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DEVELOPMENT OF A WIDEBAND WATTMETER AS A LABORATORY INSTRUMENT

BY

L. GENE LANDES and YEN YEH LIU

August 1971

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Chicago, Illinois

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16. Abstract

A portable, solid state, wideband wattmeter has been developed as a general purpose type of laboratory instrument. Its circuit and component investigations and evaluation data are presented. A prototype unit was used extensively, and served as the basis for a second instrument incorporating refined circuitry and improved packaging.

The wattmeter provides true four quadrant operation which permits instantaneous indication of real power as an oscilloscope display. Major performance factors are: frequency bandwidth DC to 1 MHz ± 1 dB; current range 10 mA to 100 amperes peak; voltage range 1 volt to 1000 volts peak; accuracy ± 2% of full scale reading. Oscilloscope data for typical switching transients in a transistor inverter circuit are included.

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DEVELOPMENT OF A WIDEBAND WATTMETER AS A LABORATORY INSTRUMENT

By Gene Landes and Yen Yeh Liu

Barnes & Reinecke, Inc.
Chicago, Illinois

SUMMARY

A portable, solid state, wideband wattmeter has been developed as a general purpose type of laboratory instrument. The unit provides true four quadrant operation which permits instantaneous indication of real power as an oscilloscope display. Major performance factors are: Frequency Bandwidth DC to 1 MHz ± 1 DB; Current Range 10 mA to 100 amperes peak; voltage range 1 volt to 1000 volts peak; accuracy ± 2% of full scale reading.

INTRODUCTION

Many switching and pulse circuits generate spikes during their transition or switching time. This transient power may be of great significance and should be taken into account to avoid catastrophic failures in the active devices. Therefore, the wattmeter which has been developed will provide very useful information of electronic circuits and components. A few possible applications are semiconductor components, transformers, inductors and capacitors which carry currents with abruptly changing waveforms.

CIRCUIT-COMPONENT INVESTIGATION

All known multiplication techniques (Refs. 1, 2 and 3) were considered along with suitable "state of the art" components in order to ascertain which methods to consider for final evaluation and design. Major findings are stated under the following appropriate topic headings.

Multipliers. - Some of the more promising multipliers which have been considered are listed in Table 1. The G. P. S. Model MU407, a quarter square multiplication type unit, has the best full-scale accuracy but

TABLE 1. MULTIPLIER EVALUATION TABLE

ANALOG MULTIPLIER	Input	Linearity 20–30°C	Scale Factor Temp. Co-ef.	Full Scale Accuracy	Abs. Error due to Ø Shift	Freq. Resp.	Tem. Co-ef. of Output Offset	Output Offset	Power Sup. Sens.
DESIRED SPECS →	± 10 volts	0.2% (1.0 Max.)			.2% at 1 MHz	1 dB out for 2 MHz out	10mV/°C Max.	100mV/Max.	50mV/V Max.
VENDOR AVAILABLE									
Intronics M502	± 10	0.5%	0.02%/°C	± 0.5%		3 dB at 3MHz	1mV/°C	trim to 0	50mV/V
M510 (Not available at this time)	± 10	1.0%	0.02%/°C	± 1%		3 dB at 10 MHz	1mV/°C		50mV/V
Hybrid Systems Corp. 105	± 10	0.25%	0.02%/°C	± 1%		3 dB at 10 MHz	1mV/°C	trim to 0	50mV/V
G.P.S. Corp. MU4060 (Not available at this time)	± 10		0.02%/°C	0.0%	1° at 150 kHz	3 dB at 5 MHz	3mV/°C	trim to 0	
Motorola MC1595	± 10	3.0%		0.75%	1% at 30 kHz	3 dB at 3 MHz	20nA/°C	50 μA Max.	15 mV/V
G.P.S. Corp. MU407	± 10		0.015%/°C	± 0.05%	1° at 30 kHz	0 dB at 1 MHz	0.5mV/°C		
Bell "Hall-Pak" HM4000	50nA– 2.5A & 0.33A			0.7%		DC – 500 kHz	0.1%/°C		
Bell "Hall-Pak" HM4500	5A –40A & 0.33A			0.7%		DC – 500 kHz	0.1%/°C		
Burr-Brown 4094/15C	± 10V	± 0.5%	± 0.1%/°C	± 1%		3 db at 1.5 MHz			± 100 mV/V
Analog Devices 422	± 10V	± 0.7%	± 0.03%/°C	± 0.7%	1° at 1 MHz	3 dB at 5 MHz	± 2mV/°C	± 25mV	± 1 mV/%

is unsatisfactory in phase shift and full output amplitude response at 1 MHz. It is satisfactory at low levels (about 1 volt).

Hybrid systems model 105 was found to be completely satisfactory for all specified conditions. Maximum amplitude error noted was 0.5% at full output in the third quadrant operation. The maximum frequency error noted was 0.8% for 1 MHz input to both X and Y. This unit was, therefore, chosen for use in the final wattmeter model. All other devices considered, including Hall systems, were found lacking in either accuracy or frequency response.

In order to minimize offset and drift problems in the multiplier, it should be operated in the 1 to 10 volt range for both X and Y. Additional circuits and components have been evaluated and designed with this as a requirement.

Voltage Sensing. - Coupling of the input voltage to the wattmeter is not a problem over the lower specified range of 1 to 10 volts. The 10 to 1000 volt range presents some challenge because of the high common mode voltage and the gain-bandwidth requirement. Several solid state amplifiers are available with about 115 volts common mode voltage rating but only 1 MHz or less gain-bandwidth product.

It is apparent that resistive attenuators must be used to reduce the highest voltage input to a safe common mode level. An amplifier must then be used with a gain-bandwidth product greater than 1 MHZ in order to make up the gain loss. One suitable unit is the Burr-Brown 1555/25 which will deliver 1 MHz full power in a closed loop gain of ten circuit.

Current sensing. - The requirement is for a clamp-on probe that will sense 1 mA to 100 amperes over the DC to 1 MHz frequency range. A number of techniques and some commercial sensors cover portions of this requirement - but not all parts simultaneously. Some of the major sensors or systems considered included:

Probe Type	Limiting Specification or Problem Area
P6042 Tektronix	0-10 amps
428B H.P.	0-10 amps DC-400 Hz
1110A H.P.	0-50 amps 50 Hz - 20 MHz
DC current transformer	DC - 1 kHz; non-linearity
Magnetic Modulator	DC - 1 kHz; micro inch mechanical tolerances
Sony magneto diode	DC - 1 kHz; 2% lin. 100 mA – 100 amps
Hudson magnistors	DC - 1 kHz; 2% lin. 1 — 10 amps

No one probe or sensor covers the entire frequency and current bands. The Tektronix P6042 easily covers the DC to 1MHz frequency range but does not cover the 10 to 100 amperes range. Attempts to procure an extended range unit were unsuccessful.

The DC current transformer and magnetic modulators have been used for years as current measuring devices in power and audio circuits. Miniature units were made up (for evaluation) with a butt gap for a clamp-on probe application. Leakage flux is a serious problem with either design. Mechanical tolerances in the microinch range and repeatability of them with opening and closing of the probe are also a major design problem. Neither problem occurs in normal closed magnetic circuit designs.

Solid state sensors, Sony magneto diodes and Hudson magnistors, were also evaluated. DC stability and noise were more of a problem on the latter item below 1 ampere level. The former item was found useful over a range of 100 ma to 100 amperes in a ferrite core magnetic circuit. Mechanical tolerances are not as critical as for the previous sensors. This is because of the larger air gap.

Since extensive development work on the Sony magneto diode probe was likely, the two contract items were completed using the Tektronix P6042 probe and a coaxial shunt as current sensors to cover the desired ranges.

Amplifiers. - Wideband voltage amplifiers are needed to amplify the current or voltage sensor signals to the 1 to 10 volt multiplier input level. The voltage amplifier requirement is for a gain of 10. Therefore, the gain-bandwidth requirement is greater than 20 MHz.

Since the overall wattmeter response is to be DC to 1 MHz within 1 dB, the amplifier response must be appreciably better. At the time of this writing suitable amplifiers were:

Source		Unity Gain-Bandwidth	Cost
Burr-Brown	3260/25	20 MHz	$95
Burr-Brown	3341/15C	50	69
DDC	VA-23	100	125
Intronics	A501	100	105

The DDC unit is somewhat superior to the other units. For this particular application, a unit such as the Burr-Brown 3341/15C is quite adequate. Two of these units are required in cascade to meet the current signal amplifier requirements.

FIRST UNIT; CIRCUIT AND PACKAGE DESIGN

A simplified diagram of the first wattmeter configuration is shown on Figure 1. Amplifier A1 is a differential voltage amplifier and with suitable range switching covers the 1 to 1000 volt range. A3 amplifies the output of A1 to the desired 1 to 10 volt range and drives the multiplier X input. Amplifier A2 is a differential amplifier for the current shunt signal. It is followed by two single ended amplifiers, A4 and A5, which raise the signal level to the desired 1 to 10 volts for the multiplier Y input. When the Tektronix P6042 probe is used, only amplifier A5 is needed.

A detailed schematic of the entire wattmeter circuit is shown on drawing 1-8108-110A in Appendix C. This includes ranging and calibration circuits. Ranging circuits are at the first amplifier inputs for both voltage and current signals in order to prevent overloads at the high signal levels. Accidental overvoltage input is prevented by the zener diode clamps CR1-4, at the inputs.

Calibration circuits are also provided at the A1 and A2 inputs. They are designed to exercise all amplifiers and the multiplier at 1, 1/2 and full scale at the X and Y inputs for both DC and AC signals. Calibration is not provided at the actual voltage or current shunt input terminals because of the impracticality of providing up to 100 amperes and 1000 volts in a small laboratory instrument.

The package design, of the unit, required careful consideration and some compromises for the prime objectives of (a) good human engineering controls, servicing, assembly (b) good performance; low lead wire capacitance to ground and other circuits. Panel controls were grouped by function; voltage, current and calibrate. Then a rear vertical chassis was designed to locate all parts in close proximity to their associated switches or amplifier modules.

SECOND UNIT; CIRCUIT AND PACKAGING DESIGN

The second wattmeter incorporates a number of improvements over the first unit:

a. A one volt full scale range

b. Pearson AC current probe input

c. Printed circuit board construction

d. An alternate wideband multiplier to replace the discontinued Hybrid Systems Model 105

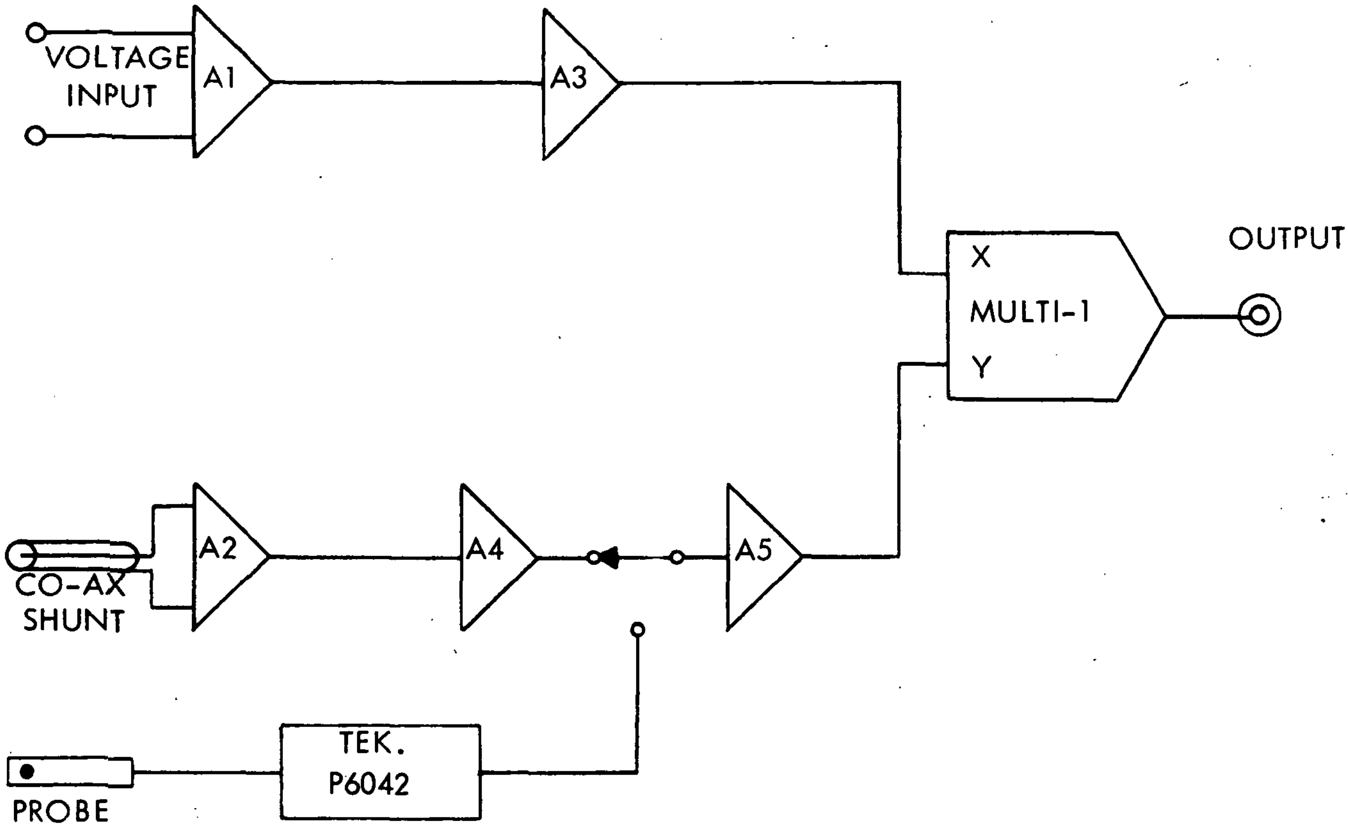


Figure 1. Simplified Block Diagram
of
Wideband Wattmeter

A simplified diagram of the second wattmeter is shown on Figure 2. This is essentially the same as the first wattmeter shown on Figure 1 except:

a. A7 has been added to cover the 0.1 to 1 volt range

b. A6 and M have been added to provide meter readout

c. An additional switch position and jack permit Pearson Probe input

A detailed schematic of the second wattmeter circuit is shown on drawing 1-8108-110C in Appendix F. This includes ranging and calibration circuits. Ranging circuits are at the first amplifier inputs for both voltage and current inputs in order to prevent overloads at the high signal levels. Additional amplification, A7, is needed on the one volt range to provide adequate drive to

