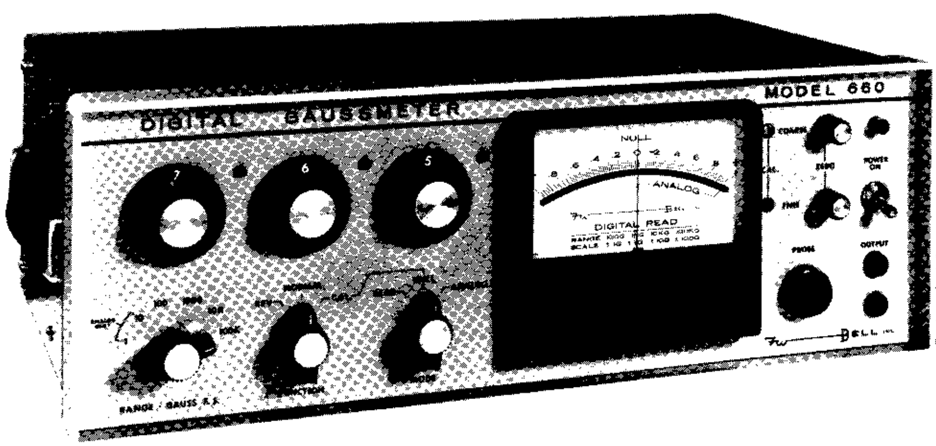
MODEL 660

DIGITAL GAUSSMETER

Operating and Maintenance Manual



F.W. BELL

6120 Hanging Moss Road • Orlando, FL 32807
Phone: 407-678-6900
TWX: 810-853-3115
Fax: 407-677-5765

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SECTION I

General Description

I-1 GENERAL

The Model 660 Digital Gaussmeter is a precision Hall effect magnetic field measuring instrument with a measurement range of 0.1 gauss to 100 k gauss. It has capabilities for (a) direct scale reading flux density measurements, (b) digital flux density measurements, and (c) measurements of small changes in field density on an expanded meter scale. It has been designed especially for use with recently developed Hall effect magnetic field probes manufactured by F. W. Bell, Inc. including the new high-linearity temperature compensated Hall-Pak generators by Bell. Transverse and axial probe configurations are available, and probes can be calibrated in the Model 660 using a simple built-in calibration procedure. Measurement resolution extends from 2 mG (milligauss) per scale division (100 mG, full-scale) to 2 gauss per scale division at 100,000 gauss full-scale. Standard probes are available for use to 30 kG.

The two basic operating modes are (1) ANALOG mode in which a linear meter scale is used for readout and a proportional output voltage is available at the output jacks, and (2) DIGITAL mode using the three manually operated digit dials for readout, plus a linear error proportional output voltage.

The ANALOG mode uses a linear scale, direct reading panel meter calibrated in gauss for flux density readout. It is useful for quickly determining the value of an unknown field or one that is varying too widely for digital readout. Also, it is valuable where a flux-proportional output voltage is needed for scanning or plotting, or for field monitoring or control.

The DIGITAL mode of operation provides maximum accuracy as well as the higher readout resolution of three digits plus the meter scale for third digit interpolation. This mode provides precise readout of steady magnetic fields. It is useful for observing and measuring small changes in large fields, for gradient measurements, and for accurate comparisons of field strengths. Incremental or interpolation sensitivity is sufficient to provide full-scale meter deflection for a change of 1 part in 1000 of the full-scale range, and a maximum resolution of 2 parts in 10^5 per minor scale division.

Digital operation of the Model 660 utilizes the potentiometric null-balance technique in which an internally generated signal is adjusted to match the input signal to be measured. The amplified difference signal appears on the panel meter as an indication of balance, or as the error between the unknown and the digitally set value. The digital mode tends to eliminate measurement errors due to amplifier non-linearity, drift, meter scale errors and variations in Hall input excitation.

Two DIGITAL operating modes are available:

(a) DIGITAL NULL. In which the panel meter operates as a null indicator in a compression circuit to assure that large unbalance signals remain on scale.

(b) DIGITAL READ. Operation in digital READ mode is the same except for linear scale readout of the difference between the digital setting and the true value. Full scale meter deflection corresponds to one digit on the third digit dial and interpolation of the 3rd digit is obtained on a linear meter scale.

Factory calibration of all probes for the 660 Gaussmeter is carried out with reference to a laboratory standard magnet of high long-term stability. This standard is measured by Nuclear Magnetic Resonance (NMR) technique and provides traceability of calibration to the National Bureau of Standards. A built-in calibration reference enables the user to recalibrate the probe without the need for a calibration magnet or standard magnetic field.

SECTION II

Specifications

II-1 ELECTRICAL AND PERFORMANCE SPECIFICATIONS

(a) Operating Modes:

1. Analog mode with linear meter scale readout and analog flux-proportional output voltage.
2. Digital NULL mode using 3 manually operated digit dials and null meter.
3. Digital READ mode using 3 manually operated digit dials plus linear-scale meter interpolation of the 3rd digit.

(b) Measurement Ranges:

Measurement of static or varying magnetic field strength in the range of 0.1 gauss full scale to 30,000 gauss (10 microtesla to 3 tesla) in decade ranges as follows:

FULL SCALE RANGE Analog Mode	FULL SCALE RANGE Digital Mode	SENSITIVITY-FULL SCALE Digital Read Mode
1 gauss	....	....
10 gauss	....	....
100 gauss	100 gauss	0.1 gauss
1000 gauss	1000 gauss	1 gauss
10 kgauss	10 kgauss	10 gauss
*100 kgauss	*100 kgauss	100 gauss

* Separate probes are available for measurements up to 10 kG and up to 30 kG. See specifications on probes.

(c) Resolution of Readout:

1. Analog Mode:
   50-0-50 division meter scale, 2% FS per scale division.
2. Digital NULL Mode:
   3 digits or 1 part in 1000 of full scale.
3. Digital READ Mode:
   3 digits plus linear meter scale interpolation to obtain maximum 2 parts in 10^5 of FS per scale division.

(d) Calibration:

Individual factory probe calibration provides:

1. Probe CAL CONSTANT referenced to standard NMR** magnet traceable to the National Bureau of Standards.
2. Individual machine-plotted probe error curve showing deviations from true linearity, usable for readout correction.
3. Accuracy of calibration using built-in reference and probe CAL CONSTANT is ±0.2%.

** Note: NMR refers to Nuclear Magnetic Resonance measurement method.

(e) Accuracy of Measurement:

Using the probe CAL CONSTANT and built-in calibration feature[1]:

MODE	PROBE RANGE	LIMITS OF ERROR
Analog, direct reading from panel meter[2]	10 kG	±0.5% of reading plus meter scale
	30 kG	±1.0% of reading plus meter scale
Analog, accuracy of analog voltage at output jacks	10 kG	±0.6% of reading plus 0.1% FS
	30 kG	±1.0% of reading plus 0.1% FS
Digital NULL, direct digit dial readout	10 kG	±0.4% of reading ±1 digit
	30 kG	±0.85% of reading ±1 digit
Digital READ, maximum capability using 3 digit dials plus meter. Probe data corrected.	10 kG	±0.3% of reading ±0.1 gauss
	30 kG	±0.5% of reading ±1.0 gauss
Deviation accuracy, digital READ mode direct panel meter readout of field changes	10 kG	±1.5% of FS deviation range[3]
	30 kG	±3% of FS deviation range[3]

[1] Improved accuracy is possible by calibration against a magnetic field having higher known accuracy.

[2] Meter scale linearity ±2.0% FS, calibrated at FS.

[3] Depends on slope of deviation error plot. Deviation range is meter scale range in digital READ mode. Maximum error shown. Sect. IV-4 describes correction.

(f) Temperature Influence:

1. Probe[4] (Hall output) Non-Temp-Compensated Type:
   −0.04% of reading per deg. C max.
   −0.025% of reading per deg. C typical
   (−20°C to +60°C)
2. Probe, Temp-Compensated Type (when used with 660 Gaussmeter):
   ±0.005% of reading per deg. C max.
   (−20°C to +60°C). Mean value.
3. Probe[5] zero field temperature influence:
   ±40 milligauss per deg. C (−20°C to +60°C)

[4] This error calibrated out by recalibration at new temperature.

[5] This error calibrated out by rezeroing at new temperature.

(g) Output Jacks:

1. Output voltage:
   1.0 volt dc FS adjustable to ±0.1%
2. Source resistance:
   110 Ω approx.
3. Maximum ac field frequency:
   10-30 Hz, depending on level
4. Response time for full scale step input:
   40 msec approx.
5. Noise:
   digital <25 mV rms
   analog <1mV rms, <3mV rms on 1 G range

(h) Stability:

1. Line voltage (Digital READ — 10 kG field):
   ±1 minor scale division, 105 to 125 V line
2. Short-term measurement error after thermal stability:
   no measurable drift in 1 hour at 25°C
3. Long-term measurement error after thermal stability:
   <1 digit per 8 hours at 25°C

(i) Operating temperature range:

rated: 0°C to +40°C
maximum: −20°C to +60°C

(j) Standard Probe Type:

	Range
STJ6-0402* Transverse	10 kG
HTB6-0608 Transverse	10 kG
STL6-0402* Transverse	30 kG
STG6-0402 Transverse	30 kG
SAK6-1805* Axial	10 kG
SAB6-1808 Axial	10 kG
SAN6-1808* Axial	30 kG
SAG6-1808 Axial	30 kG

*10X Sensitivity is 1/10 Standard Probe (1X Sensitivity)
Many other standard probes are available.

(k) Input Power Requirements:

Voltage:	105-125 V	or	210-250 V
Current:	60 mA		30 mA
	7 W		7 W
Frequency:	50-60 Hz		50-60 Hz

II-2 PHYSICAL SPECIFICATIONS, CONTROLS AND CONNECTORS

(a) Front Panel:

1. *Power.* This toggle switch turns on the primary power to the unit.

2. *Range Switch.* This switch is marked GAUSS FULL SCALE. Its purpose is to select the desired full scale measurement range. It indicates the maximum value of field strength that can be nulled with the digit dials in digital operation, and the maximum scale reading on the meter in analog operation.

3. *Function Switch.* Selects either measurement or calibrate function. It includes input polarity reversal to permit an upscale reading without physically reversing the probe. In the CAL position, the input is connected to an internal reference standard for calibration of the probe to the instrument.

4. *Mode Switch.* Used for selection of the operating mode. In the ANALOG position, the front panel meter is used as a direct linear scale readout. In the NULL position, the meter serves as a null indicator while searching for the correct field level with the digit dials. In the READ position, the meter scale gives linear interpolation between digits on the third digit dial.

5. *Digit Dials.* Used for nulling in DIGITAL mode. Flux density is indicated directly on digit dials after the nulling operation.

6. *Decimal Point Lights.* Red lights indicate the location of the decimal point in digital operation. Readings are in gauss or kilogauss as indicated by the range switch setting.

7. *Output Jacks.* The BLACK-RED front panel jacks will accept a standard double banana plug with ¾" spacing. They provide an output voltage, proportional to the meter reading, for use with external instrumentation. Output polarity is positive for upscale (+) meter readings and negative for downscale (−) meter readings. The black output jack is grounded to the instrument case.

8. *Zero Controls.* Controls marked COARSE and FINE ZERO are used to balance each probe for zero output in the absence of a magnetic field. They will also suppress small residual fields up to approximately 50 G.

9. *Calibrate Controls.* The controls marked COARSE and FINE CAL are used to adjust the calibration according to the internal calibration standard or an external calibration magnet.

(b) Rear Panel:

1. *Screwdriver Adjustment Marked I_c (R4).* This control is used to adjust the regulated Hall generator exciting current to 100 mA rms.

2. *Screwdriver Adjustment Marked OUTPUT (R5).* This adjustment calibrates the output from the front panel jacks to exactly 1.0 V dc for full scale input flux field.

(c) Overall Dimensions:

6⅛" High 16½" Wide 12½" Deep

(d) Weight:

1. Shipping 27 lbs.
2. Net 18 lbs.

SECTION III

Installation and Pre-Operational Adjustments

III-1 POWER

The power cable supplied has three conductors and is terminated in a three-prong plug recommended by the National Electrical Manufacturers' Association. The round pin is connected to the case and grounds the instrument case and output terminals when used with the appropriate receptacle. An adapter may be used for connection to a standard two contact receptacle. The ground is brought out of the adapter by means of a short wire which should be connected to a suitable ground for protection of operating personnel. Only when a ground is supplied by associated equipment should this ground be unused to prevent common ground currents.

The Model 660 is normally wired for operation from a 117 V, 50-60 Hz power source. To connect it for 234 V, 50-60 Hz operation, the dual primary of the power transformer is changed from parallel to series connection. Refer to the schematic diagram for details. When converting from 117 V to 234 V operation, replace the ⅛ ampere slow-blow fuse with a 1/16 ampere slow-blow type.

Before turning the instrument on, make certain the available power matches the voltage and frequency rating of the gaussmeter. Connect a probe to the input socket. It is important that the plug is pushed firmly into the panel socket observing the key slot, then the clamp ring screwed on until it is snug. Check the meter mechanical zero by aligning the pointer with its image in the mirror. If necessary, adjust the screw on the meter face to bring the pointer to exactly zero reading. Set the panel controls as follows:

RANGE switch to 100 kG
FUNCTION switch to NORMAL
MODE switch to NULL
DIGIT switches to 000

Determine whether the 3-prong to 2-prong line cord adapter should be used (see paragraph above). Plug in the power cord and turn the POWER switch ON. Allow 5 minutes for preliminary warm up.

III-2 PROBE ZEROING ADJUSTMENTS

These adjustment knobs are used to bring the meter reading to zero with zero field at the Hall probe. Rotate the RANGE switch counter-clockwise until reading is obtained on the meter. Adjust COARSE ZERO control to reduce reading toward zero while reducing the RANGE setting until near zero is obtained on the 100 G range. The probe must be shielded from the earth's field to obtain a true zero. The use of a zero gauss chamber is recommended. Refer to Section IV-2(b) for further details on zeroing.

III-3 CALIBRATION PROCEDURE

The calibration procedure should be carried out before using the instrument for magnetic field measurements. It must also be done whenever probes are changed. Allow sufficient time for the instrument to reach stability before calibrating. The probe zeroing adjustments described previously must first be carried out.

Calibration consists of adjusting the CAL controls in accordance with the sensitivity of the particular probe in use, using one of the following methods:

(a) Calibration against Probe CAL CONSTANT, or
(b) Calibration against a Reference Magnet

The CAL CONSTANT method is a simple, easy to apply calibration technique which provides rated accuracy as shown in the specifications. It is recommended because of its reliability, accuracy and ease of application. Calibration against a known field can provide improved accuracy only if this reference field meets the requirements for accuracy and uniformity outlined in (b) below.

(a) Calibration Against The Probe CAL CONSTANT:

The CAL CONSTANT method uses an internal calibration signal generated by high-stability resistors and standardized by factory adjustment. Each probe has been factory checked against calibration magnets under standard test conditions and is assigned a sensitivity constant, called the CAL CONSTANT. This constant is a three (3) digit number stamped on the probe name plate. To transfer this value into the instrument, turn the FUNCTION switch to CAL and the MODE switch to NULL. The RANGE switch may be in any position. Set the digit switches to the value of the CAL CONSTANT. Next adjust the COARSE and FINE CAL controls to obtain a null indication on the panel meter. This completes the calibration. Calibration by this method adjusts gaussmeter response so that gaussmeter readings duplicate the probe deviation response curve as shown on the error plot supplied with the probe.

