# INSTRUCTION MANUAL

Serial Number _____

# TYPE 3A8

## OPERATIONAL AMPLIFIER PLUG-IN UNIT

*Tektronix, Inc.*
S.W. Millikan Way ● P. O. Box 500 ● Beaverton, Oregon 97005 ● Phone 644-0161 ● Cables: Tektronix

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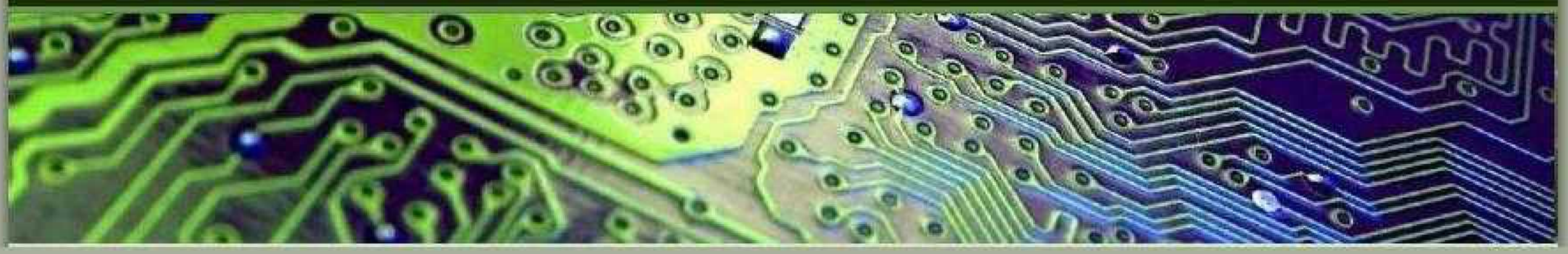

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# WARRANTY

All Tektronix instruments are warranted against defective materials and workmanship for one year. Tektronix transformers, manufactured in our own plant, are warranted for the life of the instrument.

Any questions with respect to the warranty mentioned above should be taken up with your Tektronix Field Engineer.

Tektronix repair and replacement-part service is geared directly to the field, therefore all requests for repairs and replacement parts should be directed to the Tektronix Field Office or Representative in your area. This procedure will assure you the fastest possible service. Please include the instrument Type and Serial number with all requests for parts or service.

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# CONTENTS


Section 1 Characteristics

Section 2 Operating Instructions

Section 3 Applications

Section 4 Circuit Description

Section 5 Maintenance

Section 6 Performance Check

Section 7 Calibration

Parts Ordering Information

Abbreviations and Symbols

Section 8 Electrical Parts List

Section 9 Mechanical Parts List

Section 10 Diagrams


Abbreviations and symbols used in this manual are based on, or taken directly from, IEEE Standard 260 "Standard Symbols for Units", MIL-STD-12B and other standards of the electronics industry. Change information, if any, is located at the rear of this manual.

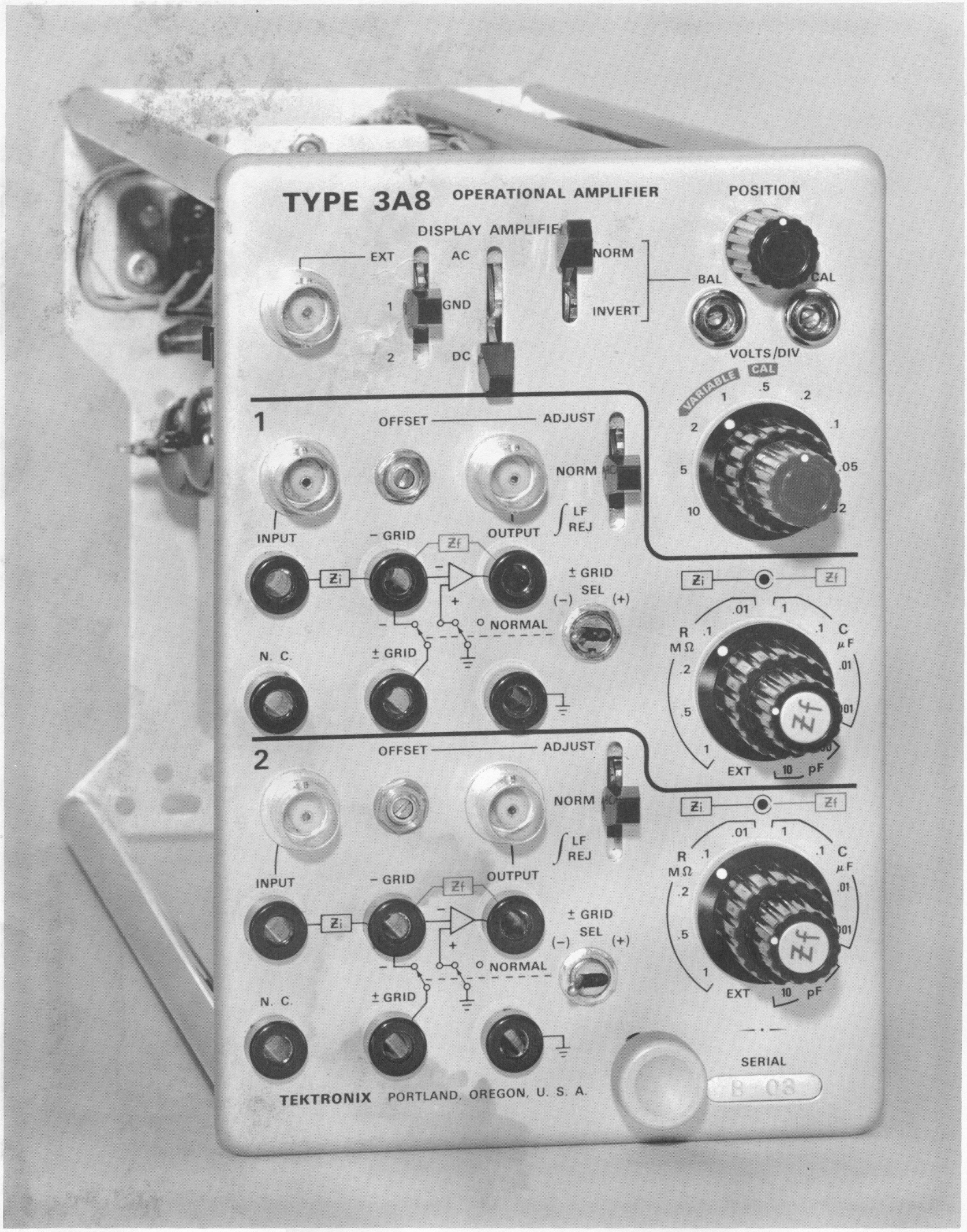



Fig. 1-1. Type 3A8 Operational Amplifier Plug-In Unit.

# SECTION 1
# CHARACTERISTICS

## Introduction

The Type 3A8 Operational Amplifier is designed to operate in all Tektronix 560-Series oscilloscopes (except the Type 560 itself) or with the Type 129 Plug-In Power Supply Unit.

The Type 3A8 contains two separate but identical Operational Amplifiers plus a Display Amplifier. The Display Amplifier monitors the output of either Operational Amplifier or it can be used as an independent oscilloscope amplifier.

Each Operational Amplifier is a high-gain amplifier with selected input and feedback impedances. The combination of input or feedback impedances and their ratio determines the operation the amplifier will perform. This can be used in applications involving precise integration, differentiation, linear and non-linear amplification, summation, phase inversion and many others.

The Type 3A8 with Log Adapter (013-0067-00) allows the display and measurement of high-amplitude signals mixed with low-amplitude signals. Pulses and transient signals spanning three voltage decades to $\pm$100 V can be displayed and measured on the same trace.

The Type 3A8 with Gating Adapter (013-0068-00) allows repetitive signals with a net integral other than zero to be integrated and displayed. Without the Gating Adapter, true integration of such repetitive signals is difficult or impossible since the integral will rapidly accumulate beyond the range of the Type 3A8.

The Type 3A8 with Leakage Current Adapter (013-0086-00) allows measurement of reverse leakage in semiconductor diodes and in small-signal transistors in a diode-connected configuration. The Leakage Current Adapter requires an external sawtooth drive to +150 V; a Type 2B67 incorporating Mod 120 H can be used for this function.

The Type 3A8 with Compensating Adapter (013-0081-00) extends the closed-loop frequency performance of the Operational Amplifiers. The adapter compensates for stray capacitance associated with the internal $Z_i$ and $Z_f$ resistors, providing an adjustment for optimum HF response.

### DISPLAY AMPLIFIER

| Characteristic | Performance Requirement | Supplemental Information |
|---|---|---|
| Bandpass | DC to $\geq$ 3.5 MHz @-3dB | With 50 kHz 4-division reference. Measured at 0.02 Volts/Div. |
| AC LF Response | $\geq$ 2 Hz @-3dB | Calculated from input resistor and coupling capacitor. Frequency = $\frac{1}{2\pi RC}$ |
| Risetime<br>0.02 to 10 V/div | $\leq$ 100 ns | |
| Transient Response<br>Overshoot<br><br><br>Other Aberrations | $\leq$ 1% at 20°C to 30°C, $\leq$ 5% at 0°C to 50°C, NORM polarity.<br>$\leq$ 3% at 20°C to 30°C, $\leq$ 7% at 0°C to 50°C, INVERT polarity.<br>$\leq$ 1% | VARIABLE at CALIB. Checked with 4 divisions at 0.02 V/div, display centered. |
| Input Characteristics (approximate) | 1 megohm parallel by 47 pF | Standardized, with 47-pF standardizer to 47 $\mu$s time constant. |
| VOLTS/DIV Accuracy | —20 mV/div to 10 V/div in nine steps. 1-2-5 sequence. Within 3% of panel-reading on all ranges after adjustment on the 0.02 Volts/Div range. Variable (uncalibrated) between steps and to $\approx$25 V/div. | Any selected VOLTS/DIV setting is adjustable to zero percent with front-panel CAL adjustment. |
| VARIABLE VOLTS/DIV Range | $\leq$ 2.5:1 | With CAL properly set. |
| Maximum Input Voltage | $\pm$600 V, combined dc and peak ac (AC or DC coupled) to 200 Hz. See derating chart. | |

## OPERATIONAL AMPLIFIERS 1 & 2

| Characteristic | Performance Requirement | Supplemental Information |
|---|---|---|
| Open-Loop Gain-Bandwidth Product | ≥ 10 MHz | |
| Closed-Loop Gain-Bandwidth product for any combination of $Z_i$ and $Z_f$ providing ≥ unity gain | 250 kHz minimum, uncompensated (to —30% point).<br>8.5 MHz minimum, compensated (to —30% point). | |
| Open-Loop DC Gain | ≥ 15,000 | |
| Output Range | | |
| Voltage | ≥ ±25 V | |
| Current | ≥ 7.5 mA, including feedback current. | |
| Input Common-Mode Range | ≥ ±25 V | |
| Long-Term Trace Drift | ≤500 μV (referred to input) per hour after 30 minute warm up | At constant line voltage and ambient temperature; averaged over 10-hour period. |
| OFFSET (output dc level) | Adjustable to zero. | |
| Grid Current | Zero ±50 picoamps, as seen at input connectors with same ambient temperature as during calibration. Zero ±200 picoamps, 0°C to 50°C. | OFFSET adjusted for minimum. |
| Output Impedances | ≤ 30 Ω at 1 MHz for compensated unity gain amplifier. | $Z_o$ at front-panel connectors for compensated unity gain amplifier. |
| Noise | ≤ 25 mV peak to peak (1 Hz to 15 MHz). | Using thermal shield. $Z_i$ at 10 kΩ, $Z_f$ at 1 MΩ, INPUT grounded. |
| | ≤ 2 mV peak to peak (1 Hz to 15 MHz). | — GRID shorted to OUTPUT. |
| $Z_i$ and $Z_f$ Accuracy | Refer to Calibration Procedure page 7-19, step 20. | |
| Resistance | 0.01, 0.1, 0.2, 0.5, and 1 megohm; ±1%. | Resistance and capacitance selected by front-panel control. Other values may be connected externally. |
| Capacitance | 10 pF, adjustable.<br>100 pF, adjustable.<br>0.001, 0.01, 0.1, and 1 μF; ±1%. | |
| Integration LF Cutoff | ≤ 2 Hz | Other cutoff frequencies obtainable with external components. |

## MECHANICAL CHARACTERISTICS

| Characteristic | Information |
|---|---|
| Construction | Alluminum-alloy chassis and panel. Glass laminate etched-circuit boards. |
| Finish | Front panel is photo-etched anodized aluminum. |
| Dimensions | 14½ inches long, 4½ inches wide and 6¼ inches high. |
| Net Weight | Approximately 4.3 lbs. |

## ACCESSORIES INCLUDED

| | | |
|---|---|---|
| 2 | Instruction Manuals | 070-0507-00 |
| 2 | Terminal Adapters | 013-0048-00 |
| 2 | Terminal Shields | 013-0049-00 |
| 2 | Adapters, BNC to Binding Post | 103-0033-00 |

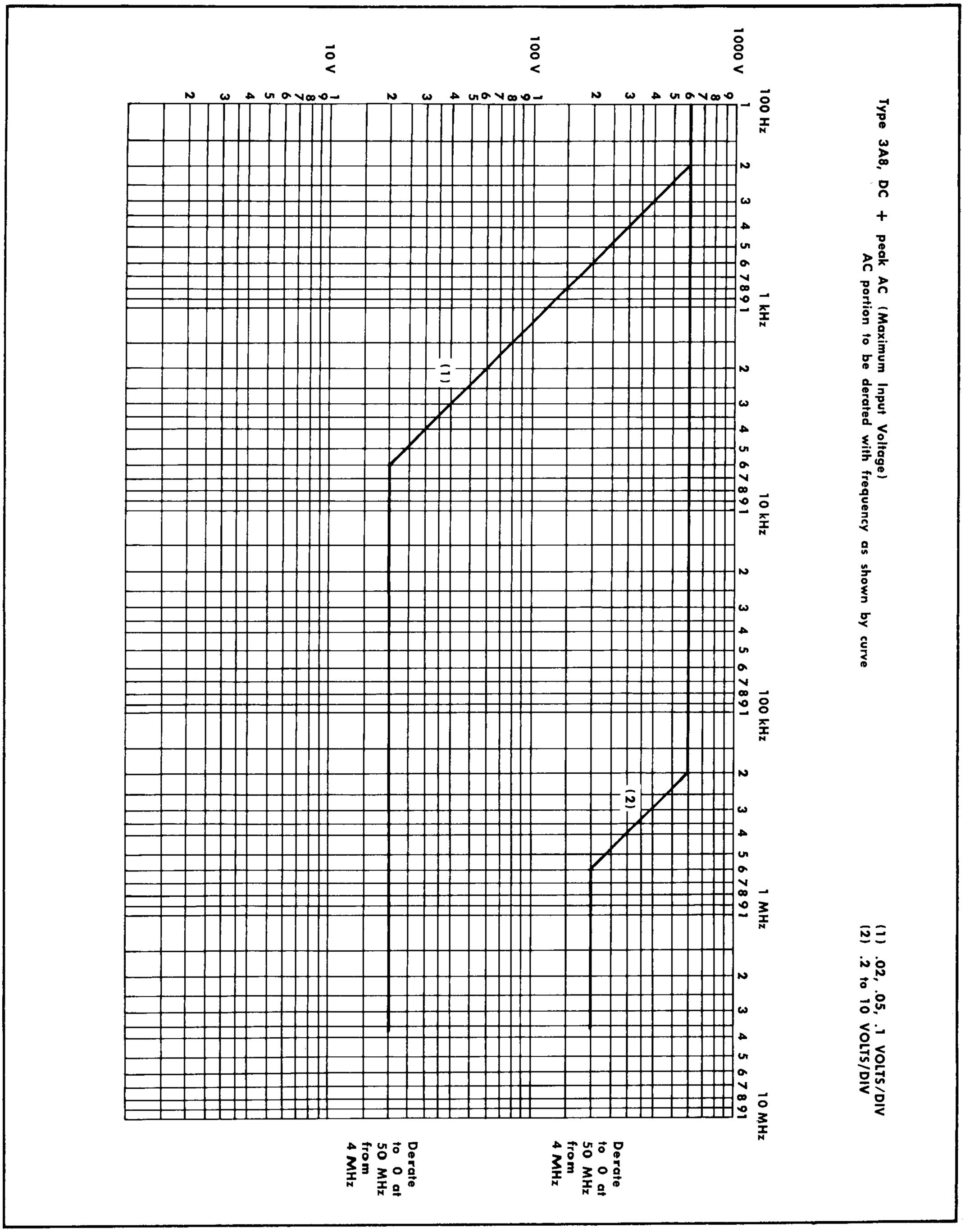



Fig. 1-2. Input voltage derating chart.

# NOTES

# SECTION 2

# OPERATING INSTRUCTIONS

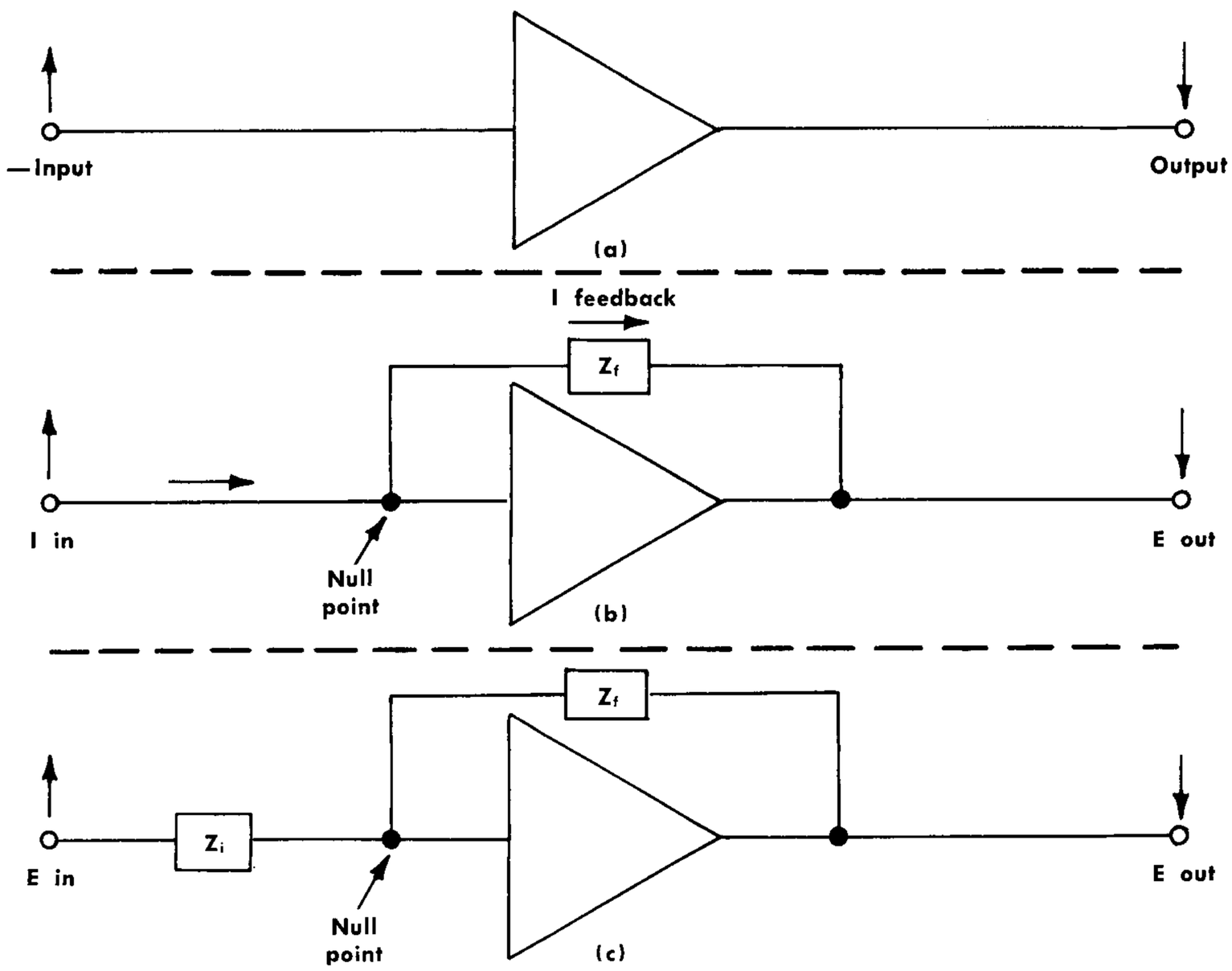
## Introduction

The major portion of this section of the manual presents basic concepts and theory of operation with emphasis on specifications and limitations of Operational Amplifiers. Effective operation depends on an understanding of these concepts. The remainder of this section is devoted to the primary functions and operations of the Type 3A8. Control functions, sample applications, general information and signal connections are described to acquaint the user with the many applications of the instrument.

Operational Amplifiers such as those contained in the Type 3A8 Plug-In Unit are capable of simulating a variety of circuits. They can be used to add, subtract, differentiate, integrate and amplify either linearly or with controlled non-linear coefficients under signal conditions.

As an electronic device, the amplifier can be used to make capacitance, resistance and impedance measurements. In solid-state fields, the amplifier has been used to study tunnel diode performance through plots of E-I and di/de curves. Diode reverse leakage current can be measured and B-H curves plotted. Many sampled data studies can also be made: sampling and sampled-pulse integrations and differentiation.

With semiconductors and tubes as external active elements, the amplifiers are used for a number of non-linear functions; compression, expansion, root and power function, limiting, clipping and fast response logarithmic amplification.




(a) The input is to the base of the triangular symbol, the output is from the apex opposite. The —input and output are out-of-phase (arrows).

(b) Feedback element $Z_f$ provides the negative feedback to permit high-accuracy operations. The amplifier seeks a null at the input by providing feedback current through $Z_f$ equal and opposite to the input current $I_{in}$. Output voltage is whatever is necessary to provide required balancing current through $Z_f$.

(c) Input element $Z_i$ converts a voltage signal ($E_{in}$) to current, which is balanced by current through $Z_f$.

NOTE: It is convenient to represent high-gain dc operational amplifiers by a triangular figure as shown. The base of the triangle is the input; the apex is the output. For most operations, the "negative" grid (i.e.,) the grid which produces a positive-going output for a negative-going input) is used, and the "positive" grid is grounded internally. Where the input grid is not identified (+ or —), the input is the negative (—) grid.

**Fig. 2-1. Conventional Operational Amplifier symbols.**

The Applications section describes many other uses of the Operational Amplifiers.

## UNDERSTANDING OPERATIONAL AMPLIFIERS

Operational amplifiers are devices which make use of negative feedback to process signals with a high degree of accuracy. In the ideal situation, this accuracy is limited only by tolerances in the values of the passive elements in the input and feedback networks.

The operational amplifier is a high-gain amplifier designed to remain stable with large amounts of negative feedback from the output to the input.

General-purpose types are used for linear amplification with precise values of gain and for accurate integration or differentiation operations.

Negative feedback ($Z_f$, in Fig. 2-lb) from the output to the input of the amplifier is obtained by inverting the input signal and coupling it through a resistor, a capacitor network or a non-linear impedance device, to the input. Generally this input is called the (—) input or (—) grid in the case of vacuum tubes.

### Operational Amplifier Seeks Voltage Null At The —Input

With negative feedback the operational amplifier operates like a self-balancing bridge, in that it attempts to provide the current needed through the feedback network to maintain the (—) input at a null (or ground potential). The output signal voltage, then, is a function of this feedback current and the impedance of the feedback element.

If the amplifier (—) input is held near ground potential by the feedback current, it will appear as a low-impedance point to any input signal. With a resistive feedback circuit, for instance, the input impedance appears as the resistance of the feedback element divided by the open circuit gain of the amplifier.

Current applied to the (—) input would tend to develop a voltage across the impedance of the feedback element and move the (—) input away from ground. The output of the amplifier, however, swings in the opposite direction and provides current to balance the input current. This effectively holds the (—) input at ground potential.

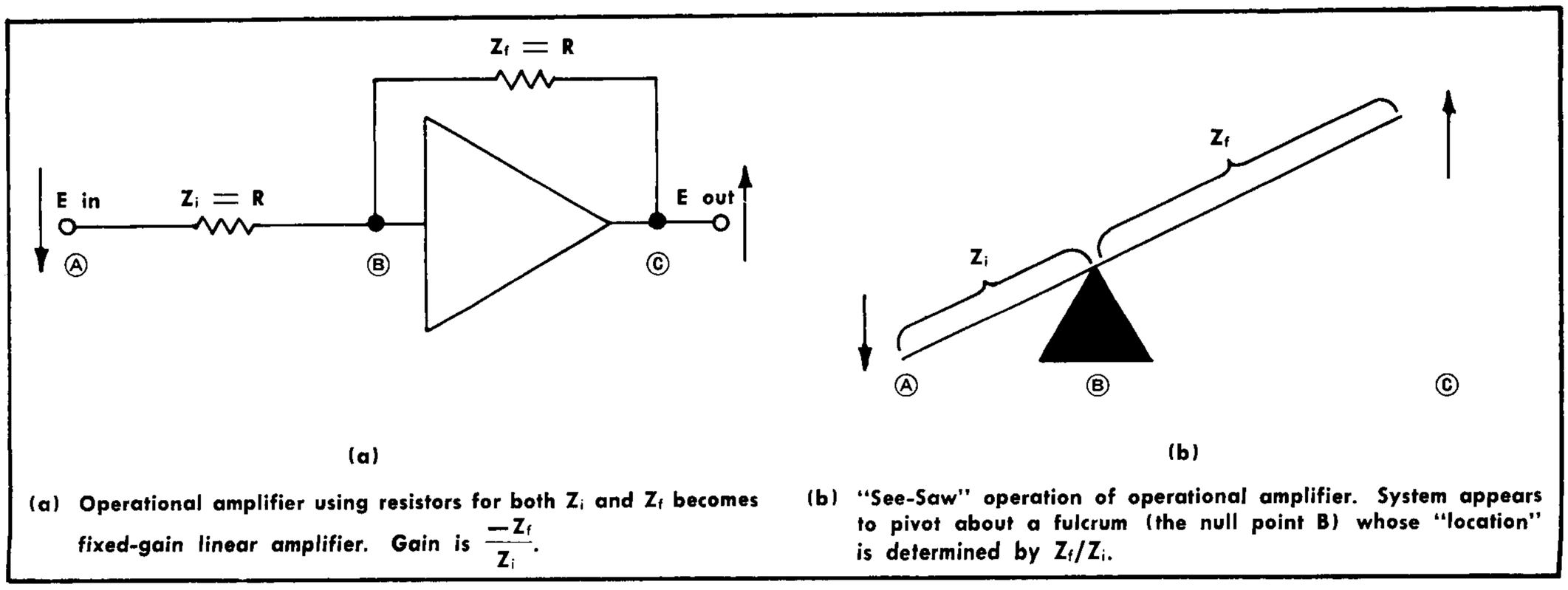
If the impedance of the feedback element ($Z_f$) is high, a high output voltage is required to provide even a small feedback current.

### Input $Z_i$ Converts Input Signal To Current

Since most applications deal with voltage signals, an additional element called input impedance ($Z_i$) is used. This impedance in series with the (—) input, converts that parameter of the input signal appearing as voltage into current. See Fig. 2-1c.

### Output Voltage ($E_o$) Is Input Current × The Feedback Impedance ($Z_f$)

The current through $Z_i$ is equal to the applied voltage at point A (Fig. 2-2), divided by the impedance of $Z_i$ or $\frac{E_{in}}{Z_i}$. Previously, it was stated that this exact value of current must flow through $Z_f$ to keep point B at ground potential. The voltage output at point C, therefore, must equal the current $\frac{E_{in}}{Z_i}$ through $Z_f$ multiplied by the impedance of $Z_f$. Since the output signal is the inverted input, it becomes $\frac{-E_{in}}{Z_i} \times Z_f$ and the voltage gain of the operational amplifier becomes $\frac{E_{out}}{E_{in}}$ or $\frac{-Z_f}{Z_i}$.




(a) Operational amplifier using resistors for both $Z_i$ and $Z_f$ becomes fixed-gain linear amplifier. Gain is $\frac{-Z_f}{Z_i}$.

(b) "See-Saw" operation of operational amplifier. System appears to pivot about a fulcrum (the null point B) whose "location" is determined by $Z_f/Z_i$.

Fig. 2-2. Operational Amplifier with resistors for both $Z_i$ and $Z_f$.

## Voltage Amplifier

If $Z_i$ and $Z_f$ are both resistors (Fig. 2-2), the operational amplifier becomes a simple voltage amplifier, with a gain of $\frac{-Z_f}{Z_i}$.

With a voltage applied to point A in Fig. 2-2, current flows through $Z_i$ and through $Z_f$ to ground, through the low impedance at point C. $Z_i$ and $Z_f$ operate as a voltage divider with a portion of the applied voltage at point B. This signal at B, even if small, is amplified by the amplifier and appears as a large signal of opposite polarity at point C. Thus, the amplifier through feedback tends to hold the voltage at B (—input) at ground potential. To insure this operation, the amplifier output must supply a voltage at point C, to produce a current through $Z_f$ which is exactly equal to the current flowing through $Z_i$. Therefore, with point B held at ground potential, the voltage across $Z_i$ equals the voltage applied at point A.

## Differentiation—Capacitor as $Z_i$ Senses Rate-Of-Change

It was noted previously that an operational amplifier with a resistor as a feedback element produces an output voltage equal to the product of the input current and the feedback resistance. If $Z_i$ is replaced with a capacitor (Fig. 2-3) the following action occurs.

Since current through a capacitor is proportional to the rate-of-change of the voltage across the capacitor, steady state dc voltage across the capacitor (assuming an ideal capacitor) will produce no current through the capacitor. Therefore, with a steady dc voltage applied to an input capacitor, there is no requirement for balancing current from $Z_f$, to maintain the ground potential at the (—) input to the operational amplifier. Output voltage, therefore, will be zero.

With a change of the voltage at the input, there will be a proportionate current flow through the input capacitor. The amount of this current flow is dependent on the voltage rate-of-change and the amount of input capacitance ($I = C\ de/dt$). To illustrate; assume the potential at the input starts at +100 volts dc, and is changed at a linear rate to +95 volts in 5 seconds. This is a rate-of-change of 1 volt per second (5 V/5 s = 1 V/second). If the value of $Z_i$ is 1 $\mu$F, a constant 1 $\mu$A flows through $Z_i$ during the 5-second period. ($I = C\ de/dt$).

The amplifier generates an equal and opposite current through $Z_f$ to balance the circuit. If $Z_f$ is a 1 MΩ resistor, the 1 $\mu$A current will generate +1 volt at the amplifier output. The output, therefore, senses the rate-of-change at the input. This operation is differentiation, sensing input voltage rate-of-change and providing an output voltage which is proportionate to that rate of change.

The actual relationship of output to input is: $E_{out} = \frac{-dE_{in}}{dt} \times RC$. The expression $\frac{dE_{in}}{dt}$, indicates the rate-of-change (in volt-seconds), of the input signal at any given instant while the R and C are the $Z_f$ and $Z_i$ respectively.

The example used a constant rate of change, and a constant voltage output was obtained. If the rate of change had not been constant, the output signal voltage would have shown this dramatically with wide variations in amplitude. The differentiator senses both rate and direction of change. It is a useful device in detecting small variations of slope or discontinuities in waveforms.

## Integration — Capacitor As $Z_f$ Senses Input Amplitude And Duration

With the resistor and capacitor used for differentiation interchanged (Fig. 2-4), the circuit characteristics are exactly opposite. In differentiation, an output voltage which was proportional to the rate of change of the input voltage

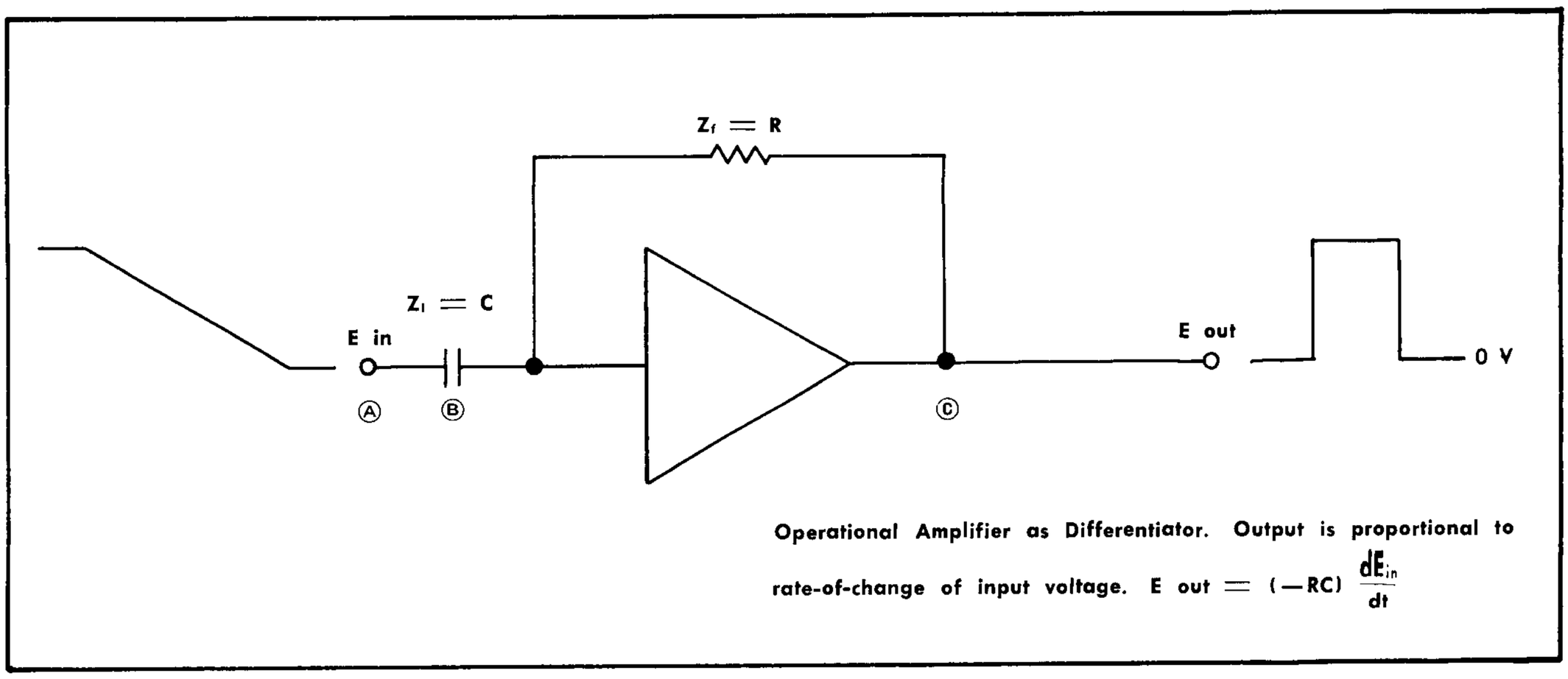



Fig. 2-3. Operational Amplifier as a Differentiator.



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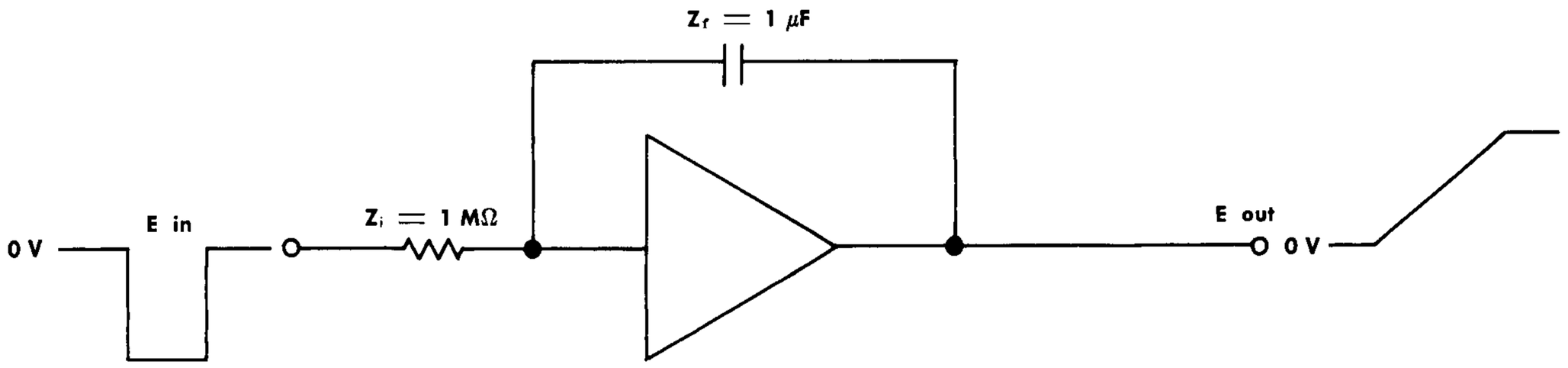



**Operational Amplifier as Integrator. Output rate of change is proportional to input voltage.**

$$\frac{dE_{out}}{dt} = \frac{-E_{in}}{RC} \text{ or } E_{out} = \frac{-1}{RC}\int E_{in}dt$$

**RC in the example here is 1 second. Output, then, is 1 volt per second per volt input, and—most important—the output level at anytime is one volt per volt-second input**

**Integration tends to eliminate the high-frequency components in a waveform. This is because the output voltage from the integrator is inversely proportional to the frequency of the input. This can be seen if we assume a sinusoidal input waveform of the form $e_i = E \sin \omega t$. Substituting for $e_i$ in the preceding equation:**

$$E_o = -\frac{1}{R_i C_f}\int E_{in} \sin \omega t \, dt$$

$$E_o = -\frac{E_{in}}{R_i C_f \omega} \cos \omega t$$

**where E is the peak amplitude, ($\omega$) is the angular frequency and t is time.**

**This equation shows that the output voltage is inversely proportional to the frequency of the input signal.**

**Fig. 2-4. Operational Amplifier as an Integrator.**

was obtained. With the resistor and capacitor interchanged, the output signal becomes a rate of change that is proportional to the input voltage.

This is integration, because the instantaneous value of the output voltage at any time is a measure of both amplitude and duration (up to that time) of the input signal.

The operational amplifier operates as an integrator in the following manner: Assume a $Z_i$ of 1 MΩ, $Z_f$ of 1 μF and an input signal of zero. With these conditions no balancing current is required through $Z_f$, so the output voltage remains at zero. Suppose a —1 volt dc signal is applied to $Z_i$. This will require a balancing current of 1 μA through $Z_f$. To produce this 1 μA balancing current through a $Z_f$ of 1 μF, a continually rising voltage must be generated at the output with a rate of rise equal to 1 volt per second.

This rate of rise continues until the input voltage is changed or the amplifier reaches its swing limit. This rate of rise is an aid in understanding the mechanism through

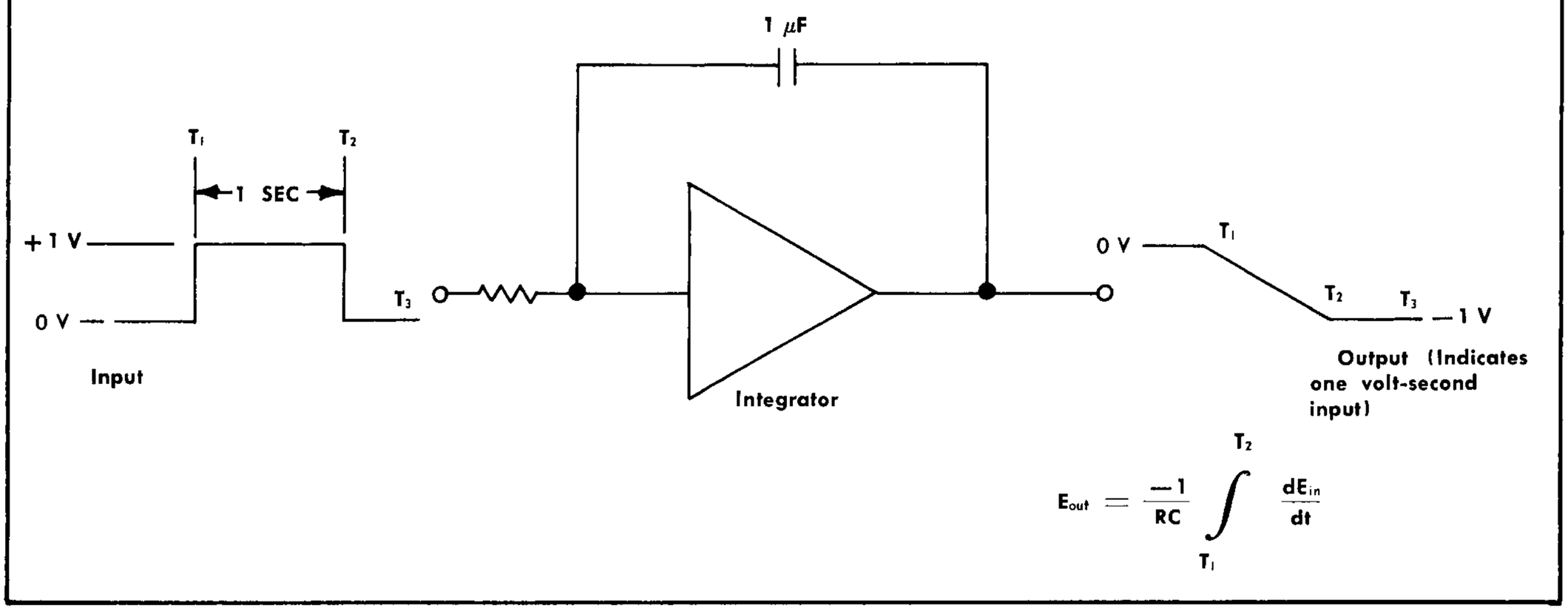
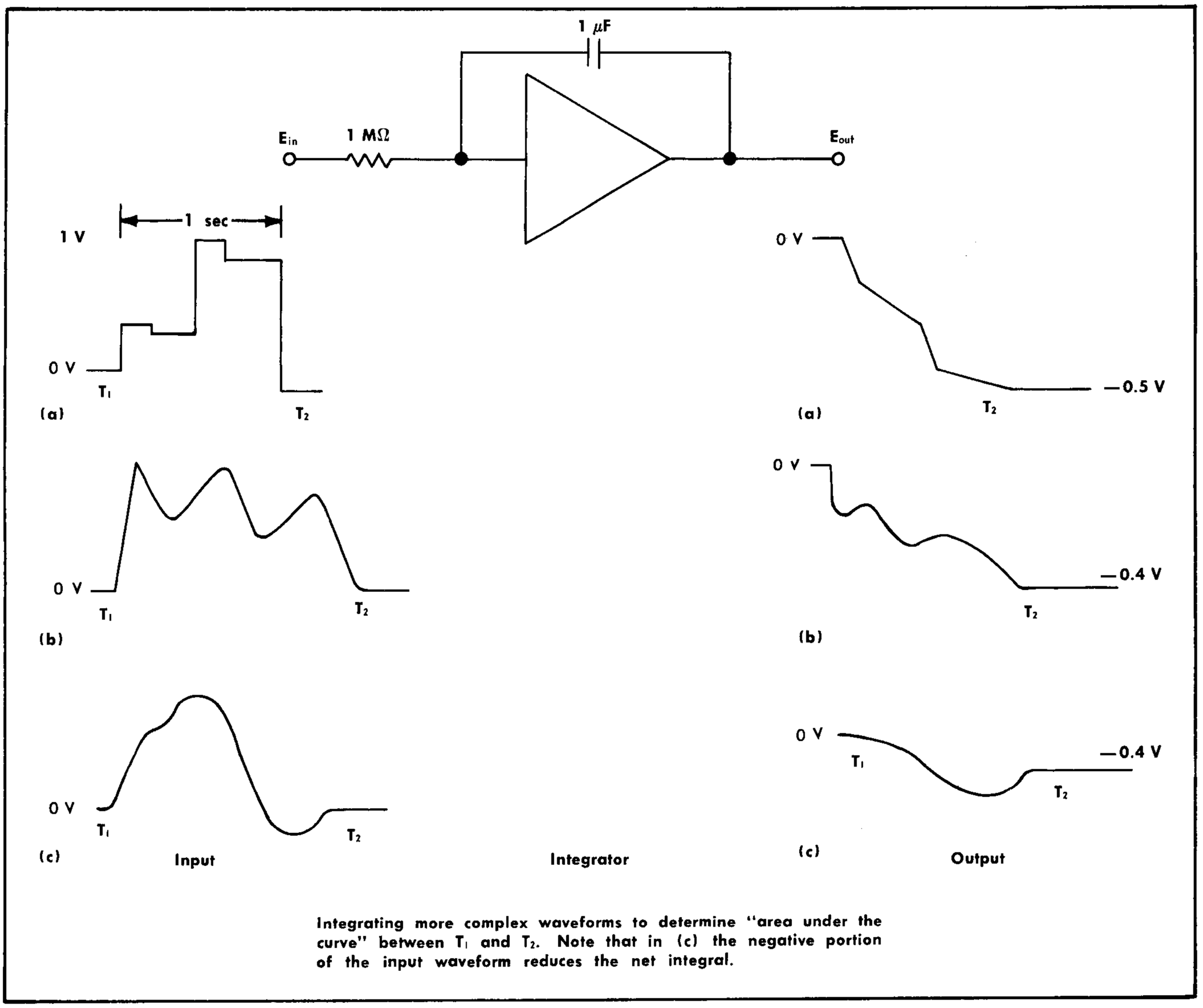



**Fig. 2-5. Simple case of integrating 1 volt-second pulse. The integrator does not improve measurement accuracy in so simple a case.**




Integrating more complex waveforms to determine "area under the curve" between $T_1$ and $T_2$. Note that in (c) the negative portion of the input waveform reduces the net integral.

Fig. 2-6. Typical waveforms at the input and output of the Integrator.

which the amplifier performs integration, but it does not provide the correct solution from an integrator. The significant characteristic is the exact voltage level after a certain interval of time, expressed in units of volt-seconds.

## Integrator Holds Final Voltage Level Until Reset

If the input signal to $Z_i$ is removed before the amplifier reaches its output limit, the output voltage remains at the level reached when the signal was removed. The requirement for the 1 $\mu$A current through $Z_f$ to balance or null the input has been removed; therefore, under ideal conditions the output voltage would remain at this level indefinitely, or until an input signal was again applied to $Z_i$.

Absolute integrator output level at the end of some interval of time, is the sum of the products of each voltage (applied to $Z_i$) times the period of each applied voltage, divided by —RC.

## Interpreting Integration Results

The mathematical expression for the output level in a given period from $t_1$ to $t_2$ is:

$$E_{out} = -\frac{1}{RC} \int_{t_1}^{t_2} E_{in}\, dt$$

The integral sign $\int$, indicates the summation of all the products ($E_{in} \times dt$) shown between the time limits of $t_1$ and $t_2$. The expression dt represents infinitely small increments of time.

Understanding manipulations in integral calculus is not necessary to operate the operational amplifiers as an integrator. The operational amplifier configurated as an integrator provides a voltage output which is proportional to the net number of volt-seconds applied to the input. If the total volt-seconds of one polarity is equalled by volt-seconds of opposite polarity, the output level at the end of the selected interval will be zero.

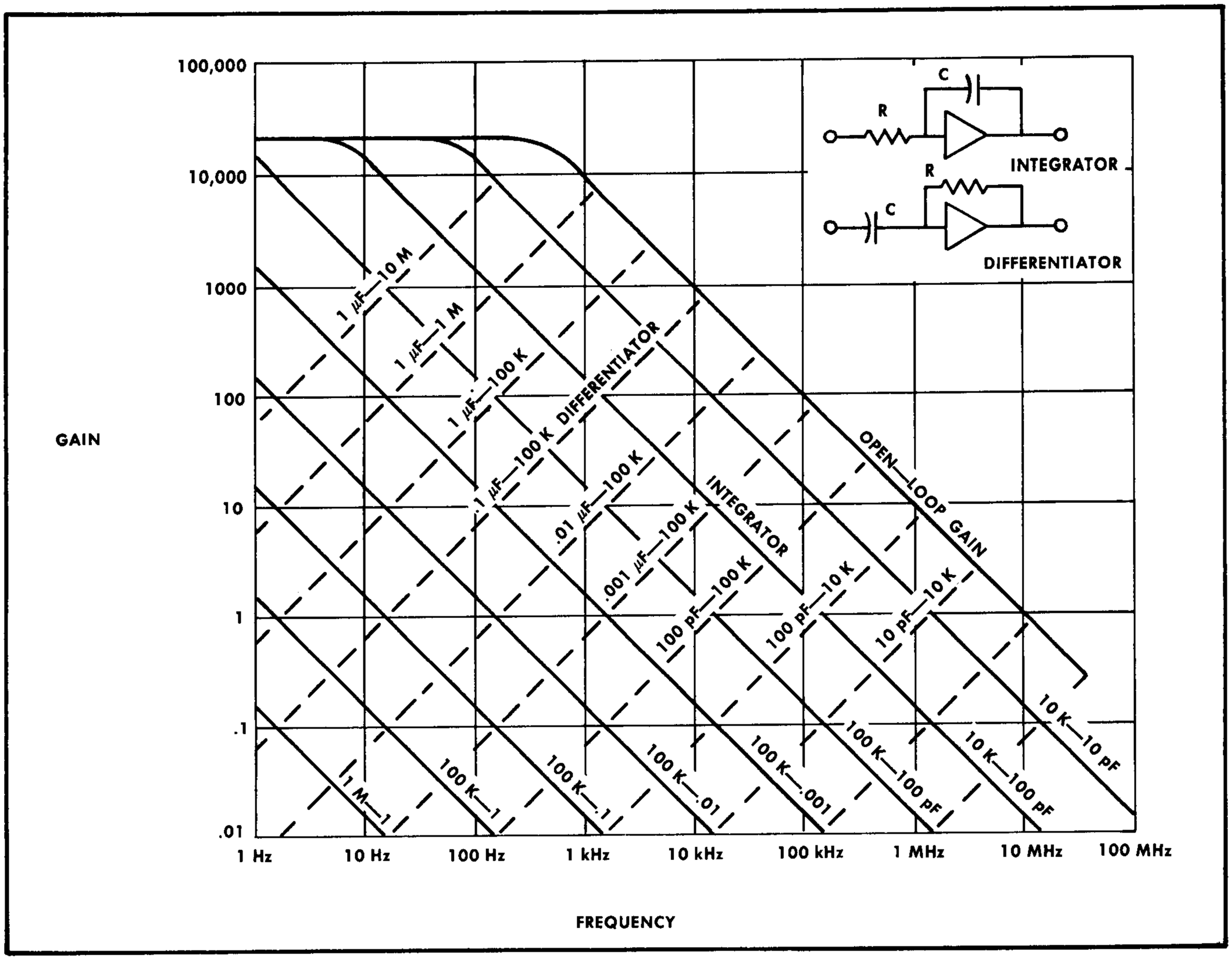



Fig. 2-7. Average gain characteristics for integration and differentiation.

## Integration Data

Example: Assume an input signal for integration is 1 volt positive pulse for a period of 1 second (Fig. 2-5). The sum of all voltage periods from $t_2 - t_1$, is one volt-second. With a $Z_i/Z_f$ combination of 1 MΩ and 1 μF, the output voltage ($E_o$) will fall at a rate of 1 volt-second times $\frac{E_{in}}{RC}$ for a period of 1 second, so the output voltage will reach —1 volt at the end of the input pulse time period and remain at this level.

Since the input signal ($E_{in}$) was 1 volt-second during the time interval $t_2 - t_1$, the output level at $t_2$ will remain constant even to a later time $t_z$ because the input voltage ($E_{in}$) has not changed. This is often referred to as taking the area under the curve, since the area under the waveform plotted against time (i.e., the area bounded by $t_1$, $t_2$, the amplitude of the waveform and the 0 line) is the number of volt-seconds involved. In addition, the instantaneous value of $E_{out}$ at any time is proportional to the input volt-seconds to that selected time.

## Using Other R and C Values

The preceding example used an RC of 1 ($1 \times 10^6 \times 10^{-6}$) and the numerical value of the output voltage at the end of the integrating period was the number of volt-seconds in the input waveform. Other values of R and C will require additional calculation to find the input volt-seconds. The output voltage must be multiplied by —RC. Example: If R is 200,000 Ω, C is 0.01 μF and the output after the selected period is —2.5 volts, then multiplying —2.5 by $2 \times 10^5 \times 1 \times 10^{-8}$ yields —5 mV/s. Due to the polarity reversal in the amplifier it is necessary to multiply by —RC to obtain the proper sign in the answer.

If the waveform contains both positive and negative polarities during the integrating period, as in Fig. 2-6c, the output will be proportional to the difference between the volt-seconds of the two polarities, because the integrator is an averaging device. The two polarities may be added by preceding the integrator with an absolute value amplifier (full wave rectifier), to invert one of the two polarities.

## Operational Amplifier Specifications and Limitations

The ideal amplifier for an Operational Amplifier would provide an infinite amount of gain, infinite input impedance and zero output impedance. With these ideal conditions the operational amplifier could process signals with an accuracy limited only by the tolerances in the values of the passive elements in the input and feedback networks.

The practical amplifier has finite values for all three, which determine the limits of accuracy in all applications. Some of the prominent limitations are:

1. Open loop gain
2. Gain-bandwidth product
3. Output current and voltage capabilities
4. Signal source impedance

## Open Loop Gain

The accuracy of all operations is ultimately limited by the open loop gain of the amplifier, a determinate of how close the amplifier holds the null at the (—) input. The ideal amplifier with infinite gain would hold the null exactly at 0 volts and the impedance would be exactly zero ohms.

The practical amplifier however, with its finite gain, does not quite null the (—) input at zero ohms, but moves $\frac{1}{A}$ times the output voltage swing. (A = Open loop gain of the amplifier.) $E_{in} = \frac{E_{out}}{A}$. The input impedance, therefore, appears as the quantity $\frac{Z_f}{1 - A}$. See Fig. 2-8.

NOTE

**The input impedance at the (—) input is obtained by the following mathematical derivation:**

**Since** $Z_{in} = \frac{E_{in}}{I_{in}}$ **and** $I_{in} = \frac{E_{in} - E_{out}}{Z_f}$ **;**

**then** $Z_{in} = \frac{E_{in}}{\frac{E_{in} - E_{out}}{Z_f}}$ **which equals** $\frac{\frac{E_{out}}{A}}{\frac{\frac{E_{out}}{A} - E_{out}}{Z_f}}$

**or** $\frac{Z_f}{1 - A}$

If the voltage swing $\frac{E_{out}}{A}$, is a significant fraction of the input signal $E_{in}$, or if the impedance $\frac{Z_f}{1 - A}$, is a significant fraction of $Z_i$, there will be a definite error in the output signal to be added to the error introduced by the tolerances of the passive elements, $Z_i$ and $Z_f$. The exact value of this error is $1 - \frac{A}{A - 1 - \frac{Z_f}{Z_i}}$ If the ratio of $Z_f/Z_i$ is small and A is large, this error is not serious.

## Shunt Impedance Across —Input

The true impedance from the (—) grid to ground is $\frac{Z_f}{1 - A}$, and with large values of A, is a very low value, calculated as virtual ground. However, when A becomes small and $Z_f$ becomes large, the shunt impedances (particularly capacitive reactance) can interfere with the operation. See Fig. 2-9.

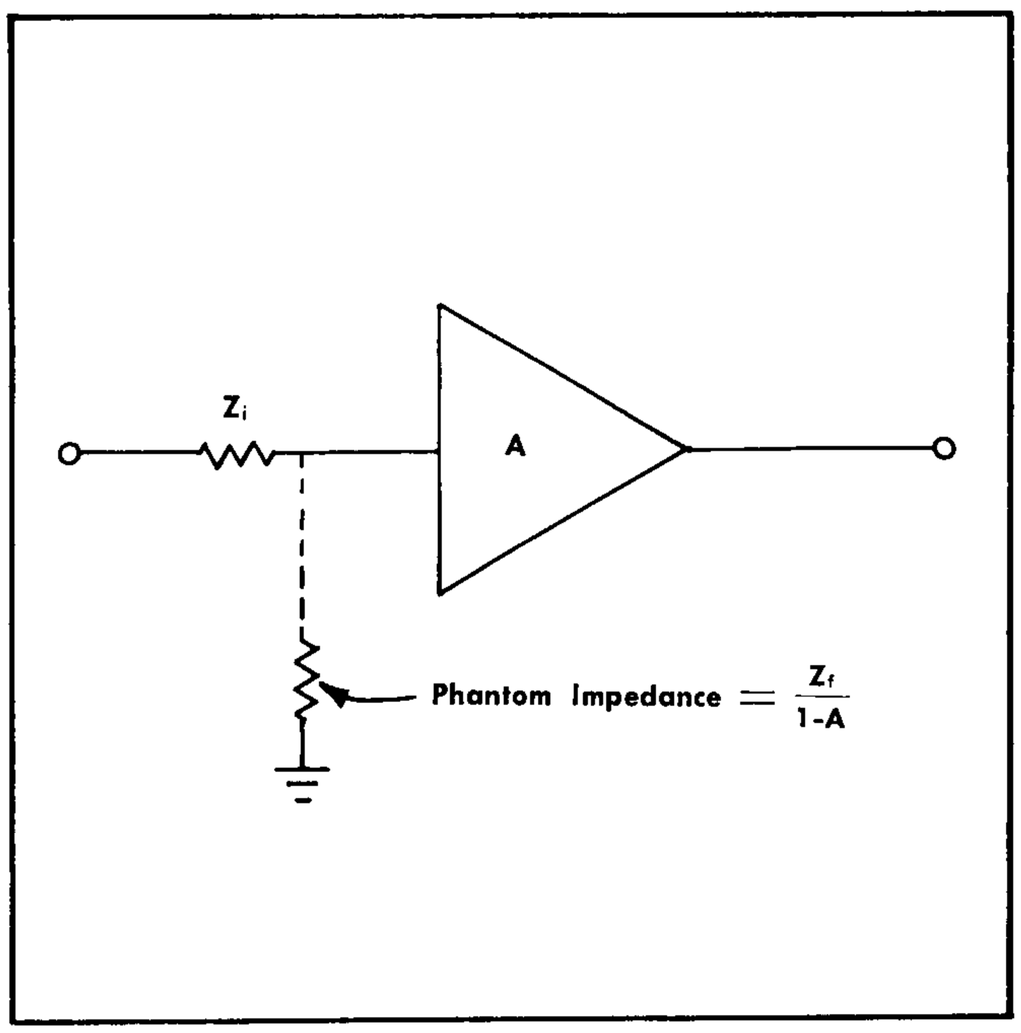



Fig. 2-8. Apparent impedance at the —input.

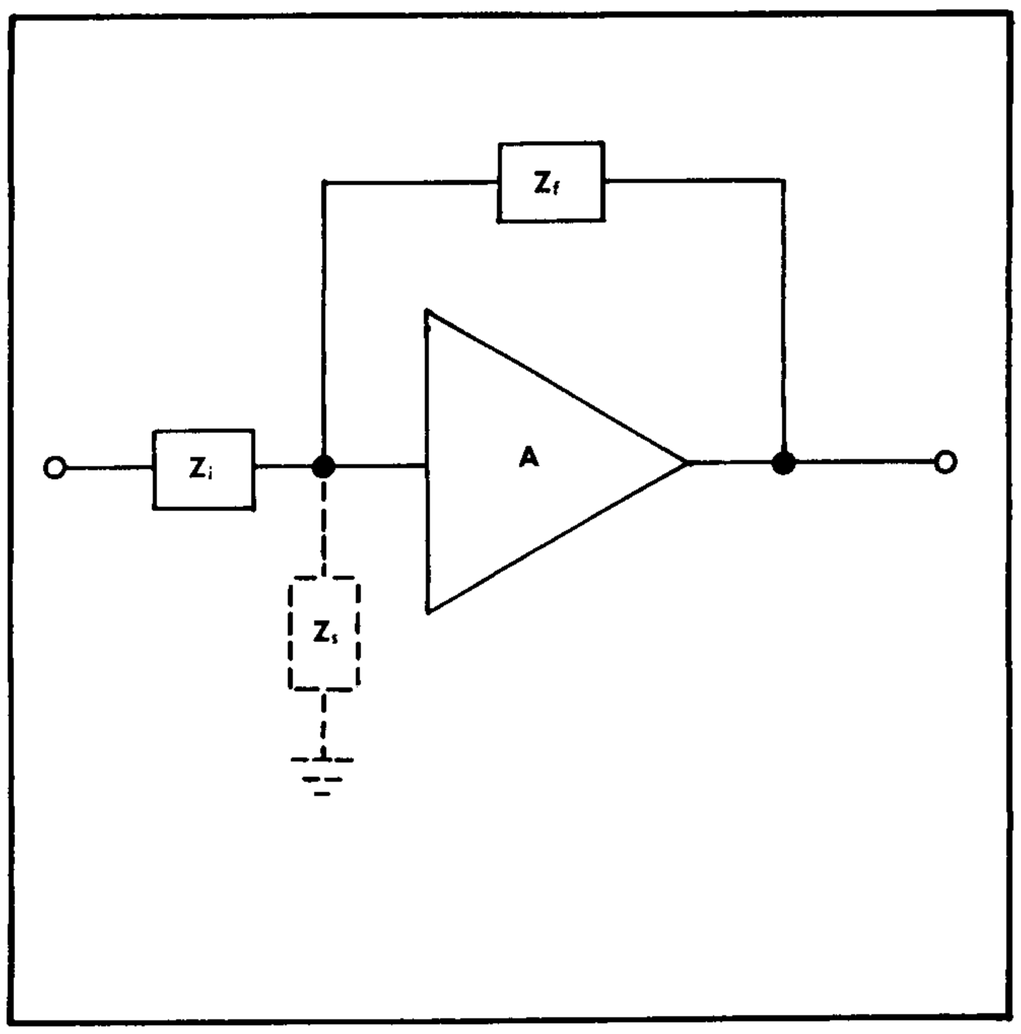



Fig. 2-9. Shunt Impedance across —input. Where $Z_s$ is large compared to $Z_i$ and $Z_f$, and open-loop gain A is high, effect of $Z_s$ is negligible.

The general expression for the closed loop gain of an operational amplifier $\frac{E_{out}}{E_{in}} = \frac{-Z_f}{Z_i}\left[\frac{A}{A - 1 - \frac{Z_f}{Z_i}}\right]$ may be modified as follows to show the effect of shunt impedance $Z_s$ across the (—) grid: $\frac{E_{out}}{E_{in}} = \frac{-Z_f}{Z_i}\left[\frac{A}{A - 1 - \frac{Z_f}{Z_i} - \frac{Z_f}{Z_s}}\right]$ keeping in mind that A is a negative number. The effect of $Z_s$ on accuracy as it becomes smaller is apparent and may become comparable to that of $Z_f/Z_i$.

The terms in the above equation can be rearranged to show the effect of $Z_s$ as related to $Z_i$:

$$\frac{E_{out}}{E_{in}} = \frac{-Z_f}{Z_i}\left[\frac{A}{A - 1 - \frac{Z_f}{Z_i}\left(\frac{Z_s + Z_i}{Z_s}\right)}\right]$$

## Closed Loop Gain Accuracy For Amplification

Common usage in the analog computer field assigns a negative number to the open-loop gain between the (—) input and output and a positive number to the gain from the (+) input. Therefore, in calculating values from formulas involving A and the (—) input, it is necessary to keep in mind that A is a negative number and the expression 1—A for instance, when A is —10,000, equals +10,001, not —9999.

One simplification has been made in this article. Closed-loop gain, commonly expressed as:

$$\frac{-Z_f}{Z_i}\left[\frac{1}{1 - \frac{1}{A}\left(1 + \frac{Z_f}{Z_i}\right)}\right]$$

has been reduced to: $\frac{-Z_f}{Z_i}\left[\frac{A}{A - 1 - \frac{Z_f}{Z_i}}\right]$

It may also be written $\frac{-Z_f}{Z_i}\left[\frac{1}{1 - \frac{1 + Z_f/Z_i}{A}}\right]$, if this seems to indicate the effect of A on accuracy more clearly.

The Type 3A8 Operational Amplifier open loop gain (A) of $>$ 15,000 at dc is large enough to reduce the error to an insignificant figure at low frequencies until closed loop gains of 1000 or more are desired.

## Gain Bandwidth Product

The gain factor A, of the operational amplifier will change with frequency; therefore, it is important to know the effective value of A for frequencies being used. In the Type 3A8 the open-loop gain factor is greater than 15,000 to approximately 1,000 Hz, then decreases in accordance with the gain-bandwidth product to unity at a frequency greater than 10 MHz.

The error introduced by this decrease in gain factor becomes significant at the higher frequencies. Consequently, to make accurate measurements, the allowable ratio of $E_{out}/E_{in}$ must be reduced when higher frequency information is processed.

When the input frequency is approximately 1/10 the open-loop gain-bandwidth product of one, open-loop gain is approximately 10 and is not sufficient to provide accuracy better than 9%, even with a closed-loop gain of unity. Moreover, the effects of added integrating components, from input and feedback elements, cause even more roll-off, so the closed-loop gain-frequency characteristics become less than the theoretical limit. Hence, for critical applications, compensation to the nominal values of $Z_i$ and $Z_f$ is recommended to reduce the gain-factor error.

NOTE

**Except in the case of straight amplification (Fig. 2-10), the compensation itself introduces possible errors which must be recognized and considered in the interpretation of the results.**

## Accuracy With Capacitors As $Z_i$ Or $Z_f$

Since it is not easy to assign a single impedance value in the error formula for $Z_i$ or $Z_f$ when one of them is a capacitor, it is convenient to use the ratio $E_{out}/E_{in}$, to represent the actual voltage gain, to compare the approximate error. The error ($\xi$) is found by the formula:

$$\epsilon = 1 - \left[\frac{\frac{E_{out}}{E_{in}} - A}{1 - A}\right]$$ , or more simply,

$$\epsilon = \frac{1 - \frac{E_{out}}{E_{in}}}{1 - A}$$, where A is the open-loop gain, and $E_{out}/E_{in}$ is the actually obtained voltage gain. Remember that both A and $E_{out}/E_{in}$ are negative numbers. Example: where A is —10,000 and the observed $E_{out}/E_{in}$ is —500, the error has been 501/10,001 or 5.095%. The output —500 then represents 94.905% of the correct value and the correct value is —500/0.94905, or almost —527.

For convenience the terms may be arranged as follows to determine how large an output signal may be allowed for a given input and an arbitrarily selected maximum error:

$$\frac{Max\ E_{out}}{E_{in}} = 1 - \epsilon(1 - A)$$

NOTE

**It is important to remember that A is not constant, but changes with frequency in accordance with the gain-bandwidth product.**

## Compensation For The Effects Of Stray Capacitance

Accuracy in high-speed operations will be affected by shunt capacitance ($C_s$) and by the distributed capacitance around $Z_i$ and $Z_f$ (Fig. 2-10). Their effect is more pronounced at higher frequencies where the effective value of A is low.

