, toggle AS5 ZERO MEASURE	7910-1810	39317	1111-0014	
		requires:				
		dress nut	5800-0800	24655	5800-0800	5310-344-3634
3.	1	Switch, toggle AS3	7910-1820	39317	1111-0054	
		requires:				
		dress nut	5800-0800	24655	5800-0800	5310-344-3634
4.	1	Knob asm., gray ZERO ADJ	5520-5220	24655	5520-5220	
		inc:				
		retainer	5220-5402	24655	5220-5402	
		washer	8140-0104	24655	8140-0104	
5.	2	Knob asm., gray GUARD or YOKE, SENSITIVITY	5520-5221	24655	5520-5221	
		inc:				
		retainer	5220-5402	24655	5220-5402	
6.	3	Knob asm., gray METER RESPONSE POWER OFF, WHEATSTONE KELVIN	5500-5221	24655	5500-5221	
		inc:				
		retainer	5220-5402	24655	5220-5402	
7.	4	Bushing, binding post	0938-7130	24655	0938-7130	
8.	4	Binding post, gold AJ1-AJ4	4060-0108	24655	4060-0108	5905-912-0007
9.	1	Shorting link, gold	0938-9503	24655	0938-9503	
10.	1	Binding Post asm., AJ5	0938-2032	24655	0938-2032	
11.	1	Spacer, binding post, gold	0938-9830	24655	0938-9830	
12.	1	Dial asm., outer Range Select	1666-1060	24655	1666-1060	
		requires:				
		bushing	4143-3253	24655	4143-3253	
13.	1	Knob asm., gray Range Select	5520-5420	24655	5520-5420	
		inc:				
		retainer	5220-5401	24655	5220-5401	
14.	1	Dial asm., inner R-G Select	1666-1110	24655	1666-1110	
15.	1	Knob, gray R-G Select	5540-3312	24655	5540-3312	
16.	10	Knob, black Decade	1650-5999	76854	294-29-001	
17.	1	Cabinet asm. comp.,	4182-2347	24655	4182-2347	
		inc:				
	1	cabinet base complete	4182-1347	24655	4182-1347	
	1	handle asm.	4182-1506	24655	4182-1506	
	1	cover	4182-8447	24655	4182-8447	
	1	gasket	5168-0680	24655	5168-0680	
	4	foot	5260-2060	24655	5260-2060	
18.	1	Window, Meter	5730-7000	24655	5730-7000	
MISCELLANEOUS						
	3	Bushing, Threaded AJ6-8 EXIT EXIT SOURCE, GROUND	4150-2600	24655	4150-2600	6625-043-2108

ELECTRICAL PARTS LIST

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
CAPACITORS					
C101	Electrolytic, 600 μF, +150-10%, 3 V	4450-5589	37942	TCM, 600 μF, 3 V	5910-929-9975
METERS					
AM1	Meter	5730-1666	24655	5730-1666	
RESISTORS					
AR1	Potentiometer, Comp., 250 Ω, ±10%	6000-0100	01121	JU, 250 Ω, ±10%	
AR2	Potentiometer, Comp., 10 T, 1 MΩ ±20%	6045-0460	01121	JJ, 10 T, 1 MΩ, ±20%	
AR3	Potentiometer, Comp., 10 kΩ ±20%	6020-0400	01121	JU, 10 kΩ, ±10%	5905-829-3323
AR151	Film, 110 kΩ, ±1%, 1/8 W	6250-3110	75042	CEA, 110 kΩ, ±1%	
AR152	Composition, 200 Ω, ±5%, 1/4 W	6099-1205	75042	BTS, 200 Ω, ±5%	5905-683-2239
AR153	Composition, 62 Ω, ±5%, 1/4 W	6099-0625	75042	BTS, 62 Ω, ±5%	
AR154	Composition, 1 kΩ, ±5%, 1/4 W	6099-2105	75042	BTS, 1 kΩ, ±5%	5905-681-6422
AR155	Composition, 10 Ω, ±5%, 1/4 W	6099-0105	75042	BTS, 10 Ω, ±5%	5905-809-8596
AR156	Composition, 100 kΩ, ±5%, 1/4 W	6099-4105	75042	BTS, 100 kΩ, ±5%	5905-686-3129
AR157	Wire Wound, 1.0 Ω, ±5%, 2 W	6760-9105	75042	BWH, 1.0 Ω, ±5%	
AR158	Composition, 750 Ω, ±5%, 1/4 W	6099-1755	75042	BTS, 750 Ω, ±5%	
AR160	Composition, 470 kΩ, ±5%, 1/4 W	6099-4475	75042	BTS, 470 Ω, ±5%	
AR161	Composition, 10 kΩ, ±5%, 1/4 W	6099-3105	75042	BTS, 10 kΩ, ±5%	5905-683-2238
SWITCHES					
AS1	Rotary, Wafer	7890-5605	76854	7890-5605	
AS3	Toggle	7910-1810	39317	1111-0014	
AS5	Toggle	7910-1820	39317	1111-0054	
AS6	Rotary, Wafer	7890-5604	76854	7890-5604	
AS7	Rotary, Wafer	7890-5606	76854	7890-5606	
DECADE SWITCH ASM. COMP.					
SWITCH ASM: 50 mΩ/step					
RESISTORS					
R1 thru R6	Pwr., Wire Wound, 0.1 Ω, ±1/2%, 1 W	6620-1031	75042	WW3J, 1 Ω, ±1/2%	
SWITCH ASM: .5 Ω/step					
RESISTORS					
R1 thru R6	Film, 1 Ω, ±1%, 300 ppm	6619-2803	75042	CEA-TO, 1 Ω, ±1%	
R8 thru R12	Pwr., Wire Wound, 0.1 Ω, ±5%, 1 W	6620-1032	75042	CEA-TO, .2 Ω, ±5%	
SWITCH ASM: 5 Ω/step					
RESISTORS					
R1 thru R6	Film, 10 Ω, ±0.1%, 50 1/8 W	6190-0001	75042	MEA, 10 Ω, ±0.1%	
R7 thru R12	Film, 2 Ω, ±1%, 300 ppm	6619-2805	75042	CEA-TO, 2 Ω, ±1%	
R13 and R14	Comp., 20 Ω, ±5%, 1/4 W	6099-0205	75042	BTS, 20 Ω, ±5%	
SWITCH ASM: 50 Ω/step					
RESISTORS					
R1 thru R6	Film, 100 Ω, ±0.1%, 100 ppm	6619-1600	75042	CEA-TO, 100 Ω, ±0.1%	
R7 thru R12	Film, 20 Ω, ±0.1%, 50 1/8 W	6190-0004	75042	MEA, 20 Ω, ±0.1%	
SWITCH ASM: 500 Ω/step					
RESISTORS					
R1 thru R6	Wire Wound, 1 K, 1 K, 1 K	6990-3210	24655	6990-3210	
SWITCH ASM: 5 K/step					
RESISTORS					
R1 thru R6	Wire Wound, 10 K, 10 K, 10 K	6990-3310	24655	6990-3310	
R7 thru R12	Film, 2 kΩ, ±.1%	6619-1120	75042	CEA-TO, 2 kΩ, ±1%	

