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GenRad

GR 1686
Digital
Capacitance Meter

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INSTRUCTION MANUAL

Pages only: part no. 1686-0150. Complete manual in labeled binder: Form 1686-0100-A.

Contents

GR 1686 Digital Capacitance Meter

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Concord, Massachusetts, U.S.A. 01742
Form 1686-0100-A
September, 1976
ID-0100

Condensed Operating Instructions

NOTE

The 1686-P1 Test Fixture is by far the most convenient device for connecting the parts to be measured. Insertion of the DUT is as easy as child's play; true "Kelvin" connections are made automatically. All common shapes and sizes are accommodated; adaptors are used for axial-lead parts, no adaptors for radial-lead parts, "either way" for pigtail leads. Colored lights show GO/NO-GO results of main-instrument limit comparisons. System interface connectors handle bias and "start" circuitry. Refer to Figure 3-1. We highly recommend that you obtain this fixture.

To operate the 1686 Digital Capacitance Meter:

a. Connect the cables and/or test fixture to the instrument (paragraph 3.1). If using externally connected equipment for control and/or data recording, refer to paragraph 2.4. Set the BIAS switch to OFF.

WARNING

For safety of the operator, we recommend that external bias be limited to a maximum of 30 volts. If necessary, with suitable precautions, a maximum of 100 volts may be used. When greater than 30 volts is used, exercise great care to avoid dangerous electrical shock. Full bias voltage appears on test-lead or test-fixture terminals and on the leads of the component under test. Capacitors remain charged after measurement. The user must follow safe procedures to assure proper discharge of measured capacitors. See the WARNING in para 3.7. For safety, all personnel operating the instrument must be aware of the potential hazard involved in external biasing. Do not leave the instrument unattended with external bias applied.

b. On the rear panel, set the LINE VOLTAGE switch to match your measured power-line voltage; set the TEST VOLTAGE control fully cw.

c. Turn the POWER switch ON. Set the FREQUENCY switch for 1 kHz (or for the desired test frequency). Set the RANGE switch to the applicable range, determined as follows. Express the desired midrange capacitance as 10^x μF. The range is x+5 for 1-kHz measurements; it is x+4 for 120-Hz (100-Hz) measurements. (See para 3.3.)

d. To use the limit comparator, set the HIGH- and/or LOW-LIMIT thumbwheel switches to the desired limit(s) and set the LIMIT switch to LIMIT. Otherwise flip this switch OFF.

e. Set the MODE switch to REPETITIVE, and adjust the interval as desired, commonly about 0.5 s. For SINGLE-MEASUREMENT MODE, refer to para 3.6.

f. Leave the BIAS switch OFF in general. However, to make measurements with bias, turn the BIAS switch to INTERNAL, or EXTERNAL, as appropriate. Refer to para 2.6 for details on supplying an external bias voltage. Be careful not to touch the lead or fixture terminals if a high external bias is applied to the instrument. See WARNING in para 3.7.

g. Insert a capacitor to be measured in the test fixture; or make the equivalent connections with the elementary test cable (para 3.1). Observe the CAPACITANCE display, range lights and D lights.

h. Adjust the RANGE, if required (para 3.3). Notice that the RANGE lights will guide you quickly to the optimum range.

i. To measure dissipation factor, turn the D dial until the D lamps change state. If D is of secondary importance, leave the dial set to about .01 and watch the associated lamps for indication of a lossy capacitor.

Specifications

Ranges: Full-scale capacitance readings, accuracy multipliers (M), and applied voltage multipliers (A) are tabulated.

Switch position	Full scale at 1 kHz	M	Full scale at low f	M	A
1	199.99 pF	3	1.999 nF	2	5
2	1999.9 pF	1	19.99 nF	1	1
3	19.999 nF	1	199.9 nF	1	1
4	199.99 nF	1	1.999 µF	1	1
5	1999.9 nF	1	19.99 µF	1	1
6	19.999 µF	1	199.9 µF	1	1
7	199.99 µF	3	1.999 mF	2	0.1
8	1999.9 µF	10	19.99 mF	3	0.1
9	---		199.9 mF	5	0.1
Note*	---		(1000.0 mF)	5	0.1

***This extension of range 9 is useful even though range light indicates measurement exceeds full scale.**

Range lights indicate correct range setting. Dissipation Factor: D = 0 to 10.

Accuracy: Basically 0.1% for 1-kHz measurements. 0.5% for low-frequency measurements. For temp 15 to 35°C, relative humidity 0 to 90%:

CAPACITANCE error at 1 kHz:

$$\pm\left[\left(0.1 + 0.2\,D + \frac{C_{full\ scale}}{C_{reading}}\frac{D^2}{20}\right)\%\ \text{of reading} + .01\ \%\ \text{of full scale}\right](M);$$

CAPACITANCE error at 120 Hz:

$$\pm\left[\left(0.25 + 0.2\,D + \frac{C_{full\ scale}}{C_{reading}}\frac{D^2}{20}\right)\%\ \text{of reading} + .05\ \%\ \text{of full scale}\right](M)$$

also on range 9 only, add:

$$\pm\left(25\ \frac{C_{reading}}{1\ \text{Farad}}\right)\ \%\ \text{of reading};$$

DISSIPATION FACTOR error:

$$\pm\left[.001 + .0002\ \frac{C_{full\ scale}}{C_{reading}} + .05\,D\,(1 + D)\right]\ M$$

also, on range 9 only, for C up to 200 mF, add D error term of $\pm C_{reading}/1$ F. For C above 200 mF, D readout may be invalid. TEMPERATURE: for Δt°C above 35°C or below 15°C, increase multiplier M by factor $(1 + 0.1\,\Delta t)$.

Speed: 250 msec, for complete measurement.

Display: CAPACITANCE: 4½ digits, LED display with decimal point and over-range indication. Full-scale reading 19999 at 1 kHz and 1999 at low freq. DISSIPATION FACTOR: colored lights indicate whether D is above or below dial setting. (Dial can be used to determine D.)

Applied Voltage (Variable): Max ac test voltage, applied to capacitor being measured, is 1 V x A. (A=Voltage multiplier; see Range table). Applied voltage is variable from max. to 1/20 max. Maximum power is 1/8 W.

Frequency: 1 kHz ±2% and 120 Hz, normally synchronized to 60-Hz power line (100 Hz is the low frequency for 50-Hz line).

Bias: For capacitors, 2 V internal and 0 to 100 V external.

Measurement Mode: SINGLE: on command. REPETITIVE: adjustable rate, 0.25 s to 10 s per measurement. Previous readout is displayed during period of new measurement.

Data Outputs (TTL Logic): Open collector, active low. Each of the following outputs will sink 40 mA (max) from an external source of +30 V (max); low output = +0.4 V (max). BCD measurement value, decimal points, high D, reset, strobe, over-range.

Data Inputs: REMOTE START: A positive transition in < 1 µs, from $0\ V < V_L < 0.4\ V$ to $+2\ V < V_H < +30\ V$, initiates a measurement. LAMP TEST: A connection to ground lights all segments of the four principal digits of the LED display (8 8 8 8) to check operation.

Limit Comparator: CONTROLS: high- and low-limit digital switches. Limit enable/off toggle switch. DISPLAY LIGHTS: Go, high D, low, high. DATA OUTPUTS (TTL LOGIC): Open collector, active low. Each of the following outputs will sink 40 mA (max) from an external source of +30 V (max); low output = +0.4 V (max). Busy, go, high D, high limit, low limit, fail. SUPPLEMENTARY OUTPUTS: (*Clamp*). This line is to be tied to the external supply (+30 V max) to suppress inductive transients from external relay coils. (*Tone*) To drive a miniature speaker (or headphone) tied between this output and ground. Signal gives 1/4-sec audible burst (250-Hz tone) when measured value falls outside the selected high and low limits. (Not activated by D failures). (*Interface*) Lines for interfacing with a digital printer (i.e., GR 1785), a component sorter, a component handler for a specific application, and/or to interface with a multiple limit comparator. DATA INPUTS: (*Remote Start*) A positive transition of <1 µs from $0V < V_L < 0.4V$ to $+2V < V_H < +30V$ initiates a measurement. (*Limit Disable*) Performs the same function as the toggle switch. V_H input turns limit comparator off. Open circuit is equivalent to V_L, which turns it on.

Environment: TEMPERATURE: 15 to 35°C normal operation, 0 to 50° operation at slightly reduced accuracy, −40 to +75° storage. HUMIDITY: 0 to 95% at 35° C.

Supplied: Power cord, measurement cables, 30-pin and 36-pin connectors.

Available: Test fixture (with 4-terminal clips, start switch, and go/no-go lights for use with limit comparator). GR 1784 Multiple-Limit Comparator for multiple category sorting. Standard capacitors.

Power: 90 to 127 or 180 to 253 V, 48 to 440 Hz, 40 W.

Mechanical: Bench or rack models. DIMENSIONS (wxhxd): Bench, 17.00x5.59x16.25 in. (432x142x413 mm); rack, 19.00x5.22x16.63 in. (483x133x422 mm). WEIGHT: 23 lb (10.5 kg) net, 32 lb (14.5 kg) shipping.

1686 Digital Capacitance Meter	Catalog Number
60-Hz Line Freq (120-Hz Test), bench	1686-9700
50-Hz Line Freq (100-Hz Test), bench	1686-9800
Rack Hardware Kit	0480-9703
1686-P1 Test Fixture with Kelvin Clips	1686-9600

Contents

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Form 1686-0100-A
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Warranty

GenRad

This product is warranted to be free from defects in material and workmanship and, when properly used, will perform in accordance with specifications. Any GR-manufactured instrument, module, or part found not to meet this standard within a period of one year after original shipment will be repaired or replaced at no charge when returned to a GR service facility.

GR policy is to maintain repair capability for a period of ten years after the original shipment and to make this capability available at the then prevailing schedule of charges for any product returned to a GR service facility. Changes in the product not approved by GR shall void this warranty. GR is not liable for consequential damages.

This warranty is in lieu of all other warranties, expressed or implied, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose.

Introduction—Section 1

1.1 PURPOSE

The 1686 Digital Capacitance Meter is an all solid-state instrument that automatically measures series capacitance at two frequencies, 1 kHz and 120 (or 100) Hz. These measurements can be made on command or repetitively, with measurement repetition interval variable between 0.25 s and 10 s. Results are displayed on a digital readout.

The basic accuracy is 0.1% + 2 counts for 1-kHz measurements and 0.25% + 1 count for low-frequency measurements. For 1-kHz measurements, the full-scale digital readout indication is 19999; for low-frequency operation it is 1999. The decimal point and units are also displayed.

The range is manually set. The meter measures capacitance from .01 pF (one digit) to 200,000 μF (200 mF) or more and automatically indicates whether the range being used is optimum, too low, or too high.

The dissipation factor, D, is also indicated. The value of D is obtained by a manual dial adjustment. However, if this dial is set to the desired D limit, there is an automatic indication if this limit is exceeded.

Data outputs are also furnished for the measured capacitance and whether the measured D is within the limit set at time of measurement, to allow data recording, limit comparison, or process control. A built-in, two-limit comparator facilitates go/no-go sorting. Multiple-limit comparators, data printers, card punches, and handlers are also available from GenRad, separately or as a system. The data output (digital signal) levels are standard TTL, open-collector, for total interface flexibility.

The instrument's analog circuit provides for low impedances to be measured by means of a four-terminal connection to the "unknown" capacitor being measured. (Impedances of test fixture and leads have a minimal effect.) Guarded, three-terminal measurements can also be made with negligible error, regardless of substantial stray capacitance to ground.

The analog-to-digital conversion of the measurement result is made by an ac-dc ratio meter capable of high accuracy and stability.

A built-in limit comparator is provided. It compares the measured capacitance and dissipation factor, D, with limits you set on the front panel. Any upper and lower limits of C within the range of the meter can be selected on thumbwheel switches, up to 199.9 mF. Any upper limit of D can be set on the D dial.

The comparator is a module that enhances the operation of the meter, making it particularly useful for manual, semi- or fully-automatic selection and sorting applications, as well as intricate laboratory measurements. Visual indications of comparison results as well as respective control signals available for use by external equipment permit these various operations to be easily performed with a minimum of operator involvement.

Comparisons of quantities usually requiring laboratory techniques can also be easily made, such as: small impedance differences, semiconductor capacitances, capacitance drift with temperature, etc. And, with suitable recorders such as the GR 1785 Line Printer or other recorders, records of all types of data can be kept, including changes in measurements as a result of environmental effects.

A GR 1784 Multiple-Limit Comparator that makes comparisons of up to 4 pairs of limits is also available. See para 1.6.

1.2 FUNCTIONAL DESCRIPTION.

Refer to Section 4 for a general and detailed functional description of the instrument.

1.3 GENERAL PHYSICAL DESCRIPTION.

The instrument is supplied in a bench configuration. It can be set in a tilted position on a bench, for easy viewing of the front panel, by use of the bail under the front of the cabinet. For mounting in an EIA standard 19-inch relay rack, a kit of hardware is readily available and easy to use.

The 4 connections to the capacitor being measured, as well as data and control signal connections are made at 2 rear-panel connectors. A cable, supplied, connects to a test fixture or set of test leads (stackable, with alligator clips), also supplied.

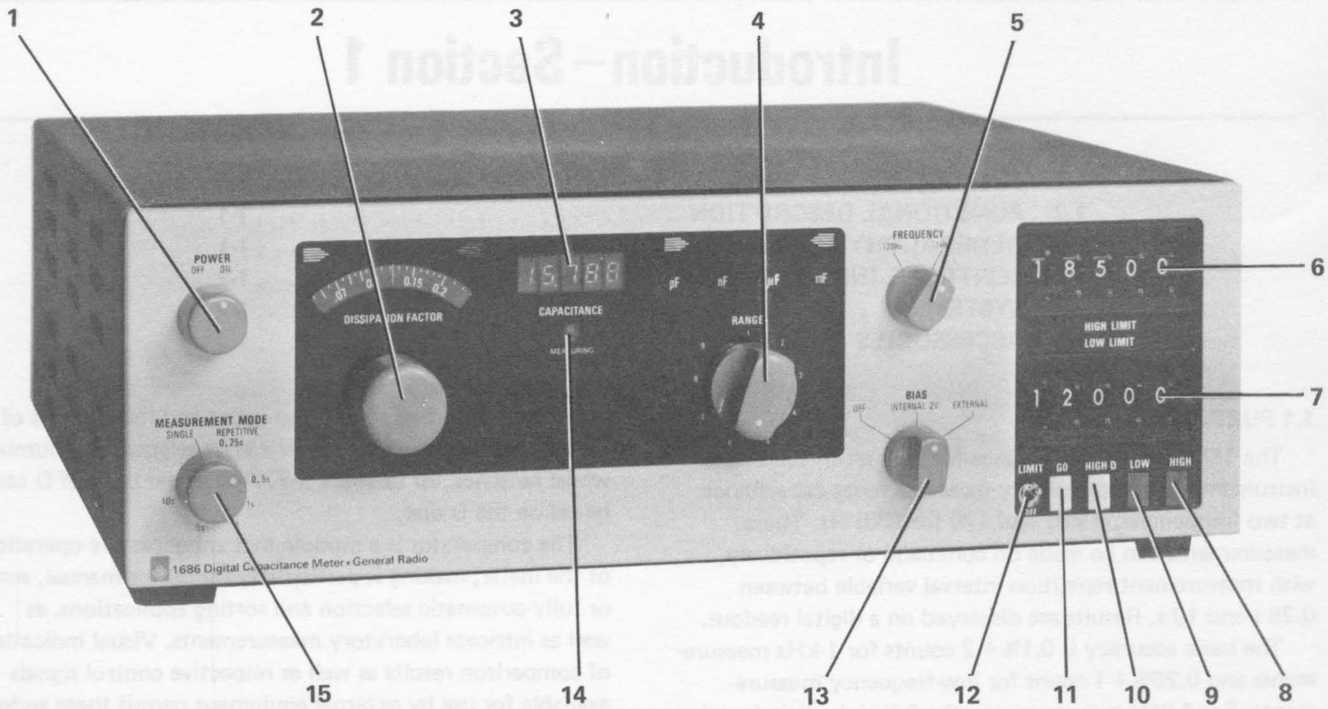


Figure 1-1. Front-panel controls and indicators.

The unit has its own power supply, including a 2-V internal bias supply for capacitors under test. The instrument requires ac power, 48 to 440 Hz, and can be switched to accommodate line voltages of 90 to 127 V and 180 to 253 V, in 5 ranges selectable at the rear panel. Proper fuses for these ranges are provided in fuse holders on the rear panel.

In the center of the instrument are 2 large circuit boards, the bridge board across the bottom and the logic (control) board above, hinged for convenient access. Behind the limit comparator panel are 2 smaller boards for circuitry associated with it. The power supply is at the far left. Further details are given in Section 5.

Physical characteristics of the unit are described further in the specifications at the front of this manual. Complete dimensions for the bench and rack -mount configurations are given in Section 2.

1.4 CONTROLS, INDICATORS, AND CONNECTORS.

Figure 1-1 shows the front panel controls and indicators. Table 1-1 identifies them, with descriptions and functions. Similarly Figure 1-2 shows the rear panel; and Table 1-2 identifies and describes the rear-panel controls and connectors.

1.5 SYSTEMS.

Because additional equipment can expand the basic capabilities of most GR instruments, including this one, facilities are available to supply complete systems; inquiries are invited. Each system, custom tailored to individual requirements and including only equipment necessary to perform the required task, is completely assembled and checked as a unit. Generally, such systems have wide application and can be used for laboratory development, production monitoring, final quality assurance, production-lot sorting, incoming inspection, environmental testing, reliability evaluation, etc., typically providing semi- or fully automatic operation.

1.6 ACCESSORIES

1.6.1 Accessories Supplied.

Refer to Table 1-3 for a list of accessories supplied with the instrument. The test-fixture cable is always used, whether you have a test fixture (such as GR 1686-9600) or whether you use the elementary measurement cable to make banana-plug or alligator-clip connections to the capacitor being measured.

1.6.2 Recommended Test Fixture. Figure 1-3.

The GR 1686-9600 Test Fixture is highly recommended as an accessory. Employing Kelvin contacts for both radial-lead and axial-lead components of all common sizes, it effectively and conveniently provides a 4-terminal measurement connection for components and parts under test. The fixture permits rapid manual measurements of components while providing high accuracy by reducing the effects of stray impedances on measurement accuracy.

The figure shows the fixture in use. It is connected by cable to the rear-panel TEST FIXTURE connector. If you

Table 1-1

FRONT-PANEL CONTROLS AND INDICATORS

Figure 1-1 Ref. No.	Name	Type	Function
1	POWER Switch, S504	Rotary switch; 2 positions: OFF, ON.	ON applies power; OFF disconnects both wires of ac power line from internal circuit, including fuses.
2	DISSIPATION FACTOR dial (D dial), R501	Continuously adjustable rotary dial and associated indicator lamps. Scale 0 to ∞, with divisions from 0.001 to 20. (Green lamp DS504; red, DS503.)	Indicates dissipation factor D over range 0 to 10, two ways: (1) Pass/fail. Dial is set to D limit and left there; lighted arrows indicate pass (green light) or fail (red light), for each measurement. (2) D measurement. After any measurement of C, the dial can be rotated to the point where the indication passes from one arrow to the other; corresponding dial reading is the measured D.
3	CAPACITANCE display, 1685-4710	Numerical readout, LED display, 4½ digits.	Gives visual indication of measured capacitance to 5 places at 1 kHz, to 4 places at low frequency. First digit becomes a blinking "E" if measured C C exceeds full scale for the range selected.
4	RANGE switch, S501	Rotary switch with associated indicator lamps (DS502, left →; DS501, right ←). Positions 1. . .9.	Selects 9 capacitance ranges; see Table 3-2. The lamps indicate that the correct range is set when both lamps are out. If one lamp is lit, turn the switch in the indicated direction to reach the proper range. In position 8 (or lower), the capacitance range is a decade higher for low-frequency measurement than for 1-kHz measurement. In position 9, only low-frequency measurement can be made; this range has (in addition to the normal decade in which the range lights stay out) an extension (higher) decade of capacitance that is useful even though the range light indicates →. There is no particular low-capacitance limit for range 1.
5	FREQUENCY switch, S502	Rotary switch; 2 positions; 1 kHz, 120 Hz (or 100 Hz).	Selects the test frequency, as indicated. The lower frequency is normally twice the power-line frequency.
6	HIGH LIMIT switch, S6. . .S10	Thumbwheel switch, 5 digits	Selects the upper limit for comparison.
7	LOW LIMIT switch, S1. . .S5	Thumbwheel switch, 5 digits	Selects the lower limit for comparison.
8	HIGH light, DS4	Indicator lamp, red.	Lights if measured capacitance exceeds selected HIGH LIMIT.
9	LOW light, DS3	Indicator lamp, red.	Lights if measured capacitance falls below selected LOW LIMIT.
10	HIGH D light, DS2	Indicator lamp, white.	Lights if measured dissipation factor D exceeds the value set on the D dial at the time of measurement.

Table 1-1 (Cont)
FRONT-PANEL CONTROLS AND INDICATORS

Figure 1-1 Ref. No.	Name	Type	Function
11	GO light, DS1	Indicator lamp, green.	Lights if measured parameters are within the limits (inclusively) as set by LIMIT switches and D dial, at time of measurement.
12	LIMIT/OFF switch, S11	Toggle switch, 2 positions.	When set to LIMIT, enables limit comparator; OFF disables it.
13	BIAS switch, S503	Rotary switch; 3 positions; OFF, INTERNAL 2 V, EXTERNAL.	When set to INTERNAL 2 V, furnishes 2-V bias for the capacitor under test. The EXTERNAL position allows an external bias voltage of up to 100 V to be applied to the capacitor under test, via the rear-panel TEST FIXTURE connector.
14	MEASURING light	Red LED indicator, CR1.	When illuminated, indicates meter is making a measurement.
15	MEASUREMENT MODE control, S506/R500	Continuously adjustable control with switch, labeled: SINGLE, REPET-ITIVE, 0.25. . .10 s.	When set to REPETITIVE and adjusted between 0.25 and 10 s, the meter makes repetitive measurements at approximately the indicated rate. If the switch is set to SINGLE, a single measurement is made, initiated by an external device such as a test future, component handler, recording device, etc. connected to the rear panel.

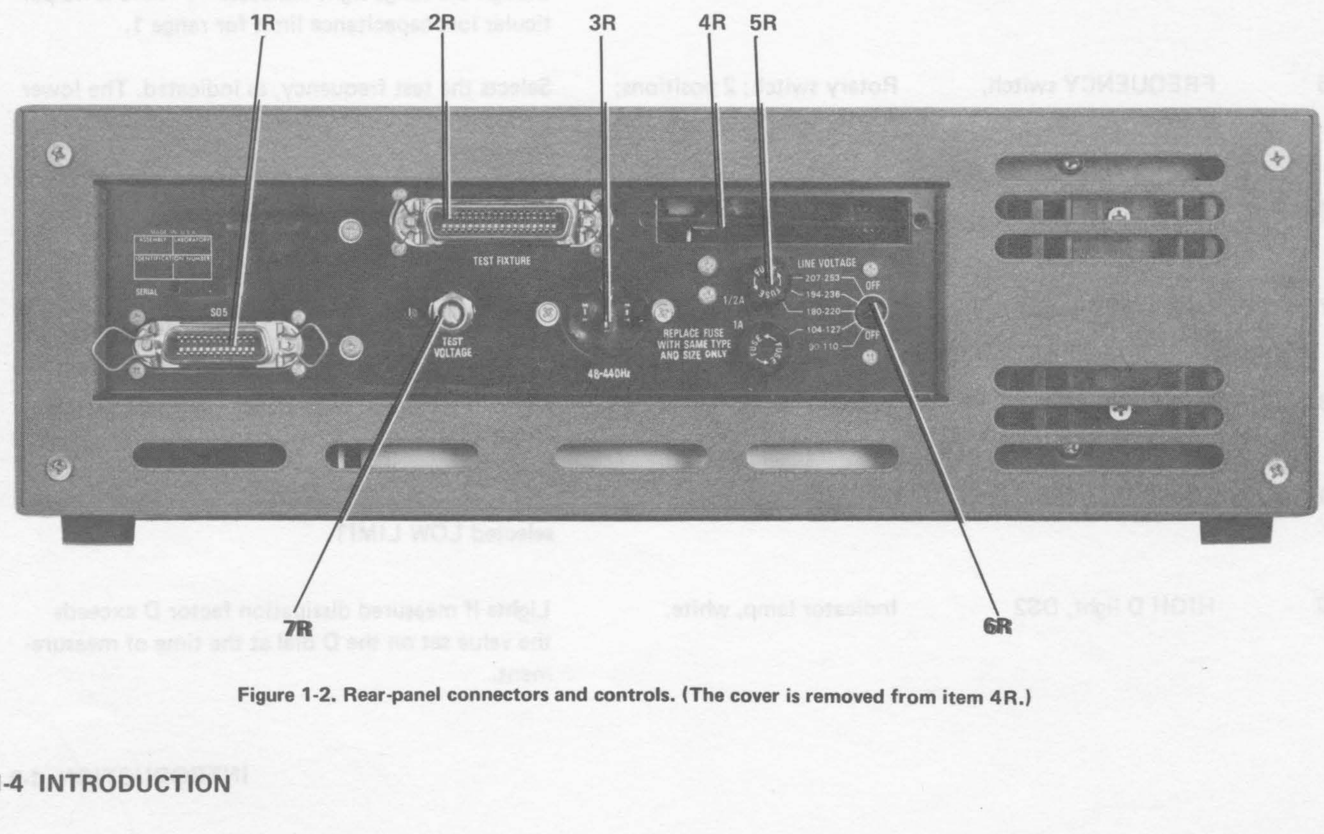


Figure 1-2. Rear-panel connectors and controls. (The cover is removed from item 4R.)

Table 1-2
REAR-PANEL CONTROLS AND CONNECTORS

Figure 1-2 Ref. No.	Name	Type	Function
1R	Comparator connector, labeled S05	Socket, 24 contacts, accepts Cinch or Amphenol no. 57-30240.	Supplies results from the internal limit comparator to peripheral equipment such as parts handler and speaker. Accepts a start signal and comparator disable signal. (Refer to Section 2.)
2R	TEST FIXTURE connector, S010	Socket, 36 contacts, accepts Cinch or Amphenol no. 57-3060.	Cable connection for test fixture, printer, and other peripheral equipment. (Refer to Section 2.)
3R	Power connector, S504 (labeled 48-440 Hz)	Safety shrouded 3-wire plug conforming to International Technical Commission 320.	Ac power input. Use appropriate power cord, with Belden SPH-386 socket or equivalent.
4R	Data output board-edge connector, L-S01	Set of 30 contacts on edge of Logic Board, recessed behind a cover plate.	Supplies measurement data, status and timing signals to (and accepts a start signal from) associated equipment such as multiple-limit comparator, parts handler, computer. (Refer to Section 2.)
5R	Fuses, F1 labeled 1 A, F2 labeled ½ A	Fuse in extraction post holder.	Short-circuit protection. The lower current fuse acts only on the 3 highest-voltage settings of the LINE VOLTAGE switch. Use Bussman type MDL or equivalent fuses.
6R	LINE VOLTAGE switch, S505	Screwdriver operated rotary switch, 6 positions: OFF, 90-110, 104-127, 180-220, 194-236, 207-253 (no stops).	Adapts power supply to line-voltage ranges as indicated.
7R	TEST VOLTAGE control, R510	Screwdriver operated potentiometer. Max position is cw.	Adjusts level of voltage applied to capacitor under test, from A (max, normal; see Table 3-2), continuously down to .05 A volts rms.

select SINGLE MEASUREMENT MODE, measurement is started when the bar across the front of the fixture is pressed down. Indicator lamps mounted on the fixture give GO/NO-GO indications (green and red lights) unless the limit comparator is turned OFF. For details, refer to para 3.1.

1.6.3 Other Accessories Available.

Other accessories that are available enhance this capacitance meter with data printing, card punching and externally applied bias voltages, and also aid in performing operational checks, calibration and testing. Table 1-4 lists GR manufactured accessories available. Consult GR for other items available, such as component handlers, other data recorders, and environmental test equipment that can be supplied separately or on a system basis.

NOTE

Some of the standards shown in this table are recommended for calibration and other procedures in the service section. Refer to Table 5-1.

Table 1-3
ACCESSORIES SUPPLIED

Quantity	Description	GR Part Number
1	Power cord, 210 cm (7 ft) long, 3-wire AWG 18, with molded connector bodies. End with Belden SPH-386 socket fits instrument. Other end is stackable (hammerhead) conforming to ANSI standard C73.11-1966.	4200-9625
1	Measurement cable, 140 cm (55 in.) long, with 36 pin connector at each end. Fits TEST FIXTURE connector.	1686-0291
1	Elementary measurement cable, 20 cm (8 in.) long, fits the cable above, has 5 stackable banana plugs for connection to the capacitor being measured and ground, when a test fixture is not used.	1686-9602
1	Connector for your cable, 36-pin. Fits TEST FIXTURE connector. Cinch "Micro-ribbon" or Amphenol No. 57-30360.*	4220-3036*
1	Connector for your cable, 30-pin. Fits board-edge contacts (S01) at rear of Logic Board. Interior portion of connector is Amphenol No. 225-21521-401-117.*	4230-1023

*For replacement, the commercially available part is recommended.

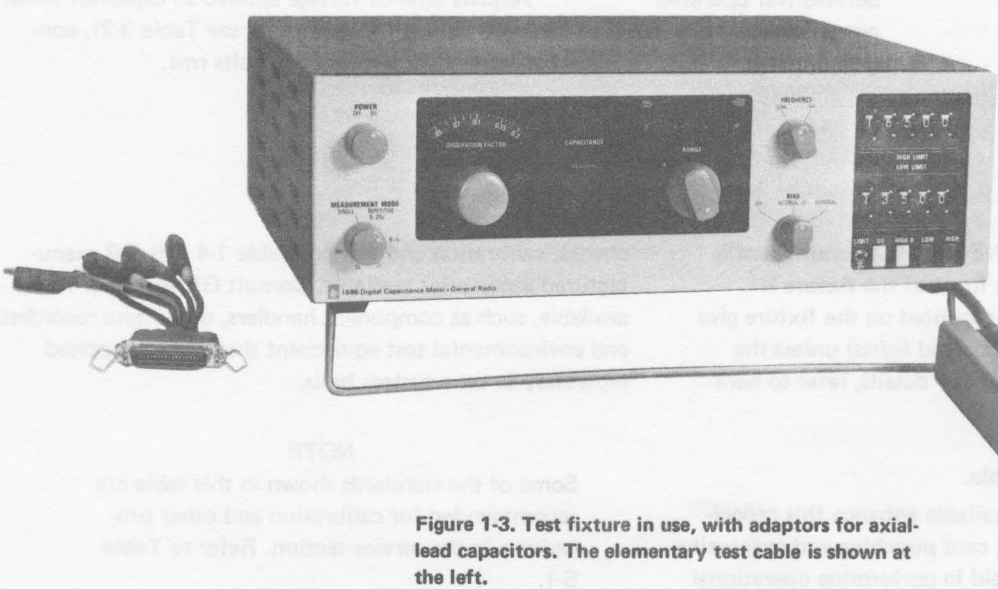


Figure 1-3. Test fixture in use, with adaptors for axial-lead capacitors. The elementary test cable is shown at the left.

Table 1-4
ACCESSORIES AVAILABLE

Name	Type or Part No.	Function
Test Fixture	GR 1686-9600	Convenient 4-terminal test fixture for manually inserted axial-lead and radial-lead capacitors. Adjustable to accomodate all common sizes. Base contains start switch and supplementary GO/NO-GO lights.
Data Printer	GR 1785	Precise, compact, and economical means of recording measurement data. Has up to 21-column capacity with a printing rate of three lines per second minimum. A two-color ribbon can be controlled to print red or black on roll and/or fanfold paper.
Multiple Limit Comparator	GR 1784	Designed for use with the 1686 Digital Capacitance Meter, 1685 Digital Impedance Meter and 1683 Automatic RLC Bridge. Makes comparisons with up to 4 pairs of limits, each containing a high and low value. Lamps (and electrical TTL open-collector, active-low outputs for external use) are furnished for high, low and go indicators for each set of limits. Indicator lamps and output signals are also furnished for priority sorting (indication of first "go" in set of 4 limit pairs), total limit failures, and loss-limit failures. Unit is also stackable, with all data available as output via a 50-pin connector and all comparison results on another connector.
Standard Capacitor	GR 1417 Four-Terminal Capacitance Standard; 1 μf to 1 F. Ratio accuracy: ±0.1%.	Instrument check and test.
Reference Standard Capacitor	GR 1404-A (1000 pF). 1404-B (100 pF). 1404-C (10 pF).	Instrument check, calibration, and test.
Standard Capacitors	GR 1409-9706 (.001 μF) 1409-9712 (.01 μF) 1409-9720 (0.1 μF) 1409-9725 (1.0 μF) Accuracy ±.05% of nominal capacitance.	Instrument check and calibration.
Decade Capacitor	GR 1412-BC Decade Capacitor, 50 pF to 1.11115 μF, accuracy ±0.5% ±5 pF.	Instrument check, calibration and test.
Precision Decade Capacitor	GR 1413; 0 to 1.11111 μF, .05% basic-accuracy.	Instrument check, calibration and test.
Decade Capacitor	GR 1419-K; 100 pF to 1.10 μF, accuracy 0.5%	Instrument check, calibration and test.
Precision Decade Capacitor	GR 1423; 100 pF to 1.111 μF, ±.05% basic accuracy.	Instrument check, calibration and test.
Rack Adaptor Set	GR 0480-9703	Provides the hardware for mounting the instrument in a standard 19-in. rack. (Refer to Section 2.)

Installation–Section 2

2.1 UNPACKING AND INSPECTION.

If the shipping carton is damaged, ask that the carrier's agent be present when the instrument is unpacked. Inspect the instrument for damage (scratches, dents, broken knobs, etc.) If the instrument is damaged or fails to meet specifications, notify the carrier and the nearest GenRad field office. (See list at back of this manual). Retain the shipping carton and the padding material for the carrier's inspection.

2.2 DIMENSIONS.

Figure 2-1 shows the overall dimensions in bench- and rack-mount configurations.

2.3 MOUNTING.

The instrument is supplied in the bench configuration, i.e., in a cabinet with resilient feet for placement on a table and with a tilting feature for convenience. A conversion kit supplies the hardware for rack mounting, as described below.

2.3.1 Bench Mounting.

The bench cabinet is made of formed and welded 1/8-in. aluminum, finished in baked-on, medium gray crackle paint and has a bail to allow easy viewing of the instrument. The instrument is retained in the case by four rear-panel screws held in place by O-rings to prevent loss. To remove the instrument from its case, loosen the four rear panel screws and withdraw the instrument. To insert the instrument into the case, carefully push it all the way into the case, making sure to keep all cables and connector-retainer clips clear of interference. Secure the four rear-panel screws.

2.3.2 Tilting.

A convenient bail can be pulled down to raise the front of the instrument and provide a better view of the front-panel indicators. The bail is a ⊔-shaped metal bar, with its ends retained and pivoted in the front feet, under the instrument. To tilt the instrument, pull down on the bail.

2.3.3 Rack Mounting. Figure 2-2.

To install the instrument in an EIA standard RS-310 19-in. relay rack with universal hole spacing, proceed as follows:

a. Obtain a GR 0480-9703 rack adaptor set.

b. Disconnect any cabling from the rear panel of the instrument. Loosen the 4 Phillips-head screws in the rear panel of the cabinet (the screws are held in place on the cabinet by rubber O-rings to prevent loss), and slide the instrument out of the cabinet.

c. Push out the 4 knockouts (C), as shown in the figure. Use a punch or similar tool and push out from the inside of the cabinet.

d. If the instrument is to be mounted directly above another instrument, push out the 4 feet from the bottom of the cabinet.

e. Attach the rack adaptors (Q) with the 4 screws (L) as shown.

f. Replace the instrument in the cabinet and secure in place with the Phillips-head screws.

g. Place the instrument in the rack and secure it with 4 dress-panel screws (N), inserted through holes in the handles, as shown. No rear support is necessary.

2.3.4 Reconversion to Bench Mounting.

To convert from rack to bench use, remove the rack adaptor hardware (brackets Q and screws L, N) and replace the feet in the bottom of the cabinet. The rigid feet with slots go in the front positions, holding the bail for optional tilting.

2.4 EXTERNAL-DATA CONNECTIONS.

2.4.1 General.

The external-data connections are made via Data Output and Comparator Connectors. (Refer to para 1-4.) Each of them, in this order, are dealt with in the following paragraphs. If your peripheral equipment requires measurement results

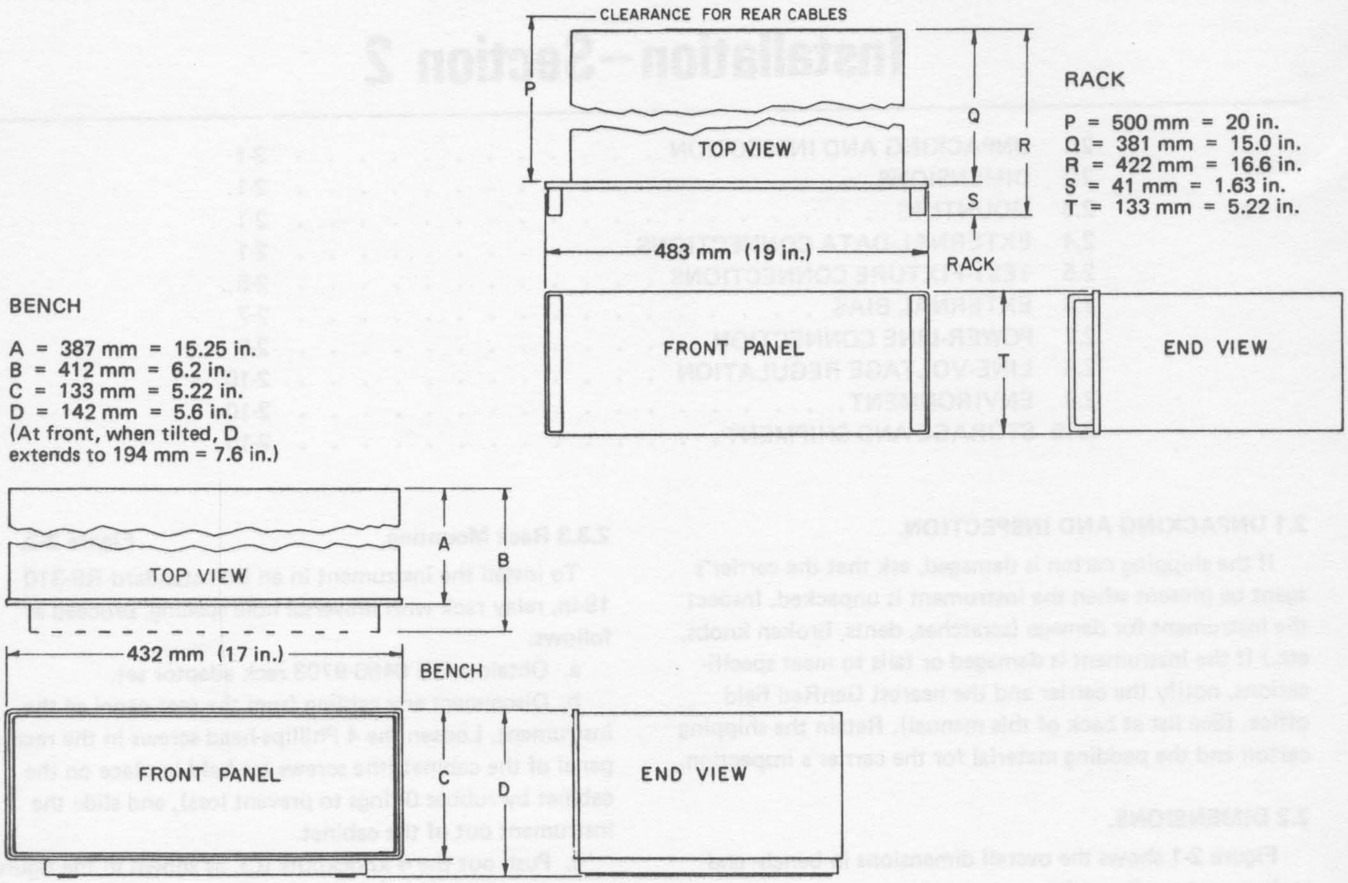


Figure 2-1. Dimensions of the instrument in bench and rack-mounting configurations.

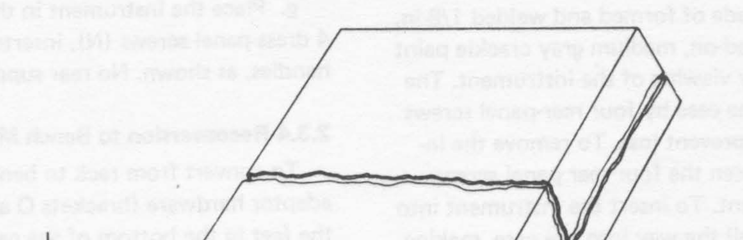


Figure 2-2. Rack-mount assembly.

in BCD form for printing, computation, or limit comparisons, refer to para 2.4.2. If it requires comparison results from the limit comparator within this instrument, refer to para 2.4.3.

NOTE

External-data connections are NOT essential for operation. For initial setup and demonstration of the instrument, skip to para 2.5.

All data outputs (including limit-comparator outputs) are standard TTL (T^2L) logic, open-collector, active low. Each output is capable of sinking up to 40 mA, maximum, from an external source of up to +30 V. The low output is +0.4 V, maximum. Open-collector circuitry furnishes total interface flexibility. If Data Output signals are used to drive peripheral logic circuits, the user must add pullup resistors to the logic devices (if not already present). They are not required for the Limit Comparator outputs. Each set of output signals can be inverted (as a group) to be open-collector, active high, by a simple plug-in substitution of the output IC. For example, substitute a type 7407 hex buffer/driver for a type 7406 hex inverter buffer/driver or vice versa, if desired.

Provisions are made for two control inputs, remote start and lamp test. For the former, a positive step input initiates a measurement cycle; with $0\ V < V_L < 0.4\ V$ and $+2\ V < V_H < +30\ V$. (Open-circuit is equivalent to the V_L input). A ground at the lamp-test input lights all segments of the four right hand digits of the CAPACITANCE display (8888), to check operation of the LED indicator. This lamp test does not check decimal points.

2.4.2 Data Output Connector, L-S01. Figure 2-3.

Output signals available at this board-edge connector allow the recording of measurement data by external data printers and recorders. Available data includes the capacitance readout numbers and location of decimal point, but not the units of capacitance. The connector also provides for the input of some control signals furnished by peripheral devices. Figure 2-3 shows the connector and lists its signals by corresponding pin numbers. Table 2-1 is a more informative listing, with brief descriptions of the signals. This information is useful as a guide in the assembly of a cable to tie into your peripheral equipment.

This cable connector (P/N 4230-1023), supplied with the meter, consists of a socket and cover assembly. The socket alone is commercially available (Amphenol no. 225-21521-401-117); it is a 15-position, 30-contact board-edge connector with solder terminals for connecting cable wires. The cover fits over the wiring side of the connector. It connects to S01, on the logic board, recessed in the instrument's rear panel. The connector is keyed so that it will seat properly only if it is oriented properly on the circuit-board edge.

BCD DATA OUTPUTS				PIN
Spill	DATA	$\overline{17}$		8
Most-significant digit	DATA	$\overline{16}$	8	14
	DATA	$\overline{15}$	4	M
	DATA	$\overline{14}$	2	D
	DATA	$\overline{13}$	1	B
	DATA	$\overline{12}$	8	P
	DATA	$\overline{11}$	4	L
	DATA	$\overline{10}$	2	C
	DATA	$\overline{9}$	1	A
	DATA	$\overline{8}$	8	N
	DATA	$\overline{7}$	4	K
	DATA	$\overline{6}$	2	F
	DATA	$\overline{5}$	1	1
Least-significant digit	DATA	$\overline{4}$	8	R
	DATA	$\overline{3}$	4	J
	DATA	$\overline{2}$	2	H
	DATA	$\overline{1}$	1	2

DECIMAL-POINT OUTPUTS*		
4th decimal	$\overline{ADP}$	9
3rd decimal	$\overline{BDP}$	12
2nd decimal	$\overline{CDP}$	13

*Examples of displays: 04.321 μF (4th decimal point is lit), 0432.1 μF (2nd decimal).

SIGNAL OUTPUTS		PIN
$\overline{STROBE}$ (after measurement)		3
$\overline{E}$ (overrange or error)		4
$\overline{RESET}$		10
$\overline{HID}$ (high D, low Q)		11
SIGNAL INPUTS		
$\overline{LT}$ (lamp test)		6
REMOTE START		7
GND (ground connections)		S & 15
SPARES		
INTERFACE 1	Connected only for external	E
INTERFACE 2	applications, as required	5

Figure 2-3. Data output board-edge connector, seen from rear of instrument.

Table 2-1
SIGNALS AT THE DATA OUTPUT CONNECTOR, L-S01

Signal Name	Pin No.	Function and Description
BCD DATA OUTPUTS*	As identified in Figure 2-3	Measurement data in BCD form. All data outputs are open-collector, active low. Details on logic levels are given in the text. If the test frequency is 1 kHz, the most significant digit (0 or 1) is on pin 8; if 120/100 Hz, on pin B.
$\overline{ADP}$, $\overline{BDP}$, $\overline{CDP}$*	9, 12, 13, respectively	Decimal-point indicator signals for display components DS4, DS3, & DS2 respectively. (For identity refer to footnote in Figure 2-3.) Logic 0 is active function. Refer to Table 3-2 for usage of decimal points for various ranges.
$\overline{STROBE}$*	3	Transition to logic 0 indicates data is available for recording; the measurement has been made and the limit comparator in this instrument has made its comparison. Refer to timing diagram, Figure 6-9, if necessary.
$\overline{E}$*	4	Logic 0 indicates measured capacitance exceeds full scale on the selected range (19999 counts if test frequency is 1 kHz, 1999 counts if otherwise) and the letter E appears in spill-digit position (left) in CAPACITANCE display. Subsequent transition to logic 1 occurs when meter circuits reset for new measurement sequence (although previous displayed value remains displayed until just before $\overline{STROBE}$ occurs).
$\overline{HID}$*	11	Logic 0 indicates measured dissipation factor exceeds setting of D dial (D limit); associated fail arrow is lighted (red).
INTERFACE 1, INTERFACE 2	E, 5, respectively	Available connections for external equipment, to be used as required. Provide hardware connections between peripheral equipment connected to this Data Output connector and any connected to the Comparator connector, (with possibility of connection within this instrument). See also Table 2-2.
$\overline{LT}$ (lamp test)*	6	Input connection for testing the CAPACITANCE display. When this pin is grounded, the display should be 8888, to check operation of all segments of the four least-significant digits. Does not light the decimal points, nor the spill-digit.
REMOTE START	7	Input connection for remotely starting a measurement sequence. Positive input step initiates measurement: $0\ V < V_L < 0.4\ V$ to $+2\ V < V_H < +30\ V$ (Open circuit is equivalent to V_L.) For use in single-measurement mode.
GND	S, 15	Ground-reference connections.

*Negative true logic.

2.4.3 Comparator Connector, A-S05. Figure 2-4.

General. The Comparator connector, labeled S05 on the rear panel, is a 24-pin connector, as shown in the figure. The mating cable connector is Cinch or Amphenol 57-30240. (Refer to para 1.6.) Most of the signals at this connector are outputs from the built-in limit comparator. Because these signals are useful for automatic handling equipment, there is also provision for connecting a measurement-start (input) signal here. A key to pin numbers and functional descriptions are given in the list of signals, Table 2-2.

Comparator Outputs. The 6 main outputs are those driving inductive loads in the simplified circuitry of Figure 2-5. This represents a typical application, in which it is important to use the "clamp" connection, as explained below.

The clamp is a protective circuit, for use with inductive loads (such as relays) or when spikes are present, to prevent voltages from exceeding +30 V and reaching the breakdown voltage of the hex buffer-drivers that provide these output signals.

The clamp is internally connected to six diodes, whose anodes are tied, one each, to the six data-output lines. The line called "CLAMP" is to be tied to the external supply (+30 V, max.) to suppress inductive transients from external relay coils or similar devices.

CAUTION

For proper operation, when using the clamp feature, use only one positive-voltage power supply for any or all 6 loads, keep its voltage at or below 30 V, and connect it directly to CLAMP.

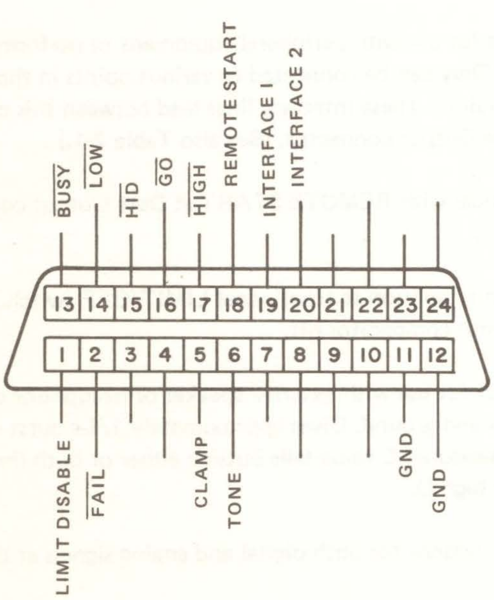


Figure 2-4. Comparator connector, S05, seen from rear of instrument.

For the 6 main outputs, the TTL open-collector feature allows high-voltage output for interfacing with high-level circuits (such as MOS) or for driving high-current loads, such as lamps or relays, up to 30 V. Three other outputs are also furnished: TONE, INTERFACE 1, and INTERFACE 2.

The audio output "TONE" can be used to drive a miniature speaker or headphone tied between this output and ground. The signal gives a 1/4-s burst of 250-Hz frequency when the measured C value is outside the established limits.

The INTERFACE lines allow external devices such as printers, multiple-limit comparators, component handlers, etc. to be connected for specific applications. These lines can be tied internally to various control signals available on the comparator or logic boards in the instrument. The connections are also paralleled with 2 pins in the Data Output connector. Refer to the schematic drawings in Section 6, if necessary.

NOTE

Two other outputs from the comparator are available on the TEST FIXTURE connector. They are $\overline{\text{PASS}}$ and $\overline{\text{FAIL}}$ (respectively the inverse of $\overline{\text{GO}}$ and of $\overline{\text{FAIL}}$). See para 2.5.

Data Inputs. These 2 include REMOTE START, a signal that initiates a measurement cycle on a positive step input: $0\ V < V_L < +0.4\ V$ to $+2\ V < V_H < +30\ V$. (Open is equivalent to V_L input.) The other input signal, LIMIT DISABLE, performs the same function as the LIMIT/OFF switch on the front panel. Logic high (V_H) turns the limit comparator off; open circuit or V_L turns the comparator on.

2.4.4 Interchanging Active Levels.

The active levels of digital-logic output signals can be reversed by internal change. That is, active lows can be substituted for highs, and vice versa, by the substitution of 7407 hex buffer-drivers for 7406 hex inverter buffer-drivers, and vice versa. (For example, if you want the 6 main outputs from S05 to be active high and if you are not using the BCD data outputs from S01, the type 7407 on the comparator 'A' board, can be interchanged with any of the 3 type 7406's on the logic board. This will reverse the active outputs of the comparator board and certain outputs – not needed – from the logic board.) Full substitutions can be made to change all levels. In addition, type 7404, 7405, 7416, and 7417 IC packages can be substituted for any 7406 or 7407 output circuit.

2.5 TEST-FIXTURE CONNECTIONS. Figure 2-6.

The rear-panel connector labeled TEST FIXTURE makes connection, via cable, to the test fixture or equivalent devices. Typically, the cable is GR 1686-0291 and the test fixture, GR 1686-9600. (See para 1.6.) Instead of this test

Table 2-2

SIGNALS AT THE COMPARATOR CONNECTOR, A-S05

Signal Name	Pin No.	Function and Description
CLAMP	5	A protective circuit. Connection to dc power supply of devices (relays) driven by the 6 circuits shown in Figure 2-5 provides diode protection against damage by switching-transient voltage spikes. Connect to positive dc supply, +30 V max.
$\overline{\text{BUSY}}$	13	Logic high (open collector) indicates meter and comparator busy. Goes high at time of reset and goes low when comparison completed (both low and high limits).
$\overline{\text{LOW}}$*	14	Logic low if measured C is lower than low limit. LOW lamp lights at same time, $\overline{\text{FAIL}}$ output goes low, and GO lamp is held extinguished.
$\overline{\text{HIGH}}$*	17	Logic low if measured C is higher than high limit. HIGH lamp lights at the same time, $\overline{\text{FAIL}}$ output goes low, and GO lamp is held extinguished.
$\overline{\text{HID}}$*	15	Logic low if measured dissipation factor exceeds D limit. Fail arrow (red) associated with D dial is also lit. The GO lamp is held extinguished.
$\overline{\text{GO}}$*	16	Logic low if measured C and D values are at or within limits established at time of measurement. Accordingly, the GO lamp is lit and the $\overline{\text{BUSY}}$ signal is logic low.
$\overline{\text{FAIL}}$*	2	Logic low if measured C violates either of its 2 limits or D exceeds the D limit.
INTERFACE 1, INTERFACE 2	19, 20, respectively	Connections for use with peripheral equipment to perform specific operations. They can be connected to various points in this instrument, as required. These interface lines lead between this connector and the Data Output connector. (See also Table 2-1.)
REMOTE START	18	Input. Identical with REMOTE START at Data Output connector; see Table 2-1.
LIMIT DISABLE	1	Performs same function as front-panel LIMIT/OFF switch. Logic high turns limit comparator off.
TONE	6	Audio output for use with external speaker or headphone connected between this and ground. Gives approximately 1/4-s burst of 250-Hz tone when measured C value falls outside either or both limits. Not activated by high D.
GND	11, 12	Ground connections for both digital and analog signals at this connector.

*These signals convey comparison results after $\overline{\text{BUSY}}$ goes to logic low.

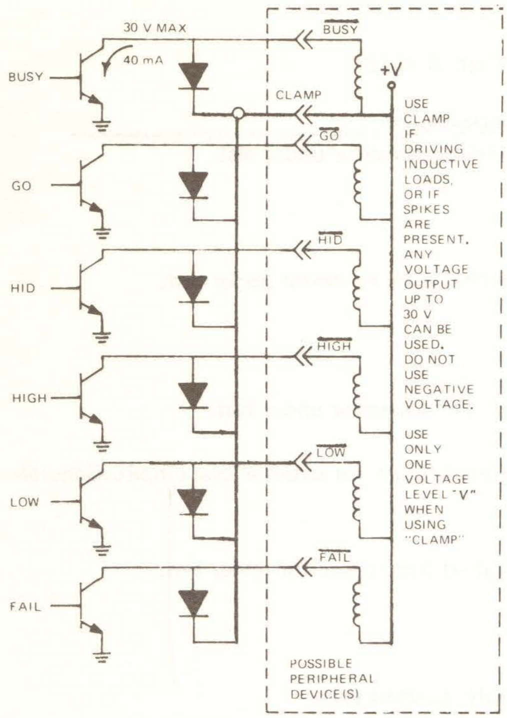


Figure 2-5. Elementary circuitry for the 6 comparator output signals that can be used with the "clamp" function. The area enclosed in the dashed-line block is peripheral; area to left represents part of the Comparator A Board.

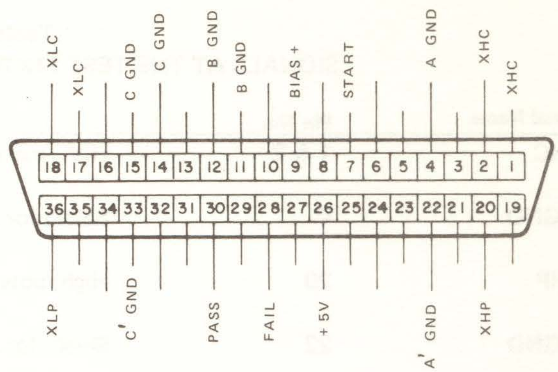


Figure 2-6. Test-fixture connector, S010, rear view.

fixture, you can use the elementary measurement cable (supplied) or a more elaborate fixture, which could be part of automatic handling machinery.

The 5-terminal connections for the capacitor being measured are of primary importance — a "potential" and a "current" connection to each end of the capacitor and a ground. (The use of 5 terminals instead of only 2 has to do with eliminating the effects of cable and test-fixture "stray" impedances from the measurements; refer to para 3.1.) Also found on this connector are outputs for "pass" and "fail" lights, and input to start the measurement cycle if you are using single-measurement mode, input from an external bias voltage source, and a dc output for possible use in active circuitry, Refer to Table 2-3.

For special equipment, the following connectors should be used. Mount an Amphenol No. 57-40360 connector on a test fixture, to receive the GR 1686-0291 cable. For a special cable, use an Amphenol No. 57-30360 cable connector (like the one supplied) to fit the TEST FIXTURE connector directly.

2.6 EXTERNAL BIAS. Figures 2-7, 2-8, 2-9.

2.6.1 Application of Bias.

Up to 100 V can be applied externally to the instrument, to bias the capacitor under test. As described above, the connections to the instrument are included in the TEST FIXTURE connector. In the typical situation, with a test fixture connected to that connector, the external bias power supply must be connected "through" the test fixture. If you are using the 1686-9600 Test Fixture, connect the bias power supply (with bias network described below) to the smaller connector on the fixture.

A low-impedance, regulated power supply is recommended as the external bias supply. It should have an output impedance low enough so that the applied ac test voltage will not be appreciably changed compared to the normal condition with the BIAS switch OFF. The output-impedance requirement depends on the measurement range being used, as illustrated. On range 1, the supply can have a rather high impedance. On the 5 middle ranges, the output impedance should be small compared to 10 ohms, and on ranges 7. . .9, it should be small compared to 1 ohm. Of course, a low impedance can be used for all ranges. If a shunt capacitor is used to obtain this low impedance, its reactance can be as large a one-half the above values. Output impedance is generally not a problem for "hard-regulated" supplies. However, such supplies generally do not operate properly with reverse current flowing into them.

One method to prevent a negative dc regulator current is to load the regulator with a bleeder resistor such that the dc current is greater than the peak ac current (142 mA). Refer to Figure 2-8. A bleeder current of at least 150 mA is recommended; thus, with a given resistor, there is a minimum permissible bias voltage. Power dissipation in the bleeder sets a limit on the maximum voltage. In order to make a full range of bias voltages available, you need a set of bleeder resistors; Table 2-4 lists a possible set. However,

Table 2-3

SIGNALS AT THE TEST FIXTURE CONNECTOR, G-S010

Signal Name	Pin No.	Function and Description
XHC	1 & 2	High, current connection (I+) to capacitor under test.
A GND	4	Shield for XHC.
XHP	20	High, potential connection (P+) from capacitor under test.
A'GND	22	Shield for XHP.
XLC	17 & 18	Low, current connection (I–) to capacitor under test.
C GND	14 & 15*	Shield for XLC. Guard. Ground return for external bias circuit. General-purpose analog ground.
XLP	36	Low, potential connection (P–) from capacitor under test.
C'GND	33	Shield for XLP.
BIAS+	9	Connects external bias supply, positive side.
START	7	Negative step (typically by switch closure to B GND) starts a measurement cycle if instrument is in single-measurement mode.
PASS	30	Logic high if measured C and D values are at or within the limits established at time of measurement. Inverse of $\overline{GO}$ (Table 2-2). Will drive a lamp.
FAIL	28	Logic high if measured C violates either of its 2 limits or D exceeds the D limit. Inverse of $\overline{FAIL}$ (Table 2-2). Will drive a lamp.
+5V	26	Dc bus providing +5 V (0.1 A max) for external circuitry.
B GND	11 & 12*	Digital ground. Ground return for START, PASS, FAIL, and +5V.

*Pins 12 and 15 are NOT connected in the measurement cable 1686-0291.

for a fixed bias voltage, this method is simple and has the advantage of lower time delay than the method described below.

