

Model 258

Volt-Ampere-Wattmeter

(Serial Nos. greater than 92,000)

(212) 255-2940

clarke·hess



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ABBREVIATIONS AND CONDENSATIONS USED IN THIS MANUAL

AC	Alternating Current
C	Capacitor
COM	Common
CR	Crystal Rectifier - Diode
D	Diode
DC	Direct Current
FS	Full Scale
(ftf)	(from the front)
HFC	High Frequency Clock
I	Current
IC	Integrated Circuit
LED	Light Emitting Diode
LFC	Low Frequency Clock
LL	Load Latch Pulse
NGT	Negative Going Transition
NP	Negative Polarity Pulse
PF	Power Factor
PGT	Positive Going Transition
PP	Positive Polarity Pulse
PROM	Programable Read Only Memory
Q	Transistor or Latch Output Signal
R	Resistor
S	Switch
V	Voltage
VA	Volt Amperes

WARRANTY

All CLARKE-HESS instruments are warranted against defects in materials and workmanship. This warranty applies for one year from the date of delivery of the instruments. The CLARKE-HESS Communication Research Corp. will repair or replace instruments that prove to be defective during the warranty period. For such repair or replacement, the instrument must be returned to us (See Section 5-0 for details) and must, in our opinion, not have been subjected to unreasonable usage or internal reworking. No other warranty is expressed or implied.

CLARKE-HESS assumes no liability for secondary charges or for consequential damages.

MODEL 258 V-A-W METER
TRUE RMS, WAVESHAPe INDEPENDENT CURRENT, VOLTAGE AND POWER MEASUREMENTS
50 Hz to above 1000 kHz

COMPLETE IEEE-488 PROGRAMING as a SELF CONTAINED OPTION

While the Model 258 may be equipped with a large assortment of input VOLTAGE and/or CURRENT ranges. The standard version is supplied with the following ranges.

VOLTAGE RANGES

FULL SCALE VOLTAGE	CALIBRATED RANGE	NORMAL RESOLUTION	EXPANDED RESOLUTION
20.00 V	2.00 - 40.00 V	10 mV	4 mV
100.0 V	10.0 - 200.0 V	100 mV	20 mV
200.0 V	20.0 - 400.0 V	100 mV	40 mV

CURRENT RANGES

FULL SCALE CURRENT	CALIBRATED RANGE	NORMAL RESOLUTION	EXPANDED RESOLUTION
50.00 mA	5.00 - 100.00mA	10 uA	10 uA
250.0 mA	25.0 - 500.0 mA	100 uA	50 uA
500.0 mA	50.0 - 1000 mA	100 uA	100 uA
2500 mA	250 - 5000 mA	1 mA	500 uA

POWER AND POWER X 10 RANGES

There are TWELVE Full Scale POWER ranges and TWELVE Full Scale POWER X 10 ranges. For the indicated VOLTAGE and CURRENT ranges the Full Scale values for POWER vary from 1.000 W to 500.0 W while for POWER X 10 they vary from 100.0 mW to 50.00 W. The "5000 digit expansion feature" will allow the Full Scale value of any range to be set to 5000 digits. This means that with expanded resolution on the 1.000 W range the available resolution is 0.2 mW while on the 100.0 mW range the expanded resolution is 20 uW.

VOLTAGE and CURRENT ACCURACY

All voltage ranges and all current ranges have identical frequency responses.

Accuracy : $\pm 0.5\%$ Rdg $\pm 0.5\%$ Range 50 Hz to 1000 kHz.
 $\pm 0.5\%$ Rdg $\pm 1.0\%$ Range 1000 kHz to 1500 kHz.

POWER or POWER X 10 ACCURACY for LOADS of ANY Power Factor.

50 Hz to 1000 kHz
 Accuracy : $\pm 0.75\%$ of input Volt-Ampere product $\pm 0.75\%$ of range

DESCRIPTION

The Model 258 is an AC coupled, broadband, waveshape independent and power factor independent, true RMS reading instrument. It has the same high accuracy for true average POWER readings from 50 Hz to 1000 kHz and the same high CURRENT and VOLTAGE accuracy from 50 Hz to 1000 kHz. Since the instrument is RMS reading all VOLTAGE and CURRENT readings are positive. POWER or POWER X 10 readings may be either positive or negative depending upon the circuit connections and upon the direction of current flow through the input CURRENT transformer.

The POWER X 10 position offers ten times the resolution of the POWER position. It may be employed when both the CURRENT and the VOLTAGE inputs are 40% or less of FULL SCALE. (30% with crest factors greater than four.)

As pointed out under "Wide Measurement Range" the Model 258 may be equipped with a large assortment of input VOLTAGE and/or CURRENT ranges. The standard version is supplied with the following ranges.

VOLTAGE RANGES

FULL SCALE VOLTAGE	CALIBRATED RANGE	NORMAL RESOLUTION	EXPANDED RESOLUTION
20.00 V	2.00 - 40.00 V	10 mV	4 mV
100.0 V	10.0 - 200.0 V	100 mV	20 mV
200.0 V	20.0 - 400.0 V	100 mV	40 mV

CURRENT RANGES

FULL SCALE CURRENT	CALIBRATED RANGE	NORMAL RESOLUTION	EXPANDED RESOLUTION
50.00 mA	5.00 - 100.00 mA	10 μ A	10 μ A
250.0 mA	25.0 - 500.0 mA	100 μ A	50 μ A
500.0 mA	50.0 - 1000 mA	100 μ A	100 μ A
2500 mA	250 - 5000 mA	1 mA	500 μ A

POWER AND POWER X 10 RANGES

There are TWELVE Full Scale POWER ranges and TWELVE Full Scale POWER X 10 ranges. For the indicated VOLTAGE and CURRENT ranges the Full Scale values for POWER vary from 1.000 W to 500.0 W while for POWER X 10 they vary from 100.0 mW to 50.00 W. The "5000 digit expansion feature" will allow the Full Scale value of any range to be set to 5000 digits. This means that with expanded resolution on the 1.000 W range the available resolution is 0.2 mW while on the 100.0 mW range the expanded resolution is 20 μ W.

ACCURACY and INPUT IMPEDANCE
VOLTAGE CHANNEL

Input Impedance: 1 Megohm and 7 pF.
All voltage ranges have identical frequency responses.
RMS values between one tenth and twice the nominal Full Scale Value

Accuracy: $\pm 0.5\%$ Rdg $\pm 0.5\%$ Range 50 Hz to 1000 kHz.
 $\pm 0.5\%$ Rdg $\pm 1.0\%$ Range 1000 kHz to 1500 kHz.

ACCURACY and REFLECTED IMPEDANCE
CURRENT CHANNEL

Input is via two broadband CURRENT transformer inputs. With the CT-411 transformer the reflected impedance is 0.2 milliohm for the ranges of 500.0 mA or higher. The reflected impedance increases for lower current ranges. With the CT411 transformer full scale ranges below 500.0 mA require multiple primary turns on the current transformer. Since the reflected impedance increases with the square of the turns ratio the reflected impedance with the 10 turns required for a full scale sensitivity of 50.00 mA is 100 times the 0.2 milliohms from a single turn or 20 milliohms.

Accuracy: Same as in the voltage case

POWER or POWER X 10 ACCURACY for
LOADS of ANY Power Factor

Accuracy: $\pm 0.75\%$ of input VA $\pm 0.75\%$ of range.
50 Hz to 1000 kHz

The -3 dB frequency for the CT-411 transformer is about 1 Hz therefore the CURRENT transformer will contribute about +0.6 degrees of current channel phase shift at 100 Hz. Less than 0.06 degrees of phase shift will result from the transformer above 1000 Hz. A 0.168 μ F series coupling capacitor is included in the input attenuator of the voltage channel to cause a 1 Hz breakpoint in the voltage channel also. This "phase matching" of the two channels allows reasonable low power factor power measurements to be made down to 50 Hz.

CREST FACTOR

(Ratio of peak input to Full Scale RMS value of the range.)

Greater than FOUR for all ranges and functions. (The highest VOLTAGE range may be further restricted by either dynamic range limits or an absolute peak limit of 900V.) Typical "excess peak error" is 0.1% for a Full Scale RMS pulsed waveshape having a crest factor of SIX.

DISPLAY

The Model 258 has a full four digit display made up of 10.9 mm (0.43 inch) high LED units mounted in sockets on a separate display board. A non-glare optical filter covers the display. Decimal point and full scale switching with functions and/or ranges is automatic. Four separate light emitting diodes indicate NEGATIVE power, OVERLOAD, MILLIWATTS, and F.S. = 5000. The display board is interchangeable WITHOUT changing the calibration status of the instrument. By using the leading zero suppression in conjunction with the "overload" lamp, the full scale equals 5000 digit position, and the twice full scale linearity of the Model 258 it is possible to make power readings of up to 19,999 digits (Current and Voltage each at twice full scale hence power at four times full scale.)

COMPUTER CONTROL-OPTICALLY
ISOLATED IEEE-488 BUS OPTION

An optically isolated IEEE-488 option is available which allows the Model 258 to function as both a TALKER and as a LISTENER. Thus the instrument may be both controlled as to FUNCTION and RANGE and may supply its DISPLAY reading for remote reading and/or calculation. Controlling software is simple and straightforward. (Option may be retrofitted.)

ISOLATED ANALOG OUTPUT

An optically isolated ANALOG is available. This circuit has a 1000 ohm output impedance. A full scale output on the Model 258 results in a 1.000V output from the ANALOG output. The output isolation is achieved by transmission of a pulse width modulated signal through an optical isolator and the subsequent demodulation of this signal. Up dating of the analog output occurs at a rate of ten pulses per second. Output from rear mounted, isolated BNC connector.

MEASUREMENT RATE/SETTLING TIME

The measurement rate of the Model 258 is normally set at 10 readings/sec (8.33/second for 50 Hz. operation).

The Model 258 is normally supplied so that it settles to within 0.5% of its final value within 1.3 seconds. At least a five to one reduction in this time is possible by reducing two filter capacitors from 10 μ F to 1 μ F. Such a reduction may lead to a slight increase in low frequency jitter.

DIMENSIONS and WEIGHT

Width: 290 mm (11.4 inches)
Height: 132 mm (5.2 inches)
Depth: 330 mm (13 inches)
Weight: 4.5 kg (10 lbs.)

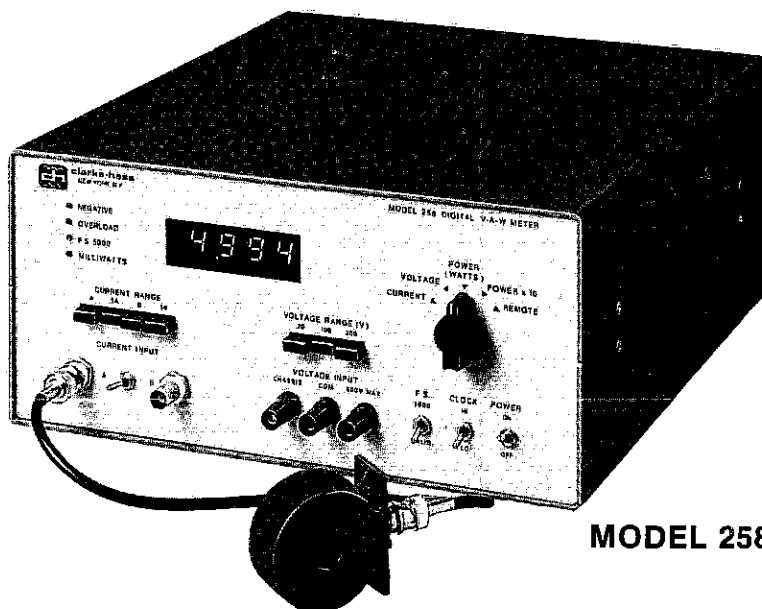
RACK MOUNT AVAILABLE

POWER REQUIREMENTS

95-105 V, 105-125 V or 210-250 V, 50-60 Hz. Less than 25 Volt-Amperes. Specify line voltage when ordering. Transformers are hard wired. Field modification requires soldering rather than changing a switch setting.

DIGITAL V-A-W METER

50 HERTZ—1 MEGAHERTZ



MODEL 258

WIDE RANGE OF TRUE AVERAGE POWER READINGS

The Model 258 V-A-W meter provides broadband true average POWER readings from below 100 Hz to above 1 Megahertz. These AC coupled power measurements are independent of frequency, waveshape distortion or load power factor. From 50 Hz to 1000 kHz the power accuracy is specified as $\pm 0.75\%$ of the RANGE $\pm 0.75\%$ of the input Volt-Ampere product. This accuracy specification is for loads of any power factor. For zero power factor loads these specifications are typically conservative by at least a factor of five.

TRUE RMS BROADBAND CURRENT AND VOLTAGE READINGS

True RMS, waveshape and distortion independent measurements of the VOLTAGE and CURRENT are possible between 50 Hz and 1500 kHz. Accuracy of the AC coupled inputs from 50 Hz to 1000 kHz are specified as $\pm 0.5\%$ of the range $\pm 0.5\%$ of the input. From 1000 kHz to 1500 kHz the error specification is increased by a factor of 1.5. Typical accuracy is $\pm 0.25\%$ from 50 Hz to 1500 kHz.

EXPANDED RESOLUTION

A front panel switch allows one to set the full scale value of any range to 5000 digits. Thus a 100.0 W range may be expanded by a factor of five to offer 20 mW resolution.

HIGH CREST FACTOR

Both the current input transformer and the instrument can deal with highly distorted AC inputs. Except for the highest voltage range, which may be peak limited, all ranges can deal with full scale inputs having CREST FACTORS of at least FOUR (typically SIX). A CREST FACTOR of SIX means that the instrument will deal with an input having a peak value of SIX times the nominal RMS value of the range without causing peak clipping. Again, with the sometime exception of the highest voltage range, each range will deal with sinusoidal inputs of at least TWICE the nominal value of the range. That is a 200.0 V sinusoidal input will be correctly measured on the 100.0V range.

WIDE MEASUREMENT RANGE

The Model 258 has three VOLTAGE, four CURRENT, twelve POWER and twelve POWER X 10 ranges. The voltage ranges may be modified at the factory for full scale values between 100.0 mV and 500.0 V. There is a 25/1 limitation to the ratio between the highest and the lowest voltage ranges in a given instrument. Thus 20.00 V and 500.0 V are possible while 10.00 V and 500 V are not possible in the same meter. Full scale current ranges from 50.00 mA to 50.00 A are possible. Power ranges are formed by the product of the voltage and current full scale values.

Special current input transformers may be supplied that offer greater sensitivity or clamp-on capabilities. There is normally a sacrifice of low frequency performance with such transformers.

WIDE CHOICE OF RANGES

Because all the decimal point and full scale information is kept in programable memories it is possible to provide CURRENT and VOLTAGE ranges in multiples of 1, 2, 2.5 or 5. Because POWER is the product of the VOLTAGE and CURRENT ranges a necessary restraint upon the possible combinations in a V-A-W meter is that the VOLT-AMPERE product must also be a multiple of these same numbers. Thus one can combine 250.0 mA with 10.00 V, or 20.00 V but not with 25.00 V or 50.00 V. To ease calibration difficulties the lowest voltage range should not exceed 25.00 V. A standard set of voltage and current ranges is listed on the other side of this page.

STRAIGHTFORWARD RESULTS IN PREVIOUSLY DIFFICULT MEASUREMENT SITUATIONS

The wide range and distortion handling capabilities of the Model 258 allow it to be used for measurements as diverse as ferrite core losses from 1 kHz to 1 MHz, high frequency lamp losses at 200 kHz, switching power losses in the PWM waveshape portion of a 150 kHz switching power supply, or RF power consumption in a 300 kHz induction heating system.

LOW CIRCUIT LOADING

The VOLTAGE input of the Model 258 has a normal input impedance of 1 Megohm in parallel with several pF. For CURRENT ranges equal or greater than 500.0 mA the impedance reflected in series with the load is 0.2 milliohms. For CURRENT ranges between 50.00 and 250.0 mA the reflected impedance is 20 milliohms.

IEEE-488 and ANALOG OPTIONS

The Model 258 may be equipped with an optically isolated analog output. An analog output of 1.000V corresponds to a full scale reading on the display for any function.

The Model 258 may be equipped with an optically isolated IEEE-488 card. This option allows collection of the data stored in the display as well as control of all functions, remote switching between all voltage ranges and remote switching between either pair of current ranges. (Special arrangements can be made to supply switching between all current ranges if required.) Readings are normally available via the bus at a rate of 10 per second.



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I. BASIC FEATURES, CONTROLS, AND OPERATION.

1-1. INTRODUCTION

The V-A-W Meter is a electronically sophisticated but easy to use solid state instrument. The meter is specified for POWER measurements from 50 Hz to 1000 kHz and for VOLTAGE and CURRENT from 50 Hz up to 1500 kHz. Within its frequency limitations the readings should be INDEPENDENT of WAVESHAPE or DISTORTION or POWER FACTOR.

This chapter of the Instruction Manual outlines the basic features of the instrument, the controls and terminals available on the instrument, and the configurations and connections necessary to make measurements with it.

Later chapters of the manual contain, information on current transformers, information on calibration equipment, the performance tests and calibration procedures, the theory of operation, repair procedures, the parts lists, and the set of schematic diagrams.

1-2. BASIC CONTROLS, INPUTS AND OUTPUTS.

The front panel CONTROLS for the Model 258 consist of the following:

The five position rotary FUNCTION SELECTOR switch.

The four CURRENT range pushbuttons.

The three VOLTAGE range pushbuttons.

The three toggle switches in the lower right hand corner.

The line power ON-OFF switch.

The CLOCK high/low switch.

The FULL SCALE 5000/Calibrated switch.

The front panel TERMINALS consist of the following:

The two black VOLTAGE input terminals.

The two BNC CURRENT input connectors

The single green CHASSIS connection.

The front panel OUTPUTS consist of the following:

The four digit DISPLAY.

The four indicator lamps.

NEGATIVE indicates that the POWER reading is negative.
(Because of the TRUE RMS nature of the VOLTAGE and
CURRENT readings they are always POSITIVE.)

OVERLOAD indicates that the output reading exceeds 1.5 times full scale hence the user should check that the operating controls are properly set. Readings are often VALID with this lamp lit.

F.S. 5000 indicates that the FULL SCALE 5000 switch is on.

MILLIWATTS indicates that the DISPLAY reading is MILLIwatts rather than watts.

* * * * *

The REAR panel of the instrument contains the following:

The line cord receptacle.

The 0.5 Ampere line power input fuse.

The output opening for the IEEE-488 or BCD/REMOTE options.

The output for the ANALOG option.(Only present if option is installed)

1-3. SPECIAL FEATURES

This section provides a brief introduction to several of the special features of the Model 258. This material should allow the user to avoid some apparent problems in their initial measurements with the meter.

POLARITY

The POLARITY indicator is only useful in the POWER or POWER X 10 cases. (Power flow may be in either direction while TRUE RMS voltage and current readings are always positive.) In the Model 258 reversing the direction of the passage of the current through the primary of the CURRENT TRANSFORMER will always reverse the sign of the POWER reading. If there is any initial doubt about the sign of the POWER reading then adding a resistor in parallel (or in series) with the load will resolve the question. For positive POWER the reading will increase. Negative POWER readings are still covered by the accuracy specifications.

FLASHING DISPLAY

Another aspect of the TRUE RMS operation is that the dynamic range of the squared signals is much greater than the range of the input quantities. That is a 30/1 range of input voltage leads to an internal signal variation of 900/1. This means that with an applied signal of 1/30 th of the full scale input the internal signal level - before the square root is taken - will only be (1/900)th as large as it would have been in the full scale case. As one might expect this large dynamic range will eventually lead to noise or jitter at low inputs. For VOLTAGE and CURRENT readings below 7% of the nominal full scale values the DISPLAY has been programed to FLASH rather than to provide a steady reading as it does in all cases for POWER or POWER x10. This FLASHING operation is normal it merely indicates that one has either no input or a very small input coupled with a CURRENT or VOLTAGE setting of the FUNCTION switch.

DISPLAY READING WITH NO INPUT.

Both a CURRENT and a VOLTAGE pushbutton should always be depressed. With no button activated one of the input amplifiers is left with an open circuited input and the DISPLAY reading may be both large and uncertain.

FULL SCALE: 5000/Calibrated Switch.

In order to provide the user with greater resolution on any range in which the nominal full scale value is not 5000 digits this switch allows the nominal FULL SCALE on any range to be increased to 5000 digits. The F.S = 5000 lamp should always indicate that this switch is in its 5000 position. Thus with a 10.00 volt input on the 20 V range and this switch in the 5000 position the reading should be 25.00, while with a 34.00 V input on the same scale the reading should be 85.00. Throwing this switch when the meter has a 100.0 watt input will change the display reading to 500.0. With the IEEE-488 bus option the serial poll indicates the position of this switch.

"FIVE DIGIT" OPERATION

V-A-W meter readings of up to 10,000 digits in VOLTAGE and CURRENT and of up to 20,000 digits in POWER are possible. This is true since, within the CREST FACTOR limitations, the linearity of the V-A-W meter circuitry allows both the VOLTAGE and the CURRENT channels to handle inputs of twice their nominal values. In cases of near unity power factor this will allow valid POWER readings of near 20,000 digits. (These readings require that the F.S. = 5000 switch be in the "5000" position.)