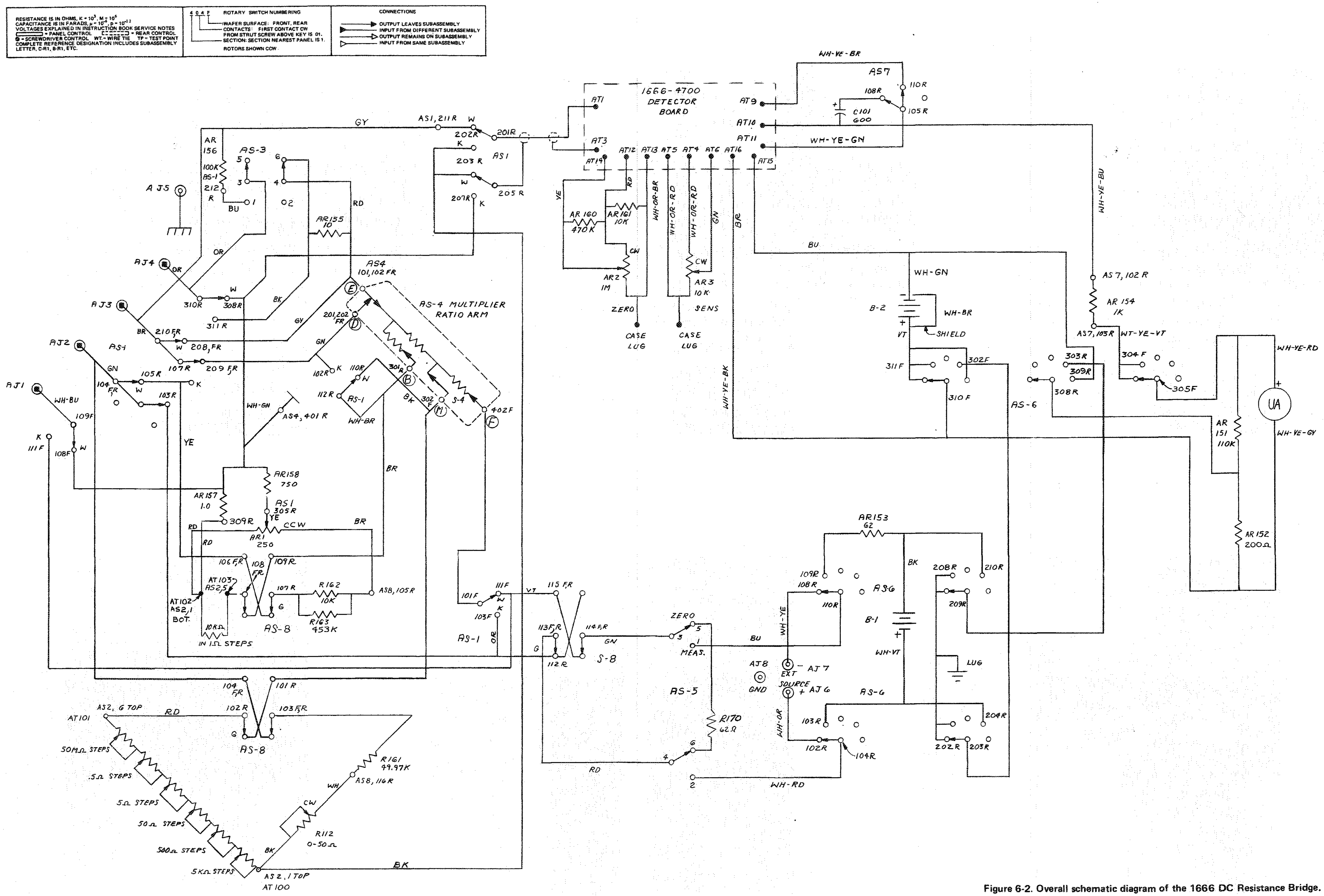
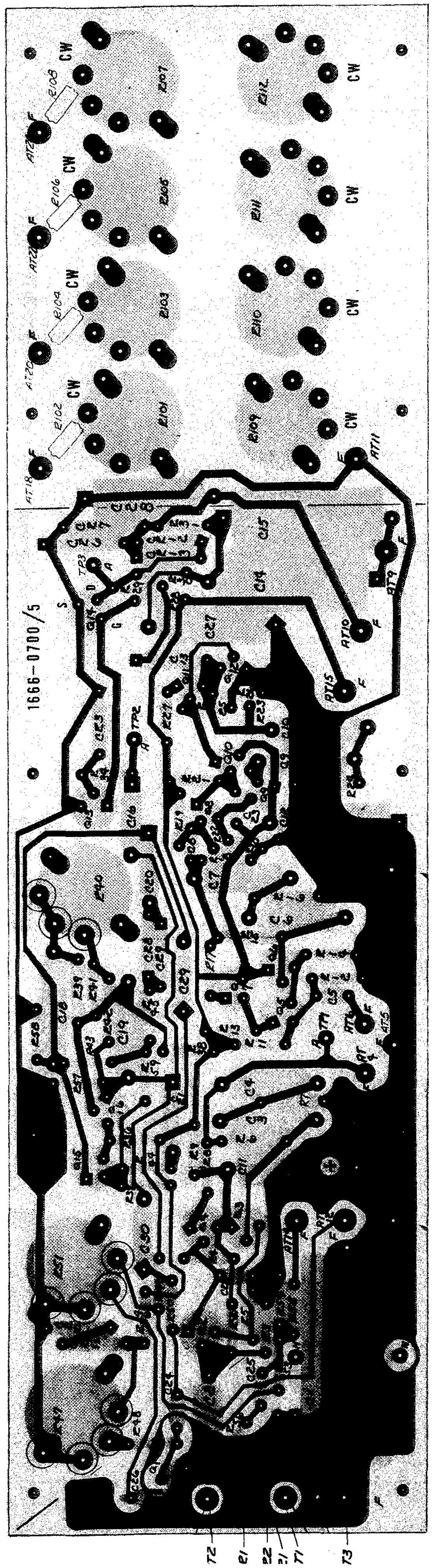


Figure 6-2. Overall schematic diagram of the 1666 DC Resistance Bridge.