Table 2-4

BIAS-SUPPLY BLEEDER RESISTOR

Resistance	Bias range	Dissipation
12 Ω	1.8 to 11 V	10 W
68	10.2 to 26	10
150	23 to 43	12
270	41 to 77	22
500	75 to 100	20

Another practical method is to use the circuit illustrated in Figure 2-9, where the ac current is attenuated before reaching the regulator, so that the dc bleeder current can be substantially less. From the "ac voltage" requirement, for $R_B = 1\ \Omega$, you need $C >> 1.6$ mF. At any one bias voltage, R_2 is bounded by the "negative regulator current" requirement and its own dissipation limit; thus, $\omega R_1 CE/0.15 > R_2 > E^2/P$. If you want E = 100 V, then $\omega R_1 C > 3$; and if you want any given value of R_2 to be usable over a range of voltage, choose $\omega R_1 C$ even larger. For example, take C = 6.8 mF and $R_1 = 1.5\ \Omega$ (or 4.7 mF and 2.2 Ω); then $\omega R_1 C = 6.3$ at 100 Hz. If the power rating P of R_2 is 5 W, then a set of 3 resistors R_2 can be used for 3 ranges of bias voltage E as follows: R_2 = 68, 680, 2200 Ω; for 1.7-18, 17-58, 53-100 V, respectively. If you prefer a single value of R_2, take R_1 45 times larger than the example above and use $R_2 = 2200\ \Omega$ for any bias in the range E = 1.2 to 100 V. (However, this simpler circuit will require a noticeably longer time to charge large capacitors.)

The instrument is fitted with a reliable power connector that is inconformance with the International Electrotechnical Commission publication 320. The 3 flat contacts are surrounded by a cylindrical plastic shroud that eliminates the possibility of electrical shock whenever the power cord is being unplugged from the instrument. In addition, the center ground pin is longer, which means that it mates first and disconnects last, ensuring user protection. This panel connector is a standard 3-pin grounding-type receptacle, the design of which has been accepted world wide for electronic instrumentation, and is rated for 250 V at 6 A. It also meets requirements of Underwriter's Laboratories in the U.S. and the Canadian Standards Association. The receptacle accepts power cords fitted with the Belden type SPH-386 connector. Its GR part number is 4240-0210.

The associated power cord for use with that receptacle is GR part no. 4200-9625. It is a 210-cm (7-ft), 3-wire, 18-gauge cable with connector bodies molded integrally with the jacket. The connector at the power-line end is a stackable hammerhead design that conforms to the "Standard for Grounding Type Attachment Plug Caps and Receptacles," ANSI C73.11-1963.

2.8 LINE-VOLTAGE REGULATION.

The accuracy of measurements accomplished with precision electronic test equipment operated from ac line sources can often be seriously degraded by fluctuations in primary input power. Line-voltage variations of ±15% are commonly encountered, even in laboratory environments. Although most modern electronic instruments incorporate some degree of regulation, possible power-source problems should be considered for every instrumentation setup. The use of line-voltage regulators between power lines and the test equipment is recommended as the only sure way to rule out the effects on measurement data of variations in line voltage.

The GR 1591 Variac® Automatic Voltage Regulator is a compact and inexpensive equipment capable of holding ac line voltage within 0.2% accuracy for input ranges of ±13%. It will assure, for example, that an instrument rated for 100-125 (or 200-250) V can be operated reliably in spite of varying input voltages in the range 85-135 (or 170-270) V. The 1 kVA capacity of the GR 1591 will handle a rack full of solid-state instrumentation with no distortion of the input waveform. This rugged electromechanical regulator comes in bench or rack-mount versions, each with sockets for standard 2- or 3-wire instrument power cords.

2.9 ENVIRONMENT.

The 1686 Meter can be operated in bench- or rack-mount configurations. Keep it and all connections to the parts under test away from electromagnetic fields that may interfere with measurements.

Refer to the Specifications at the front of this manual for temperature and humidity tolerances.

2.10 STORAGE AND SHIPMENT.

2.10.1 Packaging.

To protect valuable electronic equipment during storage or shipment, always use the best packaging methods available. Your GR field office can provide packing material such as that used for original factory packaging. Contract packaging companies in many cities can provide dependable custom packaging on short notice. Here are two recommended packaging methods:

Rubberized Hair. Cover painted surfaces of instrument with protective wrapping paper. Pack instrument securely in strong corrugated container (350 lb/sq in. bursting test), with 2-in. rubberized hair pads placed along all surfaces of the instrument. Insert fillers between pads and container the ensure a snug fit. Mark the box "Delicate Instrument" and seal with strong tape or metal bands.

Excelsior. Cover painted surfaces of instrument with protective wrapping paper. Pack instrument in strong corrugated container (350 lb/sq in. bursting test) with a layer of excelsior about 6 in. thick, packed firmly against all surfaces of the instrument. Mark the box "Delicate Instrument" and seal with strong tape or metal bands.

2.10.2 Special Reshipment Instructions.

For service/repair shipment, refer to para 5.1.

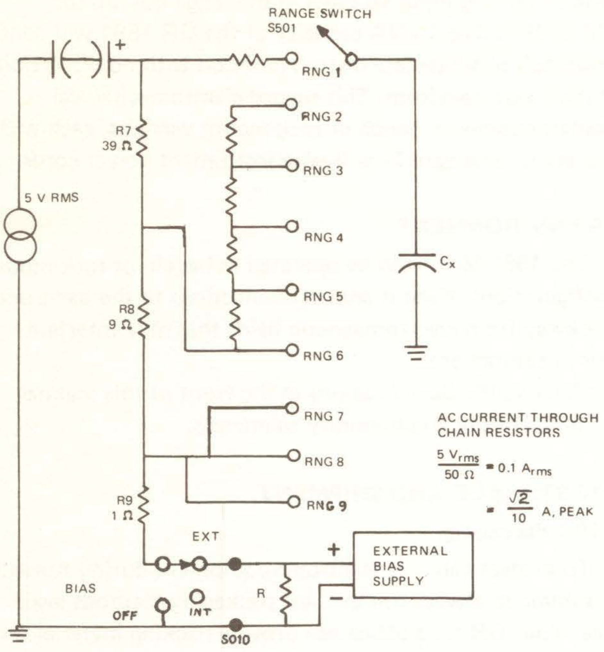
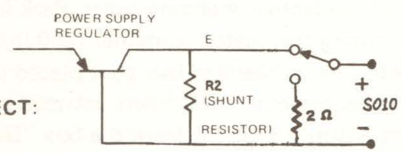


Figure 2-7. External bias connection, with external bleeder resistor R used to prevent the ac current peak (142 mA) from momentarily reversing the current in the bias power supply.

$$\text{POWER} = \frac{E^2}{R2}$$



TO KEEP ACV CORRECT:

$$Z_o << R_B,$$

WHERE

R_B = R9 (1 Ω, THE CHAIN RESISTOR).

TO PREVENT NEGATIVE REGULATOR CURRENT:

$$\frac{E}{R2} > \frac{\sqrt{2}}{10} \text{ A}.$$

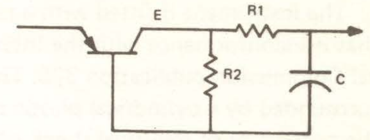
Figure 2-8. Factors in the choice of bleeder resistor connected across the bias power supply to keep its electronic regulator in operation, for a limited range of voltage. Do not overlook the charge/discharge switch, external to the 1686.

WARNING

Charged capacitors are hazardous. Be sure external bias supply and network do not endanger operator. Refer also to WARNING in Condensed Operating Instructions and para 3.7.3.

2.6.2 Discharge.

It is important to provide a discharge switch in the external bias circuit for discharging the capacitor under test and the capacitor "C" described above (if used).



$$\text{DC POWER} = \frac{E^2}{R2}$$

TO KEEP ACV CORRECT

$$\frac{1}{\omega C} << R_B,$$

WHERE

R_B = R8 AND R9 OR JUST R9 (1 Ω).

TO PREVENT NEGATIVE REGULATOR CURRENT

$$\frac{E}{R2} > \frac{\sqrt{2}}{10\sqrt{1 + \omega^2 R1^2 C^2}} \text{ A}$$

OR APPROXIMATELY

$$\frac{E}{R2} > \frac{\sqrt{2}}{10\,\omega R_1 C} \text{ A}.$$

Figure 2-9. Addition of a series resistor and shunt capacitor to the circuit of the previous figure enables the use of lower-power components. The switch shown previously is still required.

Perhaps turning off the bias power supply will do this, but it is generally necessary to have a sturdy switch, as shown in Figure 2-8.

There are several reasons for not using the BIAS switch on the front panel for discharging. Turning that switch from EXTERNAL to OFF when a large capacitor charged to high voltage is attached to the test fixture is liable to damage the internal-bias circuit components as well as the BIAS switch itself. However, as a safety precaution, the BIAS switch can be turned to OFF after the discharge has been accomplished, before the operator removes the capacitor from the test fixture. Refer to para 3.7.

2.7 POWER-LINE CONNECTION.

The power transformer primary windings can be switched, by means of the five-position switch on the rear panel, (Figure 1-2), to accept line voltages of 90-110, 104-127, 180-220, 194-236, or 207-253 V, alternating current, at a frequency of 50 to 60 Hz. Using a small screwdriver, set this switch to match the measured voltage of your power line.

Operation is satisfactory with power-line frequencies up to 440 Hz, with lower line-voltage limits increased by 5%, or down to 45 Hz, with upper limits reduced by 5%. However, if the line frequency is much different from 60 Hz (for the 1686-9700) or 50 Hz (for the 1686-9800), some simple internal changes are required. Refer to para 3.5.

Be sure the fuses have the current ratings shown on the rear panel, regardless of your power-line voltage.

Connect the 3-wire power cable (P/N 4200-9625) to the line and to the power connector on the rear panel (Figure 1-2).

Operation – Section 3

3.1 CONNECTIONS.

CAUTION

Be sure the LINE VOLTAGE switch on the rear panel is correctly set before connecting the power cord.

3.1.1 Power and Data Connections.

Connections for power, external control and for data outputs are described in Section 2. Para 3.5 gives details for changing the instrument's "low" test frequency. This is normally 120 or 100 Hz, synchronized to the power line (mains), depending on which version of the instrument you have. (Refer to listing at the end of specifications, at the front of this manual).

The rest of para 3.1 is concerned with connecting the capacitor to be measured.

3.1.2 General-Purpose Test Fixture.

The GR 1686-P1 Test Fixture (catalog no. 1686-9600) is highly recommended for its convenience and reliability. It accommodates every common size of axial-lead and radial-lead capacitor, with true 4-terminal connections made automatically. It also has colored lights to indicate go/no-go results (duplicating these on the 1686 front panel) and a "start" bar to press if you're using the single-measurement mode. Connect the fixture to the instrument and insert the capacitor under test as follows:

a. Plug the measurement cable 1686-0291 (supplied) – either end – into the TEST FIXTURE connector on the rear panel. Use the clips that are alongside the panel connector to secure the cable connector.

b. Connect the test fixture to the other end of that cable, similarly.

c. To connect radial-lead capacitors, insert one capacitor lead into each test slot, endwise (like pushing a 2-pin plug into a socket).

d. Bias is applied, if you choose (with the BIAS switch), in the polarity labeled on the fixture. Refer to para 3.7. Therefore, be sure to orient polarized capacitors accordingly.

WARNING – DANGER

Electrical energy stored in charged capacitors can be dangerous to the operator. Full bias voltage appears on test-lead and test-fixture terminals and the leads of the capacitor under test when an external bias source is connected and the BIAS Switch is set to EXTERNAL. Never leave the instrument unattended with external bias applied.

Provide adequately for discharge in the external circuit, if you use external bias. (Refer to para 2.6.) Establish and follow safe procedures to assure proper discharge of measured capacitors and the bias circuit. Be sure all personnel operating the equipment are aware of the potential hazard involved in external biasing.

e. To connect axial-lead capacitors, insert the adaptors supplied with the test fixture, one into each slot, far enough apart to allow the body of the capacitor to come between them. Insert one lead of the capacitor into the slot of each adaptor, sidewise (like placing a matchstick between the blades of scissors). Observe the preceding comments about bias.

f. Observe the following information:

The test fixture receives the capacitor leads with a wiping action that cuts through a film of wax. However, avoid inserting dirty wires into the fixture.

The basic test slots accomodate a pair of parallel wires of any diameter from 0.25 mm (.01 in., AWG 30) to 1 mm (.04 in., AWG 18) spaced from 6 to 98 mm apart (0.23 to 3.9 in.) or equivalent strip conductors. Each wire must be at least 1 cm long (0.4 in.). The divider between the test slots contains a shield, at guard (ground, bias zero) potential, with its edges slightly exposed.

The adaptors (for axial-lead components) accomodate wires of any diameter up to 1.5 mm (.06 in., AWG 15). The body of the capacitor that will fit between these adaptors can be up to 80 mm long and 44 mm diameter (3.1 x 1.7 in.). Each wire must be at least 3 mm long (0.12 in.).

Measured values of electrically small capacitors depend somewhat on test-fixture geometry. Refer to "3-terminal use" in para 3.1.3.

3.1.3 Elementary Measurement Cable.

This short cable, 1686-9602, is supplied for general use if you do not have a test fixture and to accomodate any capacitor that does not readily fit the general-purpose test fixture. This cable is useful in early stages of developing a special test fixture or probe that you may need, a project that is beyond the scope of this manual. The 5 elementary terminals are explained and some uses of the cable outlined below. References to the bridge-circuit signal names can be better understood by reference to the theory, Section 4. Characteristics of multi-terminal capacitors are illustrated in following paragraphs.

Identification of Terminals. In Table 3-1, the 5 terminals are listed, each with the corresponding signal name as labeled in this instrument and the appearance of the cable tip.

Non-Critical Use, Moderate Capacitance. For common 2-terminal capacitors, with values in instrument ranges 4, 5, 6, the elementary measurement cable is easily connected by stacking its terminals as follows:

a. Plug the [I+] tip into the [P+], and connect the latter, with or without a slip-on alligator clip, to one terminal (or lead) of the capacitor being measured.

b. Plug the [I–] tip into the [P–] and connect this similarly to the other terminal of the capacitor.

Table 3-1

MEASUREMENT TERMINALS

Terminal	Cable Tip	Signal Description	Signal Name
I+	Red	High, current connection. If bias used, WARNING: HAZARD, both terminals with red plugs are positive with respect to 3 with black plugs.*	XHC
P+	Red & white	High, potential connection. Bias hazard, when connected to I+.	XHP
I–	Black	Low, current connection.	XLC
P–	Black & white	Low, potential connection.	XLP
G	Black & green	Guard connection; analog ground.	C GND

*Notice that, in use, I+ and P+ must be connected to one side of the capacitor being measured; I– and P–, to the other side.

Three-Terminal Use, Small Capacitance. For capacitors that have 3 terminals (one being case, shield, or ground, see para 3.1.5), typically with capacitance values in ranges 1 ... 5, use this procedure:

a. Stack [I+] and [P+] as above and connect the latter to one insulated terminal of the capacitor being measured.

b. Stack [I–] and [P–] as above and connect to the other insulated terminal.

c. Connect the [G] tip to the case, shield, or ground terminal of the device being measured and to any nearby floating conductors including bench-top ground plane if there is one, not otherwise grounded.

NOTE

Small-capacitance 2-terminal capacitors can be measured with high precision only if the effects of fringing and capacitances to conductors in the environment are brought under control. In practice, the test-fixture geometry must be carefully specified. The smaller the capacitance, the more difficult it is to maintain this geometry as required for precise, repeatable measurements.

Electrically small 2-terminal capacitors can best be measured in a guarded test fixture with specified geometry (see para 3.1.4). To approximate such definite geometric requirements with the elementary measurement cable, use a procedure like this:

Decide on a guard or ground-plane geometry that is reasonable in light of typical applications of the capacitor and can be specified for comparison and for other measurements. For example, a cylindrical capacitor with axial leads, and a non-conducting outer surface can be laid directly on a ground plane, a flat metal sheet. (Lead geometry is important too; in this example, the leads should be straight and truly concentric.)

Decide on connector geometry that can be specified and conveniently kept unaltered as the measured capacitor is removed. Connect to the capacitor as in steps a and b above and to the ground plane as in step c. It may be necessary to apply a correction to the displayed capacitance to account for characteristics of this geometry (or any test fixture).

"Zero" Correction for Cable Capacitance. The elementary measurement cable adds capacitance, effectively in parallel with the capacitor being measured, because shielding of the leads is imperfect. The 1686-9602 cable adds about 6 pF in a typical application, but because the physical arrangement and spacing of the cable branches and tips are significant, a correction should be determined for each measurement setup.

To measure the cable capacitance directly, first make the setup to measure a capacitor. (The measurement is then $C_X + C_C$, that is, the sum of the capacitance to be measured and the cable capacitance.) Then disconnect the stacked combination of cable tips I+/P+ from the capacitor terminal and hold them about 0.5 cm from the capacitor terminal. Do this with a minimum of relocation of the cable branches. Ground yourself by touching the G terminal. The instrument now measures the cable capacitance C_C that should be subtracted from the previous result to obtain C_X. For a more detailed description of this procedure, refer to para 3.11.

Four-Terminal Use, Large Capacitance. For capacitors that have 4 terminals, typically with capacitance values in ranges 5. . .9, connect the elementary measurement cable tips as follows:

1. [I+], red, to high current terminal
2. [P+], red & white, to high potential terminal
3. [I–], black, to low current terminal
4. [P–], black & white, to low potential terminal
5. [G], black & green, to capacitor case, if this 5th terminal is provided. Otherwise, the guard connection can be omitted.

NOTE

> Large-capacitance 2-terminal capacitors can be measured with high precision only if the effects of lead and contact impedances are brought under control. In practice, 4-terminal connections must be used and the geometry of the test leads specified.

Electrically large 2-terminal capacitors can best be measured if 2 connections to each terminal can be made very close to the capacitor body, at mechanically fixed, definable places (not at the ends of long insulated pigtails). The requirements can be met adequately with the elementary measurement cable as follows. Use a slip-on alligator-clip adaptor on each of the banana-plug tips if it is convenient.

a. Connect [P+] to one terminal or lead of the capacitor, close to its body.

b. Connect [I+] to the same terminal or lead, nearby, NOT to the other cable tip directly.

c. Connect [P–] to the other terminal or lead of the capacitor, close to its body.

d. Connect [I–] to the same terminal or lead, nearby, NOT to the other cable tip directly.

e. The guard connection is not needed for capacitance larger than 10 μF. (Nevertheless, connect [G] to the frame or shield, if any exists that is NOT tied to either of the 2 main terminals.)

Figure 3-1 illustrates the use of this cable in making 4-terminal connections. Sketch "a" shows schematically that the 4 cable leads always join in 2 junctions (A, A'). It is essentially the device between these junctions (length R) that is being measured (Z_X in a following discussion).

Sketch "b" shows the attachment of 4 measurement-cable terminals (using alligator clips) to the 2 ends of an axial-lead capacitor. Notice that the "potential" connections are closer to the body of the capacitor than the "current" connections. This is the recommended arrangement (but valid measurements can be made with one or both "current" connections closer to the body). The important points are:

1. Both I+ and P+ connect to one end,
2. Both I– and P– connect to the other end, and
3. The instrument measures whatever is included between the closest clip on one side of the capacitor and the closest clip on the other side.

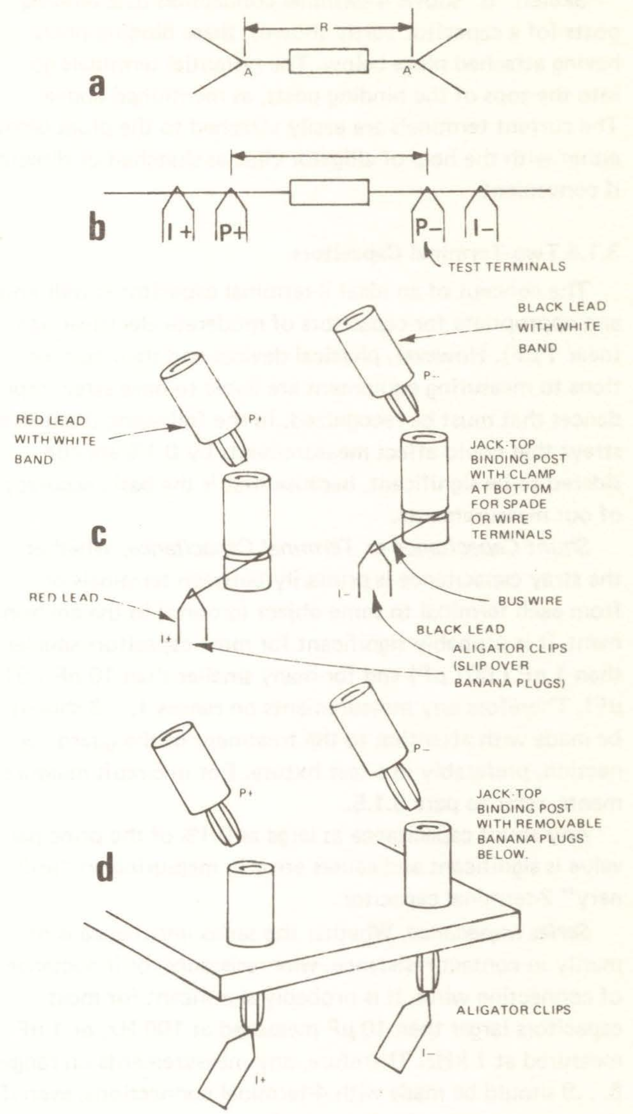


Figure 3-1. Four-terminal connections to a part being measured.

Sketch "c" shows 4-terminal connection to 2 binding posts (of a capacitor not shown). A short length of wire is clamped in each binding post and connection made by a "current" terminal (using an alligator clip) to each wire. The "potential" terminals of the measurement cable are plugged into the binding posts. Observe that the P+ (red & white) and I+ (red) terminals must connect together – at the binding post that should be positive if bias is used.

Sketch "d" shows 4-terminal connection to 2 binding posts (of a capacitor partly shown), these binding posts having attached plugs below. The potential terminals go into the tops of the binding posts, as mentioned above. The current terminals are easily attached to the plugs below either with the help of alligator clips as sketched or directly if convenient.

3.1.4 Two-Terminal Capacitors.

The concept of an ideal 2-terminal capacitor is well known and appropriate for capacitors of moderate electrical size (near 1 μF). However, physical devices and their connections to measuring equipment are liable to have stray impedances that must be recognized. In the following discussion, strays that could affect measurements by 0.1% are considered to be significant, because that is the basic accuracy of our measurements.

Shunt Capacitance or Terminal Capacitance. Whether the stray capacitance is primarily between terminals or from each terminal to some object (ground) in the environment, it is probably significant for most capacitors smaller than 1 nF (.001 μF) and for many smaller than 10 nF (.01 μF). Therefore any measurements on ranges 1. . .3 should be made with attention to the treatment of the guard connection, preferably in a test fixture. For in-circuit measurements, refer to para 3.1.5.

Any shunt capacitance as large as 0.1% of the principal value is significant and causes error in measuring an "ordinary" 2-terminal capacitor.

Series Impedance. Whether the series impedance is primarily in contact resistance, wire resistance, or inductance of connecting wires, it is probably significant for most capacitors larger than 10 μF measured at 100 Hz, or 1 μF measured at 1 kHz. Therefore, any measurements on ranges 6. . .9 should be made with 4-terminal connections, even if the capacitor has only 2 terminals.

Coaxial capacitors. The coaxial capacitors are true 2-terminal devices that can be measured with very high precision even though electrically small. To measure them with this instrument would require a special test fixture, which itself would be a 3-terminal device. Description of such a fixture is beyond the scope of this manual.

3.1.5 Three-Terminal Capacitors. Figure 3-2.

Although an ideal capacitor has only 2 terminals, every physical capacitor has stray capacitance between each terminal and one or more conductors in the environment, generally including "ground". In order to be of any use, or to be measured, a capacitor must be reasonably close to such outside conductors, close enough so that these stray capacitances (if not rigidly controlled) cause errors in the measurement of small C values. One part of the approach to minimizing these errors is to make measuring equipment that is relatively insensitive to impedance between either of the 2 main terminals and a guard (ground) terminal. The other part is to make 3-terminal (guarded or shielded) capacitors. An electrically small 2-terminal capacitor has no intrinsically true value. (Because of strays, its value must be defined with respect to test-fixture geometry.) On the other hand, a shielded (3-terminal) capacitor has a true value that is easily defined, is practically independent of test-fixture geometry, but requires a 3-terminal bridge or measuring instrument to evaluate it.

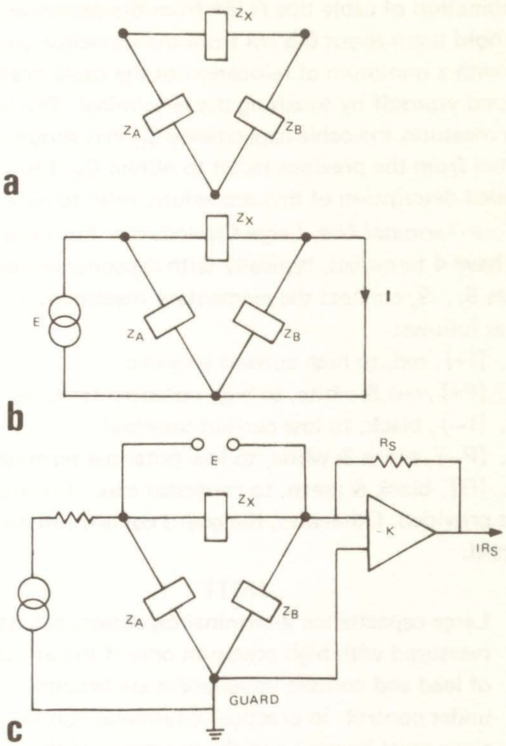


Figure 3-2. Three-terminal capacitor, with impedance Z_X is shown at (a) by itself, at (b) connected to ideal voltage source and current meter, and at (c) connected to elements of the measurement circuit.

A 3-terminal capacitor, represented by "a" in the figure, has a shielding enclosure around it. Z_X represents the basic capacitor. Z_A and Z_B are stray capacitances from the terminals to the enclosure, which serves as guard. The structure is made so that the stray capacitance due to fields outside the enclosure between the terminals is negligible.

Sketch "b" illustrates how Z_X can be measured. Voltage source E (having zero internal impedance) impresses E volts across Z_X. No current flows through Z_B, being shunted by the zero-impedance circuit that measures I coming through Z_X. Of course, $Z_X = E/I$.

Sketch "c" illustrates, in essence, how the 1686 circuit accomplishes the measurement. The voltage E across Z_X is measured, via potential connections rather than at the source, so we have in effect a zero-impedance source of E volts. The voltage across Z_B is kept practically zero by current feedback so we have in effect a zero-impedance shunt across it. The output voltage from the amplifier "–K" is a measure of the current I. As before, $Z_X = E/I$.

In-Situ measurements. A capacitor can be measured "in situ" (i.e., while connected in a passive network), with accuracy, under the following conditions. Refer to figure.

1. No significant current path in parallel with the branch to be measured Z_X. (Any such path is included in the measurement.)

2. Impedance Z_A is appreciably larger than the measuring-voltage source impedance, which depends on range as follows: for ranges 1. . .9 source impedances are 47 k, 20 k, 2 k, 200, 22, 10, 1, 1, and 1 Ω respectively.

3. Impedance Z_B is 1000 X larger than the detector input impedance (R_s/K), which depends on range as follows: for ranges 1. . .9, input impedances are: 100, 100, 10, 1, 0.1 Ω, 10 m, 1 m, and 0.1 mΩ, respectively.

Notice that the in-situ circuit is a generalization of the 3-terminal-capacitor circuit. In general Z_A and Z_B are likely to contain resistors, inductors, and capacitors (not only stray capacitances). Therefore you need to verify that the above conditions are satisfied, even for large-valued capacitors.

3.1.6 Four-Terminal Capacitors. Figure 3-3.

Every physical capacitor, to be used or measured, must have connections (leads or wires). The ideal capacitor has 2 terminals, but if a real capacitor has 2 leads, they add impedance to the device. This series impedance causes errors and uncertainty in the measurement of large C values. One part of the approach to minimizing these errors is to make measuring equipment that (using 4 terminals) can measure the impedance between 2 junctions remote from the instrument. The other part is to make 4-terminal capacitors. Such capacitors have the 2 junctions built in (rather than being formed by clips or plugs as described in para 3.1.3), so they have easily defined "true" values, practically independent of test-fixture geometry, but require 4-terminal bridges or measuring instruments to evaluate them.

In the diagram, sketch "a" represents a capacitor with impedance Z_X and leads with resistances R. (The lead self inductances, not shown, can be considered similarly.) If lead impedances are significant (and they are liable to be significant if Z_X is 200 Ω or less) they introduce error and uncertainty.

Sketch "b" represents a 4-terminal capacitor with value Z_X defined between 2 junctions. The impedances of the 4 leads are of secondary importance, so they can be extended beyond the 4 terminals, through cables (and a test fixture perhaps) to the measuring instrument.

Sketch "c" illustrates, in essence, the 1686 "potential" measuring circuit connected to such a 4-terminal capacitor. The differential amplifier draws no current through R2 and R4; therefore it measures the voltage E across Z_X. The test signal is applied as shown in Figure 3-2, c, which also shows how the current I through Z_X is measured (using amplifier "–K".) As before, $Z_X = E/I$.

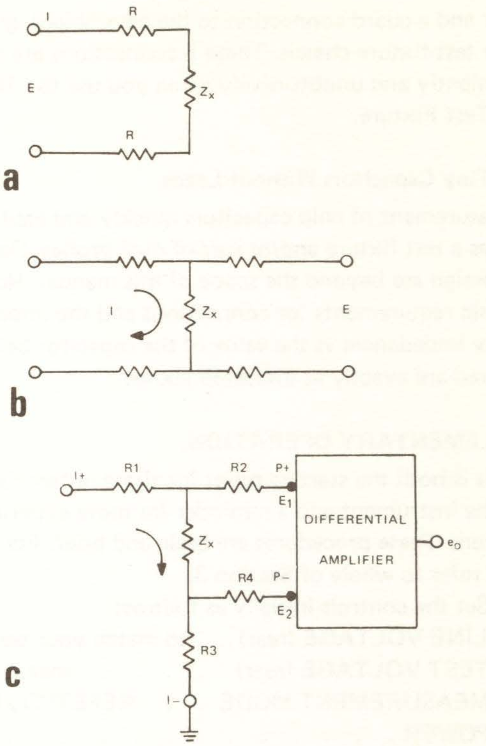


Figure 3-3. Four-terminal network. In (a), Z_X is the impedance to be measured, with test lead resistances R. In (b), 4 leads are shown, a "current" pair and a "potential" pair. In (c), the potential pair is shown connected to a component of the measuring instrument.

Z_X in general includes self inductance in the heart of the capacitor, inductance that is intrinsic and should be constant. However, mutual inductances are more elusive sources of error. They should be minimized within the 4-terminal capacitor by good design and in the test cable arrangement (or test fixture) by keeping the coupling between the current and potential leads as small as possible. The 1686 test cable has very low coupling because of the geometry of the leads in the cable. Additional inductance at the end of the leads can be reduced by keeping the loop formed by the current leads and the loop formed by the potential leads: 1) as small as possible, 2) separated from each other, and/or 3) at right angles to each other. (See para 3.9.6 and 3.9.7).

If the leads are to be extended, the current leads should be twisted together, and the potential leads should be twisted together.

3.1.7 Five-Terminal Connections.

The 5 connections from the capacitance meter to the capacitor being measured are enumerated in para 3.1.3. Although they are not all necessary for every measurement, they should all be connected as a matter of course. Essentially, this means a 4-terminal connection to the capacitor proper and a guard connection to the case, shield, ground, and/or test-fixture chassis. These 5 connections are made conveniently and unobtrusively when you use the 1686-9600 Test Fixture.

3.1.8 Tiny Capacitors Without Leads.

Measurement of chip capacitors quickly and easily requires a test fixture and/or pair of dual probes. Details of their design are beyond the scope of this manual. However the basic requirements for connections and the importance of stray impedances vs the value of the capacitor being measured are exactly as discussed above.

3.2 ELEMENTARY OPERATION.

This is both the starting point for those unfamiliar with the instrument and a reminder for more experienced operators. These procedures are basic and brief. For greater detail, refer to whole of Section 3.

a. Set the controls initially as follows:

LINE VOLTAGE (rear)	to match your power line
TEST VOLTAGE (rear)	max clockwise
MEASUREMENT MODE	REPETITIVE 0.25 s
POWER	ON
DISSIPATION FACTOR	.01
RANGE	5
FREQUENCY	1 kHz
BIAS	OFF
LIMIT/OFF switch	OFF

b. Insert the capacitor to be measured in the test fixture (or see para 3.1).

c. Turn the RANGE switch if necessary to extinguish the associated indicators (arrows).

d. Read the measured C on the digital CAPACITANCE display.

e. Above the DISSIPATION FACTOR dial read "satisfactory" (green light) or "high D" (red) with respect to the dial setting.

3.3 CAPACITANCE RANGES AND DISPLAYS.

3.3.1 Ranges.

The 1686 Digital Capacitance Meter automatically shows which range is suitable, by the 2 white arrow-shaped indicators above the RANGE switch. Select the proper measurement range by turning the RANGE switch in the direction indicated by the arrows. Allow the instrument time for at least one measurement, so you can see the results, before turning this switch another step. Turn the switch until the lights extinguish. This sets the range so that the measurement result will be approximately between full scale and 1/10th of full scale, for best resolution and accuracy.

Only occasionally, for values very close to full scale or 1/10 of full scale, are these arrows liable to be in error. Best resolution is obtained between 2000 and 19999 for

Table 3-2

FULL-SCALE CAPACITANCE FOR EACH RANGE AND TEST FREQUENCY; MULTIPLIERS M AND A

Switch position	1 kHz Full-scale C	1 kHz M	Low frequency Full-scale C	Low frequency M	A
1	199.99 pF	3	1.999 nF	2	5
2	1999.9 pF	1	19.99 nF	1	1
3	19.999 nF	1	199.9 nF	1	1
4	199.99 nF	1	1.999 μF	1	1
5	1999.9 nF	1	19.99 μF	1	1
6	19.999 μF	1	199.9 μF	1	1
7	199.99 μF	1	1.999 mF	2	0.1
8	1999.9 μF	10	19.99 mF	3	0.1
9	-----		199.9 mF	5	0.1
Note*	-----		(1000.0 mF)	5	0.1

*This extension of range 9 is useful even though range light indicates measurement exceeds full scale.

1 kHz, and 200 and 1999 for 120-Hz test frequency. An arrow may indicate that a measurement of 19995, for example, should be made on the next range, when in fact the measurement is valid.

The range must be increased if possible whenever the letter E appears in the digital display, indicating that the measurement exceeds full scale. On Range 9 at 120 Hz (100 Hz), valid measurements are possible up to 5 times "full scale."

If you know the value of the capacitor being measured or have a reason to select a particular range, refer to Table 3-2. This gives, for each range and test frequency, the full-scale capacitance that can be measured and multipliers M and A. Multiplier M appears in the accuracy formula. (See para 3.9 and the Specifications.) Multiplier A gives the relative level of the test voltage applied. (See para 3.7 and the Specifications.) As given in the accuracy formula, accuracy on range 9 (and 9 extended) suffers from an error term proportional to C_X, reaching 25% when $C_X = 1F$.

3.3.2 Displays.

The main CAPACITANCE display is the digital readout, which is complete with decimal point and units (shown by illuminated letters to the right of the digital window).

During measurement (for about 250 ms) the small red MEASUREMENT light is on. When it goes out, the CAPACITANCE display is updated. This display remains unchanged until it is updated again, after the next measurement.

If the display is less than full scale, it is valid, even though a range-change arrow may be lit. However, if the display is less than 1/10 full scale, you can obtain better resolution by switching to a lower range (if there is one). On range 1, measurements below 1/10 of full scale will not light a range-change arrow, because there is no lower range.

If the display includes the letter E, at the left, it is invalid (the measurement has exceeded full scale) except on Range 9, for low-frequency measurements. To obtain a valid measurement, turn the RANGE switch to a higher range. (Occasionally the instrument may be so far "off range" that is does not "recover" promptly. Normal operation is most quickly restored if you turn MEASUREMENT MODE switch momentarily to SINGLE, then back to REPETITIVE.)

3.4 DISSIPATION-FACTOR DIAL AND LIGHTS.

The dissipation-factor lights indicate immediately after each measurement whether the measured capacitor is more lossy (red light) or less lossy (green light) than the setting of the DISSIPATION-FACTOR dial. If you set the dial properly for the type of capacitor being measured, this kind of indication is usually adequate.

However, to measure D for each capacitor, simply turn the dial (in the direction indicated by the associated light) to the point where the lights change. Read D from the dial at that point. Notice that the instrument can be either remeasuring the same capacitor, any number of times, or holding the desired measurement while you determine D in this way. The dissipation-factor indicators relate the previous measurement to the present-time setting of the dial. (In contrast, the HIGH D and GO lights of the limit comparator relate the previous measurement to the D dial setting at the time of measurement.)

3.5 TEST FREQUENCY.

3.5.1 Frequency Selection.

Set the FREQUENCY switch to the desired test frequency. The choice of test frequency is often specified in formal test procedures for capacitors. If not, the choice depends to some degree on the value to be measured.

In general, use 1 kHz for greatest accuracy unless the capacitor being measured is liable to have a self resonance as low as 32 kHz. (This will cause a 0.1-% error. For example, a series inductance of .05 µH, which can be expected in 5 cm or 2 in. of wire, will resonate with an ideal 500-µF capacitor at 32 kHz. However, for the same error contribution at 100 Hz, resonance at 3.2 kHz, the ideal capacitor is 100 times larger, i.e., 50 mF.)

Select 120 Hz (100 Hz) for very large capacitors. In particular, the instrument requires this selection for all measurements above 2 mF (on ranges 8, 9, and 9 extended). Notice that the D of any capacitor depends on test frequency.

As shown in Table 3-2, a change from 1 kHz to 120/100 Hz increases the full-scale C of any range by a factor of 10 (while at the same time reducing resolution and accuracy). See also para 3.9.

3.5.2 Changing the Low Test Frequency (120 or 100 Hz).

The low test frequency (selected when the FREQUENCY switch on the front panel is not set to 1 kHz) is normally 120 Hz or 100 Hz, as labeled, for instrument type number 1686-9700 or -9800, respectively. Normally, the low frequency is synchronized with the power line (60 Hz or 50 Hz, respectively). The choice between 120 and 100 Hz and synchronization to the power line can be implemented in either instrument by changing a few connections on the Bridge Board, as follows:

a. For 120 Hz, insert (solder) a jumper across R144 and another across R279. For 100 Hz, cut or remove these jumpers. There is a pair of holes in the circuit board for each jumper, which should be U-shaped, about 10 mm (0.4 in.) between legs.

b. For 120 Hz, remove (lift out) a jumper between WT33 and WT34 and another between WT35 and WT36. For 100 Hz, insert these jumpers. Each of these wire-tie points is a slotted terminal that will receive and grip a wire pressed into the slot (as one might press a pencil between the blades of partly opened scissors). Each jumper should be straight, about 15 mm (0.6 in.) long.

c. For synchronization, connect (leave connected) the white-green-brown wire of the power-supply cable to WT7 at the left rear corner of the Bridge Board. For asynchronous operation (test-frequency accuracy about ±2%), disconnect this wire from WT7 and insulate the loose end.

NOTE

Be sure to disconnect this wire if you have selected 120 Hz and the power line is NOT 60 Hz or if you have selected 100 Hz and it is NOT 50 Hz.

Refer to para 5.5 and 5.6 for disassembly procedures and an illustration of the Bridge Board showing the pertinent locations.

3.5.3 Power-Line Frequency.

The instrument operates on ac power with a line frequency of 45 to 440 Hz. (See para 2.7.) Most users have either 50- or 60-Hz power and are expected to purchase the corresponding instrument by type number (see above and the listing with Specifications) or make the appropriate wiring changes to convert from one to the other. The changes have to do with test frequency and synchronization, not the instrument's power supply. If your power line is neither 50 nor 60 Hz, ±2%, be sure to let the instrument's oscillator run asynchronously (step c above).

3.6 MEASUREMENT MODE.

3.6.1 Repetitive.

Select this mode, by turning the MEASUREMENT MODE control away from the ccw position, and the instrument will make one measurement after another endlessly at intervals of 0.25 to 10 s per measurement. Select the desired interval by turning the control; an approximate scale is provided on the front panel. A short interval is usually preferred, especially if capacitor values are random unknowns, so the correct range can be selected quickly with the help of the RANGE lights.

Use of a long measurement interval is appropriate in some situations, such as measurement of capacitor that is changing. The measurements should be made at the desired rate for recording data, without the distraction of extra measurements between data points.

3.6.2 Single.

Select this mode by turning the MEASUREMENT MODE control to the ccw stop and the instrument will make one measurement per "start" command. This mode is convenient to use when you have the 1686-9600 Test Fixture because you can start a measurement at an appropriate moment (after the capacitor is in place) and the display will remain fixed for observation and recording even while the capacitor is being removed. There is a convenient "start" bar on this test fixture and each of the 3 rear-panel connectors has a "start" circuit. Refer to para 2.4 and 2.5.

3.7 APPLIED VOLTAGES.

3.7.1 Test Voltage.

Maximum. Normal; automatically applied when the rear-panel TEST VOLTAGE control is fully cw. This voltage is A volts, where A is 5, 1, or 0.1 on ranges 1, 2. . .6, or 7. . .9 respectively. (See Table 3-2.)

Reduced. Optional; selected when rear-panel TEST VOLTAGE control is not fully cw. Using that control, reduce the level as desired on ranges 1. . .6, as may be necessary for measurement of nonlinear components or may be required by certain formal test procedures that restrict the signal voltage applied to the capacitor under test. The reduced level can be as low as 5% of maximum.

Operation at a low test voltage, however, results in a less accurate measurement. Thus, the maximum signal level (control fully cw) should be used whenever possible. At lower levels, the accuracy specification should be multiplied by:

$$1/2 \left[1 + \frac{\text{maximum signal level}}{\text{actual signal level}}\right]$$

NOTE

Do not reduce the level appreciably on ranges 7. . .9, because doing so can result in improper meter operation. Normal test voltage is so small on these ranges that reduction should rarely be necessary. Always check that the TEST VOLTAGE adjustment is set for a maximum test voltage level under normal conditions.

3.7.2 Internal Bias Voltage. Figure 3-4.

The easiest way to apply bias to the capacitor being measured is to turn the BIAS switch to INTERNAL. The 2-V bias is automatically applied; the polarity is indicated on the 1686-9600 Test Fixture and tabulated in para 3.1.3. To discharge the capacitor *when internal bias is used,* turn the BIAS switch slowly to OFF. Notice that both charge and discharge processes require time, as explained below.

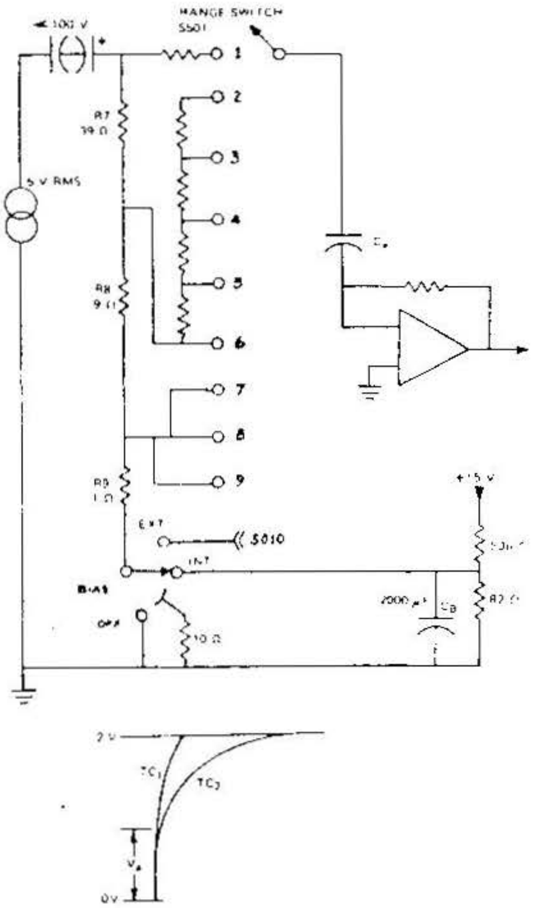
Charging Time for Internal Bias. The figure shows the bias-supply switch configuration, with a capacitor (C_X) under test in the circuit. This capacitor is connected to the internal bias supply when the BIAS switch is set to INTERNAL or when the switch is already set to INTERNAL and the capacitor is connected to test terminals. For capacitors under 20 μF, the charging time constant TC_1 is less than 3 ms. The voltage will be within 5% of the final value in a period of three time constants.

The figure also shows an approximation of the charging time (TC_2) when a capacitor greater than 20 μF is connected to the bias supply. As shown, the charging time using the internal bias is $TC_2 = 72\ (C_X + 2000)\ \mu s$, for C_X in μF. The minimum time is 0.144 s, and the maximum can be 1.5 s for a 20,000-μF capacitor. However, for $C_X < 20\ \mu F$, the charging time is much less than this formula indicates (because the internal capacitor C_B provides most of the charge).

Discharging Internally Biased Capacitors. Internally biased capacitors can be discharged within the instrument, by slowly turning the BIAS switch to OFF. The switch connects a 10-Ω discharging resistor across C_X as you rotate it from INTERNAL BIAS to OFF (between detent positions). The corresponding time constant is less than $(C_X)(11\ \Omega) + 3$ ms, assuming the switch is turned off slowly, for range 7, 8, or 9. For example, $(20{,}000\ \mu F)(11\ \Omega) + 3\ ms = 250\ ms$. Finally, in the OFF position, the switch connects a short circuit, which quickly completes the discharge.

3.7.3 External Bias Voltage.

For bias other than 2 V, use an external bias supply. Refer to para 2.6 for a complete discussion of requirements, including external RC circuitry and discharge provisions.



TC_1 = CHARGING TIME CONSTANT IF C_B NOT APPRECIABLY DISCHARGED ($C_x < 20\ \mu F$)

$TC_1 = < 3ms$

TC_2 = CHARGING TIME CONSTANT OF C_B AND C_x

$\cong 72\ \Omega\ (C_B + C_x) = 72\ (2000\ \mu F + C_x)$

$$V_a = 2\ V\ \frac{C_B}{C_B + C_x} = 2\ V\ \frac{2000\ \mu F}{2000\ \mu F + C_x}$$

NOTE

$V_a < 1.98$ V IF $C_x < 20\ \mu F$, SO THAT TC_2 NOT IMPORTANT FOR VALUES UNDER 20 μF. IF $C_x = 2000\ \mu F$, $V_a = 1$ V.

Figure 3-4. Bias circuitry and capacitor charge-time formulas. Between INTERNAL and OFF positions of the BIAS switch, the capacitor being measured discharges through a 10-Ω resistor.

WARNING

Electrical energy stored in charged capacitors can be dangerous to the operator. Full bias voltage appears on test-lead and test-fixture terminals and the leads of the capacitor under test when an external bias source is connected and the BIAS switch is set to EXTERNAL. Never leave the instrument unattended with external bias applied.

Establish and follow safe procedures to assure proper discharge of measured capacitors and the bias circuit. Be sure all personnel operating the equipment are aware of the potential hazard involved in external biasing.

Do NOT use the BIAS switch to charge or discharge capacitors with external bias. Use a switch in the external bias circuit, with a resistor that can dissipate the full amount of energy stored. Leave the BIAS switch set to EXTERNAL while any external bias voltage is applied to the test circuit.

Do NOT raise the external bias level above 100 V, max. For safety, a limit of 30 V max is recommended.

Charging Time for External Bias. The time it takes to charge externally biased capacitors depends on the bias supply used. If the supply has zero internal resistance, then TC_2 (see figure) will be less than 3 ms, up to 2000 μF, and less than 30 ms at 20,000 μF. Generally, $TC_2 = (C_x)(1\ \Omega) + 3ms$, for ranges 7. . .9.

If the supply has a capacitor output as shown in Figure 2-9, then the charge time is the same as that of the internal supply, except $TC_2 = R_1 C$. Similarly, $V_a = (C/C+C_x)$ (supply voltage). If the supply is current-limited, $t = C_x V/I_{max}$ is added to the charging time.

Discharging Externally Biased Capacitors. Do not turn the BIAS switch to OFF while an externally charged capacitor is connected to the instrument. This may damage it. The user should supply a switch or device to discharge the capacitors, as mentioned above. Also, observe the warning at the beginning of this paragraph.

3.8 LIMIT COMPARISON.

The limit comparator provides a convenient means for screening a lot of capacitors, to accept those with C values on or between 2 limits and D value below a limit, to reject those that fail any of the 3 limits. Proceed as follows. (It is helpful to first put one of the lot in the test fixture, select the appropriate range, and obtain a sample display).

a. Set the HIGH LIMIT thumbwheel switches to the highest acceptable C value as it would appear on the CAPACITANCE display. Disregard the decimal point. (Example: if the largest acceptable capacitor would measure 150.00 μF, set the HIGH LIMIT to 15000.)

b. Set the LOW LIMIT thumbwheel switches to the low C limit, similarly, remembering that the range switch will NOT be changed during this set of measurements. (Example: if the smallest acceptable capacitor would measure 017.00 μF, set the LOW LIMIT to 01700, compatible with the above example.)

c. Set the DISSIPATION FACTOR dial to the D limit (the largest acceptable value). See para 3.4.

d. Flip the LIMIT/OFF switch to LIMIT.

e. After any measurement, observe the comparator lights: GO indicates satisfaction of the limits; any of the other 3 lights, failure. (HIGH D means high dissipation factor; LOW, low capacitance; HIGH, high capacitance.) If you have the 1686-9600 Test Fixture, notice that its green light, GO, duplicates the GO light on the 1686 front panel. The red light, NO-GO, on this test fixture shines when the measured capacitor "fails", regardless of the limit failed.

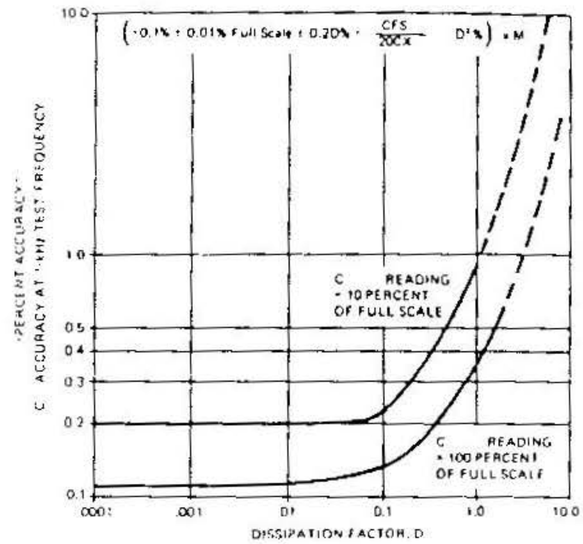
3.9 ACCURACY.

The specified accuracy of the 1686 Digital Capacitance Meter is given in Specifications at the front of this manual. If the following explanations, graphs, or examples differ from the Specifications, assume the latter to be correct (and the following text to be in need of revision).

To see at a glance what accuracy can be expected with various parameters, refer to the following graphs.

3.9.1 Accuracy vs Dissipation Factor — Figures 3-5, 3-6.

The graphs of accuracy vs D show that capacitance measurement accuracy is affected only by D greater than 0.1. For negligible D, these curves flatten out at accuracy levels that reflect the ±2- or ±1- count uncertainly in the digital readout (.01% of full scale for 1 kHz, .05% of full scale for 120 Hz) and the fraction of readout/full-scale C. Thus (for 1 kHz measurements) the 2-count uncertainty, which is .01% of full scale adds only .01% to the uncertainty of a full-scale reading (a slight effect compared to the basic 0.1% accuracy). But the same uncertainty is 0.1% of a tenth-of-full-scale reading, in effect doubling the "basic" number.



*NOTE: Multiply this accuracy scale by M, which is 1 for middle ranges. See Table 3-2.

Figure 3-5. Capacitance accuracy as a function of dissipation factor. (test frequency 1 kHz).

Notice that the purpose of these 2 graphs is to show the effect of D, principally between 0.1 and 1.0. The effect of reading C less than full scale is better shown on another graph; see below.

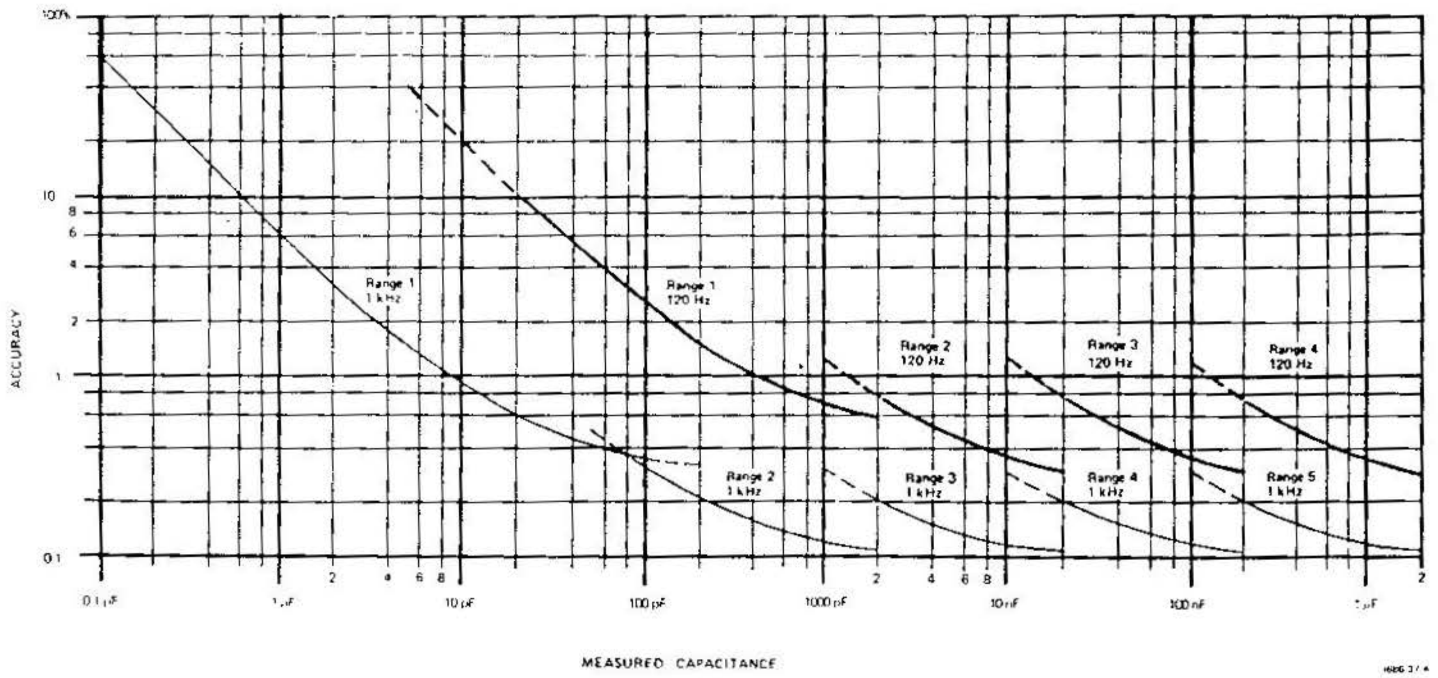
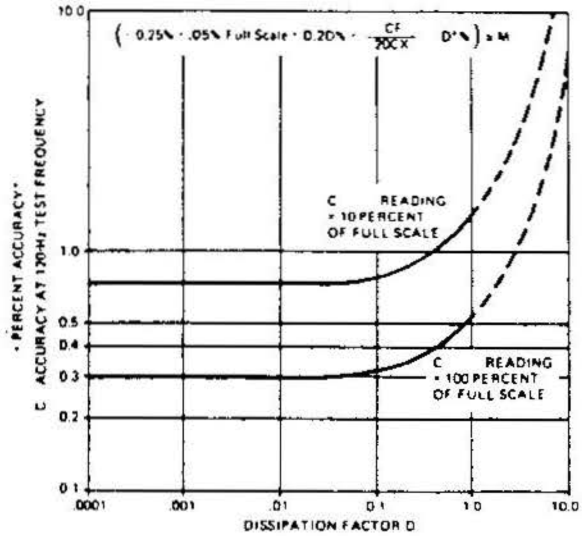


Figure 3-7A. Accuracy as a function of measured capacitance, for each range, for low dissipation factor (below .03).



*NOTE: Multiply this accuracy scale by M, which is 1 for middle ranges. See Table 3-2.

Figure 3-6. Capacitance accuracy as a function of dissipation factor (test frequency 120 Hz).

3.9.2 Accuracy vs Capacitance, Range, and Test Frequency. Figure 3-7.

Refer to the graph for a panoramic display of the overall accuracy of C measurements (for small D) over the entire multiple-range capacitance spectrum for this instrument. This graph illustrates, for example, that measurements of C less than 1/10 of full scale on any range are less accurate than the same measurement on a lower range (if any). It also illustrates why a test frequency of 1 kHz is generally preferred. This graph does not include the effects of large D nor the error contributions described below.

3.9.3 Three-Terminal Circuit Errors.

In para 3.1.5, Z_A and Z_B represent stray or extraneous (in situ) impedances between each terminal of Z_X that is being measured and guard (ground). We now consider the effects of these on accuracy.

High-side Impedance to Guard. Z_A, if small enough, loads down the test-signal source and has the effect of reducing the test voltage. The effect on accuracy is this factor:

$$\frac{1}{2}\left[1 + \frac{Z_A + R_o}{Z_A}\right]$$

where R_o is the source impedance, which depends on range as follows: for ranges 1. . .9, R_o = 47 k, 20 k, 2 k, 200, 20, 8, 1, 1, and 1 Ω, respectively. For example, if $Z_A = R_o$, this factor is 1.5; therefore if accuracy would otherwise be 0.2%, the effect of Z_A is to make accuracy 0.3%.

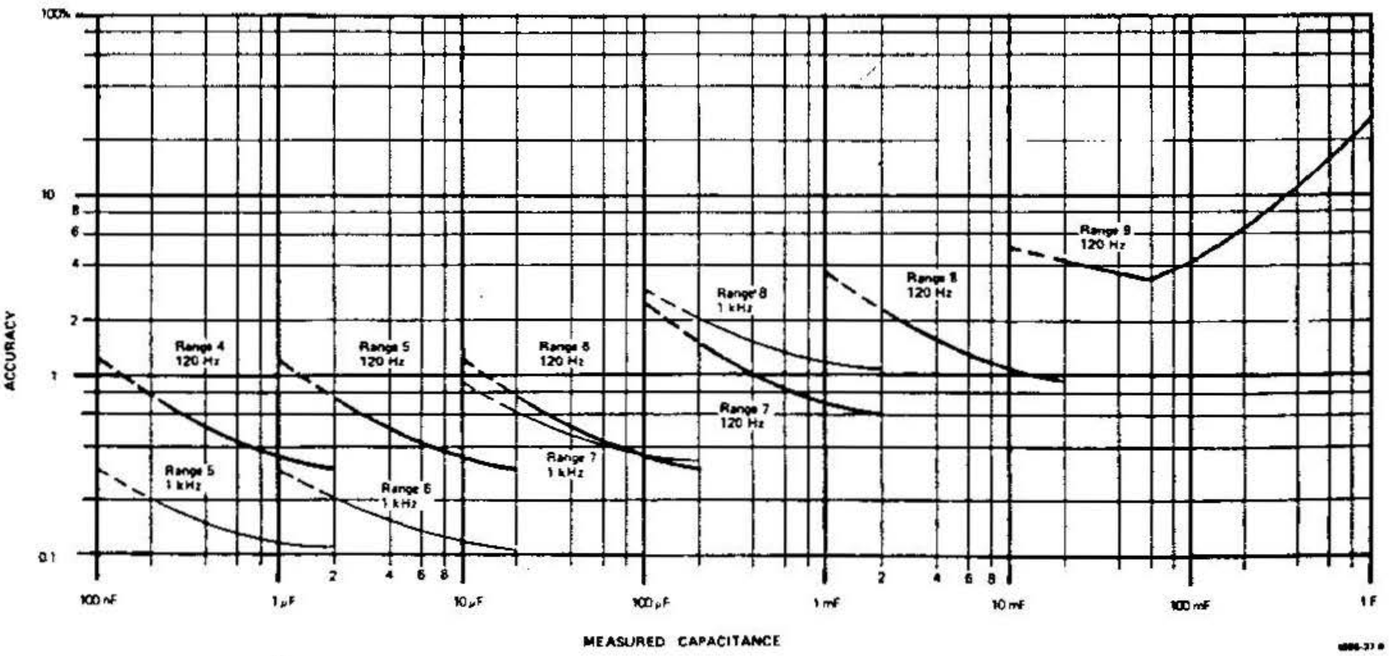


Figure 3-7B. Accuracy chart, continued from part A.