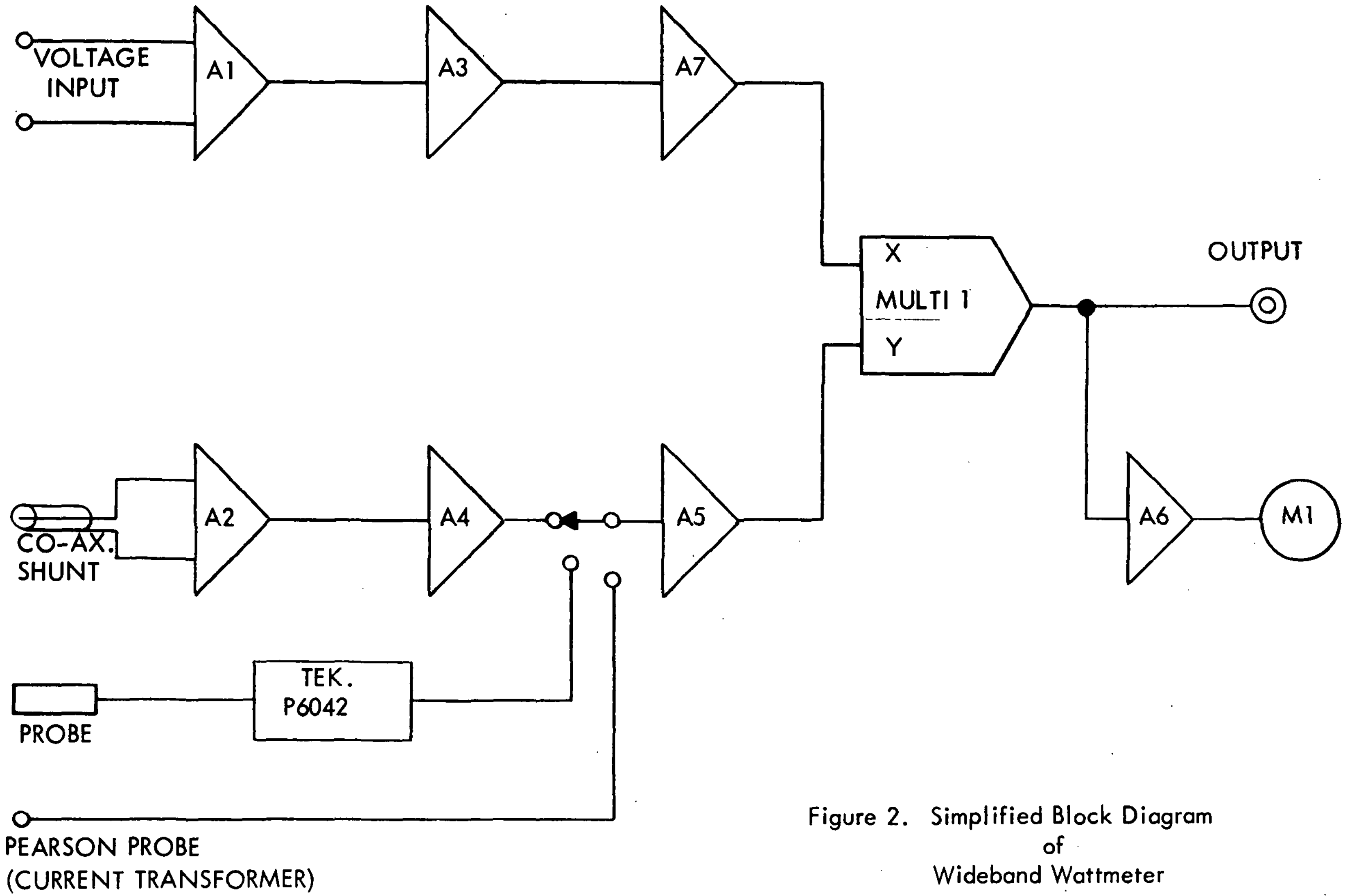


Figure 2. Simplified Block Diagram
of
Wideband Wattmeter

the multiplier. Accidental overvoltage input protection is provided by the Zener diode clamps CR1-4 at the inputs. Zener clamps CR8, CR10, CR24, CR26 permit fast amplifier recovery, A3, A7, and thus facilitate measuring repetitive pulse waveforms where a portion of the signal is overrange. The signal that is within range will then be faithfully reproduced.

Average power indication is provided by meter, M1, and its associated driver, A6. The meter characteristics combined with some circuit filtering provide time averaging from the high frequency end down to about 10 Hz.

CONCLUSIONS

A portable solid state wideband wattmeter has been developed as a general purpose laboratory instrument. DC to 1 MHz response within 1 dB is attainable with present state of the art amplifiers and multipliers.

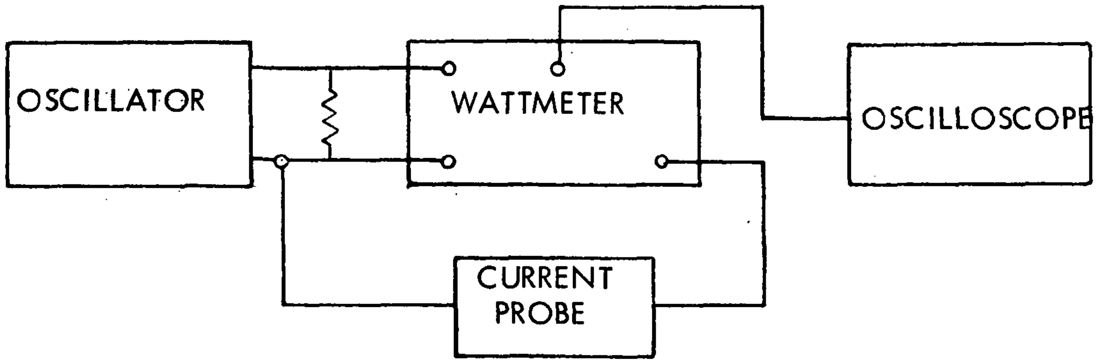
REFERENCES

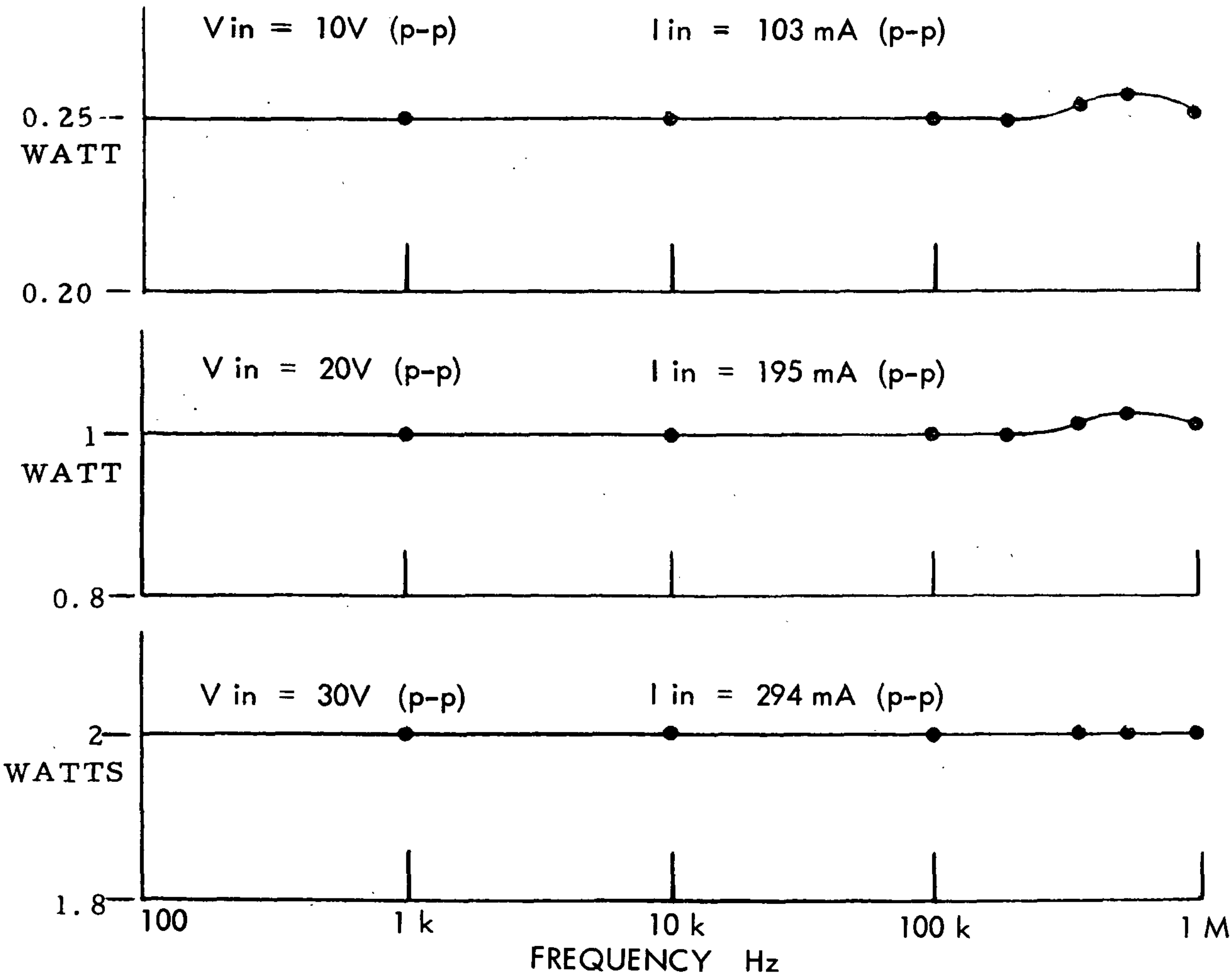
No.	Description
1	Greenwood, Holdson, MacRae: <u>Electronic Instruments</u> Chap. 3 Sect. 11-17, McGraw Hill, 1948
2	Zuch, Eugene L: Characteristics and applications of Modular Analog Multipliers. Electronic Instrument Digest, Vol. 5 No. 4, April 1969 PP 10-22
3	Vranik, James E: Design and Performance of a High-Frequency Wattage-to-Voltage Converter. NASA TN D-5674, Feb. 1970
4	Schwarz, Francisc C. and Voulgaris, Nicholas C: A Wide-Band Wattmeter for the Measurement and Analysis of Power Dissipation in Semiconductor Switching Devices. IEEE Transactions on Electron Devices, Sept. 1970

APPENDIX A

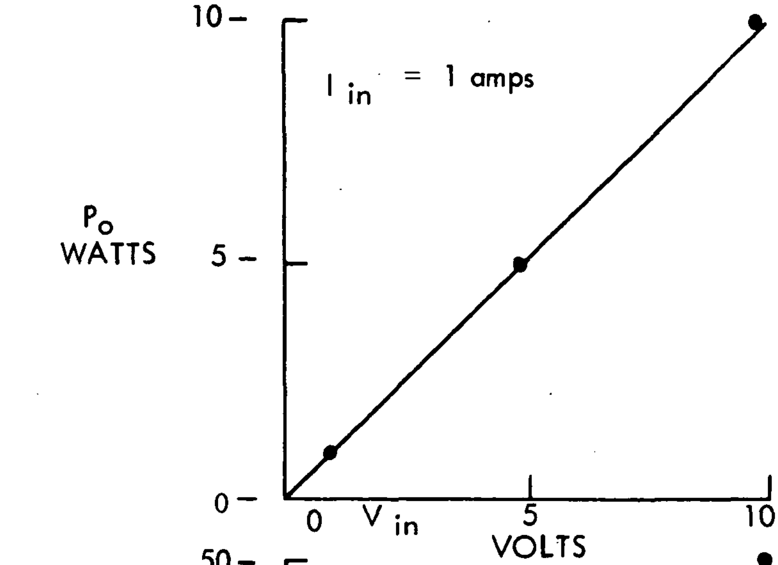
FIRST UNIT PERFORMANCE DATA

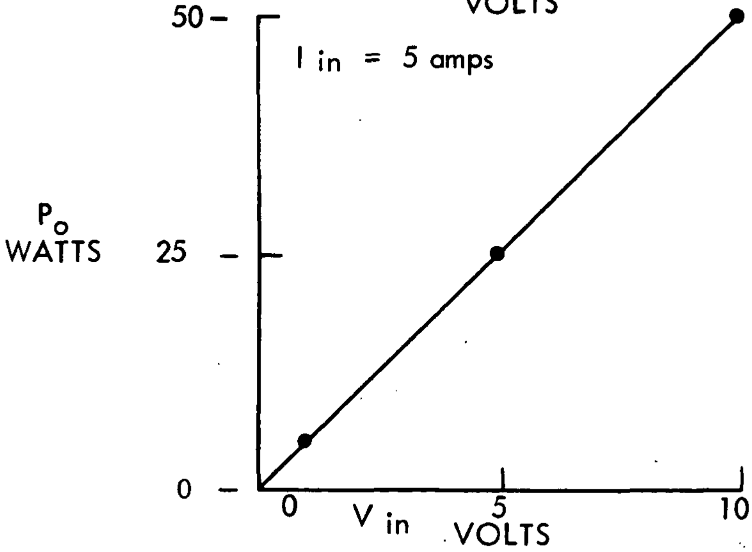
WIDEBAND WATTMETER FREQUENCY RESPONSE TEST
CONSTANT AC VOLTAGE AND CURRENT IN
OUTPUT WATTS VS FREQUENCY



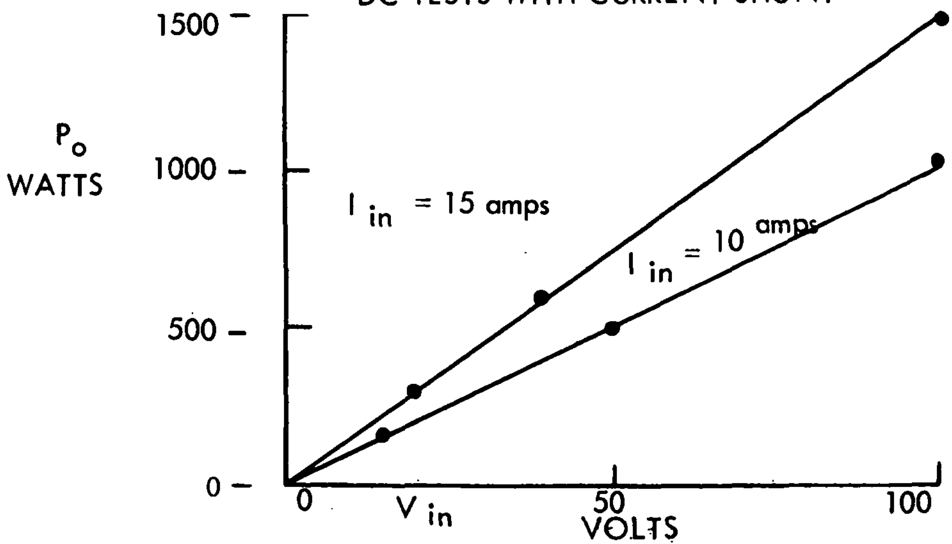


WIDEBAND WATTMETER DC TESTS
WITH P6042 CURRENT PROBE





DC TESTS WITH CURRENT SHUNT



APPENDIX B
OPERATING INSTRUCTIONS
MODEL 8108-110A

General - This wattmeter is designed to work into a cathode ray oscilliscope (CRO) input. The conventional high impedance CRO probe may be used if connected close to the wattmeter output connector or up to 3 feet of coaxial cable may be used direct connected. Current input signal may be from a Tektronix P6042 probe (0-10 amps.) or a B & R shunt assembly. The latter item is necessary for the 10-100 ampere range. The shunt supplied with the wattmeter is 0.01 ohms rated for 5 watts average power.

