LB-1051

AN IMPROVED

LOW-CAPACITANCE PROBE

RADIO CORPORATION OF AMERICA

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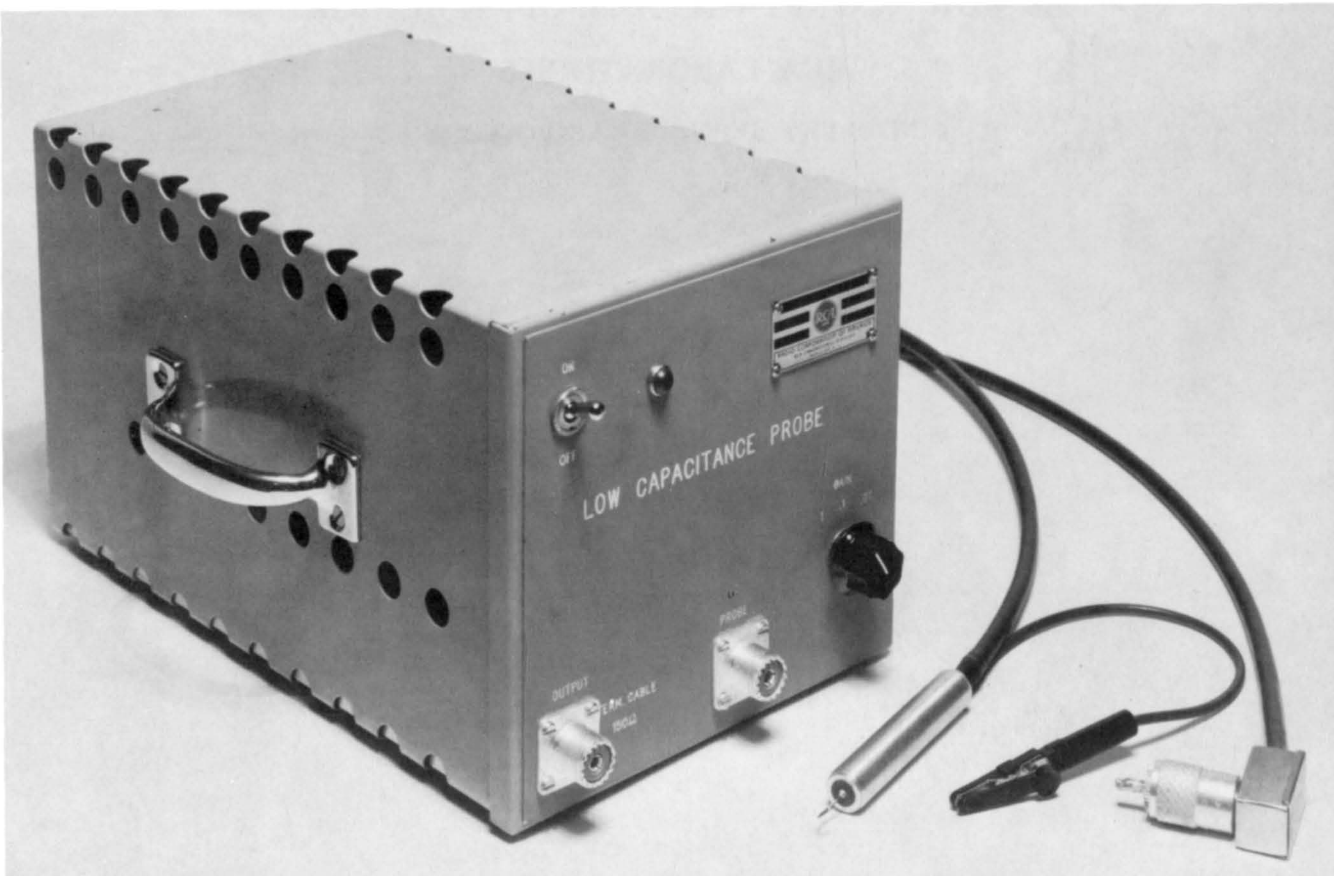
Approved

Stuart Wm Seeley.



Low-capacitance probe

An Improved Low-Capacitance Probe

The experimental oscilloscope probe described in this bulletin was developed to satisfy the need for a dependable laboratory instrument having excellent transient response for square-wave testing. It is also suitable for use as a general purpose oscilloscope accessory. A two-stage amplifier, using mutually-coupled video peaking, and a compensated RC divider having improved mechanical stability provide unity gain from probe input to amplifier output with a 3-db band-pass of 17 Mc. To obtain the required characteristics, some care is required in the selection of vacuum tubes with low-interface, and rated transconductance. It has been found that these requirements have not materially increased the service problem.

General Description

Fig. 1 is a block diagram of the low-capacitance probe. The probe head and range switch form a compensated RC attenuator. This attenuator is a version of the one described in *LB-794, 'Shielded Low-Capacitance Video-Frequency Oscilloscope Probes'*, modified to use a rigid resistor mount for increased mechanical stability and simplified compensation arrangement.

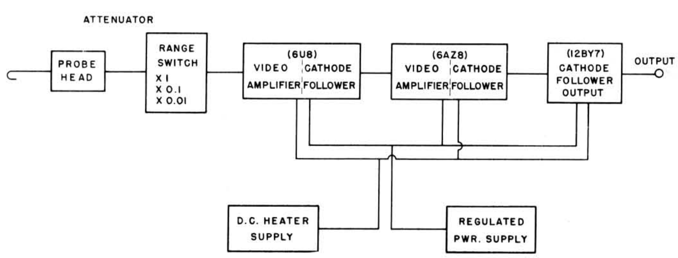


Fig. 1 – Block diagram of the low-capacitance probe.

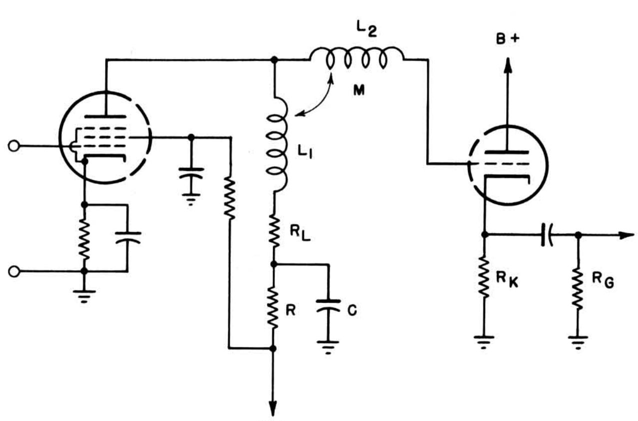


Fig. 2 – Basic video-amplifier circuit.