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
CAPACITORS					
C1	Mylar, 1 μF, ±10%, 200 V	4860-8274	84411	663UW, 1 μF ±10%	
C2	Mylar, .047 μF, ±10%, 100 V	4860-8200	84411	663UW, .047 μF, ±10%	
C3 and C4	Mylar, .01 μF, ±2%, 100 V	4860-7650	84411	663UW, .01 μF, ±2%	
C5	Ceramic, .01 μF, +80-20%, 100 V	4401-3100	80131	CC61, .01 μF, +80-20%	5910-974-5697
C6 and C7	Mylar, .01 μF, ±2%, 100 V	4860-7650	84411	663UW, .01 μF, ±2%	
C8	Ceramic, .01 μF, +80-20%, 100 V	4401-3100	80131	CC61, .01 μF, +80-20%	5910-974-5697
C9 and C10	Mylar, .01 μF, ±2%, 100 V	4860-7650	84411	663UW, .01 μF, ±2%	
C11 and C12	Electrolytic, 120 μF, ±20%, 10 V	4450-5616	56289	150D127X0010R2	
C13	Tantalum, 6.8 μF, ±20%, 6 V	4450-4800	56289	150D685X0010A2	5910-936-1332
C14 and C15	Electrolytic, 200 μF, +150-10%, 6 V	4450-2610	37942	TT, 200 μF, 6 V	5910-945-1836
C16	Tantalum, 6.8 μF, ±20%, 6 V	4450-4800	56289	150D685X0010A2	5910-936-1332
C18	Mylar, .02 μF, ±1%, 100 V	4860-7853	84411	663UW, .0200 μF, ±1%	
C19	Mylar, .01 μF, ±2%, 100 V	4860-7650	84411	663UW, .01 μF, ±2%	
C20 and C21	Tantalum, 6.8 μF, ±20%, 6 V	4450-4800	56289	150D685X0010A2	5910-936-1332
C22	Ceramic, .01 μF, +80-20%, 100 V	4401-3100	80131	CC61, .01 μF, +80-20%	5910-974-5697
C23	Ceramic, 1000 pF, ±10%, 500 V	4404-2108	72982	811, .001 μF, ±10%	5910-928-1476
C24 and C25	Ceramic, .01 μF, +80-20%	4401-3100	80131	CC61, .01 μF, +80-20%	5910-974-5697
C26	Ceramic, 47 pF, ±5%, 500 V	4410-0475	80131	CC61, 47 pF, ±5%	
C27 and C28	Electrolytic, 50 μF, +150-10%, 3 V	4450-5590	37942	TT, 50 μF, 3 V	
C29 and C30	Tantalum, 6.8 μF, ±20%, 6 V	4450-4800	56289	150D685X0010A2	5910-936-1332
DIODES					
CR1 and CR2	Type 1N4009	6082-1012	24446	1N4442	5961-929-9967
CR3	Type 1N118A	6082-1006	98925	1N118A	
CR6 and CR7	Type 1N118A	6082-1006	98925	1N118A	
CR8 thru CR13	Type 1N4009	6082-1012	24446	1N4442	5961-929-9967
RESISTORS					
R1	Film, 10 kΩ, ±1%, 1/8 W	6250-2100	75042	CEA, 10 kΩ, ±1%	5905-883-4847
R2	Composition, 3 MΩ, ±5%, 1/4 W	6099-5305	75042	BTS, 3 MΩ, ±5%	
R3	Composition, 1 MΩ, ±5%, 1/4 W	6099-5105	75042	BTS, 1 MΩ, ±5%	
R4	Comp., 47 kΩ, ±5%, 1/4 W	6099-3475	75042	BTS, 47 kΩ, ±5%	5905-683-2246
R5	Composition, 22 kΩ, ±5%, 1/4 W	6099-3225	75042	BTS, 22 kΩ, ±5%	5905-687-0002
R6	Film, 348 kΩ, ±1%, 1/8 W	6250-3348	75042	CEA-TO, 348 kΩ, ±1%	
R7	Film, 1.27 kΩ, ±1%, 1/8 W	6250-1127	75042	CEA, 1.27 kΩ, ±1%	5905-771-0281
R8	Composition, 10 kΩ, ±5%, 1/4 W	6099-3105	75042	BTS, 10 kΩ, ±5%	5905-683-2238
R9	Composition, 2 kΩ, ±5%, 1/4 W	6099-2205	75042	BTS, 2 kΩ, ±5%	5905-686-3370
R11	Composition, 1 MΩ, ±5%, 1/4 W	6099-5105	75042	BTS, 1 MΩ, ±5%	
R12	Composition, 470 kΩ, ±5%, 1/4 W	6099-4475	75042	BTS, 470 kΩ, ±5%	
R13	Composition, 22 kΩ, ±5%, 1/4 W	6099-3225	75042	BTS, 22 kΩ, ±5%	5905-687-0002
R14	Composition, 10 kΩ, ±5%, 1/4 W	6099-3105	75042	BTS, 10 kΩ, ±5%	5905-683-2238
R15	Film, 348 kΩ, ±1%, 1/8 W	6250-3348	75042	CEA-TO, 348 kΩ, ±1%	
R16	Film, 1.27 kΩ, ±1%, 1/8 W	6250-1127	75042	CEA, 1.27 kΩ, ±1%	5905-721-0281
R17	Composition, 4.7 kΩ, ±5%, 1/4 W	6099-2475	75042	BTS, 4.7 kΩ, ±5%	5905-686-9992
R18	Composition, 10 kΩ, ±5%, 1/4 W	6099-3105	75042	BTS, 10 kΩ, ±5%	5905-683-2238
R19 and R20	Composition, 1 MΩ, ±5%, 1/4 W	6099-5105	75042	BTS, 1 MΩ, ±5%	
R21 and R22	Composition, 22 kΩ, ±5%, 1/4 W	6099-3225	75042	BTS, 22 kΩ, ±5%	5905-687-0002
R23	Film, 348 kΩ, ±1%, 1/8 W	6250-3348	75042	CEA-TO, 348 kΩ, ±1%	
R24	Film, 1.27 kΩ, ±1%, 1/8 W	6250-1127	75042	CEA, 1.27 kΩ, ±1%	5905-721-0281
R25	Composition, 22 kΩ, ±5%, 1/4 W	6099-3225	75042	BTS, 22 kΩ, ±5%	5905-687-0002
R26	Composition, 2 kΩ, ±5%, 1/4 W	6099-2205	75042	BTS, 2 kΩ, ±5%	5905-686-3370
R27	Composition, 100 Ω, ±5%, 1/4 W	6099-1105	75042	BTS, 100 Ω, ±5%	
R28	Composition, 100 kΩ, ±5%, 1/4 W	6099-4105	75042	BTS, 100 kΩ, ±5%	5905-686-3129
R29 thru R31	Composition, 2 kΩ, ±5%, 1/4 W	6099-2205	75042	BTS, 2 kΩ, ±5%	5905-686-3370

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
RESISTORS (Cont)					
R34	Composition, 10 kΩ, ±5%, 1/4 W	6099-3105	75042	BTS, 10 kΩ, ±5%	5905-683-2238
R36	Composition, 510 Ω, ±5%, 1/4 W	6099-1515	75042	BTS, 510 Ω, ±5%	5905-801-8272
R37	Composition, 22 kΩ, ±5%, 1/4 W	6099-3225	75042	BTS, 22 kΩ, ±5%	5905-687-0002
R38	Composition, 27 kΩ, ±5%, 1/4 W	6099-3275	75042	BTS, 27 kΩ, ±5%	5905-683-3838
R39	Film, 23.2 k, ±1%, 1/8 W	6250-2232	75042	CEA, 23.2 kΩ, ±1%	
R40	Potentiometer, Wire Wound, 5 kΩ, ±10%	6056-0142	11236	115, 5 kΩ, ±10%	
R41	Film, 33.2 k, ±1%, 1/8 W	6250-2332	75042	CEA, 33.2 k, ±1%	
R42	Film, 14 kΩ, ±1%, 1/8 W	6250-2140	75042	CEA, 14 kΩ, ±1%	
R43	Composition, 16 kΩ, ±5%, 1/4 W	6099-3165	75042	BTS, 16 kΩ, ±5%	
R44	Composition, 13 kΩ, ±5%, 1/4 W	6099-3135	75042	BTS, 13 MΩ, ±5%	5905-702-4439
R45	Composition, 22 kΩ, ±5%, 1/4 W	6099-3225	75042	BTS, 22 kΩ, ±5%	5905-687-0002
R46	Composition, 10 kΩ, ±5%, 1/4 W	6099-3105	75042	BTS, 10 kΩ, ±5%	5905-683-2238
R47	Potentiometer Wire Wound, 10 kΩ, ±10%	6056-0144	11236	115, 10 kΩ, ±10%	
R48	Composition, 1 MΩ, ±5%, 1/4 W	6099-5105	75042	BTS, 1 MΩ, ±5%	
R49 and R50	Composition, 20 kΩ, ±5%, 1/4 W	6099-3205	75042	BTS, 20 kΩ, ±5%	5905-686-3368
R51	Potentiometer Wire Wound, 1 kΩ, ±10%	6056-0138	11236	115, 1 kΩ, ±10%	
R53	Composition, 160 kΩ, ±5%, 1/4 W	6099-4165	75042	BTS, 160 kΩ, ±5%	
R54	Composition, 30 kΩ, ±5%, 1/4 W	6099-3305	75042	BTS, 30 kΩ, ±5%	5905-803-2908
R55	Composition, 470 kΩ, ±5%, 1/4 W	6099-4475	75042	BTS, 470 kΩ, ±5%	
R56	Composition, 1 MΩ, ±5%, 1/4 W	6099-5105	75042	BTS, 1 MΩ, ±5%	
R57 and R58	Composition, 4.7 kΩ, ±5%, 1/4 W	6099-2475	75042	BTS, 4.7 kΩ, ±5%	5905-686-9992
R59	Composition, 7.5 kΩ, ±5%, 1/4 W	6099-2755	75042	BTS, 7.5 kΩ, ±5%	
R101	Potentiometer Wire Wound, 100 Ω ±10%	6056-0132	11236	115, 100 Ω, ±10%	
R102	Film, 226 Ω, ±1%, 1/8 W	6250-0226	75042	267 Ω, ±1%	
R103	Potentiometer Wire Wound, 1 kΩ, ±10%	6056-0138	11236	115, 1 kΩ, ±10%	
R104	Film, 2.67 Ω, ±1%, 1/8 W	6250-1267	75042	CEA, 2.67 kΩ, ±1%	5905-683-5564
R105	Potentiometer Wire Wound, 10 kΩ, ±10%	6056-0144	11236	115, 10 kΩ, ±10%	
R106	Film, 26.7 kΩ, ±1%, 1/8 W	6250-2267	75042	CEA, 26.7 kΩ, ±1%	
R107	Potentiometer Wire Wound, 10 kΩ, ±10%	6056-0144	11236	115, 10 kΩ, ±10%	
R108	Film, 95.3 kΩ, ±5%, 1/8 W	6251-2953	75042	CEA-TO, 95.3 kΩ, ±5%	
R109	Potentiometer Wire Wound, 10 Ω, ±10%	6056-0126	11236	115, 10 Ω, ±10%	
R110	Potentiometer, Wire Wound, 100 Ω ±10%	6056-0132	11236	115, 100 Ω, ±10%	
R111	Potentiometer Wire Wound, 1 kΩ, ±10%	6056-0138	11236	115, 1 kΩ, ±10%	
R112	Potentiometer Wire Wound, 50 Ω, ±10%	6056-0130	11236	115, 50 Ω, ±10%	
TRANSISTORS					
Q1	E101	8210-1187	17856	E101	
Q2 and Q3	2N4250	8210-1135	93916	2N4250	
Q4	2N4384	8210-1131	93916	2N4384	
Q5 and Q6	2N3905	8210-1114	04713	2N3905	
Q7	2N3903	8210-1132	93916	2N3903	
Q8 and Q9	2N3905	8210-1114	04713	2N3905	
Q10	2N3903	8210-1132			
Q11	2N3905	8210-1114	04713	2N3905	
Q12	2N3903	8210-1132	93916	2N3903	
Q13	2N3905	8210-1114	04713	2N3905	
Q14	E113	8210-1229	17856	E113	
Q15 and Q16	2N3903	8210-1132	93916	2N3903	



