OPERATING AND MAINTENANCE MANUAL

PHASE ANGLE VOLTMETER
MODEL 213C

THE FOLLOWING PATENTS HAVE BEEN ISSUED FOR A NUMBER OF CIRCUITS IN THIS INSTRUMENT:

3,267,358
1,060,991
780,031

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SECTION 1

INTRODUCTION

1.1 GENERAL

The Model 213C Phase Angle Voltmeter (fig. 1-1) is a completely transistorized instrument which combines the ability to measure both phase angle and magnitude of comples ac signals and vector components with respect to a reference voltage. Designed for phase sensitive operation at a prespecified frequency within 30Hz to 10 kHz, it utilizes passive phase-shifter circuits to assure long-term stability and high accuracy over the spectrum. Front-panel controls permit instantaneous selection of range and function.

As a TOTAL voltmeter, the Model 213C is capable of measuring signals within a frequency range of 10 Hz to 100 kHz. The Model 213C has its frequency response limited to that of the signal isolation transformer. The signal input voltage, in the transformer mode, is limited to .75f. (f = signal frequency in Hertz)

As a phase-sensitive null meter, the Model 213's 2 μV nulling sensivity permits high-resolution ratio-metric measurements. This allows measurement of low-level voltages of the reference frequency in the presence of noise, hum, and other spurious signals. As a phase meter, angles are read on a parallax-free scale calibrated in 1° increments.

1.2 BOTH REFERENCE AND SIGNAL ISOLATION

The Model 213C includes a front panel switch for switching the transformer in or out of the signal input circuit.

NOTE

Input voltages in the transformer mode are limited to .75f.
(f = signal frequency in Hertz)

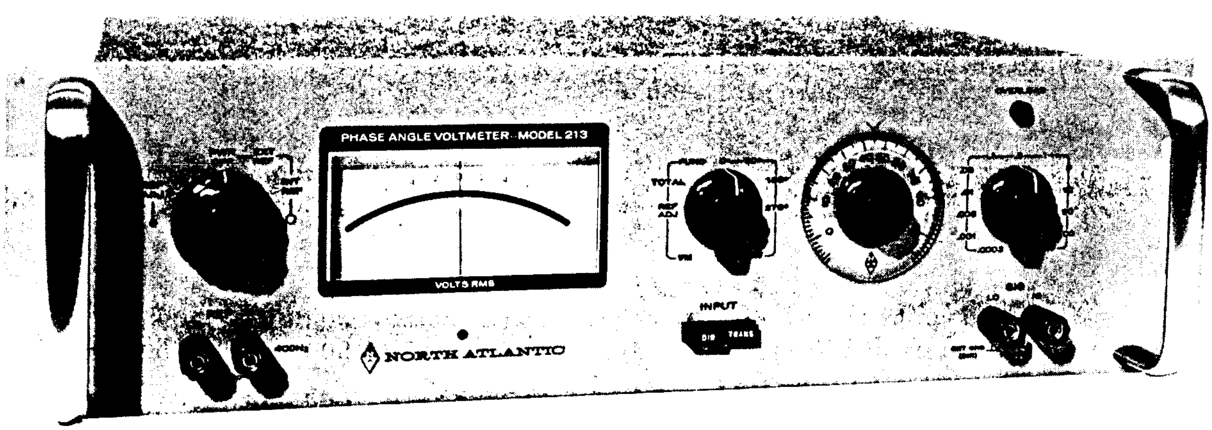


Figure 1-1. Phase Angle Voltmeter, Model 213C

.3 APPLICATIONS

The Model 213C is used in the following applications.

- Phase-Sensitive Null Indicator
- Measures separately the in-phase and quadrature components of an ac signal.
- Measures phase shift in any ac system.
- Sensitive ac electronic voltmeter
- Testing of servos, computers, synchros, resolvers, inductosyn.
- Precise ac ratiometry
- Phasing of servo motors, chopper amplifiers, magnetic amplifiers.
- Measuring both torque and non-torque producing signals in servo amplifiers.
- Align carrier amplifier and notch networks.
- Impedence meter
- Power factor meter
- Measuring response of vibrational system.

Detailed descriptions of these applications are shown in the Application Notes in Appendix A.

1.4 GENERAL SPECIFICATIONS

The specifications in table 1-1 apply to the Model 213C Phase Angle Voltmeter. Where a special modification or variation is involved, the governing specification will either be a separate specification control document, the purchase order, or a supplement contained in this manual. Specifications for individual instruments are always identified by a specification "S" number appearing on the instrument nameplate - e.g. 213C-S1234.

Table 1-1. Specifications

Item	Specification
Voltage range (full scale output)	300μV to 300V in 13 ranges
Frequency ranges	
Total mode - direct input	10Hz to 100kHz
Transformer input	20Hz to 3kHz*
Fundamental and phase sensitive modes	Single prespecified frequency with ±5% bandwidth in a range between 30Hz and 10kHz.
Voltage accuracy	
Total mode - direct input	±2% of full scale, 20Hz to 50kHz ±5% of full scale, 50kHz to 100kHz
Transformer input	±2% of full scale, 60Hz to 2kHz* ±5% of full scale, 20Hz to 60Hz, 2kHz to 3kHz
Fundamental and phase sensitive modes	±2% at phase sensitive frequency of operation.
ıase accuracy	±1° as read on the calibrated Phase dial, ±3% full scale angle using E cos θ characteristic (See Application Notes)

Table 1-1. Specifications (Continued)

Item	Specification
Calibration	
Voltage	Zero center, low stiction meter calibrated 3-0-3 and 10-0-10 scales
Phase dial	Continuously calibrated in 1° increments from -6° to +96° over four quadrants 0°, 90°, 180°, 270°.
Resolution	-0.2°
Signal input impedance	
Direct mode	10 megohms shunted by 75 μμf nominal (150 μμf with rear input terminals)
Transformer mode	300kΩ min. at 400 Hz
Reference input impedance	300kΩ (nom.) (100kΩ nom. for frequencies below 400 Hz)
Reference input voltage	1.5 V to 200 V max., 400 Hz to 10 kHz; 3.8 V to 200 V max. below 400 Hz.
Signal input dc voltage level	
Transformer mode	0 V (with no external blocking capacitor)
Direct mode	400 V
Transformer common mode rejection (at 400 Hz)	
Zero source impedance	.0025% max.
1 K source impedance	.004% max. (1 K in series with high input) .006% max. with rear input terminals
Overload	10 x full scale signal input OVERLOAD light will completely ignite at approximately 12 x full scale setting.
Noise	Less than 15 μV, Total and Fundamental modes
Nulling sensitivity	Less than 2 μV, Phase Sensitive modes.
Fundamental mode frequency response	See diagram (fig. 4-4)
Harmonic rejection phase sensitive modes	
At 400 Hz	55 DB
All other frequencies of operation	40 DB to 70 DB depending on frequency of operation (see fig. 4-4)

*Typical for pre-specified phase sensitive frequency of 400 Hz.

Table 1-1. Specifications (Continued)

Item	Specification
Non-coherent signal rejection	For frequencies removed from signal frequency by approximately 5 Hz or more (effective pass band of meter movement), response is essentially zero for levels up to 10 x the value of the full scale range in use. Internal filters will increase the allowable level of the non-coherent signal to 300 x the value of the full-scale range in use on the most sensitive ranges, provided the non-coherent signals are in the stop band of the filter.
Power	115 V/125 V or 230 V/250 V ±10%, 45-440 Hz, 10 VA
Fuse	
For 115 V/125 V power	.5 A, type 3 AG. S.B.
For 230 V/250 V power	.25 A, type 3 AG. S.B.
Size	
Panel	5-1/4" x 19" W
Depth behind panel	12"
Width behind panel	16-3/4"
Weight	Approximately 15 lbs.
Mounting	Rack or bench mounted.
Front panel paint	Semi-gloss gray #26280
Line cord	6' long with ground pin
Front panel input	Inputs are standard, 5-way binding posts, spaced on 3/4" centers.

1.5 REAR PANEL FEATURE CODE LABEL EXPLANATION

Table 1-2 explains the feature codes on the rear-panel label.

Table 1-2. Rear Panel Feature Code Explanation

Feature No.	Feature Description	Option	Rear Input: 5-way binding posts	Rear Input: MS	External Meter: Terminal strip	External Meter: 5-way binding posts
F11	Internal code number for frequency specified					
F12	Rear panel configuration	1.	---	--	---	---
		2.	yes	--	---	---
		3.	---	yes	---	---
		4.	---	--	---	yes
		5.	---	yes	yes	---
		6.	yes	--	---	yes
		7.	---	yes	---	yes
		8.	---	---	yes	---
		9.	yes	---	yes	---
F13	Input power line voltage	1. 115V 2. 230V				

SECTION 3

OPERATING INSTRUCTIONS

3.1 METER ZERO

Prior to making any connection, check the meter to see that it reads 0. If it does not, reset the meter to read 0 by means of the Zero Adjust screw which may be reached through a hole below the meter on the front panel. This adjustment must be done with the power off, and with the instrument in the normal horizontal or near horizontal position.

3.2 POWER LINE VOLTAGE

The Model 213C is normally wired for 115 V/ 125 V operation with switch S6 in the 115 V position. If it is desired to operate the instrument from a 230 V/250 V source, remove the top cover and set S6 to 230 V position.

NOTE

Be sure to use the proper fuse for the desired operating voltage. 115 V/125 V source will be .5 amp., type 3 AG fuse, and 230 V/250 V source will be .25 amp., type 3 AG fuse.

3.3 GROUNDING

All electrical circuits and power grounds are floating (in the Direct Mode) with respect to the chassis. The instrument is supplied with a three-prong power plug. The round pin is wired to the chassis. Common grounding of power, chassis, and circuit ground is accomplished by means of a link on two rear panel terminals, one of which is chassis ground, and the other input circuit ground. The circuit ground must be connected to chassis ground either at these terminals or remotely.

Circuit ground is automatically tied to chassis ground in the Transformer Mode independent of the link connection. Dependent upon specific application, it may be more desirable to wire the chassis such that it is not connected directly to house ground. In those cases, extreme caution must be taken to avoid any personal injuries due to the resultant shock hazard. As a general rule, every effort must be made to ensure that the chassis is wired to a house ground at all times.

Great care should be given to grounding methods used to avoid ground loops and stray fields.

3.4 LOW FREQUENCY, HIGH-LEVEL VOLTAGES

When the instrument is operated in the Transformer Mode, care must be taken not to apply high-level voltages at a low frequency such that the 0.75 f (f = Hz) maximum voltage rating of the input transformer is exceeded. The same precaution applies to the reference input transformer in those instruments whose phase-sensitive frequency is 400 Hz or above. The maximum voltage rating of the reference input transformer is 0.5 f (f = Hz).

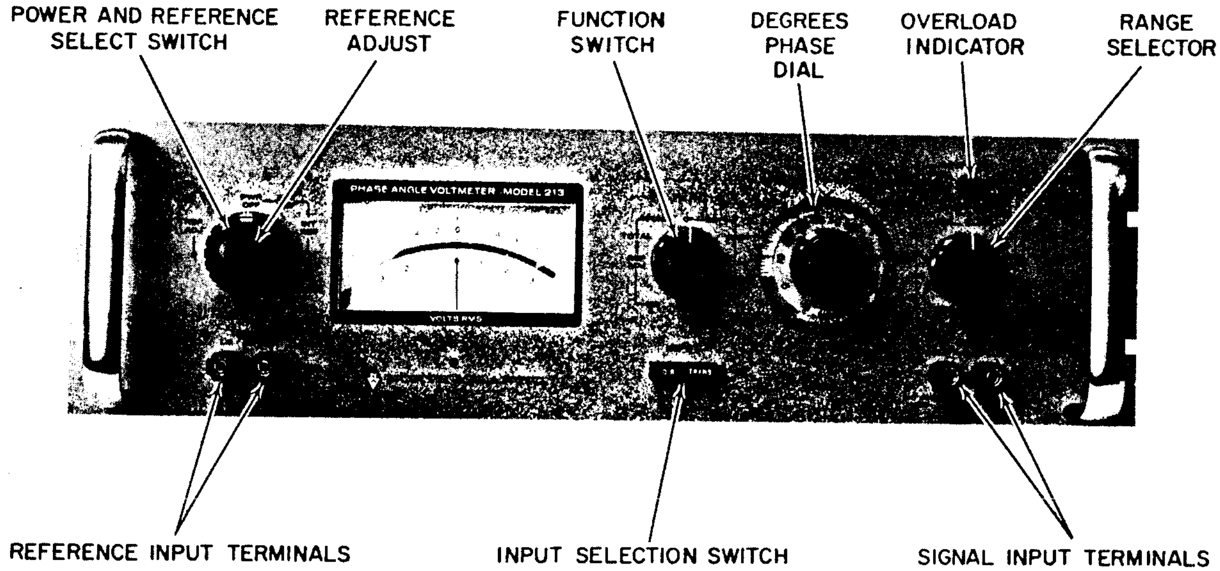
In the event that signals containing dc are to be injected in the Transformer Mode, a large blocking capacitor should be used externally.

CAUTION

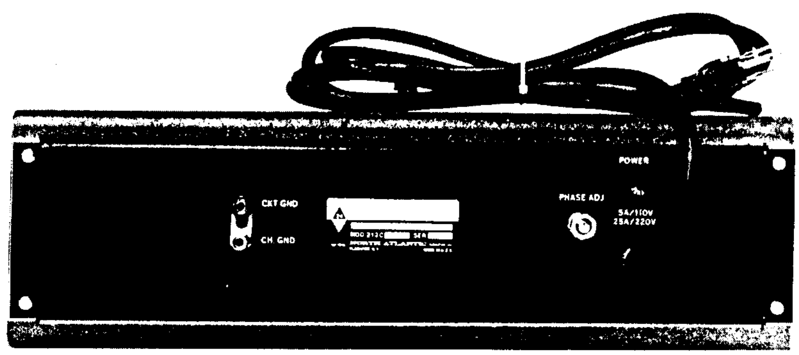
Maximum signal input must not exceed 300 V rms and maximum reference input must not exceed 200 V. Higher voltages will break down the input capacitors in the instrument. (See table 1-1.)

3.5 CONTROLS, DISPLAYS, INPUTS (Figure 3-1)

Prior to attempting to operate the instrument, it is advisable that the user familiarize himself with every control, display, and input connection as described in table 3-1.



FRONT PANEL



REAR PANEL

Figure 3-1. Controls and Indicators

Table 3-1. Controls and Indicators

Control/Indicator	Function
Pow[illegible]d Reference select switch	If the pre-specified phase sensitive operating frequency of the voltmeter is 60 Hz or 400 Hz, the power switch will consist of two positions for selecting either External Reference Input or Internal Line Reference Voltage. Power will be indicated by the illumination of the meter face.

Table 3-1. Controls and Indicators (Continued)

Control/Indicator	Function
Reference Adjust control	The Reference Adjust control is used for adjusting the reference level to read half scale (red line) on the meter. This control is used when the Function switch is in the REF ADJ position.
Function selector switch	The Function selector selects the desired mode of operation for the instrument. In the four PAV (Phase Angle Voltmeter) positions, the instrument is connected so that it may read a voltage E cos θ, where θ is the angle by which the signal vector leads the reference vector. Any of the four quadrants may be selected over which the calibrated degrees phase shifter will operate. Thus, the total angle by which the reference vector is shifted in degrees will be either 0°, 90°, 180°, or 270° plus the reading of the Degrees Phase dial. There are three VM positions. In the TOTAL position, the instrument functions as a standard voltmeter and will read all voltages over a frequency range of 10 Hz to 100 kHz. In the FUND position, the instrument reads the total vector of the fundamental component of the input signal. (See figure 4-4 for filter characteristics.) The Function selector must be positioned in the REF ADJ position in order to make the proper reference adjustment.
Range selector switch	The Range selector is a rotary switch which selects the proper attenuators for the desired full-scale voltage as marked on the front panel.
Degrees Phase dial	The Degrees Phase dial is calibrated to read the degrees of phase shift introduced by the calibrated phase shifter networks within the particular quadrant selected by the Function selector. The Degrees Phase dial is calibrated from -6° to +96° in 1° graduations. Mechanical positioning of this dial on its shaft is critical and for this reason, should it be necessary to repair or replace, the procedure under Phase Dial Alignment (para. 5.6.3) should be followed.
PHASE ADJ control (R98 - located on the rear panel)	R98 is a screwdriver adjust control used to align the signal and reference channels. Its function is to trim the instrument for minor variations in the frequencies of measured signals from the pre-specified frequency.

Table 3-1. Controls and Indicators (Continued)

Control/Indicator	Function
OVERLOAD indicator	The OVERLOAD indicator turns on whenever a prescribed signal level is exceeded. This indication warns of impending amplifier overload and the resultant inaccuracies which will occur when large saturating signals are present. The OVERLOAD indicator is factory set to turn on when the input exceeds 10 x full scale. (The instrument will function within its specified accuracy up to, and including, a 10 x overload.)
Meter	The meter is a zero center low stiction microammeter calibrated to read the rms value of a sinewave. For all voltmeter readings, the pointer deflects to the right. For phase-sensitive measurements, the meter deflection may be to the left or right. It has a calibrated zero center 3-0-3 and 10-0-10 with mirror backing for more precise readability. CAUTION By its nature, the instrument is required to handle inputs considerably in excess of its full-scale reading. Although a high overload capability has been designed in, discretion should be used to avoid application of signals in a manner which will drive the needle hard against the stops. Therefore, always approach a measurement from the least sensitive position and return to this position before making circuit adjustments. This approach will avoid any damage which may occur to the meter.
Input terminals	These terminal posts are on standard 3/4" spacing and will accommodate banana plugs, wire, or alligator clips. The reference and signal input terminals are designated HI and LO which indicates polarity with respect to each other (i.e., HI is inphase with high; LO is inphase with low). The signal LO terminal is tied to circuit ground in the direct position. In the transformer position it is tied to the low side of the primary and the primary shield.
INPUT selector switch	The INPUT selector switch is a push button switch which removes the input transformer from the input circuit in the DIR position allowing for single-ended, direct-coupled inputs. In the TRANS position floated inputs or differential inputs, as well as, single ended, isolation inputs, may be fed into the Signal Channel.

3.6 OPERATION

Plug the instrument into the proper power source. Turn the Power switch ON and allow the instrument to warm up for a short period (3 to 5 minutes) for stable operation.

CAUTION

Before making measurements, review the section on grounding techniques in the Application Notes.

3.6.1 Measuring Voltage

Set the Range selector to the appropriate scale and the Function selector to the appropriate position. Connect the voltage to be measured to the SIG input terminals and read the voltage from either the 0-10 or 0-3 volts scales using the proper scale factor as determined by the Range selector position.

With the Function selector in the TOTAL position, the voltmeter operates as a standard ac voltmeter. This reads the total vector voltage at any frequency (within specifications) including all harmonic effects. With the Function selector in the FUND position, response of the instrument is determined by filter characteristics.