To interpret these readings one must note that the left most digit in the display is "blanked" when it is zero and that the OVERLOAD lamp comes on at about 1.5 times full scale. Because of the linearity a POWER reading of 205.0 watts is possible on the "CALIB." position of a nominal 100 watt range. If the "5000/CALIB" switch is moved to "5000" then the reading will become 25.0 with

the left hand digit blanked and the OVERLOAD LAMP ON. This reading is interpreted as being 10250 digits which is 5 X 205.0 watts. If the input is increased to 230.0 watts then the display reading will become 150.0. Unexpectedly LOW display readings should always lead one to check the position of the 5000/Calib. switch.

POWER x 10

Since reducing the VOLTAGE and the CURRENT each by a factor of three reduces the POWER resulting from their product by a factor of nine the POWER-X-10 function allows one to get reasonable power readings in these "down scale" conditions. Whenever possible one should stay as far "up scale" as possible. Thus with a 24 V and a 70 mA set of inputs (assuming that the V-A-W meter has minimum ranges of 20 V and 50 mA) one should use the 20 V and the 50 mA ranges together with the POWER function instead of the 100 V and the 250 mA ranges together with the POWER-X-10 ranges. However with a 7 volt input and a 15 mA input for a unity power factor case one would only get a .105 watt reading on POWER while on POWER-X-10 the reading should be 105.0 mW. In general BOTH the VOLTAGE and the CURRENT should be at or below 40% of the nominal full scale value of a range before one uses the POWER-X-10 function. (With inputs with large CREST FACTORS one may have to reduce this limit further.)

CLOCK : High/Low Switch.

In order to provide its flat response from near DC to above 1000 kHz the V-A-W meter uses several circuit techniques that are discussed in Chapter VI. In all but one case these manipulations are completely "invisible" to the user. The CLOCK High/Low switch is provided as an escape from this special case. There is an internal chopping process at about 1670 Hz (LOW) or 1740 Hz (High). If one operates at a frequency within several Hertz of this frequency, or of its odd harmonics, then jitter or beats may occur in the output display. Switching the CLOCK "HI/LO" switch to the other position will shift the internal chopping frequency by about 68 Hertz and the beats should disappear.

A C Coupling

The input of the CURRENT channel is AC coupled via the input current transformer. (The paint on the current transformer should NOT be counted on as voltage insulation.) The input of the VOLTAGE channel is AC coupled via an internal coupling capacitor in series with a 1 Megohm resistor. The capacitor has a DC blocking capability of 100 V. Large DC, or very low frequency inputs above 70 V RMS may require an additional EXTERNAL blocking capacitor. From the theoretical discussion in Chapter III it will be apparent that this external capacitor should have a capacitance value exceeding 0.25 uF if the low frequency channel matching with respect to phase is not to be disturbed.

II. OPERATION

2-1. CONDENSED OPERATING INSTRUCTIONS - GENERAL

This chapter outlines the procedures for making measurements of VOLTAGE, CURRENT, and POWER with the Model 258 Digital V-A-W Meter. In addition it points out some of the possible pitfalls in making such measurements.

The V-A-W Meter contains only one fuse which is the general power supply fuse that is located on the rear panel near the line cord receptacle. This rear panel fuse has a $\frac{1}{2}$ Ampere rating for 100 V or 115 V line operation and a $\frac{1}{2}$ Ampere rating for 230 V or 240 V line operation. The Model 258 V-A-W Meter is supplied for operation from 50/60 Hertz power lines.

The V-A-W Meter has an INTERNAL CONNECTION between the COMMON VOLTAGE lead and the outside connector of the BNC CURRENT inputs. Connections to the instrument should be made so that NO EXTERNAL CURRENTS ARE CAUSED TO FLOW THROUGH THIS CONNECTION. That is the current transformer shell should be insulated from its primary winding.

The COMMON terminal should be connected to the "low" side of the circuit under test. To avoid unwanted capacitive coupling into the V-A-W meter via its external shield the CURRENT TRANSFORMER should also be placed on the "low" side of the load.

The Model 258 V-A-W Meter reads AC coupled VOLTAGE and CURRENT in a true RMS fashion. Since the ROOT MEAN SQUARE operation involves squaring then taking the square root a 31.6 to 1 range in the voltage or current being measured leads to a 1000 to 1 variation of certain of the voltages internal to the instrument. Each range should make accurate measurements of inputs that have a 40 to 1 range, that is from 2 times the nominal FULL SCALE value down to 1/20 th of the nominal FULL SCALE value. At 1/20 th of FULL SCALE a jitter term of ± 1 digit is normal. In general one is always better off making readings as far "up scale" as possible. The typical CREST FACTOR of SIX of the V-A-W meter allows one to stay "up scale" even with waveshapes that have pronounced spikes or peaks.

With no input the V-A-W meter should normally read 000. (The left hand zero is blanked when not in use.) The ZERO should be checked in the POWER position since very low values of voltage or current may have jitter. The display for VOLTAGE and CURRENT is "flashed" for reading below 1/20th of full scale to remind one that one is really reading off the calibrated area of the scale.

2-2. CONDENSED OPERATING INSTRUCTIONS - VOLTAGE.

To make a VOLTAGE measurement.

- (a) Place the FUNCTION selector switch on VOLTAGE.
- (b) Push in the appropriate one of the VOLTAGE RANGE selector buttons. The 20 V range is generally usable for sine waves up to 40 V RMS, the 100 V range is generally usable to 200 V RMS and the 200 V range is usable to 400 V RMS.
- (c) Connect the desired voltage between the VOLTAGE COMMON (the low side of the voltage to be measured) and the right hand VOLTAGE terminal.
- (d) Read the DISPLAY.
- (e) Since the Model 258 is AC coupled it will NOT read DC voltages. For AC voltages the meter reads the TRUE RMS values of the voltage. (The low frequency -3dB frequency for the VOLTAGE channel of the Model 258 is about 1 Hz. The high frequency -3dB frequency is above 5 MHz.)

NOTE: The left hand VOLTAGE terminal (green) connects directly to the metal case of the V-A-W Meter.

NOTE: The input to the HIGH side of the VOLTAGE input of an instrument with voltage ranges of 20,100, and 200 V is equivalent to a capacitor of 15pF. Other voltage range combinations may require different values of input capacitance.

2-4 CONDENSED OPERATION INSTRUCTIONS - CURRENT

To make a CURRENT measurement.

- (a) Place the FUNCTION switch on CURRENT.
- (b) Push in the desired CURRENT RANGE selector button. Again each of the ranges may be used up to 2 times its nominal FULL SCALE value. As in the voltage case one should always try to keep the readings as far up scale as possible.
- (c) Connect the load so that the CURRENT to be measured flows through the primary of the current transformer that is connected to the appropriate BNC connector.
- (d) Read the DISPLAY.

LOSS IN THE CURRENT PATH

From the viewpoint of the circuit being measured the V-A-W Meter CURRENT input imposes a series impedance that varies with the TRANSFORMER selected and with the internal transformer termination supplied by the V-A-W meter. The table below indicates the coupled impedance for the current transformer/termination combinations that are normally supplied.

TRANSFORMER	Coupled Impedance	Assumed	V-A-W Termination
CT-411 Single Turn	0.2 milliohm	30 kohm	
CT-411 Ten Turns	20.0 milliohm	30 kohm	

2-5. CONDENSED OPERATING INSTRUCTIONS - POWER

To make a POWER measurement one must set the FUNCTION selector switch on POWER, connect the voltage input, let the load current flow through the appropriate current transformer and depress the appropriate RANGE selector buttons.

There are several possible configurations with respect to POWER. The sign may be either positive or negative depending upon the direction of POWER flow. Reversing the flow through the current transformer will always reverse the sign. Depending upon whether the VOLTAGE leads are connected "inside" or "outside" the CURRENT transformer will determine whether the VOLTAGE input impedance or the coupled loss from the transformer is included in the measured POWER.

2-5. CONDENSED OPERATION INSTRUCTIONS - POWER x 10

The connections and operation of the meter are identical for the POWER and for the POWER x 10 cases. When both the CURRENT and the VOLTAGE are at or below 40% of their nominal full scale values then the POWER x 10 FUNCTION will provide an extra digit of resolution and accuracy for power readings.

2-6. POSITION OF CLOCK "HI/LO" SWITCH.

Unless one is attempting to measure a frequency that falls almost on top of the internal chopping frequency the position of this switch should not matter. If one has any question about its possible effect one should throw it back and forth and note that the two readings are the same. In the LO position the nominal chopping frequency is 1665 Hz while in the HI position it is about 1733 Hz. If beats or jitter occur in one position then the reading in the other position is the correct one.

III. CURRENT TRANSFORMERS AND CAPACITIVE ATTENUATORS

The Model 258 V-A-W meter uses a broadband current transformer as the input to its CURRENT channel. Therefore the proper use and calibration of the instrument requires an understanding of the properties and limitations of these devices.

Unless the proper precautions are observed the low frequency amplitude and phase performance of the V-A-W meter could be completely dominated by the characteristics of the current transformer that is used as the input device.

A conventional 100/1 current transformer consists of a one turn primary and a 100 turn secondary winding on a laminated iron core. If there is neither flux leakage nor any losses then the ampere-turns in the primary equals the ampere turns in the secondary so that a one ampere primary current produces a 10 mA secondary current. While such transformers suffice for the measurement of single frequency currents with analog meters they are often unsatisfactory when any one or more of the following properties matters: distortion, wide dynamic range, phase shift, or frequency response. Since all of these properties are likely to be important in most of the cases where a broadband V-A-W meter is employed such classic current transformers are usually inadequate as the current input device for a broadband V-A-W meter.

3-1 LOW FREQUENCY RESPONSE- LINEAR CASE.

In dealing with a current transformer, as with most other practical devices, one can not ever take anything for granted. Since there is an iron core one can not be sure that that phase shift and frequency response characteristics will not be at least partially level sensitive. In fact in all available devices they are. For the moment we ignore these effects and consider only the case where the device may be considered as linear and level independent.

From the linear viewpoint one can model the secondary of a transformer and that works into a resistive load by the circuit shown in Figure III-1.

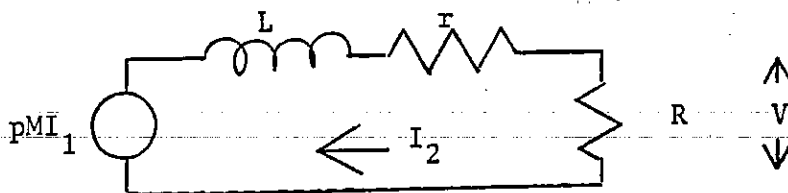


Figure III-1 Model for the secondary of a current transformer.

In Fig. III-1 M is the mutual inductance, L is the secondary inductance, r is the winding resistance of the secondary, and R is the load resistance. If one writes an expression for the secondary current then if R is a true resistance the voltage across the load will be a true representative of this current.

If one uses the operational notation $p=j\omega$ then:

$$V_2 = I_2 R = \frac{(I_1 R) (pM/L)}{p + [(r + R)/L]} \quad (\text{III-1})$$

At a high enough frequency the p terms will dominate and the output voltage will be independent of frequency. When $\omega L = (r + R)$ then the amplitude will be reduced to 0.707 of the high frequency value and will be shifted in phase by 45 degrees. If W is defined as $(r + R)/L$ then one can tabulate the relative amplitude and phase shifts as a function of the ratio of the actual radian frequency, ω , to the -3 dB radian frequency, W .

Table III-1

ω / W	Amplitude/ A	Phase Shift in degrees
1.00	0.707	45.0
3.16	0.953	17.7
10.00	0.9950	5.71
31.62	0.9995	1.81
100.00	0.99995	0.57
1000.00	0.999999	0.057

3-1-1 LOW FREQUENCY PHASE SHIFT ERROR TERMS - LINEAR CASE.

From Table III-1 we see that by ten times the break frequency the maximum amplitude error that one can expect is 0.5%, while by 31.6 times the -3dB break frequency the maximum amplitude error is 0.05%. Thus if one is attempting to measure CURRENT the transformer should be invisible by thirty times the break frequency. On the other hand if one is attempting to measure POWER, particularly in a low power factor case, then the phase shift becomes a much more serious problem.

As one can see from the data in this Table as one increases the frequency above the -3dB point the amplitude error decreases quadratically while the phase error only falls off linearly. Thus even at 100 times the break frequency one still has a phase angle from the transformer of 0.57 degrees or 1/100 of a radian. This much phase shift means that if one tries to measure the power in a zero power factor load one will get a reading of 1% of the input VOLT-AMPERES from the phase shift term even if the measurement frequency is 100 times the break frequency of the transformer. Thus a current transformer with a 1kHz break frequency will still be giving measurement problems with low power factor loads at frequencies as high as 200 kHz.

The Model CT-411 used with the Model 258 has a -3dB break frequency below 1 Hz hence the lowest frequency at which one would expect an error of 1% of the input volt-amperes product, even for a zero power factor load, would be above 100 Hz.

In the V-A-W meter the crucial thing is THE PHASE SHIFT BETWEEN THE VOLTAGE CHANNEL AND THE CURRENT CHANNEL rather than the phase shift of either channel. Therefore one can reduce the effect of the current channel phase shift by introducing a deliberate but equal phase shift in the voltage channel. By adding the proper R-C combination in the input of the voltage channel one can trade the introduction of an additional 0.5% amplitude error in the voltage channel at ten times the -3dB frequency for at least a ten to one reduction in the phase error at this and all higher frequencies. (Even if the phase matching between the channels is off by 10% one will still have a ten to one reduction in the differential phase error.)

In the present versions of the Model 258 the VOLTAGE input attenuator is capacitive. In this case the proper choice of a shunt resistor allows the phase matching of the two channels.

3-1-2 CHANNEL PHASE SHIFT IN WATTMETERS.

To see the general significance of the phase shift between channels one can consider the operation of any wattmeter in connection with a general linear load.

At any single frequency one can model any linear load as the combination of a series resistor (the loss term) and a series reactance (the energy storage term). To be specific let us assume that the reactance term is inductive. As we shall see the final result is just as valid for the capacitive case. Again the same general result may be obtained by assuming either a current or a voltage drive. To be specific we assume a driving current with the value $i(t) = I \sin(\omega t)$. This current results in a load voltage, $v(t)$

$$v(t) = (I r) \sin(\omega t) + I(\omega L) \cos(\omega t) \quad (\text{III-2})$$

Now we assume that the combination of the wattmeter and its voltage or current sensing elements are not perfect with respect to internal phase shifts. For convenience we lump all of these phase shifts into one total differential phase angle, θ . When this phase shift is included then from the viewpoint of the circuit we may consider that the internal current term that is going to be multiplied by the voltage to produce the instantaneous power may be represented by the new variable $i(t)_3$:

$$i(t)_3 = I \sin(\omega t) \cos \theta + I \cos(\omega t) \sin \theta \quad (\text{III-3})$$

When the multiplier in the wattmeter has formed the product of the voltage and the current terms and the "DC" terms that are proportional to the average power are extracted and the the definition for I is changed from peak to RMS then the average power read by the properly calibrated wattmeter will be equal to:

$$P = I^2 r \cos \theta + I^2 (wL) \sin \theta \quad (\text{III-4})$$

Now if theta is small then $\cos \theta$ may be approximated by one and the $I^2 r$ term will be the "correct" result for the power dissipated in the load and that the second term will be an error term. From Table III-1 we see that if we are at 31 times the break frequency then the $\cos \theta$ term will be within 0.05% of unity for both the current and the voltage hence should not be worse than 0.1% in the power term and may reasonably be neglected. In the same frequency region it is a very good approximation to replace the $\sin \theta$ term by the angle in radians. (In this case theta is the DIFFERENCE between the current and the voltage phase shift terms.) When this is done the expression for power may be written as:

$$P = I^2 r (1 + Q \theta) \quad (\text{III-5})$$

where Q is the ratio of the load reactance to the load resistance. This expression is just as correct for the capacitive load case if the proper expression, that is $Q = 1/(wCr)$, is used for Q in that case.

One may write an analogous expression for the case where one uses a parallel loss, R, and a parallel reactance term to model the load. In this case it is usually more convenient to assume a voltage drive. The resulting expression for the average power is: (Now Q equals the ratio of resistance to reactance.)

$$P = V^2 G (1 + Q \theta) \quad \text{where } G = 1/R \quad (\text{III-6})$$

These last two expressions turn out to be very useful in understanding the limitations of wattmeters in general.

The first general observation that may be drawn is that the importance of the differential phase shift term, θ , is directly related to the Q of the load being measured. Thus in the case of a purely resistive load the phase shift error term disappears.

On the other hand if $Q=100$, which corresponds to a POWER FACTOR of 0.01, then a differential phase angle of 1 milliradian (0.057 degree) will lead to an error of 10% of the reading. (Since the reading in this case should only be 1% of the input volt ampere product the error in terms of the volt ampere product will only be 0.01%) If one has achieved an input break point matching within 10% in the two channels, and IF ALL THE OTHER CHANNEL MATCHING IS PERFECT, then this much error would occur at 100 Hz.

3-1-3 MEASUREMENT AND/OR CORRECTION OF ERROR TERMS.

In attempting to use or to calibrate a V-A-W meter at low frequencies with low power factor loads then one must bear the PHASE SHIFT "error" term in mind. If one wishes to use a different CURRENT transformer as an input then one must give serious consideration to the properties of the new transformer.

Table III-2 indicates the -3 dB frequency, in Hertz, and the maximum current full scale display available from several of the transformers that might be considered for use with the Model 258.

TABLE III-2

Device designation	-3dB Frequency assuming a 50 ohm termination (except for CT-411)	Max. Sensitivity Single Turn V-A-W
CT-411	1 Hz	500.0 mA
Ion Physics CM-100-M	1200 Hz	50.00 mA
Ion Physics CM-10-M	60 Hz	500.0 mA
P6022 (Sensitive Position)	8500 Hz (Ext.Term.)	50.00 mA
P6022 (Less Sensitive Position)	935 Hz (Ext.Term.)	500.0 mA
P6022 (Direct - No Ext.Term.)	4000 Hz	50.00 mA

If any of the transformers, other than the CT-411, are to be used with the Model 258 then the addition of shunt resistance in the voltage box of a Model 258 with a capacitive voltage attenuator will allow one to increase the frequency of the pole in the voltage channel to match the break frequency of the transformer. (In a unit with a resistive input attenuator one can use an external coupling capacitor to achieve the same result.) Without such a correction the frequency at which low power factor errors equal the desired reading may be near the upper frequency limit of the Model 258.

Low frequency phase errors may be measured by using a "known" low loss load or a calibrator with a known value of phase shift between the voltage and the current channels. As an example of the low loss load case let us assume that one has a 5 uF, polypropylene capacitor that has a value of $Q = 2,000$ at 80 Hz. Now at 80 Hz the reactance of this capacitor will be 400 ohms hence with a 20 V drive the resultant current will be about 50 mA. The resultant I^2r term will 0.5 milliwatt, hence in the 5000 digit expansion position of the Model 258 the ideal reading, assuming a 50 mA and a 20 V set of ranges for the V-A-W meter, will be between 2 and 3 digits. Any actual reading on the V-A-W meter for this input, with this load, of between 0 and 6 digits indicates that the overall differential phase shift between the two channels is less than 0.5 milliradian or 0.0286 degrees.

3-1-4 LOAD POWER FACTOR CORRECTION OR "TUNING"

As we saw in Eq. III-5 the effect of differential phase shift errors in a wattmeter depend directly upon the Q of the load being measured. Thus if one can reduce the Q of the load one can reduce the importance of channel phase mismatching. A way to do this with an inductive load is to "tune" the load with a low loss capacitance so that from the viewpoint of both the generator and of the wattmeter the resultant load is closer to a purely resistive one.

From the viewpoint of the generator one can view this operation as one of "matching" whereby a series capacitive element lowers the overall impedance seen by the generator and raises the voltage available to the load, while a parallel capacitive element raises the overall impedance seen by the generator and raises the current available to the load. In measuring a ferrite core over a range of frequencies parallel matching may be appropriate at low frequencies while series matching is required at high frequencies.

If the losses in the added capacitive element are either small with respect to those of the element under test, or if they are known separately, then by making the wattmeter measurements of the composite load instead of the inductive portion alone one may be able to reduce the effective Q term to less than 5 or 10% of the original value. Such a reduction will reduce the effect of any differential phase shift error by a factor of 10 to 20.

3-2 LOW FREQUENCY RESPONSE - NON LINEAR

In addition to the linear low frequency problems caused by the interaction of resistance and inductance the fact that the transformer has an iron core causes the possibility that the phase shift and the frequency response characteristics will be at least partially level sensitive. In addition to such shifts there may be either gradual or sharp distortions in the output waveshapes as the frequency is reduced.

The type of low frequency distortion that occurs will depend upon the type of iron used in the transformer core and to some extent upon the construction technique employed in assembling the device. In some devices, such as the CT 411 transformer, a sharp distortion will occur at some low enough frequency that the integral of the ampere-turns over a half cycle causes core "saturation" and hence distortion. In other devices such as the Ion Physics or Tektronix units, the distortion is more gradual but just as real. This distortion means that even the best current transformers may have a number of different low frequency limitations.

Allowing any appreciable DC to pass through the transformer reduces the size of the AC signal that will cause distortion.

One can not make a general statement as to which low frequency limit will occur first. In fact both a fall off and phase shift from the "linear" network elements and distortion may occur at the same time. If a transformer

is to be used within factor of TWO of its nominal lower frequency breakpoint then caution indicates that one should examine its output on an oscilloscope while it is excited with the waveshape in question and while it is loaded with the expected terminating resistor. Since "saturation distortion" is both level sensitive and frequency sensitive one needs to make this examination under the expected measuring conditions.