The CAL CONSTANT should be regarded as a 25°C (77°F) value. Non-compensated (NC) probes read correctly at 25°C when calibrated by this method. The actual temperature of the (NC) Hall probe during this calibration is not important, but the probe is considered calibrated at 25°C, its readings should be corrected for other temperatures as described in Section IV-2(f).

In case it is not practical to bring the probe to 25°C during calibration, the CAL CONSTANT can be corrected for the actual probe temperature by the formula below, CAL CONSTANT (corrected) =

$$\text{CAL CONST (25°C)} \left(1 - (t_p - 25)\frac{TC}{100}\right)$$

where: t_p is the probe temperature in deg. C during calibration

TC is the temperature coefficient of the probe excluding compensation (typical mean value is -0.025% per deg. C)

For example, a TC probe having a CAL NUMBER of 850 is to be calibrated when the probe temperature is 30°C (86°F). The corrected CAL CONSTANT for 30°C is found as follows:

$$\begin{aligned} \text{CAL CONSTANT (30°C)} & \\ &= 850\left(1 - (30-25)\frac{-0.025}{100}\right) \\ &= 850\,[1 + 5 \times 0.00025] \\ &= 850 + 1.0625 \\ &= 851\ (+) \end{aligned}$$

The digit dials would be set to 851 instead of 850. Note that the correction is approximate, based on a typical value of probe temperature coefficient, but it is of small magnitude. After the TC probe is calibrated, no further correction for temperature is needed during readout. Notice that the negative value of TC is carried into the formula, causing the corrected CAL NUMBER to be increased in the example given. If the probe temperature was less than 25°C, the corrected CAL CONSTANT would be decreased.

A temperature change in deg. F can be converted directly to a deg. C change by multiplying by 5/9.

(b) Calibration Against A Reference Magnet:

The requirements for a calibration magnetic field are:

1. Flux density preferably not less than 1000 gauss, 10 kG preferred.
2. Field accuracy should be better than 0.1% absolute.
3. Field uniformity 1 part in 10^4 per cm^3 or better.
4. Magnet pole pieces within 1 or 2 deg. C of room temperature.

SECTION IV

Operating Instructions

IV-1 MEASUREMENT PROCEDURE

(a) General:

After completing the pre-operational adjustments described in Section III, the unit is ready for operation. Allow sufficient time after turn-on for the unit and probe to reach operating temperature. Due to the very high resolution of readout in the DIGITAL mode, it is advisable to position the probe securely in the measurement position using a probe holding fixture or clamp whenever possible. It may be difficult or impossible to get a good field measurement in digital operation unless the probe position is stable and the field itself is reasonably uniform and stable at the point of measurement. A well regulated power supply is essential for electromagnets because line voltage fluxuations produce random field changes, which appear greatly magnified by the gaussmeter. The probe can be hand-held only when using the analog mode of operation.

The following paragraphs describe in detail the analog and digital operating modes, the effects of probe temperature variations and use of the output jacks. They are recommended reading for those who expect maximum usefulness from the gaussmeter. As a general rule the analog mode should first be used during set-up to determine the approximate value of the field, and other preliminary tests. The digital mode should be used only for the final measurement where accuracy is required. See Section III-1 for power requirements before turning the unit on.

(b) Zeroing:

Zero controls are provided on the gaussmeter to enable the meter reading to be adjusted to a zero reading. This is necessary for two reasons; (1) Hall probes do not produce exactly zero output when the magnetic field is zero and; (2) small undesired residual or stray fields at the probe during measurement have the effect of a zero offset on the reading. The zero controls can electrically cancel out one or both of the above effects. The field at the probe can be reduced to essentially zero by the use of a "zero gauss chamber." This is a mu-metal shield can which serves to bypass external fields around the probe. Slip the end of the Hall probe down inside the zero chamber for a near-zero field condition, and then adjust the zero controls to obtain a zero meter reading on the lowest range to be used.

Maximum sensitivity for zero adjustment is obtained in Digital mode on the 100 gauss range with digit dials set to 000. Standard probes have a zero chamber packaged with them.

Use care not to place the zero gauss chamber in a strong magnetic field. Also, it must not be allowed to come into direct contact with a magnet since it may become slightly magnetized and will not provide a true zero. It can be demagnetized by slowly passing the chamber through the ac field of a demagnetizer coil carrying ac line current.

The measurement of the absolute value of magnetic field strength implies a true zero reference. Consequently, a zero chamber must be used to obtain essentially true zero adjustment for all absolute field measurements.

Readings taken in the presence of the earth's ambient field will generally have the earth's field, or some component of it, included in the reading of the unknown field. Thus it may be necessary to subtract the ambient field reading from the total to obtain the value of the unknown field. A method of avoiding this subtraction is to take a "relative measurement" in which the total field is measured relative to the ambient field. To do this, the ambient field is canceled in the gaussmeter reading by adjustment of the zero controls in the presence of the ambient field without using the zero gauss chamber. The ambient field becomes the reference for the measurement, and the gaussmeter will read any change in field from this reference directly, thus subtraction of the ambient is not necessary.

A word of caution about relative measurements — errors may result unless the probe is carefully clamped in position before zeroing. Also, the method is successful only if the field to be measured can then be presented to the probe without changing the probe position with relation to the ambient field, and without altering the ambient field at the probe during measurement. The change in field at the probe will then be measured by the gaussmeter as an absolute value, and the ambient field excluded from the reading. Since the probe position must remain fixed during the measurement, this method is not always practical. The zero controls are capable of suppressing residual fields up to about 50 gauss.

Since the ambient due to the earth's field seldom exceeds 1 gauss, the precautions mentioned above apply only when measuring fields less than 500 or 1000 gauss. When in doubt, the ambient field should be measured, both as to magnitude and direction. If a magnet being measured should have an iron structure which will modify the ambient field by its presence, it may be necessary to take several measurements in different orientations with respect to the earth's field. Obtain the two extreme values and use the mean value between these as the correct value.

The zero adjustments should be checked frequently, if possible, during the course of a measurement, particularly when using low gaussmeter ranges. If a change in temperature occurs at the probe, rezeroing may be necessary. Zero drift versus temperature is very small and is not compensated. The zero controls are never used to shift the calibration of the gaussmeter.

(c) Calibration Check:

A calibration check can easily be made at any time during a series of measurements without disturbing the probe if the CAL CONSTANT method is used. Refer to the instructions in Section III-3 on Calibration.

(d) Analog Mode Operation:

The range switch should first be set to a value higher than the expected value of the field to be measured. The analog mode is useful to quickly determine the approximate field value prior to a more accurate digital measurement. Align the probe for maximum output reading in the field whenever the absolute field magnitude is to be measured. An upscale (+ or right hand) meter deflection will be obtained when the field vector enters a transverse probe at right angles to the flat element surface and thru the circle-and-cross symbol marked on the element. If the reading is downscale (negative) the probe may be turned over, or the function switch operated to the REVERSE position, so that an upscale reading is obtained. If the reading is less than 10 percent of scale, switch to the next lower range.

The value of the magnetic field is read from the meter scale with a full scale value as indicated by the range switch setting. For example, a reading of .95 on the 1 k range is a reading of $.95 \times 1000$ or 950 gauss.

The entire meter scale may be used for analog readout to measure either a positive (+) or negative (−) field direction. The upper right hand portion of the scale (+) is marked ANALOG to indicate that analog readings must appear in this segment if a digital measurement is to be taken of this value by switching from ANALOG to DIGITAL mode. It is desirable, therefore, to use the right hand (+) analog portion in analog mode to eliminate the necessity for reversal in the event that a digital reading is to be taken of the field.

While in analog mode —

(1) Align the probe properly in the field.

(2) Read the field as indicated by the meter.

(3) Notice if the reading is consistent and stable.

The Hall probe must be carefully positioned in the field to the correct location and oriented to respond to the magnitude (maximum reading) without alignment errors. The probe temperature should be known at the time of measurement. It is important that the zero procedure be carried out before calibrating by this method. Set the RANGE switch for the flux density rating of the reference magnet to be used. Insert the probe into the magnet using the DIGITAL mode. Set the digit dials to read the value of the known field plus the deviation shown on the probe deviation curve. Adjust next the CAL controls to read this value exactly. Read the paragraphs below for a description of the deviation curve and its use.

This calibration assures that the instrument readout values have the same distribution of errors as shown on the linearity deviation curve for the probe being calibrated. This curve is machine plotted using a precision electromagnet and is the error plot for the particular probe measured. It shows how the actual probe output deviates from the true linear value over the measurement range.

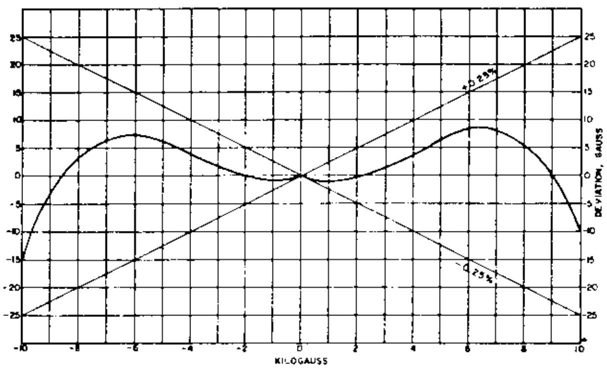


FIG. III-1 — TYPICAL PROBE DEVIATION PLOT MIL-STD-793-1(WP)

The probe deviation curve Fig. III-1 is plotted with actual flux density along the horizontal X-axis and output deviations, in gauss, vertically along the Y-axis. Thus, the locus of deviation errors of 0.25% of the actual field for any field value will appear on the sheet as a diagonal line passing through the 0.25%-of-value points.

To duplicate the curve in the gaussmeter, adjust the gaussmeter calibration CAL controls until the gaussmeter reads the value of the calibration field plus the deviation shown by the curve sheet for that field density. That is, if a 9.80 kG calibration magnet were being used and the curve showed that the probe output is low by 10 G at the 9.80 kG level, the gaussmeter would be adjusted to read 9800 −10 G or 9.79 kG. To accomplish this, set the MODE switch to NULL and the digit switches to 9.79 kG. The COARSE CAL control is then adjusted to obtain a meter null. The MODE switch is then set to the READ position so that the FINE CAL control may be used to adjust to the exact desired value.

Use of the deviation curve in measurement is explained in Sect. IV-3.

*Probes should be calibrated at 25°C. If the (NC) Hall probe is not at 25°C during calibration, a correction should be made for it and for the magnet temperature. The Hall probe correction is based on the nominal -0.025% per degree C coefficient using the formula:

$$B\ (\text{corrected}) = B\ (\text{actual}) \left(1 + (t_p - 25)\frac{TC}{100}\right)$$

where: t_p is the probe temperature in deg. C during calibration in the magnet.

TC is the probe temperature cofficient (typical mean value is −0.025% per deg. C)

Thus if the probe temperature is above 25°C, B (corrected) will be reduced because TC is a negative number. Adjust the gaussmeter to read the corrected value of flux density.

*Correction factor does not apply to 10X probes.

III-4 CALIBRATION OF THE OUTPUT VOLTAGE AT OUTPUT JACKS

The open circuit output voltage appearing at the output jacks has been factory adjusted to agree with the field reading within ±0.1%, however, this adjustment (R5) can be altered if necessary to calibrate to external instrumentation such as a digital voltmeter. Remove the rear access plate to reach R5. Obtain a full scale digital reading of 99X and then switch to ANALOG MODE. Adjust R5 for exactly 1.000 volt reading on external DVM. The load on the output jacks should not be less than about 5 kΩ. Do not make any other adjustments, see Sect. VI Maintenance.

In the analog mode a dc voltage at the output jacks, which is proportional to meter reading, is available to drive external measurement, display, or recording equipment. The full scale voltage is one volt, no load. It has positive polarity for upscale meter readings and reverses to negative polarity for downscale readings. An oscilloscope connected to the output terminals can be used to observe field transients and wave forms within approx. 30 Hz (cps) bandwidth. A digital voltmeter on the output jacks can be used to monitor the flux value directly in gauss or in kilogauss on a 1 volt full scale range. The output will drive an X-Y plotter or chart recorder on a linear flux scale*.

* See Section IV-2 (g), Use of Output Jacks.

The analog mode is also used to evaluate variations in a magnetic field before determining the proper full scale range for a digital measurement. This is described in (e) 2 below. Refer to Section IV-5 for information on field direction measurement.

(e) Digital Mode Operation:

1. *General Description*

In digital operating mode the three digit dials are rotated to produce a "null" or center scale reading on the meter. The internal reference signal, controlled by the digit dials, is thus adjusted to cancel the upscale flux signal from the Hall probe. A negative probe signal, (which appears in the left half of the meter scale in analog), *must be reversed before using digital mode*. In digital mode, meter deflection results from the difference between the actual field value and the setting of the digital dials. In digital NULL operation, all difference readings are compressed to fall within the meter scale range and large differences can be accommodated. The meter thus operates as a null meter to indicate balance. The meter deflection is non-linear and after null balance has been achieved, all readings are taken from the three digit dials. Meter sensitivity in digital mode is increased 1000 times that in analog mode to provide the necessary 3rd digit resolution.

In digital READ mode, the meter compression circuit is removed providing a linear meter scale to indicate the actual difference, in gauss, between the Hall probe output value and the 3 digit dial settings. In this mode, the meter full scale sensitivity is 0.1 percent of full scale range. This corresponds to 1 digit in the 3rd place. Thus, a full scale meter reading occurs for a change of 1 digit on the 3rd digit dial, and linear interpolation of the 3rd digit is available on the meter scale. This provides for the increased readout resolution necessary to obtain 0.1% of reading or better over the entire decade range. *It requires, however, that the digit dials must be correctly set to the nearest digit before switching into the digital READ mode* to avoid "banging the meter." It also means that the field value must remain within this narrow range in order to remain "on scale."

The first and second digit dials are numbered 0 to 9 to obtain the first 2 significant digits. The 3rd digit dial has an additional 10th position marked X. Thus, a setting of 99X is equal to 990 +10 or 1000 and is a full scale digital setting.

2. *Selection of Range*

The gaussmeter range selected for analog operation is also correct for digital NULL operation in most cases. A higher range may be required if the field is varying in time or if it contains rapid fluxations or noise superimposed on the static value. Peak-to-peak noise up to about 200% of the static dc value will not seriously influence the measured value in the digital NULL mode. This is not the case in digital READ where field variations should not exceed full scale meter range, peak-to-peak. For example, to measure a 2000 gauss field having ±1% noise (±20 gauss fluxuations), it is necessary to switch up to the 100 kG range. This is because the 10 kG range will accommodate only ±10 gauss variations full scale in the READ mode.

To simplify the correct choice of range, the meter scale is marked to show the meter scale range for digital READ operation. These meter ranges are simply ±0.1% or 1 part in 1000 of the gaussmeter full scale range in use. These values are reproduced below:

(Gaussmeter) RANGE (FS)	100 G	1000 G	10 kG	100 kG
(Meter) SCALE (FS)	±0.1 G	±1 G	±10 G	±100 G

A simple test to determine if readings are within range and if there is no excessive flux noise beyond the response range of the gaussmeter is to switch the 3rd digit dial by one digit and observe that the meter reading also changes by an amount equal to 1 digit, or a full scale change. Full meter scale is defined as the scale distance from zero center to end scale, a total of 50 minor scale divisions in either an upscale +, or downscale −, direction. A calibrated oscilloscope, connected to the output terminals will indicate overscale flux signals within the bandwidth of the gaussmeter, digital READ mode.