Operating Voltage. - The unit can be powered from a 115 volt 60 Hz supply. Regulating range for the internal power supply is 105-132 VAC at 47-440 Hz. Maximum power required is 35 watts.

CONTROLS AND CONNECTORS - Figure B-1 shows the front panel controls and connectors on the wattmeter and describes the function of each.

Installation -

1. Connect a Tektronix P6042 current probe with a 50 ohm coaxial cable to the wattmeter (or a current shunt to the MS connector).
2. Connect the wattmeter to the oscilloscope input with 3 feet or less of 50 ohm coaxial cable.
3. Turn all three units on and allow five minutes warm-up time.
4. Set the oscilloscope controls as follows:

Volts/div.	5 volts
Variable (volts/div.)	calibrated
input coupling	ground

5. Set the wattmeter controls as follows:

Voltage Calibrate:	DC and 10V
Voltage range:	100 V
Current Calibrate:	OFF


OUTPUT SENSITIVITY — TABLE OF WATTS/VOLT AT OUTPUT
POWER OUTPUT
VOLTAGE CALIBRATE
SELECTS 0, 5, 10V
SELECTS DC, OFF, AC
CURRENT CALIBRATE
SELECTS DC, OFF, AC
SELECTS 0, 5, 10V
VOLTAGE EQUIVALENT OF 0, 1/2 and FULL SCALE
OVERRANGE - Lights when Voltage input is overrange
OVERRANGE - Lights when current input is overrange
VOLTAGE RANGE - Sets Full scale range without overload
CURRENT RANGE Selects P6042 For 0-10A and Shunt for 10 - 100A
VOLTAGE INPUT - Differential
POWER ON - Applies power to wattmeter
B & R SHUNT - 100 mv input for 100 amps
INDICATOR- lights when power is on
TEKTRONIX P6042 PROBE - 50 Ohm input

FIGURE B-1

Installation - (Cont'd)

5. Set the wattmeter controls as follows: (cont'd)

Current Range:		0-10A for the P6042 probe
	or	10-100A for the current shunt

NOTE: If shunt is used, ignore instructions 6 through 12.

6. Set the P6042 controls as follows:

output DC level	mid range
current/div balance	mid range
current/div	1 A

7. Center the trace on the CRT, then switch input coupling to DC.
8. Place the probe in the front-panel receptacle. Momentarily depress the DEGAUSS lever and release. (Time required for probe degaussing is 200 milliseconds.)
9. Adjust OUTPUT DC LEVEL to center the trace vertically on the CRT.
10. Set the CURRENT/DIV switch to the suitable position for the measurement to be made and again degauss the probe.
11. Adjust CURRENT/DIV BALANCE to center the trace vertically on the CRT.
12. Remove the probe from the front-panel receptacle, move the slider back, and place the probe around the conductor under test. Push the slider forward into the locked position.
13. Place the probe around the conductor under test (or insert the current shunt into the circuit per Figure B-2).
14. Set the wattmeter calibrate switches to OFF.
15. Set the wattmeter voltage range as desired.
16. Connect the wattmeter voltage input terminals to the circuit under test.
17. Observe the watts output as a vertical scale deflection on the CRO. The watts/volt output sensitivity is determined from the front panel table:

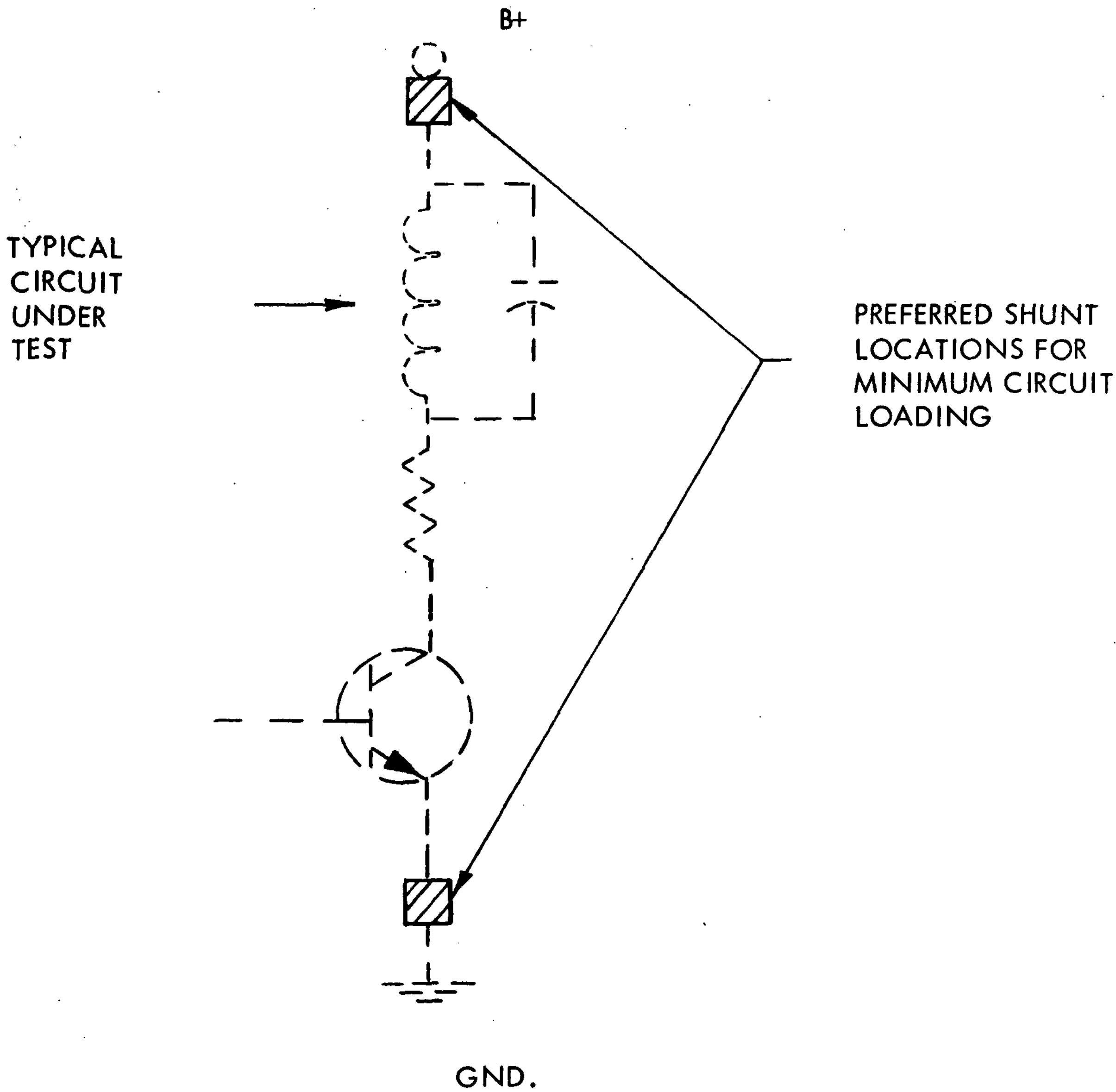


Figure B-2. SHUNT INSTALLATION

17. (Cont'd)

i.e: for current shunt; 10 x voltage range setting = watts/volt

for P6042; P6042 current/div x voltage range = watts/volt

calibrate; cal. voltage x calibrate current (voltage equiv.) divided by 10 = output voltage

18. If either overrange light comes on, the appropriate range switch should be set to the next larger range. If the output is less than one volt, one or both current and voltage range switches may be set to a lower scale as long as the overrange light does not come on.

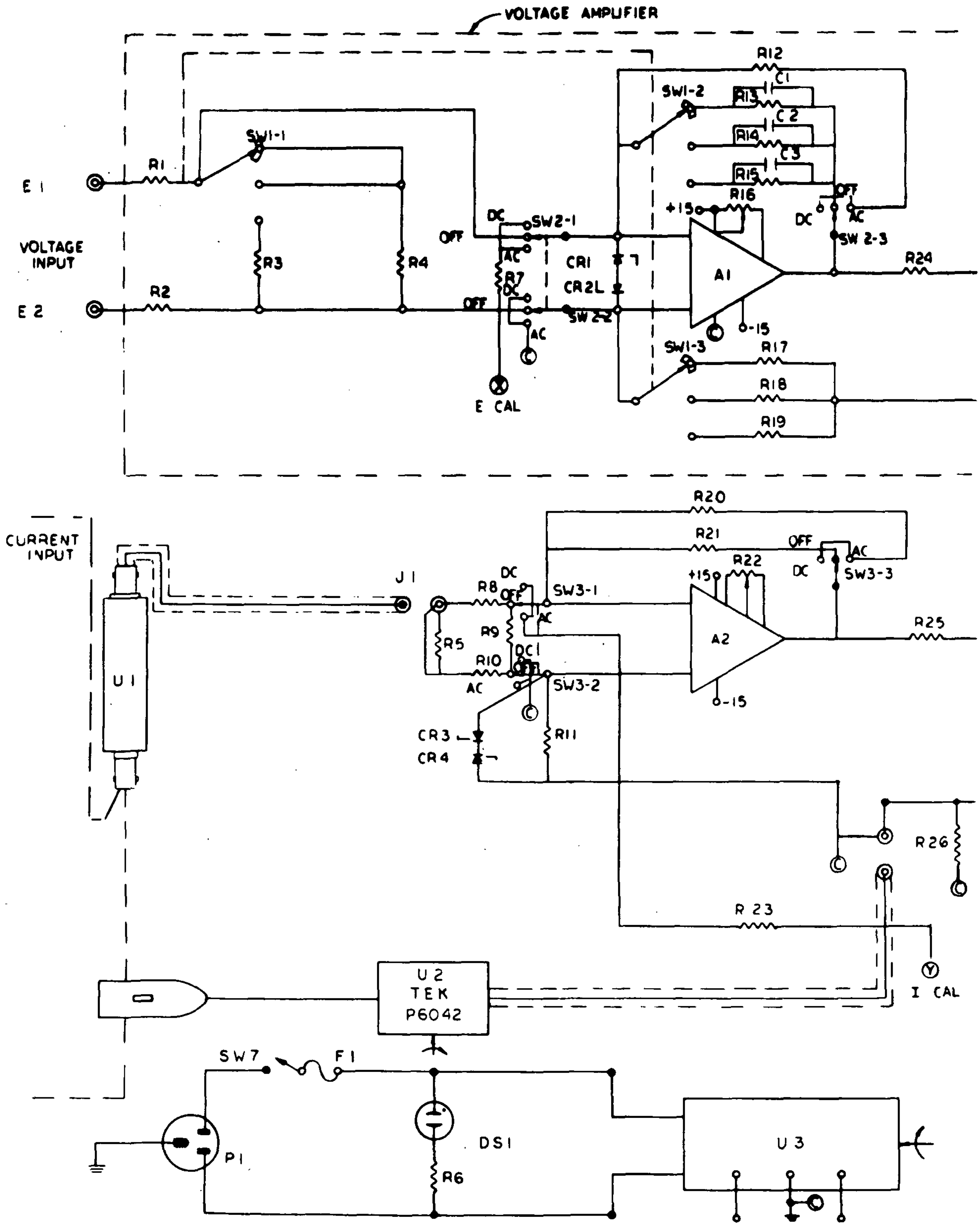
CALIBRATION - The wattmeter may be calibrated by external voltage and currents or by use of the built-in calibration. Internal calibration circuits permit exercising all amplifiers and the multiplier at 0, 1/2 and full scale for each input (0, 1/4, 1/2 and full scale on wattage). Normal calibration results are as follows:

VOLTAGE	CURRENT	OUTPUT (VOLTS)
0	0	0 (Checks offset voltage)
10	0	0 (Checks cross-coupling)
0	10	0 (Checks cross-coupling)
5	5	2.5 (1/4 scale)
5	10	5.0 (1/2 scale)
10	5	5.0 (1/2 scale)
10	10	10.0 (full scale)

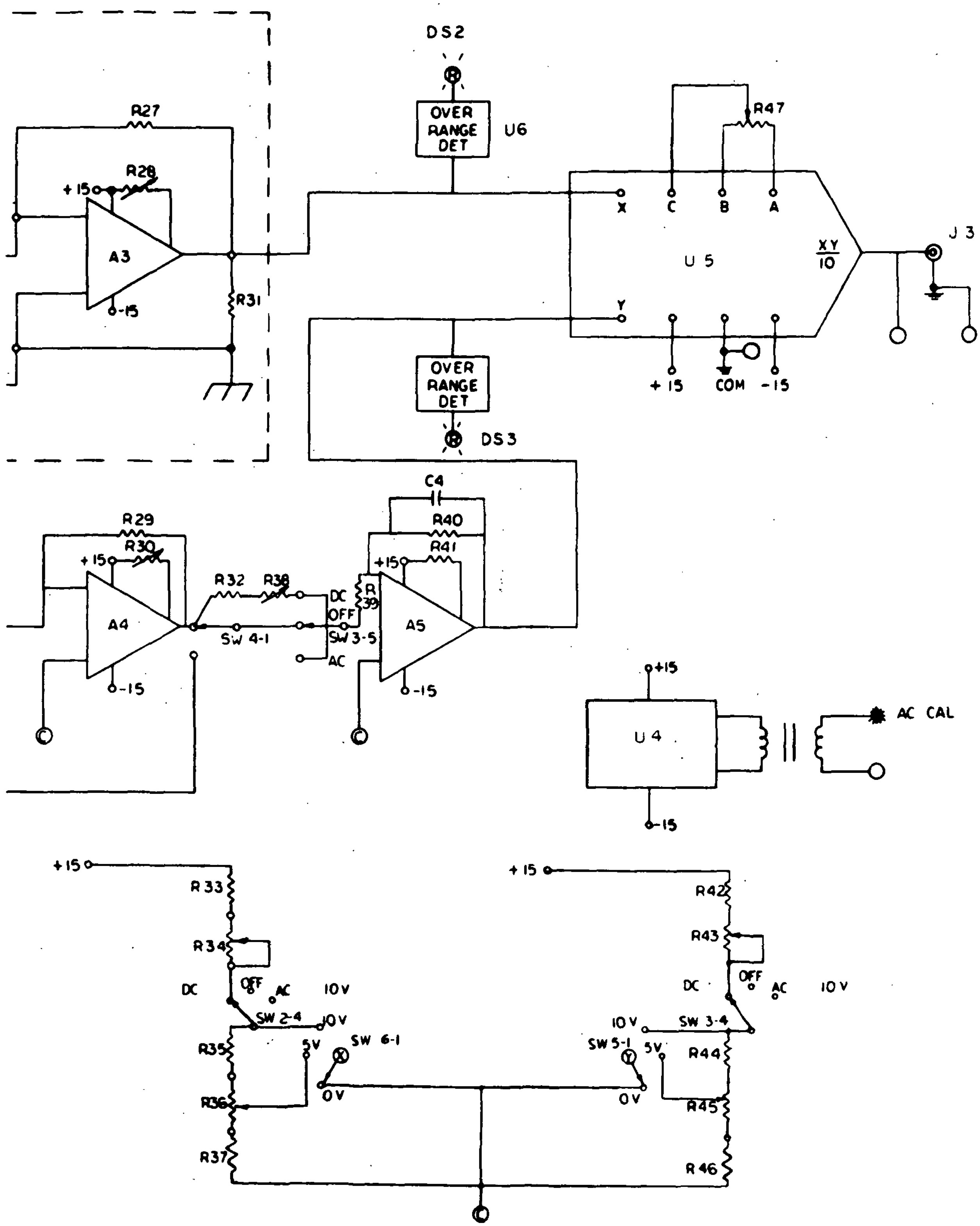
all AC values are zero to peak values.