Notice that with no input to the instrument (terminals not shorted), the meter deflects on the low ranges. This condition is, and represents, a true measurement of stray fields capacitively coupled to the input. Shielding the input will reduce this deflection to a minimum level. Measurements made on high impedance circuits require that special attention be paid to capacitive as well as inductive pickup.

Twisted and/or shielded cable will reduce the effect, though the cable capacity could serve to load the source. Care must be taken, where possible, to insure that ground loops do not exist by virtue of the signal and reference grounds being connected. These loops can result in erroneous readings. (Refer to the Application Notes.)

3.6.2 Measuring Phase Angle

3.6.2.1 Reference Adjustment

a. Set the Function selector to the REF ADJ position.

b. Inject the reference signal into the REF terminals and adjust the REF ADJ control to cause the meter to read a value as indicated by the red mark on the meter scale. The red line adjustment will vary somewhat as a function of the Phase dial setting. This is normal and does not indicate malfunction. The red line setting may be made at any setting of the Phase dial.

3.6.2.2 Preliminary Phase Adjustment (R98)

a. This adjustment is factory set and should seldom need to be touched except following servicing and/or component replacement. Using a signal source, equal to full scale on any range greater than 1.0 volts, connect the signal to both SIG and REF inputs and adjust the reference level in accordance with paragraph 3.6.2.1.

b. Place the Function selector to 0° position and the Degrees Phase dial to 90°, and then Function selector to 90° position and the Degrees Phase dial to 0°.

If the meter does not read zero for both these tests, use the rear-panel PHASE ADJ control, R98, to provide a zero which is the best compromise for both cases. This control adjusts the phase shift between the signal and reference channels. In general, once this setting is made there is little reason to re-adjust the control.

3.6.2.3 Phase Angle Measurements - with Calibrated Degrees Phase Dial

a. Set Function switch to REF ADJ position. Connect a reference input to the REF

terminals, and adjust the reference level by REF ADJ control for red line.

b. Set Function switch to FUND position. Inject the signal to be measured into the SIG terminals with the Range selector set to a position that will allow a maximum on scale reading.

c. Turn the Degrees Phase dial to cause the meter to read a null on any phase sensitive position of the Function switch. This step is to provide a coarse measurement of the phase angle.

d. Switch the Range switch to more sensitive positions until the OVERLOAD light comes on. Then uprange one position so that the OVERLOAD lamp is off.

e. Adjust the Degrees Phase dial more precisely for a null on the meter. Switch Range switch two positions less sensitive.

f. Switch the Function selector to a position (0°, 90°, 180°, 270°) which gives a meter deflection to the right.

g. The phase angle is the sum of the Function selector setting of step f and the Phase dial setting of step e.

3.6.2.4 Measurement of In-Phase (0°) and Quadrature (90°) Components

a. With reference level properly set, place Function selector to 0° position. Set the Degrees Phase dial to 0°.

b. The meter now reads the in-phase component of a signal. This is also E cos θ where θ is the angle between the reference and signal.

c. Switch the Function selector to 90°. The meter now reads the quadrature component, or E sin θ.

In general, one of these components is usually much smaller that the other and for greater accuracy, it is convenient to change the range of the instrument. This can be done until the OVERLOAD lamp lights, thereby warning of an impending overload condition. This light indicates that the total signal exceeds ten (10) times the full-scale value. Measurements can be made for overloads up to 10 times full scale. Measurements under all these conditions will be most accurate if the zeroing process described in the Application Notes is followed.

3.6.2.5 Measurements Under Most Sensitive Conditions

Measurements under overloaded (less than 10 times) conditions can be made where it is desired to increase the null capability or to make the small quadrature signal level measurements. As stated previously, the signal levels in the SIG channel may be 10 times the full-scale reading as indicated by the Range switch setting. Under some special conditions, these signals may exceed this 10 times specification by small amounts without overloading the amplifiers in the signal circuits. These signals, however, should never be increased beyond the level which will cause the OVERLOAD indicator to light.

Accurate measurement of phase angles can be made using the E cos θ or E sin θ characteristic. Voltage measurements are made from the in-phase (0°) or quadrature (90°) component of the fundamental signal and the total vector amplitude as measured in the FUND position. The quotient will then be the cosine, or sine, or tangent of the unknown phase angle. Trigonometric tables, slide rule, or graphs included in the Application Notes are suitable for converting to degrees. The accuracy achievable using this technique depends upon the procedure, and for that reason, it is suggested the Application Notes be reviewed before using this method.

3.6.3 Differential Measurements and Common Mode Rejection

3.6.3.1 Differential Measurements Using an Input Transformer

In making differential measurements using

a transformer, there are two sources of error. One is due to capacity from either side of the primary to the high side of the secondary as shown in figure 3-2 (A). This can result in an output even if $E_1 = E_2$. Due to coupling into the output impedance of the secondary, this effect is minimized if a secondary shield is used, connected as shown in figure 3-2 (B). Note that these capacitors are now capacitors to ground and will cause no coupling to the secondary.

The other source of error is capacity to ground, phase shifting the signal from a source with a finite source impedance as shown in figure 3-2 (C). This also can cause an output even if $E_1 = E_2$.

This effect is minimized if a double shielded wire and a primary shield is used as shown in figure 3-2 (D). This will connect the capacity from the inner conductor to the inner shield (C_1) across the transformer which, when nulled, introduces no error. Capacity from the inner to outer shield (C_2), and capacity from the primary shield to secondary shield (C_3) is across E_2. If E_2 has a low source impedance, this will introduce no error.

Therefore, for maximum accuracy in making differential measurements, the lowest impedance source should be connected to the low input terminal.

If it is desired to make differential measurements when high source impedances are present in both input leads, it is sometimes possible to drive the primary shield at a voltage equal to E_1 and E_2. This, in effect, places C_3 and C_2 across a third source, independent of the voltages being measured. This is shown in figure 3-2 (E).

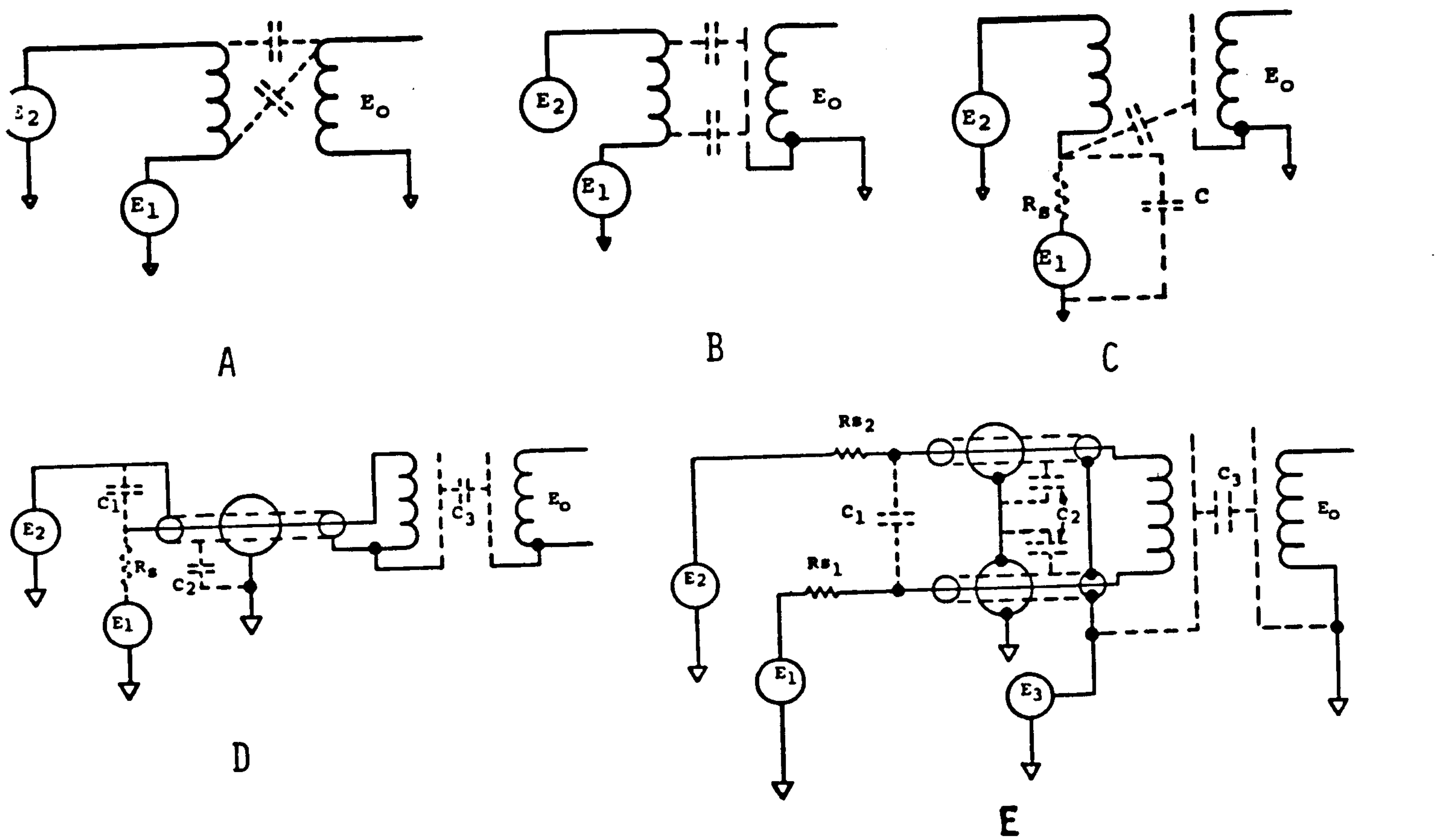


Figure 3-2. Differential Measurements and Common Mode Rejection

If it is desired to improve the differential measurement capability over and above that provided by the VM 213C, it is recommended that the user employ a high-quality bridge null transformer.

3.6.3.2 Common Mode Rejection (CMR)

Mode Rejection defines the ability of an instrument to measure a voltage existing between its two input leads (Differential Mode Voltage) in the presence of a voltage to ground common to both input leads (Common Mode Voltage). This type of measurement is frequently encountered when making ungrounded or differential measurements such as the output of the ac bridges.

Common Mode Rejection, espressed in per cent, is defined as:

$$\frac{\text{Differential Output}}{\text{Common Mode Voltage}} \times 100\%$$

It can be measured by shorting the input leads together and applying a Common Mode Voltage to both input terminals, (figure 3-3 (A)), and reading the output of the meter. Should it be desired to measure CMR with a source resistance, use the circuit of figure 3-3 (B).

An example of this calculation would be the meter reading 10 mV with a CMV of 100 V. The CMR would then be

$$\frac{10 \times 10^{-3}}{100} \times 100 = 0.01\%$$

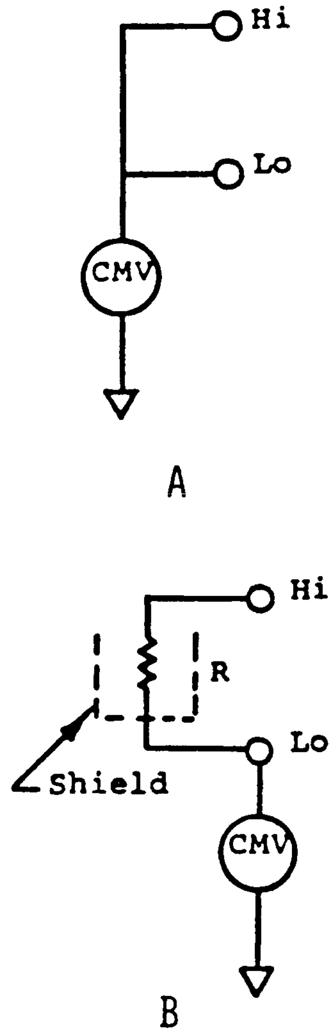


Figure 3-3. Common Mode Rejection

SECTION 4

THEORY OF OPERATION

4.1 INTRODUCTION

The block diagram of figure 4-1 will serve to illustrate the principles of operation of the Phase Angle Voltmeter. The Phase Angle Voltmeter is a multi-function instrument, and the following will describe each of these functions.

4.2 GENERAL THEORY

4.2.1 Total and Fundamental Voltmeter

When operating as a Total and Fundamental voltmeter, the instrument uses only the signal channel circuitry. The signal amplifier, in conjunction with the range attenuator, functions as a conventional ac electronic voltmeter. The signals applied to the input are amplified and fed to the full-wave rectifier circuit and indicated on the meter, which is calibrated in rms. (See table 4-1 for errors due to harmonics.)

As a Fundamental Voltmeter, a harmonic filter is switched into the circuit and the meter reads only those frequencies within the pass band of the filter. (See figure 4-4 for filter characteristics.)

4.2.2 Phase Angle Voltmeter

As a Phase Angle Voltmeter, the reference channel is activated and operates in conjunction with the Fundamental mode circuitry of the signal channel. The reference signal is phase shifted by the calibrated reference phase bridge circuitry, amplified, and then filtered. The reference channel output serves to gate the demodulator portion of the meter circuit. The relationship of this gating voltage to the signal being measured will determine the magnitude and the polarity indicated on the meter.

For those signals which are in-phase, a signal of maximum amplitude will be indicated and for those signals which are 90° out-of-phase (Quadrature), a minimum signal will be read. Where the instrument is being used to read quadrature signals, these signals may exceed the indicated range by up to 10 times without overloading the signal amplifier circuits. This capability provides a means for much more accurate measurements of quadrature voltages and computation of phase angles.

4.3 DETAILED THEORY

4.3.1 Signal Input Attenuator

The signal amplifiers of the Model 213C always operate with the same basic sensitivity (300 µV). This requires attenuators for reducing higher level voltages to this range. The input attenuator actually consists of two separate voltage divider networks. The first provides a 1000:1 reduction for voltages .3 volts and above. The second provides seven attenuator ranges from 1:1 to 1000:1. This latter attenuator provides attenuation for signals up to and including 100 mV and is added to the attenuation of the 1000:1 divider for signals between 1 volt and 300 volts.

At low frequencies, the 1000:1 attenuator ratio is determined solely by the resistors employed. At higher frequencies, capacitive compensation is necessary to compensate for circuit strays. This converts the attenuator to a capacitive divider at high frequencies. The crossover from resistive to capacitive attenuation occurs at approximately 600 Hz. This attenuator when properly adjusted not only provides proper attenuation at both high and low frequencies, but also has essentially zero phase shift over the rated frequency range. (See Adjustment Procedure (para. 5.6.2) for proper alignment.)

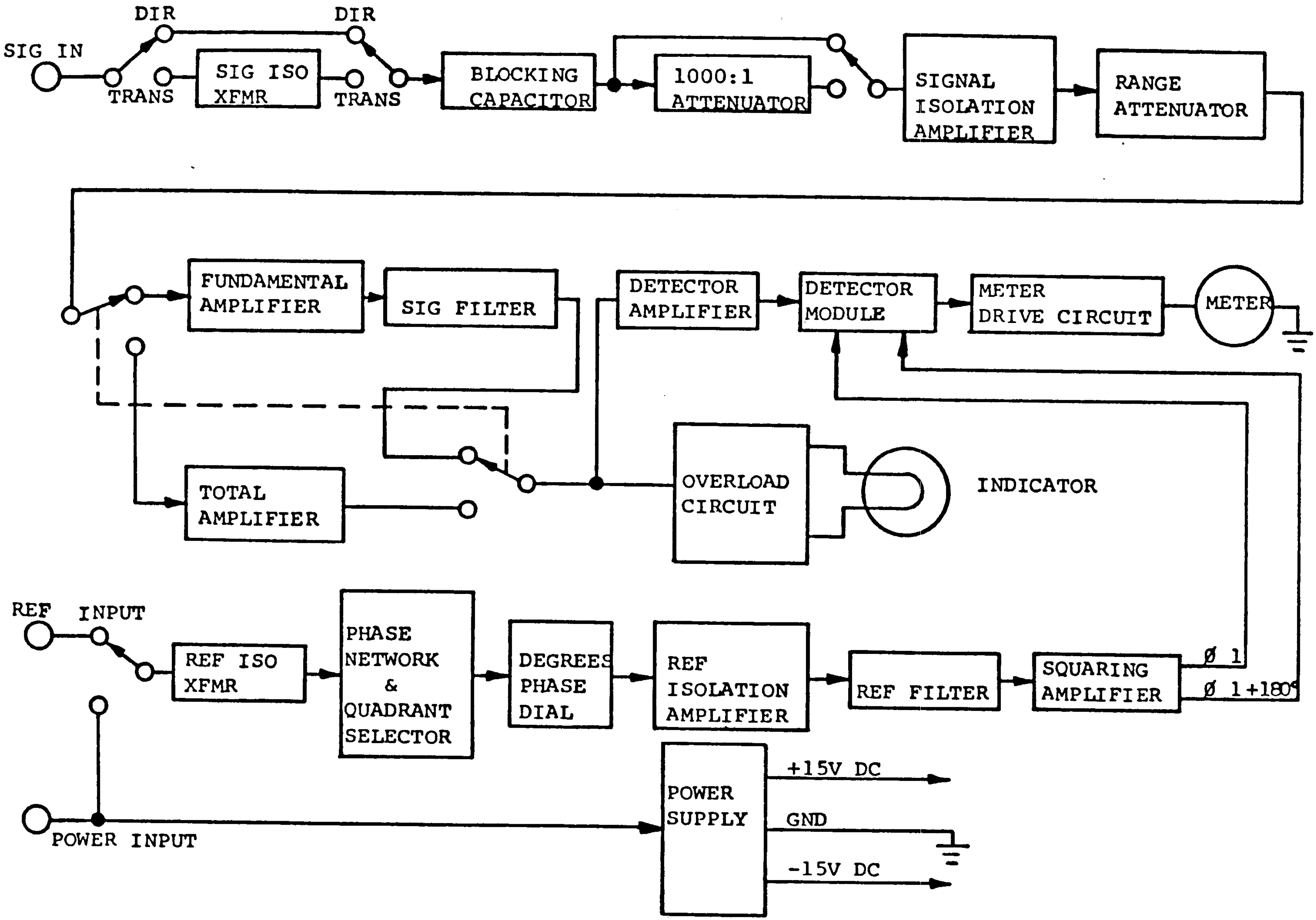


Figure 4-1. Phase Angle Voltmeter Model 213C, Block Diagram

4.4 AMPLIFIERS

4.4.1 Signal Isolation Amplifier

The signal isolation amplifier provides a high input impedance to the input signal and a low output impedance to the range attenuator. It has a gain of 3.2 and provides a wide band frequency response with minimal phase shift and low noise. R25, C17, R33, and CR7, 8, 9, and 10 provide overload protection for the amplifier and will allow 300 V rms to be applied indefinitely to the input with the Range switch on the 300 μV range.

4.4.2 Amplifiers

The amplifiers (Z2, Z3, Z4, Z6, and Z7) that are used in this voltmeter are dual operational amplifiers. They are all used in a high feedback gain configuration to assure maximum stability with time and temperature.

Z6 A and B are the Fundamental and Total mode amplifiers. Each amplifier has a gain adjust pot for adjusting the meter to a full scale. Each amplifier is in a non-inverting configuration with a nominal gain of 150.