3. *Digital Measurement*

In the digital mode a simple nulling technique is used in which the digit dials are rotated so as to bring the meter reading to center scale zero, or as near to zero as possible. *Always use the digital NULL mode to first obtain a null reading on the meter.* This places the digits to the correct settings before expanding into digital READ mode. If this is not done, an offscale meter reading will occur which indicates that the digital dials are not set to the nearest digit in the 3rd place. Readings taken in digital NULL mode are limited in accuracy to the nearest whole digit in the 3rd place. Digital READ mode will permit resolution of the 3rd digit since each major meter scale division corresponds to a 4th digit reading. In general, the readout resolution thus obtained is greater than the absolute accuracy capability of the gaussmeter. After taking a digital READ reading, switch back to the NULL mode to take advantage of the meter protection afforded by the NULL mode compression circuit.

In the digital nulling operation, note that the meter reads on the positive + (upscale) side when the unknown field *exceeds the digital setting*. As the digital knob settings are increased, the meter will approach zero and if the setting exceeds the field signal from the Hall probe, a negative — (downscale) meter reading then indicates that the field is *less than the digital setting*. The location of the decimal point is shown by the red light dot between digit knobs. Its position also depends upon whether a gauss or kilogauss range is being used. Readings up to 1000 gauss are indicated in gauss. Higher ranges are in kilogauss.

For accurate digital readings, it may be necessary to recheck the probe position after switching from analog to digital mode because of the greater resolution of the digital readout. Recheck the probe alignment and angular position in the field; it should be adjusted for a maximum (+) reading to read magnitude. Variations observed as the probe is moved laterally across the field are good indications of the field uniformity and the observed gradient will be a limiting factor in the ability to make an accurate determination of field value.

4. *Example of Digital Measurement*

The following is a hypothetical measurement situation to illustrate digital operation.

a. Analog reading is 7400 gauss on 10 kG range, right-hand + portion of analog scale.
b. No instability or variations are indicated.
c. Switch to digital NULL and set digit dials to 7.40.
d. Meter now indicates upscale (+) by about 10% of scale.
e. Switch 3rd digit dial from zero to 1.
f. Meter still indicates +, switch 3rd digit to 2.
g. Meter drops past zero to − side of scale.
h. Field reading is between 7.41 and 7.42 kG, set to 7.41.

i. Set to digital READ mode.

j. Meter reading +.4, digit dials 7.41, final reading is therefore, 7.414 kG.

k. Switch to 7.42 on digit dials, meter now reads −.6.

l. Reading is 7.42 minus .006 or .6 of one digit below 7.42 which is 7.414 kG.

m. Since readings agree and meter change for 1 digit was from +.4 to −.6, this equals 1 digit and reading is correct and valid. This resolution, however, is in excess of the absolute accuracy of the gaussmeter.

n. An oscilloscope connected to the output jacks in digital mode indicates that noise and field variations are less than ±1 volt full scale.

(f) Corrections for Probe Temperature:

All Hall probes exhibit a small temperature coefficient of Hall output. The approximate value of this coefficient is given in the specifications for the particular probe used. Low temperature-coefficient probes are recommended for accurate work where the temperature of the probe is not known or where variations in temperature may occur during measurement.

Probes vary in output readings at the rate of about -0.025%, per degree C. That is, an increase in probe temperature will reduce output readings by 0.025% of reading for each 1°C rise in probe temperature. When using 1X type probes, compute temperature corrections with reference to the calibration temperature of 25°C.

The following formula can be used to correct gaussmeter readings for probe temperature when using 1X type probes.

$$B_a = B_i \left(1 - (t_{pm} - t_{pc}) \frac{TC}{100}\right)$$

where: B_a = actual value of field being measured

B_i = field value indicated by the gaussmeter

t_{pm} = temperature of probe during measurement in deg. C

t_{pc} = probe calibration temperature = 25°C

TC = temperature coefficient of Hall element in percent per deg. C. (nominal value typical probe −0.025% per deg. C).

Inserting values given above for t_{pc} and TC, the formula is: (For 1X Probes).

$$B_a = B_i + B_i\,(t_{pm} - 25) \times .00025$$

as an example, if probe temperature during measurement was 33°C,

$$(33 - 25) \times .00025 = .002$$

and the indicated field B_i must be increased by an amount equal to .002 B_i or an increase of $\frac{.002}{100} = 0.2$ percent to obtain the corrected actual field.

(g) Use Of Output Jacks:

In digital operation the signal voltage at the output is proportional to meter reading as in analog mode, providing 1 volt dc for a full scale signal. Since the meter reading in digital mode is a difference reading between Hall signal and digital dial setting, it can be advantageously used as a control signal in a field controlling system. The output voltage is positive (+) for an upscale meter reading and changes polarity to negative (−) for a downscale reading. Thus, the signal indicates both the amount of error in the flux signal relative to the digital setting and the direction of the error.

A digital voltmeter may be connected to the output jacks in the analog mode to read or monitor flux density directly in gauss or kilogauss. If the voltmeter reading does not agree with the digital mode gaussmeter reading, refer to Section III-4 — Calibration of Voltage of Output Jacks. The voltmeter should be used on the 1 volt full scale range.

External instruments connected to the output jacks can also be used to record, measure or display small variations in a large static field which fall within the bandwidth of the gaussmeter. This reading will quickly determine whether variations are within range. If an oscilloscope shows a distorted or clipped waveform on peaks, the next higher range must be used.

See Section II-1(g) and II-2(a)7 and Section III-1 for further information concerning output specifications and grounding.

IV-2 USE OF THE PROBE DEVIATION CURVES

Each probe is supplied with a deviation error plot which shows the deviation or error in the probe output from a true straight line representing zero error. The deviations are given on a gauss scale to simplify their use in correcting readout data. Use of these data can result in improved accuracy by eliminating probe non-linear response from the readout data. Curves are described in Section III-3(b). See Fig. III-1.

To use the curves for data correction, locate the indicated field value on the horizontal scale using the right half of the curve for + fields, the left half for − fields. Read the deviation in gauss from the curve. If the deviation is positive (above the axis) the probe output is high and the error is to be subtracted from the indicated value. Negative probe deviations are added to readings to obtain a corrected value.

Use of the probe deviation curves for incremental measurements is described in Section IV-4 below.

IV-3 USE OF THE DIGITAL MODE FOR INCREMENTAL MEASUREMENTS

The digital READ mode of operation is particularly well suited for measurements of small changes in magnetic fields or for comparison of field values which are nearly the same. Changes in field at the probe may be due to changes in the excitation current in an electromagnet, to external influences, to the effect of test parameters in the field or to displacement of the probe to a new position in the field. In any case, changes as small as 2 parts in 10^5 of full scale or 2 parts in 10^4 at the low end of a range can be read out as one minor division in the meter scale in digital READ mode. Care must be used in attempting to interpret this high resolution in terms of true gauss changes.

Use of the probe deviation curve to correct incremental readings is similar to that described for single readings, Sect. IV-3, Fig. III-1, except that two readings are involved and, therefore, two corrections are required. Normally, for small changes the two error values fall too close together on the curve to distinguish between them. It is the difference in the deviation or error values, however, that applies to a difference reading. The errors may be increasing or decreasing as flux increases, for example, depending upon the slope of the error curve at the nominal field value. The best procedure is, therefore, to sketch in a straight line on the deviation plot which is tangent to the error plot curve at the nominal field value. This gives the slope of the curve at that point. Compute the slope as deviation gauss change from the vertical scale to absolute gauss change on the horizontal scale. Multiply this ratio by 100 to obtain percent rate error, positive if increasing (upward slope), negative if decreasing (downward slope). Apply this percentage as a correction to the incremental reading, adding the percentage to the reading if it is negative and subtracting if it is positive. For example, a two gauss increase is observed in an 8000 gauss field. The slope of the error curve at 8000 gauss is found to be negative 0.8 percent, for example. The corrected reading is then 2 (1 + .008) = 2 + .016 = 2.016 gauss change.

IV-4 FIELD DIRECTION MEASUREMENT

The directional response of the Hall probe makes possible the determination of the direction of a magnetic field or the measurement of the component of the field in a desired direction. As shown in Fig. IV-4 the Hall element is responsive to the magnetic field vector which is at right angles to the plane of the Hall plate (the ceramic package). A magnetic field which passes thru the Hall element at angle θ to the normal will produce an output proportional to B cos θ, since B cos θ is the component of B normal to the surface.

To measure the absolute magnitude of a field, the probe must be rotated and aligned for a maximum output field reading. This aligns the Hall element normal to the field vector where θ = zero.

A more precise method for determination of field direction makes use of the sharp null obtainable in the $\theta = 90°$ plane (the plane of the Hall plate surface). By alignment of the probe for a null in the output, field direction in one plane is established. A second null alignment at 90° to the first will determine a second plane. The field vector lies at the intersection of these two planes. The sharpness of the null can be increased by switching to a lower gaussmeter range when close to the null alignment. The resolution obtainable by this method generally exceeds the accuracy because of minute variables in the encapsulation of the Hall element.

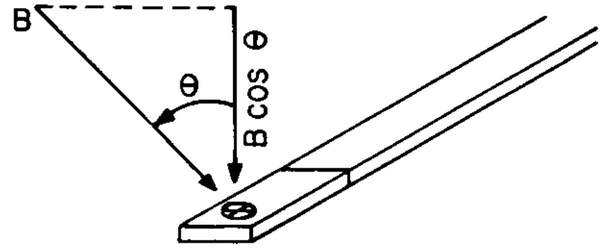


Fig. IV-4 DIRECTION RESPONSE OF HALL ELEMENT

IV-5 TOTAL FLUX DETERMINATION

The Hall-effect sensing device is inherently responsive to magnetic flux density and not to total flux lines. It is not dependent on rate-of-change of flux as is a search coil.

From the basic definitions:

Number of GAUSS = Number of WEBERS PER SQUARE METER $\times 10^4$

Number of GAUSS = Number of LINES PER SQUARE INCH $\times$ .1550

The Hall probe is equally useful in homogenous, uniform low-gradient fields and in high-gradient fields, although the low-gradient fields are capable of more accurate measurement. If the flux density is uniform and unidirectional over a given area, the total flux through the area is found by multiplying by the area in question.

$$\text{(Flux) WEBERS} = \text{GAUSS} \times \text{SQ. METERS} \times 10^{-4}$$
$$= \text{GAUSS} \times \text{SQ. CM} \times 10^{-8}$$
$$\text{(Flux) LINES} = \frac{\text{GAUSS} \times \text{SQ. INCHES}}{.1550}$$

When the Hall generator is moved in a plane, the component of flux normal to this plane will be indicated. If the field varies in magnitude over the area, it is necessary to integrate the values of flux density over the area in question. The flux density value indicated by the Hall probe output is the effective value over the active area of the Hall generator. Fortunately, the Hall-Pak devices have extremely small active areas. The standard transverse probe active area is only about .003 square inch, and sensitivity is essentially uniform over this area.

Absolute measurements of total flux of magnets having odd shape or high length-to-diameter ratio are best made using the search coil and standard fluxmeter methods. In many cases, however, valuable data are obtained by air-gap flux density measurements when the magnet is mounted in its working structure. Also, accurate comparison data can be obtained on almost all magnets of various sizes and shapes using a Hall probe to measure pole face density in comparison to a magnet selected as a standard of reference. The incremental feature is most valuable for this type of work.

SECTION V
Theory of Operation

V-1 GENERAL

The basic principle of magnetic flux measurement used in the Model 660 Gaussmeter may be described as a flux-modulated carrier-amplifier system. The output from the Hall generator is accurately proportional to flux density. A locally generated 1 kHz ac carrier signal, fed as an exciting current to the Hall element, causes input chopping action. The result is an ac Hall output when the probe is placed in a static (dc) magnetic field.

The ac flux modulated carrier signal is amplified and then restored to dc in the synchronous demodulator without loss of polarity — or field direction — information. The dc output drives the panel meter and after amplification is available at the output jacks for external use.

Digital operation is obtained by the method of zero suppression and scale expansion. Zero suppression or nulling results from cancellation of the flux signal by a separate reference signal controlled by the digital dial attenuators. This calibrated (digital) signal, by careful phase control, can completely cancel the flux signal. Cancellation occurs at an electrical summing junction where the difference between the Hall and digital signals appears. This difference is amplified 1000 times for scale expansion so that full scale meter reading represents a difference of 1 part in 1000 of full scale range. The amount of digital signal required to cancel or null the flux signal is a measure of the field strength and is indicated on the digital dials at null. Small incremental changes in flux density are read directly on the meter in the digital READ mode. The high linearity of the Hall generator preserves the linear output-per-gauss relationship over the entire usable gauss range.

V-2 THE SENSING ELEMENT

The Hall generator used for magnetic flux sensing is a semiconductor device operating on the Hall-Effect principle. It consists of a thin rectangular wafer of high-purity indium arsenide with 4 leads attached. Fig. V-1.

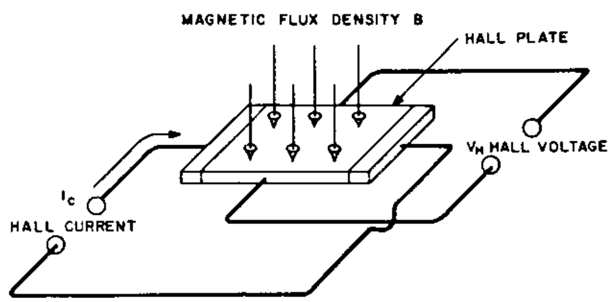


Fig. V-1 THE HALL GENERATOR

The application of control current I_c to the Hall generator results in a flow of charge carriers through the semiconductor material in the direction of its long dimension. When the Hall generator is placed in a magnetic field, the Lorenz force, acting on the moving charges, deflects them at right angles to the direction of their motion through the Hall plate. This is the same force that deflects the electron beam in a cathode ray tube.

The resulting build-up of charge carriers along the sides of the wafer produces the Hall voltage, and this voltage appears as an output at connections made on each side of the element. Hall voltage V_H is directly proportional to the flux density B and to the magnitude of control current I_c.

$$V_H = K_H (\bar{B} \times \bar{I}_c)$$

The three factors V_H, I_c and B are mutually perpendicular. If the magnetic flux vector B is not perpendicular to the face of the Hall generator, the Hall output will be proportional to the component of B that is perpendicular to the element. The constant of proportionality K_H is called the Hall sensitivity constant, and is approximately 0.075 volt per kG-ampere.

