NORTH ATLANTIC

industries, inc.

OPERATING AND SERVICE INSTRUCTIONS

WITH PARTS LIST

PHASE ANGLE VOLTMETER

MODELS 213B & 213C

Circuits in this instrument are covered under
Patent No. 3,267,358, 1,060,991 and 780,031.

NORTH ATLANTIC INDUSTRIES, INC.
Plainview, New York

CODE IDENTIFICATION 07342

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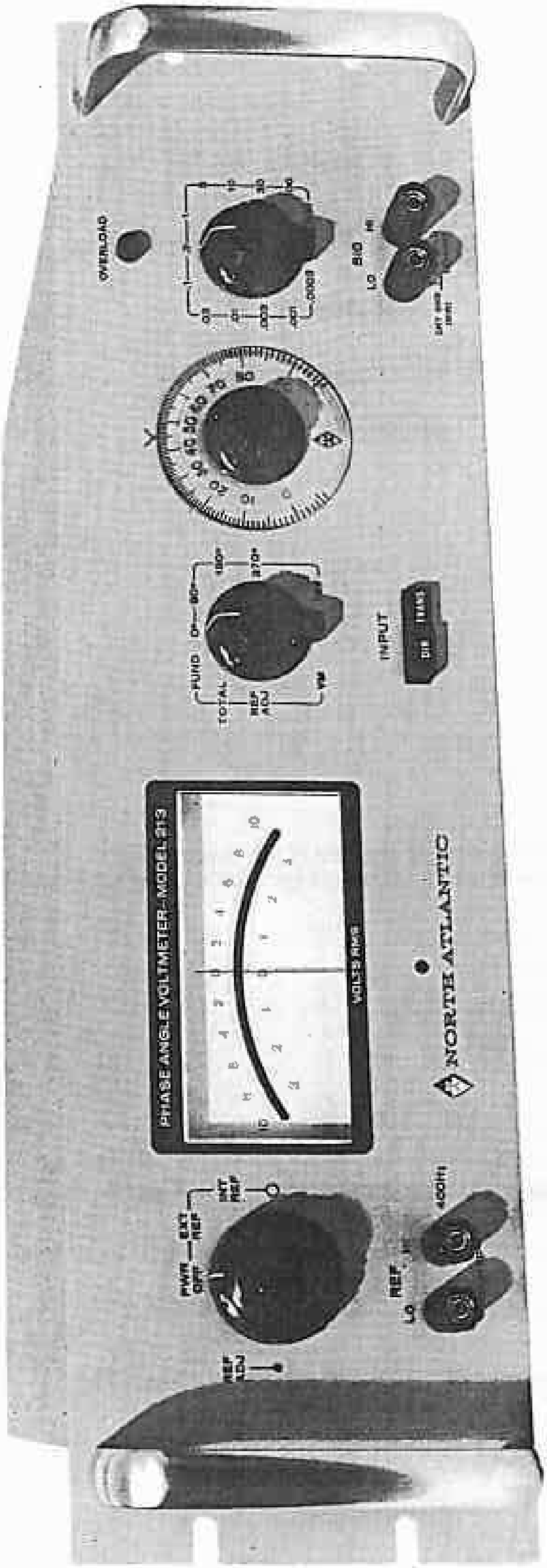
PHASE ANGLE VOLTMETER - MODEL 213
NORTH ATLANTIC
OVERLOAD
INPUT
VOLTS RMS
TOTAL
FUND
REF ADJ
PWR OFF
EXT REF
INT REF
SIG
LO
HI
REF

CAUTION

High voltage exists at several points in the instrument. Normal precautions consistent with good practice should be taken to reduce shock hazard.

A potential shock hazard exists when ungrounded power source or ungrounded case operation is employed. Persons operating the instrument should be made aware of, and take precautions against, this condition.

North Atlantic Industries, Inc. cannot be held responsible for damage to person or property in the process of, or as a result of, operation, maintenance, calibration, or setting up of the instrument.

ERRATA SHEET

Phase Angle Voltmeter
Models 213B & C

Page 5.11

PROCEDURE FOR SELECTING C79 TRANS MODE
PHASE SHIFT (2KHz or Below)

Add to step 7: Meter should read 0 ±3 small divisions of null reading in step 4 above.

Add steps:

8. If the reading is more than three small divisions, but the total deviation in step 7 is less than 3 small divisions (i. e., Direct = -1 division; Trans = -4 divisions) adjust C11 to split the error around zero (+1.5, -1.5).

9. If an adjustment of C11 is required, recheck voltage accuracy (para. 5.5.2.2, page 5.3) and frequency response (para. 5.5.2.3, page 5.4).

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200 terminal drive, plainview, n. y. OVerbrook 1-8600

SECTION I

1.1 INTRODUCTION AND DESCRIPTION.

The Model 213 Phase Angle Voltmeter is a completely transistorized instrument which combines the ability to measure both phase angle and magnitude of complex AC signals and vector components with respect to a reference voltage. Designed for phase sensitive operation at a pre-specified frequency within 30Hz to 10KHz, 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 213 is capable of measuring signals within a frequency range of 10Hz to 100KHz. 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 2µV nulling sensitivity 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.

The Model 213 is available in two basic configurations:

1.2 MODEL 213B - REFERENCE ISOLATION BUT NO SIGNAL ISOLATION.

The Model 213B will perform all the basic functions for which the instrument has been designed, except that it does not contain any means for isolating signal inputs.