NOTE

The board is shown foil-side up. The number appearing on the foil side is not the part number. *Symbolism* Gray area = part; black circuit pattern = etch; Square pad in ckt pattern = collector, cathode (of diode), or + end of capcaitor.

Figure 6-3. Etched circuit assembly (P/N 1666-4700).

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
R121	Wire Wound, 1.0032 Ω, ±.025%, 1 W	6983-1005	24655	6983-1005	
R122	Wire Wound, .10.32 Ω, ±.025%, 1 W	6983-2003	24655	6983-2003	
R123	Wire Wound, 100.32 Ω, ±.025%, 1 W	6983-3015	24655	6983-3015	
R124	Wire Wound, 1.010 kΩ, ±.025%, 1 W	6983-4042	24655	6983-4042	
R125	Wire Wound, 9.995 kΩ, ±.025%, 1 W	6983-4043	24655	6983-4043	
R126	Wire Wound, 99.95 kΩ, ±.025%, 1 W	6991-2902	24655	6991-2902	
R127	Wire Wound, 999.5 kΩ, ±.025%, 1 W	6991-2903	24655	6991-2903	
R131	Composition, 180 Ω, ±5%, 1/4 W	6099-1185	75042	BTS, 180 Ω, ±5%	5905-682-4107
R132	Composition, 18 kΩ, ±5%, 1/4 W	6099-3185	75042	BTS, 18 kΩ, ±5%	5905-687-0000
R133	Composition, 1.8 MΩ, ±5%, 1/4 W	6099-5185	75042	BTS, 1.8 MΩ, ±5%	5905-688-3738
R134A, and R134B	Composition, 100 MΩ, ±10%, 1/2 W	6100-7105	01121	EB, 120 Ω, ±5%	
R141	Composition, 120 Ω, ±5%, 1 W	6110-1125	01121	RC32GF121J	5905-279-1726
R142	Composition, 430 Ω, ±5%, 1 W	6110-1435	01121	RC32GF431J	
R143	Composition, 820 Ω, ±5%, 1/2 W	6100-1825	01121	RC32GF821J	5905-279-2651
R144 thru R146	Composition, 1 kΩ, ±5%, 1 W	6110-2105	01121	RC32GF102J	5905-473-5251
R162	Film, 10 kΩ, ±0.1%, ±50 ppm 1/2 W	6188-2100	75042	MEC-T2, 10 kΩ, ±1%	
R163	Film, 453 k, ±1%, 1/4 W	6350-3453	75042	CEB, 453 k ±1%	

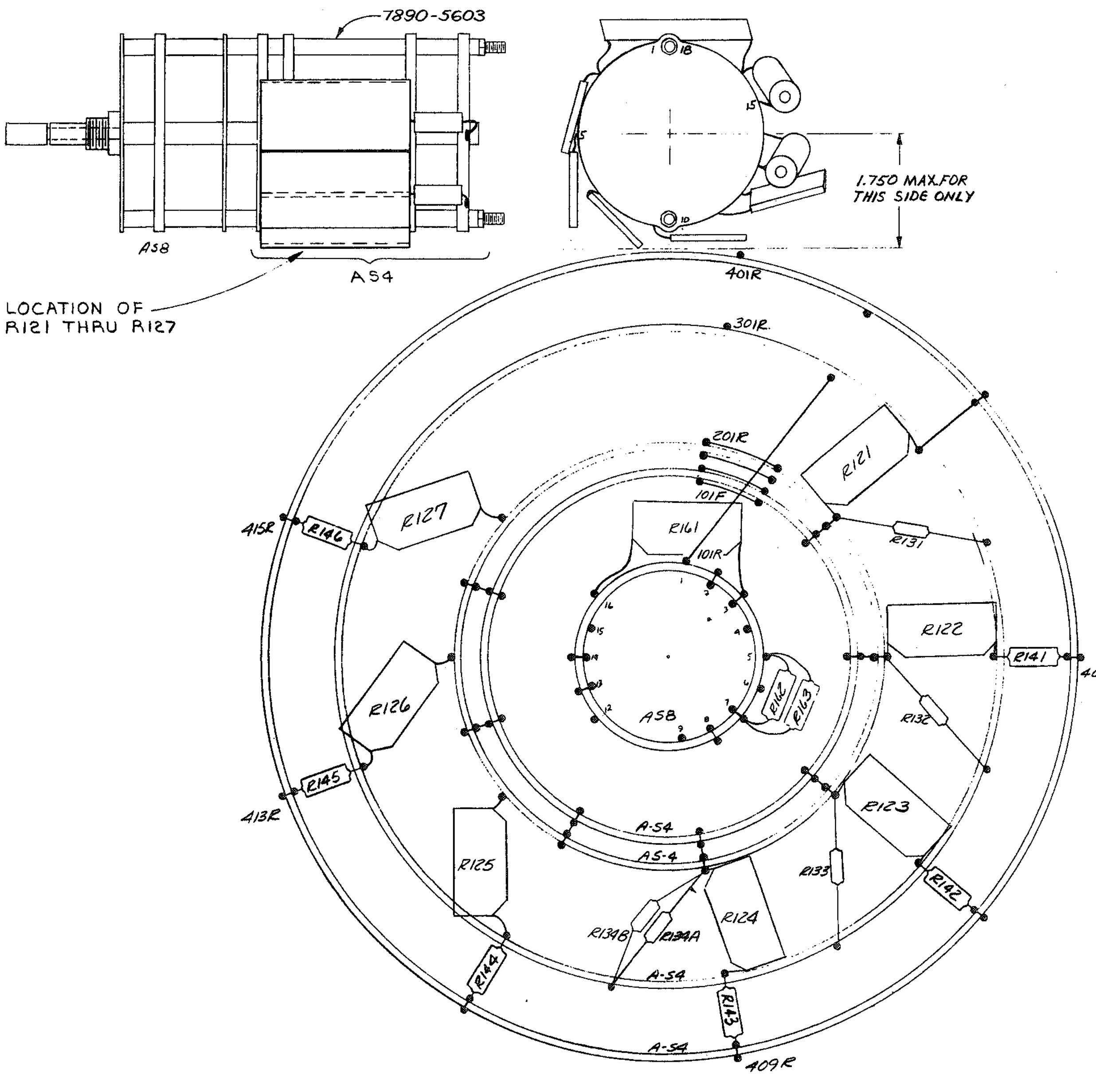


Figure 6-5. Standard arm switch assembly (AS4, AS8)(P/N 1666-2050).

