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AMPLITUDE CALIBRATOR FOR OSCILLOSCOPES

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Boulder, Colorado 80303

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary

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AMPLITUDE CALIBRATOR FOR OSCILLOSCOPES

James R. Andrews and Eugene E. Baldwin
National Bureau of Standards
Boulder, Colorado 80303

The amplitude calibrator is designed to provide known dc voltage levels or 1 kHz square waves from ± 1 mV to ± 5 V. It features selectable output impedances of < 0.1 Ω, 50 Ω, and 1 MΩ. The instrument is designed with sufficient current capability to deliver its indicated voltage into a 50 Ω termination. To protect delicate sampling oscilloscopes, a limiter circuit can also be activated to limit the output voltage to ± 1.8 V.

Key words: Calibration; calibrators; instrumentation; oscilloscope calibrator; oscilloscopes

1. Introduction

This report describes equipment developed by NBS for calibration of the vertical axis of an oscilloscope. The amplitude calibrator (fig. 1) provides voltages from ± 1 mV to ± 5 V with ΔV steps of 1 mV to 500 mV in a 1, 2, 5 sequence and a 0 to 10 multiplier in unit steps with a source impedance of < 0.1 Ω, 50 Ω, or 1 MΩ. It produces either dc or a 1 kHz square wave.

This report describes in detail the circuit design. Schematic diagrams, parts list, and p.c. artwork are included. A complete alignment and calibration procedure is provided.

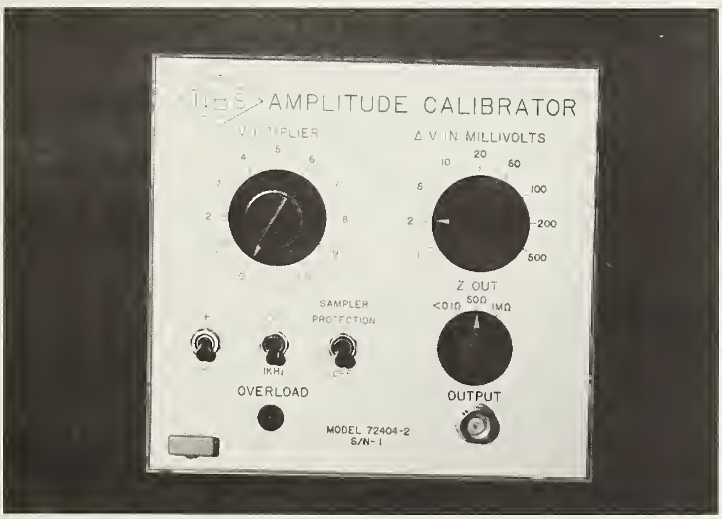


Figure 1. NBS amplitude calibrator.

2. Specifications and Features

NBS Amplitude Calibrator Model - 72404-2

I. Output voltages:

a. $\pm$ 1 mV to $\pm$ 5 V

b. ΔV steps - 1 mV to 500 mV in a 1, 2, 5 sequence.

c. multiplier - 0 to 10 in unit steps.

d. open circuit output voltage is 2X the indicated value when the output impedance switch is in the 50 Ω or 1 M Ω positions.

II. Voltage accuracy: within $\pm$ 0.25% (typically < 0.1%) except $\pm$ 0.4% at 2 mV and $\pm$ 0.7% at 1 mV.

III. Output impedance: adjustable with 3 position switch to (a) < 0.1 Ω, (b) 50 Ω, $\pm$ 0.1% and (c) 1.0 M Ω, $\pm$ 0.1%.

IV. Operating modes: (a) DC or (b) 1 kHz square wave. Square wave baseline is 0 volts. Frequency accuracy is $\pm$ 0.01%.

V. Sampler protection: switch selectable internal circuit limits output voltage to a maximum of $\pm$ 1.8 volts nominal.

VI. Overload protection: overload lamp lights if output current exceeds $\pm$ 225 mA, nominal, and the maximum output current is limited to $\pm$ 275 mA. The lamp also lights if the multiplier and ΔV switches would create an output in excess of $\pm$ 1.2 volts when the sampler protection circuit is on.

VII. Output connector: BNC

VIII. Controls: (a) ΔV in mV, (b) multiplier, (c) polarity (+ or -), (d) mode (dc or 1 kHz), (e) sampler protection (on or off) and (f) output impedance.

IX. Construction: the unit is a double-wide, plug-in module designed to be operated in a Tektronix TM-500 mainframe.

3. Circuit Description and Schematics

The block diagram of the amplitude calibrator is shown in figure 2. Detailed schematic diagrams are found in figures 3 through 7.

The internal voltage standard for the unit is $\pm$ 10.000 V found at TP7. An LM399H, IC-10, is used as a precision voltage reference. It is a temperature stabilized, active reference zener. It features a typical temperature coefficient of 0.00003%/^{o}C (0.0002%/^{o}C max.). The actual reference voltage is a nominal 6.95 V ($\pm$ 0.35 V). The $\pm$ 10.000 V internal standard voltage is obtained from the 6.95 V reference using the IC-1 and the resistors R_a, R_b, and R_c. The reference voltage is very stable with time and temperature but it is not well known (i.e., large variation in actual voltage from one unit to the next.) Thus it is necessary to provide a means of varying the gain of IC-1 to accurately set the internal standard at precisely $\pm$ 10.000 V. Resistor R_c is used for this function.

Switch S1 provides the polarity function by alternately grounding either the positive or negative terminal of the 6.95 V reference. The 1 kHz square wave function is obtained using the integrated analog switch, IC-4. It grounds at a 1 kHz rate the center point of resistors R_a and R_b, thus forcing the input to IC-1 to zero. As a result the voltage at TP7 switches from $\pm$ 10.000 V to 0.00 V.

The ΔV function (1 mV to 500 mV in a 1-2-5 sequence) is provided by the variable gain amplifier used as an active attenuator IC-2. The gain of this stage is set by the input and feedback resistor ratio

$$V(TP8) = V(TP7) \times R_e/R_d.$$

Resistors R_e and R_d are precision, 0.1%, resistors and are switched by a common switch to give TP8 voltages ranging from +10 mV to +5.000 V.

Following IC-2 is the multiplier attenuator, R_f. This is a passive voltage divider made up of ten, 1 kΩ, 0.1% resistors. This provides the unit step multiplier function (0, 1, 2, etc. up to 10). To avoid upsetting the accuracy of R_f it is followed by a very high input impedance voltage follower, IC-3.

Also following the multiplier attenuator is the sampler protection circuit. Most sampling oscilloscopes have a dynamic range of ± 1 V and burnout limits of ± 3 V. Thus the maximum output from this amplitude calibrator could easily destroy a sampling oscilloscope input circuit. To protect against this a limiter circuit can be switched in to limit the output voltage to a nominal ± 1.5 V.

The next circuit is a hybrid power amplifier consisting of IC-3 and complementary NPN-PNP Darlington amplifier pairs. This power amplifier is capable of delivering up to ± 10 V at 200 mA. The voltage gain of this stage is unity. The circuit includes short circuit protection.

Beyond the power amplifier is an additional switch to determine the output impedance. The output impedance of the power amplifier is typically 0.1 Ω. Higher impedances are obtained by inserting a series 50 Ω or 1 M Ω resistor. The output voltage in the 50 Ω and 1 M Ω position is calibrated in terms of the voltage delivered to a load resistance matched to the source resistance. Thus it is necessary to double the open circuit source voltage. For example when the ΔV is 500 mV, the multiplier is 10 and the Z Out is 50 Ω or 1 M Ω, then the open circuit output voltage is ± 10.000 V instead of ± 5.000 V. This is accomplished by an additional switch section of the Z Out switch changing resistor R_d in the ΔV active attenuator.

The calibrator also includes an overload lamp. It lights whenever there is an overload or fault condition such as a short circuit on the output. It also lights if the sampler protection circuit is enabled and an output voltage is selected which exceeds the limiter voltage. The remainder of this section deals with particular comments related to the actual circuits.

In the ± 10 V standard circuit, IC-1, in figure 3, the resistors R_a and R_b and the switch IC-4 are actually five resistors and four CMOS switches. Each CMOS switch has a finite on resistance of the order of 100 Ω. A single section switch will not give a perfect 0 V input to IC-1. It was necessary to use multiple sections as a ladder attenuator to achieve the desired accuracy.

The 1 kHz square wave drive signal for IC-4 is derived from a 1 MHz crystal oscillator, IC-5a, and three ÷10 dividers, IC-6, 7 and 8. IC-9 is an additional ÷10 which provides a 100 Hz drive signal for the external, companion, plug-in, mercury switch pulse generator.

The active ΔV attenuator, IC-2, is seen to have nine (R33-R41) additional resistors in the + input. These are chosen to approximate the parallel combination of Rd and Re to provide offset current compensation for IC-2. Likewise the extra resistors (R54-R65) in the multiplier attenuator, figure 4, provide the same function for IC-3 in conjunction with R66.

The sampler protection limiter consists of diodes CR1 and 2 and transistors Q1-Q4. The forward diode drops of CR1, Q1 and Q2 in series provide the equivalent of a + 1.5 V clamp. Diode CR2, Q3, and Q4 provide the same function for negative voltages. The transitors are connected as high β Darlington amplifiers. When they start to conduct they turn on Q14 which in turn lights the overload lamp.