APPENDIX C

SCHEMATIC & PARTS LIST - FIRST UNIT


VOLTAGE AMPLIFIER
E 1
VOLTAGE INPUT
E 2
R1
R2
R3
R4
SW1-1
SW1-2
SW1-3
R12
C1
R13
C2
R14
C3
R15
R16
+15
OFF
DC
AC
SW2-1
SW2-2
SW 2-3
R7
CR1
CR2L
A1
-15
R24
R17
R18
R19
E CAL
CURRENT INPUT
U1
J1
R20
R21
R22
SW3-1
SW3-2
SW3-3
R8
R9
R5
R10
A2
R25
R11
CR3
CR4
R26
R 23
I CAL
U 2
TEK
P6042
SW7
F1
DS1
R6
P1
U 3

SCEMATIC



WIDEBAND WATTMETER - FIRST UNIT

BILL OF MATERIAL

CLIENT: NASA

Schematic, Wideband Wattmeter

Dwg. No. 1-8108-110

B & R PROJECT NO.

SHEET 1 OF 2

DETAIL DRAWING NO.	PART NAME	QUANTITY	DESCRIPTION	REMARKS
A1	Amplifier, Solid State Operational	1	Fast Settling, FET Analog Devices Model 45K	
A2	Amplifier, Solid State Operational	1	Wideband, High Current Burr-Brown Model 1527/25	
A3, 4, 5	Amplifier, Solid State Operational	3	Fast Slewing, Wideband Burr-Brown Model 3341/15C	
C1, 4	Capacitor, Fixed, Dipped Mica	2	1.0 PF ± 0.5 PF, 500 VDC Elmenco No. DM5-010D	
C2	Capacitor, Fixed, Dipped Mica	1	33PF ± 5%, 500 VDC CM05ED330J03	
C3	Capacitor, Fixed, Dipped Mica	1	390 PF ± 5%, 500 VDC CM05 FD391 J03	
DS1	Neon Lamp and Lamp Holder Assy	1	MS25257-4-C7A	
DS2, 3	Incandescant Lamp and Holder	2	MS25256-6-330	
F1	Fuse, Cartridge	1	1A, 250V Type 3AG	
J1	Receptacle, Connector, Electrical	1	MS3102A-14S-2P	
J2, 3	Receptacle, BNC, Electrical	2	JAN NO. UG 290/U	
P1	Plug with card, 3-conductor	1	18 AWG, 6 Ft. Belden No. 17406	
R1, 2	Resistor, Fixed, Film, High Stability	2	490 K ohms ±1% RN 65D 4993F	
R3, 11, 21	Resistor, Fixed, Film, High Stability	3	1000 ohms ±1% RN 65D 1001F	
R4, 8, 10	Resistor, Fixed, Film, High Stability	3	10 K ohms ± 1% RN 65D 1002F	
R5	Resistor, Fixed, Composition	1	91 ohms ±5% RCR20G910JS	
R6	Resistor, Fixed, Composition	1	62K ohms ±10% RCR05G623JS	
R7, 13, 17, 40	Resistor, Fixed, Film, High Stability	4	49.9 K ohms ±1% RN65D4992F	
R9	Resistor, Fixed, Film, High Stability	1	200 ohms ±1% RN65D2000F	
R12, 14, 18, 23, 25	Resistor, Fixed, Film, High Stability	5	4.99 K ohms ±1% RN65D4991F	
R15, 19, 20	Resistor, Fixed, Film, High Stability	3	499 ohms ±1% RN65D4990F	
R16, 38	Resistor, Variable Wirewound	2	1000 ohms ±10% Spectrol No. 94-1-1-102	
R22, 28 30, 41	Resistor, Variable Wirewound	4	2000 ohms ±10% Spectrol No. 94-1-1-202	
R24, 39	Resistor, Fixed, Film High Stability	2	2.49 K ohms ±1% RN65D2491F	
R26	Resistor, Fixed, Composition	1	51 ohms ±5% RCR 20G510JS	

DESIGNERS & ENGINEERS

BARNES & REINECKE INC.
CHICAGO, ILLINOIS

BILL OF MATERIAL

CLIENT: NASA

Schematic, Wideband Wattmeter

Dwg. No. 1-8108 -110

B & R PROJECT NO. 1-8108

SHEET 2 OF 2

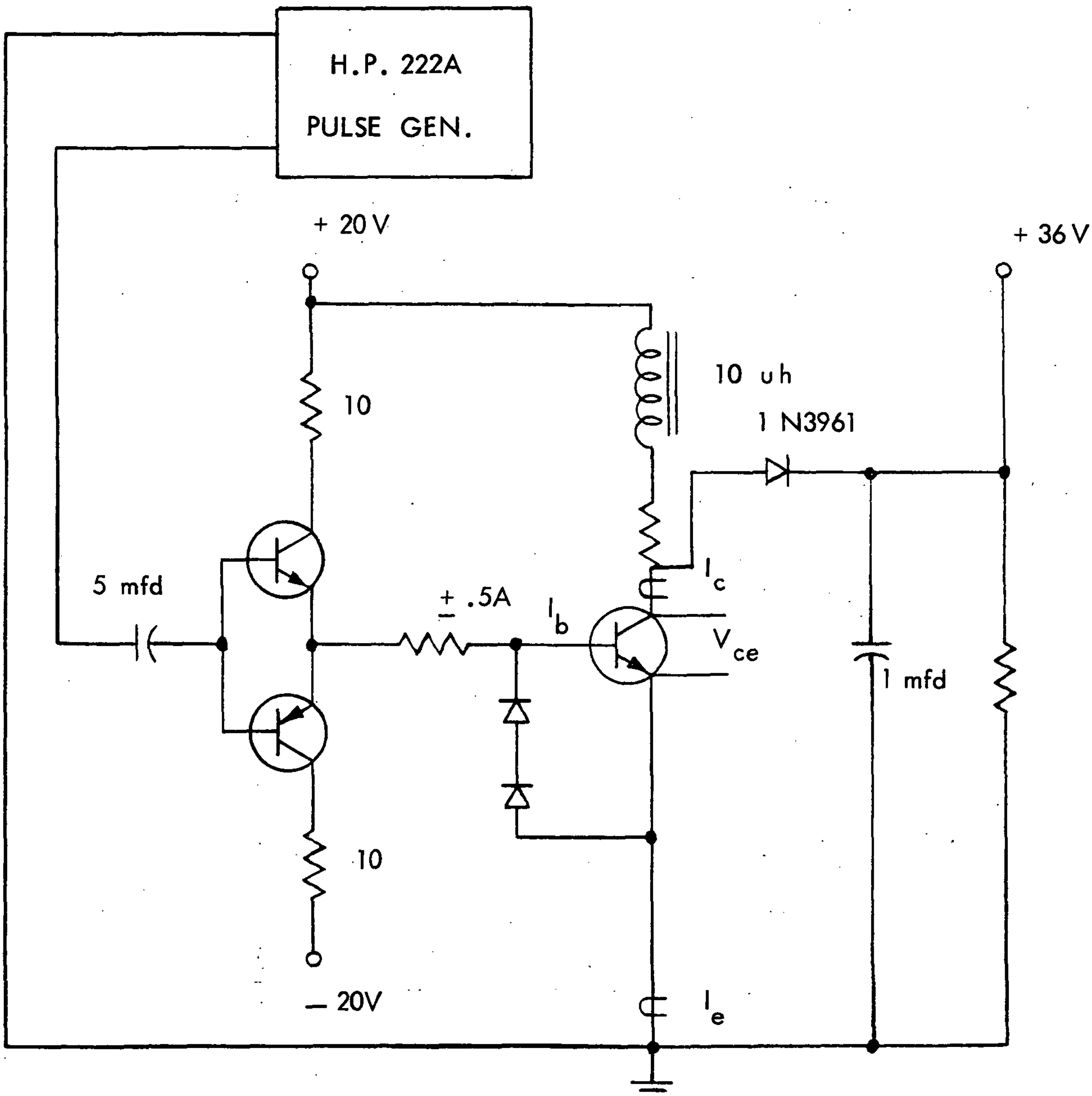
DETAIL DRAWING NO.	PART NAME	QUANTITY	DESCRIPTION	REMARKS
R27, 29	Resistor, Fixed, Film, High Stability	2	24.9 K ohms ±1% RN65D2492F	
R31	Resistor, Fixed, Composition	1	100 K ohms ±5% RCR07G104JS	
R32	Resistor, Fixed, Film, High Stability	1	22.1 K ohms ±1% RN65D2212F	
R33, 42	Resistor, Fixed, Film, High Stability	2	453 ohms ±1% RN65D453DF	
R34, 36 43, 45	Resistor, Variable Wirewound	4	20 ohms ±1% Clarostat No. 43C2-20	
R35, 37 44, 46	Resistor, Fixed, Film, High Stability	4	487 ohms ±1% RN65D4870F	
R47	Resistor, Variable Wirewound	1	20 ohms ±10% Spectrol No. 78-1-1-200	
SW1	Switch, Rotary, Miniature ceramic	1	3P5T, Shorting, Centralabs No. PA 2006	
SW2, 3	Switch, Rotary, Miniature ceramic	2	5P3T, Non-shorting, Centralabs No. PA2015	
SW, 4, 5, 6	Switch, Rotary, Miniature ceramic	3	1P12T, Non-shorting, Centralabs No. PA 2001	
SW7	Switch, Toggle, Sealed Lever	1	SPST - MS35058-21	
U1	Current Shunt, Co-Axial, Wideband	1	0 - 100A, 0.01 ohm CVR T & M Reaearch Product	
			Model No. A-2-01	
U2	Current Probe Unit	1	DC to 500 MHz, 1 mA/Div. Tektronix Model P6042	
U3	Power Supply, DC, Dual-Tracking	1	± 12 to ± 15V, 400 mA Lambda Model LXD-3-152	
U4	Oscillator, Solid State Precision	1	7.07 VRMS, 1 KHz	
U5	Multiplier, Solid State Analog	1	Wideband, Precision Hybrid systems Model 105	
U6	Over-range Detector Assy	1	Dwg # 1-8108-111	