Low-side Impedance to Guard. Z_B, if small enough, shunts current around the detector circuit, which has an input impedance of R_S/K. The effect on accuracy is this term:

$$\frac{R_S}{K Z_B} \ (100\%) = \frac{R_S \omega C_B}{K} \ (100\%)$$

For ranges 1. . .9, $R_S/K \cong$ 100, 100, 10, 1, 0.1 Ω, 10 m, 1 m, and 0.1 mΩ, respectively. For example, if C_B = 1000 pF, range 2 in use at 1 kHz, this term is .06%; therefore if accuracy would otherwise be 0.14%, the effect of Z_B is to make accuracy 0.2%. This effect is generally less of a problem at lower test frequencies.

3.9.4 Four-Terminal Circuit Errors.

In para 3.1.6, R_1 and R_3 represent series impedances through which the test-signal current passes but which are not supposed to contribute voltage to the potential measuring circuit, a differential amplifier. We now consider the effects of having R_3 large enough to affect the accuracy of measurements. The voltage IR_3 is a "common mode" voltage that ideally should have no effect on the measurement of E, but is in fact rejected by a finite factor, greater than 1000 for test frequency of 120 Hz.

Effect on D Measurement. Estimate the D error as follows. R_3 reduced by the common-mode rejection factor "appears" to be in series with Z_X. For example, if R_3 = 1 Ω, a phantom resistor of 1 mΩ (or less) is in series with the measured capacitor; if its reactance is 2 Ω, the effect of R_3 is a dissipation factor of .0005; if the measured D is .0015, there is a possible error of 33%; and finally, the effect of R_3 can be subtracted, to yield a corrected D = .001. (This approximation is useful only if the effect of R_3 is small compared to the measured D.)

The common-mode response of the differential amplifier is not only finite (though small), it is also phase-shifted. Thus, to include the worst case, one should use the magnitude of the impedance in the "R_3 leg" for R_3 (not only the resistance). For D-accuracy estimates, assume the common-mode rejection factor is 1000.

Effect on C Measurement. Estimate the C error as follows. A reactance related to R_3 (in a somewhat more complex way than above) "appears" to be in series with Z_X. As a rule of thumb, for R_3 use the magnitude of the impedance in the "R_3 leg" and for the common-mode rejection factor use 1000 or 333, depending on whether the test frequency is the low frequency or 1 kHz, respectively. For example, if R_3 = 1 Ω, at 1 kHz, a phantom reactance of 3 mΩ (or less) is in series with the measured capacitor; if its reactance is 2 Ω, the effect of R_3 is a possible error of 0.15%; finally, if the readout and accuracy (except for R_3) is 70 µF ± 0.4%, the effect of R_3 can be included by writing 70 µF ± 0.55%. The value of R_3 for the 1686 instrument with the measurement cables supplied is 0.1 Ω. However, R_3 could be larger in some test setups.

3.9.5 Corrections for Geometry.

Accuracy in measurement of electrically small 2-terminal capacitors requires close attention to the geometry of connections (preferably in a test fixture), as discussed in para 3.1.3. One or both of the following corrections may be necessary, to maximize the usefulness and reproducibility of results.

a. Correct the measured value of the capacitor under test by subtracting a "zero correction", i.e., a measurement made with the capacitor removed (test terminals, ground plane, fixture, etc. stationary). Be sure that there is a connection between I+ and P+ and another between I– and P–. (If the 1686-9600 Test Fixture is used, put a short length of bare wire into each slot where capacitor leads normally go).

b. If you are concerned about agreement between measurements made with more than one instrument, use the following correction also. (A different correction is required for each type and physical size of capacitor, for each measuring setup.) Obtain a known-valued capacitor, electrically the smallest available in the given type. (If you have no better way of determining its value, use an average of measurements by the best available methods.) With each instrument and measuring setup, measure this known capacitor (making the zero correction described above). Subtract the known capacitance to obtain what we'll call "fixture correction." Now, for every capacitor of that physical type and size measured in this particular setup, subtract this "fixture correction" as well as the "zero correction".

3.9.6 Lead Inductance.

The inductance of any lead wires included as part of the measured capacitor (length A A' or R in Figure 3-1) will cause the measured capacitance to be larger than it would be ideally (with no inductance). The measured capacitance is $C/(1 - \omega^2 LC)$, where $\omega = 2\pi f$. Therefore, the corresponding accuracy term is $100\%/((1/\omega^2 LC) - 1)$. This is significant only for very large values of C and/or extremely long leads.

3.9.7 Mutual Inductance in Cables.

The mutual inductance between the "current" circuit and the "potential" circuit has a similar effect on measurement of very large values of C. Measured capacitance (the displayed value) is $C / (1 - \omega^2 MC)$, where M is the mutual inductance, which can be either positive or negative. It is this phenomenon which accounts for much of the error in Range 8 at 1 kHz and Range 9 at low frequency. (See Figure 3-7.)

A typical value on M is a fraction of +1 µH, for this instrument with the recommended cable and test fixture. For exacting work, M of your equipment can be measured as follows. Using a standard capacitor of large, known value C, obtain the CAPACITANCE display, C_{meas}. Then: $M = (1 - C/C_{meas})(1 / \omega^2 C)$.

Knowing M, at least approximately, you can easily correct measurements of large capacitance to obtain more accurate values. The corrected value of C is: $C_{meas} / (1 + \omega^2 M C_{meas})$.

3.10 TYPICAL USES WITH EXTERNAL DEVICES.

Figure 3- 8 is a block diagram application drawing illustrating the use of the rear-panel data and control signals in conjunction with external equipment. A digital printer is shown connected to the rear-panel connector of the main instrument, and a mechanical parts handler is shown connected to the rear-panel connector of the limit comparator "A" board.

The digital printer, in addition to the BCD and decimal point data input lines, has two additional input lines (for control), plus one output line. One of these control inputs is the PRINT START command and the other is the RED SELECT line. The latter, when activated, causes the printer to print out in red (rather than black). The one printer output line, designated $\overline{\text{BUSY}}$ at the printer, is a line that goes high at the end of the print operation, signifying that the printer has finished printing the measurement value (PRINTER DONE).

The mechanical handler is a device designed (or purchased) by the user for use in an incoming inspection operation where many parts of the same value are to be measured and checked against the comparator high- and low-limit

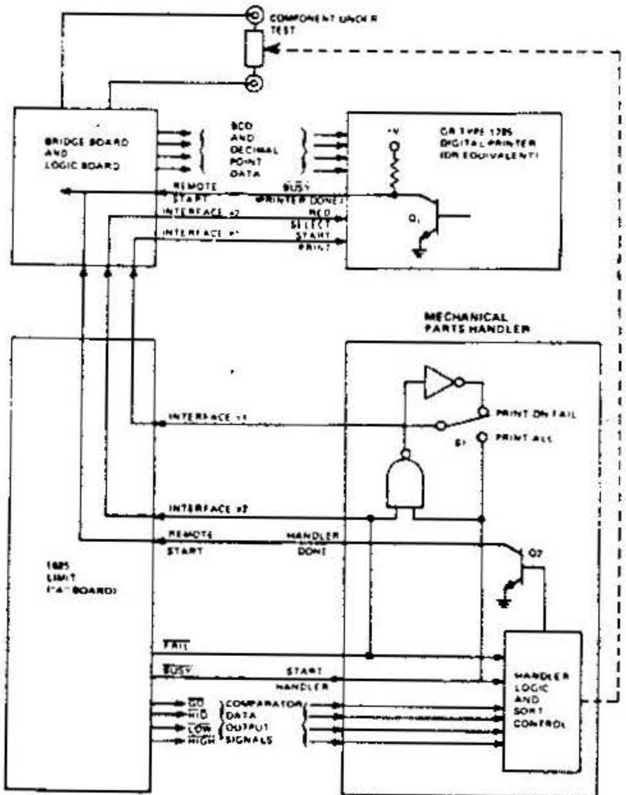


Figure 3-8. Application in a system with a parts handler and printer.

values. The handler is shown receiving the comparator output data signals, as well as two control signals, $\overline{\text{BUSY}}$ and $\overline{\text{FAIL}}$.

Use of the REMOTE START, INTERFACE #1, INTERFACE #2, $\overline{\text{BUSY}}$, and $\overline{\text{FAIL}}$ lines available at the rear are clearly illustrated. Switch S1 in the handler, labelled PRINT ALL/PRINT ON FAIL is strictly an optional feature.

The sequence of operations for the configuration shown would be as follows:

First, all BCD and decimal point data are produced on the 1686 logic board and impressed upon the data output lines. The $\overline{\text{FAIL}}$, $\overline{\text{GO}}$, $\overline{\text{HID}}$, $\overline{\text{LOW}}$, and $\overline{\text{HIGH}}$ signals are then produced on the limit option "A" board.

Then signal $\overline{\text{BUSY}}$ is issued from the limit option "A" board. This signal is used to start both the handler and the printer. The handler proceeds to mark or to sort the just-measured component into the correct line, and to begin moving a new component mechanically into place while the printer proceeds to print out the value of the component, depending upon the position of switch S1 and the state of the $\overline{\text{FAIL}}$ line from the "A" board.

When the printer has completed its operation, it turns off transistor Q1. And when the handler has finished its operation, it turns off transistor Q2. Since the printer and the handler operate at independent rates, transistors Q1 and Q2 will shut off at different times. Therefore, the last one to turn off is the one that produces the low-to-high logic transition on the REMOTE START line required to initiate a new measurement.

Having initiated a new 1686 measurement cycle, the above sequence of operation is then automatically repeated. Note that the MODE switch on the front panel of the 1686 must be in its SINGLE MEASUREMENT position in this application.

An alternative configuration employing the GR 1784 Multiple Limit Comparator is fast and convenient to use. It enables, for example, sorting of components into ±20%, ±10%, ±5%, and ±1% categories, as desired. All of the signals required to run such a comparator are available from the DATA OUTPUT connector. Figure 3-9 is a block diagram showing this configuration.

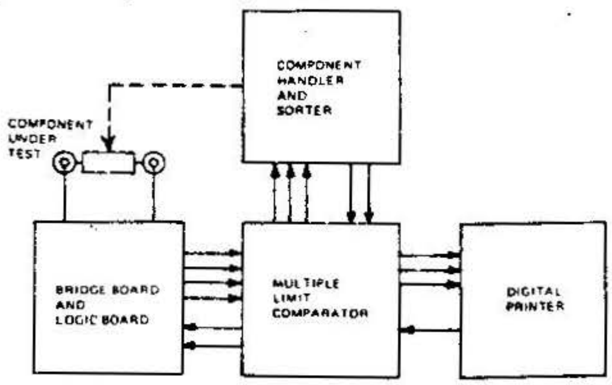


Figure 3-9. External multiple-limit comparator application.

3.11 CORRECTION FOR CABLE.

The elementary measurement cable adds capacitance in parallel with the DUT (because shielding of the leads is imperfect). The 1686-9602 cable adds about 5 or 6 pF. Because the physical arrangement and spacing of the cable branches and connectors is significant, a correction should be determined for each measurement setup. The following procedure applies to connection with a precision 3-terminal capacitor, GR 1404 or 1413, for example:

a. Install an adaptor, GR 874-Q2, on each of the two coaxial connectors, L and H, of the capacitor.

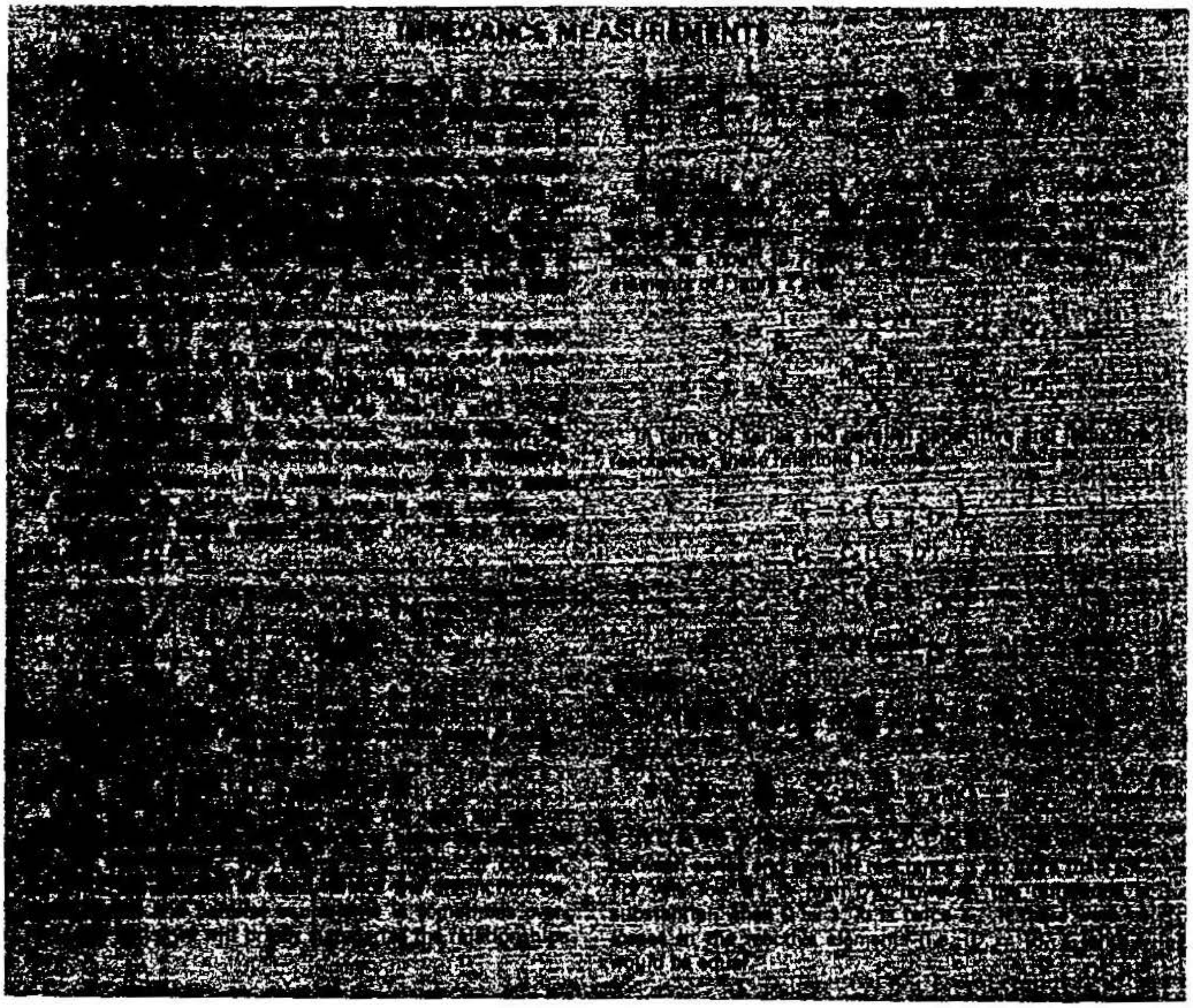
b. Connect cable branch G to the ground post of the "low" terminal adaptor. With a clip lead or plain wire, connect this point to the ground post of the "high" adaptor.

c. Connect cable branch P- to the main post of the "low" adaptor and stack I- on top of P-, as described above. Similarly, connect P+, with I+ stacked on top of it, to the main post of the "high" adaptor.

d. Measure this total capacitance, the sum of the desired measurement and the cable capacitance, $C_X + C_C$.

e. Carefully lift the stacked pair of cable tips, I+/P+, from the "high" adaptor and hold them about 0.5 cm (¼ in.) above the binding post where they were connected. Do NOT rearrange the cable branches or change their spacing more than is absolutely necessary to follow these directions. Hold the plastic tips (rather than the wires) and touch the guard (G) circuit firmly with a couple of fingers, to minimize the effect of capacitance in your body.

f. Measure the cable capacitance, C_C. Subtract this result from that of step d, to obtain the desired measurement, C_X.



Theory—Section 4

4.1 INTRODUCTION.

The 1686 Digital Capacitance Meter measures series capacitance and dissipation factor, D at two frequencies: 1 kHz and 120 (or 100) Hz. With the front-panel MODE switch, the instrument can be controlled for measurement at intervals of 0.25 s to 10 s. The front-panel digital readout gives readings of C, and the front-panel dial reads D. A limit comparator is provided for making C-high and low and D-high comparisons, furnishing pass-fail indications as well as indicating the limit(s) the measured capacitor exceeded in case of any failure.

Figure 4-1 is a block diagram of the meter. The meter is comprised of an amplifier, or "half-bridge", circuit and an AC-DC ratio meter capable of high accuracy with good noise immunity. The ratio meter is a combination of a dual-slope integrator and an integrating phase-sensitive detector. The bridge and ratio meter circuitry is mounted on the 1686-4720 bridge board on the floor on the instrument. A logic board (P/N 1685-4700), located above the bridge board (on hinges that allow easy access to board components), furnishes all control and counting circuits for the ratio meter.

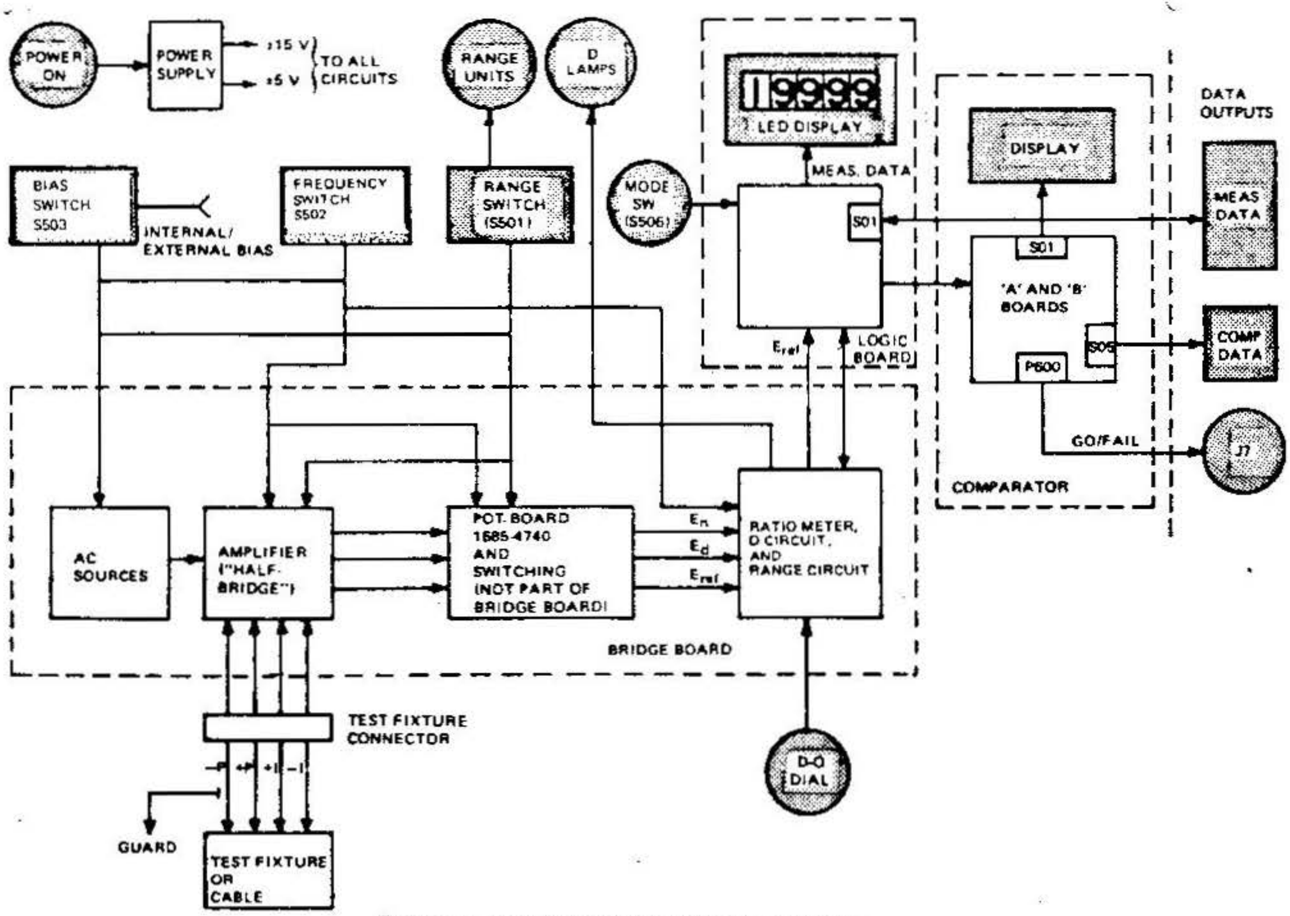


Figure 4-1. Digital Capacitance Meter block diagram.

A power supply board (P/N 1686-4730) furnishes all DC voltages to all the circuit boards, including the internal 2-V bias voltage for capacitors under test. The board is at the left front of the instrument, under a metal cover.

The bridge board contains:

1. A wien-bridge oscillator that produces a 1-kHz or 120- (or 100-) Hz, 5-V rms, maximum, a-c test signal.

2. A linear measurement circuit that has two arms, or networks. One of these detects the voltage across the part under test. The other has a ratio arm resistor of various decade values, selected by the RANGE switch, that produces a voltage directly proportional to the current through the part under test. For ac measurements, the signals are phase-shifted so that the outputs are inphase (actually $-E_n$ and E_d are exactly 180° out of phase) when a pure reactance is being measured.

3. A ratio meter circuit that comprises a main AC-DC integrator and comparator, an auxiliary integrator, and a dual-slope integrator and comparator.

4. A circuit for detecting high and low dissipation factor values for capacitors. The circuit is used in conjunction with the front-panel D dial, which sets the D limit, and with the D lights that indicate if the limit has been exceeded.

5. A range-finding circuit that detects overrange and underrange conditions and indicates these by illuminating the lamps associated with the front-panel RANGE switch.

There is a small potentiometer board (P/N 1686-4740) mounted on the back of FREQUENCY switch S502. This board contains adjustable resistors used to calibrate the bridge at both test frequencies and to align the D measurement circuit. The resistors are factory adjusted.

The logic board contains:

1. A circuit that determines, by means of a one-shot flip-flop and the front-panel MODE switch, the mode of measurement (single or repetitive) and the time interval (if repetitive).

2. A circuit that produces 20 or 200 burst (BST) pulses for the ratio meter. The pulses are derived from the reference signal.

3. A circuit that produces the correction signal, $\overline{\text{CTN}}$, if the main integrator output exceeds the established threshold.

4. A counter comprised of 4 decade stages and one flip-flop. The counter counts BST pulses; strobes denominator ($\overline{\text{CTN}}$) pulses, if any, into the third decade counter; and counts while up-count (UPC) and down-count (DNC) pulses, are produced, storing the counts, which are a measure of the value of the impedance under test.

5. A 60-kHz oscillator that serves as a clock for the counter and for furnishing UPC and DNC timing pulses.

6. Logic circuits that produce, under control of the above mentioned circuits, switching signals (UPC, DNC, SUD, STC) for the ratio meter.

7. Circuit that detects the count-complete signal (CP2) from the ratio meter.

8. Quadruple bistable latches and 2 dual 4:1 multiplexers that furnish data stored in the counter to the readout display and to the rear-panel DATA connector and the comparator.

9. Scan oscillator and associated flip-flops and IC gates that produce time-state and timing signals for reading out measurement data from the latches and multiplexers to the appropriate light-emitting diode's (LED's) in the readout display. These same signals are furnished to the comparator, for various timing operations.

10. Transistor drivers for signals applied to all the readout LED segments and for enabling the LED's.

11. Provision for supplying instrument timing and status signals to peripheral items, including the limit comparator, and for accepting external control signals.

The power supply consists of a transformer and rectifier assembly and a power supply board, P/N 1686-4730. The transformer is mounted at the left-hand rear of the instrument as viewed from the front. The rectifiers are mounted just to the rear of the board, in front of the transformer, on the transformer terminal board. The board is mounted in front of the transformer, under a metal cover. Three filter capacitors are located beneath the circuit board. The power supply furnishes +5V and ±15V to all circuit boards in the instrument.

The limit comparator is comprised of two circuit boards and a front-panel assembly. These units are installed separately in the unit. The front-panel assembly contains digit-switches, for establishing the high and low limits for comparison, and lamps that indicate the status of the comparisons.

The circuit boards are designated A and B (P/N's 1685-4750 and -4760, respectively). The B board contains four dual multiplexers that, under control of logic-board timing signal, switch the status of the digit-switches, first the low-limit switches then the high-limit switches, to the A board where the switch settings are compared with the measured value.

The A board contains a number of timing circuits that sequentially compare each digit of the measured value with the BCD data from each limit comparator switch, beginning with the low-limit switch. When the measured value fails to compare with any limit digit, the appropriate lamp(s) light.

The comparator has provisions for furnishing status signals to peripheral equipment and allowing external connections to be made to the logic board for unique operations.

4.2 CIRCUIT DESCRIPTIONS.

4.2.1 General.

The following paragraphs contain descriptions of the 1686 circuits in the signal-flow order shown in Figure 4-2. To obtain a general overall view of how the instrument operates and how it functions in comparison to other bridges, refer to the diagram.

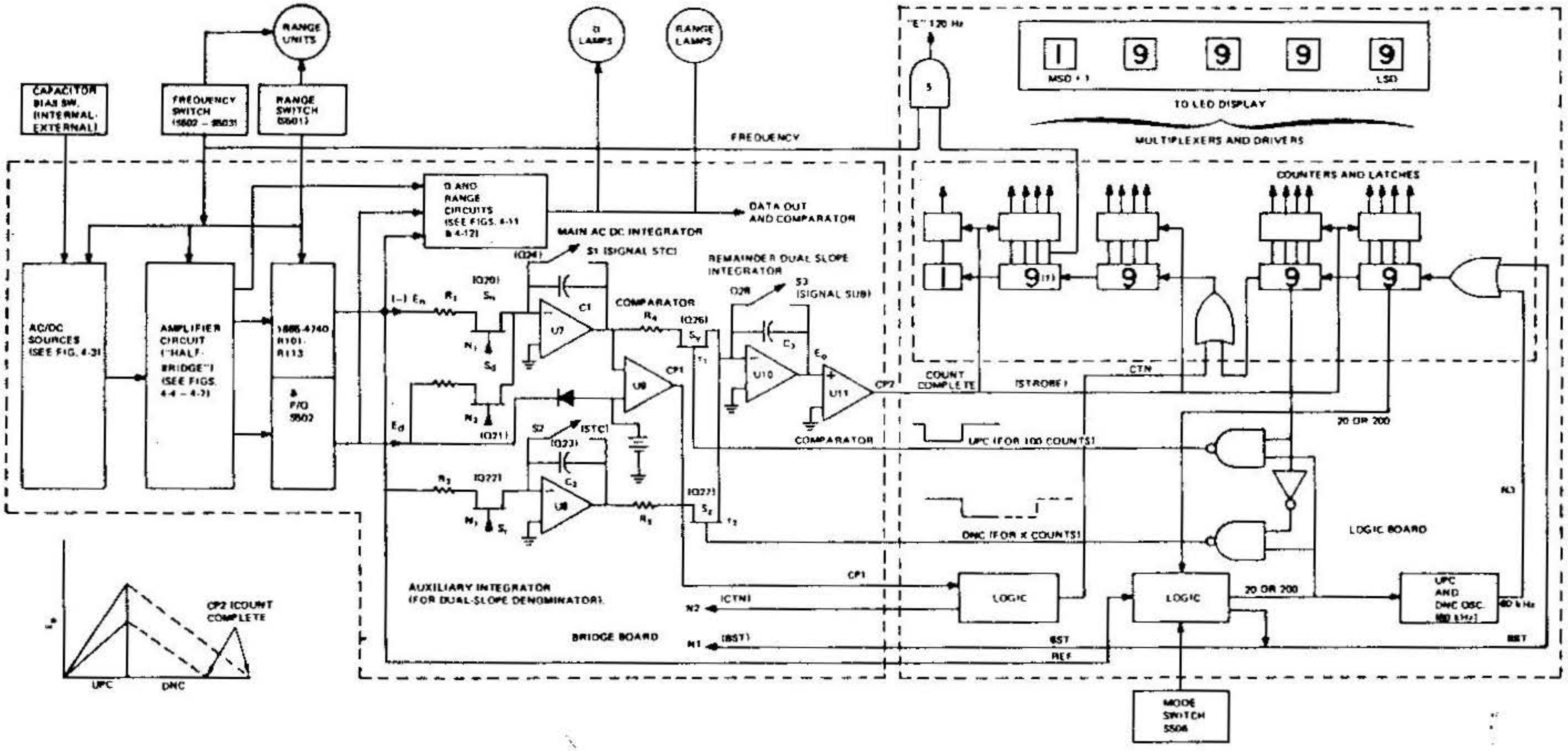


Figure 4-2. Detailed block diagram of the 1686 Digital Capacitance Meter.

SEQUENCE OF OPERATION

1. S1, S2, AND S3 CLOSED (INITIAL CONDITIONS).
2. PRESS MODE SWITCH (START).
3. DELAY AND CLEAR CIRCUITS (RESET).
4. OPEN S1 AND S2 (BY MEANS OF SIGNAL STC).
5. APPLY N1 BURST (BST) PULSES (20 FOR 120-Hz OPERATION; 200 FOR 1-kHz) TO S_n AND S_τ.
6. IF CPI HIGH, APPLY N2 PULSE(S) CTN TO S_d AND COUNT PULSES. (USE 'HUNDREDS' DECADE COUNTER.)
7. COUNT BST PULSES WITH COUNTER. (USE 'UNITS' AND 'TENS' DECADES.)
8. AFTER 20 OR 200 BST PULSES, OPEN S3. ('UNITS' AND 'TENS' DECADES AUTOMATICALLY RESET.)
9. CLOSE S_y FOR TIME IT TAKES COUNTER TO COUNT 100 UP-COUNT (UPC) PULSES. TIME=100/60 kHz. (DECADES 'UNIT' AND 'TENS' AUTOMATICALLY RESET.)
10. OPEN S_y AND CLOSE S_z.
11. COUNTER COUNTS N3 DOWN-COUNT (DNC) PULSES (60-kHz RATE).
12. COUNT N3 PULSES UNTIL E_0 CROSSES ZERO LEVEL (PRODUCES COUNT COMPLETE , CP2.)
13. STROBE COUNT OUT OF ALL COUNTERS INTO LATCHES AND THROUGH MULTIPLEXERS TO LED DISPLAY. THIS IS MEASUREMENT VALUE.

ALSO REFER TO TIMING DIAGRAM, FIGURE 6-9.

4.2.2 Component Identification and Definitions.

Component Identification. In the following paragraphs, references are made to components shown in the schematics. Since many of the logic integrated circuits referenced on the schematics have several components in a single package that has a single reference designator, it is necessary to use a scheme that identifies, where necessary, the particular circuit in the package. Packages are identified on the schematics either by numbers or by numbers preceeded with the letter U.

To identify most circuits in a package, the output pin or terminal is used in the text, in addition to the letter designation. (For example, a NAND gate can be referenced IC5-9 or U5-9, where 5 is the package reference designator and 9 is the output terminal of a particular gate in the package.)

In the case of flip-flops (F-F's), the Q terminal is referenced to identify the particular F-F in the package. (For example, U8-6, where U8 is the package designator and 6 is the Q terminal of the particular F-F.) Reference designators for other components such as transistors, resistors, etc., are standard.

Logic Definitions. In the text, a "high" level (or a logic 1) is defined as positive TTL-compatible logic, +3.5V to +5V. Where open-collector circuits are used, the high, or logic 1, can be a maximum of 30 V (or $+2\ V < V_H < +30\ V$).

A "low" (or logic 0) is approximately 0 V. Where open-collector circuits are used, the low is $0\ V < V_L < 0.4\ V$, where the "open" is equivalent to V_L.

4.2.3 Bridge Board. **Figure 6-4.**

General. Figure 4-2 is a fairly detailed block diagram of the instrument. This description follows the signal path shown in the Figure.

Oscillator and Dc Source. Figure 4-3 shows the equivalent circuit of the Wien-bridge oscillator. The oscillator can be considered to be two parts, a frequency-determining network (C_A, C_B and R_A), that supplies positive feedback to sustain oscillation, and a voltage divider (R_F and R_E) that furnishes negative feedback to stabilize the amplitude. The oscillator has two frequencies, 120 Hz (or 100 Hz) and 1 kHz, selected by means of front-panel FREQUENCY switch S502, which changes the values of R_A and C_A by switching

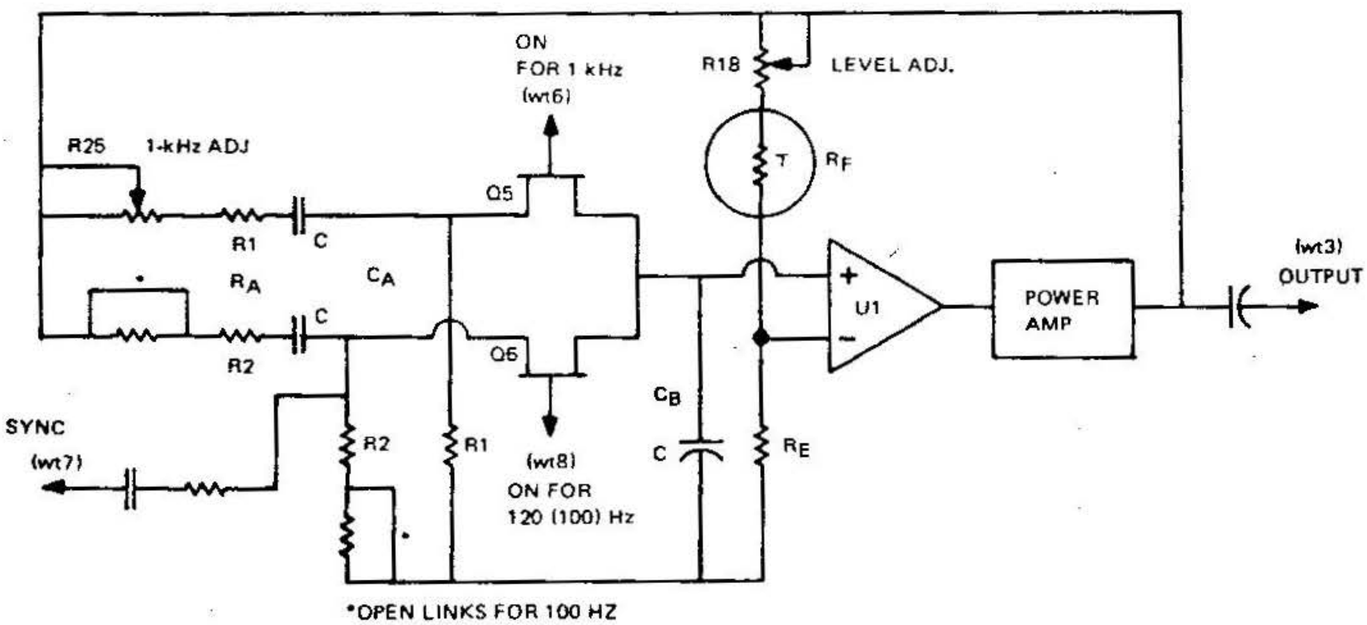


Figure 4-3. Oscillator equivalent circuit.

in either Q5 or Q6, respectively. Figure 6-4 shows the connections. R_F is a thermistor that adjusts itself to the value needed to maintain a constant amplitude. The circuit oscillates at frequency $F = 1/2\pi RC$. R25 is a 1-kHz frequency adjustment. The oscillator can furnish low frequencies of either 120 or 100 Hz. The latter is obtained by removing the shorting wires across R144 and R279 to increase the resistance values. If the desired oscillator signal is twice the line frequency (50 or 60 Hz), the synchronization signal to WT7 should be solder-connected. If the oscillator signal is not twice the line frequency the synchronization line should be disconnected, in which case the frequency will be accurate to ±2%.

The input to the power amplifier comprised of Q1-Q4 is a 5-V, rms, 120-Hz or 1-kHz signal from the bridge oscillator. The amplifier can supply 0.1 A rms of current with low distortion. The circuit is short-circuit proof.

The 5-V oscillator-amplifier output is applied to 9-position RANGE switch S501 which divides the open-circuit signal level, to give 5 V on range 1, 1 V on ranges 2. . .6, and 0.1 V on ranges 7. . .9. Series resistors are also added (R1-R6) to limit the short-circuit current.

Dc Bias Circuit. As shown in the circuit schematic, Figure 6-4, the internal DC bias is derived from the instrument's DC power supply that furnishes +15 V to a voltage divider network on BIAS switch S503. The voltage divider is comprised of R10 and R11. There are 4-switch positions shown on the schematic. Switch position 3 supplies 2 V to the part under test. Switch position 4 allows an external bias of up to 100 V to be applied to the part under test.

Switch position 1 removes the bias; switch position 2 is undetented and is used to discharge C502 when the switch is between positions 1 and 3.

Amplifier Circuit. The circuit contains amplifiers that furnish voltage outputs proportional to the voltage across and the current through the unknown, two phase-shift networks for the ac measurements for bringing the signals in phase for purely reactive unknowns, and an AC-DC ratio meter that indicates the ratio of the vector components of two voltages obtained from the amplifiers, to obtain the desired measurement value.

The voltage and current-sensing amplifiers are illustrated in Figure 4-4. The circuit is described as a "half-bridge" because of the similarity in function to the unknown and ratio arms of a passive four-arm impedance bridge. The section that furnishes the output proportional to the voltage across the unknown can be considered the Z_x arm; the section that furnishes a voltage that is proportional to the current through the unknown can be considered the R_s arm.

In addition to furnishing the voltage proportional to the current through the unknown, the R_s arm also furnishes a reference for the ratio meter for the capacitance measurements (Reference signals are via the logic board.)

Figure 4-5 shows the "half bridge" configuration for capacitance measurements. For capacitance measurements, the signals are phase shifted so that the signals are inphase. ($-E_n$ and E_d are actually exactly 180° out of phase.) Bandpass networks are used to perform the phase shifting.

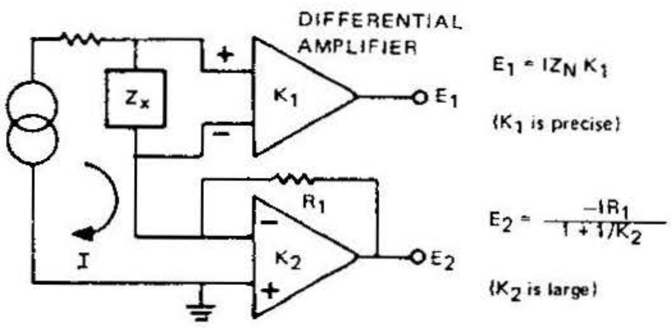


Figure 4-4. Basic "half-bridge" containing two arms, Zx and Rs.

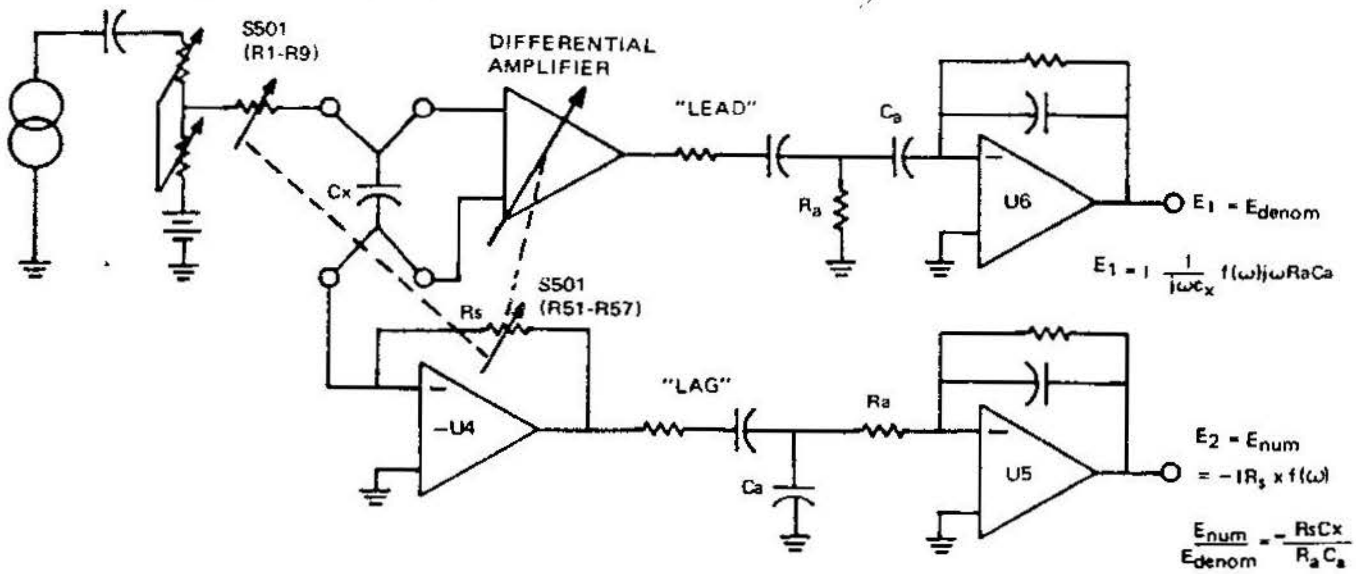
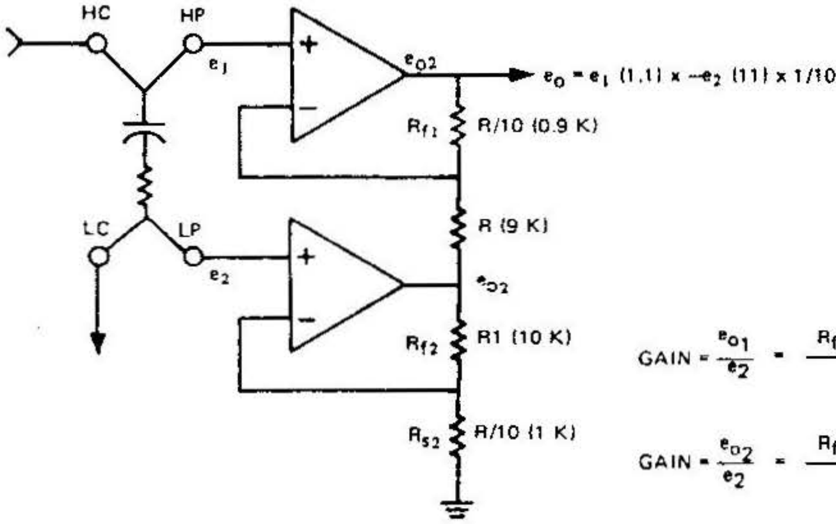


Figure 4-5. Series capacitance (C_s) bridge configuration.

Z_X *Arm.* Figures 4-8 and 4-9 are more detailed equivalent diagrams of the Z_X arm. A differential amplifier comprised of operational amplifiers U2 and U3 is employed to detect the voltage drop across the unknown. The gain of both amplifiers is determined by the resistors in their feedback network, as shown in Figure 4-8. Each input is amplified by the same factor (as determined by the resistors), so that the output is proportional to the difference between the input voltages.

The attenuator, comprised of components mounted on RANGE switch S501, determine the amplifier's overall gain, as shown in Figure 4-9, which identifies the components and illustrates how the gain is obtained for the various ranges.

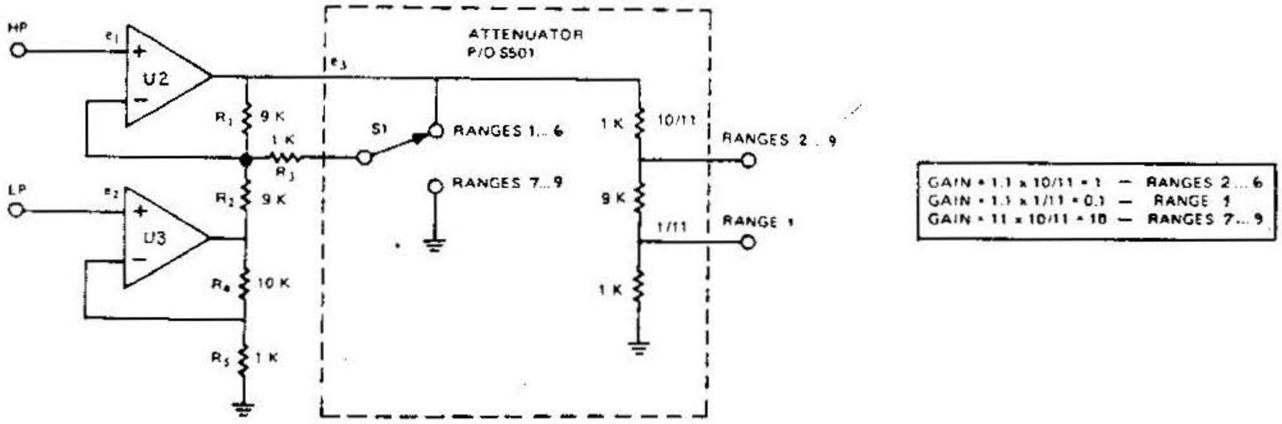
> **NOTE**
> Figures 4-6 and 4-7 have been deleted from this manual.



$$\text{GAIN} = \frac{e_{o1}}{e_2} = \frac{R_{f1} + R_{s1}}{R_{s1}} = \frac{R_{f1}}{R_{s1}} + 1 = \frac{9 + 0.9}{9} = 1.1$$

$$\text{GAIN} = \frac{e_{o2}}{e_2} = \frac{R_{f2} + R_s}{R_{s2}} = \frac{R_{f2}}{R_{s2}} + 1 = \frac{10 + 1}{10} = \frac{11}{10} = 1.1$$

Figure 4-8. Zx bridge arm equivalent circuit.



RANGES 1. . .6:

$$e_3 = e_1 \frac{\frac{R1\ R3}{R1 + R3} + R2}{R2} - e_2 \frac{R4 + R5}{R5} \times \frac{\frac{R1\ R3}{R1 + R3}}{R2}$$

$$e_3 = e_1 \frac{9.9}{9} - e_2 \cdot \frac{11}{1} \times \frac{0.9}{9}$$

$$e_3 = (e_1 - e_2)\ 1.1$$

RANGES 7. . .9:

$$e_3 = e_1 \frac{R1 + \frac{R2R3}{R2+R3}}{\frac{R2\ R3}{R2+R3}} - e_2 \frac{R4 + R5}{R5} \times \frac{R1}{R2}$$

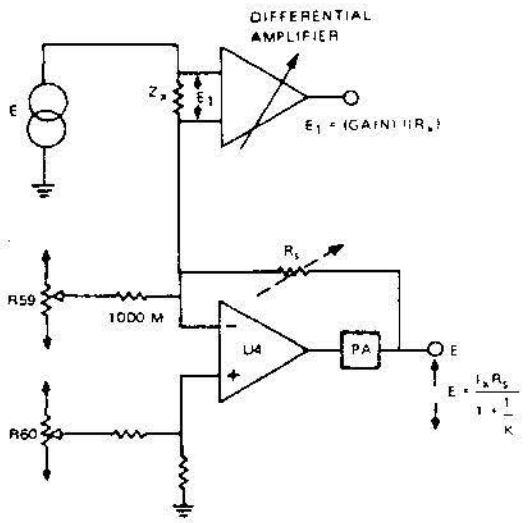
$$e_3 = e_1 \frac{9.9}{0.9} - e_2 \frac{11}{1} \times \frac{9}{9}$$

$$e_3 = (e_1 - e_2)\ 11$$

Figure 4-9. Zx bridge arm and output attenuator equivalent circuit.

There is a gain of 1 for the middle ranges (2. . .6), a gain of 0.1 for range 1, and a gain of 10 for ranges 7. . .9.

R_s Arm. As shown in Figure 4-10, the R_s arm is comprised of operational amplifier U4 and a power amplifier comprised of transistors Q7-Q10. The arm resistance is selected by means of RANGE switch S501, which switches in various values for R_s in the amplifier feedback loop. Table 4-1 lists the resistors (R51-R57) in the ratio arm for the 9 instrument ranges.



E_1 = VOLTAGE TO DIFFERENTIAL AMP
$E_1 = I_x Z_x$
Z_x = UNKNOWN
Z_A = SHUNT RESISTANCE
R_s = RATIO ARM (SELECTED BY RANGE SWITCH)

Figure 4-10. R_s arm equivalent circuit.

Table 4-1
R_s VALUES AND DIFFERENTIAL AMP GAIN

Range	Resistor	Differential Amp Gain
1	100 kΩ	0.1
2	100 kΩ	1
3	10 kΩ	1
4	1 kΩ	1
5	100 Ω	1
6	10 Ω	1
7	10 Ω	10
8	1 Ω	10
9	0.1 Ω	10

U4 is followed by a push-pull, unity-gain power amplifier (Q7-Q10) required to obtain the higher currents used on the lower impedance ranges. The ratio-arm resistor, R_s, and the differential amplifier gain determine the impedance range.

The bandpass network acts to phase-shift the signals so that they are inphase when a pure reactance is being measured. Figure 4-5 shows the equivalent circuit. The ratio of the transfer functions of these two circuits is $j\omega R_a C_a$, giving the required 90° phase shift. (Since only the ratio E_1/E_2 is desired, the transfer functions of each separately is not critical.)

If the unknown capacitor in Figure 4-5 has loss, and the effective series value of capacitance C_{xs} is desired, then the unknown in Figure 4-5 should be represented as a series resistance, R_x, and a series capacitance, C_{xs}.

Then,
$$E_1 \sim I \;\; R_x + \frac{1}{j\omega C_{xs}} \;\; j\omega R_a C_a \, f(\omega),$$
$$E_2 \sim IR_s \;\; f(\omega).$$

If E_{apb} is defined as the component of E_a inphase with E_b, then

$$E_{apb} = \text{Real} \left[\frac{E_a}{E_b} \right] \left| E_b \right|$$

It is easy to see that

$$\frac{E_2 p_2}{E_1 p_2} \sim \frac{R_s C_{xs}}{R_a C_a}$$

Note that the f (ω) terms cancel out. Thus, the series value of C_x is measured.

Ratio Meter. The principle of the ratio-meter operation is described below. Refer also to Figure 4-2 in this section of the manual. The meter makes a ratio measurement in two steps. First, the main integrator (U7) determines the first digits of the result by a pulse-counting technique; then the auxiliary integrator (U8) and the dual-slope integrator (U10) determine the remaining lesser digits.

The main integrator is a combination of a phase-sensitive detector and integrator. To start its operation, its capacitor (C40 for 1-kHz; C40 and C41 for 120-Hz operation) is unshorted, and a train of pulses N1 (200 for 1-kHz, 20 for 120 Hz) is applied to the switch (Q20) that connects the numerator voltage to the input. These pulses are square waves inphase with the reference signal. Each pulse will cause an increase in the integrator output that is proportional to the size of the vector components of the numerator voltage, which is inphase with the reference.

The output of the integrator is connected to a comparator (U9) that is offset by a threshold voltage derived from the denominator signal. Whenever this threshold level is exceeded, the next pulse in the train is also applied to the denominator switch (Q21). At the end of the burst, a total of N2 denominator pulses will have been applied; the number of pulses depends on the relative size of the numerator.

At the end of the burst, the output of the integrator, which is termed the remainder voltage, is

$$E_{rem} = \frac{N1\,E_{npr}}{\pi R1\,C1\,f_1} - \frac{N2\,E_{dpr}}{\pi R2\,C1\,E_1 f_1}, \qquad (1)$$

where Enpr and Edpr are the vector components of the numerator and denominator signals inphase with the reference signal, and f_1 is the frequency

Note the same capacitance appears for dc resistance measurements

$$E_{rem} = \frac{N1E_n}{2f\,R1C} - \frac{N2E_d}{2f\,R2\,C}, \qquad (2)$$

where f is 1 kHz.

Thus,

$$\frac{E_{npr}}{E_{dpr}} = \frac{N2}{N1}\cdot\frac{R1}{R2} + \frac{\pi R1C1f_1}{N1}\cdot\frac{E_{rem}}{E_{dpr}}. \qquad (3)$$

The first term in this expression for the ratio is used to determine the first digits of the measurement. The count N2 is injected into the third digit of the display counter, thus giving a reading of N2x100.

To determine the remainder count, the ratio E_{rem}/E_{dpr} is taken into account. The value of E_{dpr} is determined by the auxiliary integrator, U8, to which the burst of N1 pulses is applied. At the end of the burst, the integrator output

$$E_{aux} = \frac{E_{dpr}N1}{\pi R3\,C2\,f_1}, \qquad (4)$$

or

$$E_{dpr} = \pi R3C2f_1\,E_{aux}. \qquad (5)$$

Substituting this in (3)

$$\frac{E_{npr}}{E_{dpr}} = \frac{N2}{N1}\cdot\frac{R1}{R2} + \frac{R1C1}{R3\,C2}\cdot\frac{E_{rem}}{E_{aux}} \qquad (6)$$

E_{rem}/E_{aux} is measured in a dual-slope integrator (U10). E_{rem} is applied to this integrator through R4 for time t_1, which is the time for 100 cycles of the 60 kHz (f_2) oscillator. This $t_1 = 100/f_2$, and this produces an output voltage

$$\frac{E_{rem}\,100}{f_2\,R4\,C3}.$$

E_{aux} (of opposite sign) is then applied until the output of the integrator is returned to zero, as determined by a comparator (U11). The time it takes to return the output to zero, t_2, is determined by counting the cycles of f_2 during this period. This $t_2 = N3/f_2$.

Since the positive (up) voltage due to E_{rem} equals the negative (down) voltage due to E_{aux}

$$\frac{E_{aux}\,N3}{C3\,R5\,f} = \frac{E_{rem}\,(100)}{R4\,f\,C3}$$

or

$$\frac{E_{rem}}{E_{aux}} = \frac{N3}{100}\cdot\frac{R4}{R5}$$

Substituting this in (6)

$$\frac{E_{npr}}{E_{dpr}} = \frac{N2}{N1}\cdot\frac{R1}{R2} + \frac{C1\,R1\,R4}{R3\,C2\,R5}\cdot\frac{N3}{100}. \qquad (7)$$

The count, N3, is displayed as the last two bits of the display (which can spill into the more significant bits, if necessary).

At 1 kHz, N1 = 200, C1 R1 R4/R3 C2 R5 = 1/100 and R1/R2 = ½

so that

$$\frac{E_{npr}}{E_{dpr}} = \frac{100\,N2 + N3}{10000}, \qquad (8)$$

and a full-scale reading is 19999.

And at 120 Hz, N1 = 20, C1 R1 R4/R3 C2 R5 = 1/10,

so that

$$\frac{E_{npr}}{E_{dpr}} = \frac{100\,N2 + N3}{1000}, \qquad (9)$$

and a full-scale reading is 1999.

An important advantage of this circuit is that the critical main integrator uses the same capacitor (C1) for integrating both the numerator and denominator signals; therefore, it need not be highly precise. The components (including that of C2) are important in determining the remainder count, N3, as shown in equation 7, but the N3 count is only a small percent of the total reading.

D Circuit. Figure 4-11 shows the equivalent D circuit. The circuit is comprised of a NAND gate and FET switch; an inverting amplifier (U17); RC filters; the front-panel D potentiometer, R501, and associated filter network; a comparator; and a bistable flip-flop comprised of Q34-Q37 that controls the state of the front-panel D lamps.

The dissipation-factor is obtained by using the phase angle difference, ϕ, between the numerator and denomina-

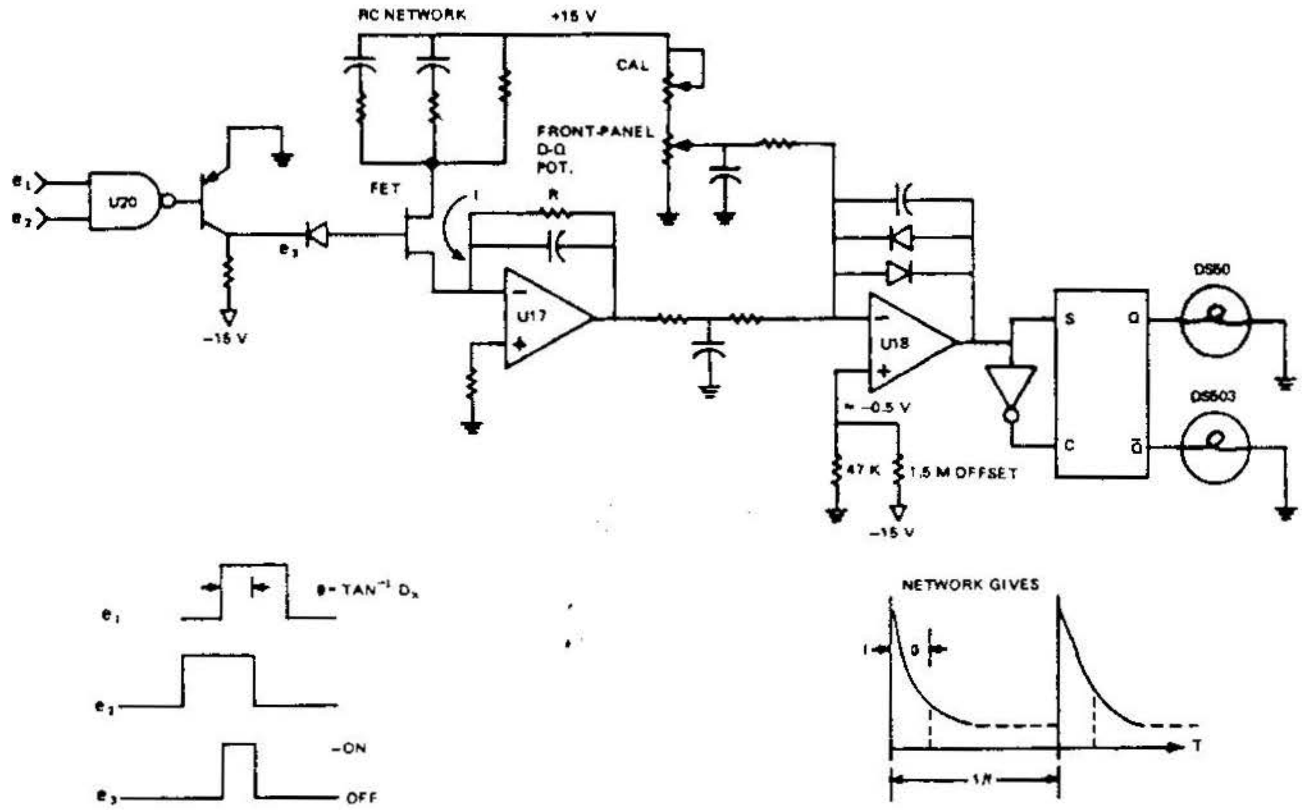


Figure 4-11. Simplified D circuit.

tor signals, as shown in Figure 6-4. Both of these signals are converted into pulses which are applied to the NAND gate. This gives an output pulse whose length is proportional to the phase angle difference. If the phase angle, and not dissipation factor were desired, the RC network shown in Figure 4-11 would just comprise a resistor, which would pass a fixed current for the length of the phase-difference pulse. U17 and the RC network at its output would then filter the signal to give a DC current proportional to the phase angle (Ø) difference. Normally, this dc current would be balanced by the DC current furnished from the D potentiometer to produce a high or low 'D' indication.

Since the measured value is dissipation factor, however, which is tan Ø, and not Ø in characteristic, and since it is desirable to have the D meter scale nonlinear (approximately logarithmic over the middle part of the scale), an RC network is used at the input to U17 instead of a single resistor so that the current flowing through the network is not constant, but time dependent. This gives greater sensitivity to low D reading, and compresses the scale at high D readings.

Two input RC networks are used, one for each test frequency. Each differs in the capacitor used, and the appropriate network is selected for the test frequency being used. The proper RC current-source network and FET gate is selected by means of front-panel PARAMETER switch S502. When set to a 120-Hz position, for example, the switch furnishes a negative voltage to wire-tie (WT) 27 and a positive voltage to WT25. The negative voltage, which passes through diode CR33, holds FET Q27 and, therefore, the 1-kHz section of the D circuit, turned off. A negative voltage is also furnished by transistor Q30, via diodes CR30 and CR31, to both Q31 and Q32. If Q30 is turned on, the cathodes of CR30 and 31 will go to ground, and the FET that has the positive voltage applied to it via the PARAMETER switch will be turned on, since the FET gate input will also go to ground. (The negative voltage already at the gate of Q31 will remain negative, since the negative voltage is also applied to the anode of CR30 and cannot go to ground through the diode.)