The power amplifier is also shown in figure 4. IC-3 provides a high impedance load for the multiplier attenuator and also drives the output power transistors, Q5-Q8. To avoid "cross-over" distortion and non-linearities at low output levels the bias is arranged such that the output transistors are always conducting. The bias network is made up of diodes CR3-CR6 and resistors R69, 70, 71, 73, and R5. The diodes provide temperature compensation for the temperature characteristic of the transistors' base-emitter junction voltage. The JFET transistors Q15a and b are used as constant current sources to force the output transistors to always conduct a few mA of current. The actual idling current can be adjusted with R5. The actual output current is monitored by sensing the voltage drop across the 3.3 Ω resistors, R72 and R74. If the current exceeds 250 mA, then the voltage drop is sufficient to turn on transistor Q9 (or Q10) which in turn kills the base drive at Q5 (or Q7) and very effectively limits the output current. At a slightly lower current of 225 mA, Q11 (or Q12) starts to conduct which in turn turns on Q13 and Q14 thereby lighting the overload lamp.

Each op-amp in the calibrator is equipped with a null adjustment pot. It is quite important, especially for the mV output levels, that each op-amp be precisely nulled to 0 V. To facilitate these adjustments, slide switches have been provided on the circuit boards.

It is important that the spurious noise output of this calibrator be kept to an absolute minimum. The major internal source of EMI is the 1 MHz crystal oscillator and the divider chain. To insure a quiet output signal, line filters consisting of C12, C13, C16, C19, R65 and C20 are used. The power supply lines on each card are filtered with tantalum and ceramic capacitors and RF chokes are used in the wiring between cards. In addition RC filters are used in the V+ and V- lines for each op-amp.

Figure 5 shows the wiring between the various pc cards and the front panel controls. Figure 6 shows the power supply card. Main dc power is derived from the TM-500 main-frame through the plug-in connector. The $\pm$ 33.5 V supply is pre-regulated to $\pm$ 20 V using CR9, CR11, Q16, Q18 and power transistors in the main-frame. Integrated circuit voltage regulators, IC11 and 12, are then used to obtain the required $\pm$ 15 V. These voltages are further dropped to $\pm$ 7.5 V for the CMOS ICs using CR10, CR12, Q17 and Q19.

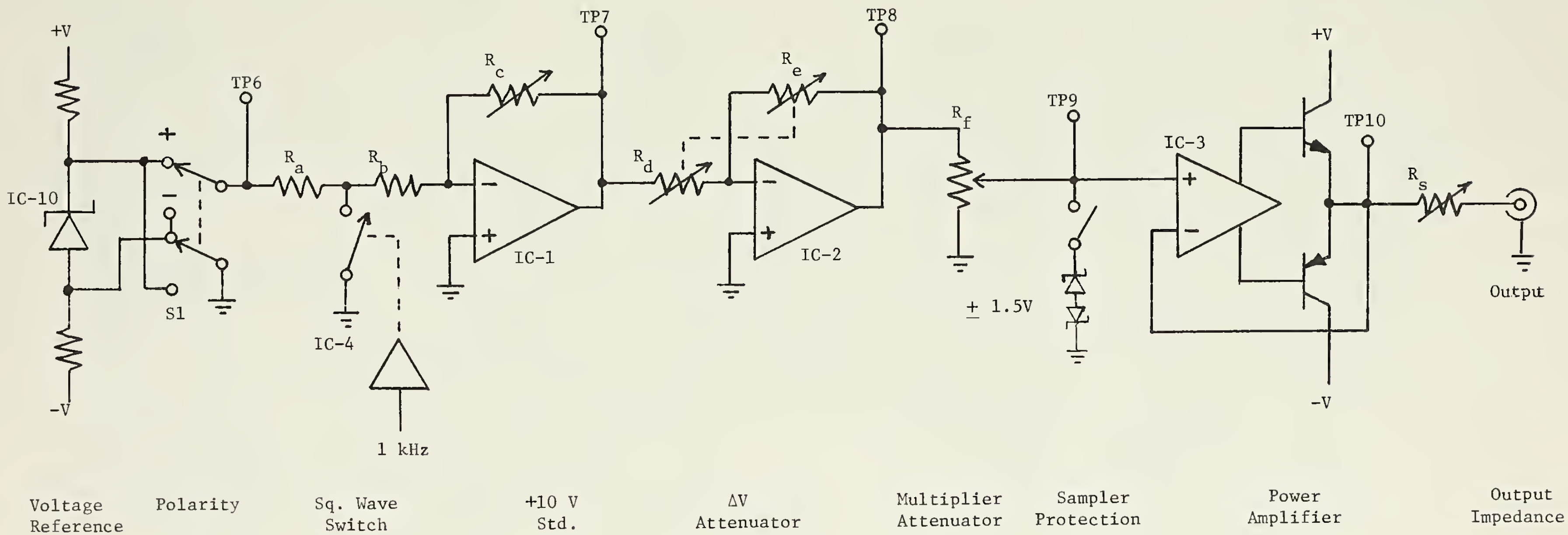


Figure 2. Block diagram of amplitude calibrator.

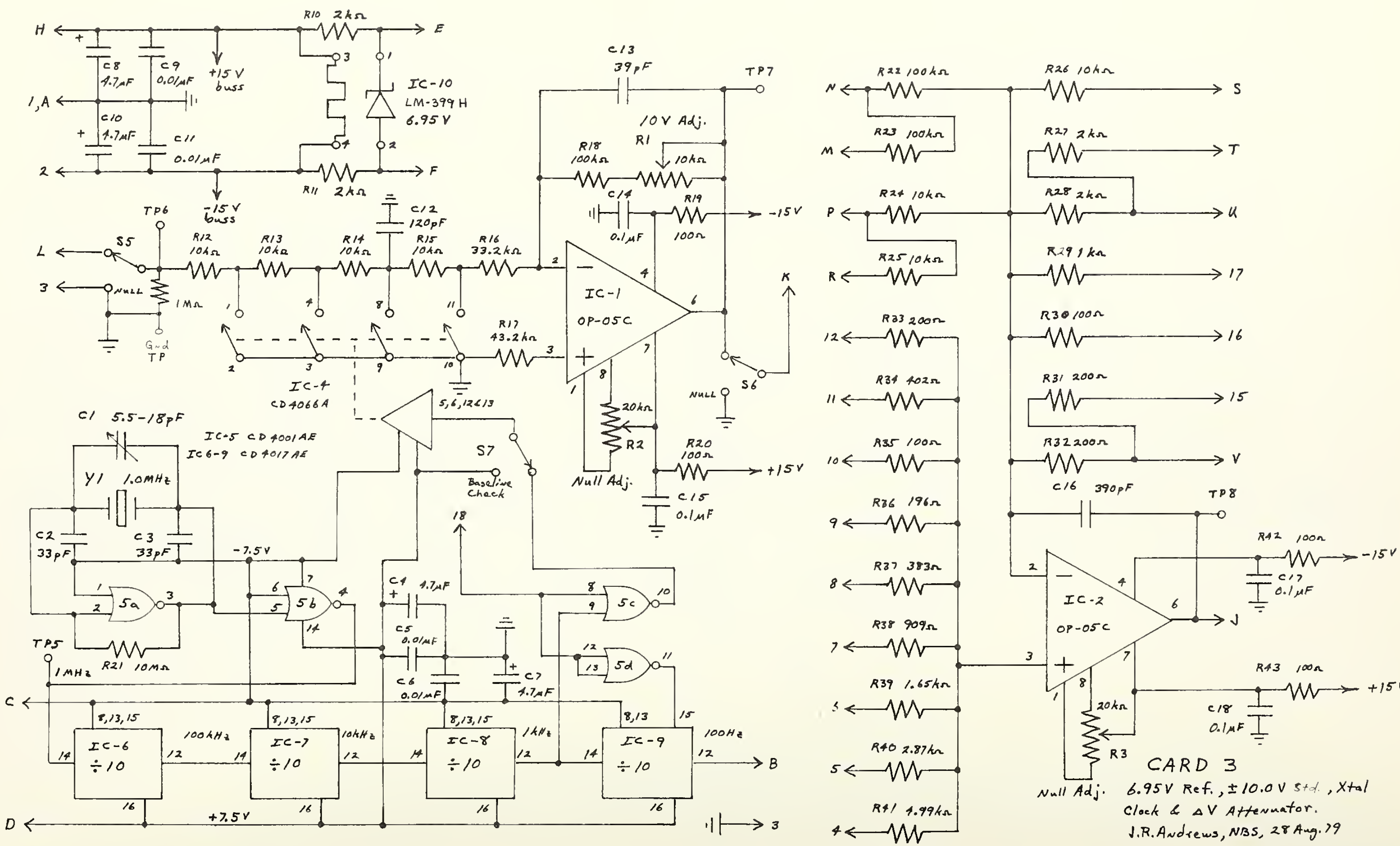


Figure 3. Schematic (1 of 4)