1.3 MODEL 213C - BOTH REFERENCE AND SIGNAL ISOLATION.

The Model 213C differs from the Model 213B not only by the addition of signal isolation, but it also 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)

1.4 APPLICATIONS.

A. Phase-Sensitive Null Indicator

B. Measures separately the in-phase and quadrature components of an AC signal.

C. Measures phase shift in any AC system.

D. Sensitive AC electronic voltmeter

E. Testing of servos, computers, synchros, resolvers, inductosyn.

F. Precise AC ratiometry

G. Phasing of servo motors, chopper amplifiers, magnetic amplifiers.

H. Measuring both torque and non-torque producing signals in servo amplifiers.

I. Align carrier amplifier and notch networks

J. Impedance meter

K. Power factor meter

L. Measuring response of vibrational system.

Detailed descriptions of these applications are shown in the Application Notes in Section VIII.

1.5 GENERAL SPECIFICATIONS.

The following specifications apply to all North Atlantic Models 213B and 213C Phase Angle Voltmeters. 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. 213B-S1234.

Voltage Range (Full-Scale Output)	300µV to 300V in 13 ranges
Frequency Ranges	Total Mode - Direct Input: 10Hz to 100KHz 213C Only - Trans. Input: 20Hz to 3KHz*

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

Frequency Ranges (Cont'd)	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, 10Hz to 20Hz, 50KHz to 100KHz 213C Only - Trans. Input: ±2% of Full Scale, 60Hz to 2KHz*; ±5% of Full Scale, 20Hz to 60Hz, 2KHz to 3KHz Fundamental and Phase Sensitive Mode - ±2% at phase sensitive frequency of operation.
Phase Accuracy:	±1° as read on the Calibrated Phase Dial, ±3% Full Scale Angle using E cos θ characteristic (See Application Notes)
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:	Model 213B - 10 megohms shunted by 65$\mu\mu$f nominal. (140$\mu\mu$f with rear input terminals) Model 213C Direct Mode: 10 megohms shunted by 75$\mu\mu$f nominal (150$\mu\mu$f with rear input terminals) Transformer Mode: 300K Min at 400Hz
Reference Input Impedance	300K Nom. (100K Nom. for frequencies below 400Hz)
Reference Input Voltage:	Model 213B, 213C: 1.5V to 200V max., 400Hz to 10KHz; 3.8V to 200V max. below 400Hz.
Signal Input DC Voltage Level:	Model 213B - 400V max. Model 213C Transformer Mode: 0V (with no external blocking capacitor) Direct Mode: 400V
Transformer Common Mode Rejection: (at 400Hz)	Zero Source Impedance: .0025% max. 1K Source Impedance: .004% max. (1K 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 15μV, Total and Fundamental Modes.
Nulling Sensitivity:	Less than 2μV, Phase Sensitive Modes.
Fundamental Mode Frequency Response:	See Diagram, Figure 4.4

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

Harmonic Rejection: Phase Sensitive Modes	At 400Hz; 55DB All Other Frequencies of Operation 40DB to 70DB depending on frequency of operation - see Diagram, Figure 4.4.
Non-Coherent Signal Rejection:	For frequencies removed from signal frequency by approx-mately 5Hz 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:	115V/125V or 230/250V ±10% - 45-440Hz-10VA
Fuse:	For 115/125V Power: .5A, type 3AG. S.B. For 230/250V Power: .25A, type 3AG. S.B.

1.6 MECHANICAL SPECIFICATIONS.

Size:	Panel is 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.

Specifications subject to change without notice.

SECTION II

PREPARATION FOR USE

2.1 REMOVAL FROM PACKAGE.

This instrument has been thoroughly tested, inspected, and evaluated at the factory prior to shipment. Particular care has been taken in the design of the special wrapping and packaging material used in the container to ensure that no damage results from the typical handling encountered during shipment. However, upon removal from the package, the instrument should be externally inspected for any obvious damage. Should such damage be observed, refer to the Warranty in Section VIII. The instrument may now be mounted (either rack or bench) and checked per Performance Evaluation Procedure. (Paragraph 5.5)

SECTION III

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

Note

> Be sure to use the proper fuse for the desired operating voltage. 115V/125V source will be .5 amp., type 3AG fuse, and 230V/250V source will be .25 amp., type 3AG 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 (Model 213C), care must be taken not to apply high-level voltages at a low frequency such that the 0.75f (f = Hz) maximum voltage rating of the input transformer is exceeded. The same precaution applies to the reference input transformer (Models 213B & C) in those instruments whose phase-sensitive frequency is 400Hz or above. The maximum voltage rating of the reference input transformer is 0.5f (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 300V RMS and maximum reference input must not exceed 200V. Higher voltages will break down the input capacitors in the instrument. (See Specifications, Section I.)

3.5 CONTROLS, DISPLAYS, INPUTS. (See Figures 3.1 and 3.2.)

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

3.5.1 POWER AND REFERENCE SELECT SWITCH.

If the pre-specified phase sensitive operating frequency of the voltmeter is 60Hz or 400Hz, 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.

3.5.2 REFERENCE ADJUST.

The REFerence ADJust Control is used for adjusting the reference level to read half scale (red line) on the meter.