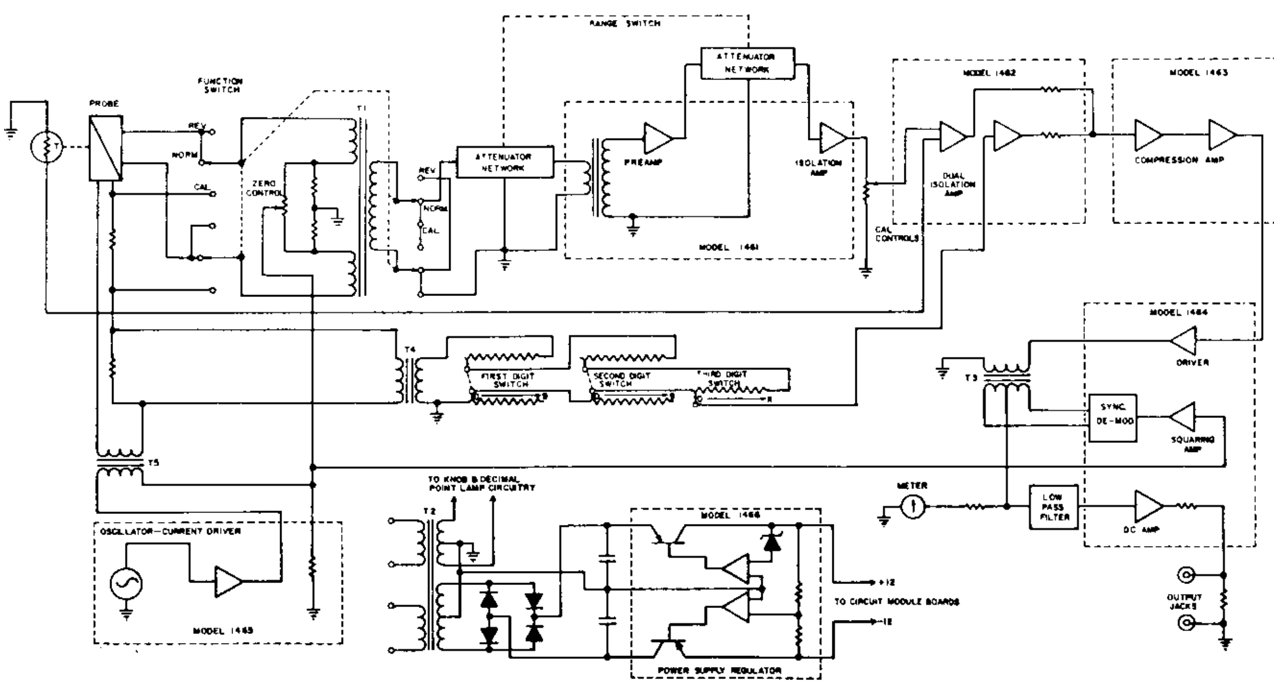


Fig. V-2 FUNCTIONAL BLOCK DIAGRAM — MODEL 660

V-3 CIRCUIT OPERATION

This section briefly describes the overall gaussmeter operation. See the Functional Block Diagram Fig. V-2. Additional descriptions covering more detailed operating theory of the individual module boards (amplifier, oscillator, etc.) are contained in Section VI, MAINTENANCE.

(a) Hall Input Section:

This section includes an input balancing network containing the probe zeroing controls. These operate by injecting a cancellation signal into the primary of input transformer T1. The controls have sufficient range to compensate for the ohmic unbalance inherent in the Hall generator and for steady ambient magnetic fields up to approximately 50 gauss.

The 100 mA control current, supplied by the local 1 kHz oscillator, is fed to the probe sensing element. The balance network cancels the residual output of the element to zero. Residual reactive signals are held to extremely low levels by the non-inductive construction of the Hall generator, by special cable construction and by inductive balancing in the probe connector and gaussmeter.

In the presence of a static (dc) magnetic field, the Hall generator produces a 1 kHz ac output signal. The multiplying property of the Hall generator provides that if the direction of the dc field is reversed, the ac Hall output voltage will shift in phase by exactly 180°. The amplitude of the 1 kHz Hall voltage is a measure of flux density B. When the magnetic field is alternating, and the frequency of the ac field is low compared with the 1 kHz carrier frequency, the Hall output is a double sideband suppressed-carried signal. Sidebands are equally spaced on each side of 1 kHz by the frequency of the ac field.

(b) Attenuator Section:

The field-proportional Hall output signal passes through transformer T1 which isolates against undesired probe noise pickup. As shown, the signal is next attenuated by the input range attenuator according to the setting of the RANGE switch. In the ANALOG setting of the MODE switch, the RANGE switch inserts additional attenuation between the preamplifier and first isolation amplifier. In the NULL and READ settings of the MODE switch, the preamplifier output is connected directly to the isolation amplifier input, thus providing the increased sensitivity necessary for digital operation. Both attenuator networks are precision voltage dividers capable of handling the wide range of levels encountered with relative simplicity and extreme accuracy.

(c) Amplifier-Demodulator Section:

The Hall signal amplifier consists of circuit boards 1461, one half of 1462, 1463, and the driver section of 1464. The driver output is coupled to the synchronous demodulator through transformer T3.

The synchronous demodulator is used to convert the 1 kHz amplified Hall signal to a linear proportional dc output suitable for operating the meter and for external readout. The demodulator is a full-wave transistor switching type circuit operating in phase synchronism with the 1 kHz carrier. A reference square wave switching signal is generated by the squaring amplifier section of the 1464 module board. The transistor switches alternately close the circuit to ground on opposite ends of the center-tapped secondary of transformer T3. Thus, full-wave rectification occurs at the 1 kHz rate and a dc output voltage appears at the transformer center-tap. If the magnetic field polarity reverses, the carrier appears 180° to the switching signal, and rectification produces a dc output of the opposite polarity. The use of a synchronous demodulator has the advantages of extremely good linearity and of recovering the dc polarity information in the output. Also, random noise and quadrature signals cancel; only the desired flux signal produces an output.

(d) DC Amplifier Section:

An L-C filter removes the 1 kHz carrier as well as high frequency noise components so that the dc amplifier input contains only the dc level plus very low frequency sidebands of the carrier. The dc amplifier is primarily a current amplifier used to provide a relatively low impedance at the OUTPUT jacks and to prevent external loading of the jacks from affecting the accuracy of measurements made using the internal panel meter. A large amount of overall negative feedback provides excellent linearity and stability.

(e) Digital Attenuator Section and Summing Circuit:

A portion of the 1 kHz oscillator output feeds the digital attenuator system. This signal is fed through isolation transformer T4 to the step attenuator switches. The attenuator output is adjustable in 10%, 1% and 0.1% steps by means of the 3 digit dials. This signal is then fed to one half of the dual isolation amplifier (Model 1462). The two sections of this module thus handle the amplified Hall signal and the attenuated comparison signal. The outputs from these two amplifier channels are adjusted by a phasing capacitor to be exactly 180° out of phase. They are then combined in a resistance summing network. Thus, when the amplitude of the digital attenuator section is exactly equal to the amplified Hall signal, the signals cancel at the Model 1462 output and no signal is seen by the compression amplifier. This would give a null reading on the panel meter in the digital operating mode indicating that the digital setting matched the Hall output. In the digital NULL mode, compression in the 1463 amplifier will prevent meter overload while searching for a null indication with the digital attenuator switches. In the digital READ mode, compression is removed so that deviations in the third digit can be read off directly on the linear meter scale.

(f) Oscillator-Current Driver Section:

A Wein bridge oscillator is used to generate a low distortion sine wave output and is provided with amplitude regulating circuitry. The current amplifier supplies a 100 mA 1 kHz output current that is essentially independent of load resistance up to a maximum 3 volts output. This circuitry is contained in the Model 1465 module board.

(g) Power Supply:

The power transformer T2 has a center-tapped 12 V secondary winding for operation of the knob and decimal point indicator lamps. The transformer also provides a center-tapped winding used with a full-wave bridge rectifier and input filter capacitors to provide the nominal +19 V and −19 V input for the Model 1466 power supply regulator. This regulator provides a constant low ripple +12 V and −12 V output for operation of the circuit module boards.

The power transformer is well shielded and has dual primaries for parallel and series connection for 117/234 V ac primary pbwer. It is designed for operation on either 50 or 60 cycle current.

SECTION VI

Maintenance

VI-1 INTRODUCTION

This section contains the necessary instructions and diagrams for maintaining the Model 660 Gaussmeter. In addition to the schematic diagrams, a block diagram giving typical signal-voltage levels is provided to aid in troubleshooting. See Figure VI-1.

Repair and adjustment of the instrument should be attempted in the field only where adequate test equipment and qualified personnel are available. Refer to the warranty page for the procedure to be followed should factory repair service be required.

VI-2 TEST EQUIPMENT

The following test equipment is required to test and adjust the Model 660 Gaussmeter:

(a) A high-impedance dc voltmeter having 2% or better accuracy.

(b) A high-impedance ac voltmeter having 2% or better accuracy.

(c) A high-quality oscilloscope having response to dc.

VI-3 COVER REMOVAL

CAUTION—Always disconnect power cord from power line when removing or replacing cover.

To remove the cover, it is only necessary to remove the three screws on the rear of the unit and slide the cover off.

VI-4 PRELIMINARY PERFORMANCE TESTS

This paragraph describes a rapid overall test for proper operation. If difficulty is encountered, proceed to paragraph VI-5.

(a) Preliminary:

1. See that all circuit module boards are firmly seated in their correct sockets. Refer to the layout diagram located between the screwdriver adjustments on the rear control bracket showing correct circuit module board positions.
2. Check fuse for burnout. Correct fuse is:
   1/8 A 3AG slow-blow for 117 V operation.
   1/16 A 3AG slow-blow for 234 V operation.
3. Inspect for overheated, burned, or blackened parts or wires.
4. Carefully inspect the probe for damaged element or cable, or poor plug contacts.
5. Check meter mechanical zero before turning unit on.
6. Set controls as follows before turn on:
   RANGE switch to 100 k
   FUNCTION switch to NORMAL
   MODE switch to NULL
   DIGIT switches to 000
7. Plug probe securely into front panel PROBE socket.

(b) Line Current Check:

1. Connect to rated power source. Line current after warmup should be:
   at 117 V line, 0.060 A nominal
   at 234 V line, 0.030 A nominal

(c) Amplifier (CAL) Test:

1. Turn FUNCTION switch to CAL position. Meter should read upscale.
2. Rotate COARSE CAL control R82 over its full range. Meter reading should vary smoothly over about 25% of the right half of the meter scale.

(d) Digital Attenuator Check — CAL Position:

1. With the COARSE CAL control turned maximum counterclockwise, adjust digit dials for a null reading on the panel meter. Digit dials should read *approximately* 300.
2. Adjust digit dials to 1000 (99X). Turn COARSE CAL control clockwise to obtain a null reading on panel meter. COARSE CAL control should then be about two turns from maximum clockwise position.

(e) DC Amplifier Test — CAL Position:

1. With digits set to 1000 (99X) and COARSE CAL control set for a null as in (d) above, turn MODE switch to ANALOG position.
2. Connect a dc DVM to OUTPUT jacks. Voltmeter reading should be +1.0 V. Panel meter will remain at null reading.
3. Turn FUNCTION switch to NORMAL with MODE switch in ANALOG. With probe removed from magnetic field, turn RANGE switch to 1 G and adjust ZERO controls for a zero-center null reading on meter. Probe should be shielded from a magnetic field for proper zeroing. Return RANGE switch to the 100 kG range.
4. Voltage at output jacks should be zero within a few millivolts.

VI-5 ADJUSTMENTS AND PERFORMANCE TESTS

IMPORTANT — None of the adjustments described in this section should be disturbed unless the unit is malfunctioning and the tests indicate that adjustment is necessary. These tests and adjustments are designed to assure correct overall performance. Before making any adjustments, the Model 660 should be turned on for at least one hour with cover in place. Line voltage should be rated value (117 V or 234 V).

(a) Meter Mechanical Zero:

For this test, the meter terminals may be short-circuited with a jumper wire, or the instrument turned off, allowing a few seconds for complete discharge of all capacitors. The unit must be in the normal horizontal operating position. Read the meter accurately by aligning the pointer with its image in the mirror. If necessary, adjust the screw on the meter face to bring the pointer to exactly zero.

(b) Power Supply Voltage Adjustment:

Rheostat R12 on the 1466 module board is used to adjust the regulated power supply voltage. R12 should be adjusted for 12.0 V on the lower of the + and − supply lines. The other polarity line should then be between 12.0 and 13.0 V dc.

(c) Oscillator Frequency and Feedback Adjustments:

The oscillator in the 1465 module board is factory adjusted to operate at a frequency of 990 ±20 Hz. If necessary, RX or CX may be selected to bring frequency to the correct value. This adjustment should be made only if accurate frequency measuring equipment is available. The feedback control R28 should be adjusted for 175 mV dc across CR4.

(d) Control Current Adjustment (I_c):

Temporarily disconnect the Hall probe from the PROBE socket and connect a 1 Ω ½% resistor between the two vertical pins of the socket (pins A and D). Using an ac DVM, adjust R4 on the rear control panel to obtain exactly 100 mV across the 1 Ω resistor. Reconnect probe to PROBE socket. With correct control current, the voltage drop across R9 should measure 94.3 mV

(e) Detector Switching Symmetry Adjustment:

The oscilloscope should be connected to the test output terminal of the 1464 module board. By expanding the horizontal sweep and using the horizontal position control, it should be possible to make the upper square wave plateau fill the screen horizontally, then by moving the trace horizontally, compare it quite accurately with the length of the bottom plateau. R20 should be adjusted for exact symmetry.

(f) DC Amplifier Zero Adjustment:

Set RANGE switch to the 1 G range. Probe should be removed from magnetic fields. FUNCTION switch should be in NORMAL position and MODE switch in ANALOG. Set ZERO controls for a null indication on panel meter. Turn RANGE switch to 100 kG. Connect dc DVM to OUTPUT jacks. If necessary, adjust R3 on 1464 module board for zero output voltage.

(g) Isolation Amplifier Phase Adjustment:

For this adjustment, it is necessary to place the probe in a stable dc magnetic field of about 1000 G, with polarity to give an upscale reading. The RANGE switch is set to 1000 G, the FUNCTION switch to NORMAL, and the MODE switch to NULL. Set digit switches to 1000 (99X). Adjust the COARSE CAL control to obtain a null reading on the panel meter. Then set the MODE switch to the READ position. Connect the oscilloscope across the primary (red-blue) of T3 and adjust C5 on the 1462 module board for minimum signal indication on the oscilloscope.

If necessary, adjust the FINE CAL control to maintain a null indication on the panel meter while adjusting C5. When properly adjusted, the signal should be predominantly second harmonic of the 1 kHz Hall signal and have a peak-to-peak amplitude of not greater than 9 V. If the null is out of range of C5, it may be necessary to change the value of CX which parallels it to make adjustment possible.

(h) Compression Amplifier Phase Adjustment:

Set up same as (g) above, except set MODE switch to ANALOG and connect oscilloscope to yellow (sec. center-tap) lead of T3. CX on 1463 module board is selected for proper detector output waveform. See Fig. VI-1.

FIG. VI-1 DETECTOR OUTPUT WAVEFORM.

(i) Quadrature Adjustments:

Set the RANGE switch to 1 G, FUNCTION to NORMAL, and MODE switch to ANALOG. Place the probe in a zero gauss chamber or shield can and carefully adjust the COARSE and FINE ZERO controls to obtain a null reading on the panel meter. Connect the oscilloscope across the primary (red-blue) of T3. Signal at this point should be less than 0.5 V peak-to-peak. If the quadrature signal exceeds this, it means that:

1. The probe quadrature adjustment (in probe connector) has been disturbed, or
2. The probe cable has been overstressed or cable wires shifted at probe or connector end due to loosening of strain relief.
3. The probe input socket J1 wiring adjustment has been altered or has loosened due to hard usage.