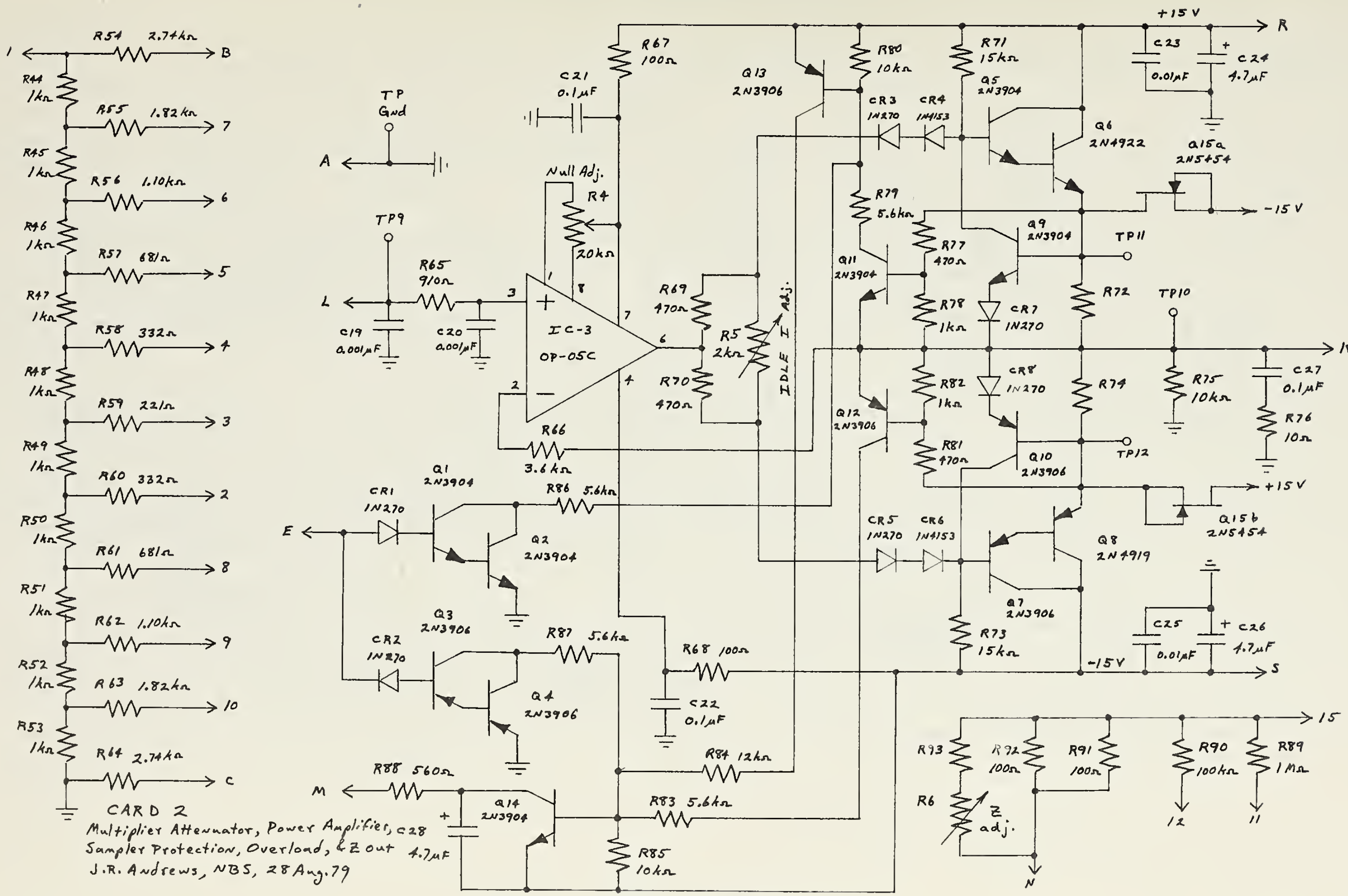


Figure 4. Schematic (2 of 4)

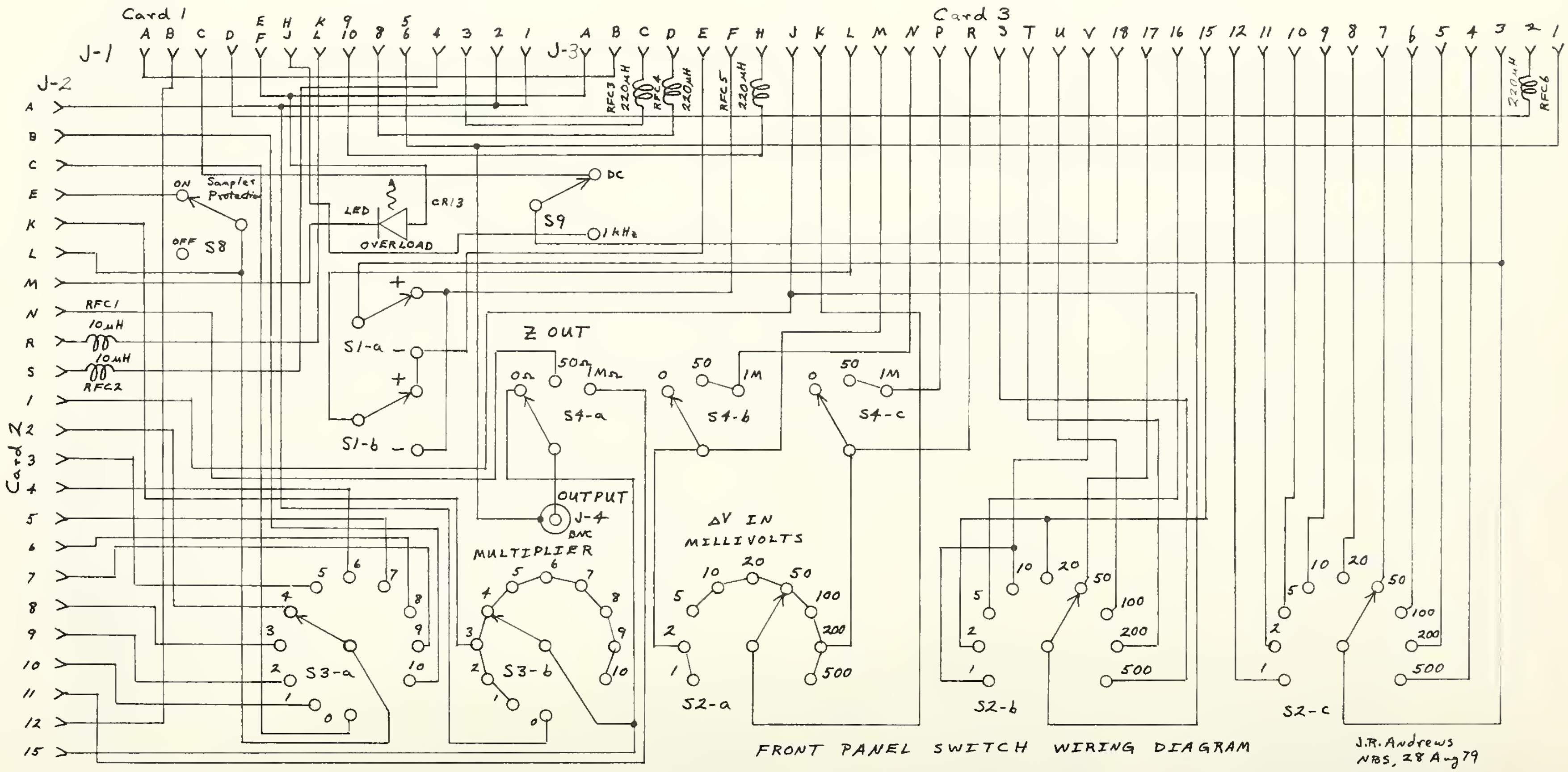


Figure 5. Schematic (3 of 4)

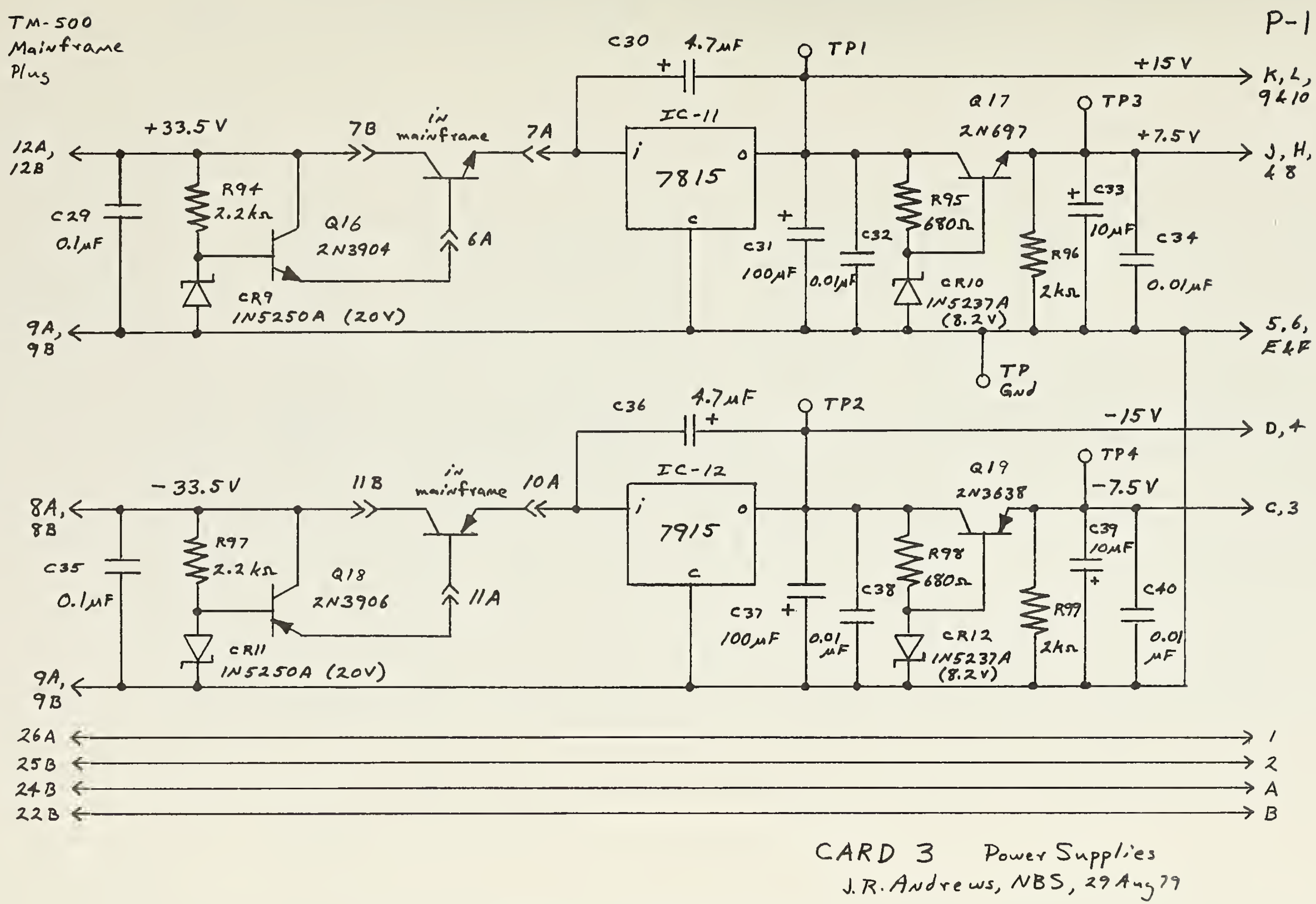


Figure 6. Schematic (4 of 4)