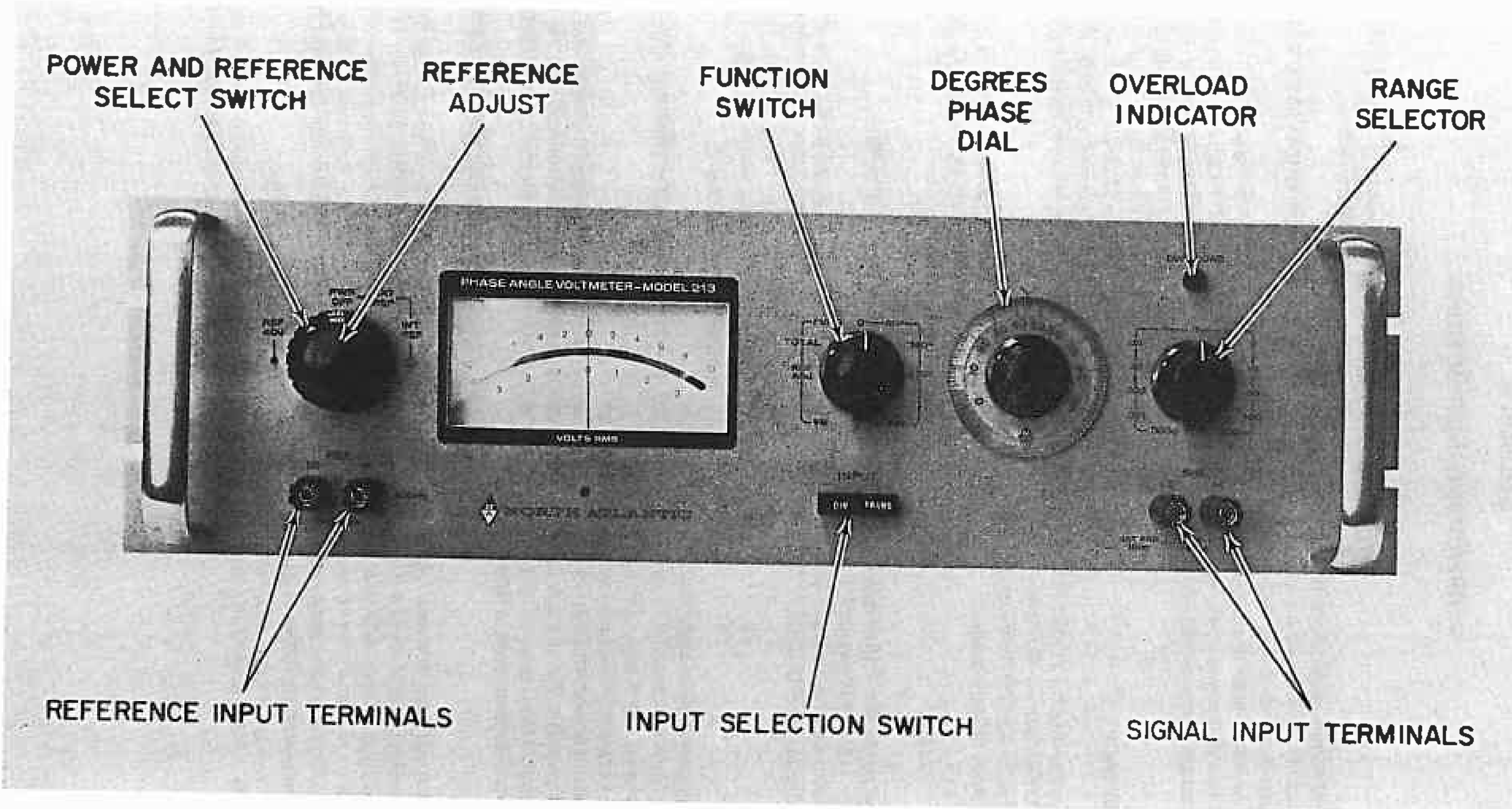


Figure 3.1 Front Panel Controls

Figure 3.2 Back Panel View

This control is used when the FUNCTION switch is in the REFerence ADJust position.

3.5.3 FUNCTION SELECTOR.

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 10Hz to 100KHz. In the FUNDamental position, the instrument will read 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 REFerence ADJust position in order to make the proper reference adjustment.

3.5.4 RANGE SELECTOR.

The RANGE Selector is a rotary switch which selects the proper attenuators for the desired full-scale voltage as marked on the front panel.

3.5.5 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, paragraph 5.6.3, should be followed.

3.5.6 PHASE ADJUST. (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.

3.5.7 OVERLOAD INDICATOR.

The lamp marked OVERLOAD 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.)

3.5.8 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 fullscale 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.

3.5.9 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 high and low which indicates polarity with respect to each other (i.e. high is inphase with high; low is inphase with low).

On Model 213C - The signal low 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.

(The Following Applies to Model 213C Only.)

The Model 213C instruments are characterized by the inclusion of a Signal Isolation Transformer with facility for switching the transformer in or out of the circuit. The items listed here exist on the Model 213C front panel only.

INPUT Selector Switch - The INPUT Selector Switch is a push button switch which removes the input transformer from the input circuit in the DIRect position allowing for single-ended, direct-coupled inputs. In the TRANSformer 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. (Section VIII)

3.6.1 TO MEASURE 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 SIGnal 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 FUNDamental 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 required 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 virture of the signal and reference grounds being connected. These loops can result in erroneous readings. (Refer to the Application Notes in Section VIII.)

3.6.2 TO MEASURE PHASE ANGLE.

3.6.2.1 REFERENCE ADJUSTMENT.

A. Switch the FUNCTION Selector to the REFerence ADJust position.

B. Inject the reference signal into the REFerence terminals and adjust the REFerence ADJust 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 SIGnal and REFerence inputs and adjust the reference level in accordance with the preceding paragraph 3.6.2.1.