Z7 and its associated circuitry is the signal channel filter. This low pass active filter provides harmonic rejection in the Fundamental and Phase Sensitive modes. Typical characteristics are shown in figure 4-4.

Z3A is the reference isolation amplifier which provides a non-inverting unity gain and high input impedance to prevent loading of the phase pot, R4. Z3B provides a gain of 35 for the reference signal.

Z2 A and B is the reference channel filter. Its components and circuitry are exactly the same as the signal channel filter.

Z4 A and B is the reference squaring amplifier. This amplifier provides two 30 V P-P square waves which are 180° out of phase with each other and are used to gate the phase sensitive detector.

Detector and Meter Drive Amplifiers Z5 and Z9 are single stage operational amplifiers which remove the effects of nonlinear switching elements in the Detector Module. Its configuration also provides full-wave switching operation.

4.5 DETECTOR CIRCUIT

4.5.1 Detector Module Z8

The detector is a proprietary module which functions in the Total and Fundamental modes as a full-wave rectifier averaging detector, and in the phase angle modes functions as a phase sensitive detector.

The detector's phase sensitive operation can be likened to that of a set of commutating switches. The reference signal causes signal current to flow through the meter in alternate directions in each half cycle of the reference signal. (See figure 4-2.) When the reference and signal are in-phase (fig. 4-2A), the average value of this current will be maximum and the meter will read a maximum voltage. When the signals are 90° apart (fig. 4-2B), the average will be zero and no reading will result. The equation governing this is:

$$I\ \text{Meter (avg)} = K\,E\cos\theta$$

where K = proportionality constant
E = rms of signal
θ = angle between signal and reference

Detector saturation effects will limit this characteristic equation to the design levels for the instrument. Under special conditions, such as are described in the appended Application Notes, the reference level is increased to improve accuracy for high signal levels. Measurements at the quadrature null point ($\theta = 90°$) are relatively unaffected by saturation.

The response of the Detector is limited to signals at the reference frequency as well as to odd-order harmonics. Response for this type detector to odd-order harmonics will never be greater (usually less, depending upon phase angle) than the fundamental response multiplied by a factor 1/n,

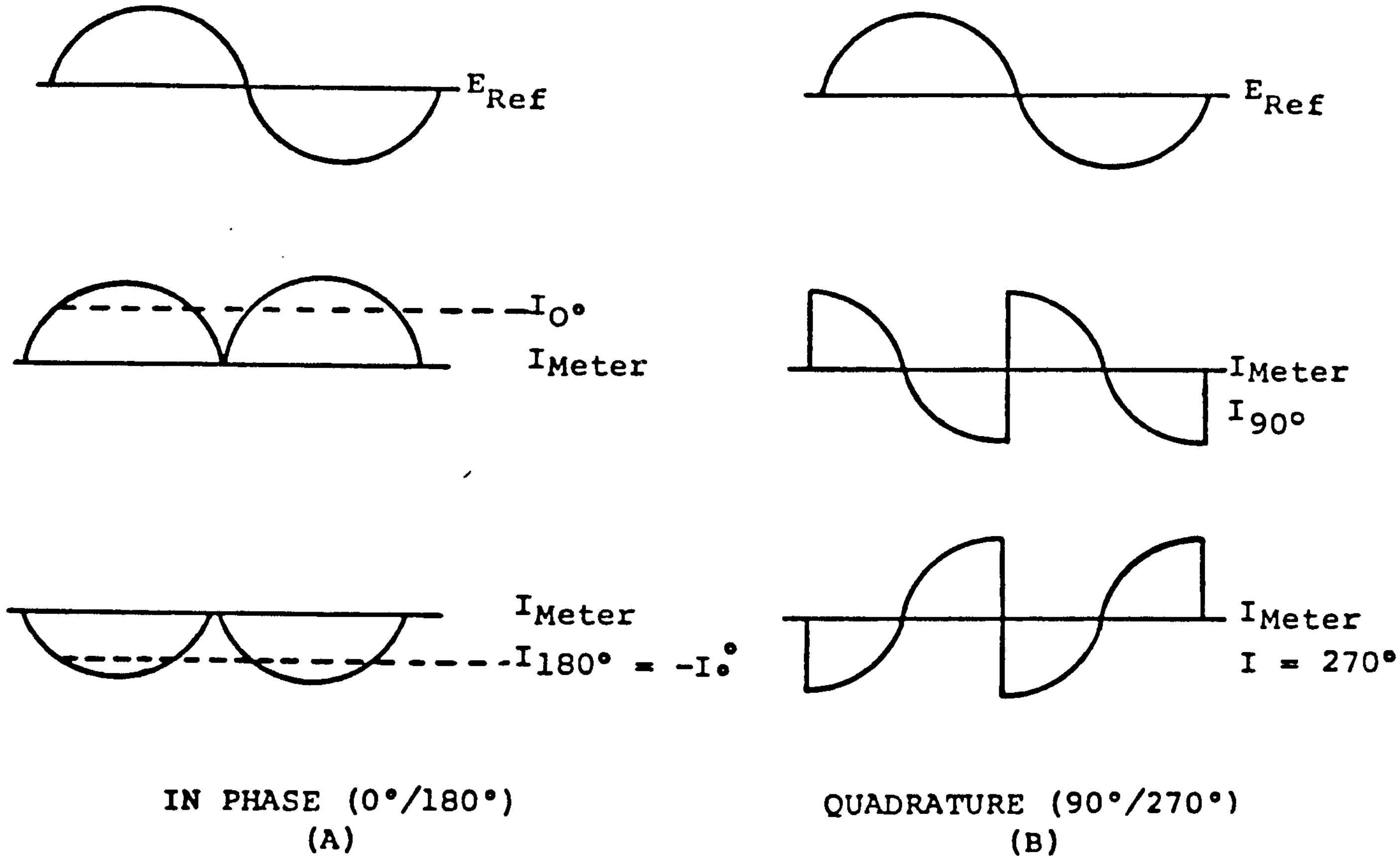


Figure 4-2. Phase Detector Waveforms

where n is the order of the harmonic. Where a signal channel filter is used, there is, of course, essentially no response to harmonics in the signals.

All other frequencies are rejected except for signals very near to the reference frequency and its odd harmonics. Here, the meter movement will oscillate between 0 degrees in-phase and 180 degrees out-of-phase and at a frequency proportional to the difference between the input frequency and the fundamental or third harmonic of the reference signal. Response of this nature is limited to frequency differences of about 5 Hz (meter pass band).

The effect of reference harmonics is much less inportant than that of signal harmonics because the harmonic content can never do more than shift the point at which the current starts to flow. Expressed otherwise, there is an equivalent error in degrees which results from harmonics in the reference channel. For measurements using the Degrees Phase dial, the error can be removed by trimming. For measurements using E cos θ characteristic, the effect is small because the meter reading as a function of current integrated over an entire cycle and the small error produced by distortion has a correspondingly small effect on the total current.

When used as a conventional Total or Fundamental voltmeter, the Detector is switched to a full-wave rectifier configuration. Operation is identical to that of a full-wave bridge power supply in which the meter movement acts as the load.

4.5.2 Effects of Distortion

The current through the meter in the latter circuit is proportional to the average value of the voltage waveform applied. Calibration of the meter in rms is based on a ratio between the average and effec-

tive values of a true sinusoidal voltage. Deviation from a true sinewave may cause errors in the meter indication. Table 4-1 lists the range of possible errors due to the second and third harmonic distortion.

Table 4-1. Errors Due to Harmonics in a Typical Average Detector

Harmonic order	Harmonic content	Error
2nd	10%	Nil
2nd	20%	0 to +2%
2nd	50%	0 to +10%
3rd	10%	-4% to +4%
3rd	20%	-6% to +8%
3rd	50%	-10% to +16%

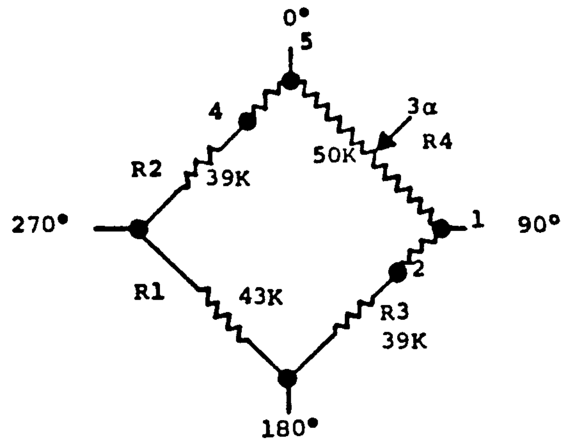
4.5.3 Overload Circuit

The Overload detector circuit is designed to operate as a switch. When the signal level exceeds a level of approximately 12 times full scale, the circuit will switch turning on the OVERLOAD indicator. The signal amplifiers will operate up to and including 10 times overload. The indicator is set to light above this level, and ordinarily measurements may not be made as long as the indicator is lit.

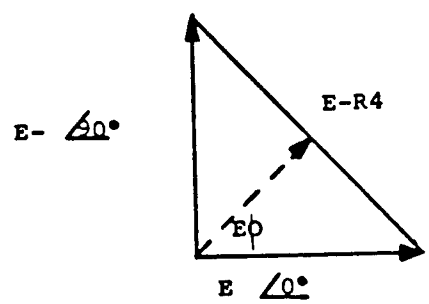
4.6 PHASE BRIDGE NETWORK

The Phase Bridge Network is required to generate the precision phase shifts in the reference channel. These networks are designed for specific frequencies as required by the individual user. An output of 0°, 90°, 180°, and 270° is provided and is selected by the Function switch. Angles in any quadrant are determined by connecting the Degrees Phase dial potentiometer to any two adjacent points through the Function switch. This provides a phase shift capability of 0° to 360° as determined by the Function switch setting plus the Degrees Phase dial (phase potentiometer) setting (fig. 4-3).

The voltage E-R4 appears across the Degrees Phase dial potentiometer R4 between the taps, terminals 1 and 5. When E/0° is



PHASE SHIFT BRIDGE



E/0° = E/90°

$\theta = \theta \text{ Max } \frac{\text{Tan } \phi}{1 + \text{Tan } \phi}$

ϕ = Electrical Phase Angle

θ = R4 Shaft Angle

Frequency in Hz

Figure 4-3. Voltage Vector at Phase Potentiometer

set equal to E/90°, the electrical angle E/φ is a non-linear function of the potentiometer shaft angle. This is compensated by a non-linear Degrees Phase dial.

The 90° angular rotation is shifted to any quadrant by the four corners of the bridge being rotated to cause the desired quadrant voltage to appear across the Degrees Phase dial potentiometer. This is performed by the Function switch.

4.7 POWER SUPPLY

The power supply can be operated at 45 Hz - 440 Hz, 115 V/125 V. An internal switch is provided for operation at 230 V/250 V. The ac voltage is full-wave rectified, filtered, and applied to Q1 and Q2 which provide a constant +15 V and -15 V dc output. CR5 and CR6 are 16 V zener diodes.

4.8 FILTERS

The filters used are fifth order, 0.5 DB, Chebyschev, low pass active filters which are operated in a restricted portion of the pass band. This is to maintain the amplitude gradient over this band within the instrument's specifications and to restrict the phase variation. Figure 4-4 is a typical filter response. F_m designates the geometric mean frequency of the usable band. The upper-frequency limit is determined by the amplitude vs. frequency characteristic. Lower-frequency limit is determined by the amount of rejection of the third harmonic of this frequency.

Many resistor and capacitor components in the filter are changed for different frequencies. Refer to the Filter Component table on the schematic (fig. 6-1) for these changes.

NOTE

When making phase-sensitive measurements, the detector circuit inherently has a high second harmonic rejection (approx. 55 DB) and 10 DB additional rejection of the third harmonic. This additional harmonic rejection is individually added to the filter rejection when operating in any phase-sensitive mode.

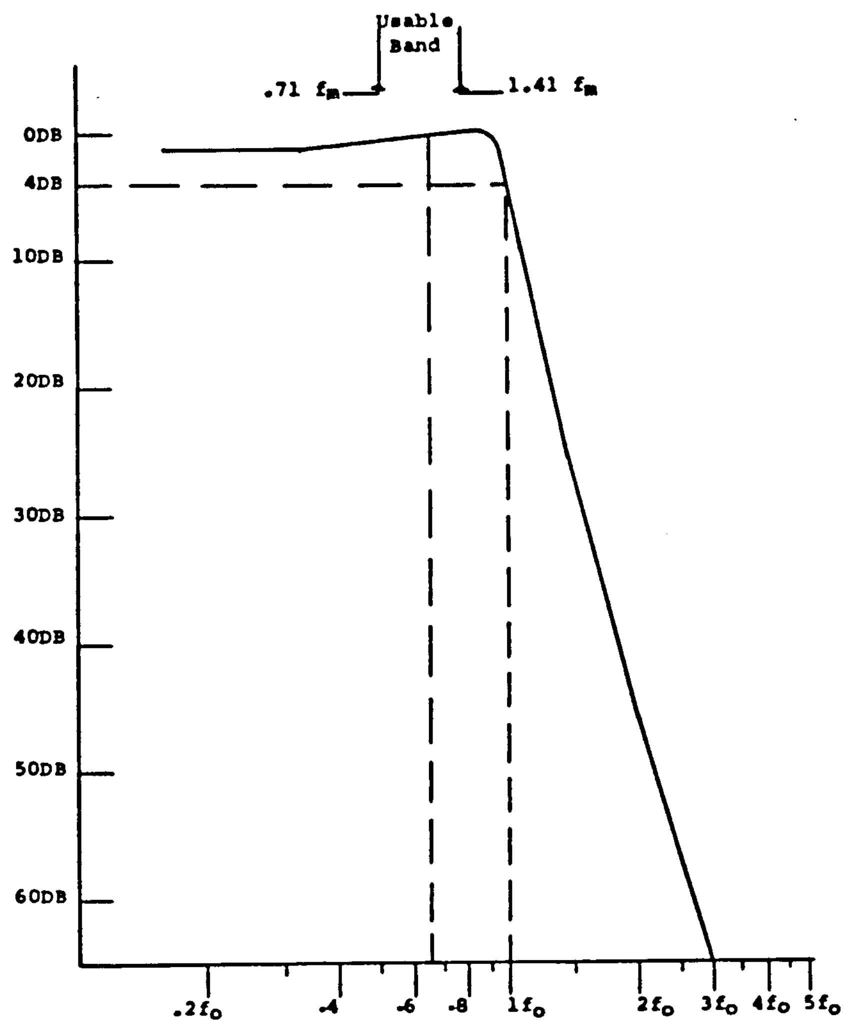


Figure 4-4. Typical Filter Characteristics

4.9 INPUT ISOLATION TRANSFORMERS

The Model 213C has a reference isolation transformer in its reference input. This will allow a common reference signal to be connected to the instrument without creating a ground loop.

The Model 213C is characterized by the inclusion of a signal isolation transformer in its signal input, as well as containing the above mentioned reference isolation transformer. The INPUT DIR/TRANS switch provides a means of switching this signal isolation transformer in and out of the signal input as desired. This transformer may be used for making single-ended, as well as differential, measurements.

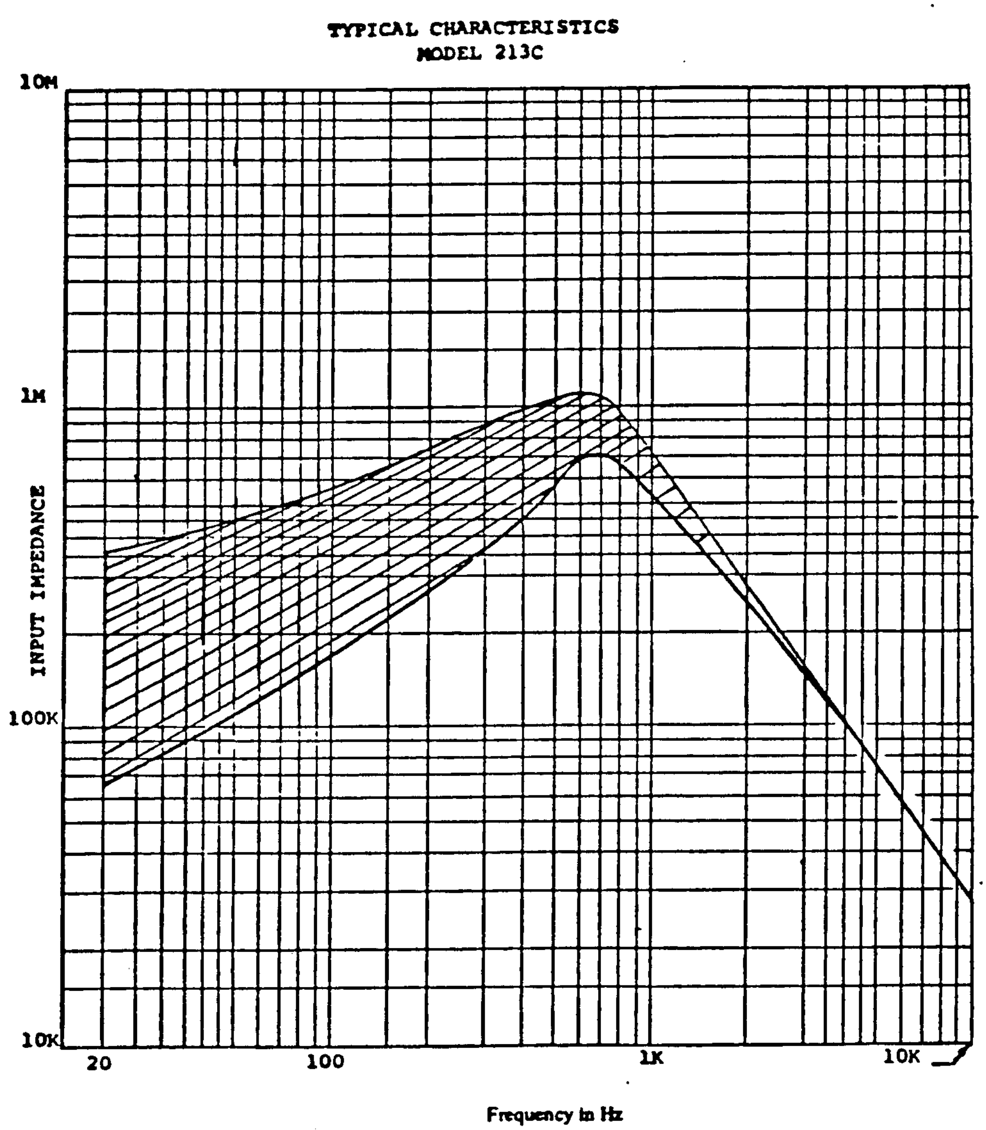


Figure 4-5. Input Impedance vs. Frequency (Transformer Mode)

SECTION 5

MAINTENANCE

5.1 INTRODUCTION

This section contains instructions for the general maintenance of the Phase Angle Voltmeter. Performance testing, alignment procedures, and troubleshooting are described here.