4. Parts List

Part Number	Description	Value
Card 3		
R1	Resistor, trimmer, 10 turn	10 kΩ
R2	Resistor, trimmer, 10 turn	20 kΩ
R3	Resistor, trimmer, 10 turn	20 kΩ
R10	Resistor, composition 1/4W, 5%	2 kΩ
R11	Resistor, composition 1/4W, 5%	2 kΩ
R12	Resistor, metal film, 1/8W, 1%	10 kΩ
R13	Resistor, metal film, 1/8W, 1%	10 kΩ
R14	Resistor, metal film, 1/8W, 1%	10 kΩ
R15	Resistor, metal film, 1/8W, 1%	10 kΩ
R16	Resistor, metal film, 1/8W, 1%	33.3 kΩ
R17	Resistor, metal film, 1/8W, 1%	43.2 kΩ
R18	Resistor, metal film, 1/8W, 1%	100 kΩ
R19	Resistor, composition 1/4W, 5%	100 Ω
R20	Resistor, composition 1/4W, 5%	100 Ω
R21	Resistor, composition, 1/4W, 5%	10 MEG Ω
R22	Resistor, precision, 1/2W, 0.1%	100 kΩ
R23	Resistor, precision, 1/2W, 0.1%	100 kΩ
R24	Resistor, precision, 1/2W, 0.1%	10 kΩ
R25	Resistor, precision, 1/2W, 0.1%	10 kΩ
R26	Resistor, precision, 1/2W, 0.1%	10 kΩ
R27	Resistor, precision, 1/2W, 0.1%	2 kΩ
R28	Resistor, precision, 1/2W, 0.1%	2 kΩ
R29	Resistor, precision, 1/2W, 0.1%	1 kΩ
R30	Resistor, precision, 1/2W, 0.1%	100 Ω
R31	Resistor, precision, 1/2W, 0.1%	200 Ω
R32	Resistor, precision, 1/2W, 0.1%	200 Ω
R33	Resistor, metal film, 1/8W, 1%	200 Ω
R34	Resistor, metal film, 1/8W, 1%	402 Ω
R35	Resistor, metal film, 1/8W, 1%	100 Ω
R36	Resistor, metal film, 1/8W, 1%	196 Ω
R37	Resistor, metal film, 1/8W, 1%	383 Ω
R38	Resistor, metal film, 1/8W, 1%	909 Ω
R39	Resistor, metal film, 1/8W, 1%	1.65 kΩ
R40	Resistor, metal film, 1/8W, 1%	2.87 kΩ
R41	Resistor, metal film, 1/8W, 1%	4.99 kΩ
R42	Resistor, composition, 1/4W, 5%	100 Ω
R43	Resistor, composition, 1/4W, 5%	100 Ω
R100	Resistor, composition, 1/4W, 5%	1M Ω

Part Number	Description	Value
Card 3		
C1	Capacitor, trimmer	5.5-18 pF
C2	Capacitor, silver mica	33 pF
C3	Capacitor, silver mica	33 pF
C4	Capacitor, tantalum	4.7 μF, 25 V
C5	Capacitor, disc ceramic	0.01 μF, 50 V
C6	Capacitor, disc ceramic	0.01 μF, 50 V
C7	Capacitor, tantalum	4.7 μF, 25 V
C8	Capacitor, tantalum	4.7 μF, 50 V
C9	Capacitor, disc ceramic	0.01 μF, 50 V
C10	Capacitor, tantalum	4.7 μF, 25 V
C11	Capacitor, disc ceramic	0.01 μF, 50 V
C12	Capacitor, silver mica	120 pF
C13	Capacitor, silver mica	39 pF
C14	Capacitor, plastic	0.01 μF, 100 V
C15	Omitted	
C16	Omitted	
C17	Capacitor, plastic	0.1 μF, 100 V
C18	Capacitor, plastic	0.1 μF, 100 V
Y1	Crystal, 1.0 MHz., .001%	
IC1	Operational amplifier	OP-05C
IC2	Operational amplifier	OP-05C
IC4	Integrated circuit, CMOS	CD4066A
IC5	Integrated circuit, CMOS	CD4001AE
IC6	Integrated circuit, CMOS	CD4017E
IC7	Integrated circuit, CMOS	CD4017E
IC8	Integrated circuit, CMOS	CD4017E
IC9	Integrated circuit, CMOS	CD4017E
IC10	Integrated circuit, voltage reference	LM-399H
S5	Switch, slide, miniature	1 pole, 2 position
S6	Switch, slide, miniature	1 pole, 2 position
S7	Switch, slide, miniature	1 pole, 2 position

Part Number	Description	Value
Card 2		
R44	Resistor, Precision, 1/2 W., 0.1%	1 kΩ
R45	Resistor, Precision, 1/2 W., 0.1%	1 kΩ
R46	Resistor, Precision, 1/2 W., 0.1%	1 kΩ
R47	Resistor, Precision, 1/2 W., 0.1%	1 kΩ
R48	Resistor, Precision, 1/2 W., 0.1%	1 kΩ
R49	Resistor, Precision, 1/2 W., 0.1%	1 kΩ
R50	Resistor, Precision, 1/2 W., 0.1%	1 kΩ
R51	Resistor, Precision, 1/2 W., 0.1%	1 kΩ
R52	Resistor, Precision, 1/2 W., 0.1%	1 kΩ
R53	Resistor, Precision, 1/2 W., 0.1%	1 kΩ
R54	Resistor, Metal Film, 1/8 W., 1%	2.74 kΩ
R55	Resistor, Metal Film, 1/8 W., 1%	1.82 kΩ
R56	Resistor, Metal Film, 1/8 W., 1%	1.10 kΩ
R57	Resistor, Metal Film, 1/8 W., 1%	681 Ω
R58	Resistor, Metal Film, 1/8 W., 1%	332 Ω
R59	Resistor, Metal Film, 1/8 W., 1%	221 Ω
R60	Resistor, Metal Film, 1/8 W., 1%	332 Ω
R61	Resistor, Metal Film, 1/8 W., 1%	681 Ω
R62	Resistor, Metal Film, 1/8 W., 1%	1.10 kΩ
R63	Resistor, Metal Film, 1/8W., 1%	1.82 kΩ
R64	Resistor, Metal Film, 1/8 W., 1%	2.74 kΩ
R65	Resistor, Metal Film, 1/8 W., 1%	909 Ω
R66	Resistor, Metal Film, 1/8 W., 1%	3.57 Ω
R67	Resistor, Composition, 1/4 W., 5%	100 Ω
R68	Resistor, Composition, 1/4 W., 5%	100 Ω
R69	Resistor, Composition, 1/4 W., 5%	470 Ω
R70	Resistor, Composition, 1/4 W., 5%	470 Ω
R71	Resistor, Composition, 1/4 W., 5%	15 kΩ
R72	Resistor, Composition, 1/2 W., 5%	3.3 Ω
R73	Resistor, Composition, 1/4 W., 5%	15 kΩ
R74	Resistor, Composition, 1/2 W., 5%	3.3 Ω
R75	Resistor, Composition, 1/4 W., 5%	10 kΩ
R76	Resistor, Composition, 1/4 W., 5%	10 Ω
R77	Resistor, Composition, 1/4 W., 5%	470 Ω
R78	Resistor, Composition, 1/4 W., 5%	1 kΩ
R79	Resistor, Composition, 1/4 W., 5%	5.6 kΩ
R80	Resistor, Composition, 1/8 W., 5%	10 kΩ
R81	Resistor, Composition, 1/4 W., 5%	470 Ω
R82	Resistor, Composition, 1/4 W., 5%	1 kΩ
R83	Resistor, Composition, 1/4 W., 5%	5.6 kΩ
R84	Resistor, Composition, 1/4 W., 5%	12 kΩ
R85	Resistor, Composition, 1/8 W., 5%	10 kΩ
R86	Resistor, Composition, 1/4 W., 5%	5.6 kΩ
R87	Resistor, Composition, 1/4 W., 5%	5.6 kΩ
R88	Resistor, Composition, 1/2 W., 5%	560 Ω