DESIGNERS & ENGINEERS

BARNES & REINECKE INC.
CHICAGO, ILLINOIS

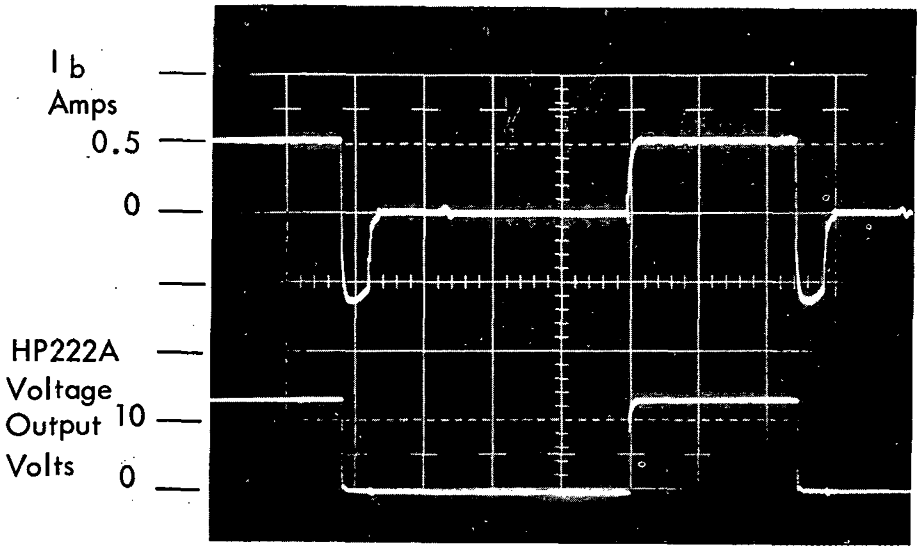
APPENDIX D

SECOND UNIT PERFORMANCE DATA



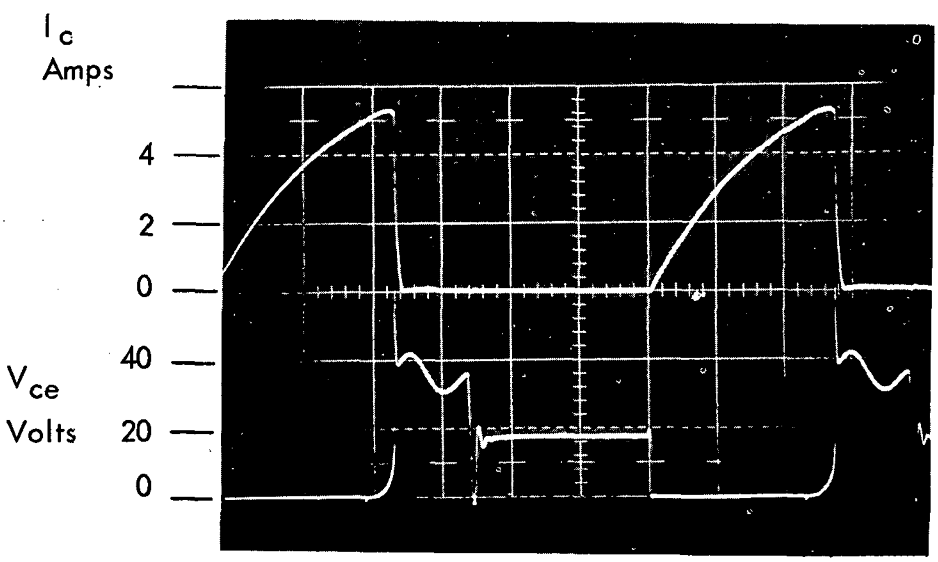
SCHEMATIC TEST CIRCUIT

(1) Base current of Power Transistor



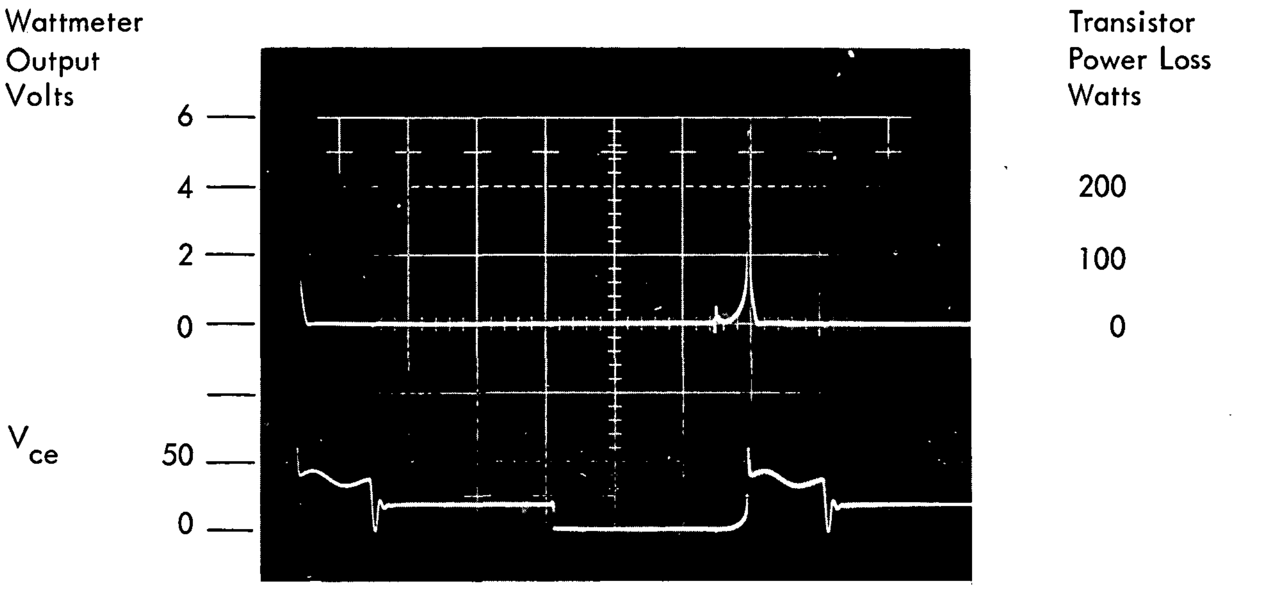
10 μ SEC/CM

(2) Collector current and voltage of Power Transistor



10 μ SEC/CM

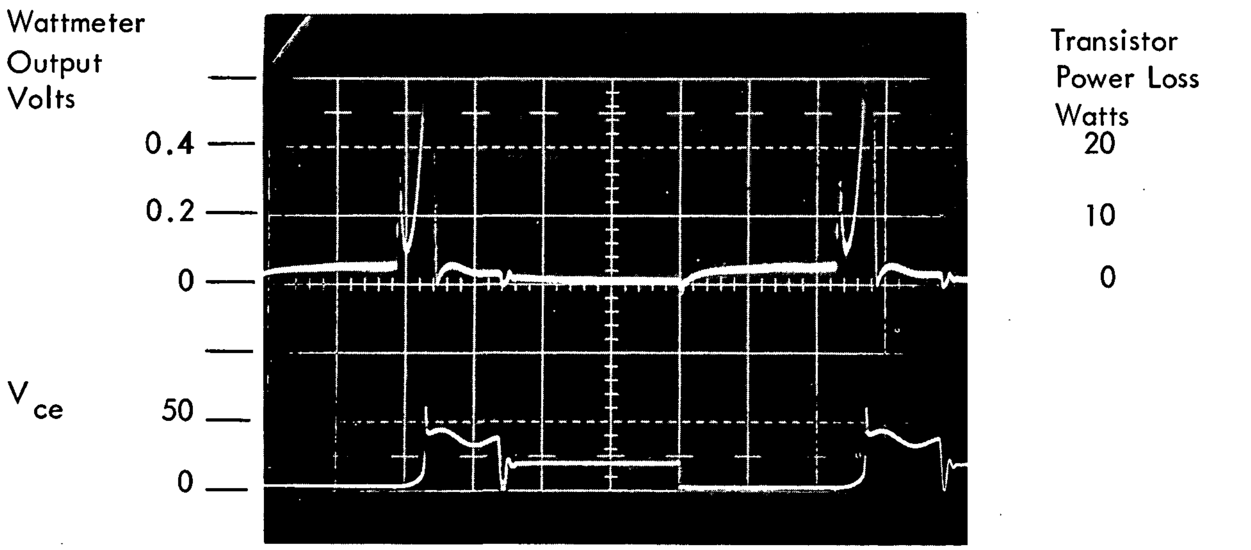
(3) Collector power dissipation of Power Transistor



10 µSEC/CM

Note: Wattmeter Settings
100 volts, 10 amps
P6042 - 0.5 amps/div

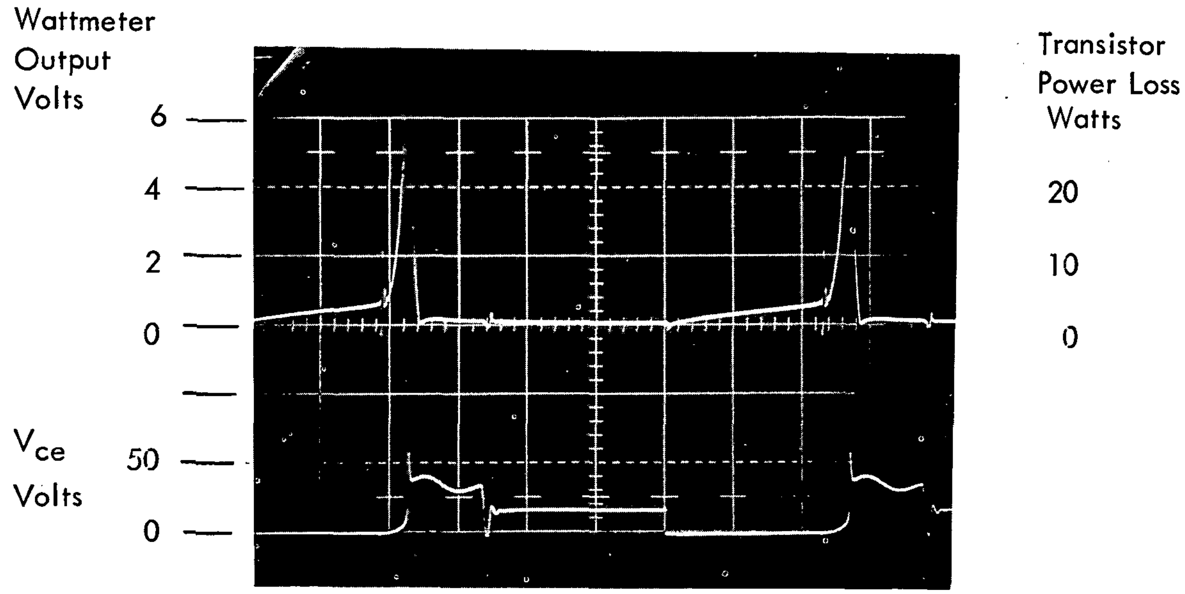
(4) Collector power dissipation



10 µSEC/CM

Note: Wattmeter Settings
100 volts, 10 amps
P6042 -0.5 amps/div

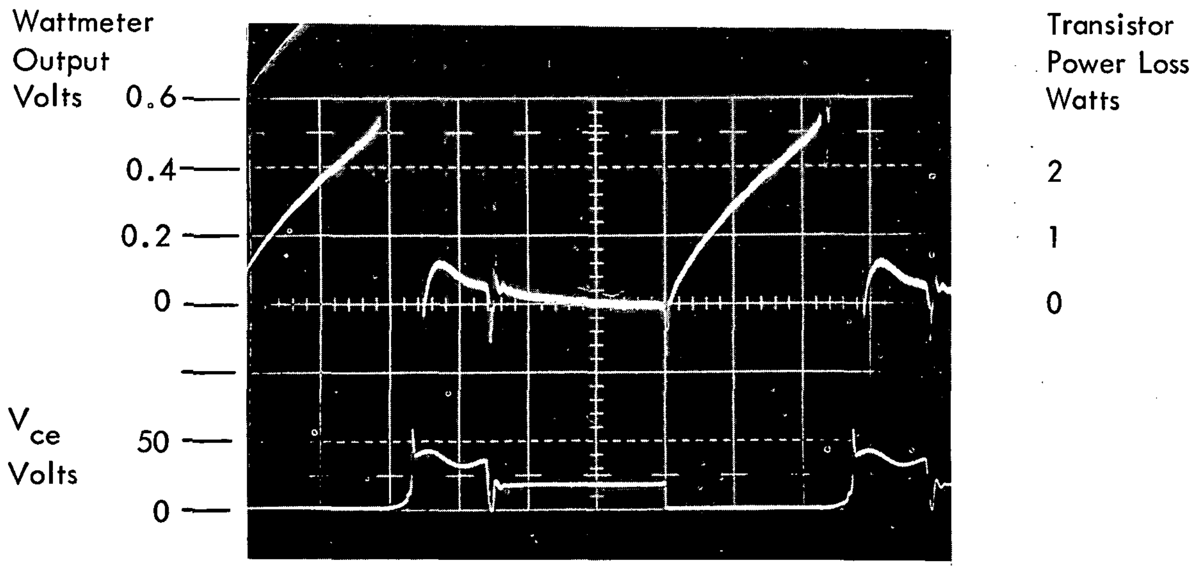
(5) Collector power dissipation



10 μ SEC/CM

Note: Wattmeter Settings
10 volts, 10 amps
P6042 - 0.5 amps/Div

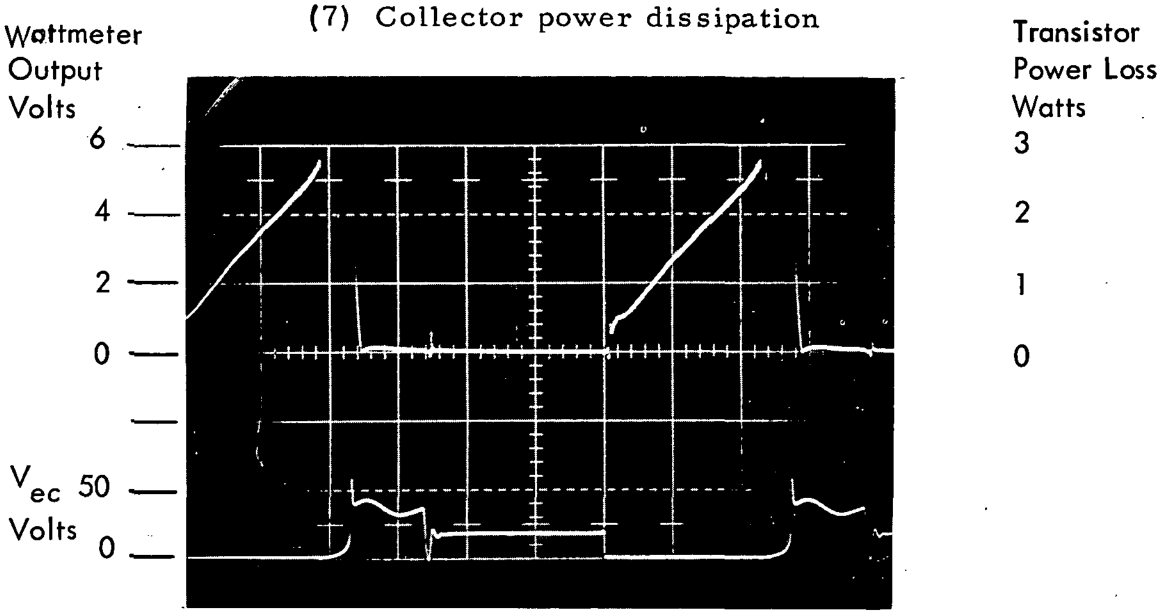
(6) Collector saturation loss



10 μ SEC/CM

Note: Wattmeter Settings
10 volts, 10 amps
P6042 - 0.5 amps/Div

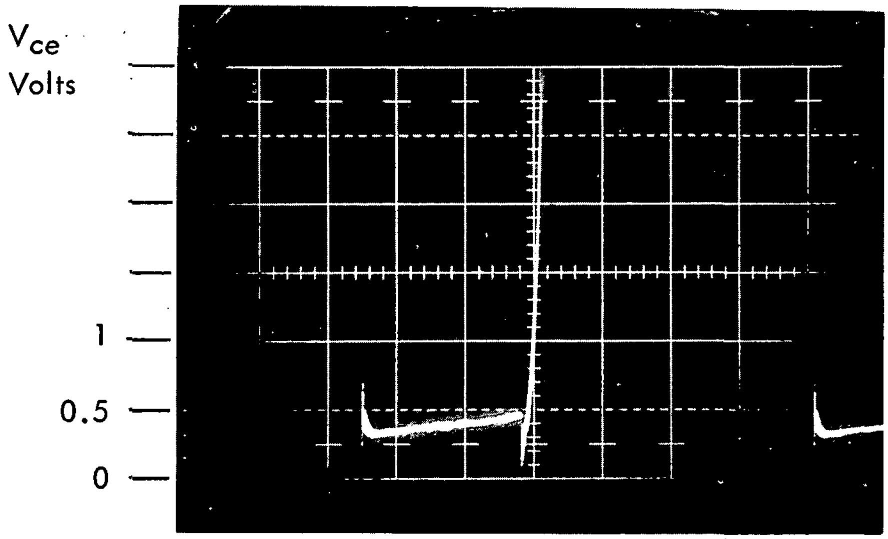
(7) Collector power dissipation



10 μ SEC/CM

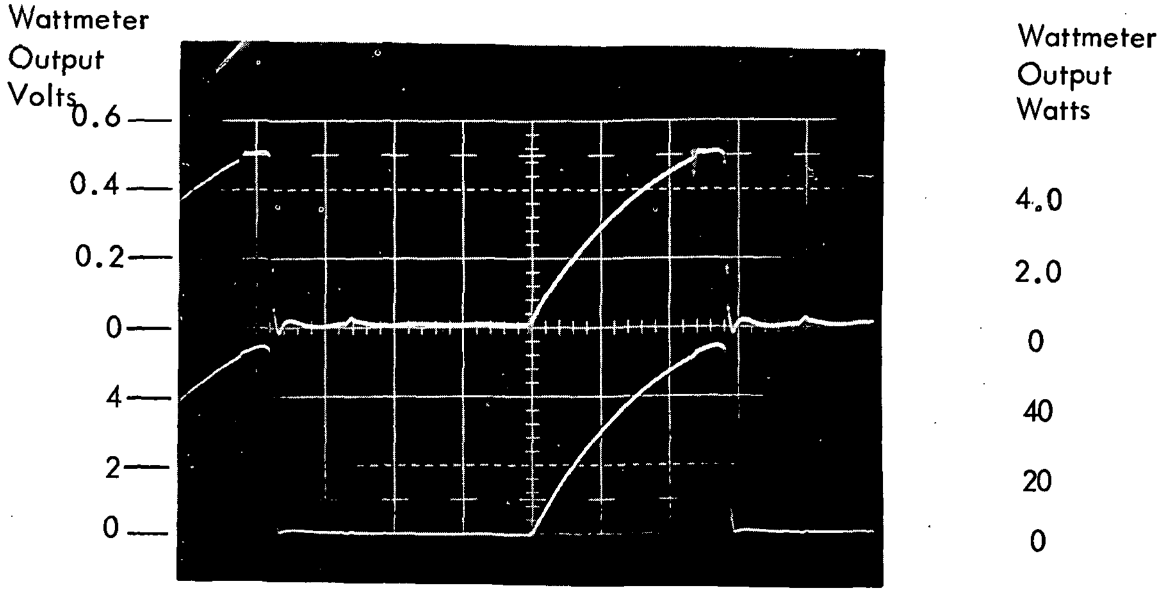
Note: Wattmeter Setting
1 volt, 10 amps
Tek P6042-0.5 amps/div