5.2 COVER REMOVAL

In order to service, it is necessary to remove the top cover of the instrument via the removal of five screws. For additional troubleshooting and maintenance, it may become necessary to remove the bottom cover of the instrument which may easily be accomplished by removing five screws.

5.3 REPLACEMENT OF PRINTED CIRCUIT CHASSIS COMPONENTS

There are a number of components which are mounted directly to the printed circuit chassis, all of which are easily accessible. In the event that any of these must be replaced, normal precautions consistent with good manufacturing practice should be followed.

There are also a number of components which are mounted to switch assemblies. In the event there is a failure in any of these components, it is recommended that extreme care be exercised in the removal of these components so as to not damage the switch wafer.

5.4 REPLACEMENT OF FUSE

A power fuse is mounted on the rear panel of the unit and may easily be replaced by removing the fuseholder cap. This fuse will normally be a .5 amp fuse, type 3 AG, for 115 V operation. For those instruments which operate with 230 V power source, this fuse should be a .25 amp, type 3 AG.

5.5 PERFORMANCE EVALUATION

It is the purpose of this procedure to assist a qualified technician in the recalibration of the Model 213C Phase Angle Voltmeter. Under normal circumstances, this instrument, due to the use of solid-state circuitry, should require a minimum of service and recalibration.

The Test Procedure portion may be used for incoming acceptance test or for periodic calibration checks. It is recommended that the initial periodic check be made after three months and future checks be extended to six months or yearly checks.

The Alignment Procedure may be used for recalibration in the event there is failure which requires the replacement of any component in the instrument.

5.5.1 Equipment Required

Refer to table 5-1 for list of equipment required.

5.5.2 Procedure

5.5.2.1 Preliminary Checks

a. Before turning on equipment, check mechanical zero of the meter (para. 5.6.1) and rezero if necessary.

b. Ground Isolation Check (instrument turned off):

   (1) Check resistance between chassis ground and circuit ground at the signal input terminals. (Link must be removed.) This should read open.

c. Noise Check (instrument on, chassis connected to house ground, ground link in place):

   (1) Short SIG input terminals, apply a 100 V REF signal, and adjust the reference level to red-line value.

Table 5-1. Equipment Required

Test equipment	Capability/type	Application
Variable voltage source	Frequency accuracy ±5% Voltage 0 to 300 V Frequency range 10 Hz to 100 kHz	Voltage and frequency response calibration
Scale voltmeter, monitor	Accuracy: ±0.5% Calibrated full scale 400 Hz*	Voltage calibration
Voltmeter, monitor	Flat frequency response: ±0.25%, 10 Hz to 100 kHz	Frequency response
AC ratio box (2)	Accuracy ±10 ppm	Voltage calibration
Phase generator**	Dytronics Model 411	Phase calibration
High impedance ohmmeter	Hewlett-Packard Model 412 or equivalent	Phase dial alignment
Oscilloscope	Tektronix Model 422 or equivalent	Troubleshooting

*This frequency is the pre-specified phase-sensitive operating frequency. Since 400 Hz is a common frequency, it is used throughout this section.

**See paragraph 5.5.2.7 for less convenient methods of Phase Angle generation.

(2) Reading on the meter should not exceed 15 μV on any range in the Total and Fundamental modes. In the PAV (Phase Sensitive) modes, the meter indication should be less than 2 μV.

5.5.2.2 Voltage Check

a. Set the Function switch to TOTAL and the INPUT switch to DIR.

b. Connect the instrument as shown in figure 5-3A, and adjust the Variable Voltage Source amplitude to 100 V. Adjust reference level to red-line value.

c. Apply a voltage to the SIG input terminals corresponding to the full-scale indication at each position of the Range switch by setting the ac Ratio Box as required. The accuracy of the input voltage should be ±0.5%. The Model 213C should indicate these values ±2% of full scale.

(1) Set Range switch to 300 μV.

(2) Apply a 300 μV ±0.5%, 400 Hz* to the SIG input terminals. Meter should now read 300 μV ±2%.

(3) Set Range switch to 1 mV.

(4) Apply a 1 mV, ±0.5%, 400 Hz* to the SIG input terminals. Meter should now read 1 mV ±2%.

(5) Set Range switch to 3 mV.

(6) Apply a 3 mV ±0.5%, 400 Hz* to the SIG input terminals. Meter should now read 3 mV ±2%.

*Use the pre-specified phase-sensitive operating frequency.

(7) Set Range switch to 10 mV.

(8) Apply a 10 mV ±0.5%, 400 Hz* to the SIG input terminals. Meter should now read 10 mV ±2%.

(9) Set Range switch to 30 mV.

(10) Apply a 30 mV ±0.5%, 400 Hz* to the SIG input terminals. Meter should now read 30 mV ±2%.

(11) Set Range switch to 100 mV.

(12) Apply a 100 mV ±0.5%, 400 Hz* to the SIG input terminals. Meter should now read 100 mV ±2%.

(13) Set Range switch to 300 mV.

(14) Apply a 300 mV ±0.5%, 400 Hz* to the SIG input terminals. Meter should now read 300 mV ±2%.

(15) Set Range switch to 1 V.

(16) Apply a 1 V ±0.5%, 400 Hz* to the SIG input terminals. Meter should now read 1 V ±2%.

(17) Set Range switch to 3 V.

(18) Apply a 3 V ±0.5%, 400 Hz* to the SIG input terminals. Meter should now read 3 V ±2%.

(19) Set Range switch to 10 V.

(20) Apply a 10 V ±0.5%, 400 Hz* to the SIG input terminals. Meter should now read 10 V ±2%.

(21) Set Range switch to 30 V ±2%.

(22) Apply a 30 V ±0.5%, 400 Hz* to the SIG input terminals. Meter should now read 30 V ±2%.

(23) Set Range switch to 100 V.

(24) Apply a 100 V ±0.5%, 400 Hz* to the SIG input terminals. Meter should now read 100 V ±2%.

(25) Set Range switch to 300 V.

(26) Apply a 300 V ±0.5%, 400 Hz* to the SIG input terminals. Meter should now read 300 V ±2%.

d. Switch the Function switch to FUND and repeat step c above.

e. Switch the INPUT switch to TRANS with the Function switch in FUND position. Repeat step c above.

f. Linearity Check - Inject a full-scale signal into the SIG input terminals. Switch the Function switch to FUND. Change input SIG down scale in discrete steps. Meter should indicate corresponding levels as follows (±2%).

Range	Input	Meter X Full Scale
1V	1.0V	1.0
1V	.8V	.8
1V	.6V	.6
1V	.4V	.4
1V	.2V	.2
1V	.1V	.1

5.5.2.3 Frequency Response (Fig. 5-3D)

a. Set Function switch to TOTAL. Set Range switch to 0.1 V. Set INPUT switch to DIR.

b. Using the Variable Voltage Source, inject a signal equal to 0.09 V at 400 Hz*. Monitor this input voltage with the Monitor Voltmeter. (It is necessary that the frequency response be flat to within 0.5% over a range of 10 Hz to 100 kHz.)

c. Sweep the frequency of the Variable Voltage Source from 10 Hz to 100 kHz and maintain a constant amplitude output. Meter should indicate a 0.09 V ±2% from 20 Hz to 50 kHz, and 0.09 V ±5% from 10 Hz to 100 kHz.

---

*Use the pre-specified phase-sensitive operating frequency.

d. Switch Range switch to 1.0 V and set Variable Voltage Source to 0.9 V and repeat step c.

NOTE

Meter should read 0.9 V instead of 0.09 V.

5.5.2.4 Signal and Reference Channel Phase Alignment

a. Using the test circuit shown in figure 5-3B, set the Variable Voltage Source to 400 Hz*, and adjust the amplitude to nominally 100 V.

b. Turn Function switch to REF ADJ and adjust the reference level for red-line value on the meter scale.

c. Set Function switch to FUND, Range switch to 0.010 V, and connect 90° RC network (phase generator) to SIG input terminals. Adjust the Variable Voltage Source slightly until a full-scale reading (0.01 V) is obtained on Phase Angle Voltmeter.

d. Set Degrees Phase dial to 0°. Set Function switch to 0°. Set Range switch to 0.001 V (approx. 10 times overload).

e. Adjust PHASE ADJ control R98 (rear-panel control) for zero reading on meter.

NOTE

Signal and reference channel are now phase aligned. The 0° Function and 0° Degrees Phase dial positions are now calibrated.

5.5.2.5 Phase Check

The following checks should be made at 400Hz* using figure 5-3C. (For methods of generating phase angles, see paragraph 5.5.2.7.)

*Use the pre-specified phase-sensitive operating frequency.

a. Using a 10 volt level into the REF input terminals, set Function switch to REF ADJ position and set REF ADJ control to cause the meter to read red-line (red-line is marked at half-scale on the meter).

b. Set Function switch to 90°. Set Degrees Phase dial to 0°. Set Range switch to 0.001 V.

c. Inject the 0.010 V (10 times overload 0° signal from the Phase Generator into the SIG input terminals).

d. Adjust Degrees Phase dial to cause the meter to read a null (0). The indicated angle should be ±1° of the input angle (i.e., with a 0° input, the Degrees Phase dial should read between -1° and +1°).

e. Repeat steps c and d in 10° increments to 90°. The Degrees Phase dial readings should all be within ±1° of the input angle.

5.5.2.6 Overload Check

a. Using the test connections of paragraph 5.5.2.5a, set the Degrees Phase dial to 0°, the Function switch to 90°, and the Range switch to 0.1 V.

b. Inject a 0° signal into the SIG input terminals at approximately 1.0 V level (10 X overload). Meter will indicate zero.

c. Gradually increase the input signal until OVERLOAD light comes on. This should occur at approxiamtely 12 X overload (1.2 V).

5.5.2.7 Phase Angle Generation

The test procedure requires that phase angles other than 90° or 0° be used for some checks. A phase generator may be used for this purpose. Refer to user's manual for procedure.

If a phase angle generator is not available, it is suggested that the following methods be used:

5.5.2.7.1. RC Passive Phase Shifter

Precise phase angles can be generated using the circuit configuration shown in figure 5-1. These networks are very useful and are simple to construct. They do require, however, accurate measurement of component values. They may be constructed with the aid of the design equations shown in figure 5-1. The components should be high-quality, stable devices; such as mica, or polystyrene capacitors, and metal film or deposited carbon resistors.

5.5.2.7.2. Ratio Box Phase Shifter

This circuit (fig. 5-2) is somewhat less complicated than the previous circuits in that it required only a precise 0 and 90 signal be generated by use of passive networks, but it does require a Ratio Box. The Ratio Box selected must be accurate at the operating frequency. The components again must be high quality and drift free. It may be seen that any angle between 0 and 90 can be selected depending on the setting of the Ratio Box. It should be noted, however, that the amplitude of the 0 and 90 signal should be set equal to each other. The output amplitude will vary through a minimum of 0.707 of the 0 and 90 signal at 45 (Ratio Box setting of 0.5). Phase network component values and Ratio Box settings are determined by the equation shown in figure 5-2.

5.6 ALIGNMENT PROCEDURE

5.6.1 Preliminary Checks

Meter Mechanical Zero Check

Using the access hole below the front-panel meter window, adjust the mechanical movement for an exact center scale position as follows:

a. Adjust the zero adjuster in a direction which will drive the pointer toward the zero scale mark of the instrument.

b. While continuing to drive the pointer in the direction selected in a, set the pointer on the zero scale mark while tapping the instrument case. Once it has been selected, do not change the direction of drive until the pointer is on the zero mark.

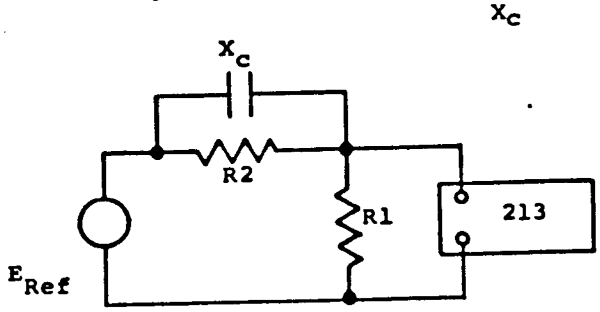
c. With the pointer set on the zero mark, reserve the direction of motion of the zero adjuster and drive it far enough to introduce mechanical freedom (play) in the zero adjuster, but not far enough to disturb the position of the pointer.

5.6.1.1 Ground Isolation Check

Check resistance between chassis ground and circuit ground at the signal input terminals (link must be removed). This should read open. Replace link.

$$\text{Attenuation} = \frac{R_1}{|Z|} \qquad \text{Providing } R_1 // |Z|$$

$$\text{Phase Shift} = \text{Tan}^{-1}\frac{R_2}{X_c}$$



$$Z = \frac{R_2}{1 + j\frac{R_2}{X_c}}$$

$$Z = \frac{R_2 X_c\sqrt{X_c^2 + R_2^2}}{X_c^2 + R_2^2}$$

Figure 5-1. RC Passive Phase Shifter

5.6.1.2 Power Supply Check

Set Range switch to 300 V, turn instrument on, and measure the following with respect to ground:

a. Using the circuit schematic (figure 5-6 check +15 V at TP8, -15 V at TP7. Each should read 15.4 V ± .8 V.

b. Check ripple with an ac VTMV. Should not exceed the following:
+ 15 V 3mV rms;
- 15 V 3mV rms.

5.6.1.3 Dc Meter Offset

a. Set INPUT switch to DIR position.

b. Short SIG input terminal to ground.

c. Set Function switch to REF ADJ position.

d. Set Reference switch to EXT REF position. (60Hz-400Hz units only.)

e. Feed in 10V 400Hz* to REF input terminals.

f. Set REF ADJ knob for a red line reading on meter.

g. Set Function switch to 0° position.

h. Set Range switch to 0.1V position.

i. Connect an ac voltmeter to TP12 and adjust R111 for a minimum ac reading.

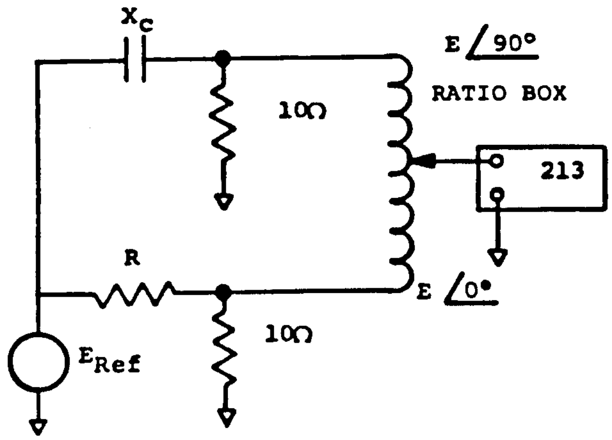
j. Adjust R95 for zero reading on the meter.

k. Make sure that the meter reads the same (zero) in FUND and 0° positions of the Function switch.

5.6.1.4 Noise Check

a. Short SIG input terminals; apply a 100V REF signal.

b. Reading on the meter should not exceed 15μV on any range in the TOTAL and FUND modes. In the PAV (Phase Sensitive) Modes, the meter indication should be less than 2μV.



$$\frac{X_c}{10} \gg 1000$$

$$R = X_c$$

E∠0° and E∠90° must be set equal within 1/4%

Ratio Box setting =

$\frac{1}{1 + \text{ctn}\,\theta}$ **where θ is desired phase shift**

Figure 5-2. Ratio Box Phase Shifter

5.6.2 Voltage Alignment

Connect as shown in figure 5-3A and refer to figure 5-5 for location of printed circuit chassis trim controls. Turn instrument on, and allow a 15-minute warm up.

The following adjustments are for the purpose of calibrating the basic voltage gain of the instrument in the TOTAL and FUND Modes. It also incorporates the "broadband" adjustment of the 1000:1 standard input attenuator.

NOTE

Set INPUT switch to DIR

5.6.2.1 Fundamental Adjustment

a. Set Variable Voltage Source to 100V as measured on the Monitor Voltmeter

---

*Use the pre-specified phase-sensitive operating frequency.

at 400Hz*.

b. Set Range switch to 0.1V, Function switch to FUND.

c. Set Ratio Box to .001000 (0.1V).

d. Adjust FUND ADJ potentiometer (R47) for full-scale indication on the meter.

5.6.2.2. Total Adjustment (Same as in Para. 5.6.2.1.)

a. Set Function switch to TOTAL.

b. Adjust TOTAL potentiometer (R53) for a full-scale reading on the meter.

c. Set INPUT, switch to TRANS and perform paragraphs 5.6.2.1. and 5.6.2.2.

5.6.2.3. 1000:1 Input Attenuator Adjustment

. Set INPUT, switch to DIR.

NOTE

This attenuator must operate over the entire frequency range of the instrument in the TOTAL Mode. Therefore, it must be adjusted for a "flat" amplitude characteristic and a minimum phase shift over this range.

b. For instruments which operate at a phase sensitive frequency between 160Hz and 1kHz connect instruments as shown in figure 5-3A.

(1) Set Variable Voltage Source for precisely 10V as measured on the Monitor Voltmeter at 400Hz*.

(2) Set Ratio Box to .001000(0.01V).

(3) Set Function switch to REF ADJ. Set REF ADJ control for the red-line mark on the meter.

(4) Set Range switch to 0.001V and Function switch to 90°.

(5) Rotate Degrees Phase dial until meter reads precisely zero.

(6) Set Range switch to 10V position, and Function switch to FUND.

(7) Set Ratio Box for 1.000000 (10V).

(8) Adjust R22 for full-scale reading on meter. (See figure 5-5.)

(9) Set Function switch to 90° and Range switch to 1V (10 x overload).

(10) Adjust C11 for zero reading on meter. (See figure 5-5.)

(11) Repeat steps (6) through (10) until best results are obtained. This is required due to the interaction of the two controls.

c For Instruments which operate at Phase sensitive frequencies below 160Hz or above 1kHz, connect as in figure 5-3D.

(1) Set the Range switch to the 1V position and the Function switch to TOTAL. (In Model 213C instruments, set INPUT switch to DIR.)

(2) Apply a 1V ±0.5%, 50Hz signal to the SIG input terminals. Monitor with meter which has a frequency response flat within ±.5%.

(3) Adjust R22 for full-scale reading on the meter. (See figure 5-5.)

(4) Reset the SIG to 10kHz, 1V ±0.5%.

(5) Adjust C11 for a full-scale reading on the meter. (See figure 5-5.)

(6) Recheck Steps (2) through (5), readjusting as necessary. The 1000:1 input attenuator is now "broadbanded" and will have minimal phase shift.

*Use the pre-specified phase-sensitive operating frequency.

5.6.3. Degrees Phase Dial Alignment on Phase Shifter Potentiometer, R4.

NOTE

This should be checked before proceeding to Phase Alignment.

The following is a procedure for mechanically aligning the Degrees Phase dial on the shaft of phase shifter potentiometer R4. This is necessary in the event that a Degrees Phase dial, Phase potentiometer, or both are disassembled or replaced. The 0° and 90° points on the Degrees Phase dial must be aligned to coincide with the taps of the potentiometer. This should only be done using a high-impedance ohmmeter (i.e. HP412) as damage to the precision phase potentiometer can occur if excessive voltage is applied.