Part Number	Description	Value
Card 2		
R89	Resistor, Precision, 1/8 W., 0.1%	1 MΩ
R90	Resistor, Precision, 1/8 W., 1%	100 kΩ
R91	Resistor, Power, 3 Watt, 5%, Selected	100 Ω
R92	Resistor, Power, 3 Watt, 5%, Selected	100 Ω
R93	Selected	
R4	Resistor, Trimmer, 10 turn	20 K Ω
R5	Resistor, Trimmer, 10 turn	2 K Ω
R6	Selected	
C19	Capacitor, Disc Ceramic	0.001 μF
C20	Capacitor, Disc Ceramic	0.001 μF
C21	Capacitor, Plastic	0.1 μF, 100 V
C22	Capacitor, Plastic	0.1 μF, 100 V
C23	Capacitor, Disc Ceramic	.01 μF, 50 V
C24	Capacitor, Tantalum	4.7 μF, 25 V
C25	Capacitor, Disc Ceramic	.01 μF, 50 V
C26	Capacitor, Tantalum	4.7 μF, 25 V
C27	Capacitor, Plastic	0.1 μF, 100 V
C28	Capacitor, Tantalum	4.7 μF, 25 V
IC3	Operational Amplifier, Precision	OP-05C
Q1	Transistor, Si, NPN	2N3904
Q2	Transistor, Si, NPN	2N3904
Q3	Transistor, Si, PNP	2N3906
Q4	Transistor, Si, PNP	2N3906
Q5	Transistor, Si, NPN	2N3904
Q6	Transistor, Si, NPN, Power	2N4922
Q7	Transistor, Si, PNP	2N3906
Q8	Transistor, Si, PNP, Power	2N4919
Q9	Transistor, Si, NPN	2N3904
Q10	Transistor, Si, PNP	2N3906
Q11	Transistor, Si, NPN	2N3904
Q12	Transistor, Si, PNP	2N3906
Q13	Transistor, Si, PNP	2N3906
Q14	Transistor, Si, NPN	2N3904
Q15	Transistor, Si, Dual J-F.E.T.	2N5454
CR1	Diode, Signal, Ge	1N270
CR2	Diode, Signal, Ge	1N270
CR3	Diode, Signal, Ge	1N270
CR4	Diode, Signal, Si	1N4153
CR5	Diode, Signal, Ge	1N270
CR6	Diode, Signal, Si	1N4153

Part Number	Description	Value
Card 2		
CR7	Diode, Signal, Ge	IN270
CR8	Diode, Signal, Ge	IN270
Card 1		
R94	Resistor, Composition, 1/4 W, 5%	2.2 kΩ
R95	Resistor, Composition, 1/4 W, 5%	680 Ω
R96	Resistor, Composition, 1/4 W, 5%	2 KΩ
R97	Resistor, Composition, 1/4 W, 5%	2.2 KΩ
R98	Resistor, Composition, 1/4 W, 5%	680 Ω
R99	Resistor, Composition, 1/4 W, 5%	2 KΩ
C29	Capacitor, Disc Ceramic	0.1 μF, 100 V
C30	Capacitor, Tantalum	4.7 μF, 25V
C31	Capacitor, Electrolytic	100 μF, 25V
C32	Capacitor, Disc Ceramic	0.01 μF, 50V
C33	Capacitor, Tantalum	10 μF, 25V
C34	Capacitor, Disc Ceramic	0.01 μF, 50V
C35	Capacitor, Disc Ceramic	0.1 μF, 100V
C36	Capacitor, Tantalum	4.7 μF, 25V
C37	Capacitor, Electrolytic	100 μF, 25V
C38	Capacitor, Disc Ceramic	0.01 μF, 50V
C39	Capacitor, Tantalum	10 μF, 25V
C40	Capacitor, Disc Ceramic	0.01 μF, 50V
Q16	Transistor, Si, NPN	2N3904
Q17	Transistor, Si, NPN	2N697
Q18	Transistor, Si, PNP	2N3906
Q19	Transistor, Si, PNP	2N3638
IC11	Integrated Circuit, Regulator, +15V	7815
IC12	Integrated Circuit, Regulator, -15V	7915
CR9	Diode, Zener, 20V	IN5250
CR10	Diode, Zener, 8.2V	IN5237
CR11	Diode, Zener, 20V	IN5250
CR12	Diode, Zener, 8.2V	IN5237
Front Panel		
S1	Switch, Toggle, 2 pole, 2 position miniature	
S2	Switch, Rotary, 3 Section, 1 Pole, 9 Position, Shorting. Centralab PSA208 or Equiv.	
S3	Switch, Rotary, 2 Section, 1 Pole, 11 Position, Shorting, Centralab PSA204 or Equiv.	

Part Number	Description	Value
Front Panel		
L.E.D.	Diode, Light-emitting, Red	
J-4	Connector, B.N.C., Female Panel Mount	
S4	Switch, Rotary, Miniature, 2 Pole, 2 Position	
S8	Switch, Toggle, Miniature, 1 Pole, 2 Position	
S9	Switch, Toggle, Miniature, 1 Pole, 2 Position	
	Front Panel - special built by NBS shops per attached drawing, figure 2-7.	
Miscellaneous		
	Blank Plug-In Kit, double wide,	Tektronix #040-0754-05
	Connector, 20 Contact, .156" spacing or Equiv., Keyed between 2-B and 3-C	TRW 251-10-30-160
	Connector, 30 Contact, .156" Spacing or Equiv., Keyed between 3-C and 4-D	TRW 251-15-30-160
	Connector, 36 Contact, .156" Spacing or Equiv., Keyed between 1-A and 2-B.	TRW 251-18-30-160
RFC1	R.F. Choke, Miniature	10 μH
RFC2	R.F. Choke, Miniature	10 μH
RFC3	R.F. Choke, Miniature	220 μH
RFC4	R.F. Choke, Miniature	220 μH
RFC5	R.F. Choke, Miniature	220 μH

5. Construction

This instrument is designed to be operated in and powered by a Tektronix TM-500 mainframe. It is built in a double-wide, blank, plug-in kit. There are three printed circuit boards. Figures 7-11 are photographs of the assembled instrument and the separate p.c. boards. Figures 12-14 are the art work for the p.c. boards.

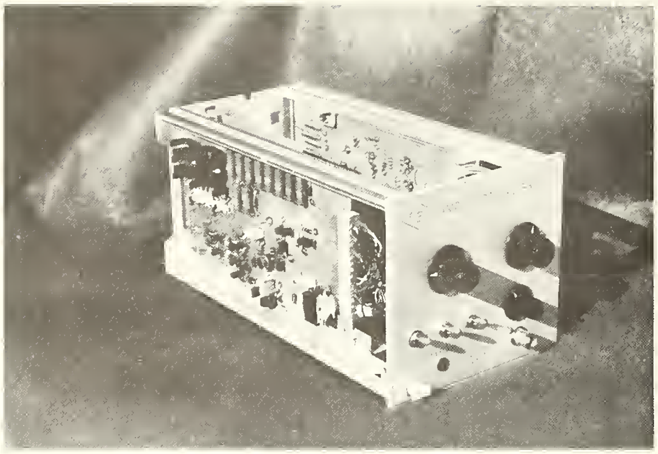


Figure 7. Photo of assembled instrument (cover plates removed).

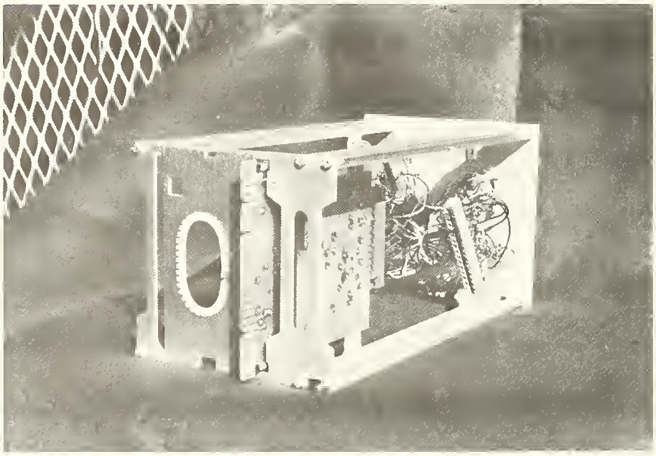


Figure 8. Rear view. (Partially disassembled)

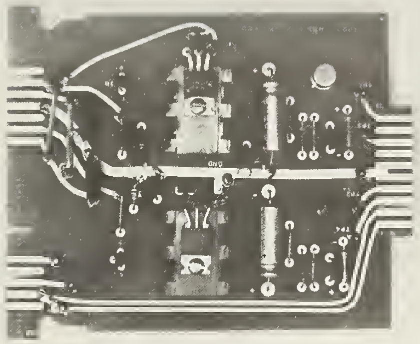


Figure 9. P.C. Board #1.

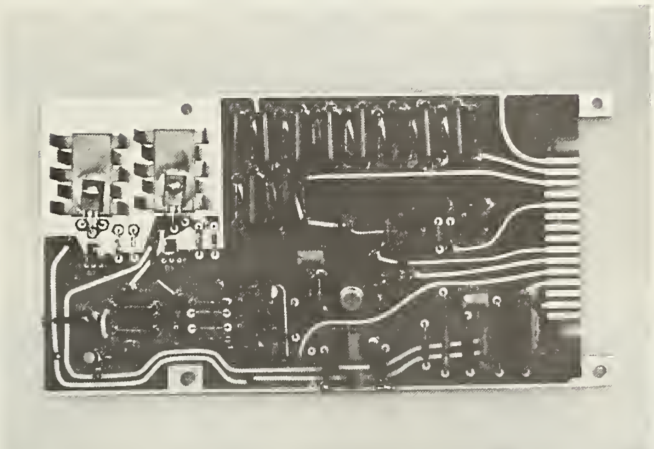


Figure 10. P.C. Board #2.