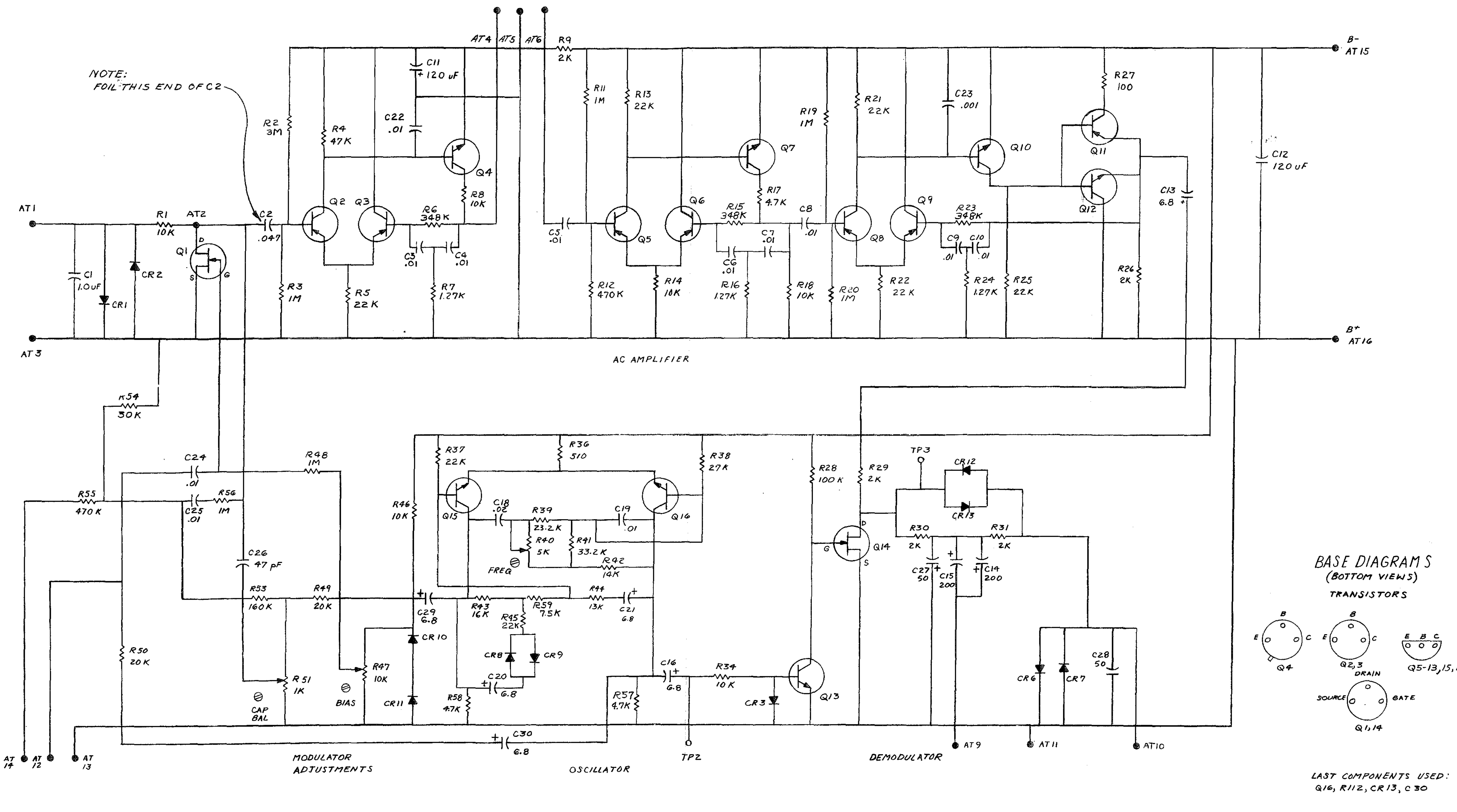


Figure 6-4. Schematic diagram of the detector board (P/N 1666-4700).

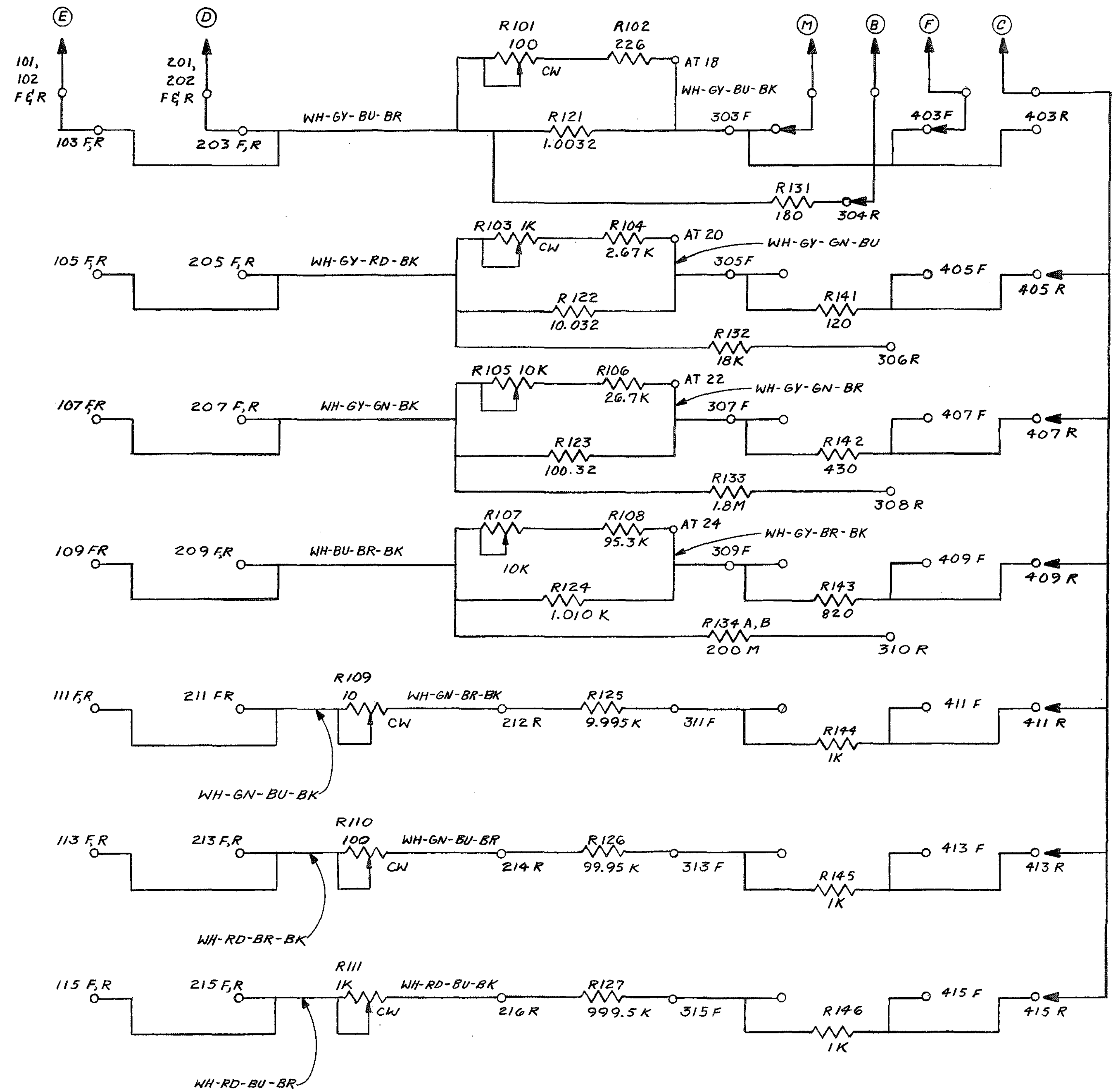


Figure 6-6. Schematic diagram of the standard arm.