To correct for stray capacitance and the variations of A, the 100 pF and 10 pF values for $Z_i$ and $Z_f$ in the Type

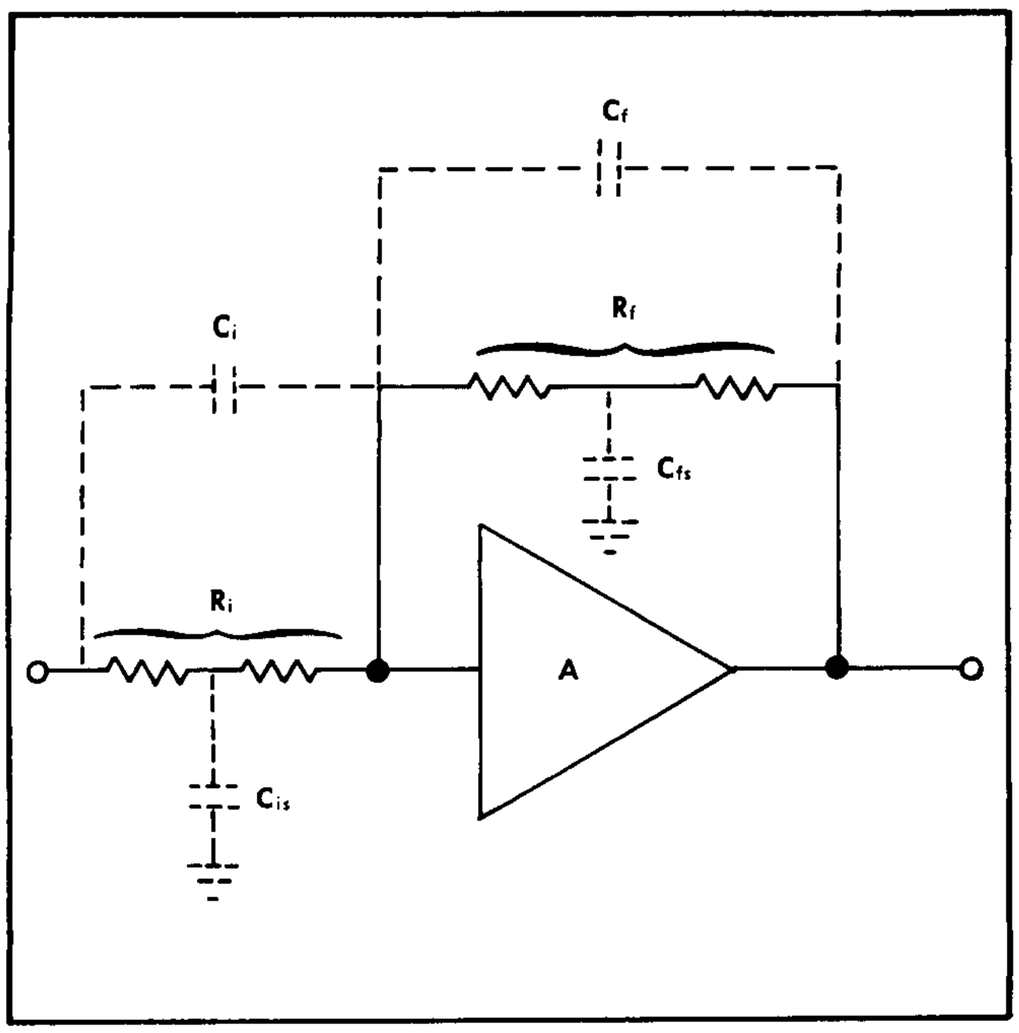



**Fig. 2-10. Where $Z_i$ or $Z_f$ is a resistor, and particularly if a large (> 100 k) value, more serious errors may be caused by capacitance from the resistor body (highest impedance point) to ground, and, in the case of $R_i$ during integration, end-to-end capacitance of $R_i$. Time constants involved in shunt capacitance $C_{fs}$ and $C_{is}$ are approximately RC/4.**

3A8 Operational Amplifiers are adjusted and compensated under dynamic conditions. No external compensation is normally required. If $Z_i$ and $Z_f$ values in this range are used externally, they will require compensation. Trim or pad as necessary under conditions similar to the contemplated measurements.

Compensation for resistors used as $Z_i$ or $Z_f$ can only be partial, since the optimum value for compensation varies with the application. It is therefore necessary, when dealing with short duration or high frequency signals to compensate with external components.

Figure 2-11 through 2-13 illustrate the corrections necessary to improve operational accuracy for each of the basic operations.

## Errors Due To Signal Source Impedance

A part of $Z_i$, the input element of the operational amplifier circuit, is the source impedance of the signal being processed. Linear operations using precision input and feedback components will be accurate only if the source impedance of the signal is very small compared to the impedance of the input component, or the value of the input or feedback component is trimmed to allow for the impedance of the signal source.

## Output Current And Voltage Limits

Any operational amplifier is limited in the amount of current and voltage it can deliver to its feedback network

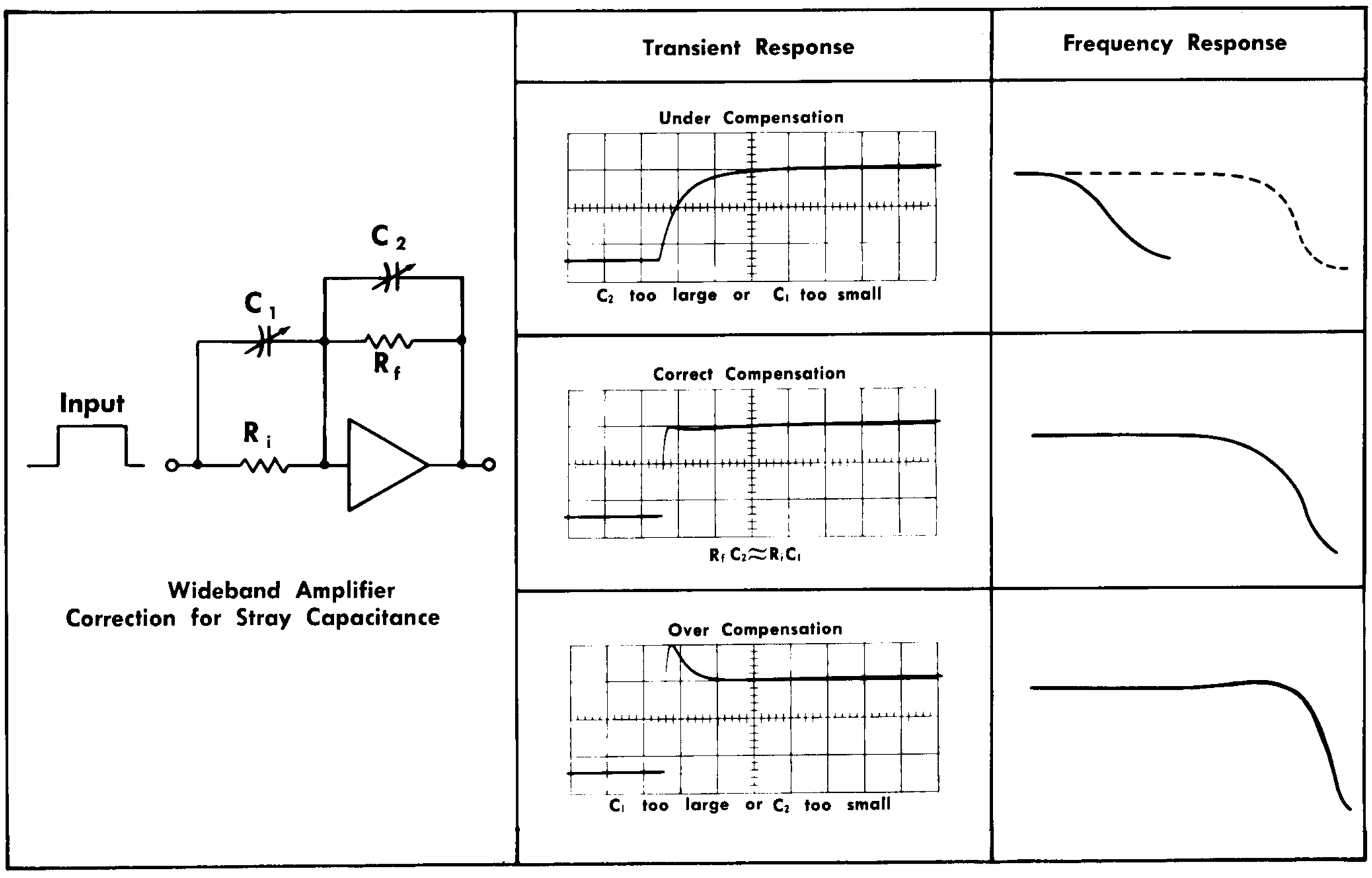



**Fig. 2-11. Wideband Amplifier — Correction for stray capacitance.**



Ⓐ

and any external load. If these limits are exceeded during any part of an operation, the accuracy of that part of the operation will be impaired.

In the case of the Type 3A8, maximum rate of change at output will be limited by the available current and should not exceed 30 V per $\mu$s when loaded by the 47 pF of the oscilloscope amplifier, and about 10 pF of other loading (e.g., $Z_f$).

## Compensated Differentiator

Without compensation, the differentiator may respond to a sudden change in $\frac{dE_{in}}{dt}$ by overshoot followed by sinusoidal ringing. This is because excess output voltage must be developed to charge the input capacitance via $R_f$, plus the distribution stray capacitance of $R_f$ itself. Current is also required to obtain a null at the —input. As soon as the stray capacitances are charged, excess current through $R_f$ upsets the null, and the output must swing in the opposite direction to re-establish the null and discharge the capacitance associated with $R_f$. This produces the ringing. A small capacitance across $R_f$ (Fig. 2-12) provides the current needed to establish the null at the start of the waveform without having to develop excess voltage across $R_f$.

This capacitance limits the output voltage maximum to approximately $\frac{-dE_{in}\ C_i}{C_2}$. After an abrupt change in the input waveform, when $dE_{in}$ is small but $\frac{dE_{in}}{dt} \times RC$ is large, the output voltage limitation of $\frac{-dE_{in}\ C_i}{C_2}$ may result in a significant error. The solution in this case is to select a larger value of $C_i$ and smaller values for $R_f$ and $C_2$ (keeping the $R_f\ C_i$ time constant the same) to minimize the error, and keep its duration as short as possible.

## Integrator Compensation Rarely Needed

Compensation to integrate fast-rise input signals is not recommended. The added components introduce more stray capacitance. It is recommended that smaller values of $R_i$ and a larger $C_f$ be used to maintain the same time constant. The limitations in this would be the amount of loading by $R_i$ that can be tolerated by the signal source.

## Using Standard Waveforms For Comparison

The use of standard waveform (pulses and ramps) with known parameters, is of considerable help in adjusting

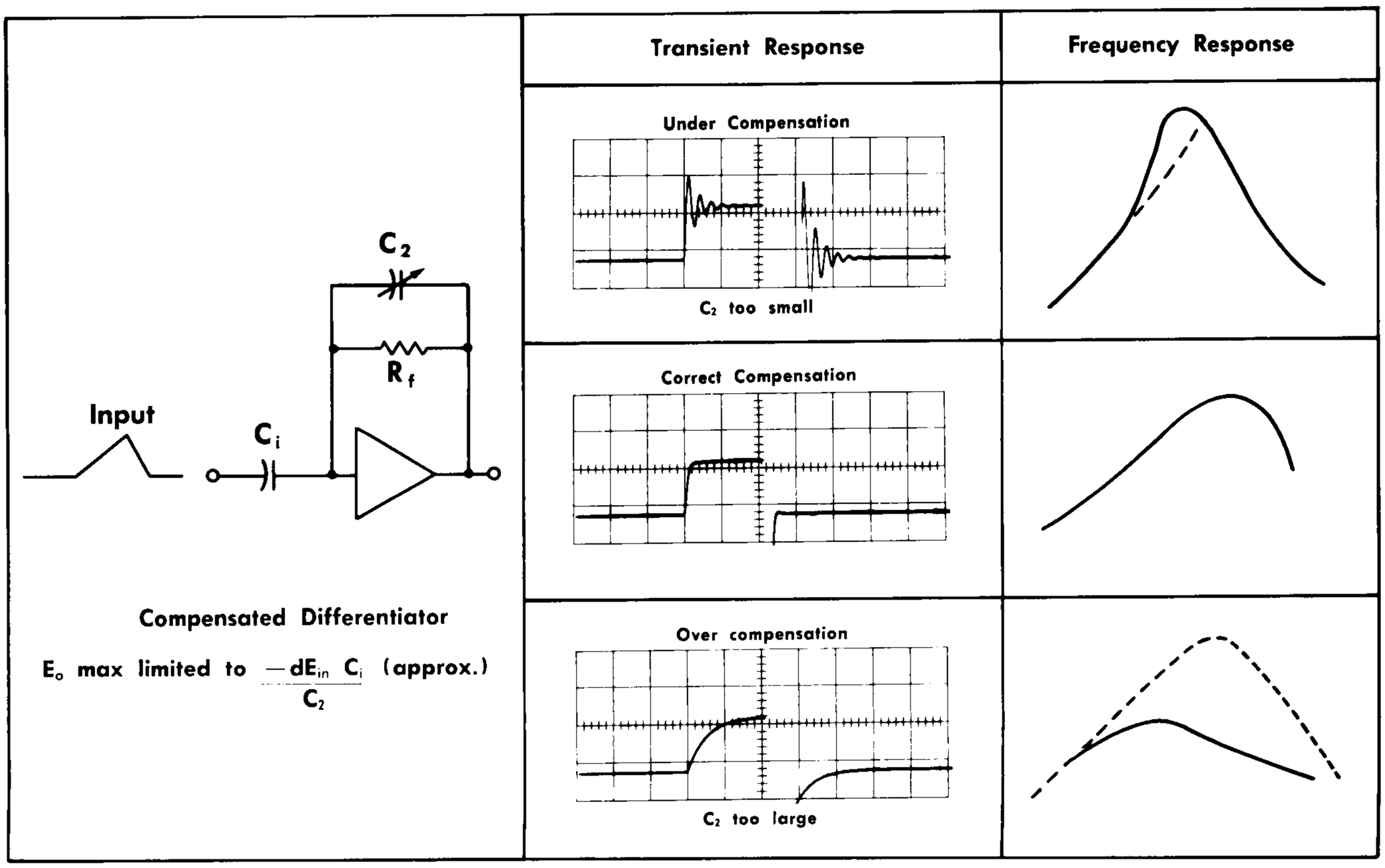



**Fig. 2-12. Compensated differentiator. $E_o$ max limited to $\frac{-dE_{in}\ C_i}{C_2}$ (approximate).**

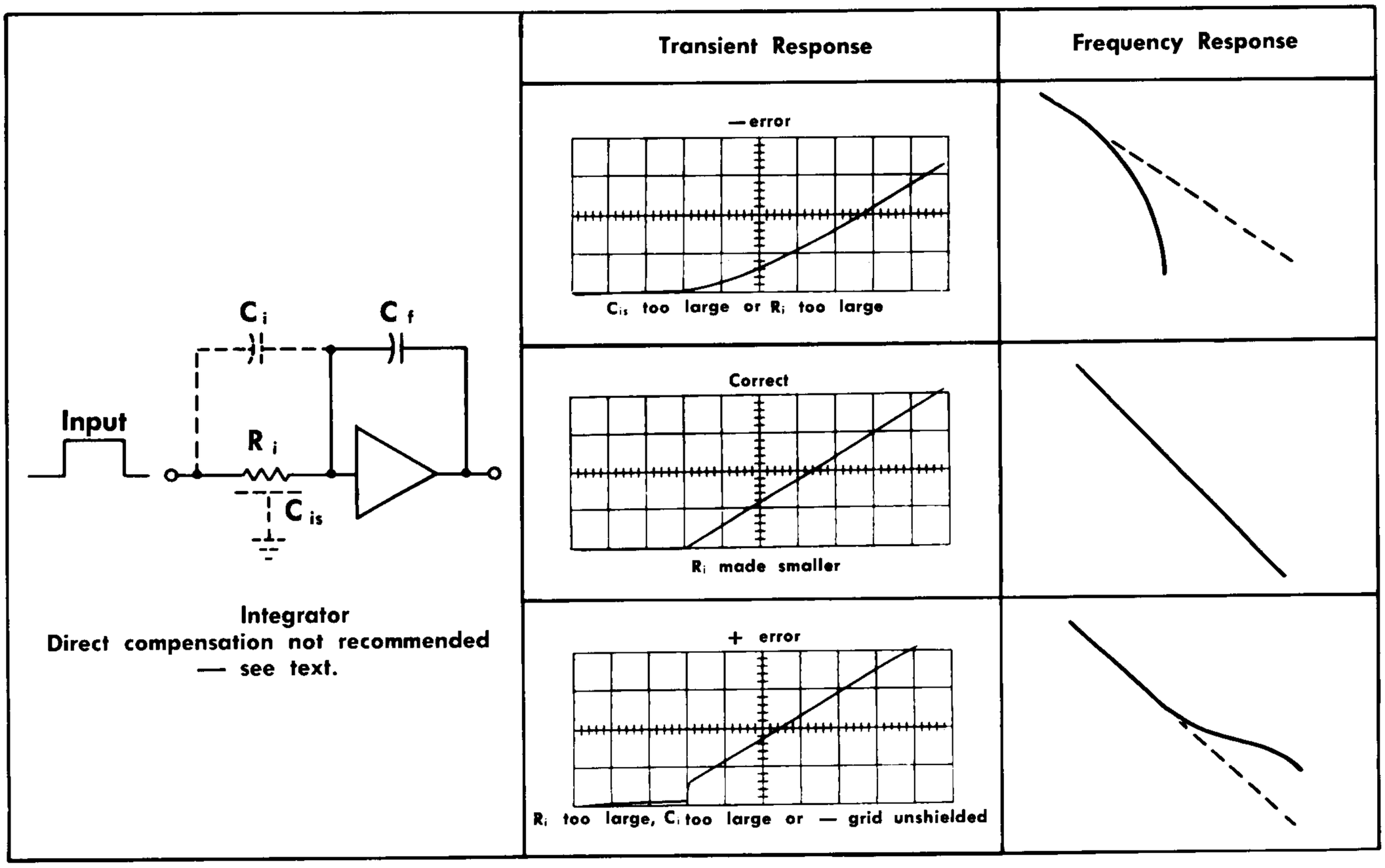



**Fig. 2-13. Integrator — Direct compensation not recommended.**

compensation and assuring best accuracy for critical measurements near the limits of the instrument's capabilities. Selection of time and amplitude parameters close to those of waveforms to be measured will give best assurance against possible systems errors.

The integrating interval ($t_1$ to $t_2$) has been mentioned several times. Frequently it is desired to integrate repetitive signals that are not perfectly symmetrical about zero volts. This causes a dc voltage accumulation that will eventually drive the operational amplifier to its limit. Therefore, some means of returning the output to zero after time $t_2$ (the end of the integrating interval) is required.

For slow work, a pushbutton switch that can discharge $Z_f$ manually is usually sufficient. Other circuits which will perform this function automatically are illustrated in the Applications section. When the integrating interval is quite short compared to the signal period (low duty factor), RC networks may be placed around $Z_f$ to return the output level to 0 V through a time constant much longer (e.g., 100X) than the integrating interval.

In the Type 3A8, the $\int$LF REJ switch position performs this function whenever $Z_f$ is set to a capacitive value.

Since the $\int$LF Reject circuit operates continually to return the integrator output to zero, it is necessary to keep the integrating interval short with respect to the LF Reject time-constant and to measure $E_{out}$ before it has started to decay.

Use of resetting or LF reject circuits may also be required when small values of C are used for $Z_f$, since the small grid current in the (—) input grid even in the absence of an input signal will cause a rise in output voltage as the Operational Amplifier tries to hold the (—) input null with balancing current through $Z_f$. (Minimize according to calibration procedure.)

For sine waves, the gain of the integrator varies inversely with frequency, the actual gain being $\frac{-1}{2\pi fRC}$, except as limited by the open-loop gain (at low frequencies) and the open-loop gain-bandwidth product at high frequencies (see Fig. 2-7). At low frequencies, the gain becomes less than the formula would indicate, the effect becoming noticeable at the point where the formula indicates a gain of approximately $\frac{1}{3}$ the open loop gain. At high frequencies, the error becomes significant above approximately 1/10 of the open-loop gain-bandwidth product. Except as limited above, the integrator shifts the phase of the input sine wave by $\approx +90°$.

## General Information

The Type 3A8 Plug-In Unit contains two separate but identical Operational Amplifiers plus a display or deflection amplifier. The Display Amplifier monitors the output of either Operational Amplifier, or it can be used as an independent oscilloscope amplifier.

The Type 3A8 may be operated in any Tektronix 560 Series (except the Type 560) oscilloscope or the Type 129 Plug-In Power Supply Unit. In either case, the Operational Amplifier outputs can be fed to other equipment.

## Display Amplifier

The amplifier may be used to process signals from either Operational Amplifier; or by connecting signals to the EXT input connector and setting the input selector switch to EXT position, the amplifier will process external signals as a conventional display amplifier.

A selector switch provides means to ac or dc couple the selected signal to the amplifier. The switch also has a GND position to permit the operator to ground the amplifier input grid, and charge or discharge the input coupling capacitor so that the charging pulse does not reach the grid of the input tube. In many cases the ac component of the signal is of interest. Ac coupling blocks the dc component of the signal and permits observation of ac information at high sensitivities. Dc coupling must be used to measure dc component of the signals or to observe very low frequency information, because the ac response is down 30% at approximately 2 Hz.

Display polarity is selected with the NORM-INVERT switch. Vertical deflection sensitivity factor is set with the VOLTS/DIV switch. Nine calibrated deflection factor positions from .02 to 10 volts per division are provided. The VARIABLE control used in conjunction with the VOLTS/DIV selector provides continuous uncalibrated variations from 0.02 to approximately 25 volts per division.

## Operational Amplifiers

The Operational Amplifier selector switch provides selection of $Z_i$ and $Z_f$ combinations. For linear amplification, both $Z_i$ and $Z_f$ are normally resistors. The ratio of $Z_f/Z_i$ basically determines the gain of the amplifier.

To integrate, $Z_f$ is normally a capacitor and $Z_i$ a resistor. The combination of $Z_f/Z_i$ determines the time constant and affects the characteristic of the operation. The typical combination selected has the same time-constant as the period of the input signal.

To differentiate the input signal, $Z_f$ is normally a resistor and $Z_i$ a capacitor. The combination selected, again normally has the same time-contsant as the period.

Most basic operations can be performed through selection of the internal values of $Z_i$ and $Z_f$; however, with the selector switch set to EXT, any desired combination of $Z_i/Z_f$ can be applied through the jacks on the front panel.

# ADAPTERS FOR THE OPERATIONAL AMPLIFIERS

## Terminal Adapter

A convenient means to mount external parts is provided by the Terminal Adapter assemblies received with the Type 3A8. The components can be installed on the adapter and then inserted in the front-panel jacks. The standard ¾-inch

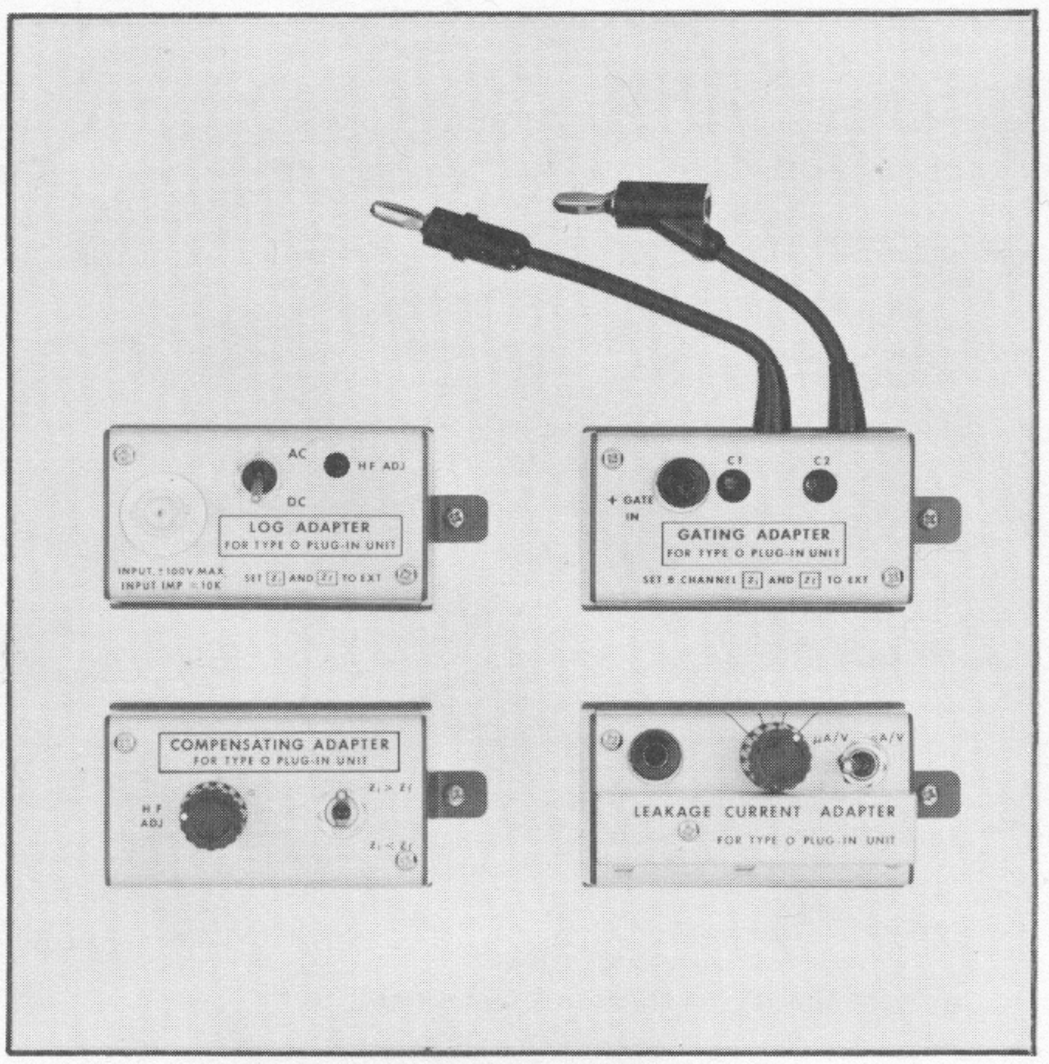



**Fig. 2-14. Four adapters to extend the capabilities of the Type 3A8 Operational Amplifier.**

spacing of the jacks on the front panel permits the use of double banana plug connectors such as General Radio 274-B.

## Compensating Adapter

For extending the high-frequency performance of either operational amplifier when the internal $Z_i$ and $Z_f$ resistors are used in any combination for gain or attenuation. The adapter compensates for stray capacitance associated with the internal resistor, providing an adjustment for optimum HF response.

## Log Adapter

Mixed low and high-amplitude signals can be measured using the Log Adapter. Pulses and transient signals spanning three voltage decades to ±100 volts can be displayed and measured on the same trace.

## Gating Adapter

With the Gating Adapter, repetitive signals with a net integral other than zero can be integrated and displayed. With the Gating Adapter plugged into Operational Amplifier No. 2 of the Type 3A8, the Operational Amplifier No. 1 is gated on or off. The signal applied is then amplified, integrated, or differentiated only during the "on" time.

## Leakage Current Adapter

Adapts the Type 3A8 for measurement of reverse leakage in semiconductor diodes and in small signal transistors in diode-connected configuration. The Leakage Current Adapter requires an external sawtooth drive to +150 volts; a Type 2B67 incorporating Mod No. 120 H can be used for this function.

## FIRST TIME OPERATION

Initial operation requires that certain adjustments be checked. Preset the controls as follows:

| | |
|---|---|
| **Operational Amplifiers, 1 and 2** | |
| $Z_i$ | 1 MΩ |
| $Z_f$ | 1 MΩ |
| ADJUST-NORM-$\int$LF REJ | ADJUST |
| ±GRID SEL | (—) |
| **DISPLAY AMPLIFIER** | |
| Source | EXT |
| Coupling | GND |
| Polarity | NORM |
| POSITION | Centered |
| VOLTS/DIV | .02 |
| VARIABLE | CAL |

After inserting the Type 3A8 into the vertical compartment of the oscilloscope and switching the POWER switch on, allow 20 minutes for the instrument to stabilize. Adjust the oscilloscope time base controls for a free-running sweep. Center the sweep with the POSITION controls and adjust the Intensity, Focus and Astigmatism controls for a well focused trace of nominal brightness.

**NOTE**

**This procedure is based on use of a 60-Hz Calibrator. The user will have to change the Time/DIV settings, if a 1-kHz Calibrator is used for the following samples.**

With the input selector switch of the Display Amplifier in the GND position, set the BAL adjustment for minimum trace shift as the NORM-INVERT switch is switched from NORM to INVERT.

Apply the signal from the oscilloscope Calibrator to the EXT Input connector of the Type 3A8 Display Amplifier. Set the oscilloscope Calibrator switch to .1 Volt position. Set the time-base unit Time/DIV switch to 10 mSEC, Trigger Source switch to Int, Coupling switch to AC and the Slope switch to the + position.

Set the Type 3A8 input coupling switch to DC and the VARIABLE control to CAL position. Adjust the time-base unit Triggering Level control for a stable display.

Adjust the Type 3A8 CAL adjustment for a signal amplitude of 5 major divisions. The deflection sensitivity of the Display Amplifier should now be calibrated to 20 mV/Div.

Disconnect the oscilloscope Calibrator. Recheck the setting of the BAL adjustment.

Set the source switch of the Type 3A8 to position 1. With no signal applied to the Operational Amplifier, the output dc level should be zero. To adjust the dc level, preset the controls as follows:

**Time-Base Unit**

| | |
|---|---|
| Time/Div | 1 mSEC |
| Triggering | |
| Slope | + |
| Coupling | AC |
| Source | Int |
| Trigger Mode or Level | Free Run |

**Type 3A8**

| | |
|---|---|
| Display Amplifier | |
| VOLTS/DIV | 10 |
| VARIABLE | CAL |
| Input Coupling Switch | GND |
| **Operational Amplifiers, 1 and 2** | |
| ADJUST-NORM-$\int$LF REJ | ADJUST |
| ±GRID SEL | (—) |

Position the sweep to the horizontal center line of the graticule with the POSITION control. The zero input dc level of the amplifier then corresponds to the graticule line. Set the input selector switch to DC position.

Adjust the OFFSET adjustment so the trace is positioned on the dc zero reference line previously established.

**NOTE**

**There is a thermal lag in this adjustment because the OFFSET adjustment is altering the heater power to the tubes in the input circuit.**

Increase the sensitivity of the Display Amplifier by setting the VOLTS/DIV attenuator switch to a lower setting, then readjust the OFFSET adjustment for a more precise setting. Some drift and noise may be noticeable with these control settings due to the high gain. Return the ADJUST-NORM-$\int$LF REJ switch to the NORM position.

Set the Display Amplifier input selector switch to 2 and adjust the OFFSET adjustment for Operational Amplifier No. 2 as above.

## Sample Amplification

Connect the output of the oscilloscope Calibrator to the Input connector for No. 1 Operational Amplifier. Set the Calibrator output voltage to .1 volt.

Set the source switch for the Display Amplifier to 1, the VOLTS/DIV switch to .1, and the coupling switch to DC.

Set the No. 1 Operational Amplifier for a gain of —1, by setting both $Z_i$ and $Z_f$ switches to 1 MΩ. Set the Time-Base unit Time/Div switch to 10 mSEC and adjust the Triggering Level control for a stable display.

There should now be a waveform amplitude of 1 major division on the crt graticule area. Thus for 0.1-volt signal in, —0.1 volt out is obtained, to give a gain ($E_o/E_i$) of —1.

Change the $Z_i$ switch setting to .5 MΩ. The combination of $Z_f/Z_i$ is 1/.5 or 2. There should now be 2 major divisions of signal amplitude or 0.2 volts. The gain is —2 calculated. Select other combinations of $Z_f/Z_i$ to illustrate the amplification characteristics of the Operational Amplifier.

**NOTE**

**Because of the signal inversion through the Operational Amplifier, the gain is referred to as a negative (—) quantity. As different values of input voltage and $Z_i/Z_f$ combination are used there may be combinations which will introduce error in the output. This is due to an increase in signal source impedance to $Z_i$ as described earlier under Signal Source Impedance.**

## Sample Integration And Differentiation

In integration, the input component is a resistor while the feedback component is a capacitor. This is analogous to the simple RC circuit. When set up for integration, the output ($e_o$) of the operational amplifier is approximately:

$$e_o \approx -\frac{1}{R_i C_f}\int e_i\, dt$$

The output voltage is inversely proportional to the time constant and directly proportional to the integral of the input signal voltage. The time constant of values chosen is normally the period of the signal to be integrated.

In differentiation, a capacitor is used as the input component while the feedback component is a resistor. It is similar in some respects to a simple RC differentiation circuit, except that the high gain of the amplifier allows differentiation to be obtained with high output signal level.

In differentiation, the approximate output voltage from the operational amplifier is given by the equation

$$e_o \approx -R_f C_i \frac{de_i}{dt}$$

where $e_o$ is the output voltage, $R_f$ is the feedback resistance, $C_i$ is the input capacitance, $e_i$, is the input voltage. The output voltage varies directly with the input time constant and the input voltage rate of change.

In addition to demonstrating integration and differentiation with the Operational Amplifiers, the following will show the need of the $\int$LF REJ circuit and high frequency compensation.

Connect the Type 3A8 and oscilloscope as shown in Figs. 2-15 and 2-16. Set the oscilloscope and Type 3A8 controls as follows:

**Time-Base Unit**

| | |
|---|---|
| Time/Div | 2 mSEC |
| Triggering | |
| Slope | + |
| Coupling | AC |
| Source | Line or Int |
| Trigger Mode | Normal |
| Level | Midrange or Auto |
| Oscilloscope Calibrator | 20 Volts |

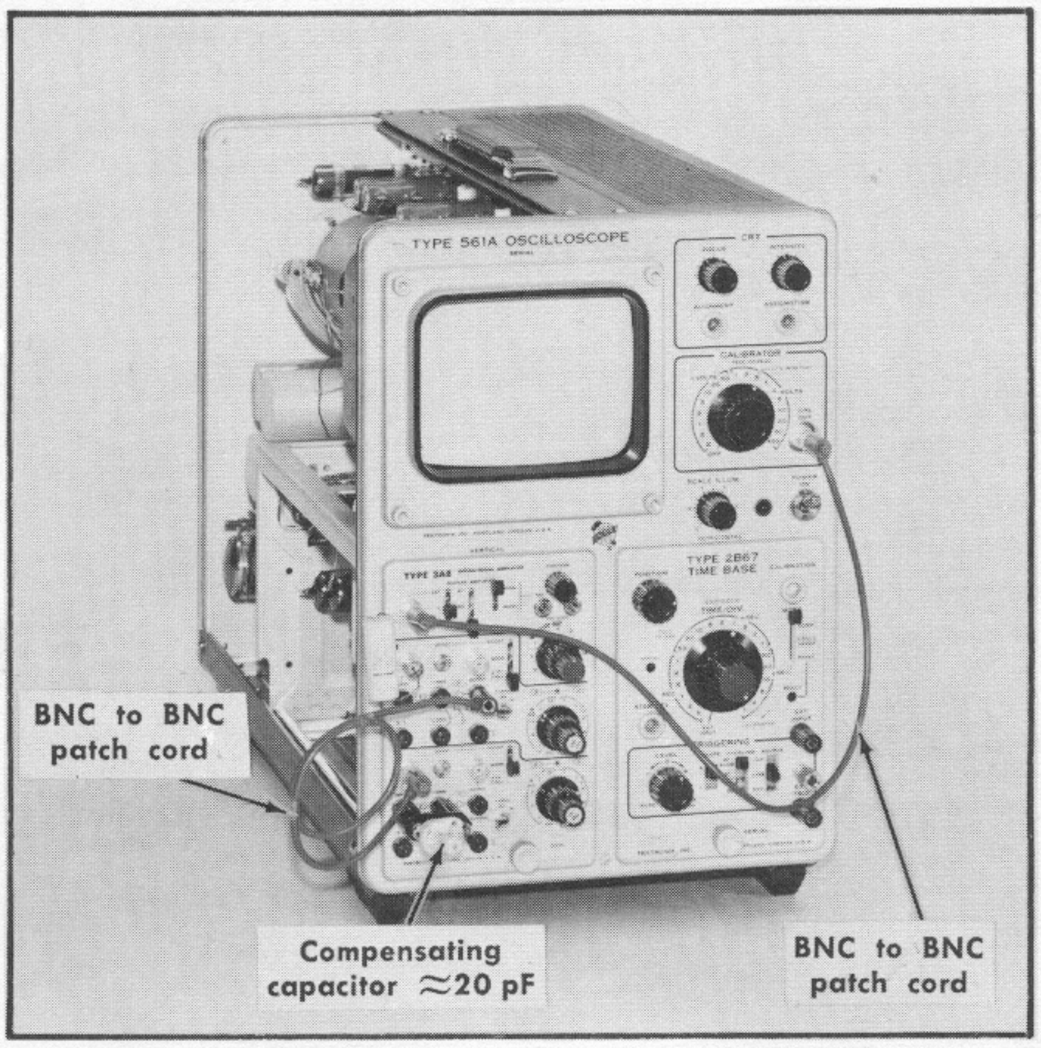



**Fig. 2-15. Operational setup to demonstrate integration and differentiation.**

**Type 3A8**

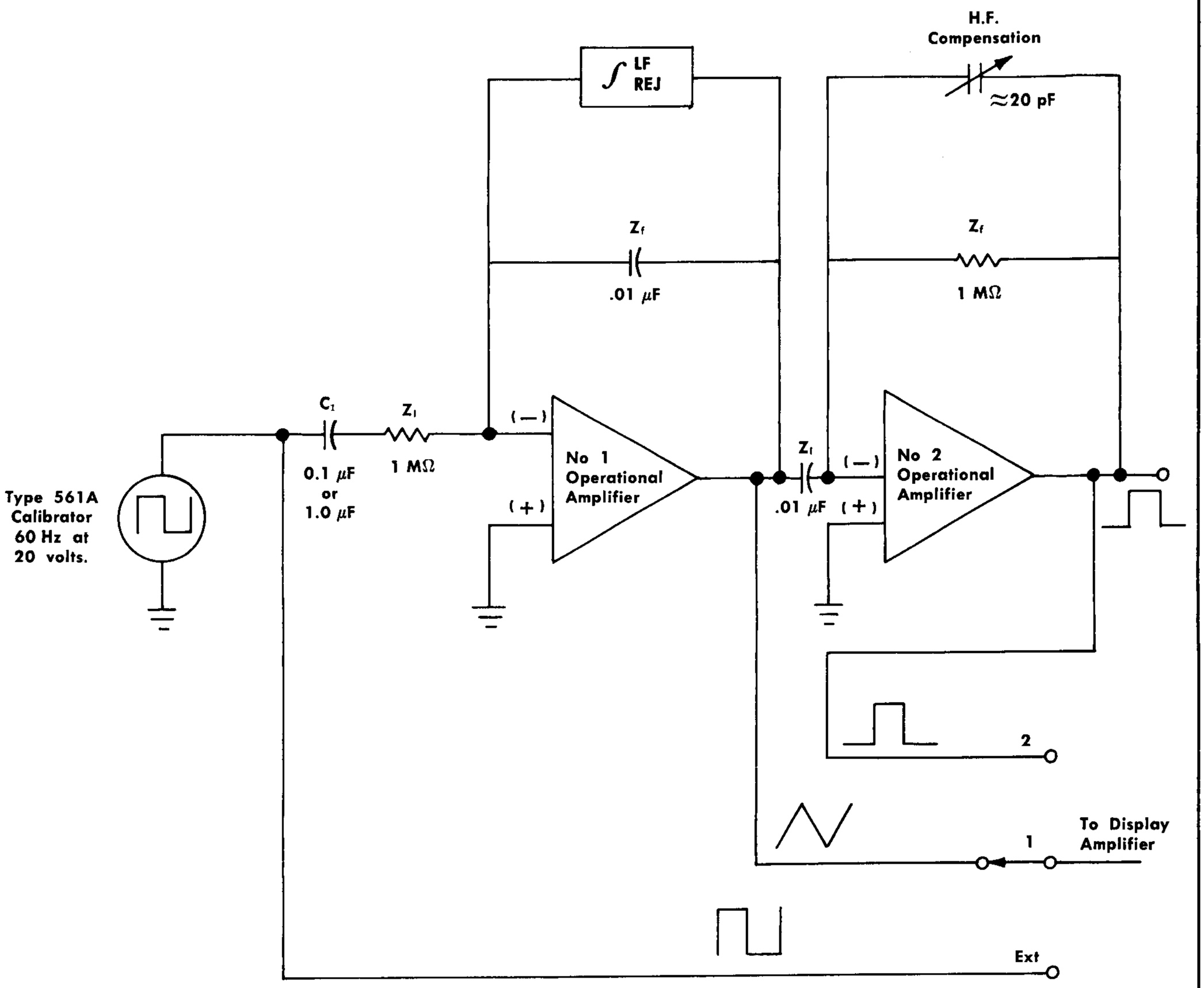
| | |
|---|---|
| Display Amplifier | |
| Coupling | DC |
| NORM-INVERT | NORM |
| VOLTS/DIV | 5 |
| VARIABLE | CAL |
| 1 Operational Amplifier | |
| NORM-$\int$LF REJ | $\int$LF REJ |
| ± GRID SEL | (—) |
| $Z_i$ | 1 MΩ |
| $Z_f$ | .01 μF |
| 2 Operational Amplifier | |
| NORM-$\int$LF REJ | NORM |
| ± GRID SEL | (—) |
| $Z_i$ | .01 μF |
| $Z_f$ | 1 MΩ |

Set the input selector switch for the Display Amplifier to EXT position and adjust the time-base Triggering Level control for a stable display. Observe the 20-volt Calibrator waveform.

Switch the input selector switch to position 1 and observe the integrated waveform.

**NOTE**

**Since ac-coupling capacitor C1 averages the 20-volt positive-going square wave into alternate positive and negative pulses of about 10 V, the integrated output will be a triangular waveform having an amplitude of:**




**NOTE:**
**0.1 μf for $C_1$ will produce slight distortion of integral which probably cannot be detected by the observer, however it will be very noticeable in the differential waveform.**

**Requirements:**

**(1) 0.1 μf capacitor**
**(2) BNC to BNC patch cords. (Part No. 012-0084-00)**
**(1) 1.0 μf capacitor**

**Fig. 2-16. Sample circuit for Integration and Differentiation.**

$$E_{out} = \frac{-1}{RC} \int E_{in}\, dt$$

$$= \frac{-1}{1 \times 10^{6} \times 10^{-8}} \times 10\,V \times 8.33\,ms^{1}$$

$$= -8.33\,V \text{ or } 8.33\,V\ p\text{-}p$$

The ∫LF REJECT circuit provides the initial charging path for the coupling capacitor and thereafter eliminates any long-term effects of leakage, grid current, and dc drift of the amplifier.

The $E_{in}$ and dt values in the foregoing example are for a 50% duty factor. While these values would be different for other duty factors, it is interesting to note that their product is a constant.

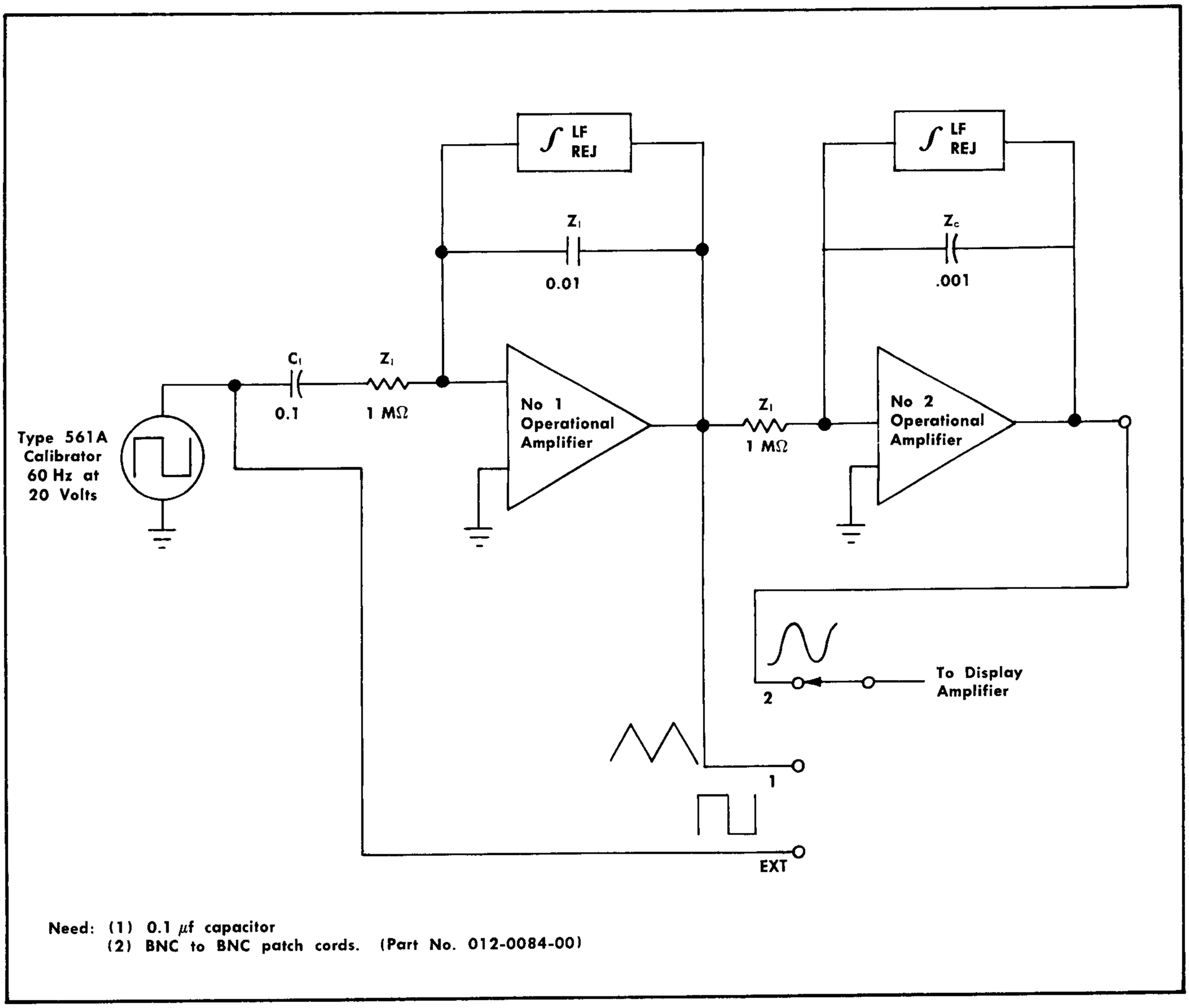
You probably will measure slightly less than the calculated 8.33 volts. This is due in part to the combination of three factors.

1. The output impedance of the Calibrator adds to $Z_i$.

2. The coupling capacitor impedance adds to $Z_i$ in the low-frequency portion of the squarewave.

3. The ∫LF Reject circuit supplies some of the (—) grid nulling current which would otherwise be adding to the charge accumulation of $Z_f$.

[1]Period of one-half cycle from 60-Hz Calibrator.




Need: (1) 0.1 $\mu f$ capacitor
(2) BNC to BNC patch cords. (Part No. 012-0084-00)

Fig. 2-17. Sample circuit for single and double Integration.

In this demonstration, the effect of each of the three factors is quite small.

Set the Display Amplifier input selector switch to 2 and observe the differentiated waveform of the No. 1 Operational Amplifier output waveform. Adjust the high-frequency compensating capacitor for optimum square corner. Note the effect of compensation; insufficient compensation causes ringing at the corner of the waveform while over-compensation tends to produce undershoot or a rounding of the corners. (Any aberrations in the waveform such as slope are due to the coupling capacitor.) This illustrates one of the practical applications of differentiation, in that the aberrations that are not visible in the integrated waveform are clearly discernible after the signal is differentiated.

Try different combinations of $Z_i/Z_f$ and observe the effect for both the integrator and the differentiator. Remember the Calibrator output impedance is a part of $Z_i$.

## Sample Single And Double Integration

Connect the oscilloscope and the Type 3A8 as shown in Figs. 2-15 and 2-17.

Remove the compensating capacitor for the No. 2 Operational Amplifier and set $Z_i$ to 1 MΩ and $Z_f$ to .001 $\mu$F. Set the $\int$LF REJ-NORM-ADJUST switch to $\int$LF REJ position.

Observe the double and single integrated Calibrator waveform. $\int$LF REJ works best with low duty factor signals. Integration period should be very short compared to the reject circuit time constant. The ratio of the reject circuit impedance to the input impedance ($Z_i$) should be low.

If it is necessary to integrate for periods of several seconds where the low frequency reject time-constant decays the integral and therefore cannot be used, the circuit in Fig. 2-18a can be used.

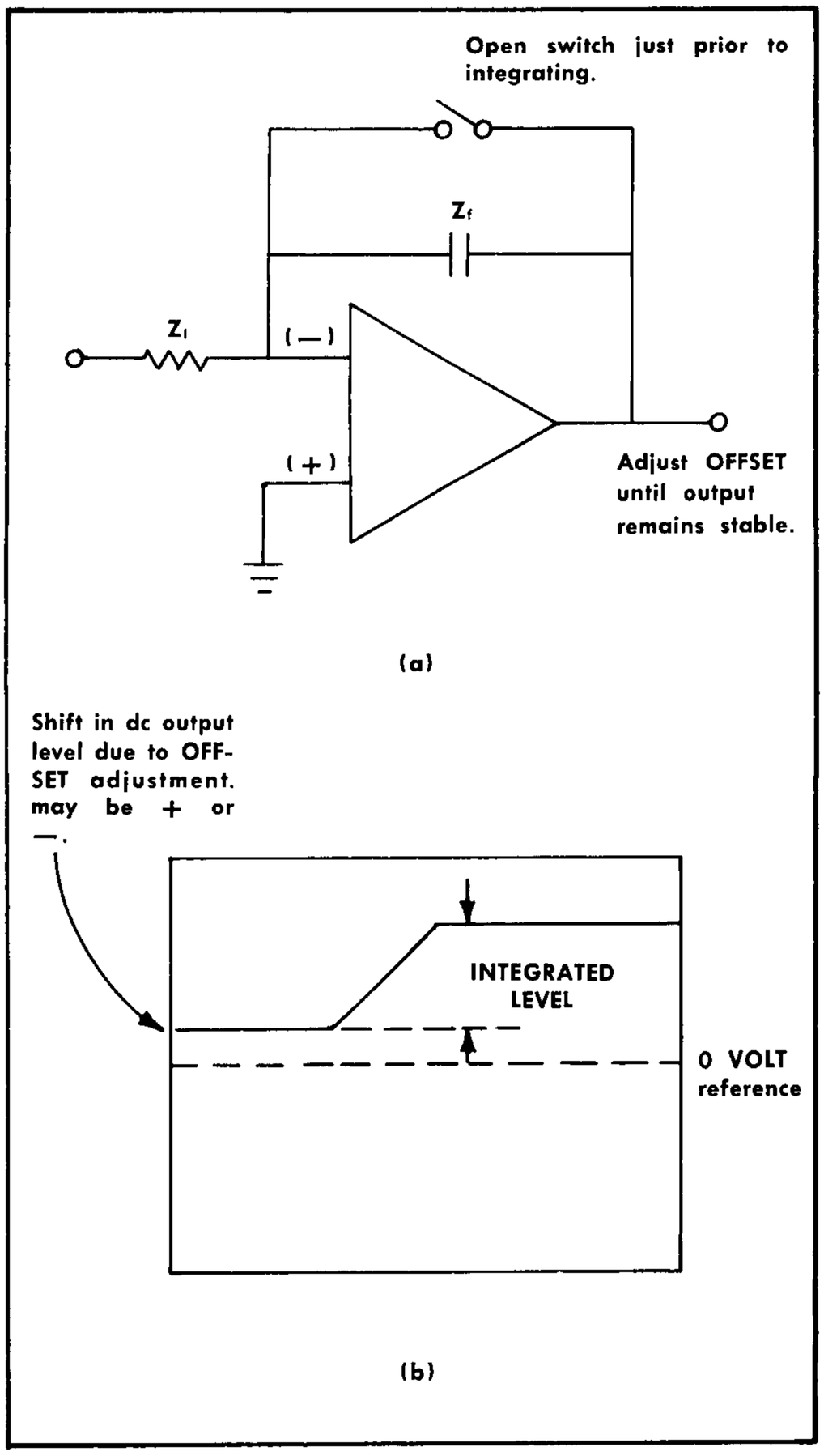



**Fig. 2-18. Integrating and measuring over a long period with respect to low-frequency reject time.**

With no signal in, the OFFSET can be adjusted to offset grid emission current with a slight sacrifice to the output dc level. Measure the integration from the adjusted dc level as shown in Fig. 2-18b.

## Signal Connection Precautions

Certain precautions should be taken in connecting signals to the input of the Operational Amplifiers to assure good results. When low level signals are connected, it may be necessary to use shielded leads to minimize stray pickup. This is important when the unit is used for differentiation; high-frequency noise may be troublesome with differentiation, since the output of the differentiator is proportional to frequency.

Precautions for connecting signals to the Display Amplifier are similar to those for the Operational Amplifiers. Avoid errors in reading by guarding against stray electric or magnetic coupling between circuits, in particular the input signal leads. Unshielded leads of appreciable length are not suitable even for the audio-frequency range. Shielded input cables are recommended for low frequency measurements from a high-impedance source. When shielded leads are used, the shields should be securely grounded to the chassis of both the signal source and the amplifier.

In broadband applications, use coaxial cables and terminate to prevent ringing and standing waves. The termination normally is placed at the amplifier end of the cable, although some sources may require a termination at the source. Try to simulate actual operating conditions for the equipment being tested, by approximating its normal load.

Consider the effect of loading due to the input circuit of the Display Amplifier. The input impedance of the amplifier is 1 megohm paralleled by 47 pF.

## Use Of Probes With The Type 3A8 Unit

Standard Tektronix probes can be used with the Display Amplifier of the Type 3A8 unit. Attenuator probes reduce both capacitive and resistive loading on the signal source. They also permit larger amplitude signals to be displayed than would otherwise be possible.

When attenuator probes are used, they must be properly compensated. This compensation is easily accomplished using the oscilloscope Calibrator signal. Adjust the probe compensation for optimum square corners on the displayed Calibrator waveform.

The attenuation factor of the probe must be considered when measurements are made. The vertical deflection sensitivity of the Type 3A8 Unit is effectively increased by the attenuation factor of the probe. A 10× probe used with a VOLTS/DIV switch setting of 5 provides an actual deflection factor of 50 volts/div.

## Signal Connection To The ± GRID

The ± GRID jack can be used to connect signals to either input grid of the Operational Amplifiers. The input grid selected is determined by the position of the ± GRID SEL switch. Signals connected to the — GRID jack are applied to the (—) grid, regardless of the positions of the ± GRID SEL switch. Signals applied to the (—) grid are inverted at the output of the amplifier while signals applied to the (+) grid are not inverted.

Both grids of the amplifier can be active, as in a differential amplifier. Two methods of connecting the (—) grid when the (+) grid is used are: 100% feedback from amplifier output to the (—) grid input, and a feedback element connected from the amplifier output to the (—) grid. The (—) grid circuit affects the Operational Amplifier characteristics when the (+) grid is driven; therefore, with the ± GRID SEL switch in the (+) position, both the (—) and (+) grid circuits must be properly connected.

Input signals applied to either grid through either the — GRID or ± GRID jacks bypass the internal input impedance set by the $Z_i$ control.

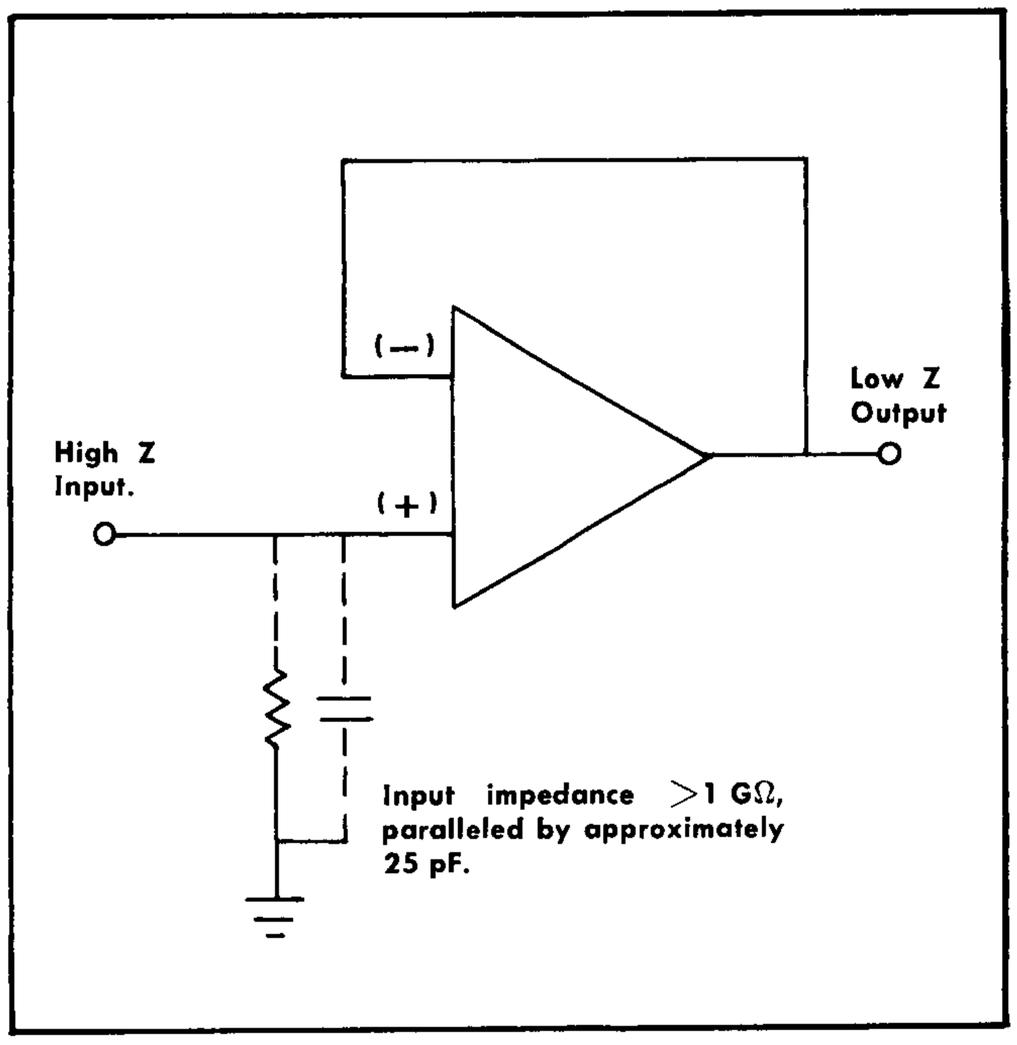



**Fig. 2-19. Circuit for measuring high impedance source signals.**

Access to the (+) grid increases the versatility of the Type 3A8 unit over conventional Operational amplifiers. External components can be used to provide positive rather than negative feedback to the Operational Amplifier. Applications using the + GRID input are described in the Applications section of this manual. Typical ± GRID use is illustrated in Fig. 2-19. Here, a signal may be transferred from a high-impedance source to a low-impedance load without dc offset or attenuation. This system provides a dc coupled, high impedance input (greater than 1 GΩ) with unity gain and very low output impedance.

## Connecting External Feedback Components

Because of the limited number of internally mounted components, it will occasionally be necessary to mount external feedback components on the Type 3A8 unit. Adapter boards (013-0048-00) received with the instrument provide a convenient means of mounting external parts. The components can easily be installed and the adapters inserted in the jacks on the front panel of the Type 3A8 unit. The cam on the adapter may be reversed to flip the ± GRID SEL in the desired position. The standard ¾-inch spacing of the jacks on the front panel also permits use of double banana plug connectors such as General Radio Type 274-B.

NOTE

The physical and electrical length of the feedback path has a direct effect on the operation. The added stray capacitance and/or inductance introduced by long feedback lines can cause the system to oscillate or, in less severe cases, introduce a significant deviation from the desired closed-loop characteristics.

## Output Connections

The three basic Operational Amplifier applications described employ the Type 3A8 unit and its associated oscilloscope. Type BNC OUTPUT connectors from each Operational Amplifier provide means of connecting the output signal to an external device.

A banana type OUTPUT jack, located to the left of the $Z_i/Z_f$ selector switch provides the means to connect external components to augment the internal values of the $Z_f/Z_i$ selector. This jack is across the BNC OUTPUT connector located directly above. Either of the OUTPUT connectors can be used to connect one Operational Amplifier to the other.

The BNC OUTPUT connector can drive a coaxial cable connected to a fairly remote system which may require the use of the Type 3A8 Operational Amplifier features. Remember, however, that with high speed signals, the cable capacitance will subtract from the output current available for the desired load.

# SECTION 3
# APPLICATIONS

This section explains typical applications for the operational amplifier. The circuits shown were selected and developed to show some of the many possible applications for wide-band operational amplifiers in extending the versatility and flexibility of the oscilloscope. Circuits are shown in basic, generalized forms. Choice of components for a particular application is left to the user. In a few cases, where application is specified or the component selection techniques are not evident, the notes indicate types and brands of components known to be satisfactory.

Most of the circuits can be conveniently built using the Tektronix Terminal Adapter, part number 013-0048-00, available through Tektronix Field Offices. Tektronix does not however, undertake to supply the other specialized components or hardware that may be required. These should be obtained or fabricated locally. An exception can be made in the case of certain diode types made to Tektronix specifications for which suitable equivalents may not be available locally, but which are stocked by Tektronix for instrument replacement purposes. These may be purchased in small quantities through your Tektronix Field Office or overseas distributor. Information concerning various semiconductors referred to in the notes may be found in the appendix for this section.