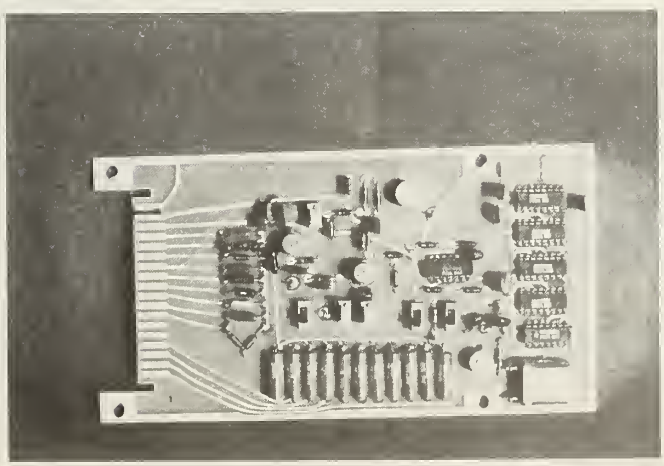
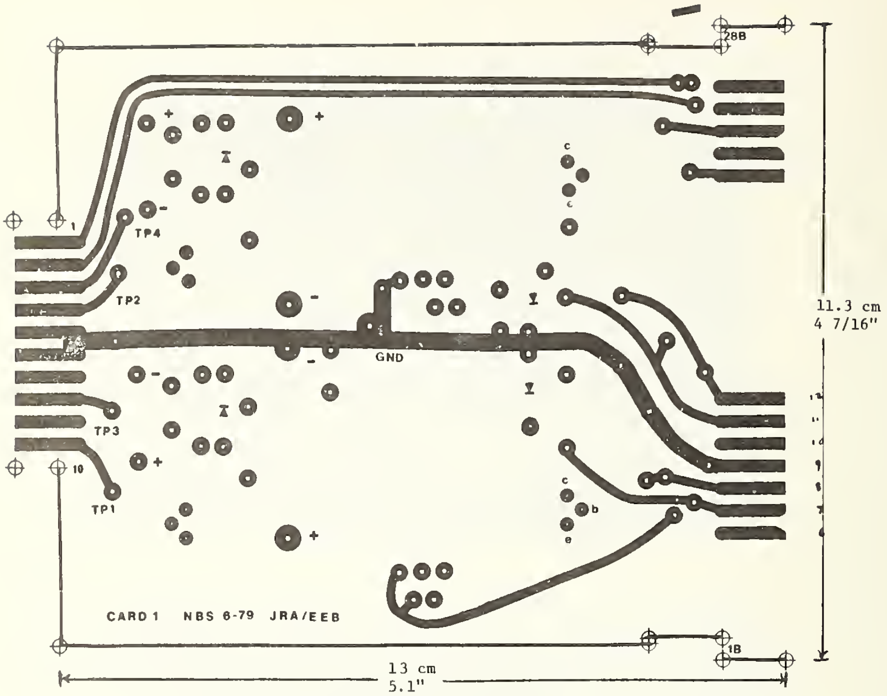
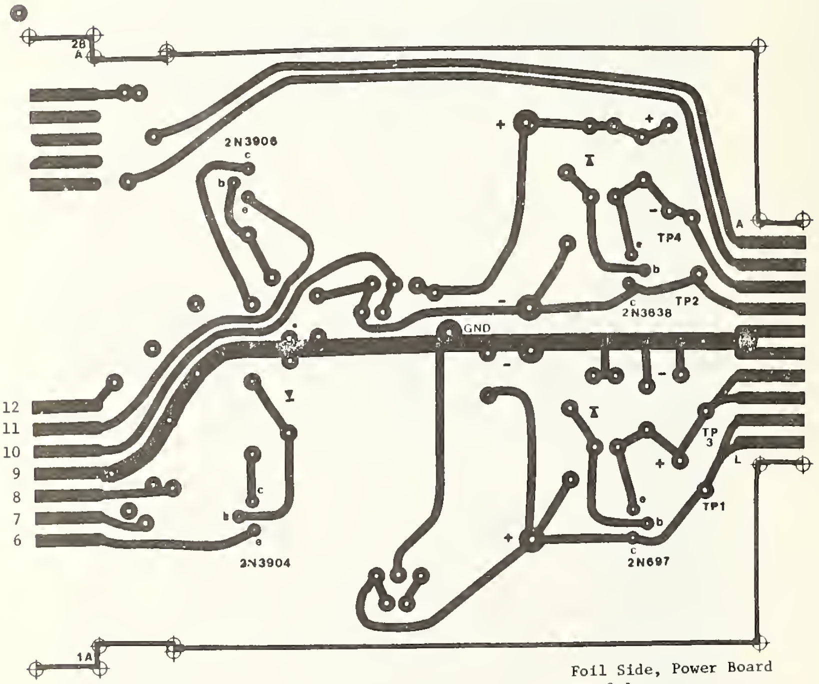


Figure 11. P.C. Board #3.

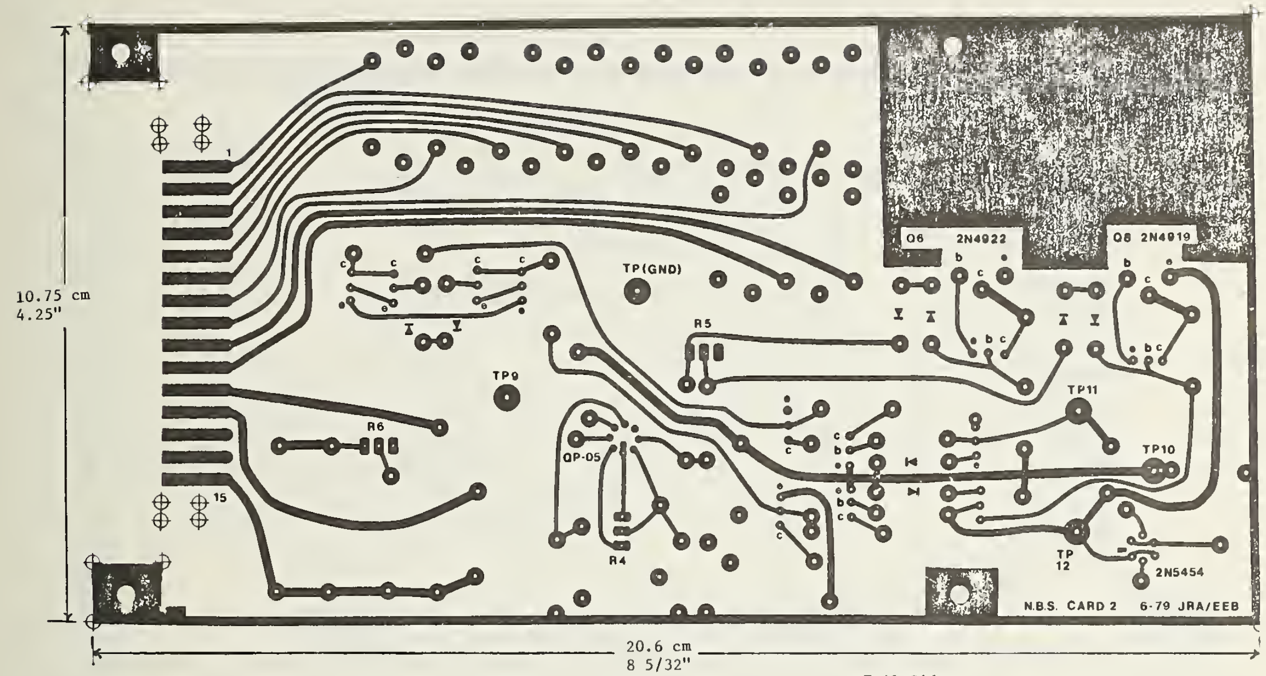


Parts Side 2:1

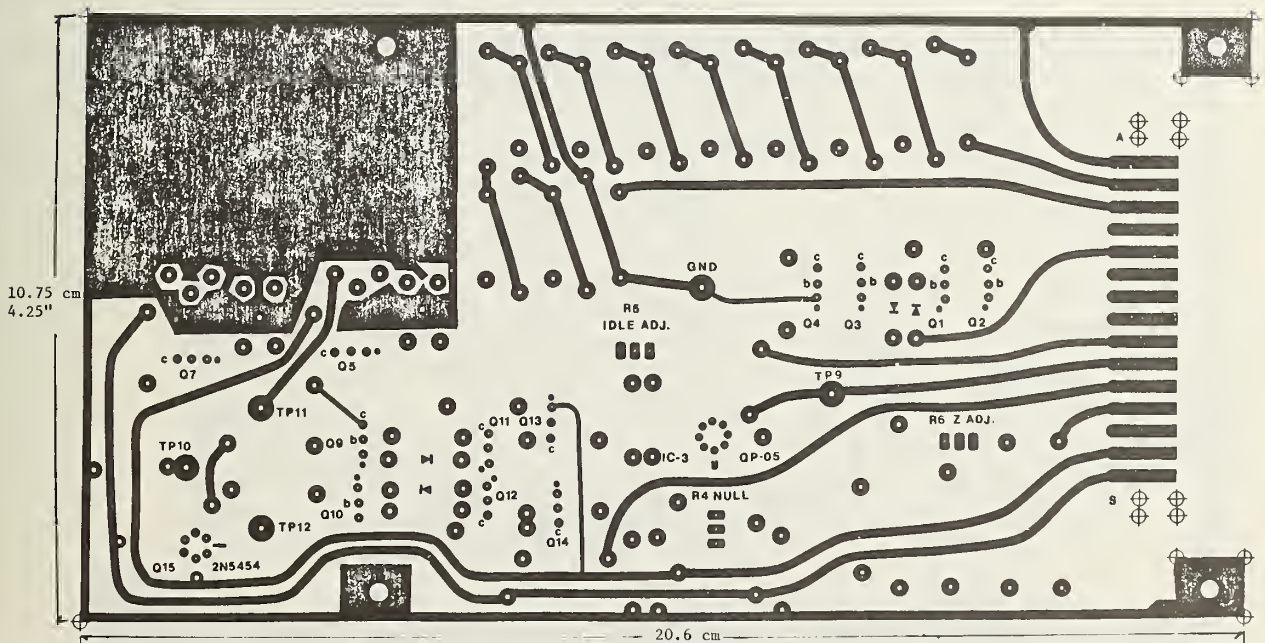


Foil Side, Power Board
2:1

Figure 12. P.C. Board #1 art work.