CAUTION

Do not use Simpson, Triplett, or other VOM.

a. Turn power off.

b. Set Function switch to any PAV position.

c. Connect the ohmmeter between the wiper of R4 and the CCW tap point and rotate Degrees Phase dial for minimum resistance reading. Loosen Degrees Phase dial clamping screws and shift it until dial reading is exactly 90°. Tighten clamping screws. Connect ohmmeter between the wiper of R4 and the CW tap point and rotate Degrees Phase dial until wiper of R4 is on CW tap point (minimum resistance reading). The Degrees Phase dial should now read 0°. If not, note the difference and reposition dial so as to achieve the best compromise reading between the two taps. For example, if the 0° point reads low, the 90° point should read high by the same amount. Fully tighten knob set screw and recheck to make sure Degrees Phase dial has not slipped during tightening.

5.6.4. Phase Alignment

This alignment will adjust the instrument for zero phase shift between the signal and reference channels.

a. Connect the Model 213 as shown in figure 5-3C. If a Phase Generator is not available, a precise 90° phase shifted signal may be generated as indicated in figure 5-3B.

b. Set the Function switch to FUND and Range switch to 0.01V and apply a 90° phase shift to the signal input.

c. Adjust the Variable Voltage source to cause a full-scale reading on the meter.

d. Set the Function switch to REF ADJ. Set the REF ADJ control to the red-line mark on the meter.

e. Set Function switch to 0° and Degrees Phase dial to 0°.

f. Set Range switch to 0.001V (10 X overload) and adjust Phase control R98 (fig. 5-5) to cause the meter to read 0.

g. Set Function switch to 90° and Degrees Phase dial to 90°.

h. Meter should read zero. If an error exists, re-adjust Phase ADJ control R98 to divide the error between steps f and g.

5.6.5. Phase Bridge Alignment

NOTE 1

Be sure to perform 5.6.4 before this procedure.

NOTE 2

The following procedure requires the use of an accurate Phase Generator. If a generator is not available, use the procedure in 5.6.5.2.

5.6.5.1. Procedure Using an Accurate Phase Generator

a. Connect the Model 213 as in figure 5-3C.

b. Set the Function switch to FUND.

c. Set Range switch to 0.01V.

d. Adjust the Variable Voltage source to cause a full-scale reading on the meter.

e. Set Function switch to REF ADJ position and set the REF ADJ control for red line on the meter.

f. Set Function switch to 0°.

g. Set Phase dial to 90°.

h. Set Range switch to 0.001V position.

i. Set Phase Generator for 0° phase shift.

j. Adjust R16 for a meter null.

k. Set Phase dial to 45°.

l. Set Phase Generator for a 135° phase shift.

m. Adjust R8 for a meter null.

n. Set Function switch to 90°.

o. Set Phase Generator for a 45° phase shift.

p. Adjust R9 for a meter null.

q. Repeat Steps f to p to obtain best settings, as they are interactive.

5.6.5.2. Alternate Procedure

a. Connect the Model 213 as in figure 5-3A to obtain 0° signal input. Using a 100V reference level into the REF input terminals, set Function switch to REF ADJ position and set REF ADJ control to cause the meter to read red-line value.

b. Set Function switch to 90°. Set Degrees Phase dial to 0°. Set Range switch to 0.001V.

c. Inject a 0.010V (10 X overload) 0° signal into the SIG input terminals.

d. Adjust R16 for a meter null.

e. With the Monitor Voltmeter, measure the voltage at TP2.

f. Connect the Monitor Voltmeter to TP3 and adjust R8 to obtain a reading exactly the same as measured at TP2.

g. Connect the Monitor Voltmeter to TP9 and adjust R9 to obtain a reading exactly the same as measured at TP2.

h. Repeat Steps d through g to obtain best settings as they are interactive.

5.6.6. Overload Lamp Adjustment

a. Set Function switch to 90°.

b. Set Range switch to 1.0 volts.

c. Feed in 12 volts rms.

d. Adjust R116 so that the OVERLOAD light is lit. It should be off when 11 volts is applied.

5.6.7. Selecting R135 Trans. Mode Phase Shift (2kHz or Above)

NOTE

This procedure is performed at the factory and is not required unless the Signal Isolation Transformer is replaced.

a. Set INPUT switch to DIR. Set Range switch to 100mV position.

b. Feed in 10V (pre-specified frequency) into REF input terminals. Feed in 100mV to SIG input terminals (pre-specified frequency).

c. Set Function switch to REF ADJ and adjust reference level for red line.

d. Set Range switch to 10mV position. Set Function switch to 90° and adjust Phase dial for a null.

e. Set INPUT switch to TRANS. Do not touch Phase dial setting.

f. Select R135 so that meter indicates the same null reading as in step d.

g. Set Range switch to 100mV position. Set Function switch to 0° position. Meter should read full scale.

h. If meter does not read full scale, it may be necessary to decrease C79 slightly, and then re-select R135 for a null as in step f.

i. Repeat step g.

5.6.8. Selecting C79 Trans Mode Phase Shift (2kHz or Below)

NOTE

This procedure is performed at the factory and is not required unless the Signal Isolation Transformer is replaced.

a. Set INPUT switch to DIR. Set Range switch to 100mV position.

b. Feed in 10 volts (pre-specified frequency) into REF input terminals. Feed in 100mV to SIG input terminals.

c. Set Function switch to REF ADJ and adjust reference level for red line.

d. Set Range switch to 10mV position. Set Function switch to 90° and adjust Phase dial for a null.

e. Set INPUT switch to TRANS. Do not touch Phase dial setting.

f. Select a capacitor that will cause the meter to read between 0 and +3 small divisions.

g. Set Range switch to 10V position and apply a 100V input signal. Meter should read 0 ±3 small divisions.

5.6.9. T1 - Phase Shift Balance Trim Selection (Frequencies Below 400Hz)

NOTE

This is normally a factory adjustment. It should only be necessary to perform this trim in the field if T1 is replaced.

The purpose of this procedure is to balance the phase shift of the two secondary voltages (E31 and E27) with respect to the center tap (E28).

a. Apply 10V reference to REF input terminals and adjust for red line.

b. Set Function switch to 90°.

c. Set Phase dial to 90°.

d. Set Range switch to 1mV position.

e. Measure voltage at E31 and E27 with respect to E28 using a VTVM. If

voltages are unequal by more than 5%, place a resistor from E31 to E28 or from E27 to E28 so that these voltages are equal to within 5%.

NOTE

At frequencies above 75Hz, a capacitor will be more effective than a resistor in achieving this balance.

f. Apply 10mV rms at 90° phase shift with respect to the reference to the SIG input terminals.

g. Adjust R98 for a null on meter

h. Set Function switch to 0°.

i. Set Phase dial to 0°.

j. Meter should read a null. If the meter does not read 0(±2 small divisions),T1 will require a trim.

NOTE

If the pre-specified operating frequency is 75Hz or above, the trim will be a resistor. If below 75Hz, the trim will be a capacitor. For example, 120Hz might require a resistor of approximately 6.8K ; 50Hz might require a capacitor of approximately 0.018 F.

k. Select a trim (R or C depending on frequency) that will reduce the null to 0 (less than 2 small divisions) and connect it between E31 and E28.

l. If connecting a trim across E31 and E28 causes the null to increase in the same direction, repeat the above procedure substituting 0° for 90° in steps b and c and substitute 90° for 0° in steps g and h. Then connect the trim across E27 and E28.

m. Repeat steps a through l and re-trim, if necessary, there may be slight interaction.

5.6.10 Frequency Response (Figure 5-3D)

a. Set Function switch to TOTAL. Set Range switch to 0.1V. Set INPUT switch to DIR.

b. Using the Variable Voltage source, inject a signal equal to 0.09V at 400Hz*. Monitor this input voltage with the Monitor Voltmeter. (It is necessary that the frequency response be flat to within 0.5% over a range of 10Hz to 100kHz).

c. Sweep the frequency of the Variable Voltage source from 10Hz to 100kHz and maintain a constant amplitude output. Meter should indicate a 0.09V ±2% from 20Hz to 50kHz, and 0.09V ±5% from 10Hz to 100kHz.

d. Set Range switch to 1.0V and set Variable Voltage source to 0.9V and repeat step c.

NOTE

Meter should read 0.9V instead of 0.09V.

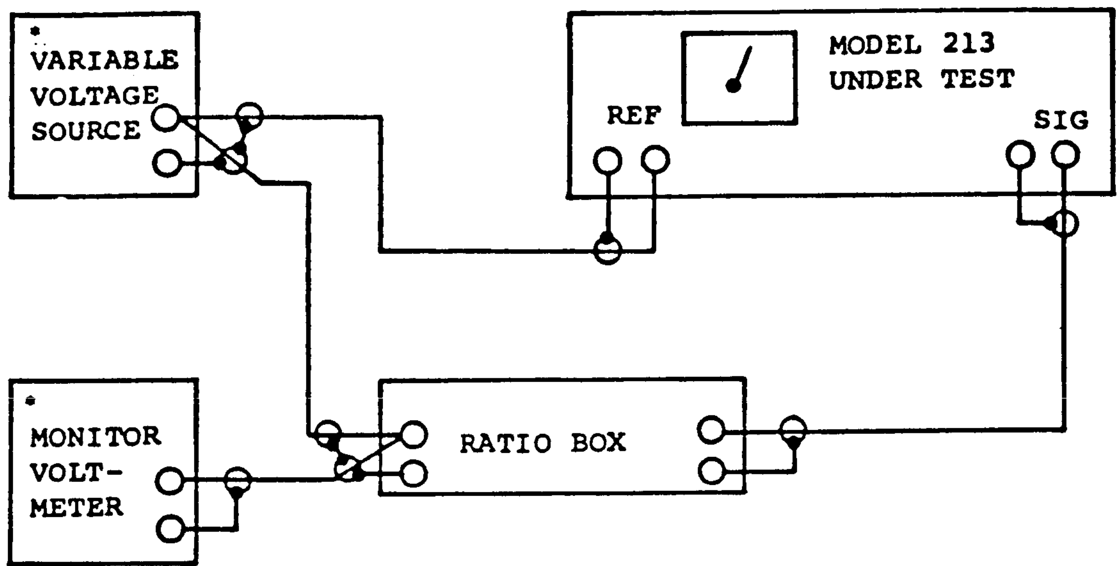
e. If the voltage peaking is excessive at 100kHz increase the value of C95. If the roll-off is excessive at 100kHz, decrease the value of C95 until the above specifications are met.

5.7 TROUBLESHOOTING

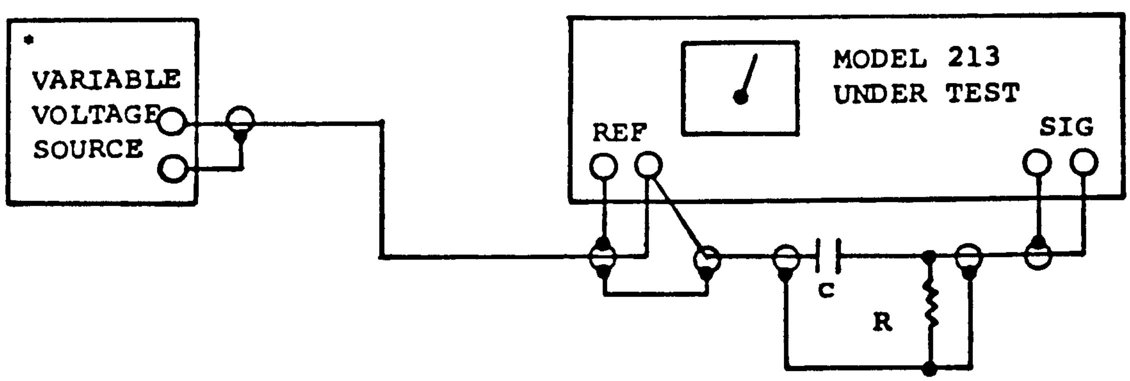
5.7.1 Troubleshooting Procedures

Table 5-2 contains troubleshooting procedures for the Phase Angle Voltmeter. It lists trouble indications and denotes the probable cause based on the observed symptoms.

*Use the pre-specified phase-sensitive operating frequency



A



400Hz

C = 500pf

R = 80Ω

For other frequencies

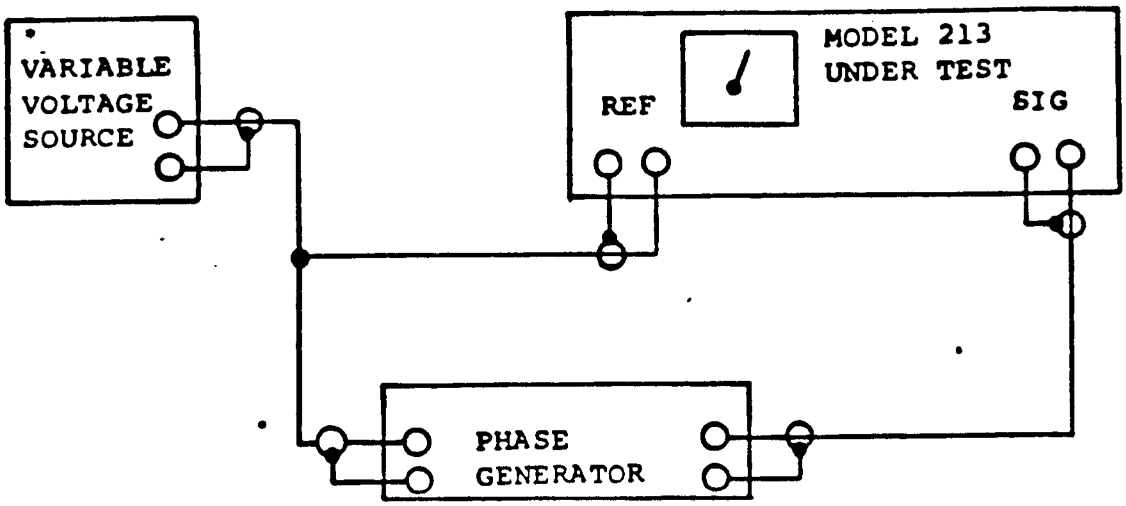
X_c approx. 10000 times R

R less than 200Ω

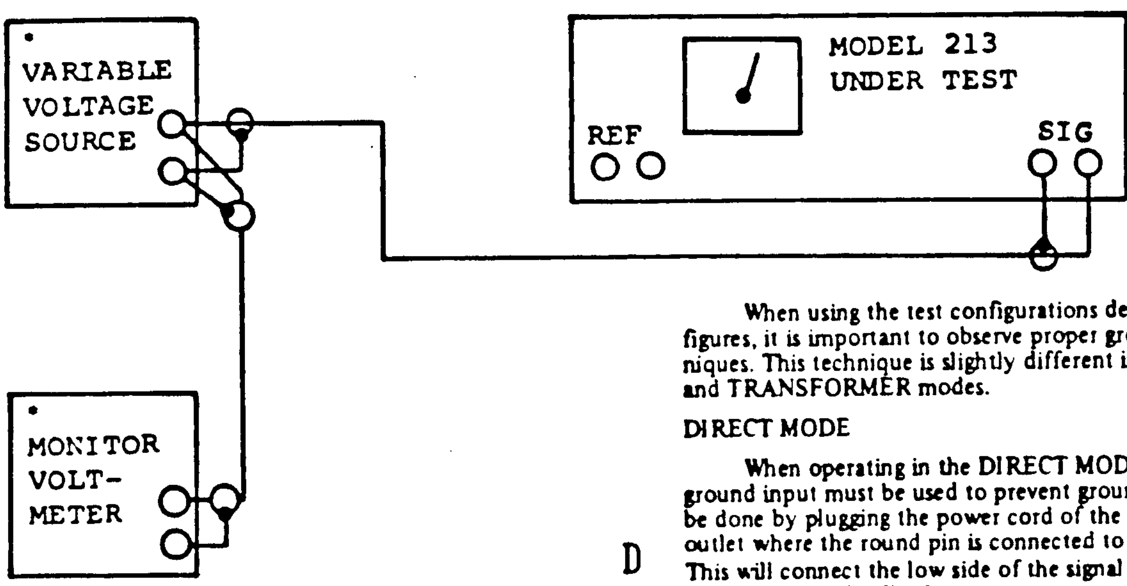
B

* For test equipment specifications see table 5-1.

Figure 5-3. Test Circuits (Sheet 1 of 2)



C



D

* For test equipment specifications see table 5-1.

When using the test configurations described in these figures, it is important to observe proper grounding techniques. This technique is slightly different in the DIRECT and TRANSFORMER modes.

DIRECT MODE

When operating in the DIRECT MODE, a single house ground input must be used to prevent ground loops. This can be done by plugging the power cord of the VM-213 into an outlet where the round pin is connected to a house ground. This will connect the low side of the signal input terminals to house ground. All other instruments connected to this low side must be then isolated from house ground by appropriate isolation plugs (3 pin to 2 pin adapters, not utilizing the ground lead).

TRANSFORMER MODE

When operating in the TRANSFORMER MODE, care must be taken to avoid common mode voltages between the signal input and the chassis-circuit ground of the instrument. This can be accomplished by connecting the low side of the input to the chassis of the VM-213 or to a house ground provided the round pin of the power plug is connected to house ground as above.

Figure 5-3. Test Circuits (Sheet 2 of 2)

o support troubleshooting operations refer to schematic diagram and parts location and identification diagram in section 6.

Refer to the parts list in section 6 for replacement part data.

Table 5-2. Troubleshooting Procedure

Trouble	Probable cause
Meter lamps do not light when power is applied.	Check fuse F1 and meter lamps
Meter pegs on any position of Range switch.	No-15vdc at TP7. Check Q2, CR6 and/or associated components.
Meter reads to the left of zero in the TOTAL and FUND Modes.	No+15vdc at TP8. Check Q1, CR5, and/or associated components.
Meter indicates in FUND Mode but not in TOTAL Mode.	Check Z6B and associated circuitry.
Meter indicates in TOTAL Mode but not in FUND Mode.	Check Z6A, signal filter Z7, and associated circuitry.
Meter indicates in REF ADJ Mode but does not indicate in TOTAL or FUND Modes.	If an ac signal appears at TP10, the trouble is probably in the Range Attenuator or check for an open switch contact on S1-B or S2-D1 and D2. If an ac signal does not appear at TP10, check the Signal Isolation Amplifier or the 1000:1 Attenuator.
Inaccurate meter readings on one or more specific ranges.	Check Range Attenuator resistors R35 through R41.
Meter indicates on the lower ranges (0.1V or below) but does not indicate on the upper ranges (0.3V or above).	Check 1000:1 Attenuator components C9, C11, C12, R22, R23, and R24.
Meter indicates in TOTAL, FUND and REF ADJ Modes but not in 0° or 90° Modes.	Check for presence of 30V peak-to-peak square waves at TP5 and TP6. They should be 180° out-of-phase with each other. If they are not observed then check Z4 and associated circuitry. If they are observed, check S2-F2 and S2-G1 for proper continuity in positions 4 through 7. If that is OK, then replace Z8 Detector module.
Meter indicates TOTAL and FUND Modes but not in 0°, 90° or REF ADJ Mode.	Check Reference Filter Z2, Reference Isolation Amplifier Z3, Reference Phase Bridge, or Reference Isolation Transformer T1.