B. Place the FUNCTION Selector in the 0° position and the DEGREES Phase Dial at 90°, and then FUNCTION Selector in 90° position and the DEGREES Phase Dial at 0°.

If the meter does not read zero for both these tests, use the rear-panel screwdriver adjustment, 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 MEASUREMENT-WITH CALIBRATED DEGREES PHASE DIAL.

A. Set FUNCTION Switch to REF. ADJ. position. Connect a reference input to the REFerence terminals, and adjust the reference level by REFerence ADJust Control for red line.

B. Set FUNCTION Switch to FUNDAMENTAL position. Inject the signal to be measured into the Signal 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 up-range 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 in the 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 than 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 SIGnal 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 FUNDAMENTAL 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 appended 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 (VM213C). 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 (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 (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 (C). This also can cause an output even if $E_1 = E_2$.

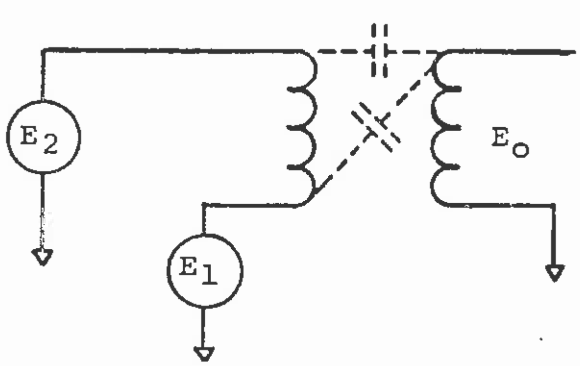


Figure (A)

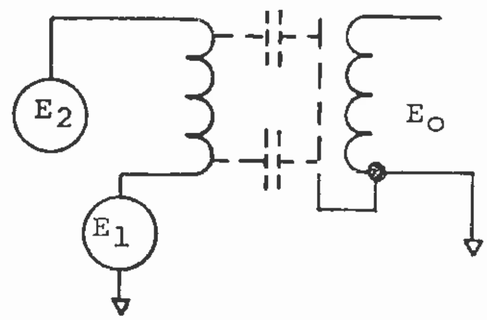


Figure (B)

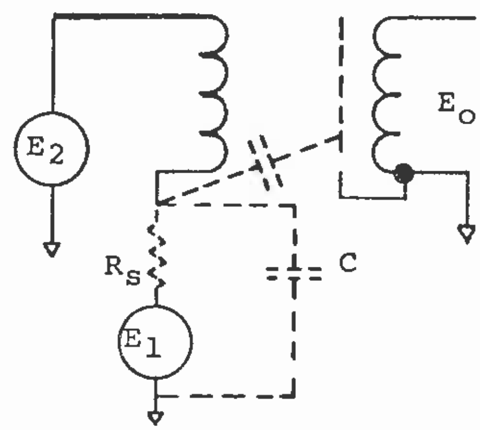


Figure (C)

This effect is minimized if a double shielded wire and a primary shield is used as shown in Figure (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 (E).

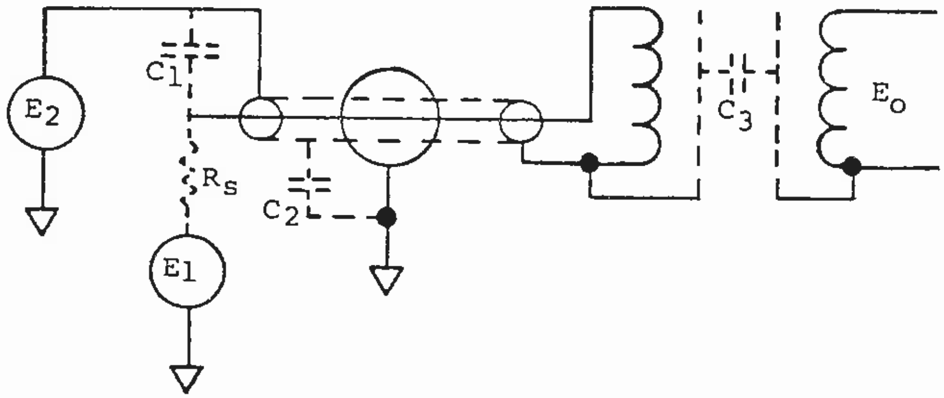


Figure (D)