Note that jumpers must be added to the 120-Hz current-source network if the instrument is to be operated in the 100-Hz test frequency mode. (Refer to Section 2 of the manual.)*

To ensure that the circuit operates when the D factor is zero, the offsets (the Ø adjustments) on the potentiometer board (P/N 1686-4740) are adjusted slightly so that there is a minimum pulse at the FET gates. This allows the D

*The instrument is purchase connected for a 50- or 60-Hz line frequency and, therefore, 100- or 120-Hz test frequency, respectively.

switch to be adjusted through zero to a negative value to obtain a balance around zero for a capacitor with a D factor of zero. To do this, a certain amount of pulse is required through the NAND and FET gate so that the circuit can operate; the slight adjustment in lead or lag of the Ø potentiometers will allow this to occur. The full-scale reading is set by R236, which varies the voltage on the D potentiometer.

When the output of U18 is positive, which means that the input is negative and, therefore, the measured D exceeds the value set on the dial, Q34 is turned on and Q37 is turned off. Q34 turns on Q35, which causes approximately +5 V to be applied, via WT24, to lamp DS504, turning on the lamp. This indicates the dial should be set to a larger value if it is desired to obtain the exact reading. If the output of U18 is negative, indicating a positive input to U18 and, therefore, a setting on the dial larger than the measured value, Q34 is turned off and Q37 is turned on. This, in turn, turns on Q36 and lamp DS503 on the front panel. This indicates that the dial should be set to a lower value if it is desired to obtain the exact reading.

If the exact setting is set on the dial, a slight amount of ac on the input U18 causes both D lamps to be illuminated.

Range Circuits. The range circuits detect signal levels that indicate that the range selected by means of the front-panel RANGE switch may either be too high or too low, or is within the proper range. If the selected range is too high or too low, the circuits furnish signals that light direction lamps on the front panel, to indicate the direction that the dial should be turned to obtain the correct range. To do this, a high-range detector and a low-range detector circuit are employed to sense by means of comparing at a junction the dc level of each "half-bridge" signal (e_n and e_d). If signal e_n is greater than twice signal e_d, the high-range lamp will light, indicating that the measurement is too high for the range and the range should be increased. If signal e_n is less than 1/5th e_d, the low-range lamp will light, indicating the range should be decreased.

Figure 4-12 shows the equivalent range circuits. The numerator and denominator signal are each applied to isolation amplifiers and summed in a weighted resistor network. The summing point is shunted to ground by an FET gate (Q44) driven by the reference signal. This results in phase detection of the signals.

The two signals are of opposite polarity; therefore, if $E_n/R1 > E_d/R2$, the output, e_3, will be positive, and the HIL lamp will light. The value of E_n/E_d at which this occurs depends on the ratio R1/R2, and is set just below a full-scale reading. If the HIL lamp is lit, it indicates a higher range should be used.

The LOL lamp is actuated in the same manner if $E_n/R3 < E_d/R4$. R3 and R4 are chosen to light the lamp if the reading is just below 1/10th full scale, where a lower range should be used for better resolution.

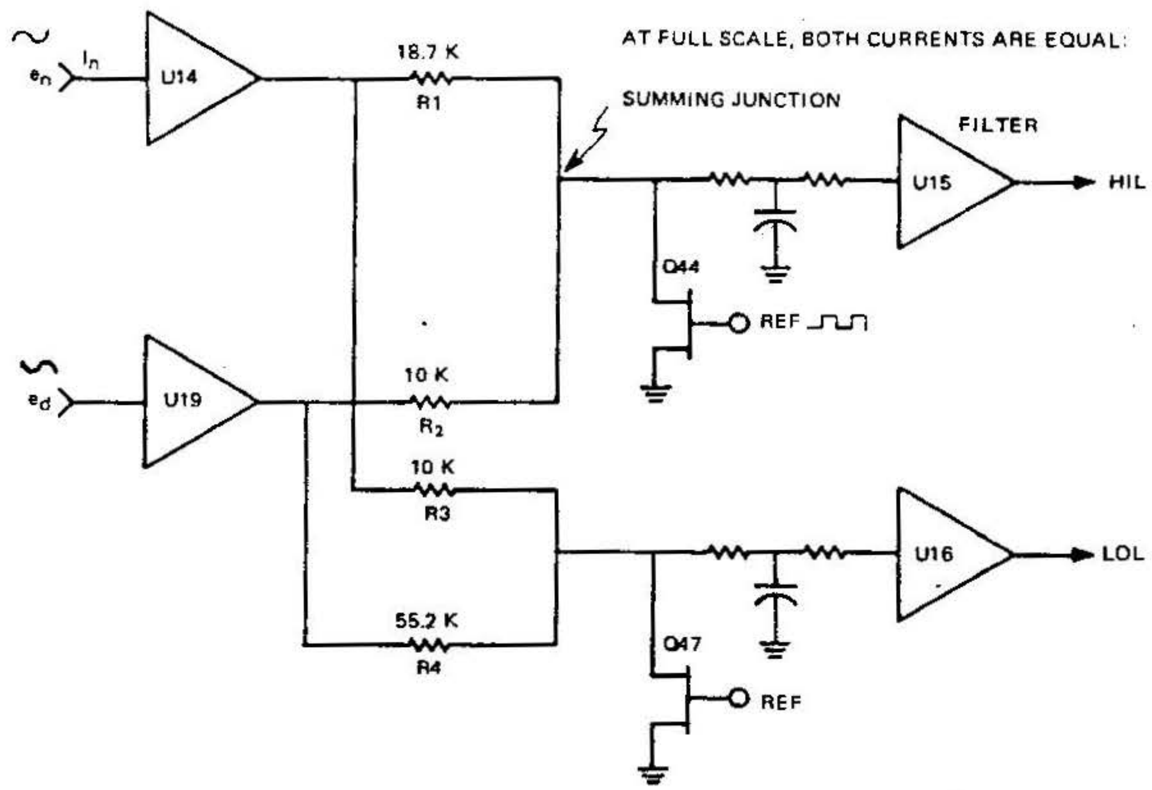


Figure 4-12. Equivalent range circuit.

The range lamps function continuously and do not require a start pulse. They are, however, only approximate. The actual digital reading may indicate that the range that is set is not exceeded (no E readout), even though the HIL lamp is illuminated, or that a lower range is preferable (one reading less than 1/10th full scale), even though the LOL lamp is not illuminated.

Range 9 should not be used at 1 kHz. If one attempts to do so, there will be no units indicated for the CAPACITANCE display.

RANGE and FREQUENCY Switches. Figure 6-8 is the schematic of the front-panel RANGE and FREQUENCY switches, S501 and S502 respectively. Figures 6-7 and 6-6 are the respective layout drawings of the switches.

S501 is a 9-position rotary switch having six wafers on which are mounted capacitors and resistors. The layout drawings identify and show the locations of the components. The schematic of the ratio meter and "half-bridge" circuits (Figure 6-4) shows the components and illustrates their functions in the circuits. Besides their main function of establishing the analog measurement, the RANGE and FREQUENCY switches are also used for other purposes. As shown in switch schematic, Figure 6-8, the high and low range-direction lamps are activated (or disabled) via S502 and S501. Note that for certain switch positions no range lamp(s) will light. In Figure 6-8, the RANGE switch is shown set to range 1; the FREQUENCY switch is shown set to 120 Hz (100 Hz).

The range lamp indication that normally occurs to indicate that the measurement is less than 1/10th full scale will not occur on range 1 (signal LOL is disabled at S501).

The +5 V used to illuminate the range direction lamps is applied to contact 201F of S502. By tracing this signal through the various switch contacts, it will be seen that the range direction lamps are held illuminated for the ranges mentioned above. For other ranges, the lamps are illuminated by signals LOL and HIL when the measurements are less than 0.1 full scale or within 5% full scale, respectively.

The same +5 V used to hold the lamps illuminated in ranges 1 and 9 is also used to activate the D-Q circuit by furnishing via contact 218F of S502, the +5 V to WT23 on the bridge board. An effective high signal is applied to WT9 on the bridge board by means of the same +5-V source. This selects the reference signal for the range circuits from the "lag" (numerator) section of the "half-bridge."

The decimal point selection for the readout display is made by means of S501 and S502, as shown in Figure 6-8. A +5-V dc signal is furnished over either line A, B or C to the logic board via connectors J502 and S02. Table 3-2 in Section 3 gives the decimal-point placement for each of the eight ranges for the selected ranges. Lines A, B and C are for decimal points DP4, DP3 and DP2, respectively, as shown in Figure 6-11, the schematic diagram of the display board. Lines A, B and C are also available at the rear-panel data output connector, L-S01, for use by external equipment.

S502 also selects the units symbol lamps for use with the RANGE switch. The switch also is used for the test-frequency selection, for D circuit frequency selection, and for selection of an additional capacitor in the main integrator circuit, for the 120-Hz mode of operation.

When S502 is set to the 120-Hz position, a positive voltage is applied to WT's 8, 26, and 13 to enable the 120-Hz (or 100-Hz) oscillator, enable the 120-Hz (or 100-Hz) section of the D circuit, and select the additional sampling capacitor in the integrator, respectively. These connections are also shown on the bridge board schematic.

When set to the 1-kHz position, the switch furnishes a positive voltage to WT's 6 and 27 to enable the 1-kHz oscillator and 1-kHz section of the D circuit. The alternate switch furnishes a negative voltage to the WT's not connected to the positive voltage.

Figure 6-5 shows the layout of the BIAS switch, S503. The switch schematic is contained in the bridge board schematic, Figure 6-4.

4.2.4 Logic Board.

General. The following is a description of the sequence of measurement operations, and includes primarily the operation of the logic circuit board, which furnishes the timing and control signals for the measurements. Figure 4-2 is a block diagram of the ratio meter and a portion of the logic board circuitry. Included in the figure is a brief sequence of operations of the unit. The following paragraphs expand on this brief description, to explain the reasons why and how the control signals produce this operational sequence for all measurements.

Refer to Figure 6-10 for the logic board schematic. It is suggested that the reader also refer to the timing diagram of Figure 6-9, when reading the following description.

Reset, Burst and Time Signals. The logic circuit operation up through the period designated BURST at the top of Figure 6-9 is described in this paragraph. When power is initially applied to the instrument, transistor Q27 turns on momentarily. This triggers U38, which produces a RESET pulse at U38-1 and U38-6 to initialize (reset) all logic storage elements.

When the START switch is pressed, one-shot IC38 is triggered by signal START at pin 4. The one-shot produces a 15-ms pulse at pins 6 and 1 that is used to reset decade counters U2, U3, U8, U13 and U26. These counters are used to count burst pulses (20 or 200), comparator pulses (CP1) that correct the integrator threshold, up-count (UPC) and down-count (DNC)-time pulses, and display, via their outputs which are applied to other devices, the value of the part under test. The CP1 count X100 and DNC-time counts comprise the value of the part under test.

IC38 can also be triggered by an external REMOTE START signal applied to its input pin No. 3 via either the rear-panel MEASUREMENT-DATA connector or the Limit Option module, allowing external devices to initiate measurements. Figure 6-10 shows the MODE switch set to SINGLE MEASUREMENT. If repetitive measurements are being made (MODE switch set to REPETITIVE), timer U39 will be triggered at pin 2, since its input at pin 4 is switched to a logic 1 (high) to enable U39 in this mode. The triggering will occur after data is made available for display and/or recording. U39 is automatically re-triggered by pulse $\overline{SD3}$ after counters U2, U3, U8, U13 and U26 have achieved a new value and have stopped counting. U39 causes the output of NAND gate U16-8 to go low for a period determined by timing resistors R500 and 501 on the MODE switch. The low (signal TIME) at the output of gate U16 is applied to pin 5 of IC38, inhibiting U38. When signal TIME goes high after the controlled time (approximately 0.25 s min, 10 s max.), the combination of the low at pin 4 of U28 and the positive-going edge at pin 5 automatically triggers one-shot U28 to produce a RESET pulse at its pin 6 output (and a $\overline{RESET}$ pulse at its pin 1 output), and a new measurement cycle is therefore automatically initiated.

The $\overline{RESET}$ pulse from IC38, pin 1, holds STC low, but allows STC to go high when it ($\overline{RESET}$) goes high. (The input to U37-12, designated CC on the timing diagram, stays high during the time period.) When STC goes high, it opens switches S1 and S2 shown in Figure 4-2 (Q23 and Q24, respectively, in Figure 6-4). These FET switches then remain open until the measurement is completed.

The $\overline{RESET}$ pulse from IC38 also sets cross-coupled flip-flop U29-6, which, at the end of the pulse, causes pin 9 of of J-K flip-flop U28 to go high and pin 12 to go low, allowing the next falling edge of signal REF to change the state of U38. (Signal REF is the reference signal produced by the oscillator on the 1685-4720 bridge board.)

The high now at pin 11 of U28 enables NAND gate U29-11, allowing the next and subsequent REF pulses to pass through the gate as signal BST. The signal is then designated signal BST.

Signal BST, or "burst," is fed back to the bridge board, via S02-C, where it is used as the pulse train for gating of the main AC-DC integrator circuit, as described in paragraph 4.2.3.

The burst is 20 counts when making 120-Hz measurements and 200 counts (or pulses), when making 1-kHz measurements. These pulses must be counted, and decade counters U2 and U3 are employed for this purpose, as well as for other counting functions. Signal BST is applied to NAND gate U32-8. Since J-K flip-flop U36 is held reset by the Q output of J-K flip-flop U34-15, there is a high at pin 10 of U32. This allows BST pulses to pass and be counted by decade counter U3.

For 120-Hz measurements, U3 counts 20 pulses. On the 10th and 20th pulses pin 11 goes low (goes high at the 8 count and again at count 18). If measurements are being made at 120 Hz, pin 5 of U37 is low, since the front-panel FREQUENCY switch, shown connected to the base of Q20, keeps Q20 turned off, which in turn keeps a high at pin 9 of U37. Since pin 10 (signal S) of U37 is high during this time, there is a low on pin 5 of U37. The output of the decade counter therefore does not pass through either U35-6 or U37-6, but it causes U37-3 to go to 1 and U35-3 to go to 0. This clocks J-K flip-flop U34, causing its Q output to go to 1 at pin 11. On pulse 20, pin 11 of U3 again goes low. This results in pin 6 of U34 going low, causing U34 to change state again, its Q side going low. This in turn causes J-K flip-flop U34-15 to change state, its Q output going high and its $\overline{Q}$ output going low. $\overline{Q}$ going low resets cross-coupled flip-flop U29 and J-K flip-flop U28, which terminates the BST signal. It also causes flip-flops U34 to be disabled, since the J and K inputs are now 0, via signal S from U33-8. However, U34 remains in the same state until reset at the start of a new measurement cycle.

Note that if the instrument was in the 1-kHz mode of operation, pin 5 of U37 would be high, since Q20 would be conducting. U37, under this condition, allows the output of the first decade counter, U3, to be coupled to U2. Since pin 5 of U37 is now high, pin 5 of U35 is also high. The other input of this NAND gate is connected to pin 11 of U2, the output of the second decade of counting.

In the 1-kHz mode, U3 counts to 10, then U2 counts, via U37-6, until a count of 100 is reached, at which time J-K flip-flop U34-11 is set via U35-6 in a manner similar to that of the 120-Hz mode. The counting process continues in U2 and U3 until U2-11 again goes low (200 pulses have now been counted), thereby causing U34-11 to go low. This causes U34-15 to be set. The outputs at U34-15 and U34-14 perform the same functions described in the previous paragraph.

After full counts, the decade counters are back at their original states (reset state), so that there is no need to actually force a reset in the counters. Note that U34 is reset by a low signal STC (see timing diagram) at a time somewhat after BST is completed, but long before the start of a new measurement cycle (leading edge of the RESET signal).

During the time that the BST pulses are being counted, CP1 pulses can be produced on the bridge board, depending on the value of the unknown. These pulses are fed to the logic board, which produces pulses, as shown in the timing diagram of Figure 6-9.

Pulse CP1 enables J-K flip-flop U28 that produces pulses P and $\overline{CTN}$. Pulse CP1 is produced on the bridge board by the comparator (U9) connected to the main AC-DC integrator. When the integrator exceeds the established threshold level, as described in para. 4.2.3, pulse CP1 is produced by the comparator. CP1 ultimately produces a pulse ($\overline{CTN}$) that is time-synchronized to the next BST pulse and is fed back to the main integrator to turn on an FET gate (Q21) that samples the denominator signal (E_d) from the bridge circuit, to perform an arithmetic decision function by a fixed amount. The $\overline{CTN}$ pulse(s) is also counted by counter U8, via U31-3, which represents the third most significant digit of the readout display. Each $\overline{CTN}$ pulse, therefore, has a value of 100 counts in the counter chain of U3, U2, U8, U13, and U26.

CPI going high asynchronously enables the J and K inputs of U28. U35-11, driven by U28-15 and U33-12, then produces the desired CTN pulse in time synchronization with a BST pulse, as mentioned above and as shown in Figure 6-9. CPI goes low as the result of the effect of CTN on the analog circuitry of the bridge board. (U7 slews, causing the output of comparator U9 to go low.)

This completes the description of logic circuit operation up through the time period designated BURST (at the top of the timing diagram of Figure 6-9). At this point, the counter comprising U3, U2, U8, U13, and U26 is in the following condition: U3 and U2 each contain zero, and the section U8, U13, and U26 contains the count of the number of CP1 (or $\overline{CTN}$) pulses that have occurred.

The up-down integration portion of the measurement cycle is described next. (See interval designated INTEGRATE at the top of the timing diagram of Figure 6-9). Note that signal "S", going low at the end of the BURST, forces U37-8 high, thereby enabling U37-6 to pass pulses from U3-11 to U2-14.

Counting Cycles of $\overline{UPC}$ and $\overline{DNC}$ (fHz). Signal $\overline{UPC}$ is a dc logic signal established by a fixed count of 100 cycles of 60 kHz from U27 and is used to establish the fixed time (T_1) in which the gate (Q26) for the positive, variable slope of the remainder dual-slope integrator is closed (Q26 is on). Signal $\overline{DNC}$ is a time-variable pulse count for the fixed falling slope of the integrator output. When the falling slope crosses the zero threshold, the count stops, and the pulses counted during this period, T_2, together with the previous $\overline{CTN}$ count, constitute the measurement result. DC logic signal $\overline{DNC}$ enables FET gate Q27 of the integrator circuit.

Decade counters U3, U2, U8 and U13, and J-K flip-flop U26-15 keep count of the pulses that determine the UPC and $\overline{DNC}$ time periods. U3 and U2 are only used for UPC-time counting. The J-K flip-flop indicates the "spill", or most-significant-digit +1 count, for the 1-kHz measurement mode of operation, to indicate a 19999 count on the readout display.

For the 120-Hz mode, pin 12 of counter U13, which is the 1-count output of the counter, serves as the "spill" bit for a maximum count of 1999 on the display in this mode of operation.

At the conclusion of the BST count, J-K flip-flop U36 is enabled by J-K F-F's 34, which put a logic 1 on the reset (R) input of F-F36, allowing the F-F to be synchronized and clocked by the next 60-kHz pulse from the oscillator, U27-6.

The falling edge of this pulse causes the Q side of U36 to go to 1. This enables NAND gate U32, which is also connected to the 60-kHz oscillator. This operation syncronizes the oscillator so that a full width 60-kHz pulse, and not part of a pulse, is passed through U32 to the decade counters.

F-F U36, when set, defines signal SUD as going high. This signal enables F-F U26, the $\overline{UPC}$ and $\overline{DNC}$ output NAND gates (U31), and the CP2 (zero threshold crossover signal) input gate, U32-3. Signal SUD also turns on FET gate S3 shown in Figure 4-2 (Q28 in the schematic, Figure 6-4).

Signal $\overline{UPC}$ is forwarded to the bridge board and applied to FET gate S_y (Q26 on the schematic). The duration of the UPC pulse is determined by 100 counts of the 60-kHz, as counted by U3 and U2. When the 100th pulse is counted, pin 11 of U2 goes low. Since pin 11 is connected to the clock input of F-F U26, and the J-K inputs of this flip-flop are enabled by signal SUD, which is now high, F-F U26 is set, its Q output going to 1. This results in a number of things: It disables $\overline{UPC}$ NAND gate U31-11 (which was previously activated by the $\overline{Q}$ output of U26 and the Q side of U36) and enables $\overline{DNC}$ NAND output gate U31-8, causing signal DNC to go low. It also enables the count-complete (CC) NAND gate (U32-6) and also allows the coupling of decade counter U2 to counter U8, through NAND gate U31-6.

U31-6 is enabled by the Q side of U36, which goes high after pin 11 of U2 goes low. This particular negative-going edge of the 100th UPC pulse at U2-11 does not introduce a count into U8. Immediately thereafter, however, U31-6 is enabled for counting DNC pulses from U2-11. Note that U3 and U2 are automatically in their reset state at the conclusion of the 100th UPC pulse, ready to count DNC pulses (60-kHz pulses from U32-8).

When U26 is set, signal $\overline{DNC}$, a dc level, goes low at the output of U31-8 (TP13). $\overline{DNC}$ stays low until the downward ramp of the integrator (U10) output crosses zero volts, at which time signal CP2 goes low, producing a count complete (CC) logic-low signal at U32-6. This DNC time period is designated T_2 in Figure 4-2.

When CC goes low, the actual measurement process is completed, and the measured value is contained in counter chain U3, U2, U8, U13, and U26. No further counting will take place in this chain until a new measurement is initiated. All of the remaining timing in Figure 6-9, and the remaining circuitry in Figure 6-10 is involved with the processing of the measured value, synchronizing it with the display timing, comparing it with the selected limits of the limit option, etc.

The occurance of the negative edge of CC is, therefore, the point at which an entirely new sequence of operations is initiated on the logic board.

Note that CC going low brings STC low via U37-11 and U33-6. This closes S1 and S2 on the bridge board, thereby discharging C1 and C2 of Figure 4-2. Also, STC low resets F-F's U34; and the resulting low at U34-15 resets U36 at [illegible], causing U30-15 to go low. This disables U32-11 so that no further 60-kHz pulses can reach U3-14, thereby terminating the counting process (note the resulting low of SUB in Figure 6-9).

Signal $\overline{CC}$ is also delivered to cross-coupled pair U16, which, when set, signifies that a new value (NV) is now present in the counter chain. Signal NV is actually set in time-synchronization with signal $\overline{D1}$, via U16-11 (see Fig. 6-9), where the timing for $\overline{D1}$ (and also $\overline{D2}$, $\overline{D3}$, and $\overline{D4}$) originates from scan oscillator U27-8 (1 kHz). (The 60-kHz from U27-6 and the 1-kHz from U27-8 are asynchronous with each other.) Signal NV is now used to enable the generation of strobe pulses SD3 (strobe data during time D3) and SDL (strobe data into latches U15, U10, U9, U14 and U25).

When SDL goes high (U4-2, U4-4, U4-6, U4-10), the measurement value contained in the BCD counter chain is strobed into latches U15, U10, U9, U14, and U25 and is presented to the inputs of the two dual 4:1 multiplexers, U20 and U23, ready for display. The BCD latch output is also available for data output. (See U18, U19, and U22 at the lower right of Figure 6-10.)

The proper BCD digit is passed from the latches to 7-segment decoder U24, via multiplexers U20 and U23, whose multiplexing control is derived from scan oscillator U27-8 via U21. The outputs of U21 are also decoded in U17 to produce the 4 time states designated $\overline{D1}$, $\overline{D2}$, $\overline{D3}$, and $\overline{D4}$. (See Figure 6-9 and 6-10.) These time states are ultimately fed to Q1, Q2, Q3, and Q4 to activate respective display digits 1, 2, 3, and 4. (Digit 4 is the least significant-right-most digit.)

Error Signal E. In the 120-Hz measurement mode (Q20 not conducting), if a count $\geqslant$ 2000 DNC pulses is achieved prior to CC going low, an over-range error, or 'E', condition has occurred. In this case the spill digit, taken from pin 12 of counter U13 (which is high for a count of 1999, and goes low for a count of 2000), causes IC5-8 to go from a low to a high condition. This in turn produces a negative-going edge at U5-6 that sets and latches F-F U6, thereby producing signal E at U6-15.

If measurements are being made in the 1-kHz mode (Q20 conducting), an over-range, or 'E', condition occurs when 20,000 is counted prior to CC going low. In this case the spill digit, occurring at U26-15 (which is high for a count of 19,999, and goes low for a count of 20,000), causes IC5-3 to go from a low to a high. As in the 120-Hz mode, signal E is again produced at U6-15. (See Note 2 of Figure 6-9.)

Signals E and $\overline{E}$ are used for a number of different applications, as follows:

1. To produce an E readout in place of the spill, or 1, digit on the left-most readout display digit, through transistor drivers Q24 and Q11, which are turned on. (Q9 on, holds Q10 off, to inhibit the display of spill 1.)

2. To furnish a low ($\overline{E}$) signal to the rear-panel MEASUREMENT-DATA connector, for use by peripheral equipment to signal an over-range condition.

3. To furnish a high E signal for use by the optional limit comparator to signal an overrange condition and inhibit the comparison. (F-F U6-15 is reset at the start of a new measurement, disabling the overrange-inhibit condition.)

Display Readouts. As mentioned previously, the BCD counter chain U3, U2, U8, U13 and U26-15 counts the DNC pulses until the zero crossover signal, CP2, occurs. After this, in time synchronization with the leading edge of the first D4 pulse, which occurs after the negative edge of CP2, the contents of the counter are strobed into latches U9, U10, U14, U15 and cross-coupled pair U25 by pulse SDL. F-F 26-15 contains the spill digit for the 1-kHz measurement mode.

Cross-coupled flip-flop U25, when set, turns on Q22 directly. This causes Q10 to be turned on, activating the one-digit (spill) indicator. If, in this case, the DNC count exceeds 19,999, the E signal is produced, as previously described, which causes Q10 to be turned off by Q9 and Q11 to be turned on. This causes the E symbol to be displayed in place of the "1" digit. Note that the output of pair U25 does not pass through multiplexers U20 and U23.

The BCD values stored in latches U9, U10, U14 and U15 are presented to the inputs of dual 4:1 multiplexers U20 and U23, which comprise four 4:1 multiplexers. The four outputs of each latch are applied to the 4 sections of the multiplexers, one output to each section. The multiplexers furnish 4 output signals simultaneously, corresponding to the 4 BCD bit outputs of a latch. The 4 multiplexers are strobed separately and sequentially by the states of address signals CTR1 and CTR2, so that each numeral is displayed sequentially at the correct digit position of the readout display. (The correct display digit is selected by decoding CTR1 and CTR2 in U17 to produce signals $\overline{D4}$, $\overline{D3}$, $\overline{D2}$, and $\overline{D1}$, which are applied to digit drivers Q4, Q3, Q2, and Q1, respectively.) The multiplexer outputs are applied to BCD-to-seven-segment decoder/driver U24, which decodes the four inputs, 7(A), 1(B), 2(C), 6(D), as shown in the truth table below. Input pin 3 of the decoder is the lamp test (LT) input, and pin 5 is the ripple blanking input (RBI). The latter pin is held at logical 1 at all times.

The decoder outputs for the desired numerals to be displayed are logic 0's. (Refer to Figure 6-10, which shows the association between the decoder letter-designated outputs and the display numeral.) When the output(s) go to 0, the associated transistors Q12-Q18 are turned on, activating the letter-designated, or numeral-segment, lines.

Each line is applied to all LED's of the display. Therefore, it is necessary to enable a particular digit position at the appropriate time, as mentioned previously, to display the stored data correctly. The digit display order is 4-3-2-1, as

TRUTH TABLE SN5446A, SN5447A, SN7446A, SN7447A

	INPUTS							OUTPUTS						
DECIMAL OR FUNCTION	LT	RBI	D	C	B	A	BI/RBO	a	b	c	d	e	f	g
0	1	1	0	0	0	0	1	0	0	0	0	0	0	1
1	1	X	0	0	0	1	1	1	0	0	1	1	1	1
2	1	X	0	0	1	0	1	0	0	1	0	0	1	0
3	1	X	0	0	1	1	1	0	0	0	0	1	1	0
4	1	X	0	1	0	0	1	1	0	0	1	1	0	0
5	1	X	0	1	0	1	1	0	1	0	0	1	0	0
6	1	X	0	1	1	0	1	1	1	0	0	0	0	0
7	1	X	0	1	1	1	1	0	0	0	1	1	1	1
8	1	X	1	0	0	0	1	0	0	0	0	0	0	0
9	1	X	1	0	0	1	1	0	0	0	1	1	0	0
10	1	X	1	0	1	0	1	1	1	1	0	0	1	0
11	1	X	1	0	1	1	1	1	1	0	0	1	1	0
12	1	X	1	1	0	0	1	1	0	1	1	1	0	0
13	1	X	1	1	0	1	1	0	1	1	0	1	0	0
14	1	X	1	1	1	0	1	1	1	1	0	0	0	0
15	1	X	1	1	1	1	1	1	1	1	1	1	1	1
BI	X	X	X	X	X	X	0	1	1	1	1	1	1	1
RBI	1	0	0	0	0	0	0	1	1	1	1	1	1	1
LT	0	X	X	X	X	X	1	0	0	0	0	0	0	0

defined by signals $\overline{D4}$, $\overline{D3}$, $\overline{D2}$, and $\overline{D1}$ from U17. (See Figure 6-9.) Lines K4, K3, K2 and K1 at S03 are activated in this order. These lines strobe the cathodes of the associated LED's.

The timing established by F-F's U21, which produce signals CTR 1 and CTR 2, is shown in Figure 6-13, the comparator schematic diagram. F-F's U21 are simply wired as a divide-by-four count down pair.

In addition to producing signals that enable the appropriate LED's, signals $\overline{D1}$ thru $\overline{D4}$ are also used for some other functions, as illustrated in timing diagram, Figure 6-9. Signal D3 is applied, through inverter IC12-2, to NAND gate U11-8, to produce strobe signal SD3 (strobe data during D3 time), under the following conditions. Since signal CC and $\overline{D1}$ have set cross-coupled flip-flop U16, signal NV is a logic 1 level at pin 11 of U11-8. F-F U6-11 was set (at pin 7) when signal up-count (UPC) went low during the counting of UPC pulses (Figure 6-9). U6 remains set, with its Q output at a logic 1 level, enabling pin 9 of U11-8 so that the next inverted $\overline{D3}$ pulse can produce signal $\overline{SD3}$.

F-F U6 gets reset when pulse $\overline{D2}$ goes low, which occurs after $\overline{D3}$ goes low. $\overline{D2}$ is inverted and applied to gate U11-12. Since a logic 1 level (signal NV) is applied to pin 2 of the gate, the next positive pulse from the scan oscillator (signal SCAN), which is one-half the pulse width of the "D" signals, causes the output of U11-12 to go to 0 and reset F-F U6-11. The flip-flop remains reset until a new measurement cycle occurs.

Signal $\overline{SD3}$ is applied to U39, triggering the timer which, in the REPETITIVE MODE, produces a "TIME" signal at U16-8, the duration of which is determined by timing resistors R500 and 502 on the MEASUREMENT MODE front-panel switch. Signal "TIME," while low, inhibits one-shot IC38. The positive-going trailing edge of signal TIME triggers one-shot U38 to initiate a new measurement sequence. (See Note 3 in Figure 6-9.) The duration of signal TIME is the time allowed for a value to be displayed and for a limit comparison to be made. This time can be varied, as desired, to allow data to be recorded, etc. The time can be varied from approximately 1/4 s to 10 s.

Signal SD3 also serves as a strobe signal for external equipment to signify that data is available for recording, actuate handlers, etc.

Signals $\overline{D4}$ and $\overline{SDL}$ are also forwarded, via S04, to the limit comparator to provide gating and timing signals for the comparator. At the time that multiplexers U20 and U23 read out data for the selected digits, the data is also made available to the comparator, via S04, as signals A0 thru A4, A4 being the "spill" digit for 1-kHz operation.

Decimal point indications for the readout display are established by the front-panel RANGE switch. The switch applies +5 V via S02-12-13, and -14 to the appropriate 75-Ω current limiting resistor, R56, R68 and R69, and to the readout digits via the appropriate decimal-point line (DP2-DP4). The switched +5 V is also routed through transistor drivers Q23, Q26, and Q25 to the rear-panel DATA connector, via non-inverting buffers U30-12, U30-8, and U30-10, respectively. When the +5 V is applied to one of the 3 transistors, the transistor is turned on, producing a low output at the DATA connector.

Output Signals. In addition to providing timing signals for the bridge board, signals produced on the logic board are also furnished to the optional limit comparator, if installed, and to the rear-panel DATA connector.

Limit Comparator Signals. The signals furnished to the limit comparator are shown at the top of Figure 6-10, at connector S04.

As described previously, signals A0 thru A4 are the measurement-value data bits obtained from the multiplexers when they are strobed at the desired time. Signals CTR1 and CTR2, which are used on the logic board to establish the timing of signals D1-D4, are also supplied to the comparator where they are used to establish and initiate additional sequenced timing events. For example, when CTR1 and CTR2 are both high on the comparator logic board (1685-4750) they signify that time state 1 (the time during which signal D1 is active) has just been completed and that time state 4 (defined by D4 active) is just beginning. See Figures 6-9 and the timing diagram on Figure 6-12.

Signal $\overline{SDL}$ at connector S04, as mentioned previously, defines that the measurement is completed and that data is now available for display. Timing signal D4 is also forwarded to the comparator, for gating purposes.

In addition, the overrange, or error, signal, "E"; scan oscillator signal "SCAN"; and the "RESET" signal are also supplied to the comparator. These signals were described previously.

A signal designated DQL is also sent to the comparator via S04. This signal is a logic 1 level if the D measurement exceeds the selected limit determined by the setting of the front-panel D dial. Signal DQL is taken from the high-D lamp.

The "REMOTE START" signal at S04 is an input signal from the comparator, the positive-going edge of which turns on Q21 to initiate a new measurement at U38.

There are two other connections. These are designated INTERFACE 1 and INTERFACE 2. These are through connections from S01 to S04 that allow peripheral equipment connected externally to the comparator, (e.g., a mechanical parts handler) to interface directly to other peripheral equipment; for example, a GR Type 1785 printer connected to the rear-panel DATA output connector.

Output Data Connections. The data and control output signals available to run peripherial equipment and the control-signal input provisions available from peripheral equipment are described in Section 2 of the manual.

Note that the BCD data outputs shown on the lower right on the schematic (Figure 6-10) are taken from latches U9, U10, U14, U15, and U25-2. Therefore, the least-significant-digit output at S01-2 is derived from U15-5, and the most-significant-digit output at S01-14 is taken from U14-16; the MSD+1 output is taken from U25-2. It is important to note that U18, U19, and U22 are plugged into sockets on the board, so that these IC's can be easily replaced if positive-true output logic levels are desire instead of the negative-true logic output supplied with the instrument. All DATA output lines are open-collector, with a 30-V breakdown limit.

4.3 LIMIT COMPARATOR

4.3.1 General

The optional Limit Comparator is comprised of two circuit boards, the type 1685-4750 limit option board 'A' and the type 1685-4760 limit option board 'B'; a front-panel assembly; and various cables (both separate and attached to the front-panel assembly) that plug into the comparator boards and connectors mounted on the chasses. The cables interface the panel, comparator boards, and the meter logic and bridge boards. Figure 6-3 is a block diagram showing the interconnections between the comparator's components and the meter.

The general principle of the comparator is to take data from the meter after the measurement is completed and then compare the data, first against the low limit (established by means of the comparator LOW LIMIT digi-switches) and then against the high limit (established by means of the HIGH LIMIT switches).

The comparison is first made for the two-most-significant digits, MSD+1 and MSD. This involves a 5-digit comparison for the first compare operation. Four-digit comparisons are made for the following 3-numeral comparisons (3 rightmost readout digits). Although comparisons are made for each digit, the results of the particular comparison are not used if a more significant digit is found to be outside the selected limits.) The comparisons are done during time state signals D4, D3, D2, and D1, respectively. (These signals, or time-states, are described in para. 4.2.4, and are shown in Figures 6-9 and 6-12.)

Both the low-limit comparison and high-limit comparisons are made even if the low-limit comparison, made first, is unacceptable. Multiplexers on the 'B' board switch the selected high- and low-limit values to a 5-bit comparator on the 'A' board in which the limit comparisons are made. The central part of the limit-comparator option is the 5-bit TTL/MSI 9324 IC comparator. The IC makes the comparison for both the low and high limits, with the correct limit data for each digit being switched to the IC comparator at the proper time by the multiplexers.

4.3.2 Comparator Board B (P/N 1685-4760)

Figure 6-13 shows the schematic of the 'B' board and includes the wiring representations of the LOW- and HIGH-LIMIT front-panel digi-switches, including the BCD outputs (1-2-4-8) of each switch.

The board includes a pull-up resistor for each line, and 4 SN74153 dual 4-line-to-1-line multiplexers that switch their inputs to the 5-bit comparator on the comparator 'A' board.

The leading edge of pulse $\overline{SDL}$ activates the comparator. (See Figure 6-12.) When $\overline{SDL}$ occurs, the output of cross-coupled pair (U15-11 (designated signal GATE), enables strobe pulses for comparator U2. These pulses, designated COMPARE, are initiated in time synchronization with the positive transitions of the SCAN signals. Details on the actual comparison operation are given further on in this paragraph.

Although U6 is enabled by the leading edge of $\overline{SDL}$, U6 will not change state until the next time $\overline{CTR2}$ goes low at U11-8. From the timing diagram, it is obvious that the first 4 of the 8 COMPARE pulses occur before U6 changes state (before signal COMP-4 goes high). Then the last 4 COMPARE pulses occur. Referring to Figure 6-13, the inputs to the multiplexers from the LOW-LIMIT digit-switches are selected when $\overline{COMP\text{-}4}$ is low. (A low at pin 15 of each multiplexer enables input pins 10,11,12, and 13.) Conversely, the inputs to the multiplexers from the HIGH LIMIT digit-switches are selected when COMP-4 is low. (A low at pin 1 of each multiplexer enables input pins 6, 5, 4, and 3.) Figure 4-13 shows a functional block diagram of the multiplexer.

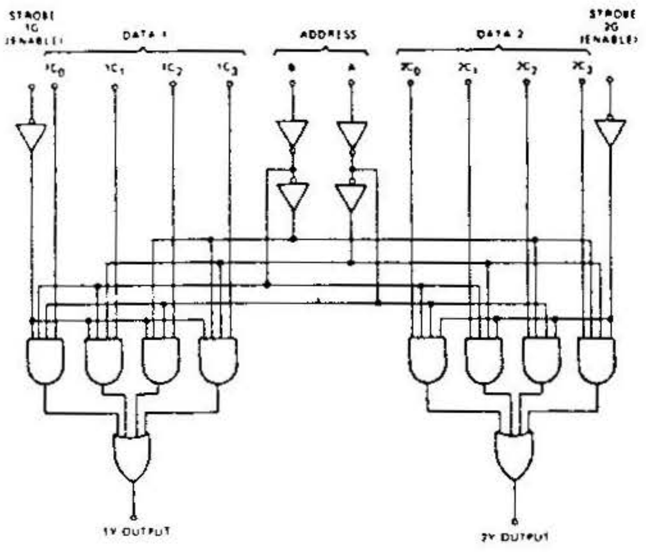


Figure 4-13. Multiplexer functional block diagram.

From the timing diagram in Figure 6-12, it is clear that $\overline{SDL}$ goes low in time synchronization with $\overline{CTR1}$ and $\overline{CTR2}$ going low (during time state 4, when D4 is active). These two signals are applied to pins 14 and 2 of each multiplexer; when these two pins are low, multiplexer input pins 10 and 6 are selected. (The levels at pins 1 and 15 then determine which of the levels (pin 6 or 10) is passed to U1.) Thus, the first digit to be multiplexed after the arrival of $\overline{SDL}$ is the MSD from the LOW-LIMIT digit-switches. This MSD is strobed into the comparator (U2 on the 'A' board) by the first COMPARE pulse. As signals $\overline{CTR1}$ and $\overline{CTR2}$ continue, successive digits from the LOW-LIMIT switches are selected, the LSD being strobed into the comparator by the fourth COMPARE pulse.

Signal COMP-4 changes state after the fourth COMPARE pulse, so that the second time that $\overline{CTR1}$ and $\overline{CTR2}$ go through their sequence to enable the multiplexers during time periods D4, D3, D2, and D1, respectively, the digits from the HIGH-LIMIT switches are selected (MSD first; LSD last). All 4 multiplexers are strobed in the same manner, providing four data outputs to the A board via U1.

Note that signals $\overline{CTR1}$ and $\overline{CTR2}$ are always in the process of exciting the multiplexers, so that the multiplexers are always producing an output of some type; however, in the absence of any COMPARE pulses, any such outputs are ineffective and produce no results.

The MSD+1 line from the digit-switches (high and low) are not multiplexed. They are applied directly to the 5-bit comparator (U2) via NAND gates U16-12 and U16-6, where they are strobed through only during time state D4.

4.3.3 Comparator Board A (P/N 1685-4750)

Inputs. Figure 6-12 is the schematic of the A board. This board performs the comparison between the measured value and the high and low limits established by means of the respective comparator digit-switches.

The RESET pulse that occurs at the beginning of a measurement sequence resets the board circuitry. After the component under test is measured, signal $\overline{SDL}$ is produced on the meter's logic board. This signal strobes data stored in the decade counters into the associated latches for use by multiplexers on the logic board. Signals CTR1 and CTR2 on that board sequence the data out of 2 multiplexers similar to ones used on the comparator B board. This data is strobed out on 4 parallel lines. The data on the lines is the BCD equivalent of one numeral of the display. The 4 NAND gates of each of the 4 multiplexer sections on the logic board are strobed sequentially, once each during times D4, D3, D2, and D1 by the various interactions of signals CTR1 and CTR2 as described previously. This provides BCD equivalents each time for one display digit, for a total of 4 digits.

In addition to furnishing these data to the readout displays, the logic-board data are routed to the A board, via S04, over lines designated A0 thru A3. Another line, A4, is the most-significant-digit +1 line, or "spill" line, taken from a cross-coupled F-F on the logic board. These lines are applied to 5-bit comparator U2 on the A board.

The lines from the low and high-limit multiplexers on the B board are applied to pins B0 thru B3 of the 5-bit comparator, via connector S03. The MSD+1 digits from the high- and low-limit digit-switches are applied to comparator input B4, via NAND gates IC16-12 and -6 and IC 15-3. These lines are not multiplexed, but are selected via the NAND gates by the same signals that enable the B-board multiplexers for high- and low-limit comparisons, as described earlier.

Signal GATE enables one-shot IC12, which allows signal SCAN from the comparator logic board to produce pulses approximately 1 μs wide that are fed to U5-6 and U5-8. If there is no overrange condition (signal E low) and the limit comparator is not disabled either by its front-panel LIMIT-OFF enable-disable switch or by a logic 1 applied to the rear-panel connector LIMIT DISABLE pin, IC-5-8 enables the 5-bit comparator by applying a logic 0 pulse to pin 1 of U2. This is signal COMPARE shown in Figure 6-12. Eight COMPARE pulses are applied to the comparator, as described previously.

When the 5-bit comparator is enabled by the COMPARE pulses from gate IC5-8, corresponding digits of the measured-value-data and the digit-switches data are compared with each other in the IC.

Five-Bit Comparator. The 5-bit comparator is a Fairchild 9324 (or equivalent) high-speed expandable, 5-bit comparator that furnishes a comparison between two 5-bit words and gives three outputs: "less than", "greater than," and "equal to". A high level at pin 1 forces all three outputs low. A low level enables the comparison function.

Figure 4-14 shows the schematic diagram of the comparator. The measured-value inputs come in on the "A" pins; the digit-switch limits come in on the "B" pins. Signal $\overline{E}$ input (active low enable) is signal COMPARE, which

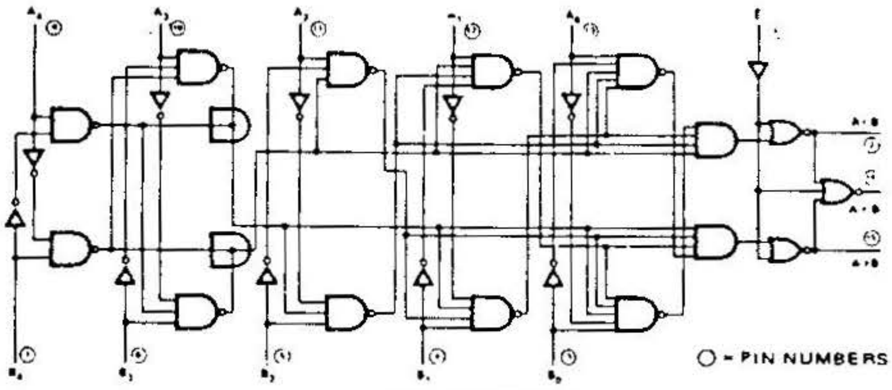


Figure 4-14. Comparator logic diagram.

goes low eight times during a comparison. The first comparison (during D4 time) is a 5-bit comparison consisting of the MSD+1 digit and the 4 bits that comprise the MSD. Then 4-bit comparisons are made for the 3 remaining digits. (This makes a total of 4 comparisons for the low-level limit.) A comparison is then made in the same manner for the high limit (regardless of whether the low-limit was acceptable or not) for a total of 4 high-limit comparisons, or a total of 8 comparisons for the low and high limits.

The low-limit operation compares A inputs (data) against the B (limits), normally to find if A is greater than B (A > B). Then the high-limit comparison is made to find if A is less than B (A < B).

The A>B (pin 15) and A<B (pin 2) outputs of the comparator are fed to 4 cross-coupled pairs via NAND gates U9-8, U10-8, U9-6, and U3-8. These gates feed, respectively, cross-coupled pairs U5-12 and U4-6, U10-11 and U10-3, U10-6 and U4-8, and U3-11 and U3-6. Outputs from these cross-coupled pairs are used to light appropriate lamps and produce status signals indicating the results of the comparison process. Pins 2 and 15 of U2 normally reside at logic zero (low). A positive-going pulse occurs at pin 15 if A>B; a positive-going pulse occurs at pin 2 if A<B. The width of the pulse is defined by the width of the COMPARE pulse at U2, pin 1.

The cross-coupled pairs driven by the A>B and A<B outputs from U2 are mandatory in the circuit because U2 performs only a digit-by-digit comparison of its two BCD input numbers. Thus, if A = 1.719 and B = 1.284, and the values are compared from MSD to LSD (in this order), the first (MSD) comparison will produce no pulse at either output of U2. The second digit comparison will obviously produce an A>B pulse, the third an A<B pulse, and the last (LSD) comparison an A>B pulse. Since an A > B output is produced prior to any A < B output, it clearly signifies that the overall number A is greater than the number B. The cross-coupled pairs driven by U2 store this type of information during the comparison process.

Low-Limit Comparison. The low-limit process can be followed through on the logic diagram, Figure 6-12. At the beginning of a measurement sequence, the RESET pulse sets U4-6, U10-3, U4-8, and U3-6 high. During the low-limit comparison, signal COMP-4 is low, inhibiting U9-8 and U10-8, leaving only U9-6 and U3-8 capable of responding to A>B and A<B output pulses from U2. Clearly, if an A>B pulse occurs before an A<B pulse, the low-going pulse produced at U3-8 sets cross-coupled pair U3-11 and U3-6, so that U3-6 goes low, thereby inhibiting any subsequent A<B pulse from getting through gate U9-6. (The cross-coupled pair driven by U9-6, when set, signifies that the overall number A is less than the number B, and that a low-limit failure has in fact occured.) Thus, since the cross-coupled pair driven by U-96 cannot be set when A>B occurs before A<B, the failure condition cannot be produced; the low-limit comparison operation is a success.

If, however, an A<B pulse occurs before an A>B pulse, U9-6 goes low, setting cross-coupled pair U10-6 and U4-8, to produce the low-limit failure condition. Note that any subsequent A>B pulse from U2 will set cross-coupled pair U3-11 and U3-6, thereby preventing U9-6 from passing any more A<B pulses; however, this action is meaningless since the failure condition has already been produced.

High-Limit Comparison. The high-limit comparison operation is performed in a manner similar to the low-limit comparison. The only significant difference is that after the 4 low-limit COMPARE pulses, signal COMP-4 goes high. (Therefore, $\overline{\text{COMP-4}}$ goes low.) Under these conditions, NAND gates U9-6 and U3-8 are gated off, and NAND gates U9-8 and U10-8 are enabled. The high-limit failure condition is produced by an A>B pulse occuring before an A<B pulse, and the status is stored in cross-coupled pair U5-12 and U4-6. Note that U5-12 has an additional input at pin 2. This input, from U5-6, is normally dc high, thereby enabling gate U5-12. If there is an over-range condition, however, signal E, applied to the A board at S04, pin 4, from the logic board, goes from a logic low to logic high. This action disables U5-8 via U1-10, so that no COMPARE pulses can be produced. However, a negative going pulse is produced at U5-6, which forces the high-limit failure condition to be set at U5-12 and U4-6.

Result of the Comparison Process. Note that if neither a low-limit failure condition or a high-limit failure condition is produced, U4-6 and U4-8 will reside high at the conclusion of the overall comparison process; U5-12 and U10-6 will be low. The results of the comparison process are fed from these 4 outputs to the various output functions of the board.

Consider the function of one-shot U8. A failure condition at U4-8 will produce a negative-going edge at U8-3; similarly, a failure condition at U4-6 will produce a negative-going edge at U8-4. In either case, one-shot U8 will be triggered, to produce an output pulse at U8-6 that enables U3 at pin 1 for approximately 0.25 s. During the 0.25 s, U3-3 delivers a 250-Hz signal (1 kHz ÷ 4) to transistor Q7, and subsequently to pin 6 of the rear-panel output connector (S05) through a 10-Ω, 1/2-W resistor. Pin 6 is intended to drive some type of audio alarm (e.g., a miniature 8-Ω or 10-Ω speaker) connected between pin 6 and ground of the instrument. Thus, in a manual sorting operation where an operator may be testing a large number of parts of the same value, the great percentage of which are good, the occasional failure will be vividly brought to attention so that the operator responds accordingly. The 10-Ω, 1/2-W resistor feeding pin 6 renders the pin short-circuit proof to ground (i.e., prevents the burn-out of Q7). Diode CR2 prevents any possible inductive transients at pin 6 from reaching and damaging transistor Q7.

The $\overline{\text{LOW}}$ and $\overline{\text{HIGH}}$ output functions at the rear connector (at S05 pins 14 and 17 respectively), as well as the LOW and HIGH front-panel indicator lamps (DS3 and DS4), are activated in the following manner. A low-limit failure produces a high at U10-6. This turns on Q1, which brings S05, pin 14, low and lights the red LOW-LIMIT failure lamp on the front of the Limit Option module. Similarly, a high-limit failure sets U5-12 high, thereby turning on Q2 to activate the HIGH output functions. Normally, on a failure, either a high-limit failure or a low limit failure is expected, but never both. However, both failure conditions can and will be produced if the low-limit value dialed in on the digit-switches is higher than the dialed-in high-limit value, and the measured value lies in between these two limit values.

The results of the comparison process at U4-8 and U4-6 are fed to two of the inputs to NAND gate U14-6. Therefore, if either of these lines is low, signifying a failure, the output of U14-6 will be a guaranteed high, thereby forcing U1-6 low and ensuring that Q4 is off. This inhibits the front-panel GO indicator lamp from being lit and prevents the $\overline{\text{GO}}$ output line at S05 pin 16 from going low. (A low signifies the "GO" condition – negative-true logic.) The Q4 output is also fed to the base of Q9; if Q4 is off, Q9 is also turned off. Q9 drives the PASS lamp on the P1 test fixture, via S06, pin 4, from the A board.

If, however, a failure condition is *not* produced, then U4-8 and U4-6 remain high at all times during and after the compare operation. Therefore, one-shot U8 never fires, and the inputs at U14-3 and U14-4 keep gate U14-6 in an enabled condition. Note that this does not produce a GO condition; it merely enables a GO condition. There are two other conditions that must be met before a GO condition can be produced (before Q4 can be turned on). First, the DQL line input to the board must be low. (A high, signifying a HID failure on the bridge board, would turn on Q5 via latch IC15-8, and, therefore, hold Q4 turned off.) Second, if the above conditions are met, Q4 is allowed to turn on via U14-5 only after U6-8 goes low (i.e., after signal DONE is produced – see the timing diagram in Figure 6-12). Thus, only after the full completion of the comparison operation can a "GO" indication, if any, be produced.

Note that signal DQL, in addition to operating Q5, via latch IC15-8, also turns on Q3 in the presence of a HID fault condition, thereby turning on the front-panel HIGH-D lamp (DS2) and bringing the rear-panel HID line low at S05, pin 15. Also note that the base of Q3 is gated by the DONE signal, via U1-12. Therefore, even though the high-D information is available from the bridge board long before the comparison operation takes place, this information is not made available externally until the comparator results are also available.

An asynchronous failure condition, FAIL, (i.e., not gated by signal DONE) is available at rear-panel connector S05, pin 2 (a low signifies a failure condition); this signal (produced at U14-8 by a low on any one of its 3 input lines) is also fed to Q8 which, when turned on, lights the FAIL lamp on the P1 test fixture.

Output signal $\overline{\text{BUSY}}$ is normally high and goes low soon after signal DONE is produced (when both inputs to U7-11 go high–see timing diagram). Therefore, signal $\overline{\text{BUSY}}$, when low (negative true), can be used to signal externally connected equipment that the results of the comparison process are now complete and are available as dc levels at the rear panel output connector, and that these signals will not change while BUSY is low. Signal $\overline{\text{BUSY}}$ is reset (goes high) when a new measurement sequence is initiated.

The line designated CLAMP, at S05, pin 5, is *not* an output signal. Pin 5 is to be tied to the V+ terminal of an external voltage source, where this source is the one used to power the relays that may be connected to S05-14, S05-17, etc. (The negative side of the source is connected to instrument ground.) Refer to Section 2 for details.

External Signals. Two connectors are available for the transfer of data and control signals between the comparator and external equipment devices. The PASS and FAIL signals are furnished to rear-panel TEST FIXTURE connector for use with the Test Fixture PASS-FAIL indicator lamps (or other applications, as desired; refer to Section 2). The signals are not routed directly to S010 from the circuit board. They are routed via connector J06, on the side of the chassis.

Other signals are available via connector S05 at the rear of the comparator. The connector is a 24-pin Amphenol-type connector available to the user.

Most of the signals available via the connector were described in the previous paragraphs. Section 2 contains a list of the signals and describes their functions. Details are also given on mating connectors.

Lines INTERFACE 1 and INTERFACE 2 at the rear-panel comparator connector comprise two independent copper paths between this comparator connector and the rear-panel connector of the main instrument. This provides a means whereby external equipment connected to each can directly interface with one another. A positive-going transition of signal REMOTE START can be used as an alternate means to start a measurement operation via an external device connected to comparator. The LIMIT DISABLE signal at S05, pin 1, is an input signal to the A board which, when pulled high, turns on Q6, thereby performing the same function as switch S11 in its OFF position – that is, inhibiting the generation of COMPARE pulses at U5-8.

4.4 POWER SUPPLY.

The instrument's power supply furnishes regulated +15 and −15 V for the analog circuits and regulated +5 V for the logic circuits. The power supply is comprised of a transformer rectifier bridge assembly (5 V), mounted in the left rear of the chassis; 4 separate rectifiers on a transformer terminal board; a power supply board, P/N 1686-4730, containing two regulators; (+15 V and −15 V); and a 5-V regulator. The power supply board is mounted in front of the transformer and rectifier (bridge) assembly, under a metal cover secured by 3 screws. The 5-V voltage regulator package (U501), which is a part of the +5-V supply, is mounted on a heat sink at the rear of the chassis. The bridge rectifier (CR501-CR504) for the 5-V supply is mounted at the rear of the power supply board.

The rectifiers for the ±15-V section of power supply are mounted on a terminal board assembly on top of the transformer. The assembly contains rectifiers CR6-CR10 and some resistors. Filter capacitors (C501, C503, and C504) for the supplies are below the power supply board.

A capacitor (C505) connected to the input of the 5-V regulator and one (C506) connected to the output are soldered to the regulator-package pins.

The tapped power transformer (T1) and associated selector switch permit selection of a wide range of operating voltages. The switch positions and selections, in order, are OFF, 90-110 V, 104-127 V, 180-220 V, 194-236 V, and 207-253 V. Figure 4-15 shows the transformer configuration for each voltage range.

A connection from a full-wave rectified output of the transformer is made to the oscillator on the bridge board. This is done via WT's 7 and 18 and allows synchronization of the oscillator with the line voltage, when the desired oscillator 120- or 100-Hz oscillator frequency is twice that of the line frequency.

Regulation for the +5-V supply is furnished by a National Semiconductor type LM 323K 3-A, 5-V positive regulator, mounted on the heat sink at the rear of the chassis. The regulator is a 3-terminal regulator and is virtually blowout proof; it provides current limiting, power limiting and thermal shutdown. A 1-μF capacitor is used on the input, since the regulator is mounted more than 4 inches from the filter capacitor. A capacitor at the output reduces load transient spikes that may be created by fast switching logic; it also can swamp out stray load capacitance. Maximum output voltage is 5.25 V, minimum 4.75 V.

The main element in the ±15 V supply is a Silcon General type SG3501 dual-polarity tracking regulator that furnishes balanced ±15-V outputs. The regulator is factory-set and provides thermal shutdown, current limiting, and power limiting.

The package regulates the negative voltage, and the positive output tracks the negative. Negative regulation is accomplished by providing a constant-voltage reference for the negative error amplifier in the package; the reference input to the positive error amplifier is grounded. This latter amplifier forces its other input, which is the center-tap between equal resistors, to also be at zero volts, thus requiring the positive output to be equal in magnitude but opposite in polarity to the negative output. The tracking will hold all the way from approximately 1 V above the reference voltage to a maximum value of about 2 V less than the input supply voltage.

Power transistors Q1 and Q2 are connected to the package, along with other components in the configuration shown in the schematic, to allow additional current handling capability. The 100-ohm base-to-emitter resistors, R1 and R2, provide a path for the regulator standby current; base-to-ground capacitors C5 and C6 minimize the risk of oscillation. The WT's designated at the outputs of the supplies are located on the power supply board.

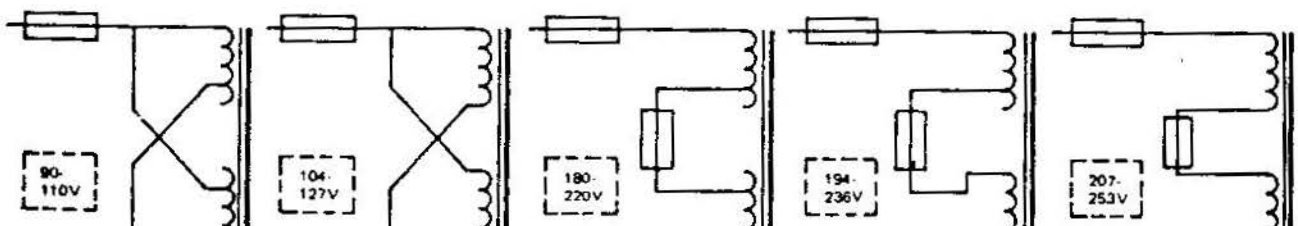


Figure 4-15. Elementary transformer primary schematic.

Service and Maintenance—Section 5

WARNING

Dangerous voltages are present inside the case of this instrument. For safety, do not remove instrument from its case. Refer all servicing to qualified personnel.

5.1 GR FIELD SERVICE.

Our warranty (at the front of this manual) attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible. If the difficulty cannot be eliminated by use of the following service instructions, please write or phone the nearest GR service facility (see back page), giving full information of the trouble and of steps taken to remedy it. Describe the instrument by type, serial, and ID numbers. (Refer to front and rear panels.)

5.2 INSTRUMENT RETURN.

Before returning an instrument to GenRad for service, please ask our nearest office for a "Returned Material" number. Use of this number in correspondence and on a tag tied to the instrument will ensure proper handling and identification. After the initial warranty period, please avoid unnecessary delay by indicating how payment will be made, i.e., send a purchase-order number.

For return shipment, please use packaging that is adequate to protect the instrument from damage, i.e., equivalent to the original packaging. Advice may be obtained from any GR office.

5.3 REPAIR OF PLUG-IN BOARDS.

This instruction manual contains sufficient information to allow the repair of faulty circuit boards by an experienced, skillful electronic technician. If for any reason the boards cannot be repaired, the instrument or boards can be returned to GR for repair.

For prompt replacement of etched-circuit logic, display and comparator board(s), a replacement can be ordered, and the faulty board returned after receipt of the replacement. Contact your nearest GenRad Repair Facility (see last page), supplying them the type, serial number and identification number of the instrument; the board part number (refer to the parts list for the number; the number etched in the foil is generally NOT the part number) and letter designation (if any); and a purchase order number. The P.O. number allows for billing if the unit is out of warranty and/or for identification of the shipment. The repair facility will arrange for the prompt delivery of a replacement.