TABLE III-3
Onset of Low Frequency Core Saturation Distortion

Device Designation	Maximum Value over a half cycle for the integral of $i(t)$ with respect to time. Ampere-seconds
CT-411	0.19 A-s
ION PHYSICS (CM-100-M)	0.0005 A-s
ION PHYSICS (CM-10-M)	0.01 A-s
ION PHYSICS CM-1-L	0.70 A-s
TEKTRONIX P6022	9. A-microsecond

It is believed that any of the devices listed in Table III-3 have, except for the onset of low frequency distortion and assuming that one stays above at least twice the -3dB break frequency, both amplitude and phase characteristics that are reasonably independent of amplitude. This statement can NOT be made for the run-of-the-mill current transformer.

3-3-1 HIGH FREQUENCY AMPLITUDE PERFORMANCE

The transformers supplied with the V-A-W meter will almost never impose a high frequency limit upon the system. Rise times of 10 nanoseconds and upper -3dB frequencies of 25-35 MHz or more are common. Again such performance can not be assumed for the ordinary current transformer that may be constructed of such low grade steel that it exhibits excessive loss by 200, 400, or 1000 Hz.

3-3-2 HIGH FREQUENCY PHASE PERFORMANCE

While the transformer itself does not generally present a phase problem at high frequencies the DELAY associated with the cable connecting the current transformer to the V-A-W may pose such a problem. At 1000 kHz (1 MHz) an additional length of 30.5 cm (12 inches) of RG-58A/U cable will have the effect of adding about 1% of the input volt-ampere product to the output power reading in low power factor measurements. This effect is linear with frequency so that at 100 kHz the effect will only be one tenth as large. However if one is trying to make calibrated power measurements at high frequencies in low power factor situations then one MUST NOT CHANGE CABLE LENGTH IN MID-STREAM. The instrument is normally supplied and calibrated with a 61 cm (24 inch) cable to connect the current transformer to the instrument.

In general changing the length of the voltage leads is much less critical since their high terminating impedance prevents appreciable phase shifts in them.

3-4 PEAK CURRENT OR CREST FACTOR LIMITATIONS

As long as the low frequency distortion limitations are avoided the transformers supplied with the V-A-W meter usually have peak current carrying abilities at least 1000 times their RMS rating hence they almost never impose any peak or crest factor current limits.

3-5 REFLECTED LOADS INTO THE CIRCUIT BEING MEASURED

In the case of an ideal current transformer one reflects the sum of the load and the secondary winding resistance through the square of the turns ratio to find the effective series resistance placed into the primary circuit. As a practical matter the devices supplied with the V-A-W meter may have a different effective turns ratio from the load viewpoint and from the current reduction viewpoint. In addition an internal load may have to be considered when figuring the reflected loss. Table III-4 indicates the reflected loss terms to be expected from some of the current transformers that could be used with the Model 258.

TABLE III-4

Device	Reflected Load assuming a 50 ohm load. (except for the CT-400)
CT-411 (Single Turn)	0.2 milliohm
CT-411 (Ten Turn Primary)	20 milliohm
ION PHYSICS (CM-100-M)	22.6 milliohm
ION PHYSICS (CM-10-M)	0.57milliohm
ION PHYSICS CM-1-L	0.53milliohm
P-6022(either position)(Ext.Term.)	30. milliohm

3-6 CAPACITIVE ATTENUATORS

It can be shown that most of the quantities of interest about a capacitor or inductor can be derived from measurements of the current, voltage, and power passing through it or into it. If one assumes that the current is sensed with a broad band current transformer then one should sense the voltage in a manner that both matches the low frequency amplitude and phase characteristics of the current transformer and that causes minimal loading of the test circuit. (The current transformer used with most Clarke-Hess V-A-W Meters has a low frequency response that may be represented by a zero at the origin and a pole at about 1Hz.)

While inductive voltage dividers are used as very accurate voltage dividers over narrow ranges of frequency no commercial units are known that will deal with the 4-5 decades of frequency that are required by the broadband V-A-W meter. (What is required over this whole frequency range is amplitude flatness within $\pm 0.1\%$ or $\pm 0.2\%$ coupled with high frequency phase variations on the order of 1-2 milliradians and low frequency phase variations in the voltage channel that match those of the current transformer.)

If these arguments exclude transformers and other inductive devices as possible input transducers then one is left with resistive, capacitive, or R/C attenuators. The classic instrument approach to the attenuator that must handle DC is the "compensated" R-C attenuator. A simple resistive attenuator is not practical if one tries to operate at any sort of reasonable impedance level and over a wide range of frequencies. This is true since some stray capacitance will always occur across the high impedance. For example 1 pF of stray capacitance across 1 Mohm will cause 45° of phase shift by 159 kHz and 5.7° by 15.9 kHz.

The "compensated" attenuator approach admits of this stray capacitance, indeed often adds extra capacitance to "swamp" or stabilize the stray component. It then adds additional capacitance across the shunt resistive element to make the shunt R-C time constant equal to the high impedance series R-C time constant. When this is done then the pole and zero in the transfer function cancel and the attenuator is theoretically frequency independent. Difficulties with this approach are several fold. One is that practical values of shunting capacitance often force the pole and zero of the transfer function to occur in the frequency band of interest. Therefore a failure to get them adjusted to exactly the same frequency results in phase and/or amplitude bumps. Another practical difficulty is that some of the small capacitance across the high impedance series arm is apt to be distributed rather than lumped into a single element and some of this capacitance may be directly to ground rather than straight across the resistor. These distributed terms will not be cancelled out by a single shunt capacitance.

When only AC signals need to be dealt with then one can leave out the resistive elements. In this case one has a capacitive attenuator. Such units have long been in use as the method to reduce very high voltages down to

manageable levels. If such an attenuator works into a resistive load then it will have a low frequency break point. The trick is to tailor the low frequency response so that it matches that of the current transformer. It turns out that with practical values this can be done.

When dealing with a capacitive attenuator one must find a reasonable way to characterize it in terms of the capacitors used to construct it. (In the compensated resistive attenuator the equivalent loss terms of the capacitors generally do not matter since they are swamped out by the deliberate resistive elements in parallel with them.)

To examine this problem consider the capacitive attenuator that can be modeled - at a single frequency - as a series arm with a capacitor, C, that has a parallel loss term, R, and a shunt arm that has capacitor k, with a parallel loss term, r. Then add a further loss term, RR in parallel with r. If the appropriate conductance term for each resistor is written as the equivalent "gee" term then the condition for no variations in amplitude or phase shift as the frequency is varied is that $C/G = k/(g+GG)$ or that $Q_C = Q_{kk}$ where Q_{kk} is the Q of the capacitor k when loaded with the extra resistor, RR. (This extra physical resistor both provides a DC return for the input amplifier in the voltage channel of the V-A-w meter and if the proper value is selected will provide the desired low frequency phase response. Its choice will be discussed subsequently.)

In the capacitive attenuator one does not deliberately add the components R and r, these are the inherent losses in the capacitors. It follows that one does not in general have any values for these components or does know how they may vary with frequency. Therefore it is often easier to think in terms of the loss in the capacitor as expressed by dissipation factor or its reciprocal, Q.

If the values of the loaded Q's are reasonably high, as they must be to produce a decent attenuator, and if k is much larger than C as it will be in a 100/1 or larger step-down attenuator, then one can show that the transfer functions for the assumed network may be approximated very closely by :

$$(v_o/v_i) = [C/(C + k)][1 + j(1/Q_{kk}) - j(1/Q_C)] \quad \text{(III-7)}$$

Thus when the values of Q are large the amplitude ratio of the attenuator reduces to $[C/(C+k)]$. When the two Q values are equal then there is no phase shift, while if they differ but are both high the net phase angle in radians will be equal to the ratio of the imaginary to the real part. Thus 10^3 times the difference of the reciprocals of the Q 's will yield the phase angle in milliradians.

To keep the net phase angle from the attenuator below 1 milliradian requires that the Q's of the two capacitors be matched as follows:

Q_{max}	20.4	52.6	111	250	428	666	1000
% difference	2	5	10	20	30	40	50

To achieve a phase error of less than 100 uradians with the same degree of matching will require that the initial Q values be ten times larger.

What a phase error of 1 mradians means in terms of the voltage attenuator in a wattmeter is that if one has a full scale input of say 5000 digits of volt-ampere product then there will be a 1/1000 or 5 digit error. In terms of the input V-A product this is an error of 0.01%. In terms of a load with a power factor of 0.001 it is a 100% error in the reading. To reduce this error to 10% of the reading will require that one reach the 100 uradian contour. If one can keep the Q values of both capacitors above 10,000 then the worst phase error will always be less than 100 uradian. With loads with power factors greater than 0.01 one will not get an error of more than 1% of the reading from this source.

From this discussion it follows that one does not make a decent capacitive attenuator from any old capacitors that happen to be lying around the laboratory. It is necessary that one have the means to measure the Q of the capacitors over the frequency band of interest. It is further necessary that the Q values be high and that if they vary with frequency that the two different values have similar variations with frequency.

It turns out that many "good" capacitors tend to have Q values that are reasonably independent of frequency over quite wide ranges of frequency. Thus Q is a much more convenient term to consider than is the resistance itself. If Q is frequency independent then at low frequencies the resistive terms from the capacitors will tend to be much larger than the real resistance, RR, and hence may be ignored..

To deal with the low frequency response one considers only C,k, and RR. In this case the transfer function has a zero at the origin and a pole at $GG/[k + C]$. If k is 1990 pF, C is 10 pF, so that one has a 200/1 attenuator then a value of 82 Mohms for RR will lead to a -3dB frequency of about 1 Hz which matches the response of the assumed current transformer almost exactly. (In practice one should choose RR on the basis of experimental low power factor measurements in the 50-400 Hz region.)

With this approach one may construct voltage inputs with unity gain attenuators for full scale values of between 50.00 millivolts and 1000 millivolts, or plug-in capacitive attenuators with 1/1, 10/1, 100/1, or 200/1 ratios.

For instruments with no more than three voltage ranges and a variation between the full scale values of these ranges of 25 or less one builds the attenuator into the instrument. If one wishes either more ranges or a wider dynamic range then external plug in attenuators are possible. (Almost by definition the plug in units will be more prone to poor connections and other practical difficulties, hence they are NOT recommended unless they are really necessary.

Whether internal or external there are some practical constraints on what is possible. If one wishes to keep the value of RR and of the low frequency breakpoint both constant then the total of C and k must always stay close to 2000 pF. Thus a 200/1 ratio will require a 10 pF series element with a nominal 2000 pF shunt element. If one wishes to go to a 500/1 ratio while not reducing the input capacitance below 5 pF (too small a value may be hard to control with respect to stray capacitance) then the shunt element will have to be 2500 pF and RR will have to be loaded down to 65.6 Mohms.

If multiple attenuators are used then decimal point and/or full scale PROM's can be supplied for both attenuators however there is no way to provide internal switching between the PROMs when switching external attenuator boxes. With a computer connected to the V-A-W meter then as long as the computer "knows" while attenuator is in place the decimal point placement may be done automatically.

At the highest frequencies the capacitive input circuit may take more current than a resistive attenuator. For example a compensated attenuator consisting of 1 Megohm in parallel with 1.5 pF operating at 1 MHz will look like 1 Mohm in parallel with a reactance of about 106 kohms. Therefore a 500 V, 1 Megahertz source will have to supply about 5mA of reactive current as well as 250 mW of power. If one substitutes a capacitive attenuator with a 5 pF input capacitor then at 1 MHz one will draw 15.7 mA of reactive current from a 500 V 1000kHz source. There is no general rule that says which type of situation will be most satisfactory from the source viewpoint. At lower frequencies the capacitive attenuator will take less current than the resistive one.

If the attenuator is connected "outside" the current transformer winding then this extra current will not be sensed by the current input. In this case the drop caused by the load current flowing through the winding and the reflected resistance of the current transformer will be included in the measured voltage. In the case of 50 or 250 mA current inputs the impedance in the current transformer branch is on the order of 100 milliohms hence one should generate worst case error voltages of less than 25 mV and worst case power errors of about 6mW. With higher current inputs and thus single turn primary operation for the current transformer this impedance should drop to less than 5 milliohms hence the drop will normally be negligible.

If the voltage leads are connected directly across the load then the extra reactive current taken by the attenuator will be registered by the current reading however to the extent that this current is purely reactive there should be essentially no error in the power readings.

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IV. CALIBRATION EQUIPMENT AND TECHNIQUES.

The Model 258 is a "state of the art" instrument therefore to calibrate it requires equipment or techniques that may not be completely familiar even in a well equipped calibration laboratory. For this reason it seems desirable to include a discussion of instruments and ideas that may be useful before going through the detailed performance tests and calibration procedures outlined in the next chapter.

To calibrate a Model 258 at a single frequency one needs "absolute" sources of VOLTAGE, CURRENT, and POWER. To insure constant outputs over the required frequency range one requires sources of these quantities that are "flat" from 50 Hz to 1500 kHz. In addition one requires at least some known phase shift situations at specific frequencies in the same frequency range. (Note that the "flat" quantities do not have to be "accurate" as long as they are constant with frequency.)

The chapter will begin with a discussion of some of the commercial equipment that is suitable for calibrating an instrument such as the Model 258.

4-1 VOLTAGE SOURCE AND/OR MEASUREMENT

There are several approaches to obtaining a "flat" voltage over a range of frequencies. One is to put the problem back upon a manufacturer. In this case one buys what is known as a "voltage calibrator". Such a device is supposed to produce a voltage within some specified amplitude limits over some specified frequency range. In addition the calibrator will have some allowable output current or power limitation and will have some distortion limits.

The second approach is produce the desired voltage over the desired frequency range, but to admit that it is probably NOT completely "flat" hence it must be measured and then one must either adjust the amplitude at each frequency or one must apply a correction factor at each frequency.

In either approach one must take care that the measuring part of the system operates in the same fashion as the device under test since "flat" with respect to "average" and "flat" with respect to "peak" and "flat" with respect to "RMS" are usually NOT the same.

A brief explanation of the workings of the VOLTAGE channel in the Model 258 will help in deciding what voltages are really necessary to check or to calibrate a Model 258 V-A-W meter. The Model 258 has three voltage ranges. The nominal full scale magnitudes of these ranges may vary from 1 V to 200 V with some set such as 20 V/ 100V/ and 200 V or 10 V/ 20 V/ and 100 V being typical. Whatever the set of ranges all the voltage inputs share a common input attenuator and a common input buffer stage. The division into separate ranges is done in a low impedance switching section (all impedances below 250 ohms) at the output of the buffer stage. Each range has a separate full scale

and 1/20 th full scale amplitude control. Since the only place the three VOLTAGE ranges differ is in the low impedance switching network one has only a single set of frequency controls for the VOLTAGE channel. Thus while three different levels are convenient to check or to set the absolute values of the three ranges only one wideband VOLTAGE level is necessary to check the flatness of all three ranges.

4-1-1 COMMERCIAL VOLTAGE CALIBRATORS.

A Fluke Model 5200 A C Calibrator is an example of a commercial voltage calibrator that will provide a "flat", true RMS voltage source up to 1200 kHz for a 1V, 2V, or 10V range. For a 10 V output on the 10 V range the nominal accuracy from 100 kHz to 1000 kHz is specified as $\pm 0.36\%$ which is three times the specified accuracy of the Model 258. (The typical accuracy of the voltage channel of the Model 258 is expected to be equal or better than 0.36% from 50 Hz to 1500 kHz hence in fact the use of the Fluke Model 5200 as a calibration source will not provide the factor of at least 5 which one would like to have between the calibration instrument and the unit under test.)

Another commercial AC voltage calibrator that covers the desired frequency range is the Julie Research AC-125 which claims a $\pm 0.2\%$ accuracy for frequencies up to 1100 kHz at amplitudes up to 12 V.

With either of these units and a V-A-W meter in which the lowest full scale is 10 V one will have full scale capability. When the V-A-W meter's lowest scale is the 20 V range then one is going to be working at about half scale (2500 digits in the 5000 digit full scale configuration) in voltage and in power.

4-1-2 COMMERCIAL GENERATORS

If one wishes to try the generator/meter approach then again there are several possibilities. The first approach is to obtain a generator with an adequate output voltage and current capability directly, the other path is to generate the desired frequency coverage and then to use a separate broadband amplifier to obtain the desired output levels.

As a voltage source for either possibility a number of commercial function generators will supply a reasonably flat sinusoidal voltage output up to at least 1000kHz. This source can then be measured with a wideband true RMS voltmeter. Function generators by companies such as WAVETEK, H-P, or EXACT can produce up to 30-32 V peak to peak sine wave into an open circuit. This means a peak voltage of 16 volts and an RMS voltage of about 11 V. With a 10 V scale on the V-A-W meter this yields a full scale reading however with a 20 volt scale one must do the calibration at half scale. Since this is at a level of 2500 digits, assuming the full scale equal 5000 digits position is used, it is possible to see a variation of 0.04% with the V-A-W meter. This resolution turns out to be beyond the accuracy specifications of most commercial true RMS voltmeters that might be used to monitor the function generator output.

the V-A-W meter or other voltmeter. If one is dealing with a Model 258 the normal input impedance is 1 megohm hence at 20 V this extra current can not exceed 20 microamperes. If one attempts to use a thermocouple or other "low" impedance instrument to monitor the VOLTAGE then this extra CURRENT may indeed become very significant.

If the VOLTAGE connection are made from the high side of the load to the other side of the sampling loop then the effective magnitude of the load resistor has been modified by the sampling loop.

This problem will be more apparent the lower the load impedance. For example for a 0.1% amplitude error with a 10 ohm load the extra resistance introduced by the sampling loop must be less than 10 milliohms while the extra inductive reactance must be less than 440 milliohms. With both of these restrictions can usually be met with a short heavy piece of braid. (At 1000 kHz it only take about 67 nanohenries to produce an inductive reactance of 440 milliohms). ~~Table III-4 in Chapter III indicates the magnitude of reflected impedance that one can expect from different current transformers. Obviously these impedance problems will be less severe when one goes to a larger load resistor and thus to a smaller load current. Moving to a lower CURRENT range may cause one to change the number of turns used for the primary of the current transformer which may in turn increase the reflected impedance.~~

As another example assume that one wishes to check the 50 mA CURRENT and POWER ranges using a CT-411 transformer with a TEN turn primary and a 400 ohm load resistor. The magnitude of the resistance of the sampling loop will depend upon the wire size used. With # 20 wire this resistance can easily be made to be less than 50 milliohms which will add to the reflected impedance from the transformer of 20 milliohms. Since this total is less than one part in 5000 of the load impedance one would expect to ignore it. The inductance of the TEN turns will be on the order of 1.7 microhenries hence by 1 megahertz it will have an inductive reactance of about 10.5 ohms. When compared to the 400 ohm load this increase in impedance will increase the magnitude of a 5000 digit display by 1.5 digits at 1000 kHz. This means that the VOLTAGE reading may be unchanged but the CURRENT reading will be reduced by 1.5 out of 5000 digits from what one would have expected from dividing the VOLTAGE by 400 ohms.

With respect to POWER the inductance will also introduce a phase shift of 1.43 ° at 1000 kHz. This phase shift should cause a 1.5 digit decrease in the POWER reading FROM THE PRODUCT OF THE VOLTAGE AND THE CURRENT READINGS. (This assumes that the internal phase shift between the two channels is zero and that the load resistor itself is completely non-reactive.)

If the instrument has an internal differential phase shift then the "error" term may add or subtract hence the actual reading might be 1.5 digits higher or lower than the expected product.)

In any case the expected errors in either of these cases are small with respect to the accuracy specifications of the V-A-W meter, hence this is a possible connection.

Unless one is dealing with very low impedance loads then it appears that connecting the VOLTAGE from the high side of the load resistor to the "far" (the amplifier ground side) of the CURRENT sampling loop offers the least troublesome set of errors.

V. PERFORMANCE TESTS AND CALIBRATION PROCEDURES.

This chapter is concerned with checking the performance of the Model 258 and with the recalibration of any functions that may have been disturbed by component replacement. The EVEN sections of the chapter outline a performance test for a particular range or function or input while the following ODD section outlines the procedure to followed when recalibrating this range or function. IN OUR EXPERIENCE THE MODEL 258 RARELY REQUIRES RECALIBRATION UNLESS SOME PART HAS BEEN REPLACED. THE USER IS URGED TO BE VERY CERTAIN THAT RECALIBRATION IS REALLY REQUIRED BEFORE STARTING ANY PROCEDURE.

5-1. CALIBRATION EQUIPMENT AND STANDARDS.

All of the performance tests assume that one has placed the 5000/CALIB. switch in the 5000 position so that the full scale reading is always 5000 digits. In this configuration the Model 258 has a resolution of at least 1 part in 5000 or 0.02%. It will be apparent that unless the calibration equipment employed is stable and accurate to beyond this limit that one may be measuring the variations in the calibration equipment rather than checking the Model 258.

The tests may be considered in three parts. There are single frequency accuracy tests, there are AC "flatness versus frequency" tests for VOLTAGE, CURRENT, and resistive POWER, and there are tests for proper operation in the POWER case with low power factor loads at various frequencies.