## Application Index

### BASIC APPLICATIONS


| | Page |
|---|---|
| Amplification | |
| Basic circuit, frequency compensation, gain correction | 3-2 |
| Summation | |
| Basic circuit, weighting, compensation, gain correction | 3-3 |
| Integration | |
| Basic circuit, drift compensation, dc rejection | 3-4 |
| Differentiation | |
| Basic circuit, compensation, noise reduction | 3-5 |
| Voltage-Current Conversion | |
| Current-to-voltage, current-to-voltage high sensitivity, voltage-to-current, current to current | 3-6 |
| Amplification—High Input Impedance | 3-7 |
| Bandpass Amplifiers | 3-8 |
| Summation—Slideback Techniques | |
| Slideback amplifier, slideback with compression, "window" amplifier | 3-9 |
| Integration—Gated Operation | |
| Gated integrators: Relay gating, universal bridge gating | 3-10 |
| Differentiation | |
| Gated operation, linearity studies | 3-11 |
| Voltage—Current Conversion | |
| Constant voltage with current monitor, constant current with voltage monitor | 3-12 |


### NONLINEAR AMPLIFIERS


| | |
|---|---|
| Low-Frequency Applications ("Log" diodes) | 3-13 |
| Wideband Amplifiers (Signal Diodes) | 3-14 |
| Transistors As Passive Nonlinear Elements | 3-15 |
| Vacuum Triodes As Nonlinear Elements | 3-16 |
| Zener Diodes As Nonlinear Elements | 3-17 |
| Zener Diodes—Simulation of Nonlinear Mechanical Phenomena | |
| Dead-zone, backlash, relay analogs | 3-18 |
| Absolute Value Amplifiers | 3-19 |


### PULSE AND DIGITAL TECHNIQUES


| | |
|---|---|
| Switching Circuits | |
| Bistable comparators | 3-20 |
| Bistable Multivibrators | 3-21 |
| Digital Conversions | |
| Pulse-height-to-time, time-to-voltage, voltage-to-frequency, binary-to-voltage | 3-22 |
| Peak Memory Circuits | 3-23 |
| Sample-Hold Amplifier | 3-24 |


### SAMPLING OSCILLOSCOPE TECHNIQUES


| | |
|---|---|
| Processing of Equivalent-Time Signals in Real Time | |
| Integration, differentiation, risetime compensation | 3-25 |


### WAVEFORM GENERATION


| | |
|---|---|
| L.F. Function Generators | 3-26 |
| Sine Wave Generators | 3-27 |
| Arbitrary Function Generators | 3-28 |
| Arbitrary Function Generators—Optical Techniques | 3-29 |


### SEMICONDUCTOR STUDIES


| | |
|---|---|
| Tunnel Diode Studies—Curve Tracing | 3-30 |
| Tunnel Diode Studies—Switching Characteristics | 3-31 |
| Voltage-Current Conversions | 3-32 |
| Zener Diode Tests | 3-33 |
| Transistors | 3-34 |


### COMPONENT TESTS


| | |
|---|---|
| B-H Loop Plotting | 3-35 |
| Inductor Measurements | 3-36 |
| Resistance Measurements | 3-37 |
| Capacitance Measurement (1 pF-10 $\mu$F) | 3-38 |
| Dielectric Tests | 3-39 |


### MISCELLANEOUS APPLICATIONS


| | |
|---|---|
| Velocity Acceleration Studies | 3-40 |
| Risetime Beam Intensifier | 3-41 |
| Phase—Plane Plot | 3-42 |

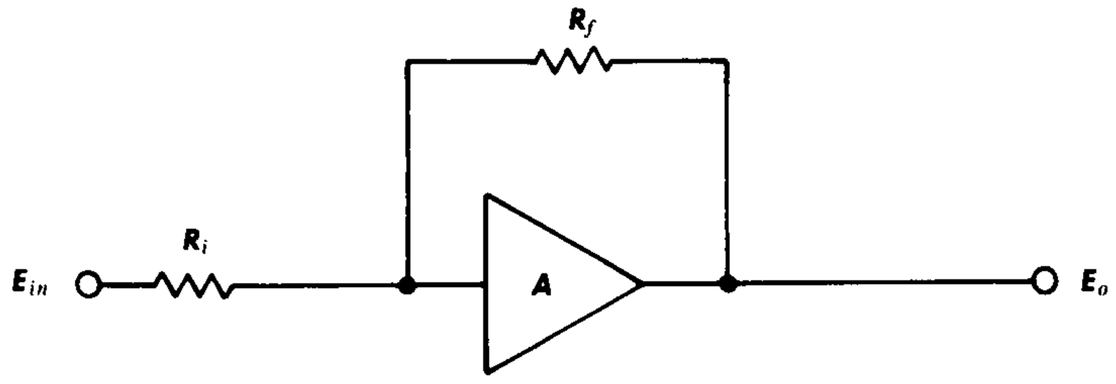
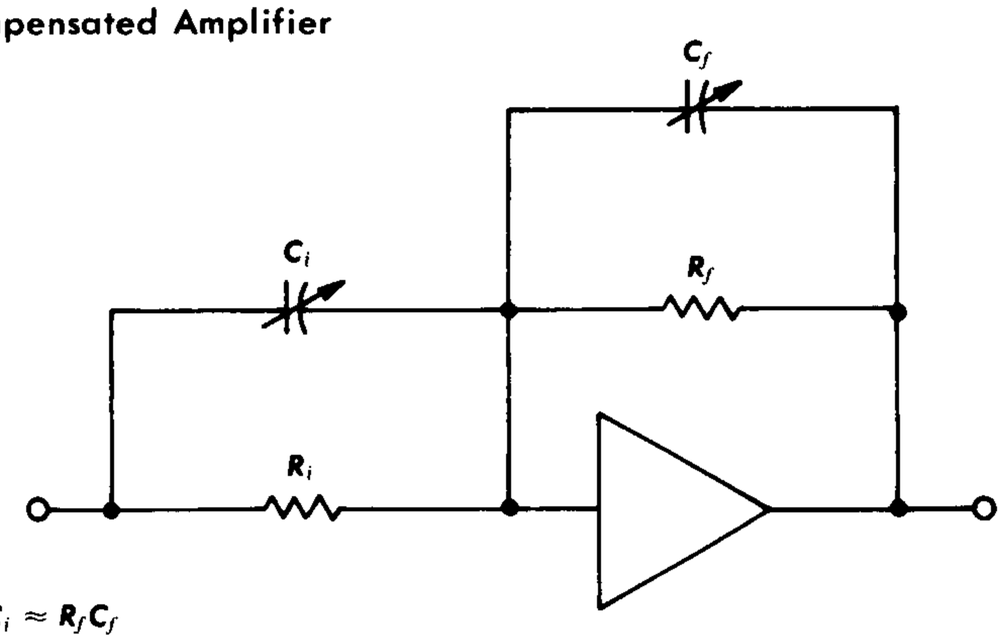
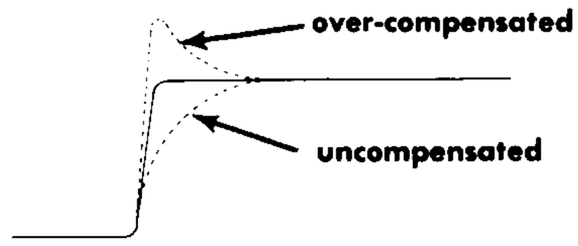
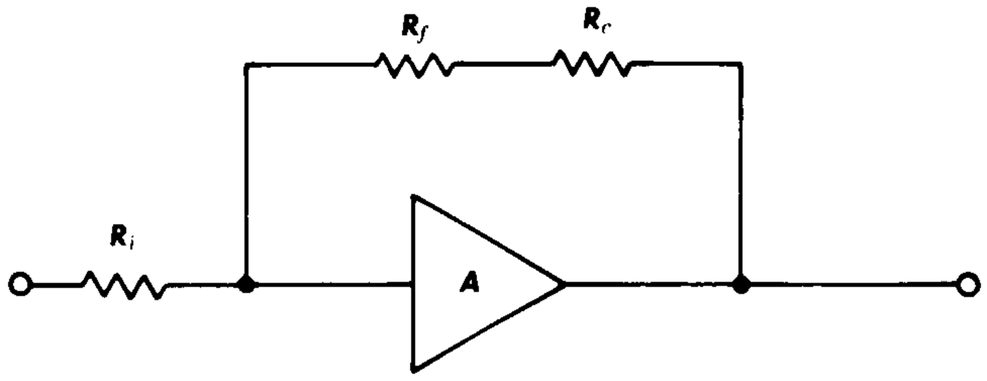
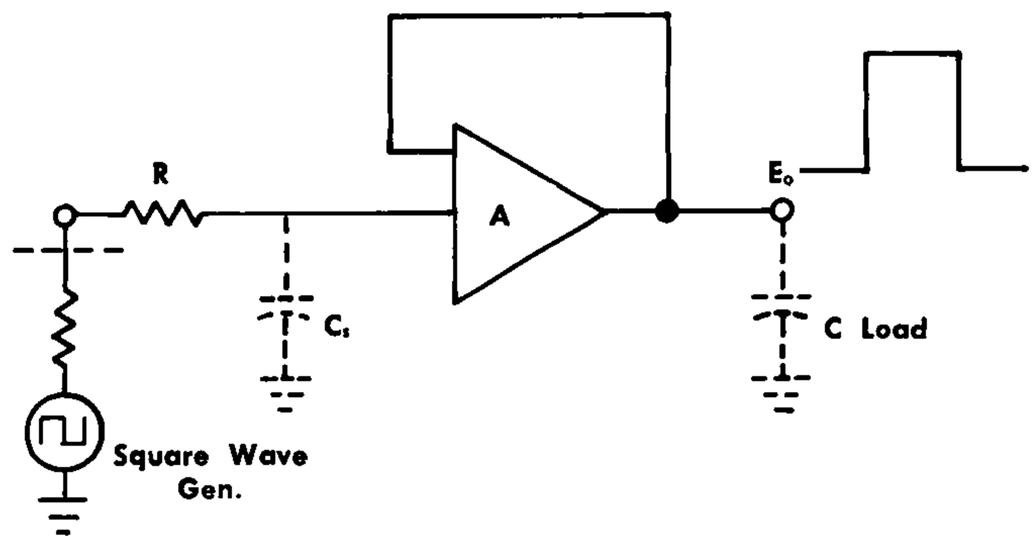

### APPENDIX

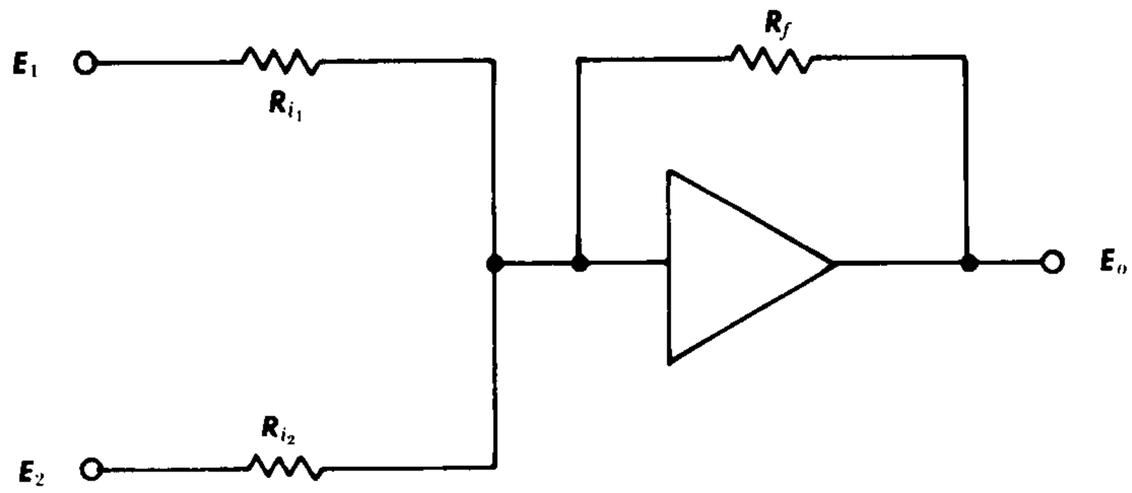
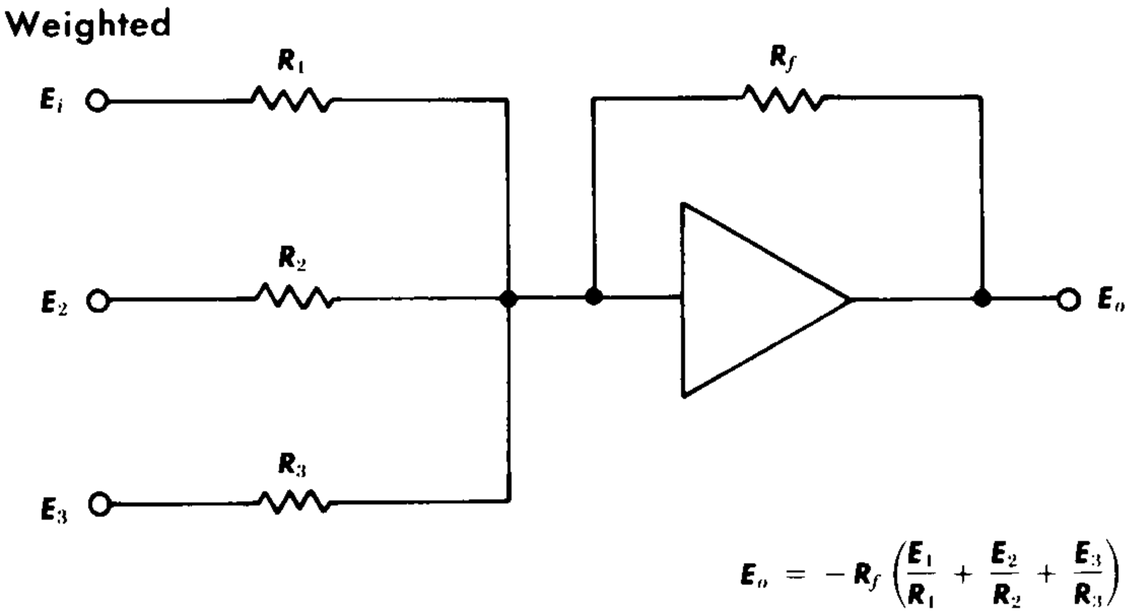
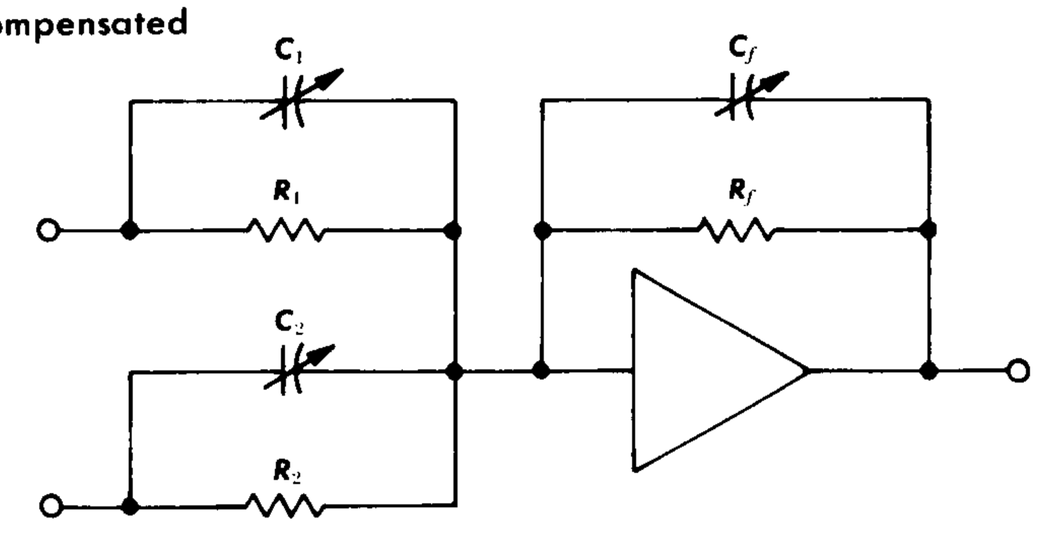
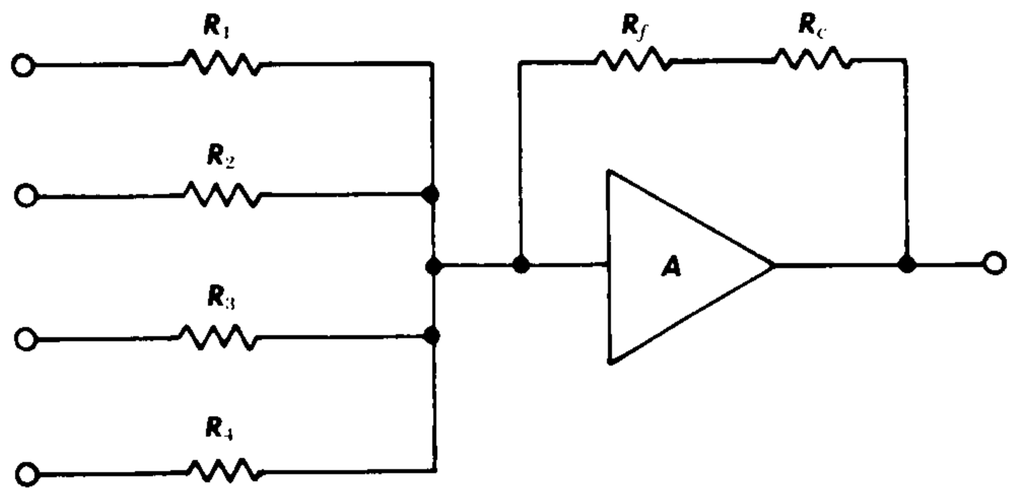

Semiconductors, diode selection, etc.
Scaling factors for sampled data
Bibliography


**Mathematic symbols**

| | |
|---|---|
| $\approx$ | Approximately equal to |
| $>$ | Greater than |
| $<$ | Less than |
| $>>$ | Large compared with |
| $<<$ | Small compared with |

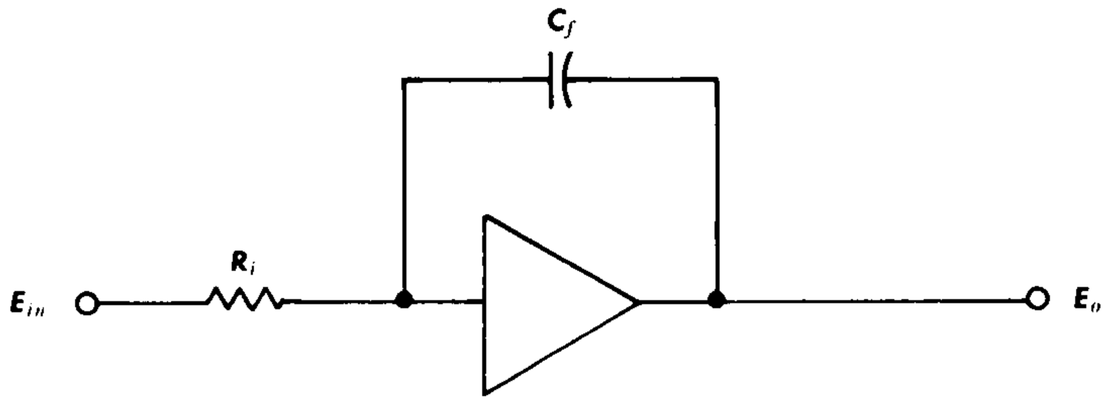
# BASIC OPERATIONS

| Amplification | Notes |
|---|---|
| **Basic Amplifier**<br>  <br><br>$E_o = \frac{-E_{in}R_f}{R_i}\left(\frac{A}{A - 1 - \frac{Z_f}{Z_i}}\right)$<br>(A is negative) | Gain of the amplifier is determined by the ratio $R_f/R_i$. If open loop gain A is large compared to $R_f/R_i$; $E_o \approx \frac{-R_f}{R_i} E_{in}$. |
| **Compensated Amplifier**<br>  <br><br>$R_iC_i \approx R_fC_f$ | High frequency response and risetime are considerably enhanced when stray capacitance is compensated. $C_i$ and $C_f$ values should be kept as small as possible (5-30 pF).<br>Step-function response:<br>  <br> |
| **Gain-Corrected Amplifier**<br>  <br><br>Unless open loop gain $A \gg \frac{R_f}{R_i}$, gain accuracy may be preserved only by trimming value of $R_f$ or $R_i$. | Gain-correction resistance is necessary if accuracy is required at high gain. Error for a given $R_f/R_i$ is:<br>$\left[1 - \left(\frac{A}{A - 1 - \frac{R_f}{R_i}}\right)\right] \times 100\%$. (A is negative)<br>Correcting resistor $R_c = -R_f\left(\frac{1 + \frac{R_f}{R_i}}{A + \frac{R_f}{R_i}}\right)$<br>Correction may also be made by shunting $R_i$. |
| **Follower Compensation**<br>  <br><br>$Z_i$ and $Z_f$ Ext. | R works against $C_s$ to limit the applied signal. When 'R' is zero, ring of output signal (amplitude and frequency) is greatly affected by $C_{load}$.<br>With $C_{load}$ of 47 pF (input) —18 inches of 50 Ω coax — and 15 pF (input to Type 1A2), a 1.2 k R gave optimum response. |

| Summation | Notes |
|---|---|
| **Basic Circuit**<br>  <br><br>$E_o = -(E_1 + E_2)$ if $R_{i_1} = R_{i_2} = R_f$ | If all resistors are of equal value, gain is unity for each input. For increased gain, $R_f$ may be increased. |
| **Weighted**<br>  <br><br>$E_o = -R_f\left(\frac{E_1}{R_1} + \frac{E_2}{R_2} + \frac{E_3}{R_3}\right)$ | Gain for any input is $-R_f/R_i$, permitting easy component selection for operations such as $(0.3E_1 + 7E_2 + 4E_3)$. |
| **Compensated**<br>  <br><br>$R_1C_1 \approx R_2C_2 \approx R_fC_f$ | The summing amplifier cannot be as well compensated as simple amplifier because of input loading. Inputs may be separately adjusted if opposite input is grounded during adjustment and process is repeated to eliminate interaction. Compensation of 3- and 4-input summing networks becomes increasingly more difficult and less practical. |
| **Gain-Corrected**<br>  <br><br>**Unless** $\left(\frac{R_f}{R_1} + \frac{R_f}{R_2} + \frac{R_f}{R_3} + \frac{R_f}{R_4}\right) \ll A$, $R_f$ **should be increased beyond nominal value to preserve accuracy.** | Gain error for any input will be<br>$\left(1 - \frac{A}{A - 1 - \left(\frac{R_f}{R_1} + \frac{R_f}{R_2} + \frac{R_f}{R_3} + \frac{R_f}{R_4}\right)}\right) \times 100\%$<br>where $A$ is open-loop gain (a negative number)<br>Value of correcting resistor $R_c$ should be $\left[-R_f\left(\frac{G+1}{G+A}\right)\right]$ where<br>$G = \left(\frac{R_f}{R_1} + \frac{R_f}{R_2} + \frac{R_f}{R_3} + \frac{R_f}{R_4}\right)$ |

## Integration

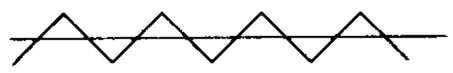
### Basic Circuit



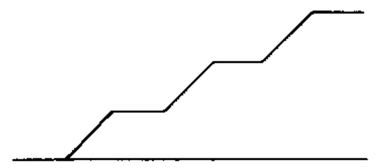

$$E_o = \frac{-1}{R_i C_f} \int E_{in} dt$$

Gain (sinewaves) $= \dfrac{-1}{2\pi f R_i C_f}$ except as limited by open loop gain.

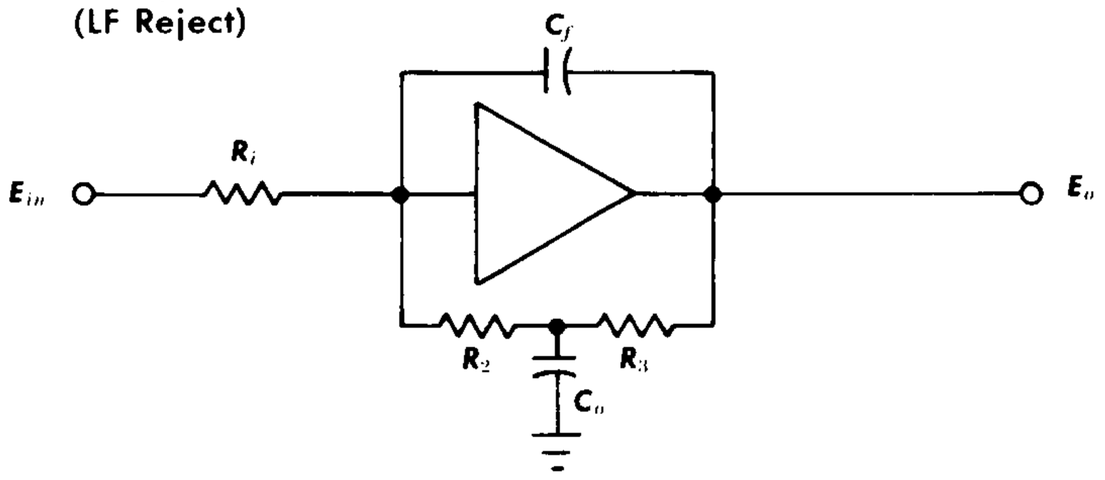
**Square-wave response (for input symmetrical about 0 V):**



**Square-wave response, unidirectional input:**



### Drift Compensation (LF Reject)

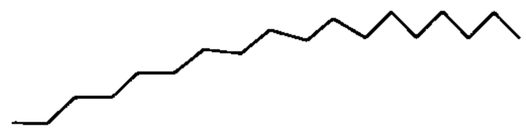



**Reset time-constant** $T_r = (R_2 + R_3)C_f$ **LF Reject time-constant** $T_L = \dfrac{R_2 R_3 C_o}{R_2 + R_3}$

Response to dc and low-frequency information (including input grid current) is limited by LF REJECT circuit. DC response is limited to $\dfrac{-E_{dc}(R_2 + R_3)}{R_i}$.

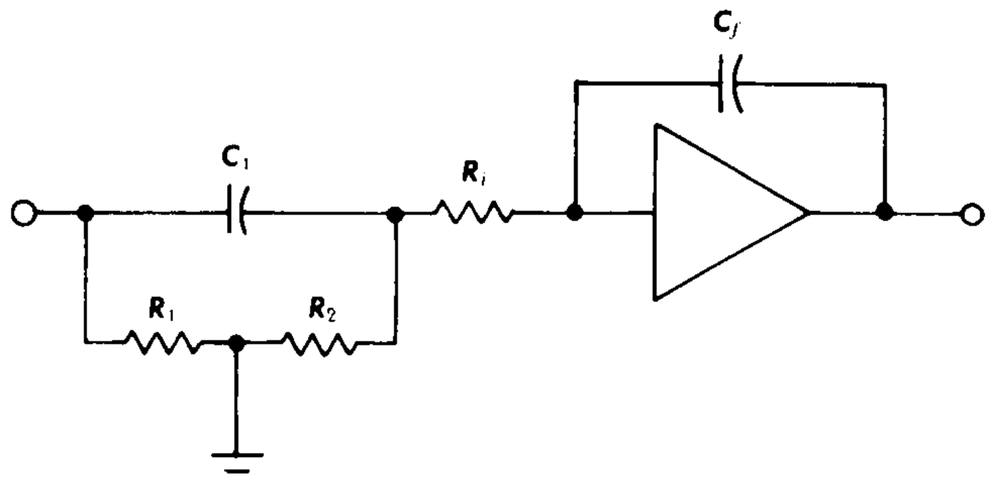
Capacitor $C_o$ delays "dc" feedback by a value approaching $T_L$, thus improving short-term accuracy.

**Square-wave response (Input unidirectional):**



**For accuracy, keep integrating interval** $< 0.3\sqrt{R_2 R_3 C_o C_f}$

### DC Rejection (AC Integration)

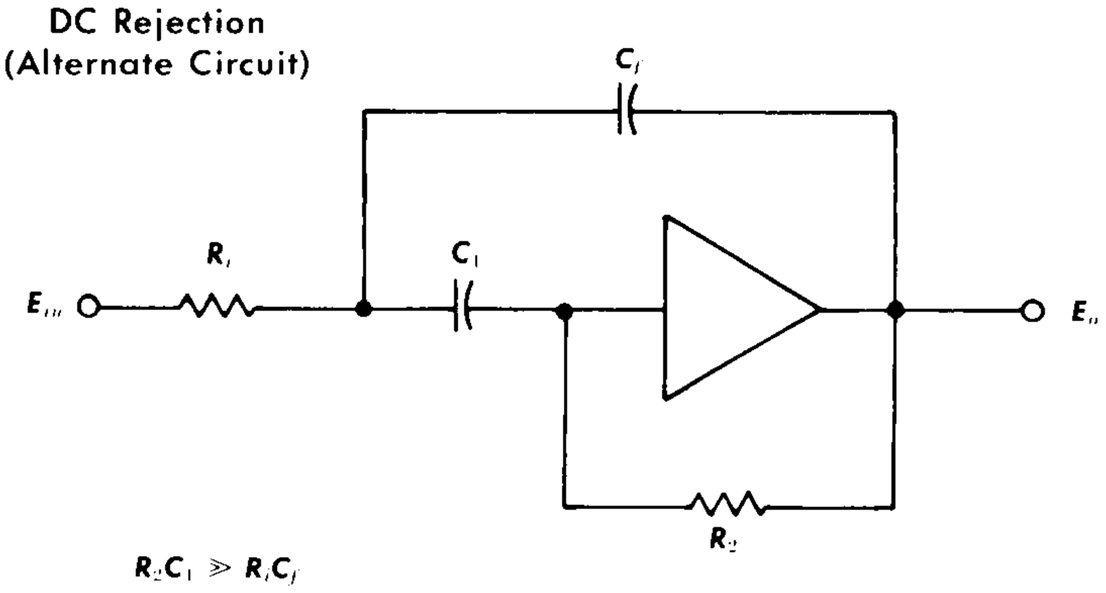



$C_1 \gg C_f$ **Integrating interval** $\ll R_i C_1$

Input blocking capacitor $C_1$ prevents dc level of $E_{in}$ from being integrated. If dc level is high, resistors $R_1$ and $R_2$ minimize effect of capacitor leakage current.

This circuit does not reject input grid-current, but may be used in conjunction with LF Reject circuit above, if limitations of each circuit are observed.

### DC Rejection (Alternate Circuit)



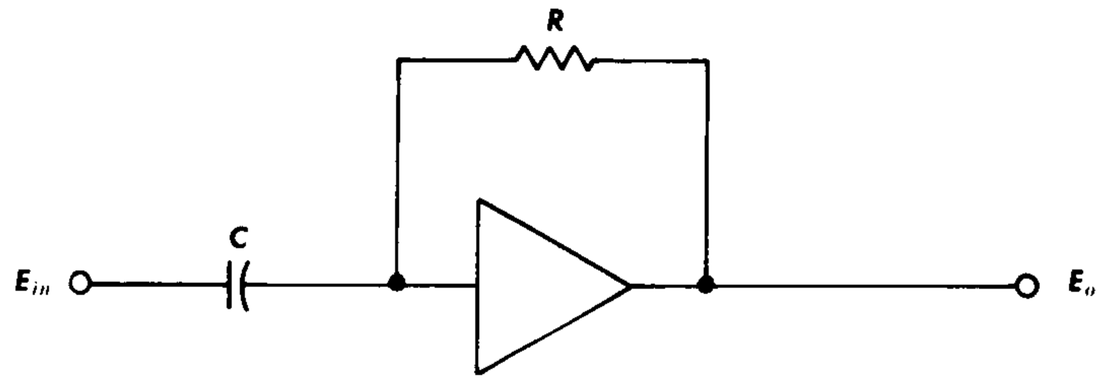
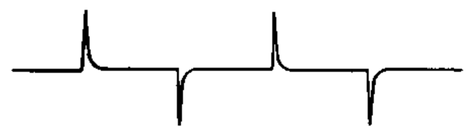
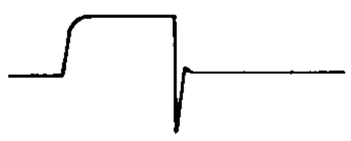
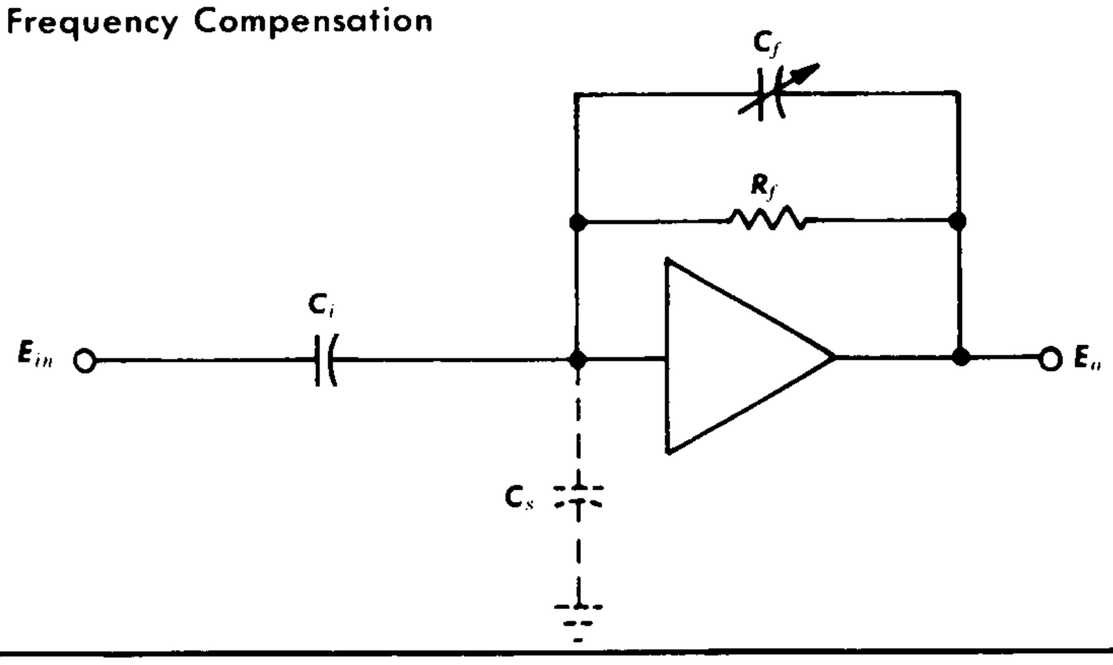
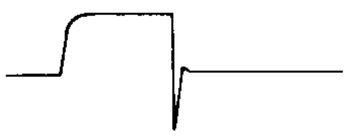
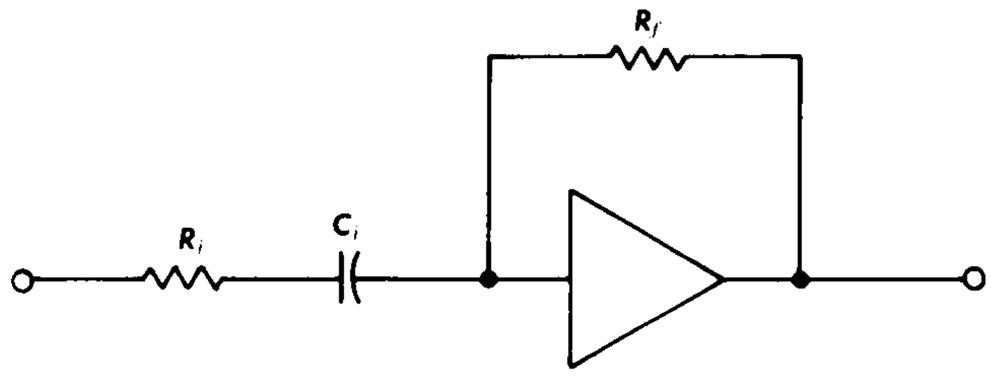

$R_2 C_1 \gg R_i C_f$

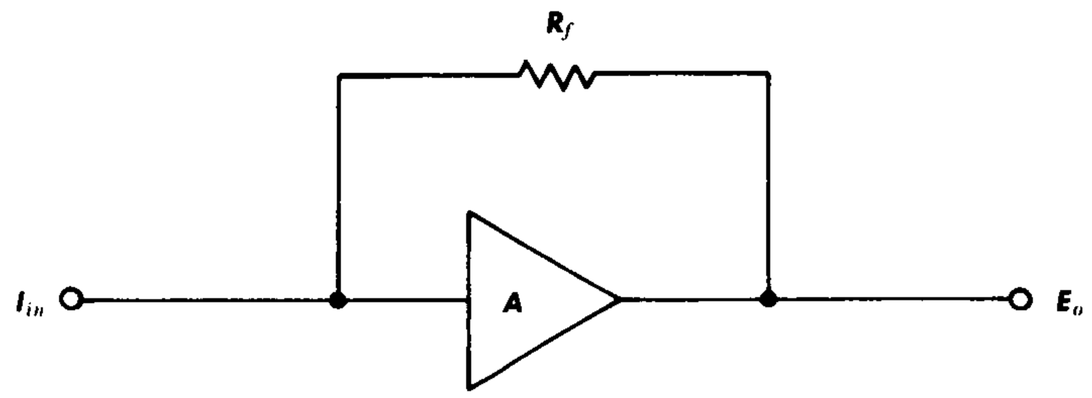
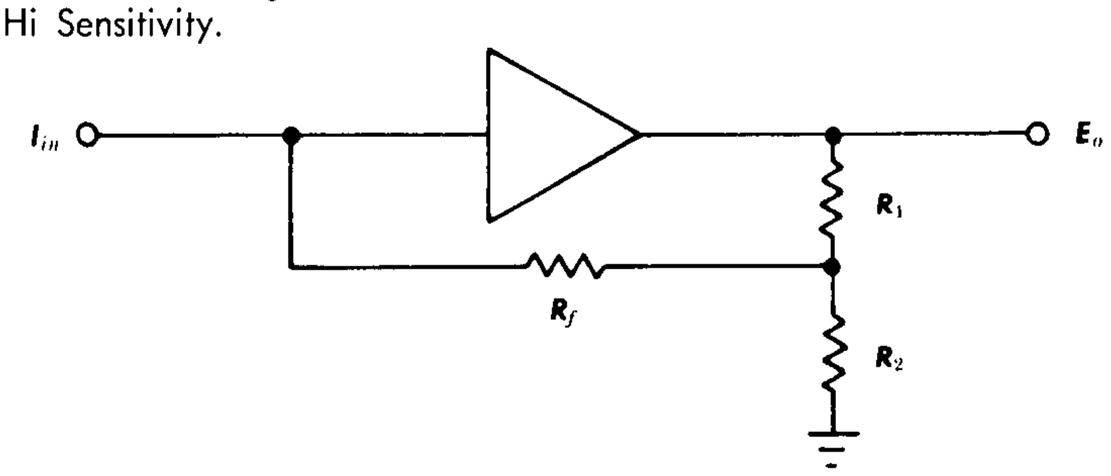
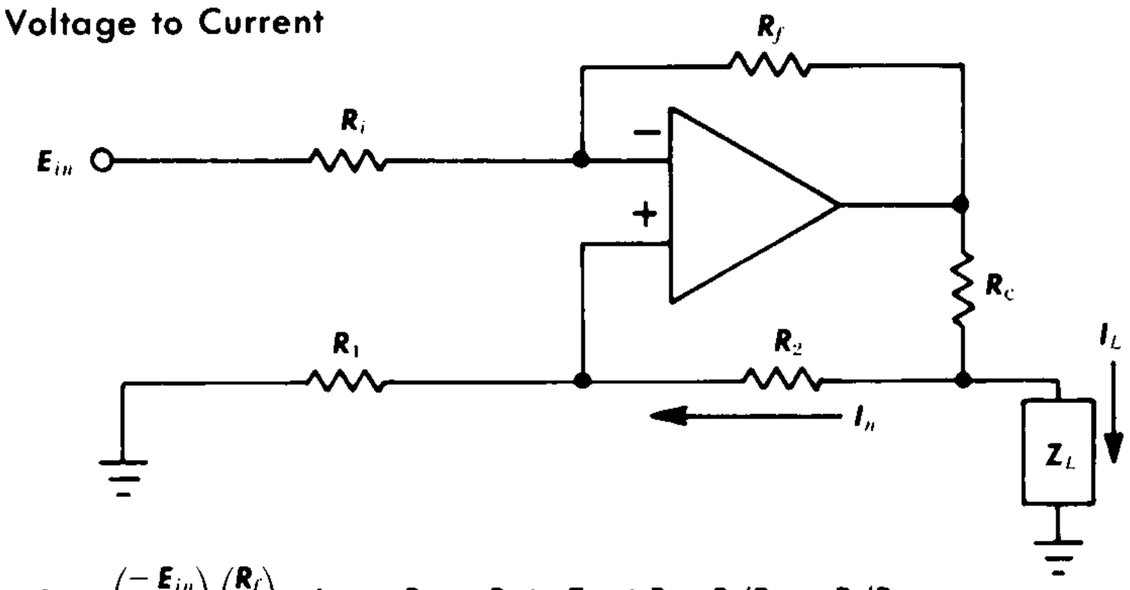
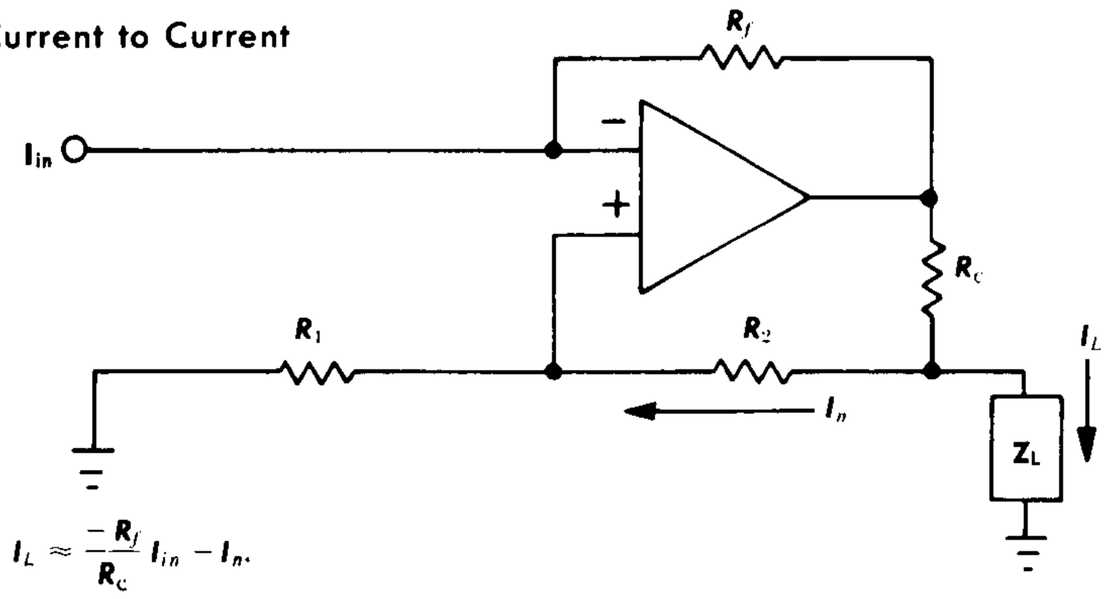
This circuit combines the dc signal rejection and grid-current rejection of the two circuits above, but with fewer components.

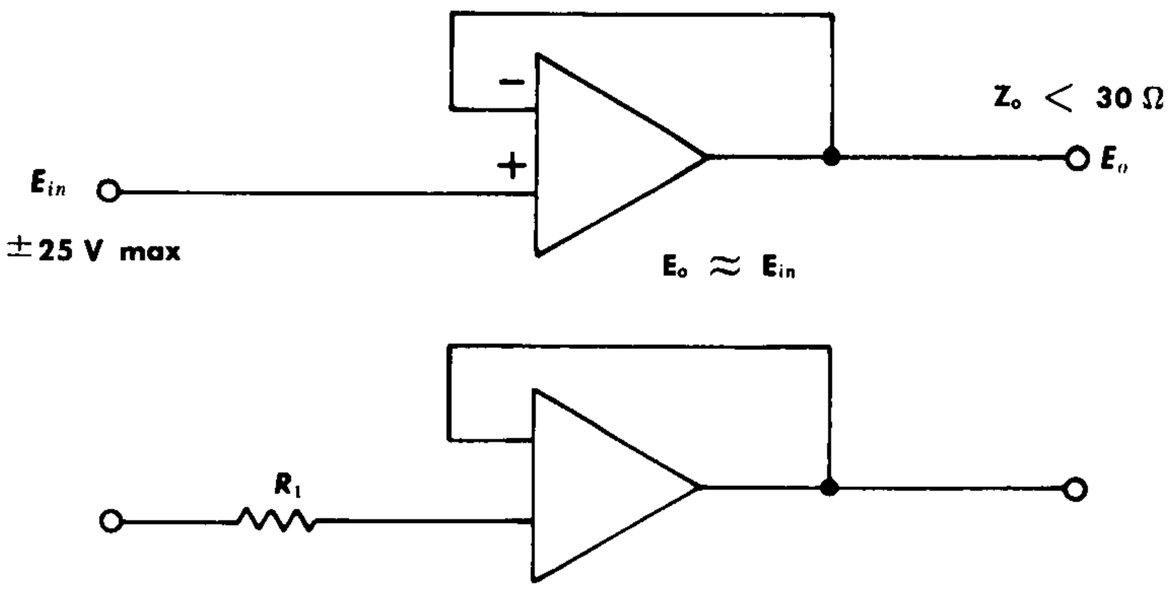
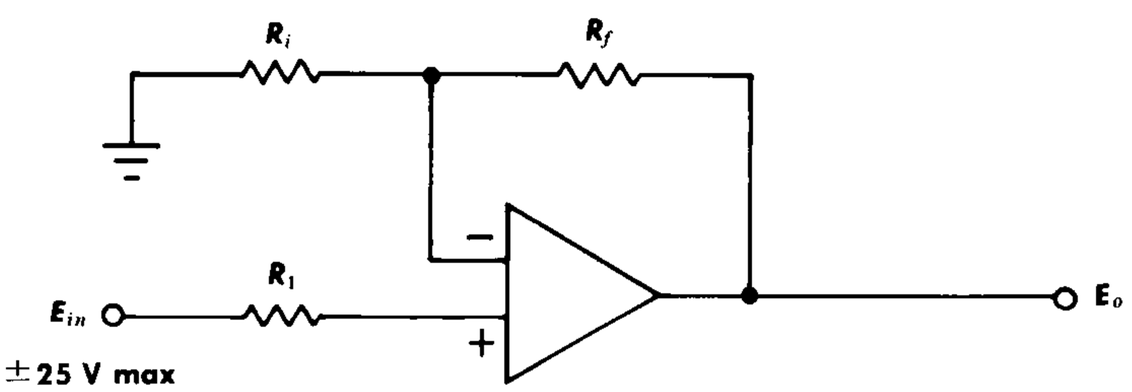
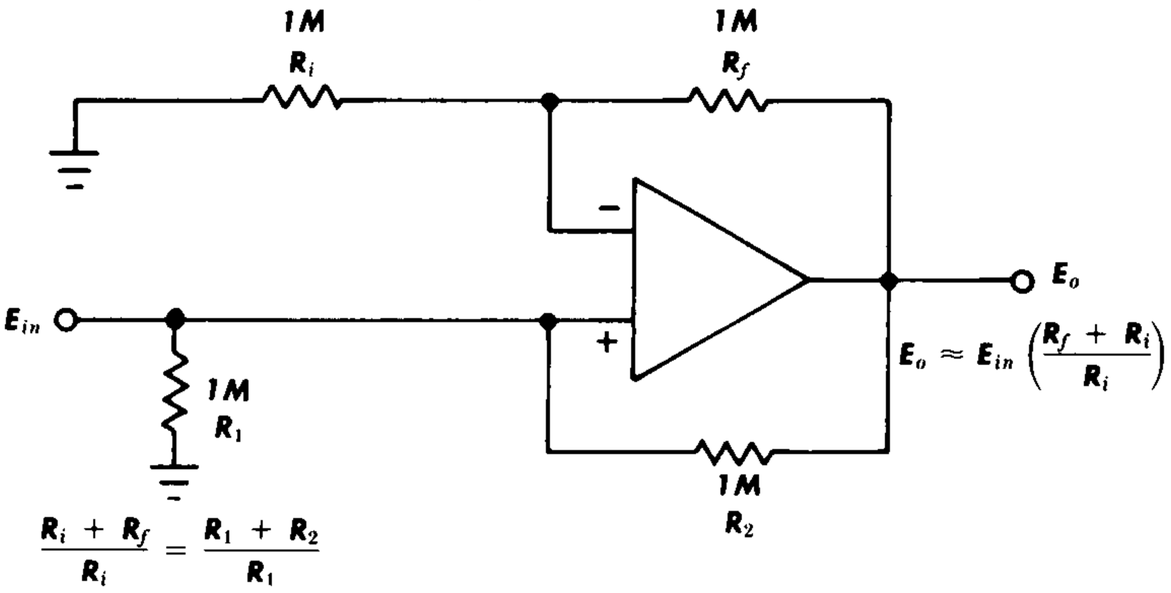
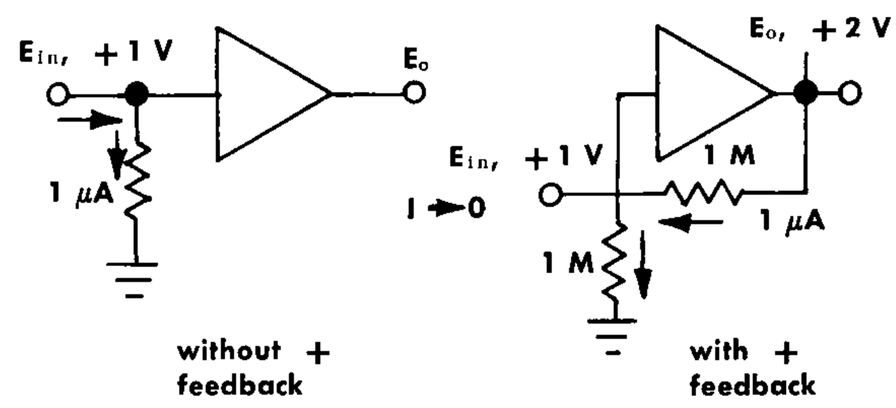
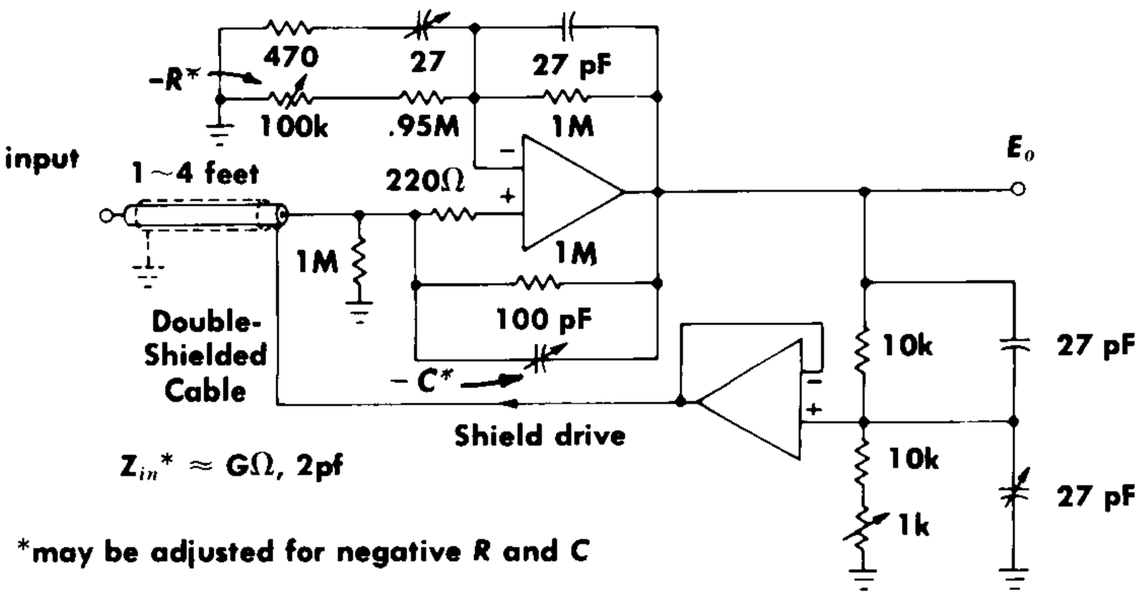
For operational accuracy, integrating interval should be kept less than $0.3\sqrt{R_i C_f R_2 C_1}$



Ⓐ

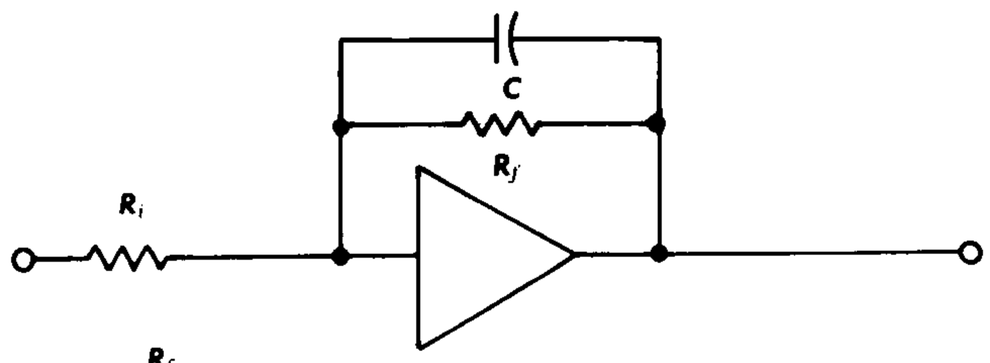
| Differentiation | Notes |
|---|---|
| **Basic Circuit**<br>  <br><br>$E_o = -RC\left(\frac{dE_{in}}{dt}\right)$ | Gain (sinewaves) = $-2\pi fRC$, except as limited by open-loop gain-bandwidth product.<br>**Squarewave response**<br>  <br>**Sawtooth response**<br>  |
| **Frequency Compensation**<br>  <br> | Lag in current through $R_f$ may produce ringing after sudden change of dE/dt. Adjust $C_f$ using dE/dt comparable to that to be measured:<br>**Uncompensated**<br> <br>**Sawtooth response:**<br>**Compensated**<br>  |
| **Noise suppression**<br>  <br><br>$R_i \ll R_f$ | Series resistance limits response of differentiator to wideband noise components above the frequency range of interest. Output swing is limited to $-dE_{in}$ $R_f/R_i$, so $R_i$ should be on the order of $R_f/100$ if possible, to preserve accuracy in range of interest. |

| Voltage-Current Conversion | Notes |
|---|---|
| **Current-to-Voltage**<br>  <br><br>$E_o = -I_{in}R_f\left(\frac{A}{A-1}\right)$ | Input current limitation $\frac{E_o max}{R_f}$ or 0.5 $I_o max$, whichever is smaller. With finite value of A,<br>$E_o = -I_{in}R_f\left(\frac{A}{A-1}\right)$ (A is negative).<br>If A is large or source impedance is high, $E_o \approx -I_{in}$ $R_f$. Source impedance of $I_{in}$ should be $>>$ $\frac{R_f}{A-1}$. |
| Current-to-Voltage,<br>Hi Sensitivity.<br>  <br><br>Effective value of $R_f = R_f\left(\frac{R_1+R_2}{R_2}\right)$<br>$E_o \approx -I_{in}R_f\left(\frac{R_1+R_2}{R_2}\right)$ | At low frequencies, sensitivity improvement to 50:1 may be practical. Input current loss to ground through $R_f$ and $R_2$ causes error<br>$\varepsilon = \frac{KR_f}{KR_f + (R_f + \frac{R_1}{K})(1-A)}$<br>Feedback division causes a second error $\varepsilon = \frac{K-1}{A-1}$<br>where $K = \frac{R_1+R_2}{R_2}$ and A = open loop gain (negative). $R_2$ may be trimmed to correct these errors. |
| **Voltage to Current**<br>  <br><br>$I_L \approx \left(\frac{-E_{in}}{R_c}\right)\left(\frac{R_f}{R_i}\right) - I_n$ $\quad R_1 + R_2 \gg Z_L < R_c$ ; $R_f/R_i = R_2/R_1$ | With positive feedback, — grid seeks null at + grid level rather than ground. Circuit operates to keep drop constant across $R_c$. Variations in $Z_L$ control the + grid level. As value of $Z_L$ approaches or exceeds $R_c$, effective input impedance at A drops, due to shift of — grid null point.<br>$Z_{eff} = \frac{R_i}{1 + \frac{Z_L}{R_C}\left(\frac{R_f}{R_i + R_f}\right)}$ when $R_f/R_i = R_2/R_1$.<br>Ideally, signal source impedance should be low, $R_c$ larger than $Z_L$, and $R_i$ large enough so that $Z_{eff} >>$ signal source impedance. Practically, $R_1$ may be padded to correct for these sources of error. $E_{in} >> Z_L I_L$ for optimum accuracy. |
| **Current to Current**<br>  <br><br>$I_L \approx \frac{-R_f}{R_c} I_{in} - I_n$.<br>$R_1 + R_2 \gg Z_L < R_c$ | In the ideal case, source impedance of $I_{in}$ is very large and shift of — grid level has negligible effect.<br>In practice, $R_c$ and $\frac{R_1}{R_1 + R^2}$ must be selected so that the system is stable and $I_L$ will be constant for all expected values of $Z_L$. Voltage at — grid is $\left(\frac{-R_f I_{in}\ R_L}{R_c}\right)\left(\frac{R_1}{R_1+R_2}\right)$.<br>Ideally, $R_c > Z_L$, $R_2/R_1 = R_f/R_{source}$, and $I_{in} << I_L$. Practically, $R_2/R_1$ should be made $\geq 1$ |

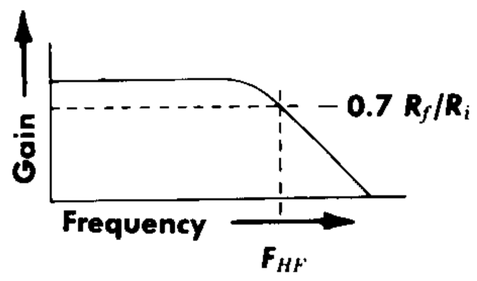
| Amplification — High Input Impedance | Notes |
|---|---|
| Unity Gain Follower Amplifier<br>  | Input resistance typically $\geq$ 1 G $\Omega$. Input C $\approx$ 18-25 pF. Output is not inverted. For wideband compensation, select $R_1$ for optimum transient response (Typ. 220-820$\Omega$). |
| **Non-Inverting Amplifier with Gain**<br>  | Feedback divider may be used to obtain gain $> 1$, or to correct unity gain circuit for gain of 1.0.<br>For gain of 1.0, select $R_f = R_i\left(\frac{1}{G} - 1\right)$ **where G is the observed gain without correction. $R_i$ may be any convenient value $>$ 10 k.** |
| **High Input Impedance Amplifier**<br>  | Negative feedback via $R_f$ sets gain; positive feedback via $R_2$ raises effective value of $R_1$, also decreases effective input C. The amplifier supplies most of the current required to drive input impedance.<br>  |
| **Negative Impedance Amplifier**<br>  | Capacitive compensation is added to the above circuit. The second amplifier drives the coax shield in phase with the signal, further reducing input C. Negative resistance and negative capacity may be achieved by adjusting —R and —C control.<br>With values shown, gain $\times$ 2, bandwidth $\approx$ 5 MHz using Type 3A8 unit from low-Z signal source. From high-Z signal source, bandwidth may be as low as $\frac{1}{2\pi\ RC}$ where R and C are the $Z_{in}$ settings. |

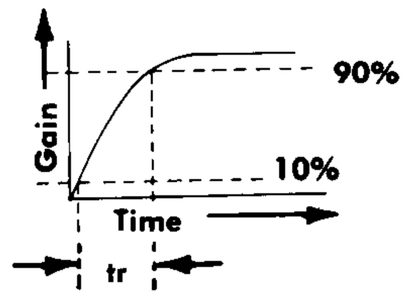
## Bandpass Amplifiers

### Low-pass Amplifier




L.F. Gain $= -\frac{R_f}{R_i}$



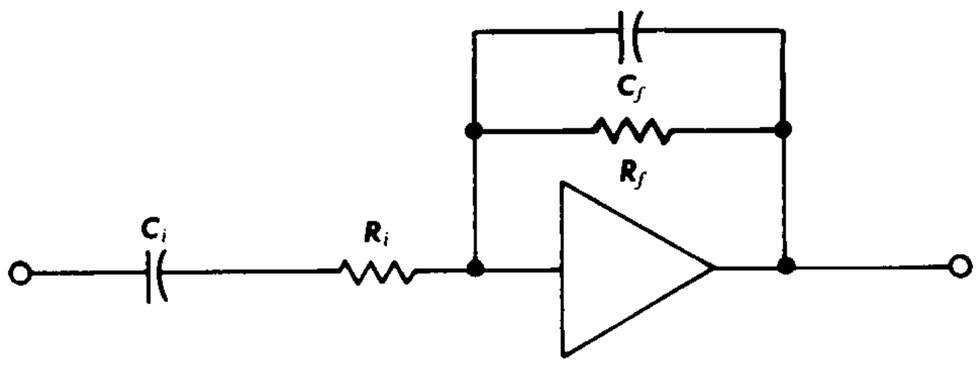

$f_{HF}$ = −3db point

$= \frac{1}{2\pi R_f C_f}$ Hz

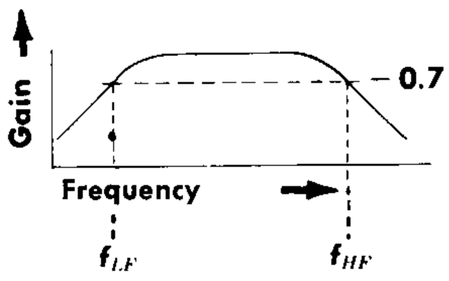
Rolloff above this point approaches $6_{db}$/octave.

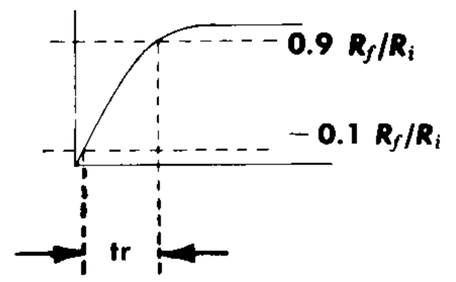
Risetime tr $= 2.2R_fC_f$
Response to step-function

### Bandpass Amplifier




Mid-Frequency Gain $= -\frac{R_f}{R_i}$

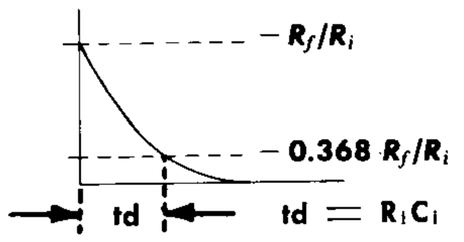



tr $= 2.2\ R_fC_f$
Step function response

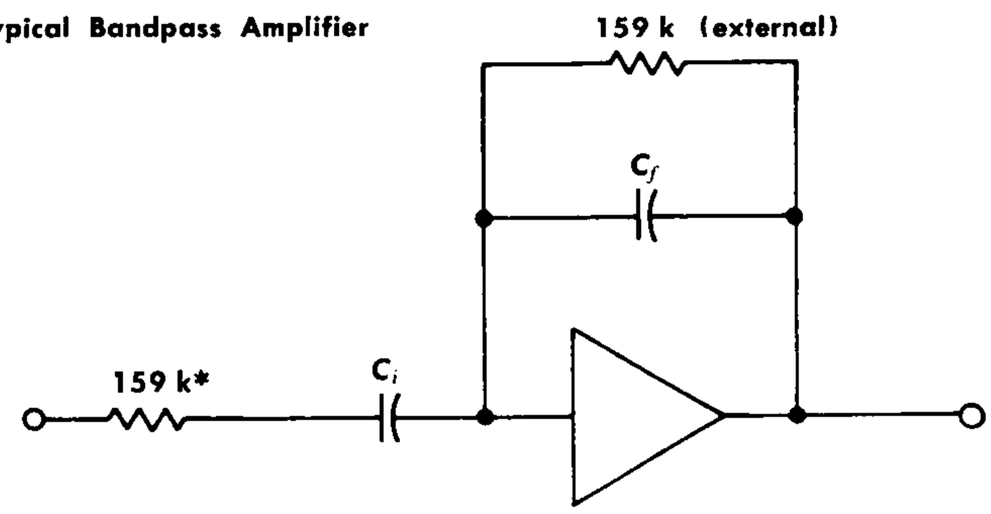
$f_{LF} = \frac{1}{2\pi R_i C_i}$

$f_{HF} = \frac{1}{2\pi R_f C_f}$



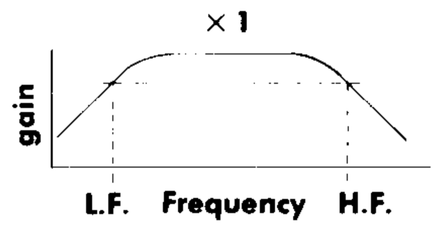

Rolloff, approaches 6 db/Octave.