The amplifier section uses two dual-purpose tubes, each connected as a pentode amplifier direct-coupled to a cathode follower to reduce circuit capacitance. A triode-connected pentode is used as the cathode-follower output stage. Fig. 2 shows the basic video-amplifier circuit. Mutually-coupled peaking provides a nominal gain of 13, and a bandwidth of approximately 20 Mc per stage.

A regulated power supply feeds the two amplifier stages and the screen of the output cathode follower. Plate voltage for the output cathode follower is supplied from the unregulated supply. This arrangement represents an effective compromise between regulated current requirements and amplifier stability. The power supply is designed to operate efficiently over a wide input voltage range, and with severe line voltage transients. All amplifier heaters use d.c. supplied from a bridge rectifier using germanium diodes.

The overall probe specifications are given in Table I.

Construction and Operation

Probe Head

Figs. 3 and 4 and 5 show the mechanical construction and assembly of the probe head. Three 1.5-megohm high-frequency resistors are cemented inside the Rexolite mount. The feed-through capacitance is formed by wrapping four turns of No. 30 Formvar wire around the resistor pigtail and cementing with coil dope. The entire assembly is mounted in the probe chassis by soldering the resistor pigtails in the fibre washers. The front washer is peened into the probe chassis. The rear washer has a guide slot, and may be removed for servicing.

TABLE I

Probe Specifications

Input impedance	4.5 megohm shunted by 2.4 $\mu\mu f$ (with probe hook)
Output impedance	70 ohms
Output voltage p-p	2 volts (4.5 volts max.)
Gain (with 150Ω output termination)	1, 0.1, 0.01
Rise Time (measured with oscilloscope and square wave generator having displayed rise time of 0.035 μsec)	0.042 μsec
Bandwidth	17 Mc at 3 db
Noise and hum in output	> 5 mv
Line voltage regulation range	95-135 v.
Tube Complement	
1st Video Amplifier	6U8
2nd Video Amplifier	6AZ8
Output cathode follower	12BY7
Rectifier	6X4
Series Regulator	12B4
Regulator Amplifier	6AU6
Voltage reference	5651

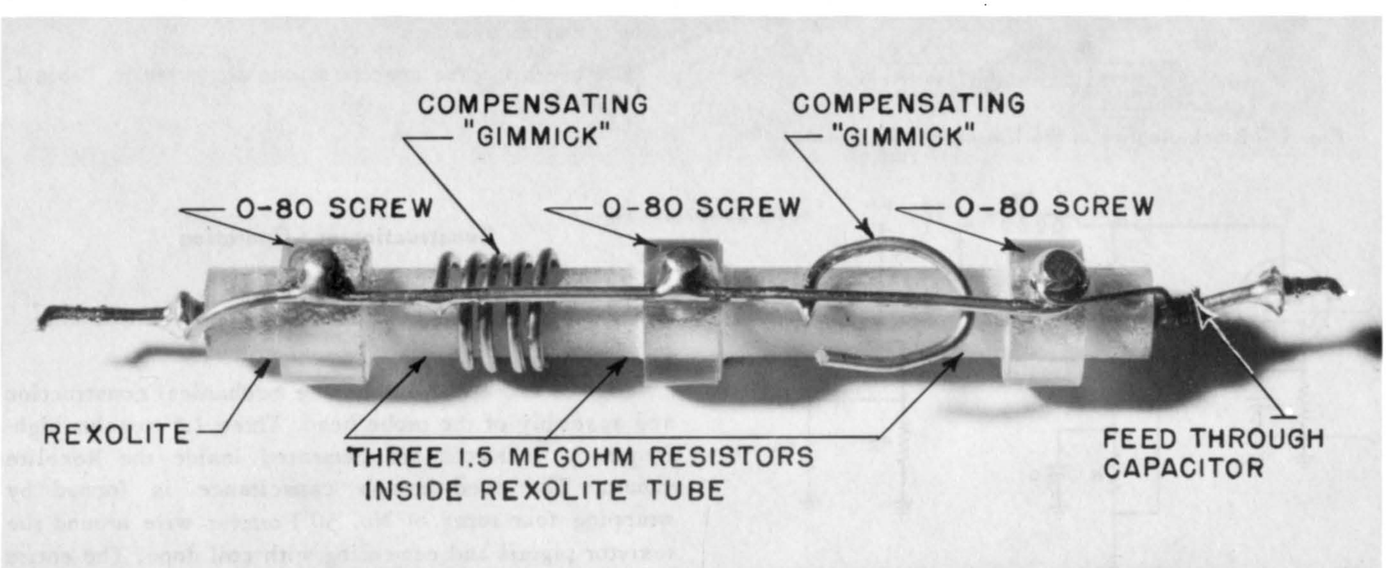


Fig. 3 – Resistor mount.

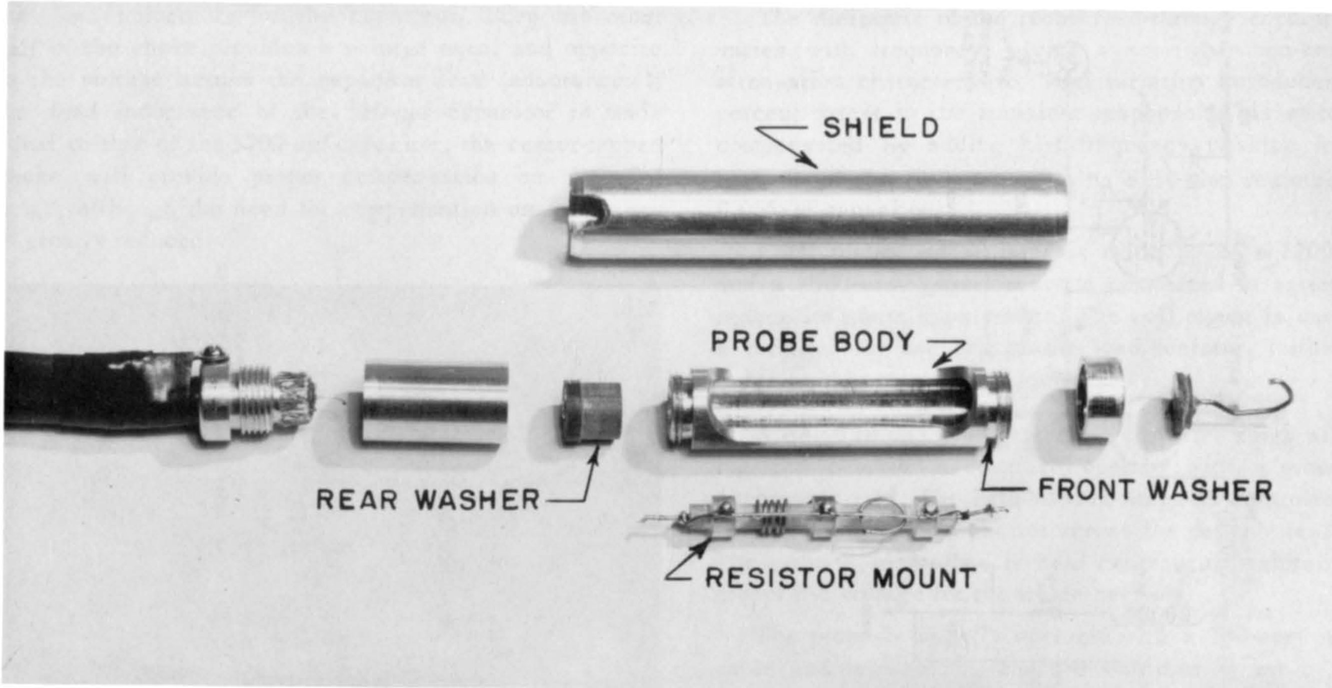


Fig. 4 – Disassembled probe head.