Another aspect that must be kept in mind while making any comparisons between the Model 258 and other meters or calibrators is that the Model 258 is TRUE RMS AC reading. For example if a full scale sinusoidal voltage has a 2% third harmonic distortion added to it the reading of a Model 258 will increase by one part in 5000, while if the same distorted voltage is read with an ideal full wave, average reading meter the reading may vary by ± 100 digits out of 5000 depending upon the phase relationship of the distortion to the fundamental. Even 0.1% odd harmonic distortion from a generator or a coupling transformer may cause a 0.1% difference between the Model 258 and some other meters that are highly accurate in their own realm.

The full scale readings of a Model 258 set on CURRENT, VOLTAGE, or RESISTIVE power are typically held to well within (a factor of at least five is typical for VOLTAGE or CURRENT) ± 50 digits from the lowest specified frequency out to beyond 1500 kHz (1.5 MHz). For operation near full scale the specified accuracy from 50 Hz to 1000 kHz is $\pm 1\%$ for VOLTAGE or CURRENT and $\pm 1.5\%$ for POWER. In terms of digits out of 5000 digits these percentages turn into ± 50 digits for VOLTAGE or CURRENT and into ± 75 digits for POWER or POWER X 10. As pointed out in Chapter IV several companies produce voltage calibrators that offer better than 0.5 % accuracy to at least 1,000 kHz.

As a practical matter commercial instruments that can provide 50 mA or 500 mA, at 100 kHz or more are rare. In fact many commercial current calibrators have an upper frequency limit of 5 kHz, 1 KHz or even less. If a voltage calibrator has enough output current capability, say at least 25 mA, then such a generator may combined with a non-reactive resistor to provide a current source to investigate the flatness of the the 50 mA range of the Model 258.

To completely perform the tests outlined in this chapter one requires some set or combination of equipment as described in Chapter IV that provides CURRENT and VOLTAGE and that operates satisfactorily out to at least 1000 kHz. If the equipment is not of the self contained calibrator type then one also requires comparison meters that are accurate to within at least $\pm 0.3\%$ out to at least 1000 kHz.

5-2. PERFORMANCE TESTS - METER "ZEROS"

The downscale performance of the Model 259 V-A-W meter must be considered in two separate parts. One part for VOLTAGE and CURRENT and another part for POWER and P X 10. Both the POWER and the POWER X 10 functions have individual zero controls and both should indeed read close to 000 with no inputs.

In a high field environment the high input impedance and broadband of the VOLTAGE input may lead to pickup that is interpreted as an error in the zero reading. If such seems to be the case then one should switch to a higher VOLTAGE range or short the VOLTAGE input before drawing any conclusions.

Both one CURRENT and one VOLTAGE button should be depressed during all attempts to read the POWER zeros.

Since the POWER accuracy specifications have a $\pm 0.75\%$ of full scale term the POWER or POWER X 10 "zero" readings could lie within ± 37 digits of 0000 and still meet this requirement. Normally the POWER and POWER X 10 zeroes are expected to be within $\pm 1-2$ digits (on the basis of 5000 digits for full scale) of zero.

Since the VOLTAGE and CURRENT ranges are all true RMS their far downscale values are noisy. Because of this fact the performance for these functions is only specified between RMS values of 1/10 and twice the nominal full scale values. For best overall linearity one adjusts the individual range "zero" controls for these functions at 1/20th of full scale and lets the no input or true "zero" values be whatever they turn out to be. Thus with no inputs to the meter the VOLTAGE or CURRENT readings seem large and jittery even though the POWER zero may be reading within 1 or 2 digits of 000.

Since by definition RMS values are always positive the meter has been designed so that if the VOLTAGE or CURRENT ranges attempt to go negative then the RMS operation is cancelled and the jitter ceases. This means that with a zero reading of -001 all four functions will read this same value.

In this last case the VOLTAGE and CURRENT readings will still "flash" to indicate that they are below 5 % of their full scale readings.

5-3 CALIBRATION ADJUSTMENT - POWER ZEROS

The Model 258 may be thought of as having a MAIN zero control, P15, a separate "zero" control for each current and voltage range and another zero control for POWER and yet another zero control for POWER X 10. If the MAIN control is left untouched then the POWER X 10 control should not have any influence on the POWER zero however the reverse is not true.

If some component change should cause the MAIN zero control to be adjusted then one must assume that ALL the other zero controls may need adjustment. Because they are "uncoupled" in the Model 258 the POWER control, P127, and the POWER X 10 control, P16, may be adjusted to read 000 whenever desired without changing the setting of other "zero" controls.

Because of the RMS nature of the VOLTAGE and the CURRENT ranges the "zero" controls for these cases are adjusted at (1/20th) of full scale rather than at a true zero input. These adjustments are discussed under the sections on CURRENT and VOLTAGE adjustments.

5-4 PERFORMANCE TESTS - LOW FREQUENCY AC. - VOLTAGE

The performance tests for CURRENT or VOLTAGE can be done in either order. Since the adjustments for the two functions DO have two common controls, P 66, and P 74 it is usually desirable to adjust one function completely and then to "match" the other one to it. Since it usually easier to measure the voltage we consider the VOLTAGE to be the basic FUNCTION. Within the VOLTAGE function the lowest range is considered as the primary range. For illustrative purposes we shall assume that this range is a 20.00 V range. If your instrument has different voltage scales please make the necessary mental adjustments. The other two voltage ranges have separate "ZERO" and FULL SCALE adjustments. The full scale adjustments for the other ranges are made AFTER the lowest (20 V) range has been adjusted, hence they are normally checked after the 20 V range has been shown to be correct.

THE PERFORMANCE TESTS SHOULD BE DONE FOR BOTH CURRENT AND VOLTAGE BEFORE ANY ADJUSTMENTS ARE MADE TO EITHER FUNCTION.

Unless detailed linearity data is required it is usually adequate to check the accuracy and linearity of the VOLTAGE at the three levels of 1/10, 1, and 1.7 times full scale. On the 20 V range this means at levels of 2.00, 20.00 and 34.00 V. This initial accuracy check is normally made at some convenient frequency such as 10 kHz or 50 kHz. (While the tables below indicate the limits of the specifications one really expects considerably better performance. With a sine wave input the VOLTAGE ranges of a correctly adjusted Model 258 are normally expected to be linear within ± 5 digits from 1/10th to twice the nominal full scale value of the range.)

INPUT VOLTAGE	ALLOWABLE READING (5000 digit Full Scale)	
2.00 V	4.77 - 5.27	5.02 ± 4.6%
20.00 V	49.50 - 50.50	50 ± 1%
34.00 V	84.33 - 85.67	85 ± 78%

To check the linearity, rather than the frequency response, one should compare the relative values of the 2 V and the 34 V readings to the 20 V reading rather than dealing in absolute values. In an well functioning Model 258 these two readings should each be well within 5 digits of the "proper" relative value. That is if the 20 volt reading is 5010 digits then the 2 V reading should be between 496 and 506 digits while the 34 V reading should be between 8512 and 8522 digits.

If the 20 V range checks out then, if desired, the linearity test may be repeated for the 100 V and the 200 V ranges. The 200 V relative voltage levels are just ten times those for the 20 V range. The absolute limits for the 100 V range are listed below.

INPUT VOLTAGE	ALLOWABLE READING (5000 digit Full Scale)	
10.0 V	47.7 - 52.7	→ ± 4.6%
100.0 V	495.0 - 505.0	→ ± 1%
110V 170.0 V	843.3 - 856.7	± 78%

5-5. CALIBRATION ADJUSTMENTS - AC - VOLTAGE (LOW FREQUENCY)

Before making any calibration adjustments it is wise to make sure that they are REALLY necessary. One way to convince oneself of this is to check various ranges and functions at various frequencies before adjusting anything.

CHECK THE PERFORMANCE OF THE CURRENT RANGES BEFORE ADJUSTING THE VOLTAGE !

If only one of the higher two VOLTAGE ranges is in error then they have separate FULL SCALE adjustments P 138 and P 140 that are located in the VOLTAGE BOX. These are single turn potentiometers that may be reached through holes in the lid of the VOLTAGE BOX once the bottom cover is removed from the Model 258. Each of these ranges also has its own "ZERO" or 1/20th of FULL SCALE control, P124 and P125. (On the Main board, front left corner)

If the 20 V (or the lowest voltage range in cases where this is NOT 20.00 V) range is in error then one has FOUR controls to consider. These are P 123 the individual range "zero" control, P 74 the 1/10th full scale VOLTAGE and CURRENT control, P1 the VOLTAGE channel gain control, and P 66 the FULL SCALE control for VOLTAGE and CURRENT. If the main ZERO control, P15, is NOT disturbed, then the "zero" or (1/20th) of full scale controls may be adjusted separately for each range.

Before making any adjustments of P1 or P66 one should determine whether BOTH the VOLTAGE and the CURRENT full scale values are in error. If both require adjustment in the same direction (Ageing of some component in the square root circuit might cause this effect.) then P66 should be adjusted. If only the VOLTAGE channel requires a change then P1 should be used. Adjusting P1 will change the POWER gain, while adjusting P66 will NOT change the POWER gain.

The controls for the 20 V range have some interaction hence if a complete recalibration is necessary one must go through the procedure twice to see if any touch up is necessary. (After a full scale input has been applied one should give the instrument several minutes to settle before making any adjustments of the 1/20th of full scale value.)

A. Apply a 1.000 V input (1/20th of FULL SCALE) and adjust P 123 for a an average reading of 250 digits (out of 5000 digits) . The display will flash and may have one or two digits of "jitter" since one is reading "off scale".

B. Apply a 2.000 V input (1/10th of FULL SCALE) and adjust P 74 for a reading of 500 digits (out of 5000 digits). Once P 74 has been adjusted on this range it must be left alone during subsequent range adjustments. The downscale values of other ranges can be adjusted at either 1/10th or at 1/20th of full scale with their individual "zero" control potentiometers

C. Apply a 20.000 V input (FULL SCALE) and adjust P 66 (or P1)for a reading of 5000 digits. P 66 controls the FULL SCALE reading of both CURRENT and VOLTAGE while P 1 controls the FULL SCALE reading of VOLTAGE alone and P 11 controls the FULL SCALE reading of CURRENT alone. (Of course if P 66 has been adjusted in the VOLTAGE case it must NOT be readjusted if CURRENT calibration is also necessary.) Repeat steps A.-C. to see if any readjustment is necessary. (P58 is an overall gain control that may also be used for a slight adjustment of both current, voltage, and power). Allow ADEQUATE settling time when returning to the 1 V level after the 20 V measurements. !

D. Apply a 34.000 V input (1.7 times FULL SCALE) and note that the reading is well within the performance test limits of paragraph 5-4.

5-6 PERFORMANCE TESTS - CURRENT AND CURRENT TRANSFORMERS

For these tests one must consider the transformer/meter combination as a whole. There are two CURRENT inputs, A and B. These two inputs may operate with two different transformers or with different primary windings around or through the primary of the same transformer. Each input is further divided into an A and 5A or a B and 5B range.

From the information in Chapter III, one can see that the actual measurement frequency should be at least 31 times the -3dB break frequency for the transformer in question to reduce the extra amplitude error from the transformer to below 0.05%. With the CT-411 transformer this minimum frequency would be about 31 Hz. With a transformer such as the Ion Physics CM-100 this

minimum test frequency would be 37 kHz, while with the Ion Physics CM-10 transformer the minimum test frequency would be 2 kHz.

If a low frequency current calibrator is all that is available this will pose no problem in examining a instrument equipped with a CT-411 however it will rule out direct current measurements with an Ion Physics CM-100.

5-7 CALIBRATION ADJUSTMENTS - CURRENT - (SINGLE FREQUENCY)

If one assumes that the VOLTAGE ranges have already been adjusted then P66 and P74 MUST NOT BE ADJUSTED AT THIS TIME. There is a separate overall gain control, P11 for the CURRENT ranges and there are individual "ZERO" and FULL SCALE adjustments for each of the four CURRENT inputs. Unless some drastic change has been made P11 should not require adjustment. Each range can have its (1/20th) setting and its full scale setting "trimmed" without causing any interaction with other ranges. Assuming that the measurement frequency is at least 31 times the -3dB break frequency for the current transformer in use one drives in an current of (1/20th) of full scale and sets P126 on the A range for a reading of 250 digits. Then with a full scale current for the same range one adjusts P113 for a display reading of 5000 digits. Both the Gain and the "Zero" adjustment potentiometers are arranged physically in the same order as the CURRENT range buttons on the front panel. (IN THE CASE OF SOME EARLY INSTRUMENTS THE "A" "ZERO" CONTROL IS AT RIGHT ANGLES TO THE OTHER CONTROLS AND TO THEIR FRONT LEFT.)

If large adjustments in the "zeros" are necessary then there may be some interaction between the controls. Repeating the procedure a second time should remove any errors from this source.

To avoid confusing possible frequency and amplitude errors one should adjust all four CURRENT ranges to the same FULL SCALE and 1/20 th FULL SCALE values (in digits).

5-8 PERFORMANCE TEST - RESISTIVE LOAD, SINGLE FREQUENCY, AC - POWER

The POWER performance may be checked against a power calibrator, against another wattmeter, or against a combination of a voltage calibrator and a set of appropriately sized, non-reactive resistors.

In any case one should bear in mind that the Model 258 measures the power as the products of the voltage and current THAT IT SEES. Thus if the voltage terminals measure the generator voltage while the current inputs measure the total current from the generator the POWER reading should be this product.

If a WIDEBAND power calibrator is available it may be used to set appropriate combinations of VOLTAGE and CURRENT. These values should check individually when read upon the Model 258.

The most widely available POWER calibrator consists of a VOLTAGE calibrator and a stable and non-reactive resistor of the appropriate value. For a 20 V / 50 mA combination an appropriate value for the resistor is in the neighborhood of 400 ohms while for a 10 V / 500 mA combination it would be about 20 ohms, and so forth. The resistor should be of adequate wattage that self heating will not cause resistance changes during the measurement. Three 1200 ohm or four 1600 ohm RN60C metal film resistors should be adequate for the 50 mA case.

If both the Model 258 VOLTAGE and CURRENT are accurate, or if their individual errors are known, then the desired POWER reading FOR A RESISTIVE LOAD consists of the product of the VOLTAGE and CURRENT readings. (If the 5000 digit scales are used then one must use the appropriate conversion factors NOT just multiply the CURRENT and VOLTAGE displays.

If both the CURRENT and the VOLTAGE readings are near 5000 digits then the allowable error in the POWER reading is ± 75 digits. (5000 digit full scale.) With a resistive load the actual difference between the POWER reading and the VOLT-AMPERE product should be less than ± 10 digits for the near full scale case from the lower limit of the transformer to above 1 Megahertz.

Once the positive POWER case has been examined one can reverse the current transformer direction to examine the negative POWER case. In this case the NEGATIVE lamp should flash and the POWER reading should again be equal to the product of the VOLTAGE and CURRENT readings. The differences between positive and negative inputs are normally less than five digits out of 5000 digits for near full scale operation. (Obviously the POWER zero setting must be near zero if the positive and negative readings are to have the same magnitude.)

Other tests may be run to investigate linearity and/or various combinations of low CURRENT coupled with high VOLTAGE or vice versa. There are no separate linearity adjustments. At a frequency of at least ten times the lower frequency break frequency of the transformer in use - a typical Model 258 should have linearity errors of less than 0.1% of full scale over its whole range of specified inputs or outputs.

5-9 CALIBRATION ADJUSTMENT - LOW FREQUENCY AC - POWER

The POWER reading may be set with P 84. If some component such as IC 17 should ever require replacement then P 58 may be used to provide a small adjustment for VOLTAGE, CURRENT, and POWER without disturbing their relative relationships. If either P1 or P11 are adjusted then P84 will probably require adjustment. A reasonable frequency at which to make this adjustment is 50 kHz, or 100 kHz if that is the top frequency available from the calibrator.

The POWER ZERO control P127 should be adjusted to 000 before the full scale adjustment is made.

5-10 PERFORMANCE TEST - RESISTIVE LOAD, SINGLE FREQUENCY, AC - POWER x 10

The same equipment that was used in Section 5-8 may be used for this test. In this case both the VOLTAGE and the CURRENT should be kept at 40 % or less of their full scale values.

The POWER x 10 readings should be the product of the VOLTAGE and the CURRENT readings. If a value of exactly 0.31623 - that is the reciprocal of the square root of ten - times the input VOLTAGE is used with the same load resistor for the P x 10 case as was used for the POWER case then the POWER x 10 readings in digits should be exactly the same as the POWER reading obtained previously.

The POWER x 10 zero - P16 - adjustment should be checked and if necessary adjusted before this test is performed.

5-11 CALIBRATION ADJUSTMENT - RESISTIVE AC - POWER X 10

If the POWER X 10 value requires adjustment then P 14 is the control. If the POWER x 10 "phase controls" C 25 and C27, should ever require adjustment then P14 may require touching up since there is a slight interaction.

5-12-A PERFORMANCE TESTS - RESISTIVE LOAD, AMPLITUDE VS FREQUENCY

If a broadband voltage calibrator is used in conjunction with a non-reactive resistor then one may check the VOLTAGE, CURRENT, POWER, and POWER-x-10 readings simultaneously.

If the same CURRENT transformer is used for all the CURRENT inputs then one can make a circuit argument concerning the "sameness" between the frequency response of all four of the CURRENT inputs. This is the same idea used in the VOLTAGE case. That is that the only circuit difference between the different CURRENT ranges takes place in a low impedance attenuator section, HENCE ALL FOUR CURRENT RANGES SHOULD HAVE THE SAME FREQUENCY RESPONSE. Once this concept is accepted then one need only investigate the frequency response for one VOLTAGE, one CURRENT, one POWER and one POWER X 10 range.

Before recording data it is normally wise to "scan" the frequency range from 50 Hz to 1500 kHz, or whatever portion of this band is of interest or is available from the existing equipment. REMEMBER THAT THE POWER READING IS ONLY SPECIFIED TO 1000 kHz. If there appear to be undue variations then check for proper connections, check for unwanted ground loops, or for unsuspected reactances. Noting whether the variations are present in VOLTAGE, CURRENT, and POWER (below 1000 kHz) or just in one of them may be useful in understanding the problem. If some other method of measurement is available then use it to see if the difficulty is in the generating or in the measuring equipment.

At this point one might make a Table to record CURRENT, VOLTAGE, and POWER and if the calibrator amplitude is easy to adjust, POWER x 10. A reasonable set of frequencies would be 50 Hz, 100 Hz, 1, 10, 50, 100, 200, 300, - - 900, 1000, 1100, 1200, 1400, 1500, and 1600 kHz. (POWER is only specified to 1000 kHz but it is useful to record it to at least 1200 kHz) One might initially only record the data for the first five frequencies then data for alternate values. One can then fill in whatever extra data appears necessary.

A useful line to include in this Table is one for the calculated value of the Volt-Ampere product. Ideally with a pure resistive load this product should continue to equal the power for all frequencies. A properly adjusted Model 258 running at about the full scale levels in all quantities might reasonably be expected to have the VOLT-AMPERE vs POWER difference remain within $\pm 0.25\%$ of each other from 50 Hz to 1000 kHz

In making these measurements one should take care that the current transformer primary is physically fixed so that it is both reasonably near the center, if it is a single wire, and so that it does not move during the test. At high frequencies some slight changes may occur if the primary is moved around during the test.

5-12-B PERFORMANCE TESTS - REACTIVE LOAD SITUATIONS

Since the amplitude and "phase" controls for the Model 258 interact it is wise to check both the amplitude and the phase data BEFORE attempting to make any adjustments.

Between the various ranges of the Model 258 and the various load combinations that one can imagine there are almost an infinity of possible low power factor or "high Q" tests. If the user has a particular set of reactances with KNOWN LOSSES these may be used to set up a performance test.

In the general case our experience indicates that an adequate test for the low power factor case is to use capacitors with a known and low loss coefficient as a nearly zero power factor load. (Mica or polypropylene capacitors - watch out for steel leads - generally have acceptably low losses) One can then add a known resistor in parallel to add a known power loss. For the 50 mA / 20 V combination a 400 pF capacitor will draw full scale current at 1 MHz. Thus this capacitor can be used as a nearly zero power factor load, then it can be used in parallel with a 10 kohm metal film resistor to produce a P.F.=0.04 load, and then it can be used in parallel with a 400 ohm resistor to produce a P.F.= 0.5 load (As a practical matter many generators or amplifiers have a definite upper limits on the capacitance that they can drive, hence one must check that the capacitive load does not cause either oscillation or unwanted output voltage variations in the calibration equipment.)

The capacitor load should be connected in series with the transformer primary. The load should be connected to the HIGH side of the VOLTAGE while the transformer primary is connected to the VOLTAGE COMMON terminal. With this connection the POWER loss measured by the meter will be the capacitor loss plus the loss reflected through the transformer.

With the CT-411 TRANSFORMER and a ten turn primary the reflected loss term should be less than 20 milliohms. If one adds a further 80 milliohms as the loss from the ten turn primary winding then the power loss from a 50 mA current will be 0.25 mW. A 20 V and 50 mA combination coupled with the 5000 digit scale expansion has a POWER resolution of 0.2 mW hence if the capacitive load were truly lossless then the ideal reading would be +1 digit.

At 1000 kHz one will have 1.000 VA in the load. If the capacitor Q equals 1000 then the capacitor loss will be 1 mW or 0.1% of actual input Volt-Ampere product. In this case this would amount to an additional 5 digits for an overall value of +6 digits. Since a high quality mica or polypropylene capacitor might have a Q value between 500 and perhaps 2500 one might reasonable expect the readings to lie between +3 and + 12 digits if the meter were perfectly adjusted and if the input Volt-Ampere product is held at 1.000 and the input CURRENT is held at 50.0 mA.