### Typical Bandpass Amplifier



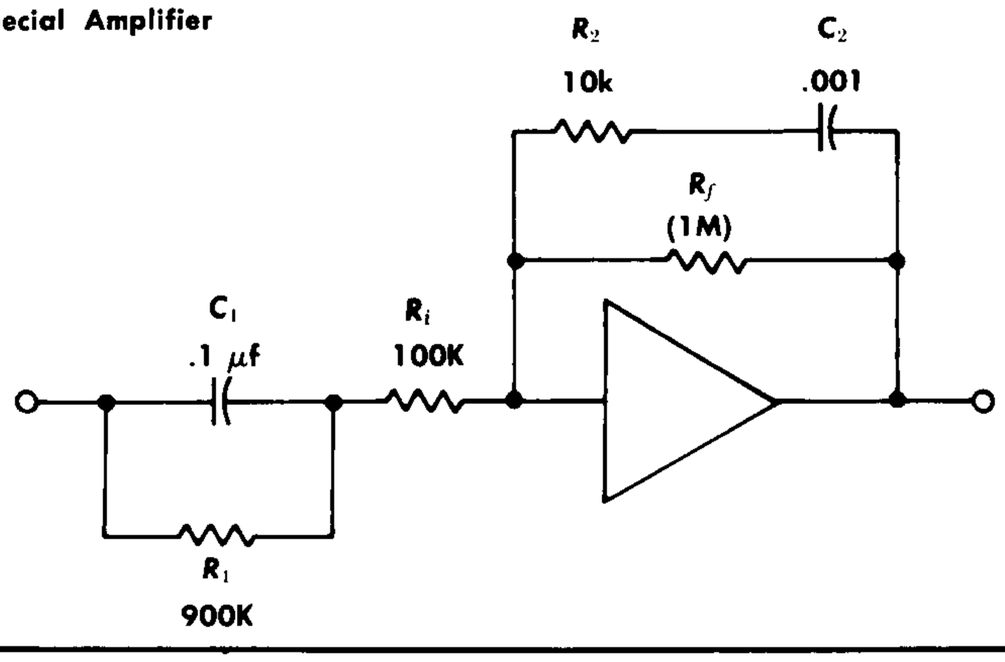

$C_i$ and $C_f$ selected by switch: 10pf − 1 $\mu$fd

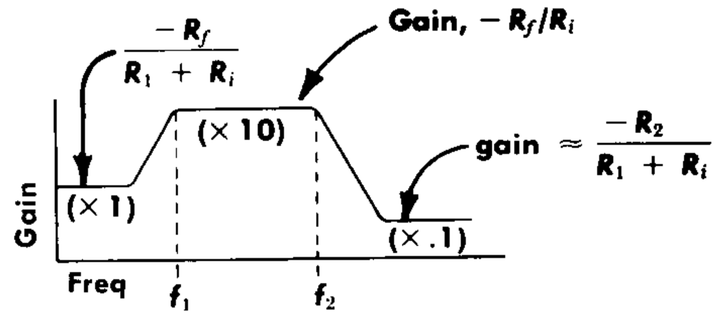
*Including signal source impedance




| L.F. | $C_i$ | H.F. | $C_f$ |
|---|---|---|---|
| 1 Hz | 1 $\mu$F | 100 kHz | 10 pF |
| 10 Hz | .1 | 10 kHz | .001 $\mu$F |
| 100 Hz | .01 | 1 kHz | .001 |
| 1 kHz | .001 | 100 Hz | .01 |
| 10 kHz | .0001 | 10 Hz | .1 |
| 100 kHz | 10 pF | 1 Hz | 1 $\mu$F |

### Special Amplifier

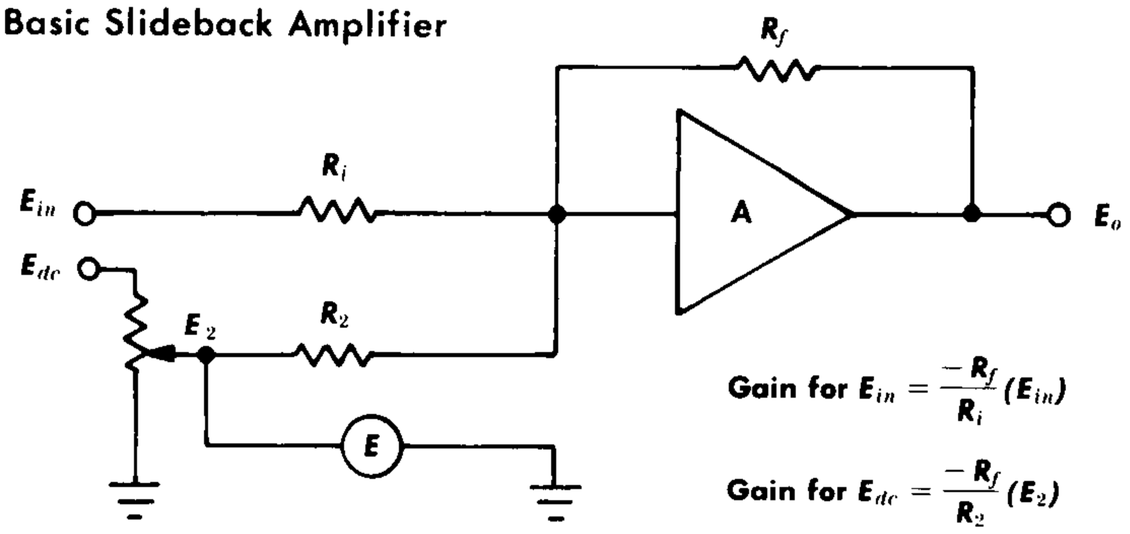
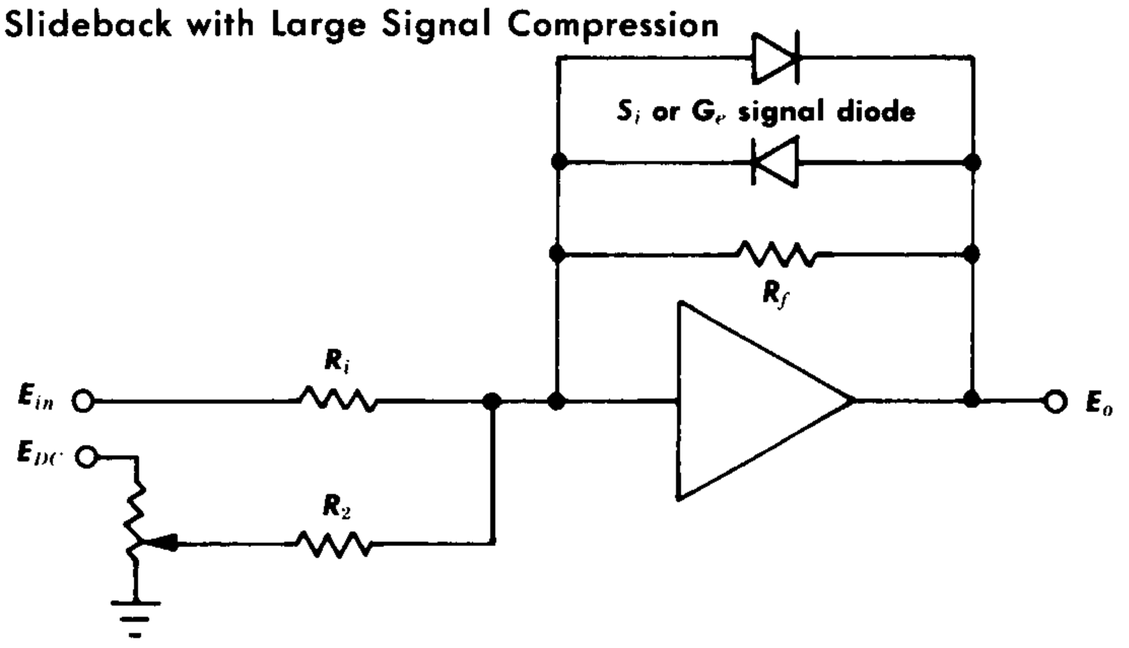
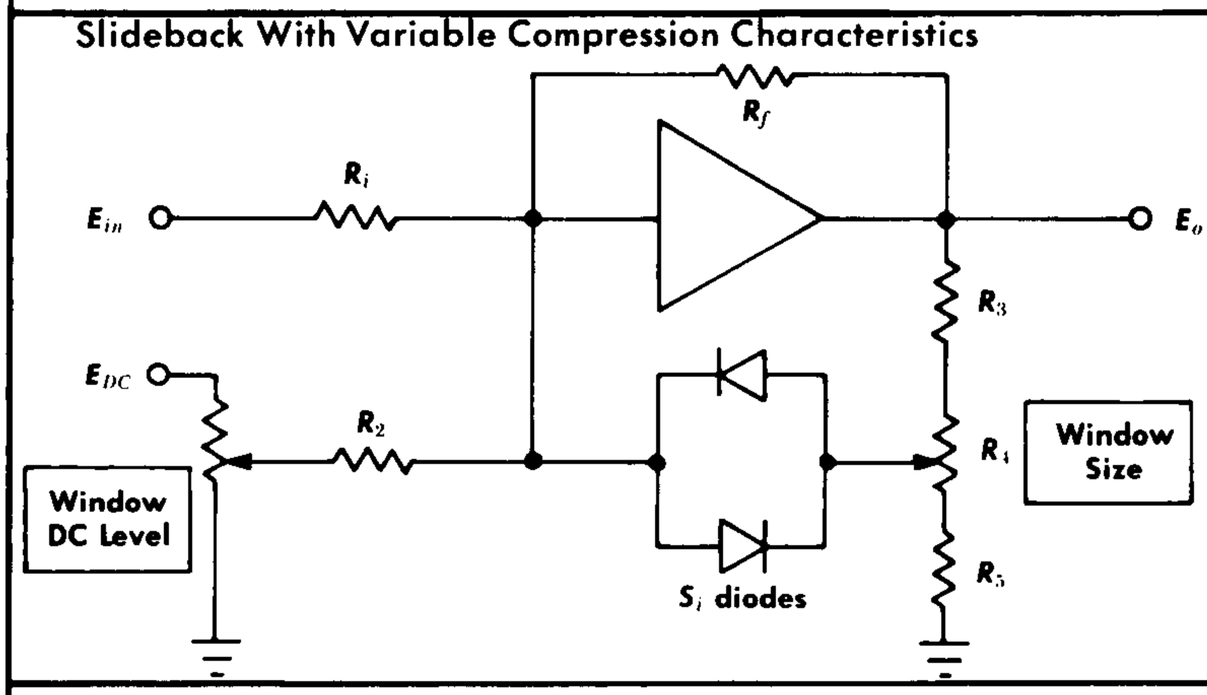



(15.9 Hz) (159 Hz)

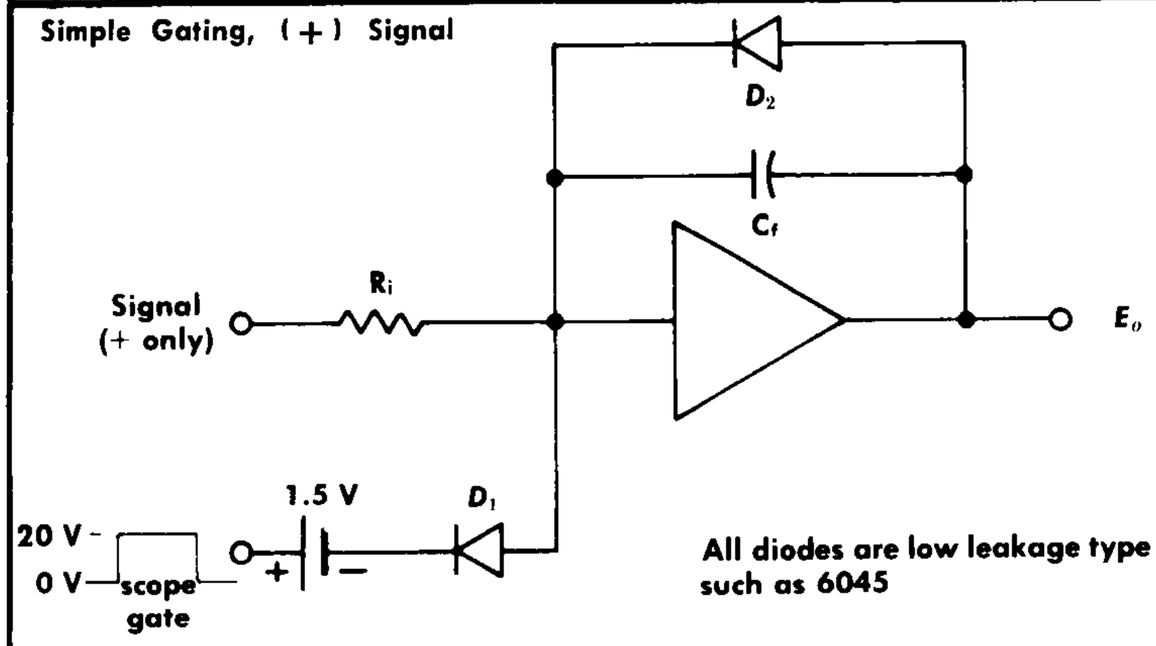
$f_1 = \frac{1}{2\pi R_i\ C_1}$ Hz

$f_2 = \frac{1}{2\pi R_f\ C_2}$ Hz

| Summation — Slideback Techniques | Notes |
|---|---|
| **Basic Slideback Amplifier**<br>  <br><br>**Gain for $E_{in}$** $= \frac{-R_f}{R_i}(E_{in})$<br>**Gain for $E_{dc}$** $= \frac{-R_f}{R_2}(E_2)$<br>$E_o \approx -R_f\left(\frac{E_{in}}{R_i} + \frac{E_2}{R_2}\right)$ | Dc offset voltage may be added to signal to permit dc coupled observation or measurement of a small signal at an elevated dc level. If $R_2 < R_i$, offset voltage source may be smaller than level to be offset.<br>Loading effect of $R_2$ will be negligible if $\frac{R_f}{R_i} + \frac{R_f}{R_2} << A$. For error-correction techniques, see page 3-3<br>Use of low $\frac{R_f}{R_2}$ gain, and voltmeter at point E permits high-resolution dc and ac measurements by slideback-null technique. |
| **Slideback with Large Signal Compression**<br>  <br> | For observation of a small signal superimposed on a large one, compression of the large signal is desirable. Amount of compression will depend on diodes. Silicon diodes (e.g. 6045, 6061) provide a linear output window of about ± 250 mV. Germanium diodes (e.g., T12G, T13G, 6075) provide continuous compression (no linear "window"). Additional diodes or resistors in series with diodes shown may be added to alter compression. |
| **Slideback With Variable Compression Characteristics**<br>  <br> | "Window Size" control, affects compression slope outside of "window" as well as size of window. Output divider ($R_3 + R_4 + R_5$) should not be less than 20 K and gain should be low, for accuracy. Output inside the "window" will be linear over the range $E_o = \pm 0.25\,k$, where k is $R_3 - R_4 - R_5$ divider ratio. |

## Integration — Gated Operation

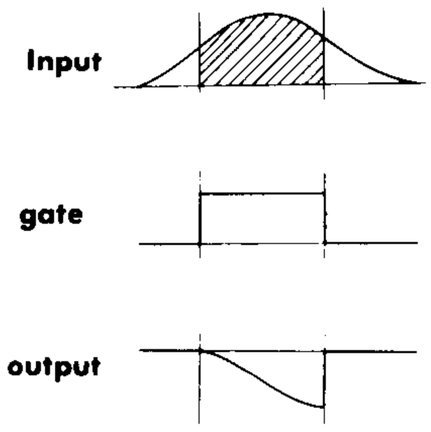
### Simple Gating, (+) Signal



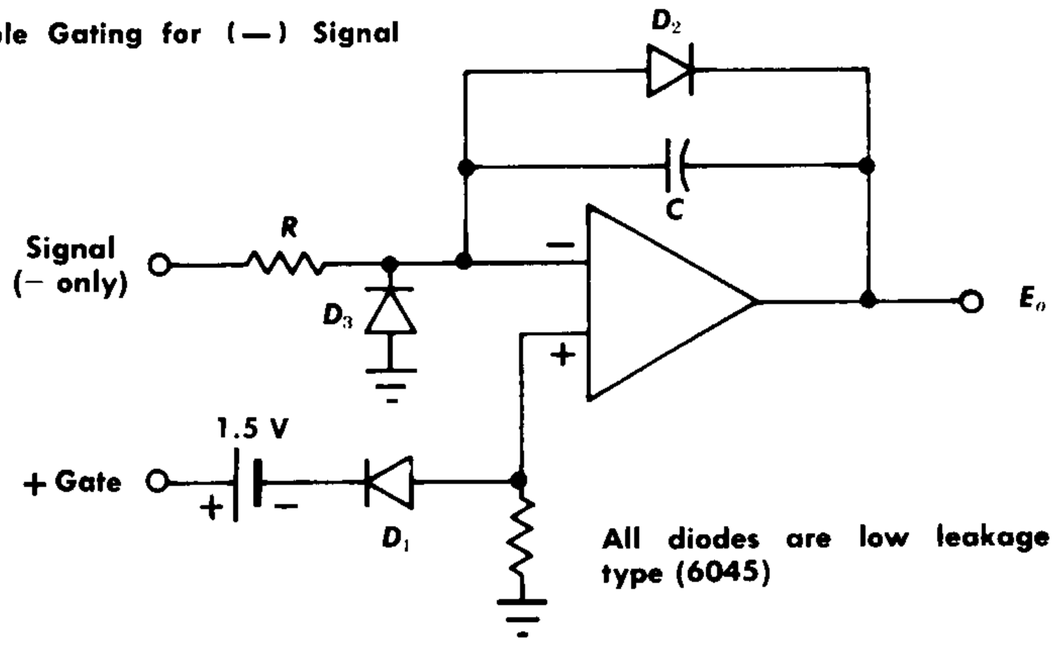

Notes

Gated integrator accepts positive signals only. When gate is zero, output is clamped by $D_2$ to approx. +0.5 V.

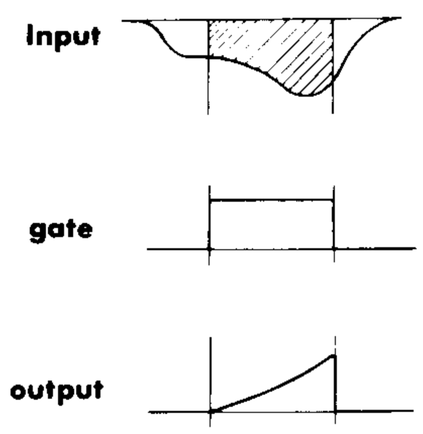
Small mercury cell may be used to obtain —1.5 V "off" level of gate.



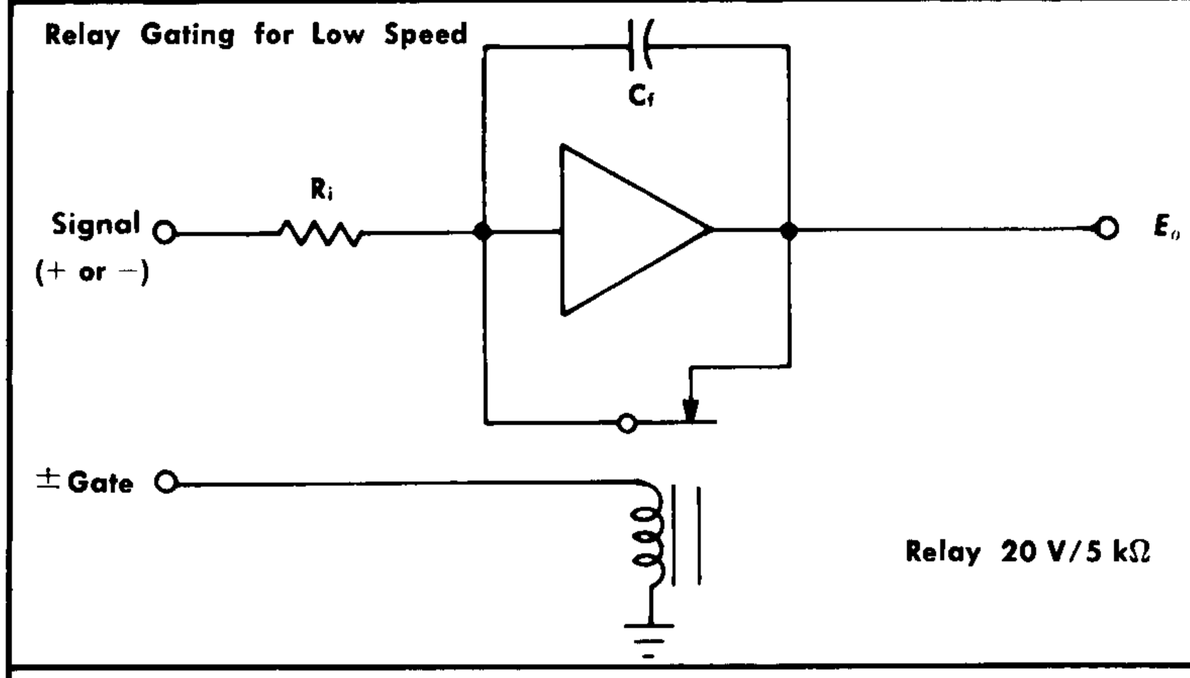

### Simple Gating for (—) Signal




Negative signal can be gated by rearranging the circuit. The gate will drive + grid. When gate is zero, output is clamped to approx. — 0.5V.

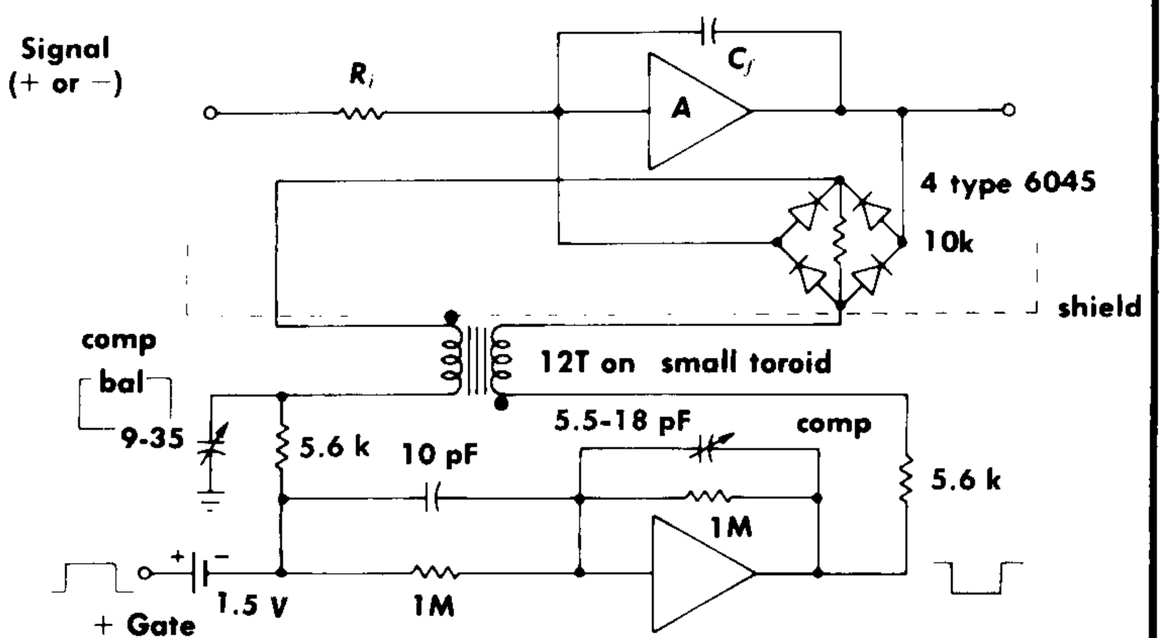



### Relay Gating for Low Speed

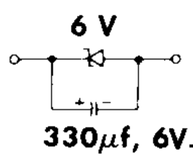



For very slow speed applications, relay can serve for simple gating. Input can be + or —.

### Signal (+ or —)




This arrangement uses diode bridge and gating amplifier. It can accept + or — input signals. Output signal should not exceed the gating voltage. Using oscilloscope gate, any portion of curve may be integrated, using sweep delay facility. For singleshot or low duty-cycle work, battery, or oscilloscope + Gate circuit modification must be used to keep Gate level negative during "off" time. If "off" time is less than 9× "on" time, battery may be replaced by capacitor and zener diode.

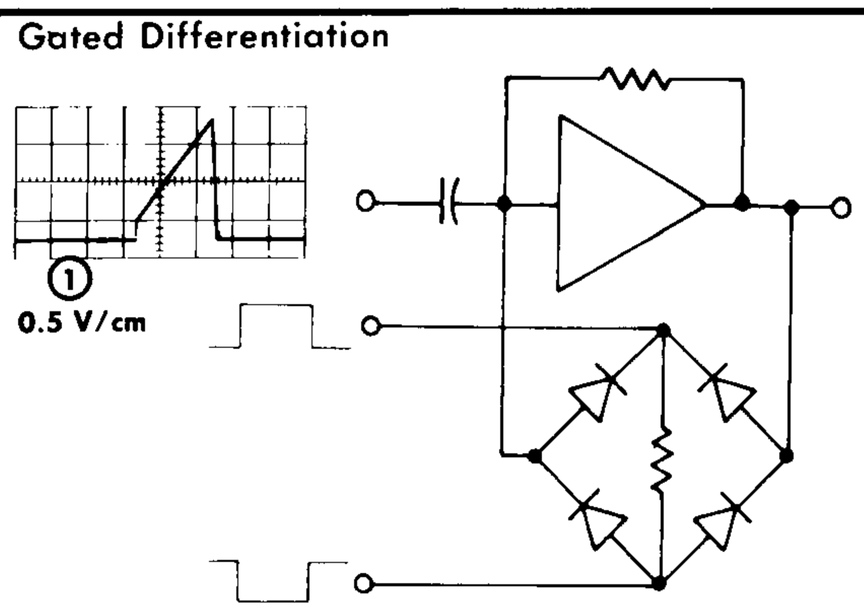



Note:
Similar to Tektronix gating adapter Part No. 013-0068-00

**Off time ≈ 2 sec max for value shown**

## Differentiation

### Gated Differentiation




For gate-driving circuit, see opposite page

### Notes

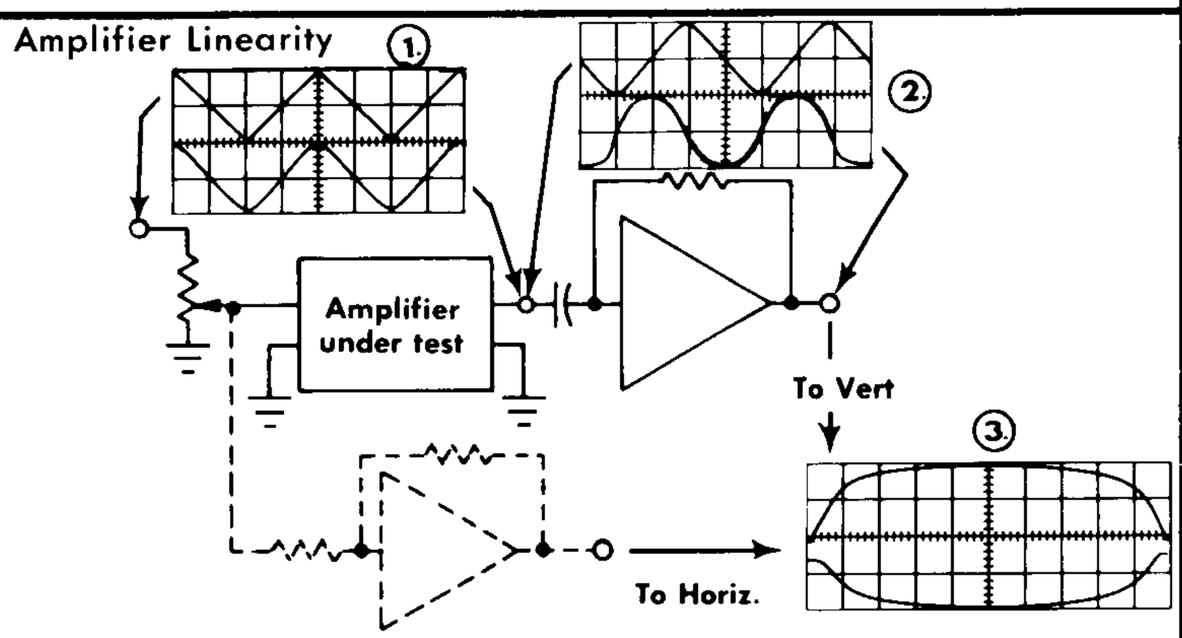
1. Waveform to be differentiated.

2. Differentiation without gating. Steps at start and end of ramp produce large transient which may overload scope input, make measurement of ramp linearity difficult.

3. Gated operation. Transients are eliminated, allowing accurate evaluation of ramp.

For gate-driving circuit, see opposite page

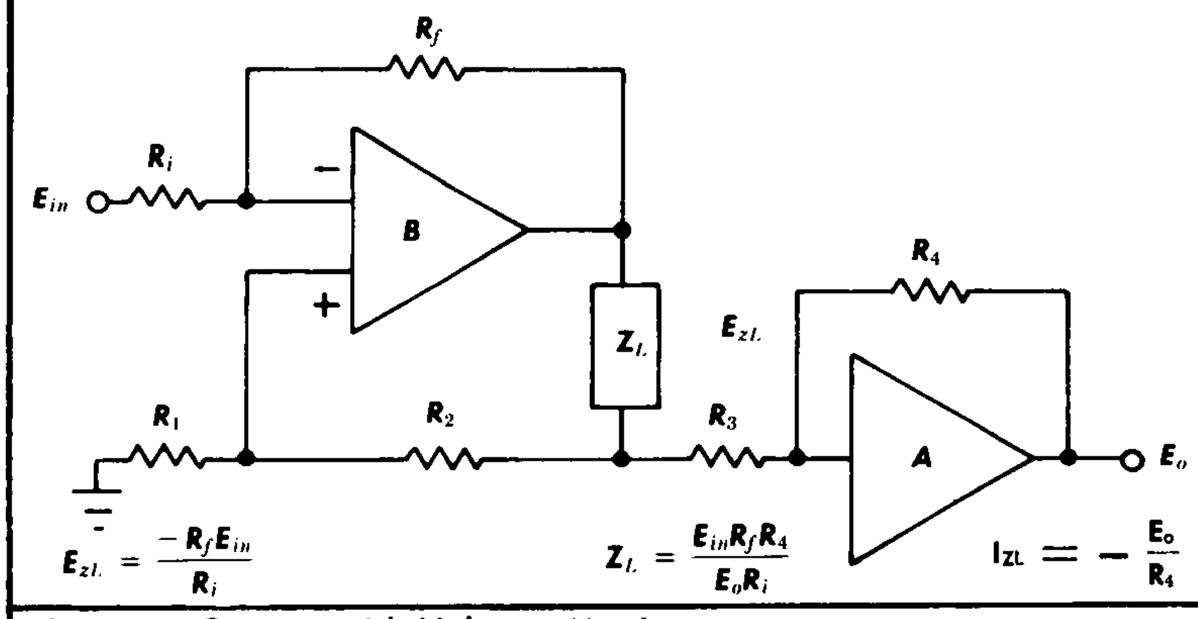
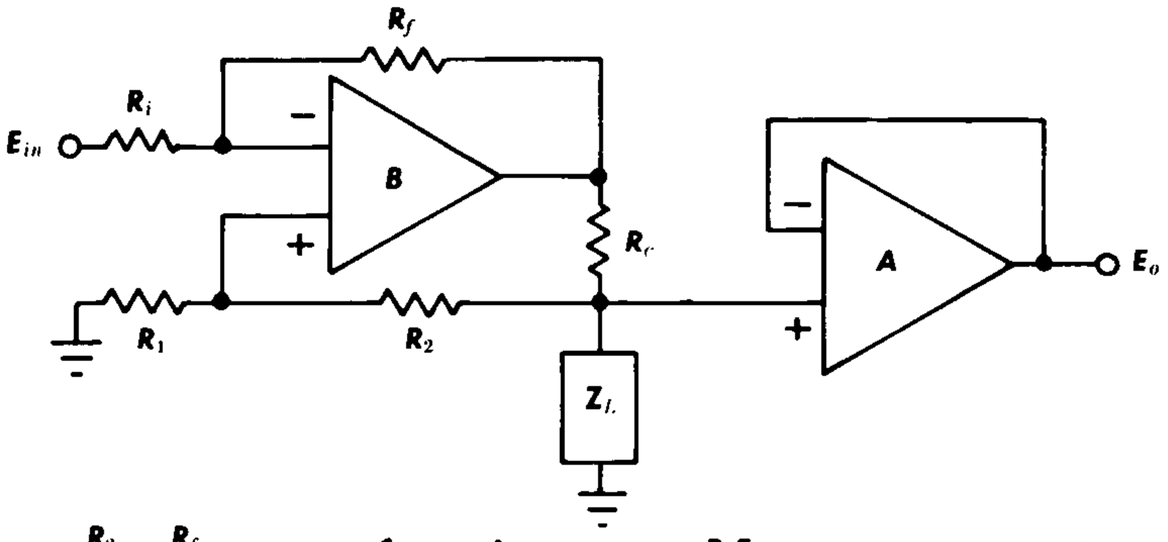
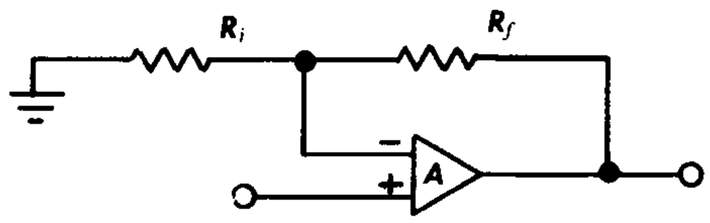
### Amplifier Linearity



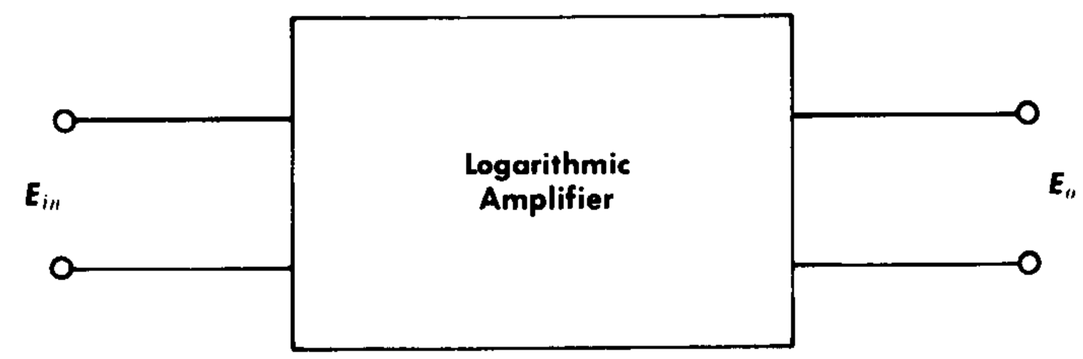
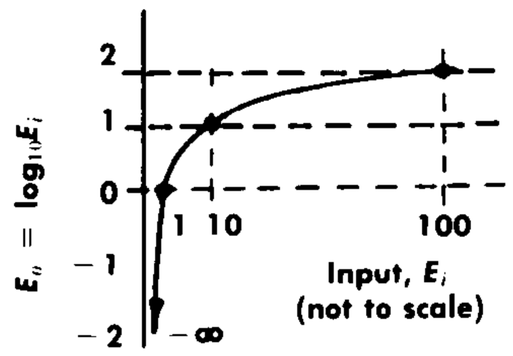
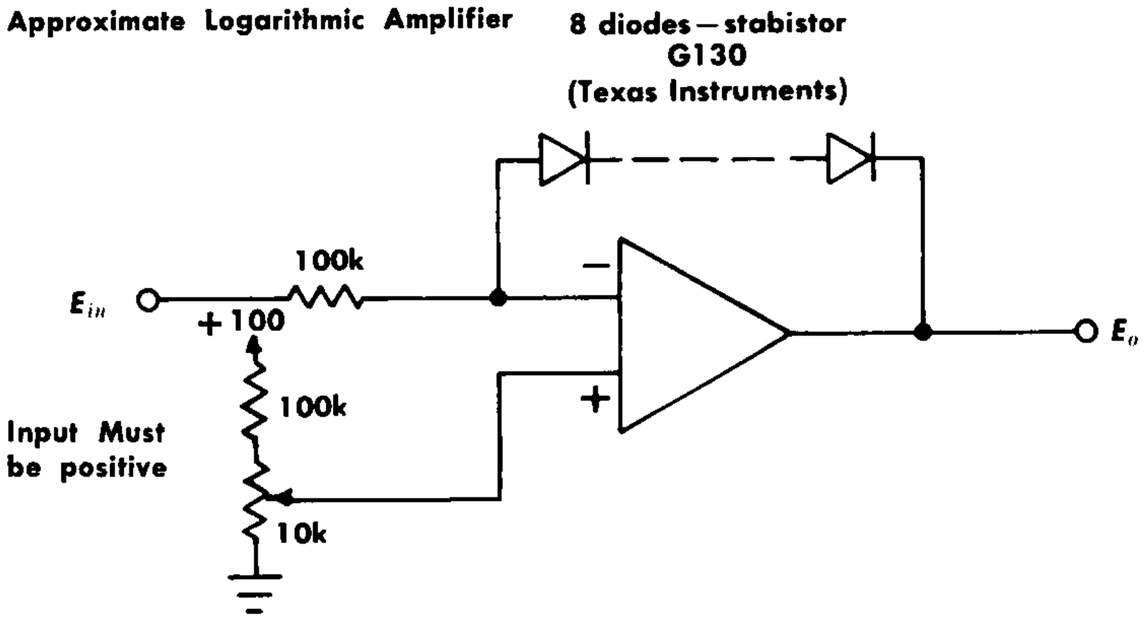
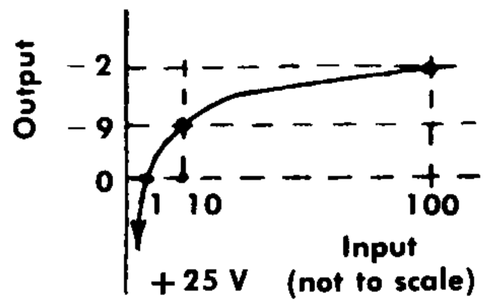
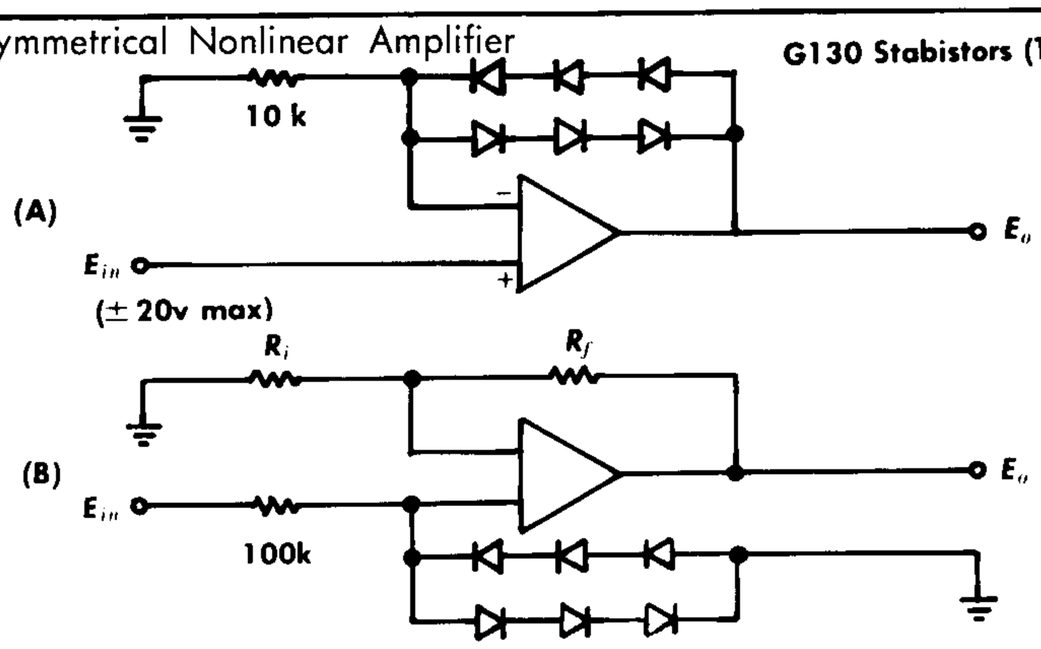
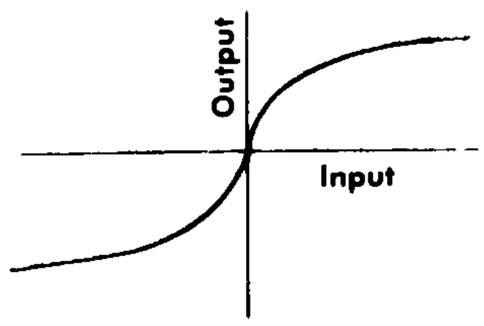
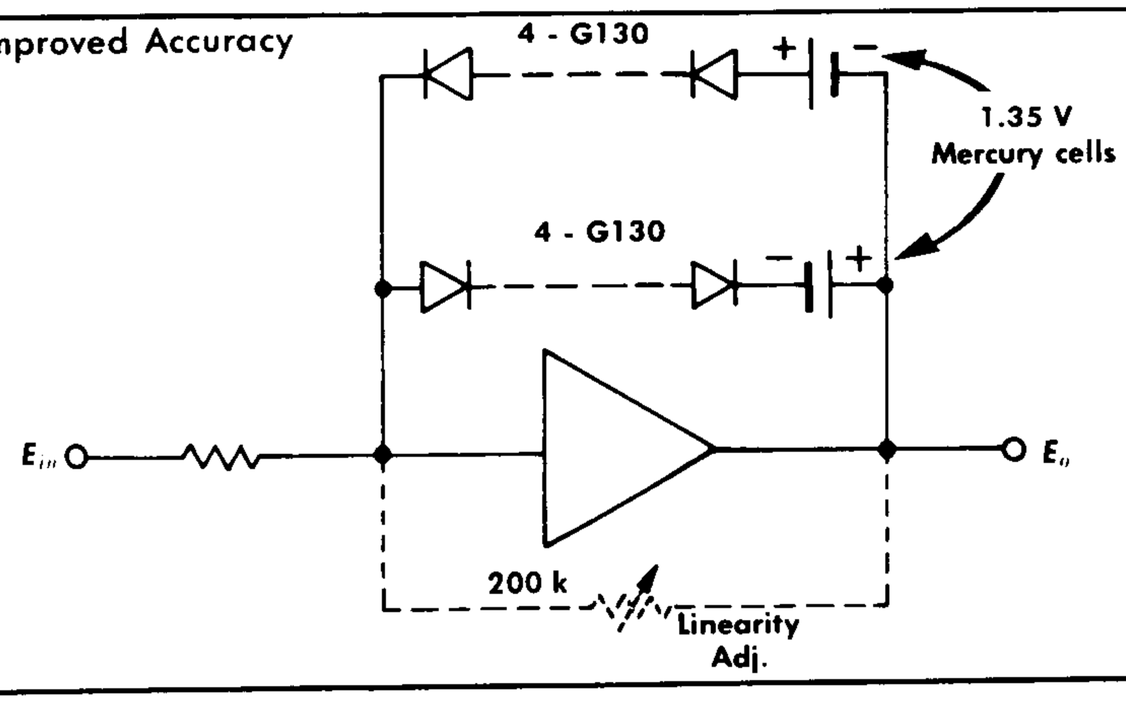

1. Input to and output of Amp. under test.

2. Output of Amp. under test. Differentiated waveform.

3. Elliptical display on oscilloscope.
   Vertical: Differentiated output.
   Horizontal: Input ramp to amplifier under test.

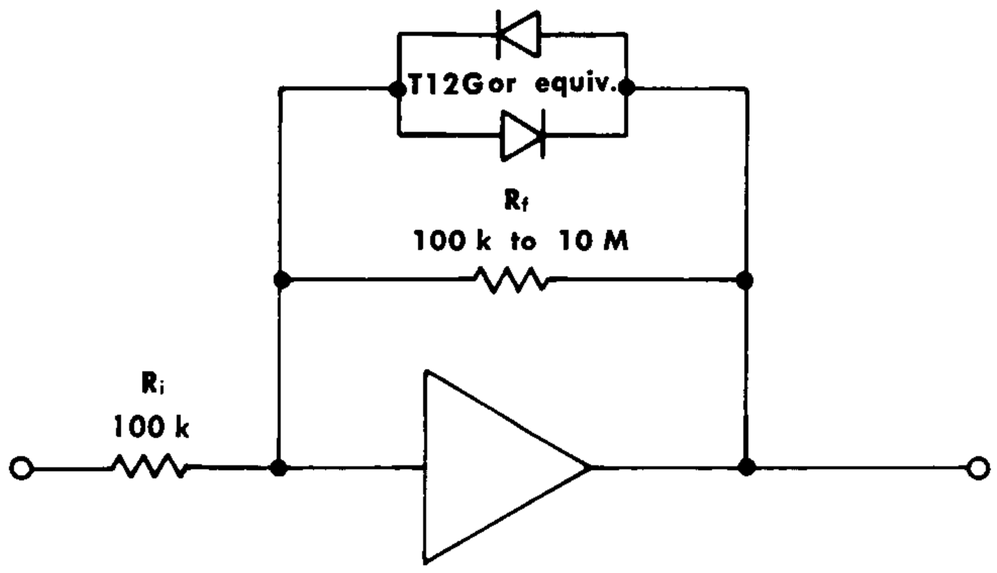
| Voltage-Current Conversions | Notes |
|---|---|
| **Constant Voltage with Current Monitor**<br>  <br><br>$E_{zL} = \frac{-R_f E_{in}}{R_i}$ $\quad Z_L = \frac{E_{in} R_f R_4}{E_o R_i}$ $\quad I_{ZL} = -\frac{E_o}{R_4}$ | A practical circuit for component-testing, where $Z_L$ need not be grounded. $R_2/R_1$ should be equal to $R_i/R_f$ and $R_3 < Z_L << (R_1 + R_2)$. $R_1$ may be trimmed or padded to correct for tolerance or system errors.<br>Type 3A8, $E_{zL}$ and $E_o$ should not exceed $\pm 25$ V. $(I_{zL} + I_{RL})$ should not exceed 7.5 mA. |
| **Constant Current with Voltage Monitor**<br>  <br><br>$\frac{R_2}{R_1} = \frac{R_f}{R_i}$; $R_c > Z_L \ll (R_1 + R_2)$ $\quad I_L = \frac{-R_f E_{in}}{R_i R_c}$; $\quad E_o \approx E_{Z_L}$ | Monitor amplifier A has very high (GΩ) input impedance, so has negligible effect on current through $Z_L$. A small (≈ 2%) correction may be necessary for gain of A where high accuracy is required, thus:<br>$R_f = R_1 \left(\frac{1}{\text{Observed Gain}} - 1\right)$<br>  <br> |

# NONLINEAR AMPLIFIERS

| Low-Frequency Applications ("Log" diodes) | Notes |
|---|---|
| **Theoretical Logarithmic Amplifier**<br>  |  <br>An advantage of a true log amplifier is its capability to accept a wide range of input signal levels. Since input can not be negative, a symmetrical amplifier is recommended for ac measurements. |
| **Approximate Logarithmic Amplifier** 8 diodes—stabistor G130 (Texas Instruments)<br>  |  <br>Simulating a true log amplifier. Bias is adjusted to give zero volt output when input is +1 V. When input is zero, amplifier saturates to ≈25 volts. Many germanium diodes can be used such as T12G. Stabistors are recommended for more dynamic range and controlled characteristics. |
| Symmetrical Nonlinear Amplifier G130 Stabistors (T.I.)<br>  |  <br>Circuit (A) provides very high (≈GΩ) input resistance for low level applications. $E_{in}$ ±20 V max. Circuit (B) permits output level to be adjusted by selection of $R_f$ and $R_i$. |
| Improved Accuracy<br>  | Small mercury cells may be used for bias to obtain better accuracy, especially at low levels. Disconnect cells when not in use. Improvement for a given application is obtained with a linearity adjustment pot. |

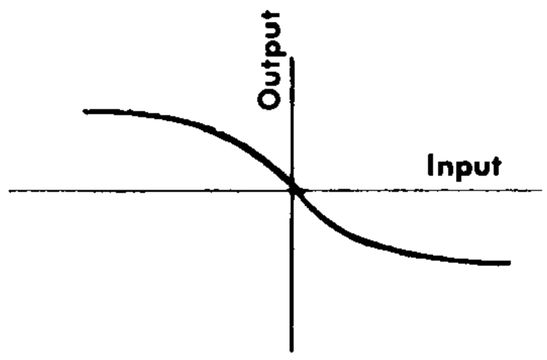
## Wideband Amplifiers (Signal Diodes)

### Simple Nonlinear Amplifier

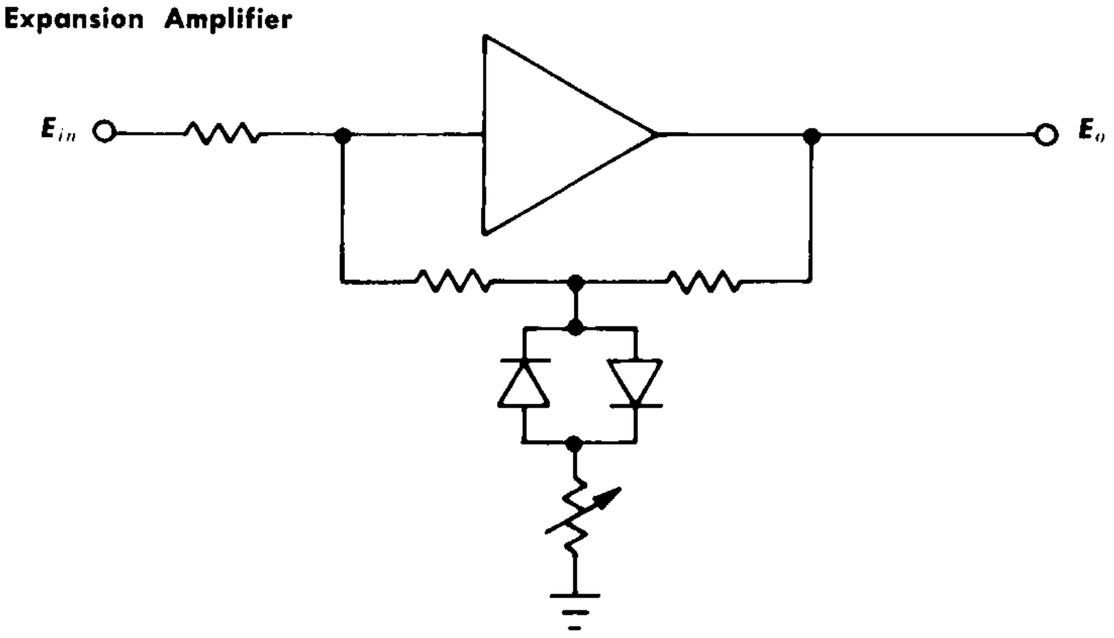


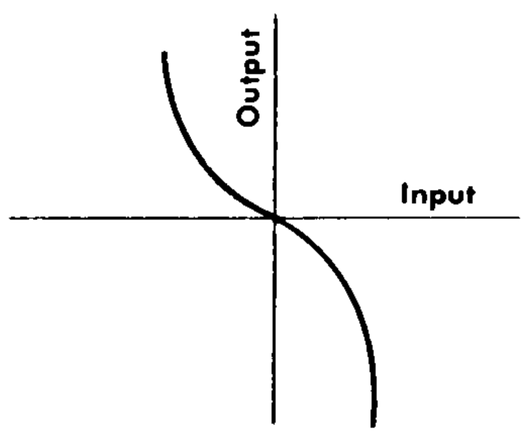

### Notes

If Germanium diodes are placed in the feedback circuit, this amplifier acts as compression type amplifier.



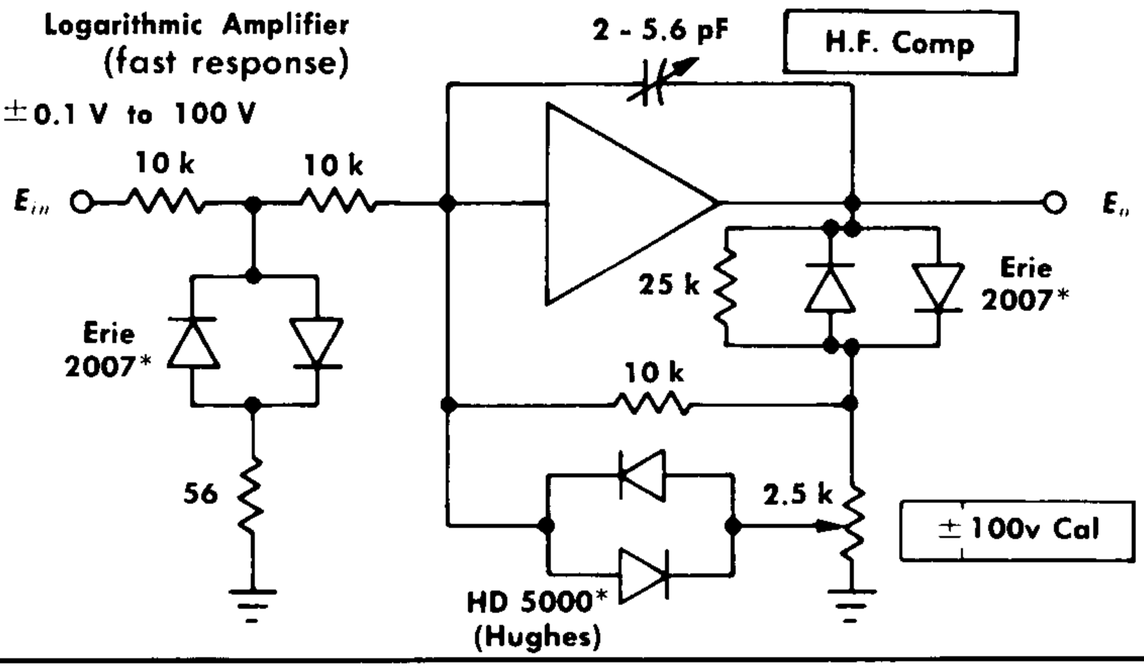

### Expansion Amplifier



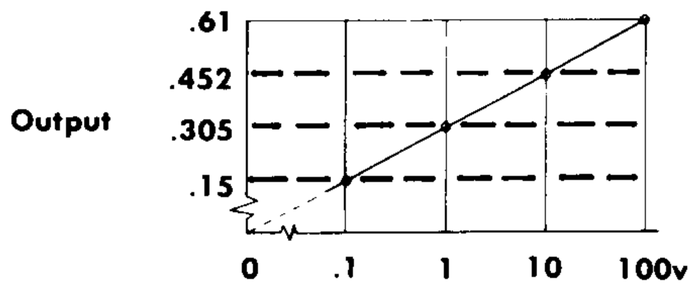




### Logarithmic Amplifier (fast response)

±0.1 V to 100 V



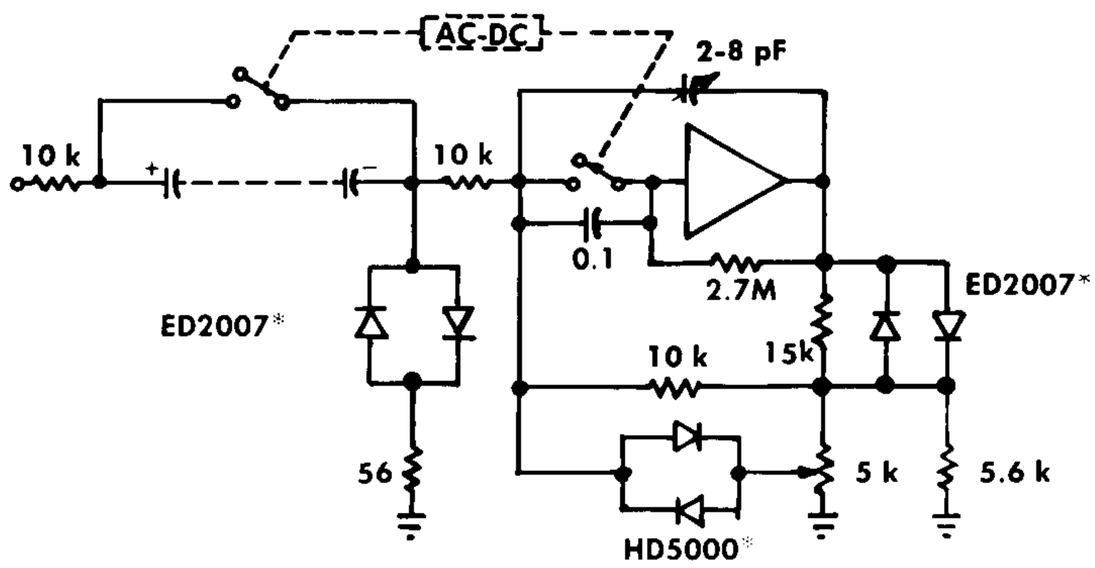

$E_o$ .305 + .15 $\log_{10} E_{in}$



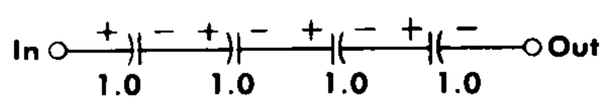

$T_r$ ≈200 ns
$T_f$ ≈300 ns
For 10 V signal.

Diode pairs must be carefully selected.

### Same, with AC-coupling option

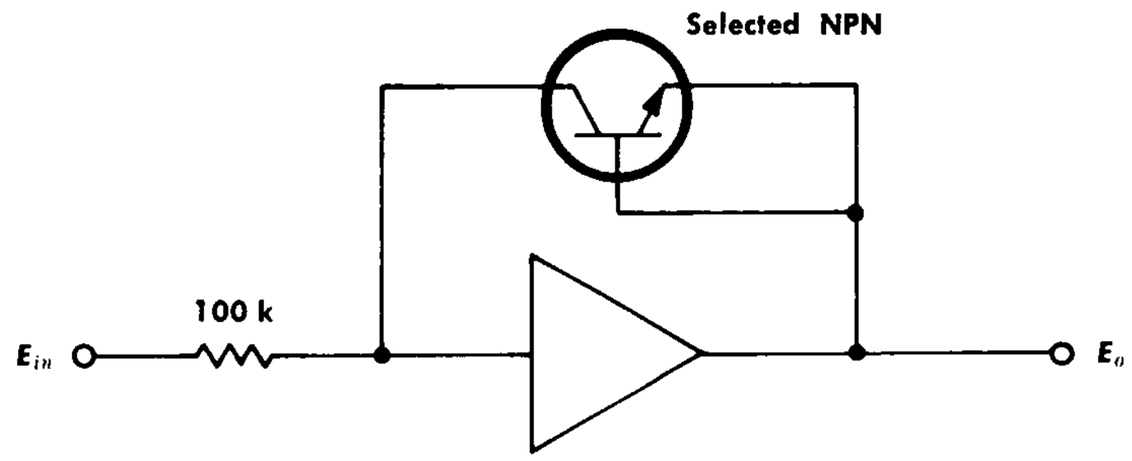
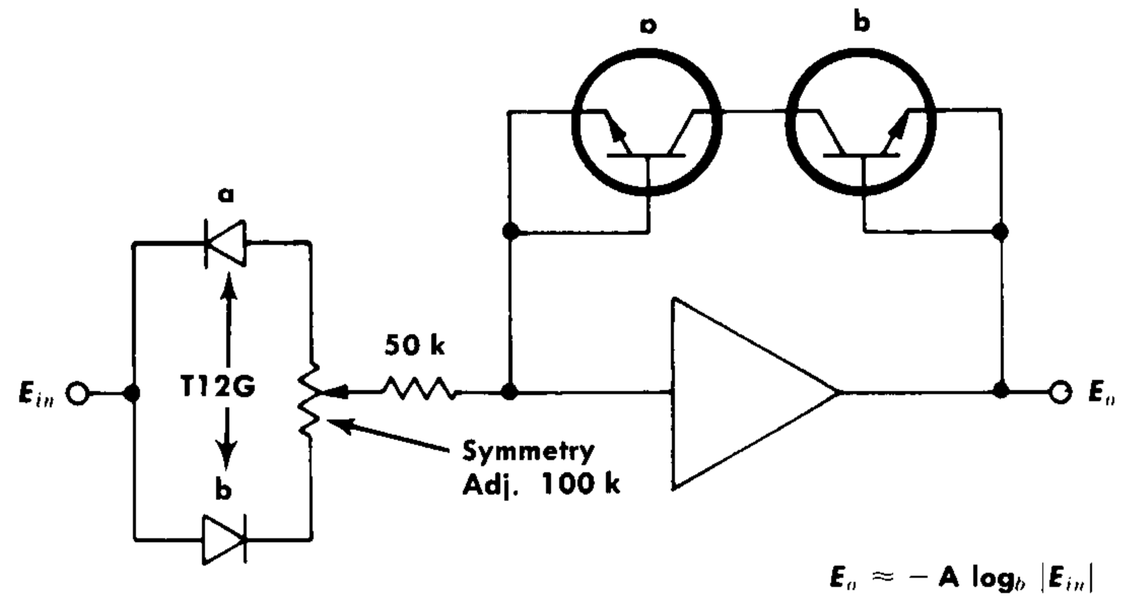
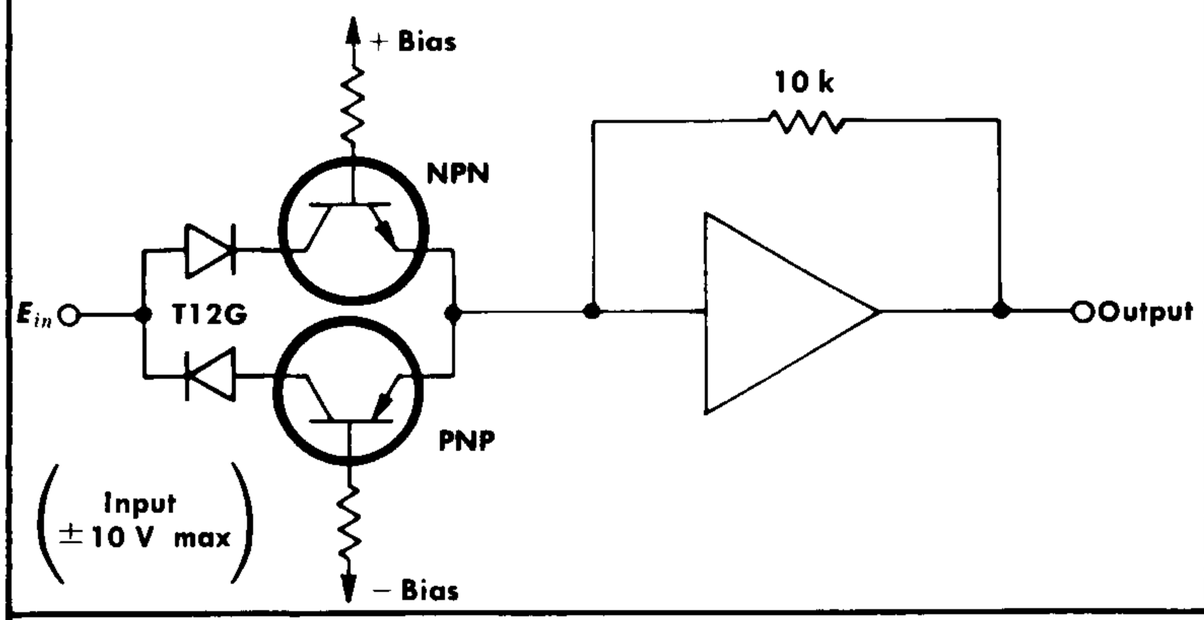
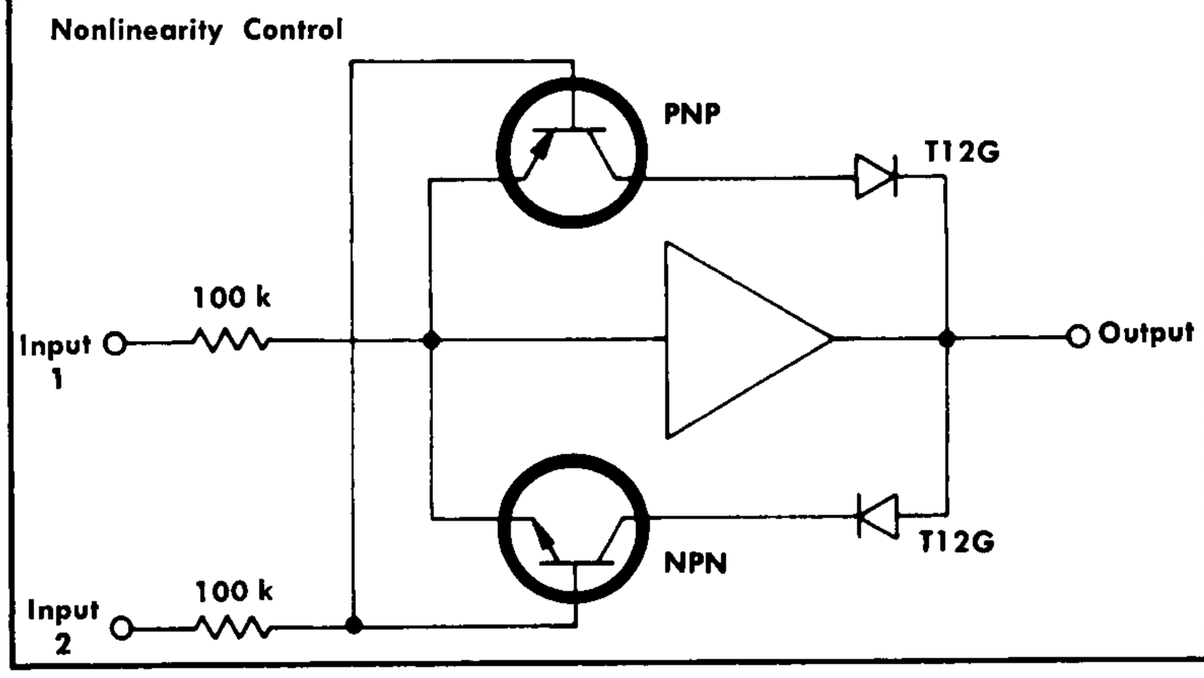


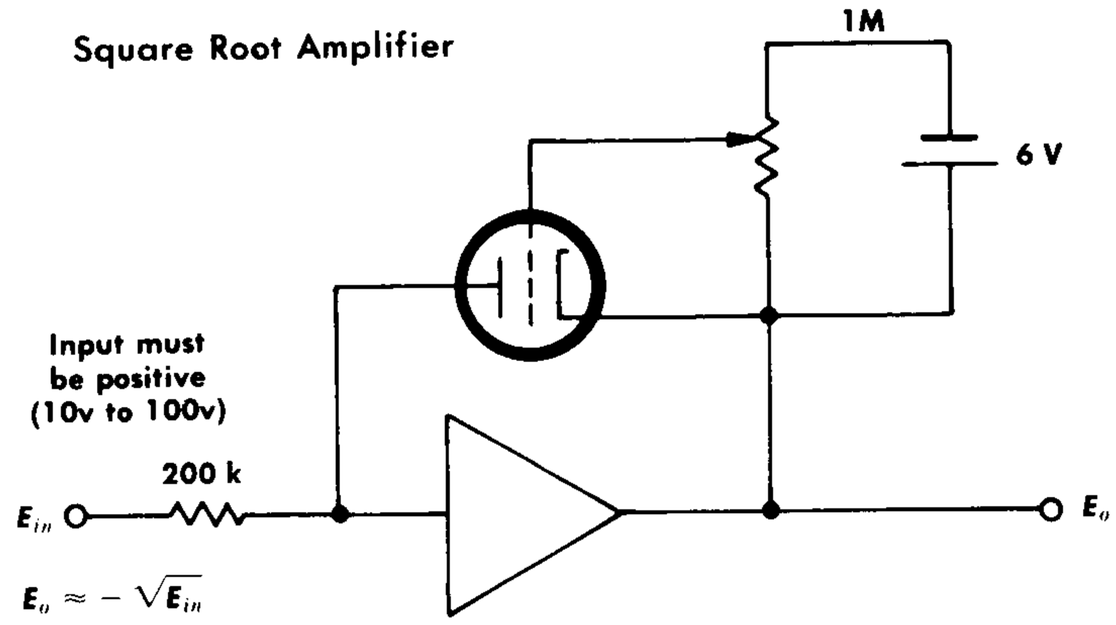
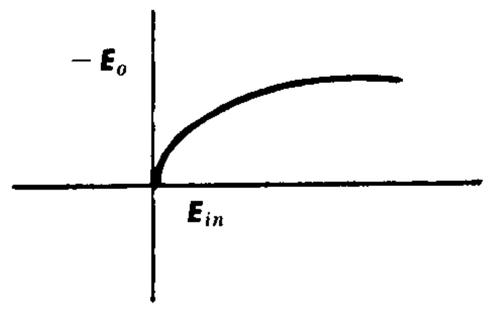
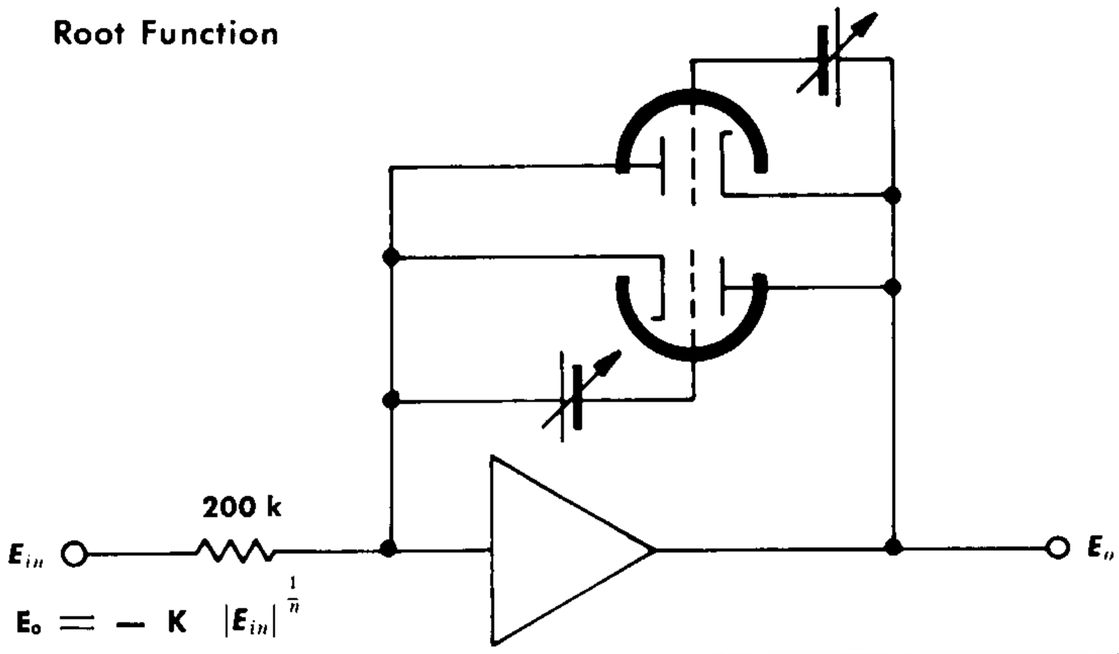
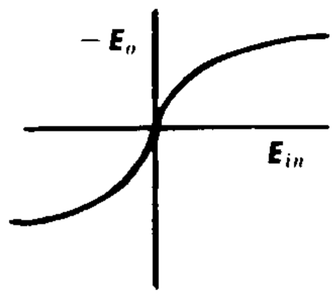
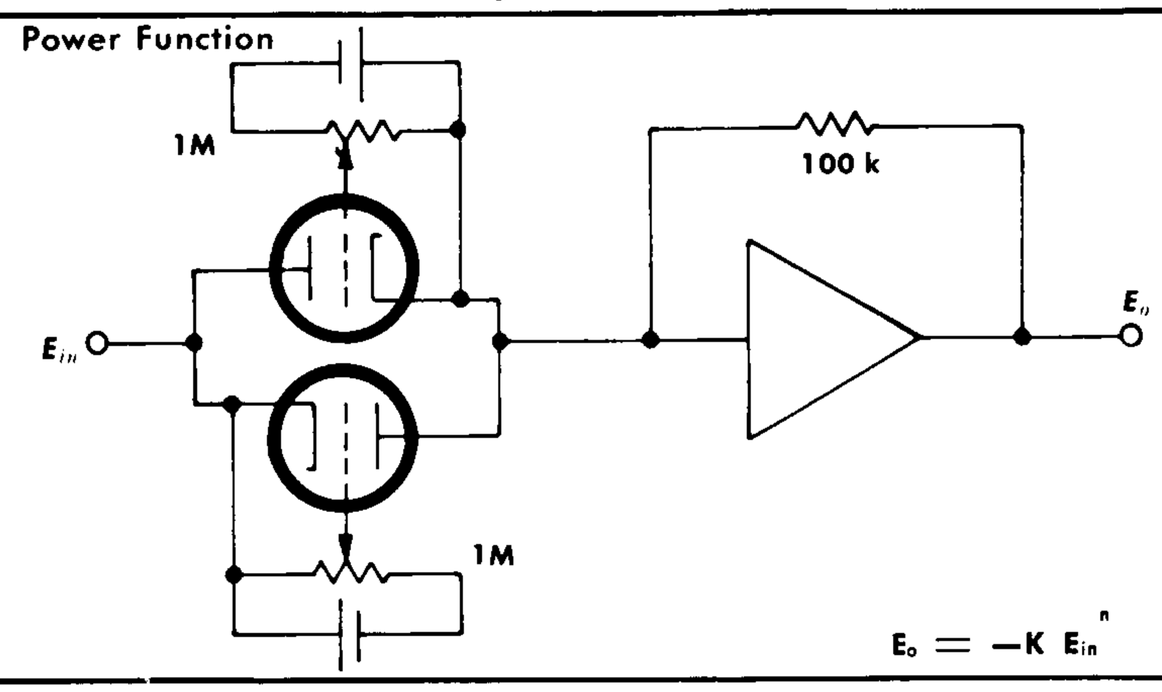
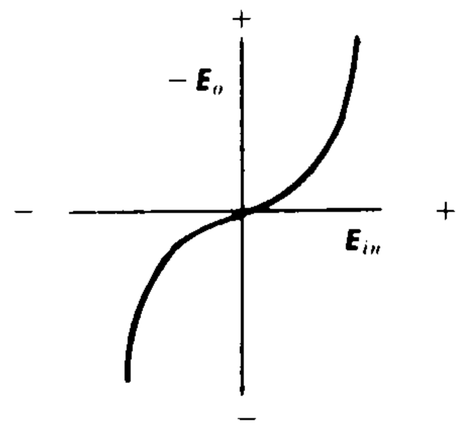

Input time constant can be long with use of tantalum electrolytic capacitors connected in series, thus:




The tantalum capacitors can have a small reverse bias, so two 0.5 μF 100 V, or four 1.0 μF 50 V units can be made to provide 0.25 μF 100 V service. This entire adapter is available (assembled and calibrated) from Tektronix, under P/n 013-0067-00.