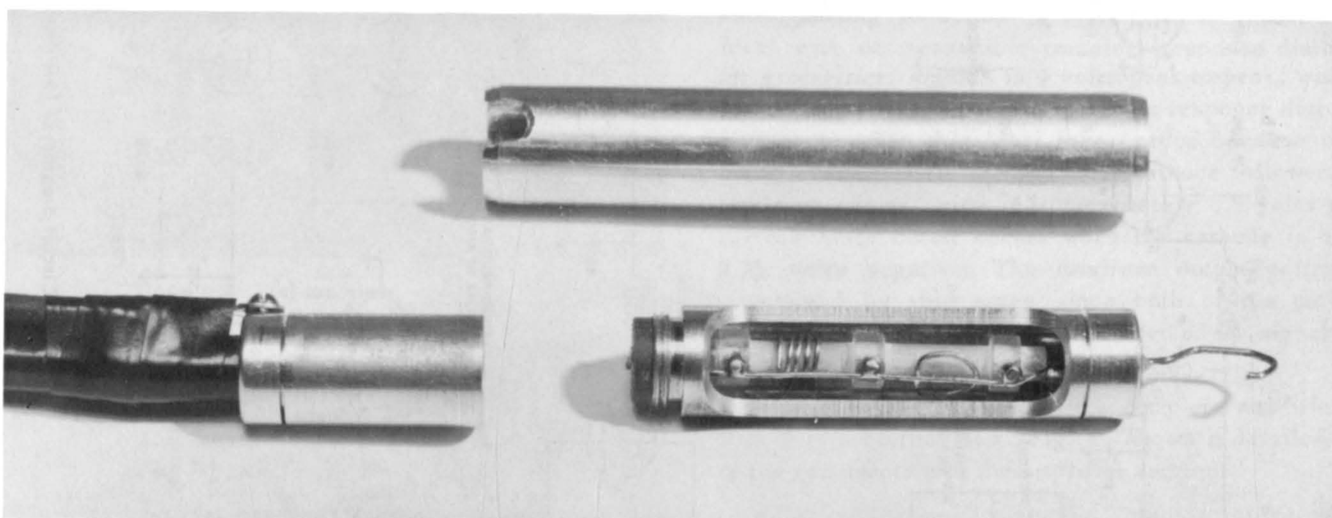


Fig. 5 – Assembled probe head.

The input capacitance of the probe is approximately 1.6 $\mu\mu f$. This capacitance is divided approximately equally between the stray capacitance and the feed-through capacitance. The accessory probe hook adds an additional 0.8 $\mu\mu f$.

Amplifier and Power Supply

A circuit diagram of the complete amplifier is given in Fig .6. The attenuator resistance values are chosen to give accurate attenuation ratios on each step, after the probe compensation has been completed on the ×1 range. It should be noted that the switch is wired such that the RC networks for the ×0.01 ranges are paralleled with ×1 network. Fig. 7 shows the mechanical construction of the attenuator switch. A short length of braid is used to ground the switch and the cathode of the first stage at the probe input connector to minimize hum pickup.

The small center-tapped choke, mounted on the switch (Fig. 10) compensates for the lead inductance of the 5700-$\mu\mu f$ capacitor on the ×0.01 range. The effect of this lead inductance is eliminated by making the inductance of one half of the center-tapped choke equal to