If one adds a 1% metal film 10,000 ohm resistor in parallel with the low loss 400 pF capacitor then the POWER reading should INCREASE by V^2/R or exactly 40 milliwatts if the voltage is held at exactly 20 V. (As a practical matter a capacitive load often causes an amplifier's output to RISE with frequency hence one should somehow establish whether one really has a constant voltage output as frequency is varied. With an appropriate correction for voltage changes such a resistive addition to a 400 pF capacitor load for a Model 258 "tracked" within 0.1 mW out to 1000 kHz and within 0.8 mW out to 1400 kHz. The effective Q of this composite load is varying with frequency. At 1000 kHz it is $(10,000/400) = 25$ while at 500 kHz it is 12.5 .

If one combines the 400 pF low loss capacitor in parallel with a pure resistor of about 400 ohms then one will have a load with a variable power factor that will go from near unity at 100 kHz to about 45° at 1 MHz. If the calibrator or generator can handle the capacitive load while holding its output voltage constant then ideally the CURRENT and the VOLT-AMPERES should increase linearly with frequency while the POWER remains constant at V^2/R . If the calibrator voltage does not remain constant then one must first take its variations into account before computing V^2/R . For this case the VOLT-AMPERE product will increase from about full scale at 100 kHz to 1.5 times full scale at 1000 kHz. Thus the allowable error will increase from ± 75 digits at 100 kHz to ± 93 digits at 1000 kHz.

5-13 CALIBRATION ADJUSTMENTS : AMPLITUDE and PHASE vs FREQUENCY

As might be expected there are a number of frequency adjusting controls. The user is normally well advised to approach these controls with caution. THEY SHOULD NOT BE TOUCHED UNLESS ONE IS SURE THAT THEY ARE AT FAULT AND ONE IS SURE THAT THEY HAVE THE NECESSARY EQUIPMENT TO COMPLETE THE JOB.

In addition to the controls that will be outlined there are apt to be various unspecified "tweaking" compensation networks in the vicinity of the CURRENT and VOLTAGE amplifiers and the multiplier. These circuits were factory adjusted and should NOT require adjustment.

Since the controls MAY interact one should consider the complete picture before making any adjustments.

Table 7-6 lists all the frequency controls while Drawing 25815 in Chapter IX indicates their position. C-1 is a VOLTAGE channel amplitude control while C-11 is a corresponding CURRENT channel amplitude control. C-133 in the voltage box provides a second voltage control, however unless the voltage box is disturbed this control should not require adjustment. If it were to be adjusted the correct procedure would be to adjust C-133 to make the 200 kHz value of the VOLTAGE equal to the average of the 1 and 10 kHz values.

If C-11 or C-1 were to be adjusted a normal procedure would be to use them to bring the 1 MHz value into line with the 10 and 100 kHz values. There will be an interaction between the adjustments of C-1 and C-133. Hence if one is adjusted the other may require adjustment. If only C-1 or only C-11 is adjusted this is sure to upset the phase shift between the two channels so read on BEFORE making such an adjustment.

An unmarked variable capacitor may exist between IC-13 and IC-15. If it exists this capacitor will offer a small high frequency phase adjustment without causing appreciable amplitude changes.

C-26 and C-28 offer both amplitude and phase adjustment of VOLTAGE, CURRENT, and POWER while C-25 and C-27 operate only in the POWER x 10 case.

As a general rule if a high frequency "phase" deviation is removed, half with C-26 and half with C-28 then the variation of the amplitude response will be minimal. (C-25 and C-27 for the POWER x 10 case). On the other hand if a 1 MHz amplitude variation is removed half with C-26 and half with C-28 then the variation in the phase response will be minimal.

As an example assume that the POWER reading with a capacitive load is in error at 1000 kHz but that the VOLTAGE and CURRENTS amplitudes are correct. One should record all three values then rotate C-26 to remove half the phase error and then C-28 to remove the other half. Turning C-26 will introduce a variation in both the VOLTAGE and CURRENT amplitudes however an equal movement in C-28 should remove this variation while continuing to reduce the phase

error. If only one channel has an amplitude error then either C-1 or C-11 should be used. However before making the amplitude adjustment investigate the low power factor case and record its readings so that its change with the C-1 or C-11 adjustment can be noted.

After the VOLTAGE, CURRENT and POWER cases are all correct then the manipulation of C-25 and C-27 should allow one to correct both the amplitude and phase characteristics for the POWER x 10 case.

5-14 SIMPLIFIED CALIBRATION PROCEDURE.

The following sample calibration procedure is suggested as a means of reducing some of the possible problems in obtaining equipment for the calibration of the Model 258.

If a Fluke Model 5100 B or similar calibrator is available then it may be used directly to check and, if necessary, to set the absolute value for all the VOLTAGE ranges. It is good practice to vary the frequency from such a calibrator to show that the readings and or settings are independent of frequency. The calibrator may also be used to check out the LINEARITY of the VOLTAGE ranges.

The Fluke 5100 B may also be used for the direct checking and/or calibration of the CT-411 transformer in conjunction with the CURRENT inputs. A frequency of 5000 Hz should be used for this purpose. After the LINEARITY is checked one may vary the frequency to determine the low frequency response of the TRANSFORMER/METER combination.

The Fluke 5100 B calibrator can usually supply at least 50 mA from its 19.999 V range. Therefore 19.9999 V from the calibrator and a resistor in the neighborhood of 400 ohms will allow one to obtain readings of CURRENT, VOLTAGE, POWER and P X 10 from 50 Hz to 50 kHz:

If a low loss 16,000 pF capacitor is substituted for the 400 ohm resistor then there will be a capacitive current of about 50 mA which according to the arguments above should lead to a reading of between 3 and 12 digits. (From the specification viewpoint the worst case allowable readings would lie between ± 75 digits.

Obviously if a calibration source is available that will supply higher currents and voltages at higher frequencies it should be used instead of the outlined arrangement.

IN MAKING SUCH MEASUREMENTS WITH THE TEN TURN CURRENT TRANSFORMER PRIMARY BE SURE TO PUT THE LOAD IMPEDANCE ON THE "HIGH" SIDE OF THE TRANSFORMERS OR CAPACITIVE COUPLING MAY CAUSE HIGH FREQUENCY ERRORS !

5-15 PERFORMANCE and CALIBRATION - INTERNAL REFERENCE SOURCE

The +10V Reference Supply may be checked at the test point located behind IC 224. When read on a high quality, high input impedance, DC meter the +10 V supply should read within ± 10 mV of 10.000 V. The adjustment for this supply, P19, should only be varied in an extreme case since this supply is used as an internal reference source by both the -15V supply and by the A/D conversion circuitry.

If for some reason the control, P19, is reset then it will be NECESSARY to recheck and perhaps to reset all the other gain controls of the V-A-W meter.

VI. THEORY OF OPERATION

Geographically the V-A-W Meter is broken into four printed circuit boards plus its front and rear panel controls and terminals.

Electrically the main printed circuit board may be thought of as being broken down into an ANALOG section, a DIGITAL section, and a POWER SUPPLY section.

The three smaller printed circuit boards include the DISPLAY / Counter / Latch board, which plugs into the main circuit board; the board with the Terminating Resistors for the CURRENT transformers - this board is mounted on the current input terminals; and the VOLTAGE INPUT board, which is mounted inside the bottom mounted voltage attenuator box.

The last Chapter of this Instruction Manual contains separate schematic diagrams for all five of the boards or sections capitalized above.

The VOLTAGE input board and the CURRENT termination board both feed directly into the ANALOG section of the main printed circuit board. The DISPLAY board connects electrically to the DIGITAL section of the main board while the POWER SUPPLY services all the other boards and sections except the CURRENT termination board, which is passive.

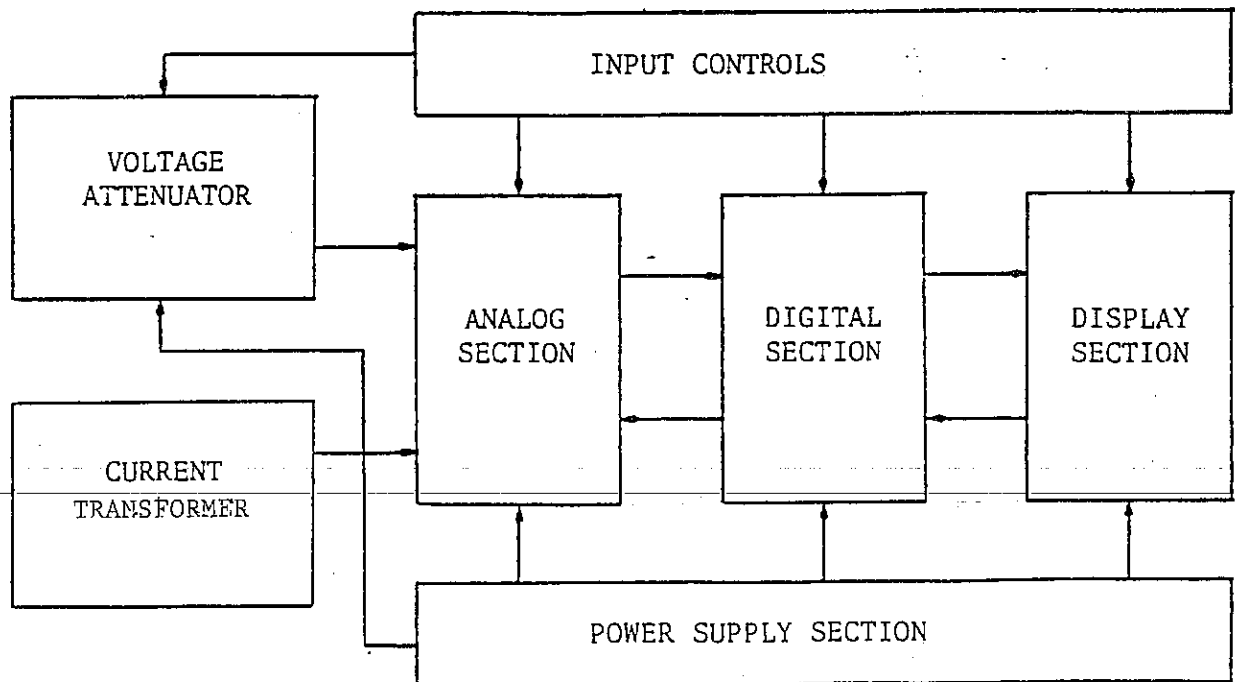


Figure 6-1-1. Breakdown of VAW Meter Circuits.

6-0 GENERAL OPERATION

The signals to be measured enter the V-A-W Meter via the Voltage and/or Current Input Terminals. The Voltage signals are attenuated, frequency compensated, and converted to an impedance level of less than 250 ohms. At this point the voltage range selection takes place and then the signals are sent on to the Voltage Amplifier portion of the Analog section of the main printed circuit board. The initial voltage amplification and range selection takes place in the Voltage Attenuator Box.

The Current signals are converted to voltages (nominal values of 50 mV RMS for Full Scale sine waves on the "A" and "B" ranges and nominal values of 250 mV on the "5A" and "5B" ranges.) These signals then pass through a buffer amplifier, and individual, low impedance, gain control adjustment attenuators, before reaching the channel selection switch and the main Current Amplifier.

The ANALOG Section contains Current and Voltage Amplifiers, the CMOS switches necessary to "steer" the input signals along the proper paths, the Chopper switches, the Multiplier, the Demodulator Circuitry, and the Integrator and Comparator parts of the A/D converter. In general terms the ANALOG section of the meter is located on the left hand (from the front) section of the main printed circuit board.

The DIGITAL Section contains the decoding and logic circuitry necessary to translate the Function and Range Switch commands into Decimal Point and Full Scale settings and into the necessary control signals to operate the instrument. This section also contains the High, Low, and Chopper Clock generation circuitry, the Output Over Range and the Input I/V Under Range, the Polarity determining circuitry, and the Drivers for the various electronic switches. Most of the Digital logic circuitry is of the CMOS type.

The DISPLAY/Counter/Latch board contains the four digit LED output display, the four LED signal lamps, the Counter portion of the A/D converter, the BCD latches that "hold" the output display values for operating the IEEE-488 bus option, and various auxiliary control and driver circuitry.

6-1. CURRENT TRANSFORMER TERMINATING RESISTOR BOARD

This board is located directly behind the current input terminals. It is reached by removing the bottom half of the V-A-W Meter case.

The board may contain two sets of terminating resistors one for the inputs A and 5A and one for the inputs B and 5B. Each set of resistors may have an adjustment potentiometer P 101 or P105 that allows the input impedance to be set exactly to the correct value. The input impedance desired depends upon the current transformer to be used with the Model 258.

In the normal instrument the CT-411 is used with a terminating impedance of about 30 kohms. In this case there are no potentiometers.

With the CM-100 and CM-10 transformers or with a direct coupled P6022 probe one normally sets the input impedance at 50.0 ohms. In either case this board is made up entirely of passive components.

6-2. VOLTAGE ATTENUATOR BOARD AND BOX

The Voltage Attenuator Board is located inside the VOLTAGE ATTENUATOR BOX which is in turn located just behind the Voltage Input Terminals.

The Voltage Box contains the capacitive input voltage divider, a unity gain buffer with a low output impedance and the low impedance 2nd and 3rd voltage range calibration attenuators. For instruments with a minimum voltage range of 20 V the input voltage divider has a 1/200 ratio. The attenuator output passes through the buffer, IC130 to the 2nd attenuator (P140,R140,R141) and the 3rd attenuator (P138,R138, and R141). The switch IC131 allows the circuit to select the appropriate range.

The use of a capacitive voltage divider instead of a resistive one allows ~~better low frequency phase tracking between the voltage channel and the transformer coupled current channel.~~

A "full scale" RMS voltage input on any range should cause a voltage box output of approximately 100 mV RMS at pin 5 of IC 3 on the main printed circuit board.

6-3 DISPLAY BOARD

The Display Board contains the visual and electrical outputs from the V-A-W Meter. In addition it contains the instrument's counting circuitry. This circuitry provides the timing necessary for various "control" functions within the rest of the instrument as well as the timing necessary for the A/D conversion of the DC output from the Analog Section of the Meter.

The Display Board also houses a set of Binary Coded Decimal (BCD) latches that "hold" the electrical equivalent of the number displayed by each LED digit. This number is updated with the display (normally at a rate of 10/second for 60 Hz operation and 8-1/3/second for 50 Hz operation). The Load Latch (LL) pulse from the Digital Section controls the latch updating. Since the LL pulse width is nominally in the neighborhood of 60 usec the latch data is valid for 99.94 out of every 100 milliseconds. A HOLD terminal is available on the display board. Grounding this terminal allows the present value of the latched signal to be "held" for as long as is desired.

The Display Board communicates with the rest of the instrument through a 16 pin connector, J1. If the BCD latch data is required, it is available at two 14 pin DIP sockets located at the top of the display board. These sockets would normally be connected to an isolated BCD board or to an isolated IEEE-488 bus board via a pair of ribbon connectors.

Incoming information applied to the display board includes the Decimal Point setting, the drive signals for the four indicator lamps, the LL pulse, the High Frequency Clock signal, and two control signals known as ACTIVE and NOT SIGNAL. The two signals that leave this board and return to the Digital Section are a negative going pulse that occurs every 900 counts and a positive going pulse (100 nsec to the 10% point) that occurs every 999-1/2 counts. The negative going pulse lasts from 900 to 999-1/2 counts. The clock that reaches this board and is counted has rates of 100 kHz, 200 kHz, 250 kHz, or 500 kHz (depending upon the portion of the control cycle and on the Full Scale setting of the Meter). Because of the different possible frequencies this pulse width has four possible correct widths. Their relationship will become clear when the Digital Section is discussed. All of the circuitry to the display board operates from the +5V power supply of V-A-W meter.

6-4-1. AMPLIFIER/MULTIPLIER/INPUT CMOS SWITCHES

One of the outputs from the individual amplitude adjustment potentiometers, P110 - P113 is selected by the static switch set, S 110-113, contained in IC 10. This output is applied to the input of the CURRENT amplifier IC 2.

The analog signals from the voltage attenuator box are fed to the VOLTAGE amplifier IC 1. These two amplifiers are wideband, high input impedance, negative feedback amplifiers. The voltage amplifier has a nominal voltage gain of 6.2, while the current amplifier has a nominal voltage gain of 12.5. Each amplifier has an individual gain control and an individual frequency response control. The output of IC 1 may be viewed at the left end of R 3 (located behind C 1) while the output of IC 2 may be viewed at the left end of R 13 (located behind C 11) Since these are broadband amplifiers the direct connection of high capacitance leads - such as the twisted pair that is often used in conjunction with a multimeter - may cause oscillation. Inclusion of a series resistor, say 5 kohms, should prevent this problem. (If the display reading changes when a meter or oscilloscope is connected to the amplifier output then oscillation should be suspected.) When the amplified inputs leave IC 1 and/or IC 2 they are controlled by the static switches S20-23 contained in IC 13. The output of IC 13 enters two sets of dynamic switches S30-37 contained in IC 14 and IC 15. The switches in IC 13 "steer" the input signals based upon the position of the FUNCTION switch to produce CURRENT, VOLTAGE, or POWER readings. The dynamic switches in IC14 and IC 15 chop the input signals with two quadrature square waves to produce the composite signals that are then supplied to the broad band semiconductor multiplier, IC 17

The extra gain required in the POWER x 10 position is obtained in the multiplier by closing switches S 200 and S 201 to decrease the resistances between pins 7-8 and 11-12 of IC 17. There are adjustable, low power factor "phase "controls for both the POWER and the POWER x 10 positions connected to the multiplier.

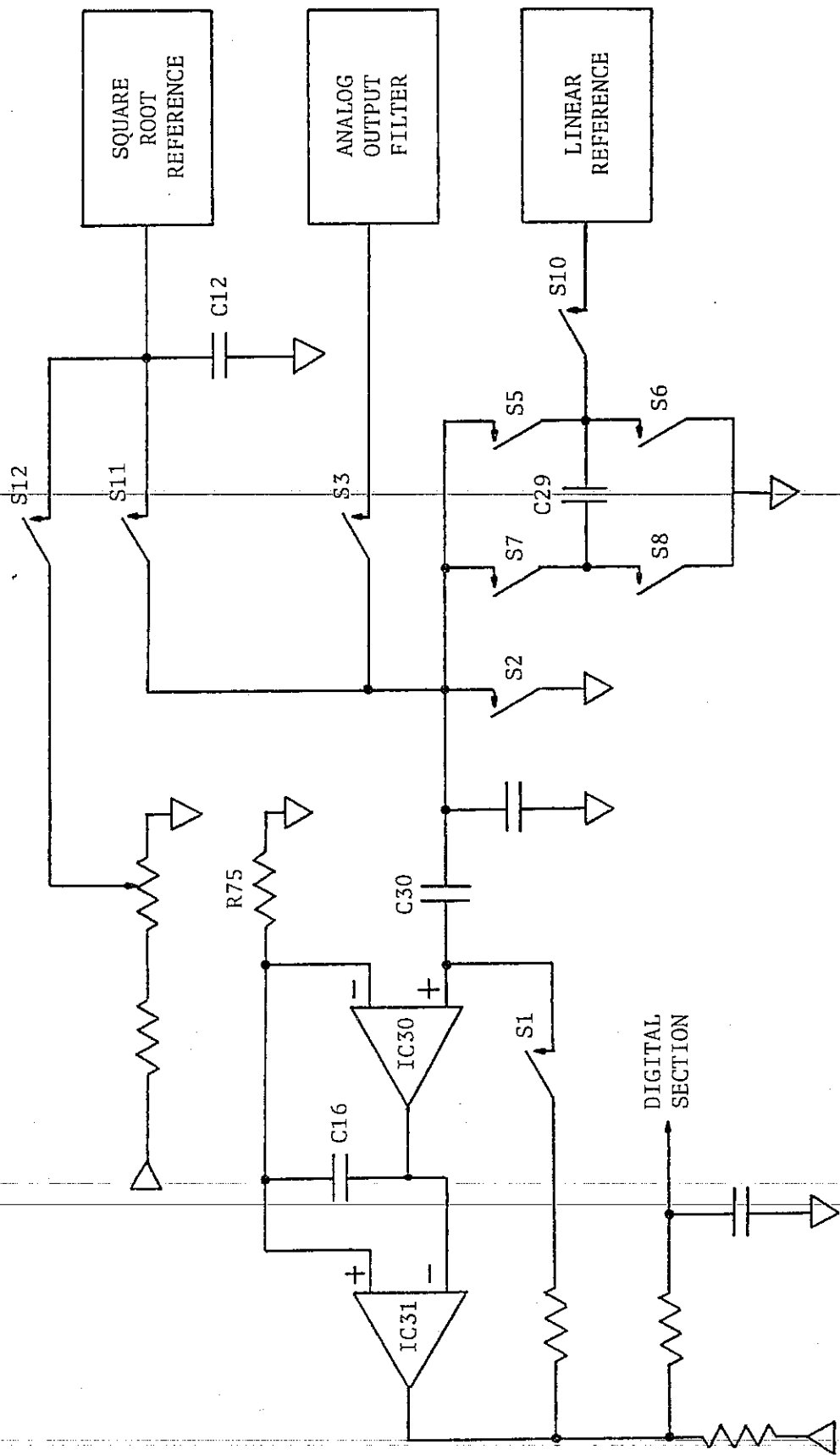


Figure 6-4-1 A/D Converter Analog Switches

Table 6-6-1. Switch Drive Signals.