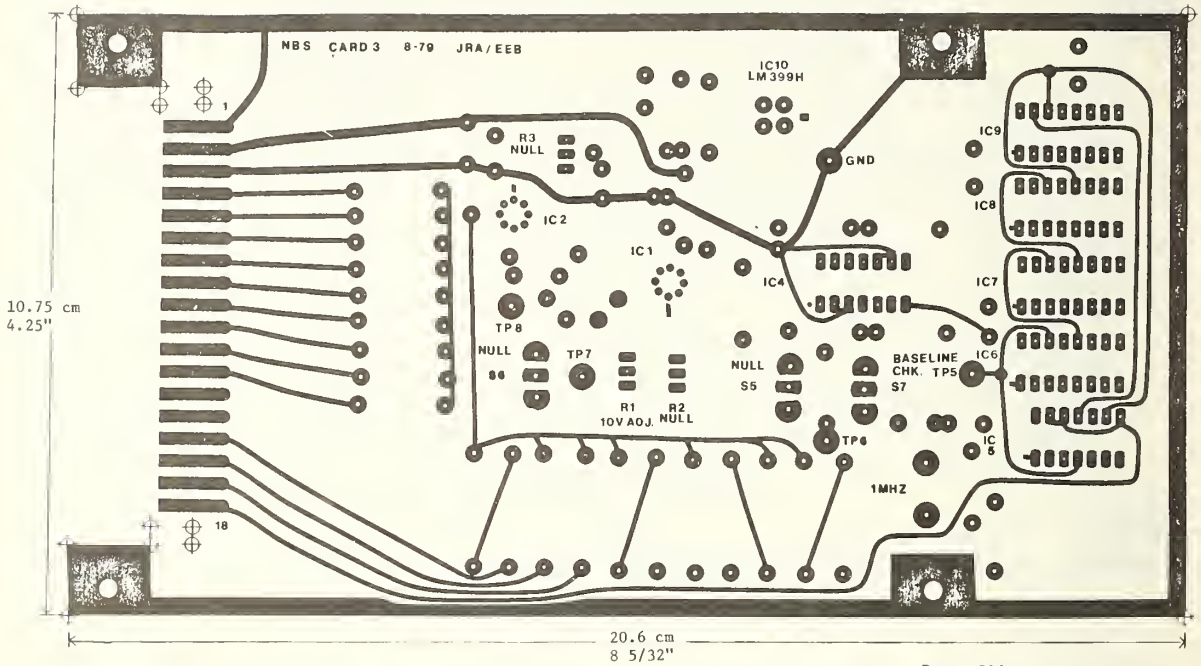


Foil Side

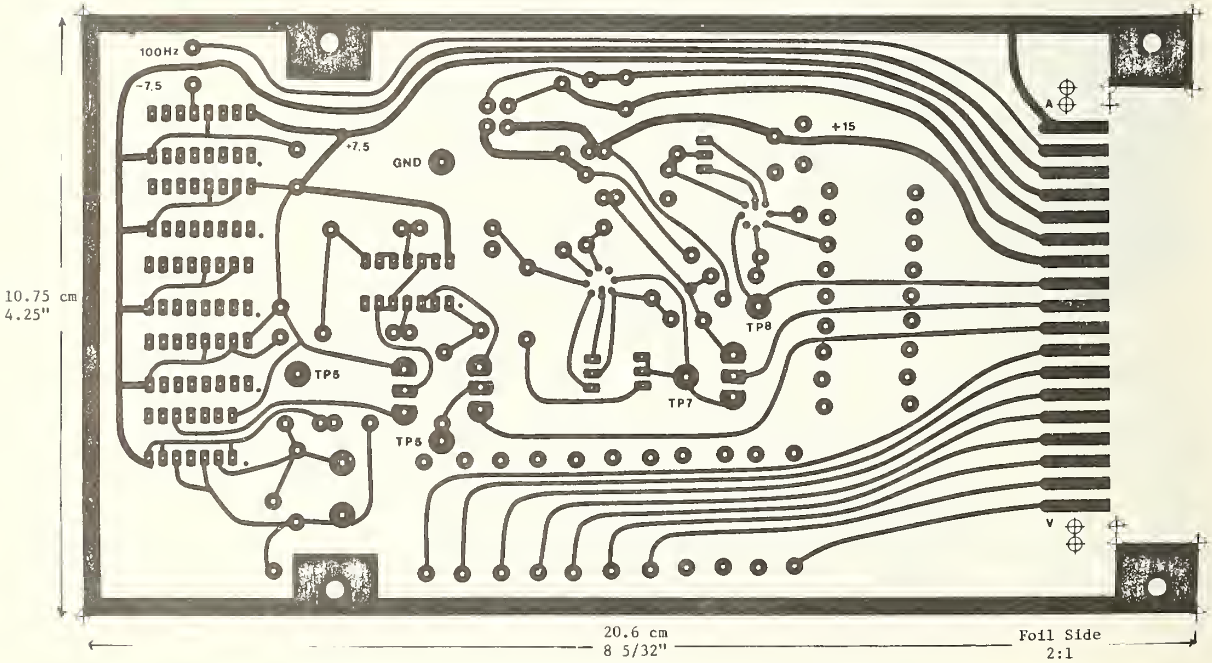


Parts Side

Figure 13. P.C. Board #2 art work.



Parts Side



Foil Side
2:1

Figure 14. P.C. Board #3 art work.

6. Alignment Procedure

1. Using an extender cable, install the unit in a TM 500 mainframe (power off during insertion or removal). Turn on the power. Allow 30 minutes warm-up.
2. Power Supplies:
   a. Check TP1 for + 15 V dc, ± 5% (±0.75V).
   b. Check TP2 for -15 V dc, ± 5%.
   c. Check TP3 for +7.5 V dc, ± 5%. (±0.4V)
   d. Check TP4 for -7.5 V dc, ± 5%.
3. Frequency Calibration:
   a. Connect an accurate digital counter to TP5.
   b. Adjust C1 for a frequency of 1.000 MHz, ±0.01%. (±100 Hz).

4. Voltage Reference:
   a. Connect an accurate DVM (HP-3490 or equiv.) to TP6 (neg. lead to the ground TP).
   b. Set S5 to normal.
   c. Set the polarity switch, S1, to +.
   d. TP6 voltage should read 6.95 V ±0.15 V.

5. ± 10 Volt Standard:
   a. Connect the DVM to TP7.
   b. Set mode switch, S9, to DC.
   c. Set S5 to Null and S7 to Normal.
   d. Adjust R2 for 0 volts, ± 5 μV, at TP7.
   e. Set S5 to Normal.
   f. Adjust R1 for -10.000 volts, ±2 mV, at TP7.
   g. Set the polarity switch, S1, to --.
   h. Check that TP7 voltage is + 10.000 volts, ± 2 mV.
   i. Set S7 to baseline check.
   j. Check that TP7 voltage is 0 volts, ± 20 μV.
   k. Repeat steps c through j until specs are met.
   ℓ. Reset S5 and S7 to Normal.

6. ΔV Attenuator:
   a. Connect the DVM to TP8.
   b. Set S6 to Null.
   c. Set the ΔV switch, S2, to 1 mV.
   d. Set the Z Out switch, S4, to < 0.1 Ω.
   e. Adjust R3 for TP8 voltage of 0 μV ± 0.5 μV.
   f. Set S2 and S4 to all possible combinations and check that TP8 voltage remains at 0 μV ± 3-1/3 μV.
   g. Reset S6 to Normal.

7. Power Amplifier:

   a. Set the multiplier switch, S3, to 0.

   b. Set the sampler protection switch, S8, to Off.

   c. Connect the DVM positive lead to TP11 and the negative lead to TP12.

   d. Adjust the idle current pot, R5, for a DVM reading of +20 mV, $\pm$ 20%.

   e. Connect the DVM to TP10 (negative lead to the ground TP).

   f. Adjust R4 for TP10 voltage of 0V, $\pm$ 5 μV.

   g. Repeat steps c through f until both specs. are met.