Table 5-2. Troubleshooting Procedure (Continued)

Trouble	Probable cause
	NOTE In order to obtain a red line indication on the meter in REF ADJ position, the following approximate voltages should be: Z3 pin 2 - 1.4v rms TP11 - 1.1v rms
Meter does not indicate in any position of the Function switch.	Check Z9, Z5, and associated circuitry. NOTE For a full-scale deflection of the meter, the following voltages with their related positions of the Function switch should be at TP1: TOTAL Approx. +415mV dc FUND Approx. +415mV dc *0° Approx. +415mV dc *90° Approx. 0V dc
Proper voltages appear at TP1 and the meter still does not indicate	Check R113, R114, C70, CR13, and CR14, and S2-C1 and C2. If still no indication, replace meter.
Meter indicates in Direct Mode but not in Transformer Mode	Check for open Signal Isolation Transformer T3 or defective S5.
Meter indicates properly in 0°, 90°, 180° and 270° when REF ADJ is set for a 1.1v rms reading at TP11, but fails to operate in the REF ADJ, TOTAL, and FUND Modes.	Check S2-F2 and S2-G1 continuity. If it still does not indicate, replace Detector Module Z8.
OVERLOAD lamp remains lit or does not light.	Check Q5, Q6, and associated circuity.

*Phase Dial set to 0° and 0° phase shift between Reference and Signal inputs. REF ADJ set for 1.1V rms at TP11.

5.7.2. Circuit Voltages

Table 5-3 provides circuit voltage readings.

NOTE

All voltage measurements should be made with respect to circuit ground. Ripple measurements at TP7 and TP8 should be referenced to the power supply circuit ground at the plus end of C8 and the minus end of C7.

Voltages listed in the table 5-3 are nominal and based on the following conditions, unless otherwise noted:

- Range switch set to 10V.
- Reference switch to EXT.
- INPUT switch to DIR.
- Phase dial set to 0°.
- Sig. input 10V rms, 400Hz, 0°phase; Reference input 10V rms, 400Hz, 0° phase.
- Reference Adj. set for red line.

Table 5-3. Circuit Voltages

Location	Voltages	Function switch position
TP8	+15Vdc 3mV rms	0°
TP7	-15Vdc 3mV rms	0°
TP10	32mV rms	0°
Z6A, pin 12	145mV rms	0°
Z7A, pin 2	135mV rms	0°
S2-E, arm	120mV rms	0°
S2-E, arm	120mV rms	Total
TP2	28mV rms (90° signal)	0°
TP3	28mV rms (0° signal)	0°
TP9	28mV rms (180° signal)	0°
Z3A, pin 12	28mV rms	0°
Z3A, pin 12	20mV rms 28mV rms	Phase dial to 45° Phase dial to 90°
Z3B, pin 2	1.6V rms	0°

Table 5-3. Circuit Voltages (Continued)

Location	Voltages	Function switch position
Z2A, pin 12	1.56V rms	0°
TP11	1.3V rms	0°
TP5	30V pp 	0°
TP6	30V pp 	0°
TP4	560mV rms	0°
TP1	+415mVdc +415mVdc +415mVdc 0Vdc +415mVdc 0Vdc	Total Fundamental 0° 90° 180° 270°

REPLACEMENT PARTS LIST

Note

Consistent with North Atlantic Industries' policy of continuously up-grading components and improving circuits, we reserve the right to substitute components which are functionally interchangeable for any of the parts shown in this parts list.

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
C5, C6	805652	2	Capacitor, Fixed, Elec. 150uf, 50V, -10% +100%	14655	BR150-50
C7, C8, C43, C44	801193	4	Capacitor, Fixed, Elec. 47uf, 20V, ±20%	56289	150D476X0020RZ
C9	802571	1	Capacitor, Fixed, Polystyrene, .027uf, 100V ±5%	84171	IPT-273J
C11	800102	1	Capacitor, Variable 3-12uuf	91674	503-041C0P017R
C14	805603	1	Capacitor, Fixed, Ceramic 10Pf, 1000V ± .5pf	91674	831-000C0G0100D
C15	800510	1	Capacitor, Fixed, ELEC. 10µf, 15V, ±20%	56289	150D106x0015B82
C16	803060	1	Capacitor, Fixed, Elec. 200uf, 15V -10% +75%	56289	30D207G015DH4
C17, C13	804456	2	Capacitor, Fixed, Film .1uf, 80V ±10%	56289	192P1049R8
C18, C19	803342	2	Capacitor, Fixed, Elec. 25uf, 25V -10% +75%	56289	30D256G025CB0
C20, C22, C35, C42, C50, C56, C78, C82, C83, C84, C85	805638	11	Capacitor, Fixed, Ceramic 100Pf, 1000V ±10%	91674	831-000X5F0101K
C21, C24, C65	805619	3	Capacitor, Fixed, Ceramic 5Pf, 1000V ± .25pf	91674	831-000C0G0509C
C23, C25, C27, C28, C40, C41, C55, C57, C61, C63, C68, C69	803406	12	Capacitor, Fixed, Ceramic .01uf, 25V +80% -20%	91674	5835-000-Y5U-103Z
C26	805620	1	Capacitor, Fixed, Ceramic 5000Pf, 1000V ±10%	91674	811-000X5R0502K
C29	805602	1	Capacitor, Fixed, Ceramic 200Pf, 1000V ±10%	91674	831-000X5F0201K
C34, C38, C47, C54	800877	4	Capacitor, Fixed, Ceramic 390Pf, 600V ±10%	91674	831-000-X5F-391K
C58, C59	806726	2	Capacitor, Fixed, Elec. 100uf, 10V ±10%	06751	TS3K-10-1071
C60, C62	801365	2	Capacitor, Fixed, Mica 150Pf, 500V ±5%	72136	DM15-F151J
C66	805623	1	Capacitor, Fixed, Ceramic 500Pf, 1000V ±10%	91674	831-000X5F0501K
C67, C77	802638	2	Capacitor, Fixed, Mica 20Pf, 500V ±5%	72136	DM15-200J
C70	803453	1	Capacitor, Fixed, Elec. 22uf, 6V ±20%	56289	150D226X0006B2
C71, C86	804063	2	Capacitor, Fixed, Mica 10Pf, 500V ±10%	72136	DM10-100K
C72	801092	1	Capacitor, Fixed, Elec. 1uf, 20V ±20%	56289	150D105X0020A2
C73, C91	803342	2	Capacitor, Fixed, Elec. 25µf, 25V	56289	30D256G025CBO
C75	801643	1	Capacitor, Fixed, Mica 82Pf, 500V ±5%	72136	DM-15-820J
C76	806687	1	Capacitor, Fixed, Film .022uf, 80V ±5%	06001	AE15P.223J
C79, C92			Capacitor, Fixed, Mica Select at Test		
	802168		From 200uuf, 500V, ±5%	84171	SCDM10-201J
	802341		220uuf, 500V, ±10%	84171	DM15-221K
	802310		Nominal 250uuf, 500V, ±5%	84171	DM15-251J
	802311		270uuf, 500V, ±5%	84171	DM15-271J
	802342		300uuf, 500V, ±10%	84171	DM15-301K
	802242		330uuf, 500V, ±5%	84171	DM15-331J
	802312		360uuf, 500V, ±5%	84171	DM15-361J
	801786		390uuf, 500V, ±5%	84171	DM15-391J
	801971		470uuf, 500V, ±10%	84171	DM15-471K
	802313		510uuf, 500V, ±5%	84171	DM15-511J

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
C81	805628	1	Capacitor, Fixed, Elec. 100uf, 20V ±10%	06751	TS4K-20-107K
C87, C88, C89, C90	801749	4	Capacitor, Fixed, Mica 33pf, 500V, ±10%	72136	DM15-330K
C94	802310	1	Capacitor, Fixed Mica 250pf, 500V, ±5%	72136	DM-15-251J
C95		1	Capacitor, Fixed Mica Select at Test Range 0pf to 39pf, 500V, ±5%	72136	Type DM-15-XXXJ
CR1, CR2, CR3, CR4	800323	4	Diode, 1N645	01295	1N645
CR5, CR6	804098	2	Diode, 1N4745A	04713	1N4745A
CR7,CR8,CR11, CR12,CR15,CR16	802924	6	Diode, 1N3069	07263	1N3069
CR9, CR10	807063	2	Diode, 1N5226	04713	1N5226
CR17	807124	1	Diode, 1N5242A	04713	1N5242A
DS1 (OVLD)	804507	1	Light Cartridge (red)	72765	407-603
DS2, DS3	803611	2	Light (Meter), GE#51	08806	GE#51
F1	803877	1	Fuse, .5A (115V Power) S.B.	75915	313.500
	807117	1	Fuse, .25A (230V Power) S.B.	75915	313.250
M1	202556	1	Meter	NAI	
Q1, Q6	802107	2	Transistor, 2N697	04713	2N697
Q2	803528-2	1	Transistor, (Special) (Replacement 2N2904)	NAI	
Q3	202837	1	Transistor, 2N3819 (Special)	NAI	
Q4	803661	1	Transistor, 2N3906	04713	2N3906
Q5	805025	1	Transistor, 2N2222	QPL	JAN2N2222
Q7, Q8	803662	2	Transistor, 2N3819	04713	2N3819
R1	802723	1	Resistor, Fixed, Comp. 43K, 1/4W ±5%	01121	CB4335
R2, R3	803238	2	Resistor, Fixed Dep. Carbon 39K, 1/4W ±1%	12126	M1/4-39K-±1%
R4	201568	1	Resistor, Variable 50K (Phase Dial)	NAI	
R5, R14, R30	806658	3	Resistor, Fixed Film 2.2K, 1/4W ±2%	16299	C4-2.2K±2%
R6, R13	803693	2	Resistor, Fixed Comp. 820Ω, 1/4W ±5%	01121	CB8215
R7, R12	806659	2	Resistor, Fixed Film 150Ω 1/4W ±2%	16299	C4-150Ω±2%
R8, R9	806721	2	Resistor, Variable 100Ω	80294	3389P100Ω
R10, R17	805616	2	Resistor, Fixed Film 845Ω, 1/4 W ±2%	16299	C4-845Ω±2%
R11	806660	1	Resistor, Fixed film 18K, 1/4W ±2%	16299	C4-18K±2%
R15	806680	1	Resistor, Fixed Film 16K, 1/4W ±2%	16299	C4-16K±2%
R16	806722	1	Resistor, Variable 5K	80294	3389P5K
R18, R20, R109, R115, R139	801397	5	Resistor, Fixed Comp. 5.1K, 1/4W ±5%	01121	CB5125
R19, R21	807110	2	Resistor, Fixed Wirewound 150Ω, 7W ±5%	80183	244E1515
R22	806725	1	Resistor, Variable 1K	80294	3389P1K
R23	805400	1	Resistor, Fixed Film 9.53K, 1/4W ±2%	16299	C4-9.53K±2%
R24	806664	1	Resistor, Fixed Film 10M, 1/2W ±1%	91637	HMF-1/2-10M±1%-T-1
R25	801362	1	Resistor, Fixed Wirewound 18K, 5W, ±3%	91637	RS-5-18K±3%
R26	802730	1	Resistor, Fixed Comp. 1M, 1/4W ±5%	01121	CB-1055
R27	803389	1	Resistor, Fixed Comp. 10M, 1/4W ±5%	01121	CB-1065
R28	802087	1	Resistor, Fixed Comp. 620K, 1/4W ±5%	01121	CB-6245
R29	803388	1	Resistor, Fixed Comp. 3.3K, 1/4W ±5%	01121	CB-3325
R31	806663	1	Resistor, Fixed Film 1K, 1/4W ±2%	16299	C4-1K±2%

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
R32	801406	1	Resistor, Fixed Comp. 3K, 1/4W ±5%	01121	CB-3025
R33	803223	1	Resistor, Fixed Comp. 470Ω, 1/4W ±10%	01121	CB-4715
R34	801986	1	Resistor, Fixed Comp. 100K, 1/4W ±5%	01121	CB-1045
R35	803000	1	Resistor, Fixed Film 10Ω, 1/8W ±1/4%	12126	M1/8-10Ω–±1/4%
R36	803431	1	Resistor, Fixed Film 21.6Ω, 1/8W ±1/4%, TC ± 150 PPM	27690	M60-*
R37	801478	1	Resistor, Fixed Film 68.4Ω, 1/8W ±1/4%, TC ± 150 PPM	27690	M60-*
R38	801477	1	Resistor, Fixed Film 216Ω, 1/8W, ±1/4%, TC ± 150 PPM	27690	M60-*
R39	801476	1	Resistor, Fixed Film 684Ω, 1/8W ±1/4%, TC ± 150 PPM	27690	M60-*
R40	801475	1	Resistor, Fixed Film 2.16K, 1/8W ±1/4%, TC ± 150 PPM	27690	M60-*
R41	801474	1	Resistor, Fixed Film 6.84K, 1/8W ±1/4%, TC ± 150 PPM	27690	M60-*
R42, R48, R45 R51	806156	4	Resistor, Fixed Film 10K, 1/4W ±2%	16299	C4-10K±2%
R43	806665	1	Resistor, Fixed Film 2.0K, 1/4W ±2%	16299	C4-2.0K±2%
R44, R50, R55	802232	3	Resistor, Fixed Comp. 1.5K, 1/4W ±5%	01121	CB1525
R46, R52	806667	2	Resistor, Fixed Film 300Ω, 1/4W ±2%	16299	C4-300Ω±2%
R47, R53	806723	2	Resistor, Variable 200Ω	80294	3389P200Ω
R49	806678	1	Resistor, Fixed Film 3.0K, 1/4W ±2%	16299	C4-3.0K±2%
R54	804297	1	Resistor, Fixed Comp. 2.2M, 1/4W ±5%	01121	CB2255
R56	205285	1	Resistor, Variable 250Ω (Ref Adj)	NAI	
R66, R73, R79, R127	801094	4	Resistor, Fixed Comp. 2K, 1/4W ±5%	01121	CB2025
R82	802192	1	Resistor, Fixed, Comp. 510Ω, 1/4W, ±5%	01121	CB5115
R83	801986	1	Resistor, Fixed, Comp. 100K, 1/4W, ±5%	01121	CB1045
R90	801638	1	Resistor, Fixed Comp. 47K, 1/4W ±5%	01121	CB4735
R91, R121	801636	2	Resistor, Fixed Comp. 20K, 1/4W ±5%	01121	CB2035
R92, R104, R105, R108	805612	4	Resistor, Fixed Film 5.11K, 1/4W ±1%	16299	C4-5.11K±1%
R93	807101	1	Resistor, Fixed Comp. 6.8Meg, 1/4W, ±5%	72136	CB 6833
R95, R111	807062	2	Resistor, Variable 100K	32997	3299W104
R96, R99	802191	2	Resistor, Fixed Comp. 2.7K, 1/4W ±5%	01121	CB2725
R98	205174	1	Resistor, Variable 10K (φ Trim)	NAI	
R100, R133	801988	2	Resistor, Fixed Comp. 15K, 1/4W, ±5%	01121	CB1535
R101	801393	1	Resistor, Fixed Comp. 24K, 1/4W ±5%	01121	CB2435
R102, R103	801395	2	Resistor, Fixed Comp. 6.2K, 1/4W ±5%	01121	CB6225
R106	806371	1	Resistor, Fixed Comp. 5.1Meg, 1/4W, ±5%	72136	CB5155
R107	805613	1	Resistor, Fixed Film 10.2K, 1/4W ±1%	16299	C4-10.2K±1%
R110	807112	1	Resistor, Fixed Film 43K, 1/4W ±2%	16299	C4-43K±2%
R113	806718	1	Resistor, Fixed Film 5.6K, 1/4W ±2%	16299	C4-5.6K±2%
R114	806684	1	Resistor, Fixed Film 2.7K, 1/4W ±2%	16299	C4-2.7K±2%
R116	806724	1	Resistor, Variable 10K	32997	3389P10K

*Add full description from "Description" column.

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
R117	801985		Resistor, Fixed, Comp. 51K, ¼W 5%	01121	CB5135
R118	803784	1	Resistor, Fixed Comp. 10Ω, 1/4W ±5%	01121	CB1005
R119	802182	1	Resistor, Fixed Comp. 22K, 1/4W ±5%	01121	CB2235
R120	800785	1	Resistor, Fixed Comp. 1.2K, 2W ±5%	01121	HB1225
R128, R129, R131, R132, R134, R138, R140, R143	801006	8	Resistor, Fixed, Comp. 10K. 1/4W, ±5%	01121	CB1035
R130	801981	1	Resistor, Fixed, Comp. 100Ω, 1/4W ±5%	01121	CB1015
R135			Resistor, Fixed Selected at Test From		
	804400		270K, 1/4W ±5%	01121	CB2745
	802085		300K, 1/4W ±5%	01121	CB3045
	803553		330K, 1/4W ±5%	01121	CB3345
	806241		360K, 1/2W ±5%	01121	CB3645
	801987		390K, 1/4W ±5%	01121	CB3945
R141	802226	1	Resistor, Fixed, Comp. 200Ω, 1/4W ±5%	01121	CB2015
R142	802904	1	Resistor, Fixed, Comp. 36K, 1/4W ±5%	01121	CB3635
S1	205224	1	Switch, Range	NAI	
S2	500846	1	Switch, Function	NAI	
S3	205284	1	Switch, Power (Ref. Int-Ext)	NAI	
S5	806796	1	Switch, (Input, Dir-Trans)	31918	2D15-BL4UGR
S6	806675	1	Switch, (115V - 230V)	79727	GF-326uL
T1	800536	1	Transformer, Reference	80223	0-16
T2	202819	1	Transformer, Power	NAI	
T3	201562	1	Signal Isolation Transformer (400 Hz and above)	NAI	
	782460	1	Signal Isolation Transformer (below 400 Hz)	NAI	
Z2, Z3, Z4, Z6, Z7	804749	5	Integrated Circuit MC1437L	04713	MC1437L
Z5, Z9	806347	2	Operational Amplifier, 301A	12040	LM301A
Z8	782957	1	Detector Module	NAI	
	201722	1	Knob, Medium Round	NAI	
	201719	2	Knob, Medium Pointer	NAI	
	201946	1	Knob, Conc. Adapt.	NAI	
	205298-1	1	Button (DIR)	NAI	
	205298-2	1	Button (TRANS)	NAI	
	500268	1	Phase Angle Dial Assy.	NAI	
	202561	1	Window Meter	NAI	
	800119	2	Binding Post, Red	81073	29-1R
	800120	3	Binding Post, Black	81073	29-1B
	800546	1	Binding Post	83330	137
	800339	1	Link, Shorting	24655	938C
XF1	800117	1	Fuseholder	75915	342001
	800502	1	Line Cord	70903	17408
XDS1	804544	1	Connector, Cartridge	72765	399-058
	802952	1	Speed Clip	72619	7538-XP51