Switch	Drive Signal*
S1, S2	NOT ACTIVE or NOT LFC
S3	SIGNAL
S4	NOT LL pulse
S5	(REFERENCE) and (NP)
S6, S7 NOT (V or I)	(REFERENCE) and (PP) and
S8	(S5 drive) or NOT LFC
S10	NOT LFC
S11 (V or I)	(REFERENCE) and (PP) and
S12, S18	Inverse of S11 drive.

— — — — —
"or" is a logical OR (Either)

"and" is a logical AND (Coincidence)

NOT X is a negation of X

Switches are closed when their drive signals are at + 8 V and open when their drive signals are at -6 V.

The chopped output of the multiplier is demodulated by the combination of the dynamic switches S41-42 contained in IC 9 and the operational amplifier located in IC 16. The DC output from the operational amplifier is further filtered by R 56 and C 23. P 58 provides an overall gain control for the instrument.

6-4-3. ANALOG/DIGITAL CONVERSION

The A/D conversion is accomplished by the combination of IC30 and IC31 together with a number of logic control circuits from the Digital Section and the digital counters on the Display Board. Figure 6-6-1 highlights the major switches involved in this operation.

IC30 and 31 have their own independent Auto-Zero operation. Whenever these IC's are not "actively" performing an A/D conversion, that is, whenever the signals NOT ACTIVE or NOT LFC are present then S1 and S2 are closed while S3, 5, 7, and 11 are open.

The closure of S1 forms a loop of IC30 and IC31 that applies an "auto-zero" voltage to C30, via the ground connection supplied by S2. Since Pin 2 of IC30 is near zero volts during this period, the loop forces Pin 3 to near zero and discharges C16.

During the ACTIVE portion of the A/D conversion the bias voltage stored in C30 during the Auto-Zero cycle is added to (or subtracted from) the applied input voltage to remove the effects of long-term drift in the offset voltages of IC30.

The ACTIVE period of the A/D conversion is broken into two further periods, known as a SIGNAL and REFERENCE. During the SIGNAL period, S3 closes and the output of the Filter Circuit is applied to IC30, Pin 3 via C30. C16 is charged during this interval by a current equal to the Filter output voltage divided by R75. As outlined in a later section, the period of SIGNAL is 9.99 msec (999 cycles of a 100 kHz signal derived from the 1 MHz crystal oscillator formed by a portion of IC218).

At the end of this period S3 opens and either S11 (Voltage or Current) or S6 and S7 (Positive Power) or S5 and S8 (Negative Power) close for the length of time necessary to completely discharge C16 back to zero. This period is known as REFERENCE. The end of REFERENCE is generated by C16 reaching zero volts and causing IC31 (a comparator) to change state.

The length of REFERENCE is determined by counting a frequency of 100 kHz, 200 kHz, 250 kHz or 500 kHz depending upon the Full Scale value of the RANGE and RANGE and FUNCTION being measured. All of these frequencies are derived from the same 1 MHz crystal oscillator.

In POWER measurement case the voltage applied to IC30, Pin 3 during the REFERENCE interval is a constant and the output COUNT is directly proportional to the Filter Output applied during the SIGNAL interval.

When measuring VOLTAGE or CURRENT the voltage applied to Pin 3 of IC30 is a negative going ramp and the output COUNT is proportional to the SQUARE ROOT of the Filter Output applied during the Signal interval.

6-4-4. SQUARE ROOT GENERATOR

The negative going ramp necessary for taking the square root in the VOLTAGE and CURRENT cases is generated by a temperature compensated current source charging a capacitor. S18 opens to turn on the current source consisting of IC 20 and transistors Q16 and Q17. S12 (two CMOS switches in parallel) discharges the capacitor, C12, between cycles and S11 connects the resultant ramp to the input of IC30 during the REFERENCE interval when either VOLTAGE or CURRENT is being measured. P66 controls the size of the constant current hence the slope of the ramp, while P74 controls the initial offset of the ramp.

6-5-0. CLOCKS AND TIMING - GENERAL

The V-A-W Meter has three basic clock signals and various timing signals that are derived from or controlled by these signals.

The Low Frequency Clock (LFC) is normally produced by squaring-up and dividing down the power line frequency. For 60 Hz (50 Hz) operation the division ratio is set at six so that a basic LFC frequency of 10 Hz (8.33 Hz) is obtained.

The High Frequency Clock (HFC) is produced by divisions of 10, 5, 4, or 2 from a 1 MHz crystal oscillator. The division ratio is controlled by the FULL SCALE PROM, IC193. It depends upon the FUNCTION being measured, the FULL SCALE combination required by the RANGES, and the portion of the TIMING cycle involved.

Figure 6-6-3 illustrates some of the timing signals obtained from these clock signals. The multiplier chopping frequency is produced in an astable multivibrator, IC3, and is converted to its two half frequency, quadrature terms in a dual latch, IC 4. Figure 6-6-2 shows the relative timing of the resultant switching signals as well as indicating which switch they drive. This Figure also indicates the static "steering" of inputs to the multiplier by the switches in IC 13.

The front panel CLOCK "HI/LO" switch provides a small (about 68 Hz) shift in the multiplier chopping frequency to allow one to avoid beats caused by "almost exact" (within 2 hertz) coincidence of the internal modulation frequency, or its harmonics and the signal under test. With the switch in the "LO" position the chopping frequency is normally between 1650 Hz and 1700 Hz.

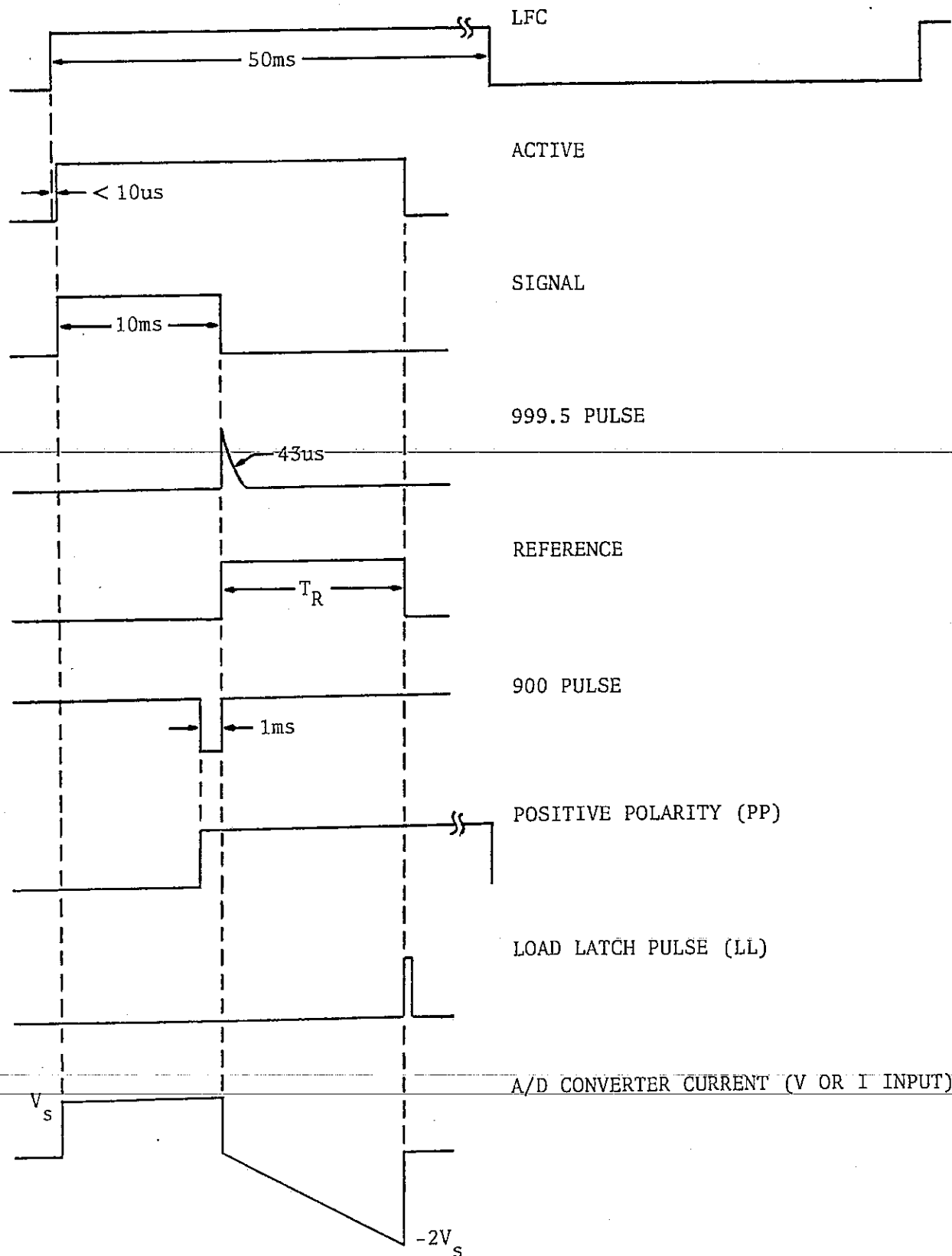


Figure 6-4-3 Relative Timing of Model 258 Control Signals.

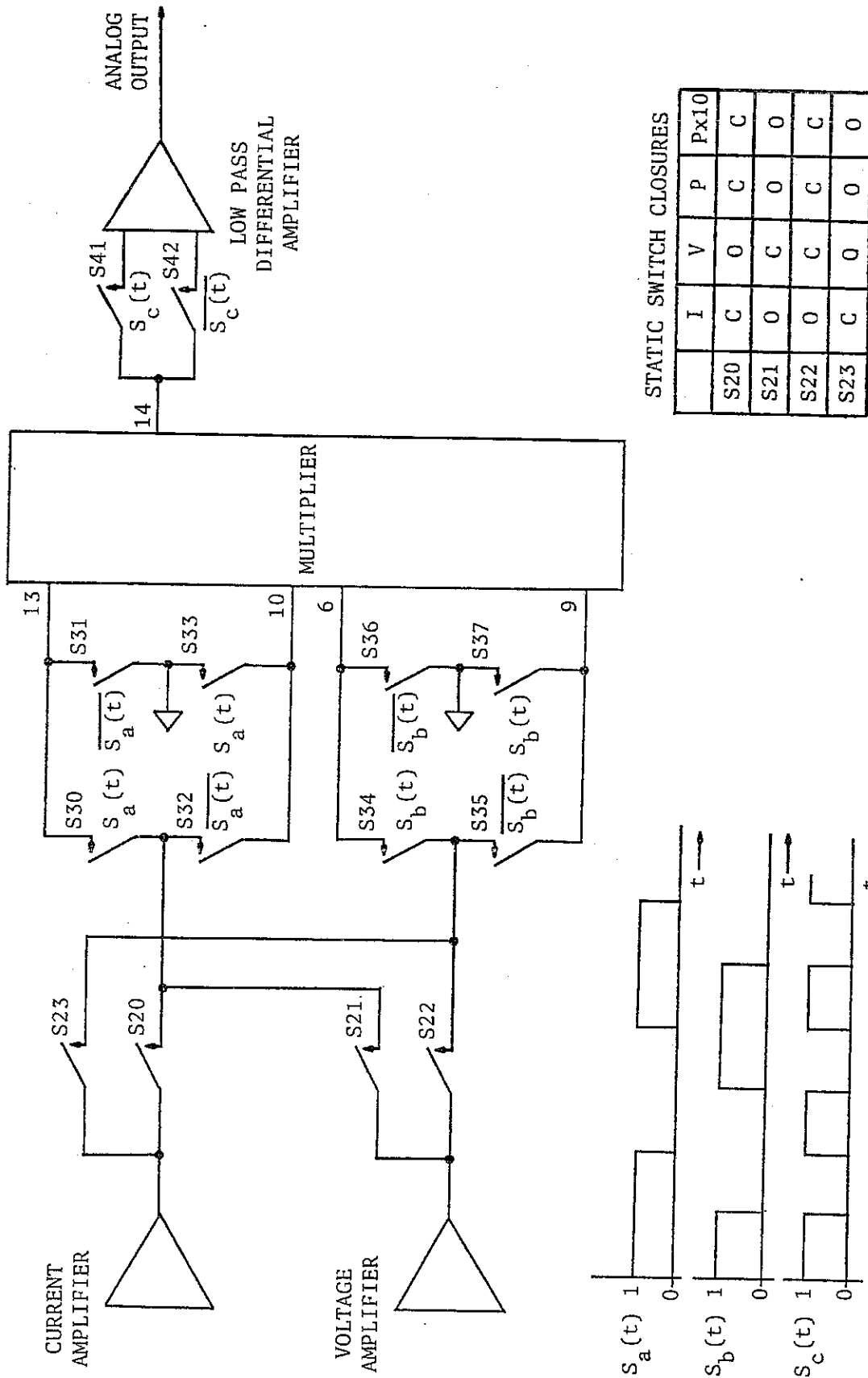


Figure 6-4-2. Chopper Stabilized Multiplier With Switching Waveforms

6-5-1 LOW FREQUENCY CLOCK, LFC

The Model 258 has a signal of line frequency that is clipped off by the resistor, R240, diode, D201, D202 combination, and then "squared-up" by two stages of inversion separated by RC filters. The final square wave is applied as an input to the programmable divider IC233. By choosing a pad, the desired division ratio is chosen. Normally the input signal is divided by 6 to produce a 10 Hz LFC signal from a 60 Hz line frequency.

If for some reason either a different line derived frequency is desired or if one wishes to obtain a non-line derived value for LFC both are possible. One should consult the factory before changing LFC by more than 10-15%. Such changes will have effects OVER RANGE capabilities, the rate of updating of the visual and BCD latch outputs, and other more subtle phenomena.

IC230 (7,6) is used to generate NOT LFC. As with most of the CMOS digital circuitry in the V-A-W Meter, the output levels of these circuits vary between a nominal value of +8 and - 6 volts.

6-5-2 HIGH FREQUENCY CLOCK, HFC

The V-A-W Meter contains a 1 MHz crystal oscillator (IC218, Pins 2-5). This frequency is divided down in IC 219 by a ratio of 10, 5, 4, or 2. The division ratio is programmed by the logic circuitry of IC 212 and IC 214 which are in turn driven by control signals from IC 193, the FULL SCALE PROM. The division ratio is always 10 during the SIGNAL interval. Its value during the REFERENCE interval depends upon the FULL SCALE required by the Meter. The relationship is presented in Table 6-5. The purpose of the crystal is to provide oscillator stability rather than oscillator accuracy. The actual frequency accuracy is normally much better than the specified value of $\pm 0.1\%$.

Table 6-5.

FULL SCALE	DIVISION RATIO	HFC during REFERENCE
1000 digits	10	100 kHz
2000 digits	5	200 kHz
2500 digits	4	250 kHz
5000 digits	2	500 kHz

HFC is transmitted to the Display Board via Pin 4 of Jack #1. It is also used as a timing signal in producing the ACTIVE pulse.

6-5-3. CHOPPING FREQUENCIES.

IC 3 is a CD 4047 that functions as an astable multivibrator to produce an output square wave in the vicinity of 3.4 kHz. This square wave is used as the demodulator drive signal for IC 9. IC 4 is a dual latch, CD4013, that is wired to produce two quadrature square waves at a frequency of half the driving waveform. These two approximately 1.7 kHz square waves are used as the drives for the switches in IC 14 and IC 15. The input signals that are chopped by these switches provide the input to the multiplier. The front panel switch CLOCK "HI/LO" provides a shift of about 68 Hz so that the 1700 Hz frequency shifts up to 1770 Hz. This allows one to avoid beats in the unlikely event that the input being measured has a significant component near 1700 or 1770 Hz.

6-5-4. ACTIVE

A pulse, ACTIVE, and its inverse, NOT ACTIVE, are produced during the period that the V-A-W Meter is producing an A/D conversion. IC220 (CD4013) is the "Active" Latch.

The CD4013 consists of two D type latches with clocks (Pins 3,11), data (Pins 5,9), reset (Pins 4,10), Q (Pins 1,13) and NOT Q (Pins 2,12) connections. The "data" is "clocked" into the latch on a Positive Going Transition (PGT). Pins 1,2,3,4,5 make up one latch while Pins 9,10,11,12, and 13, make up the other. A positive input on "reset" sets the Q outputs "low" and the NOT Q outputs "high".

Assume that initially both latches have been "reset". Now the first PGT of HFC that occurs after the PGT of LFC "clocks" the 9,10,11,12,13 latch. Pin 13 (Q) outputs ACTIVE, while Pin 12 (NOT Q) outputs NOT ACTIVE. The PGT of ACTIVE "clocks" the 1,2,3,4,5 latch, via pin 3, which turns off the IC207 (8,9,10) gate and prevents further "clocking" of the first latch. (LFC provides the "data" input to both latches.)

The end of the ACTIVE is caused by a reset pulse applied to Pin 10. This pulse is produced in IC 207, IC222 and IC238 (Pins 11,12,13) by suitable processing of the output from the comparator (IC31). To prevent ACTIVE from being accidentally terminated by a noise pulse during the SIGNAL period, IC207 (4,5,6) "ands" the reset pulse with NOT SIGNAL before it reaches the reset pin of IC220. (The other half of IC220 is reset by LFC so that ACTIVE gets a fresh start every cycle of LFC.) The comparator output is translated to the -6 V/+8 V level by pins 9 and 6 of IC 215 before being applied to the logic circuitry.

Since the HFC and the LFC signals are normally not synchronized, there is up to 10 usec (the period of one 100kHz HFC cycle) uncertainty between the PGT of LFC and the PGT of ACTIVE.

ACTIVE (and NOT ACTIVE) are used as control signals on the main printed circuit board as well as an HFC gating signal on the DISPLAY BOARD.

6-5-5. SIGNAL

SIGNAL is a fixed time interval signal that is produced by counting the crystal controlled 100 kHz signal in IC405-408 on the DISPLAY BOARD.

If we assume that the 9,10,11,12,13 latch of IC225 is in the reset condition at the start of ACTIVE, then ACTIVE is "anded" in IC226, Pins 11,12,13, with Q of this latch to start SIGNAL (and via 11,12 of IC230 to produce NOT SIGNAL).

On the DISPLAY BOARD the Negative Going Transition (NGT) of LL is used to reset the counters (IC405 to IC408) to zero. IC402. Pins 9-13 and IC401, Pins 11,12,13 produce the negative going "clear" pulse. At the same time ACTIVE is turning on IC401, Pins 4,5,6 so that the counter can receive the 100 kHz HFC pulses at its "clock" input. Thus the counter starts its count with the PGT of HFC that follows the PGT of HFC that started ACTIVE. The SN74143 (IC405-408) counter has as NGT pulse that occurs on the count of 9. These pulses from IC405-IC407 are combined with the gated HFC in IC402 (Pins 1,2,3,4,5) to produce a positive going pulse that occurs 999-1/2 counts after the reset. This pulse is "stretched" and gated with SIGNAL (IC226, Pins 8,9,10) to produce the "clock" signal for the IC225 latch. This pulse from the display board is level shifted by pins 11 and 5 of IC 215 before being applied to the main board's logic circuits. (LFC is providing the "data" input, while "resetting" is accomplished at the end of each measurement cycle by LFC.)

The "clocking" of the latch (IC226) terminates SIGNAL and starts REFERENCE.

The actual duration of SIGNAL is very close to 9.99 msec. The difference is due to circuit delays of about 200 nsec (through IC402, CR401, R409, C403, IC 215 and IC226) and the lack of complete symmetry in HFC. The "extra" 1/2 cycle at the end of 999-1/2 counts is removed by the fact that the inversion of HFC in IC401 (4,5,6) allows the first count of IC405 to occur when SIGNAL is only a half a count wide.

In addition to its role as a switch control signal, the trailing edge (PGT) of SIGNAL reclears the IC405-IC408 counter so that it is prepared to count the REFERENCE interval.

6-5-6. REFERENCE

As outlined in the previous section the 999-1/2 count from the DISPLAY BOARD "clocks" the IC225 latch. When Q (Pin 13) of this latch goes high it combines with ACTIVE in IC226 (1,2,3) to form REFERENCE.

REFERENCE is terminated by the termination of ACTIVE which turns off the AND gate IC226 (1,2,3).

REFERENCE has a direct role in driving six of the CMOS switches listed in Table 3-1. In addition it plays an important part in setting the IC212/IC214/IC226 programming of IC219. This programming sets the frequency of HFC during the REFERENCE interval and hence the FULL SCALE capability of the V-A-W Meter.

6-5-7. LOAD LATCH PULSE, LL

The LOAD LATCH pulse, LL is formed in IC225, in which half of a CD4013 (Pins 1-5) is connected as a monostable multivibrator. The multivibrator is "clocked" (triggered) by the PGT of NOT ACTIVE that occurs at the end of ACTIVE and hence at the end of REFERENCE. The pulse width is approximately 60% of the R251, C251 product. Since the circuit is a monostable multivibrator it "resets" itself. The LL pulse appears at pin 1 of IC 225.

The LL pulse "moves" the counter output, at the end of REFERENCE, into the BCD latches and into the digit display driver latches within the SN74143's (IC405-408). If this "updating" is not desired, then grounding the HOLD input (IC401, Pin 10 and J3, Pin 9) prevents the LL pulse from reaching the counters. In the Model 258 the LL pulse is normally about 60 microseconds wide.