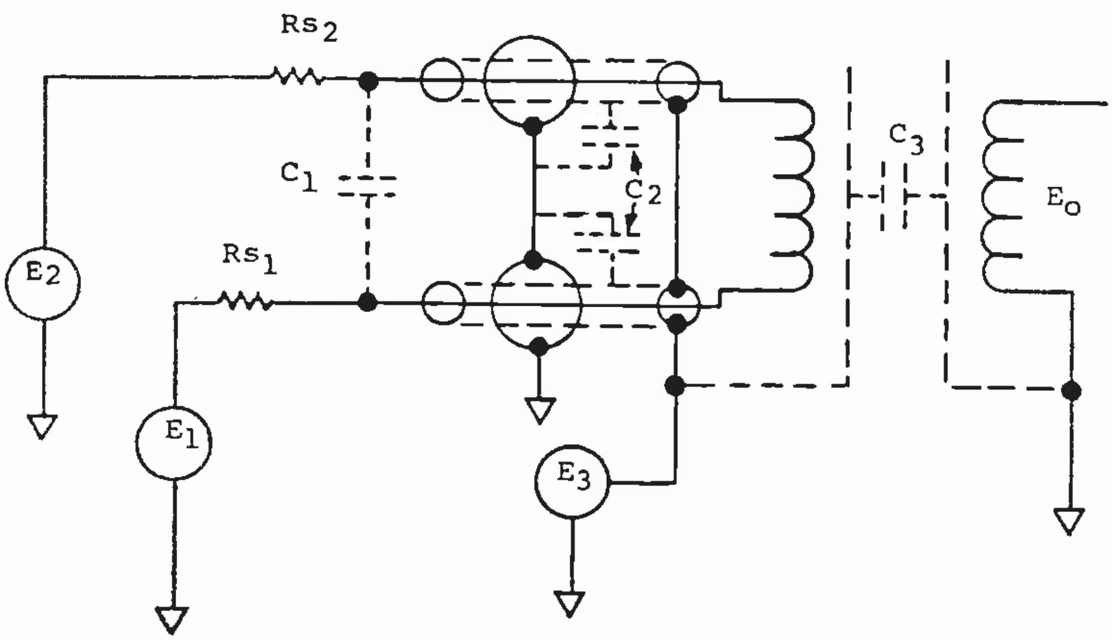


Figure (E)

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 an NAI Model T-110 Bridge Null Transformer.

3.6.3.2 COMMON MODE REJECTION (CMR). Common 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 AC Bridges.

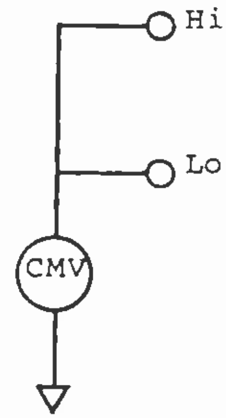


Figure (A)

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

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

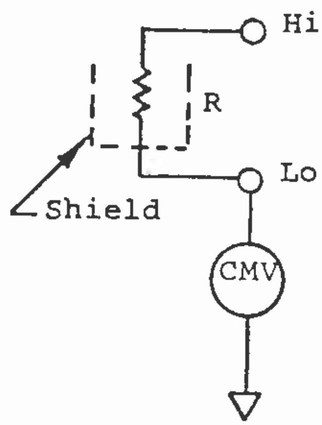


Figure (B)

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

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

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

SECTION IV

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 1, page 4.5 for errors due to harmonics.)

As a Fundamental Voltmeter, a harmonic filter is switched into the circuit and the meter will read 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 213 always operate with the same basic sensitivity (300μV). 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 100mV 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 600Hz. 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, page 5.8, for proper alignment.

4.4 AMPLIFIERS.

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 300V RMS to be applied indefinitely to the input with the RANGE switch on the 300μV range.