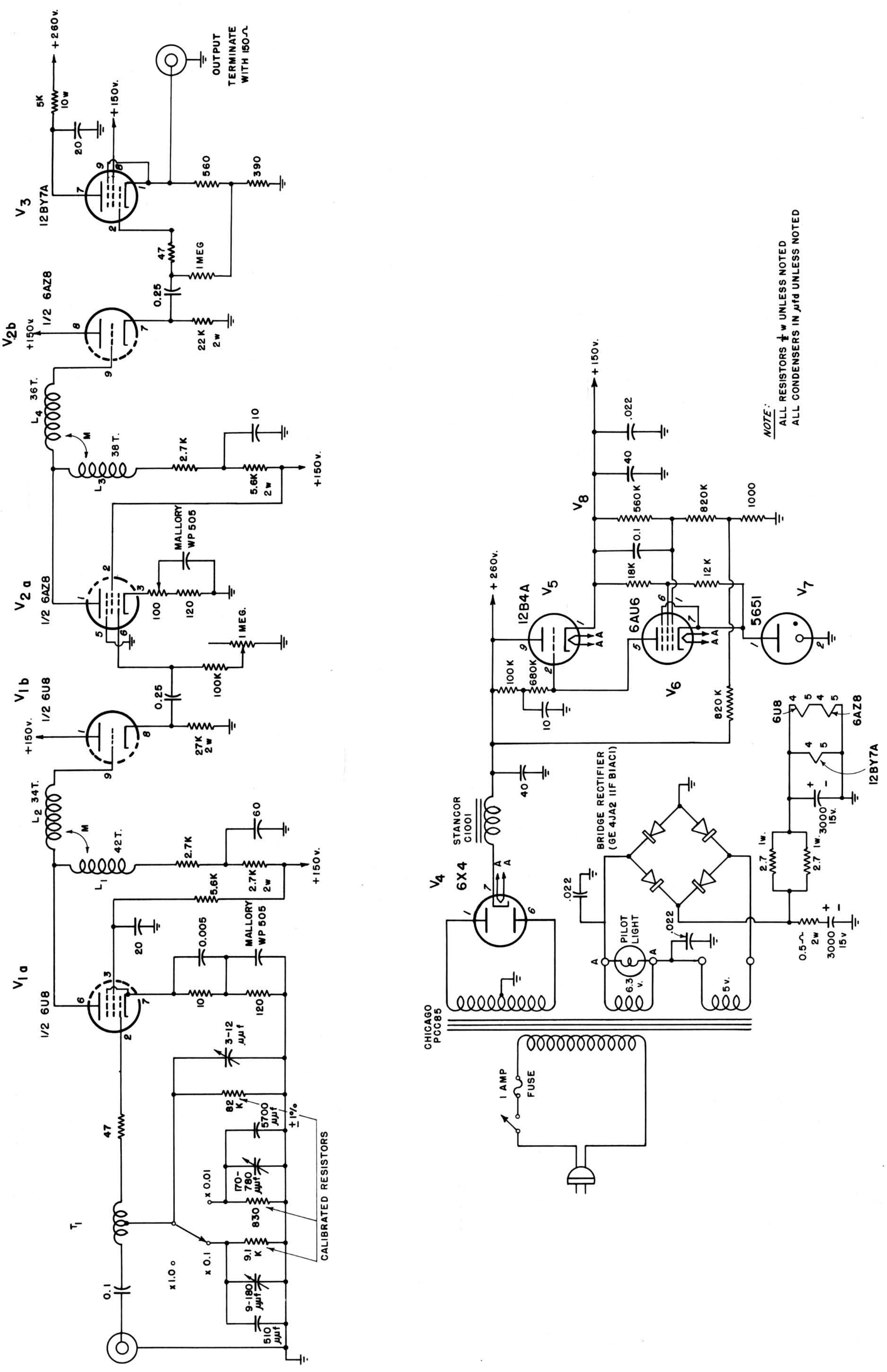
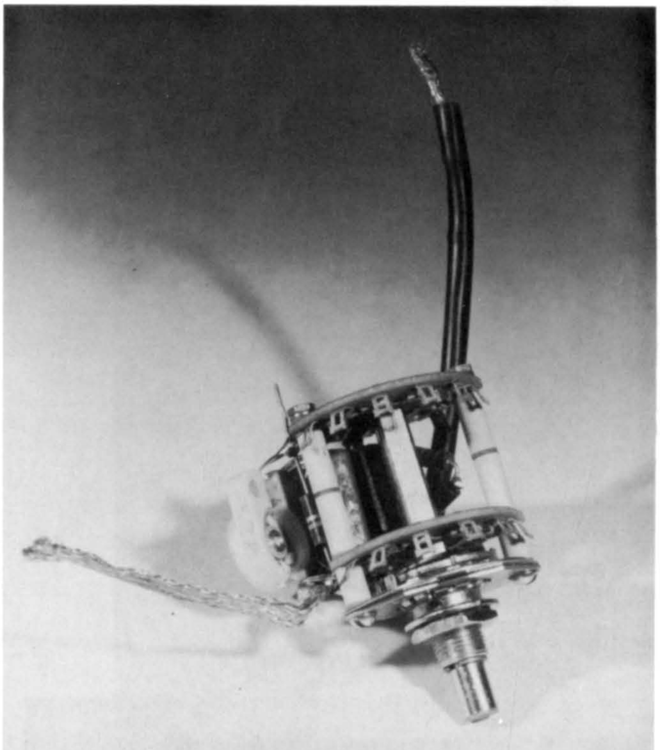
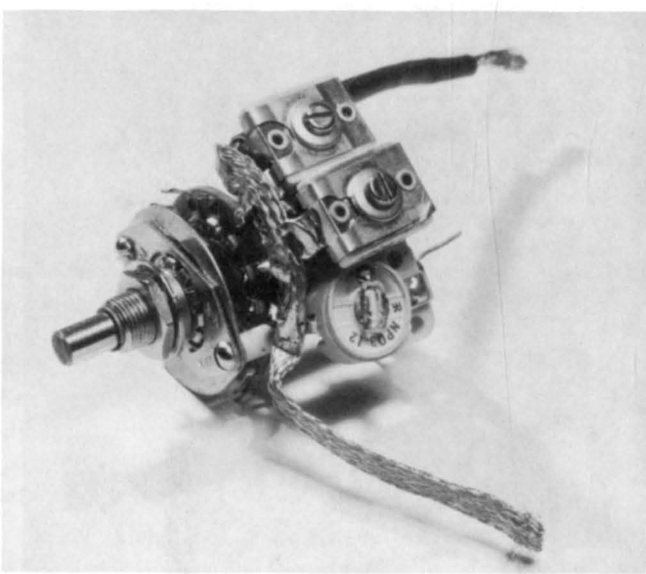


Fig. 6 – Circuit diagram of low-capacitance probe.

the lead inductance of the capacitor. Then the other half of the choke provides a voltage equal and opposite to the voltage across the capacitor lead inductance. If the lead inductance of the 510-$\mu\mu$f capacitor is made equal to that of the 5700-$\mu\mu$f capacitor, the center-tapped choke will provide proper compensation on the ×0.1 range, although the need for compensation on this range is greatly reduced.



(a)-top view



(b)-bottom view

Fig. 7 – Attenuator range switch.

The dielectric of the probe feed-through capacitance varies with frequency, giving a somewhat non-uniform attenuation characteristic. This variation introduces a 3 percent smear in the transient response. This smear is compensated by adding high-frequency peaking in the cathode of the first stage, using a 10-ohm resistor and 0.005-μf capacitor.

Each plate-load resistor is made up of a 1200-ohm and a 1500-ohm ½-watt resistor connected in series, to reduce its shunt capacitance. The coil mount is used as a terminal for one end of the load resistor, further re-reducing this shunt capacitance.

A 6AZ8 is used in the second amplifier stage allowing the pentode section to operate with a grounded suppressor grid. The gain of this stage is controlled by varying the bypass capacitor across the cathode resistor. The cathode resistance is held constant to maintain the proper d-c voltage for the triode section.

The probe is usually operated with a 150-ohm output cable and termination, and the amplifier is set to give unity gain with this termination. The output impedance of the cathode follower is approximately 70 ohms, and the probe may be used to feed a 75-ohm cable with the corresponding reduction in gain. The maximum output level with no measurable transient response distortion for symmetrical signals is 2 volts peak-to-peak, with the 150-ohm output termination. Transient response distortion may occur when this level is exceeded because of the outoff characteristic of the output cathode follower. The maximum output swing is approximately 4.5 volts peak-to-peak since cutoff occurs when the cathode is driven 2.25 volts negative. The maximum output voltage is determined by this stage since both of the previous cathode followers are operated under small signal conditions.

Fig. 8 is the top view of the complete amplifier and Fig. 9 is a bottom view. Fig. 10 shows a detailed view of the construction of the amplifier section.

Adjustment and Maintenance

The adjustment of the amplifier section requires careful attention because of the wide bandwidths. The peaking coils are adjusted by observing the transient response with a wide-band oscilloscope and square-wave generator with a combined rise time of 0.04 μsec or less.