UNLESS SPECIFIED, MAKE THE FOLLOWING CONNECTIONS

A-S4,405 F&R	TO	A-S4,305 F	BY	R141
A-S4,407 F&R	TO	A-S4,307F	BY	R142
A-S4,409 F&R	TO	A-S4,309F	BY	R143
A-S4,411 F&R	TO	A-S4,311F	BY	R144
A-S4,413 F&R	TO	A-S4,313F	BY	R145
A-S4,415 F&R	TO	A-S4,315F	BY	R146
A-S4,203 R	TO	A-S4,303F	BY	R121
A-S4,203R	TO	A-S4,304R	BY	R131
A-S4,205R	TO	A-S4,305F	BY	R122
A-S4,205R	TO	A-S4,306R	BY	R132
A-S4,207R	TO	A-S4,307F	BY	R123
A-S4,207R	TO	A-S4,308R	BY	R133
A-S4,209R	TO	A-S4,309F	BY	R124
A-S4,209R	TO	A-S4,310R	BY	R134A & R134B
A-S4,212R	TO	A-S4,311F	BY	R125
A-S4,214R	TO	A-S4,313F	BY	R126
A-S4,216R	TO	A-S4,315F	BY	R127
A-S8,105R	TO	A-S8,107R	BY	R162, R163
A-S8,116R	TO	A-S8,103F&R	BY	R161
A-S4,101F	TO	A-S4,102F		
A-S4,101R	TO	A-S4,102R		
A-S4,201F	TO	A-S4,202F		
A-S4,201R	TO	A-S4,202R		

A-S4,103F	TO	A-S4,103R	TO	A-S4,203F	TO	A-S4,203R
A-S4,105F	TO	A-S4,105R	TO	A-S4,205F	TO	A-S4,205R
A-S4,107F	TO	A-S4,107R	TO	A-S4,207F	TO	A-S4,207R
A-S4,109F	TO	A-S4,109R	TO	A-S4,209F	TO	A-S4,209R
A-S4,111F	TO	A-S4,111R	TO	A-S4,211F	TO	A-S4,211R
A-S4,113F	TO	A-S4,113R	TO	A-S4,213F	TO	A-S4,213R
A-S4,115F	TO	A-S4,115R	TO	A-S4,215F	TO	A-S4,215R
A-S4,303F	TO	A-S4,403F&R				

A-S8,102F	TO	A-S8,102R
A-S8,103F	TO	A-S8,103R
A-S8,107F	TO	A-S8,107R
A-S8,108F	TO	A-S8,108R
A-S8,113F	TO	A-S8,113R
A-S8,114F	TO	A-S8,114R
A-S8,101R	TO	A-S4,302F

FEDERAL MANUFACTURER'S CODE

From Federal Supply Code for Manufacturers Cataloging Handbooks H4-1 (Name to Code) and H4-2 (Code to Name) as supplemented through August, 1968.