The quadrature (90° phase shifted) signals generated in the gaussmeter input are the result of mutual inductive coupling between the probe control current pair and the Hall output pair. These pairs are tightly twisted except at interconnecting tie points, and where wires are positioned and cemented to minimize quadrature. These lead placement adjustments are made at the input socket J1 rear, and inside the probe connector. Socket J1 adjustment should be changed only if a probe is used that is known to be good and correctly adjusted. Perhaps the most likely point to change would be in the probe due to handling. If several probes are used, all should be checked to insure interchangeability. Extremely small changes in the position of one of the current leads with respect to one of the Hall leads will make a noticeable change in the quadrature output. Loosen the cable clamp set screw on the probe cable plug housing and carefully unscrew the housing. The approx. 1" long piece of solid wire (with tubing) may be shifted from its central position to adjust quadrature, then resealed with cement.

(j) Meter and Output Cal Adjustments:

For these adjustments it is necessary to place the probe in a stable dc magnetic field of about 1000 G, with polarity to give an upscale reading. The RANGE switch is set to 1000 G, the FUNCTION switch to NORMAL, and the MODE switch to NULL. Set digit switches to 1000 (99X). Adjust the COARSE CAL control to obtain a null reading on panel meter, then turn MODE switch to READ and make FINE CAL adjustment. Turn MODE switch to ANALOG. Adjust METER CAL R1 on the rear control panel for exactly full scale meter indication. Adjust OUTPUT CAL R5, also on the rear control panel, for exactly 1 V dc from the OUTPUT jacks.

(k) Reference Cal Adjustment:

This adjustment is factory-adjusted to provide an internal calibration reference. *Do not readjust* this control.

VI-6 TROUBLE SHOOTING

The following suggestions and procedures are recommended when difficulty is encountered in operating or using the instrument:

(a) The probe should be checked whenever erratic operation is obtained, particularly at low levels. A fractured probe element will produce unstable and erratic operation, and the zero adjustment on low ranges will become particularly unstable. Check the cable also for poor contact or wire breakage. Light finger pressure against the probe element should produce only small temporary effect.

(b) Make the preliminary performance tests, most of which can be made without auxiliary test equipment. The source of trouble should be localized, in general, with these tests.

(c) Refer to the circuit diagrams and to the parts lists, by using schematic reference symbols, to obtain detailed information on parts used. Signal levels and waveform information is given on the Signal Level Block Diagram.

(d) It is important to replace parts with the same type and electrical value as originally used. Parts having F. W. Bell, Inc. part numbers are parts designed especially for the Model 660 and should be obtained directly from the factory.

(e) Use care in replacing diodes and transistors; do not apply excessive heat to the leads. A heat sink is recommended, such as gripping with pliers on the lead between the body of the component and the soldering iron.

(f) If necessary to return this instrument to the factory for repair, refer to WARRANTY Section.

VI-7 MODEL 1461 AMPLIFIER

(a) General Description:

The Model 1461 Amplifier includes a low level, low noise preamplifier and a high input impedance, low voltage gain amplifier. It is divided into two sections for insertion of an attenuator pad.

(b) Specifications (Nominal):

VOLTAGE GAIN:
Preamplifier 750
Amplifier 1.2

INPUT IMPEDANCE:
Preamplifier 500 Ω
Amplifier > 2 MΩ

MAXIMUM INPUT VOLTAGE:
Preamplifier 3 mV rms
Amplifier 2.5 V rms

POWER REQUIREMENTS:
+12 V @ 18 mA dc

SIZE:
6½" × 3-9/16" printed circuit module card

(c) Circuit Description:

The input signal is applied through transformer T1, giving a voltage step-up ratio of 22 to the base of Q3. The output of Q3 is direct coupled to Q4 with dc bias stabilization being obtained by negative feedback from the junction of R12 and R14. Q4 is direct coupled to the emitter follower Q5 which provides a low impedance output through C7. Signal feedback for gain stabilization, as well as additional dc feedback, is applied to the emitter of Q3 by the voltage divider formed by R15 and R13. Power supply decoupling for the preamplifier is provided by R8 and C8.

The amplifier input is coupled through C1 to the base of Q1, which is biased through R3 from the voltage divider formed by R1 and R4. Direct coupling is used between Q1 and Q2 with signal and dc feedback being applied to the emitter of Q1 by the R6-R5 voltage divider. C2 bootstraps the Q1 bias network to obtain a high input impedance. The output is taken from the collector of Q2 through C3.

VI-8 MODEL 1462 AMPLIFIER

(a) General Description:

The Model 1462 Amplifier contains two similar high input impedance amplifier sections with provision for externally controlling the gain of one channel. The phase of one channel may also be adjusted to establish the proper phase relationship between channels.

(b) Specifications (Nominal):

VOLTAGE GAIN:
3 (with no load on output)

INPUT IMPEDANCE:
> 2 MΩ

MAXIMUM INPUT VOLTAGE:
1 V rms

POWER REQUIREMENTS:
+12 V @ 11 mA dc

SIZE:
6½" × 3-9/16" printed circuit module card

(c) Circuit Description:

The "A" channel input is coupled through C1 to the base of Q1, which is biased through R4 from the voltage divider formed by R1 and R5. Direct coupling is used between Q1 and Q2 with signal and dc feedback applied to the emitter of Q1 by the R7-R6 voltage divider. An external resistor between R6 and ground controls the gain of this channel. C2 bootstraps the Q1 bias network to obtain a high input impedance. The output is taken from the collector of Q2 through C3 and R9.

The "B" channel operates in a similar manner except for the lack of provisions for gain control. C5 and CX are used to adjust the phase shift of either channel if required.

VI-9 MODEL 1463 AMPLIFIER

(a) General Description:

The Model 1463 Amplifier is a high gain, feedback stabilized amplifier with restricted bandwidth centered at approximately 1 kHz to reduce noise output. Signal compression by optional output limiting is provided to prevent overload in nulling applications.

(b) Specifications (Nominal):

VOLTAGE GAIN:
3,300

INPUT IMPEDANCE:
80 kΩ

MAXIMUM INPUT VOLTAGE:
without compression, 1.8 mV rms; with compression, 0.5 rms

POWER REQUIREMENTS:
+12 V @ 12 mA and −12 V @ 5 mA dc

SIZE:
6½" × 3-9/16" printed circuit module card

(c) Circuit Description:

The Model 1463 Amplifier consists of two cascaded amplifier sections, each enclosed in a frequency selective feedback loop. The optional signal amplitude limiting circuitry is also part of the feedback network.

The input is coupled through C1 to the base of Q1, which is biased by the R2-R16 divider. CR5 prevents excessive input voltages from being applied to Q1. Direct coupling is used to Q2, Q3, and Q4 which are conventional common emitter amplifier stages. The feedback network is connected between the collector of Q4 and emitter of Q1. CX is selected to provide correct high frequency rolloff, while C10 causes increased negative feedback and thus lower output at low frequencies. C2, C4, and C17 are used to further control high frequency response. R11, R13, and R15 give dc feedback to maintain proper operating points. For ac signals with compression connected, CR1 through CR4 are in parallel with feedback resistors R11 and R13. This provides unity feedback for signal voltages in excess of the diode forward voltage drops, thus limiting gain to near unity for large signals. C8 and C11 prevent dc voltage drops across R11 and R13 from placing a bias on the diodes.

The second amplifier section consisting of Q6 and Q5 operates in a similar manner, with C15 and C16 giving the required bandwidth reduction. With compression, CR6 limits the output of Q5 to a maximum of 2 volts.

VI-10 MODEL 1464 AMPLIFIER-DETECTOR

(a) General Description:

The Model 1464 contains a full wave synchronous detector, a complementary emitter follower driver, and a dc amplifier. Circuitry is included to provide square wave switching drive for the detector transistors from an external synchronizing signal.

(b) Specifications (Nominal):

MAXIMUM VOLTAGE BETWEEN DETECTOR INPUT TERMINALS:
12 V peak

REQUIRED SYNCHRONIZING SIGNAL:
0.1 to 3 V rms

DRIVER VOLTAGE GAIN:
Unity

DRIVER INPUT IMPEDANCE:
15 kΩ

MAXIMUM DRIVER INPUT VOLTAGE:
6 V rms

DC AMPLIFIER VOLTAGE GAIN:
Unity (output unloaded)

MAXIMUM DC AMPLIFIER INPUT VOLTAGE:
5 V peak

POWER REQUIREMENTS:
+12 V @ 45 mA and −12 V @ 30 mA dc

SIZE:
6½" × 3-9/16" printed circuit module card

(c) Circuit Description:

The synchronizing signal is applied to Q9 through isolating resistor R17. The high gain direct coupled amplifier formed by Q9, Q10, and Q11 provides a square wave output which is further amplified by the complementary stage containing Q12 and Q13 to a peak-to-peak amplitude of approximately 24 V. This signal drives the bases of the complementary detector transistors Q14 and Q15 through current limiting resistors R34 and R35. The detector will then alternately connect one side and then the other of the signal applied between detector input terminals to the detector return line. R20 is adjusted for equal "on" time for Q14 and Q15.

Q7 and Q8 form a complementary emitter follower driver stage having unity voltage gain and providing a low output impedance with a relatively high input impedance.

Q1 through Q6 are direct coupled to make up the dc amplifier section. Q1 and Q2 form a difference amplifier with the input being fed to Q1 and the amplifier output to Q2. Q3 is an emitter follower which feeds voltage amplifier Q4, which is then direct coupled to complementary emitter followers Q5 and Q6. Diodes in series with the collector load of Q4 provide a small amount of forward bias for the dual emitter followers. R3 is adjusted for zero output in the absence of input, and C1, C2, and C3 are used to control high frequency response.

VI-11 MODEL 1465 AC CURRENT SUPPLY

(a) General Description:

The Model 1465 Current Supply contains a stabilized oscillator with amplitude regulation and a high output impedance current amplifier intended to maintain constant current in changing resistive or reactive load impedances.

(b) Specifications (Nominal):

OUTPUT CURRENT:
100 mA

FREQUENCY:
990 Hz

MAXIMUM OUTPUT VOLTAGE:
3 V rms

OUTPUT IMPEDANCE:
5 kΩ

POWER REQUIREMENTS:
−12 V @ 60 mA dc

SIZE:
6½" × 3-9/16" printed circuit module card

(c) Circuit Description:

Q1, Q2, and Q3 form a two stage amplifier giving a positive gain necessary for the Wein bridge oscillator. The positive feedback frequency determining network consists of R2, C3, C7, R11, and selected components RX and CX which are adjusted for correct oscillator frequency. Negative feedback for amplitude stability is achieved through the voltage divider action of R3, R17, R28, and diodes CR4 and CR5. C10, CR2, Q4, and zener diode CR3 make up a peak waveform detector. If the oscillation amplitude increases, the negative signal peaks will cause Q4 to conduct thus shunting dc current away from CR4 and CR5.

A reduction in diode current increases their dynamic impedance which increases negative feedback, thus tending to reduce the oscillation amplitude. R28 adjusts the normal range of impedance variation required of the diodes, which is obtained with 175 mV dc across CR4.

The output of the oscillator is fed through an attenuator consisting of R14, R15, and an external adjustment rheostat to the current amplifier containing Q5 through Q10. The output current is sampled by R26 and fed back to the emitter of Q5 through C2. This current feedback gives the amplifier a high output impedance, making the output current nearly independent of load impedance.

VI-12 MODEL 1466 DUAL DC REGULATOR

(a) General Description:

The Model 1466 is a dual power supply regulator giving +12 V and −12 V outputs with respect to ground with a current capability of 600 mA from each output. It will maintain regulated low ripple outputs with a wide range of input voltages.

(b) Specifications (Nominal):

INPUT:
+15 to +25 V dc
−15 to −25 V dc

REGULATED OUTPUT:
+12 V @ 600 mA max
−12 V @ 600 mA max

RIPPLE:
5 mV peak @ 600 mA load current (each output)

REGULATION AGAINST LOAD:
<−1% change in voltage for 0 to 600 mA change in output current

REGULATION AGAINST INPUT VOLTAGE:
<±1% for ±10% change in input voltage

SIZE:
6½" × 3-9/16" printed circuit module card

(c) Circuit Description:

The +12 V output is regulated by the control transistor Q1 which is driven by Q2. The action of these two transistors together is that of an emitter follower in series with the output load. This effective emitter follower is driven by amplifier Q3, the input for which is obtained from the +12 V output through the reference diode CR1 and voltage dividers R6 and R12. If the output voltage tends to increase, an increase in voltage appears on the base of Q3. This decreases its collector voltage thus decreasing conduction of Q1 and Q2, tending to reduce output voltage.

The −12 V supply operates with Q5 and Q6 forming a double emitter follower in series with the load and driven by amplifier Q4. The input to Q4 is in effect the difference between the +12 and −12 V outputs to the voltage divider formed by R5 and R10. If there is a decrease in the −12 V output, it is reflected into the base of Q4 thus increasing its collector voltage. This will increase conduction in Q5 and Q6 tending to restore output voltage. The two amplifying transistors Q3 and Q4 are fed from decoupled supplies by the R3-C3 and R7-C4 combinations to reduce the output ripple. C1 and C5 also help to reduce ripple by providing a direct path for ac signals to Q3 and Q4.

ABBREVIATIONS

Cer	Ceramic
Comp	Composition
EC	Electrolytic can
ET	Electrolytic tubular
F	Farad
FOP	Factory adjusted for optimum performance
HM	Hot molded
k	Kilo or 10^3
m	Milli or 10^{-3}
M	Mega or 10^6
MLF	Metal film
MT	Mylar tubular
pF	Picofarad or 10^{-12} F
PT	Polycarbonate tubular
μ	Micro or 10^{-6}
Var	Variable
W	Watt
WV	Working volts
WW	Wire wound

MODEL 660 CHASSIS PARTS LIST

Capacitors

Schematic Ref.	Value	Spec.	Type	Bell Part No.
C1	.68 μF ±10%	75 WV	MT	
C2	.68 μF ±10%	75 WV	MT	
C3	.22 μF ±10%	200 WV	MT	
C4	100 pF ±10%	1 kWV	Cer	
C5	1000 μF	25 WV	EC	
C6	1000 μF	25 WV	EC	

Fuse

F1 1/8 A 3AG slow-blow for 117 V operation
1/16 A 3AG slow-blow for 234 V operation

Bulbs

I1 through I6 12 V 35-45 mA Sylvania type 12ES
I7 Neon 117 V ac

Chokes and Transformers

L1	Choke	LA-1620A
T1	Input Transformer	LA-1289B
T2	Power Transformer	LB-1383
T3	Output Transformer	LA-1370
T4	Isolation Transformer	LA-1361B
T5	Current Output Transformer	LA-1364

Meter

M1	100-0-100 μA	MB-1372

Diodes

CR1 through CR4 1N2069

Switches

S1	First Digit Switch	SA-1502A
S2	Second Digit Switch	SA-1502A
S3	Third Digit Switch	SA-1501A
S4	Range Switch	SB-1850
S5	Function Switch	SA-1500A
S6	Mode Switch	SA-1498A
S7	Power Switch, Toggle	

Potentiometers

R1	5 kΩ	WW	RB-477-014
R2	50 Ω	WW	RB-477-013
R4	5 kΩ	WW	RB-477-014
R5	50 Ω	WW	RB-477-013
R81	10 Ω	WW	RB-477-012
R82	500 Ω	WW 10-Turn	RB-1503-003
R83	200 Ω	WW 10-Turn	RB-1503-001
R84	5 kΩ	HM	RB-505-021