Attenuators to cover a range of 40 db are necessary to keep the test signal output level (1 v p-p) in the proper range for each adjustment. The cathode degeneration network should be shorted out when only the amplifier is adjusted. The short should be removed for the

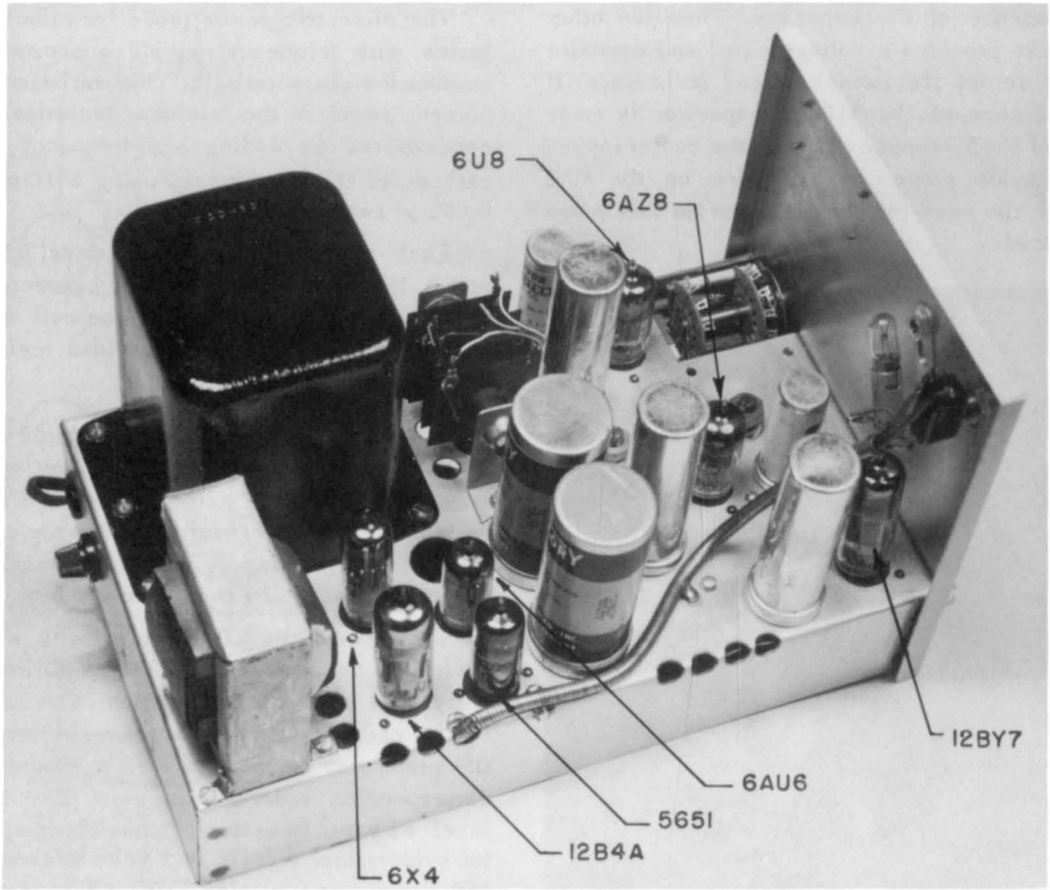


Fig. 8 – Top view of amplifier chassis.

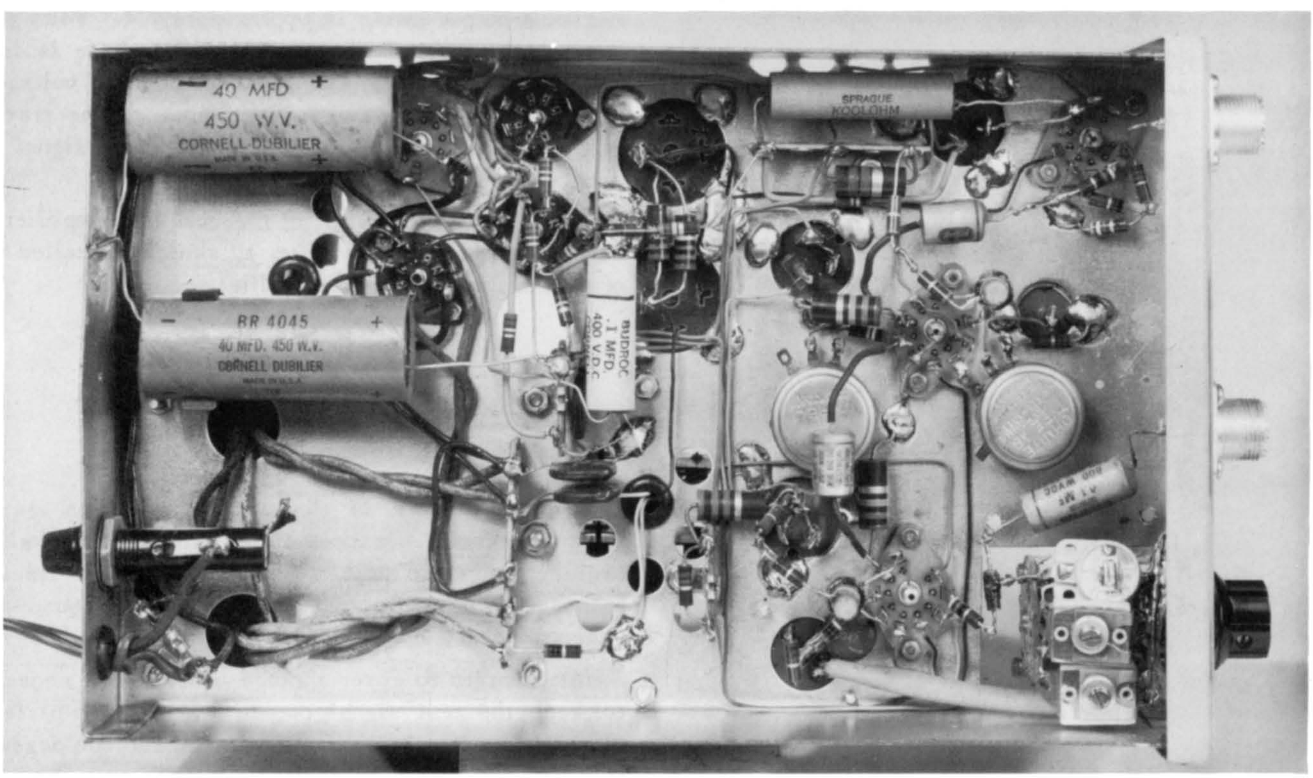


Fig. 9 – Bottom view of amplifier chassis.