(8) Collector saturation voltage



10 μ SEC/CM

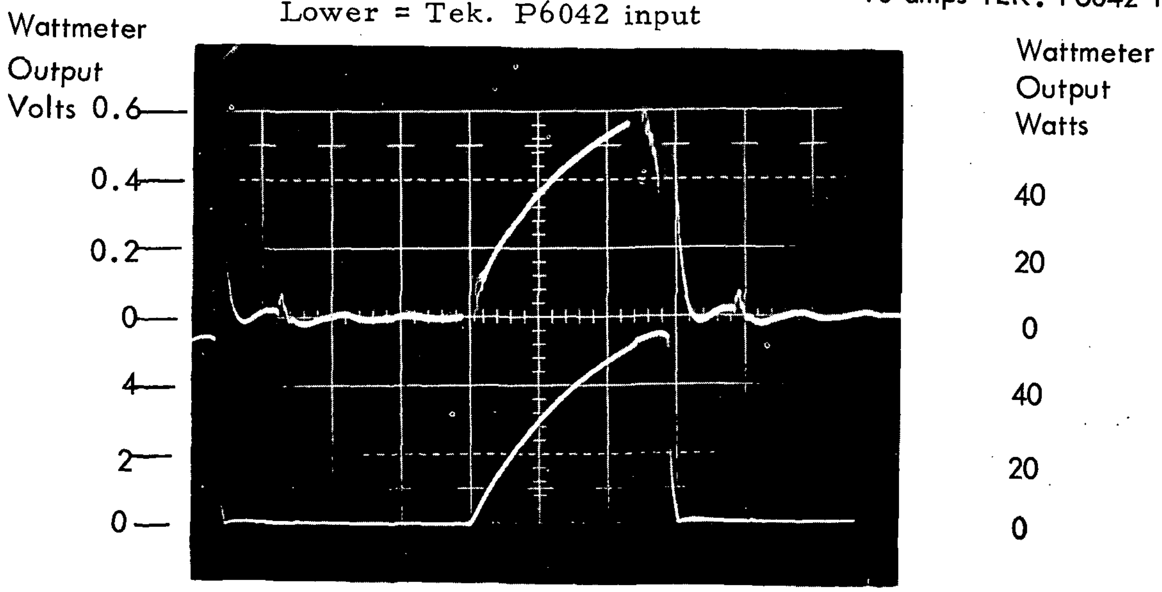
(9) Product of collector current and
DC voltage
Upper = Pearson transformer input
Lower = Tek. P6042 input



10 μ SEC/CM

Note: Wattmeter Settings
10 volts DC Cal V_{IN}
100 amps PEARSON and
10 amps TEK. P6042 1 amp/div

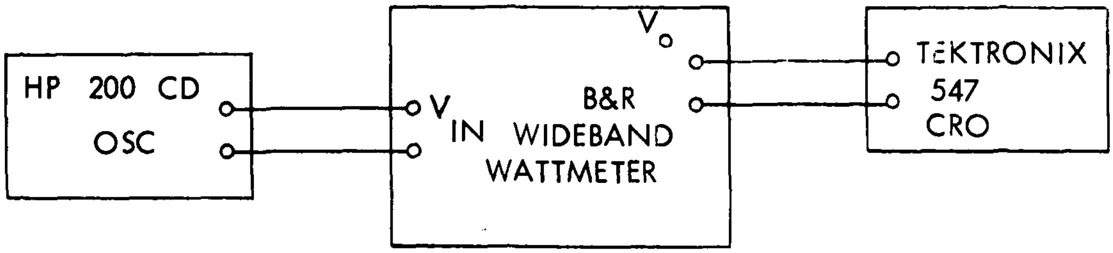
(10) Upper = Coax. Shunt input
Lower = Tek. P6042 input

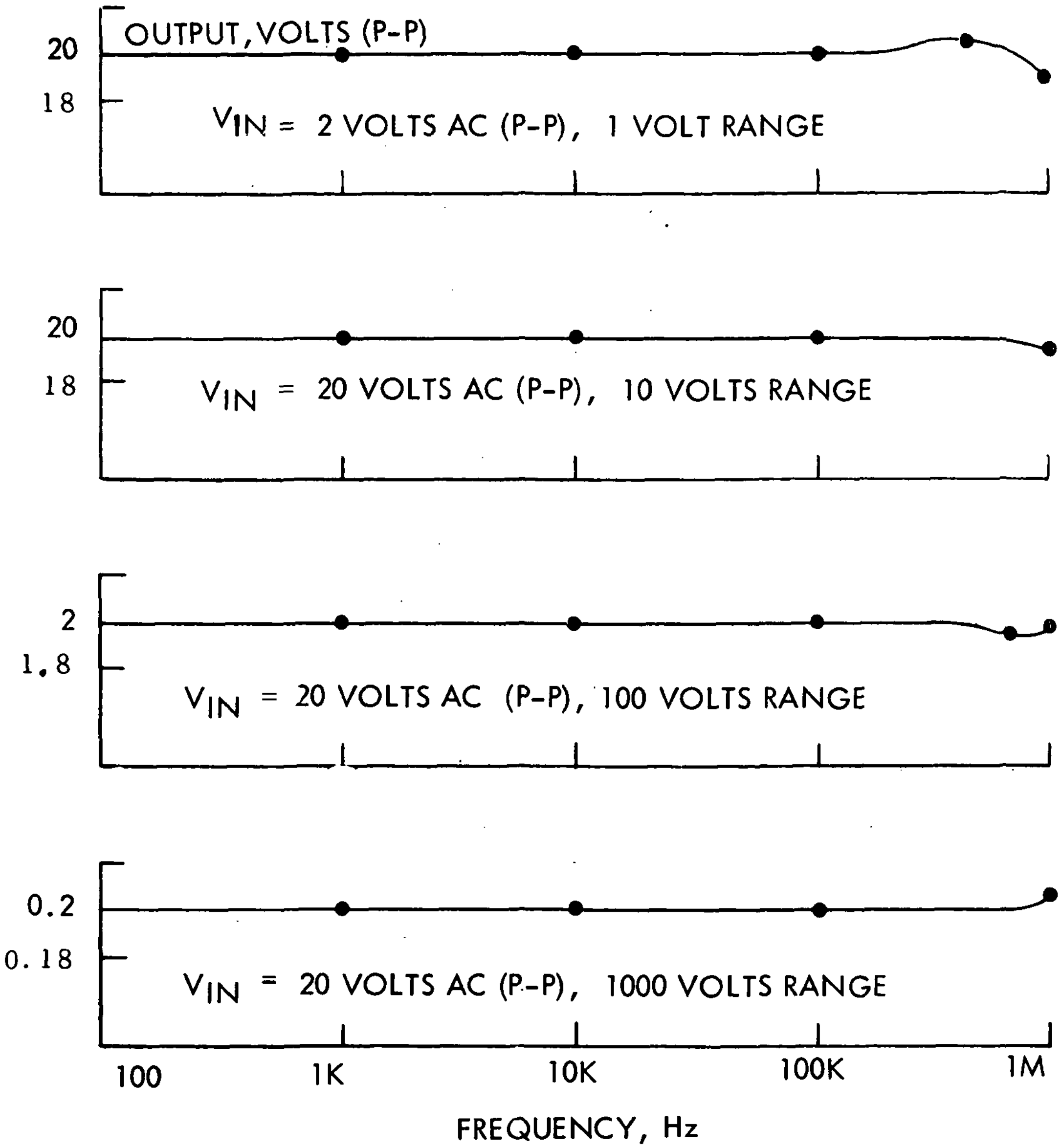


10 μ SEC/CM

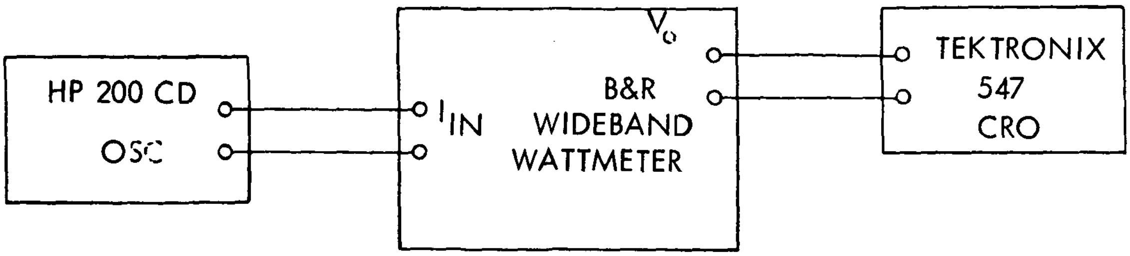
Note: Wattmeter Settings
10 volts DC CAL V_{IN}
100 amps B&R SHUNT and
10 amps TEK. P6042 -
1 amp/div

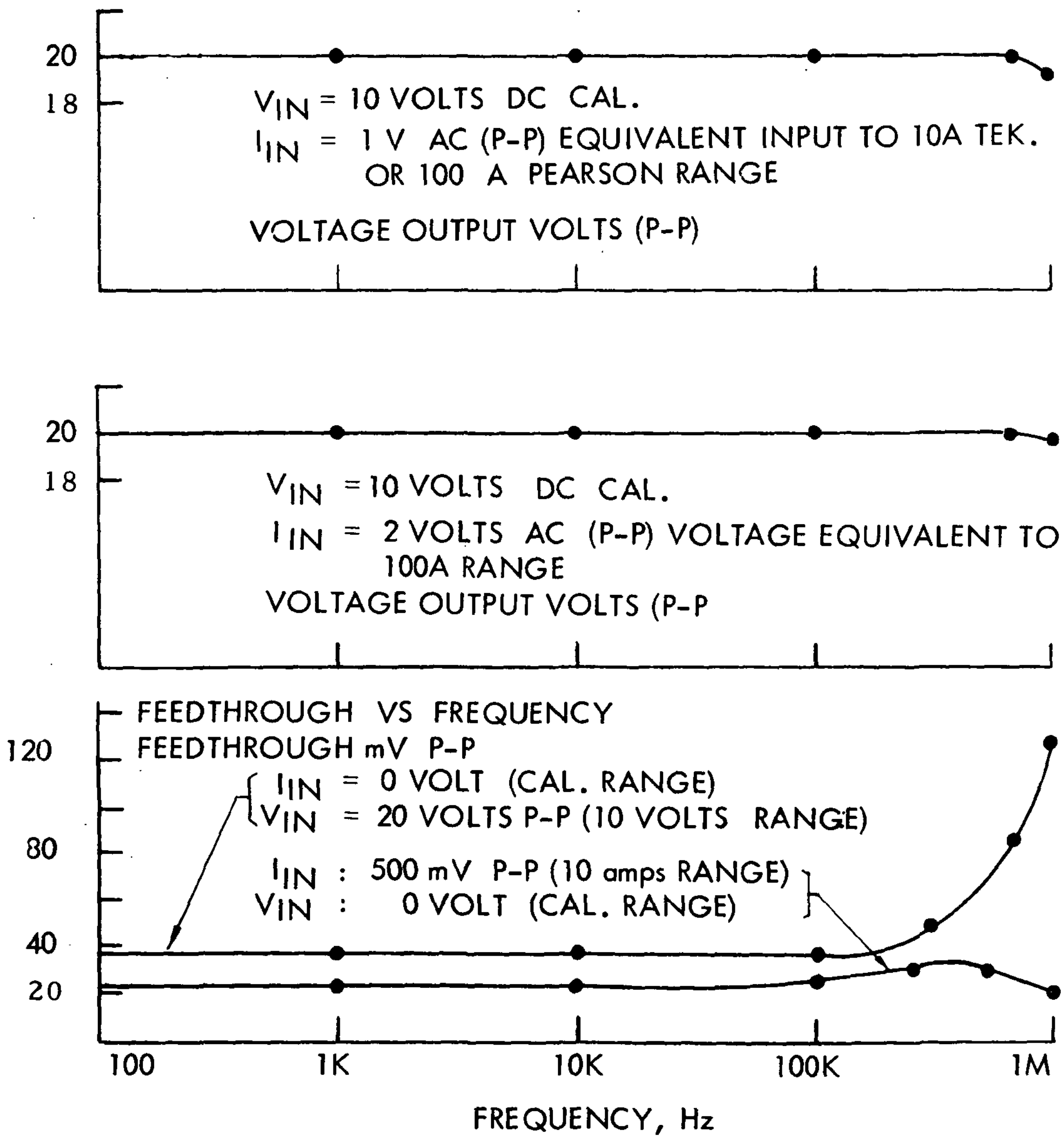
WIDEBAND WATTMETER FREQUENCY RESPONSE TEST
OUTPUT VOLTS VS FREQUENCY
I_{IN} = 10 VOLTS DC CAL.