Resistors

Schematic Ref.	Value	Spec.	Type	Bell Part No.
R3	24 Ω ±5%	2 W	WW	
R6	1 Ω ±0.5%	.1 W	WW	RL-19-1
R7	17.8 Ω ±1%	.1 W	WW	RL-20-17X8
R8	100 Ω ±1%	.1 W	WW	RL-20-100
R9	1 Ω ±0.5%	.1 W	WW	RL-19-1
R10 thru R18	100 Ω ±0.1%	.1 W	WW	RL-18-100
R19 thru R36	10 Ω ±0.1%	.1 W	WW	RL-18-10
R37 thru R46	1 Ω ±0.5%	.1 W	WW	RL-19-1
R47, R48	9 kΩ ±0.1%	.1 W	WW	RL-18-9K
R49, R50	1.111 kΩ ±0.1%	.1 W	WW	RL-18-1X111K
R51	1 kΩ ±0.1%	.1 W	WW	RL-18-1K
R52	9 kΩ ±0.1%	.1 W	WW	RL-18-9K
R53, R54, R55	450 Ω ±0.1%	.1 W	WW	RL-18-450
R56, R57, R58	55.55 Ω ±0.1%	.1 W	WW	RL-18-55X55
R59	10 kΩ ±5%	½ W	Comp	
R60	12 kΩ ±5%	½ W	Comp	
R61	15 kΩ ±1%	½ W	MLF	
R62, R63	10 Ω ±5%	2 W	WW	
R64, R65	2.7 kΩ ±5%	½ W	Comp	
R66	1 MΩ ±5%	½ W	Comp	
R67	6.19 kΩ ±1%	½ W	MLF	
R68	180 Ω ±5%	2 W	WW	
R69	226 Ω ±1%	½ W	MLF	
R70	36.5 Ω ±1%	.1 W	WW	RL-20-36X5
R71	4.32 Ω ±0.5%	.1 W	WW	RL-19 4X32
R72 thru R80	100 Ω ±0.1%	.1 W	WW	RL-18-100
R85	43 Ω ±5%	½ W	Comp	
RX	FOP	½ W	Comp	

MODEL 1461 PARTS LIST

See Master Parts List for Key to Abbreviations

Capacitors

C1	1μF	25 WV	ET
C2	10μF	15 WV	ET
C3	5000μF	10 WV	ET
C4	300μF	3 WV	ET
C5	35μF	6 WV	ET
C6	35μF	6 WV	ET
C7	250μF	12 WV	ET
C8	100μF	15 WV	ET

Resistors

R1	47 kΩ ±5%	½ W	Comp
R2	10 kΩ ±5%	½ W	Comp
R3	47 kΩ ±5%	½ W	Comp
R4	68 kΩ ±5%	½ W	Comp
R5	357 Ω ±1%	½ W	MLF
R6	75 Ω ±1%	½ W	MLF
R7	62 Ω ±5%	½ W	Comp
R8	160 Ω ±5%	½ W	Comp
R9	604 Ω ±1%	½ W	MLF
R10	243 kΩ ±1%	½ W	MLF
R11	39.2 kΩ ±1%	½ W	MLF
R12	39 kΩ ±5%	½ W	Comp
R13	180 Ω ±5%	2 W	WW
R14	8.2 kΩ ±5%	½ W	Comp
R15	6.19 kΩ ±1%	½ W	MLF
RX	FOP	½ W	Comp

Transistors

Q1	2N3710	Q3	2N4384	Q5	2N3707
Q2	2N508A	Q4	2N3707		

Transformer

T1	Input Transformer	LA-1312A

MODEL 1462 PARTS LIST

See Master Parts List for Key to Abbreviations

Capacitors

Schematic Ref.	Value	Spec.	Type	Bell Part No.
C1	1μF	25 WV	ET	
C2	10μF	15 WV	ET	
C3	250μF	12 WV	ET	
C4	100μF	3 WV	ET	
C5	5-25 pF		Var Cer	
C6	100μF	3 WV	ET	
C7	10μF	15 WV	ET	
C8	250μF	12 WV	ET	
C9	1μF	25 WV	ET	
CX	FOP	1 kWV	Cer	

Resistors

Schematic Ref.	Value	Spec.	Type	Bell Part No.
R1	150 kΩ ±5%	½ W	Comp	
R2	36 kΩ ±5%	½ W	Comp	
R3	470 Ω ±5%	½ W	Comp	
R4	47 kΩ ±5%	½ W	Comp	
R5	47 kΩ ±5%	½ W	Comp	
R6	280 Ω ±1%	½ W	MLF	
R7	619 Ω ±1%	½ W	MLF	
R8	10 kΩ ±5%	½ W	Comp	
R9	6.19 kΩ ±1%	½ W	MLF	
R10	150 kΩ ±5%	½ W	Comp	
R11	36 kΩ ±5%	½ W	Comp	
R12	470 Ω ±5%	½ W	Comp	
R13	47 kΩ ±5%	½ W	Comp	
R14	47 kΩ ±5%	½ W	Comp	
R15	301 Ω ±1%	½ W	MLF	
R16	619 Ω ±1%	½ W	MLF	
R17	10 kΩ ±5%	½ W	Comp	
R18	6.19 kΩ ±1%	½ W	MLF	

Transistors

Q1	2N3710	Q3	2N3710
Q2	2N508A	Q4	2N508A

MODEL 1463 PARTS LIST

See Master Parts List for Key to Abbreviations

Capacitors

Schematic Ref.	Value	Spec.	Type	Bell Part No.
C1	10 μF	15 WV	ET	
C2	.0022 μF ±10%	200 WV	MT	
C3	35 μF	6 WV	ET	
C4	.0022 μF ±10%	200 WV	MT	
C5	100 μF	6 WV	ET	
C6	200 μF	15 WV	ET	
C7	10 μF	15 WV	ET	
C8	10 μF	15 WV	ET	
C9	250 μF	12 WV	ET	
C10	2.0 μF ±10%	200 WV	PT	
C11	10 μF	15 WV	ET	
C12	35 μF	6 WV	ET	
C13	100 μF	6 WV	ET	
C14	10 μF	15 WV	ET	
C15	.0056 μF ±10%	200 WV	MT	
C16	.47 μF ±10%	200 WV	PT	
C17	25 pF ±10%	1 kWV	Cer	
CX	FOP	1 kWV	Cer	

Resistors

Schematic Ref.	Value	Spec.	Type	Bell Part No.
R1	16.2 kΩ ±1%	½ W	MLF	
R2	180 kΩ ±5%	½ W	Comp	
R3	7.5 kΩ ±5%	½ W	Comp	
R4	180 kΩ ±5%	½ W	Comp	
R5	3.9 kΩ ±5%	½ W	Comp	
R6	620 Ω ±5%	½ W	Comp	
R7	20 Ω ±5%	½ W	Comp	
R8	1.3 kΩ ±5%	½ W	Comp	
R9	1.8 kΩ ±5%	½ W	Comp	
R10	5.1 kΩ ±5%	½ W	Comp	
R11	16.2 kΩ ±1%	½ W	MLF	
R12	2.43 kΩ ±1%	½ W	MLF	
R13	16.2 kΩ ±1%	½ W	MLF	
R14	301 Ω ±1%	½ W	MLF	
R15	16 kΩ ±5%	½ W	Comp	
R16	200 kΩ ±5%	½ W	Comp	
R17	390 Ω ±5%	½ W	Comp	
R18	2.2 kΩ ±5%	½ W	Comp	
R19	8.87 kΩ ±1%	½ W	MLF	
R20	5.1 kΩ ±5%	½ W	Comp	
R21	75 kΩ ±5%	½ W	Comp	
R22	68 kΩ ±5%	½ W	Comp	
R23	16 kΩ ±5%	½ W	Comp	
R24	1.21 kΩ ±1%	½ W	MLF	

Semiconductors

Q1	2N3707	Q3	2N3710	Q5	2N508A
Q2	2N508A	Q4	2N508A	Q6	2N3710
CR1 thru CR4			1N270		
CR5, CR6			V64		JF-01-001

MODEL 1464 PARTS LIST

See Master Parts List for Key to Abbreviations

Capacitors

Schematic Ref.	Value	Spec.	Type	Bell Part No.
C1	220 pF ±10%	1 kWV	Cer	
C2	.0022 μF ±10%	200 WV	MT	
C3	.0022 μF ±10%	200 WV	MT	
C4	35 μF	6 WV	ET	
C5	100 μF	6 WV	ET	
C6	100 μF	6 WV	ET	
C7	10 μF	15 WV	ET	
C8	1 μF	25 WV	ET	
C9	1 μF	25 WV	ET	
C10	.015 μF ± 10%	200 WV	MT	

Resistors

Schematic Ref.	Value	Spec.	Type	Bell Part No.
R1	17.8 kΩ ±1%	½ W	MLF	
R2	18 kΩ ±5%	½ W	Comp	
R3	500 Ω Var MLF			RQ-07-500
R4	4.7 kΩ ±5%	½ W	Comp	
R5	2.67 kΩ ±1%	½ W	MLF	
R6	576 Ω ±1%	½ W	MLF	
R7	100 Ω ±5%	½ W	Comp	
R8	300 Ω ±5%	½ W	Comp	
R9	10 kΩ ±1%	½ W	MLF	
R10	100 Ω ±5%	½ W	Comp	
R11	30 kΩ ±5%	½ W	Comp	
R12	6.2 kΩ ±5%	½ W	Comp	
R13	6.2 kΩ ±5%	½ W	Comp	
R14	30 kΩ ±5%	½ W	Comp	
R15	390 Ω ±5%	½ W	Comp	
R16	174 Ω ±1%	½ W	MLF	
R17	10 kΩ ±5%	½ W	Comp	
R18	51 kΩ ±5%	½ W	Comp	
R19	270 kΩ ±5%	½ W	Comp	
R20	5 kΩ Var WW			RS-01-5K
R21	10 kΩ ±5%	½ W	Comp	
R22	15 kΩ ±5%	½ W	Comp	
R23	62 Ω ±5%	½ W	Comp	
R24	10 kΩ ±5%	½ W	Comp	
R25	2.4 kΩ ±5%	½ W	Comp	
R26	51 kΩ ±5%	½ W	Comp	
R27	390 Ω ±5%	½ W	Comp	
R28	10 kΩ ±5%	½ W	Comp	
R29	10 kΩ ±5%	½ W	Comp	
R30	100 kΩ ±5%	½ W	Comp	
R31	10 kΩ ±5%	½ W	Comp	

Schematic Ref.	Value	Spec.	Type	Bell Part No.
R32	360 Ω ±5%	½ W	Comp	
R33	360 Ω ±5%	½ W	Comp	
R34	10 kΩ ±5%	½ W	Comp	
R35	10 kΩ ±5%	½ W	Comp	
R36	56.2 kΩ ±1%	½ W	MLF	

Semiconductors

Q1	2N3707	Q6	2N3905	Q11	2N3905
Q2	2N3707	Q7	2N2430	Q12	2N1303
Q3	2N3710	Q8	2N2706	Q13	2N1302
Q4	2N508A	Q9	2N3710	Q14	2N1303
Q5	2N3903	Q10	2N3710	Q15	2N1302
CR1 thru CR3			1N461		

MODEL 1465 PARTS LIST

See Master Parts List for Key to Abbreviations

Capacitors

C1	10 μF	15 WV	ET
C2	100 μF	6 WV	ET
C3	.015 μF ±10%	200 WV	MT
C4	10 μF	15 WV	ET
C5	250 μF	12 WV	ET
C6	10 μF	15 WV	ET
C7	.015 μF ±10%	200 WV	MT
C8	10 μF	15 WV	ET
C9	10 μF	15 WV	ET
C10	10 μF	15 WV	ET
C11	10 μF	15 WV	ET
C12	100 μF	3 WV	ET
C13	.015 μF ±10%	200 WV	MT
C14	.1 μF ±10%	200 WV	MT
C15	10 μF	15 WV	ET
CX	FOP	1 kWV	Cer

Resistors

R1	30 kΩ ±5%	½ W	Comp	
R2	10.7 kΩ ±1%	½ W	MLF	
R3	5.1 kΩ ±5%	½ W	Comp	
R4	10 kΩ ±5%	½ W	Comp	
R5	510 Ω ±5%	½ W	Comp	
R6	820 Ω ±5%	½ W	Comp	
R7	62 kΩ ±5%	½ W	Comp	
R8	5.1 kΩ ±5%	½ W	Comp	
R9	3.9 kΩ ±5%	½ W	Comp	
R10	20 Ω ±5%	½ W	Comp	
R11	10.7 kΩ ±1%	½ W	MLF	
R12	68 kΩ ±5%	½ W	Comp	
R13	180 kΩ ±5%	½ W	Comp	
R14	36.5 kΩ ±1%	½ W	MLF	
R15	4.32 kΩ ±1%	½ W	MLF	
R16	20 kΩ ±5%	½ W	Comp	

Schematic Ref.	Value	Spec.	Type	Bell Part No.
R17	1.8 kΩ ±5%	½ W	Comp	
R18	5.1 kΩ ±5%	½ W	Comp	
R19	510 Ω ±5%	½ W	Comp	
R20	160 Ω ±5%	½ W	Comp	
R21	30 kΩ ±5%	½ W	Comp	
R22	2.4 kΩ ±5%	½ W	Comp	
R23	160 Ω ±5%	½ W	Comp	
R24	3 kΩ ±5%	½ W	Comp	
R25	510 Ω ±5%	½ W	Comp	
R26	2.7 Ω ±5%	2 W	WW	
R27	6.2 kΩ ±5%	½ W	Comp	
R28	1 kΩ Var WW			RS-01-1K
R29	2.7 Ω ±5%	2 W	WW	
R30	2.7 Ω ±5%	2 W	WW	
RX	FOP	½ W	Comp	

Semiconductors

Q1	2N508A	Q5	2N3710	Q9	2N3611
Q2	2N1302	Q6	2N508A	Q10	2N3611
Q3	2N1303	Q7	2N1305		
Q4	2N1305	Q8	2N1304		
CR1	1N270	CR3	1N708	CR5	1N270
CR2	1N270	CR4	1N270	CR6	1N4003