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

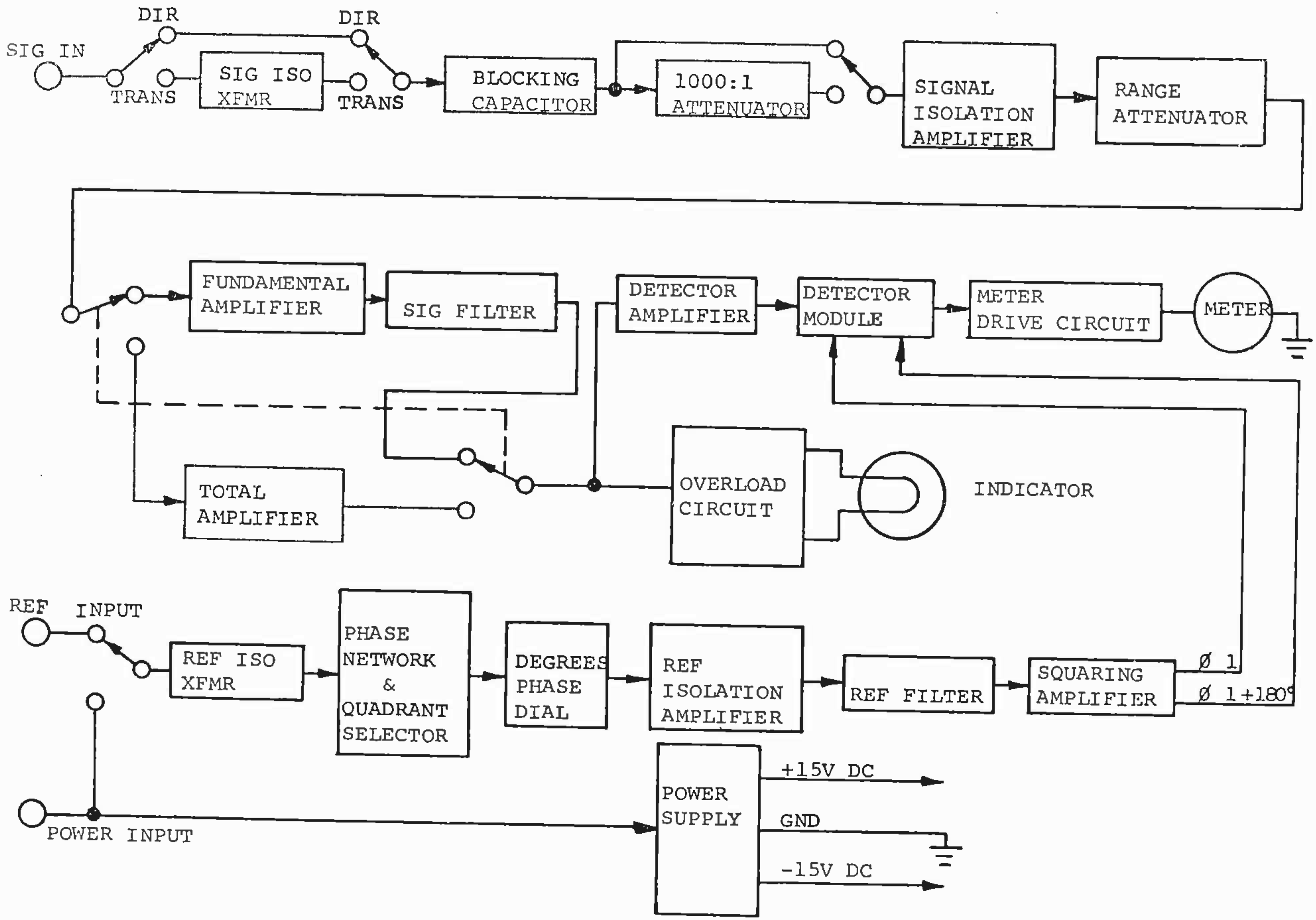


Figure 4.1 Phase Angle Voltmeter Model 213, Block Diagram

the meter to 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 30V 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.

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 (Figure 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 (Figure 4.2B), the average will be zero and no reading will result. The equation governing this is:

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

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 ($\theta = 90^\circ$) 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 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 5Hz (meter pass band).

The effect of reference harmonics is much less important 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.

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 effective values of a true sinusoidal voltage. Deviation from a true sinewave may cause errors in the meter

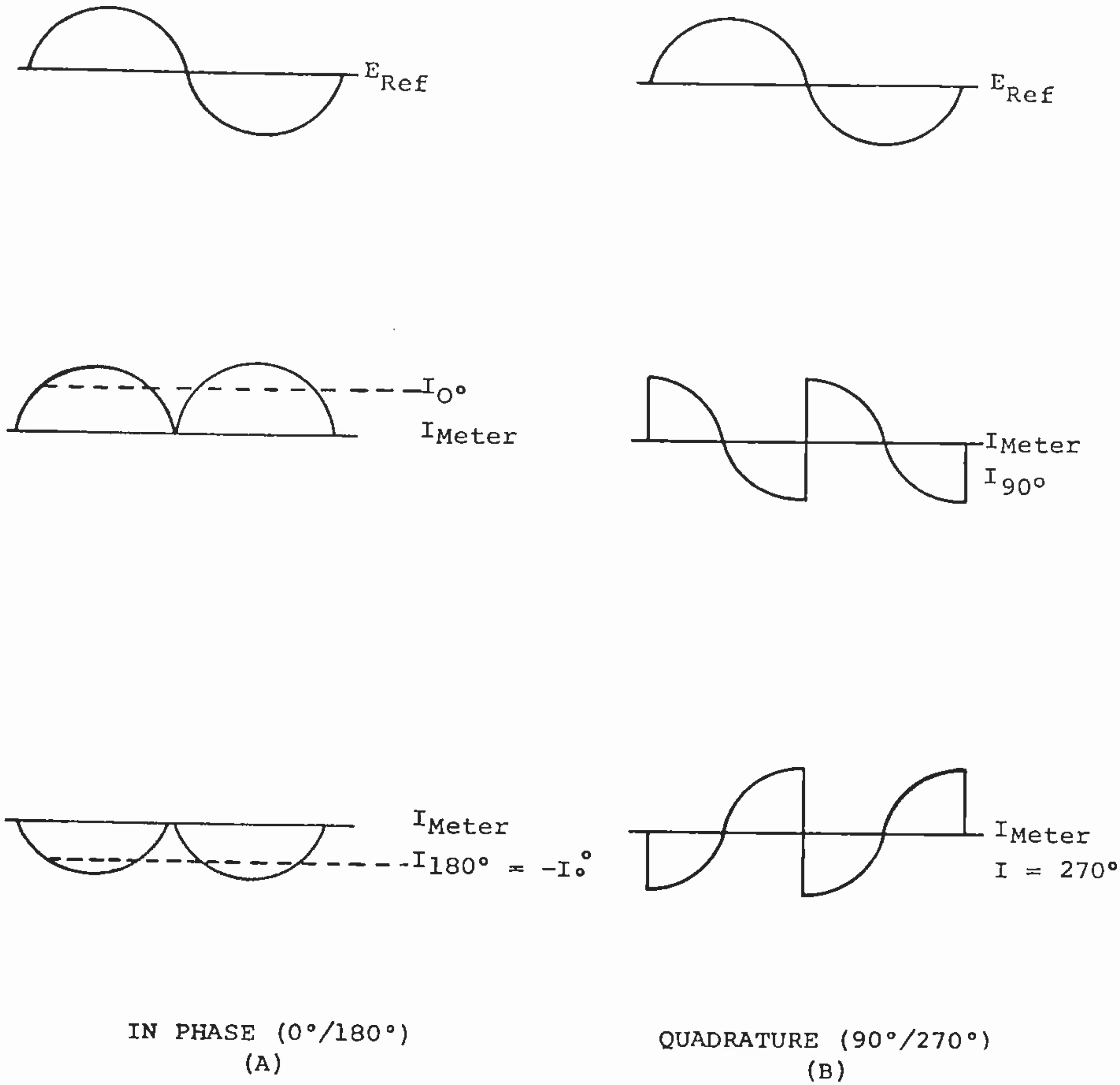


Figure 4.2 Phase Detector Waveforms

indication. Table I lists the range of possible errors due to the second and third harmonic distortion

Table I. 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%

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. (See Fig. 4.3)

The voltage E-R4 appears across the DEGREES Phase Dial potentiometer R4 between the taps, terminals 1 and 5. When $E/\underline{0^\circ}$ is set equal to $E/\underline{90^\circ}$, the electrical angle $E/\underline{\phi}$ is a non-linear function of the potentiometer shaft angle. This is compensated by a non-linear DEGREES Phase Dial. This function is described by the equation shown.