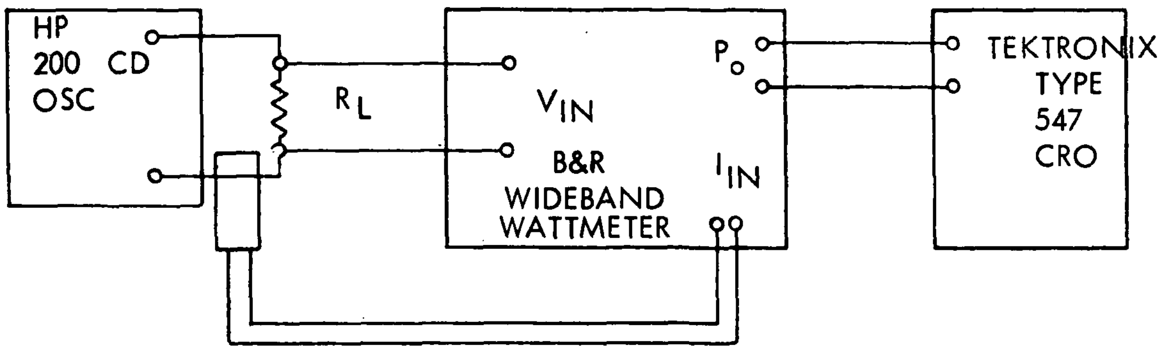


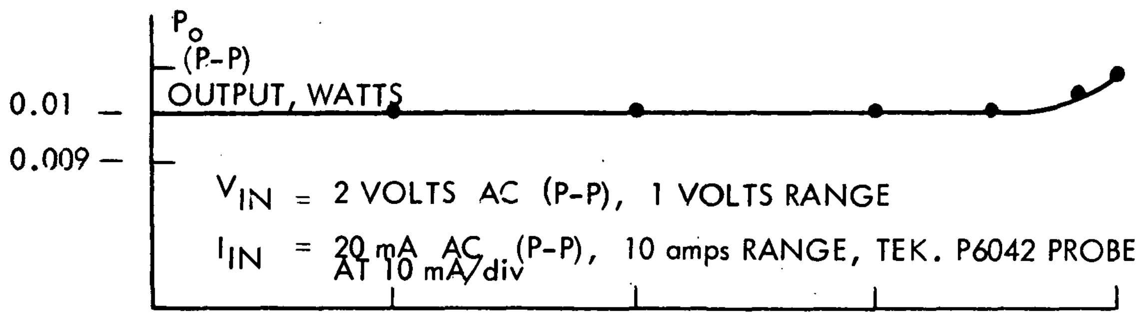
WIDEBAND WATTMETER FREQUENCY RESPONSE TEST
OUTPUT VOLT VS FREQUENCY

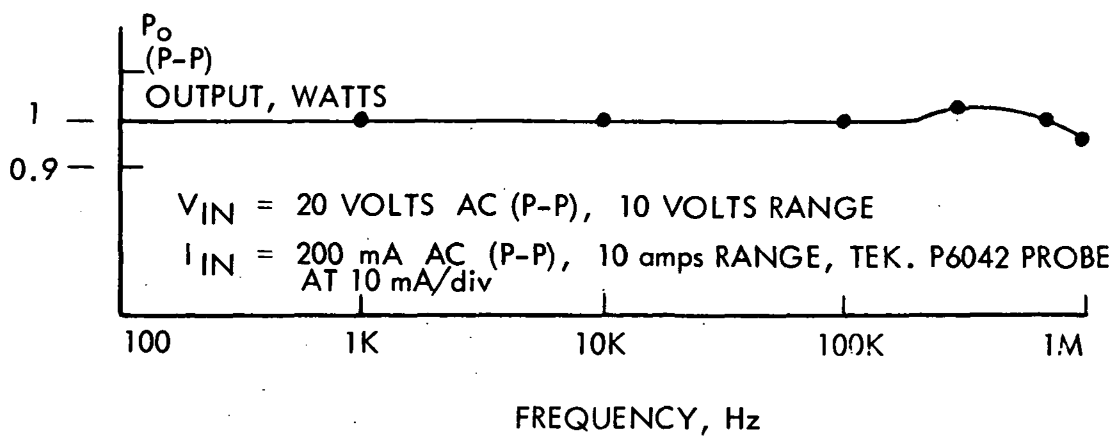




WIDEBAND WATTMETER FREQUENCY RESPONSE TEST
OUTPUT WATTS VS FREQUENCY







APPENDIX E
OPERATING INSTRUCTIONS
MODEL 8108-110C

General. - This wattmeter is designed to work into a cathode ray oscilloscope (CRO) input for instantaneous indication of power. An integral panel meter provides a simultaneous indication of true average power. Voltage input is direct to the indicated terminals. Current input may be from a Tektronix P6042 probe (0-10 amps), a B & R shunt assembly, or a Pearson current transformer. One of the latter two items is necessary for the 10-100 ampere range. The shunt is 0.01 ohms rated for 5 watts average power; the transformer is 0.0002 ohms rated at 5000 amps peak, 50 amps rms.

Operating Voltage. - The unit can be powered from a 115 volt 60 Hz supply. Regulating range for the internal power supply is 105-132 VAC at 47-440 Hz. Maximum power required is 35 watts.

Controls and Connectors. - Figure E-1 shows the front panel controls and connectors on the wattmeter and describes the function of each.

Installation. -

1. Connect a Tektronix P6042 current probe with a 50 ohm coaxial cable (Tektronix 012-0057-01) and a 50 ohm BNC termination (Tektronix 011-0049-01) to the wattmeter (or a current shunt to the MS connector or Pearson transformer with adapter, B & R 1-8108-111 to the BNC input).

2. Connect the wattmeter to the oscilloscope input with 3 feet or less of 50 ohm coaxial cable.

3. Turn all three units on and allow five minutes warm-up time.

4. Set the oscilloscope controls as follows:

Volts/div	5 volts
Variable (volts/div)	calibrated
input coupling	ground

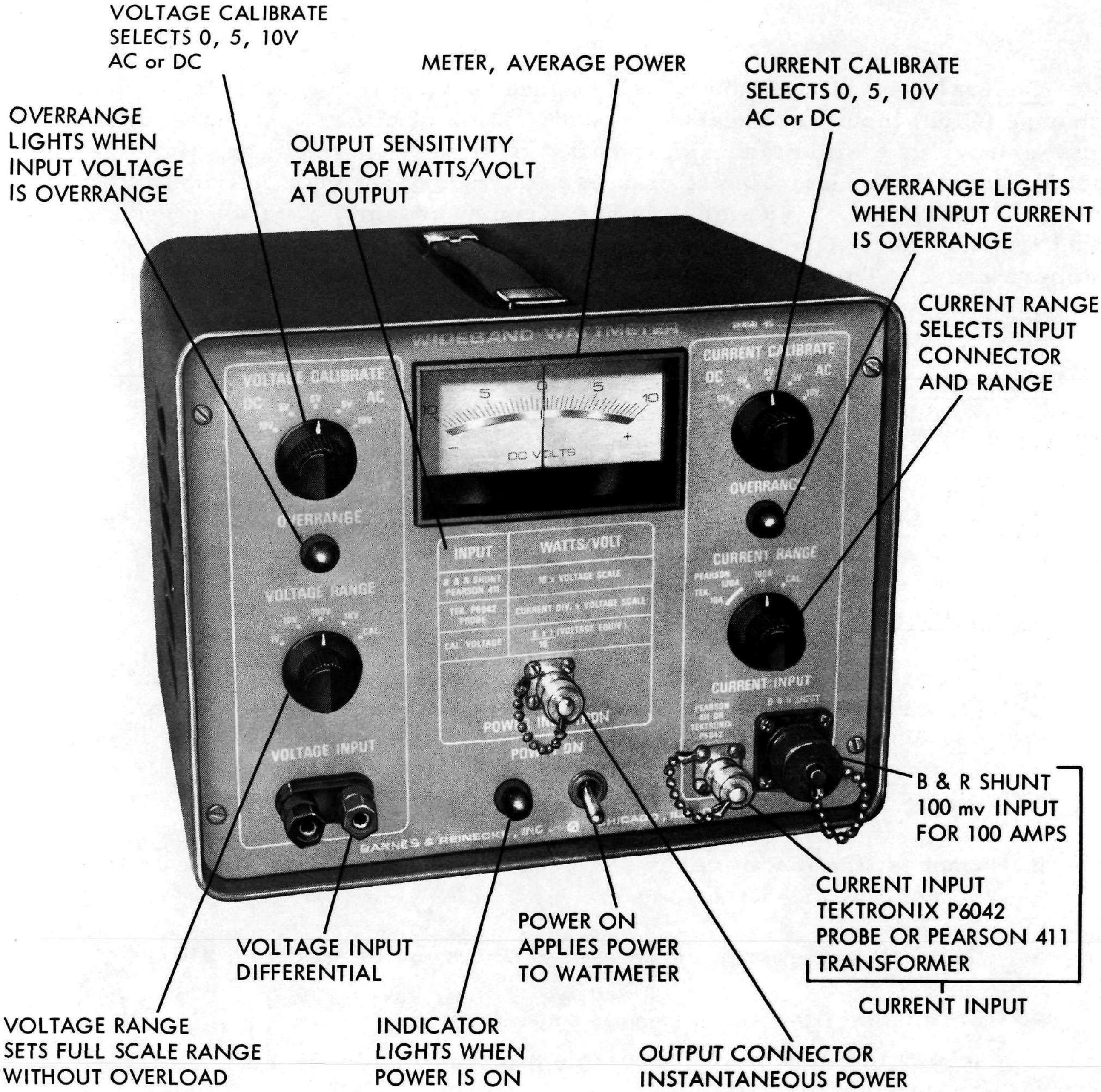

VOLTAGE CALIBRATE SELECTS 0, 5, 10V AC or DC
OVERRANGE LIGHTS WHEN INPUT VOLTAGE IS OVERRANGE
METER, AVERAGE POWER
OUTPUT SENSITIVITY TABLE OF WATTS/VOLT AT OUTPUT
CURRENT CALIBRATE SELECTS 0, 5, 10V AC or DC
OVERRANGE LIGHTS WHEN INPUT CURRENT IS OVERRANGE
CURRENT RANGE SELECTS INPUT CONNECTOR AND RANGE
B & R SHUNT 100 mv INPUT FOR 100 AMPS
CURRENT INPUT TEKTRONIX P6042 PROBE OR PEARSON 411 TRANSFORMER
CURRENT INPUT
POWER ON APPLIES POWER TO WATTMETER
VOLTAGE INPUT DIFFERENTIAL
VOLTAGE RANGE SETS FULL SCALE RANGE WITHOUT OVERLOAD
INDICATOR LIGHTS WHEN POWER IS ON
OUTPUT CONNECTOR INSTANTANEOUS POWER

Figure E-1

5. Set the wattmeter controls as follows:

Voltage Calibrate:	DC and 10V
Voltage Range:	1000 V
Current Calibrate:	OFF
Current Range:	0-10A for the P6042 probe
or	10-100A for the current shunt

NOTE: If shunt or transformer is used, ignore instructions 6 through 12.

6. Set the P6042 controls as follows:

Output DC level	mid range
Current/div balance	mid range
Current/div	1 A

7. Center the trace on the CRT, then switch input coupling to DC.

8. Place the probe in the front-panel receptacle. Momentarily depress the DEGAUSS lever and release. (Time required for probe degaussing is 200 milliseconds.)

9. Adjust OUTPUT DC LEVEL to center the trace vertically on the CRT.

10. Set the CURRENT/DIV switch to the suitable position for the measurement to be made and again degauss the probe.

11. Adjust CURRENT/DIV BALANCE to center the trace vertically on the CRT.

12. Remove the probe from the front-panel receptacle, move the slider back, and place the probe around the conductor under test. Push the slider forward into the locked position.

13. Place the probe or transformer around the conductor under test (or insert the current shunt into the circuit per Figure B-2)

14. Set the wattmeter calibrate switches to OFF.

15. Set the wattmeter voltage range as desired.

16. Connect the wattmeter voltage input terminals to the circuit under test.

17. Observe the watts output as a vertical scale deflection on the CRO. The watts/volt output sensitivity is determined from the front panel table:

i. e.: for current shunt: 10 x voltage range setting = watts/volt

for P6042 current/ div x voltage range = watts/volt

calibrate: cal. voltage x calibrate current (voltage equiv.) divided by 10 = output voltage

18. If either overrange light comes on, the appropriate range switch should be set to the next larger range. If the output is less than one volt, one or both current and voltage range switches may be set to a lower scale as long as the overrange light does not come on.

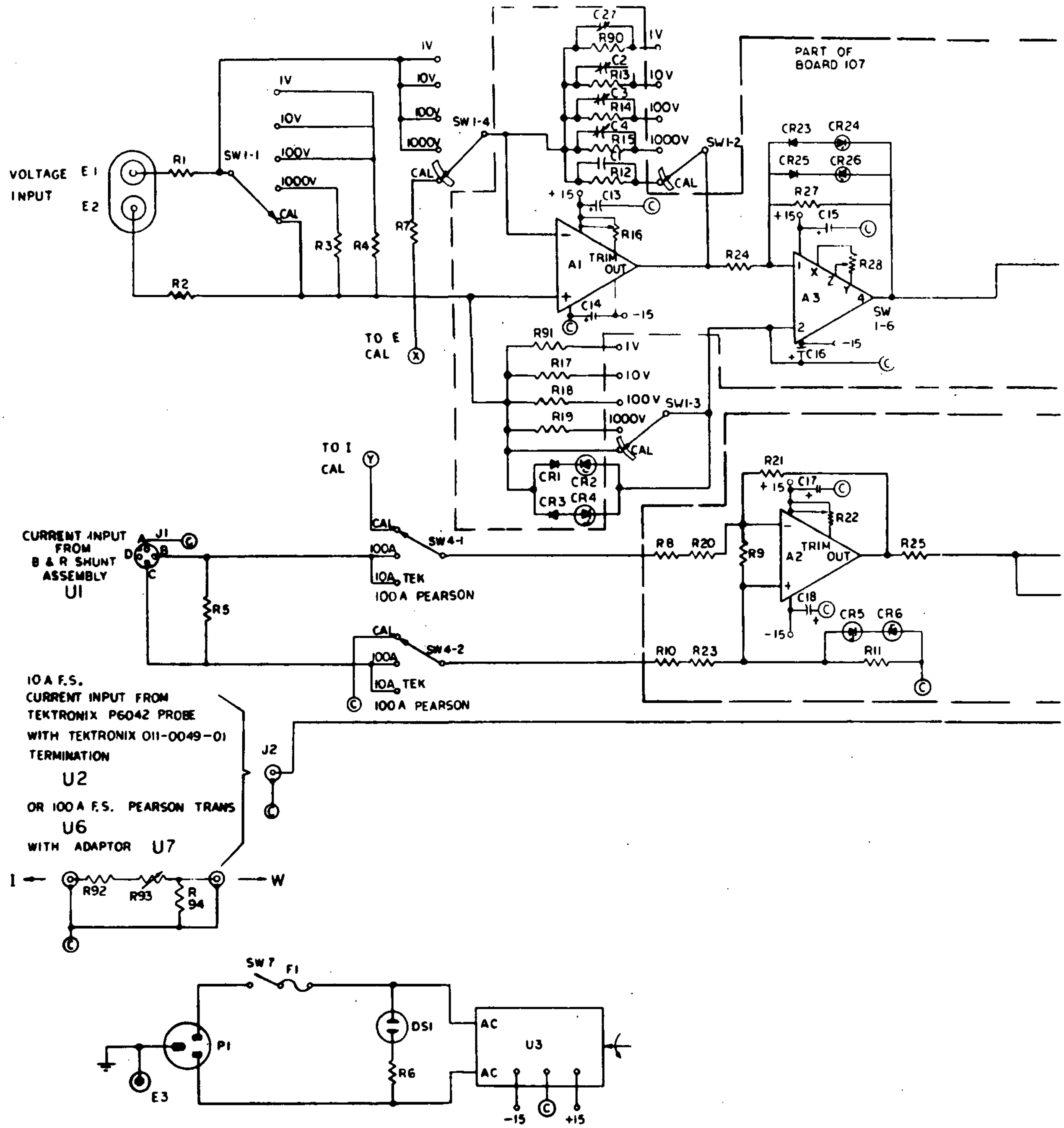
Calibration. - The wattmeter may be calibrated by external voltage and currents or by use of the built-in calibration. Internal calibration circuits permit exercising all amplifiers and the multiplier at 0, 1/2 and rull scale for each input (0, 1/4, 1/2 and full scale on wattage). Normal calibration results are as follows:

		OUTPUT (VOLTS)		
VOLTAGE	CURRENT	METER	SCOPE PK. VOLTS	
0	0	0	0	(Checks offset voltage)
10	0	0	0	(Checks cross-coupling)
0	10	0	0	(Checks cross-coupling)
5	5	1.25	2.5	(1/4 scale)
5	10	2.50	5.0	(1/2 scale)
10	5	2.50	5.0	(1/2 scale)
10	10	5.00	10.0	(full scale)