MODEL 1466 PARTS LIST

See Master Parts List for Key to Abbreviations

Capacitors

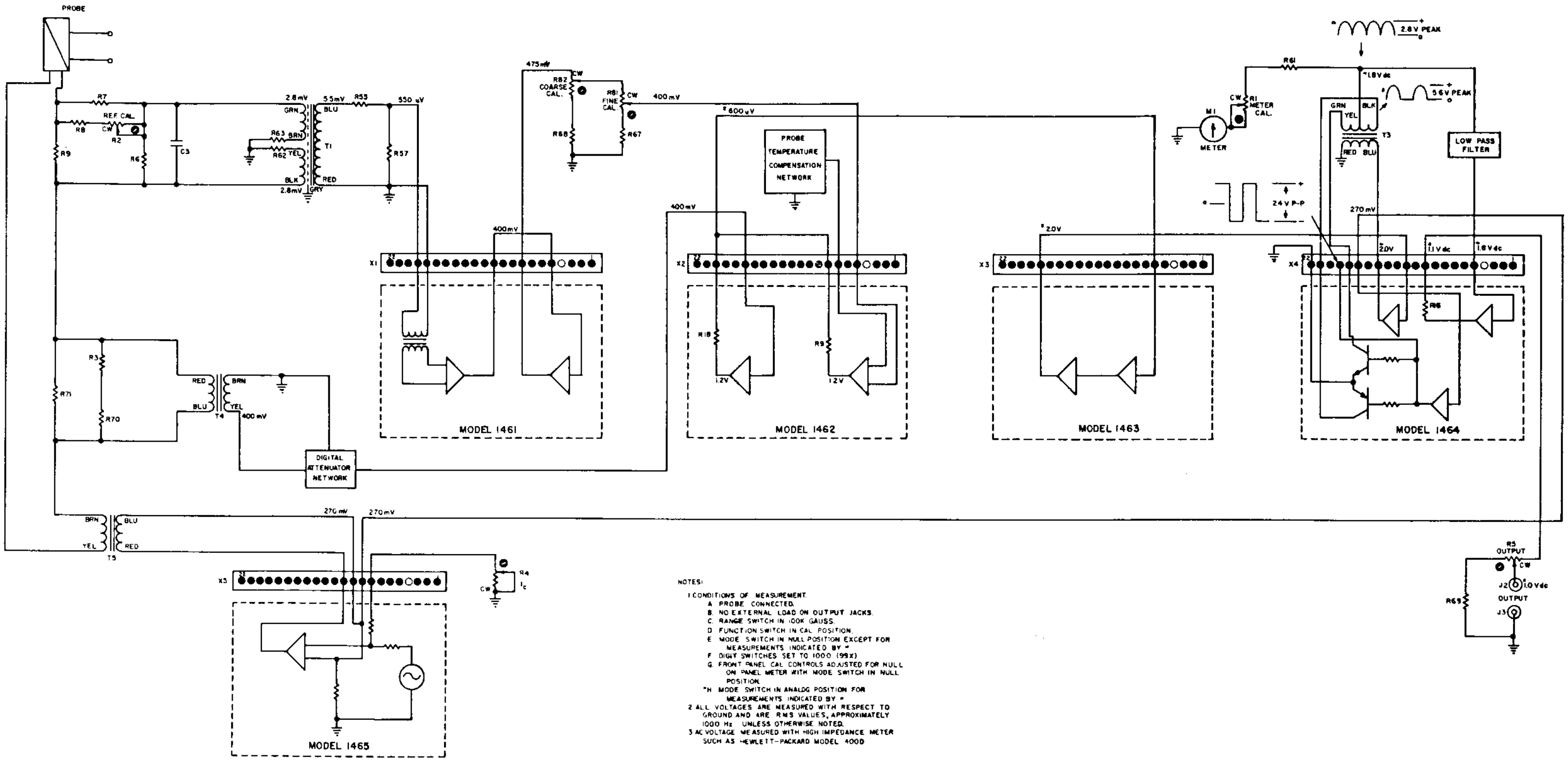
C1	10 μF	15 WV	ET
C2	50 μF	15 WV	ET
C3	25 μF	25 WV	ET
C4	25 μF	25 WV	ET
C5	10 μF	15 WV	ET
C6	50 μF	15 WV	ET

Resistors

R1	3 Ω ±5%	2 W	WW	
R2	240 Ω ±5%	½ W	Comp	
R3	3 kΩ ±5%	½ W	Comp	
R4	3 kΩ ±5%	½ W	Comp	
R5	6.2 kΩ ±5%	½ W	Comp	
R6	12 kΩ ±5%	½ W	Comp	
R7	3 kΩ ±5%	½ W	Comp	
R8	3 kΩ ±5%	½ W	Comp	
R9	200 Ω ±5%	½ W	Comp	
R10	6.2 kΩ ±5%	½ W	Comp	
R11	3 kΩ ±5%	½ W	Comp	
R12	5 kΩ Var WW			RS-01-5K
R13	160 Ω ±5%	½ W	Comp	

Semiconductors

Q1	2N3611	Q3	2N1302	Q5	2N508A
Q2	2N1302	Q4	2N508A	Q6	2N3611
CR1	1N718				

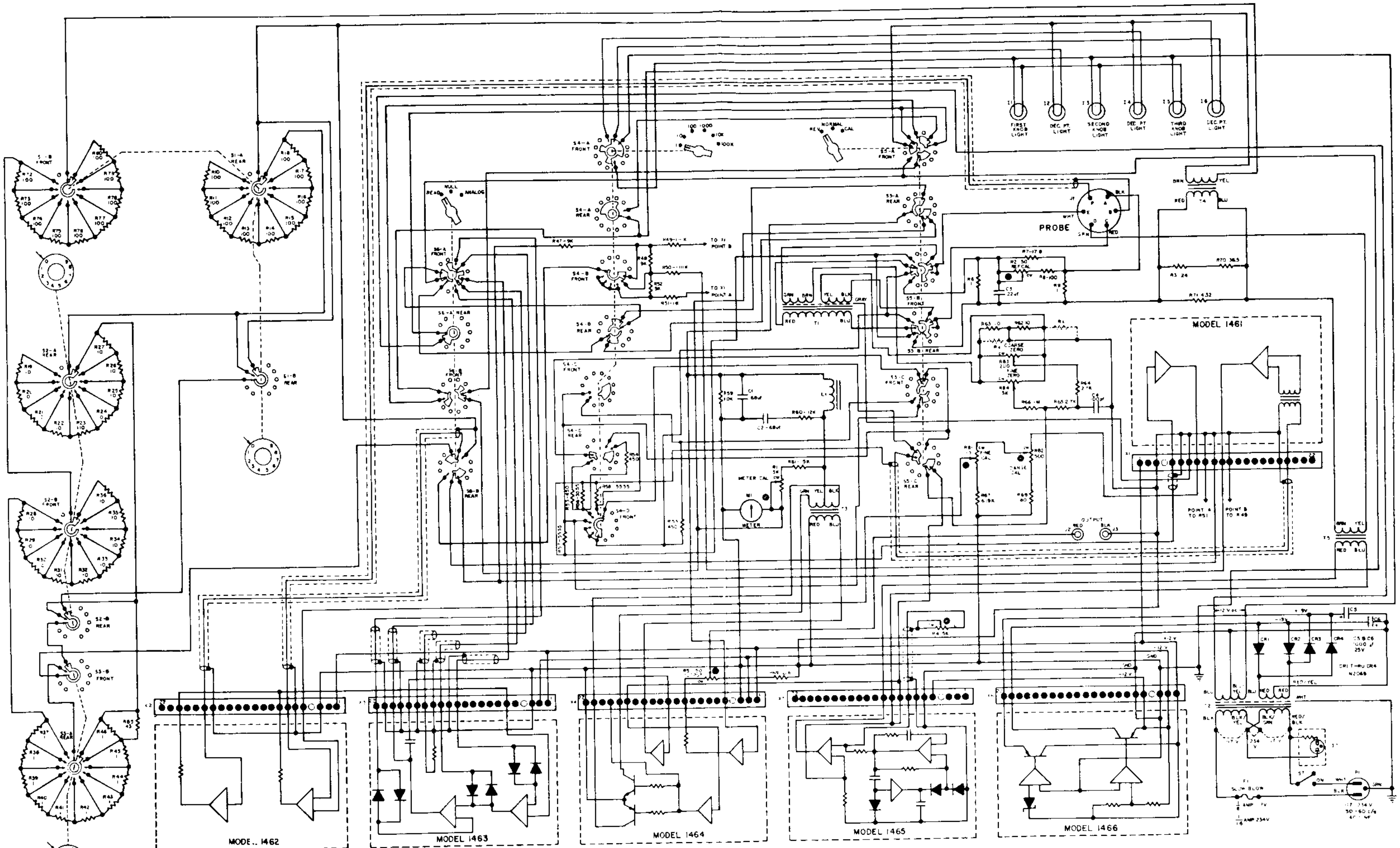


NOTES:

1 CONDITIONS OF MEASUREMENT.
- A PROBE CONNECTED.
- B NO EXTERNAL LOAD ON OUTPUT JACKS.
- C RANGE SWITCH IN 100K GAUSS.
- D FUNCTION SWITCH IN CAL POSITION.
- E MODE SWITCH IN NULL POSITION EXCEPT FOR MEASUREMENTS INDICATED BY *
- F DIGIT SWITCHES SET TO 1000 (99X)
- G FRONT PANEL CAL CONTROLS ADJUSTED FOR NULL ON PANEL METER WITH MODE SWITCH IN NULL POSITION.
- *H MODE SWITCH IN ANALOG POSITION FOR MEASUREMENTS INDICATED BY *

2 ALL VOLTAGES ARE MEASURED WITH RESPECT TO GROUND AND ARE RMS VALUES, APPROXIMATELY 1000 Hz UNLESS OTHERWISE NOTED.

3 AC VOLTAGE MEASURED WITH HIGH IMPEDANCE METER SUCH AS HEWLETT-PACKARD MODEL 400D



S1 FIRST DIGIT
S2 SECOND DIGIT
S3 THIRD DIGIT
S4 RANGE
S5 FUNCTION
S6 MODE

R_X SELECTED VALUE PARALLELING R63 OR R62

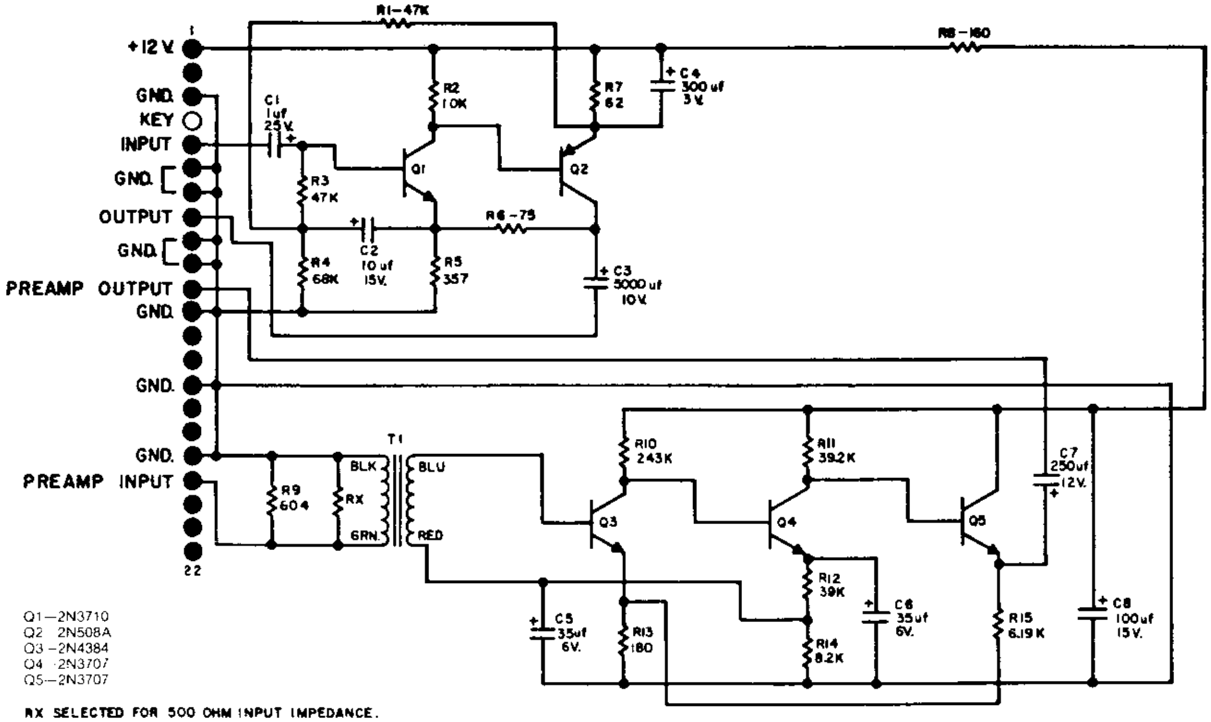


FIGURE VI-4

SCHEMATIC CIRCUIT DIAGRAM — MODEL 1461 PREAMP-AMPLIFIER

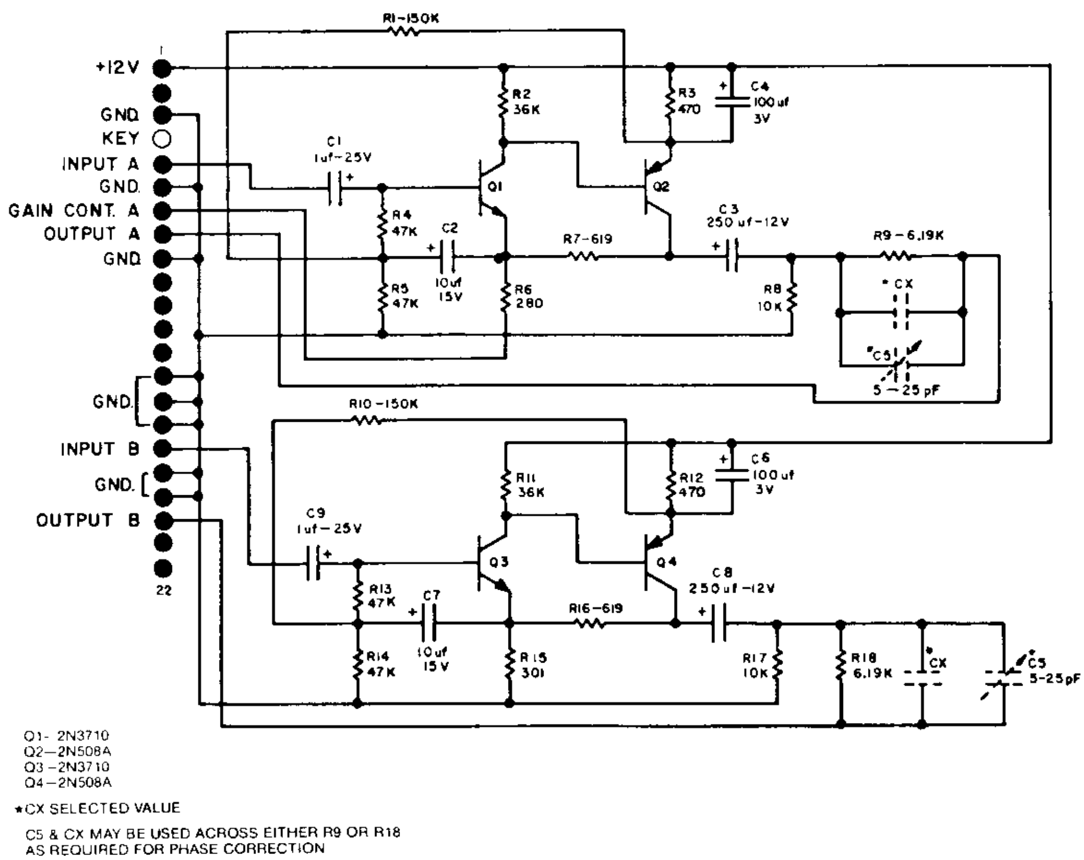
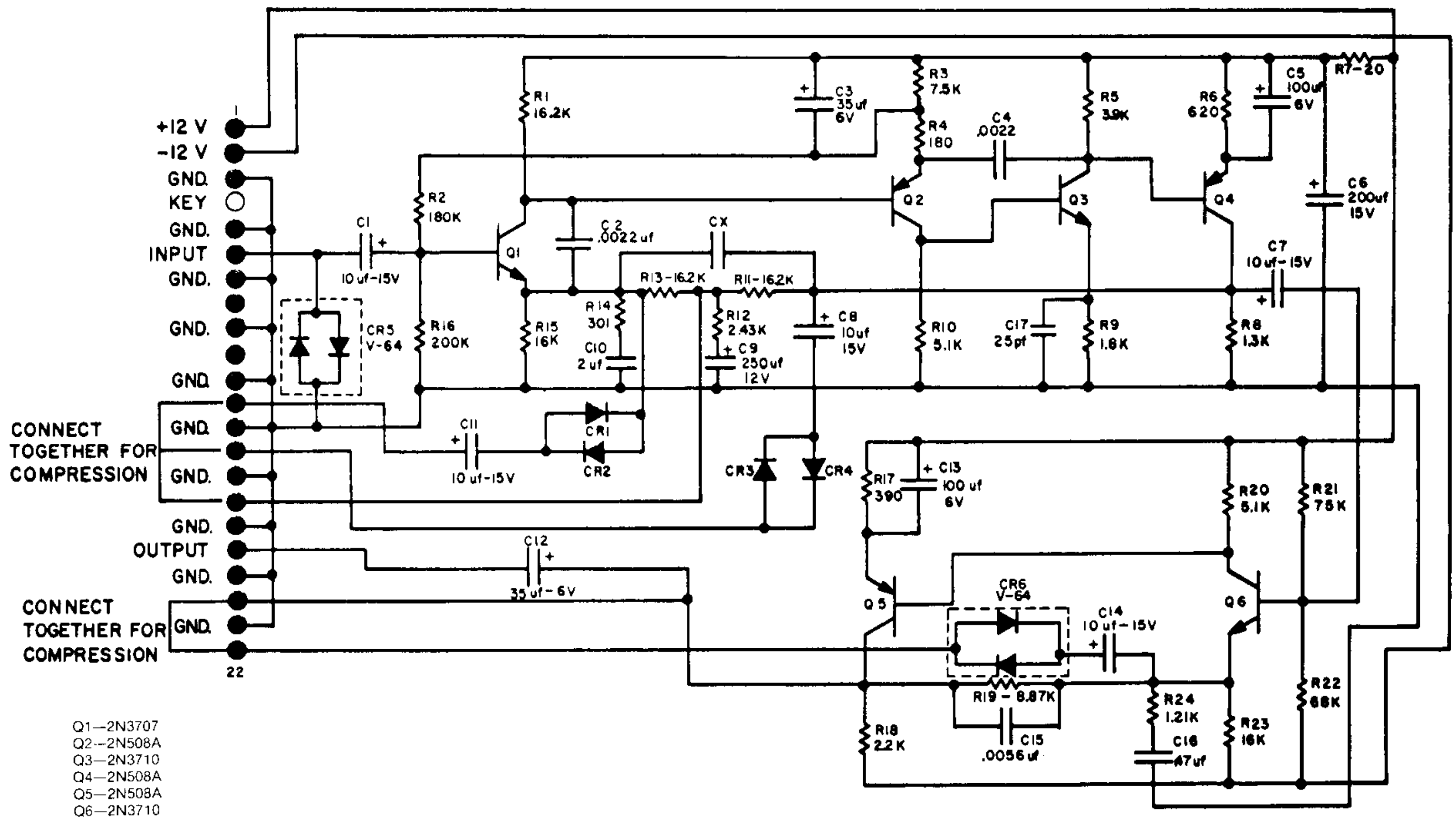