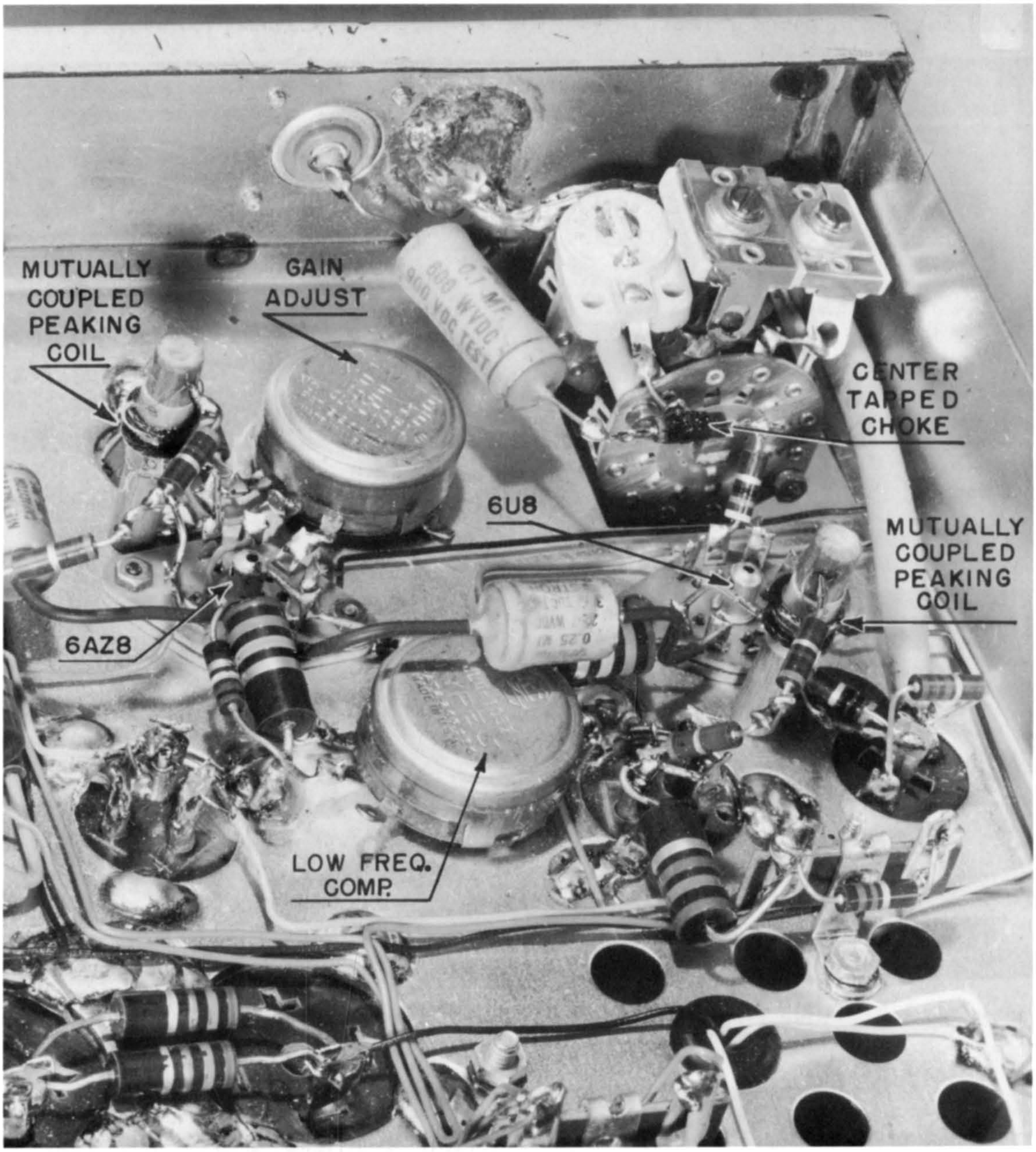


Fig. 10 – Detail of video amplifier section showing location of mutually-coupled peaking coils, center-tapped choke, and attenuator switch.

final adjustment of the probe and amplifier. Adjustment is made by setting the coupling coefficient of the individual stages to give a critically damped response. When each stage has been adjusted for critical coupling, the overall amplifier response may be checked. Slight adjustments may then be made to optimize the response. Large readjustments indicate improper peaking or other defects, such as excessive coil capacitance.

If the individual stages have been adjusted slightly below critical coupling, it is possible to obtain an overall transient response which has several ringing cycles with a period of approximately 0.04 μsec. When either or both stages are overcoupled, coil capacitance may introduce overshoot or other 'spurious' responses. Either condition is acceptable based on the following tolerances:

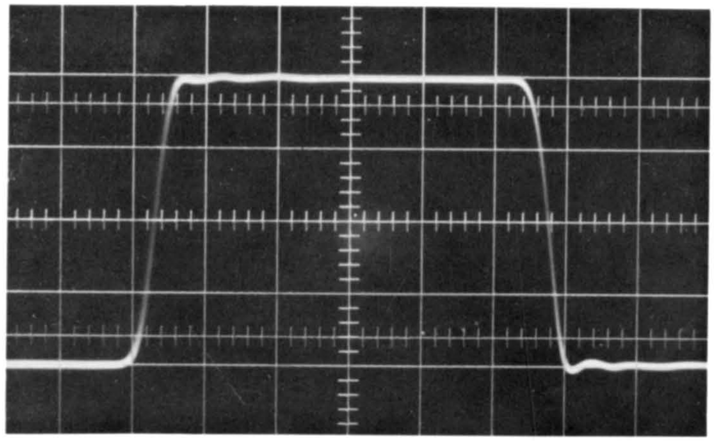
1. Ringing due to under-coupling. When the ringing period is approximately 0.04 μsec, its relative amplitude should not exceed 1/2% peak-to-peak.

2. When the period is approximately 0.1 μsec, the ringing should not exceed 1% peak-to-peak.

3. Capacitive effects (overshoot or smear) when over-coupled should not exceed 1%.

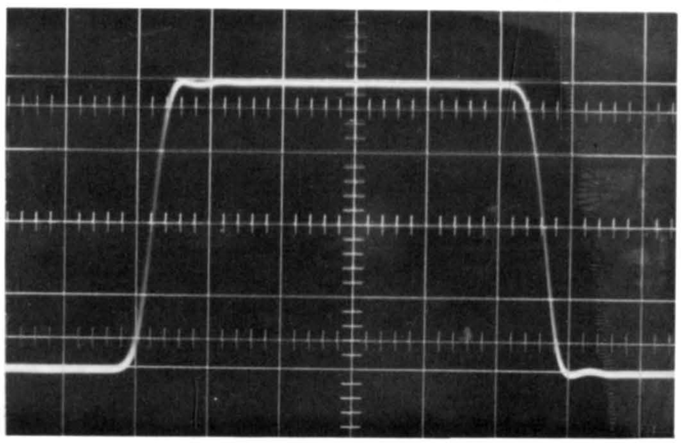
Fig. 11 shows some typical transient response characteristics of each amplifier stage, the overall amplifier, and the complete amplifier and probe.