To prevent damage to the board, return the defective board in the packing supplied with the replacement (or equivalent protection). Please identify the return with the Return Material number on the tag supplied with the replacement and ship to the address indicated on the tag.

5.4 MINIMUM-PERFORMANCE STANDARDS.

5.4.1 General.

The following paragraphs contain information to determine that the 1686 is performing within specifications. The procedures enable instrument-standards laboratories and suitably equipped service facilities to perform checks at periodic intervals and after repair, to determine that the instrument is operating properly. These procedures are bench checks that can be done with the use of front-panel controls and externally available test points. (Instrument disassembly is neither required or recommended).

NOTE

Allow 10 minutes warm-up time before performing check and calibration procedures.

Table 5-1 lists the test equipment required or recommended to perform the system minimum-performance

Table 5-1
TEST EQUIPMENT

Instrument	Requirement	Recommended*
Standard capacitors	100 pF ±.001% 1000 pF ±.001% .01 μF ±.05% 0.1 μF ±.05% 1 μF ±.05%	GR 1404-9702 (1404-B)** GR 1404-9701 (1404-A)** GR 1409-9712 (1409-L)** GR 1409-9720 (1409-T)** GR 1409-9725 (1409-Y)**
Capacitance standard	Four-terminal connections. C values in decade steps from 1 μF to 1 F. Direct-reading accuracy ±0.25% for frequencies of 100, 120, and 1000 Hz. Ratio accuracy ±0.1%.	GR 1417-9700**
Decade resistor	Up to 11 MΩ in 1-Ω steps. Accuracy ±.01%, except 1 Ω, which is 0.1%. Known zero resistance and calibration data on the 1-k, 10-k, 100-k, 1-M, and 10-MΩ positions.	GR 1433-9733 (1433-H)**
Adaptors (2 required)	GR874® to binding posts	GR 0874-9870 (874-Q2)**
Resistors, 1 each	100 Ω ±10% 240 Ω ±10% 910 Ω ±10% 1 kΩ ±10% 3.3 kΩ ±10%	Decade resistance box may be used.
Capacitors, 1 each	30 pF ±5% 70 pF ±5%	———
Decade capacitor	Up to 1 μF in 1-pF steps. Accuracy; 0.05%	GR 1413-9700
Variable autotransformer	For power line, with meters, 0 to 140 V	GR Variac® W5MT3W
Variable autotransformer	Similar, 0 to 280 V	GR Variac W20HMT3A***
Volt/ohm/meter	General purpose	Weston 661
Digital voltmeter	0.1% accuracy or better, general purpose	Data Precision 2440
Oscilloscope	50 mV/cm sensitivity, 10 MHz bandwidth,	Tektronix 547
Oscilloscope plug-in	See above	Tektronix 1A1
Frequency counter	Frequency range 100-Hz to 10-kHz; sensitivity 10 mV rms; impedance 100 kΩ; 5-digit readout	GR 1192

*Or equivalent.
**Required for para 5.4, except the 1417-9700 is optional.
***Omit if instrument is always used on line voltages less than 127 V.

checks, calibration procedures, and trouble analysis. Only the equipment indicated by double asterisk is required for the minimum performance checks. Trouble analysis should require only a DVM, oscilloscope, and possibly a frequency counter. However, all of the equipment listed in this table is required for a complete unit check and calibration.

Make the following checks using the standards listed in the table of test equipment, where applicable. Use the 1686-9602 Elementary Measurement Cable, supplied, to connect directly to each standard. Refer to para 3.1 for details on connections. Allow 10 minutes warm-up before making checks.

5.4.2 Capacitance Check.

Make the checks listed in Table 5-2. Be sure to take into account the accuracy of the standards used to perform the checks. The tabulated low and high limits are the acceptable range of measurement readouts for C standards that have exactly nominal values. If, for example, your 100-μF standard has nominal value ±0.25%, the acceptable low and high limits of C readout are 100 ± 0.6, i.e., 099.4 and 100.6 μF.

Generally, it is preferable to use a standard whose value is known to considerably better accuracy than the specification of the instrument being checked (the last column in this table). It is not necessary that the standard C be exactly nominal. For example, a 0.01-μF standard capacitor can be calibrated, i.e., measured on a precision bridge, such as the GR 1615 or 1616. If you calibrate one to be 10.0031 nF ±50 ppm, then you can use it to check the 1686 fully to its specified accuracy at 1 kHz on Range 3. However, the acceptable low and high limits are increased by .003 nF in this example, from 9.988 and 10.012 nF to 9.991 and 10.015 nF, respectively. Because the recommended standard for large values of C contains a ratio transformer, some special comments are appropriate; see below.

NOTE

On ranges 1, 2, and (usually) 3, it is necessary to subtract a "zero" correction from the CAPACITANCE display, to compensate for cable capacitance. Refer to para 3.1.3.

5.4.3 Optimal use of the 1417 Four-Terminal Capacitance Standard.

Although the direct-reading accuracy of this C standard is poor compared to the instrument being checked, on ranges 5, 6, and 7, the ratios are much better (about ±.03%) at any given signal voltage. Refer to the 1417 instruction manual for a procedure for obtaining precise values of high capacitance. In brief the essential steps are as follows:

a. Set the standard to 1 μF and measure it accurately at each frequency of interest and several signal levels. (The capacitor has special terminals for a voltmeter.)

Table 5-2
CAPACITANCE CHECK

Frequency (Hz)	C Standard	Range	Low Limit	High Limit	Accuracy (±%)
1 k	100 pF	1	99.65 pF	100.35 pF	0.35
120	1 nF	1	0.993 nF	1.007 nF	0.70
1 k	1 nF	2	998.8 pF	1001.2 pF	0.12
120	10 nF	2	09.965 nF	10.035 nF	0.35
1 k	10 nF	3	9.988 nF	10.012 nF	0.12
120	100 nF	3	099.65 nF	100.35 nF	0.35
1 k	100 nF	4	99.88 nF	100.12 nF	0.12
120	1 μF	4	0.9965 μF	1.0035 μF	0.35
1 k	1 μF	5	998.8 nF	1001.2 nF	0.12
120	10 μF	5	09.965 μF	10.035 μF	0.35
1 k	10 μF	6	9.988 μF	10.012 μF	0.12
120	100 μF	6	099.65 μF	100.35 μF	0.35
1 k	100 μF	7	99.65 μF	100.35 μF	0.35
120	1 mF	7	0.992 mF	1.008 mF	0.75
1 k	1 mF	8	0988.0 μF	1012.0 μF	1.20
120	10 mF	8	09.89 mF	10.11 mF	1.05
120	100 mF*	9	095.7 mF	104.3 mF	4.25

*This last check can be omitted, if the C standard is not available.

b. Make a set of calibration curves of capacitance vs voltage. (The curve for 1 kHz is usually flat enough so that a single number is sufficient.)

c. For checking the 1686, set the C standard to the nominal value shown in Table 5-2, measure the signal voltage on the standard during 1686 measurement, and determine a C correction from the calibration curve, as a percentage of 1 μF.

d. The effective value of the C standard is the same percentage above or below its nominal setting. Use this effective value to determine low and high limits as described above.

5.4.4 Dissipation-Factor Check.

Make the checks listed in Table 5-3, by connecting (as a 2-terminal device to be measured) the decade resistor in series with the 0.1-μF standard capacitor. In this check of D accuracy, the recommended standards are accurate enough so that it is not necessary to account for their accuracy.

However, the measurement frequency generated in the 1686 should be measured at each setting of the FREQUENCY switch and if the error is 1% or more, the corresponding D values from Table 5-3 corrected accordingly. For example, if the "1-kHz" frequency is 1010 Hz, D will be 1% higher than is shown in the first 4 rows; the limits 4.5 and 15.5 should be corrected to 4.6 and 15.6, respectively.

Of course, if your instrument measures at 120 Hz, ignore the 100-Hz portion of the table, and vice versa.

5.5 PARTS LOCATIONS AND TEST POINTS.

Most of the parts and internal adjustments are on the etched-circuit boards. Figures shown below identify the parts. Test points are on the circuit boards; the test points are shown on the schematic diagrams and they are identified on the circuit boards by the designation TP.

Other points for monitoring signals are at wire-ties, identified on the schematics and circuit boards by the designation WT. The legend on the schematic denotes if the wire-tie called out on the schematic is located on the associated circuit board or on another board or chassis component. Wire-ties on chassis components are not identified in all cases. Use the schematic diagram to locate these ties.

Filter capacitors for the transformer assembly are located beneath the power supply board, on the left-hand side of the instrument.

Reference designations for test points, wire ties, and electrical parts generally include a prefix, before a hyphen, to indicate subassembly as follows: G, chassis; L, logic board; M, display board; P, bridge board; V, power supply; W, potentiometer asm; A, B, comparator boards. Notice also that most of the chassis-mounted parts are numbered in the range 500. . .599.

5.6 REMOVAL-REPLACEMENT PROCEDURES.

5.6.1 Chassis. Figures 5-1, 5-2, 5-3

Turn off the power before removing or installing any parts. For chassis-removal procedures, refer to para 2.3.

WARNING

When the instrument is energized, there are high voltages present at the power switch, transformer, and transformer and bridge assembly at the rear of the power supply board, under the power supply's protective cover. High voltages are also present at the terminals of filter capacitors C501, C503 and C504, located beneath the power supply board.

Table 5-3
DISSIPATION-FACTOR CHECK

Range	Frequency	Series R*	Dissipation Factor Nominal	Low Limit	High Limit
4	1000 Hz	15.92 kΩ	10.	4.5	15.5
4	1000	1592 Ω	1.	0.9	1.1
4	1000	159 Ω	0.1	0.093	0.107
4	1000	16 Ω	0.01	0.008	0.012
3	120 Hz	132.7 kΩ	10.	4.5	15.5
3	120	13.27 kΩ	1.	0.9	1.1
3	120	1327 Ω	0.1	0.093	0.107
3	120	133 Ω	0.01	0.008	0.012
3	100 Hz	159.2 kΩ	10.	4.5	15.5
3	100	15.92 kΩ	1.	0.9	1.1
3	100	1592 Ω	0.1	0.093	0.107
3	100	159 Ω	0.01	0.008	0.012

*Connect 0.1-μF standard capacitor in series with accurate decade resistor set to tabulated value of R.

CAUTION

Make sure no foreign matter, especially metal, falls on the bridge or logic boards when the chassis is out of the cabinet. This may short circuit board signal lines. Also, take care to prevent any short-circuit to the chassis by any test point that protrudes from the logic board close to its hinges. Carefully bend any test point that is liable to touch, before turning power on.

NOTE

Keep POWER OFF during disassembly or reassembly.

5.6.2 Logic Board.

For access below the logic board, remove the 4 screws from periphery of the board (2 on the right side and one each at the front and rear). The left side of the board is mounted on hinges. Push the board back toward the rear as far as it will go (1 cm, 0.4 in.) and then swing the right side up with care that the attached display components are free and clear. Be sure the board is kept back while being lowered again, to prevent bending the MEASURING display light.

To remove this board, remove the 2 screws from the rear underside of the board, unplug the board from the connector J502, and disconnect the cable from L-S04.

5.6.3 Indicator Lamps.

If a front-panel lamp fails, carefully remove and replace it as follows:

a. With long-nose pliers (or a paper clip) lift the terminal end of the clip that retains the lamp in its socket; refer to Figure 5-1B. Remove the clip from the socket.

b. Tip the chassis (front panel up) so the lamp drops out.

c. For replacement, use Chicago Miniature Lamp number CM-377, General Electric type 377, or equivalent. (For confirmation, see parts list in Section 6).

d. To replace the clip on the socket, first put the hook end into the notch on the side of the socket; and then press the clip across the end of the lamp until the terminal end of the clip snaps into position.

To gain access to the limit-comparator indicator lamps, carefully turn the instrument on its side. Replace the lamps as described above.

If necessary, replace either lamp in the 1686-9600 Test Fixture as follows:

a. Remove 4 screws and feet. Slide the cover off.

b. Remove 4 screws from corners of etched board and 3 from rear panel. Lift etched board assembly out carefully.

c. Unsolder and replace one indicator (LED) at a time, so that the spacer between them remains in position. The red indicator is Hewlett-Packard 5082-4650; the green, 5082-4950. (Confirm by reference to test-fixture instruction sheet.) Reassemble the test fixture.

5.6.4 Capacitance Display Digits.

The LED display can be checked by means of the lamp-test input at the rear-panel data output connector S01; see para 2.4. Grounding this input circuit ($\overline{LT}$, pin 6) will light all of the segments, causing the display to read 8888. The most-significant digit (the "tens-of-thousands" digit 1) will not be lit, however.

If a digit requires replacement, the display board M can be removed from the logic board L-S03 by removing the two screws from the front of the board. The display board can be replaced or the defective digit can be removed from the

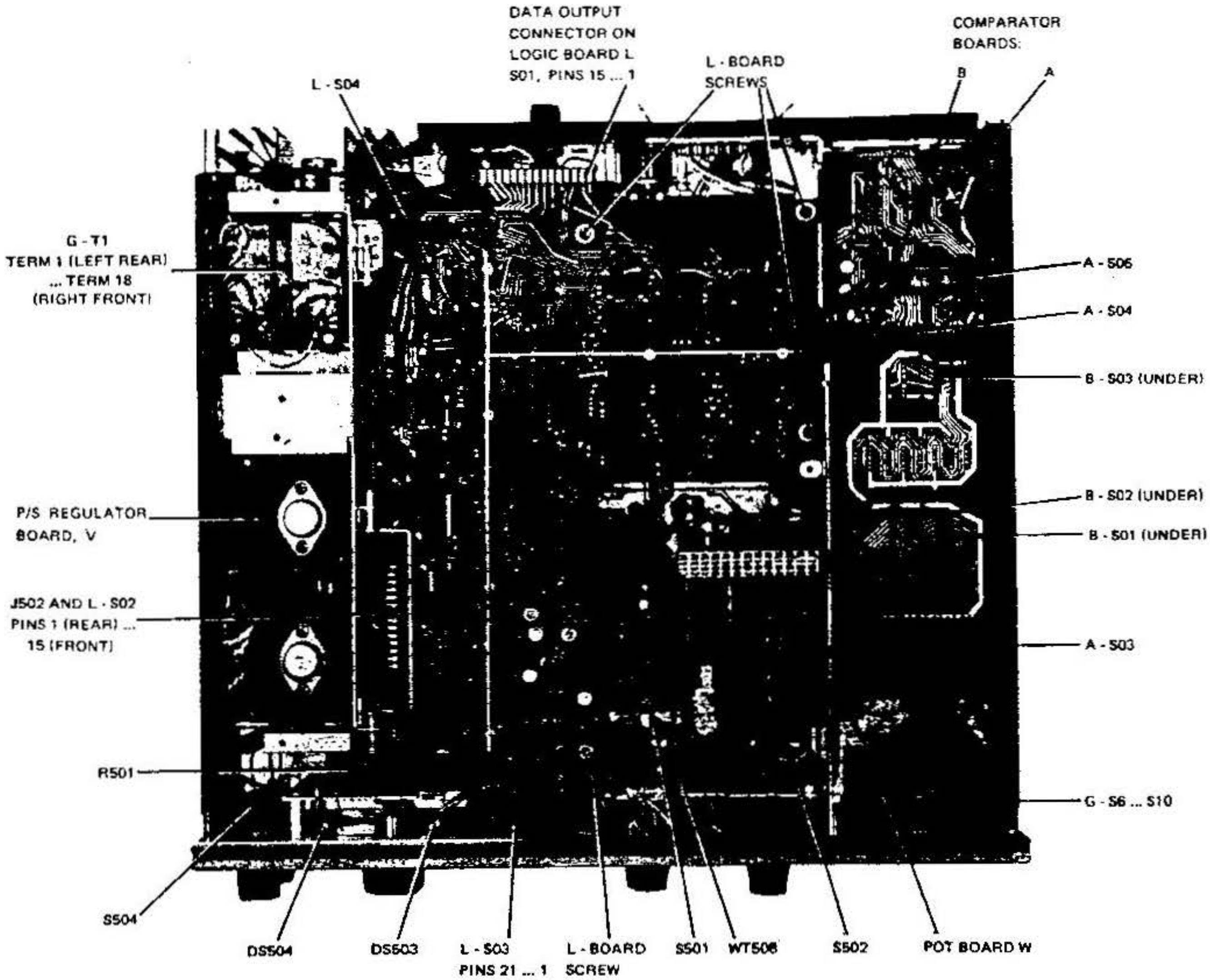


Figure 5-1A. Interior top view, showing Logic Board (L). The G- prefix is understood in front of 500-series designators.

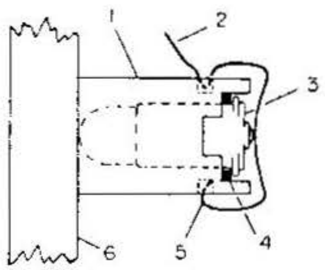


Figure 5-1B. Lamp socket details. 1 = Socket. 2 = Terminal end of clip. 3 = Lamp. 4 = Shell contact. 5 = Hooked end of clip. 6 = Panel of instrument.

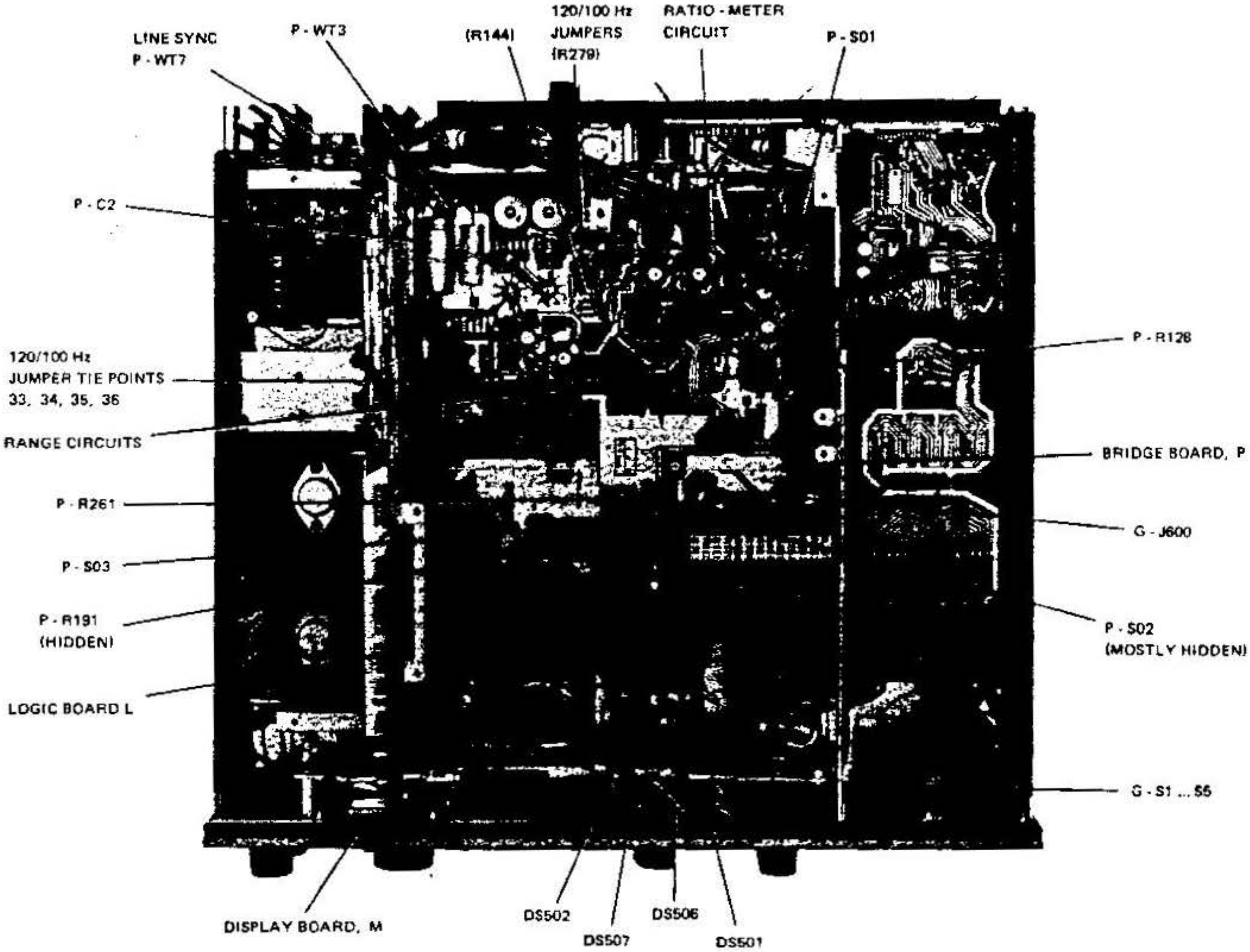


Figure 5-2. Top view with Bridge Board (P) exposed by tilting Logic Board (L) upwards.

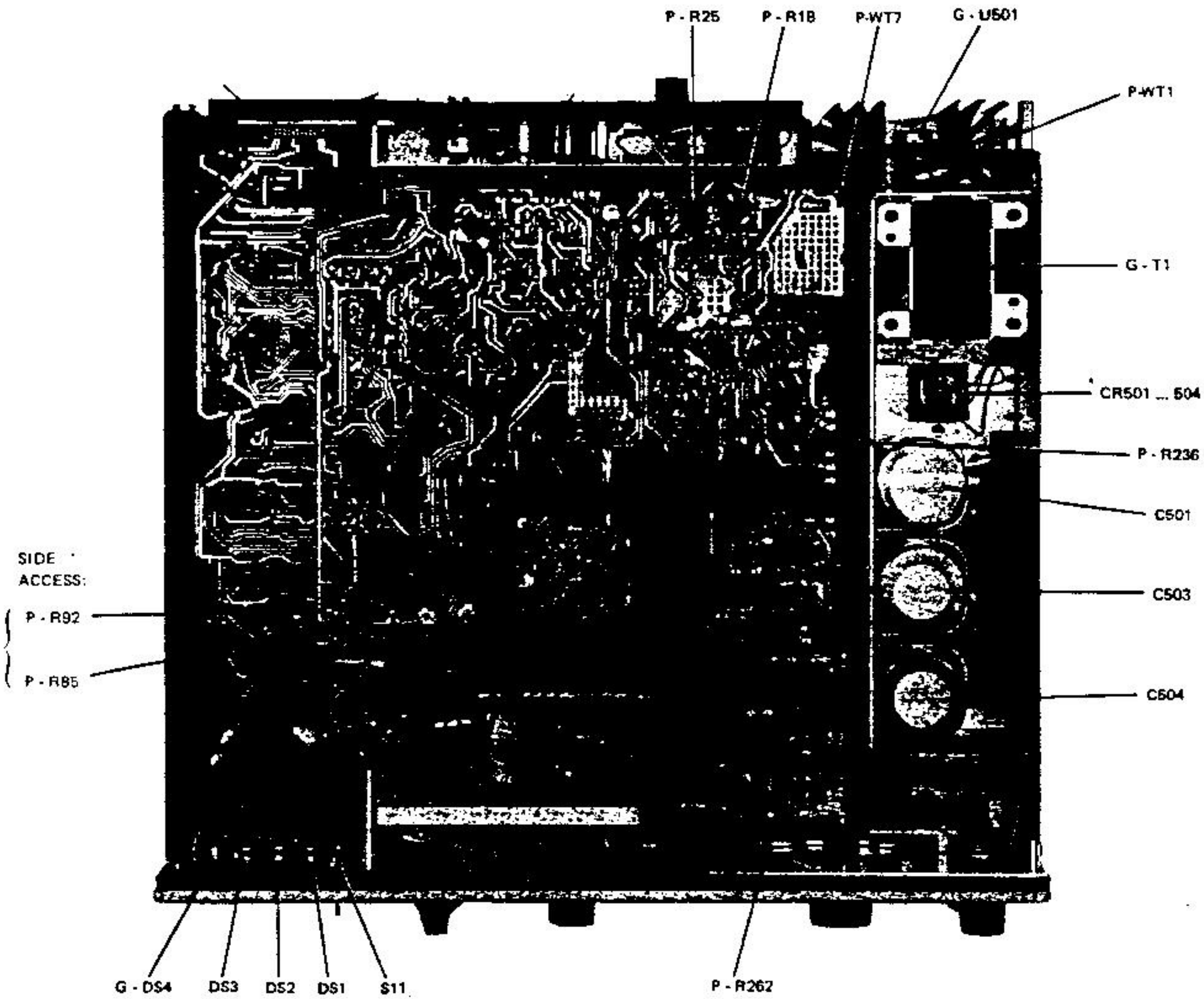


Figure 5-3. Interior bottom view.

board and replaced with a new one. To replace the board, follow the instructions given in para 5.3.

For replacement, the digital indicator (10 pins) must be unsoldered from the board and the replacement must be soldered in its place. Take care not to damage the board or the indicator; make sure that none of the tracks on the board are damaged or short-circuited. Replace with a Fairchild type FND 357 digital indicator.

If the light-emitting diode M-CR1 mounted below the display requires replacement, carefully unsolder the faulty diode and replace it with a Fairchild type FLV102 red light-emitting diode, or equivalent.

5.6.5 Limit Comparator.

To remove any parts of the limit comparator, observe how the parts are secured by retaining screws. Remove the 4 screws at corners of the B board and lift it aside. Disconnect the cables from the circuit boards. Figure 5-1 identifies the dual in-line connectors. To remove the A board, remove 4 corner screws and 4 screws around the rear-panel connector S05. Do not force the boards to remove them.

The front panel (switch assembly) of the comparator (with limit switch, 4 lights, and permanently fastened cables) is held by only 4 screws. Two of these are the smaller pair seen at the right side, just behind the front panel. (Loosen the larger pair for clearance.) The other two are symmetrically located on the left of this assembly, passing through the bracket that supports the FREQUENCY and BIAS switches. Remove the retaining screws and remove the assembly and associated cables.

5.6.6 Power Supply.

To gain access to the power supply and its components, remove the 3 screws from the protective cover on the left-hand side of the instrument; remove the cover. Power supply parts can be removed by unfastening the screws that secure the parts.

5.6.7 Knobs and Switches.

CAUTION

Do not use a screwdriver or other instrument to pry off the knob if it is tight. Do not lose the spring clip in the knob when it is removed.

To remove the knob from a front-panel control, either to replace one that has been damaged or to replace the associated control, proceed as follows:

a. Grasp the knob firmly with dry fingers close to the panel and pull the knob straight away from panel.

b. Observe the position of setscrew in bushing when the control is fully ccw.

c. Release the setscrew with an Allen wrench; pull the bushing off the shaft.

NOTE

To separate the bushing from the knob, if for any reason they should be combined off of the shaft, drive a machine tap a turn or two into the bushing to provide sufficient grip for easy separation. If the retention spring in the knob falls out, reinstall it in the interior notch with the small slit in the inner diameter of the wall.

d. If the switch is to be removed, remove the dress nut exposed after step c. (Also refer to instructions below, to gain access to the switches inside the instrument.)

Install the switches by reversing the removal procedure and performing the following steps to replace a knob:

a. Slip bushing on shaft and rotate to correct position as observed in disassembly of knob.

b. Keep bushing away from panel by at least the thickness of a filing card. Pull it out farther if necessary to prevent tip of shaft from protruding.

c. Tighten the setscrew in the bushing.

d. Place knob on bushing with retention spring opposite setscrew.

e. Push knob on until it bottoms and pull it lightly, to check that the retention spring is seated in groove in bushing.

5.6.8 Other Parts.

To gain access to various front-panel switches or parts of the switches, it may be necessary to loosen the bridge board at the bottom of the instrument. This will allow the board to be moved over to obtain space to work on the switches.

To do this, unplug the two ribbon cable assemblies from sockets S02 and S03 on the bridge board. These are the ribbon cables connected to the switches. (Refer to Figure 5-2 for the locations.) Then carefully turn the instrument on its side and remove the 8 screws from the bottom of the bridge board. Only remove those screws that hold the board on the chassis brackets, i.e., the set of 8 similar screws at front, left, and right edges. This will allow the board to be moved a few inches away from the instrument, exposing the front-panel switches. *Do not pull* the board out too far, since the board is still connected to other cables that cannot be unplugged.

5.7 REFERENCE DESIGNATIONS.

Refer to Section 6, if necessary, for a description of the reference designators used on drawings and the instrument.

5.8 PERIODIC MAINTENANCE.

Keep the instrument cover, panels, controls and connectors clean and make sure connections to the instrument are clean. The limit-comparator digit-switches require special cleaning precautions. To prevent damage to the plastic parts used on the digit-switch assembly, it is recommended that a solution of 40% isopropyl alcohol and 60% distilled water be used to clean the face of the switch. Freon TF can also be used. Wipe the switch face lightly using a Q-Tip, Kimwipe or soft cloth moistened in the cleaner approved for this application. If the alcohol and water mixture is used for cleaning, wipe the switch face dry immediately with a dry wiper. Do not blow the switch face dry or allow the cleaner to run inside the switch.

To remove solder flux near Lexan plastic, isopropyl alcohol (99%) is recommended. Apply the solvent to the terminal area with a brush or Q-Tip. Allow the solvent to act for 30 to 60 seconds, using brushing action as required. Wipe the solvent and flux off with a clean Q-Tip or Kimwipe. Repeat if necessary. Do not use excess solvent, and hold the assembly with the printed circuit boards oriented so the solvent will flow away from the switch.

5.9 CHECKS AND ADJUSTMENTS.

NOTE

Perform the "Minimum-Performance Checks" first to determine whether complete recalibration is required. Check and recalibrate only those areas that appear to be out of tolerance from the measurements made in the "Minimum-Performance" checks of para 5.4. Except for the non-powered checks (para 5.9.1, 5.9.2), provide at least 10 minutes warmup time before making any check or adjustment.

5.9.1 Initial Checks.

Refer to para 5.6 for details as how to remove the assembly from the instrument case and how to gain access to the instrument's circuit boards.

To check whether the instrument (referred to below as "the 1686") is ready for application of ac power, proceed as follows:

a. Disconnect power cord from rear-panel power connector. Turn the POWER switch ON.

b. Measure by ohmmeter the resistance across the power-connector input terminals. Note that the resistance increases as you rotate the LINE VOLTAGE switch (Table 5-4A). Rotate the switch through two sequences (one complete revolution) since there is no stop. There are two rotor positions (180° apart) for each marked position.

c. Remove the fuse F1 (1A). Check by ohmmeter that there is a direct connection between the end terminal of the fuse holder (F1) and the corresponding terminal (L) of the power connector. (The terminal nearest the fuses.)

Table 5-4A
OHMMETER MEASUREMENTS AT POWER CONNECTOR

(S505) Line Selector Sw. Position	Nominal Resistance
OFF	∞
90-110	4.8 Ω
104-127	5.5 Ω
180-220	19.2 Ω
194-236	20.4 Ω
207-253	21.8 Ω

After this check, verify that the fuse is good and reinstall it in its holder.

d. Set: LINE VOLTAGE switch . . . . 180-220. Remove fuse F2 (½A). With the ohmmeter check between the end terminal of the fuse holder (F2) and the same (L) terminal of the power plug. The resistance should be between 8.8 and 11.3 ohms.

e. Verify that the fuse (F2) is good and reinstall it. Make certain the insulating boots cover the side terminals of both fuses.

f. Set: LINE VOLTAGE switch . . . . OFF. With the high ohmmeter range, measure between the center (ground) and each other terminal of the power plug. Verify that these are open circuits.

g. Set: LINE VOLTAGE switch . . . . 104-127. Measure:

1. Left terminal of power plug to chassis — open circuit
2. Right terminal of power plug to chassis — open circuit.

5.9.2 Power Supply Checks.

a. Connect the 1686 power connector via the power cord to the output of the 120-V metered autotransformer, which is set to zero; connect this to a nominally 120-V source of ac power. Its meters should monitor line voltage and power supplied to the 1686.

b. Slowly increase the line voltage to 115 V. The line power must be between 32 and 38 W.

c. With the digital voltmeter (DVM), measure the 1686-4730 power supply (V) board (Table 5-4B, columns 1,2,3).

Table 5-4B
POWER SUPPLY OUTPUT CHECKS

Reference	Test Point	Voltmeter reading	Scope display
WT6	WT7	+4.75 to +5.25 V (dc)	<200 mV pk-pk
WT9	WT8	+14.5 to +15.5 V	<30 mV
WT9	WT10	−14.5 to −15.5 V	<30 mV

d. With the oscilloscope, check the power-supply noise at the same test points (columns 1,2,4 of the same table). Observe that there are no oscillations on the +15 and −15-V test points.

e. With the DVM connected as in step c, momentarily short each power supply to ground (one at a time), making sure that they turn back on.

f. Slowly range the line voltage from 90 to 127 V (changing the LINE VOLTAGE switch S505 as required, at about 107 V). Note that each of the 3 power-supply voltages (+5, +15, and −15) is constant within ±25 mV, over that range.

g. Do this step only if the 1686 is likely to be used with line voltage in the range 194 to 253 V. Connect the higher voltage autotransformer (initially set to zero) as in step a, to a nominally 240-V power source. With appropriate change in settings of the LINE VOLTAGE switch, range the line voltage from 180 to 253 V. The 3 power-supply outputs should be constant as in step f.

h. Set the line voltage to 115 V and the LINE VOLTAGE switch to 104-127. (Alternatively, use the available line voltage, measure it, and set the switch accordingly.) This will serve for the rest of para 5.9.

NOTE

1. Tolerances given in most of para 5.9 are "tighter" than absolutely necessary to meet specified performance of the instrument. The given tolerances indicate what is preferred. Whenever reasonable, it is good practice to make any adjustment to the center of the tolerable range.
2. It is important to have calibrated standard capacitors and (if appropriate) to use the known values to modify the limits stated in these instructions. Example: if a "1000-pF" standard, known to be 1000.1 pF, is used in procedures that specify readings of 999.5 to 1000.5 pF, modify this requirement to the range 999.6 to 1000.6 pF instead.

5.9.3 Oscillator Checks and Calibration. Figures 5-3, 5-4.

Make the following oscillator checks and adjustments, if necessary:

a. Connect the measurement cable (1686-0291) and elementary measurement cable (1686-9602) together and to the TEST FIXTURE connector. (See para 3.1.) Connect the + current (+I) and + potential (+P) leads (red) together at the end of the cable, and then connect the − current and − potential leads (black/white) together.

b. Connect an oscilloscope and a frequency counter both high leads to the plus (+) junction and both low (ground) leads to ground (black/green). Set the RANGE switch to 1. Ensure that the rear-panel TEST VOLTAGE control is set for a maximum test voltage (fully cw).

c. Set the FREQUENCY switch (S502) to 1 kHz, and MEASUREMENT MODE switch to REPETITIVE.

d. Verify on the counter that the frequency is 1 kHz ±1 Hz; and on the scope observe a clean sine wave. If necessary, adjust P-R25 to obtain the correct frequency.

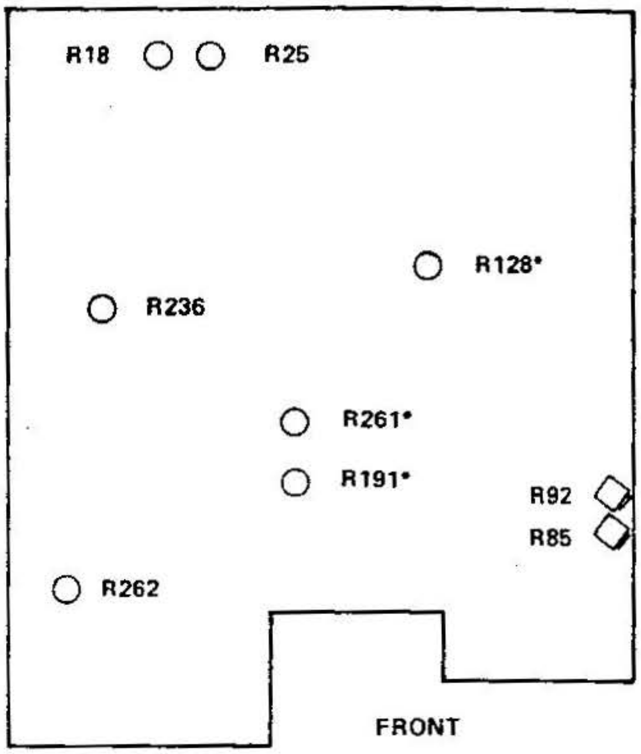


Figure 5-4. Locations of adjustments on Bridge Board (P), top view. *Tilt the Logic Board for access to adjustments with asterisks. The other adjustments are accessible from below or right side.

e. Turn the FREQUENCY switch to 120 Hz (100 Hz). The frequency should be 120 Hz ± 0.2 Hz (or 100 ± 0.2), being synchronized to the power line. The scope should show a clean sine wave.

f. Temporarily short-circuit P-WT7 to ground (P-WT1). These are on the bridge board, left rear corner, accessible from above or below. The frequency and waveform should hardly change; frequency tolerance, ±2 Hz.

g. Remove the short circuit, thus reestablishing synchronization.

h. Connect the DVM (high) to any terminal of the TEST VOLTAGE control (rear panel); connect the low to chassis ground. Be sure this control is set fully cw.

i. Set the FREQUENCY switch to 1 kHz and measure signal level. Adjust P-R18 if necessary, for a reading of 5.0 V ± .05 V rms.

j. Set the FREQUENCY switch to 120 Hz (100 Hz). The DVM should indicate 5 V ± 0.13 V rms.

k. Reconnect the DVM to measure the test voltage at the test terminals, that is, "high" to the plus (red) junction, "low" to the minus (black) junction at the end of the measurement cable.

l. Verify that the test voltage is within the limits shown in Table 5-4C. Disconnect the VTVM.

Table 5-4C

TEST VOLTAGE

Range	Voltage (rms)
1	4.80 to 5.20 V
2	0.90 to 1.10
3	0.90 to 1.10
4	0.90 to 1.10
5	0.90 to 1.10
6	0.90 to 1.10
7	0.08 to 0.12
8	0.08 to 0.12
9	0.08 to 0.12

5.9.4 Capacitance-Measurement Adjustments (1 kHz).

To check and adjust the 1-kHz C bridge circuits:

a. *Internal Zero.* Set the 1686 RANGE switch to 5 and set the FREQUENCY switch to 1 kHz. Connect measurement cables and make 2 separate junctions: positive (red leads) and negative (black/white) as in step 5.9.3.a.

b. Connect the oscilloscope to P-TP6, and set its VERT SENS control to .05 V/DIV and TIME control to 5 ms. P-TP6 is near the rear, to the right of a row of 7 wire ties (below the power plug and TEST VOLTAGE control).

c. Temporarily short-circuit P-U14, pin 3, to ground. U14 is just to the rear of the right end of the metal reinforcing bar that crosses the middle of the board. (Its pin 3 connects to R120, a rather long resistor.) Ground to any point that connects with the broad ground planes on this board, such as WT2 near the left rear corner. Adjust R128 so that the output at TP6, as seen on the oscilloscope, is zero (no slope). Remove the short-circuit from U14.

d. *Remainder Adjustment.* Connect the 1686 as shown in Fig. 5-5. Set the "C" value to 0.1 μF and the 1686 to RANGE 6. Adjust W-R107 for a 1686 reading of 0.100; center the adjustment. (The W Board is directly behind the FREQUENCY switch.)

e. *AC Numerator Adjustment.* Connect the 1686 as shown in Figure 5-6. Set the 1686 RANGE switch to 5. Observe display and adjust P-R85 if necessary so that the 1686 C display indicates 000.0, with a 30-pF capacitor connected and 000.1 with a 70-pF capacitor connected. Notice that it is possible for R191 to affect this adjustment. If R191 is near one extreme, it will be impossible to complete this step. R191 will be set in step 5.9.6, g.

f. *AC Denominator Adjustment.* Connect the 1686 as shown in Figure 5-5, with a decade capacitor for "C". Set the 1686 RANGE switch to 4 and the FREQUENCY switch to 1 kHz.

g. Set "C" to 0.1 μF. If necessary adjust P-R92 so that the 1686 indicates the same value (100 nF) with the rear-panel TEST VOLTAGE control set for maximum and for minimum test voltage levels; return the control to the maximum-voltage position (fully cw); Disconnect the capacitor.

h. Set the RANGE switch to 9 and the FREQUENCY switch to 120 Hz (100 Hz). Make sure the BIAS switch is OFF. Separate the measurement-cable terminals and connect them to the 5 binding posts at the left of the 1417 Capacitance Standard (Posts labeled potential H, potential L, plain, current H, current L correspond to cable terminals P+, P–, ground, I+, I–, respectively.)

Set the CAPACITANCE of the 1417 to 100 mF.

i. Observe display and readjust P-R92 if necessary so that the 1686 indicates 100 mF ± 3% (300 counts).

j. Reconnect the 1686, as shown in Figure 5-5. Connect a 0.1-μF capacitance standard, for "C", using the GR 1409-T. Set the 1686 RANGE switch to 4 and FREQUENCY switch to 1 kHz.

k. Check that the 1686 indicates the same value (100 nF nominal) with the rear-panel TEST VOLTAGE switch set for maximum and for minimum test voltages. Set the TEST VOLTAGE control for maximum test voltage (fully cw).

l. Insert a 240-Ω resistor in series with the –I lead (at the capacitor "high" terminal). Check that the C values measured with and without the 240-Ω resistor do not differ by more than 0.2% (20 counts). Remove the 240-Ω resistor.

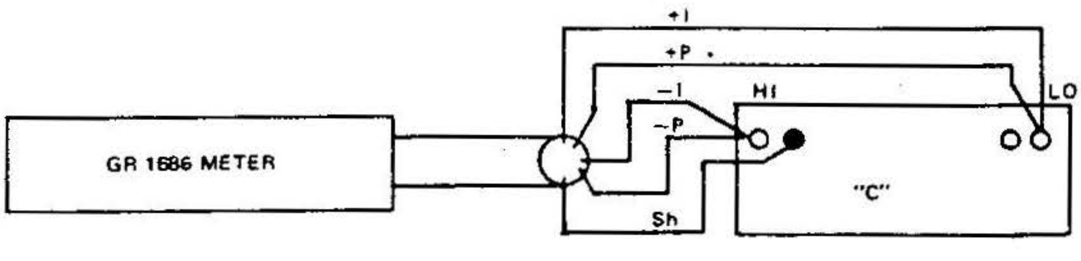


Figure 5-5. Test setup for C-measurement checks and adjustments. The capacitor is usually a precision standard. Use 1686-0291 and 1686-9602 cables (supplied).

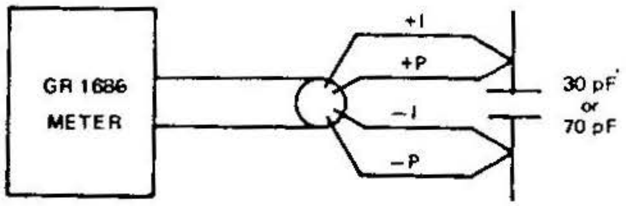


Figure 5-6. Test setup for C-measurement checks and adjustments not requiring standard capacitors.

m. *Low-D Check.* Observe display and adjust W-R105 if necessary so that the 1686 indicates the calibrated value of the 1409-T 0.1-μF standard, with no resistor in series between the —I—P junction and the high terminal of the 1409 (see below).

n. *High-D Check.* Insert a 3.3-kΩ resistor in series between the high side of the capacitance standard and the junction of the —I—P leads. Observe display and adjust W-R110 if necessary so that the 1686 indicates the same calibrated "C" value (±7 counts).

o. Because R105 and R110 interact, repeat steps m and n until the readings are the same. Remove the 0.1-μF capacitor and the 3.3-kΩ resistor.

NOTE

A "zero" correction is required for the cable, on ranges 1,2,3. Refer to para 5.4.2 and 3.1.3.

p. Set the 1686 RANGE switch to 1. Verify that FREQUENCY switch is at 1 kHz. Connect the 1686 to the 100-pF standard (GR 1404-B). The connectors on this capacitor require the use of two adaptors (874-Q2, see Table 5-1) in this application. Check that the 1686 indicates between 99.93 and 100.07 pF. If not, pad R279 (S501, 601R to 603R) to obtain the correct reading. (To decrease reading, increase R279 resistance.) Notice that this resistor is mounted on the rear of the RANGE switch, above the left strut, between the 1st and 3rd terminals, in parallel with a precision 1-kΩ resistor.

q. Set RANGE switch to 2. Connect the 1686 to the 1404-A 1000-pF standard. The 1686 must indicate between 999.5 and 1000.5 pF. (See note in para 5.9.2.)

r. Set RANGE switch to 3. Connect the 1686 to the 1409-L 0.01-μF standard. The 1686 must indicate between 9.995 and 10.005 nF.

s. Set RANGE switch to 4. Connect the 1686 to the 1409-T 0.1-μF standard. The 1686 must indicate between 99.95 and 100.05 nF.

t. Set RANGE switch to 5. Connect the 1686 to the 1409-Y 1.0-μF standard. The 1686 must indicate (the corrected value of the 1409-Y) ±5 counts. Note the difference between the 1686 reading and the corrected value of the standard capacitor.

u. Connect the 1686 to the 1417 high-capacitance standard Set the 1417 CAPACITANCE switch to 1 μF and the TEST FREQUENCY switch to 1 kHz. Determine the exact value of the 1417 at these settings by reading the 1686 display and correcting that by the difference noted in the preceding step.

Example: If the 1686 reading was 2 counts low in step t, add 2 counts to the present 1686 reading. If the reading is 1001.5 nF, the exact value of the 1417 is 1001.7 nF.

NOTE

Refer to para 5.4.3 and to the 1417 instruction sheet.

v. Set the 1686 RANGE switch to 6. Set the 1417 to the 10-μF position. The 1686 must indicate the corrected 1417 value ±5 counts.

Example: If the exact value of the 1417 was 1001.7 nF in the preceding step, it is now 10.017 μF and readings in the range 10.012 to 10.022 are satisfactory.

w. Set the 1686 RANGE switch to 7. Set the 1417 to the 100-μF position. The 1686 must indicate the corrected 1417 value ±7 counts.

Example (continuation of previous example): For exact value of 100.17 μF, readings in the range 100.10 to 100.24 are satisfactory.

Otherwise, change the value of P-R271 (nominally 510 kΩ), found between P-WT37 and WT38. To increase the readout, increase resistance; to decrease 1686 readout, decrease or pad R271. These wire ties are just to the left of P-S03 (about 15 cm, 6 in., back of a point on the front panel below the CAPACITANCE display).

x. Set the 1686 RANGE switch to 8. Set the 1417 to the 1-mF position. The 1686 must indicate the corrected 1417 value ±50 counts.

Example (continued): For exact value of 1001.7 μF, readings in the range 996.7 to 1006.7 μF are satisfactory.

y. If you changed or padded R271, above, it is necessary to repeat all of para 5.9.4, so that all its requirements are met.

5.9.5 Capacitance-Measurement Adjustments (120 or 100 Hz).

To check and adjust the 120-Hz (100-Hz) C bridge circuits:

a. Set 1686 RANGE switch to 3 and FREQUENCY switch to 120 Hz (100 Hz). Connect the 1686 as shown in Figure 5-6.

b. Check that the 1686 indicates 000.0 with a 30-pF capacitor connected and 000.1 with a 70-pF capacitor connected.

c. Set the 1686 RANGE switch to 4 and the FREQUENCY switch to 120 Hz.

d. Connect the 100-nF standard capacitor, as shown in Figure 5-5, without any resistor. Observe display and adjust W-R106 if necessary so that the 1686 indicates 100.00 nF. Set R106 in the center of the range over which this display is seen.

e. Change the 1686 RANGE to 3. Observe the display and adjust W-R104 if necessary so that the 1686 indicates the calibrated value of the 1409-T 0.1-μF standard.

f. Add a 27-kΩ resistor in series between the high side of the 0.1-μF standard capacitor and the junction of the −I−P leads. Adjust W-R109 so the CAPACITANCE display is the calibrated value of the standard. The measured D should be approx 2.

g. Set the RANGE switch to 1. Connect the 1686 to the 1000-pF capacitance standard (1404-A). The 1686 must indicate the corrected value of the standard ± 5 counts.*

h. Set the RANGE switch to 2. Connect the 1686 to the 0.01-μF standard (1409-L). The 1686 must indicate the corrected value of the standard ± 3 counts.*

i. Set the RANGE switch to 3. Connect the 1686 to the 0.1-μF standard (1409-T). The 1686 must indicate the corrected value of the standard, ± 1 count.*

j. Set the RANGE switch to 4. Connect the 1686 to the 1-μF standard (1409-Y). The 1686 must indicate the corrected value of the standard ± 3 counts. Note the difference between the 1686 reading and the corrected value of the standard capacitor.

k. Turn the BIAS OFF. Connect the 1686 to the 1417 capacitance standard. Set the 1417 switches to 1-μF and 120-Hz (100 Hz) positions. Determine the 1417 value by correcting the 1686 reading by the amount of the difference reading determined in the previous step. (Refer to the calibration of the 1417 in para 5.9.4.)

Example: If the 1686 measurement of the 1409-Y (previous step) was 2 counts low, then the 1417 value is determined by adding 2 counts to the 1686 measurement of the 1417 (present step).

l. Set the RANGE switch to 5. Set the 1417 to the 10-μF position. The 1686 must indicate the corrected 1417 reading ± 3 counts.

m. Set the RANGE switch to 6. Set the 1417 to the 100-μF position. The 1686 must indicate the corrected 1417 reading ± 3 counts.

*Refer to NOTE in para 5.9.4.

n. Set the RANGE switch to 7. Set the 1417 to the 1-mF position. The 1686 must indicate the corrected 1417 reading ± 6 counts.

o. Set the RANGE switch to 8. Set the 1417 to the 10-mF position. The 1686 must indicate the corrected 1417 reading ± 6 counts.

p. Set the RANGE switch to 9. Set the 1417 to the 100-mF position. The 1686 must indicate the 1417 reading ± 100 counts.

5.9.6 D-Measurement Checks and Adjustments (1 kHz). Figure 5-7.

a. Set the 1686 RANGE switch to 2 and FREQUENCY switch to 1 kHz. Connect the 1686 to the 0.01-μF standard 1409-L. Connect an oscilloscope to P-TP15 and set the scope time base to 0.1 ms/div. (TP15 is 3rd from the left in a row of 4 test points about 6 cm (2 1/4 in.) back from the center of the stiffener across the Bridge Board.) If necessary, adjust the nearby R261 for a square wave as seen on the scope. Disconnect oscilloscope from TP-15.

b. Set the 1686 RANGE switch to 3. Connect the 1686 as shown in the figure indicated above, so that both "R" and "C" are decade boxes, in series.

c. Set "C" to .01592 μF and set "R" to 10 Ω. Measure dissipation factor and adjust W-R113 if necessary to obtain a D reading of .001 (the point where both left and right "D" lights blink).

d. Change "R" to 50 Ω. Check for a D reading of .005 on 1686 D dial; if not correct, repeat the procedure starting at step c. Notice: There are two positions of R113 that will satisfy step c. Be sure to choose the one that also satisfies step d.

e. Set "R" to 20 kΩ and adjust P-R236 if necessary for a D reading of 2.

f. Set "R" to 100 Ω; measure D and record the D dial reading.

g. Change the 1686 RANGE switch to position 4 and adjust P-R191 if necessary for same D reading as in the preceding step. Repeat steps b thru g. (These adjustments interact.)

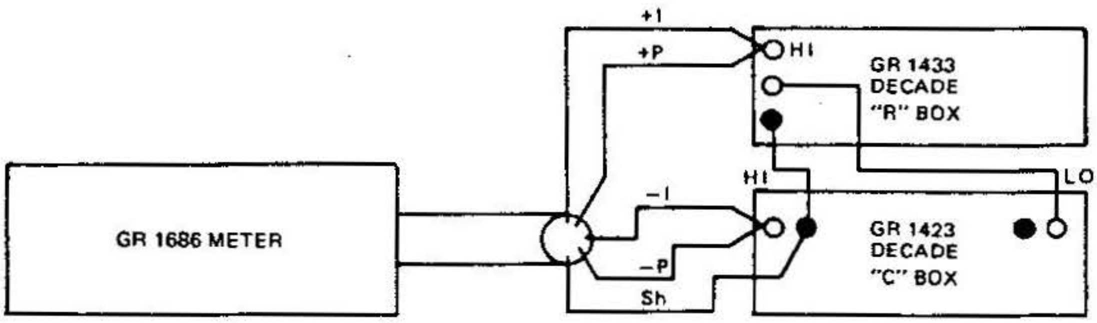


Figure 5-7. Test setup for D-measurement checks and adjustments. Both "R" and "C" are usually decade boxes. Use 1686-0291 and 1686-9602 cables (supplied).

See also para 5.9.4 "Numerator Adjustment" for possible interaction.

h. Change the RANGE switch to position 3. Check several D measurements for accuracy (to be within the specified limits) as tabulated in Table 5-5. For each row in the table, set "R" as listed for "1433". Notice that "C" should remain .01592 μF.

Table 5-5
DISSIPATION-FACTOR CHECKS, EXTENDED, 3 FREQUENCIES

GR 1433 Setting	D Nominal	Low Limit	High Limit
10 Ω	.001	.000	.002
50 Ω	.005	.0035	.0065
100 Ω	.01	.0082	.0118
200 Ω	.02	.018	.022
500 Ω	.05	.046	.054
1 kΩ	0.1	.093	0.107
2 kΩ	0.2	0.187	0.213
5 kΩ	0.5	0.46	0.54
10 kΩ	1	0.90	1.1
20 kΩ	2	1.7	2.3
100 kΩ	10	4.5	15.5

i. To take advantage of the setup, it may be convenient to check the operation of the "D Limit" function of the comparator now. Refer to para 5.9.8.

5.9.7 D-Measurement Checks and Adjustments (120 Hz or 100 Hz).

Use the same setup as before and perform the following steps:

a. Set the 1686 RANGE switch to 3 and the FREQUENCY switch to 120 Hz (100 Hz). Set "R" to 10 Ω. If measurement frequency is 120 Hz, set "C" to 0.1327 μF. If measurement frequency is 100 Hz, set "C" to 0.1592 μF.

b. Adjust W-R112 if necessary for a D reading of .001. (Set the D dial to .001 and adjust R112 for a balance as indicated by the green and red D lamps.)

c. Check several D measurements for accuracy (to be within the specified limits) as tabulated in Table 5-5.

5.9.8 Comparator Checks.

a. Connect a 1413 Decade Capacitor to the 1686 (as shown in Figure 5-5). Set the RANGE switch to 3, FREQUENCY to 1 kHz, MODE to REPETITIVE 0.5 s, DISSIPATION FACTOR dial to 0.1, and LIMIT/OFF switch to LIMIT.

b. *Low Limits.* Set the HIGH LIMIT thumbwheel switch to 19000. Start with both LOW LIMIT thumbwheel switch and decade capacitor at zero. The GO light should flash every 0.5 s.

c. Check the 5th digit (LSD) by alternately advancing the thumbwheel 1 step and then the 1-pF-per-step capacitor knob 1 step. Verify that the limit lights respond as tabulated in Table 5-6, i.e.: HIGH and HIGH D remain off, GO lights when the CAPACITANCE display is equal-to or greater-than the LOW LIMIT setting, LOW lights when the display is less than the limit.

d. Check the 4th digit similarly, advancing the 10-pF-per-step knob of the capacitor.

e. Check the 3rd, 2nd, and 1st digits similarly. It may be necessary to set some of the less-significant digits to 1 on the capacitor to assure that the digit being checked on the 1686 CAPACITANCE display tracks with the digit being set on the capacitor. Notice that the 1st digit is either 0 or 1; check it in all 5 positions labeled 0 as well as all 5 positions labeled 1, as outlined in Table 5-7.

f. *High Limits.* Set the LOW LIMIT thumbwheel switch to zero. Start with both HIGH LIMIT thumbwheel switch and decade capacitor at zero. The GO light should flash every 0.5 s.

g. Check the 5th and then the other digits similarly to the procedures above, except advance the capacitor first, as shown in Tables 5-8, 5-9. GO should light when the CAPACITANCE display is equal-to or less-than the HIGH LIMIT setting; HIGH should light when the display is greater than the limit. After checking the 5th digit (LSD), set it to 9 on the limit switch, but 0 on the capacitor, to assure that the "go" conditions are met, while you check the higher digits.)

h. *D Limit.* Connect series "R" and "C", as in para 5.9.6. Set the HIGH LIMIT to 19000, LOW LIMIT to zero, "R" to 1 kΩ, and "C" to .01592 μF. Rotate the D dial through its range and verify the following: whenever the dial is below the measured dissipation factor (approx 0.1), the HIGH D light of the comparator is on; whenever the D dial indicates above the measured D, the GO light is on.

5.9.9 Final Accuracy Checks.

Make the accuracy checks in the Minimum Performance Standards, above (para 5.4.2, with tables). No adjustments should be necessary, after you have completed the preceding parts of para 5.9.

Table 5-6
COMPARATOR LOW-LIMIT CHECK

1686 Low Limit Switch	GR 1413	GO Lamp	LOW Lamp
00000	000000 pF	ON	—
00001	000000 pF	—	ON
00001	000001 pF	ON	—
00002	000001 pF	—	ON
00002	000002 pF	ON	—
00003	000002 pF	—	ON
00003	000003 pF	ON	—
00004	000003 pF	—	ON
00004	000004 pF	ON	—
00005	000004 pF	—	ON
00005	000005 pF	ON	—
00006	000005 pF	—	ON
00006	000006 pF	ON	—
00007	000006 pF	—	ON
00007	000007 pF	ON	—
00008	000007 pF	—	ON
00008	000008 pF	ON	—
00009	000008 pF	—	ON
00009	000009 pF	ON	—
00000	000009 pF	ON	—
00000	000000 pF	ON	—

Table 5-7
COMPARATOR LOW-LIMIT 1-kHz CHECK

1686 Low Limit Switch	GR 1413	GO Lamp	LOW Lamp	HIGH Lamp
**00000	000000 pF	ON	—	—
**10000	000000 pF	—	ON	—
**10000	010100 pF	ON	—	—
**10000	020000 pF	—	—	ON*
00000	000000 pF	ON	—	—

*The 1686 must show ERROR (E)
**Repeat at least five times to check each position of switch (5 zero's, 5 one's). Rotate left wheel of 1686 LOW or HIGH LIMIT switch (as applicable) through its 10 positions.