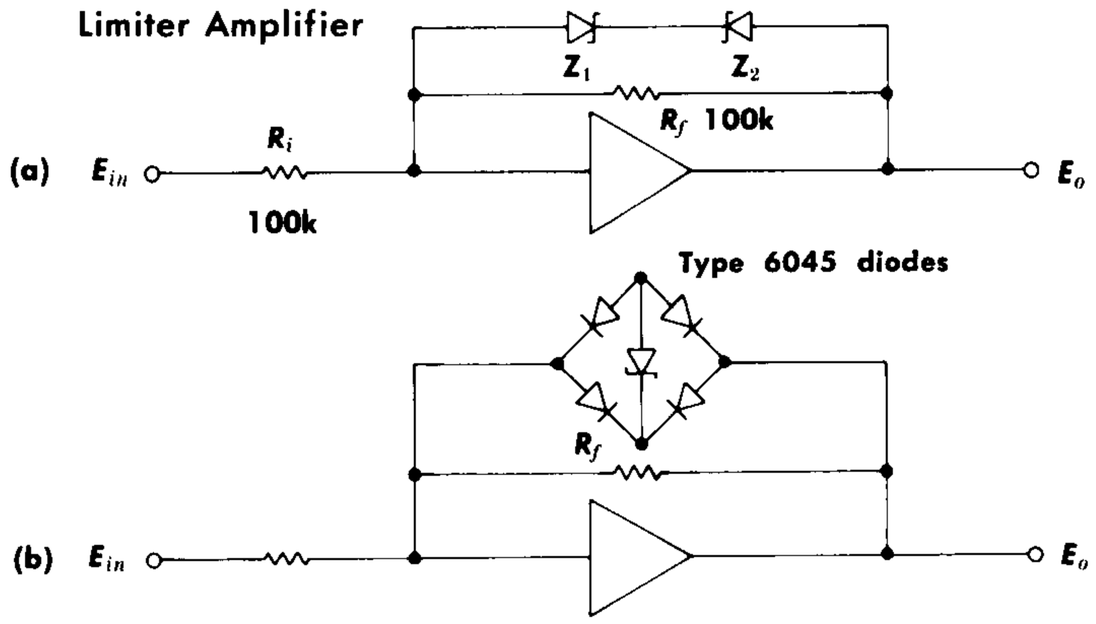
*Selected and matched. See appendix.

| Transistors As Passive Nonlinear Elements | Notes |
|---|---|
| **Approximate Logarithmic**<br>  <br><br>**Input must be positive**<br>$E_o \approx -A \log_b E_{in}$ | Certain NPN transistors exhibit logarithmic voltage-current breakdown characteristics in the reverse direction. This arrangement can accept only a positive input signal.<br>Selection of NPN transistors may make this type of logarithmic amplifier impractical since the use of certain type diodes can give more predictable logarithmic characteristics.<br>(only advantage is high level output) |
| **Symmetrical Nonlinear Amplifier**<br>  <br><br>$E_o \approx -A \log_b \lvert E_{in} \rvert$ | To accept positive and negative signal two transistors (matched) are used. Signals are same as listed above. |
| **Symmetrically Compressed Amplifier**<br>  <br> | |
| **Nonlinearity Control**<br>  <br> | |

| Vacuum Triodes As Nonlinear Elements | Notes |
|---|---|
| **Square Root Amplifier**<br>  |  <br>Certain low-$\mu$ triodes such as 12AU7 or Nuvistor 7586 may be placed in the feedback circuit to obtain square root characteristics. |
| **Root Function**<br>  |  <br>Two triodes placed back to back in the feedback circuit. By adjusting bias, the root may be varied from approximately .9 to 10. |
| **Power Function**<br>  |  <br>If the triodes are placed in the input circuit, power function may be obtained. The power may be varied from .9 to 10 approximately. |

## Zener Diodes As Nonlinear Elements

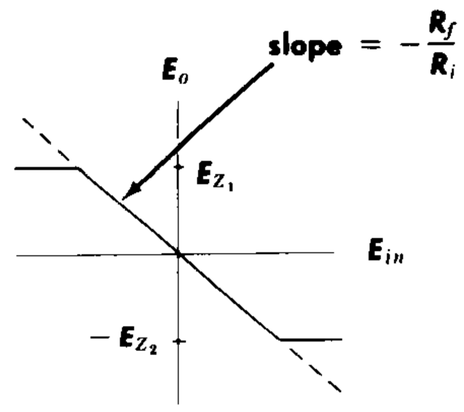
### Limiter Amplifier



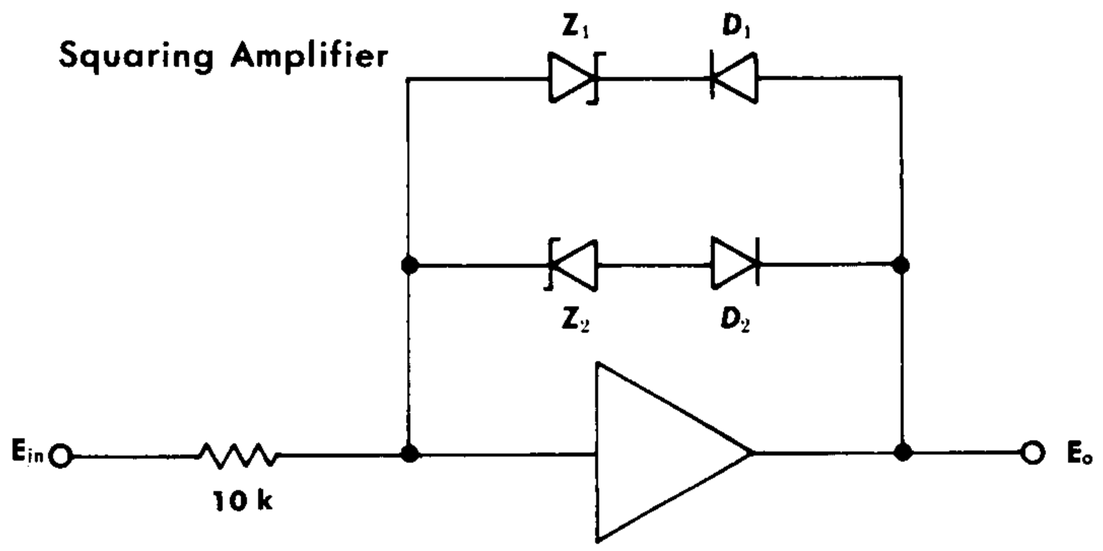

**Notes**

a. If back to back Zener diodes are inserted in the feedback circuit, the output voltage will be limited by the Zener breakdown voltage.

b. For perfect symmetry, use one Zener diode and diode bridge as shown. Low-C, low-leakage diodes allow more accurate, faster operations.

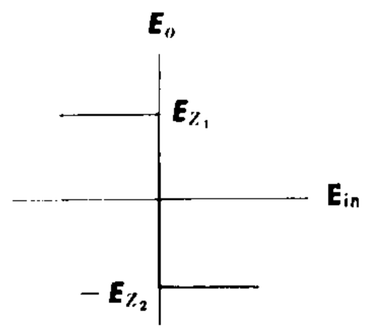



### Squaring Amplifier

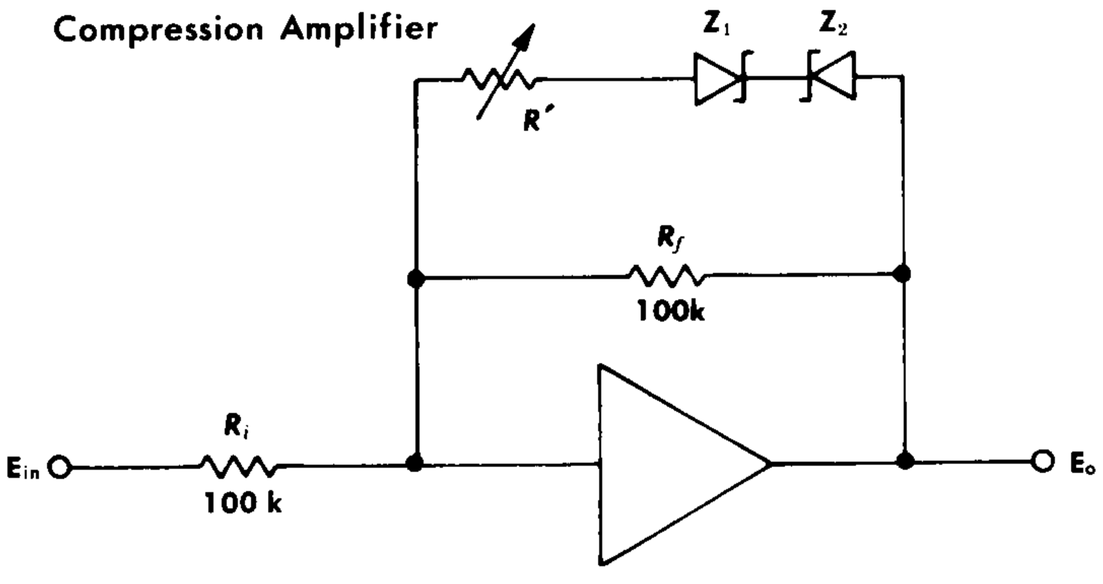



If the feedback resistor in the above amplifier is removed, the amplifier provides very high gain near zero signal. With this arrangement the Zener diodes are coupled with low capacity diodes to minimize Zener diode capacitance.

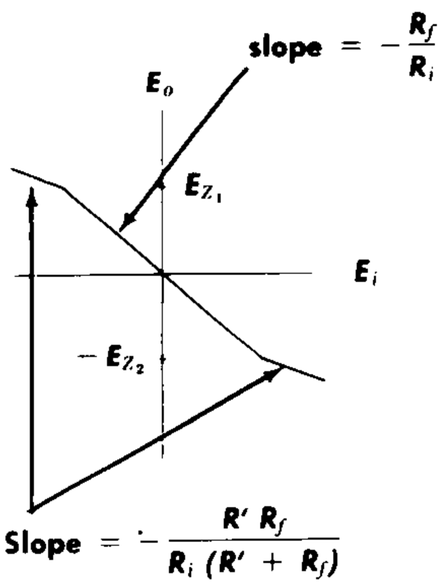
For perfect symmetry use diode bridge as above. (Additional series diodes are not required.)



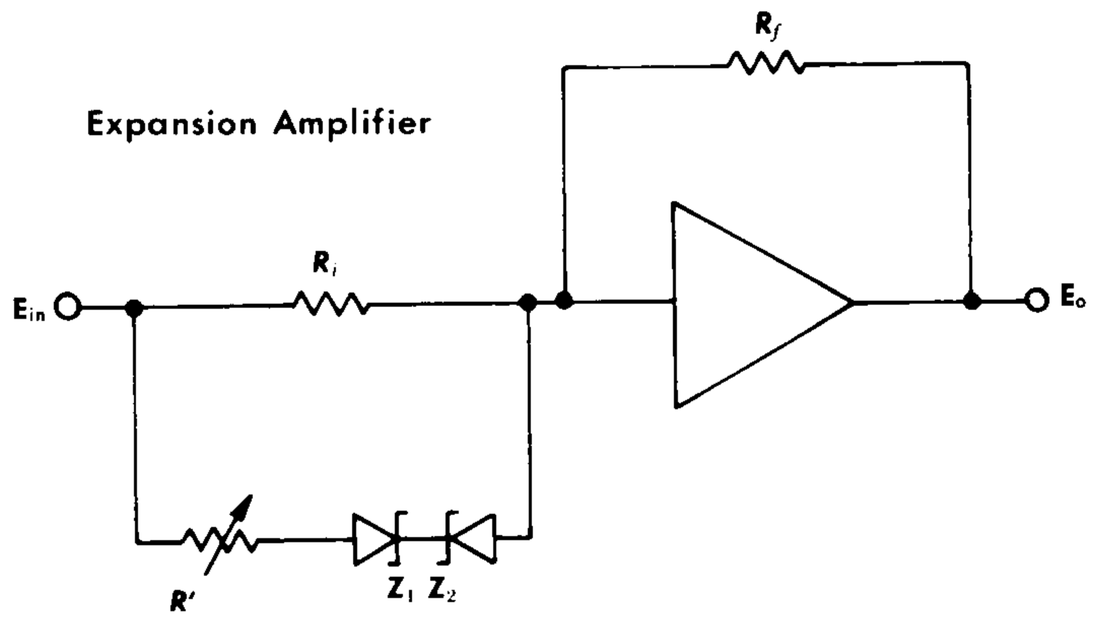

### Compression Amplifier



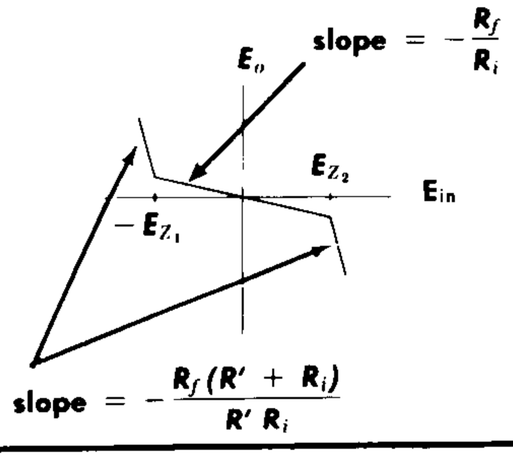

A variable resistor in series with the Zener diode in the limiter amplifier can control the amount of compression for a large signal. For symmetry, use bridge arrangement.




### Expansion Amplifier

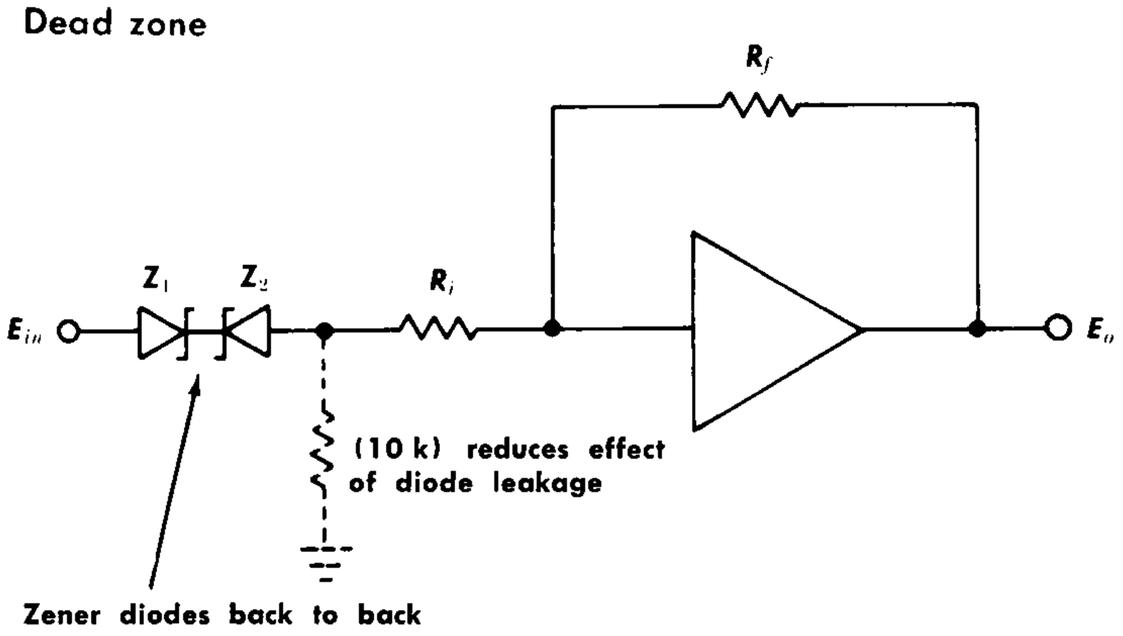



Input and output circuits are reversed in this amplifier to obtain higher gain for larger signal input. The diode bridge arrangement may again be used to provide symmetry and reduce capacitance.



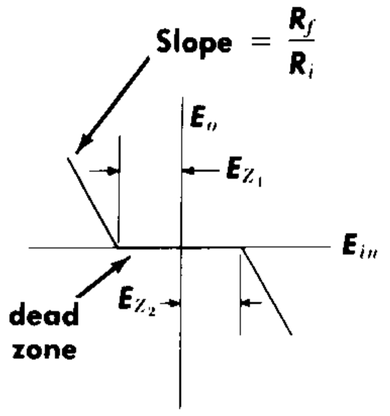
## Zener diodes—Simulation of Nonlinear Mechanical Phenomena

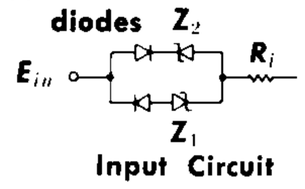
### Dead zone



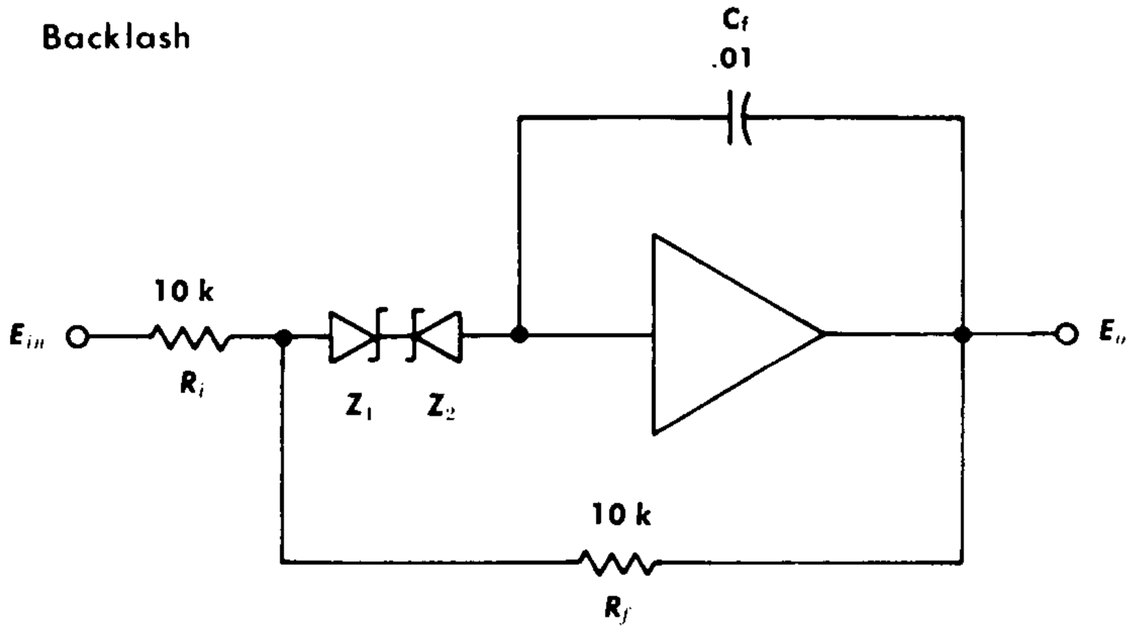

Simulating a dead zone

Bridge arrangement (p3-17 may be used where symmetry, capacitance or leakage are a problem. For asymmetrical operation with minimum leakage and C, use input circuit shown:



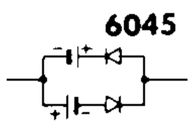

### Backlash

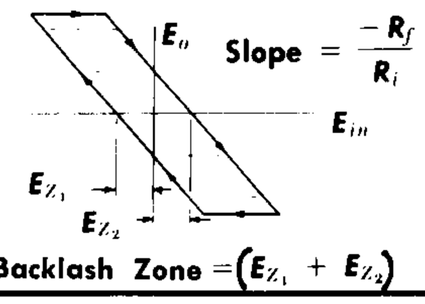



Simulation of backlash:

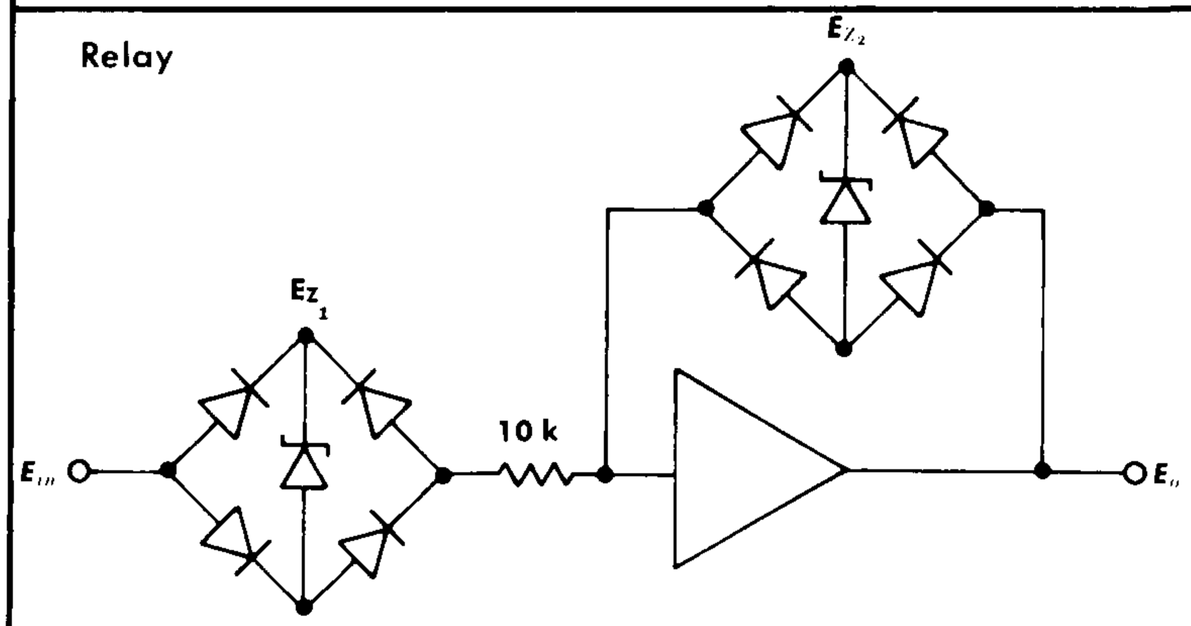
The capacitor serves as a memory to hold the output constant as $E_{in}$ moves through backlash zone (changes direction).

For low-leakage memory, use small (hearing-aid) batteries and low leakage diodes



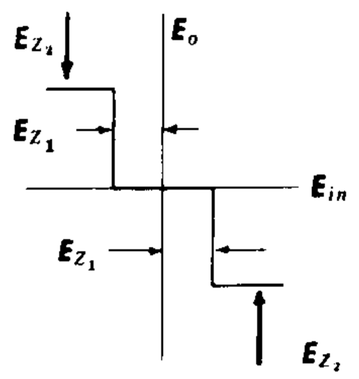




### Relay



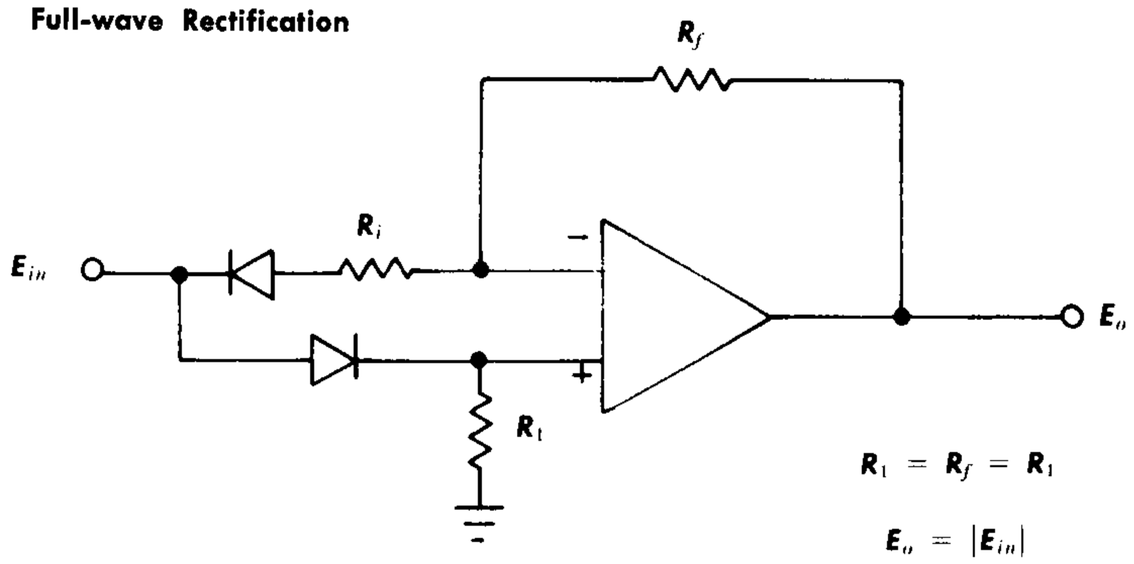

Representation of polarized double-throw relay which has equal pull-in and pull-out current.

Asymmetrical systems may be simulated by using Zener diodes and signal diodes in series as in the "Dead Zone" notes above.



## Absolute Value Amplifiers

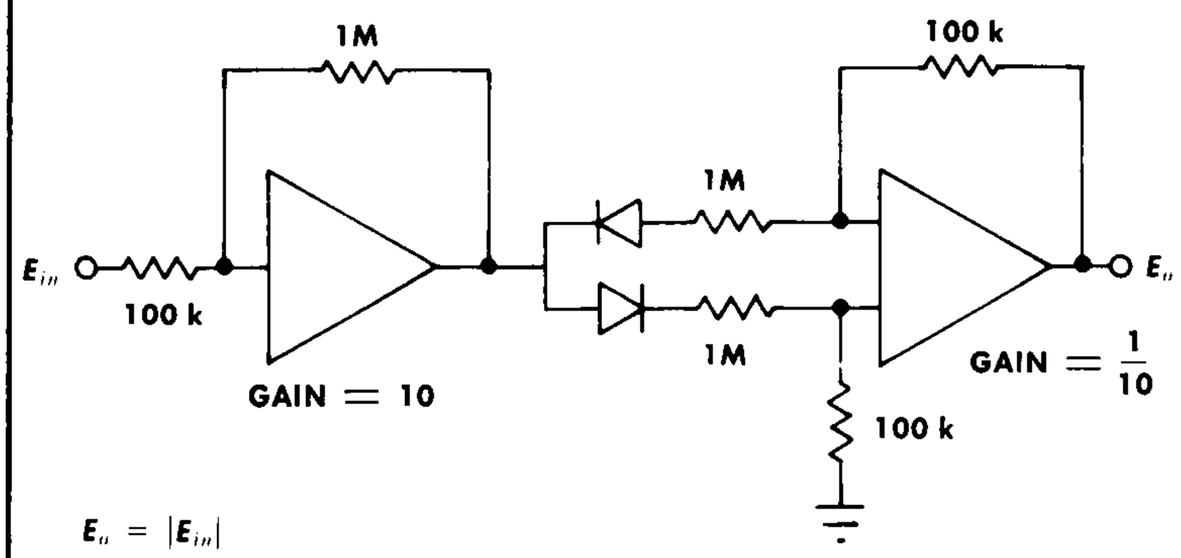
### Full-wave Rectification




$R_1 = R_f = R_1$

$E_o = |E_{in}|$

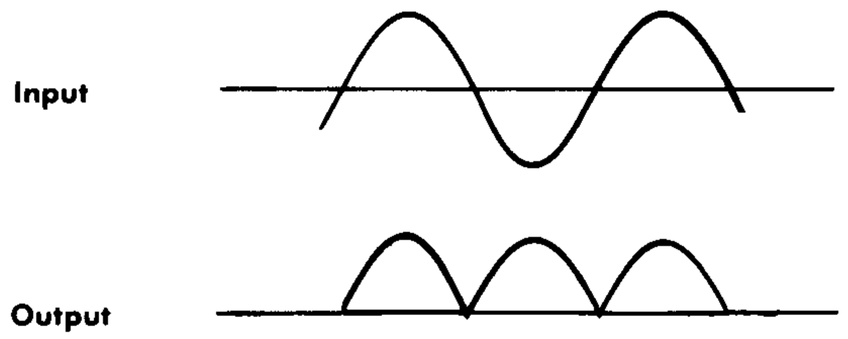
### Full-wave Rectification (low level)



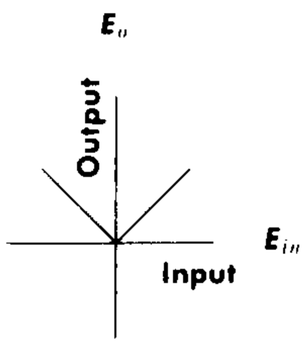

$E_o = |E_{in}|$

## Notes

Output gives full-wave rectification of input. Output is always positive sign. Diodes contribute ≈ .3 voltage drop.



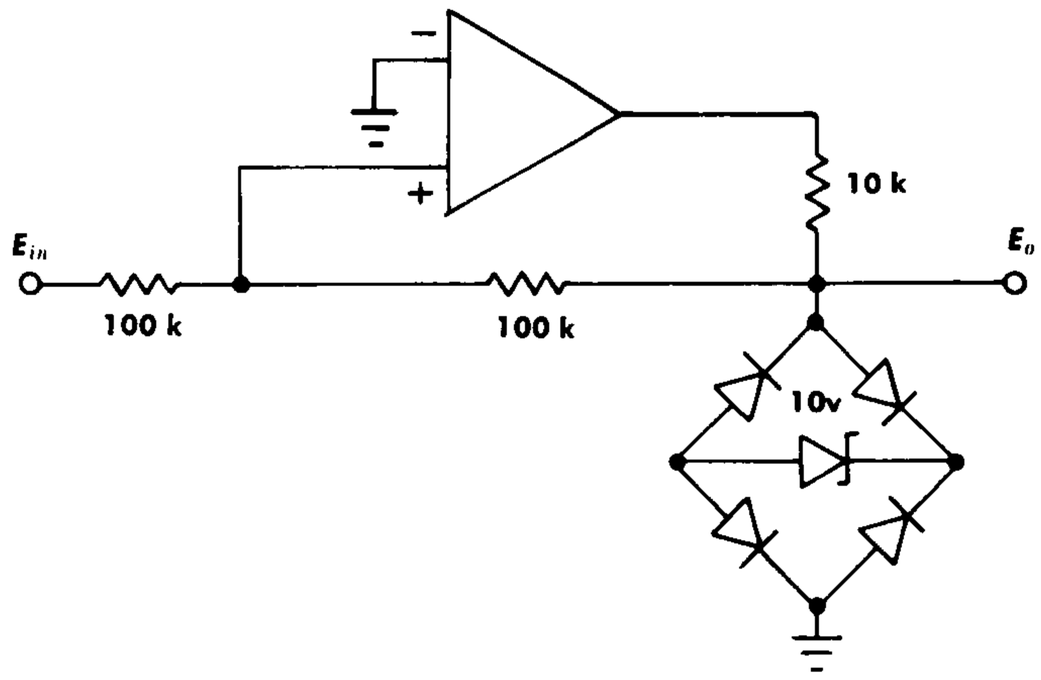

By inserting an amplifier ahead of full-wave rectifier, the effect of diode voltage drop is reduced by the factor of amplification. This technique may be applied to low level full-wave rectification.



# PULSE AND DIGITAL TECHNIQUES

## Switching Circuits

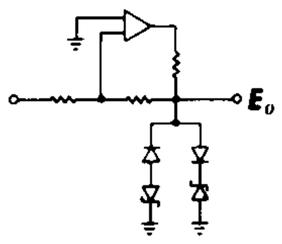
### Bistable Comparator (± input)



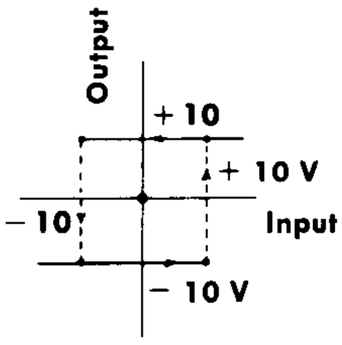

## Notes

The bistable comparator incorporates a Zener diode as a reference. The input voltage is compared against the reference diode; when the input voltage becomes equal to the Zener voltage, output will flip to 10 V of the same polarity as input.

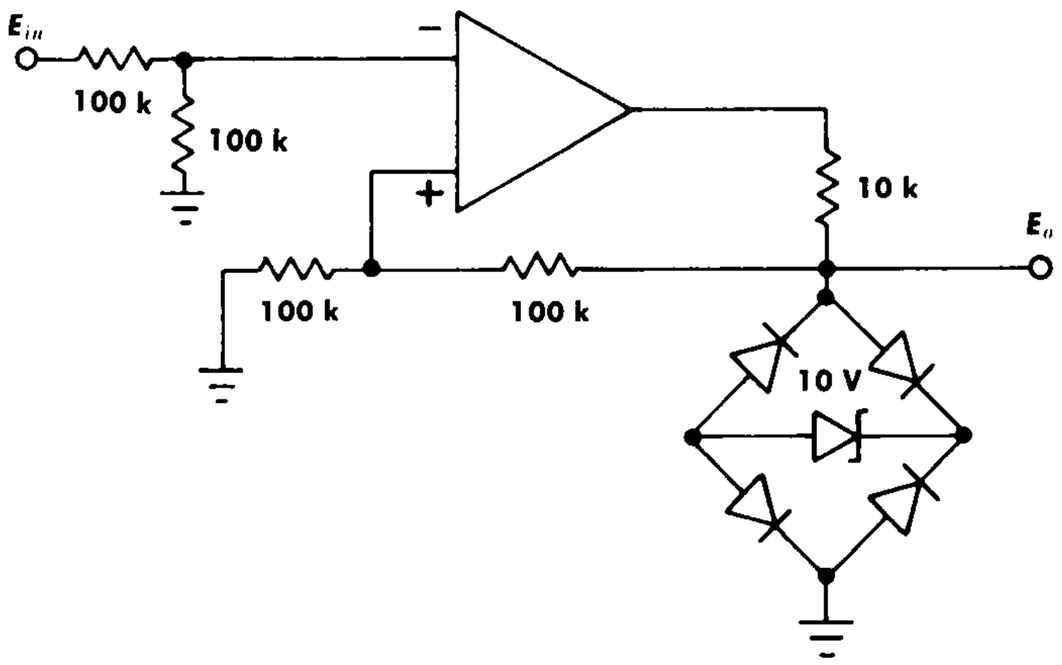
Use of different references for + and — comparisons is possible.



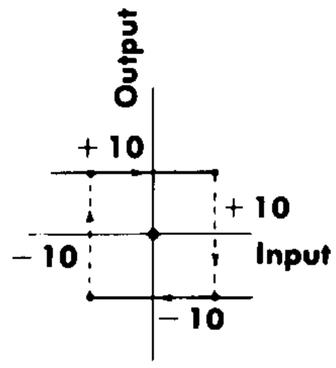

**Use of decoupling diodes improves switching time.**



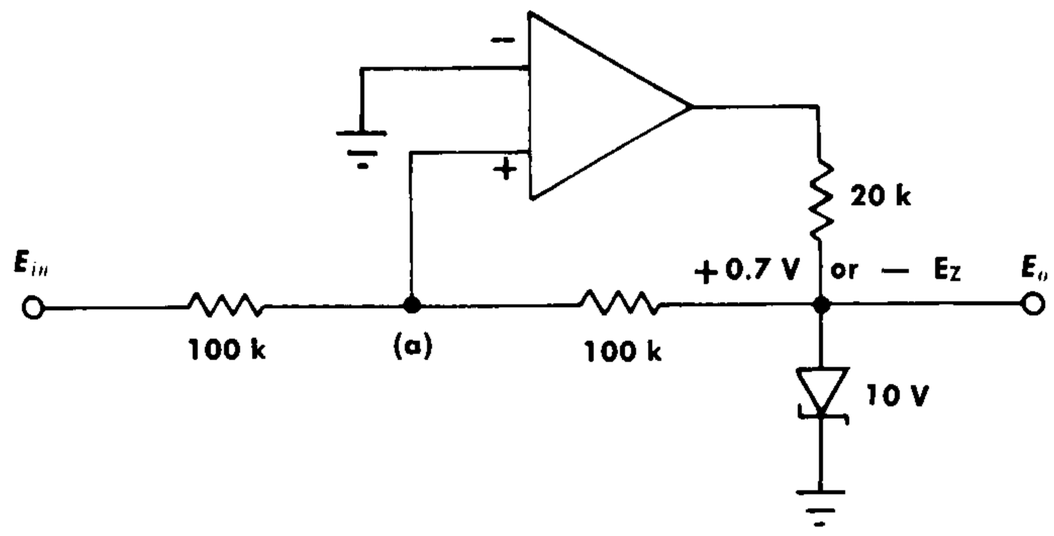

### Bistable Comparator, Inverting



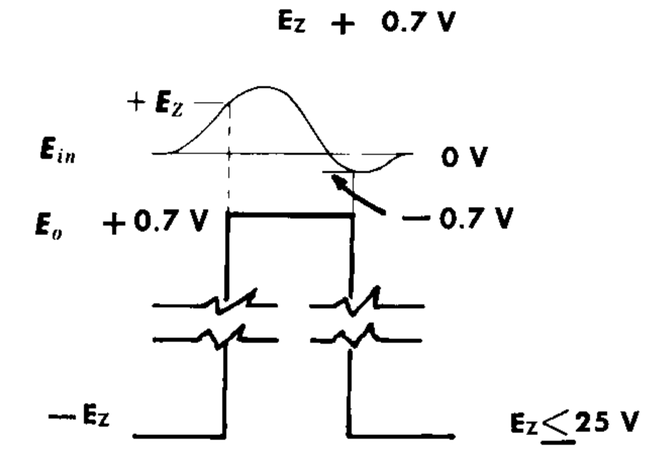

Similar to above, but output will flip to opposite polarity.




### Bistable Comparator, unidirectional

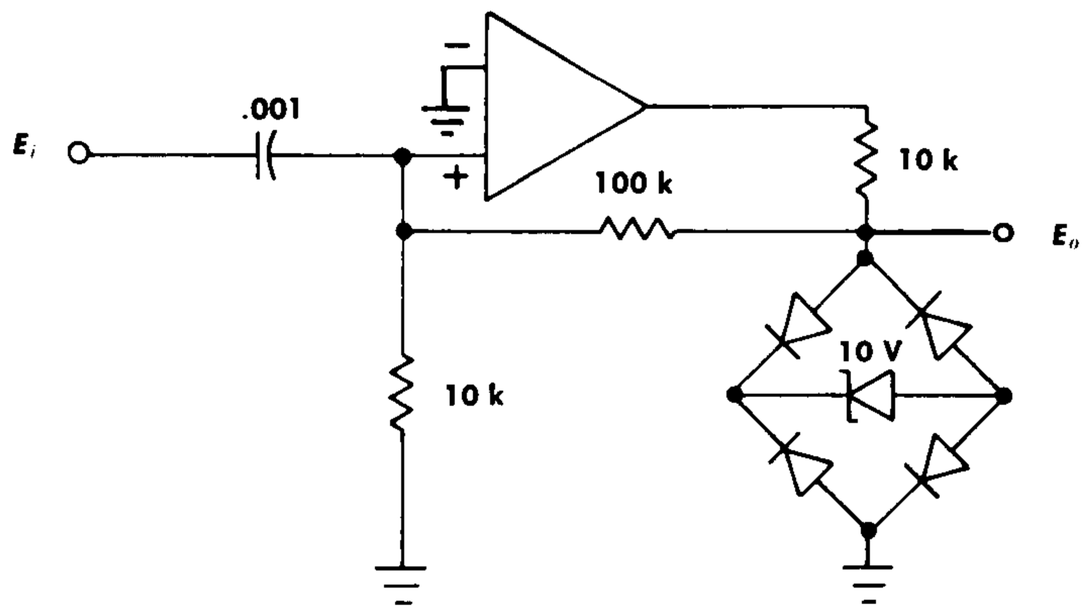



Single Zener diode flips comparator when $E_{in} = +E_z$ and resets when $E_{in} = 0.7$ V. (Reset level governed by forward resistance of Zener). Reset can be made to occur at 0 V if —grid is returned to about +0.7 v. Comparator point will become $E_z$ —0.7 v. Bias may also be injected at (a) for same result.

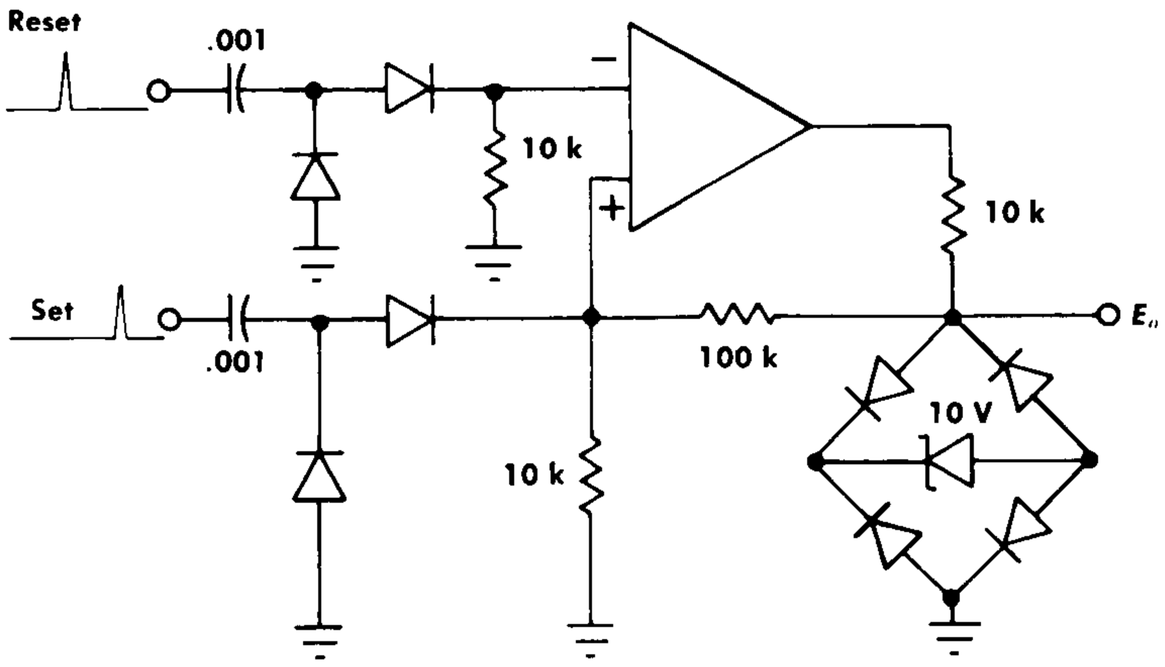


## Bistable Multivibrators

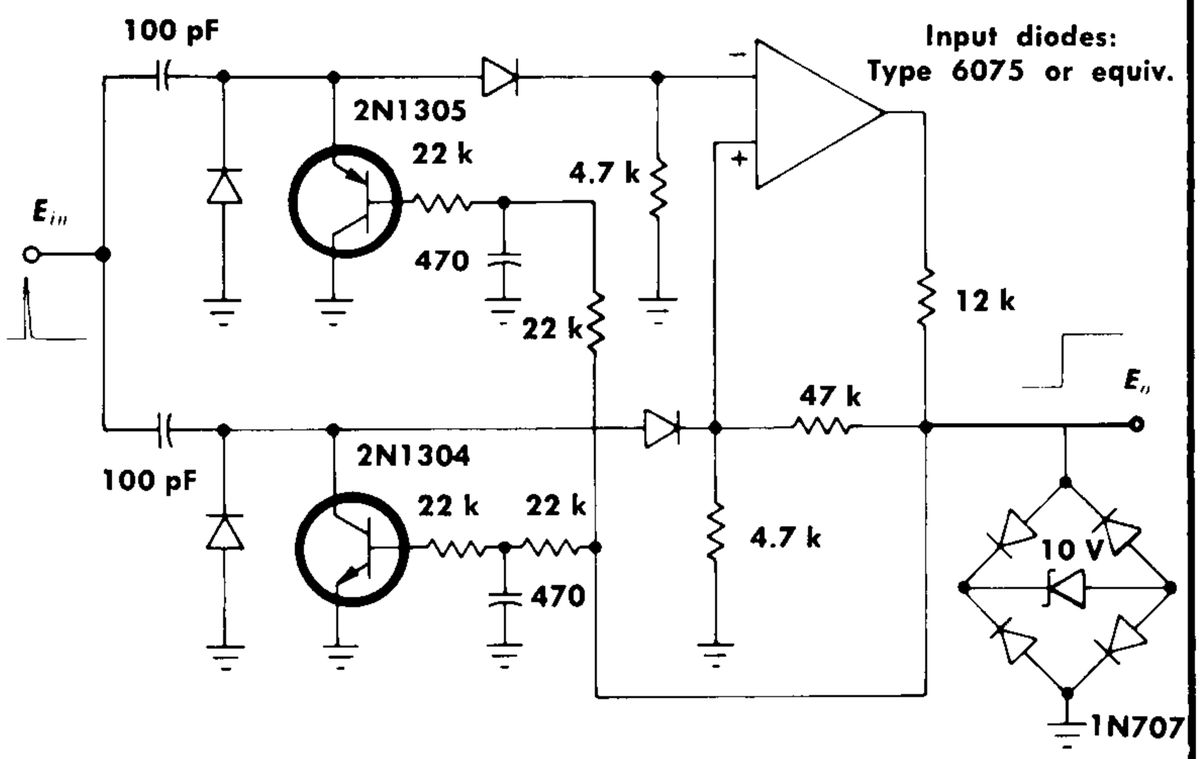
### Bistable Multivibrator (single input)




### Bistable Multivibrator (two inputs)



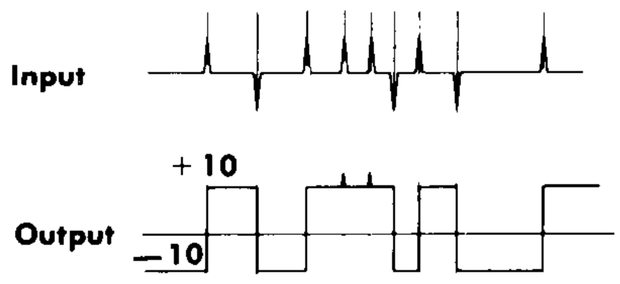

### Bistable Multivibrator (÷ 2, unidirectional input)



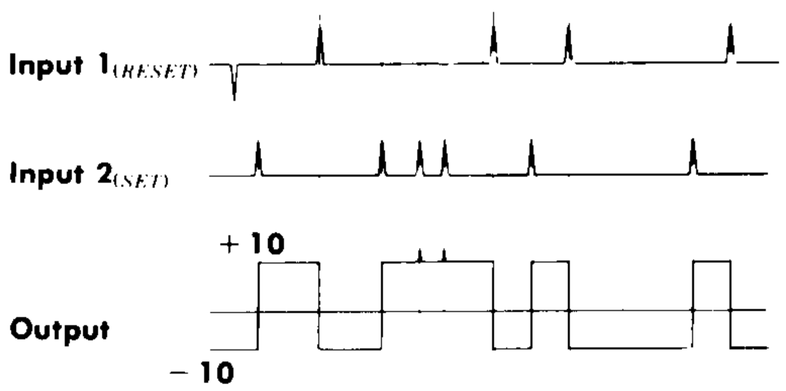

4-6045

## Notes

Output flips to ± 10 V when an opposite-polarity pulse arrives. Once flipped, additional pulse of the same polarity have no effect:

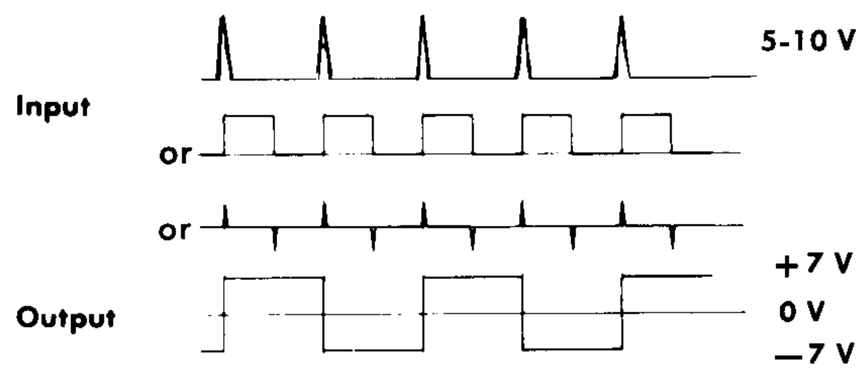



AC (pulse) toggle switch action can be obtained.




$$\text{Input amplitude} > \frac{\text{Eox10 k}}{\text{110 k}} + (2 \times 0.7\ \text{V})$$

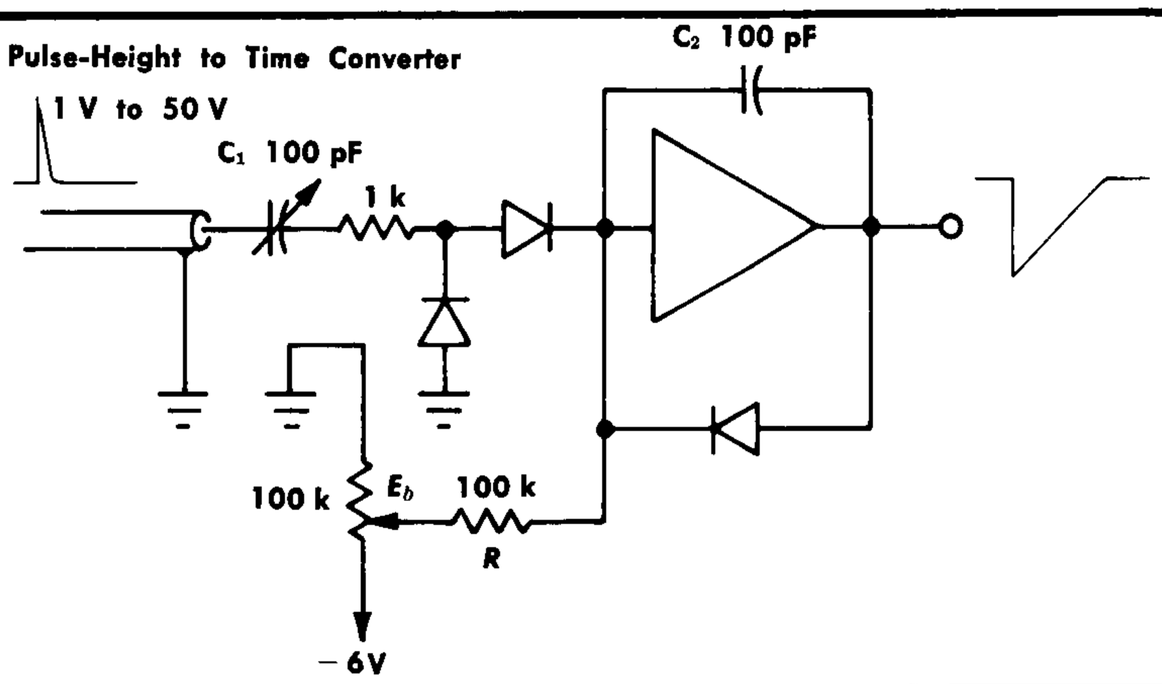
Transistors perform steering function to provide ÷ 2 action. Lag time-constant in transistor base circuits is selected for application.



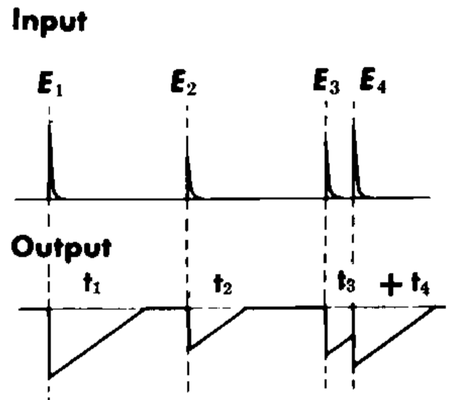

Transistors may be any moderately fast complementary pair (see appendix).

## Digital Conversions

### Pulse-Height to Time Converter

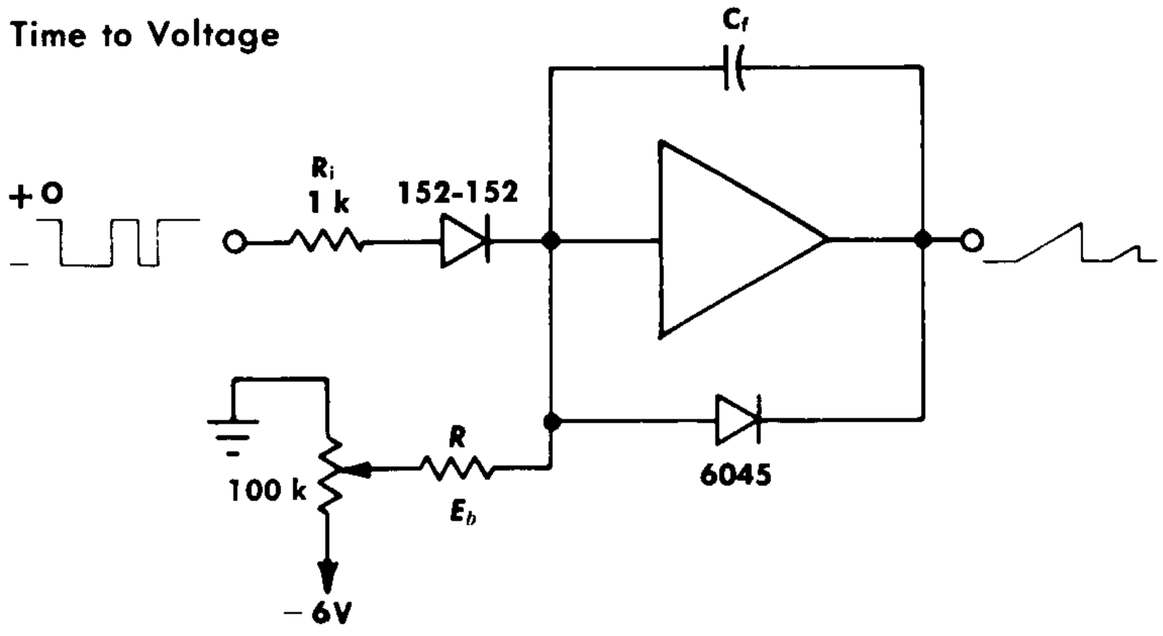



With a positive input pulse, $C_1$ and $C_2$ charge, causing the output to step down. This voltage is discharged by the integrator.

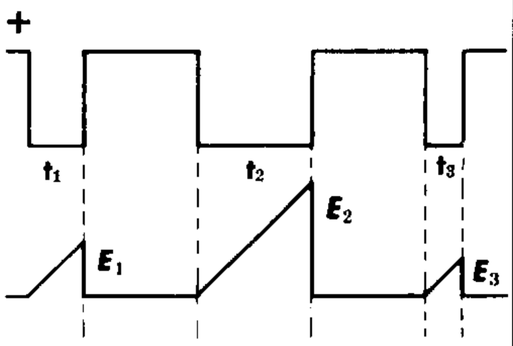



$$t \cong \frac{RC_1}{E_b} E_{pulse}$$

### Time to Voltage

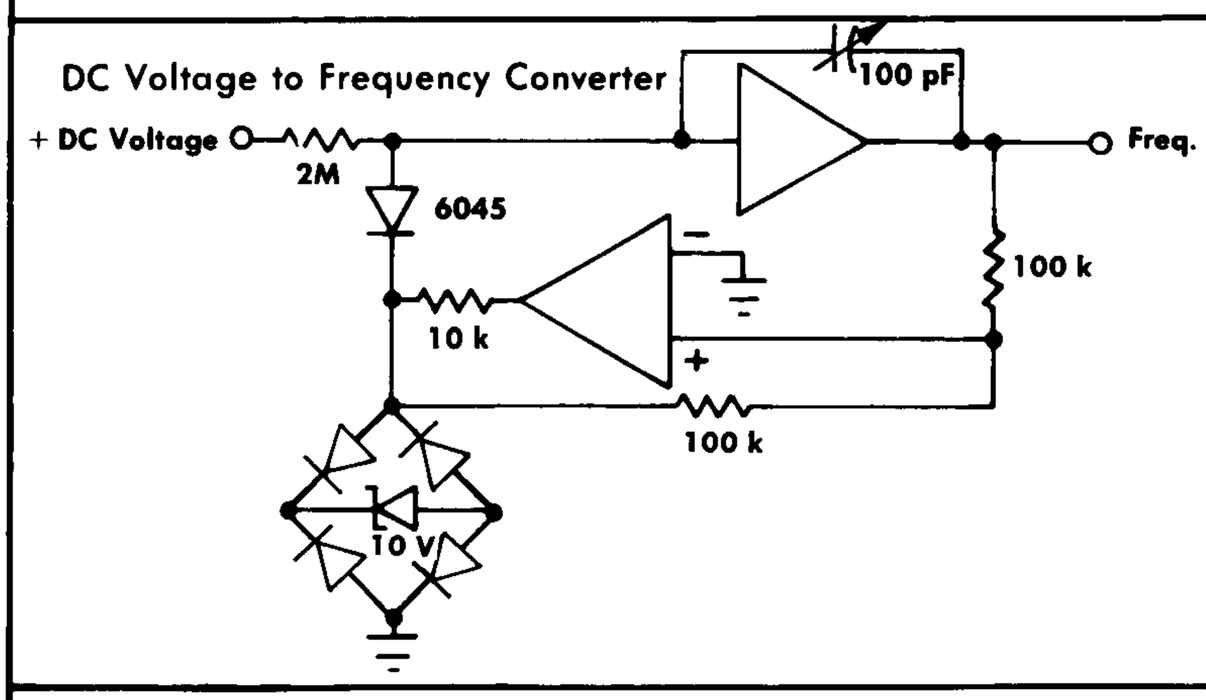



A input gate opens the diode, allowing the integrator to integrate at a constant rate. The ramp amplitude is thus proportional to the time.

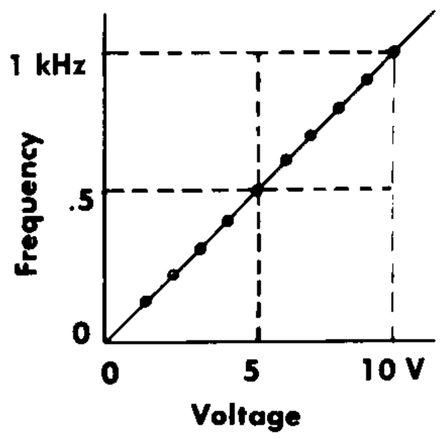



$$E \cong \frac{E_b}{RC} t$$

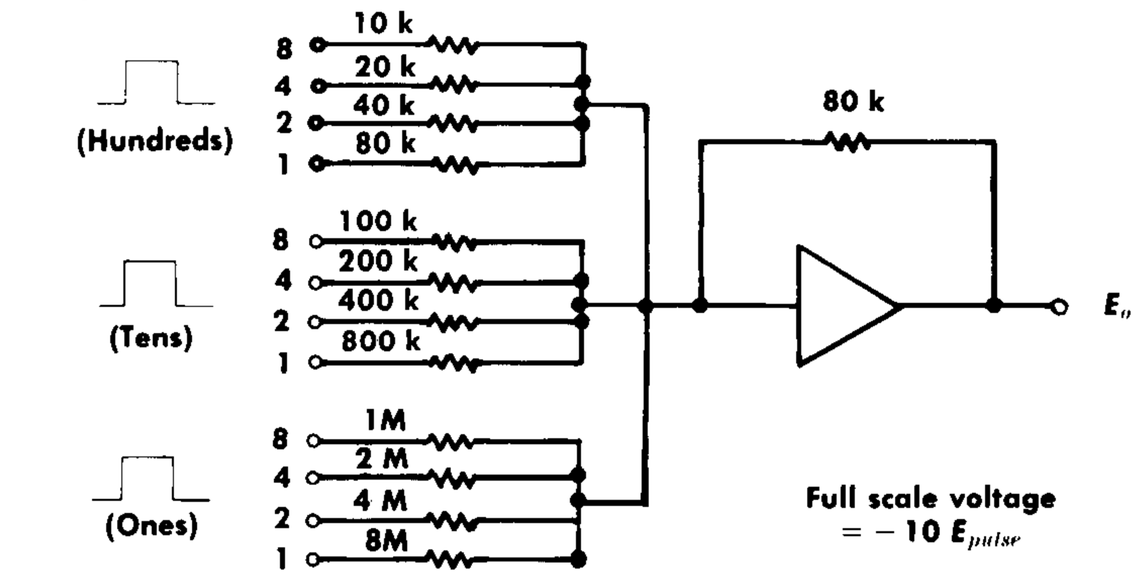
### DC Voltage to Frequency Converter




This will provide a conversion factor of approximately 1 kHz per 10 volts input.




### Binary to Voltage Converter



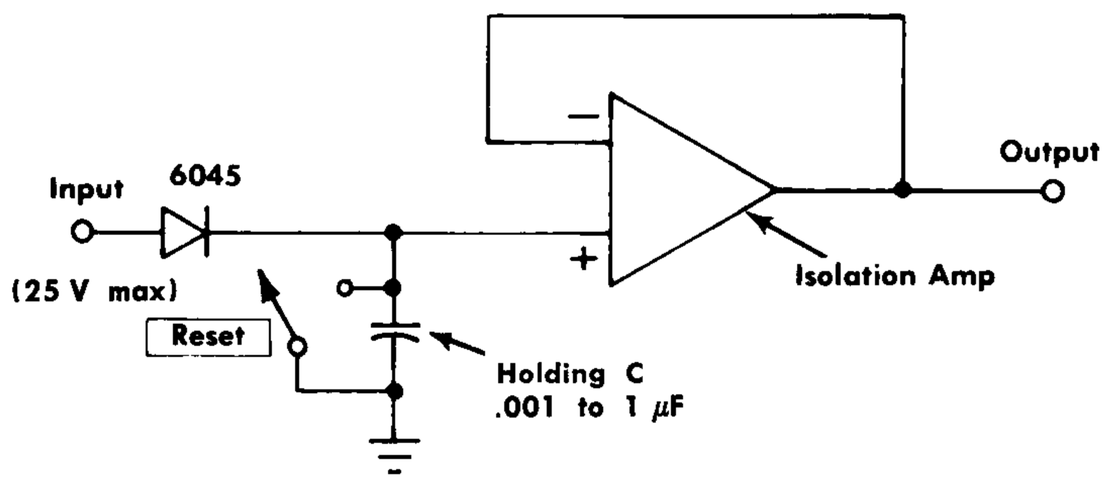

Simple binary (BCD) to voltage conversion is accomplished by summing input pulse voltages through the properly weighted input resistors.

If input pulse is —1.0 volts, the full scale voltage will be +9.99 volts.

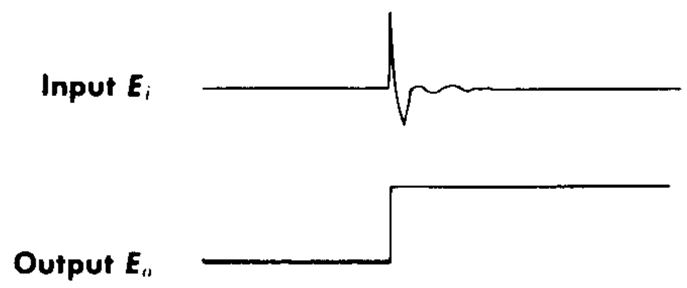
Gain error $= 1 - \frac{A}{A—1—16.65}$ if BCD signal source (esp. 'hundreds' signal) has low impedance.

## Peak Memory Circuits

### Basic Circuit

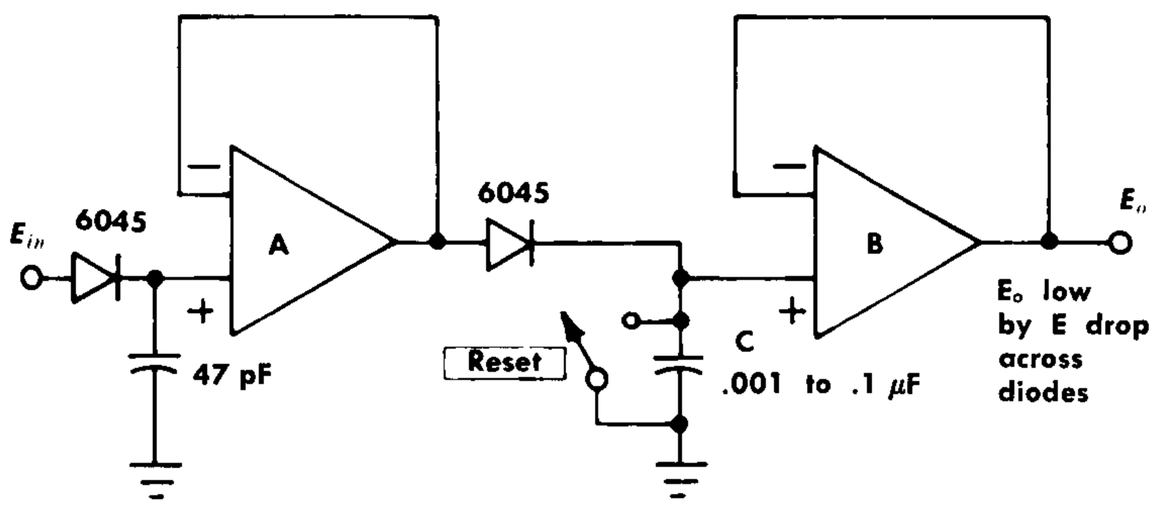


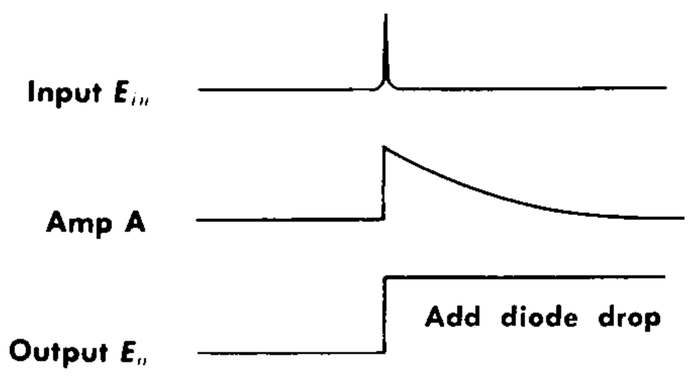

### Notes




The holding capacitor is charged through a low-leakage diode. Since the leakage of the diode (1 nA) and grid current (.5 nA) are low, voltage $E_o$ can be held a relatively long time. Limited by source Z, forward R of diode.

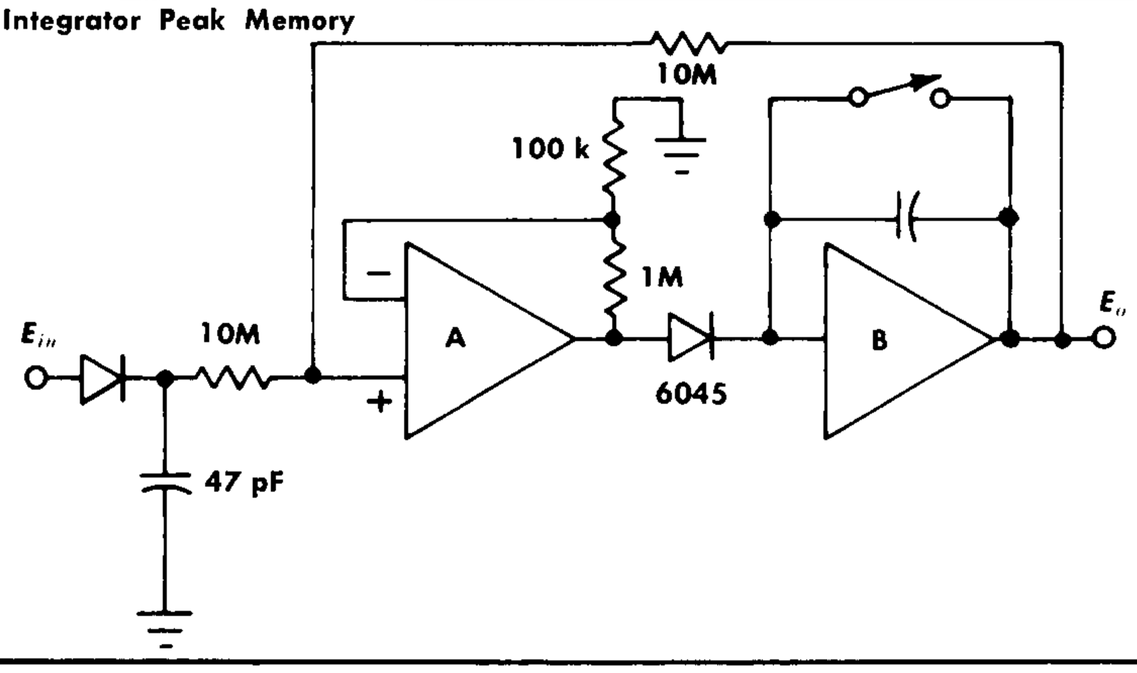
### Fast Response Peak Memory Amp.




Two amplifiers cascaded will reduce input loading.