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
ALTERNATE REFERENCE COMPONENTS - FREQUENCIES BELOW 400Hz					
R122, R123	801985	2	Resistor, Fixed, Comp. 51K, 1/4W ±5%	01121	CB5135
R130	801980	1	Resistor, Fixed, Comp. 51Ω, 1/4W ±5%*	01121	CB5105
T1	800050	1	Transformer**	80223	U-6
RESISTORS - FREQUENCIES 92Hz OR BELOW					
Note For all frequencies above 92Hz, use Band 7 resistors. Refer to page 6.8.					
R57, R69	806156	2	Resistor, Fixed, Film 10K, 1/4W ±2%	16299	C4-10K±2%
R58, R70	806680	2	Resistor, Fixed, Film 16K, 1/4W ±2%	16299	C4-16K±2%
R59, R71	806751	2	Resistor, Fixed, Film 56K, 1;4W ±2%	16299	C4-56K±2%
R60, R74	806752	2	Resistor, Fixed, Film 82K, 1/4W ±2%	16299	C4-82K±2%
R61			Resistor, Metal Film, Select at Test From		
	807558		910Ω, 1/4W, ±2%	16299	C4
	806667		1K Ω, 1/4W, ±2%	16299	C4
	803679		1.1K Ω, 1/4W, ±2%	16299	C4
R62, R72	80272[illegible]	2	Resistor, Fixed, Comp. 43K, 1/4 ±5%	01121	CB4335
R63, R76	806753	2	Resistor, Fixed, Film 9.1K, 1/4W ±2%	16299	C4-9.1K±2%
R64, R77	806754	2	Resistor, Fixed, Film 27K, 1/4W ±2%	16299	C4-27K±2%
R65, R78	801721	2	Resistor, Fixed, Comp. 12K, 1/4W ±5%	01121	CB1235
R67, R80	806682	2	Resistor, Fixed, Film 24K, 1/4W ±2%	16299	C4-24K±2%
R68, R81	806755	2	Resistor, Fixed, Film 4.3K, 1/4W ±2%	16299	C4-4.3K±2%
R75	806663	1	Resistor, Fixed, Film 1K, 1/4W ±2%	16299	C4-1K±2%
BAND 1 30Hz to 39Hz					
C1, C4	806756	2	Capacitor, Fixed, Elec. 5.6uf, 20 VDC ±5%	06751	TS2K20565
C2, C3	806764	2	Capacitor, Fixed, Film .27uf, 80 VDC ±5%	06001	AE28R274J
C30, C45	806693	2	Capacitor, Fixed, Film .1 uf, 80 VDC ±5%	06001	AE17R104J
C31, C37, C39, C46, C52, C53	806762	6	Capacitor, Fixed, Film .39uf, 80 VDC ±5%	06001	AE36R394J
C32, C33, C48, C49	806763	4	Capacitor, Fixed, Film .33uf, 80 VDC ±5%	06001	AE29R334J
C36, C51	806686	2	Capacitor, Fixed, Film .47uf, 80 VDC ±5%	06001	AE36R474J
C64	806761	1	Capacitor, Fixed, Elec. .68 uf, 20 VDC ±5%	06751	TS1K20684
BAND 2 40Hz to 59Hz					
C1, C4	806757	2	Capacitor, Fixed, Elec. 3.3uf, 20 VDC ±5%	06751	TS2K20335
C2, C3	806694	2	Capacitor, Fixed, Film .15uf, 80 VDC ±5%	06001	AE22R154J
C30, C45	806691	2	Capacitor, Fixed, Film .068uf, 80 VDC ±5%	06001	AE17R683J
C31, C37, C39, C46, C52, C53	806764	6	Capacitor, Fixed, Film .27uf, 80 VDC ±5%	06001	AE28R274J
C32, C33, C48, C49	806695	4	Capacitor, Fixed, Film .22uf, 80 VDC ±5%	06001	AE22R224J
C36, C51	806763	2	Capacitor, Fixed, Film .33uf, 80 VDC ±5%	06001	AE29R334J
C64	806762	1	Capacitor, Fixed, Film .39uf, 80 VDC ±5%	06001	AE36R394J

*Replaces 801981

**Replaces 800536

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
			BAND 3 60Hz to 92Hz		
C1, C4	806758	2	Capacitor, Fixed, Elec. 2.2uf, 20 VDC ±5%	06751	TS1K20225
C2, C3	806693	2	Capacitor, Fixed, Film .1uf, 80 VDC ±5%	06001	AE17R104J
C30, C45	806767	2	Capacitor, Fixed, Film .047uf, 80 VDC ±5%	06001	AE17R473J
C31, C37, C39, C46, C52, C53	806765	6	Capacitor, Fixed, Film .18uf, 80 VDC ±5%	06001	AE22R184J
C32, C33, C48, C49	806694	4	Capacitor, Fixed, Film .15uf, 80 VDC ±5%	06001	AE22R154J
C36, C51	806695	2	Capacitor, Fixed, Film .22uf, 80 VDC ±5%	06001	AE22R224J
C64	806764	1	Capacitor, Fixed, Film .27uf, 80 VDC ±5%	06001	AE28R274J
			BAND 4 93Hz to 137Hz		
C1, C4	806759	2	Capacitor, Fixed, Elec. 1.5uf, 20 VDC ±5%	06751	TS1K20155
C2, C3	806691	2	Capacitor, Fixed, Film .068uf, 80 VDC ±5%	06001	AE17R683J
C30, C45	806693	2	Capacitor, Fixed, Film .1uf, 80 VDC ±5%	06001	AE17R104J
C31, C37, C39, C46, C52, C53	806762	6	Capacitor, Fixed, Film .39uf, 80 VDC ±5%	06001	AE36R394J
C32, C33, C48, C49	806763	4	Capacitor, Fixed, Film .33uf, 80 VDC ±5%	06001	AE29R334J
C36, C51	806686	2	Capacitor, Fixed, Film .47uf, 80 VDC ±5%	06001	AE36R474J
C64	806765	1	Capacitor, Fixed, Film .18uf, 80 VDC ±5%	06001	AE22R184J
			BAND 5 138Hz to 204Hz		
C1, C4	806760	2	Capacitor, Fixed, Elec. 1.0uf, 20 VDC ±5%	06751	TS1K20105
C2, C3	806767	2	Capacitor, Fixed, Film .047uf, 80 VDC ±5%	06001	AE17R473J
C30, C45	806691	2	Capacitor, Fixed, Film .068uf, 80 VDC ±5%	06001	AE17R683J
C31, C37, C39, C46, C52, C53	806764	6	Capacitor, Fixed, Film .27uf, 80 VDC ±5%	06001	AE28R274J
C32, C33, C48, C49	806695	4	Capacitor, Fixed, Film .22uf, 80 VDC ±5%	06001	AE22R224J
C36, C51	806763	2	Capacitor, Fixed, Film .33uf, 80 VDC ±5%	06001	AE29R334J
C64	806688	1	Capacitor, Fixed, Film .12uf, 80 VDC ±5%	06001	AE22R124J
			BAND 6 205Hz to 309Hz		
C1, C4	806761	2	Capacitor, Fixed, Elec. .68uf, 20 VDC ±5%	06751	TS1K20684
C2, C3	806689	2	Capacitor, Fixed, Film .033uf, 80 VDC ±5%	06001	AE15R333J
C30, C45	806767	2	Capacitor, Fixed, Film .047uf, 80 VDC ±5%	06001	AE17R473J
C31, C37, C39, C46, C52, C53	806765	6	Capacitor, Fixed, Film .18uf, 80 VDC ±5%	06001	AE22R184J
C32, C33, C48, C49	806694	4	Capacitor, Fixed, Film .15uf, 80 VDC ±5%	06001	AE22R154J
C36, C51	806695	2	Capacitor, Fixed, Film .22uf, 80 VDC ±5%	06001	AE22R224J
C64	806766	1	Capacitor, Fixed, Film .82uf, 80 VDC ±5%	06001	AE17R823J

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
BAND 7 310Hz to 464Hz					
R57, R69	806678	2	Resistor, Fixed, Film 3K, 1/4W ±2%	16299	C4-3K±2%
R58, R70	806679	2	Resistor, Fixed, Film 5.1K, 1/4W ±2%	16299	C4-5.1K±2%
R59, R71	806680	2	Resistor, Fixed, Film 16K, 1/4W ±2%	16299	C4-16K±2%
R60, R74	807122	2	Resistor, Fixed, Film 22K, 1/4W ±2%	16299	C4-22K±2%
R61			Resistor, Metal Film, Select at Test From		
	807558		270 Ω, 1/4W, ±2%	16299	C4
	806667		300 Ω, 1/4W, ±2%	16299	C4
	803679		330 Ω, 1/4W, ±2%	16299	C07
R63, R76	806684	2	Resistor, Fixed, Film 2.7K, 1/4W ±2%	16299	C4-2.7K±2%
R64, R77	806685	2	Resistor, Fixed, Film 8.2K, 1/4W ±2%	16299	C4-8.2K±2%
R67, R80	805639	2	Resistor, Fixed, Film 7.5K, 1/4W ±2%	16299	NA60-7.5K±2%
R68, R81	805640	2	Resistor, Fixed, Film 1.3K, 1/4W ±2%	16299	NA60-1.3K±2%
R62, R72	801721	2	Resistor, Fixed, Comp. 12K, 1/4W ±5%	01121	CB1235
R65, R78	801398	2	Resistor, Fixed, Comp. 3.6K, 1/4W ±5%	01121	CB3625
R75	806667	1	Resistor, Fixed, Film 300Ω, 1/4W ±2%	16299	C4-300Ω±2%
C30, C45	806689	2	Capacitor, Fixed, Film .033uf, 80 VDC ±5%	06001	AE15R333J
C64	806720	1	Capacitor, Fixed, Film .056uf, 80 VDC ±5%	06001	AE17R563J
C36, C51	806694	2	Capacitor, Fixed, Film .15uf, 80 VDC, ±5%	06001	AE22R154J
C32, C33, C48, C49	806693	4	Capacitor, Fixed, Film .1uf, 80 VDC ±5%	06001	AE17R104J
C1, C4	806686	2	Capacitor, Fixed, Film .47uf, 80 VDC, ±5%	06001	AE36R474J
C2, C3	806687	2	Capacitor, Fixed, Film .022uf, 80 VDC, ±5%	06001	AE15R223J
C31, C46, C52, C53, C37, C39	806688	6	Capacitor, Fixed, Film .12uf, 80 VDC, ±5%	06001	AE22R124J
BAND 8 465Hz to 699Hz					
C1, C4	806763	2	Capacitor, Fixed, Film .33uf, 80 VDC ±5%	06001	AE29R334J
C2, C3	806771	2	Capacitor, Fixed, Film .015uf, 80 VDC ±5%	06001	AE15R153J
C30, C45	806687	2	Capacitor, Fixed, Film .022uf, 80 VDC ±5%	06001	AE15R223J
C31, C37, C39, C46, C52, C53	806766	6	Capacitor, Fixed, Film .082uf, 80 VDC ±5%	06001	AE17R823J
C32, C33, C48, C49	806691	4	Capacitor, Fixed, Film .068uf, 80 VDC ±5%	06001	AE17R683J
C36, C51	806693	2	Capacitor, Fixed, Film .1uf, 80 VDC ±5%	06001	AE17R104J
C64	806768	1	Capacitor, Fixed, Film .039uf, 80 VDC ±5%	06001	AE17R393J
BAND 9 700Hz to 1.05Hz					
C1, C4	806695	2	Capacitor, Fixed, Film .22uf, 80 VDC ±5%	06001	AE22R224J
C2, C3	806690	2	Capacitor, Fixed, Film .01uf, 80 VDC ±5%	06001	AE13R103J
C30, C45	806771	2	Capacitor, Fixed, Film .015uf, 80 VDC ±5%	06001	AE15R153J
C31, C37, C39, C46, C52, C53	806720	6	Capacitor, Fixed, Film .056uf, 80 VDC ±5%	06001	AE17R563J
C32, C33, C48, C49	806767	4	Capacitor, Fixed, Film .047uf, 80 VDC ±5%	06001	AE17R473J
C36, C51	806691	2	Capacitor, Fixed, Film .068uf, 80 VDC ±5%	06001	AE17R683J
C64	806769	1	Capacitor, Fixed, Film .027uf, 80 VDC ±5%	06001	AE15R273J

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
			BAND 10 1.06KHz to 1.57KHz		
C1, C4	806694	2	Capacitor, Fixed, Film .15uf, 80 VDC ±5%	06001	AE22R154J
C2, C3	806774	2	Capacitor, Fixed, Film .0068uf, 80 VDC ±5%	06001	AE13R682J
C30, C45	806690	2	Capacitor, Fixed, Film .01uf, 80 VDC ±5%	06001	AE13R103J
C31, C37, C39, C46, C52, C53	806689	6	Capacitor, Fixed, Film .033uf, 80 VDC ±5%	06001	AE15R333J
C32, C33, C48, C49	806769	4	Capacitor, Fixed, Film .027uf, 80VDC ±5%	06001	AE15R273J
C36, C51	806767	2	Capacitor, Fixed, Film .047uf, 80 VDC ±5%	06001	AE17R473J
C64	806770	1	Capacitor, Fixed, Film .018uf, 80 VDC ±5%	06001	AE15R183J
			BAND 11 1.58KHz to 2.36KHz		
C1, C4	806693	2	Capacitor, Fixed, Film .10uf, 80 VDC ±5%	06001	AE17R104J
C2, C3	806776	2	Capacitor, Fixed, Film .0047uf, 80 VDC ±5%	06001	AE12R472J
C30, C45	806774	2	Capacitor, Fixed, Film .0068uf, 80 VDC ±5%	06001	AE13R682J
C31, C37, C39, C46, C52, C53	806687	6	Capacitor, Fixed, Film .022uf, 80 VDC ±5%	06001	AE15R223J
C32, C33, C48, C49	806770	4	Capacitor, Fixed, Film .018uf, 80 VDC ±5%	06001	AE15R183J
C36, C51	806769	2	Capacitor, Fixed, Film .027uf, 80 VDC ±5%	06001	AE15R273J
C64	806773	1	Capacitor, Fixed, Film .0082uf, 80 VDC ±5%	06001	AE13R822J
			BAND 12 2.37KHz to 3.55KHz		
C1, C4	806691	2	Capacitor, Fixed, Film .068uf, 80 VDC ±5%	06001	AE17R683J
C2, C3	806779	2	Capacitor, Fixed, Film .0027uf, 80 VDC ±5%	06001	AE12R272J
C30, C45	806776	2	Capacitor, Fixed, Film .0047uf, 80 VDC ±5%	06001	AE12R472J
C31, C37, C39, C46, C52, C53	806771	6	Capacitor, Fixed, Film .015uf, 80 VDC ±5%	06001	AE15R153J
C32, C33, C48, C49	806772	4	Capacitor, Fixed, Film .012uf, 80 VDC ±5%	06001	AE15R123J
C36, C51	806770	2	Capacitor, Fixed, Film .018uf, 80 VDC ±5%	06001	AE15R183J
C64	806776	1	Capacitor, Fixed, Film .0047uf, 80 VDC ±5%	06001	AE12R472J
			BAND 13 3.56KHz to 5.34KHz		
C1, C4	806768	2	Capacitor, Fixed, Film .039uf, 80 VDC ±5%	06001	AE17R393J
C2, C3	806781	2	Capacitor, Fixed, Film .0018uf, 80 VDC ±5%	06001	AE12R182J
C30, C45	806781	2	Capacitor, Fixed, Film .0018uf, 80 VDC ±5%	06001	AE12R182J
C31, C37, C39, C46, C52, C53	806690	6	Capacitor, Fixed, Film .01uf, 80 VDC ±5%	06001	AE13R103J
C32, C33, C48, C49	806773	4	Capacitor, Fixed, Film .0082uf, 80 VDC ±5%	06001	AE13R822J
C36, C51	806772	2	Capacitor, Fixed, Film .012uf, 80 VDC ±5%	06001	AE15R123J
C64	806778	1	Capacitor, Fixed, Film .0033uf, 80 VDC ±5%	06001	AE12R332J

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
BAND 14 5.35KHz to 7.9KHz					
C1, C4	806769	2	Capacitor, Fixed, Film .027uf, 80 VDC ±5%	06001	AE15R273J
C2, C3	806783	2	Capacitor, Fixed, Film .012uf, 80 VDC ±5%	06001	AE12R122J
C30, C45	806781	2	Capacitor, Fixed, Film .0018uf, 80 VDC ±5%	06001	AE12R182J
C31, C37, C39, C46, C52, C53	806774	6	Capacitor, Fixed, Film .0068uf, 80 VDC ±5%	06001	AE13R682J
C32, C33, C48, C49	806774	4	Capacitor, Fixed, Film .0068uf, 80 VDC ±5%	06001	AE13R682J
C36, C51	806773	2	Capacitor, Fixed, Film .0082uf, 80 VDC ±5%	06001	AE13R822J
C64	806780	1	Capacitor, Fixed, Film .0022uf, 80 VDC ±5%	06001	AE12R223J
BAND 15 8KHZ to 10KHz					
C1, C4	806770	2	Capacitor, Fixed, Film .018uf, 80 VDC ±5%	06001	AE15R183J
C2, C3	802333	2	Capacitor, Fixed, Mica 910pf, 500V ±5%	72136	DM-19-911J
C30, C45	806783	2	Capacitor, Fixed, Film .0012uf, 80 VDC ±5%	06001	AE12R122J
C31, C37, C39, C46, C52, C53	806776	6	Capacitor, Fixed, Film .0047uf, 80 VDC ±5%	06001	AE12R472J
C32, C33, C48, C49	806777	4	Capacitor, Fixed, Film .0039uf, 80 VDC ±5%	06001	AE12R392J
C36, C51	806775	2	Capacitor, Fixed, Film .0056uf, 80 VDC ±5%	06001	AE13R562J
C64	806782	1	Capacitor, Fixed, Film .0015uf, 80 VDC ±5%	06001	AE12R152J