6-5-8. POLARITY SIGNALS

The positive Polarity Pulse, PP, and the Negative Polarity Pulse, NP, are generated in the Polarity Latch, IC231. The operation of the CD4013 with its dual Type D latches is similar to the description of the generation of ACTIVE. Both latches are reset by LFC. The latches are both clocked by the NGT that occurs on the 900th count during the SIGNAL period. This pulse is also level shifted between the DISPLAY board and the main board by pins 13 and 4 of IC215. IC238 (1,2,3) provides gating while C261, R261, D261, and IC230 (14,14) shape and invert the pulse. The latch "data" is the state of the comparator output at this instant. That is, the decision as to whether a positive or a negative signal is being fed into IC30 is made in a 1.5 usec interval 9 msec after the application of the signal.

The NP pulse causes the MINUS lamp to flash. The choice of NP or PP decides the polarity of the reference voltage (supplied by C29) that will be applied to the IC30 input during REFERENCE when measuring POWER or POWER X 10. Since the VOLTAGE and CURRENT readings must always be positive (except for zero input) the choice does not arise when measuring V or I.

IC222 (1,2,3,11,12,13), IC230 (4,5,9,10,14,15) provide inversions and gating necessary for the proper operation of the polarity latches.

6-6-0. DIGITAL CONTROL CIRCUITRY

The group of circuits discussed in this section receive dc signals from the FUNCTION switch and from the RANGE switches. They combine these inputs to produce the settings for the DECIMAL POINTS, the MILLIWATT lamp, the FULL SCALE readings, as well as to produce various other "housekeeping" signals necessary for the proper operation of the V-A-W meter. When the REMOTE or IEEE-488 bus options are installed then any headers in sockets IC206-206 must be replaced with 4019 CMOS integrated circuits. These units are AND/OR Select Gates that are activated by placing the FUNCTION switch in the REMOTE position. When these IC's are activated then the control information comes from the REMOTE board or from the IEEE-488 bus board rather than from the front panel switches.

6-6-1. DECIMAL POINT DECODING

IC192 is a 1024 Bit Programmable Read Only Memory (PROM) that has been programmed to provide the necessary decoding operations between the input RANGE and FUNCTION switches and the DECIMAL POINTS. IC202 has inputs on PINS 1-7 and 15 and outputs (labeled MILLIWATT on Drawing 2559) to the MILLIWATT lamp and the DECIMAL POINTS on the three right hand digits of the display. IC202 operates from the +5V power supply of the V-A-W Meter. R221 A-H provides a set of resistors to couple the +8/-6 volt logic outputs to the +5 volt level required by IC192 and IC193.

6-6-2. FULL SCALE DECODING

In drawing 25816 the outputs from the sockets IC206-206 are labeled indicating the FUNCTION or RANGE button that causes this output to go HIGH. This data is combined with the output of the front panel 5000/Calibrated switch and with the output of the FULL SCALE PROM, IC 193, to produce the control signals for the High Frequency Clock (HFC) generator, IC219, the drive signals for the switches contained in IC13 and IC10 and the POWER X 10 drive for one of the switches in IC9. During the REFERENCE interval the output of IC219 may be 100kHz, 200kHz, 250 kHz or 500kHz depending upon the FULL SCALE output desired. In the Digital Schematic the 3,4,5, and 6 pins of IC 193 are labeled as to the pin that is high for a given counting frequency.

These control signals then act upon IC212, IC214, and portions of IC238 and IC239 to control the division ratio of IC219 and hence to produce the desired value of HFC.

6-7-0. OVER AND UNDER RANGE CIRCUITRY

IC's 232 and 234 together with Q219 and IC207 (1,2,3) make up the sensing and driving circuitry that determine when the OUTPUT OVER RANGE lamp flashes and when the V, I readings are low enough that DISPLAY flashing (periodic blanking) should occur.

6-7-1. OUTPUT OVER RANGE

The 1,2,3,4,5 portion of IC234 forms a CD4013 monostable multivibrator similar to the Load Latch monostable, IC225. The monostable is "clocked" (triggered) by the PGT of NOT SIGNAL. That is, the monostable turns on at the end of SIGNAL which is the same as the beginning of REFERENCE. The pulse width is set by adjusting P252 or in an extreme case by changing C252 or R252.

The PGT of the Q is used as the clock for the 1,2,3,4,5 portion of IC232 (CD4013) operating as a normal latch. The "data" for this latch (Pin 5) is ACTIVE. Thus if ACTIVE is still present at the end of the monostable pulse then REFERENCE is deemed to have been too long and the OVER RANGE lamp is turned on via Q219. Since the IC232 latch is not reset until the beginning of SIGNAL the LED is on (when on at all) for between 70% and 80% of the time.

By adjusting P252 the OVER RANGE can be set to come on from about 10% above FULL SCALE to about 90% above FULL SCALE. It is normally set at the factory to come on at about 50% above FULL SCALE. Thus the output is still VALID when the lamp turns on but one is being warned that the limit of the usable region may be being approached.

6-7-2-. INPUT UNDER RANGE

The 9,10,11,12,13 portion of IC234 (CD4013) makes up a monostable multivibrator that senses whether the input reading is too low. The monostable is "clocked" (triggered) by the PGT at the end of NOT SIGNAL (the beginning of REFERENCE). The Q Output (Pin 13) of the monostable provides the "data" input (Pin 9) to the 9,10,11,12,13 portion of IC232 (CD4013) which functions as a normal latch. In this case the latch is "clocked" (pin 11) by the PGT at the end of ACTIVE (the end of REFERENCE). Thus if the monostable pulse is still there when ACTIVE ends then REFERENCE is assumed to be too short for a valid Voltage or Current reading. The latch output (Pin 3) is "anded" with the (V or I) signal from pin 4 of IC229 in IC207 (1,2,3) to produce a "blanking"

signal for the DISPLAY driver circuits in IC405-408 (pin 5 of each IC). The SN74143 (IC405-408) blanks when Pin 5 is HIGH. Resistor 236 is included to isolate the +8V "on" output of IC207 from the +5V logic of the SN74143. If IC207 is removed (or fails) or if R236 is removed (or fails) then the display will blank unless the common connection to Pin 5 on IC 405-408 is grounded.

P253 allows one to adjust the width of the "under-range" monostable pulse and hence the point at which UNDER RANGE blanking starts. Since the latch is reset by SIGNAL the display will normally be blanked for nearly 90% of the time, assuming that it is blanked at all. Blanking is normally set at the factory to occur at about 5% of FULL SCALE.

6-8-0. POWER SUPPLIES

The V-A-W Meter has six dc supply voltages. All supplies are well regulated to remove line voltage variations.

6-8-1. +5V SUPPLY

The +5V, 1 Ampere supply is produced by a full wave rectified, capacitor input dc supply feeding an LM340K-5 (or equivalent) regulator. This power supply feeds the DISPLAY board as well as IC202, and IC208 on the main printed circuit board.

6-8-2. ±15V SUPPLIES

The +15V supply is controlled by IC310 which is a u723 voltage regulator adjusted for a nominal output of +15V. The input to both the + and -15V supplies is a nominal +20V bridge rectifier/capacitor filter combination. The -15V supply is referenced to the +10V reference supply by the 1,2,3 amplifier in IC320 (LM1458) and the voltage divider R317, R318. Q311 (2N2905A) is the -15V pass transistor.

The ±15V supplies feed the multiplier (IC17), its output demodulator the square root circuitry, and various control potentiometers.

6-8-3. +8V and -6V SUPPLIES

The +8V supply is controlled by IC303 which is a u723 voltage regulator adjusted for a nominal output of +8V. The input to the +8V regulator is from the +20V bridge rectifier-capacitor source for the ±15V supply. The output of IC303 controls a rear panel, heat sink mounted pass transistor, Q305, that supplies the actual +8 V to the rest of the V-A-W meter.

The -6V supply is "mirrored" from the +8V supply via the 5,6,7 portion of IC320 (LM1458) and the voltage divider R307, R308. The rear panel, heat sink mounted pass transistor, Q304, for the -6V supply is fed from the -20V filter capacitor.

The +8V and -6V supplies are used by all CMOS logic circuits as well as by all the analog circuitry except the multiplier, its demodulator circuitry, and the square root circuitry.

6-8-4. +10V REFERENCE.

IC18 and P19 make up a +10 volt REFERENCE that is fed from the +15V supply. The output for this supply is available at a test point located behind IC224. This reference supply is used to provide a reference voltage to set the -15V power supply and to provide a reference for the square root circuitry. P19 allows a certain amount of adjustment of the reference voltage. DO NOT ADJUST THIS VOLTAGE WITHOUT CAREFUL READING OF THE CHAPTER ON CALIBRATION!

6-9 IEEE-488,REMOTE,ANALOG, ENERGY AND OTHER OPTIONS.

The Model 258 may have an optically isolated IEEE-488 bus card installed as an option. This option has a separate isolated power supply and is optically isolated from the bus control and data lines. This option allows the instrument to function as both a TALKER or a LISTENER. All of the RANGES and FUNCTIONS may be selected remotely via the bus. (At the present time the BUS can not control the front panel aA/B toggle switch).

Instead of the BUS the Model 258 may have an optically isolated set of boards installed that allow complete TTL compatible, "contract closure type" of REMOTE control and optically isolated readout of the BCD data equivalent to the display reading.

An isolated ANALOG output is available that provides an analog signal that tracks the display reading. This output is normally set to provide a 1.000 V output for a full scale reading. The nominal output impedance of this output is 1,000 ohms. Transmission to the optical output occurs via a PWM link that is up dated 10 times/second.

An isolated ENERGY output is available that provides a pulse output proportional to the display reading. Thus if the display reads 1000 digits for one hour one will get 1000 pulses from the ENERGY output during this period. If the V-A-W meter is set upon POWER and the reading is 10.00 watts then there will be 100 pulses per watt-hour. By bridging one of the divide by ten modules in the circuit one may obtain a ten times increase in sensitivity or resolution. If the V-A-W meter is set on CURRENT then the output is proportional to AMPERE-HOURS, etc.

A RACK MOUNTING kit is available for the Model 258.

IEEE-488 BUS OPTION FOR MODEL 258

INTERFACE LEVELS

SH 1	Source Handshake	Complete
AH 1	Acceptor Handshake	Complete
T 6	Talker	Basic Talker, Serial Poll, Unaddress if MLA
L 4	Listener	Basic Listener, Unaddress if MTA
SR 0	Service Request	None
RL 2	Remote Local	No Local Lockout
PP 0	Parallel Poll	None
DC 0	Device Clear	None
DT 0	Device Trigger	None

Full Scale switch on "CALIB."

Serial Poll returns "0" if the Model 259 is on "Local".

~~Serial Poll returns "4" if the Model 259 is on "Remote".~~

Full Scale switch on "5000".

Serial Poll returns "2" if the Model 259 is on "Local"

Serial Poll returns "6" if the Model 259 is on "Remote"

INPUT FUNCTIONS DEFINITIONS

I1	5 mA	V1	20 V
I2	50 mA	V2	200 V
I3	500 mA	V3	1000 V
I4	5000 mA		

F1	CURRENT
F2	VOLTAGE
F3	POWER
F4	POWER X 10

ACCEPTABLE COMMAND STRINGS:

- a) I1V2F4(CR)(LF) or I1V2F4(LF) or I1V2F4(E0I)
- b) F4V2I1(CR)(LF) or V2F4I1(CR)(LF)
- c) I1(CR)(LF); I2F4(CR)(LF)

As a TALKER the option supplies the four digit display reading with the sign and the decimal point. As a LISTENER the option will allow the choice of the CURRENT range, the VOLTAGE range, and one of the four FUNCTIONS. The serial poll (see above) supplies information as to LOCAL or REMOTE and as to the position of the 5000/CALIB switch. The BUS functions are OPTICALLY ISOLATED from the V-A-W meter functions.

VII. REPAIR AND ADJUSTMENT

- Like Grounding

7-0 INTRODUCTION

The V-A-W Meter is sometimes required to operate in hostile surroundings. The instrument has been designed to stand up in these conditions. In spite of these precautions accidents may happen or components may occasionally fail for no apparent reason. This chapter attempts to present a rational approach toward restoring the V-A-W Meter to service should failure occur.

If the trouble cannot be eliminated through the use of these instructions, please write or telephone our Service Department giving the instrument type number, the trouble, and the steps taken to remedy it. By return mail, or on the telephone, you will either receive simple instructions as to the cause and repair of the defect, or authorization to return the instrument (when covered by warranty) to our factory for repair or replacement.

Instruments no longer covered by our WARRANTY will be repaired or recalibrated after proper customer authorization is received to cover the estimated costs.

* * * * *

Printed Circuit Wiring

If it should be necessary to remove a wire or component from the printed circuit board, one should use reasonable care and a LOW wattage (less than 50 watt) soldering iron. (Soldering guns are NOT recommended.) High wattage irons may damage either the board or the wiring. A solder "snuffer" or a solder absorbent such as "Dri Wick" may be helpful in removing old solder before attempting to remount a component or to reconnect a wire.

* * * * *

In attempting any repair one should make maximum use of the instrument's own indicators as well as any information about past history that may indicate a likely area to explore for trouble. For example does the CURRENT section work while the VOLTAGE section does not operate correctly.

The V-A-W Meter has a visual digital DISPLAY as well as an OUTPUT OVER RANGE LED indicator. By observing the DISPLAY and the LED's as one switches through the FUNCTIONS and the RANGES, one can sometimes narrow down the possible sources of trouble.

A general strategy for dealing with a non-operative instrument is to check the POWER SUPPLIES (Section 7-1), then check the DIGITAL section (Section 7-4), then work through the ANALOG section. Unless the power supplies and the digital portions of the instrument are working properly the output of the analog section does not have a chance to reach the output display.

7-1. POWER SUPPLY VOLTAGES (Drawing 25818)

Once the top cover of the instrument has been removed (two screws on each side of the instrument) it only takes a moment to check the six power supply voltages. A test point for each voltage is indicated below. All of them occur on the rear 10 cm (4 inches) of the main printed circuit board; that is, back close to the various regulators. The range of acceptable values for the power supplies is listed in the table below:

Table 7-1. Acceptable Power Supply Values

<u>Nominal Value</u>	<u>Acceptable Range</u>	<u>Test Point</u>
+10	9.990 to 10.010	Behind IC224
+15	+14.5 to +15.3	Front of R 315
-15	-14.5 to -15.3	Rear of R 318
+ 8	+ 7.5 to + 8.1	Rear of R 305
- 6	- 5.5 to - 6.3	Rear of R 308
+ 5	+ 4.8 to + 5.2	Right of C 351B

If voltage is wrong, but not zero, try switching off the line power momentarily in case a brief short circuit has caused a supply to "latch-up" improperly.

If either the +8 V or -6 V supply is low while their corresponding 20 V input supplies are correct then either IC303 is defective or some IC is trying to draw excess current. Experience indicates that the CMOS switches -

CD4016 - are the most likely to have been "zapped" into a state that is causing them to draw more current than they should. Either a "touch test" may indicate the excessively hot culprit or a measurement of the voltage drop down the power supply leads may indicate the source of the difficulty.

Since the positive regulators, IC303 and IC310, are in sockets they may be interchanged BRIEFLY if one of them is suspected of being defective. They should be returned to their original sockets.

If the -15 V, the +8 V, or the - 6 V supply is zero then the corresponding pass transistor is a likely suspect. If both the negative supplies are inoperative then IC320 may be the source of the difficulty.

The -6 V supply can not operate properly unless the + 8 V supply operates properly. The +10 V supply can not operate unless the + 15 V supply operates. The -15 V supply can not operate unless the + 10 V supply operates.

Excessive ripple--at the line frequency instead of at twice it--will result from the failure (open) of any one of the diodes D301 to D306.

If IC removal is undertaken to remove an apparent cause of excess loading, one should take two precautions:

- (1) Turn off the power when removing and installing each Integrated Circuit.
- (2) Keep track of the position from which each IC is removed and restore it (if good) to the same position.

7-2. ANALOG SECTION - GENERAL

One may "trouble shoot" the VOLTAGE and CURRENT input stage for gross defects by using an AC voltmeter or an oscilloscope . With a full scale sinusoidal input to the lowest voltage channel one should get about 100 mV RMS at the output of the voltage box amplifier (Pin 5 of IC3) and about 625 mV RMS at the output of IC3 (left end of R3) (A 3-5 kohms "isolation" resistor may be necessary between the external probe or lead to prevent IC3 from oscillating when the voltage is being measured or observed).

With the "A" CURRENT button depressed and the FUNCTION switch on CURRENT and the input CURRENT toggle switch to the left then the application of a voltage of about 50 mV across the left hand BNC input should produce about 50 mV at the output of IC110 (the right end of R122) and about 625 mV at the output of IC2 (left end of R13) (again the "isolation" resistor may be necessary). Large (1 to 8 Volt) values for any of these voltages usually means a defective IC. Removal of the IC should remove the offending voltage. When removing IC's one should turn off the power. After checking the ICs one should return the good units to their original positions.

The final output of the ANALOG section is at the right end of R 56. With a full scale AC VOLTAGE input one should measure between 600 and 800 mV of DC at this point when the FUNCTION switch is on VOLTAGE and approximately zero on all other functions. Since the DC at this point is proportional to the SQUARE of the input voltage if one halves the input voltage to the instrument the measured value of the DC voltage should fall by a factor of four.

If these tests work but the DISPLAY is not correct then the problem must lie in the DIGITAL section or in the DISPLAY board. If the DISPLAY is suspected and two instruments are available one may trade the DISPLAY boards in either direction. The Model 259 and 258 have identical DISPLAY boards. The Model 255/256 display boards are slightly different however in a pinch they will probably give an indication of proper or improper operation.

7-3. MULTIPLIER / CHOPPER SECTION.

If the output is present at pin 10 of IC 2 and IC 3 but is not present at R 56 then the problem must lie in the multiplier, its chopping circuits, or the demodulator IC 16. With a low frequency AC input one can examine the signal at either end of R 9 or R 19. A chopped sine wave at the frequency of the input and with a somewhat negative average (about -1.2 V) value should be present at all four points. The waveshapes at all four points should be very similar. Any difference between the waveshapes probably indicates trouble with one of the switches in IC14 or IC15 or with their drive signals from IC 4.

With only a single input and the FUNCTION switch on POWER then the chopped signal should only be present at one of these resistors. (See Drawing 25814 for IC 13's connections.) If these waveforms are not present then check at the front of R 39 and R 37 for a +8 V/-6 V square wave at about 1700 Hertz. If the square wave gets to IC 17 but not to resistors 9 and 19 and if IC 17 is receiving its proper power supply voltages at pins 5 and 15 then IC 17 may have failed. (In our experience such a failure is very rare. DO NOT REPLACE IC17 UNLESS YOU ARE QUITE CERTAIN THAT IS NO LONGER FUNCTIONING)

The output of IC 17 can be examined by removing IC 9 and inserting a 30 kohm resistor from pin 2 of the socket to the GROUND test point. With a low frequency AC VOLTAGE input and the FUNCTION switch on VOLTAGE there should be a chopped sine wave visible across this resistor. With the FUNCTION switch moved to POWER (and assuming that there is no CURRENT input) the chopped signal should vanish. If these waveforms are all present but there is still no output at R 56 then either IC 9 or IC 16 must have failed. If an external voltmeter is used to monitor the expected DC output at the right end of R 56 (about 750 mV) for a full scale input) then IC 254 may be substituted for IC 9. Removing this IC will of course prevent the latter portion of the V-A-W Meter from operating properly.

Table 7-6.

Table of Internal Adjustments

MAIN PRINTED CIRCUIT BOARD

P1	Voltage Channel Gain Control
C1	Voltage Channel Frequency Adjustment
P11	Current Channel Gain Control
C11	Current Channel Frequency Adjustment
P14	Power x 10 Gain Adjustment
P15	Overall ZERO Adjustment
P16	Power x 10 ZERO Adjustment
P19	+10 Volt Reference Supply Adjustment
P30	"High"/"Low" ZERO Adjustment
C25	Power x 10 Phase Adjustment - Left Hand
C26	Power Phase Adjustment - Left Hand
C27	Power X 10 Phase Adjustment - Right Hand
C28	Power Phase Adjustment -Right Hand
P58	Overall GAIN Control
P66	Overall Voltage/Current Gain Control
P74	Voltage/Current "1/10 Scale" Adjustment
P84	Power "Full Scale" Adjustment
P110	B Current Range Gain Control
P111	5B Current Range Gain Control
P112	5A Current Range Gain Control
P113	A Current Range Gain Control
P120	5A Current Range Zero Control
P121	B Current Range Zero Control
P122	5B Current Range Zero Control
P123	Left Hand Voltage Range Zero Control
P124	Middle Voltage Range Zero Control
P125	Right Hand Voltage Range Zero Control
P126	A Current Range Zero Control
P127	Power Zero Control
P252	Output Overload Level Control
P253	Voltage and Current Under-range Flashing Control

CURRENT TERMINATION BOARD

P101	A and 5A Input Impedance Adjustment
P105	B and 5B Input Impedance Adjustment

VOLTAGE ATTENUATOR BOARD

C133	Voltage Frequency Compensation
P138	100 V Range Adjustment
P140	200 V Range Adjustment

7-4. INTEGRATOR/COMPARATOR/ "DIGITAL" SECTION

For testing purposes the Model 258 may be split into TWO parts at R56. First check that the right end of R81 has a DC voltage between 0.65 and 0.85V. If it does then proceed, if it does not then deal with IC 20 and its surrounding circuitry to solve this problem. If an "Easy Hook" type of lead is connected from the right end of R81 to the left end of R 56 (both of these resistors are in the fourth column of components from the left side of the board.) then all the FUNCTION / RANGE combinations should read approximately their FULL SCALE values. In each case the decimal point should be in the appropriate position.