Sweep Speed 0.10 μsec/cm (1Mc)



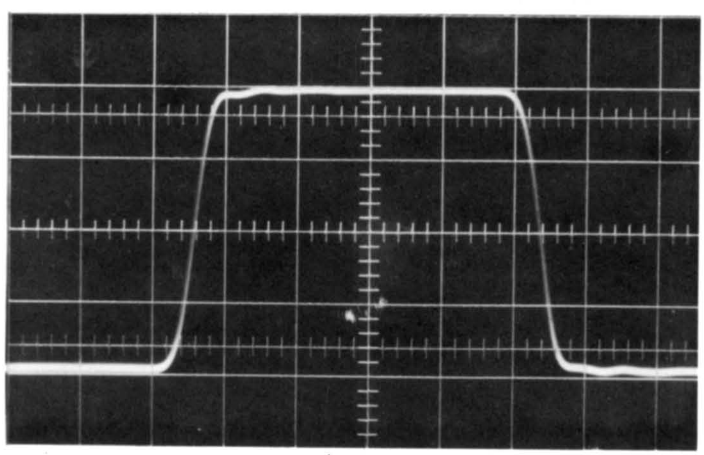
First stage & output cathode follower

Rise Time 0.040 μsec. Output 1.0 volt p-p



Second stage & output cathode follower

Rise Time 0.041 μsec. Output 1.0 volt p-p

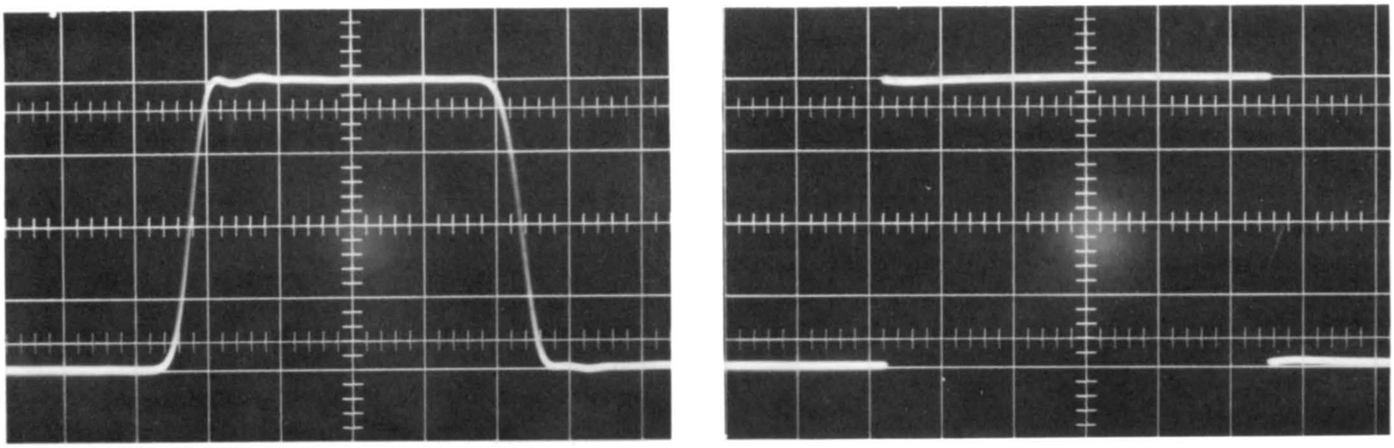


Overall amplifier

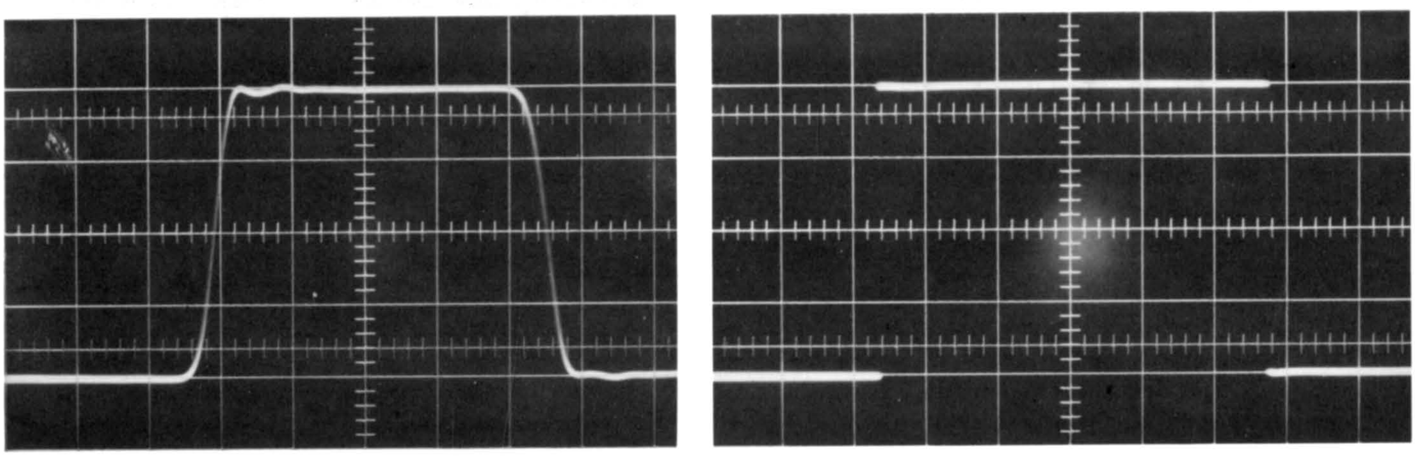
Rise Time 0.042 μsec. Output 1.0 volt p-p

Fig. 11a – Typical interstage and overall amplifier transient response.