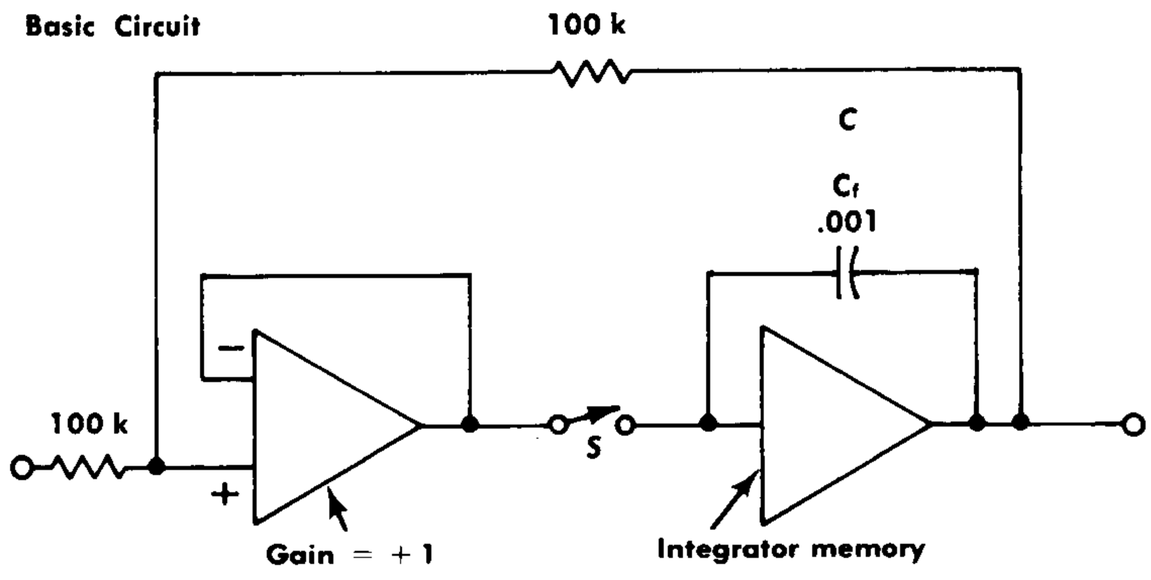
### Integrator Peak Memory




Integrator is used as memory to improve dc accuracy.

## Sample-Hold Amplifier

### Basic Circuit

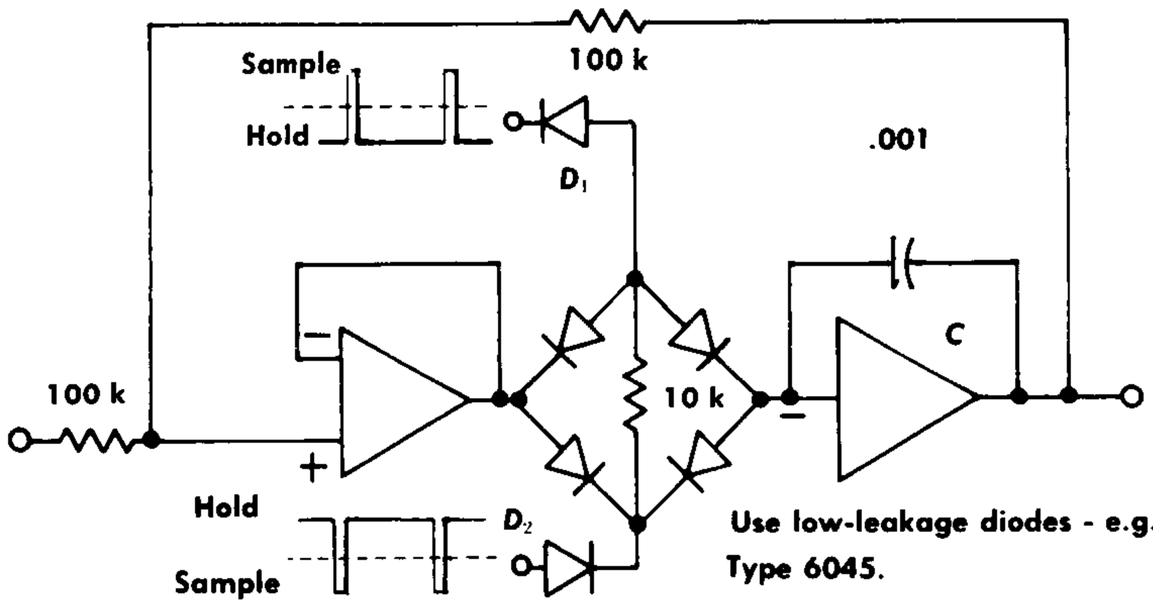



S - switch momentary close to sample

(Illustration of sample hold circuit.)

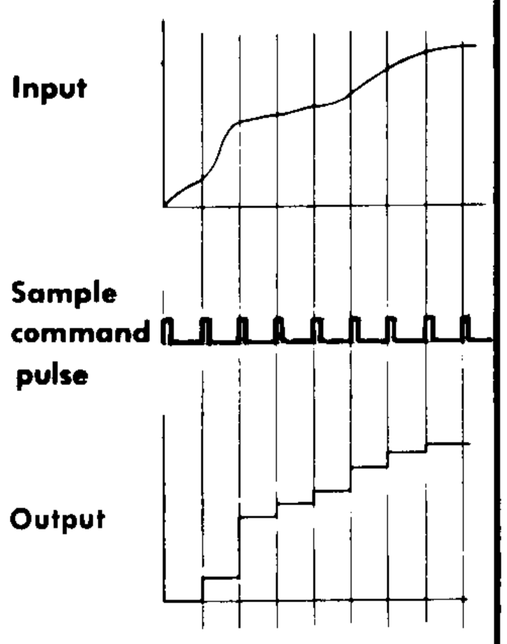
This circuit is often called **integrator memory:** When the switch is closed the capacitor is charged by the first amplifier. When the switch opens the integrator holds the voltage until the switch is closed again.

### Sample Hold amplifier (Passive gate)

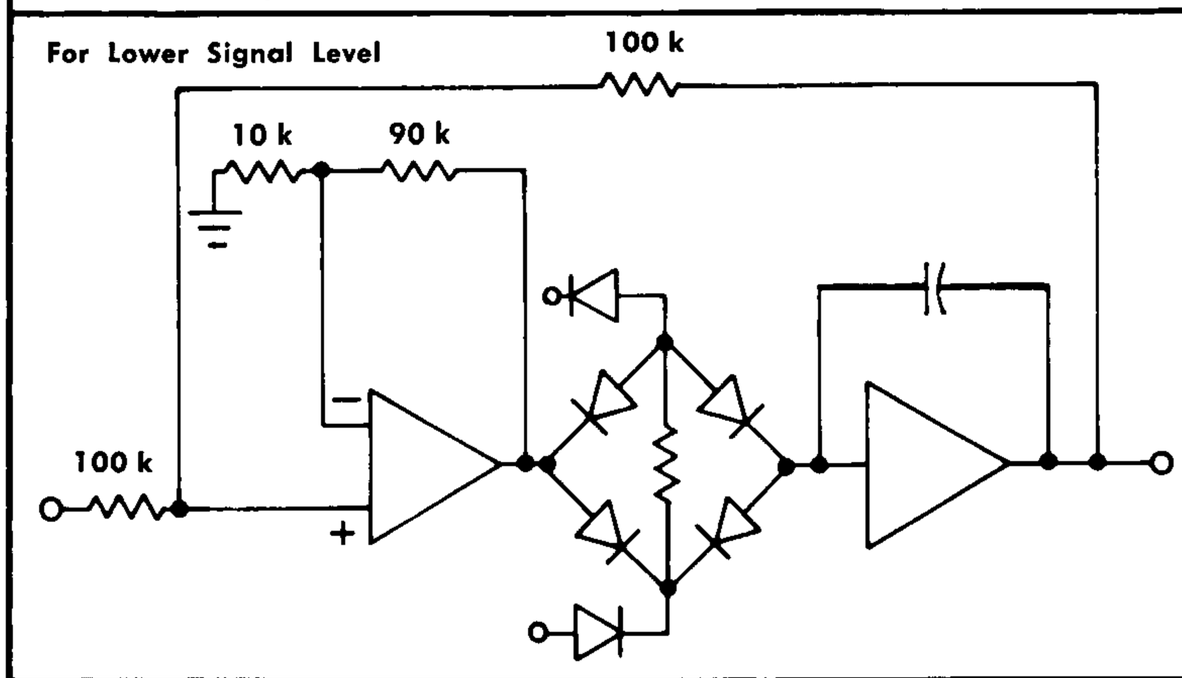



Use low-leakage diodes - e.g., Type 6045.

Passive gate provides output of $E_{in} - 2E_d$ for each sample, where $E_d$ is forward drop of gate diodes. Advantage of passive gate is that "sample" command + and — pulses need not be perfectly balanced since $D_1$ and $D_2$ simply disconnect during "sample" time.

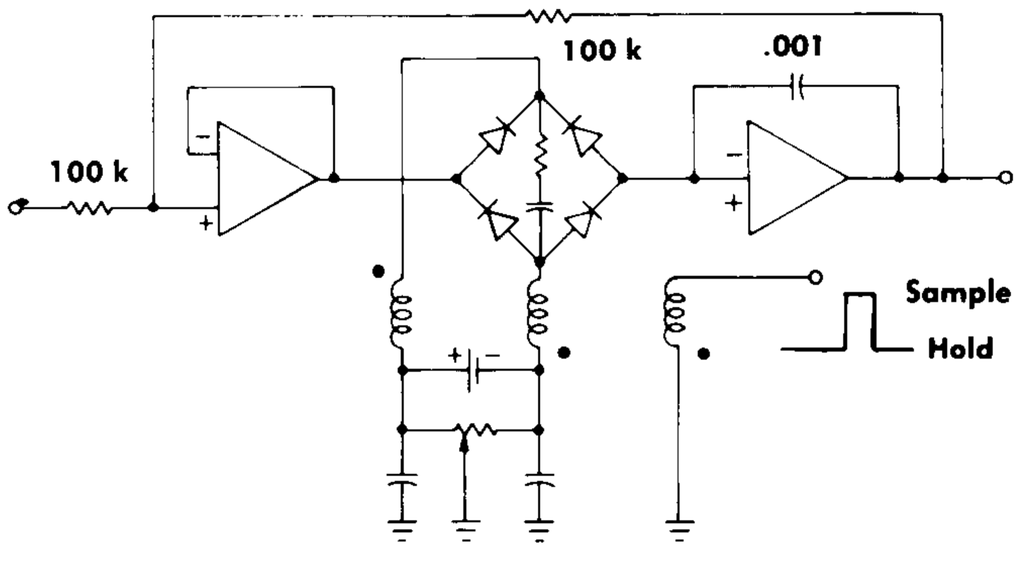



### For Lower Signal Level



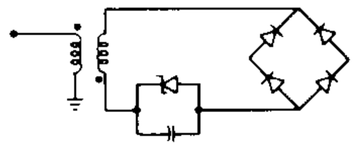

If diode forward drop is significant in the circuit above, gain may be added to input amplifier to minimize this effect.

### Driven Gate




As above, but battery provides "hold" voltage; balanced "sample" pulse obtained via pulse transformer. Battery voltage must be greater than expected input voltage; "sample" command pulse larger than battery voltage.

Battery may be eliminated if sampling rate is high and hold time is not long:

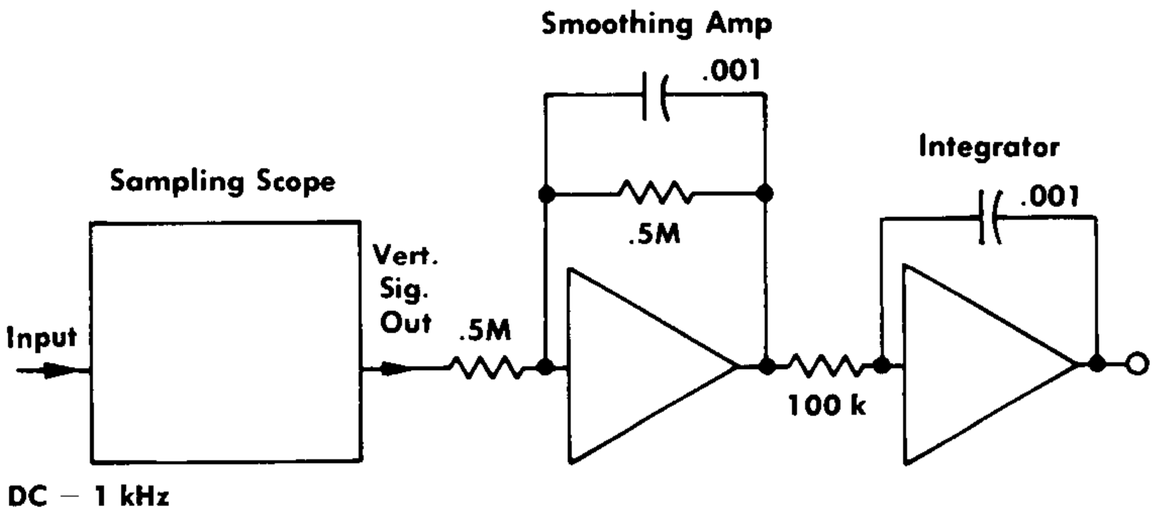


$E_{Zener} > E_{in}$ **max.**

# SAMPLING OSCILLOSCOPE TECHNIQUES

## Processing of Equivalent-Time Signals In Real Time.

### Sampling Integration

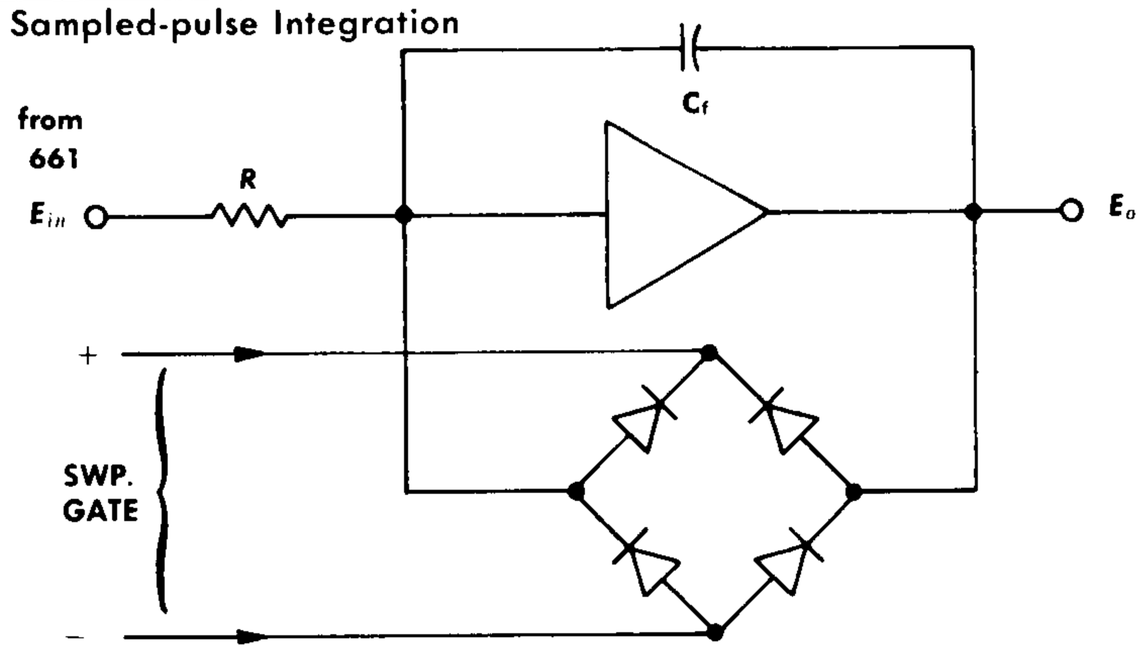



Notes

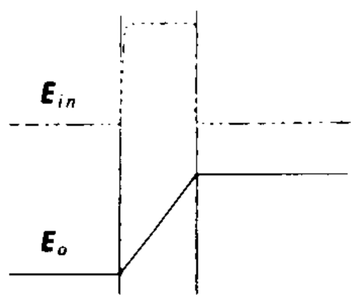
Sampled-data contains many high frequency components as well as desired lower frequency signals. In many operations, it may be necessary to insert a smoothing amplifier before the linear operation. It is possible to integrate a repetitive signal to approximately 1 GHz using sampling scope vertical signal out.

For differentiation and integration it may be necessary to drive the sampling oscilloscope horizontal with a slow external ramp to force a fixed real-time equivalent-time scaling factor (See Appendix).

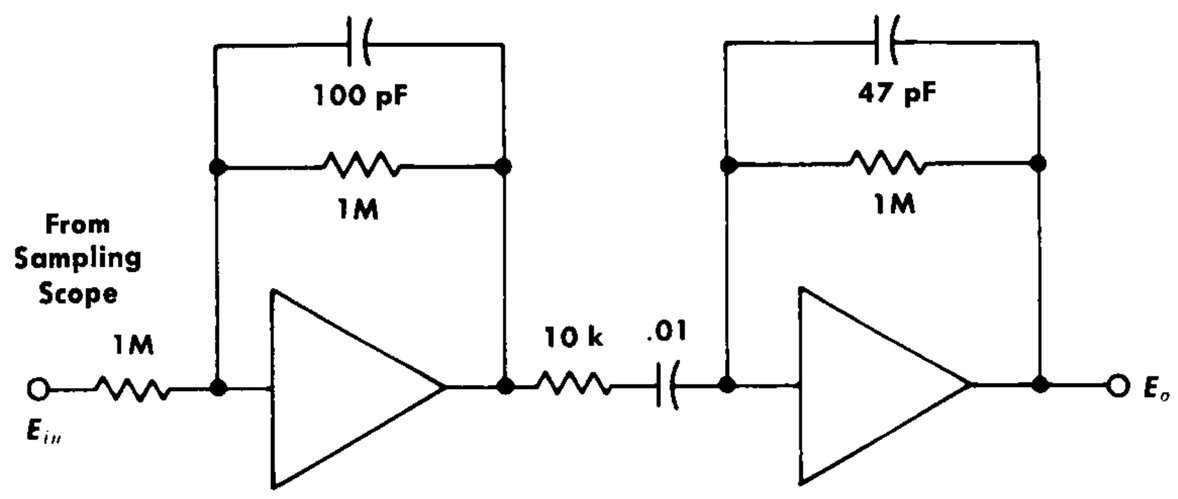
### Sampled-pulse Integration




Sampled-pulse may be integrated to obtain area of the pulse in volt seconds. Proper scaling factor to convert real time to sampling time is necessary; real - to equivalent-time ratio must be held constant. For details of gating circuit, see gated integrator.




### Sampled-pulse Differentiation

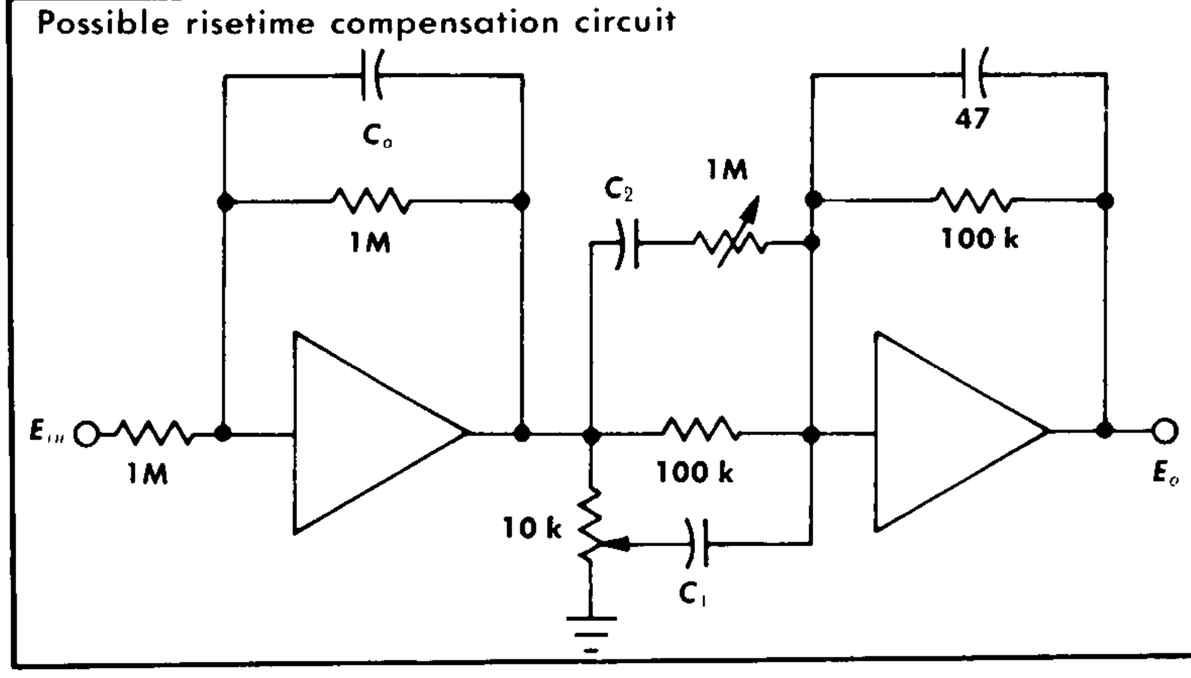



Differentiation of sampled pulse may be performed after passing the sampled signal through a smoothing amplifier.

Additional H.F. limiting circuit is necessary in differentiation. Here again, time-scaling factor must be held constant in sampling oscilloscope.




### Possible risetime compensation circuit

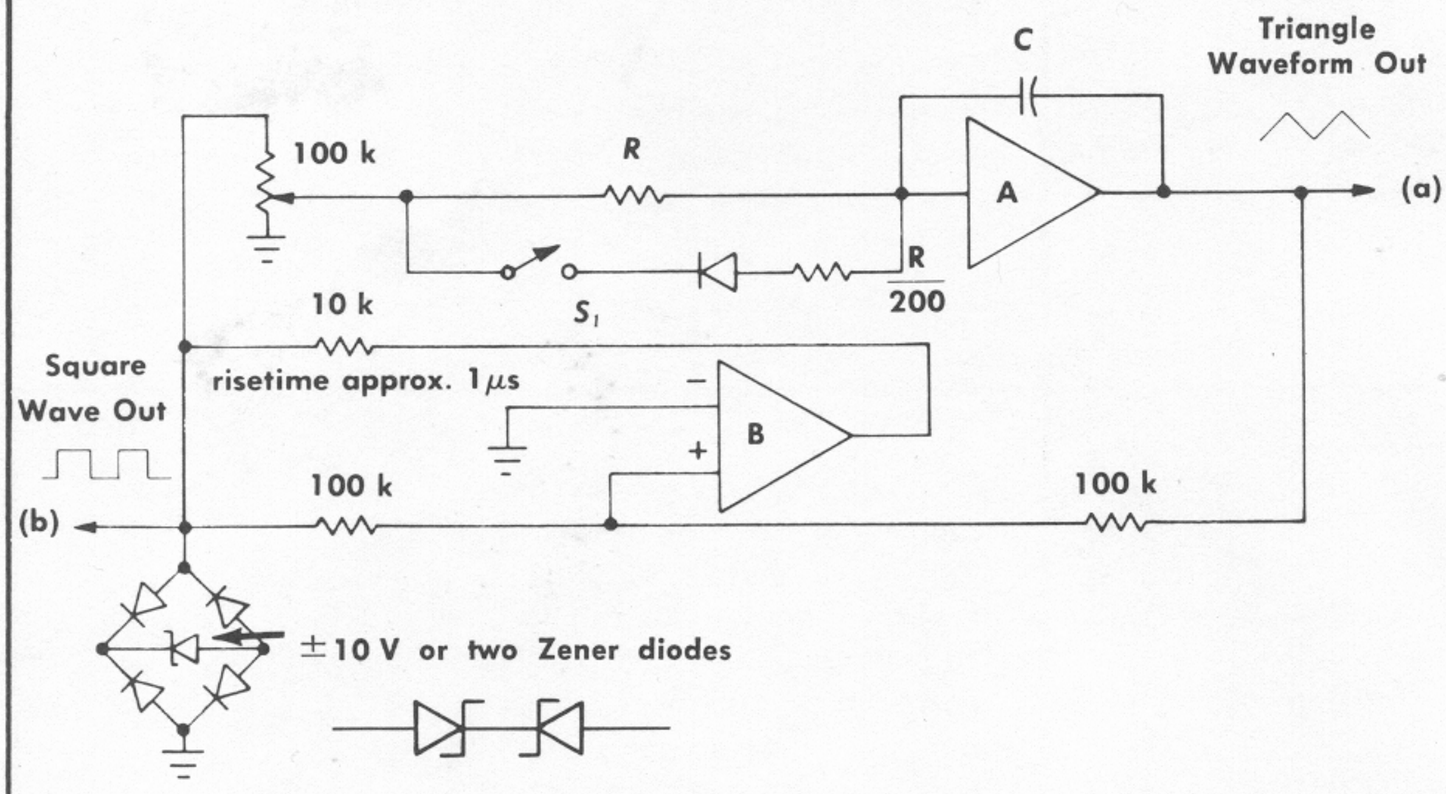



This circuit can provide possible risetime improvement, however this type of compensation is applicable only to a given frequency and a given sweep speed.

# WAVEFORM GENERATION

## L. F. Function Generators

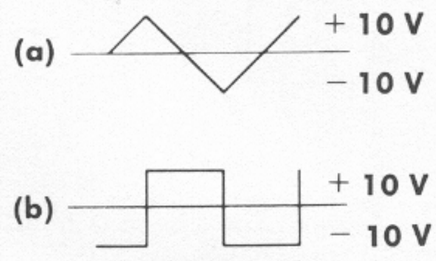
### Triangle, Square, Sawtooth Pulse and Generator




### Notes

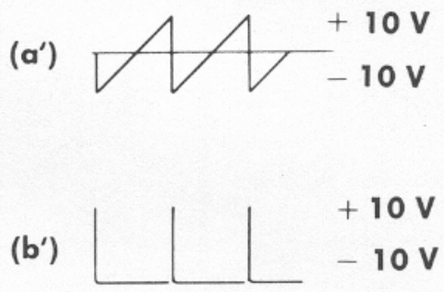
Combining an integrator and a bistable comparator, precise low frequency waveforms can be generated. Operational amplifier B is working as a bistable comparator which switches when input reaches + or − 10 volts for ± 10 volts square wave output.

**Normal waveforms at (a) and (b) are**



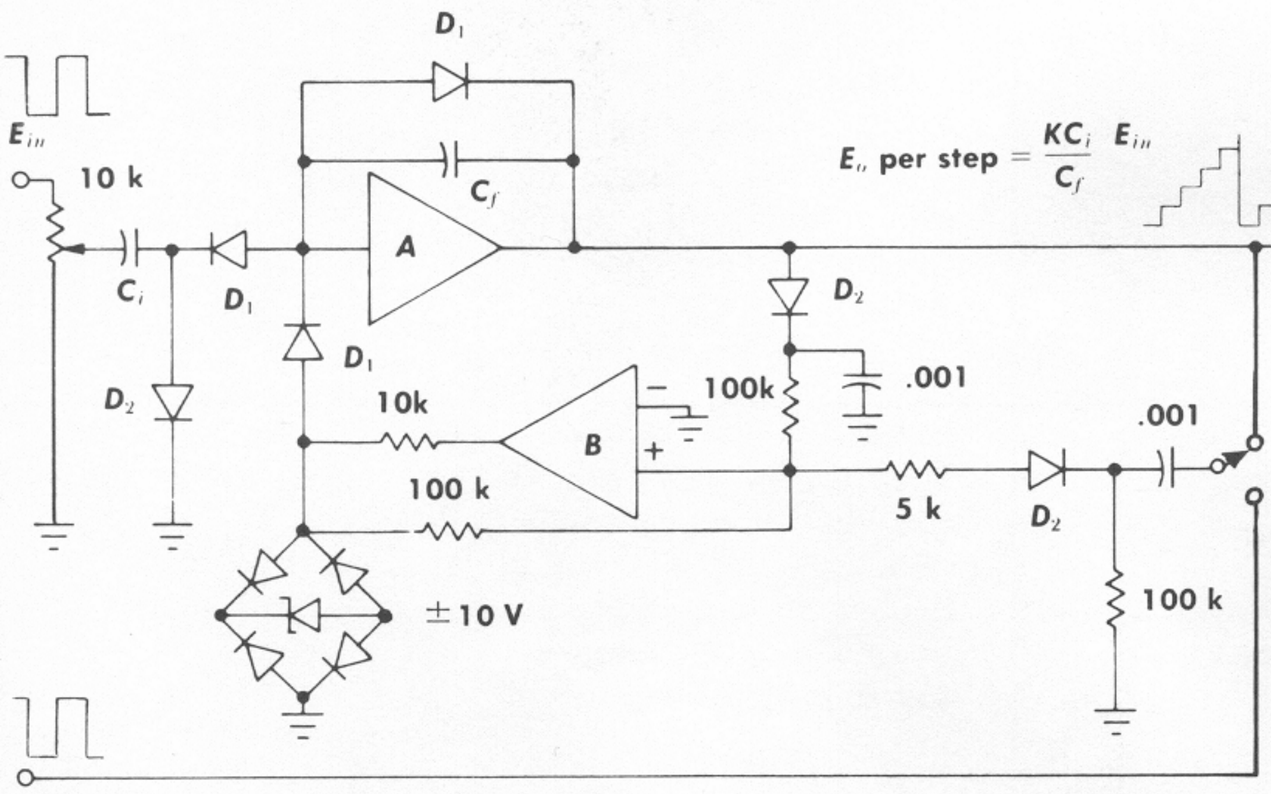

$$f = \frac{1}{4RC}$$

**When switch $S_1$ is closed,**




$$f = \frac{1}{2RC}$$

### Stair-step Generator

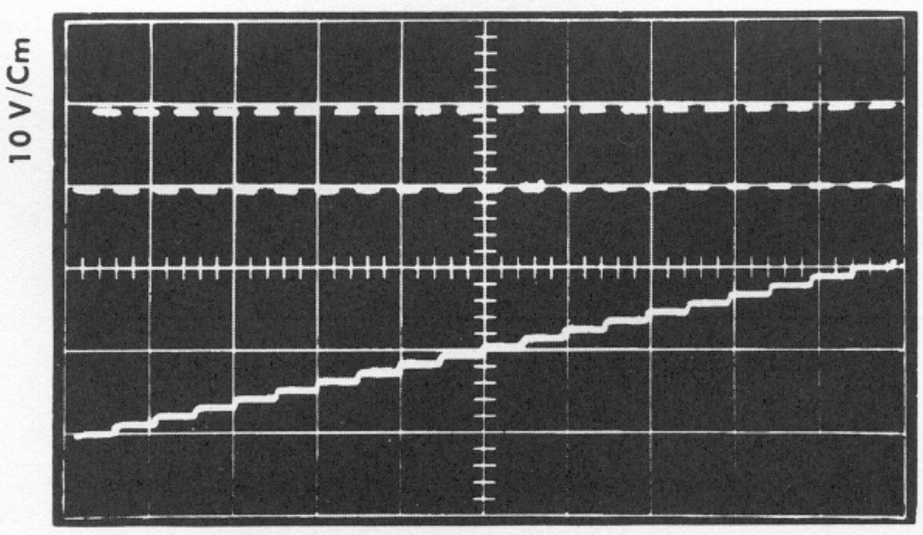



Ext Trig. (Single trigger should be negative going)

$D_1$ = very low leakage silicon diodes (Type 6045 or equiv.)

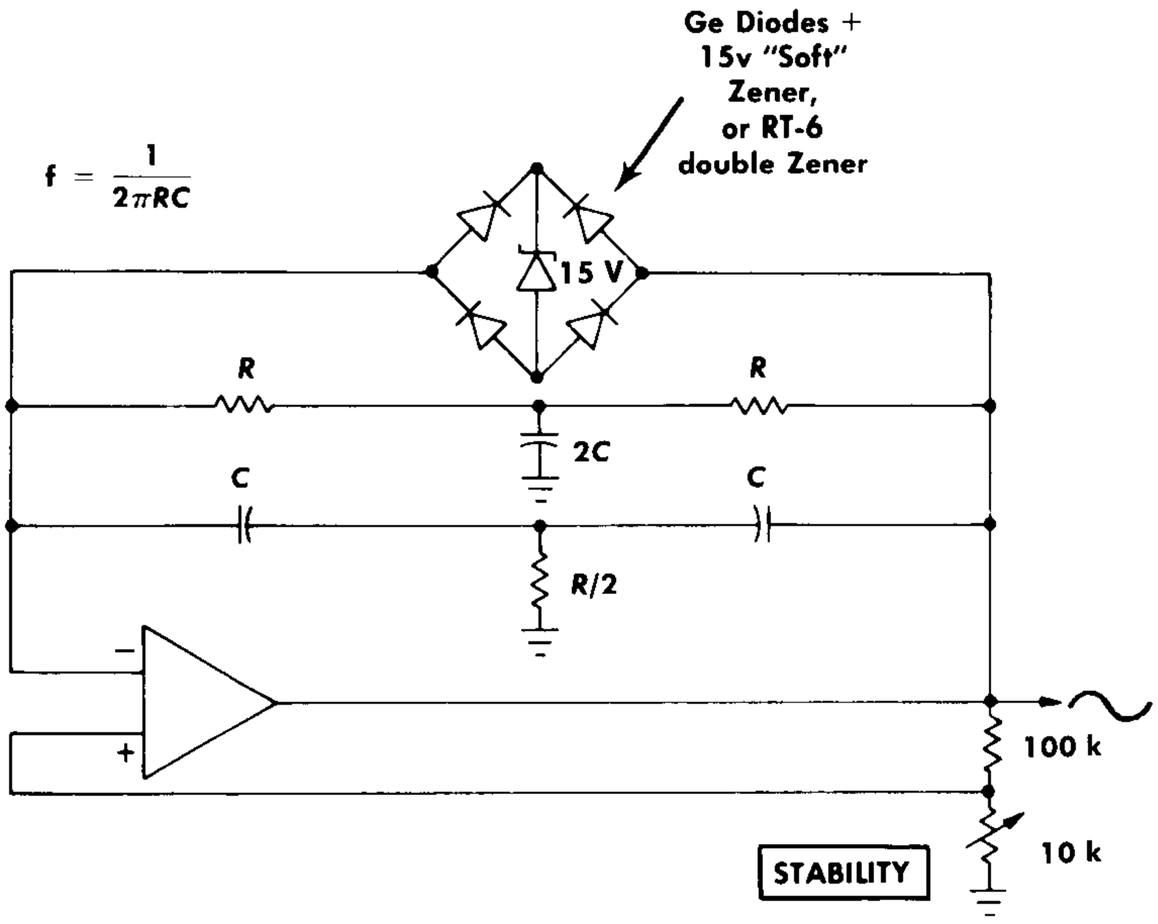
$D_2$ = Any signal diodes (T12G or equiv.)

This arrangement provides a convenient laboratory stair-step generator. In applications such as pulse rate countdown, transistor base drive, or pulse-controlled time base. Amplifier A operates as a pulse integrator and amplifier B functions as a bistable comparator. Through use of the trigger selector switch, the circuit can operate in either a repetitive or triggered mode.




STAIR-STEP Generator 5 V/cm  Sweep 2 msec/cm

## Sine Wave Generators




## Notes

A very low frequency sinewave can be generated with twin 'T' filter network in the feedback loop of an operational amplifier. Positive feedback is provided to sustain oscillation. Amplitude is controlled by the nonlinear impedance of Zener diode in the negative feedback. Adjust STABILITY control for stable output and best waveshape.

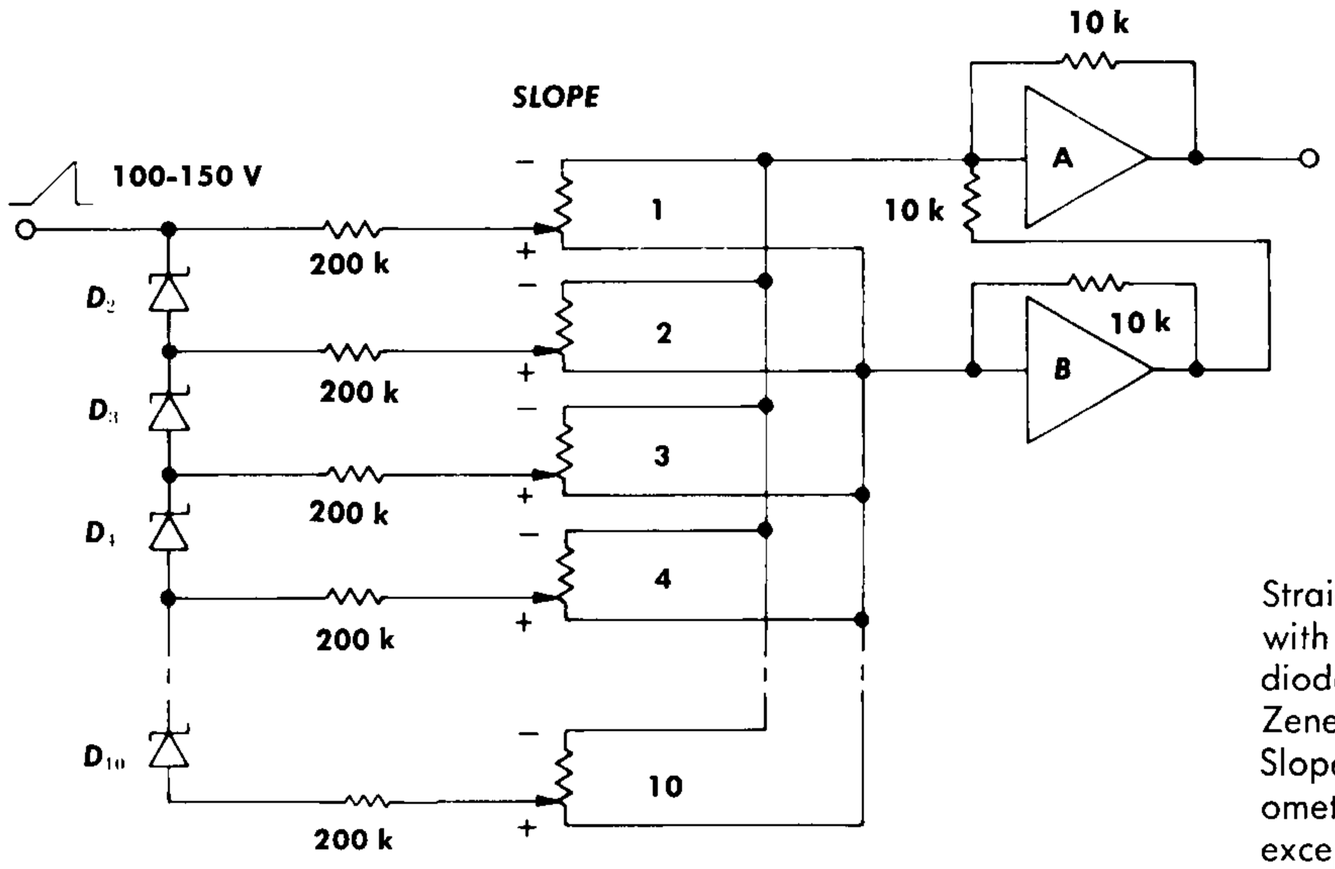
(c)


$f = \frac{1}{2\pi RC}$

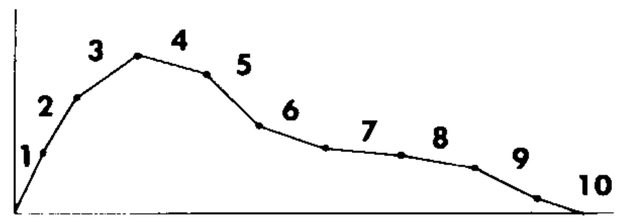
Zener type should be selected for a gradual ("soft") knee. If an output amplitude of 4v p-p is adequate, Type RT-6 double Zener may be used to replace bridge circuit. Reject Zener diodes (High dynamic impedance) often work quite well.

## Arbitrary Function Generators

### Segments Function Generator

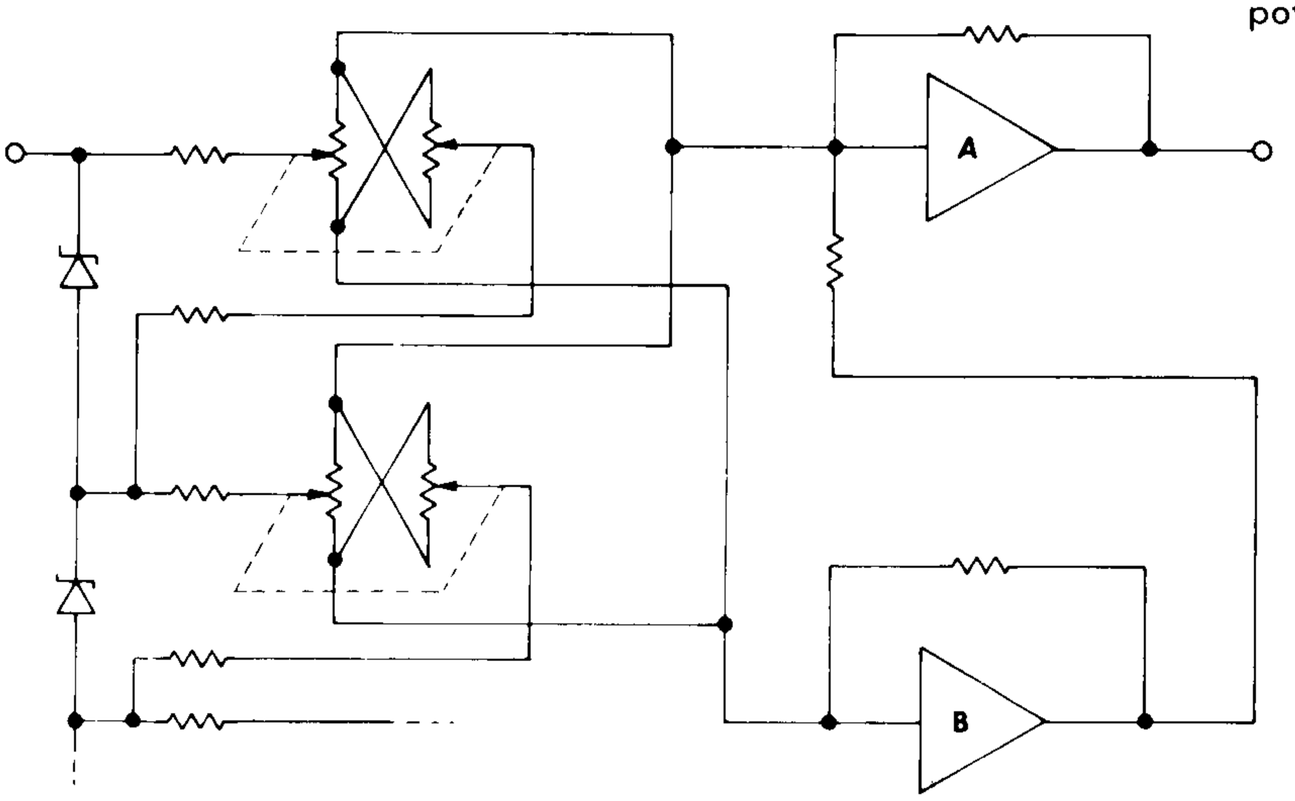



**9 Diodes, $D_2$ to $D_{10}$ are 12 to 15 V Zener diodes For 100 V sawtooth, use 8-10 V Zener diodes.**




Straight line approximated function can be generated with the aid of Zener diodes and potentiometers. Zener diodes are normally cut-off. As sawtooth is applied Zener diodes start conducting at even voltage intervals. Slope of each segment is adjusted by the potentiometers. Note that no external voltages are required, except the sweep sawtooth.

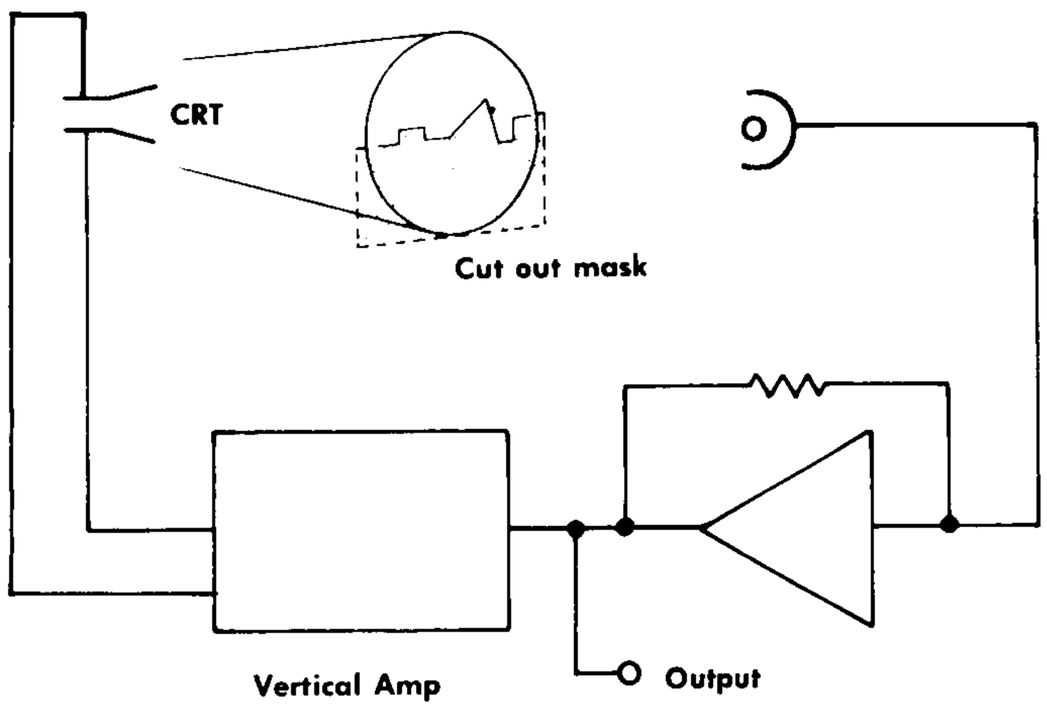
### Segments Function Generator (Independent Segments)



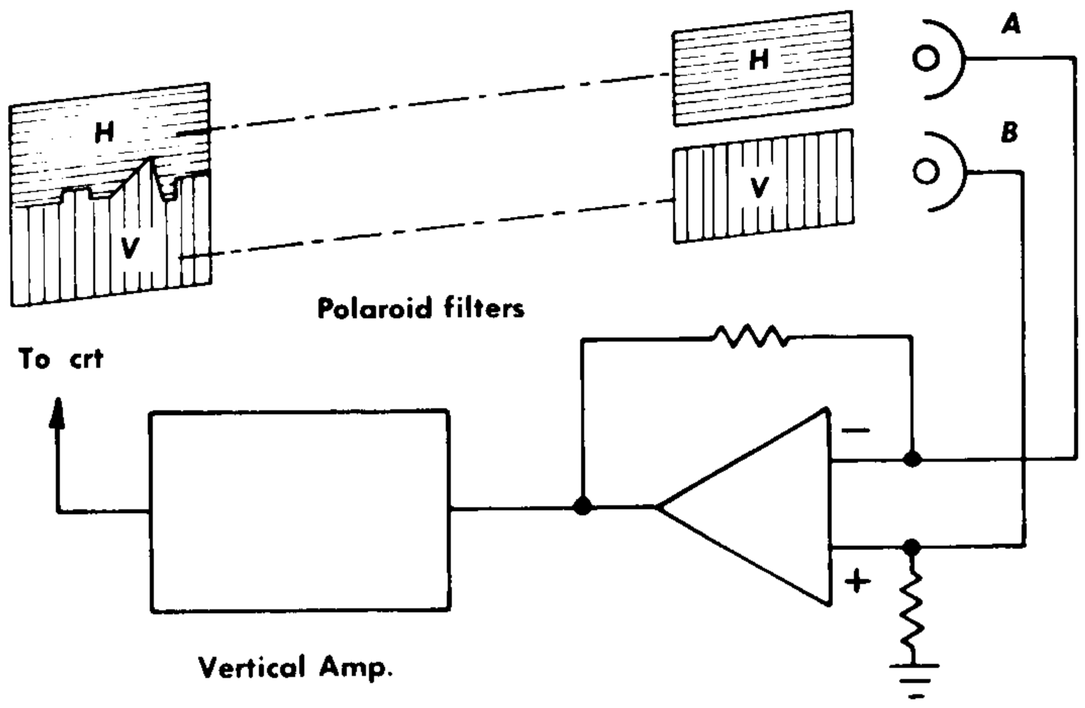

Segment slopes in the above circuit are additive. To obtain more independent adjustment of segments 2-10, cancelling signal is fed back to earlier-segment potentiometers.

## Arbitrary Function Generators—Optical Techniques

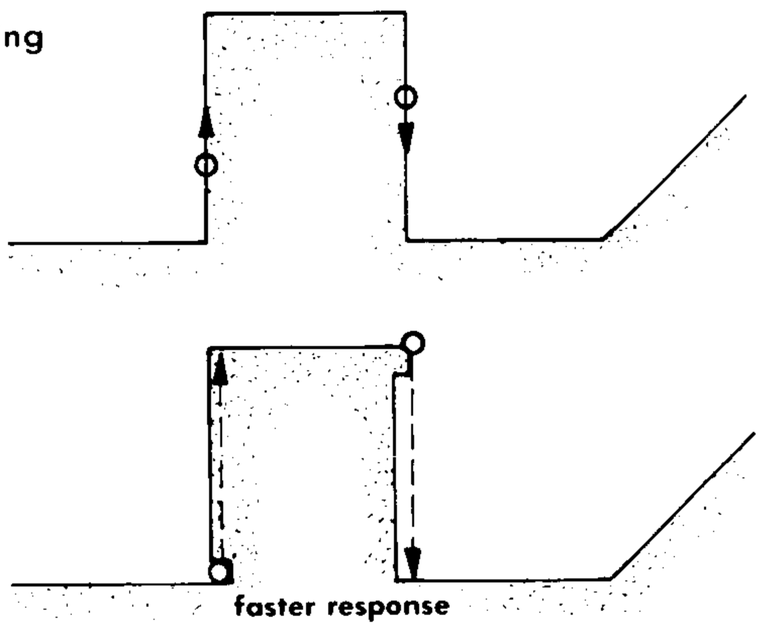
### Simple System




### Differential Fast System




### Mask Cutting




### Notes

A light sensitive element is placed in front of the crt and the mask. If the beam is above the mask, a negative signal will be produced to force the beam to move down. Normally the beam is positioned above the mask so the beam tries to go up; however, the light feedback does not allow the beam to show too much. As a result the beam follows the cut out mask. Dc coupled signal can be obtained at the output of operational amplifier.

With the simple system, spot size must be small to obtain good resolution. When operated at a low light level it will suffer in speed of response.

The differential system incorporates polaroid filter masks and two light sensing elements. Substantial improvement in speed and resolution may be expected.

When the beam spot is in H plane the light is sensed by light sensor A. B will not receive light since the filter is out of phase. The signal from A will force the beam to move down. If the beam spot is in V plane, it will be forced upward by B.

The light pickup is differential. The beam action is moved push-pull. With a cadmium sulfide photocell (Clairex CL-404), response is limited to the millisecond region. Faster response may be obtained from vacuum phototubes, phototransistors or photomultipliers. System is ultimately limited by oscilloscope delay phosphor risetime and decay, etc. (1 $\mu$sec response is probably the practical limit.)

**Suggested application:** integration or differentiation of photographed or drawn waveforms or shapes.

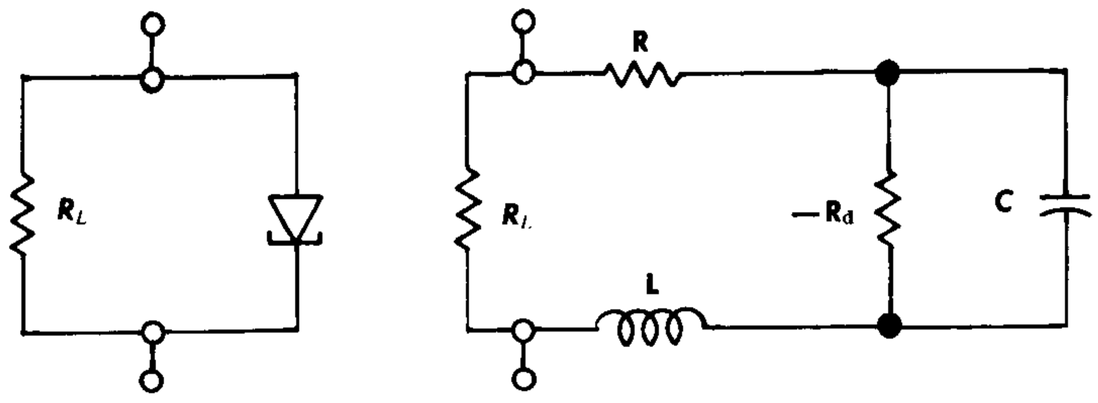
The mask can be under cut to improve response time. The polaroid filter may be cut by using a hot resistance wire; the temperature can be adjusted by controlling current.

# SEMICONDUCTOR STUDIES

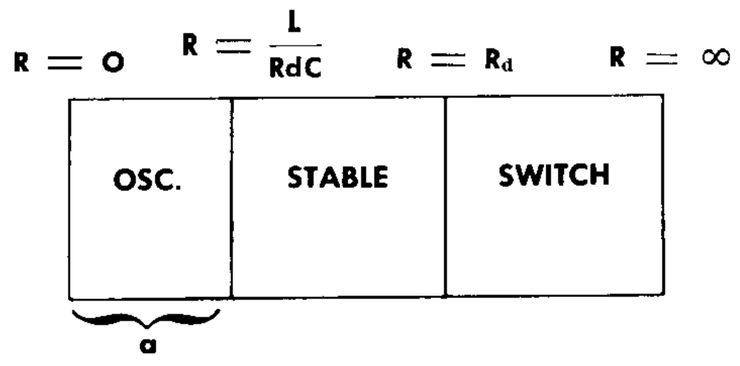
## Tunnel Diode Studies—Curve Tracing

### Notes

### Tunnel Diode Stability

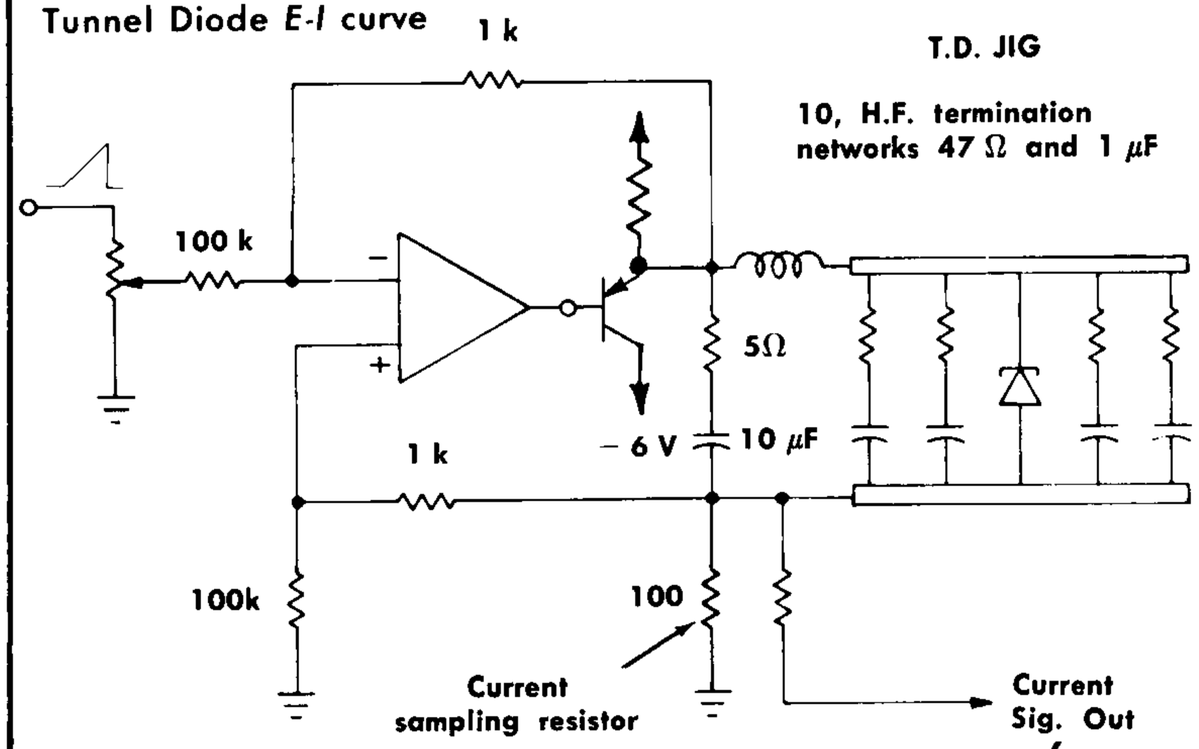



Tunnel diode stability criteria are given



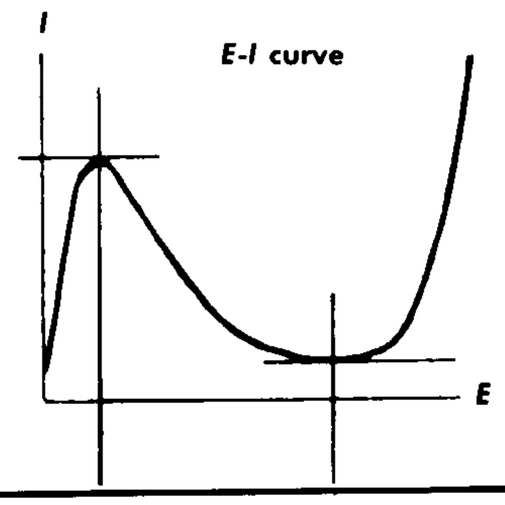

a. (can be made conditionally stable at low frequency)

### Tunnel Diode *E-I* curve

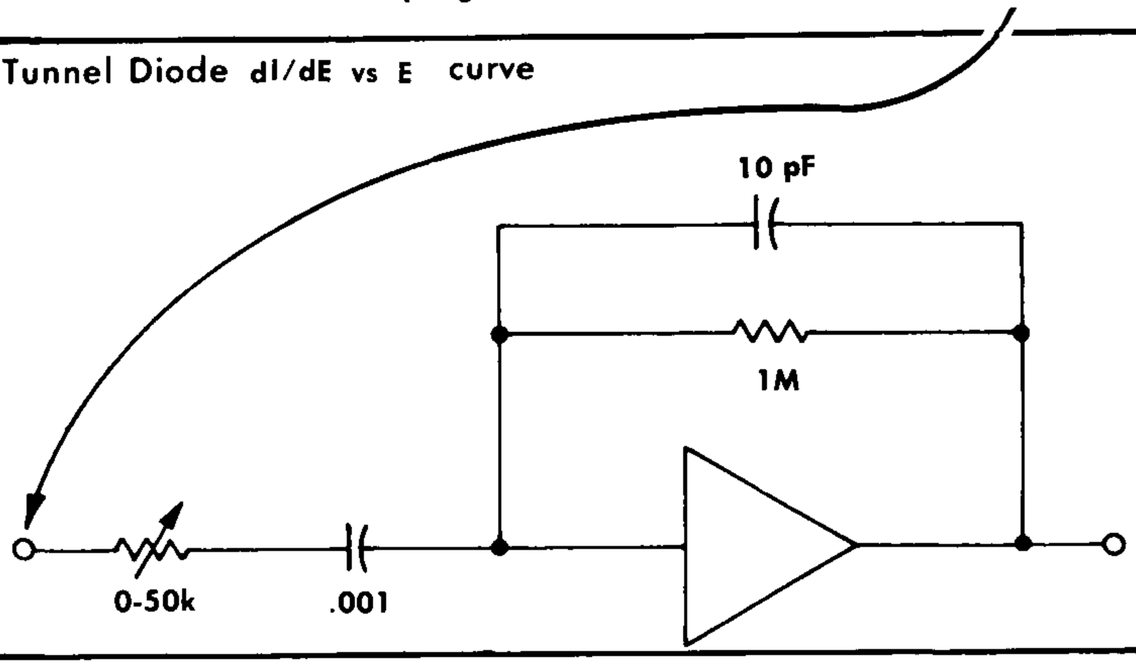



Operational amplifier with additional E.F. can drive tunnel diode with very low impedance.

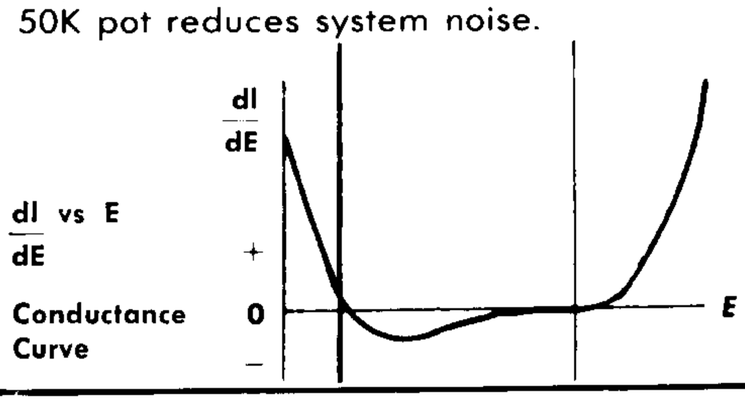
T.D. jig stabilizes diode at high frequency. Thus tunnel diode may be driven by very slow ramp.




### Tunnel Diode dI/dE vs E curve

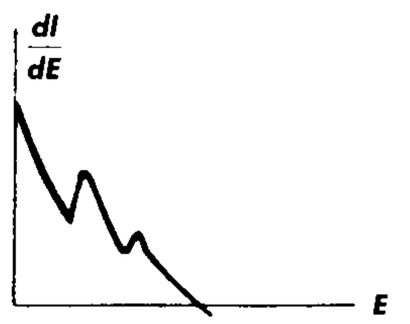



Linear drive of tunnel diode allows differentiation of current to obtain dI/dE curve, plotted against E (oscilloscope sawtooth). Input to differentiator is current signal output from curve-tracer above. 10pf capacitor compensates the differentiator; 50K pot reduces system noise.



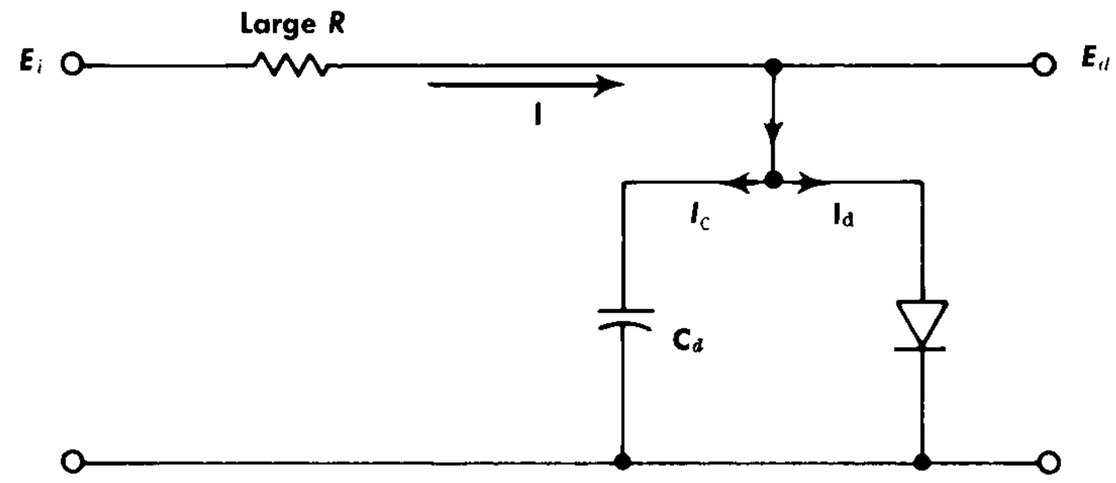

Tunnel diode quantum phenomenon may be observed at very low temperature.

Some tunnel diodes in liquid Helium indicate wiggles on the conductance curve.



## Tunnel Diode Studies, Switching characteristics

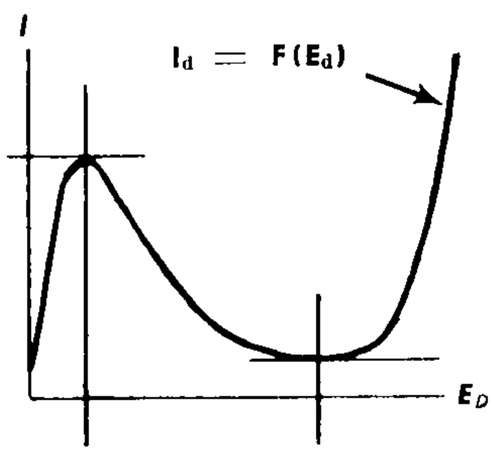
### Tunnel Diode Switching




$C_D$ = Equivalent diode capacity

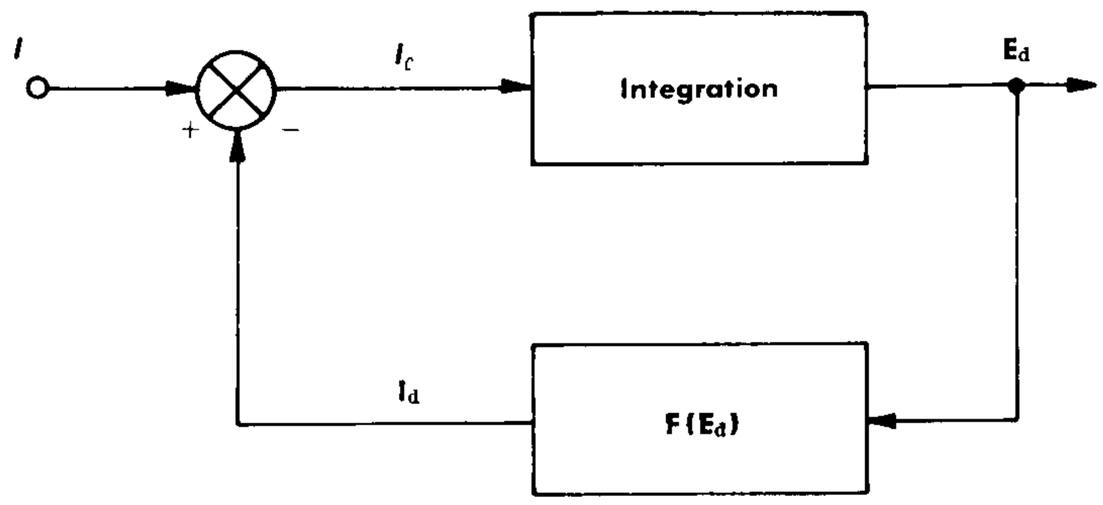
### Notes

Assumptions:
1) Lead inductance negligible.
2) Diode capacitance assumed constant.
3) Constant current applied to the diode.