If the proper displays are NOT obtained then using an oscilloscope to examine the waveshapes of Figure 4-4-3 (synchronize with the positive going transition of the LFC signal) should provide some clues as to which portion of the circuit is not functioning properly.

The signal at the right end of R75 is often particularly instructive. For the VOLTAGE and CURRENT cases this waveshape is shown in Figure 6-4-3. For the POWER case it should go positive about 700 millivolts for 10 milliseconds then negative the same amount for the same length of time.

If trouble is suspected in the CLOCK or DIGITAL circuits then leave the Model 258 in this "split" condition while examining those circuits. Test points are listed below for the waveshapes SIGNAL, ACTIVE, REFERENCE, LFC, HFC, and LL.

Location of Test Points

WAVESHAPE	LOCATION
SIGNAL	Behind IC 226
ACTIVE	Beside IC 226)Pin7)
REFERENCE	Beside IC 226(Pin3)
LFC	Beside IC 233
HFC	Rear of R214
LL	Front of R246

7-5 ADJUSTMENT PROCEDURE AFTER IC REPLACEMENT IN THE ANALOG SECTION.

Table 7-6 lists all the internal controls in the V-A-W Meter. Hopefully you as a user will never need to touch any of them. The basic adjustments of most of these controls has been covered in the CALIBRATION sections of the manual and will not be repeated here.

7-6 HIGH/LOW VOLTAGE AND CURRENT "ZERO" ADJUSTMENT.

In addition to all the separate zero controls for each current or voltage range there is an additional potentiometer, P30, that allows the Model 258 digit "zero" adjustments to be made with the HIGH/LOW front panel switch in the LOW position and then a "touch-up" adjustment to be made in the HIGH position with the additional potentiometer.

This control, P30, is located in the front right hand corner of the main printed circuit board. After the all the voltage and current ranges have been adjusted for a 250 digit reading - assuming that a voltage or current input of 1/20th of FULL SCALE has been applied and that the 5000/CALIB. switch is in the 5000 position - then the HIGH/LOW switch is moved to the HIGH position and P30 is adjusted to restore the reading to 250 digits.

In general this adjustment should only be required if IC-3 or IC-9 have been replaced. If a "large" adjustment is required then one would suggest that a different IC be tried as the replacement unit. If either IC-3 or IC-9 is changed it may be necessary to reduce the value of the 1.5 megohm resistor (R31) located vertically beside P19 before the adjustment described above is possible.

VIII. REPLACEMENT PARTS.

8-1. INTRODUCTION

This section contains a list of replacement parts for the Digital V-A-W Meter and the names of the typical manufacturers of such parts. Any replacement parts may be obtained from CLARKE-HESS. To obtain a part include:

- a. The circuit reference number of the part.
- b. Brief description of the part.
- c. Instrument model and serial number.
- d. Quantity desired.

6-2. LIST OF MANUFACTURERS

The following list contains the key to the abbreviations in the parts list. The list presents both the name and the address of the manufacturer as well as the code numbers (where applicable) for the manufacturers as listed in the Federal Supply Code for Manufacturers Cataloging Handbooks H\$-1 (Name to Code). The list order is Abbreviations/Federal Supply Code Number/Company Name/Company City and State.

Abb.	F.S. Code	Company Name	Company Address
AB	01121	Allen-Bradley	Milwaukee, Wisc.
AL	95146	Alco Electronic Products	Lawrence, Mass.
AMP	02660	Amphenol Borg Electronics	Broadview, Ill.
AM	00779	Amp Inc.	Philadephia, Pa.
AR	84171	Arco Electronics	Great Neck, N.Y.
BE	70903	Belden Mfg. Co.	Chicago, Ill.
BK	73138	Beckman Instruments Corp.	Fullerton, Ca.
BU	71400	Bussman Div., McGraw Co.	St. Louis, Mo.
BY	-	Buckeye Stamping Co.	Columbus, Oh.
CA	-	Caddock Electronics Inc.	Riverside, Ca.
CM	71744	Chicago Miniature Lamp	Chicago, Ill.
CD	14655	Cornell Dubilier Elect.	Newark, N.J.
CE	71590	Centralab Div, Globe-Union	Milwaukee, Wisc
CH	34423	Clarke-Hess Comm. Research	New York, N.Y.
CG	14674	Corning Glass Works	Corning, N.Y.
CL	12697	Clarostat Mfg. Co.	Dover, N.H.
ER	72982	Erie Tech. Products Inc.	Erie, Pa.
EJ	74970	E. F. Johnson Co.	Waseca, Minn.
FR	07263	Fairchild Semiconductor	Mountain View, Cal.
GE	03508	General Electric Semicon.	Syracuse, N.Y.

ABB.	F.S. Code	Company Name	Company Address
HP	28480	Hewlett-Packard	Palo Alto, Ca.
HH	83330	Herman H. Smith Inc.	Brooklyn, N.Y.
IR	18486	TRW Electronics Comp. Div.	Des Plaines, Ill.
KE	-	Kemet Div., Union Carbide	Greenville, S.C.
MA	37942	P. R. Mallory & Co.	Indianapolis, Ind.
MO	04713	Motorola Semiconductor	Phoenix, Ariz.
NA	10204	National Semiconductor	Santa Clara, Cal.
OH	44655	Ohmite Mfg. Co.	Skokie, Ill.
RA	02735	RCA, Semiconductors	Somerville, N.J.
RN	-	Robinson Nugent Inc.	New Albany, Ind.
SC	-	Schauer Mfg. Co.	Cincinnati, Oh.
SI	-	Signal Transformer Inc.	Inwood, N.Y.
SP	56289	Sprague Electric Co.	North Adams, Mass.
SW	82389	Switchcraft Inc.	Chicago, Ill.
SY	93332	Sylvania Semiconductor	Woburn, Mass.
TE	-	Teledyne Semiconductor	Mt. View, Ca.
TI	01295	Texas Instr. Transistors	Dallas, Texas
TR	84411	TRW Capacitor Div.	Ogallala, Neb.
UC	05397	Union Carbide Corp., Elect.	New York, N.Y.
WK	05820	Wakefield Engrg. Inc.	Wakefield, Mass.

8-3. CHASSIS, CASE, CONNECTORS, AND MAJOR COMPONENTS

Circuit Ref.	Description	Mfr.	Type or Part. No.
	Front Dress Panel	CH	CH-25807
	Rear Panel	CH	CH-25808
	Dummy Panel	CH	CH-25809
	Side Chassis	CH	CH-25810
	Cover (Top and Bottom)	CH	CH-25811
	Voltage Box	CH	CH-25820
	Covers for Voltage Box	CH	CH-25821
	Cover Plates	CH	CH-25822
	Main Printed Circuit Board	CH	CH-25880
	Current Termination Board	CH	CH-25880
	Voltage Attenuator Board	CH	CH-25882
	Display Board	CH	CH-25883
SW3,4,5	Toggle Switch	AL	MST-205N
SWI-4t	4 Section DPDT Pushbutton Switch	CH	CH-25890
SW8-7	3 Section DPDT Pushbutton Switch	CH	CH-25891
SW200,	Rotary FUNCTION Switch 5 Position	CH	CH-25892
J1	Connector Assembly, 0.156" Center Spacing	AM	583660-8
X301	Transformer	SI	DP241-8-16
X303	Transformer	SI	DP241-4-36
	Line Cord	BE	17250
	Line Cord Receptacle	SW	EAC-301

Circuit Ref.	Description	Mfg.	Type or Part No.
	Knob	BK	SS70-BL-2
	Fuseholder	BU	HKP
F301	Fuse	BU	AGC $\frac{1}{2}$
T110-112	Input Terminals	HH	1517
J101,102	Isolated BNC Connectors	AM	227222-1

8-4. VOLTAGE BOX PARTS LIST.

R130	1 Megohm, 0.1%, 1.25 W Resistor	CA	TF050
R132	4990 ohm, 1%, $\frac{1}{4}$ W Resistor	ME	5023Z
R135	147 ohm, 1%, $\frac{1}{4}$ W Resistor	AB	RN55D
R136	73 ohm, 1%, $\frac{1}{4}$ W Resistor	AB	RN55D
R137	10 ohm, 1%, $\frac{1}{4}$ W Resistor	AB	RN55D
R138	750 ohm, 1%, $\frac{1}{4}$ W Resistor	ME	5023Z
R139	200 ohm, 1%, $\frac{1}{4}$ W Resistor	ME	5023Z
R140	825 ohm, 1%, $\frac{1}{4}$ W Resistor	ME	5023Z
R141	100 ohm, 1%, $\frac{1}{4}$ W Resistor	ME	5023Z
C132	47 pF, Mica Capacitor	CD	DM15-470J
C133	3-12 pF Variable Trimmer	ST	10S-TRIKO-22
C136,137 138,139	0.1 uF, 25 V Disc Capacitor	CE	UK25-104
P138,140	100 ohm, single Turn Trimmer	BK	72PMR-101
IC 130	Unity Gain Buffer	PM	BUF03
IC131	Quad CMOS Switch	RA	CD4016BE

8-5. CURRENT TERMINATOR BOARD PARTS LIST

(Values depend upon the Current Transformers Supplied.)
 (Values below are for the 50.0 ohm input impedance cases.)

R101-104	191 ohm, 1/2 W 1% resistors	TR	RN60C
RR105-108	191 ohm, 1/2 W 1% resistors	TR	RN60CT
P101-105	100 ohm, Single Turn Pot.	BK	72PMR-101

8-6. ANALOG SECTION PARTS LIST

Resistors

Circuit Ref.	Description				Mfg.	Type or Part No.
	Ohms/Tolerance/Power/Type **					
R1	1820 1%	$\frac{1}{4}$ W	MF	AB	RN55C	
R2,12	2150 1%	$\frac{1}{4}$ W	MF	AB	RN55D	
R3,13	10.0k 1%	$\frac{1}{4}$ W	MF	AB	5023Z	
R4,14	23.2k 1%	$\frac{1}{4}$ W	MF	CG	RN55D	
R6,16	645 k 1%	$\frac{1}{4}$ W	MF	CG	RN55D	
R7,17	23.2K 1%	$\frac{1}{4}$ W	MF	CG	RN55D	
R8,18	5490 1%	$\frac{1}{4}$ W	MF	MP	5023Z	
R9,19	12.1 k 1%	$\frac{1}{4}$ W	MF	MP	5023Z	
R11	750 1%	$\frac{1}{4}$ W	MF	AB	RN55C	
R20,21	80.6 k 1%	$\frac{1}{4}$ W	MF	MP	5023Z	
R22,23	82 M 5%	$\frac{1}{4}$ W	CF	AB	CB	
R24	121 k 1%	$\frac{1}{4}$ W	MF	CG	RN55D	
R25	12.1k 1%	$\frac{1}{4}$ W	MF	MP	5023Z	
R26	4.99k 1%	$\frac{1}{4}$ W	MF	CG	RN55D	
R28	1910 1%	$\frac{1}{4}$ W	MF	MP	5023Z	
R29	1000 1%	$\frac{1}{4}$ W	MF	CG	RN55D	
R30	13.3k 1%	$\frac{1}{4}$ W	MF	AB	RN55D	
R31	1.5 M 5%	$\frac{1}{4}$ W	CF	AC	CB	
R37, 38, 39, 40	10.0 k 1%	$\frac{1}{4}$ W	MF	CG	RN55D	
R50	499k 1%	$\frac{1}{4}$ W	MF	CG	RN55D	
R51	80.6 k 1%	$\frac{1}{4}$ W	MF	CG	RN55D	
R56	49.9 k 1%	$\frac{1}{4}$ W	MF	MP	5023Z	
R58	499 k 1%	$\frac{1}{4}$ W	MF	CG	RN55D	
R65	25 k 1%	$\frac{1}{4}$ W	MF	MP	5023Z	
R68	20 k 1%	$\frac{1}{4}$ W	MF	MP	5023Z	
R69	49.9 k 1%	$\frac{1}{4}$ W	MF	MP	5023Z	
R70	36 k 5%	$\frac{1}{4}$ W	CF	AB	CB	
R71	200 k 1%	$\frac{1}{4}$ W	MF	CG	RN55D	
R72	100 k 1%	$\frac{1}{4}$ W	MF	CG	RN55D	
R73A or B	221 k 1%	$\frac{1}{4}$ W	MF	CG	RN55D	
R75	10.0 k 1%	$\frac{1}{4}$ W	MF	MP	5023Z	
R77	1 M 5%	$\frac{1}{4}$ W	CF	AB	CB	
R78	100 k 5%	$\frac{1}{4}$ W	CF	AB	CB	
R79	5760 1%	$\frac{1}{4}$ W	MF	CG	RN55D	
R80	510 5%	$\frac{1}{4}$ W	CF	AB	CB	
R81	1000 5%	$\frac{1}{4}$ W	CF	AB	CB	
R82	499 1%	$\frac{1}{4}$ W	MF	AB	RN55D	
R83	10.0 k 1%	$\frac{1}{4}$ W	MF	MP	5023Z	
R85	750 1%	$\frac{1}{4}$ W	MF	MP	5023Z	

** MF = Metal Film, CF = Carbon Film

Circuit Ref.	Description	Mfg.	Type or Part No.
R110, 113	1000 1% $\frac{1}{4}$ W MF	AB	RN55C
R111, 112	147 1% $\frac{1}{4}$ W MF	AB	RN55C
R126, 128	82 M 5% $\frac{1}{4}$ W CF	AB	CB
R127	1 M 5% $\frac{1}{4}$ W CF	AB	CB
R177, 178	634 1% $\frac{1}{4}$ W MF	AB	RN55D

Capacitors

Circuit Ref.	Description	Mfg.*	Type or Part NO.
C1, 11	Trimmer 3-12pF	EJ	275-0012-005
C2, 7#	Mica 7pF 5%	AR	DM15-050J
C4, 8,	Tantalum 100 uF 10V	KE	K100E6
C10	Disc 1000pF 25V	CE	UK25-102
C12, 16	Film 1uF 100V	FD	MPC13 1.0
C13	Mica 22pF 5%	AR	DM15-220J
C14	Mica 56pF 5%	AR	DM15-560J
C15	Mica 220pF 5%	AR	DM15-221J
C17	Mica 68pF 5%	AR	DM15-680J
C18	Disc 1000pF 5%	SP	Type DD
C19	Disc 470pF 5%	CE	Type DD
C20	Disc 0.01uF 100V	SP	TG-S10
C21	Mica 750pF 5%	AR	DM15-751J
C23A, 23B	Tantalum 10uF 16V	KE	K10E16
C25, 27	Trimmer 8-40pF	EJ	275-0040-005
C28	Trimmer 3-12pF	EJ	275-0012-005
C29, 30, 40, 41	Tantalum 10uF 25V	KE	K10E25
C42	Disc 0.1uF 25V	CE	UK25-104
C46	Mica 5 pF	AR	DM15-5R0J C48
Mica 22 pF		AR	DM15-220J
C50	Tantalum 10uF 16 V	KE	K10E16
C51, 52, 53	Tantalum 1uF 35V	KE	K1E35
C54, 55	Disc 0.1 uF 25 V	CE	UK25-104
C61, 62	Disc 0.1 uF 25 V	CE	UK25-104
C110, 177, 178	Disc 0.1uF, 25V	CE	UK25-104

Integrated Circuits

IC1, 2	Wideband Op Amplifier	HA	HA2540
IC3	CMOS Astable Multivibrator	RA	CD4047BE
IC4	CMOS Dual Latch	RA	CD4013BE
IC9, 10, 13, 14	Quad FET Switches	RA	CD4016BE
15			

IC16	DC Stabilized Op Amplifier	IN	IN7650
IC17	Multiplier	MO	MC1594
IC18	10 V Reference	TE	REF-01
IC20	Dual Op Amplifier	NA	LM1458N
IC30	FET Input Op Amplifier	RA	CA3130S
IC31	Comparator	NA	LM311N
IC110	Unity Gain Buffer	PM	BUF03

Transistors and Diodes.

D3	Silicon Diode	TI	IN914B
Q16-18, 24	NPN Transistor	TI	2N3904

8-7. POTENTIOMETERS - MAIN BOARD

(P101, 105, 138, 140 listed in Sections 8-5, and 8-4)

P1, P11	200 ohms	Twenty Turn Cermet	AB	MT=2W-201
P14	500 ohm	Twenty Turn Cermet	AB	MT-2W-501
P15, 16 19, 30	100k ohms	Twenty Turn Cermet	AB	MT-2W-104
P58	1 Meg ohm	Twenty Turn Cermet	AB	MT-2W105
P66	10k ohms	Twenty Turn Cermet	AB	MT-2W-103
P74	100 ohms	Single Turn Cermet	BK	72PMR101
P84	500 ohms	Twenty Turn Cermet	AB	MT2W-501
P110- 113	100 ohm	Single Turn Cermet	BK	72PMR101
P120- 127	1000kohm	Twenty Turn Cermet	AB	MT2W-104
P252	100kohm	Single Turn Cermet	BK	72PMR104
P253	250kohm	Single Turn Cermet	BK	72PMR250K

8-9. DIGITAL SECTION PARTS LIST

Resistors

All resistors in this section have the following characteristics unless otherwise specified: Tolerance - 5% ; Power - $\frac{1}{4}$ W ; Carbon Film; Allen Bradley Type CB. Others are Metal Film

Circuit Ref.	Description Ohms/Tolerance/Power/Type **	Mfr.*	Type or Part No.
R201,202, 203,204 205,214	10k		
R218	1910 1% $\frac{1}{4}$ W MF	AB	RN55D
R221A-H	10k 2% DIP Package	DA	
R226,228	4300		
236			
R240	10k		
R241,242	510		
R246	4300		
R250	47k		
R251	665k 1% $\frac{1}{4}$ W MF	AB	RN55D
R252	150k 1% $\frac{1}{4}$ W MF	AB	RN55D
R253	549k 1% $\frac{1}{4}$ W MF	AB	RN55D
R261	3300		
R266	1600		
R267A-E	2200 2% SIP PACKAGE	DA	

Capacitors

Circuit Ref.	Description	Mfr.*	Type or Part No.
C215	39 pF, 5%, Mica Capacitor	AR	DM15-390J
C218	47 pF, 5%, Mica Capacitor	AR	DM15-470J
C216,230	0.1 uF, 25 V, Disc Capacitor	CE	UK25-104
C219,234	10 uF, 25 V Tantalum Capacitor	KE	K10E25
C239	0.01 uF, 100 V Disc Capacitor	SP	TS-S10
C240	0.1 uF, 100 V Disc Capacitor	CE	UK25-104
C241,242	1000 pF, 25 V Disc Capacitor	SP	125LD10
C246	1000 pF, 5% Mica Capacitor	AR	DM5-102J
C251	130 pF, 5% Mica Capacitor	AR	DM15-131J
C252	0.1 uF, 25 V Disc Capacitor	CE	UK25-104
C253	1800 pF, 5% Mica Capacitor	AR	DM15-182J
C261	1000 pF, 25 V Disc Capacitor	SP	125LD10

* See Section 8-2 for Mfg.

Diodes and Transistors

Circuit Ref.	Description	Mfg.*	Type or Part No.
D201, 202 D210	High Speed Diode	TI	1N914B
Q210, 219	NPN Transistor	NA	2N3904

Integrated Circuits

IC200	Hex Inverter	RA	CD4049BE
IC201	Quad, 2 Input OR	RA	CD4071BE
IC192	1024-bit PROM	CH	CH-258192
IC193	1024-BIT PROM	CH	CH-258193
IC204-206	Quad AND/OR Select Gates	RA	CD4019BE
IC207, 211	Quad, 2 Input AND	RA	CD4081BE
IC212	Quad, 2 Input AND	RA	CD4081BE
IC214	Quad, 2 Input OR	RA	CD4071BE
IC215	Quad Driver	RA	CD4054BE
IC218	Hex Inverter	RA	CD4049BE
IC219	Divide by N Counter	RA	CD4018BE
IC220, 225	Dual Latch	RA	CD4013BE
IC222, 226	Quad, 2 Input AND	RA	CD4081BE
IC224	Level Translator	RA	CD4054BE
IC229, 230	Hex Inverter	RA	CD4049BE
IC231, 232, 234	Dual Latch	RA	CD4013BE
IC233	Divide by N Counter	RA	CD4018BE
IC238	Quad, 2 Input OR	RA	CD4071BE
IC239	Quad, 2 Input AND	RA	CD4081BE
IC250, 251, 254	Quad Switch	RA	CD4016BE

8-10 DISPLAY BOARD PARTS LIST

Circuit Ref.	Description	Mfr.*	Type or Part No.
IC401	Quad, 2 Input Open Collector NAND Gates	TI	SN74LS03
IC402	Dual, 4 Input NOR Gates	RA	CD4002BE
\$54 ⁰⁰ - IC405, 406 407, 408	Counter, BCD Latch, Seven Segment LED Driver	TI	SN74143N (12)
# 30 ²⁰ - IC409, 410, 411, 412	Seven Segment Display	HP	5082-7650

* See Section 8-2 for Mfg.

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