Code	Manufacturer
00192	Jones Mfg. Co, Chicago, Illinois
00194	Walsco Electronics Corp, L.A., Calif.
00434	Schweber Electronics, Westburg, L.I., N.Y.
00656	Aerovox Corp, New Bedford, Mass.
00779	Amp Inc., Harrisburg Pa., 17105
01009	Alden Products Co, Brockton, Mass.
01121	Allen-Bradley, Co, Milwaukee, Wisc.
01236	Leeds Radio Company, N.Y.
01255	Litton Industries Inc, Beverly Hills, Calif.
01295	Texas Instruments, Inc, Dallas, Texas
02114	Ferroxcube Corp, Saugerties, N.Y. 12477
02606	Fenwal Lab Inc, Morton Grove, Ill.
02660	Amphenol Electron Corp, Broadview, Ill.
02768	Fastex, Des Plaines, Ill. 60016
03042	Carter Ink Co., Camb. Mass. 02142
03508	G.E. Semicon Prod, Syracuse, N.Y. 13201
03636	Grayburne, Yonkers, N.Y. 10701
03888	Pyrofilm Resistor Co, Cedar Knolls, N.J.
03911	Clairex Corp, New York, N.Y. 10001
04009	Arrow-Hart & Hegeman, Hart., Conn. 06106
04643	Digitronics Corp., Albertson, N.Y. 11507
04713	Motorola, Phoenix, Ariz. 85008
05170	Engr'd Electronics, Santa Ana, Calif. 92702
05624	Barber-Colman Co, Rockford, Ill. 61101
05748	Barnes Mfg. Co., Mansfield, O. 44901
05820	Wakefield Eng, Inc, Wakefield, Mass. 01880
06743	Clevite Corp., Cleveland, O. 44110
06751	Nuclear Corp.,of America, Inc., Phoenix, Ariz
07126	Digitron Co, Pasadena, Calif.
07127	Eagle Signal (E.W. Bliss Co.), Baraboo, Wisc.
07233	Cinch-Graphik, City of Industry, Calif.
07261	Avnet Corp, Culver City, Calif. 90230
07263	Fairchild Camera, Mountain View, Calif.
07387	Birtcher Corp, No. Los Angeles, Calif.
07595	Amer Semicond, Arlington Hts, Ill. 60004
07828	Bodine Corp, Bridgeport, Conn. 06605
07829	Bodine Electric Co, Chicago, Ill. 60618
07910	Cont Device Corp, Hawthorne, Calif.
07983	State Labs Inc, N.Y., N.Y. 10003
07999	Borg Inst., Delavan, Wisc. 53115
08730	Vemaline Prod Co., Franklin Lakes, N.J.
09213	G.E. Semiconductor, Buffalo, N.Y.
09408	Star-Tronics Inc, Georgetown, Mass. 01830
09823	Burgess Battery Co, Freeport, Ill.
09922	Burndy Corp, Norwalk, Conn. 06852
11236	C.T.S. of Berne, Inc, Berne, Ind. 46711
11599	Chandler Evans Corp, W. Hartford, Conn.
12040	National Semiconductor, Danbury, Conn. 120
12065	Transitron Electronic Corp., E. Boston, Mass.
12498	Crystalonics, Cambridge, Mass. 02140
12617	Homlin, Inc., Lake Millis, Wisc. 53551
12672	RCA, Woodbridge, N.J.
12697	Clarostat Mfg Co, Inc, Dover, N.H. 03820
12954	Dickson Electronics, Scottsdale, Ariz.
13327	Solitron Devices, Tappan, N.Y. 10983
14433	ITT Semiconductors, W. Palm Beach, Fla.
14655	Cornell-Dubilier Electric Co., Newark, N.J.
14674	Corning Glass Works, Corning, N.Y.
14936	General Instrument Corp, Hicksville, N.Y.
15116	Microdot Magnetics Inc, Los Angeles, Calif.
15238	ITT, Semiconductor Div, Lawrence, Mass.
15605	Cutler-Hammer Inc, Milwaukee, Wisc. 53233
16037	Spruce Pine Mica Co, Spruce Pine, N.C.
16636	Indiana General Corp, Oglesby, Ill. 61348
17771	Singer Co, Diehl Div, Somerville, N.J.
17856	Siliconix, Inc., Sunnyvale, Calif. 94086
18736	Voltronics Corp, Hanover, N.J. 07936
19396	Illinois Tool Works, Pakton Div, Chicago, Ill.
19048	Computer Diode Corp, S. Fairlawn, N.J. 07410
19617	Cabtron Corp., Chicago, Ill. 60622
19644	LRC Electronics, Horseheads, N.Y.
19701	Electra Mfg Co, Independence, Kansas 67301
20754	KMC Semiconductor Corp., Long Valley, N.J. 07853
21335	Fafnir Bearing Co, New Briton, Conn.
22753	UID Electronics Corp, Hollywood, Fla.
23342	Avnet Electronics Corp, Franklin Park, Ill.
24446	G.E., Schenectady, N.Y. 12305
24454	G.E., Electronics Comp, Syracuse, N.Y.
24455	G.E. (Lamp Div.), Nela Park, Cleveland, Ohio
24655	General Radio Co, W. Concord, Mass. 01781
26806	American Zettlet Inc, Costa Mesa, Calif.
28520	Hayman Mfg Co, Kenilworth, N.J.
28959	Hoffman Electronics Corp, El Monte, Calif.
30646	Beckman Instruments Inc, Cedar Grove, N.J. 07009
30874	I.B.M., Armonk, New York
32001	Jensen Mfg. Co, Chicago, Ill. 60638
33173	G.E. Comp, Owensboro, Ky. 42301
34141	Koehler Mfg. Co. Inc., Marlboro, Mass. 01752
35929	Constanta Co, Mont. 19, Que.
37942	P.R. Mallory & Co Inc, Indianapolis, Ind.
38443	Marlin-Rockwell Corp, Jamestown, N.Y.
40931	Honeywell Inc, Minneapolis, Minn. 55408
42190	Muter Co, Chicago, Ill. 60638
42498	National Co, Inc, Melrose, Mass. 02176
43991	Norma-Hoffman, Stanford, Conn. 06904
49671	RCA, New York, N.Y. 10020
49956	Raytheon Mfg Co, Waltham, Mass. 02154
53021	Sangamo Electric Co, Springfield, Ill. 62705
54294	Shallcross Mfg Co, Selma, N.C.
54715	Shure Brothers, Inc, Evanston, Ill.
56289	Sprague Electric Co, N. Adams, Mass.
59730	Thomas and Betts Co, Elizabeth, N.J. 07207
59875	TRW Inc, (Accessories Div), Cleveland, Ohio
60399	Torrington Mfg Co, Torrington, Conn.
61637	Union Carbide Corp, New York, N.Y. 10017
61864	United-Carr Fastener Corp, Boston, Mass.
63060	Victoreen Instrument Co, Inc, Cleveland, O.
63743	Ward Leonard Electric Co, Mt. Vernon, N.Y.
65083	Westinghouse (Lamp Div), Bloomfield, N.J.
65092	Weston Instruments, Newark, N.J.
70485	Atlantic-India Rubber, Chicago, Ill. 60607
70563	Amperite Co, Union City, N.J. 07087
70903	Belden Mfg Co, Chicago, Ill. 60644
71126	Bronson, Homer D, Co, Beacon Falls, Conn.
71279	Cambridge Thermionic Corp, Camb. Mass. 02138
71294	Canfield, H.O. Co, Clifton Forge, Va. 24422
71400	Bussman (McGraw Eidson), St. Louis, Mo.
71450	CTS Corp., Elkhart Ind. 46514
71468	ITT Cannon Elec, L.S., Calif. 90031
71590	Centralab, Inc, Milwaukee, Wisc. 53212
71666	Continental Carbon Co, Inc, New York, N.Y.
71729	Crescent Box Corp, E. Phila, Penn. 19134
71707	Coto Coil Co Inc, Providence, R.I.
71744	Chicago Miniature Lamp Works, Chicago, Ill.
71785	Cinch Mfg Co, Chicago, Ill. 60624
71823	Darnell Corp, Ltd, Downey, Calif. 90241
72136	Electro Motive Mfg Co, Wilmington, Conn.
72259	Nytronics Inc, Berkeley Heights, N.J. 07922
72619	Dialight Co, Brooklyn, N.Y. 11237
72699	General Instr Corp, Newark, N.J. 07104
72765	Drake Mfg Co, Chicago, Ill. 60656
72825	Hugh H. Eby Inc, Philadelphia, Penn. 19144
72962	Elastic Stop Nut Corp, Union, N.J. 07083
72982	Erie Technological Products Inc, Erie, Penn.
73138	Beckman Inc, Fullerton, Calif. 92634
73445	Amperex Electronics Co, Hicksville, N.Y.
73559	Carling Electric Co, W. Hartford, Conn.
73690	Elco Resistor Co, New York, N.Y.
73899	JFD Electronics Corp, Brooklyn, N.Y. 11219
74193	Heinemann Electric Co, Trenton, N.J.
74861	Industrial Condenser Corp, Chicago, Ill. 60618
74868	Amphenol Corp, Danbury, Conn. 06810
74970	E.F. Johnson Co, Waseca, Minn. 56093
75042	IRC Inc, Philadelphia, Penn. 19108
75382	Kulka Electric Corp, Mt. Vernon, N.Y.
75491	Lafayette Industrial Electronics, Jamaica, N.Y.
75608	Linden and Co, Providence, R.I.
75915	Littelfuse, Inc, Des Plaines, Ill. 60016
76005	Lord Mfg Co, Erie, Penn. 16512
76149	Mallory Electric Corp, Detroit, Mich. 48204
76487	James Millen Mfg. Co., Malden, Mass. 02148
76545	Mueller Electric Co., Cleveland, Ohio 44114
76684	National Tube Co, Pittsburg, Penn.
76854	Oak Mfg Co, Crystal Lake, Ill.
77147	Patton MacGuyer Co, Providence, R.I.
77166	Pass-Seymour, Syracuse, N.Y.
77263	Pierce Roberts Rubber Co, Trenton, N.J.
77339	Positive Lockwasher Co, Newark, N.J.
77342	American Machine & Foundry Co, Princton, Ind. 47570
77542	Ray-O-Vac Co, Madison, Wisc.
77630	TRW, Electronic Comp, Camden, N.J. 08103
77638	General Instruments Corp, Brooklyn, N.Y.
78189	Shakeproof (Ill. Took Works), Elgin, Ill. 60120
78277	Sigma Instruments Inc, S. Braintree, Mass.
78488	Stackpole Carbon Co, St. Marys, Penn.
78553	Tinnerman Products, Inc, Cleveland, Ohio
79089	RCA, Rec Tube & Semicond, Harrison, N.J.
79725	Wiremold Co, Hartford, Conn. 06110
79963	Zierick Mfg Co, New Rochelle, N.Y.
80009	Tektronix Inc, Beaverton, Ore. 97005
80030	Prestole Fastener, Toledo, Ohio
80048	Vickers Inc, St. Louis, Mo.
80131	Electronic Industries Assoc, Washington, D.C.
80183	Sprague Products Co, No. Adams, Mass.
80211	Motorola Inc., Franklin Park, Ill. 60131
80258	Standard Oil Co, Lafeyette, Ind.
80294	Bourns Inc, Riverside, Calif. 92506
80368	Sylvania Electric Products Inc, N.Y. 10017
80431	Air Filter Corp, Milwaukee, Wisc. 53218
80583	Hammarlund Co, Inc, New York, N.Y.
80740	Beckman Instruments, Inc, Fullerton, Calif.
80894	Pure Carbon Co., St. Marys, Penn. 15857
81030	International Instrument, Orange, Conn.
81073	Grayhill Inc, LaGrange, Ill. 60525
81143	Isolantite Mfg Corp, Stirling, N.J. 07980
81349	Military Specifications
81350	Joint Army-Navy Specifications
81386	Fenwal Electronics, Framingham, Mass. 01701
81483	International Rectifier Corp, El Segundo, Calif. 90245
81751	Columbus Electronics Corp, Yonkers, N.Y.
81831	Filtron Co, Flushing, L.I., N.Y. 11354
81840	Ledex Inc, Dayton, Ohio 45402
81860	Barry-Wright Corp, Watertown, Mass.
82219	Sylvania Elec Prod, Emporium, Penn.
82273	Indiana Pattern & Model Works, LaPort, Ind.
82389	Switchcraft Inc, Chicago, Ill. 60630
82647	Metals & Controls Inc, Attleboro, Mass.
82807	Milwaukee Resistor Co, Milwaukee, Wisc.
82877	Rotron Mfg. Co. Inc., Woodstock, N.Y. 12498
83033	Meissner Mfg, (Maguire Ind) Mt. Carmel, Ill.
83058	Carr Fastener Co, Cambridge, Mass.
83186	Victory Engineering, Springfield, N.J. 07081
83361	Bearing Specialty Co, San Francisco, Calif.
83587	Solar Electric Corp, Warren, Penn.
83740	Union Carbide Corp, New York, N.Y. 10017
83781	National Electronics Inc, Geneva, Ill.
84411	TRW Capacitor Div, Ogallala, Nebr.
84835	Lehigh Metal Prods, Cambridge, Mass. 02140
84971	TA Mfg Corp, Los Angeles, Calif.
86577	Precision Metal Prods, Stoneham, Mass. 02180
86684	RCA (Elect. Comp & Dev), Harrison, N.J.
86687	REC Corp, New Rochelle, N.Y. 10801
86800	Cont Electronics Corp, Brooklyn, N.Y. 11222
88140	Cutler-Hammer Inc, Lincoln, Ill.
88219	Gould Nat. Batteries Inc, Trenton, N.J.
88419	Cornell-Dubilier, Fuquay-Varina, N.C.
88627	K & G Mfg Co, New York, N.Y.
89482	Holtzer-Cabot Corp, Boston, Mass.
89665	United Transformer Co, Chicago, Ill.
90201	Mallory Capacitor Co, Indianapolis, Ind.
90634	Gulton Industries, Inc, Metuchen, N.J. 08840
90750	Westinghouse Electric Corp, Boston, Mass.
90952	Hardware Products Co, Reading, Penn. 19602
91032	Continental Wire Corp, York, Penn. 17405
91146	ITT (Cannon Electric Inc), Salem, Mass.
91210	Gerber Mfg. Co, Mishawaka, Ind.
91293	Johanson Mfg Co, Boonton, N.J. 07005
91506	Augat Inc, Attleboro, Mass. 02703
91598	Chandler Co, Wethersfield, Conn. 06109
91637	Dale Electronics Inc, Columbus, Nebr.
91662	Elco Corp, Willow Grove, Penn.
91719	General Instruments, Inc, Dallas, Texas
91916	Mephisto Tool Co. Inc, Hudson, N.Y. 12534
91929	Honeywell Inc, Freeport, Ill.
92519	Electra Insul Corp, Woodside, L.I., N.Y.
92678	E.G.&G., Boston, Mass.
92739	Ampex Corp, Redwood City, Calif. 94063
93332	Sylvania Elect Prods, Inc, Woburn, Mass.
93618	R. & C. Mfg. Co. of Penn. Inc, Ramey, Penn.
93916	Cramer Products Co, New York, N.Y. 10013
94144	Raytheon Co, Components Div, Quincy, Mass.
94154	Tung Sol Electric Inc, Newark, N.J.
94271	Weston Instruments Inc, Archibald, Penn. 18403
94589	Dickson Co., Chicago, Ill. 60619
94800	Atlas Industrial Corp., Brooklyn, N.H.
95076	Garde Mfg. Co., Cumberland, R.I.
95121	Quality Components Inc, St. Mary's, Penn.
95146	Alco Electronics Mfg Co, Lawrence, Mass.
95238	Continental Connector Corp, Woodside, N.Y.
95275	Vitramon, Inc, Bridgeport, Conn.
95354	Methode Mfg Co, Chicago, Ill.
95412	General Electric Co, Schenectady, N.Y.
95794	Anaconda Amer Brass Co, Torrington, Conn.
96095	Hi-Q Div. of Aerovox Corp, Orlean, N.Y.
96214	Texas Instruments Inc, Dallas, Texas 75209
96256	Thordarson-Meissner, Mt. Carmel, Ill.
96341	Microwave Associates Inc, Burlington, Mass.
96791	Amphenol Corp, Janesville, Wisc. 53545
96906	Military Standards
97684	Models Inc, North Bergen, N.J.
98291	Sealectro Corp, Mamaroneck, N.Y. 10544
98474	Compar Inc, Burlingame, Calif.
98821	North Hills Electronics Inc., Glen Cove, N.Y.
99117	Metavac Inc, Flushing, N.Y. 11358
99180	Transitron Electronics Corp, Melrose, Mass.
99313	Varian, Palo Alto, Calif. 94303
99378	Atlee Corp, Winchester, Mass. 01890
99800	Delevan Electronics Corp, E. Aurora, N.Y.