Table 5-8
COMPARATOR HIGH-LIMIT CHECK

1686 High Limit Switch	GR 1413	GO Lamp	HIGH Lamp
00000	000000 pF	ON	—
00000	000001 pF	—	ON
00001	000001 pF	ON	—
00001	000002 pF	—	ON
00002	000002 pF	ON	—
00002	000003 pF	—	ON
00003	000003 pF	ON	—
00003	000004 pF	—	ON
00004	000004 pF	ON	—
00004	000005 pF	—	ON
00005	000005 pF	ON	—
00005	000006 pF	—	ON
00006	000006 pF	ON	—
00006	000007 pF	—	ON
00007	000007 pF	ON	—
00007	000008 pF	—	ON
00008	000008 pF	ON	—
00008	000009 pF	—	ON
00009	000009 pF	ON	—
00009	000000 pF	ON	—

Table 5-9
COMPARATOR HIGH LIMIT 1-kΩ CHECK

1686 High Limit Switch	GR 1413	GO Lamp	HIGH Lamp
**09999	00009 pF	ON	—
**09999	10009 pF	—	ON
**19999	10009 pF	ON	—
**19999	20009 pF	—	ON*
00009	00000 pF	ON	—

Table 5-10

TROUBLE ANALYSIS

Fault	Probable Cause	Remedy
Instrument fails to operate in any mode of operation.	Defective power supply, bridge-board oscillator; logic board BST-pulse circuitry, oscillators, or readout circuitry. NOTE If fault appears to be one that affects timing or overall performance of instrument, it is suggested that logic board be checked using timing diagram, Figure 6-9, and logic board schematic, Figure 6-10. Also check that the oscillator is operating. (Signal REF will be present.) If it appears that the fault is related to instrument accuracy (slightly inaccurate readings, for example) check the bridge board using the check and calibration procedures in para 5.9.	Perform lamp test to see if readout display is working. If display is not operating, check for power supply or readout circuit failure. Check at rear-panel S01 data output connector to see if measurement data is present. If it is, it will help isolate fault between logic board counters and drivers and readout meter and its associated logic-board circuits. Check power supply output (para 5-9) and/or voltages on logic board. Check oscillator output, if necessary, at C2 on the bridge board. If present, check the inputs and outputs of the logic board (timing diagram, Fig. 6-9), particulary signals HF, DNC, CP1 (may not always be present) and CP2. Check at both circuit boards, if present, check logic board counters and associated latches and multiplexers. Also check signal SDL on logic board, which is used to strobe data out of latches. Refer to the diagram (Fig. 6-4) showing the bridge-board signal waveforms for each FREQUENCY mode of operation, to isolate faults to the bridge-board circuitry.
Instrument operates for only certain parameters and/or only certain ranges.	No oscillator output for selected parameter, bridge section faulty, range circuitry faulty.	Check the oscillator output at C2 (WT3) on the bridge board (or signal REF on the logic board). Refer to the bridge configuration diagrams in Section 4 and Figure 6-4 showing the bridge-board signal waveforms for each parameter. From these and the parameter that is faulty, check the appropriate bridge arm(s) and parameter switch circuitry to see if signals are present. If not, check the components and connections. Also check measurements on various ranges to help isolate faults to the range circuitry on the RANGE switch. If a range is defective, refer to the bridge board schematic diagram and RANGE switch layout diagram to identify and locate components.
Measurements slightly inaccurate	Bridge-board or oscillator out of adjustment or has failed part.	Refer to paragraphs 5.4 and 5.9; use the procedure for the specific measurement parameter that is malfunctioning.
Limit Comparator not operating properly, but meter operates properly.	Comparator boards and assemblies and/or interface signals. Cable connections.	After ensuring that all connections are secured (Figure 6-3), use the timing diagram on the comparator 'A' board (Figure 6-12) and the logic board schematic and system timing diagram (Figure 6-9) to check the signals on and between the comparator boards and instrument boards. Signals between the comparator and the instrument are via connector S04 on the logic board. Use the theory of operation, if necessary, to determine the required states of other signals on the comparator boards. Replace board(s) or faulty part.
Error reset time too slow	L-Q26 and associated circuitry	Short-circuit TP-6 to ground; if reset speeds up then Q26 may be leaking.
No down-count pulse at L-TP3	CP2 pulse stuck low (L-TP14)	Check and repair associated circuit.
No reset pulse in repetitive mode.	CP2 pulse stuck high	Check and repair associated circuit.
Only "hundreds" and above readout digits operable.	Display or logic board malfunction or CP2 stuck low.	Perform lamp test to check display. Check logic board circuitry, particularly inputs from the FREQUENCY switch (signal $\overline{A2LGC}$ on board) and associated gates and flip-flops on board. Also check "count" oscillator and associated circuits. Check "units" and "tens" decade counters.
Only "units" and "tens" readout digits operable.	Bridge and logic board CP1 pulse circuitry; logic board F-F U26, gates U31 and/or counters.	Check circuitry listed under "probable cause."

Table 5-10 (cont)
TROUBLE ANALYSIS

Fault	Probable Cause	Remedy
Certain indicator lamps do not operate.	Lamp or signal circuitry.	Use the rear-panel connector or logic-board test points, where applicable, to determine if the circuitry or lamp is faulty. For example, the bridge and logic board contains a significant amount of circuitry for high-dissipation factor measurements. Signal HID can be monitored on the logic board or rear-panel data output connector (S01).

5.10 TROUBLE ANALYSIS.

Table 5-10 lists some faults that might occur in the instrument, the probable cause, and gives suggestions on how to isolate the fault. This information will help isolate a fault to a general area on circuit boards or assemblies. Integrated circuits are mounted in sockets for easy replacement of defective parts. Use the following aids to help isolate the fault to the part level.

1. Descriptions and simplified and equivalent drawings in Section 4.
2. Adjustment and calibration procedures in para 5.9.
3. Timing and schematic drawings in Section 6.
4. Waveforms and voltage levels on drawings in Section 6.
5. Test points on the circuit boards.
6. Parts list in Section 6.

For major types of faults where it appears that the instrument is not just out of calibration or adjustment (as indicated perhaps by slightly inaccurate readings as opposed to very inaccurate measurements), it is suggested that the following method be used to quickly check various parts of the instrument.

If a selection of various standards or components are available, make C measurements to see if the instrument operates in all ranges. If it operates in some ranges but not others, it may indicate that the bridge section or RANGE or FREQUENCY switches may not be operating properly but the oscillator and logic board circuits are functioning properly. (The check and calibration procedure in para 5.9 for the specific function and the bridge board waveform shown in Figure 6-4 can be used to isolate faults.)

The rear-panel data outputs can be checked to see if certain signals are present, indicating that the instrument's circuits are functioning. (For example, the RESET signal, data outputs, STROBE signal, etc.) The presence or absence of these signals will indicate a minor or major failure and help determine where a fault may lie. Remote-start the instrument to see if it functions in this manner.

If no improvements are noted, check the oscillator output (para 5-9). Then, if necessary, check the logic circuit-board signals. Use the timing diagram (Figure 6-9) and the logic circuit-board schematic (Figure 6-10) to check the logic board.

Set the instrument in the REPETITIVE mode of operation and check all the signals to and from the logic board, as shown in Figure 6-9. Test points are furnished at all board inputs and outputs.

If signal REF is missing, check the oscillator output. Signal REF is derived from the oscillator and is routed via the bridge board to the logic board, where it it used to initiate most of the timing functions on the board and in the instrument.

The oscillator can be checked by connecting an oscilloscope to capacitor C2 on the bridge board. If the signal is present, isolation of the fault can be made by further examination of the bridge board, using the bridge-board schematic and the bridge-board waveforms shown in Figure 6-4.

All the test points on the logic board should be checked. If any signal is missing, examination of the schematic diagrams and the circuitry associated with the signal will help determine the location of the fault.

In most cases it will be possible to isolate faults between the bridge and logic boards and the comparator (if included in the instrument) in this manner.

If the instrument is making measurements but the differences in the measurement and actual component values are quite large, the fault may be in either the bridge or logic board, even if all the signals shown in Figure 6-9 are present. For example, the analog circuit could be faulty, putting out a slope signal (CP2) sooner or later than normal. Or it could fail to produce signal CP1, or perhaps produce too many CP1 signals (Although it should be noted that in some cases signal CP1 may not be produced, depending on the value of the part under test. In some cases a range change will produce the signal and verify its presence.) The logic board counting and associated circuits may be faulty, resulting in improper readings. This will require further troubleshooting of the board.

In any event, systematic checking such as described above will result in isolation of the malfunction. Use the equivalent diagrams in Section 4 to determine the bridge configurations for the various FREQUENCY switch settings, if required. Read Section 4 to obtain a good understanding of how this complex instrument operates. Use this information to aid in troubleshooting.

Parts Lists and Diagrams—Section 6

1.1 GENERAL.

This section contains the parts lists, circuit-board layout diagrams and schematic and logic diagrams for the instrument. Section 4 contains functional diagrams of the various circuits shown in the schematic and logic diagrams. Section 5 contains photographs of the instrument, identifying various parts. The heavy lines on drawings denote the major signal flow in the circuits and instrument.

Reference designation usage is described in paragraph 6.2.

6.2 REFERENCE DESIGNATIONS.

Each component on an assembly is identified on equipment and drawings by means of a reference designator comprised of numbers and letters. Component types on an assembly are numbered sequentially, the numbers being preceeded by a letter designation that identifies the component (R for resistor, C for capacitor, etc.). Each assembly (typically a circuit board) has its own sequence of designators which can be identified by using prefixes, such as L- for Logic Board.

Main-frame-mounted parts are identified by numbers having three digits, the first of which is the number 5 (C501, R508, CR506, for example), and/or a prefix, G-.

The designation WT (wire-tie point) replaces the customary AT (anchor terminal) designation. The purpose of other references and symbols is given on the drawings in this section.

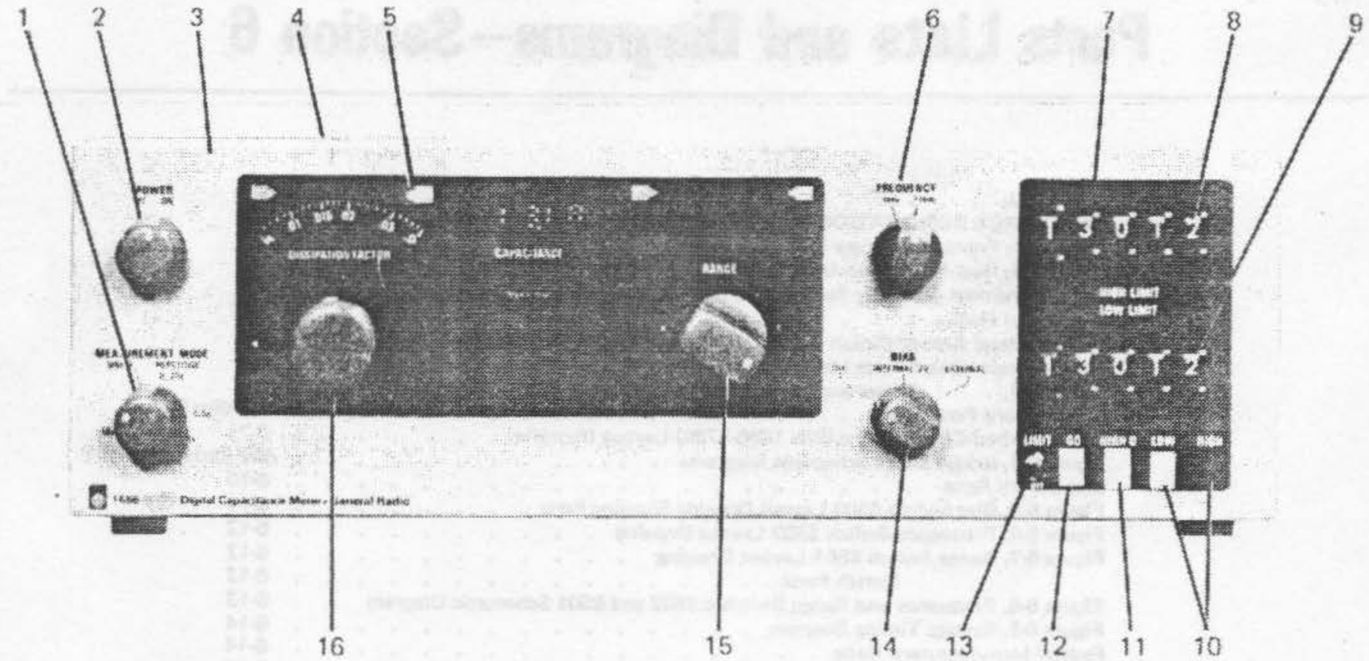


Figure 6-1. Front-panel view identifying parts.

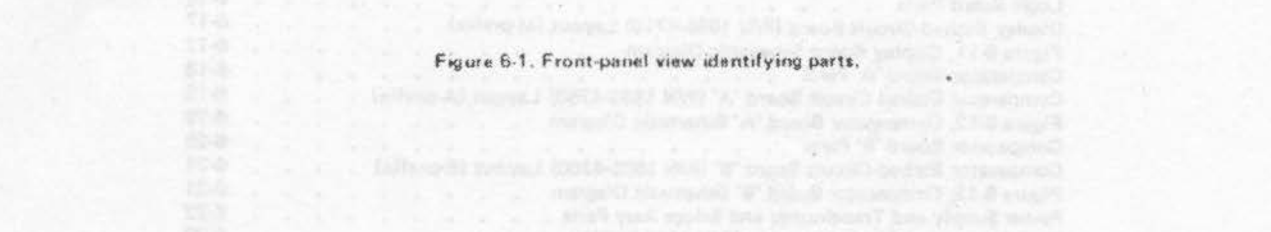


Figure 6-2. Rear-panel view, identifying parts.

MECHANICAL PARTS LIST

FRONT PANEL

FIG	QNT	DESCRIPTION*	GR PART NO.	FMC NO.	MFGR PART NO.
1	1	KNOB ASM,MEASUREMENT MODE,S506&R500	5520-5321	24655	5520-5321
		INCLUDES			
	1	RETAINER	5220-5402	24655	5220-5402
2	1	KNOB ASM,S504	5520-5321	24655	5520-5321
		INCLUDES			
	1	RETAINER	5220-5402	24655	5220-5402
3	1	CABINET ASM	1685-2030	24655	1685-2030
4	1	GASKET	5331-3099	24655	5331-3099
5	1	WINDOW ASM	1685-7021	24655	1685-7021
6	1	KNOB ASM,FREQUENCY,S502	5500-5321	24655	5500-5321
		INCLUDES			
	1	RETAINER	5220-5402	24655	5220-5402
7	1	SWITCH BRACKET ASM	1685-2050	24655	1685-2050
8	1	SWITCH,THUMBWHEEL,HIGH LIMIT,S6-S10	7917-1014	24655	7917-1014
9	1	SWITCH,THUMBWHEEL,LOW LIMIT,S1-S5	7917-1014	24655	7917-1014
10	2	HOLDER,LAMP,LOW,HIGH,DS3,DS4	5600-1032	24655	5600-1032
11	1	HOLDER,LAMP,HIGH D,DS2	5600-1021	24655	5600-1021
12	1	HOLDER,LAMP,GO,DS1	5600-1035	24655	5600-1035
13	1	SWITCH,TOGGLE,LIMIT OFF,S11	7910-0790	95146	MTA-1060
14	1	KNOB ASM,BIAS,S503	5500-5321	24655	5500-5321
		INCLUDES			
		RETAINER	5220-5402	24655	5220-5402
15	1	KNOB ASM,RANGE,S501	5500-5421	24655	5500-5421
		INCLUDES			
	1	RETAINER	5220-5401	24655	5220-5401
16	1	KNOB ASM,D,R501	5520-5420	24655	5520-5420
		INCLUDES			
	1	RETAINER	5220-5401	24655	5220-5401

REAR PANEL

FIG	QNT	DESCRIPTION*	GR PART NO.	FMC NO.	MFGR PART NO.
1	1	CONNECTOR,TEST FIXTURE,S010	4230-4036	02660	57-40360-9
2	1	DATA OUTPUT CONNECTOR,L-S01	4230-1023	24655	4230-1023
3	1	POST,FUSE EXTRACTOR,1/2A,F2	5650-0100	75915	342-004
4	1	SWITCH,POWER,LINE VOLTAGE OFF ON,S505	7890-1082	24655	7890-1082
5	1	POST,FUSE EXTRACTOR,1A,F1	5650-0100	75915	342-004
6	1	CONNECTOR,POWER,J1	4240-0210	24655	4240-0210
7	1	POTENTIOMETER,TEST VOLTAGE,R510	6050-1300	24655	6050-1300
8	1	CONNECTOR,COMPARATOR,S05	4230-4024	02660	57-40240

*Reference designator is given for the electrical part associated with the knob or other mechanical part. The G- prefix is understood.

ELECTRICAL PARTS LIST

CHASSIS MOUNTED PARTS

REFDES (G- prefix)	DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C 10	CAP MYLAR .18 UF 5PCT 100V	4860-7897	56289	4410P 0.18 UF 5PCT
C 501	CAP ALUM 22000UF 15V	4450-6509	56289	360223G015
C 502	CAP ALUM 2000 UF 6V	4450-6106	90201	TT202N006G1G1P
C 503	CAP ALUM 9700 UF 30V	4450-6511	56289	36D972G030
C 504	CAP ALUM 9700 UF 30V	4450-6511	56289	36D972G030
C 505	CAP TANT 1.0 UF 20PCT 35V	4450-4300	56289	150D105X0035A2
C 506	CAP TANT 6.8 UF 20PCT 6V	4450-4800	56289	150D685X0006A2
C 510	CAP TANT 180 UF 20PCT 6V	4450-5617	56289	150D187X0006R2
CR 501	DIODE BRIDGE	6081-1032	24655	6081-1032
CR 502	DIODE BRIDGE	6081-1032	24655	6081-1032
CR 503	DIODE BRIDGE	6081-1032	24655	6081-1032
CR 504	DIODE BRIDGE	6081-1032	24655	6081-1032
DS 501	LAMP FLANGE BASE 6.3V .075A 1000	5600-0319	71744	CM-377
DS 502	LAMP FLANGE BASE 6.3V .075A 1000	5600-0319	71744	CM-377
DS 503	LAMP FLANGE BASE 6.3V .075A 1000	5600-0319	71744	CM-377
DS 504	LAMP FLANGE BASE 6.3V .075A 1000	5600-0319	71744	CM-377
DS 505	LAMP FLANGE BASE 6.3V .075A 1000	5600-0319	71744	CM-377
DS 506	LAMP FLANGE BASE 6.3V .075A 1000	5600-0319	71744	CM-377
DS 507	LAMP FLANGE BASE 6.3V .075A 1000	5600-0319	71744	CM-377
DS 508	LAMP FLANGE BASE 6.3V .075A 1000	5600-0319	71744	CM-377
F 1	FUSE SLO-BLOW 1A 250V	5330-1400	75915	313 001
F 2	FUSE SLO-BLOW 1/2A 250V	5330-1000	75915	313 .500
J 1	RECEPTACLE POWER IEC STD 6A 250V	4240-0210	24655	4240-0210
J 502	CONNECTOR PC 15 POS DR .156 SP	4230-5230	02660	225-21521-401-117
J 503	CONNECTOR 21 CONT.050 SP 80/80	4230-7100	06928	A202-021
J 600	RECPT MIN HEX 5 CONT FEMALE	4230-5405	02660	126-218
P 10	PLUG MICRO RIB 36 CONT MALE	4220-3036	02660	57-30360
P 11	PLUG MICRO RIB 36 CONT MALE	4220-3036	02660	57-30360
R 40	RES COMP 5.1 M OHM 5PCT 1/4W	6099-5515	81349	RCR07G515J
R 249	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R 250	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R 500	POT COMP KNOB IM 20PCT SW	6045-5110	24655	6045-5110
R 502	RES COMP 1.0 M 5PCT 1/4W	6099-5105	81349	RCR07G105J
R 510	POT WW TRM 1K OHM 10 PCT 1T	6050-1300	24655	6050-1300
S 504	SWITCH ROTARY WAFER	7890-6510	76854	5-57132-017
S 505	SWITCH LINE VOLTAGE SELECTOR	7890-1082	24655	7890-1082
S 506	POT COMP KNOB IM 20PCT SW	6045-5110	24655	6045-5110
SO 10	RECPT MICRO RIB 36 CONT	4230-4036	02660	57-40360-9
U 501	IC LINEAR LM323	5432-1048	12040	LM323K

ELECTRICAL PARTS LIST

BRIDGE PC BOARD P/N 1686-4720

REFDES (P- prefix)	DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C 2	CAP ALUM 125UF 100V	4450-6156	56289	43D125G100GJ6
C 3	CAP ALUM 500 UF 20V	4450-6020	56289	30D507G020
C 4	CAP MICA 10000PF 1PCT 300V	4560-0300	81349	CM07F103F
C 5	CAP MICA 10000PF 1PCT 300V	4560-0300	81349	CM07F103F
C 6	CAP MICA 10000PF 1PCT 300V	4560-0300	81349	CM07F103F
C 7	CAP CER .3 SQ .01 UF 20PCT 100V	4400-6534	72982	8111A100Y5F103J
C 11	CAP CER .35Q 3300PF 10PCT 100V	4400-6525	72982	8131M100651332K
C 12	CAP CER .1 SQ 330PF 10PCT 100V	4400-6441	72982	8111 A200-X5R0331K
C 15	CAP CER SQ .10UF 80/20PCT 100V	4403-4100	72982	8131M100651104Z
C 16	CAP CER SQ .10UF 80/20PCT 100V	4403-4100	72982	8131M100651104Z
C 21	CAP MICA 20000PF 1PCT 300V	4560-0400	81349	CM07F203F
C 24	CAPACITOR .02 UF	0505-4413	24655	0505-4413
C 25	CAP MICA 324PF 1PCT 500V	4710-0470	81349	CM05FD324FN
C 30	CAP MYLAR .1UF 10 PCT 100V	4860-8250	56289	410P 0.1 UF 10PCT
C 32	CAP MYLAR .1UF 10 PCT 100V	4860-8250	56289	410P 0.1 UF 10PCT
C 35	CAP CER SQ .10UF 80/20PCT 100V	4403-4100	72982	8131M100651104Z
C 36	CAP CER SQ .10UF 80/20PCT 100V	4403-4100	72982	8131M100651104Z
C 37	CAP CER SQ .10UF 80/20PCT 100V	4403-4100	72982	8131M100651104Z
C 38	CAP CER SQ .10UF 80/20PCT 100V	4403-4100	72982	8131M100651104Z
C 39	CAP CER.15SQ 680 PF 5PCT 100V	4400-6450	72982	8111A102Y5D0681J
C 40	CAP POLY .05UF +0-0.5PCT 100V	4872-1202	24655	4872-1202
C 41	CAP POLY 0.45UF 0.5PCT 100V	4872-1212	24655	4872-1212
C 42	CAP POLY 0.45UF 0.5PCT 100V	4872-1212	24655	4872-1212
C 43	CAP CER MONO 0.47UF 20PCT 50VGP	4400-2054	72982	8131M0506510474M
C 44	CAP CER MONO 0.47UF 20PCT 50VGP	4400-2054	72982	8131M0506510474M
C 45	CAP MYLAR .1UF 10 PCT 100V	4860-8250	56289	410P 0.1 UF 10PCT
C 50	CAP CER MONO 0.47UF 20PCT 50VGP	4400-2054	72982	8131M0506510474M
C 51	CAP CER MONO 0.47UF 20PCT 50VGP	4400-2054	72982	8131M0506510474M
C 54	CAP MICA 2000PF 1PCT 500V	4710-2620	81349	CM06FD2000FN
C 55	CAP MICA 1200PF 1PCT 500V	4710-1210	81349	CM06FD122FN
C 56	CAP MICA 1200PF 1PCT 500V	4710-1210	81349	CM06FD122FN
C 57	CAP MICA 10000PF 1PCT 300V	4560-0300	81349	CM07F103F
C 58	CAP MICA 10000PF 1PCT 300V	4560-0300	81349	CM07F103F
C 59	CAP MICA 2000PF 1PCT 500V	4710-2620	81349	CM06FD2000FN
C 60	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 61	CAP TANT 4.7 UF 20PCT 50V	4450-4990	56289	150D475X0050B2
C 62	CAP CER MONO 0.22UF 20PCT 50VGP	4400-2052	72982	8131-M050-651-224M
C 63	CAP CER .3 SQ .01 UF 20PCT 100V	4400-6534	72982	8111A100Y5F103J
C 64	CAP CER .4 SQ .022 UF 20PCT 100V	4400-6536	72982	8111A100Y5F223J
C 65	CAP TANT 33 UF 20PCT 20V	4450-5613	56289	150D336X0020R2
C 101	CAP CER .1 SQ 33PF 5PCT 100V	4400-6485	72982	8101A100Y5F330J
C 102	CAP CER .1 SQ 33PF 5PCT 100V	4400-6485	72982	8101A100Y5F330J
C 103	CAP CER SQ 4.7PF 5PCT 100VN030	4411-2005	72982	8101A1008lG479J
C 104	CAP CER .1 SQ 33PF 5PCT 100V	4400-6485	72982	8101A100Y5F330J
C 105	CAP CER .1 SQ 33PF 5PCT 100V	4400-6485	72982	8101A100Y5F330J
C 106	CAP CER .1 SQ 33PF 5PCT 100V	4400-6485	72982	8101A100Y5F330J
C 107	CAP CER .1 SQ 33PF 5PCT 100V	4400-6485	72982	8101A100Y5F330J
C 108	CAP CER .1 SQ 33PF 5PCT 100V	4400-6485	72982	8101A100Y5F330J
C 109	CAP CER .1 SQ 33PF 5PCT 100V	4400-6485	72982	8101A100Y5F330J
C 110	CAP CER .1 SQ 33PF 5PCT 100V	4400-6485	72982	8101A100Y5F330J
C 111	CAP CER .1 SQ 33PF 5PCT 100V	4400-6485	72982	8101A100Y5F330J
C 112	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 113	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 114	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 115	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 116	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 117	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 118	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 119	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 120	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 121	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 122	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 123	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 124	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 125	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 126	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 127	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 128	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 129	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 130	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 131	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 133	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C 134	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M

ELECTRICAL PARTS LIST (cont)

BRIDGE PC BOARD P/N 1686-4720

REFDES		DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C	135	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C	136	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C	137	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C	138	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C	139	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C	140	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C	141	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C	142	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C	143	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C	145	CAP CER .3 SQ .01 UF 20PCT 100V	4400-6534	72982	8111A100Y5F103J
C	146	CAP CER .3 SQ .01 UF 20PCT 100V	4400-6534	72982	8111A100Y5F103J
C	148	CAP CER .2SQ 1000PF 10PCT 100V	4400-6519	72982	8121M100651102K
C	149	CAP CER MONO 1UF 20PCT 50VGP	4400-2070	72982	8131-M050-651-105M
C	150	CAP CER.15SQ 680 PF 5PCT 100V	4400-6450	72982	8111A102Y500681J
C	151	CAP CER .2SQ 1000PF 10PCT 100V	4400-6519	72982	8121M100651102K
C	152	CAP CER MONO 1UF 20PCT 50VGP	4400-2070	72982	8131-M050-651-105M
C	153	CAP CER .3 SQ .01 UF 20PCT 100V	4400-6534	72982	8111A100Y5F103J
C	154	CAP TANT 47 UF 20PCT 20V	4450-5614	56289	150D476X0020R2
C	155	CAP TANT 47 UF 20PCT 20V	4450-5614	56289	150D476X0020R2
C	156	CAP CER MONO .0068UF 10PCT 50V	4400-6356	72982	8121-M050-W5R-472K
C	157	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C	158	CAP CER .1 SQ 270PF 10PCT 100V	4400-6514	72982	8101A100651271K
C	159	CAP CER .4 SQ .022 UF 20PCT 100V	4400-6536	72982	8111A100Y5F223J
C	160	CAP CER .3 SQ .01 UF 20PCT 100V	4400-6534	72982	8111A100Y5F103J
C	161	CAP CER .3 SQ .01 UF 20PCT 100V	4400-6534	72982	8111A100Y5F103J
C	162	CAP CER .1SQ 100 PF 5PCT 100V	4400-6442	72982	8101A100Y5F101J
C	163	CAP CER .1SQ 100 PF 5PCT 100V	4400-6442	72982	8101A100Y5F101J
C	164	CAP CER .4 SQ .022 UF 20PCT 100V	4400-6536	72982	8111A100Y5F223J
C	165	CAP CER .1 SQ 33PF 5PCT 100V	4400-6485	72982	8101A100Y5F330J
C	166	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C	167	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
C	168	CAP CER .1 SQ 33PF 5PCT 100V	4400-6485	72982	8101A100Y5F330J
C	169	CAP CER .2SQ 2700PF 10PCT 100V	4400-6524	72982	8121M100651272K
C	170	CAP TANT 10 UF 20PCT 20V	4450-5100	56289	150D106X0020B2
C	171	CAP TANT 10 UF 20PCT 20V	4450-5100	56289	150D106X0020B2
CR	1	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	2	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	3	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	4	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	5	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	6	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	7	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	8	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	9	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	10	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	12	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	13	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	14	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	15	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	16	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	20	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	21	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	22	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	23	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	24	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	25	DIODE 1N191 90PIV IR 125UA GE	6082-1008	14433	1N191
CR	26	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	27	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	28	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	29	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	30	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	31	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	32	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	33	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	34	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	35	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	36	ZENER 1N748A 3.9V 5PCT .4W	6083-1002	14433	1N748A
CR	37	ZENER 1N748A 3.9V 5PCT .4W	6083-1002	14433	1N748A
CR	38	ZENER 1N748A 3.9V 5PCT .4W	6083-1002	14433	1N748A
CR	39	ZENER 1N748A 3.9V 5PCT .4W	6083-1002	14433	1N748A

ELECTRICAL PARTS LIST (cont)

BRIDGE PC BOARD P/N 1686-4720

REFDES		DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
Q	1	TRANSISTOR 2N3467	8210-1233	04713	2N3467
Q	2	TRANSISTOR 2N3903	8210-1132	04713	2N3903
Q	3	TRANSISTOR 2N5189	8210-1163	02735	2N5189
Q	4	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	5	TRANSISTOR E-113	8210-1229	17856	E-113
Q	6	TRANSISTOR E-113	8210-1229	17856	E-113
Q	7	TRANSISTOR 2N3467	8210-1233	04713	2N3467
Q	8	TRANSISTOR 2N3903	8210-1132	04713	2N3903
Q	9	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	10	TRANSISTOR 2N5189	8210-1163	02735	2N5189
Q	11	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	12	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	13	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	14	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	15	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	16	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	20	TRANSISTOR E-113	8210-1229	17856	E-113
Q	21	TRANSISTOR E-113	8210-1229	17856	E-113
Q	22	TRANSISTOR E-113	8210-1229	17856	E-113
Q	23	TRANSISTOR E-113	8210-1229	17856	E-113
Q	24	TRANSISTOR E-113	8210-1229	17856	E-113
Q	25	TRANSISTOR E-113	8210-1229	17856	E-113
Q	26	TRANSISTOR E-113	8210-1229	17856	E-113
Q	27	TRANSISTOR E-113	8210-1229	17856	E-113
Q	28	TRANSISTOR E-113	8210-1229	17856	E-113
Q	30	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	31	TRANSISTOR TIS-74	8210-1202	01295	TIS-74
Q	32	TRANSISTOR TIS-74	8210-1202	01295	TIS-74
Q	34	TRANSISTOR 2N3903	8210-1132	04713	2N3903
Q	35	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	36	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	37	TRANSISTOR 2N3903	8210-1132	04713	2N3903
Q	38	TRANSISTOR 2N3903	8210-1132	04713	2N3903
Q	39	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	40	TRANSISTOR 2N3903	8210-1132	04713	2N3903
Q	41	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	42	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	43	TRANSISTOR E-113	8210-1229	17856	E-113
Q	44	TRANSISTOR E-113	8210-1229	17856	E-113
Q	45	TRANSISTOR E-113	8210-1229	17856	E-113
Q	46	TRANSISTOR E-113	8210-1229	17856	E-113
Q	47	TRANSISTOR E-113	8210-1229	17856	E-113
Q	48	TRANSISTOR 2N3906	8210-1112	04713	2N3906
Q	49	TRANSISTOR 2N3906	8210-1112	04713	2N3906
R	12	RES COMP 10 OHM 5PCT 1/4W	6099-0105	81349	RCR07G100J
R	13	RES COMP 10 OHM 5PCT 1/4W	6099-0105	81349	RCR07G100J
R	14	RES COMP 47 K 5PCT 1/4W	6099-3475	81349	RCR07G473J
R	15	RES COMP 3.0 K OHM 5PCT 1/4W	6099-2305	81349	RCR07G302J
R	16	RES COMP 3.0 K OHM 5PCT 1/4W	6099-2305	81349	RCR07G302J
R	17	RES COMP 47 K 5PCT 1/4W	6099-3475	81349	RCR07G473J
R	18	POT WW TRM 1K OHM 10 PCT 1T	6056-0138	24655	6056-0138
R	19	THERMISTOR 100K OHM 20PCT	6740-2021	15801	BA-51V9
R	20	RES COMP 1.5 K 5PCT 1/4W	6099-2155	81349	RCR07G152J
R	21	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	22	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	23	RES FLM 15.8K 1 PCT 1/8W	6250-2158	81349	RN55D1582F
R	24	RES FLM 15K 1 PCT 1/8W	6250-2150	81349	RN55D1502F
R	25	POT WW TRM 1K OHM 10 PCT 1T	6056-0138	24655	6056-0138
R	26	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	27	RES FLM 133K 1 PCT 1/8W	6250-3133	81349	RN55D1333F
R	28	RES FLM 133K 1 PCT 1/8W	6250-3133	81349	RN55D1333F
R	29	RES COMP 10 M 5PCT 1/4W	6099-6105	81349	RCR07G106J
R	41	RES FLM 1K 1/10 PCT 50 PPM 1/8W	6190-2330	75042	CEA 1 K 0.1PCT T-2
R	42	RES FLM 10K 1/10 PCT 50 PPM 1/8W	6190-5660	75042	CEA 10 K 0.1PCT T-2
R	43	RES FLM 9K 1/10 PCT 50 PPM 1/8W	6190-5330	75042	CEA 9 K 0.1PCT T-2
R	44	RES FLM 9K 1/10 PCT 50 PPM 1/8W	6190-5330	75042	CEA 9 K 0.1PCT T-2
R	45	RES FLM 1K 1/10 PCT 50 PPM 1/8W	6190-2330	75042	CEA 1 K 0.1PCT T-2
R	62	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	70	RES WW AX LEAD 27 OHM 5 PCT 5W	6660-0275	75042	AS-5 27 OHM 5PCT
R	71	RES COMP 47 K 5PCT 1/4W	6099-3475	81349	RCR07G473J
R	72	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	73	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J

ELECTRICAL PARTS LIST (cont)

BRIDGE PC BOARD P/N 1686-4720

REFDES		DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
R	74	RES COMP 47 K 5PCT 1/4W	6099-3475	81349	RCR07G473J
R	75	RES WW AX LEAD 27 OHM 5 PCT 5W	6660-0275	75042	AS-5 27 OHM 5PCT
R	76	RES WW MOLDED 3.0 OHM 10 PCT 2W	6760-9309	75042	BWH 3 OHM 10PCT
R	77	RES WW MOLDED 3.0 OHM 10 PCT 2W	6760-9309	75042	BWH 3 OHM 10PCT
R	81	RES FLM 5K 1/10PCT 15PPM 1/4W	6619-3452	24655	6619-3452
R	82	RES COMP 30 K OHM 5PCT 1/4W	6099-3305	81349	RCR07G303J
R	83	RES FLM 30K 1/10PCT 15PPM 1/4W	6619-3453	24655	6619-3453
R	84	RES COMP 220 M 20PCT 1/2W	6100-7228	81349	RCR20G227
R	85	POT CERAM TRM 100K OHM 10 PCT1TS	6049-0301	80294	3329W-10-104
R	86	RES FLM 5K 1/10PCT 50PPM 1/8W	6619-1730	24655	6619-1730
R	87	RES COMP 30 K OHM 5PCT 1/4W	6099-3305	81349	RCR07G303J
R	88	RES FLM 30K 1/10PCT 15PPM 1/4W	6619-3453	24655	6619-3453
R	89	RES FLM 1K 1/10 PCT 50 PPM 1/8W	6190-2330	75042	CEA 1 K 0.1PCT T-2
R	90	RES FLM 9K 1/10 PCT 50 PPM 1/8W	6190-5330	75042	CEA 9 K 0.1PCT T-2
R	91	RES COMP 220 M 20PCT 1/2W	6100-7228	81349	RCR20G227
R	92	POT CERAM TRM 100K OHM 10 PCT1TS	6049-0301	80294	3329W-10-104
R	120	RES FLM 20K 5/100PCT 15PPM 1/4W	6619-3454	24655	6619-3454
R	121	RES FLM 10K 5/100PCT15PPM1/4W	6619-3450	24655	6619-3450
R	122	RES COMP 47 K 5PCT 1/4W	6099-3475	81349	RCR07G473J
R	123	RES COMP 47 K 5PCT 1/4W	6099-3475	81349	RCR07G473J
R	124	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	125	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	126	RES COMP 470 M 20PCT 1/4W	6099-7478	81349	RCR07G447
R	127	RES COMP 39 K 5PCT 1/4W	6099-3395	81349	RCR07G393J
R	128	POT COMP TRM 100K OHM 20PCT 1T	6040-1000	01121	YR104M
R	129	RES FLM 402K 1 PCT 1/4W	6350-3402	81349	RN60D4023F
R	131	RES FLM 84.5K 1 PCT 1/8W	6250-2845	81349	RN55D8452F
R	132	RES COMP 47 K 5PCT 1/4W	6099-3475	81349	RCR07G473J
R	133	RES COMP 160 K OHM 5PCT 1/4W	6099-4165	81349	RCR07G164J
R	135	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	136	RES FLM 10.0K 1 PCT 1/8W	6250-2100	81349	RN55D1002F
R	137	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	138	RES COMP 20 K OHM 5PCT 1/4W	6099-3205	81349	RCR07G203J
R	140	RES COMP 20 K OHM 5PCT 1/4W	6099-3205	81349	RCR07G203J
R	141	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	142	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	143	RES COMP 100 OHM 5PCT 1/4W	6099-1105	81349	RCR07G101J
R	144	RES COMP 27 K 5PCT 1/4W	6099-3275	81349	RCR07G273J
R	150	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	152	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	153	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	155	RES COMP 20 K OHM 5PCT 1/4W	6099-3205	81349	RCR07G203J
R	156	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	157	RES COMP 68 K 5PCT 1/4W	6099-3685	81349	RCR07G683J
R	158	RES COMP 16 K OHM 5PCT 1/4W	6099-3165	81349	RCR07G163J
R	159	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	160	RES COMP 68 K 5PCT 1/4W	6099-3685	81349	RCR07G683J
R	161	RES COMP 4.7 K 5PCT 1/4W	6099-2475	81349	RCR07G472J
R	162	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	163	RES COMP 68 K 5PCT 1/4W	6099-3685	81349	RCR07G683J
R	164	RES COMP 20 K OHM 5PCT 1/4W	6099-3205	81349	RCR07G203J
R	165	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	166	RES COMP 68 K 5PCT 1/4W	6099-3685	81349	RCR07G683J
R	167	RES COMP 20 K OHM 5PCT 1/4W	6099-3205	81349	RCR07G203J
R	170	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	171	RES COMP 390 K 5PCT 1/4W	6099-4395	81349	RCR07G394J
R	172	RES COMP 15 K 5PCT 1/4W	6099-3155	81349	RCR07G153J
R	173	RES COMP 200 K OHM 5PCT 1/4W	6099-4205	81349	RCR07G204J
R	174	RES COMP 5.1 K OHM 5PCT 1/4W	6099-2515	81349	RCR07G512J
R	180	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	181	RES COMP 100 OHM 5PCT 1/4W	6099-1105	81349	RCR07G101J
R	182	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	183	RES COMP 100 OHM 5PCT 1/4W	6099-1105	81349	RCR07G101J
R	184	RES COMP 390 K 5PCT 1/4W	6099-4395	81349	RCR07G394J
R	185	RES COMP 510 OHM 5PCT 1/4W	6099-1515	81349	RCR07G511J
R	187	RES COMP 200 K OHM 5PCT 1/4W	6099-4205	81349	RCR07G204J
R	190	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	191	POT COMP TRM 100K OHM 20PCT 1T	6040-1000	01121	YR104M
R	192	RES COMP 390 K 5PCT 1/4W	6099-4395	81349	RCR07G394J
R	193	RES COMP 510 OHM 5PCT 1/4W	6099-1515	81349	RCR07G511J
R	195	RES COMP 7.5 K OHM 5PCT 1/4W	6099-2755	81349	RCR07G752J
R	196	RES COMP 68 K 5PCT 1/4W	6099-3685	81349	RCR07G683J
R	197	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J

NOTE: This parts list is continued on page 6-6

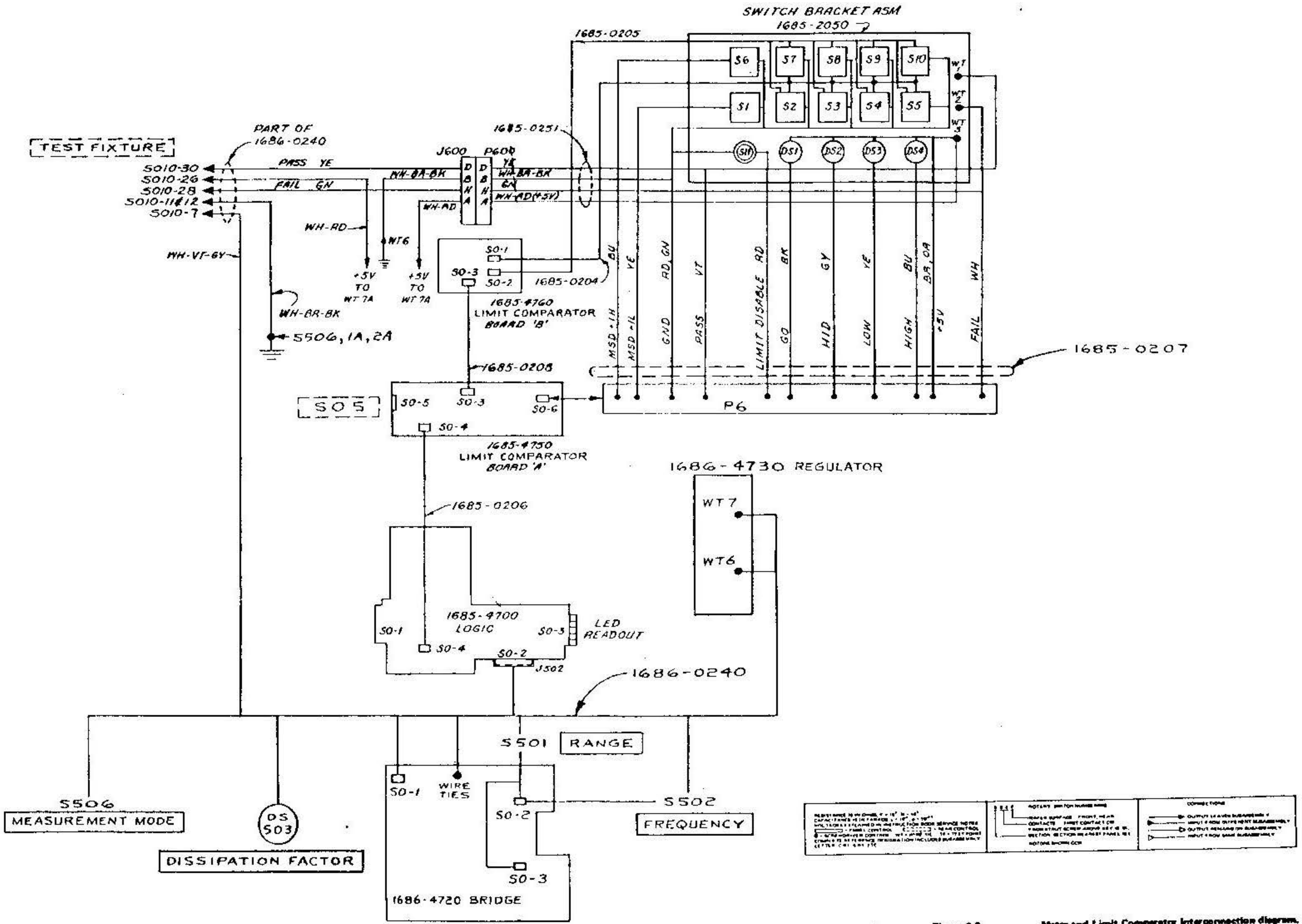


Figure 6-3. Meter and Limit Comparator Interconnection diagram.

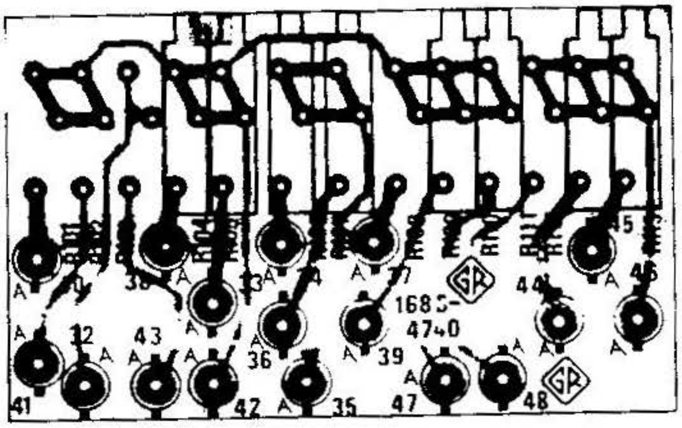
BRIDGE BOARD SIGNAL NAMES

Signal Name	Signal Location	Signal Function
REF	TP17	REFERENCE PULSE to logic board. 1 kHz for C-1K, 120 Hz for C-120. Generates burst pulse.
STC	S01-11	START COUNT. Enables main dual slope integrator (U7) and denominator integrator (U8).
BST	S01-2	BURST PULSES. 200 pulses for C-1K, 20 pulses for C-120. Establish measurement time and gate input to integrators.
CP1	U9-6	CLOCK PULSE 1. Comparator output signifies threshold crossover. Generates CTN.
CTN	S01-1	COUNT N. Determines the number of 100's count to logic board. Enables E_{dn} input to main dual slope integrator U7.
SUD	S01-13	START UP-DOWN. Enables up-down dual slope integrator (U10) for remainder conversion (units and tens digits readout).
UPC	S01-14	UP COUNT. Enables remainder input (Q26) to up-down integrator for a specified time (100-count oscillator pulses).
DNC	S01-12	DOWN COUNT. Enables denominator input (Q27) to up-down integrator for units and tens digits readout on logic board.
CP2	S01-7	CLOCK PULSE 2. Comparator output signifies DNC complete (0-V threshold). End of measurement.
CC	TP15	COUNT COMPLETE. End of measurement; enables NV flip-flop.
NV	TP21	NEW VALUE. Signifies the new value is in counters U3, U2, U8, U9, and U26.
SDL	TP22	SET DATA LATCH. Loads counter outputs into latches U15, U10, U9, U14, and U25.
$\overline{D1}$	TP20	DIGIT 1. Strobes LED readout No. 1.
$\overline{D2}$	TP19	DIGIT 2. Strobes LED readout No. 2.
$\overline{D3}$	TP18	DIGIT 3. Strobes LED readout No. 3.
$\overline{D4}$	TP17	DIGIT 4. Strobes LED readout No. 4.
RESET	TP1	RESET. Clear counters and starts new measurement.

ELECTRICAL PARTS LIST

POT PC BOARD P/N 1686-4740

REFDES (W- prefix)	DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
R 104	POT WW TRM 1K OHM 10 PCT 20T	6051-2109	80294	3005P-1-102
R 105	POT WW TRM 500 OHM 10 PCT 20T	6051-1509	80294	3005P-1-501
R 106	POT WW TRM 10K OHM 10 PCT 20T	6051-3109	80294	3005P-1-103
R 107	POT WW TRM 10K OHM 10 PCT 20T	6051-3109	80294	3005P-1-103
R 109	POT WW TRM 2K OHM 10 PCT 20T	6051-2209	80294	3005P-1-202
R 110	POT WW TRM 2K OHM 10 PCT 20T	6051-2209	80294	3005P-1-202
R 112	POT WW TRM 5K OHM 10 PCT 20T	6051-2509	80294	3005P-1-502
R 113	POT WW TRM 2K OHM 10 PCT 20T	6051-2209	80294	3005P-1-202



Potentiometer board (W) layout, P/N 1686-4740. (See Figure 6-4.)

NOTE: *Orientation:* Viewed from parts side. *Part number:* Refer to caption. *Symbolism:* Outlined area = part; black ckt pattern (if any) = parts side, gray = other side. *Pins:* Square pad in ckt pattern = collector, I-C pin 1, cathode (of diode), or + end (of capacitor).

ELECTRICAL PARTS LIST (cont)

BRIDGE PC BOARD P/N 1686-4720

REFDES		DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
R	200	RES COMP 8.2 K 5PCT 1/4W	6099-2825	81349	RCR07G822J
R	201	RES COMP 68 K 5PCT 1/4W	6099-3685	81349	RCR07G683J
R	202	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	203	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	204	RES FLM 10.0K 1 PCT 1/8W	6250-2100	81349	RN55D1002F
R	205	RES FLM 18.7K 1 PCT 1/8W	6250-2187	81349	RN55D1872F
R	206	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	207	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	208	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	209	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	210	RES COMP 4.7 K 5PCT 1/4W	6099-2475	81349	RCR07G472J
R	211	RES FLM 10.0K 1 PCT 1/8W	6250-2100	81349	RN55D1002F
R	212	RES FLM 55.6K 1/2PCT 1/8W	6251-2556	81349	RN55D5562D
R	213	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	214	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	215	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	216	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	217	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	218	RES COMP 4.7 K 5PCT 1/4W	6099-2475	81349	RCR07G472J
R	221	RES FLM 3.24K 1 PCT 1/8W	6250-1324	81349	RN55D3241F
R	222	RES FLM 24.9K 1 PCT 1/8W	6250-2249	81349	RN55D2492F
R	223	RES FLM 226K 1 PCT 1/8W	6250-3226	81349	RN55D2263F
R	224	RES FLM 3.24K 1 PCT 1/8W	6250-1324	81349	RN55D3241F
R	225	RES FLM 24.9K 1 PCT 1/8W	6250-2249	81349	RN55D2492F
R	226	RES FLM 226K 1 PCT 1/8W	6250-3226	81349	RN55D2263F
R	227	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	228	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	231	RES COMP 200 K OHM 5PCT 1/4W	6099-4205	81349	RCR07G204J
R	232	RES FLM 200K 1 PCT 1/8W	6250-3200	81349	RN55D2003F
R	233	RES FLM 49.9K 1 PCT 1/8W	6250-2499	81349	RN55D4992F
R	234	RES FLM 49.9K 1 PCT 1/8W	6250-2499	81349	RN55D4992F
R	235	RES COMP 10 OHM 5PCT 1/4W	6099-0105	81349	RCR07G100J
R	236	POT WW TRM 2K OHM 10 PCT 1T	6056-0140	24655	6056-0140
R	238	RES FLM 143K 1 PCT 1/8W	6250-3143	81349	RN55D1433F
R	239	RES FLM 49.9K 1 PCT 1/8W	6250-2499	81349	RN55D4992F
R	240	RES COMP 4.7 K 5PCT 1/4W	6099-2475	81349	RCR07G472J
R	241	RES COMP 47 K 5PCT 1/4W	6099-3475	81349	RCR07G473J
R	242	RES COMP 1.5 M 5PCT 1/4W	6099-5155	81349	RCR07G155J
R	243	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	244	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	245	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	246	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	247	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	249	RES COMP 47 K 5PCT 1/4W	6099-3475	81349	RCR07G473J
R	250	RES COMP 47 K 5PCT 1/4W	6099-3475	81349	RCR07G473J
R	251	RES COMP 47 K 5PCT 1/4W	6099-3475	81349	RCR07G473J
R	252	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	253	RES COMP 91 K OHM 5PCT 1/4W	6099-3915	81349	RCR07G913J
R	254	RES COMP 8.2 K 5PCT 1/4W	6099-2825	81349	RCR07G822J
R	255	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	256	RES COMP 16 K OHM 5PCT 1/4W	6099-3165	81349	RCR07G163J
R	257	RES COMP 91 K OHM 5PCT 1/4W	6099-3915	81349	RCR07G913J
R	258	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	259	RES COMP 20 K OHM 5PCT 1/4W	6099-3205	81349	RCR07G203J
R	260	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	261	POT COMP TRM 100K OHM 20PCT 1T	6040-1000	01121	YR104M
R	262	POT WW TRM 20 OHM 10 PCT 1T	6056-0128	24655	6056-0128
R	263	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	264	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	265	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	266	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	267	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	268	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	269	RES COMP 20 K OHM 5PCT 1/4W	6099-3205	81349	RCR07G203J
R	270	RES WW MOLDED 1.5 OHM 10 PCT 2W	6760-9159	75042	BWH 1.5 OHM 10PCT
R	271	RES COMP 510 K OHM 5PCT 1/4W	6099-4515	81349	RCR07G514J
R	272	RES COMP 4.7 K 5PCT 1/4W	6099-2475	81349	RCR07G472J
R	273	RES COMP 4.7 K 5PCT 1/4W	6099-2475	81349	RCR07G472J
R	274	RES COMP 4.7 K 5PCT 1/4W	6099-2475	81349	RCR07G472J
R	275	RES COMP 4.7 K 5PCT 1/4W	6099-2475	81349	RCR07G472J
R	277	RES COMP 200 K OHM 5PCT 1/4W	6099-4205	81349	RCR07G204J
R	278	RES COMP 5.1 M OHM 5PCT 1/4W	6099-5515	81349	RCR07G515J
R	279	RES COMP 27 K 5PCT 1/4W	6099-3275	81349	RCR07G273J

ELECTRICAL PARTS LIST (cont)

BRIDGE PC BOARD P/N 1686-4720

REFDES		DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
R	280	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	282	RES COMP 220 K 5PCT 1/4W	6099-4225	81349	RCR07G224J
R	284	RES COMP 27 M 5PCT 1/4W	6099-6275	81349	RCR07G276J
SO	1	SOCKET CABLE 14 CONTACT PC	7540-1815	71785	133-51-02-003
SO	2	SOCKET CABLE 14 CONTACT PC	7540-1815	71785	133-51-02-003
SO	3	SOCKET CABLE 14 CONTACT PC	7540-1815	71785	133-51-02-003
U	1	IC LINEAR LM301A	5432-1004	12040	LM301AH
U	2	IC LINEAR LM308	5432-1030	12[illegible]	LM308H
U	3	IC LINEAR LM308	5432-1030	12040	LM308H
U	4	IC LINEAR LM301A	5432-1004	12040	LM301AH
U	5	IC LINEAR LM308A	5432-1027	12040	LM308AH
U	6	IC LINEAR LM308A	5432-1027	12040	LM308AH
U	7	IC LINEAR LM308A	5432-1027	12040	LM308AH
U	8	IC LINEAR LM308A	5432-1027	12040	LM308AH
U	9	IC LINEAR LM301A	5432-1004	12040	LM301AH
U	10	IC LINEAR LM308A	5432-1027	12040	LM308AH
U	11	IC LINEAR LM201A	5432-1045	12040	LM201AH
U	12	IC LINEAR LM311	5432-1023	10204	LM311H
U	13	IC LINEAR LM311	5432-1023	10204	LM311H
U	14	IC LINEAR LM301A	5432-1004	12040	LM301AH
U	15	IC LINEAR LM201A	5432-1045	12040	LM201AH
U	16	IC LINEAR LM301A	5432-1004	12040	LM301AH
U	17	IC LINEAR LM301A	5432-1004	12040	LM301AH
U	18	IC LINEAR LM301A	5432-1004	12040	LM301AH
U	19	IC LINEAR LM301A	5432-1004	12040	LM301AH
U	20	ICD SN74LS132N 14D Q 2IN NANDSCH	5431-8732	01295	SN74LS132N
U	21	ICD SN74LS132N 14D Q 2IN NANDSCH	5431-8732	01295	SN74LS132N

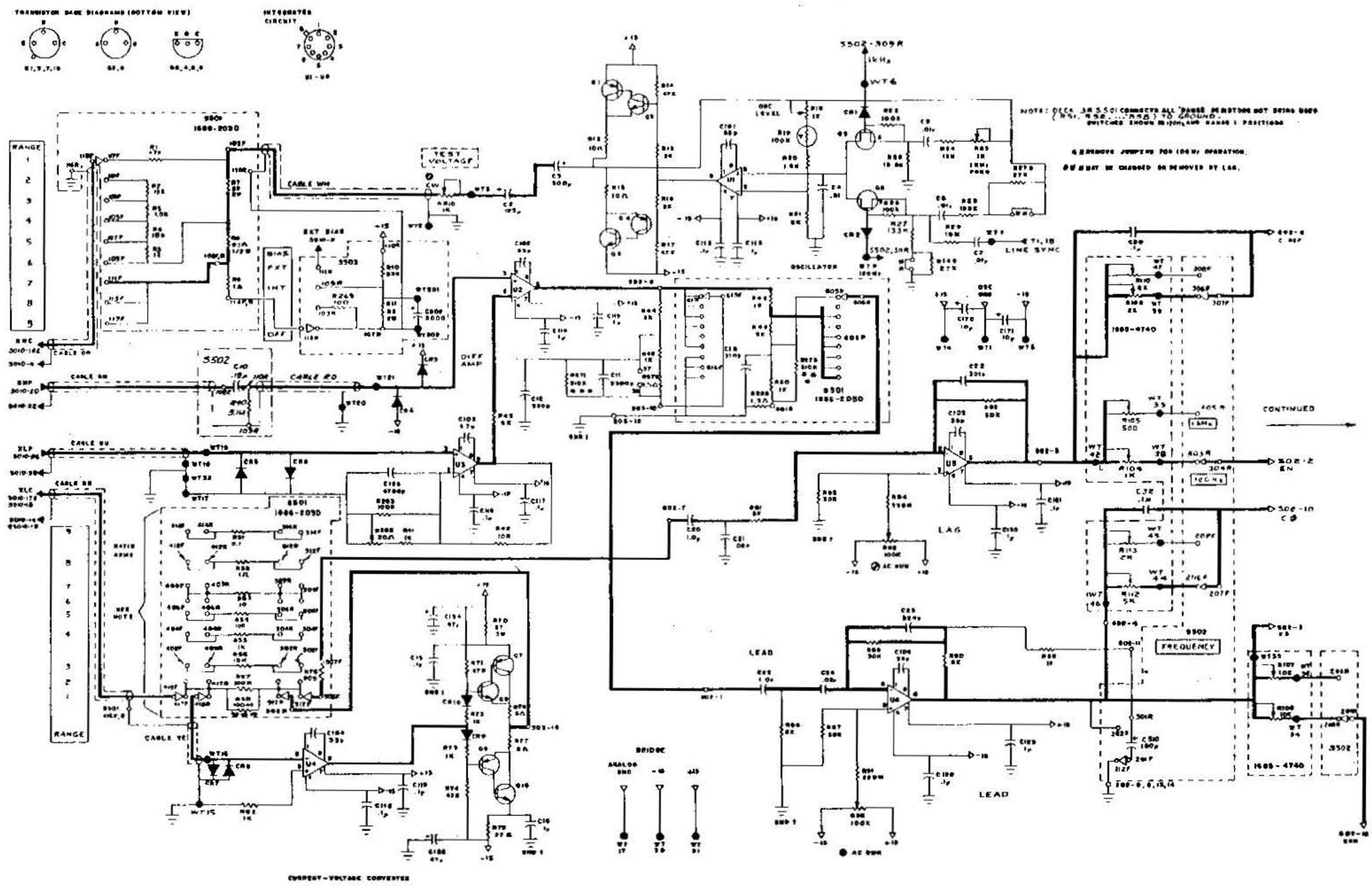


Figure 5-4A. Bridge Board (P) schematic (left).

L-1

BRIDGE BOARD WAVEFORMS

Figures 5 thru 9 show the time related waveforms, test points at which the waveforms are observed, and scope settings for a C-1K measurement of standard 0.1 µF capacitor.

NOTE: With a 1685-P1 or measurement cable with a 0.1-µF standard capacitor and a series 3.3-kΩ resistor connected, only slightly different wave waveforms will be observed.

To obtain the required waveforms

A. Set switches to the following positions:
Frequency .... C 1K
Mode .... REPETITIVE, 0.25 SEC
Range 5
External Bias .... OFF
D Dial D-0.1

B. Use the 3.3-kΩ resistor in series with a GR 1409 T (0.1 µF)

C. Set the scope switches to:
MODE .... ALT
TRIG CH1

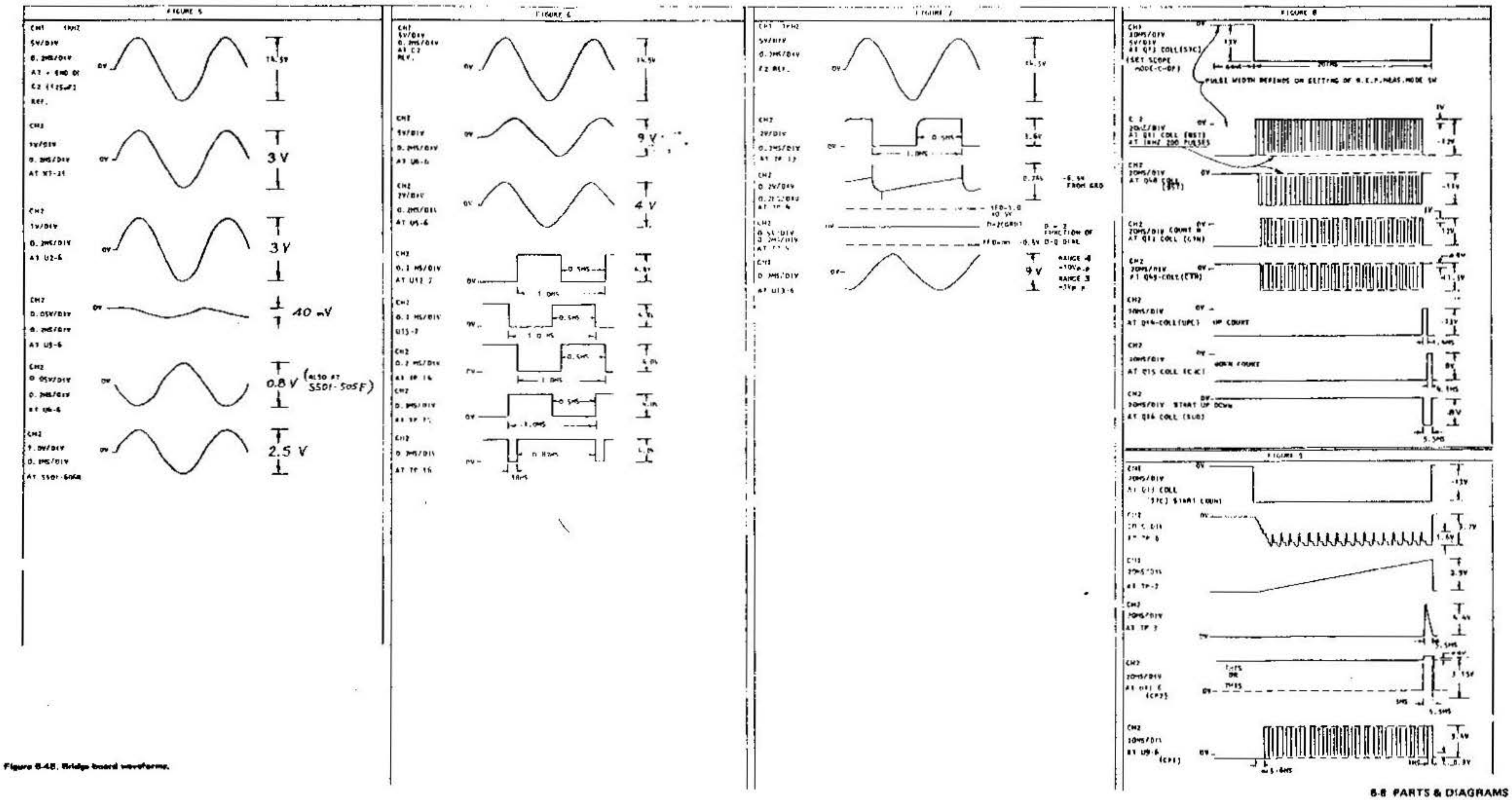


Figure 6-48. Bridge board waveforms.