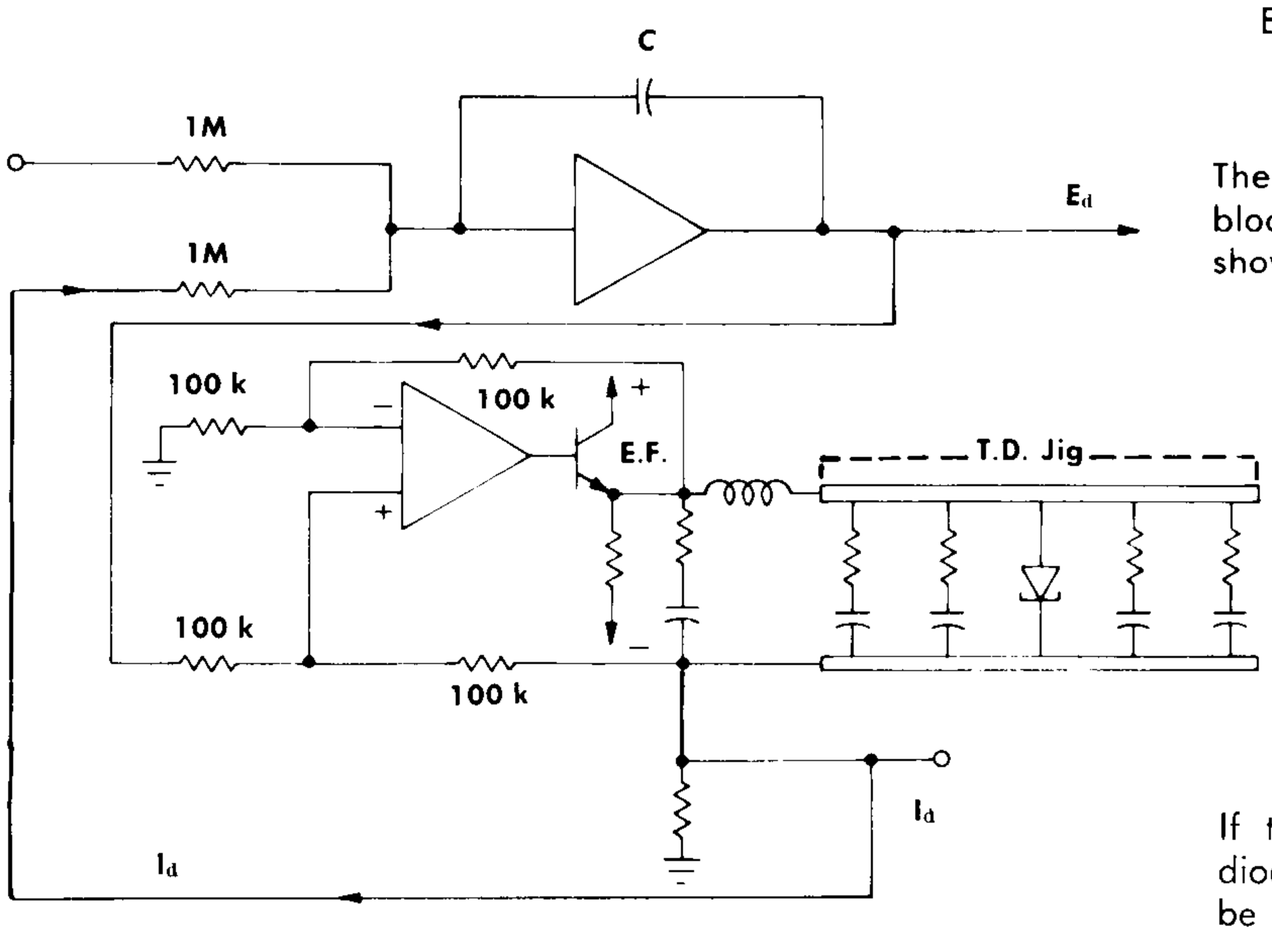



$I$ = applied current, $I_d$ = diode current.
$I_C$ = current to charge diode capacity

### Block Diagram




### Analog Solution of Risetime*




Summing all the current at the node of $E_d$, we have

$$I - I_c - I_d = \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

$$I_c = I - I_d \quad \ldots\ldots\ldots\ldots\ldots\ldots 1a$$

$$I = \frac{E_i - E_p}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

$$I_c = C_d \frac{dE_d}{dt} \quad \ldots\ldots\ldots\ldots\ldots\ldots 3$$

$$I_d = F(E_d) \quad \ldots\ldots\ldots\ldots\ldots\ldots 4$$

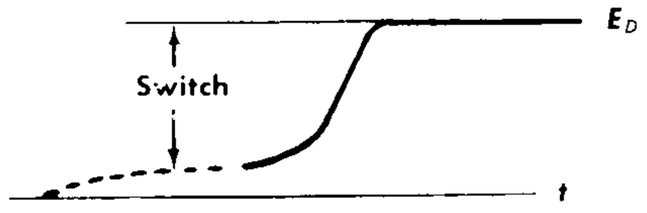
Integrating (3)

$$E_d = \frac{1}{C_d} \int I_c \, dt \quad \ldots\ldots\ldots\ldots\ldots\ldots 5$$

Subsituting eq. (1a)

$$E_d = \frac{1}{C_d} \int (I - I_d) \, dt \quad \ldots\ldots\ldots\ldots\ldots\ldots 5a$$

The equations (4) and (5a) are represented by the block diagram, and operational amplifier circuit is shown at left.

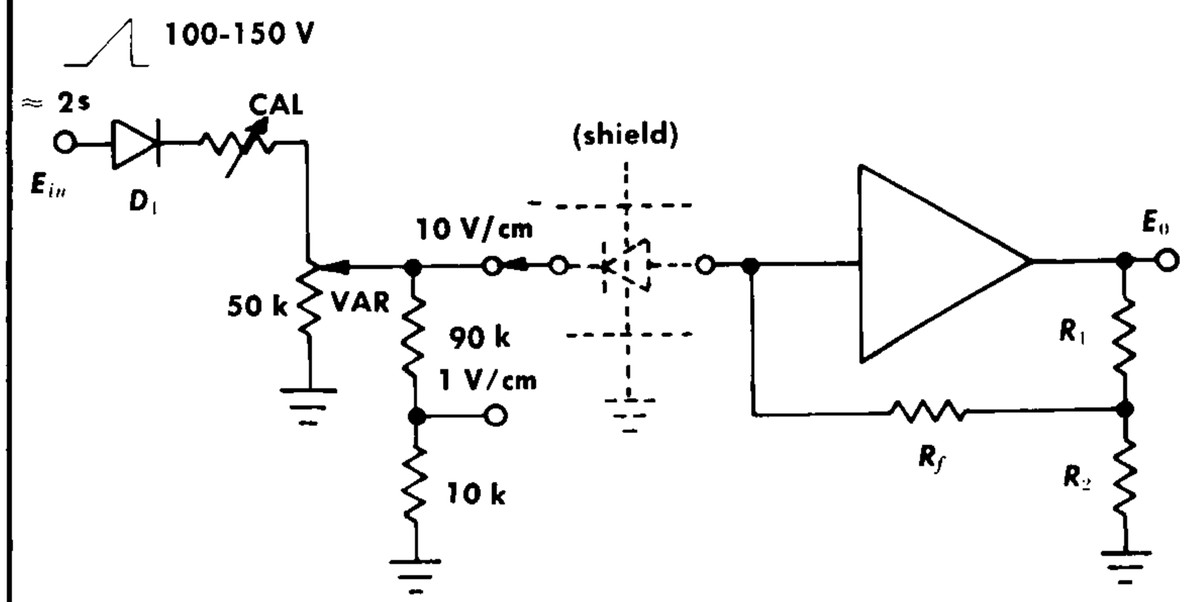



If the integrating capacitor C is chosen 0.01 $\mu$F for diode capacitance, $C_d$ 1 pF; the scaling factor will be 1 ns real time equal to 10 ms analog time.

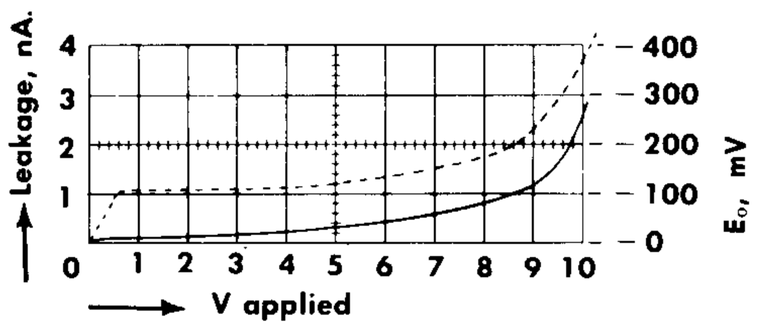
*It is possible to compute diode capacitance from diode switching time.

## Voltage-Current Conversions

### Semiconductor Leakage & Capacitance Measurement — Precalibrated Drive.




$$E_0 \approx -I_L R_f \left(\frac{R_1 + R_2}{R_2}\right). \quad \text{For } R_f = 10\text{ M}, R_1 = 90\text{ k}, R_2 = 10\text{ k}, E_o = 100\text{ mV/nA}$$




——— 200 ms/cm (Leakage)
– – – – – – 2 ms/cm (Capacitance + Leakage)

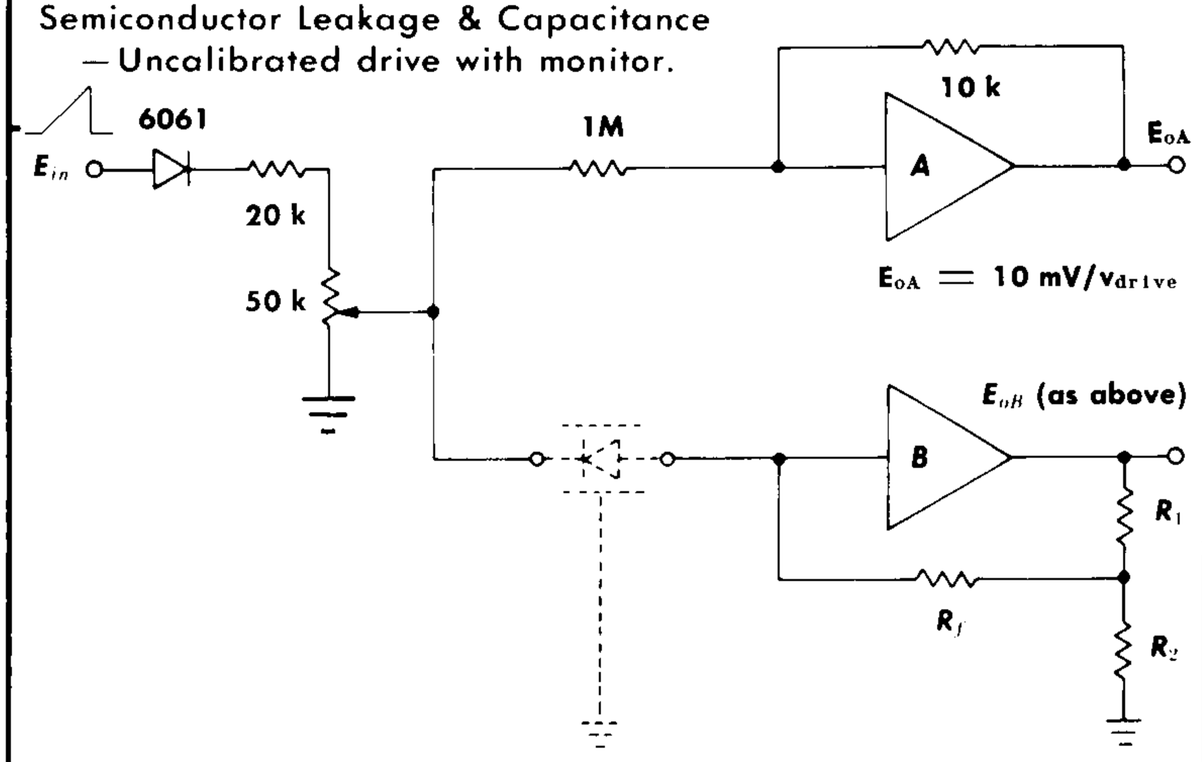
**Vertical displacement of trace at faster sweep indicates junction capacitance**

$$C = I\,dt/de = \frac{\text{Trace displacement} \times \text{Time/Cm}}{\text{Horizontal Volts/Cm}}$$

**In example shown,** $C = \frac{1\text{nA} \times 2\text{ ms}}{1\text{ V}} = 2\text{ pF}.$

Indication will be in error (especially at start of trace) if sawtooth attenuator is not compensated or if sweep is operated at a high rep rate.

### Semiconductor Leakage & Capacitance — Uncalibrated drive with monitor.

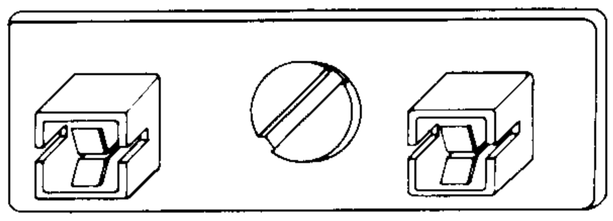



## Notes

Oscilloscope sawtooth provides both horizontal deflection and calibrated drive to junction under test. Slow sweep (e.g., 200 msec/cm) provides vertical deflection proportional to leakage; vertical displacement of trace at faster sweep (e.g., 2 msec/cm) is proportional to capacitance.

Divider $R_1$, $R_2$, permits nA sensitivity with reasonable values of $R_f$. Diode D, (use low-capacitance type) prevents slight negative quiescent level of sawtooth from forward-biasing junction under test.

Construction of test jig is critical. Leakage and capacitance paths must be to **ground**, not terminal-to-terminal. Tektronix P/N 432-0032-00 diode-holder may be used if mounted to ground plane with large binder-head screw, thus:



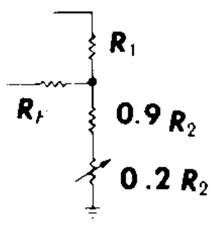
Both test jig and $R_f$ should be shielded for high-sensitivity measurements.

System errors:
Use of divider $R_1R_2$ to ground causes some input current to flow through $R_f$ and divider to ground (negligible if $K < 20$). Actual error is

$$\frac{KR_f}{KR_f + \left(R_f + \frac{R_1}{K}\right)(1 - A)} \text{ where } K = \frac{R_2 + R_1}{R_2}.$$

Error due to division of feedback voltage is $\frac{K - 1}{A - 1}$

(Open loop gain A is negative).

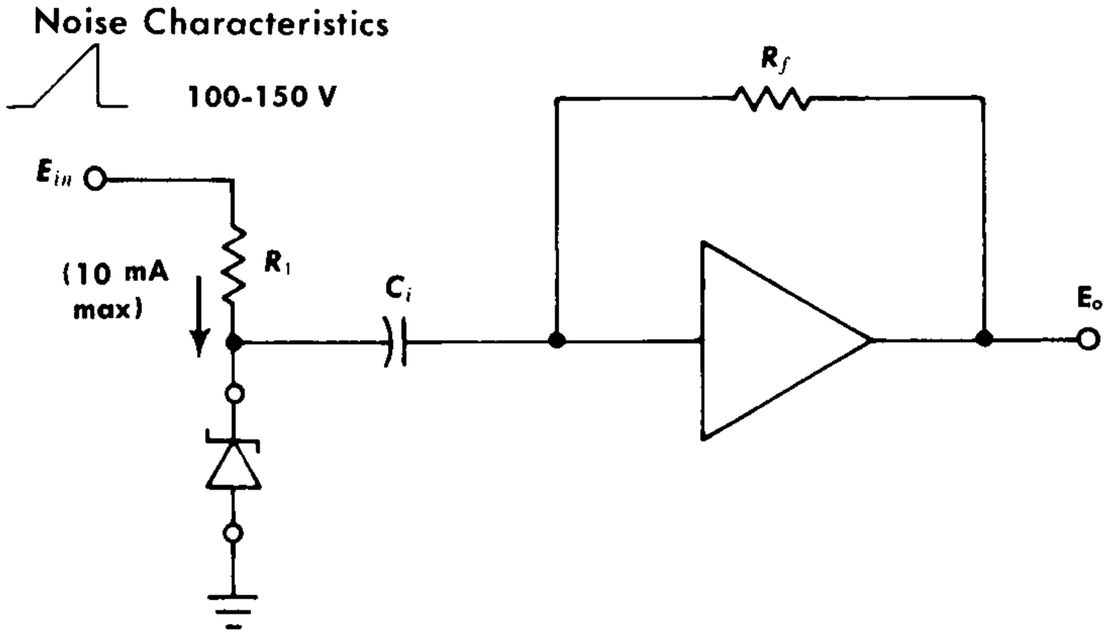



$R_2$ may be reduced in value and padded to correct accumulated system and tolerance errors:

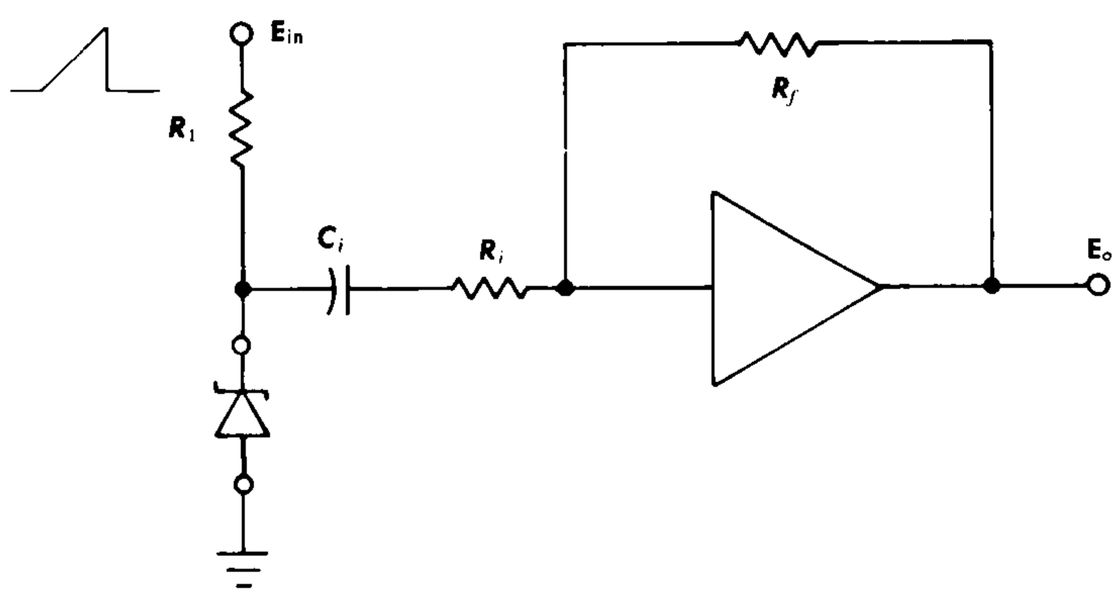
Leakage Current Adapter available from Tektronix. Order from local Field Office or representative Part No. 013-0086-00.

## Zener Diode Tests

### Noise Characteristics




### Zener Noise Measurement




## Notes

Variation of Zener noise with current may be evaluated by driving Zener with current sawtooth, differentiating output.

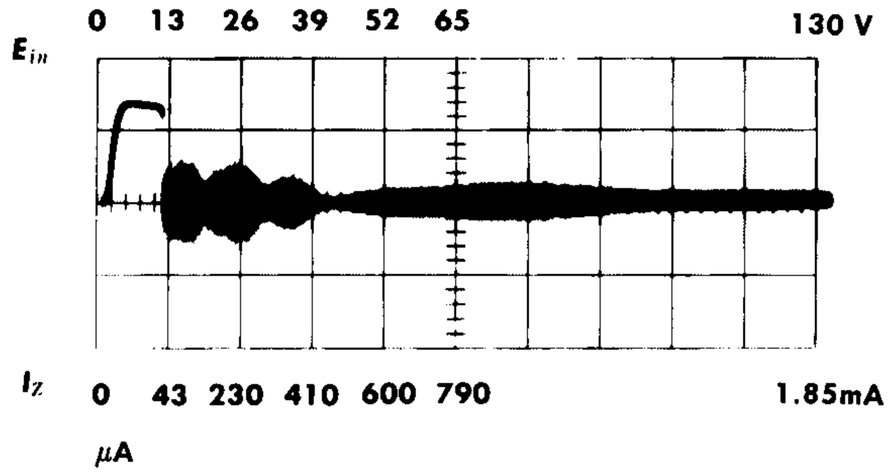
$$\text{Zener current} = \frac{(E_{in} - E_z)}{R_1}$$

Example: Motorola 1/4 M10Z10.

Vertical, 1 V/cm; Horizontal, 13 V/cm.

$R_1 = 70\,k$, $C_i = .001$, $R_f = 200\,k$. Noise minimum at 500 $\mu$A.

(Not all Zener diodes show these minima).

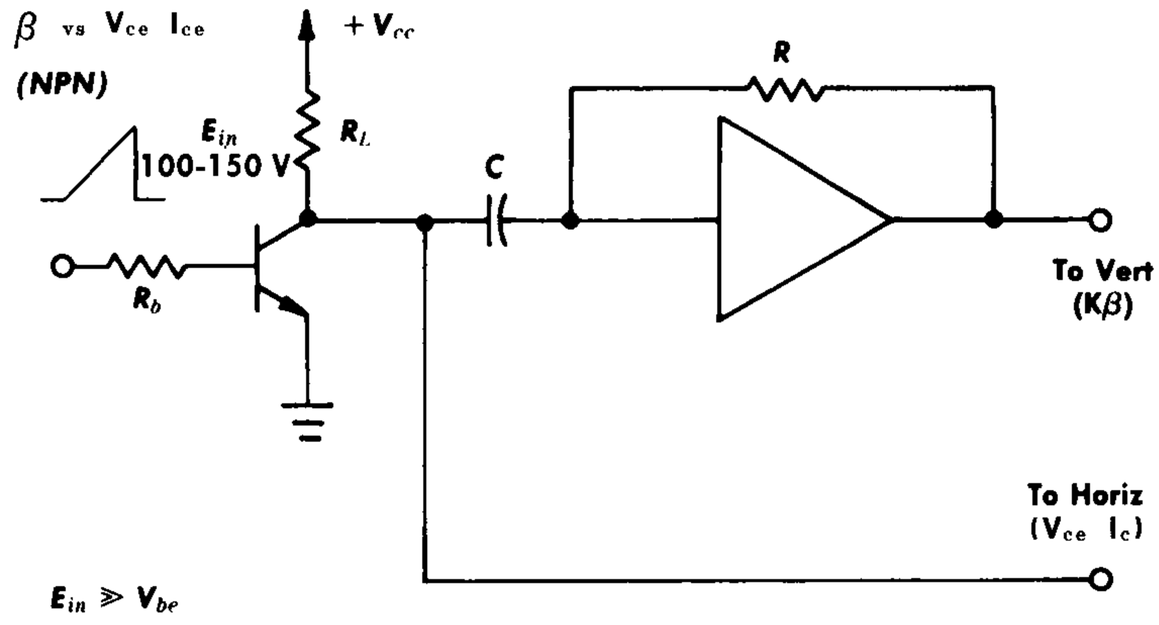



Actual (p-p) amplitude of Zener noise is obtained by adding $R_i$ to circuit.

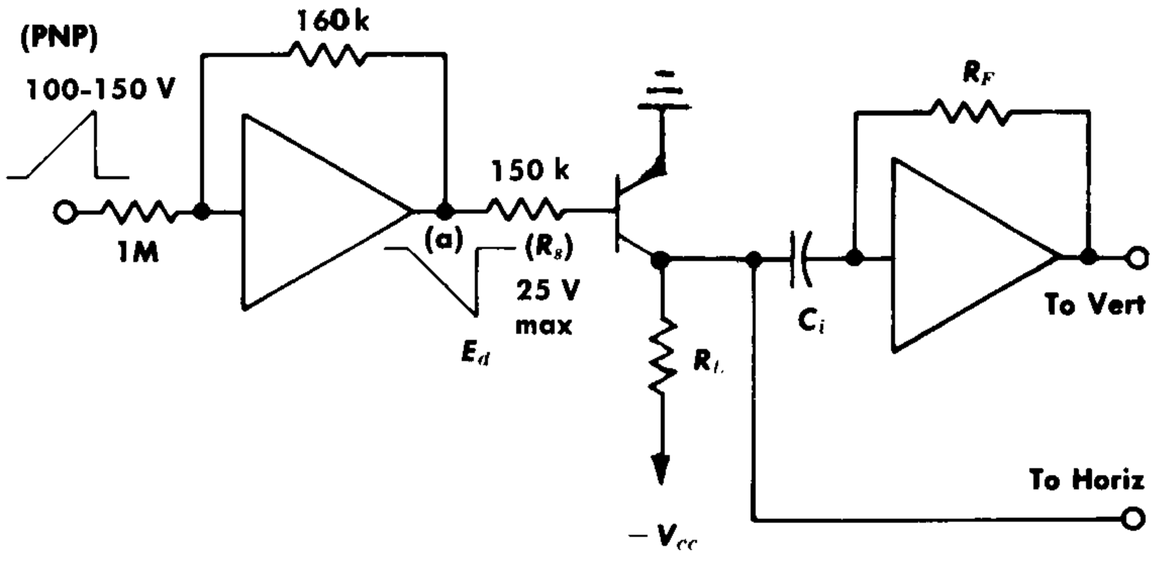
$E_o \approx \frac{R_f}{R_i}(E_{noise})$, for mid-band components.

## Transistors

### $\beta$ vs $V_{ce}$ $I_{ce}$ (NPN)




### $\beta$ vs $V_{ce}$ $I_{ce}$ (PNP)




## Notes

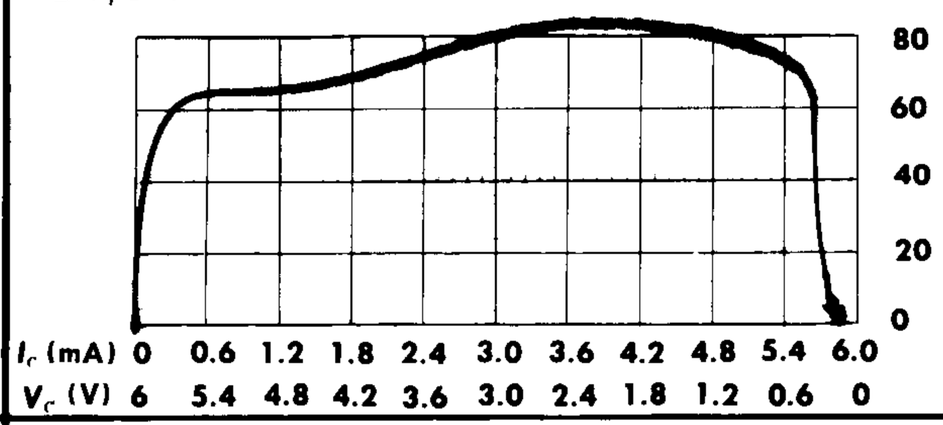
Differentiation of collector waveform as base current is linearly increased provides vertical deflection proportional to $\beta$. Horizontal deflection represents all $V_{ce}$, $I_{ce}$ points along ($R_L$) load-line.

$$\beta = \frac{-E_o R_b\ (10t)}{R_f C_i R_L E_d}$$

Where $E_d$ is the voltage of $E_{in}$ at 10t, and t is the sawtooth Time/cm setting.

For PNP, base drive must be inverted. Beta is calculated as above.

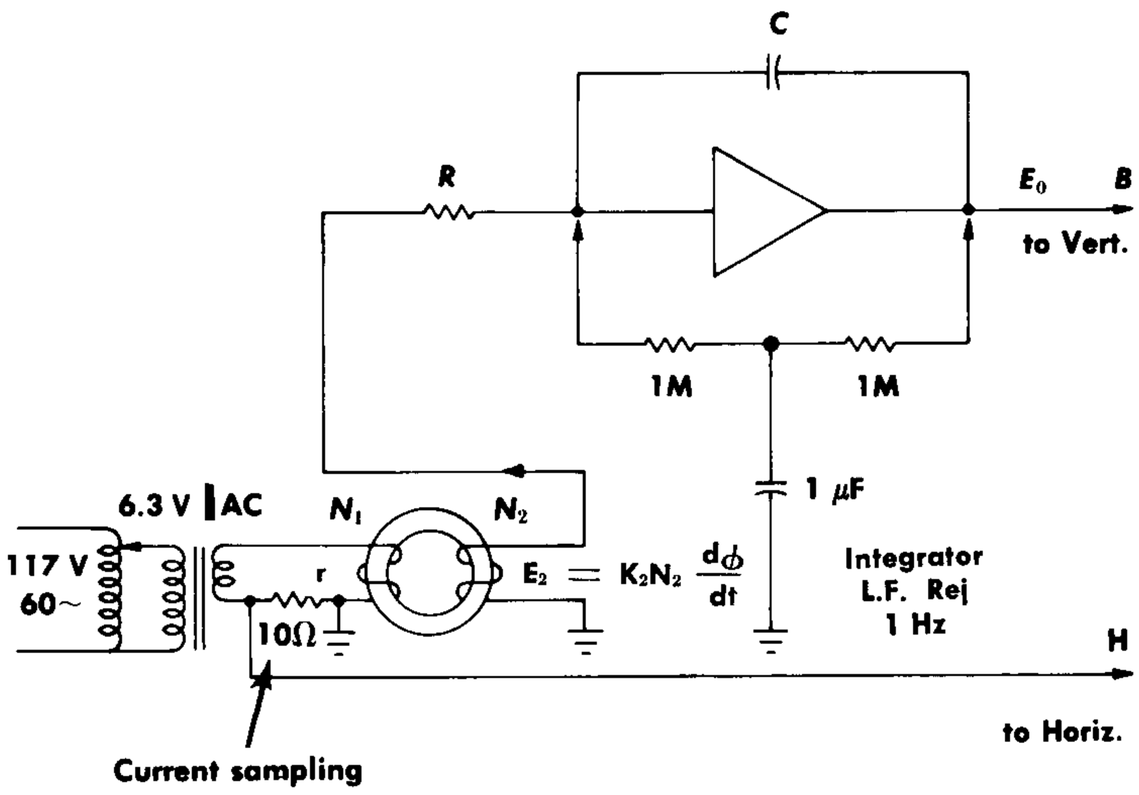
Example: 2N970, $V_{cc}$ 6 V, $R_L$ 1 k, $E_d$, 30 V, Time/cm 0.1 msec/cm, $R_f$ 500 k $C_i$ .001 $\mu$F vertical sensitivity 2 V/cm.



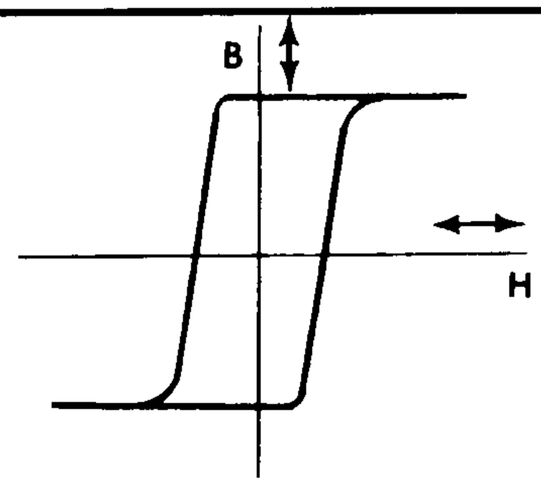
# COMPONENT TESTS

## B-H Loop Plotting

### B-H Curve Plotting




## Notes




The voltage of the secondary is $E_2 = K_2 N_2 \frac{d\phi}{dt}$

Integrating $E_2$, the output $E_o$ will be proportional to the flux $\phi$:

$E_o = \frac{-1}{RC} \int K_2N_2 \frac{d\phi}{dt} dt$ which equals

$$\frac{-K_2N_2}{RC} \phi.$$

Since $B = \frac{\phi}{A}$ (where B is flux density and A is core cross sectional area), $B = \frac{-RC}{K_2N_2A} \cdot E_o$.

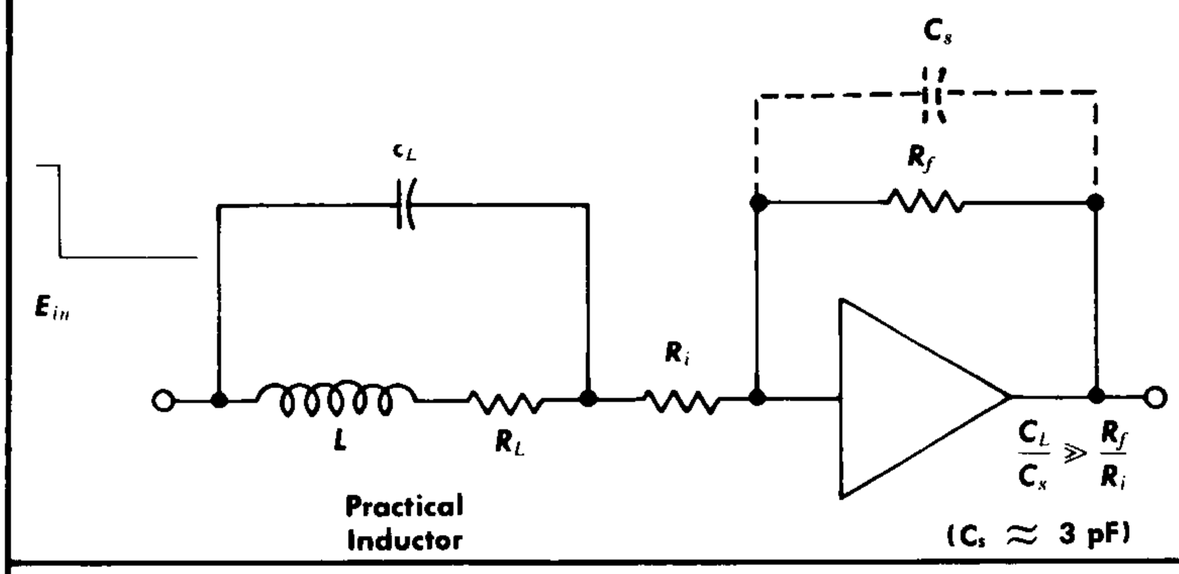
Magnetizing force, $H = \frac{K_1N_1 \cdot I}{l}$

($l$ is the flux path length and I is the current). With a current sampling resistor of 10 Ω in the primary, $I = \frac{Er}{10}$ and $H = \frac{K_1N_1E_r}{10l}$

If A and $l$ are given in square meters and meters, $K_1 = K_2 = 1$

## INDUCTOR MEASUREMENTS

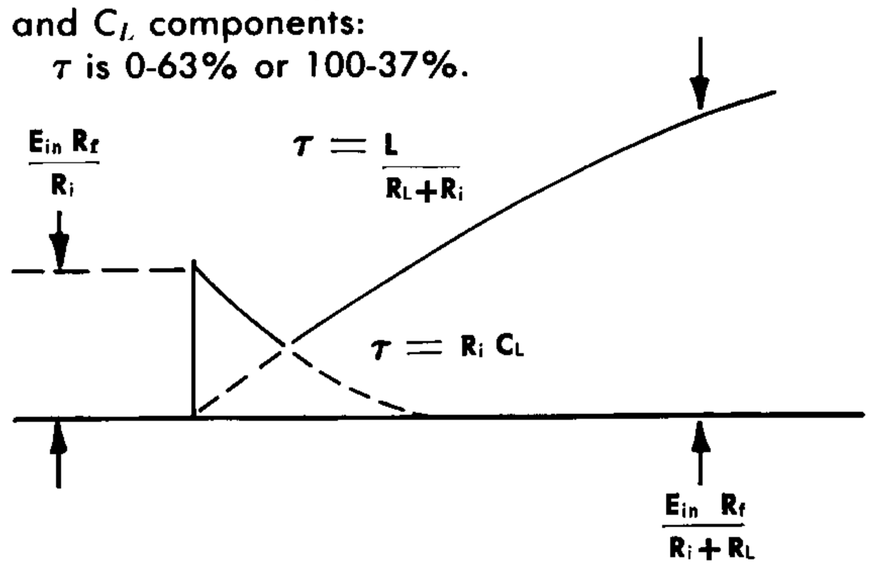
### Inductor Evaluation

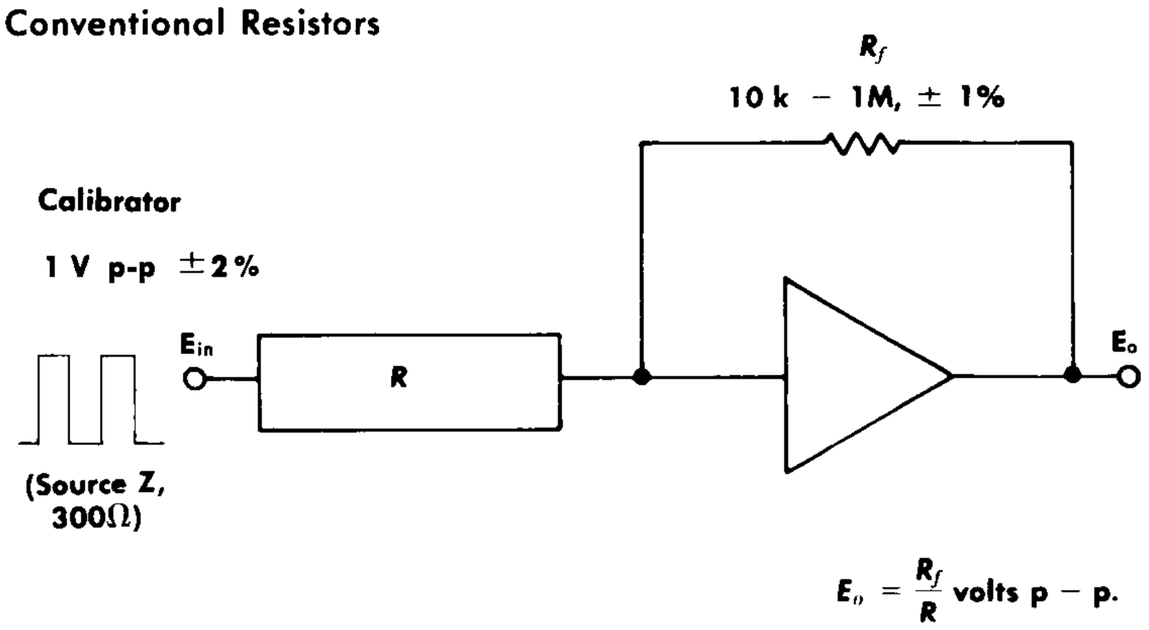
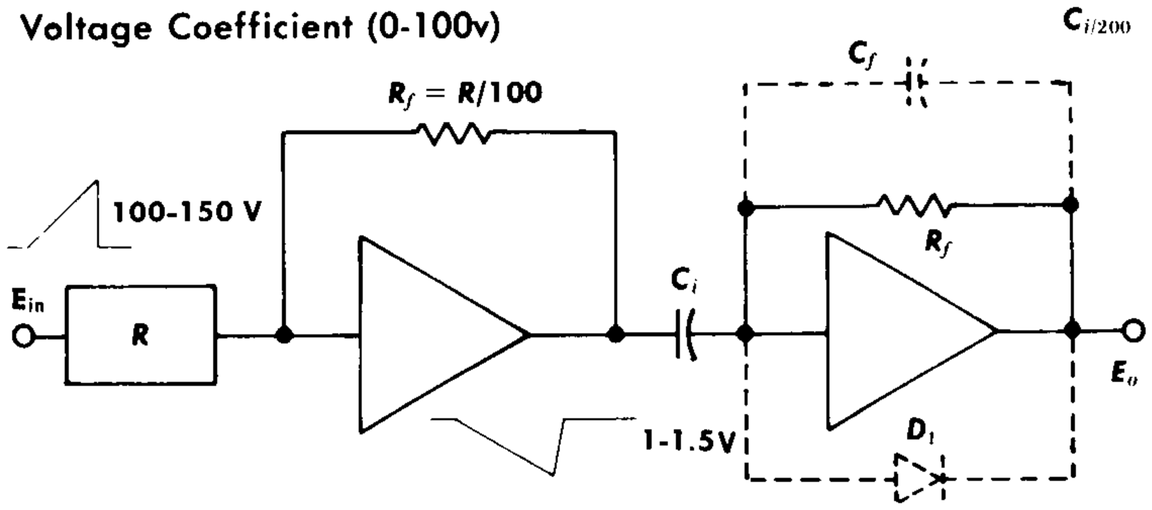
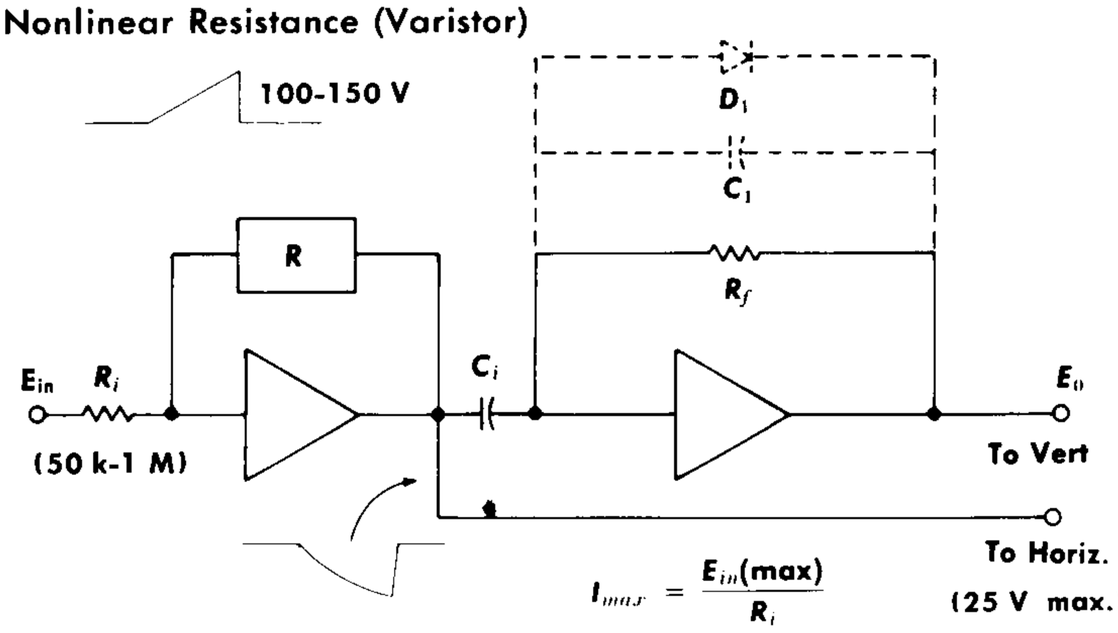
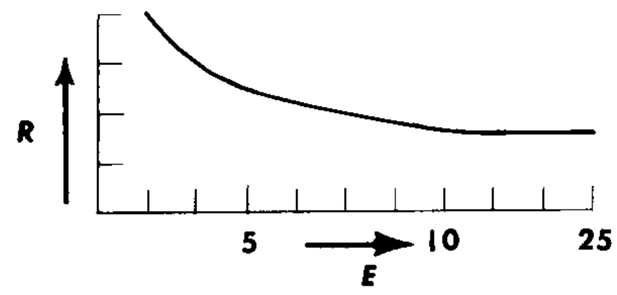



### Notes

Evaluation of step response indicates effective $R_L$ and $C_L$ components:

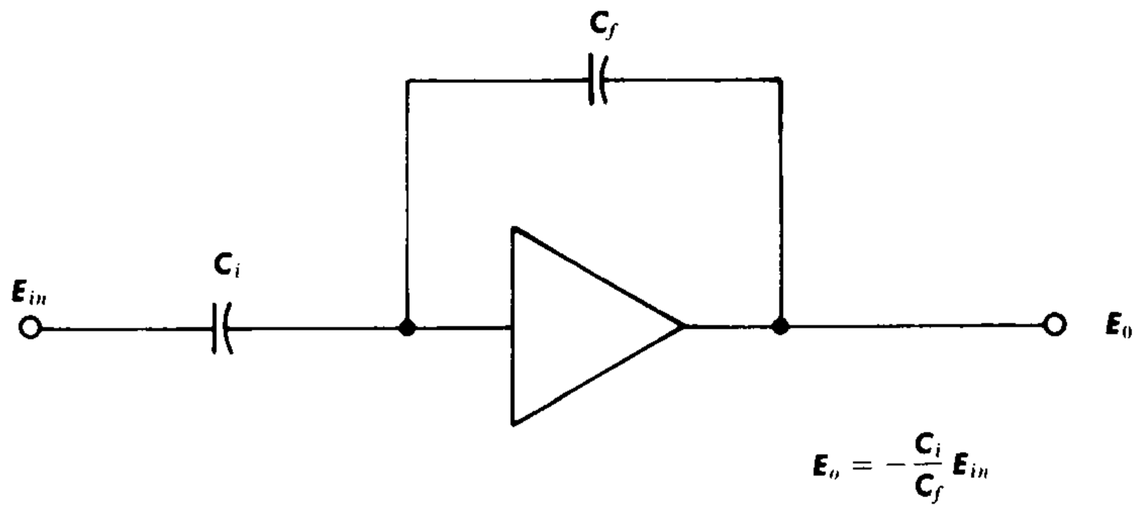
$\tau$ is 0-63% or 100-37%.



| Resistance Measurements | Notes |
|---|---|
| **Conventional Resistors**<br>  | For output 0-10 V, measurement accuracy is essentially the tolerance of the calibrator voltage and resistor used for $R_f$. Using oscilloscope calibrator and internal $Z_f$ accuracy is 3% or better. For values <50 k, drive unknown with X1 amplifier. |
| **Voltage Coefficient (0-100v)**<br>  | Resistor voltage coefficient may be determined by differentiating a ramp, the linearity of which is controlled by resistor under test. $C_f$ may be used to limit noise; Diode $D_1$ prevents sawtooth flyback from causing overload. |
| **Nonlinear Resistance (Varistor)**<br>  | First operational amplifier applies linear ramp of current to varistor used as $R_f$. Voltage across varistor is used for horizontal deflection. Output of differentiator is proportional to $R$. (Use slow sawtooth) Diode $D_1$ prevents flyback overloads; capacitor $C_1$ ($\ll C_i$) may be used to reduce noise.<br>  |

## Capacitance Measurement (1pf-10$\mu$f)

### Basic Idea

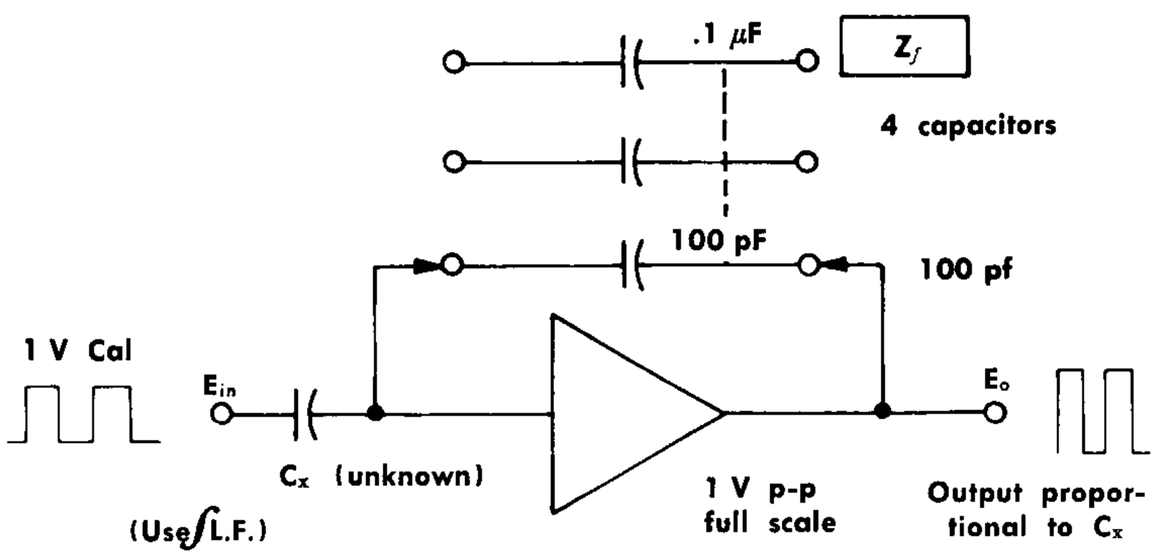



### Notes

When capacitors are placed in input and feedback, it will make an amplifier. Gain of this amplifier is $-C_i/C_f$, ratio of input C to the feedback C. Since the output voltage of the amplifier is proportional to the $C_i$, it is possible to measure capacitance.

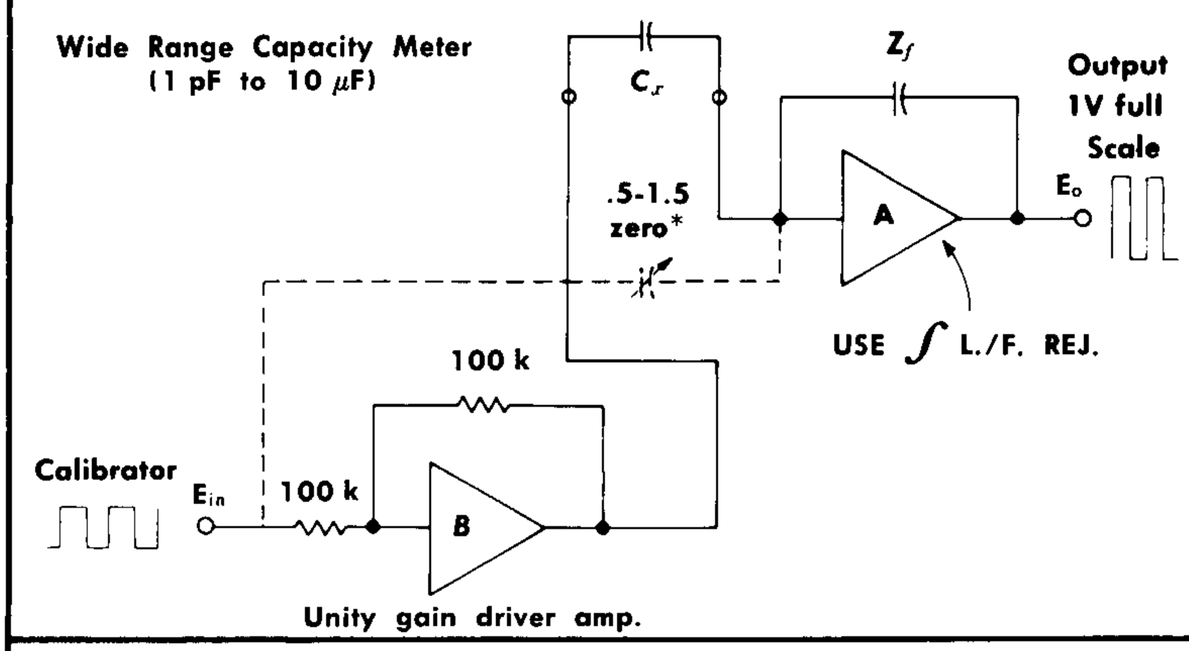
Theoretically, this amplifier should have dc response but drift and leakage limit the low frequency response. For high frequency, charging current limits the response —use smaller $C_f$ value.

### Capacity 100 pF to .1 $\mu$F




Unknown capacitor is compared to the precision internal feedback capacitor. When unknown $C_x$ is same as feedback $C_f$ the output voltage is 1 volt. The output voltage can be monitored by scope. The calibrator impedance is too high to drive higher capacitance; therefore, use of isolation amplifier is recommended as shown below.
(use L.F. Rej.)

### Wide Range Capacity Meter (1 pF to 10 $\mu$F)



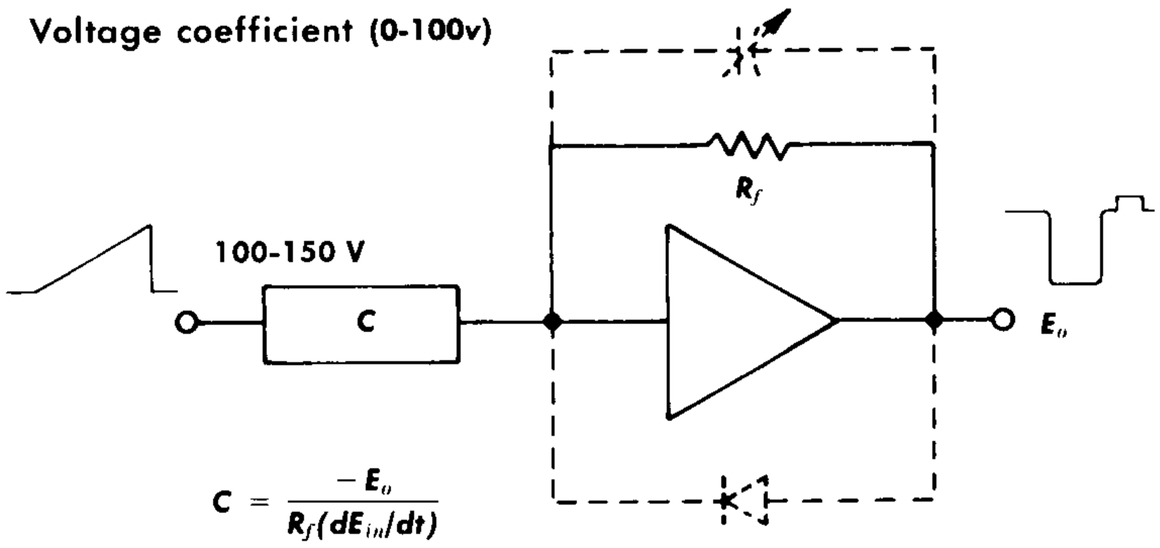

Careful arrangement enables capacitance measurement for values of 1 pF to 10 $\mu$F.

| RANGE | Cal. | $Z_f$ |
|---|---|---|
| 0 - 10 $\mu$F | 10 mV | .1 |
| 0 - 1 $\mu$F | .1 V | .1 |
| 0 - .1 | .1 V | .01 |
| 0 - .01 | .1 V | .001 |
| 0 - .001 | 1 V | .001 |
| 0 - 100 pF | 10 V | .001 |
| 0 - 10 pF* | 10 V | .0001 |

***to compensate stray capacity, adjust neutralizing C for zero $C_x$ output indication.**

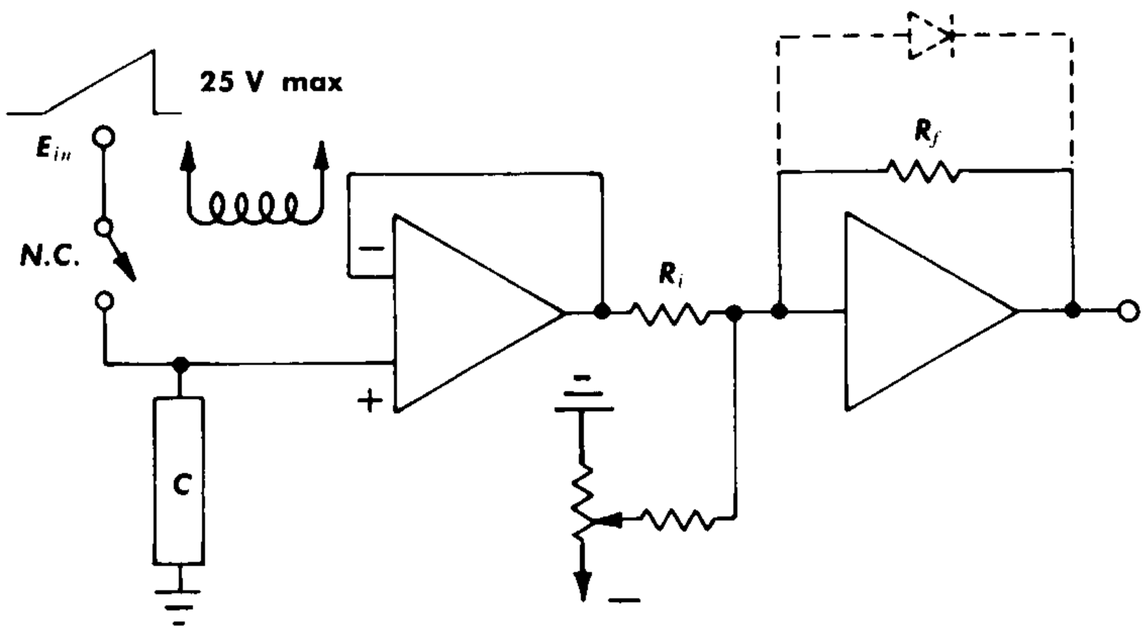
## Dielectric Tests

### Voltage coefficient (0-100v)

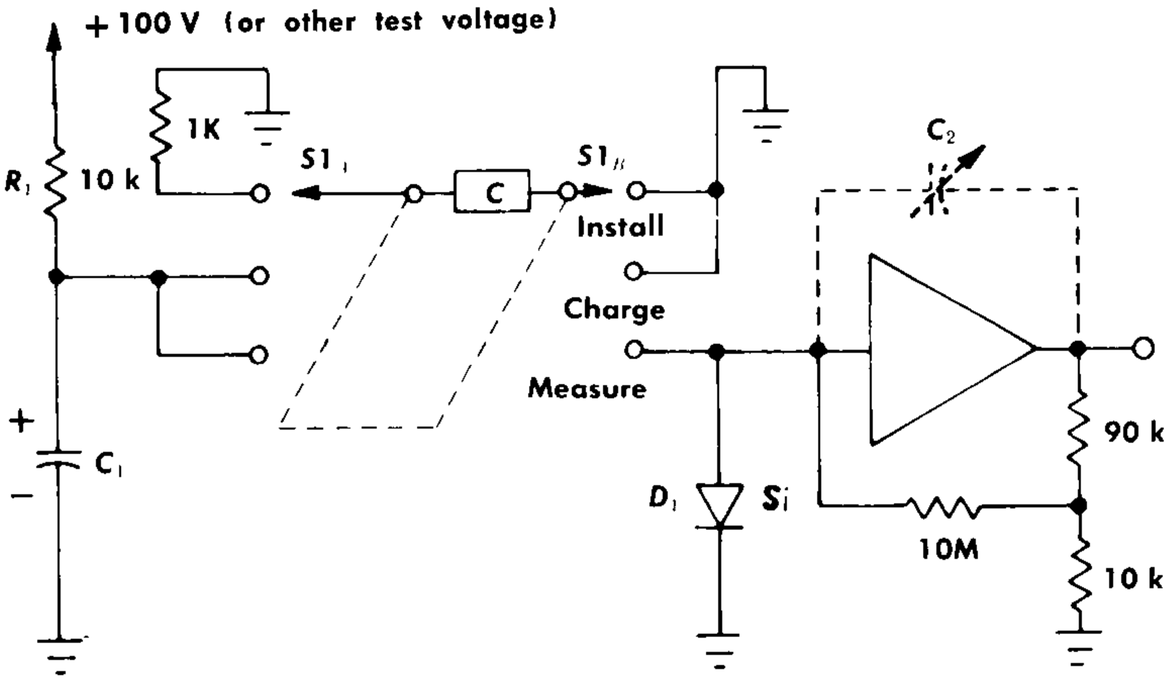



$$C = \frac{-E_o}{R_f(dE_{in}/dt)}$$

### Internal Resistance (Series)



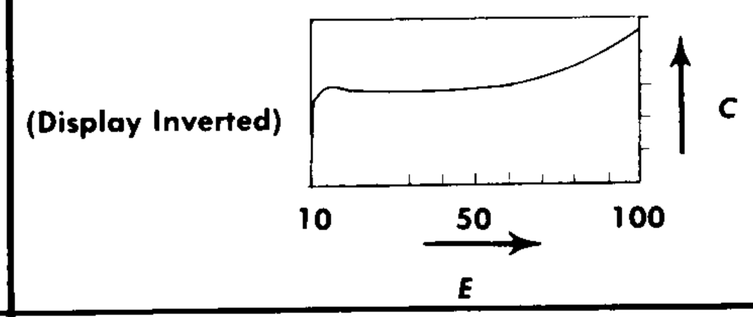

### Leakage



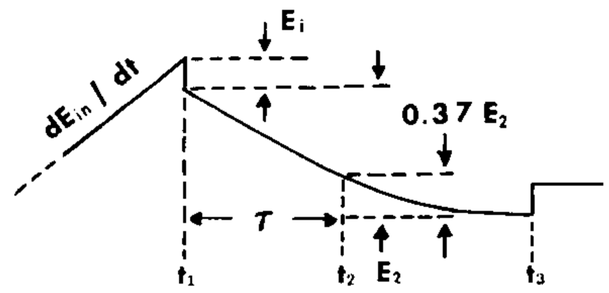

"Charge" and "measure" positions may be made spring-return for safety.

## Notes

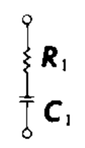
Voltage coefficient of capacitors from 1 pF to 250 $\mu$F may be evaluated by proper selection of sweep time/cm and $R_f$, using oscilloscope sawtooth. Horizontal calibration will depend on individual oscilloscope. Sweep repetition rate must be made very low (long hold-off) for large value capacitors.




Reed relay is opened just before sawtooth reaches peak. Internal resistance in capacitor will cause negative step following relay opening. Slideback arrangement allows detailed analysis of step.



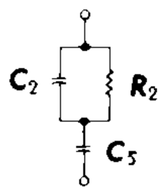

**(1)**




$$E_1 = \frac{dE_{in}}{dt} R_1C_1$$

$$\tau = 0$$

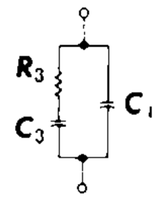
**(2)**




$$E_2 = \frac{dE_{in}}{dt} R_2C_5$$

$$\tau = R_2C_2$$

**(3)**




$$E_2 = \left(\frac{dE_{in}}{dt}\right)\left(\frac{RC_3^2}{C_4}\right)$$

$$\tau = R\left(\frac{C_3C_4}{C_3 + C_4}\right)$$

$E_{in} \gg (E_1 + E_2)$
**Ramp duration** $\gg \tau$
**Measure** $\tau$ **to 0.37** $E_2$

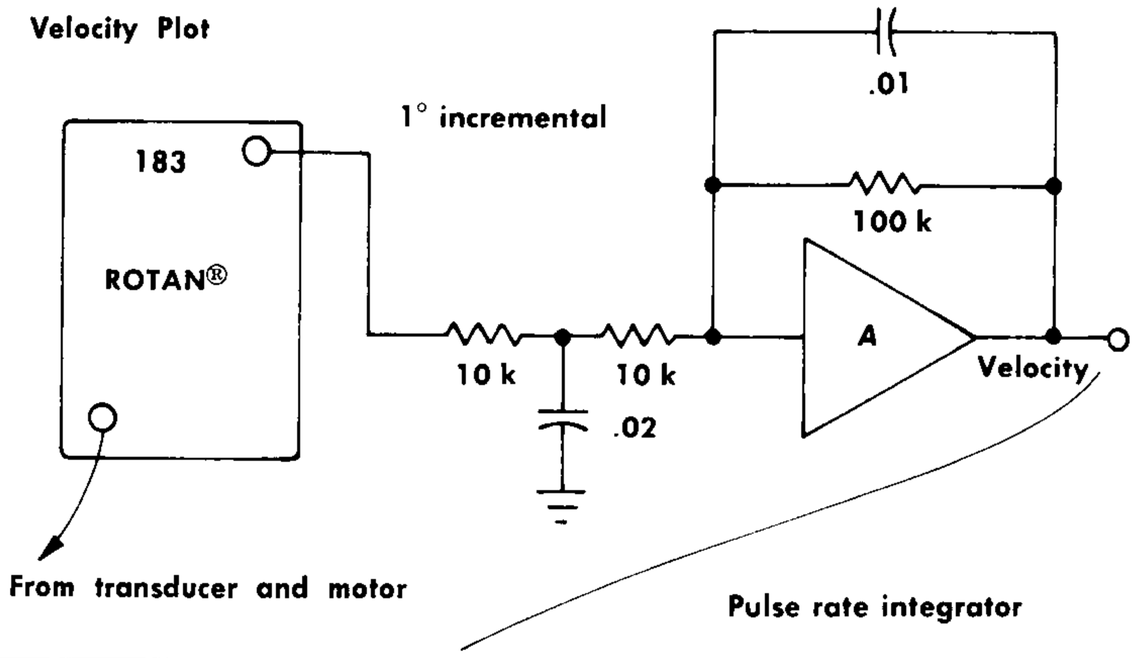
If $E_2$ is a rapid discharge induced to check for condition 3 ("soak") and discharge path is opened at $t_3$, capacitor will show buildup of open-circuit voltage.

High-sensitivity measurements are made possible by divided feedback. For values shown, sensitivity is 1 V output per 10 nA leakage. 50 mV resolution = 500 pA, or $0.2 \times 10^{12}\ \Omega$ for 100 V test voltage. Precautions must be taken to avoid excessive noise. Diode $D_1$ and Resistor $R_1$ protect against breakdown. $C_2$ reduces noise.

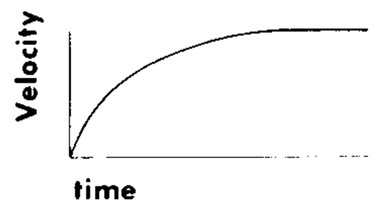
# MISCELLANEOUS APPLICATIONS

## Velocity Acceleration Studies

### Velocity Plot

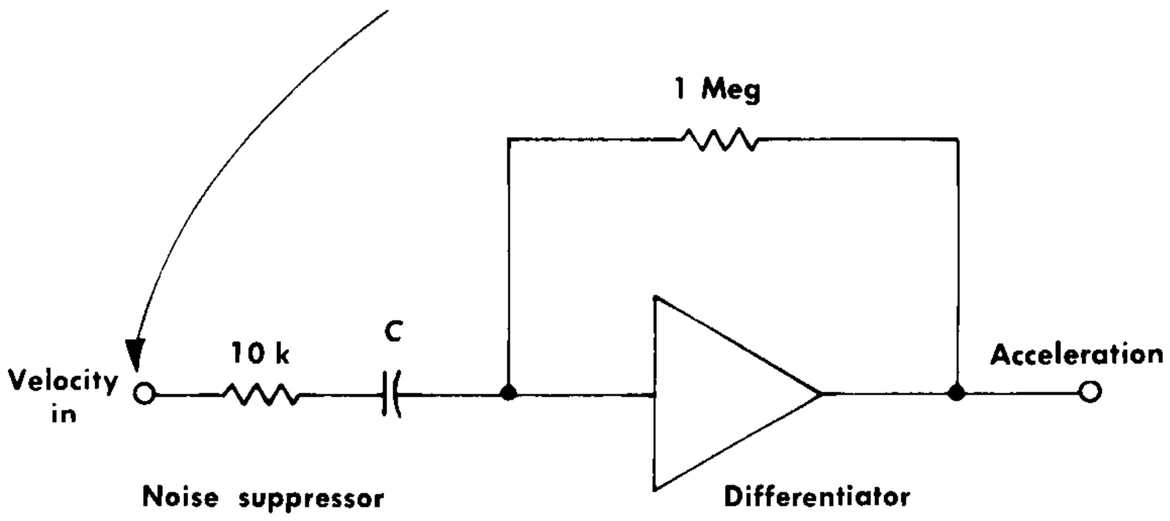


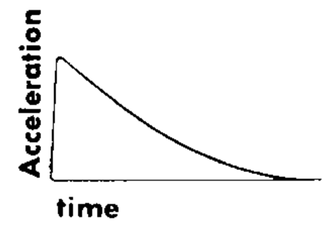

### Notes




Rotational velocity may be obtained by integrating pulse rate, using the ROTAN® 1° incremental pulse.

### Acceleration Plot

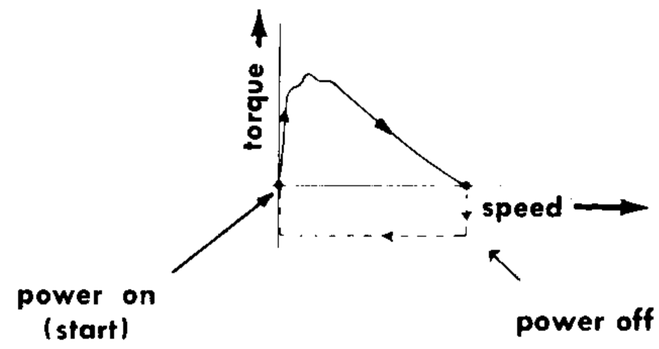



Velocity signal is differentiated to obtain acceleration. 10K resistor is added to suppress noise.