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 45Hz-440Hz, 115V/125V. An internal switch is provided for operation at 230V/250V. The AC voltage is full-wave rectified, filtered, and applied to Q1 and Q2 which provide a constant +15V and -15V DC output. CR5 and CR6 are 16V Zener diodes.

4.8 FILTERS.

The filters used are fifth order, 0.5DB, 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. 5.6 for these changes.

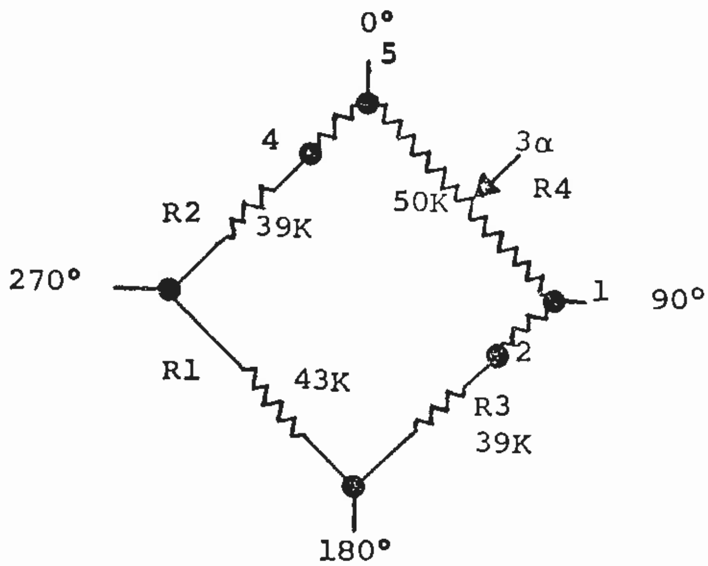
Note

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

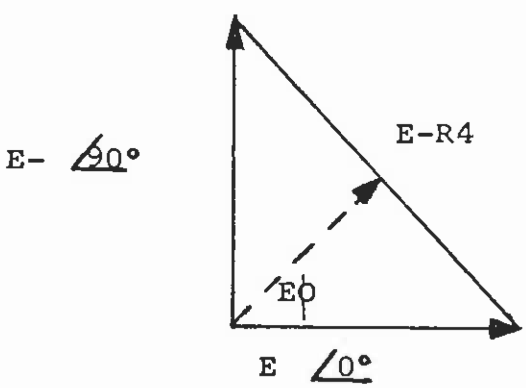
4.9 INPUT ISOLATION TRANSFORMERS.

Both Models 213B and 213C have a Reference Isolation Transformer in their 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.