6.74

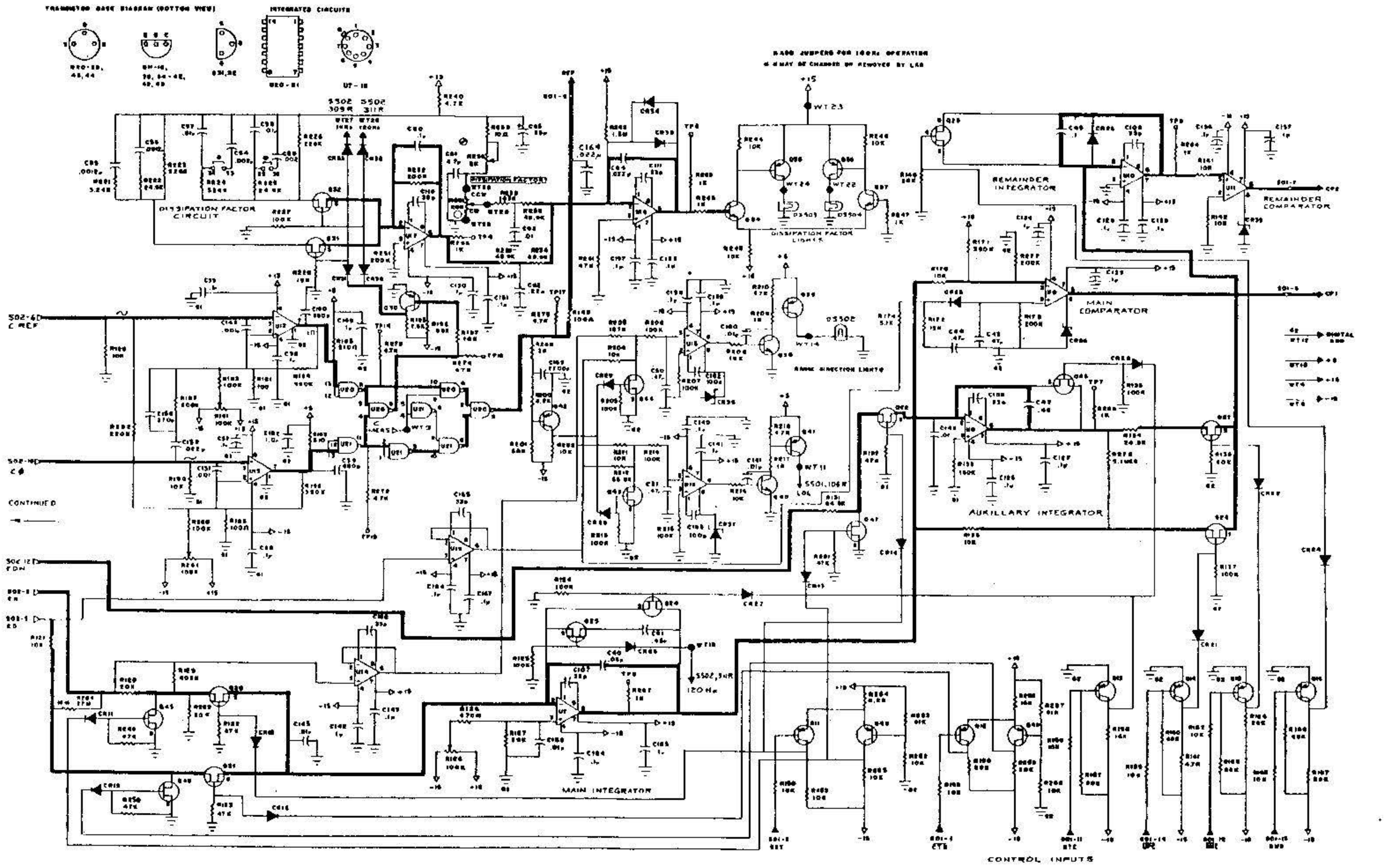


Figure 6-4C. Bridge-board (P) schematic (right).

RESISTANCE IS IN OHMS, K = 10^3, M = 10^6
CAPACITANCE IS IN FARADS, μ = 10^{-6}, p = 10^{-12}
VOLTAGES EXPLAINED IN INSTRUCTION BOOK SERVICE NOTES
▭ = PANEL CONTROL ⬚ = REAR CONTROL
● = SCREWDRIVER CONTROL WT = WIRE TIE TP = TEST POINT
COMPLETE REFERENCE DESIGNATION INCLUDES SUBASSEMBLY LETTER, C-R1, B-R1, ETC.

4 0 4 F ROTARY SWITCH NUMBERING

- WAFER SURFACE: FRONT, REAR
- CONTACTS: FIRST CONTACT CW FROM STRUT SCREW ABOVE KEY IS 01.
- SECTION. SECTION NEAREST PANEL IS 1

ROTORS SHOWN CCW

CONNECTIONS

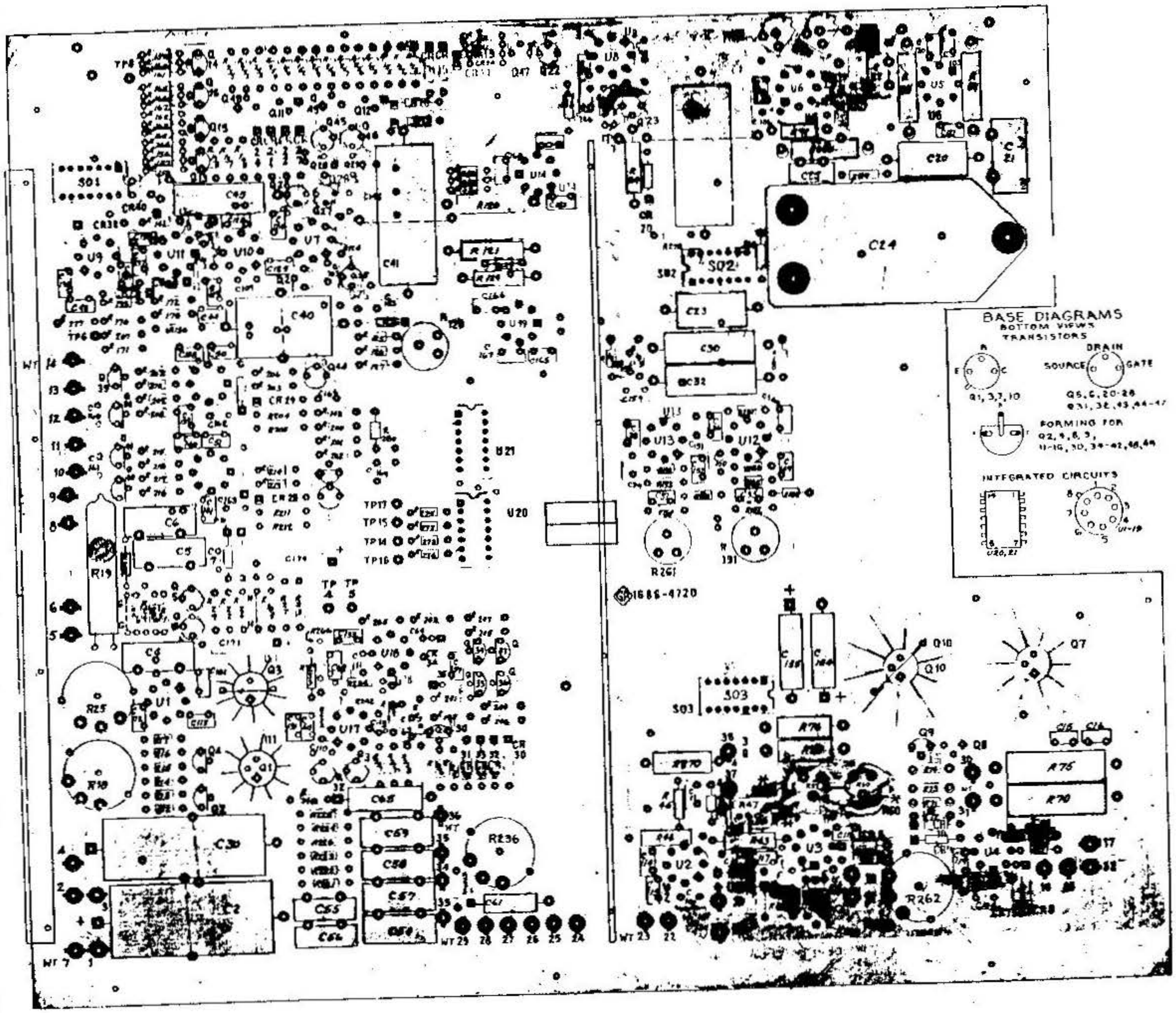
- OUTPUT LEAVES SUBASSEMBLY
- INPUT FROM DIFFERENT SUBASSEMBLY
- OUTPUT REMAINS ON SUBASSEMBLY
- INPUT FROM SAME SUBASSEMBLY

6.10a

ELECTRICAL PARTS LIST

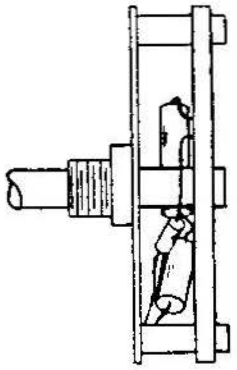
SWITCH ASM   P/N 1685-2040

REFDES (G- prefix)	DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
R 10	RES FLM 536 OHM 1 PCT 1/2W	6450-0536	81349	RN65D5360F
R 11	RES WW MOLDED 82 OHM 5 PCT 2W	6760-0825	75042	BWH 82 OHM 5PCT
R 269	RES COMP 10 OHM 5PCT 1/4W	6099-0105	81349	RCR07G100J
S 503	SWITCH ROTARY ASM (BIAS SWITCH)	7890-5622	24655	7890-5622

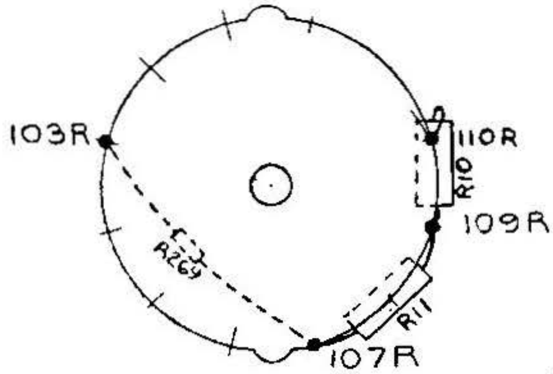


Bridge etched-circuit board (P/N 1685-4720) layout.

NOTE: *Orientation:* Viewed from parts side. *Part number:* Refer to caption. *Symbolism:* Outlined area = part; black ckt pattern (if any) = parts side, gray = other side. *Pins:* Square pad in ckt pattern = collector, I-C pin 1, cathode (of diode), or + end (of capacitor).



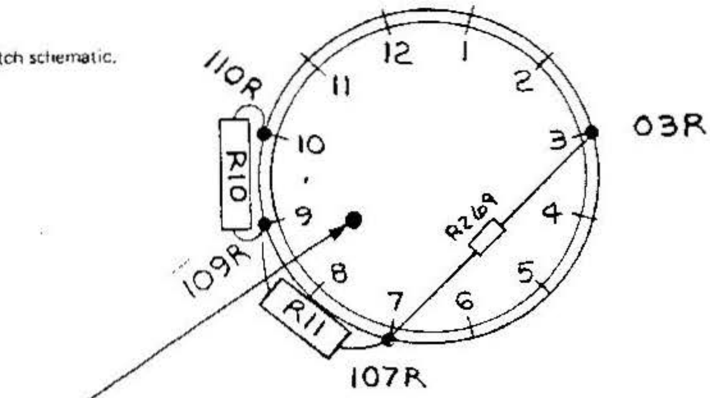
S-503



S-503, 103R TO S-503, 107R BY R269
S-503, 107R TO S-503, 109R BY R11
S-503, 109R TO S-503, 110R BY R10

NOTE

Figure 6-4 contains the switch schematic.



FRONT VIEW

Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

Figure 6-5. Bias switch S503 layout drawing showing parts.

Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

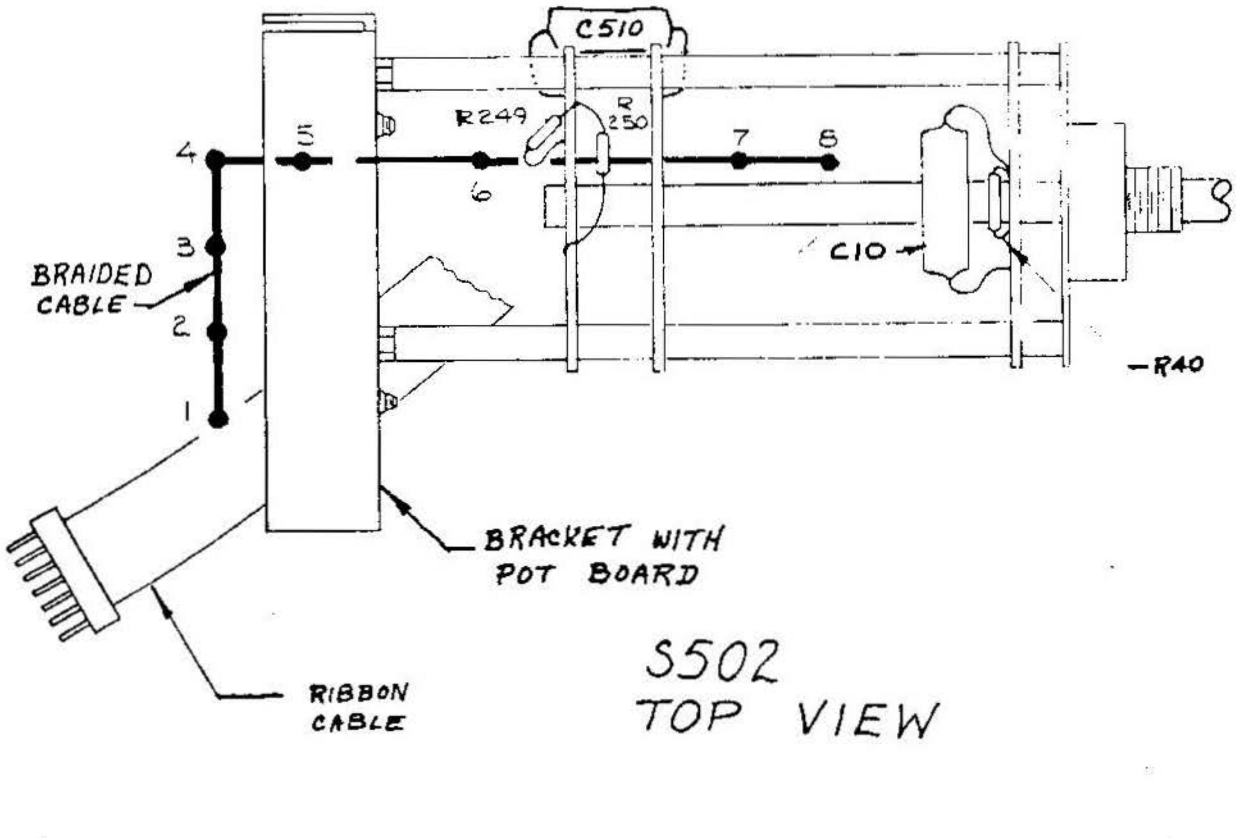


Figure 6-6. Frequency switch S502 layout drawing.

L 8lle

UNLESS SPECIFIED, MAKE THE FOLLOWING CONNECTIONS
USING ESMW-30-24. INSULATE WITH ESMP-3-24.

S501, 101F TO S501, 103F BY R2
•102F,R ——— 108F,R BY R7
103F ——— 105F BY R3
105F ——— 107F BY R4
107F ——— 109F BY R5
108F,R ——— 111F BY R8
109F ——— 108F,R
111F ——— *114F,R BY R9
111F ——— 113F TO S501, 115F
117F ——— *102F BY R1
•201R ——— 301F BY CR41 (CATHODE TO 301F)
•204R ——— 202R
•208R ——— 218R
•207R ——— 209F BY CR40 (CATHODE TO 209F)
•206R ——— 216R
302R ——— 402F,R TO S501, 502F,R BY R56
304R ——— 404F,R ——— 504F,R BY R55
306R ——— 406F,R ——— 506F,R BY R54
309R ——— 409F,R ——— 509F,R BY R53
312R ——— 412F,R ——— 512F,R BY R52
314R ——— 414F,R ——— 514F,R BY R51
317R ——— 417F,R TO S501, 517F,R BY R57 & R58
•416F,R ——— 316R
505F ——— *507F BY R78
601F,R ——— 616F BY R280
602R ——— 617F BY R48
602R ——— 603R BY R49
603R ——— 601F,R BY R50 & 279
603R ——— 616F BY C18
•116F ——— *116R
205F ——— 305F
S501, 211F TO S501, 311F

CONNECT CABLE 1685-0270 TO S501
AS FOLLOWS:
YE WIRE TO S501, 617F
BK WIRE TO S501, 615F
BU WIRE TO S501, 616F
RD WIRE TO S501, 508R

CONNECT CONTACT SPRING 5600-1025(5)
TO ONE END OF THE FOLLOWING
CONNECTOR LINKS AND THE OTHER
END TO S501 AS FOLLOWS:
5080-6055 TO S501, 104R
5080-6057 TO S501, 217F
5080-6055 TO S501, 211F
5080-6053 TO S501, 205F
5080-6054 TO S501, 318F

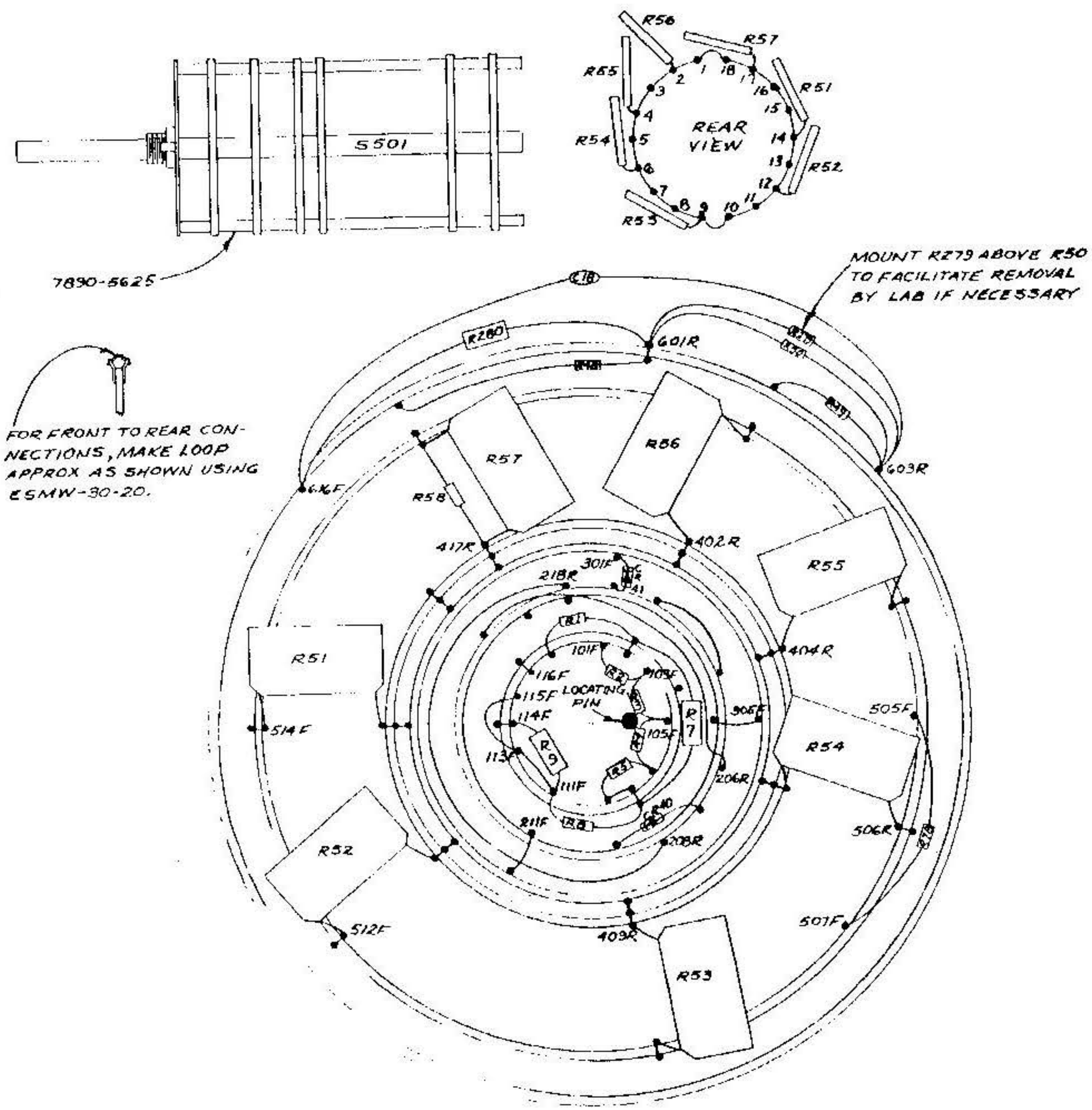


Figure 6-7. Range switch S501 l[illegible] rawing.

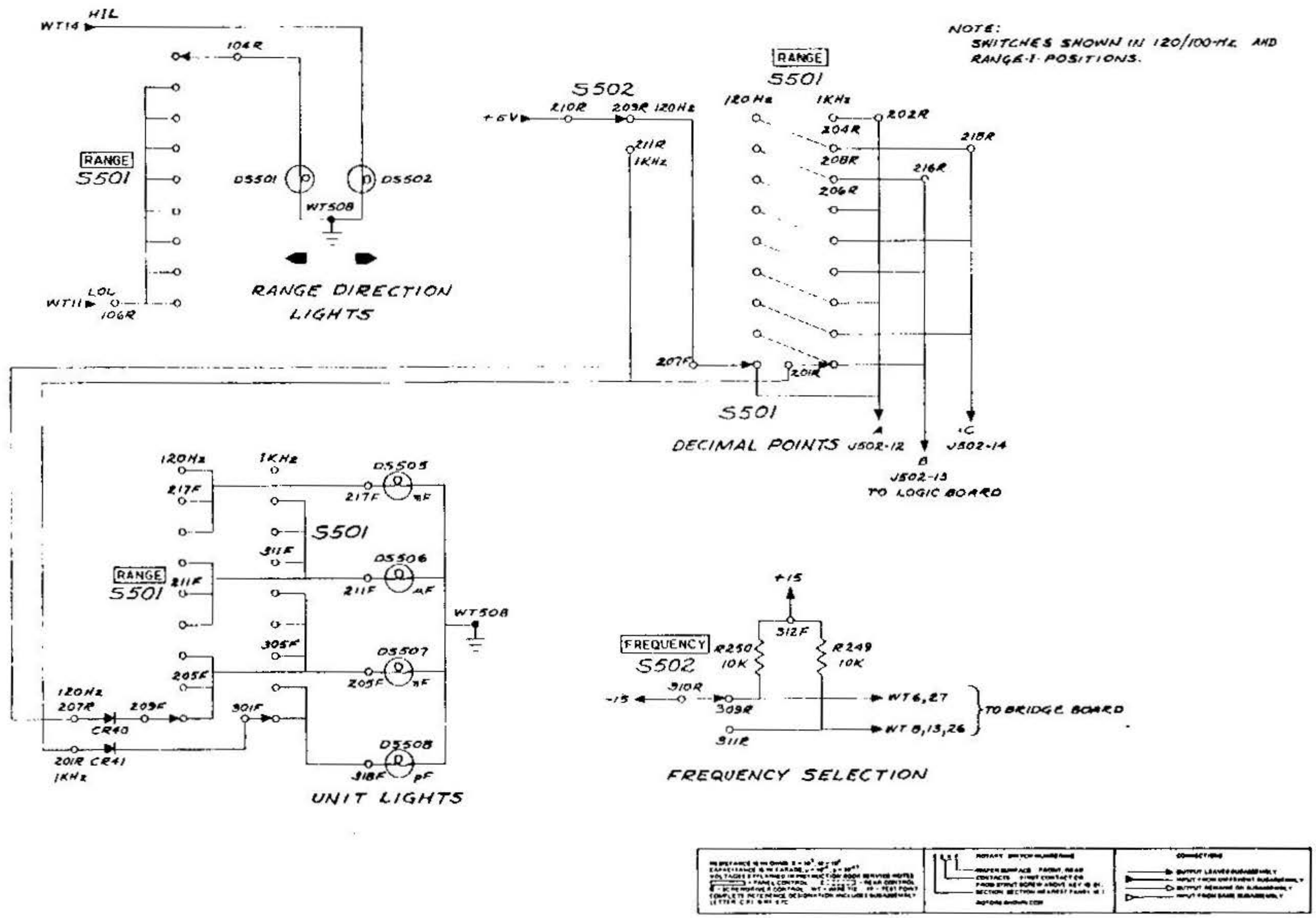
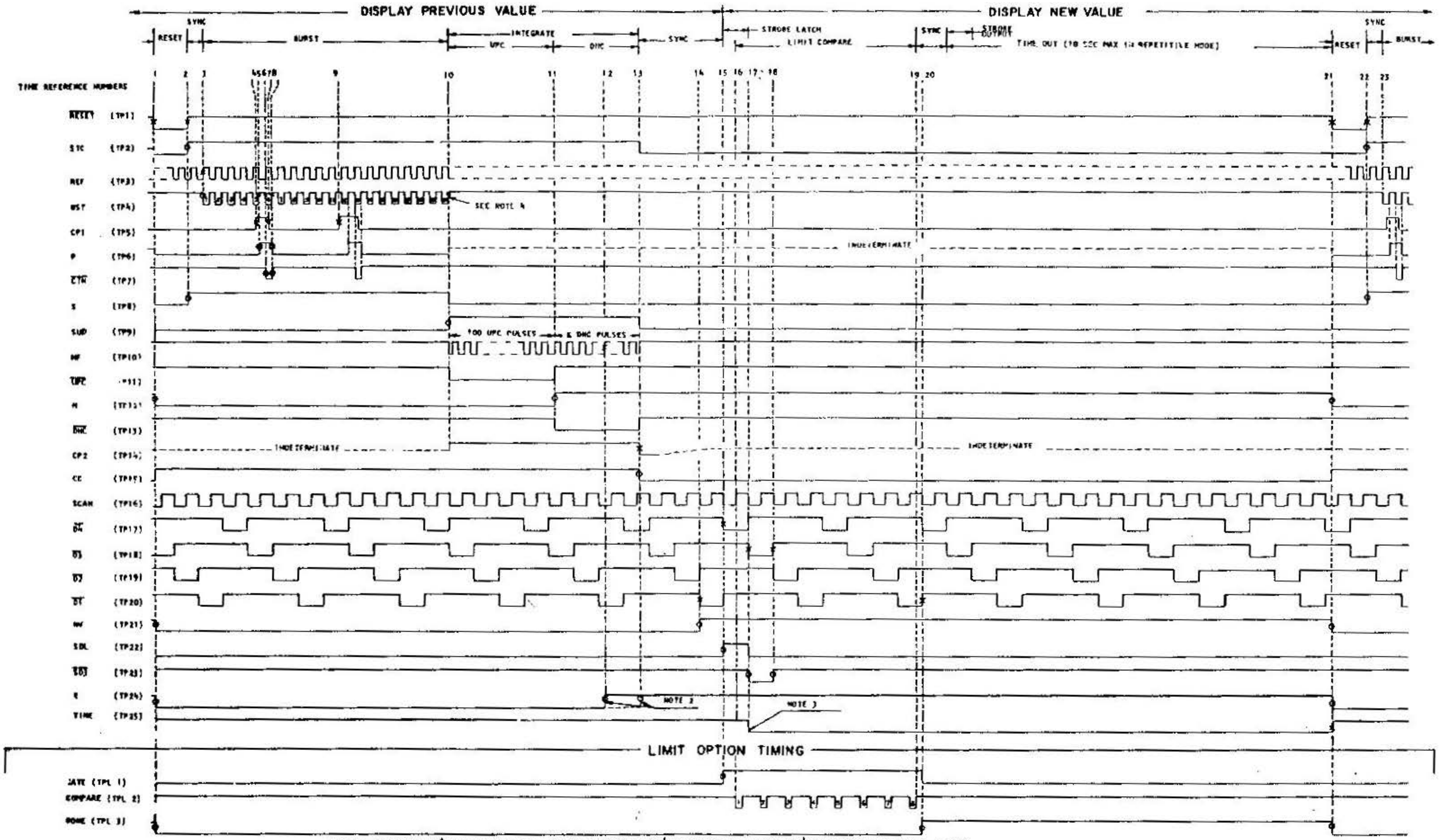


Figure 6-8. Frequency and range switches S502 and S501 schematic diagram.



NOTES 1. EDGES MARKED ↕ ARE ACTIVATING TRANSITIONS; AN EDGE MARKED ◆ IS A PRIMARY RESULT OF THE ↕ TRANSITION AT THAT POINT IN TIME.

2. THE EARLIEST TIME THAT THIS EDGE CAN OCCUR IS AFTER 2000 DNC PULSES. THE LATEST TIME IT CAN OCCUR IS SHOWN DOTTED (WHEN "CC" GOES LOW). IF IT HAS NOT OCCURED BEFORE "CC" GOES LOW, "E" WILL SIMPLY REMAIN LOW.

3. "TIME" IS ACTIVATED BY THE NEGATIVE-GOING EDGE OF "SO" WHEN THE FRONT PANEL "MODE" SWITCH IS IN THE "REPETITIVE" POSITION.

4. 20 COUNTS WHEN MAKING 120 HZ MEASUREMENTS; 200 COUNTS WHEN MAKING 1KHZ MEASUREMENTS.

Figure 6-8. System timing diagram.

ELECTRICAL PARTS LIST

RANGE SWITCH, S501
SWITCH ASM P/N 1686-2030

REFDES (G- prefix)		DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C	18	CAP CER DISC 510PF 10PCT 500V	4404-1519	72982	0831082Z5F0L511K
CR	40	DIODE 1N455 30PIV IR 30UA GE	6082-1010	14433	1N455
CR	41	DIODE 1N455 30PIV IR 30UA GE	6082-1010	14433	1N455
R	1	RES COMP 47 K 5PCT 1/4W	6099-3475	81349	RCR07G473J
R	2	RES COMP 18 K 5PCT 1/4W	6099-3185	81349	RCR07G183J
R	3	RES COMP 1.8 K 5PCT 1/4W	6099-2185	81349	RCR07G182J
R	4	RES COMP 180 OHM 5PCT 1/4W	6099-1185	81349	RCR07G181J
R	5	RES COMP 12 OHM 5PCT 1/4W	6099-0125	81349	RCR07G120J
R	7	RES WW MOLDED 39 OHM 5PCT 2W	6760-0395	75042	BWH 39 OHM 5PCT
R	8	RES COMP 9.1 OHM 5PCT 1/2W	6100-9915	81349	RCR20G9R1J
R	9	RES WW MOLDED 1 OHM 5 PCT 2W	6760-9105	75042	BWH 1 OHM 5PCT
R	48	RES FLM 1K 1/10 PCT 50 PPM 1/8W	6190-2330	75042	CEA 1 K 0.1PCT T-2
R	50	RES FLM 1K 1/10 PCT 50 PPM 1/8W	6190-2330	75042	CEA 1 K 0.1PCT T-2
R	51	RESISTOR ASM 0.1 OHM 0.25PCT	1617-1180	24655	1617-1180
R	52	RES GR 1.000 OHM .02PCT 1W	6983-1006	24655	6983-1006
R	53	RES GR 10.000 OHM .02PCT 1W	6983-2005	24655	6983-2005
R	54	RES GR 100 OHM .025 PCT 1W	6983-3000	24655	6983-3000
R	55	RES GR 1K OHM .02 PCT 1W	6983-4000	24655	6983-4000
R	56	RES GR 10K OHM .02 PCT 1W	6983-5039	24655	6983-5039
R	57	RES GR 100K OHM .020 PCT 1W	6983-6000	24655	6983-6000
R	58	RES COMP 100 M 5PCT 1/4W	6099-7105	81349	RCR07G107J
R	78	RES FLM 909 OHM 1 PCT 1/8W	6250-0909	81349	RN55D9090F
R	279	RES COMP 510 K OHM 5PCT 1/4W	6099-4515	81349	RCR07G514J
R	280	RES WW MOLDED 1.5 OHM 10 PCT 2W	6760-9159	75042	BWH 1.5 OHM 10PCT

FREQUENCY SWITCH, S502
SWITCH ASM P/N 1686-2120

REFDES (G- prefix)		DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C	10	CAP MYLAR .18 UF 5PCT 100V	4860-7897	56289	410P 0.18 UF 5PCT
C	510	CAP TANT 180 UF 20PCT 6V	4450-5617	56289	150D187X0006R2
R	40	RES COMP 5.1 M OHM 5PCT 1/4W	6099-5515	81349	RCR07G515J
R	249	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	250	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J

FEDERAL MANUFACTURER'S CODE

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

Code	Manufacturer
00136	McCoy Electronics Co., Mt. Holly Springs, PA 17065
00192	Jones Mfg. Co., Chicago, IL 60607
00194	Walsco Electronics Corp., Los Angeles, CA 90063
00327	Welwyn International, Westlake, OH 44145
00434	Schweber Electronics, Westbury, NY 11590
00656	Aerovox Corp., New Bedford, MA 02745
00779	Amp, Inc., Harrisburg, PA 17105
01009	Alden Products Co., Brockton, MA 02413
01121	Allen-Bradley Co./Electronics Div., Milwaukee, WI 53204
01255	Litton Industries Inc., Beverly Hills, CA 90213
01295	Texas Instruments, Inc., Dallas, TX 75222
01930	Amerock, Corp., Rockford, IL 61101
02111	Spectrol Electronics Corp., City of Industry, CA 91745
02114	Ferroxcube Corp., Saugerties, NY 12477
02606	Fenwal Lab Inc., Morton Grove, IL 60053
02660	Amphenol Electron Corp., Broadview, IL 60153
02768	Fastex, Des Plaines, IL 60016
03042	Carter Ink Co., Cambridge, MA 02142
03508	G. E. Semicon Prod., Syracuse, NY 13201
03636	Grayburne, Yonkers, NY 10701
03877	Transitron Electronics, Wakefield, MA 01880
03911	Clairex Corp., New York, NY 10001
04009	Arrow Hart, Hartford, CT 06106
04643	Digitronics Corp., Albertson, NY 11507
04713	Motorola, Phoenix, AZ 85008
04919	Component Mfg. Service, Inc., West Bridgewater, MA 02379
05079	Tansitor Electronics, Bennington, VT 05201
05402	Controls Co. of America, Melrose Park, IL 60160
05574	Viking Industries, Inc., Chatsworth, CA 91311
05624	Barber-Colman Co., Rockford, IL 61101
05748	Barnes Mfg. Co., Mansfield, OH 44901
05820	Wakefield Engineering Inc., Wakefield, MA 01880
06743	Clevite Corp., Cleveland, OH 44110
07126	Digitran Co., Pasadena, CA 91105
07127	Eagle Signal (E.W. Bliss Co.), Baraboo, WI 53913
07233	Cinch Graphik, City of Industry, CA 91744
07261	Avnet Corp., Culver City, CA 90230
07263	Fairchild Semiconductor, Mountain View, CA 94040
07387	Birtcher Corp., No. Los Angeles, CA 90032
07595	Amer. Semiconductor, Arlington Hts, IL 60004
07828	Bodine Corp., Bridgeport, CT 06605
07829	Bodine Electric Co., Chicago, IL 60618
07910	Cont. Device Corp., Hawthorne, CA 90250
07983	State Labs, Inc., New York, NY 10003
07999	Borg Instruments, Delavan, WI 53115
08730	Vemaline Products Co., Franklin Lakes, NJ 07417
09213	G. E. Semiconductor, Buffalo, NY 14207
09353	C & K Components Inc., Watertown, MA 02172
09408	Star-Tronics Inc., Georgetown, MA 01830
09823	Burgess Battery Co., Freeport, IL 61032
09856	Fenwal Electronics, Inc., Framingham, MA 01701
09922	Burndy Corp., Norwalk, CT 06857
11236	CTS of Berne, Inc., Berne, IN 46711
11599	Chandler Evans Corp., W. Hartford, CT 06101
11983	Nortronics Co., Inc., Minneapolis, MN 55427
12040	National Semiconductor, Santa Clara, CA 95051
12045	Electronic Transistors Corp., Flushing, NY 11364
12498	Teledyne Semiconductor, Mountain View, CA 94043
12617	Hamlin, Inc., Lake Mills, WI 53551
12672	R. C. A., Woodbridge, NJ 07095
12697	Clarostat Mfg. Co., Inc., Dover, NH 03820
12954	Dickson Electronics Corp., Scottsdale, AZ 85252
12969	Unitrode Corp., Watertown, MA 02172
13094	Electrocraft Corp., Hopkins, MN 55343
13103	Thermalloy, Inc., Dallas, TX 75234
13327	Solitron Devices, Tappan, NY 10983
13919	Burr Brown Research Corp., Tucson, AZ 85706
14196	Electronic Controls, Inc., Wilton, CT 06897
14433	I.T.T. Semiconductors, W. Palm Beach, FL 33402
14482	Watkins & Johnson Co., Palo Alto, CA 94304
14655	Cornell Dubilier Electronics, Newark, NJ 07101
14674	Corning Glass Works, Corning, NY 14830
14749	Acopian, Easton, PA 18042
14752	Electro Cube, Inc., San Gabriel, CA 91776
14936	General Instrument Corp., Hicksville, NY 11802
15116	Microdot Magnetics, Inc., Los Angeles, CA 90053
15238	I.T.T. Semiconductors, Lawrence, MA 08142
15476	Digital Equipment Corp., Maynard, MA 01754
15605	Cutler Hammer, Inc., Milwaukee, WI 53202
15782	Houston Instrument Corp., Bellaire, TX 77401
16037	Spruce Pine Mica Co., Spruce Pine, NC 28777
16179	Omni Spectra Mich Div., Farmington, MI 48024
16352	Computer Diode Corp., Lodi, NJ 07644
16636	Indiana General Corp., Oglesby, IL 61348
16758	Delco Electronic Div., GMC, Kokomo, IN 46901
16960	Precision Dynamics Corp., Burbank, CA 91504
16952	American Micro Devices, Inc., Summerville, SC 29483
17117	Electronic Molding Corp., Woonsocket, RI 02895
17771	Singer Co., Diehl Div., Somerville, NJ 08876
17850	Zeltex, Inc., Concord, CA 94520
17856	Siliconix, Inc., Santa Clara, CA 95054
18324	Signetics, Corp., Sunnyvale, CA 94086
18642	New Product Engineering Inc., Wabash, IN 46992
18677	Scanbe Manufacturing Corp., El Monte, CA 91731
18736	Voltronics Corp., Hanover, NJ 07936
18736	Computer Diode Corp., S. Fairlawn, NJ 07936
19048	Computer Diode Corp., S. Fairlawn, NJ 07410
19178	Zero Manufacturing Co., Monson, MA 01057
19373	Eastron Corp., Haverhill, MA 01830
19396	Illinois Tool Works, Paxton Div., Chicago, IL 60634
19617	Cabtron Corp., Chicago, IL 60622
19644	L.R.C. Electronics, Horseheads, NY 14845
19701	Electra Mfg. Co., Independence, KS 67301
20754	K.M.C. Semiconductor, Long Valley, NJ 07853
21335	Fafnir Bearing Co., New Britain, CT 06050
21756	Lenox-Fugle Electronics, Watchung, NJ 07060
22753	UID Electronics Div., AMF Inc., Hollywood, FL 33022

Code	Manufacturer
23338	Wavetek Div., John Fluke, San Diego, CA 92112
23342	Avnet Electronics Corp., Franklin Park, IL 60131
24355	Analog Devices, Cambridge, MA 02142
24446	General Electric, Schenectady, NY 12305
24454	General Electric Electronics Comp., Syracuse, NY 13201
24455	General Electric Lamp Div., Cleveland, OH 44112
24802	E.M.C. Technology, Cherry Hill, NJ 08034
24655	General Radio Co., Concord, MA 01742
26289	E. G. & G. Inc., Bedford, MA 01730
26806	American Zettler, Inc., Costa Mesa, CA 92626
28480	Hewlett Packard, Palo Alto, CA 04304
28520	Heyman Mfg. Co., Kenilworth, NJ 07023
28959	Hoffman Electronics Corp., El Monte, CA 91734
30646	Beckman Instruments, Inc., Cedar Grove, NJ 07009
30874	I.B.M., Armonk, NY 10504
32001	Jensen Mfg. Co., Chicago, IL 60638
33173	General Electric Comp., Owensboro, KY 42301
34141	Koehler Mfg. Co., Inc., Marlboro, MA 01752
36929	Comsolants, Co., Montreal Quebec
37942	P. R. Mallory & Co., Inc., Indianapolis, IN 46206
38443	Marlin-Rockwell Corp., Jamestown, NY 14701
39317	McGill Manufacturing Co., Inc., Valparaiso, IN 46383
40931	Honeywell, Inc., Minneapolis, MN 55408
42190	Muter Co., Chicago, IL 60638
42498	National Co., Inc., Melrose, MA 02176
43991	Norma Hoffman, Stamford, CT 06904
49671	R. C.A., New York, NY 10020
49956	Raytheon Mfg. Co., Waltham, MA 02154
50088	Mostek, Carrollton, TX 75006
53021	Sangamo Electric Co., Springfield, IL 62706
54294	Shallcross Mfg. Co., Selma, NC 27576
54715	Shure Brothers, Inc., Evanston, IL 60202
56289	Sprague Electric Co., North Adams, MA 01247
59730	Thomas & Betts Co., Elizabeth, NJ 07207
59875	T.R.W. Inc., (Accessories Div), Cleveland, OH 44117
60399	Torrington Mfg. Co., Torrington, CT 06790
61637	Union Carbide Corp., New York, NY 10017
61864	United-Carr Fastener Corp., Boston, MA 02142
63060	Victoreen Instrument Co., Cleveland, OH 44104
63743	Ward Leonard Electric, Mt. Vernon, NY 10550
65083	Westinghouse (Lamp Div), Bloomfield, NJ 07003
65092	Weston Instruments, Newark, NJ 07114
70106	Acushnet Capacitor Co., New Bedford, MA 02742
70109	Adams and Westlake Co., Elkhart, IN 46514
70485	Atlantic India Rubber Works, Inc., Chicago, IL 60607
70563	Amperite Co., Union City, NJ 07087
70903	Belden Mfg. Co., Chicago, IL 60644
71126	Bronson Homer D., Beacon Falls, CT 06403
71279	Cambridge Thermionic, Corp., Cambridge, MA 02138
71294	Canfield Co., Clifton Forge, VA 24422
71400	Bussmann Mfg. Co., St. Louis, MO 63107
71450	CTS Corp., Elkhart, IN 46514
71468	ITT Cannon Electric Inc., Los Angeles, CA 90031
71482	C.P. Clare & Co., Chicago, IL 60645
71590	Centralab, Inc., Milwaukee, WI 53212
71866	Continental Carbon Co., Inc., New York, NY 10001
71707	Coto Coil Co., Inc., Providence, RI 02905
71729	Crescent Box Corp., E. Philadelphia, PA 19134
71744	Chicago Miniature Lamp, Chicago, IL 60640
71785	Cinch Jones, Chicago, IL 60624
71823	Darnell Corp., Ltd., Downey, CA 90241
72136	Electromotive Mfg. Co., Willimantic, CT 06226
72228	Continental Screw Co., New Bedford, MA 02742
72259	Nytronics, Inc., Berkeley Hts, NJ 07922
72619	Dialight Co., Brooklyn, NY 11237
72699	General Instrument Corp., Newark, NJ 07104
72765	Drake Mfg. Co., Chicago, IL 60631
72794	Dzus Fastener Co., Inc., West Islip, NY 11795
72825	Eby Co., Hugh H, Philadelphia, PA 19144
72962	Elastic Stop Nut Corp., Union, NJ 07083
72982	Erie Technological Products, Erie, PA 16512
73445	Amperex Electronic Corp., Hicksville, L.I., NY 11801
73559	Carling Electric Co., W. Hartford, CT 06110
73690	Elco Resistor Co., New York, NY 10001
73899	J.F.D. Electronics Corp., Brooklyn, NY 11219
73957	Groov-Pin Corp., Ridgefield, NJ 07657
74193	Heinemann Electric Co., Trenton, NJ 08602
74545	Hubbell, Stratford, CT 06497
74861	Industrial Condenser Corp., Chicago, IL 60618
74868	Amphenol RF Division, Danbury, CT 06810
74970	Johnson Co., E.F., Waseca, MN 56093
75042	IRC Div. of TRW, Burlington, IA 52601
75382	Kulka Electric Corp., Mt. Vernon, NY 10551
75491	Lafayette Industrial Electronics, Syosset, NY 11791
75608	Linden & Co., Providence, RI 02905
75915	Littelfuse, Inc., Des Plaines, IL 60016
76005	Lord Mfg. Co., Erie, PA 16512
76149	Mallory Electric Corp., Detroit, MI 48204
76381	Minnesota Mining, St. Paul, MN 55101
76487	Millen Mfg. Co., Inc., Malden, MA 02148
76545	Mueller Electric Co., Cleveland, OH 44114
76854	National Tube Co., Pittsburg, PA 15230
76854	Oak Mfg. Co., Crystal Lake, IL 60014
77147	Patton MacGuyer Co., Providence, RI 02905
77166	Pass-Seymour, Syracuse, NY 13209
77263	Pierce-Roberts Rubber Co., Trenton, NJ 08638
77339	Positive Lockwasher Co., Newark, NJ 07101
77342	American Machine & Foundry Co., Princeton, IN 47570
77542	Ray-O-Vac Co., Madison, WI 53703
77630	T.R.W. Electronic Comp., Camden, NJ 08103
77638	General Instruments Corp., Brooklyn, NY 11211
78189	Shakeproof (Ill. Tool Wks), Elgin, IL 60120
78277	Sigma Instruments Inc., South Braintree, MA 02184
78488	Stackpole Carbon Co., St. Mary's, PA 15827
78553	Tinnerman Products, Inc., Cleveland, OH 44101
79089	R.C.A. Rec. Tube & Semicond., Harrison, NJ 07029
79136	Waldes Kohinoor Co., New York, NY 11101

Code	Manufacturer
79725	Wiremold Co., Hartford, CT 06110
79727	Continental WIRT Electronics Corp., Philadelphia, PA 19101
79963	Zierick Mfg. Co., Mount Kisco, NY 10549
80009	Tektronix, Inc., Beaverton, OR 97005
80030	Prestole Fastener, Toledo, OH 43605
80048	Vickers Inc., St. Louis, MO 63166
80103	Lambda Electronics Corp., Melville, NY 11746
80183	Sprague Products Co., North Adams, MA 01247
80211	Motorola Inc., Franklin Park, IL 60131
80251	Formica Corp., Cincinnati, OH 45232
80258	Standard Oil Co., Lafayette, IN 47902
80294	Bourns Laboratories, Inc., Riverside, CA 92506
80368	Sylvania Electric Products, Inc., New York, NY 10017
80431	Air Filter Corp., Milwaukee, WI 53218
80583	Hammerlund Co., Inc., New York, NY 10010
80894	Pure Carbon Co., St. Mary's, PA 15857
81030	International Instrument, Orange, CT 06477
81073	Grayhill Inc., LaGrange, IL 60525
81143	Isolantite Mfg. Corp., Stirling, NJ 07980
81312	Winchester Electronics Co., Inc., Oakville, CT 06779
81349	Military Specifications
81350	Joint Army-Navy Specifications
81483	International Rectifier Corp., El Segundo, CA 90245
81751	Columbus Electronics Corp., Yonkers, NY 10701
81831	Filtron Co., Flushing, NY 11364
81860	Barry Wright Corp., Watertown, MA 02172
82219	Sylvania Elec. Prod., Emporium, PA 15834
82273	Indiana Pattern & Model Works, LaPorte, IN 46350
82389	Switchcraft, Inc., Chicago, IL 60630
82647	Metals & Controls, Inc., Attleboro, MA 02703
82807	Milwaukee Resistor Co., Milwaukee, WI 53204
82877	Rotron Mfg. Co., Inc., Woodstock, NY 12498
83003	Varo Semiconductor Div., Garland, TX 75040
83033	Meissner Mfg., Mt. Carmel, IL 62863
83058	Carr Fastener Co., Cambridge, MA 02142
83186	Victory Engineering, Springfield, NJ 07081
83361	Bearing Specialty Co., San Francisco, CA 94101
83587	Solar Electric Corp., Warren, PA 16365
83594	Burroughs Corp., Plainfield, NJ 07061
83740	Union Carbide Corp., New York, NY 10017
84411	TRW Capacitor Division, Ogallala, NB 69153
84836	Lehigh Metal Products, Cambridge, MA 02140
84970	Sarkes Tarzian, Inc., Bloomington, IN 47401
84971	T.A. Mfg. Corp., Los Angeles, CA 90039
86577	Precision Metal Products, Stoneham, MA 02180
86684	R.C.A. (Elec. Comp. & Dev), Harrison, NJ 07029
86687	R.E. C. Corp., New Rochelle, NY 10801
86800	Cont. Electronics Corp., Brooklyn, NY 11222
88140	Cutler-Hammer Inc., Lincoln, IL 62656
88219	Gould Nat. Batteries, Inc., Trenton, NJ 08607
88419	Cornell Dubilier, Fuquay-Varina, NC 27526
88627	K & G Mfg. Co., New York, NY 10001
89482	Holtzer Cabot Corp., Boston, MA 02119
89665	United Transformer Co., Chicago, IL 60607
89870	Berkshire Transformer Corp., Kent, CT 06757
90201	Mallory Capacitor Co., Indianapolis, IN 46206
90303	Mallory Battery Co., Tarrytown, NY 10591
90634	Gulton Industries, Inc., Metuchen, NJ 08840
90750	Westinghouse Electric Corp., Boston, MA 02118
90952	Hardware Products Co., Reading, PA 19602
91002	Continental Wire Corp., York, PA 17405
91146	I.T.T. (Cannon), Salem, MA 01970
91210	Gerber Mfg. Co., Mishawaka, IN 46544
91293	Johanson Mfg. Co., Boonton, NJ 07005
91417	Harris Semiconductor, Melbourne, FL 32901
91506	Augat Brothers, Inc., Attleboro, MA 02703
91598	Chandler Co., Wethersfield, CT 06109
91637	Dale Electronics, Inc., Columbus, NE 68601
91662	Elco Corp., Willow Grove, PA 19090
91719	General Instruments Corp., Dallas, TX 75220
91836	Kings Electronics, Co., Inc., Tuckahoe, NY 11223
91916	Mephisto Tool Co., Inc., Hudson, NY 12534
91929	Honeywell, Inc., Freeport, IL 61032
92519	Electra Insul. Corp., Woodside, L.I., NY 11377
92678	Edgerton Germeshausen, Georgetown, MA 01830
92702	I.M.C. Magnetics Corp., Westbury, NY 11591
92739	Ampex Corp., Redwood City, CA 94063
92966	Hudson Lamp Co., Kearny, NJ 07032
93332	Sylvania Elect. Prods., Inc., Woburn, MA 01801
93618	R & C Mfg. Co. of Penn, Inc., Ramsey, PA 16671
93916	Cramer Products Co., New York, NY 10013
94144	Raytheon Co., Components Div., Quincy, MA 02169
94154	Tung Sol Electric Inc., Newark, NJ 07101
94271	Weston Instruments, Inc., Archbald, PA 18403
94322	Tel Labs, Manchester, NH 03102
94589	Dickson Co., Chicago, IL 60619
94696	Magnecraft Electric Co., Chicago, IL 60630
94800	Atlee Industrial Corp., Brookline, NH 03033
95078	Gentle Mfg. Co., Cumberland, RI 02864
95121	Quality Components, Inc., St. Marys, PA 15857
95146	Alco Electronics Mfg. Co., Lawrence, MA 01843
95238	Continental Connector Corp., Woodside, NY 11377
95275	Vitramon, Inc., Bridgeport, CT 06601
95348	Gordos Corp., Bloomfield, NJ 07003
95354	Methode Mfg. Co., Rolling Meadow, IL 60008
95794	American Brass Co., Torrington, CT 06790
95987	Weckesser Co., Inc., Chicago, IL 60646
96095	Hi Q Division of Aerovox Corp., Olean, NY 14760
96341	Microwave Associates, Inc., Burlington, MA 01801
96906	Military Standards
98291	Sealectro Corp., Mamaroneck, NY 10544
98474	Compar, Inc., Burlingame, CA 94010
98821	North Hills Electronic, Glen Cove, NY 11542
99117	Metavac, Inc., Flushing, NY 11358
99313	Varian Associates, Palo Alto, CA 94303
99378	Atlee Corp., Winchester, MA 01890
99800	Delevan Electronics, East Aurora, NY 14052

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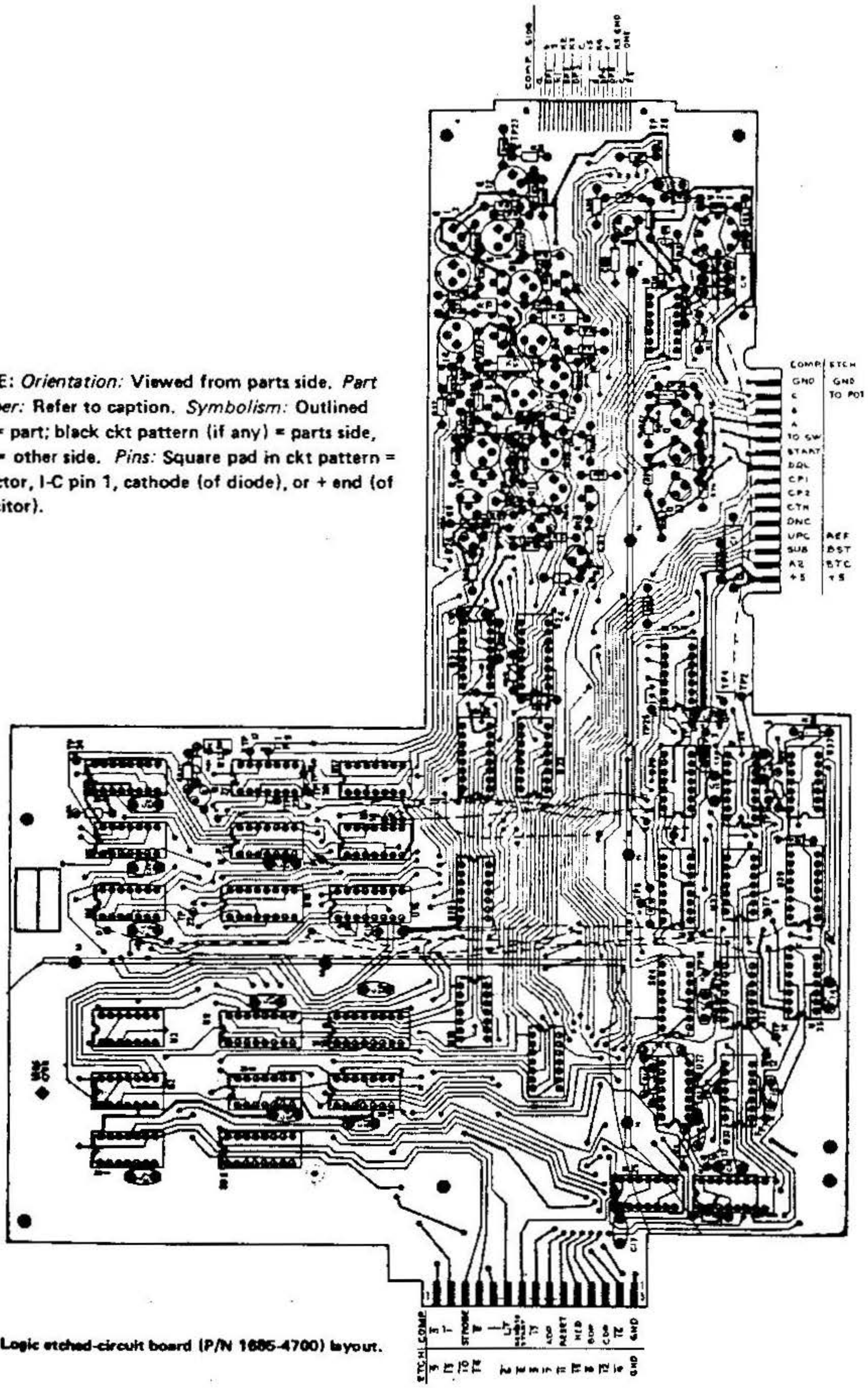
NOTE: *Orientation:* Viewed from parts side. *Part number:* Refer to caption. *Symbolism:* Outlined area = part; black ckt pattern (if any) = parts side, gray = other side. *Pins:* Square pad in ckt pattern = collector, I-C pin 1, cathode (of diode), or + end (of capacitor).



Logic etched-circuit board (P/N 1685-4700) layout.