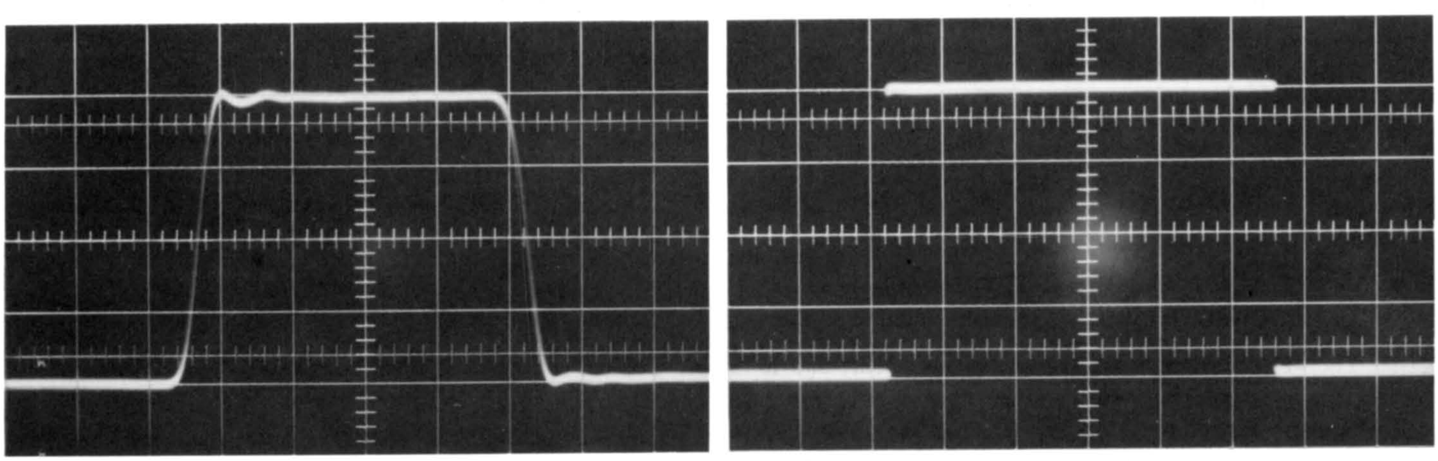
Sweep Speed 0.1 μsec/cm (1Mc) | Sweep Speed 10 μsec/cm (10kc)



Rise Time 0.042 μsec. | Input Att. x 1.0 | Output 1.0 volt p-p



Rise Time 0.042 μsec. | Input Att. x 0.1 | Output 1.0 volt p-p



Rise Time 0.040 μsec. | Input Att. x 0.01 | Output 0.18 volt p-p

Fig. 11b – Typical overall transient response.

Probe Compensation

The probe may be adjusted by use of a test jig (Fig. 12) which simulates the input resistance and capacitance of the cable and amplifier. Since the variable capacitors in the probe provide approximately ±5% variation, the jig should provide this range of capacitance adjustment and a ±5% adjustment in resistance. Adjustment of the probe requires compensation of the RC divider network for uniform attenuation, and the compensation for the stray capacitance and frequency characteristics of the 1.5-megohm resistors.

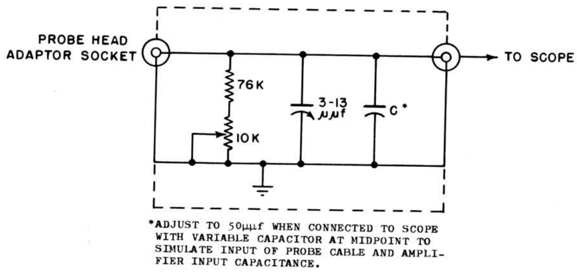


Fig. 12 – Test jig schematic.

The compensation procedure may be summarized as follows:
A 10-kc square wave is displayed and the jig capacitor is adjusted for uniform attenuation with the resistance set at 82K.

The probe compensating capacitors are adjusted to provide minimum ringing or smear following the step transition. These disturbances usually have a duration of less than 2 µsec.

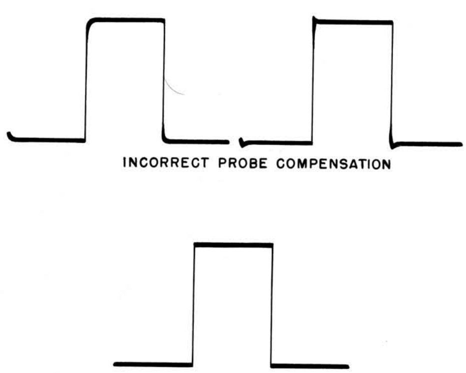


Fig. 13 – Transient response of the probe head, illustrating correct and incorrect adjustments.

The above adjustments are not independent, and it is necessary to recheck the overall response in order to find the proper relationship between the attenuation ratio and the high-frequency compensation. The proper response as illustrated in Fig. 13 is obtained when the square wave shows square corners with no brightening of the oscilloscope trace during the transition.

If this response cannot be obtained for any setting of jig resistance or capacitance, the feed-through capacitance and the amplifier-plus-cable capacitance should be measured. The required feed-through capacitance is:

$$C_F = \frac{82 \times 10^3}{4.5 \times 10^6} \times C_i = 1.8 \times 10^{-2} C_i \approx 1.08 \ \mu\mu f$$

where C_i is the sum of the amplifier and cable capacitance (approximately 60 µµf).

The feed-through and probe compensation capacitors may then be adjusted to provide the response shown in Fig. 13.

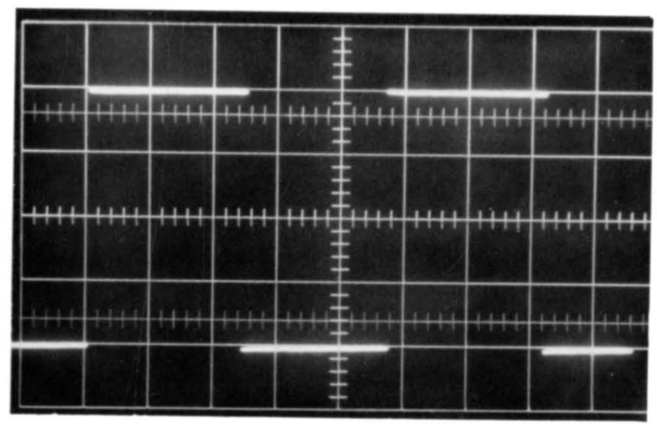


Fig. 14 – Low-frequency response of low-capacitance probe, 20 cps square wave. Sweep speed 10 m sec. per Cm

After the probe head has been adjusted in the jig, the value of resistance should be measured. The proper resistor for each range may then be installed in the attenuator switch, and the overall h-f adjustment completed.

The low-frequency compensation may be adjusted by the use of a 20-cps square wave to obtain symmetrical, rounded wave form with no tilt, as shown in Fig. 14. The low-frequency response of the oscilloscope should be checked to insure obtaining only the response of the probe.

The overall gain is then set accurately on the ×1 range, using the cathode degeneration control. This completed probe adjustments.

Power Supply

The regulated B+ voltage is 150 v ± 3 percent. The B+ voltage regulation holds above 95 volts on the line. The 820K and the 1000-ohm resistors are used to help minimize line bounce. The 0.022-µf capacitors connected to the 6.3-volt winding and across the 150-volt supply are short-lead ceramic capacitors used to prevent power-line inpulse interference from getting into the amplifier. To reduce surge currents in the 3000-μf 15-volt capacitor, a 0.5-ohm 2-watt resistor was placed in series with the capacitor.

Note on Coupling Capacitors

Because of space considerations, it is necessary to use metallized coupling capacitors. A breakdown in one of these capacitors may show up as a low-frequency output variation, sometimes with high-frequency noise, and can be seen by observing the output with a very slow speed sweep.

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