8. Output Impedance:

   a. Make up a nominal 50 ohm load using a wire wound, 50 Ω resistor of at least a 20 watt rating. Solder a coaxial cable to the resistor. The other end of the coax should be terminated in a BNC plug which is connected to one arm of a BNC tee.

   b. Using an accurately calibrated ohmmeter, measure the actual resistance of the 50 Ω load as seen at the BNC tee. Record this value. R_{load} = ________ ohms.

   c. Using the BNC tee connect both the 50 Ω load and the DVM to the BNC output connector.

   d. Set the ΔV switch to 500 mV, the multiplier to 10, the Polarity to +, the mode to DC, the Sampler Protection to Off, and the Z Out to 50 Ω.

   e. Disconnect the 50 Ω load from the BNC tee.

   f. Measure and record the output voltage. $V_{open\ ckt.}$ = _________ mV.

   g. Compute the expected output voltage when the load is connected and the source resistance is precisely 50.00 Ω.

$$V_{load} = V_{open\ ckt}\ R_{load}/(R_{load} + 50.00\ \Omega).$$

V_{load} = ____________ mV.

   h. Select an appropriate combination of R6 and R93 to be used and solder them to the circuit board.

   i. Adjust R6 until the output voltage is precisely that calculated in step g.

   j. The output resistance is now precisely 50.00 Ω.

9. The alignment is now complete.

7. Performance Check and Calibration

1. Initial Set-Up

   a. Check that all of the internal switches (S5, S6, and S7) are set to the Normal position.
   b. Install the plug-in in the mainframe. (Power off during insertion or removal).
   c. Turn on the power.
   d. Set the polarity switch, S1, to +.
   e. Set the mode switch, S9, to DC.
   f. Set the sampler protection switch, S8, to Off.
   g. Set the Z Out switch, S4, to < 0.1 Ω.
   h. Set the multiplier switch, S3, to 0.
   i. Set the ΔV switch, 52, to 1 mV.
   j. Connect a DVM (Fluke 8502A. or equiv.).
   k. Allow 30 minutes warm-up.

2. DVM Zero Check

   Check that the DVM reads 0 volts (± 1 μV) on all of its ranges.

3. Multiplier Attenuator Check

   a. Set the DVM to the 10 V range.
   b. Set the ΔV switch, S2, to 500 mV.
   c. Set the multiplier switch, S3, to its various positions and record the DVM readings. Change the DVM range as necessary. Compare the results to the specs. in the following table:

Multiplier Setting	Output Voltage	Limits	Measured Output Voltage
1	0.500 V	± 1.3 mV	________
2	1.000 V	± 2.5 mV	________
3	1.500 V	± 3.8 mV	________
4	2.000 V	± 5.0 mV	________
5	2.500 V	± 6.3 mV	________
6	3.000 V	± 7.5 mV	________
7	3.500 V	± 8.8 mV	________
8	4.000 V	± 10.0 mV	________
9	4.500 V	± 11.3 mV	________
10	5.000 V	± 12.5 mV	________

4. Polarity Check

   a. Set the ΔV switch to 500 mV.
   b. Set the multiplier switch to 10.
   c. Switch the polarity switch, S1, between + and −. Record the DVM readings. They must read ± 5.000V (±12.5 mV).

5. ΔV Attenuator Check

a. Set the multiplier switch to 10.

b. Set the polarity switch to +.

c. Set the ΔV switch to its various positions and record the DVM readings. Change the DVM range as necessary. Compare the results to the specs. in the following table:

ΔV Setting	Output Voltage	Limits	Measured Output Voltage
500	5.000V	± 12.5 mV	________
200	2.000 V	± 5.0 mV	________
100	1.000 V	± 2.5 mV	________
50	500.0 mV	± 1.25 mV	________
20	200.0 mV	± 500 μV	________
10	100.0 mV	± 250 μV	________
5	50.0 mV	± 125 μV	________
2	20.00 mV	± 50 μV	________
1	10.00 mV	± 25 μV	________

6. Z Out Voltage Shift Check

a. Set the Z Out switch, S4, to 50 Ω.

b. Set the ΔV switch to its various positions and record the DVM readings. Change the DVM range as necessary. Compare the results to the specs. in the following table:

ΔV Setting	Output Voltage	Limits	Measured Output Voltage
500	10.000 V	± 25 mV	________
200	4.000 V	± 10 mV	________
100	2.000 V	± 5 mV	________
50	1.000 V	± 2.5 mV	________
20	400.0 mV	± 1.0 mV	________
10	200.0 mV	± 500 μV	________
5	100.0 mV	± 250 μV	________
2	40.00 mV	± 100 μV	________
1	20.00 mV	± 50 μV	________

7. Z Out Impedance Check

a. Make up a nominal 50 Ω load using a wire wound, 50 Ω resistor of at least a 20 watt rating. Solder a coaxial cable to the resistor. The other end of the coax should be terminated in a BNC plug which is connected to one arm of a BNC tee.

b. Using an accurately calibrated ohmmeter, measure the actual resistance of the 50 Ω load as seen at the BNC tee. Record this value. R_{load} = ________ ohms.

c. Using the BNC tee connect both the 50 Ω load and the DVM to the BNC output connector.

d. Set the ΔV, multiplier, and Z Out switches as shown in the table below. Record the DVM readings with the load attached (V_{load}) and also with the load disconnected ($V_{open\ ckt.}$). Compute the output resistance, R_{out}, using the following equation:

$$R_{out} = R_{load} (V_{open\ ckt.} - V_{load})/V_{load}.$$

In the < 0.1 Ω position the output resistance must be no larger than 0.15 Ω. In the 50 Ω position the output resistance must be 50.00 Ω, ± 0.05 Ω.

Z Out Switch	ΔV Switch	Multiplier Switch	V_{load}	$V_{open\ ckt}$	R_{out}
< 0.1 Ω	500 mV	10	____mV	_____ mV	_______ Ω
50 Ω	500 mV	10	____mV	_____ mV	_______ Ω
< 0.1 Ω	20 mV	9	____mV	_____ mV	_______ Ω
50 Ω	20 mV	9	____mV	_____ mV	_______ Ω

e. Disconnect the BNC tee and 50 Ω load from the output connector.

f. Set the multiplier switch to 0.

g. Set the Z Out switch to 1 MΩ.

h. Using the DVM as an ohmmeter, connect it to the BNC output connector and measure the resistance. Record this value. R_{out}(1M Ω) = __________ ohms.

The output resistance must be 1.00 M Ω, ± 1 k Ω.

8. Overload Protection Check

a. Set the Z Out switch to < 0.1 Ω.

b. Set the ΔV switch to 50 mV and the multiplier switch to 0.

c. Connect a milliampmeter (1A range) to the BNC output connector.

d. Increase the multiplier switch in steps and observe the Overload lamp. The output current threshold at which the lamp lights shall be at least 210 mA, but less than 240 mA.

Overload Lamp Threshold = ________________ma.

e. Set the ΔV switch to 500 mV and the multiplier switch to 10.

f. Measure and record the maximum output current. It shall be at least 250 mA but less than 300 mA.

$I_{max.}$ = __________mA.

g. Set the mode switch to 1 kHz and verify that the overload lamp is on. Return the switch to DC.

h. Set the Z Out switch to 50 Ω and verify that the overload lamp remains off.

i. Set the polarity switch to - and repeat steps b through h.

j. Remove the milliammeter from the output connector.

9. Sampler Protection Check

a. Connect the DVM to the BNC output connector.

b. Set the polarity switch to +.

c. Set the ΔV switch to 200 mV, the multiplier to 0 and the Z Out to < 0.1 Ω.

d. Increase the Multiplier setting one unit at a time. Note the output voltage. Then set the Sampler Protection switch to on and note the output voltage. The protection threshold is the first level at which a difference is noted in the two DVM readings. Record this level. This threshold shall be at least 1.1 V but less than 1.5 V. The Overload lamp must also light when the threshold is reached.

Protection Threshold = _____________mV.

e. Set the ΔV switch to 500 mV, the Multiplier to 10, and the Z Out to 50 Ω.

f. Measure and then record the output voltage. It must be less than 2.0 V.

Protection Threshold = ______________mV.

g. Set the polarity switch to - and repeat steps c through f.

0. Square Wave Operation Check

a. Set the ΔV switch to 500 mV, the Multiplier to 10, the Z Out to < 0.1Ω, and the polarity to +.

b. Connect an oscilloscope to the output.

c. A 5 volt square wave with a baseline of 0 volts should be observed.

d. Measure and record the rising and falling transition durations (10% - 90%). They must be less than 40 μs. The waveform must be clean with no perturbations such as overshoot or undershoot.

Transition Duration = _________μs.

e. Remove the oscilloscope.

f. Connect a frequency counter to the output.

g. Measure and record the square wave repetition rate. It must be 1.0 kHz ± 0.01%.

Frequency = ______________kHz.

1. Noise Output Check

a. Using a BNC cable connect the output to the input of an AC VTVM (HP-400 or equiv.) through a 50 Ω BNC feed-thru termination.

b. Set the ΔV to 500 mV, Multiplier to 10, Z Out to 50 Ω, mode to DC, and Sampler Protection to Off.

c. Measure and record the ac noise voltage. It must be less than 200 μV rms.

Noise Voltage (high level) = ______________μV rms.

d. Set the ΔV to 1 mV and the Multiplier to 1.

e. Measure and record the ac noise voltage. It must be less than 25 μV rms.

Noise Voltage (low level) = ________μV rms.

2. The performance check and calibration is now complete.

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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The amplitude calibrator is designed to provide known dc voltage levels or 1 kHz square waves from $\pm$ 1 mV to $\pm$ 5 V. It features selectable output impedances of $< 0.1\,\Omega$, $50\,\Omega$, and $1\,M\Omega$. The instrument is designed with sufficient current capability to deliver its indicated voltage into a $50\,\Omega$ termination. To protect delicate sampling oscilloscopes, a limiter circuit can also be activated to limit the output voltage to $\pm$ 1.8 V.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Calibration; calibrators; instrumentation; oscilloscope calibrator; oscilloscopes

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