General Radio

300 BAKER AVENUE, CONCORD, MASSACHUSETTS 01742

***NEW YORK**
Delaware, New Jersey, New York, Eastern Pennsylvania
380 Midland Avenue, Saddle Brook, NJ 07662
Telephone: (NJ) 201 791-8990 (NY) 212 964-2722
TWX: 710 988-2205

***BOSTON**
Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
(SALES)
Bolton, MA 01740
Telephone: 617 646-0550
(SERVICE)
300 Baker Ave., Concord, MA 01742
Telephone: 617 369-8770 • TWX: 710 347-1051

***WASHINGTON, D.C.**
Maryland, Virginia, West Virginia, (Wash. D.C.)
15 Firstfield Road, Gaithersburg, MD 20760
Telephone: 301 948-7071 • TWX: 710 828-9741

ATLANTA
Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Tennessee
7 Dunwoody Park, Suite 115, Atlanta, GA 30341
Telephone: 404 457-2485, (FLA) 813 531-0148

DAYTON
Kentucky, Indiana, Michigan, Ohio, Western Pennsylvania
3300 S. Dixie Drive, Dayton, OH 45439
Telephone: 513 294-1500 • TWX: 810-459-1785

***CHICAGO**
Illinois, Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, Wisconsin
9440 West Foster Avenue, Chicago, IL 60656
Telephone: 312 992-0800 • TWX: 910 221-5486

***DALLAS**
Arkansas, Colorado, Louisiana, New Mexico, Oklahoma, Texas, Wyoming
777 So. Central Expressway, Suite 1-D, Richardson, TX 75080
Telephone: 214 234-3357, (HOUSTON) 713 464-5112
• TWX: 910 867-4771

***LOS ANGELES**
Arizona, Southern California, Hawaii, Nevada (Clark County only)
17361 Armstrong Avenue
Irvine Industrial Complex, Irvine, CA 92705
Telephone: 714 540-9830 • TWX: 910 595-1762

***SAN FRANCISCO**
Northern California, British Columbia, Idaho, Montana, Nevada (except Clark County), Oregon, Washington, Utah
1050 East Meadow Circle, Palo Alto, CA 94303
Telephone: 415 948-8233 • TWX: 910 373-1203
Alaska 907 279-5741

CANADA
***General Radio Canada Limited**
307 Evans Avenue, Toronto, Ontario M8Z 1K2
Telephone: 416 252-3395 • TELEX: 06-967624
Montreal 514 737-2126 • **Ottawa** 613 233-4237

EUROPE, AFRICA, and NEAR EAST
***General Radio Company (Overseas)**
P. O. Box, CH-8034 Zurich, Switzerland
Telephone: (01) 55 24 20 • TELEX: 845-53638
***Paris** 355 7546 • **Lyon** 28 01 45 • ***Milan** 29 31 29 • ***Munich** 40 18 01 • **Hamburg** 45 06 56 • ***Bourne End (England)** 22567

***ASIA, PACIFIC, and LATIN AMERICA**
General Radio International Division
Concord, Mass 01742
Cable: GENRADCO CONCORD (Mass) • TELEX: 923-354

GR COMPANIES • Grason-Stadler • Time/Data • Techware Computing Corp. GR ASSOCIATE • Micronetic Systems, Inc.

*Service Facilities

Printed in USA