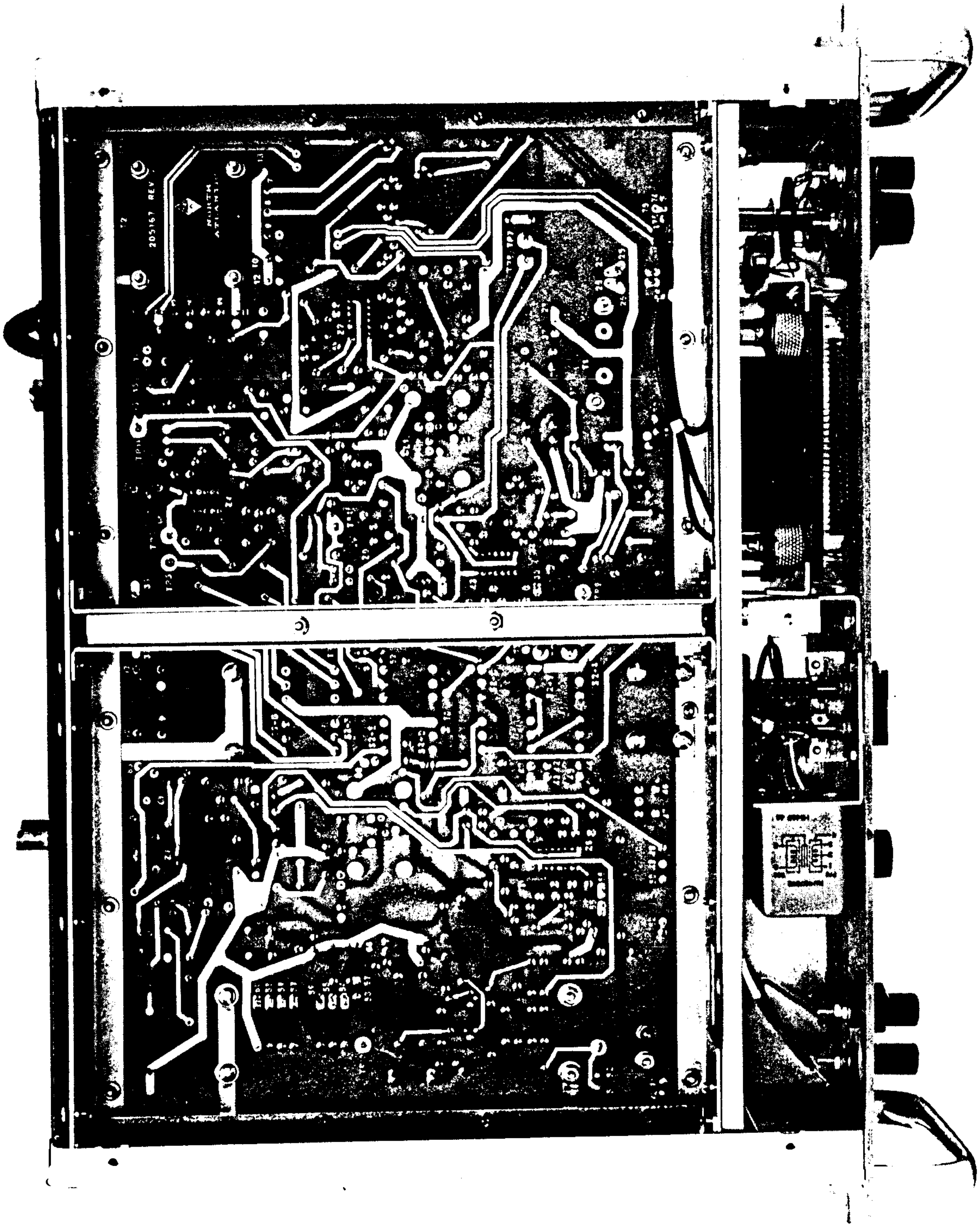


Figure 6-2. Top View, Cover Removed

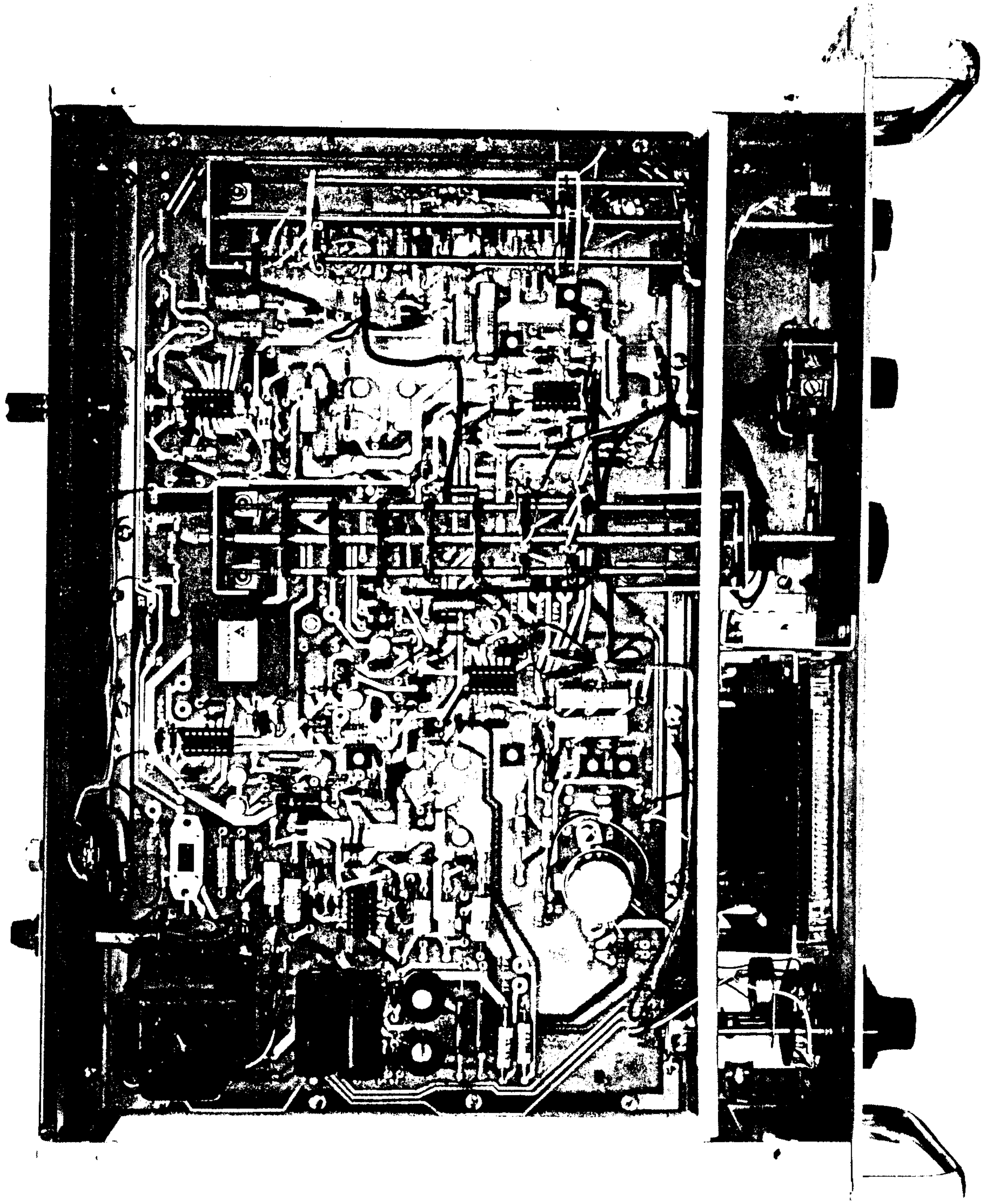
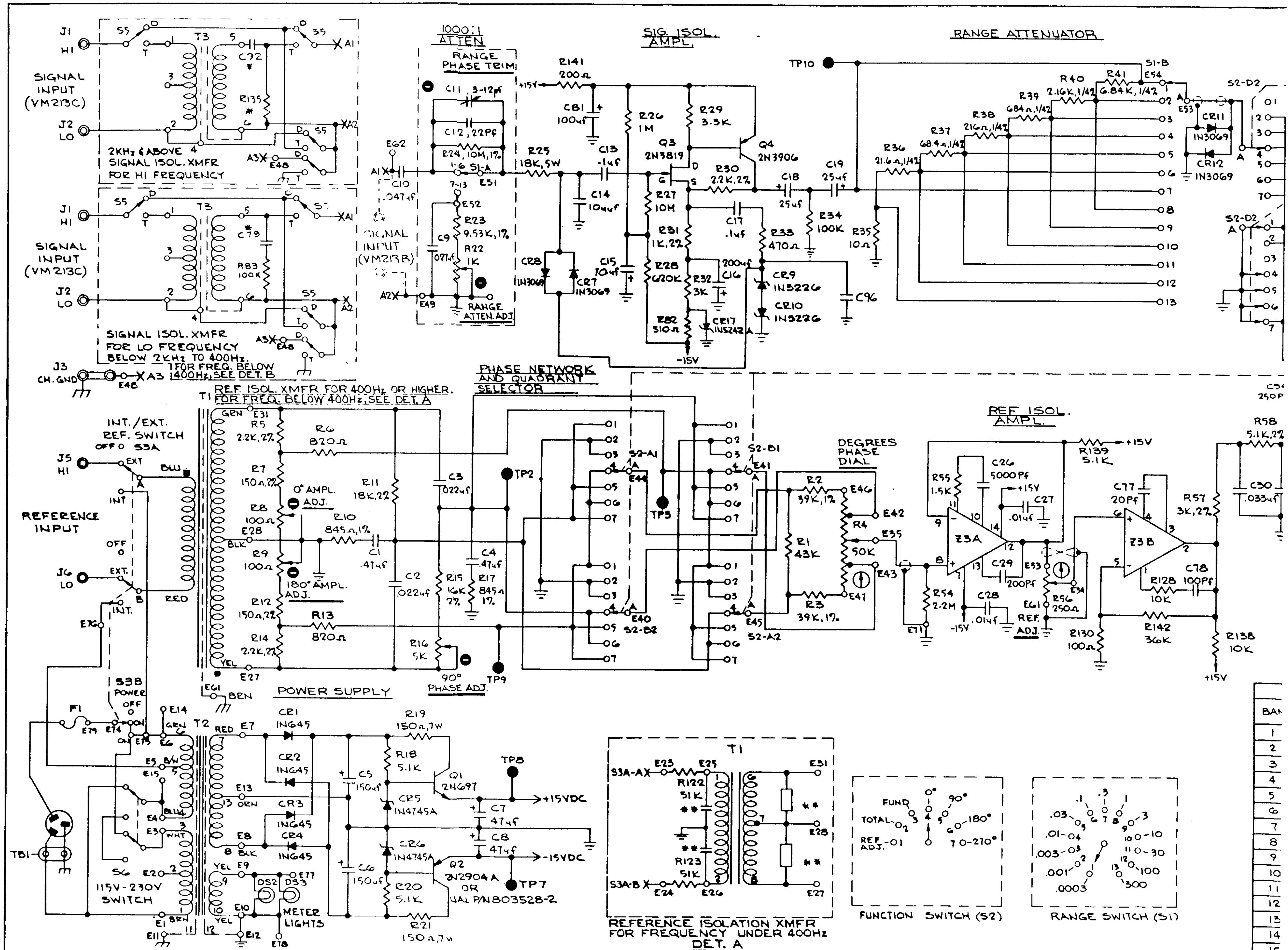
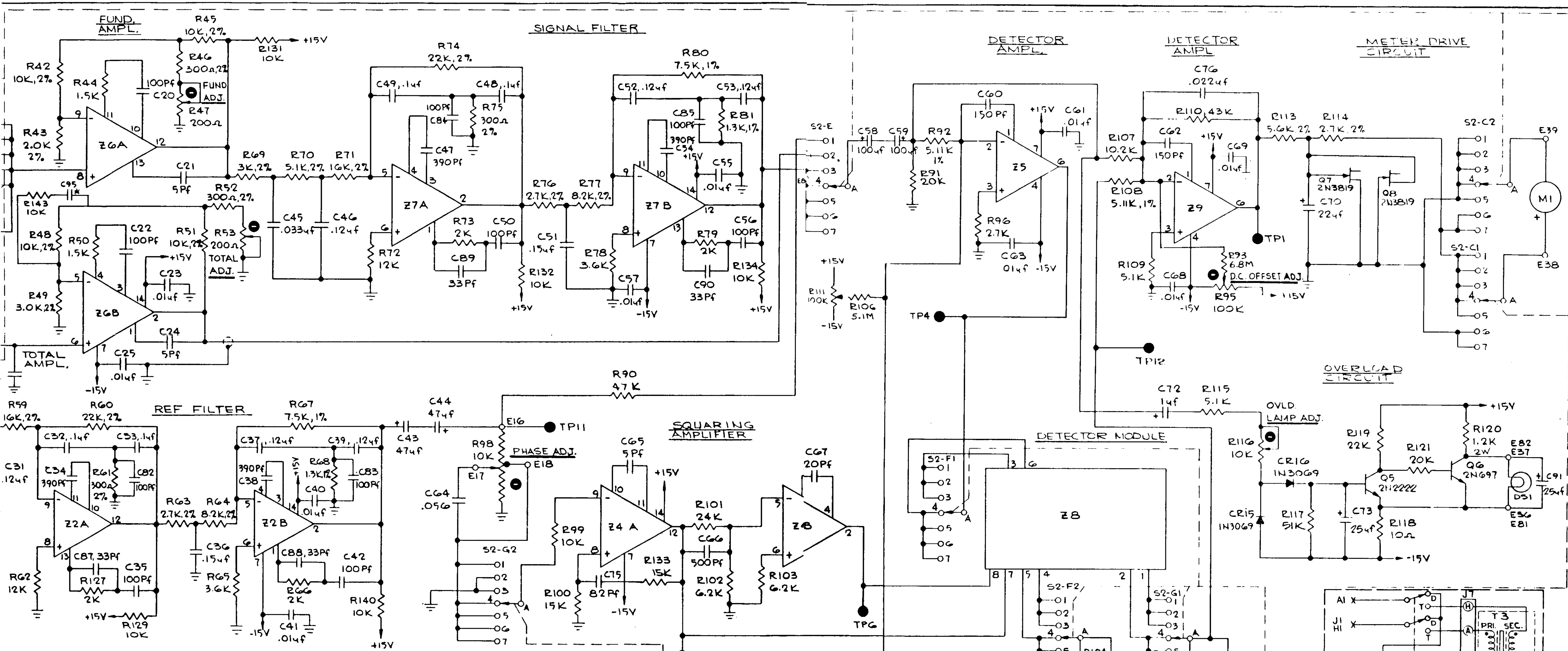
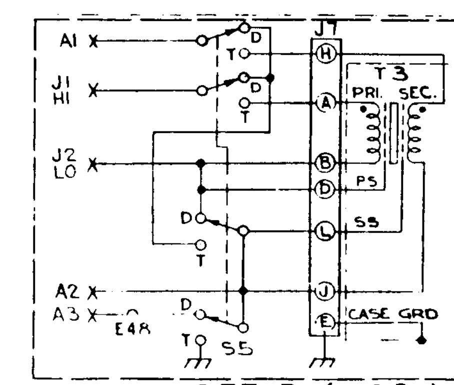


Figure 6-3. Bottom View, Cover Removed


1000:1 ATTEN
RANGE PHASE TRIM
SIG. ISOL. AMPL.
RANGE ATTENUATOR
SIGNAL INPUT (VM213C)
2KHz & ABOVE
SIGNAL ISOL. XMFR FOR HI FREQUENCY
SIGNAL ISOL. XMFR FOR LO FREQUENCY BELOW 2KHz TO 400Hz. FOR FREQ. BELOW 400Hz, SEE DET. B
SIGNAL INPUT (VM213B)
RANGE ATTEN ADJ.
REF. ISOL. XMFR FOR 400Hz OR HIGHER. FOR FREQ. BELOW 400Hz, SEE DET. A
PHASE NETWORK AND QUADRANT SELECTOR
INT./EXT. REF. SWITCH
REFERENCE INPUT
0° AMPL. ADJ.
180° AMPL. ADJ.
90° PHASE ADJ.
DEGREES PHASE DIAL
REF ISOL. AMPL.
REF. ADJ.
POWER SUPPLY
115V-230V SWITCH
METER LIGHTS
+15VDC
-15VDC
REFERENCE ISOLATION XMFR FOR FREQUENCY UNDER 400Hz DET. A
FUNCTION SWITCH (S2)
RANGE SWITCH (S1)





FREQUENCY COMPONENT TABLE

BAND WIDTH	R57 R69	R58 R70	R59 R71	R60 R74	R61 R75	R63 R76	R64 R77	R67 R80	R68 R81	R62 R72	R65 R78	C1	C2	C3	C4	C30 C45	C31 C46	C32 C49	C33 C48	C36 C51	C37 C52	C39 C53	C64	R130
30Hz - 39Hz	10K	16K	56K	82K	1K	9.1K	27K	24K	4.3K	43K	12K	5.6	.27	.27	5.6	.1	.39	.33	.33	.47	.39	.39	.68	51Ω
40Hz - 59Hz	10K	16K	56K	82K	1K	9.1K	27K	24K	4.3K	43K	12K	3.3	.15	.15	3.3	.068	.27	.22	.22	.33	.27	.27	.39	↑
60Hz - 92Hz	10K	16K	56K	82K	1K	9.1K	27K	24K	4.3K	43K	12K	2.2	.1	.1	2.2	.047	.18	.15	.15	.22	.18	.18	.27	
93Hz - 137Hz	3K	5.1K	16K	22K	300	2.7K	8.2K	7.5K	1.3K	12K	3.6K	1.5	.068	.068	1.5	.1	.39	.33	.33	.47	.39	.39	.18	
138Hz - 204Hz	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	1.0	.047	.047	1.0	.068	.27	.22	.22	.33	.27	.27	.12	
205Hz - 309Hz												.68	.033	.033	.68	.047	.18	.15	.15	.22	.18	.18	.082	↓
310Hz - 464Hz												.47	.022	.022	.47	.033	.12	.1	.1	.15	.12	.12	.056	100*
465Hz - 699Hz												.33	.015	.015	.33	.022	.082	.068	.068	.1	.082	.082	.039	↑
700Hz - 1.05KHz												.22	.01	.01	.22	.015	.056	.047	.047	.068	.056	.056	.027	
1.06KHz - 1.57KHz												.15	.0068	.0068	.15	.01	.033	.027	.027	.047	.033	.033	.018	
1.58KHz - 2.36KHz												.10	.0047	.0047	.10	.0068	.022	.018	.018	.027	.022	.022	.0082	
2.37KHz - 3.55KHz												.068	.0027	.0027	.068	.0047	.015	.012	.012	.018	.015	.015	.0047	
3.56KHz - 5.34KHz												.039	.0018	.0018	.039	.0027	.01	.0082	.0082	.012	.01	.01	.0033	
5.35KHz - 7.9KHz	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	.027	.0012	.0012	.027	.0018	.0068	.0068	.0068	.0082	.0068	.0068	.0022	
8KHz - 10KHz	3K	5.1K	16K	22K	300	2.7K	8.2K	7.5K	1.3K	12K	3.6K	.018	910Pf	910Pf	.018	.0012	.0047	.0039	.0039	.0056	.0047	.0047	.0015	↓

NOTE:

1- ALL RESISTORSARE 1/4 W, ±5% UNLESS OTHERWISE SECIFIED.
2- SCHEMATIC ASSHOWN IS 400Hz, FOR OTHER FREQUNCIES SEE COMPONENT TABLE FOR VALUE CHANGES.
3- * DENOTES SELECT AT TEST.
4- S6 IS SHOWN IN 115V POSITION.
5- ** FACTOR SELECTED RESISTOR OR CAPACITOR DEPENDING ON FREQUENCY (IF REQUIRED.
6- Z2,3,4,6,7 ARE MC1437L. Z5,9 ARE 301A.

● INTENAL TRIMPOT
⏀ EXTERNAL ADJUSTMENT
● TEST POINT
⏚ CIRCUIT GND.
⏚ CHASSIS GND.

Figure 6-4. Phase Angle Voltmeter, Schematic