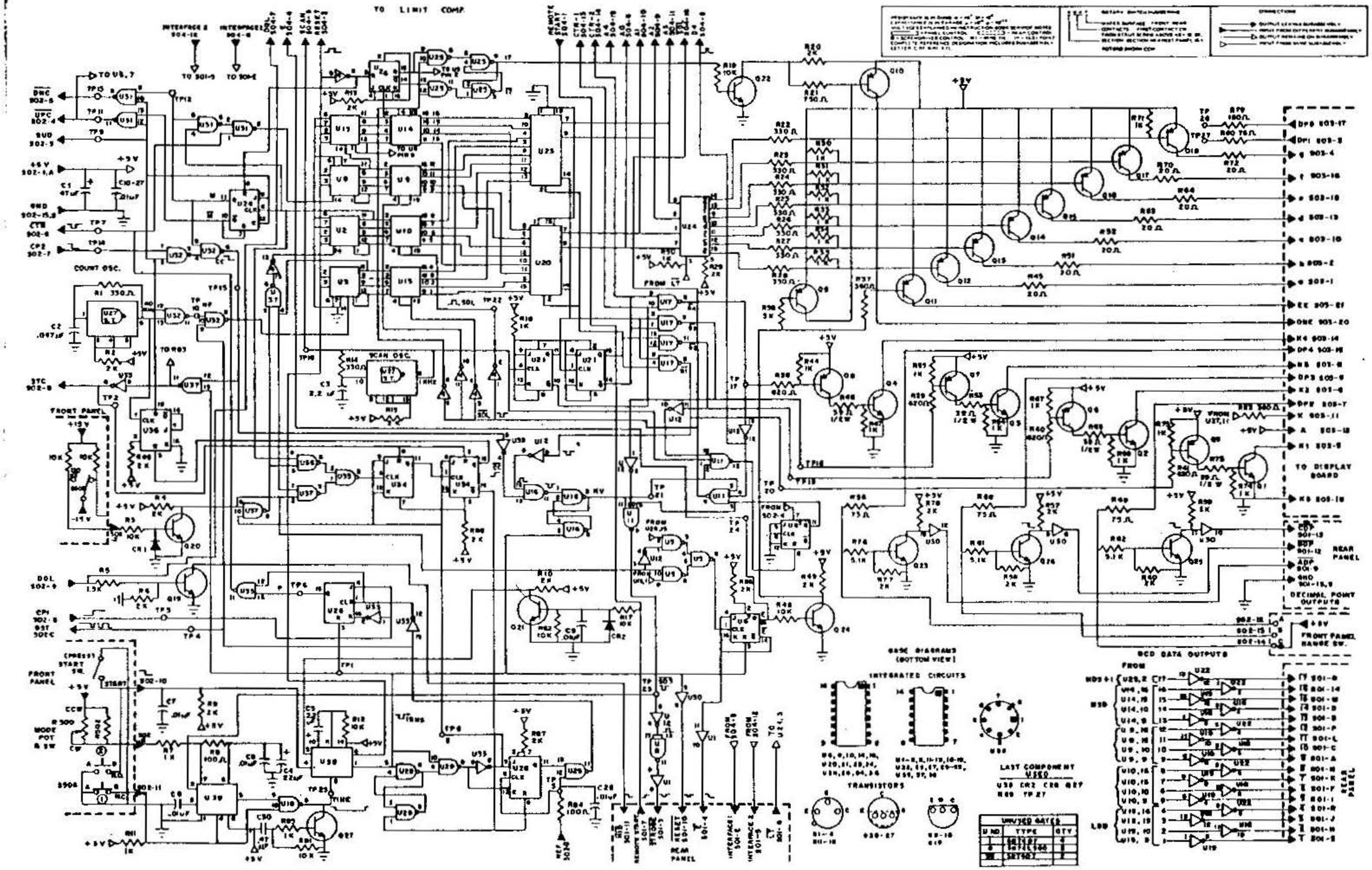


Figure 6-10. Logic board schematic diagram.

ELECTRICAL PARTS LIST

LOGIC PC BOARD P/N 1685-4700

REFDES (L- prefix)		DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C	1	CAP TANT 47 UF 20PCT 6V	4450-5500	56289	1500476X00068Z
C	2	CAP CER MONO .047UF 20PCT 50VGP	4400-2040	72982	8121N073Z5U0473M
C	3	CAP CER MONO 2.2UF 20PCT 50VGP	4400-2080	72982	8141-M050-651-225M
C	4	CAP TANT 22 UF 20PCT 15V	4450-5300	56289	1500226X0015B2
C	5	CAP TANT 2.2 UF 20PCT 20V	4450-4500	56289	1500225X0020A2
C	6	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	7	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	8	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	9	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	10	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	11	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	12	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	13	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	14	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	15	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	16	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	17	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	18	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	19	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	20	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	21	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	22	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	23	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	24	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	25	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	26	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	27	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	28	CAP CER MONO .01 UF 10PCT 50V	4400-6351	72982	8121-M050-W5R-103K
C	29	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	30	CAP CER MONO 0.47UF 20PCT 50VGP	4400-2054	72982	8131M0506510474M
CR	1	DIODE 1N4151 75PIV IR.1UA SI	6082-1001	14433	1N3604
CR	2	DIODE 1N4151 75PIV IR.1UA SI	6082-1001	14433	1N3604
Q	1	TRANSISTOR 2N2218	8210-1028	04713	2N2218
Q	2	TRANSISTOR 2N2218	8210-1028	04713	2N2218
Q	3	TRANSISTOR 2N2218	8210-1028	04713	2N2218
Q	4	TRANSISTOR 2N2218	8210-1028	04713	2N2218
Q	5	TRANSISTOR 2N4125	8210-1125	04713	2N4125
Q	6	TRANSISTOR 2N4125	8210-1125	04713	2N4125
Q	7	TRANSISTOR 2N4125	8210-1125	04713	2N4125
Q	8	TRANSISTOR 2N4125	8210-1125	04713	2N4125
Q	9	TRANSISTOR 2N4125	8210-1125	04713	2N4125
Q	10	TRANSISTOR 2N4125	8210-1125	04713	2N4125
Q	11	TRANSISTOR 2N2904	8210-1074	04713	2N2904
Q	12	TRANSISTOR 2N2904	8210-1074	04713	2N2904
Q	13	TRANSISTOR 2N2904	8210-1074	04713	2N2904
Q	14	TRANSISTOR 2N2904	8210-1074	04713	2N2904
Q	15	TRANSISTOR 2N2904	8210-1074	04713	2N2904
Q	16	TRANSISTOR 2N2904	8210-1074	04713	2N2904
Q	17	TRANSISTOR 2N2904	8210-1074	04713	2N2904
Q	18	TRANSISTOR 2N2904	8210-1074	04713	2N2904
Q	19	TRANSISTOR 2N4123	8210-1123	04713	2N4123
Q	20	TRANSISTOR 2N3414	8210-1047	03508	2N3414
Q	21	TRANSISTOR 2N3391A	8210-1092	03508	2N3391A
Q	22	TRANSISTOR 2N3414	8210-1047	03508	2N3414
Q	23	TRANSISTOR 2N3414	8210-1047	03508	2N3414
Q	24	TRANSISTOR 2N3414	8210-1047	03508	2N3414
Q	25	TRANSISTOR 2N3414	8210-1047	03508	2N3414
Q	26	TRANSISTOR 2N3414	8210-1047	03508	2N3414
Q	27	TRANSISTOR 2N3414	8210-1047	03508	2N3414
R	1	RES COMP 330 OHM 5PCT 1/4W	6099-1335	81349	RCR07G331J
R	2	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	3	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	4	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	5	RES COMP 1.5 K 5PCT 1/4W	6099-2155	81349	RCR07G152J
R	6	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	7	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	8	RES COMP 100 OHM 5PCT 1/4W	6099-1105	81349	RCR07G101J
R	9	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	10	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J

ELECTRICAL PARTS LIST (cont)

LOGIC PC BOARD P/N 1685-4700

REFDES		DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
R	11	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	12	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	13	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	14	RES COMP 330 OHM 5PCT 1/4W	6099-1335	81349	RCR07G331J
R	15	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	16	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	17	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	19	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	20	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	21	RES COMP 750 OHM 5PCT 1/4W	6099-1755	81349	RCR07G751J
R	22	RES COMP 330 OHM 5PCT 1/4W	6099-1335	81349	RCR07G331J
R	23	RES COMP 330 OHM 5PCT 1/4W	6099-1335	81349	RCR07G331J
R	24	RES COMP 330 OHM 5PCT 1/4W	6099-1335	81349	RCR07G331J
R	25	RES COMP 330 OHM 5PCT 1/4W	6099-1335	81349	RCR07G331J
R	26	RES COMP 330 OHM 5PCT 1/4W	6099-1335	81349	RCR07G331J
R	27	RES COMP 330 OHM 5PCT 1/4W	6099-1335	81349	RCR07G331J
R	28	RES COMP 330 OHM 5PCT 1/4W	6099-1335	81349	RCR07G331J
R	29	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	30	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	31	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	32	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	33	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	34	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	35	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	36	RES COMP 3.0 K OHM 5PCT 1/4W	6099-2305	81349	RCR07G302J
R	37	RES COMP 360 OHM 5PCT 1/4W	6099-1365	81349	RCR07G361J
R	38	RES COMP 620 OHM 5PCT 1/4W	6099-1625	81349	RCR07G621J
R	39	RES COMP 620 OHM 5PCT 1/4W	6099-1625	81349	RCR07G621J
R	40	RES COMP 620 OHM 5PCT 1/4W	6099-1625	81349	RCR07G621J
R	41	RES COMP 620 OHM 5PCT 1/4W	6099-1625	81349	RCR07G621J
R	44	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	45	RES COMP 20 OHM 5PCT 1/4W	6099-0205	81349	RCR07G200J
R	46	RES COMP 39 OHM 5PCT 1/2W	6100-0395	81349	RCR20G390J
R	47	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	48	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	49	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	50	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	51	RES COMP 20 OHM 5PCT 1/4W	6099-0205	81349	RCR07G200J
R	52	RES COMP 20 OHM 5PCT 1/4W	6099-0205	81349	RCR07G200J
R	53	RES COMP 39 OHM 5PCT 1/2W	6100-0395	81349	RCR20G390J
R	54	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	55	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	56	RES COMP 75 OHM 5PCT 1/4W	6099-0755	81349	RCR07G750J
R	57	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	58	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	59	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	60	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	61	RES COMP 5.1 K OHM 5PCT 1/4W	6099-2515	81349	RCR07G512J
R	62	RES COMP 5.1 K OHM 5PCT 1/4W	6099-2515	81349	RCR07G512J
R	63	RES COMP 20 OHM 5PCT 1/4W	6099-0205	81349	RCR07G200J
R	64	RES COMP 20 OHM 5PCT 1/4W	6099-0205	81349	RCR07G200J
R	65	RES COMP 39 OHM 5PCT 1/2W	6100-0395	81349	RCR20G390J
R	66	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	67	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	68	RES COMP 75 OHM 5PCT 1/4W	6099-0755	81349	RCR07G750J
R	69	RES COMP 75 OHM 5PCT 1/4W	6099-0755	81349	RCR07G750J
R	70	RES COMP 20 OHM 5PCT 1/4W	6099-0205	81349	RCR07G200J
R	71	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	72	RES COMP 20 OHM 5PCT 1/4W	6099-0205	81349	RCR07G200J
R	73	RES COMP 39 OHM 5PCT 1/2W	6100-0395	81349	RCR20G390J
R	74	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	75	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
R	76	RES COMP 5.1 K OHM 5PCT 1/4W	6099-2515	81349	RCR07G512J
R	77	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	78	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	79	RES COMP 150 OHM 5PCT 1/4W	6099-1155	81349	RCR07G151J
R	80	RES COMP 75 OHM 5PCT 1/4W	6099-0755	81349	RCR07G750J
R	81	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	82	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	83	RES COMP 360 OHM 5PCT 1/4W	6099-1365	81349	RCR07G361J
R	84	RES COMP 100 OHM 5PCT 1/4W	6099-1105	81349	RCR07G101J
R	85	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J

ELECTRICAL PARTS LIST (cont)

LOGIC PC BOARD P/N 1685-4700

REFDES		DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
R	86	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	87	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	88	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
R	89	RES COMP 2.0 K OHM 5PCT 1/4W	6099-2205	81349	RCR07G202J
SO	4	SOCKET CABLE 16 CONTACT PC	7540-1817	71785	133-51-02-006
SO	5	SOCKET CABLE 16 CONTACT PC	7540-1817	71785	133-51-02-006
U	1	IC DIGITAL SN7407N	5431-8107	01295	SN7407N
U	2	ICD SN74LS90N DE DIV BY 12BINCTR	5431-8690	01295	SN74LS90N
U	3	ICD SN74LS90N DE DIV BY 12BINCTR	5431-8690	01295	SN74LS90N
U	4	IC DIGITAL SN74LS04N	5431-8604	01295	SN74LS04N
U	5	IC DIGITAL SN74LS00N	5431-8600	01295	SN74LS00N
U	6	ICD SN7476N 16D 2JK MASL FLIFLOS	5431-8176	01295	SN7476N
U	8	ICD SN74LS90N DE DIV BY 12BINCTR	5431-8690	01295	SN74LS90N
U	9	ICD SN74LS75N 16D Q BIS LATCH	5431-8675	01295	SN74LS75N
U	10	ICD SN74LS75N 16D Q BIS LATCH	5431-8675	01295	SN74LS75N
U	11	IC DIGITAL SN74LS10N	5431-8610	01295	SN74LS10N
U	12	IC DIGITAL SN74LS04N	5431-8604	01295	SN74LS04N
U	13	ICD SN74LS90N DE DIV BY 12BINCTR	5431-8690	01295	SN74LS90N
U	14	ICD SN74LS75N 16D Q BIS LATCH	5431-8675	01295	SN74LS75N
U	15	ICD SN74LS75N 16D Q BIS LATCH	5431-8675	01295	SN74LS75N
U	16	IC DIGITAL SN74LS00N	5431-8600	01295	SN74LS00N
U	17	ICD SN74LS03N Q 2IN POS NAND GA	5431-8603	01295	SN74LS03N
U	18	ICD SN7406N 14D HX INV COL 30V	5431-8106	01295	SN7406N
U	19	ICD SN7406N 14D HX INV COL 30V	5431-8106	01295	SN7406N
U	20	IC DIGITAL SN74LS153N	5431-8753	01295	SN74LS153N
U	21	ICD SN7476N 16D 2JK MASL FLIFLO	5431-8176	01295	SN7476N
U	22	ICD SN7406N 14D HX INV COL 30V	5431-8106	01295	SN7406N
U	23	IC DIGITAL SN74LS153N	5431-8753	01295	SN74LS153N
U	24	ICD 9317594 16D 7SEG DECODER DR	5431-9627	07263	9317594
U	25	IC DIGITAL SN74LS00N	5431-8600	01295	SN74LS00N
U	26	ICD SN7476N 16D 2JK MASL FLIFLO	5431-8176	01295	SN7476N
U	27	ICD SN7413N 14D DU NAND SCHM TR	5431-8113	01295	SN7413N
U	28	ICD SN7476N 16D 2JK MASL FLIFLO	5431-8176	01295	SN7476N
U	29	ICD SN74LS132N 14D Q 2IN NANDSCH	5431-8732	01295	SN74LS132N
U	30	IC DIGITAL SN7407N	5431-8107	01295	SN7407N
U	31	IC DIGITAL SN74LS00N	5431-8600	01295	SN74LS00N
U	32	IC DIGITAL SN74LS00N	5431-8600	01295	SN74LS00N
U	33	IC DIGITAL SN74LS04N	5431-8604	01295	SN74LS04N
U	34	ICD SN7476N 16D 2JK MASL FLIFLO	5431-8176	01295	SN7476N
U	35	IC DIGITAL SN74LS00N	5431-8600	01295	SN74LS00N
U	36	ICD SN7476N 16D 2JK MASL FLIFLO	5431-8176	01295	SN7476N
U	37	IC DIGITAL SN74LS00N	5431-8600	01295	SN74LS00N
U	38	ICD SN74121N 14D MN-STBL ML VIB	5431-8021	01295	SN74121N
U	39	IC LINEAR NE555	5432-1040	18324	NE555T

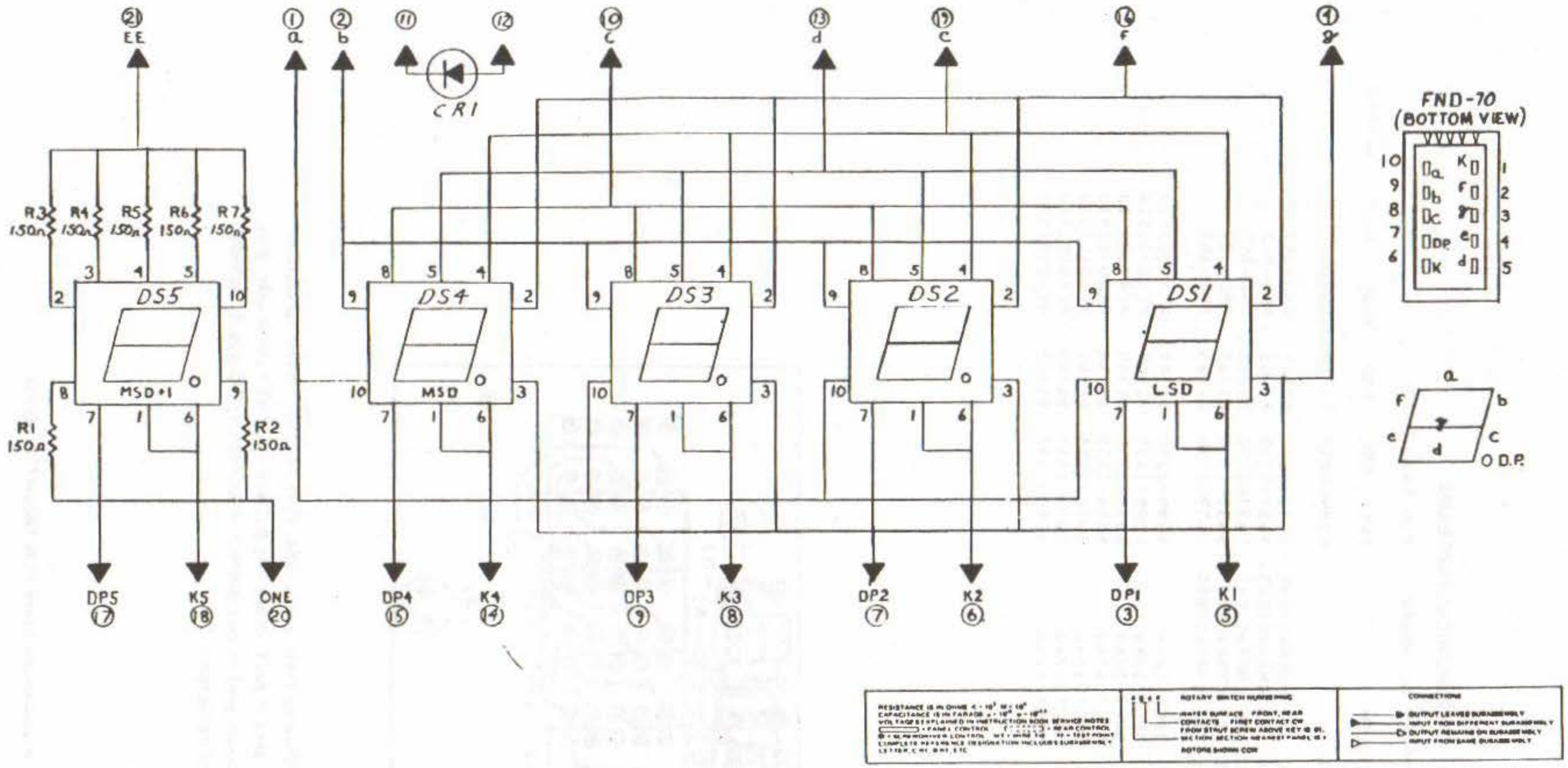
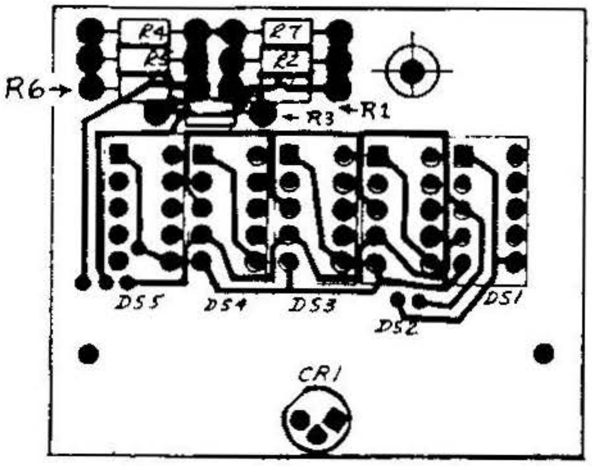


Figure 6-11. Display board schematic diagram.

ELECTRICAL PARTS LIST

DISPLAY PC BOARD   P/N 1685-4710

REFDES (M- prefix)		DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
CR	1	LED RED FLV102	6084-1099	13715	FLV102
DS	1	INDICATOR DIGITAL .27 CHARACTERS	5437-1230	07263	FND-357
DS	2	INDICATOR DIGITAL .27 CHARACTERS	5437-1230	07263	FND-357
DS	3	INDICATOR DIGITAL .27 CHARACTERS	5437-1230	07263	FND-357
DS	4	INDICATOR DIGITAL .27 CHARACTERS	5437-1230	07263	FND-357
DS	5	INDICATOR DIGITAL .27 CHARACTERS	5437-1230	07263	FND-357
R	1	RES COMP 150 OHM 5PCT 1/4W	6099-1155	81349	RCR07G151J
R	2	RES COMP 150 OHM 5PCT 1/4W	6099-1155	81349	RCR07G151J
R	3	RES COMP 150 OHM 5PCT 1/4W	6099-1155	81349	RCR07G151J
R	4	RES COMP 150 OHM 5PCT 1/4W	6099-1155	81349	RCR07G151J
R	5	RES COMP 150 OHM 5PCT 1/4W	6099-1155	81349	RCR07G151J
R	6	RES COMP 150 OHM 5PCT 1/4W	6099-1155	81349	RCR07G151J
R	7	RES COMP 150 OHM 5PCT 1/4W	6099-1155	81349	RCR07G151J



NOTE: *Orientation:* Viewed from parts side. *Part number:* Refer to caption. *Symbolism:* Outlined area = part; black ckt pattern (if any) = parts side, gray = other side. *Pins:* Square pad in ckt pattern = collector, I-C pin 1, cathode (of diode), or + end (of capacitor).

Display etched-circuit board (P/N 1685-4710) layout.

ELECTRICAL PARTS LIST

Ref Des (A-prefix)	Description	GR Part No.	Fed Mfg Code	Mfg Part No.
	COMPARATOR BOARD A (P/N 1685-4750) PARTS			
CAPACITORS				
C1	Tantalum, 47 uF ±20% 6 V	4450-5500	56289	150D476X0006B2
C2	Tantalum, 22 uF ±20%, 15 V	4450-5300	56289	150D226X0015B2
C3	Ceramic, 100 pF ±5% 100 V	4410-1225	72982	8131, 100 pF ±5% 100 V
C4 thru C11	Ceramic, .01 uF +80-20% 100 V	4401-3100	72982	805, .01 uF +80-20%
DIODES				
CR1 thru CR10	1N645	6082-1016	14433	1N645
INTEGRATED CIRCUITS				
U1	Digital, SN7405N	5431-8105	01295	SN7405N
U2	Digital, 9324PC	5431-9650	07263	9324PC
U3 and U4	Digital, SN7400N	5431-8100	01295	SN7400N
U5	Digital, SN7410N	5431-8110	01295	SN7410N
U6	Digital, SN7473N	5431-8173	01295	SN7473N
U7	Digital, SN7400N	5431-8100	01295	SN7400N
U8	Digital, SN74121N	5431-8021	01295	SN74121N
U9	Digital, SN7420N	5431-8120	01295	SN7420N
U10	Digital, SN7400N	5431-8100	01295	SN7400N
U11	Digital, SN7414N	5431-8114	01295	SN7414N
U12	Digital, SN74121N	5431-8021	01295	SN74121N
U13	Digital, SN7407N	5431-8107	01295	SN7407N
U14	Digital, SN7410N	5431-8110	01295	SN7410N
U15	Digital, SN7400N	5431-8100	01295	SN7400N
U16	Digital, SN7410N	5431-8110	01295	SN7410N
RESISTORS				
R1 thru R3	Comp., 2 kilohms ±5% 1/4 W	6099-2205	01121	RCR07G202J
R4	Comp., 20 kilohms ±5% 1/4 W	6099-3205	01121	RCR07G203J
R5	Comp., 2 kilohms ±5% 1/4 W	6099-2205	01121	RCR07G202J
R6	Comp., 1 kilohm ±5% 1/4 W	6099-2105	01121	RCR07G102J
R8 and R9	Comp., 10 kilohms ±5% 1/4 W	6099-3105	01121	RCR07G103J
R10 thru R12	Comp., 2 kilohms ±5% 1/4 W	6099-2205	01121	RCR07G202J
R13	Comp., 5.1 kilohms ±5% 1/4 W	6099-2515	01121	RCR07G512J
R14	Comp., 1 kilohm ±5% 1/4 W	6099-2105	01121	RCR07G102J
R15	Comp., 5.1 kilohms ±5% 1/4 W	6099-2515	01121	RCR07G512J
R17	Comp., 3.9 kilohms ±5% 1/4 W	6099-2395	01121	RCR07G392J
R18 and R19	Comp., 1 kilohm ±5% 1/4 W	6099-2105	01121	RCR07G102J
R20	Comp., 5.1 kilohm ±5% 1/4 W	6099-2515	01121	RCR07G512J

ELECTRICAL PARTS LIST

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.
RESISTORS (cont)				
R21	Comp., 620 ohms ±5% 1/4 W	6099-1625	01121	RCR07G621J
R22	Comp., 1 kilohm ±5% 1/4 W	6099-2105	01121	RCR07G102J
R23	Comp., 820 ohms ±5% 1/4 W	6099-1825	01121	RCR07G821J
R24	Comp., 5.1 kilohms ±5% 1/4 W	6099-2515	01121	RCR07G512J
R25	Comp., 1 kilohm ±5% 1/4 W	6099-2105	01121	RCR07G102J
R26	Comp., 620 ohms ±5% 1/4 W	6099-1625	01121	RCR07G621J
R27	Comp., 820 ohms ±5% 1/4 W	6099-1825	01121	RCR07G821J
R28	Comp., 20 kilohms ±5% 1/4 W	6099-3205	01121	RCR07G203J
R29	Comp., 2 kilohms ±5% 1/4 W	6099-2205	01121	RCR07G202J
R30	Comp., 10 ohms ±5% 1/2 W	6100-0105	01121	RCR20G100J
R31	Comp., 390 ohms ±5% 1/4 W	6099-1395	01121	RCR07G391J
R32	Comp., 510 ohms ±5% 1/4 W	6099-1515	01121	RCR07G511J
R33	Comp., 2 kilohms ±5% 1/4 W	6099-2205	01121	RCR07G202J
R34	Comp., 510 ohms ±5% 1/4 W	6099-1515	01121	RCR07G511J
R35	Comp., 1 kilohm ±5% 1/4 W	6099-2105	01121	RCR07G102J
SOCKETS				
S03 and S04	Cable, 16-contact, PC	7540-1817	71785	133-51-02-006
S06	Cable, 16-contact, PC	7540-1817	71785	133-51-02-006
TRANSISTORS				
Q1 thru Q4	Type 2N3414	8210-1047	03508	2N3414
Q5 and Q6	Type 2N3391A	8210-1092	03508	2N3391A
Q7 thru Q9	Type 2N2904	8210-1074	04713	2N2904
RECEPTACLES				
S05	Micro, Ribbon 24-contact	4230-4024	02660	57-40240

DISPLAY BOARD (P/N 1685-4710) PARTS

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.
INDICATORS				
DS1 thru DS5	Digital	5437-1230	07263	FND-70
DIODES				
CR1	Light-emitting, red	6084-1099	13715	FLV102
RESISTORS				
R1 thru R7	Comp., 150 ohms ±10% 1/4 W	6099-1159	01121	RCR07G151K

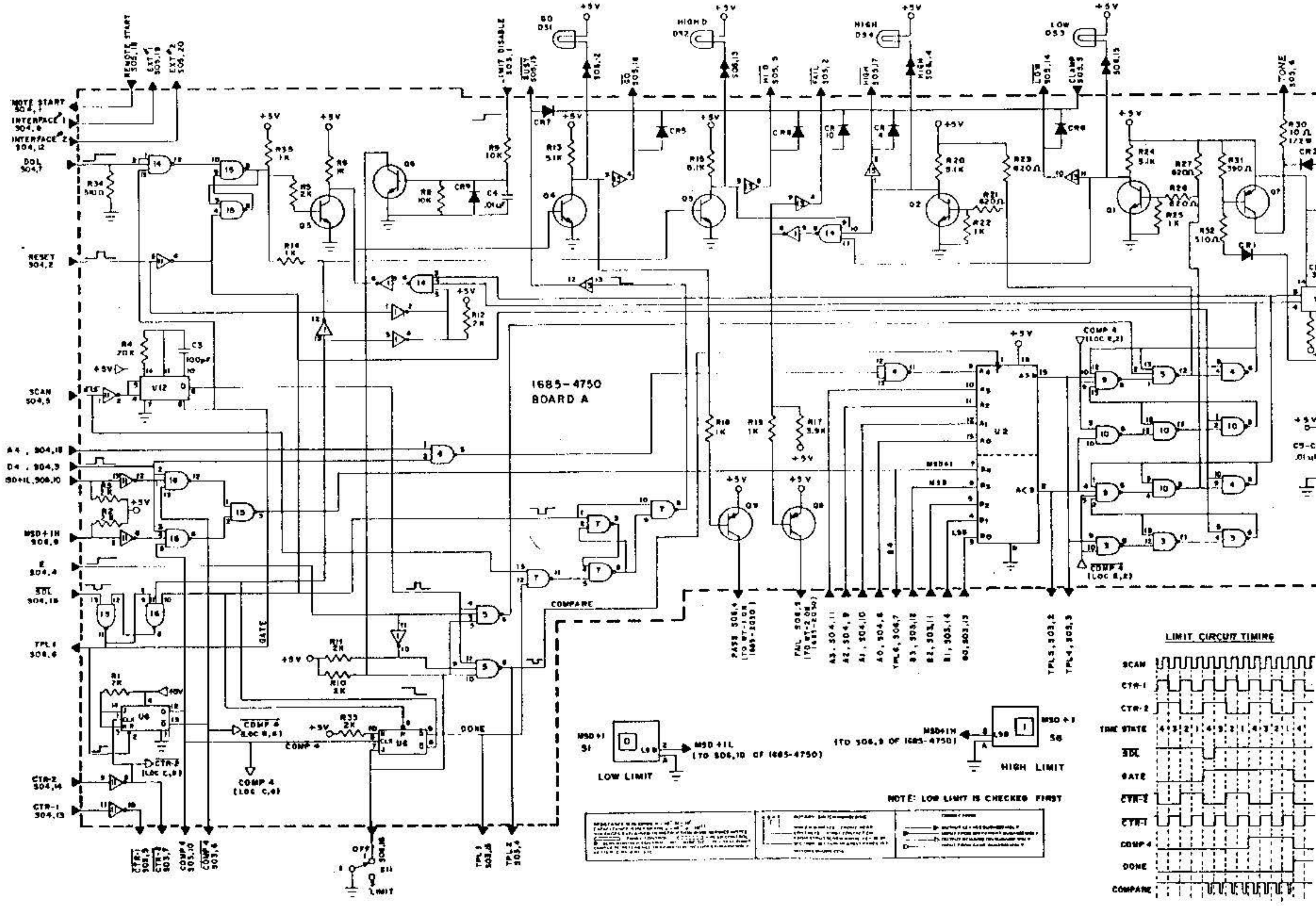
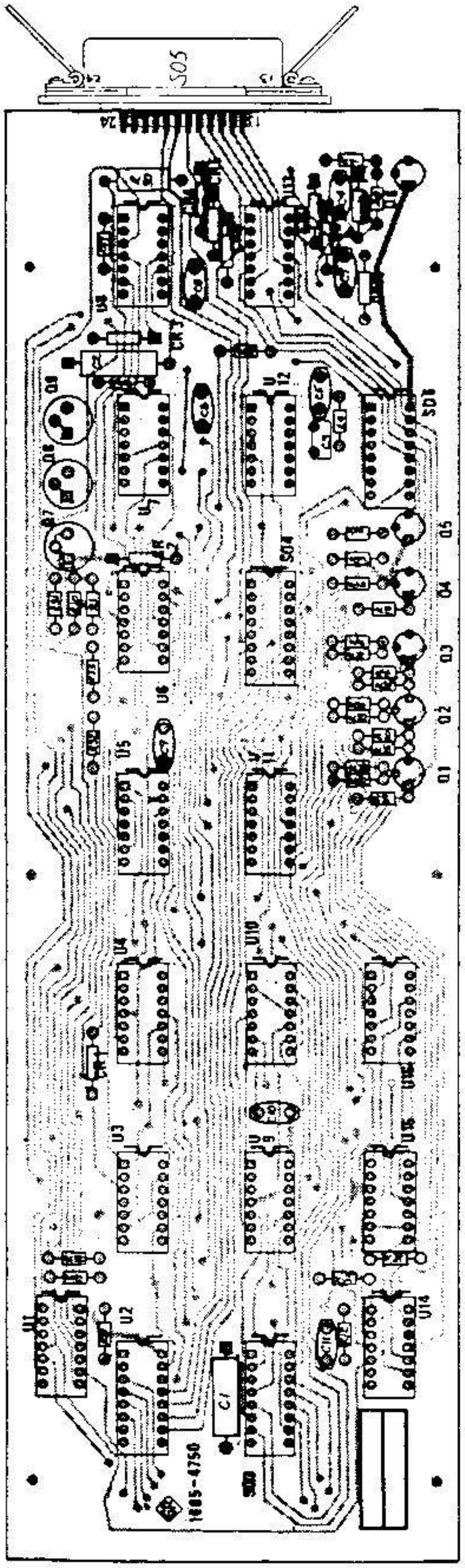


Figure 8-12. Comparator board 'A' schematic diagram.



NOTE: *Orientation:* Viewed from parts side. *Part number:* Refer to caption. *Symbolism:* Outlined area = part; black ckt pattern (if any) = parts side, gray = other side. *Pins:* Square pad in ckt pattern = collector, I-C pin 1, cathode (of diode), or + end (of capacitor).

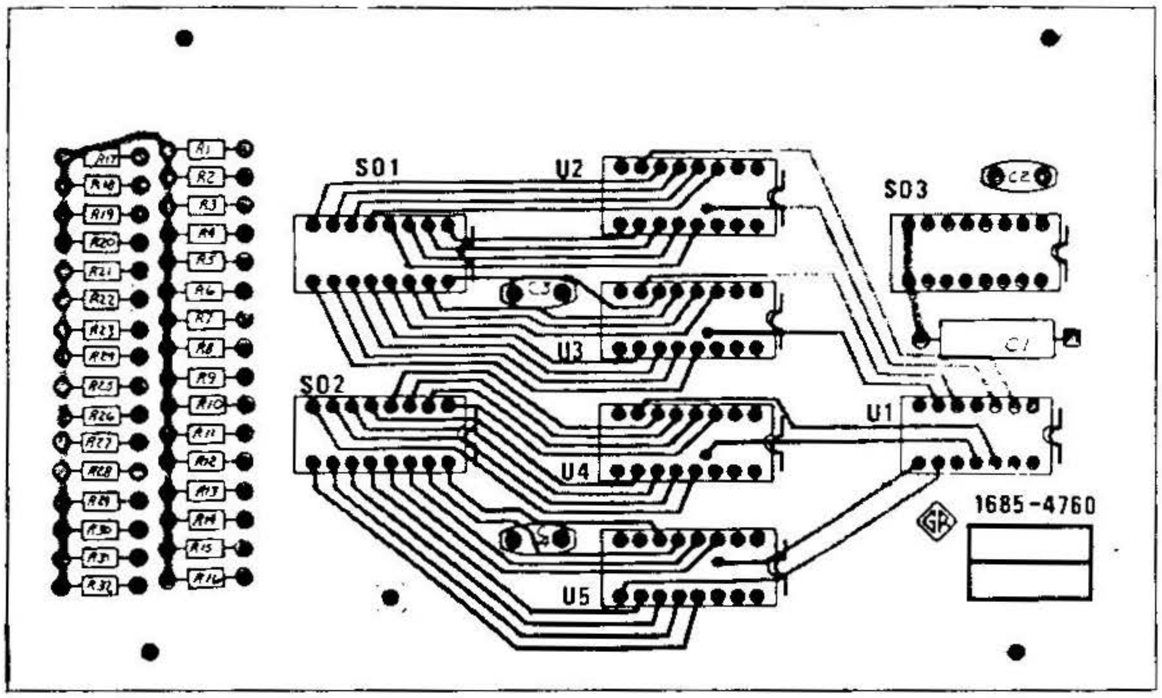
Comparator etched circuit board 'A' (P/N 1685-4750) layout.

ELECTRICAL PARTS LIST

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.
	SWITCH BRACKET ASSEMBLY PARTS			
Switch bracket Assembly Complete		1685-2050	24655	1685-2050
LAMPS				
DS1 thru DS4	6.3 V	5600-0319	71744	CM-377
SWITCHES				
S1 thru S5	Thumbwheel	7917-1014	24655	7917-1014
S6 thru S10	Thumbwheel	7917-1014	24655	7917-1014
S11	Toggle	7910-0790	95146	MTA-106D

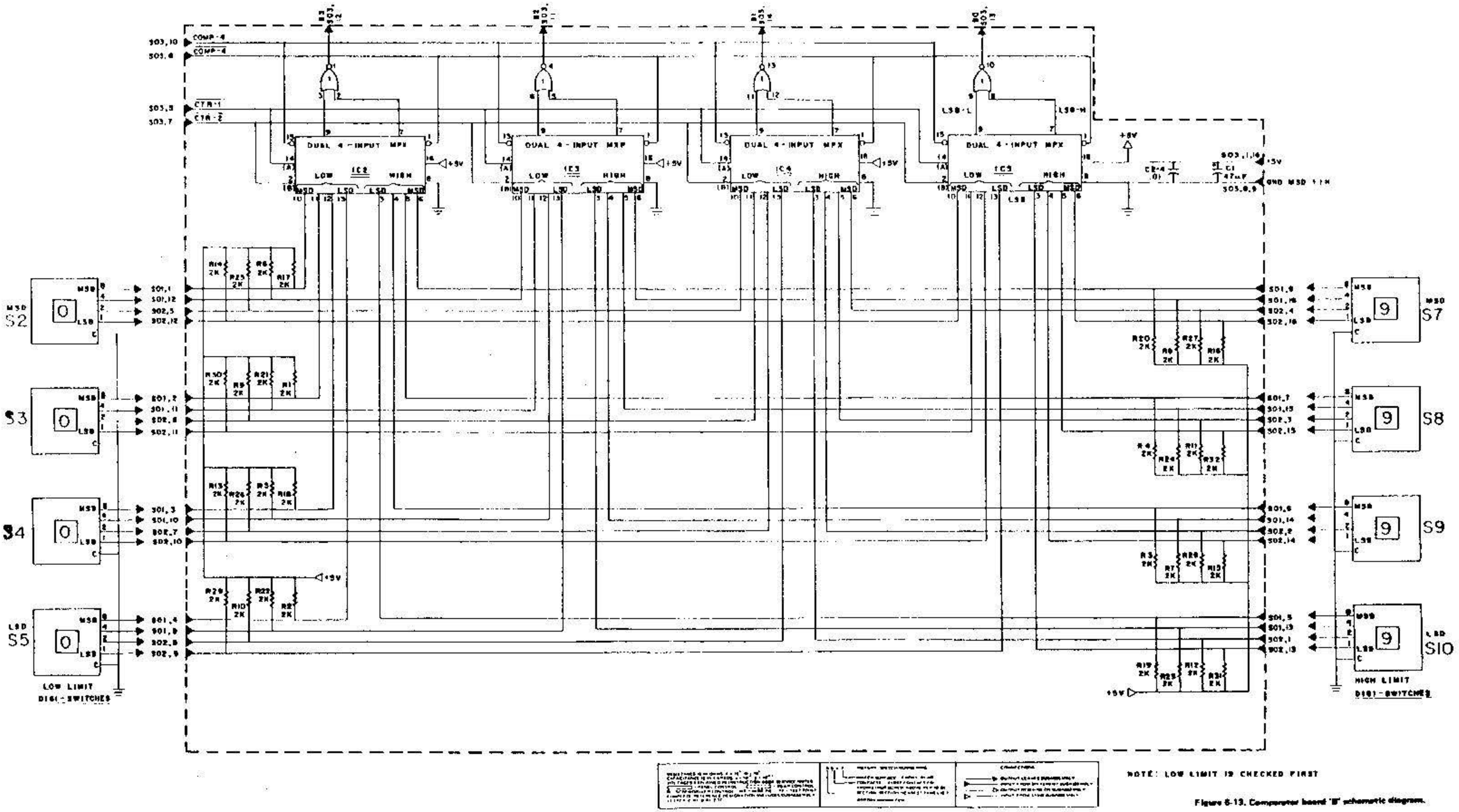
ELECTRICAL PARTS LIST

Ref Des (B- Prefix)	Description	GR Part No.	Fed Mfg Code	Mfg Part No.
	COMPARATOR BOARD B (P/N 1685-4760) PARTS			
CAPACITORS				
C1	Tantalum, 47 uF ±20% 6 V	4450-5500	56289	150D476X0006B2
C2 thru C4	Ceramic, .01 uF +80-20% 100 V	4401-3100	72982	805, .01 uF +80-20%
INTEGRATED CIRCUITS				
U1	Type SN7402N	5431-8102	01295	SN7402N
U2 thru U5	Type SN74153N	5431-8053	01295	SN74153N
RESISTORS				
R1 thru R32	Comp., 2 kilohms ±5% 1/4 W	6099-2205	01121	RCR07G202J
SOCKETS				
S01 thru S03	DIP, 16-cont, PC	7540-1817	71785	133-51-02-006



NOTE: *Orientation:* Viewed from parts side. *Part number:* Refer to caption. *Symbolism:* Outlined area = part; black ckt pattern (if any) = parts side, gray = other side. *Pins:* Square pad in ckt pattern = collector, I-C pin 1, cathode (of diode), or + end (of capacitor).

Comparator etched-circuit board 'B' (P/N 1685-4760) layout.



NOTE: LOW LIMIT IS CHECKED FIRST

Figure 8-13. Comparator board "B" schematic diagram.

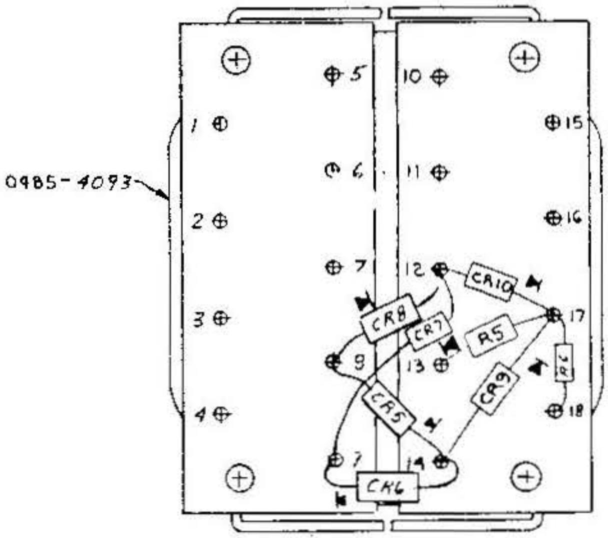
ELECTRICAL PARTS LIST

POWER SUPPLY PC BOARD P/N 1686-4730

REFDES (V- prefix)		DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C	1	CAP CER MONO 1UF 20PCT 50VGP	4400-2070	72982	8131-M050-651-105M
C	2	CAP CER MONO 1UF 20PCT 50VGP	4400-2070	72982	8131-M050-651-105M
C	3	CAP TANT 1.0 UF 20PCT 35V	4450-4300	56289	150D105X0035A2
C	4	CAP TANT 1.0 UF 20PCT 35V	4450-4300	56289	150D105X0035A2
C	5	CAP TANT 1.0 UF 20PCT 35V	4450-4300	56289	150D105X0035A2
C	6	CAP TANT 1.0 UF 20PCT 35V	4450-4300	56289	150D105X0035A2
C	7	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
C	8	CAP CER DISC .01UF 80/20PCT 100V	4401-3100	72982	0805540Z5U00103Z
CR	1	RECT 1N4140 100PIV 3A SI A1XM	6081-1014	14433	1N4140
CR	2	RECT 1N4140 100PIV 3A SI A1XM	6081-1014	14433	1N4140

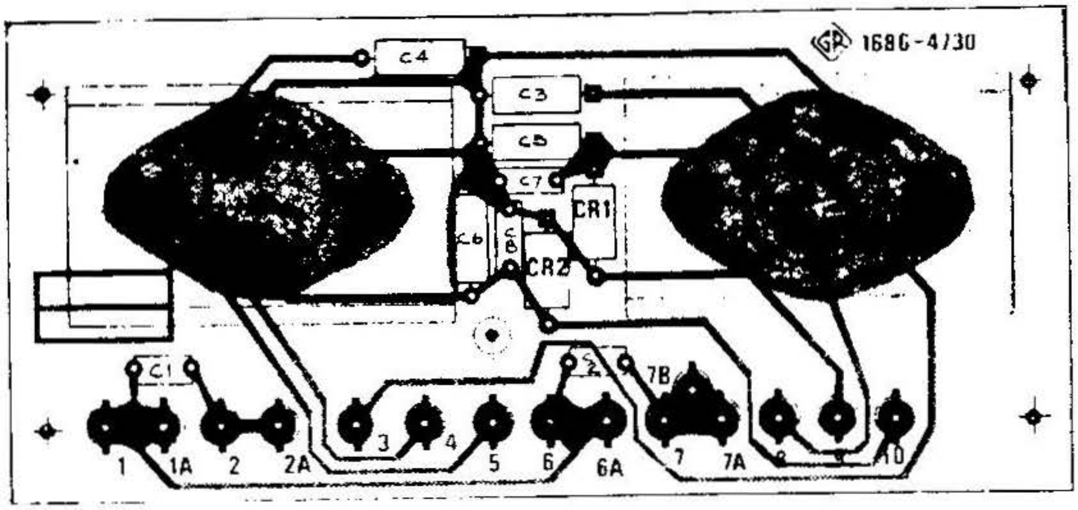
TRANSFORMER & BRIDGE ASM P/N 1685-2020

REFDES		DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
CR	5	DIODE RECTIFIER 1N4003	6081-1001	14433	1N4003
CR	6	DIODE RECTIFIER 1N4003	6081-1001	14433	1N4003
CR	7	DIODE RECTIFIER 1N4003	6081-1001	14433	1N4003
CR	8	DIODE RECTIFIER 1N4003	6081-1001	14433	1N4003
CR	9	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
CR	10	DIODE 1N459A 175PIV IR.025UA SI	6082-1011	14433	1N459A
R	5	RES COMP 10 K 5PCT 1/4W	6099-3105	81349	RCR07G103J
R	6	RES COMP 1.0 K 5PCT 1/4W	6099-2105	81349	RCR07G102J
T	1	TRANSFORMER POWER	0485-4093	24655	0485-4093



WT 9 TO WT 14 BY CR6 (CATHODE TO WT9)
WT 9 TO WT 12 BY CR7 (CATHODE TO WT9)
WT14 TO WT 8 BY CR5 (CATHODE TO WT 14)
WT 8 TO WT 12 BY CR8 (CATHODE TO WT 12)
WT12 TO WT 17 BY CR10 (CATHODE TO WT17)
WT14 TO WT 17 BY CR9 (CATHODE TO WT(17)
WT13 TO WT 17 BY R5
WT 17 TO WT 18 BY R6

Transformer and Diode Assembly (P/N 1685-2020) layout.



NOTE: *Orientation:* Viewed from parts side. *Part number:* Refer to caption. *Symbolism:* Outlined area = part; black ckt pattern (if any) = parts side, gray = other side. *Pins:* Square pad in ckt pattern = collector, I-C pin 1, cathode (of diode), or + end (of capacitor).

Power-supply board (V) layout, P/N 1686-4730.

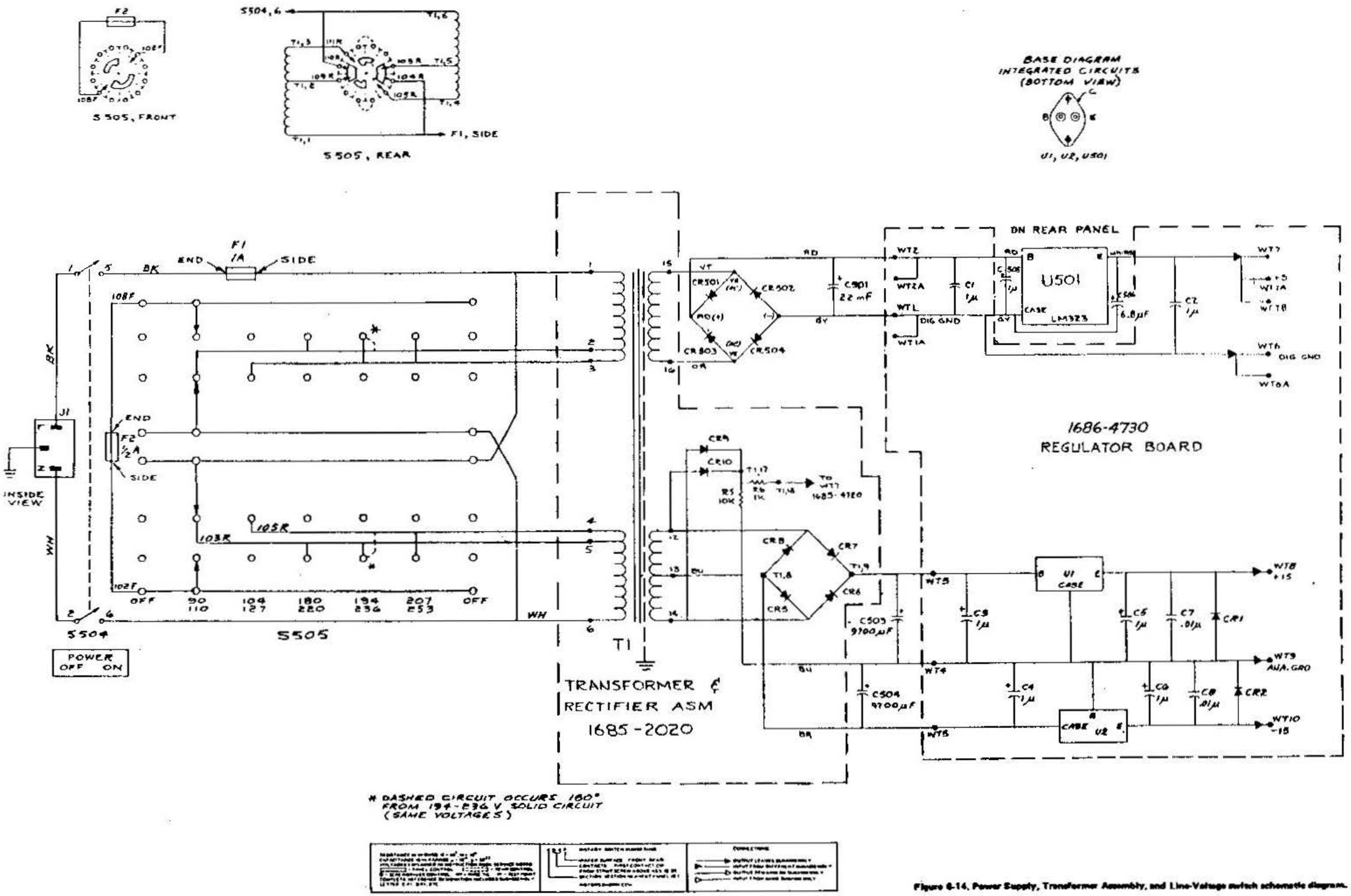


Figure 6-14. Power Supply, Transformer Assembly, and Line-Voltage switch schematic diagram.

ELECTRICAL PARTS LIST (cont)

TEST FIXTURE P/N 1686-3090

REFDES		DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C	1	CAP CER MONO 0.1UF 20PCT 50VGP	4400-2050	72982	8131-M050-651-104M
CR	1	LED GREEN	6084-1055	28480	5082-4950
CR	2	LED RED	6084-1050	28480	5082-4650
P	1	RECPT MICRO RIB 36 CONT	4230-4034	02660	57-40360
P	2	RECPT MICRO RIB 14 CONT	4230-4014	02660	57-40140
R	1	RES COMP 270 OHM 5PCT 1/4W	6099-1275	81349	RCR07G271J
R	2	RES COMP 150 OHM 5PCT 1/4W	6099-1155	81349	RCR07G151J
R	3	RES COMP 100 OHM 5PCT 1/4W	6099-1105	81349	RCR07G101J
R	4	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
R	5	RES COMP 100 K 5PCT 1/4W	6099-4105	81349	RCR07G104J
S	1	SWITCH PUSHBUTTON SPDT	7870-1560	01963	530-20P

TEST FIXTURE PC BOARD P/N 1686-4790

Includes all the above listed parts except switch S1 and indicator diodes CR1 and CR2.

ADAPTORS

For replacement of the adaptors (2 supplied), order GR part number 1686-1910.

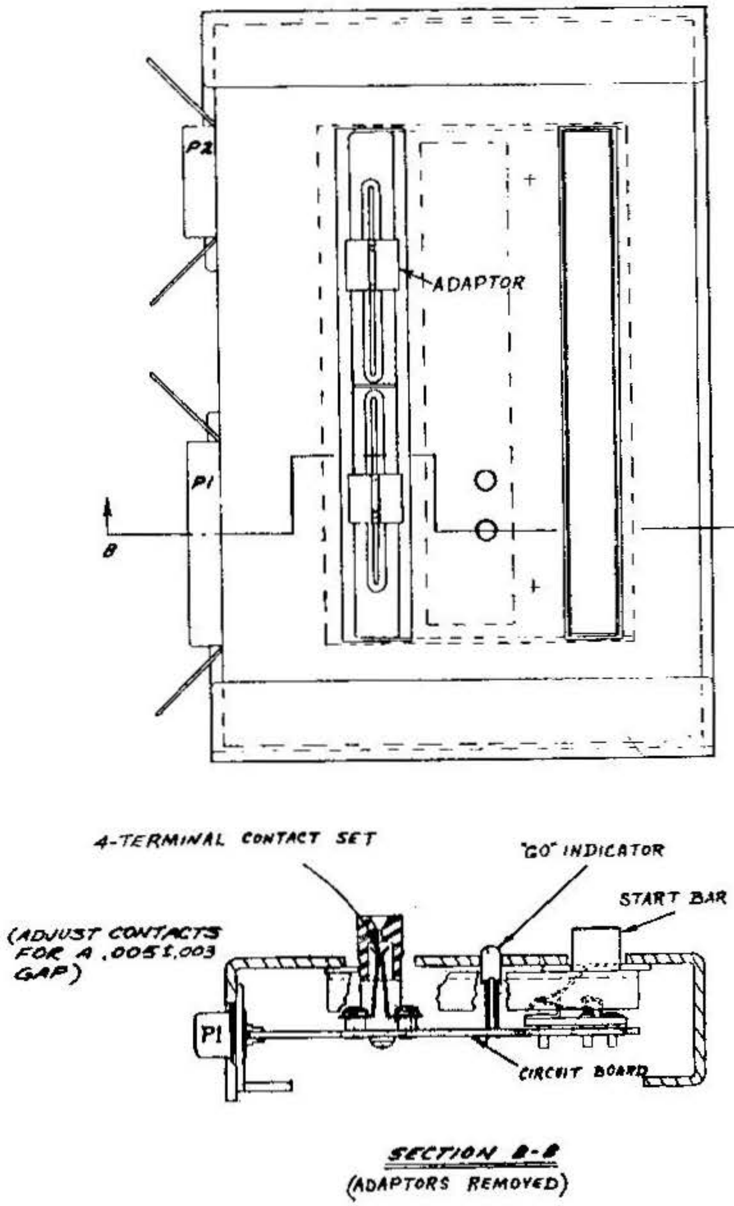
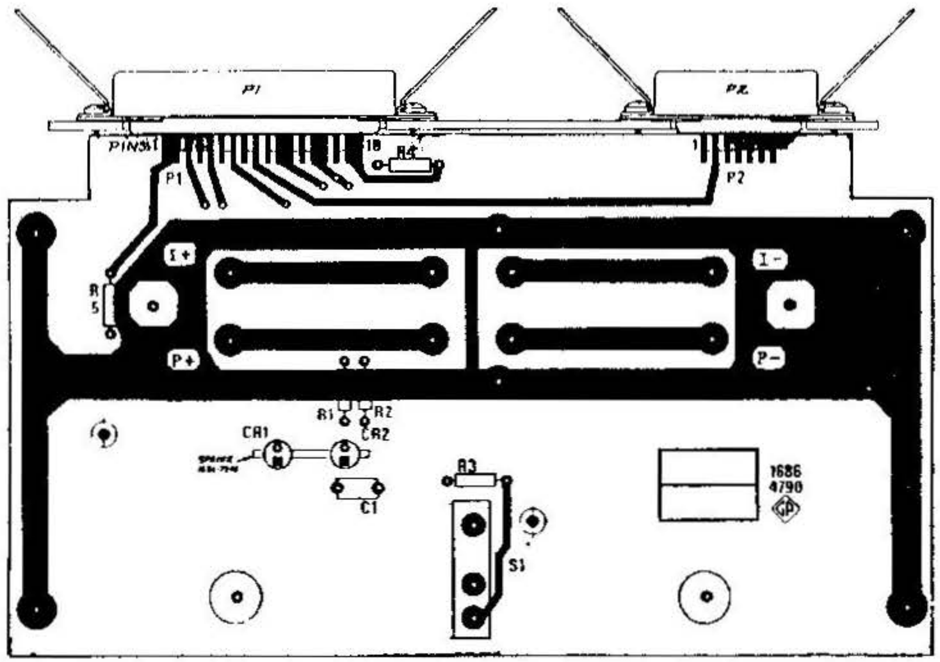


Figure 6-15. Drawing of 1686-P1 Test Fixture.



Test-fixture circuit board (Z) layout (P/N 1686-4790).

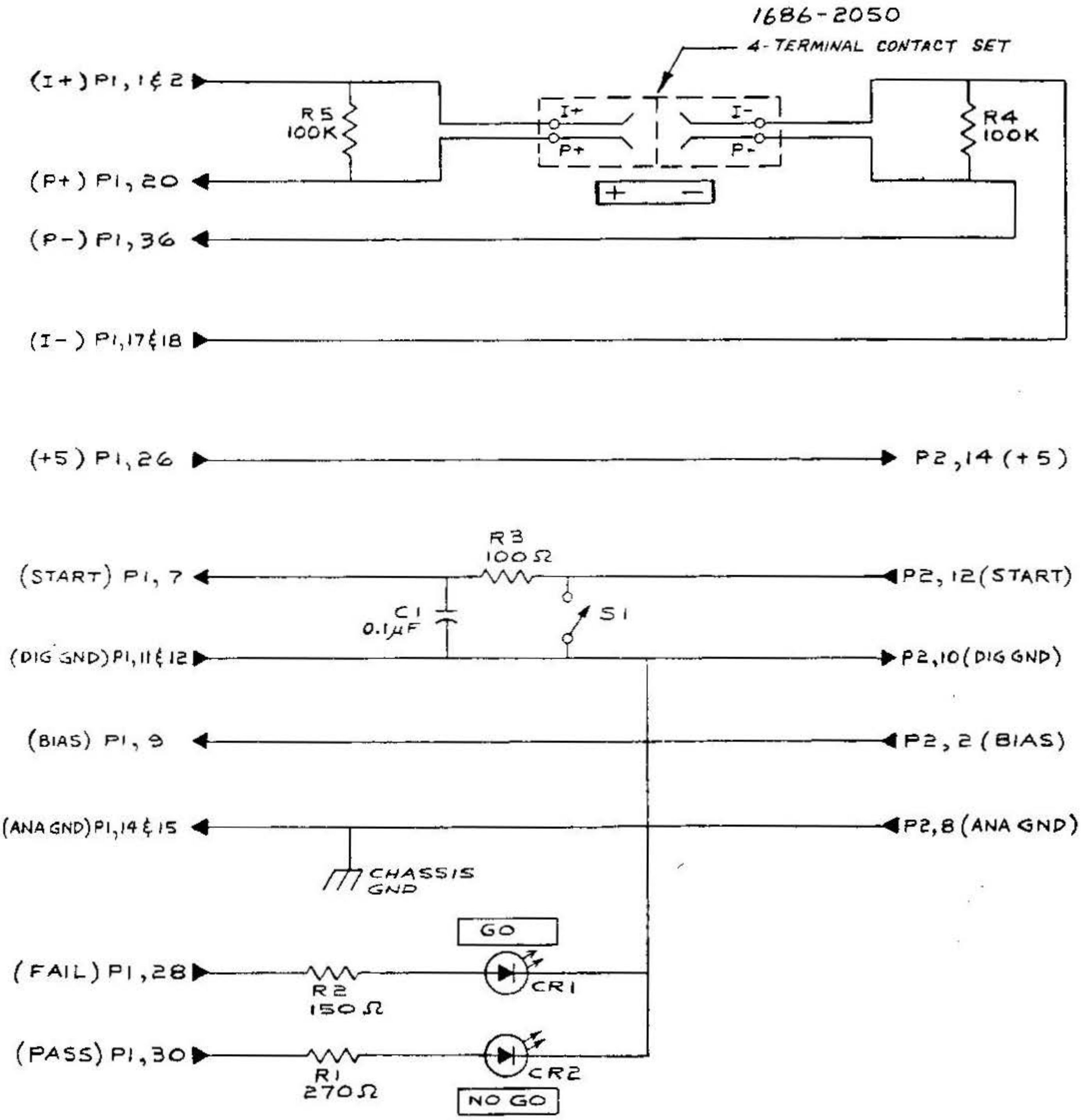


Figure 6-16. GR 1686-P1 Test Fixture schematic.