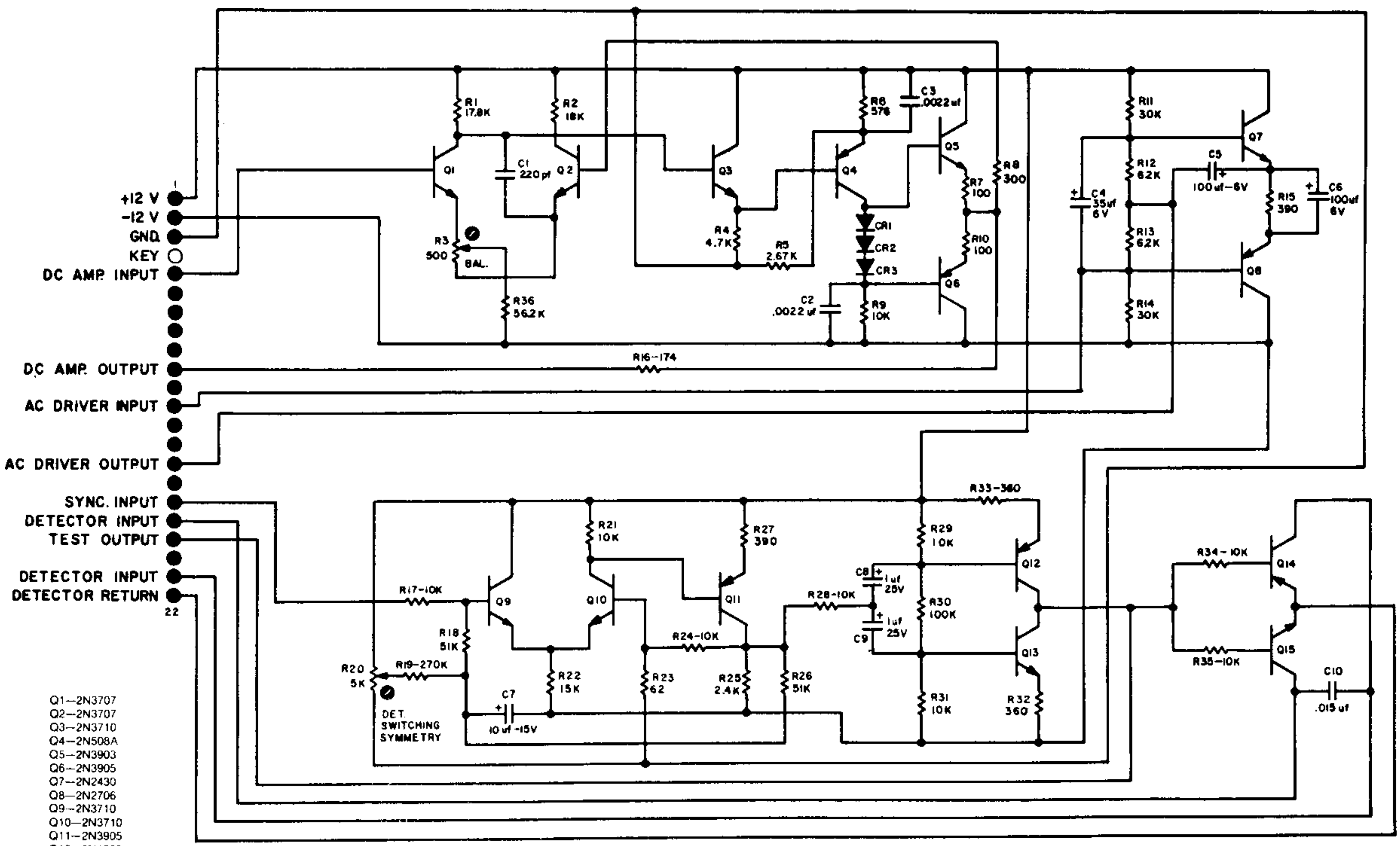
FIGURE VI-5

SCHEMATIC CIRCUIT DIAGRAM — MODEL 1462 2-CHANNEL AMPLIFIER



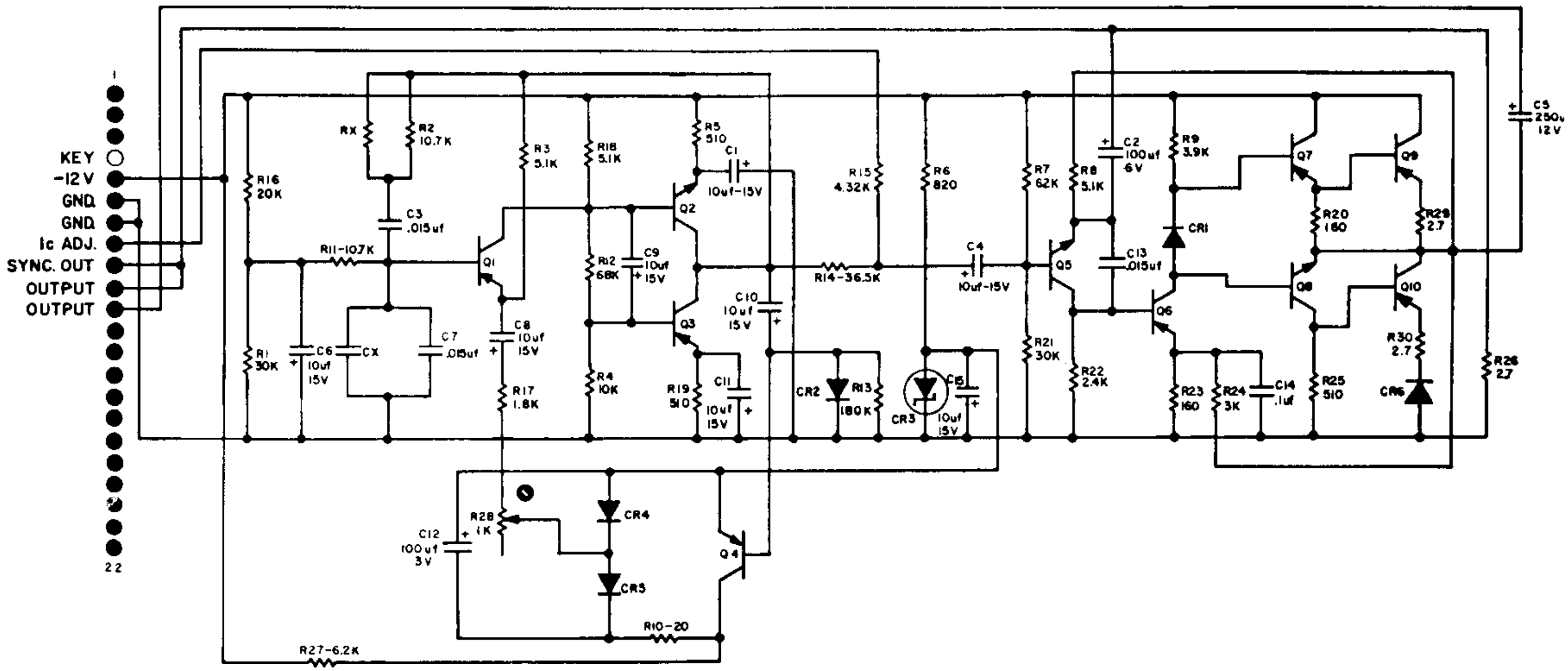
Q1—2N3707
Q2—2N508A
Q3—2N3710
Q4—2N508A
Q5—2N508A
Q6—2N3710
CR1 THRU CR4—IN270
CX SELECTED VALUE

FIGURE VI-6
SCHEMATIC CIRCUIT DIAGRAM – MODEL 1463 AC AMPLIFIER



Q1—2N3707
Q2—2N3707
Q3—2N3710
Q4—2N508A
Q5—2N3903
Q6—2N3905
Q7—2N2430
Q8—2N2706
Q9—2N3710
Q10—2N3710
Q11—2N3905
Q12—2N1303
Q13—2N1302
Q14—2N1303
Q15—2N1302
CR1—1N461
CR2—1N461
CR3—1N461

FIGURE VI-7
SCHEMATIC CIRCUIT DIAGRAM — MODEL 1464 AMPLIFIER-DETECTOR



Q1--2N508A	Q6--2N508A	CR1—1N270
Q2--2N1302	Q7—2N1305	CR2—1N270
Q3--2N1303	Q8—2N1304	CR3—1N708
Q4—2N1305	Q9 2N3611	CR4—1N270
Q5--2N3710	Q10—2N3611	CR5—1N270
		CR6—1N4003

NOTES:
1. RX & CX SELECTED TO GIVE FREQUENCY OF 990±20 HZ.

FIGURE VI-8
SCHEMATIC CIRCUIT DIAGRAM — MODEL 1465 AC CURRENT SUPPLY

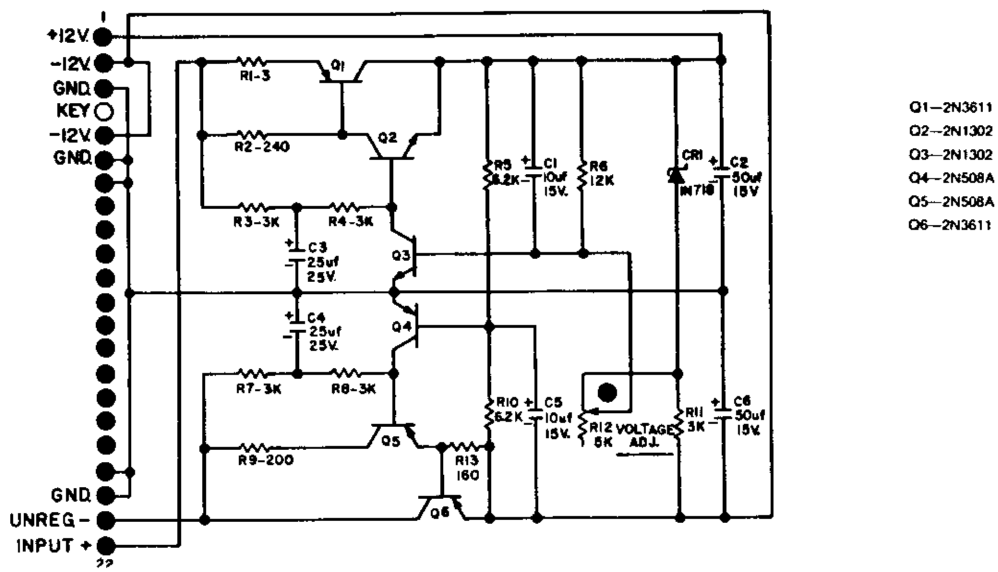


FIGURE VI-9
SCHEMATIC CIRCUIT DIAGRAM — MODEL 1466 DUAL POWER SUPPLY

WARRANTY

F.W. BELL, INC. warrants each instrument of its manufacture to be free from defects in material and workmanship. Our obligation under this warranty is limited to servicing or adjusting any instrument returned to our factory for that purpose, and to replacing any defective parts thereof. This warranty covers instruments which, within one year after delivery to the original purchaser, shall be returned with transportation charges prepaid by the original purchaser, and which upon examination shall disclose to our satisfaction to be defective. If it is determined that the defect has been caused by misuse or abnormal conditions of operation, repairs will be billed at cost after submitting an estimate to the purchaser.

F.W. BELL, INC. reserves the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

This warranty is expressly in lieu of all other obligations or liabilities on the part of F.W. BELL, INC., and F.W. BELL, INC. neither assumes nor authorizes any other person to assume for them any other liability in connection with the sales of F.W. BELL, INC. instruments.

DAMAGE IN SHIPMENT

The instrument should be examined and tested as soon as it is received. If it does not operate properly, or is damaged in any way, immediately file a claim with the carrier. The claim agent will provide report forms. A copy of the completed form should be forwarded to us. We will then make the necessary arrangements for repair or replacement. All correspondence concerning this instrument should include model and serial numbers.

SHIPPING INSTRUCTIONS

Use the original shipping carton and inserts, if possible, or pack the instrument in a sturdy container and surround the entire instrument with two or three inches of shock-absorbing material.

Ship to:

F.W. BELL, INC.
Repair Department
6120 Hanging Moss Rd.
Orlando FL 32807
Phone: 407-678-6900
TWX: 810-853-3115
Fax: 407-677-5765