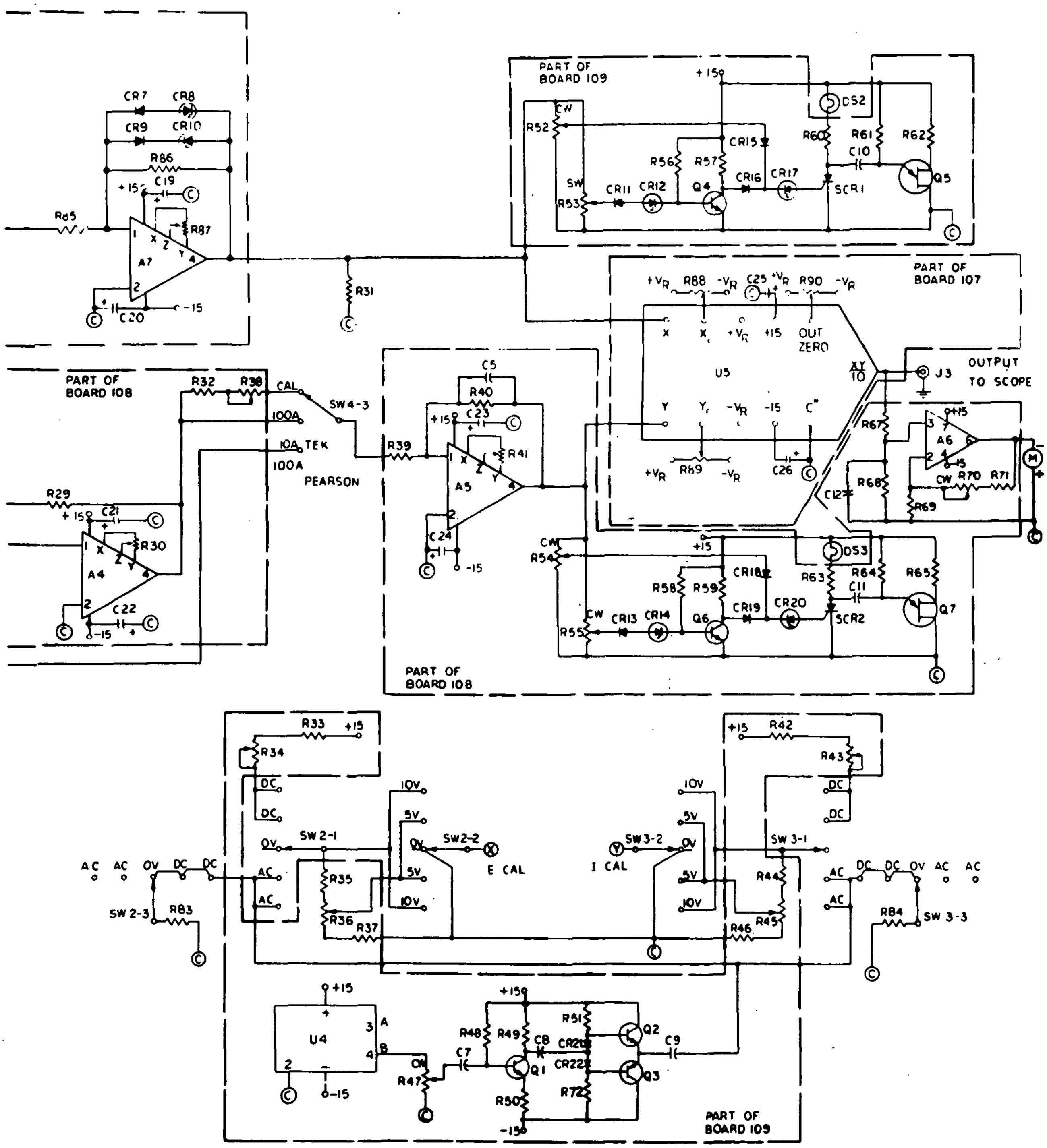
all AC values are zero in peak values.

APPENDIX F

SCHEMATIC & PARTS LIST - SECOND UNIT


VOLTAGE INPUT
E1
E2
R1
R2
SW1-1
SW1-4
SW1-2
SW1-3
PART OF BOARD 107
TO E CAL
TO I CAL
CURRENT INPUT FROM B & R SHUNT ASSEMBLY
U1
J1
SW4-1
SW4-2
100A PEARSON
10A F.S. CURRENT INPUT FROM TEKTRONIX P6042 PROBE WITH TEKTRONIX 011-0049-01 TERMINATION
U2
OR 100A F.S. PEARSON TRANS
U6
WITH ADAPTOR U7
J2
R92
R93
R94
SW7
F1
P1
E3
DS1
R6
U3

SCHEMATIC



WIDEBAND WATTMETER - SECOND UNIT

BILL OF MATERIAL

SEPT. 22,71

CLIENT: NASA

SCHEMATIC WIDEBAND WATTMETER S/N 002

DWG. NO. 1-8108-110 C

B & R PROJECT NO. 1-8108

SHEET 1 OF 4

DETAIL DRAWING NO.	PART NAME	QUANTITY	DESCRIPTION	REMARKS
A1,2	Amplifier, Solid State Operational	2	Wide Band, FET, Differential Analog Devices Model 45K	
A4,5	Amplifier, Solid State Operational	2	Fast Slewing, Wide Band Burr Brown Model 3342/15C	
A6	Amplifier, Solid State Operational, IC	1	Fairchild UA 741 C	
A3,7	Amplifier, Solid State Operational	2	Fast Slewing, Wide Band Burr Brown Model 3341/15C	
U1	Current Shunt, Co-Axial, Wide Band	1	0- 100A, 0.01 ohms, 300M HZ B&R DWG. 1-8108-101	
U2	Current Probe Unit	1	DC to 50 MHZ, 1MA/Div Tektronix Model P6042	
U3	Power Supply, DC Dual-Tracking	1	±12 to 15V, 400 mA Lambda Model LXD-3-152	
U4	Oscillator, Solid State Precision	1	7.07 VRMS, 1KHz Burr Brown 4023/25	
U5	Multiplier Analog, Solid State	1	Wideband, Precision Analog Devices Model 422A	
U6	Transformer, Current Wideband	1	Pearson Electronic Model 411	
U7	Adapter	1	B&R DWG. 1-8108-111	
Q1,2 4,6	Transistor, Silicon NPN	4	2N1711	
Q3	Transsitor, Silicon PNP	1	2N2905A	
Q5,7	Transistor Unijunction	2	2N1671B	
SCR1,2	Silicon Controlled Rectifier	2	100V, 0.8 A RMS C103A, G.E.	
R1,2	Resistor, Fixed Film, High Stability	2	499K ohms ± 0.1% RN70D4993B	Dale # MFS-1/2
R3,11,21	Resistor, Fixed, Film, High Stability	3	1000 Ohms ± 0.1% RN65C1001B	
R4,68	Resistor, Fixed Film, High Stability	2	10K ohms ± 1% RN65D1002F	
R5	Resistor, Fixed, Composition	1	91 Ohms ± 5% RCR20G910JS	
R7,40 90,91	Resistor, Fixed, Film, High Stability	4	49.9 K Ohms ± 0.1% RN65C4992B	
R9	Resistor, Fixed Film, High Stability	1	200 Ohms ± 1% RN65D2000F	
R8,10, 13,17,	Resistor, Fixed, Film, High Stability	7	4.99 K Ohms ± 0.1% RN65C4991B	
20,23, 25				
R12,14 18	Resistor, Fixed, Film, High Stability	3	499 Ohms ± 0.1% RN65C4990B	

DESIGNERS & ENGINEERS

BARNES & REINECKE INC.
CHICAGO, ILLINOIS

BILL OF MATERIAL

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SCHEMATIC, WIDEBAND WATTMETER S/N 002

DWG. NO. 1-8108-110 C

B & R PROJECT NO. 1-8108

SHEET 2 OF 4

DETAIL DRAWING NO.	PART NAME	QUANTITY	DESCRIPTION	REMARKS
R15,19 94	Resistor, Fixed Film, High Stabiliy	3	49.9 Ohms ± 1% 1/2 W RN65D49R9	
R16,22, 38	Resistor, Variable Wirewound	3	1000 Ohms ± 20% Spectrol No. 41-4-1	
R87,28 30,41	Resistor, Variable Wirewound	4	2000 Ohms ± 20% Spectrol NO. 41-4-1	
R24, 39 85	Resistor, Fixed Film, High Stability	3	2.49 K Ohms ± 0.1% RN65C2491B	
R27,29 86	Resistor, Fixed, Film, High Stability	3	24.9 K Ohms ± 0.1% RN65C2492B	
R31	Resistor, Fixed Composition		100 K Ohms ± 5% RCR07G104JS	
R32	Resistor, Fixed Film,High Stability	1	22.1 K Ohms ± 1% RN652212F	
R33,42	Resistor, Fixed Film,High Stability	2	453 Ohms ± 1% RN65D4530F	
R34,36 43,45	Resistor, Variable Wirewound	4	20 Ohms ± 20% Spectral No. 41-4-1	
R35,37 44,46	Resistor, Fixed Film,High Stability	4	487 Ohms ± 1% RN65D4870F	
R47,52 53,54 55,70	Resistor, Variable Wirewound	6	10,000 Ohms ± 20% Spectrol No. 41-4-1	Alt.Mil# RT12-C2P-103
R48	Resistor, Fixed Composition	1	620 K Ohms ± 10% RCR 20 G 624 KS	
R49	Resistor, Fixed Composition	1	1500 Ohms, ± 10% RCR 20F152KS	
R50	Resistor, Fixed Composition	1	220 Ohms ± 10% RCR20G221KS	
R51,72	Resistor, Fixed Film,High Stability	2	30.9K Ohms± 1% RN65D3092F	
R56,58	Resistor, Fixed Composition	2	2.2 K Ohms ± 10% RCR 20G 222KS	
R57,59	Resistor, Fixed Composition	2	4.7K Ohms ± 10% RCR 2oG 472 KS	
R60,63	Resistor, Fixed Composition	2	47 Ohms ± 10% RCR 20G 470 KS	
R61,64	Resistor, Fixed Composition	2	220 K Ohms ± 10% RCR 20G 224 KS	
R62,65	Resistor, Fixed Composition	2	330 Ohms ± 10% RCR 20G 331 KS	
R67	Resistor, Fixed Film,High Stability	1	100K Ohms ± 1% 1/2 W RN65D1003F	
R69	Resistor, Fixed Film, High Stability	1	4.99K Ohms ± 1% 1/2 W RN65D4991F	
R71	Resistor, Fixed Film,High Stability	1	44.2K Ohms ± 1%,1/2 W RN65D4422F	
R83,84	Resistor, Fixed Film,High Stability	2	1000 Ohms ± 5%, 1/2 W RCR 20G 102JS	

DESIGNERS & ENGINEERS

BARNES & REINECKE INC.
CHICAGO, ILLINOIS

BILL OF MATERIAL

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SCHEMATIC, WIDEBAND WATTMETER S/N 002

DWG. NO. 1-8108-110 C

B & R PROJECT NO. 1-8108

SHEET 3 OF 4

DETAIL DRAWING NO.	PART NAME	QUANTITY	DESCRIPTION	REMARKS
R88,89 90	Resistor, Variable Wirewound	3	20K Ohms ± 20% Spectrol No. 41-4-1	
R92	Resistor, Fixed Film,High Stability	1	825 Ohms ± 0.1% RN60E 8250B	
R93	Resistor, Fixed Film,High Stability	1	200 Ohms ± 20% Spectrol No. 41-4-1	
CR1,3,7 9,11,13	Diode, Silicon, High Conductance	14	IN4454/IN3064	
15,16, 18,19,				
21,22 23,25				
CR2,4 5,6	Diode,Zener,Silicon	4	10 Volts ± 5%, 1 W 1N4162A	
CR8,10 24,26	Diode, Zener,Silicon Low Leakage	4	10 Volts ± 5%, 1 W TRW # LV3100A	
CR12,14 17,20	Diode,Zener,Silicon	4	6.8 Volts ± 5%, 1W Schauer No. Sz6.8A	
C1	Capacitor Fixed Dipped Mica	1	100 Pf, 500V CM05 FD101 J03	
C27,5	Capacitor, Variable	2	2" twisted Insulating wire #20AWG	
C2	Capacitor, Variable 9-35 PF	1	JFD Type DV11-35D Type A	
C3	Capacitor, Variable 90-400 PF	1	Elmenco Type 429	
C4	Capacitor, Factory Selected, 3300 pf	1	CDE CD19FD332J03	
C7,8,12	Capacitor, Fixed	3	0.1 MFD, 100 V 225P10491	Sprague
C9	Capacitor, Fixed	1	2.0 MFD, 200 V 2DF-M2	Sprague
C10,11	Capacitor, Fixed	2	0.5 MFD, 200V 200P-2PS-P50	Sprague
C13-26	Capacitor, Fixed Electrolutic,Tantalum	14	15 UF, 20 V CSR 13E 156 KM	
SW1	Switch,Rotary,Miniature Ceramic	1	6PST, Shorting, Central-LAB. No. PA 2020	
SW2,3	Switch,Rotary,Miniature Ceramic	2	3P5T, Non-Shorting,Centralabd No. PA2007	
SW4	Switch,Rotary,Miniature Ceramic	1	3P5T, Non-Shorting, Centralabs No. PA2007	
SW7	Switch, Toggle Sealed Lever	1	SPST MS35058-21	
J1	Receptacle,Connector Electrical	1	MS3102A-14S-2P	
J2,3	Receptacle, BNC, Electrical	2	JAN NO. UG-290A/U	
DS1	Neon Lamp and Lamp Holder Assy	1	MS25257-4-C7A	

DESIGNERS & ENGINEERS

BARNES & REINECKE INC.
CHICAGO, ILLINOIS

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CLIENT: NASA

SCHEMATIC, WIDEBAND WATTMETER S/N 002

DWG. NO. 1-8108-110 C

B & R PROJECT NO. 1-8108

SHEET 4 OF 4

DETAIL DRAWING NO.	PART NAME	QUANTITY	DESCRIPTION	REMARKS
DS2,3	Incandescent Lamp & Holder	2	MS25256-6-330	
F1	Fuse, Cartridge	1	1A, 250 V Type 3AG	
M1	Meter, DC Volt 3 1/2", (+)10-0-(-)10	1	± 1% Accuracy, 10K Ohms/V 3BA-DVV-10 U10-A1MV	Modutec
P1	Plug with Cord, 3-Conductor	1	18 AWG, 6 FT. Belden No. 17406	
E1,2	Binding Post, Dual Assembly	1	H.H. Smith No. 269RB	
E3	Binding Post, Hex Nut	1	Superior No. GP30NC	

DESIGNERS & ENGINEERS

BARNES & REINECKE INC.
CHICAGO, ILLINOIS

APPENDIX G

NEW TECHNOLOGY APPENDIX

WIDEBAND WATTMETER

After a diligent review of the work performed to date under this contract, no new innovation, discovery or invention was was made. However, it is believed that the wideband wattmeter developed under this contract offers a wider usable frequency response than any existing instrument and is a definite improvement on power measurement technology.

A detailed description of the unit is given on pages 5, 6, 7, and 8. Technical details are given in Appendices D, E, and F.