PHASE SHIFT BRIDGE



$E\angle 0° = E\angle 90°$

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

ϕ = Electrical Phase Angle

θ = R4 Shaft Angle

Frequency in Hz

Figure 4.3 Voltage Vector at Phase Potentiometer

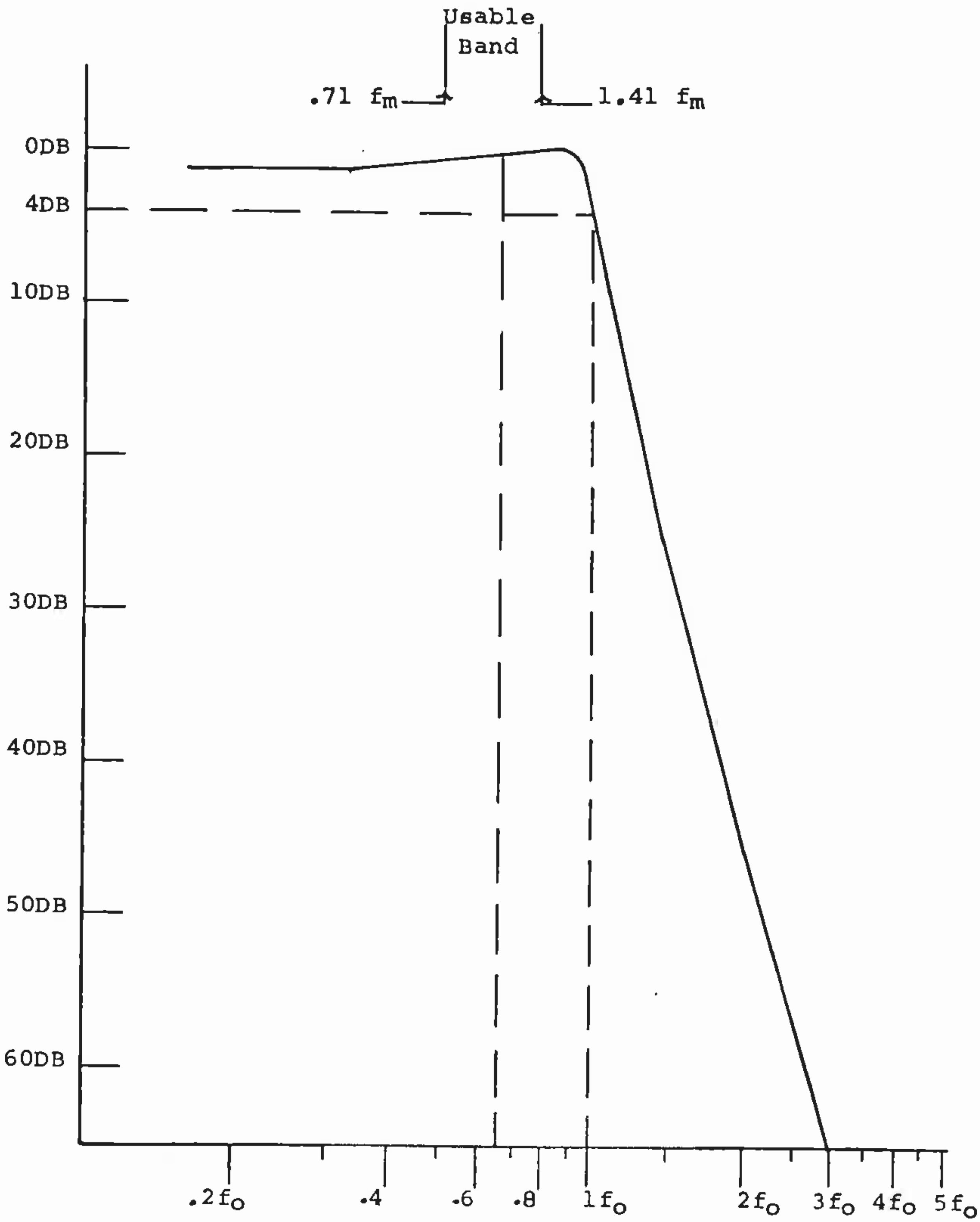
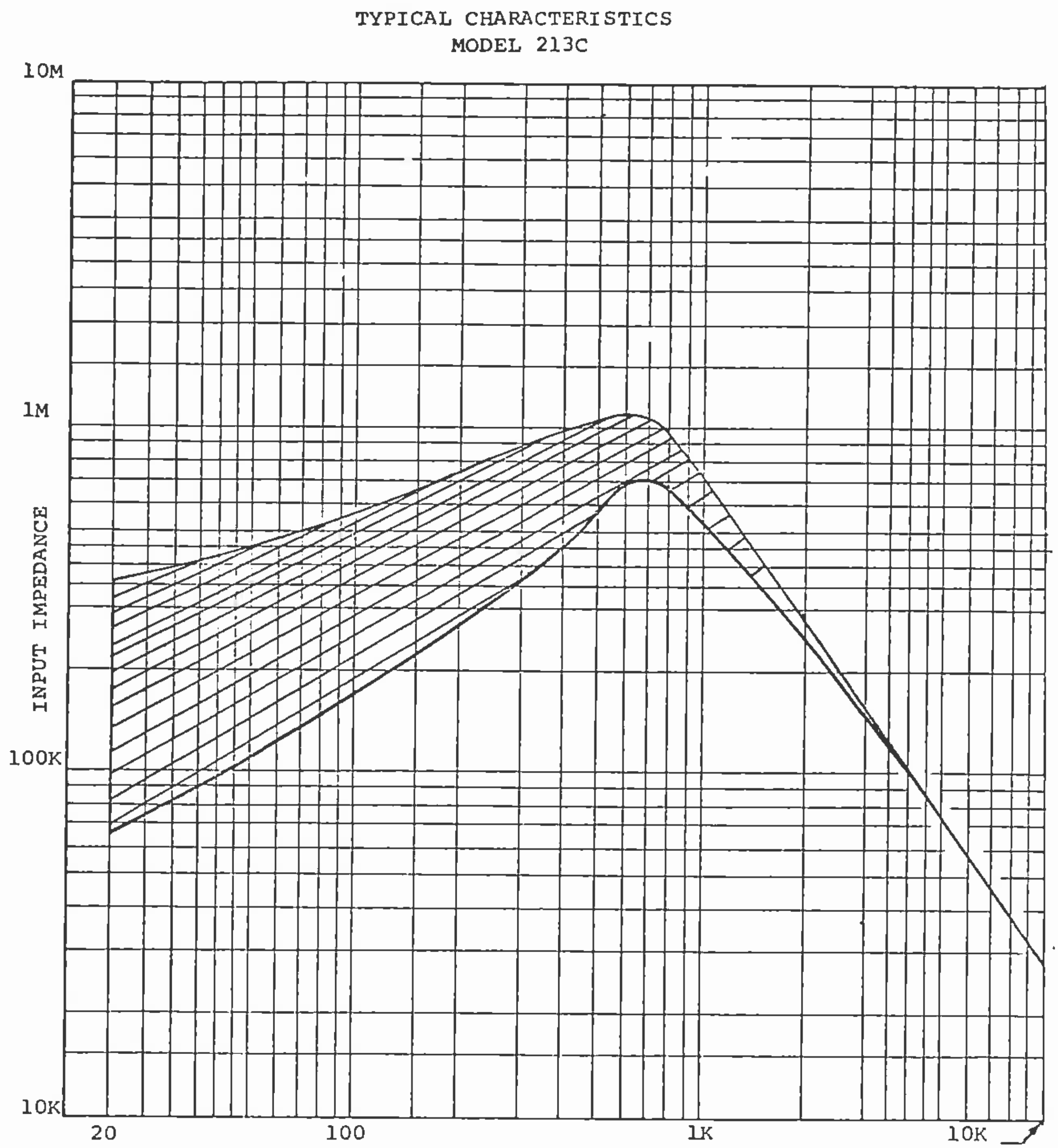


Figure 4.4 Typical Filter Characteristics



Frequency in Hz

Figure 4.5 Input Impedance vs. Frequency (Transformer Mode)