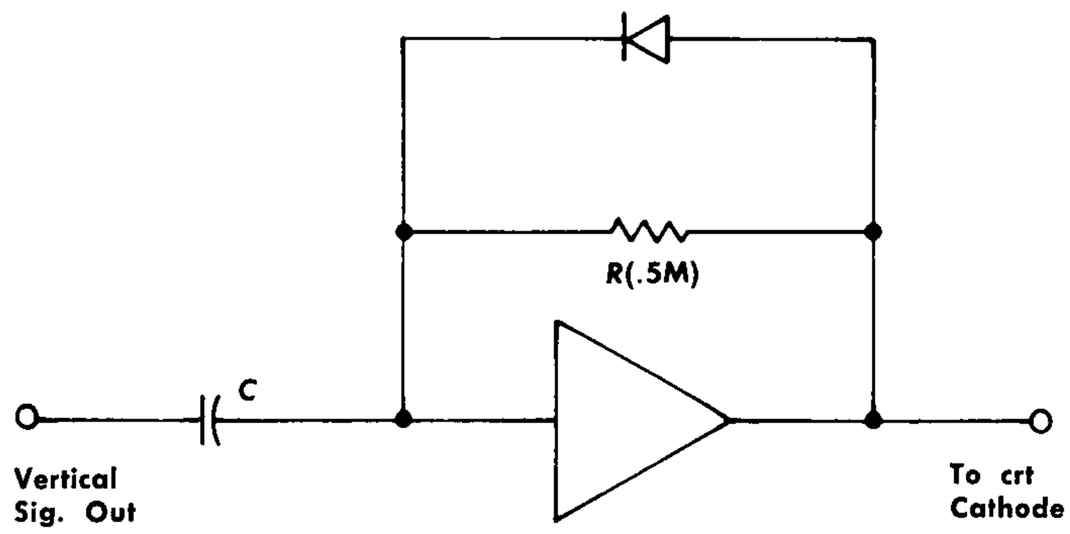
### Speed—Torque Plot

**X Y plot of velocity and acceleration gives a speed—torque plot. A typical motor characteristic may be obtained by starting and stopping the motor and observing the torque speed characteristics.**



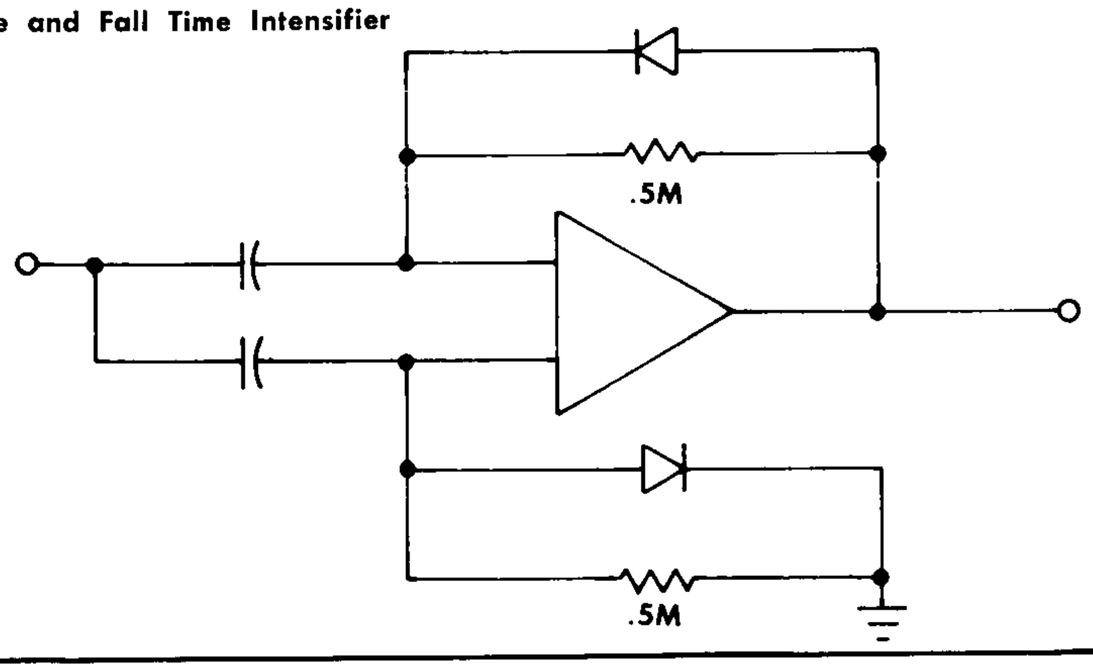
## Risetime Beam Intensifier

### Basic Idea

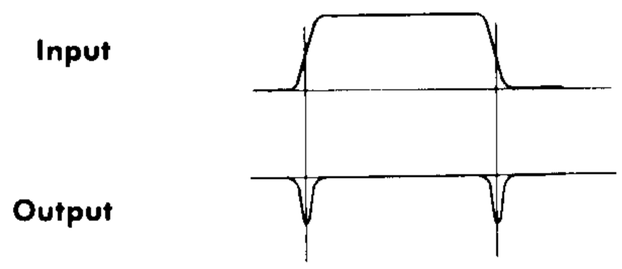



A differentiator can be used as a beam intensifier in certain experimental setups. Scope vertical signal out can provide signal to the differentiator and the output is fed to the crt cathode. A word of caution; vert. signal output should not be monitored by the same scope. Possible oscillation may result.

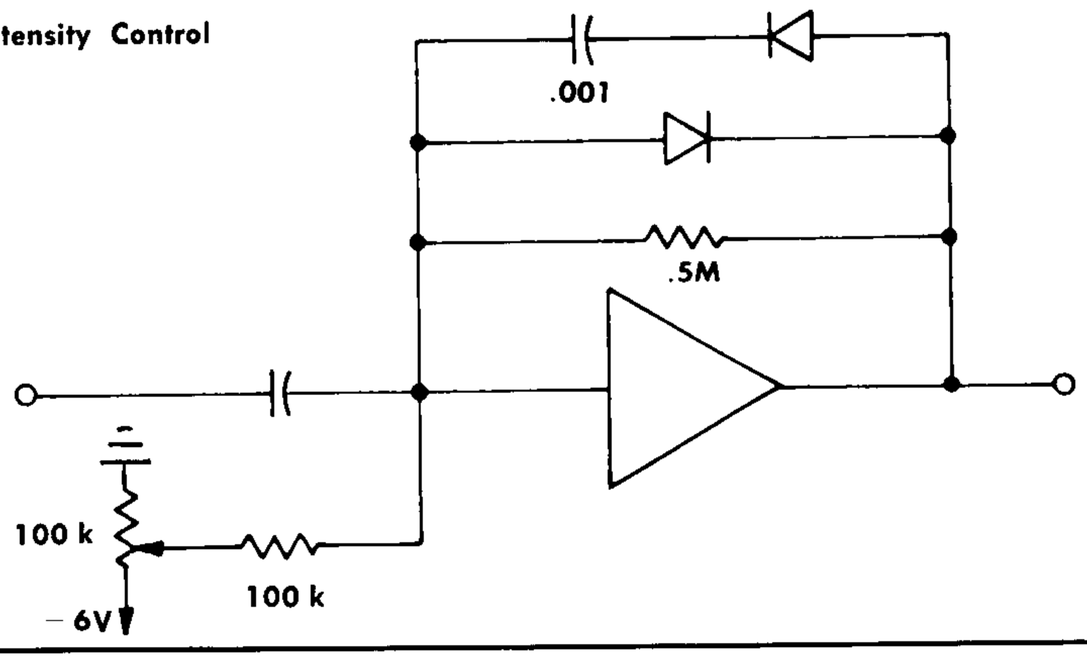
### Rise and Fall Time Intensifier




Applying signal to the both positive and negative grid, both rise and fall time can be intensified.

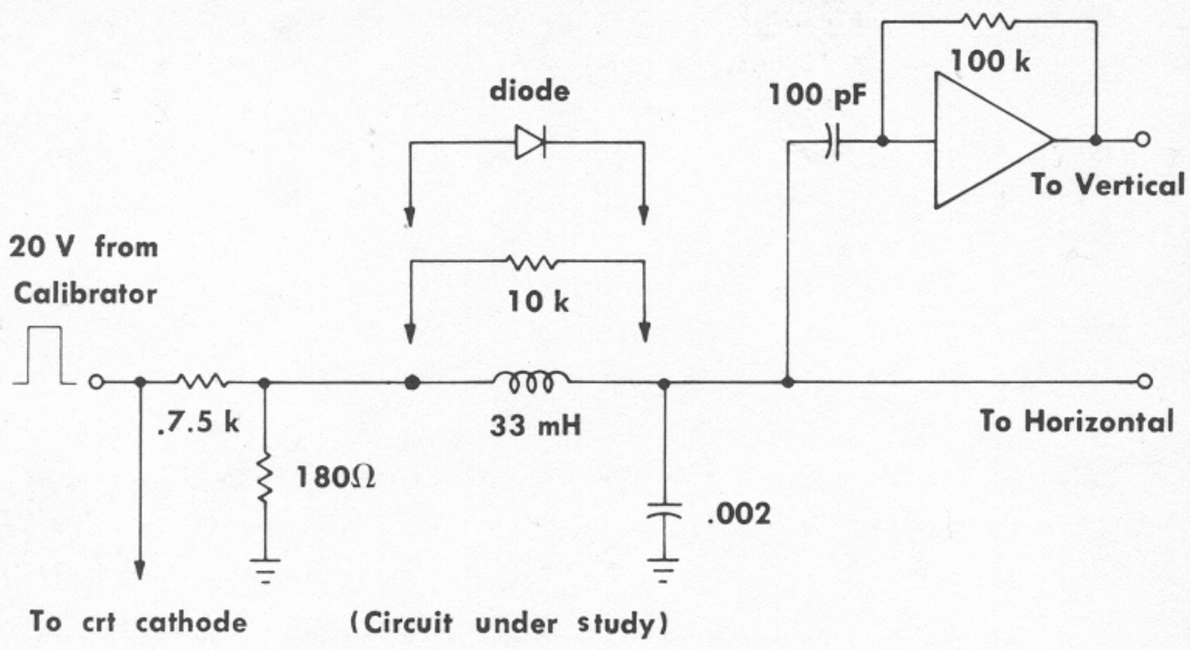



### Intensity Control




If the cathode is over-driven, serious defocusing may result. Thus means of maximum intensity limiting is desirable. In this circuit biased diodes limit the output swing to prevent defocusing.

## Phase—Plane Plot

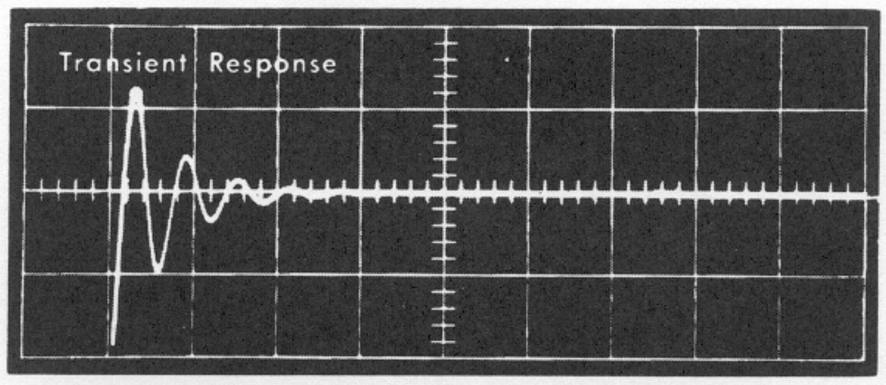


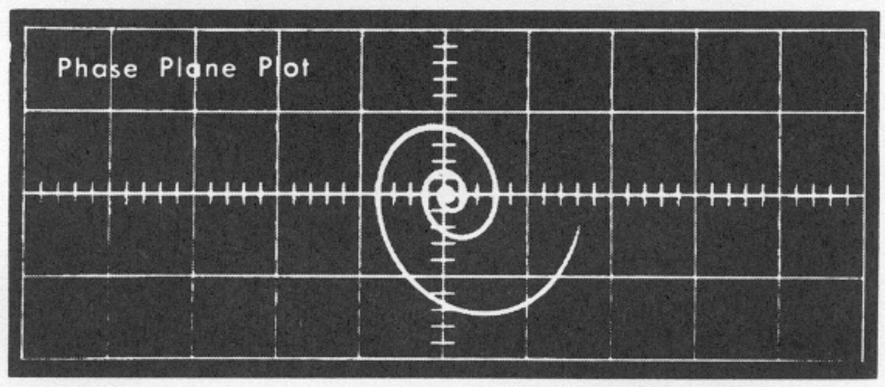

## Notes

In studying system stability of control systems or feedback systems, transient response is often employed. If non-linear element is involved in a system, stability criteria usually become quite complex and analysis is normally limited to linear approximations.

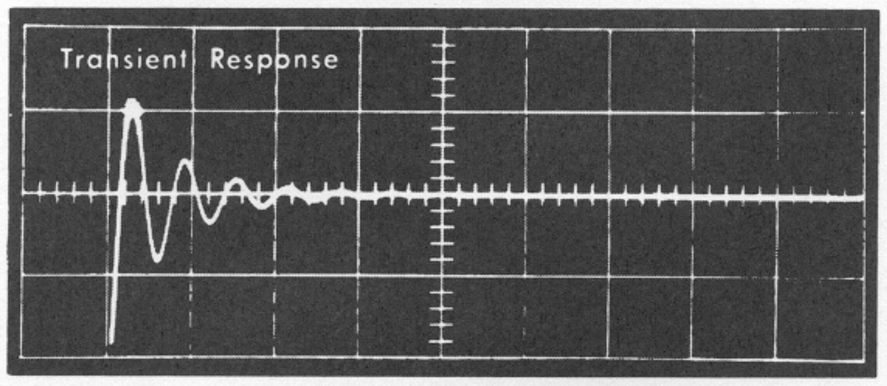
A phase-plane plot can overcome some of this limitation since it can present the stability, as well as the nature of non-linearity.

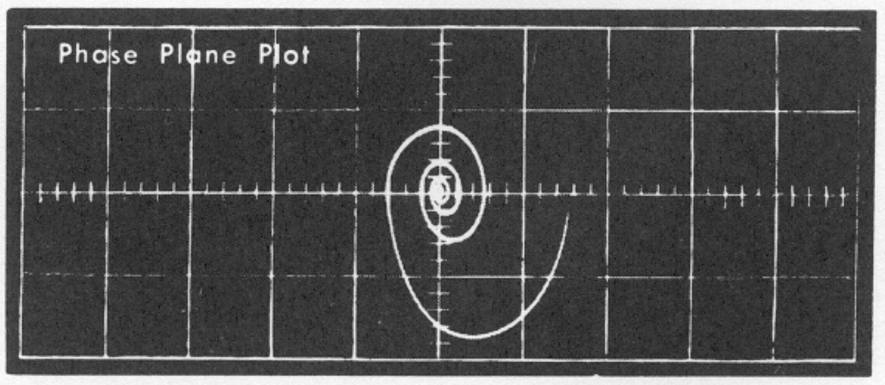
As an illustration, the effect of resistive and diode damping on an LCR circuit is compared in a transient response display and a phase-plane plot. Circuit values are chosen such that the diode does not conduct very heavily and it is very difficult to distinguish non-linearity in the transient response display. However, when the original (transient response) signal is plotted against the differentiated signal, the non-linear effect is easily observed. (See photos below.)




**10 k Damping**




**Diode Damping**

# APPENDIX

## Semiconductors:

Some of the semiconductors referred to in these notes are non-registered types selected for special characteristics and available only from the original manufactures. In a few cases (Type 6045, 6061, 6075), the diodes referred to are made to Tektronix specifications, and may be procured in small quantities from Tektronix if suitable equivalents are not locally available.

## Germanium, General Purpose Signal Diodes:

| | PIV | Fwd mA | Leakage | Procure |
|---|---|---|---|---|
| T12G (Transitron, Raytheon)<br>HD2607 (Hughes)<br>CGD-1075 (Clevite) | 75 V | 20 mA | 30 μA @ 10 V | Locally |
| Type 6075 | 25 V | 40 mA | 10 μA @ 6 V | Tektronix (152-0075-00) |
| ED-2007 (Erie Resistor Corp.) | 15 V | 5 mA | 10 μA @ 6 V | Locally |
| DR-746 (General Instruments)<br>HD2948 (Hughes) | 10-25 V | 40 mA | 10 μA @ 6 V | Locally |
| T13G (Transitron) | 25 V | 50 mA | 2 μA @ 10 V | Locally |

## Silicon Signal Diodes (Low leakage or high voltage):

| | | | | |
|---|---|---|---|---|
| HD5000 (Hughes) | 10 V | 12 mA | 0.2 μA @ 5 V | Locally |
| 6045 | 125 V | 40 mA | .002 μA @ 9 V | Tektronix (152-0045-00) |
| 6061 | | | | |
| RD2594 (Rheem)<br>ED2927 (Erie)<br>CSD2800 (Clevite) | 200 V | 100 mA | 5 μA @ 175 V | Tektronix (152-0061-00) or locally |
| G-130 (Texas Instruments) "Log Diode", "Stabistor". | | | | Locally |

## Zener Diodes:

| Voltage | Current | Use | Tolerance | Mfr. | Procure |
|---|---|---|---|---|---|
| ±6 V* | 25 mA | RT6* | ±1 V | Hoffman | Locally |
| 6 V | 60 mA | 1N753 | 5.6-6.8 V | Texas Instrs. | Locally |
| 7 V | 30 mA | 1N707 | 6.2-8.0 V | Hoffman | Locally |
| 10 V | 30 mA | 1/4M10Z10 | ±10% | Motorola | Locally |
| 15 V | 15 mA | 1N718A | ±5% | Pacific | Locally |

* Double Zener

## Transistors

| | | |
|---|---|---|
| 2N1304<br>2N1305 | General Instrument, Raytheon, Sylvania, Texas Instrs. | Locally |
| 2N706B<br>2N970 | (Motorola, Fairchild) may be substituted for {2N1304 / 2N1305} in ÷ 2 Multivibrator circuit for higher speed operation. | |
| 2N1302<br>2N1303 | May also be used in ÷ 2 Multivibrator | Locally |

## Selected Diodes:

The wideband logarithmic amplifier requires careful selection and matching of diodes to obtain calibrated symmetrical output. If undirectional operation only is needed, only half the diodes are needed—selected on the basis of the criteria below. If symmetrical operation is needed, the selected diodes must be matched pairs.

Selection Criteria (DC)

| Circuit Location, Type | @ fwd | Select for Forward Drop | Matching Criteria: Match Forward Drop Within: |
|---|---|---|---|
| Input ED-2007 (Erie Resistor Corp.) | 10 μA | 0.10-0.13 V | .004 V |
| | 10 mA | 0.35-0.50 V | .01 V |

| | | | |
|---|---|---|---|
| Feedback ED-2007 | 10 μA | 0.10-0.13 V | .004 V |
| | 1 mA | 0.25-0.13 V | .01 V |
| Feedback HD-5000 (Hughes) | 10 μA | 0.25-0.40 V | .10 V |
| | 100 μA | 0.35-0.50 V | .01 V |

Typically, it takes about 10 ED-2007's to obtain two matched pairs and 5 HD-5000's to obtain one matched pair.*

## Precision Resistors:

Precision carbon-film and metal film resistors in 1% and closer tolerance are available from most electronics suppliers. Use the smallest sizes (1/8 W, 1/4 W, etc.) compatible with power requirements for high-speed work. Use of large wire-wound precision resistors is not recommended for fast work because of excessive capacitance and (in some cases) inductance.

## Obtaining Time Scaling Factors From Sampling Oscilloscopes

In integrating or differentiating waveforms obtained from the vertical signal output of sampling oscilloscopes, it is essential to preserve a known and stable real-time: to equivalent time ratio, or scaling factor. The operations performed by the operational amplifier are in real time; the information contained in the sampling oscilloscope output is in equivalent time.

Unless some means is employed to **force** a fixed real time: to equivalent time ratio, the ratio will be dependent on the repetition rate of the signal being sampled, up to about 100 kHz above this point by the sampling-rate limiter in the sampling oscilloscope. An erratic pulse repetition or sampling rate may cause significant errors.

To force a fixed relationship between real and equivalent time, it is only necessary to drive the external horizontal input (external scan) of the sampling oscilloscope with the real-time sawtooth of the oscilloscope used with the operational amplifier. The real-time sawtooth should be properly attenuated so that it provides the **same display** on both the sampling and the real-time oscilloscopes when the sampling oscilloscope vertical signal output is displayed on the real time oscilloscope. The real-time sweep should be slow enough to provide about 100 samples/cm or more on the sampling oscilloscope, particularly during differentiation. The horizontal scaling factor under these circumstances becomes the ratio of time/cm switch settings of the sampling and real-time oscilloscopes.

It is not necessary to trigger the real-time oscilloscope sweep; it may be run at any convenient repetition rate. The retrace and hold-off of the real-time sweep will not be blanked on the sampling oscilloscope, so free-running the real-time sweep at a slow time/cm setting is generally most satisfactory.

Vertical scaling factors require no special techniques. However, since accumulated calibration errors and loading effects may be serious in some cases, it's usually advisable to obtain a 1:1 scaling factor as follows: :

1. Apply several cm of calibrator signal to the sampling oscilloscope input.

2. Using the same value $Z_i$ as will be used in the intended operation, set the operational amplifier for X (—1) amplification ($Z_f = Z_i$).

3. Adjust the real-time oscilloscope to display the same number of centimeters as the sampling oscilloscope Volts/Cm and Calibrator settings indicate **should** be displayed on the sampling oscilloscope. The vertical scaling factor is now 1:1. $Z_f$ may now be reset to the correct value for the intended operation. Since dc levels are critical in integration, the sampling oscilloscope dc offset (and/or vertical position or dc balance controls, depending on the make and model) should be carefully adjusted so that the vertical signal output is at 0 V dc when the signal waveform is at the reference level. The accuracy of this setting may be confirmed during adjustment of the vertical scaling factor, when the operational amplifier is set for X(—1) operation.

## Bibliography:

Much valuable information concerning theory, construction and applications of operational amplifiers will be found in the following:


1. G. A. and T. M. Korn,
   Electronic Analog Computers,
   McGraw-Hill Book Company, 1956.
2. C. L. Johnson,
   Analog Computer Techniques,
   McGraw-Hill Book Company, 1956.
3. N. R. Scott,
   Analog and Digital Computer Technology
   McGraw-Hill Book Company, 1960
4. A. E. Rogers, T. W. Connally,
   Analog Computation in Engineering Design,
   McGraw-Hill Book Company, 1960.
5. A Palimpsest on the Electronic Analog Art
   George A. Philbrick Researches, Inc.
   Boston, Massachusetts.

# SECTION 4

# CIRCUIT DESCRIPTION

## Introduction

This section of the manual describes the Type 3A8 plug-in unit circuitry and refers to the block diagram and circuit schematics in section 10. The reader should follow the diagrams as their description is presented.

## Block Diagram

The block diagram provides a functional representation of the main circuits used in the Type 3A8.

Signals applied to the INPUT connector of either Operational Amplifier are processed according to the combination of $Z_i$, $Z_f$. This combination of $Z_i$ and $Z_f$ can be internally selected through 6 capacitor or 5 resistor values, or when either or both $Z_f$ and $Z_i$ are in the EXT position, the impedance combinations can be externally plugged into the input banana jacks on the front panel.

Output signals from the Operational Amplifier are available at the OUTPUT connectors and may be selected by the input selector switch for the Display Amplifier. The signal is first applied through a calibrated step attenuator (SW200) which provides display sensitivity from 20 mV/Div to 10 V/Div in nine steps with 1-2-5 sequence.

The signal from the attenuator (SW200) is then applied through cathode followers V303A and V303B to a paraphase amplifier (Q324 and Q424). The input dc balance to the paraphase amplifier is adjusted and maintained in the cathode follower circuit.

The paraphase amplifier provides a balanced push-pull output signal to drive the output amplifier. Positioning and signal gain are adjusted and controlled in the paraphase amplifier stage.

A triggering signal for the time-base is provided from the isolation cathode-follower stage V344B and V444B, to pin 11 of the blue ribbon connector on the Type 3A8.

## Operational Amplifier

The two amplifiers in the Type 3A8 are identical, therefore only one will be described.

Before describing the circuits of the Operational Amplifier a review of the design goals or characteristics of the ideal amplifier is presented from the Operating Instructions of the manual. This will serve to recall some of the limitations and characteristics of the practical amplifier. Figs. 4-1 and 4-2 illustrate these characteristics.

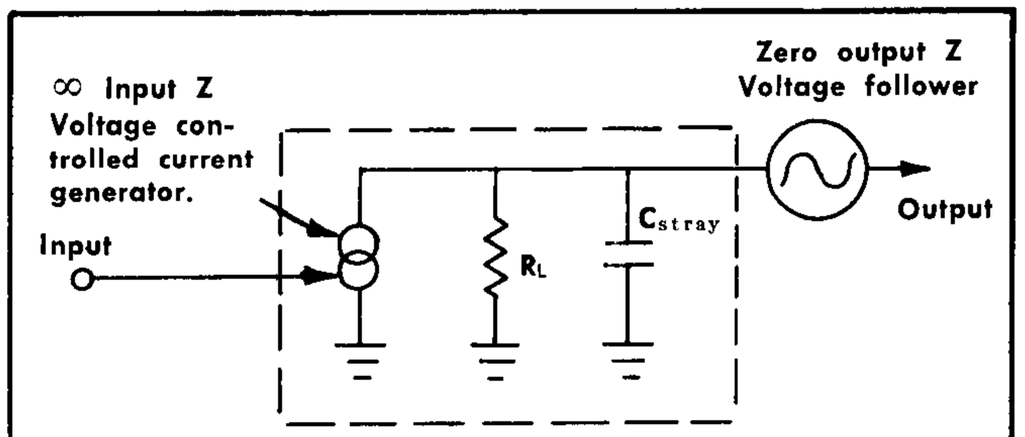
To function effectively the Operational Amplifier should approach the following design goals.

1. Infinite input impedance.

2. Infinite transconductance in the voltage-controlled current generator.

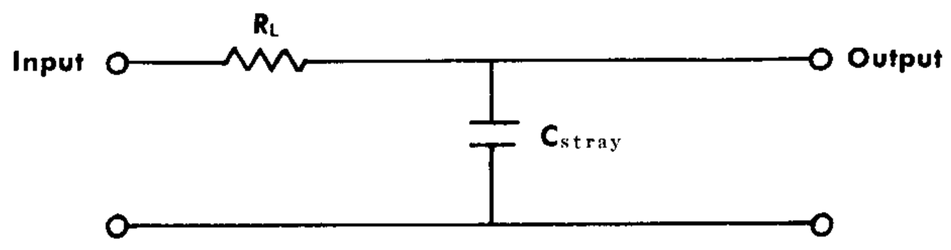
3. Infinite load resistance ($R_L$).

4. Zero load capacitance ($C_{stray}$).




**a. The ideal characteristics for an operational amplifier.**

1. **Infinite input impedance**
2. **Infinite transconductance in the voltage controlled current generator**
3. **Infinite load resistance ($R_L$)**
4. **Zero load capacitance ($C_{stray}$)**
5. **Zero output impedance**




**b. Electrical equivalent of the practical load**

**Fig. 4-1. Ideal amplifier characteristics.**

5. Zero output impedance.

Since all of these factors in the amplifier have limits, open loop gain and gain-bandwidth product will have finite values. Fig. 4-2 illustrates how these finite values in transconductance, load resistance and load capacitance affect the response of the amplifier.

The Type 3A8 Operational Amplifier contains a high gain differential amplifier for an input stage, which operates into a cathode-follower and current limited emitter-follower combination. This cathode-follower, emitter-follower stage provides the impedance transformation from a source impedance greater than 10 MΩ (at dc) to an output impedance near zero ohms. Current capabilities from the current-limited emitter follower will drive a wide range of output loads.

Input signals to the Operational Amplifier are normally applied through the INPUT connector (BNC connector J1 or the INPUT banana jack). The signals are then connected through the input impedance selected by the $Z_i$ selector switch (SW10A) to the grid of V54. ADJUST-NORM-∫LF REJ switch SW40 is normally in the NORM position.

Input signals may be applied directly to the grid of V54 through the — GRID jack or the ± GRID jack, providing the ± GRID SEL switch SW30 is in the (—) position.

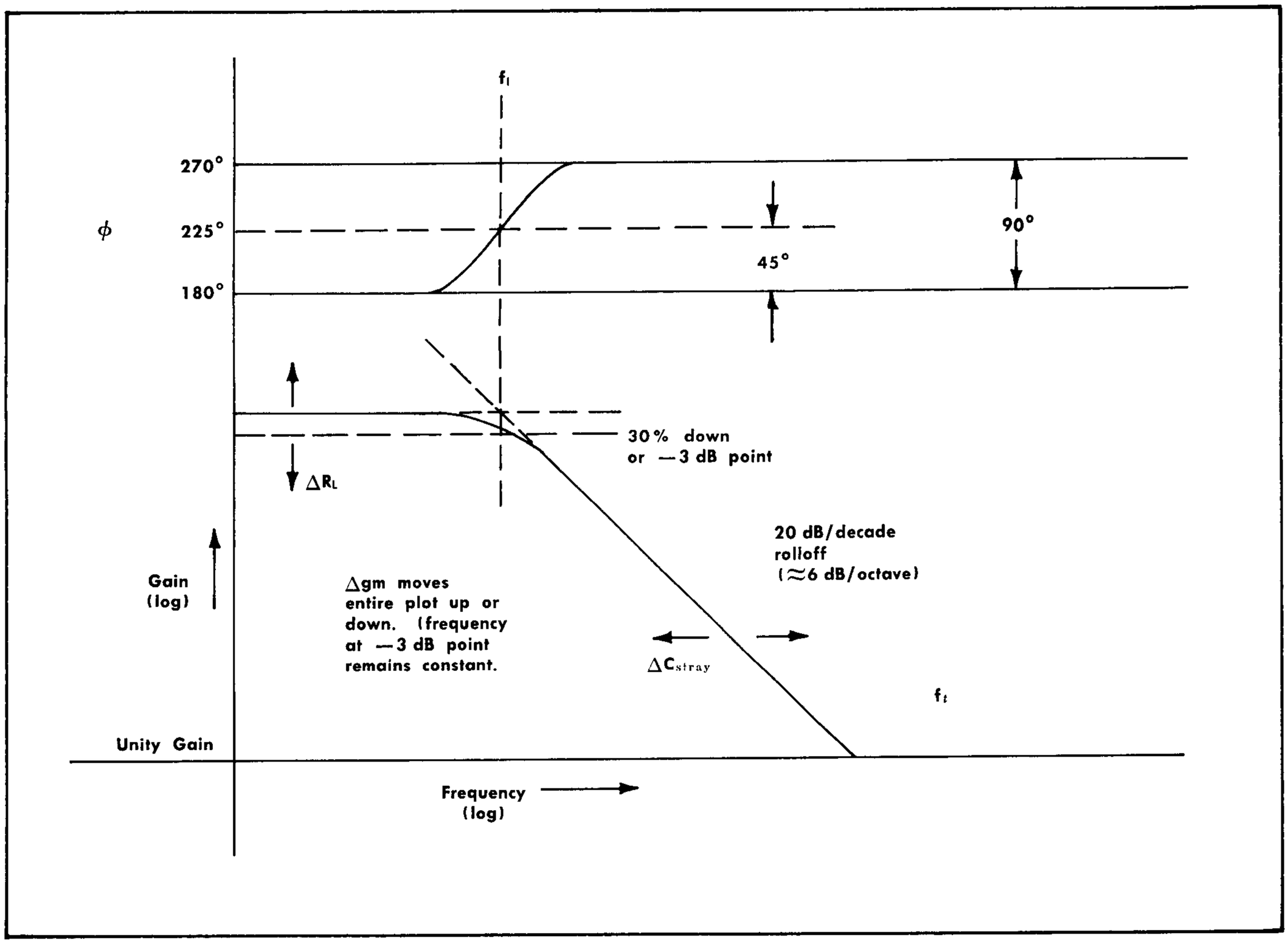



**Fig. 4-2. Response of the Operational Amplifier.**

Signals applied to the ± GRID jack are connected directly to the grid of V84 when the ± GRID SEL switch (SW30) is in the (+) position.

Tubes V54 and V84 comprise an input difference amplifier stage. Signals applied to the grid of V54 are inverted at the output, while signals applied to V84 are not inverted. Signals applied to either grid are amplified through the high gain stage consisting of V54, Q114, Q104, Q124 and Q134.

The plate of V54 terminates in the low impedance at the emitter of Q104 and sees a constant voltage source at the collector of Q114. Most of the tube (V54) plate current change ($\Delta$Ip), is transferred to the junction of the collectors of Q104 and Q124. This junction approximates a very high resistance plate load ($R_L$). The cascode arrangement of V54 and Q104 isolates this high impedance load from the plate of V54, thereby substantially reducing the effect of mu in V54. Gain is proportional to the transconductance (gm) and load resistance ($R_L$). This cascode amplifier circuit develops a dc gain greater than 15000.

Transistors Q114 and Q134 effectively increase the resistance and decrease the capacitance of the collectors of Q104 and Q124, by minimizing the inherent coupling from the collector to the base of the transistor. The decoupled base of Q114 is stabilized at an approximate 75 volts by a voltage divider R114 and R116. The collector of Q114 thus appears as a constant voltage source to the plate of V54.

In a similar way, transistor Q93 provides a constant voltage source to the plate of V83 and matches the plate voltage and impedance of V84 to that seen by V54.

To function properly, the Operational Amplifier must adjust to, and must maintain, proper dc levels. The circuit is designed so the plate voltages of V54 and V84 are constant and essentially equal. With zero volts on the input grids, the bias of V54 is forced to equal the bias of V84. OFFSET adjustment R192 provides differential control over the filament power of V54 and V84. Filament power determines cathode temperature and determines the cathode current. The OFFSET (R192) is adjusted for tube currents such that the resultant voltage difference between the input and output of the amplifier is zero. See Fig. 4-4.

The type 7586 tubes V54 and V84 are quiescently operated at a plate voltage (Ep) of approximatly 75 volts, and a plate current (Ip) of an approximate 2mA. Grid emission current with these conditions is normally less than 2 nano-amps. This grid emission current is offset by a bootstrapped current source from Q78 such that little or none of the grid emission current will flow through $Z_i$ or $Z_f$.

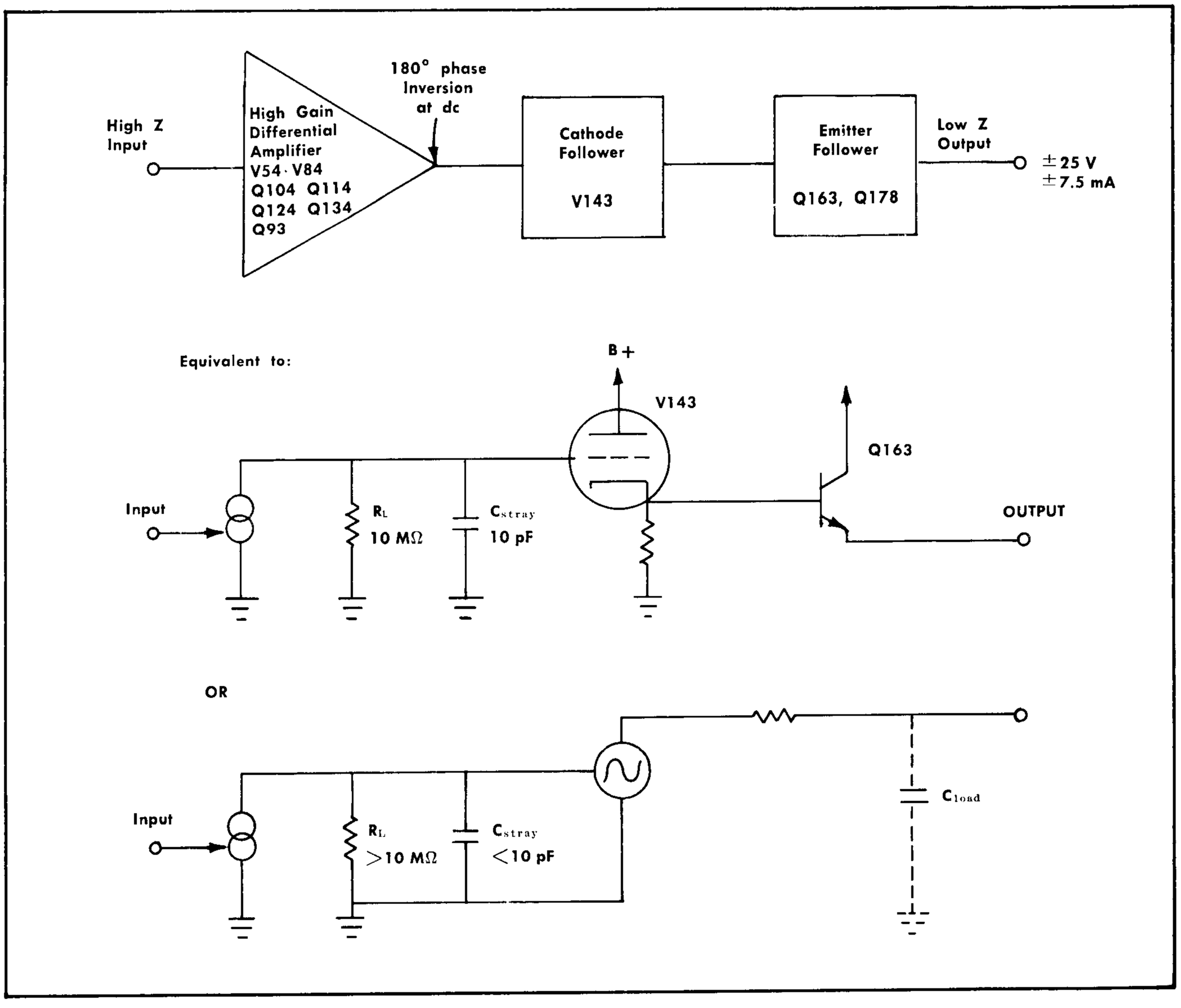



Fig. 4-3. Block diagram and equivalent circuits of Type 3A8 Operational Amplifier.

Transistor Q78 and associated circuitry long tail the cathodes of the differential amplifier and supply approximately 4 mA of current to the amplifier. This current splits between potentiometers R60 and R62 (— and + $I_g$ adjustments), which offers a voltage range across the potentiometers through zero volts with reference to the grids of V54 and V84, and provides a voltage adjustment range of approximately 200 mV. This voltage is set to supply through R58 and R68, the exact current emitted by the grids, and results in a net current of zero as seen by $Z_i$ and $Z_f$. See Fig. 4-5.

Diodes D52 and D82 limit the grid absorption current of the tubes during warm-up time.

Impedance transformation from an impedance greater than 10 MΩ to approximately 0 Ω is provided by the cathode follower V143 and emitter follower Q163.

The emitter of Q163 is long tailed through transistor Q178 to the —100 volt supply. The collector of the emitter-follower Q163 connects to a current-limited, constant-voltage source (the emitter of Q158) of approximately 29 volts. This provides a minimum 7.5 mA of current for the output load, and also short circuit protection.

The plate of the cathode-follower V143 is connected through R143 to 300 volts and clamped at +125 V by the diode D143. This provision limits the current through the tube if the output shorts and also distributes the current demands on the power supply.

Since the output impedance is not zero ohms, it is important to consider the effects of load capacitance. As capacitance increases, the cathode follower and emitter follower bandpass decreases. The frequency at which 90° phase shift occurs, therefore decreases. If the cathode follower-emitter follower phase shift approaches 90°, at $F_t$ (frequency at which the gain is unity) of the high gain differential amplifier stage, the total phase shift from the (—) grid to the output will approach 360°. This produces a highly unstable condition when feedback tightly couples the input to output.

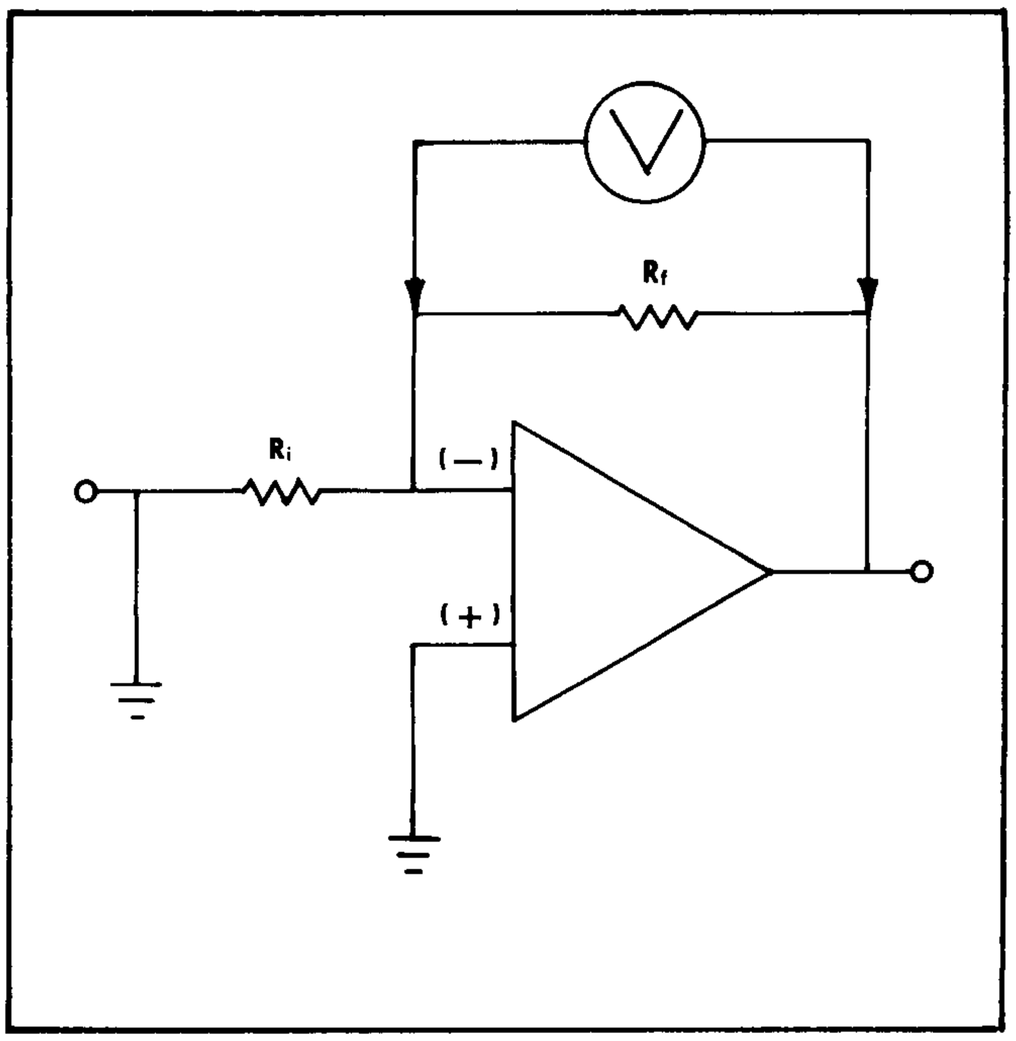



**Fig. 4-4. With an $E_p$ of 75 volts, $I_p$ level is set so the resultant voltage across the closed loop is zero.**

The amount of load capacitance that can be tolerated by the amplifier is greatly extended through the effect of C145, R141 and C141. These components cause the $F_t$ of the high gain section to decrease whenever a load causes the cathode follower-emitter follower bandpass to decrease.

In applications employing substantial load capacitance, the user may wish to reduce the $F_t$ of the high-gain section directly. The addition of a capacitor across J120 will decrease the amplifier gain-bandwidth product. See Fig. 4-6.

Feedback impedance ($Z_f$) from the output to the (—) input is normally selected by the $Z_f$ selector switch SW10B. With $Z_f$ (SW10B) in the EXT position, feedback impedance is dependent on the external components plugged into the banana jacks on the front panel. The internal impedance may also be selected to augment any external component values that are connected.

The $\int$LF REJ position of the ADJUST-NORM-$\int$LF REJ switch SW40 connects a long RC feedback circuit, R40, C40 and R30, from the output to the (—) input when the feedback impedance ($Z_f$) is any of the internal capacitors. (See Fig. 4-7.) This prevents integration of the low frequency components in the signal. High frequency components of the integrated signal are not fed back through the long RC network, so the output will approximate integration of the desired signals.

The ADJUST position of switch SW40 grounds the grid of V84 and connects V54 grid to the output through resistor divider R38, R35, to provide an approximate closed-loop gain of 100. The OFFSET potentiometer R192 can then be adjusted for tube currents such that the resultant voltage difference between the output and the input of the amplifier is zero. See Fig. 4-4.

## Input Selectors And Display Amplifier

Input signals to the Display Amplifier are selected from either Operational Amplifier or the EXT connector by means of the selector switch SW200. The selected signals are then ac or dc coupled according to the position of the coupling switch SW205 and applied through the VOLTS/DIV attenuator switch SW210.

A GND position for the coupling switch SW205 provides the no-signal input condition to check or adjust the dc level and balance of the amplifier.

The VOLTS/DIV switch attenuators are frequency-compensated dividers which reduce the input signal amplitude to a level suitable for driving the grid of the input cathode follower to the Display Amplifier. Each attenuator presents an input time constant of 47 $\mu$s (1 megohm paralleled by 47 pF) to the signal source. Frequency compensation through the attenuator is provided with a variable capacitor across the input resistor of each divider. The input capacitance to the attenuator is adjusted with a variable capacitor that shunts both resistors of the divider. For example; the 10 position of SW210 uses variable capacitors C210B and C210C.

No attenuator is used for the .02 position of the VOLTS/DIV switch and the amplifier input time constant in this position is set to 47 $\mu$s by adjusting the variable capacitor C225.

Input signals from the attenuator are applied through a protection circuit to cathode follower V303A. The amplitude of the input signal is clamped at approximately $\pm$12 volts by clamping diodes D303 and D305. This protects V303A and succeeding circuitry from excessive input signals.

NOTE

**Refer to the input signal derating chart in the Characteristics section of the manual for maximum input signal voltages that may be applied to the amplifier.**

The input stage of the Display Amplifier V303A contains a cathode follower driving an emitter-coupled paraphase amplifier through a polarity inversion selector, relay K360.

Emitter coupling produces a push-pull output signal that is T coil-coupled to the next stage. The VARIABLE control R437 (concentric with the VOLTS/DIV switch) varies the amount of degeneration between the emitters, and hence the stage gain. With the VARIABLE control at its detent position (minimum resistance), the CAL adjustment R337 is adjusted to set the amplifier maximum gain.

The emitters of the paraphase amplifier are longtailed through transistors Q324 and Q424. These transistors set the dc current of the stage and minimize common mode dc variation.

The POSITION control (R332) provides differential control of the dc collector currents of Q324 and Q424. This sets the current division through the paraphase amplifier, Q334 and Q434. Since the ratio of Q334 and Q434 emitter impedance to the combined resistance between the

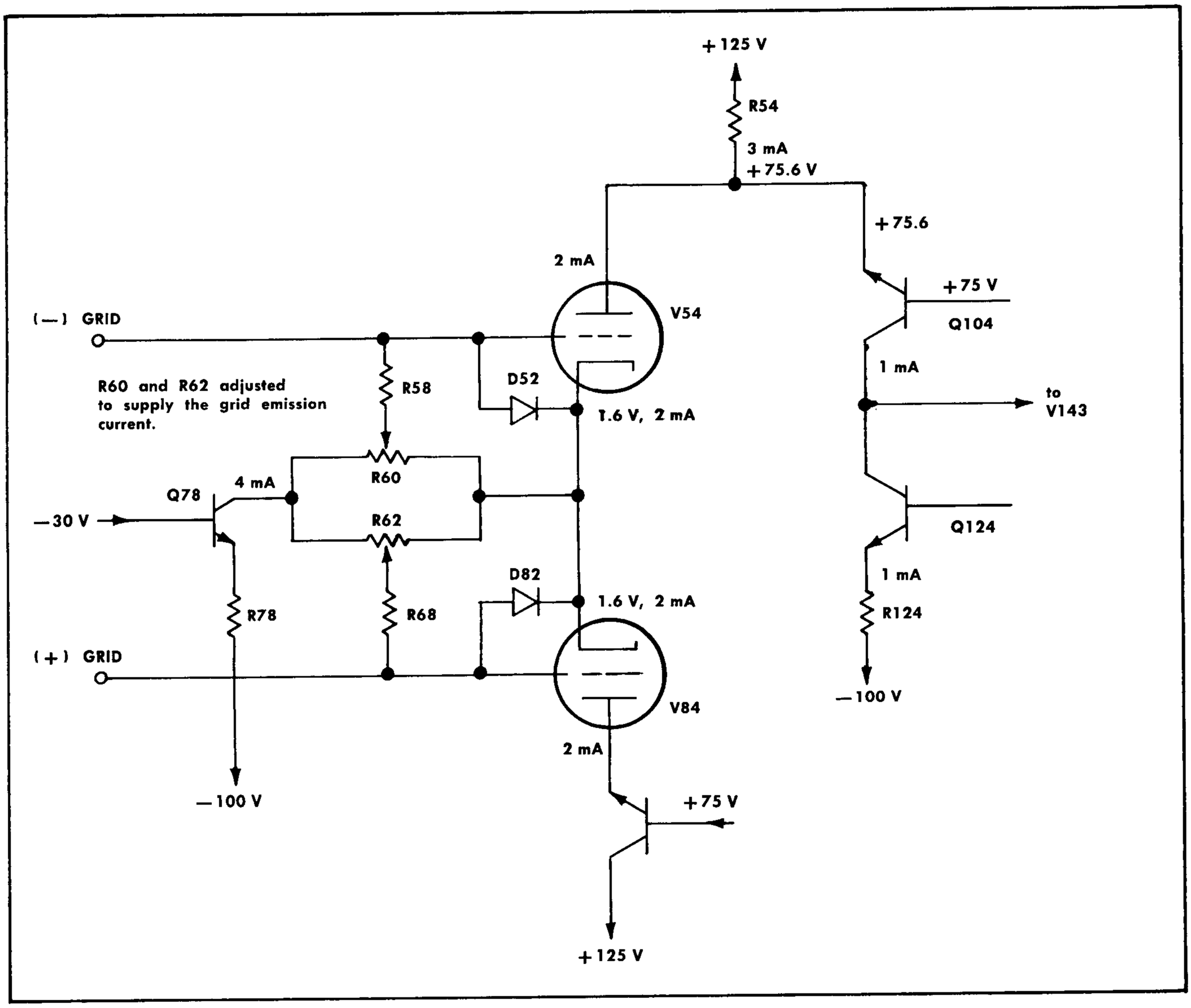



Fig. 4-5. Simplified circuit of input of differential amplifier.

two emitters (R437, R337 and R339) is relatively low, adjustment of the POSITION control tends to produce a dc imbalance. This effect is substantially reduced through feedback via R418 to the grid of cathode follower V303B. The output dc signal from the cathode of V303B is applied to the paraphase amplifier through the contacts of the NORM-INVERT relay contacts to offset any generated dc imbalance.

Collector to base capacitance of Q334 and Q434 is partially neutralized by positive feedback through C334 and C434.

The cathode potential for V303A and V303B is balanced to prevent dc shift in the output level as the NORM-INVERT relay K360 is either energized or de-energized. With no input signal and the POSITION control R332 centered, BAL adjustment R414 is normally set to balance the cathode voltages. BAL adjustment R410 is a coarse adjustment set during calibration.

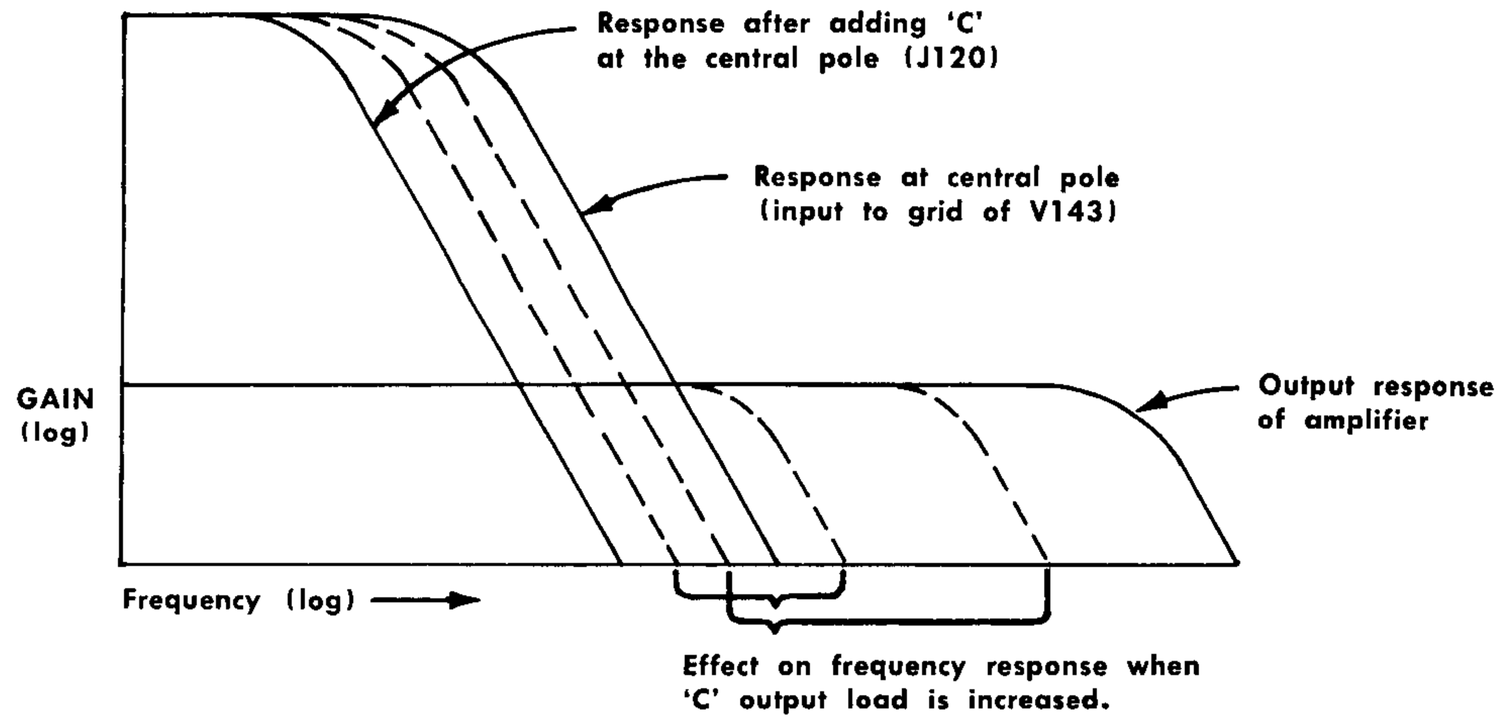
The output of the paraphase amplifier is T coil-coupled to the base of Q354 and Q454 which are in cascode configuration with the output tubes V344A and V444A respectively. Q468 limits the static current of the output stage to an approximate 48 mA, and reduces the common mode gain of the stage.

L344 and L444 are adjustable T-type coils to match the high deflection plate impedance of the crt.

V344B and V444B, the other halves of the output tubes, are connected in cascade and provide trigger pickoff for the sweep circuits. Trigger dc level is adjusted by means of R480 which sets the dc level on the cathode of V444B.

## Interconnecting Circuit

Resistors R512, R501, R502, R511 and R520 are power supply shunting resistors, some of which are shorted when either or both Operational Amplifiers are installed. This arrangement permits optimum power supply operation when the Type 3A8 is operated with either or both Operational Amplifiers removed.




**NOTE:**
For a given output load 'C' the decrease in output frequency response is much greater than the shift at the central pole. The amount of output 'C' is limited to the value where output response approaches the response of the central pole. At this point the phase shift is such as to cause the amplifier to become highly unstable. The addition of 'C' at the central pole greatly enhances the amount of output 'C' that the amplifier can tolerate.

Fig. 4-6. Effects on frequency response of the amplifier with changes in capacitance at the output load or central pole.

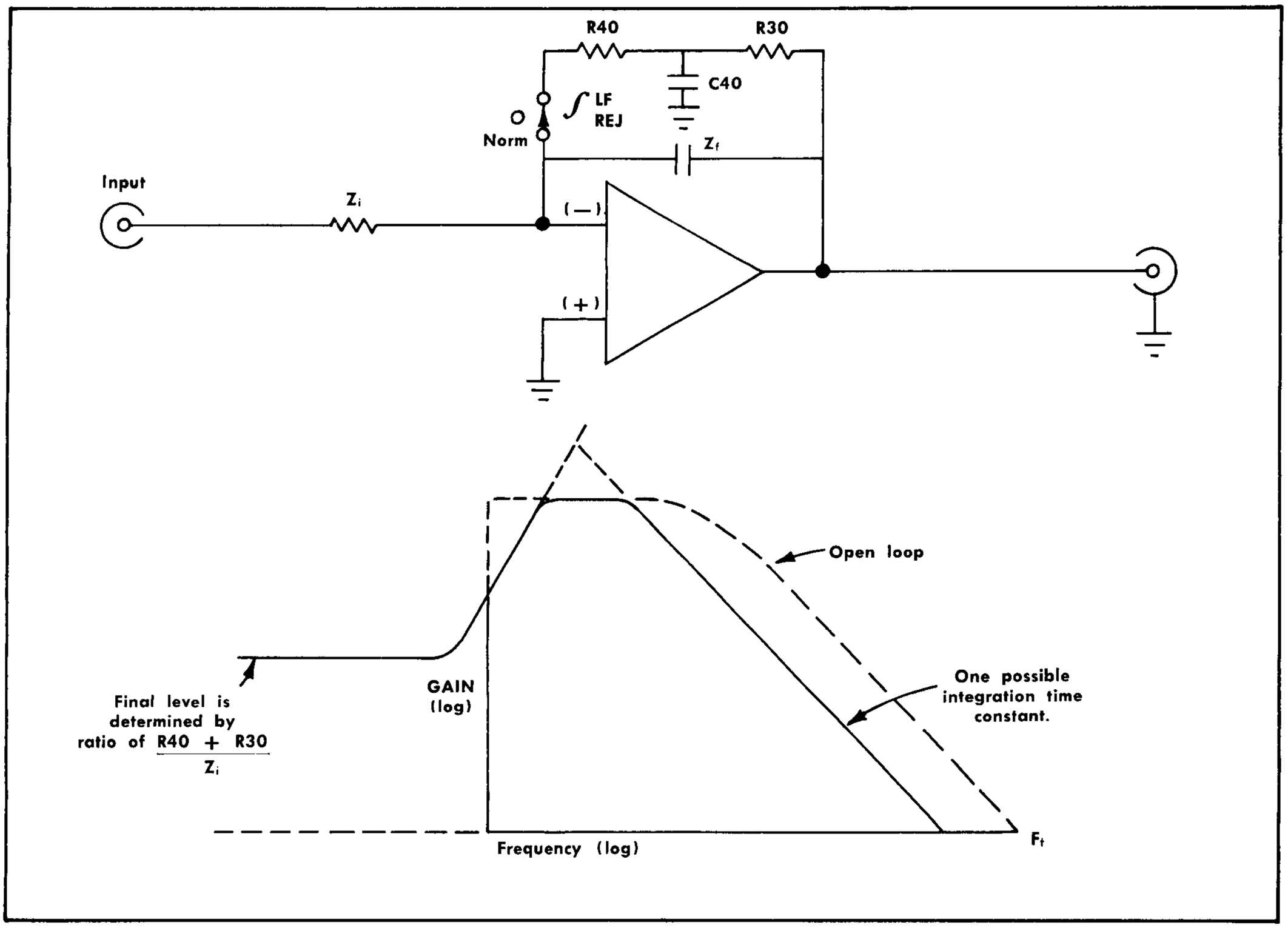



Fig. 4-7. Basic ∫LF REJ circuit and response characteristics.

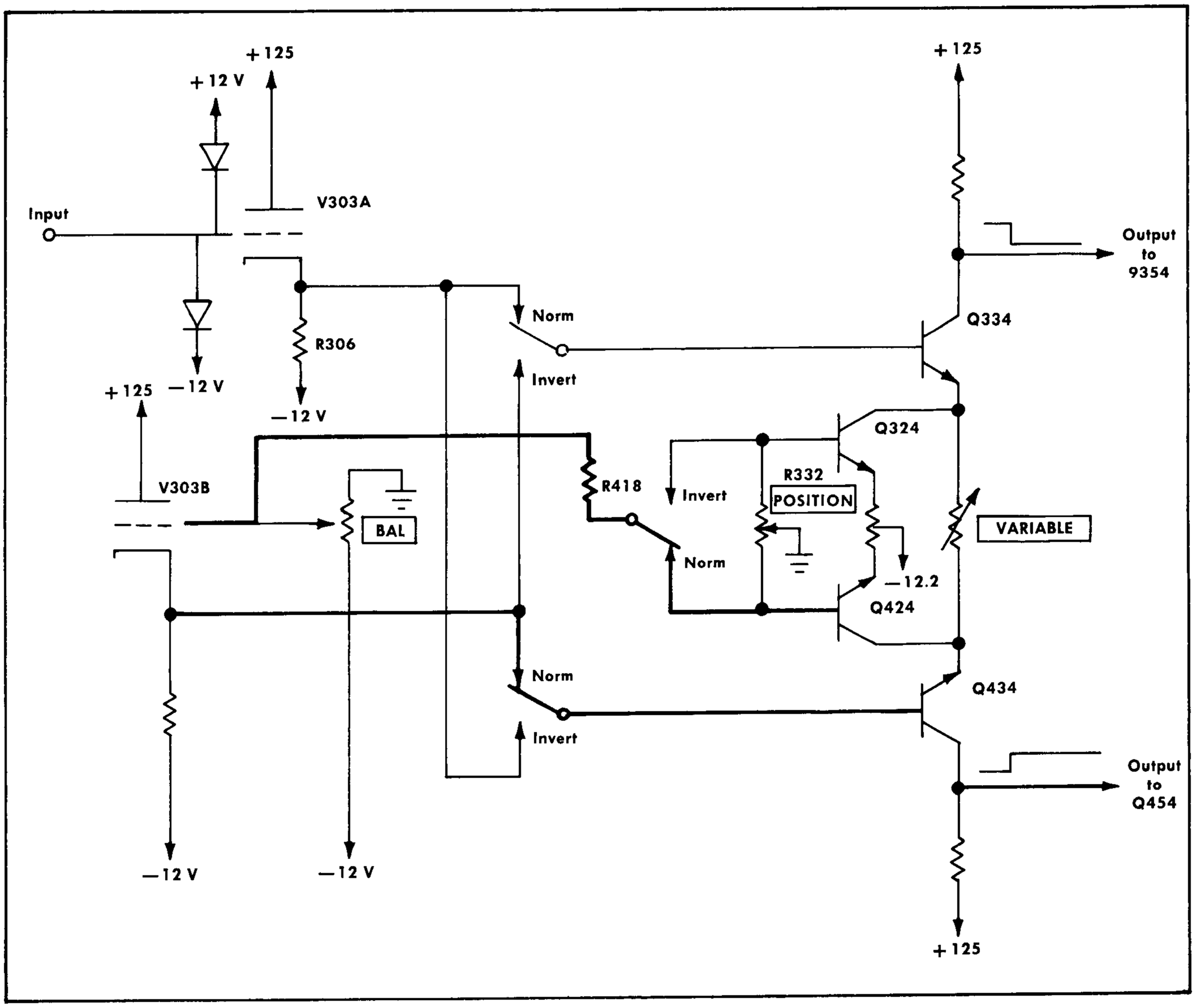



Fig. 4-8. Simplified dc balance circuit for output amplifier.

# NOTES

# SECTION 5
# MAINTENANCE

## Preventive Maintenance

Preventive maintenance consists of cleaning, visual inspection, lubrication, and if needed, recalibration. Preventive maintenance is generally more economical than corrective maintenance, since preventive maintenance can usually be done during idle periods at a time convenient to the user. The preventive maintenance schedule established for the instrument should be based on the amount of use and the environment in which the instrument is used.

**Cleaning.** Clean the instrument often enough to prevent accumulation of dirt. Dirt on the components acts as a thermal insulating blanket (preventing efficient heat dissipation) and may provide electrical conducting paths.

Clean the instrument by loosening the accumulated dust with a dry, soft paint brush. Remove the loosened dust by vacuum and/or dry, low pressure compressed air (high-velocity air can damage certain components). Hardened dirt and grease may be removed with a cotton-tipped swab or a soft cloth dampened with water and a mild detergent solution (such as Kelite or Spray White). Abrasive cleaners should not be used.

CAUTION

**Do not permit water to get inside controls or shaft bushings.**

**Lubrication.** The life of potentiometers and selector switches is lengthened if these devices are kept properly lubricated. Use a cleaning type lubricant (such as Cramoline) on shaft bushings and switch contacts. Lubricate the switch detents with a heavier grease (Beacon grease No. 325 or equivalent). Do not over-lubricate. The necessary materials and instructions for proper lubrication of Tektronix instruments are contained in a component lubrication kit which may be ordered from Tektronix. Order Tektronix Part No. 003-0342-00.

**Visual Inspection.** After cleaning, the instrument should be carefully inspected for such defects as poor connections, damaged parts, and improperly seated transistors. The remedy for most visible defects is obvious; however, if heat-damaged parts are discovered, determine the cause of overheating before the damaged parts are replaced. Otherwise, the damage may be repeated.

## Tube And Transistor Checks

Periodic preventive maintenance checks on the tubes and transistors used in the instrument are not recommended. The circuits within the instrument generally provide the most satisfactory means of checking tube or transistor usability. Performance of the circuits is throughly checked during recalibration, so substandard tubes and transistors will usually be detected at that time.

## Recalibration

To insure accurate measurements, the instrument calibration should be checked after each 500 hours of operation or every six months if used intermittently.

The calibration procedure can be helpful in isolating major troubles in the instrument. Moreover, minor troubles not apparent during regular operation may be revealed and corrected during calibration.

## CORRECTIVE MAINTENANCE

Corrective maintenance consists of component replacement and instrument repair. Special techniques or procedures required to replace components in this instrument are described in this section.

**Component Identification.** The circuit number of each electrical part is shown on the circuit diagrams in Section 10, and on the pictorial diagrams of the etched circuit boards in this section. Note that a functional group of circuits (such as the display amplifier) is assigned a particular series of numbers. Switch wafers are identified by counting from the first wafer located behind the detent section of the switch towards the last wafer. The letters F and R indicate whether the front or rear of the wafer is used to perform the particular switching function. For example, the designation 2R printed by a switch section on a schematic identifies the switch section as being on the rear side of the second wafer when counting back from the detent section.

**Parts Replacement.** Most of the electronic components in the Type 3A8 are standard items available locally. The remainder of the electronic components and most of the mechanical parts are manufactured or selected by Tektronix to satisfy particular requirements, or are manufactured for Tektronix to our specifications. However, all parts are obtainable through your Tektronix Field Office or Engineer. Before purchasing or ordering, consult the Parts Lists (Sections 8 and 9), and see Parts Ordering Information and Special Notes and Symbols on the page immediately preceding Section 8.

NOTE

**When selecting the replacement parts, it is important to remember that the physical size and shape of a component may affect its performance in the circuit. Parts orientation and lead dress should duplicate those of the orginal part, since many of the components are mounted in a particular way to reduce or control stray capacitance and inductance. After repair, circuits of the instrument may require recalibration.**

## Replacing Components On The Etched Circuit Boards Or Cards

It is best to remove the board or card from the instrument unless the back of the board is accessable. Use electronic grade 60/40 solder and a 15-watt pencil soldering iron with a $1/16$ inch wide chisel tip. The tip of the iron should be clean and properly tinned for best heat transfer in a short time to a solder connection. A higher wattage soldering iron, if applied for too long a period, ruins

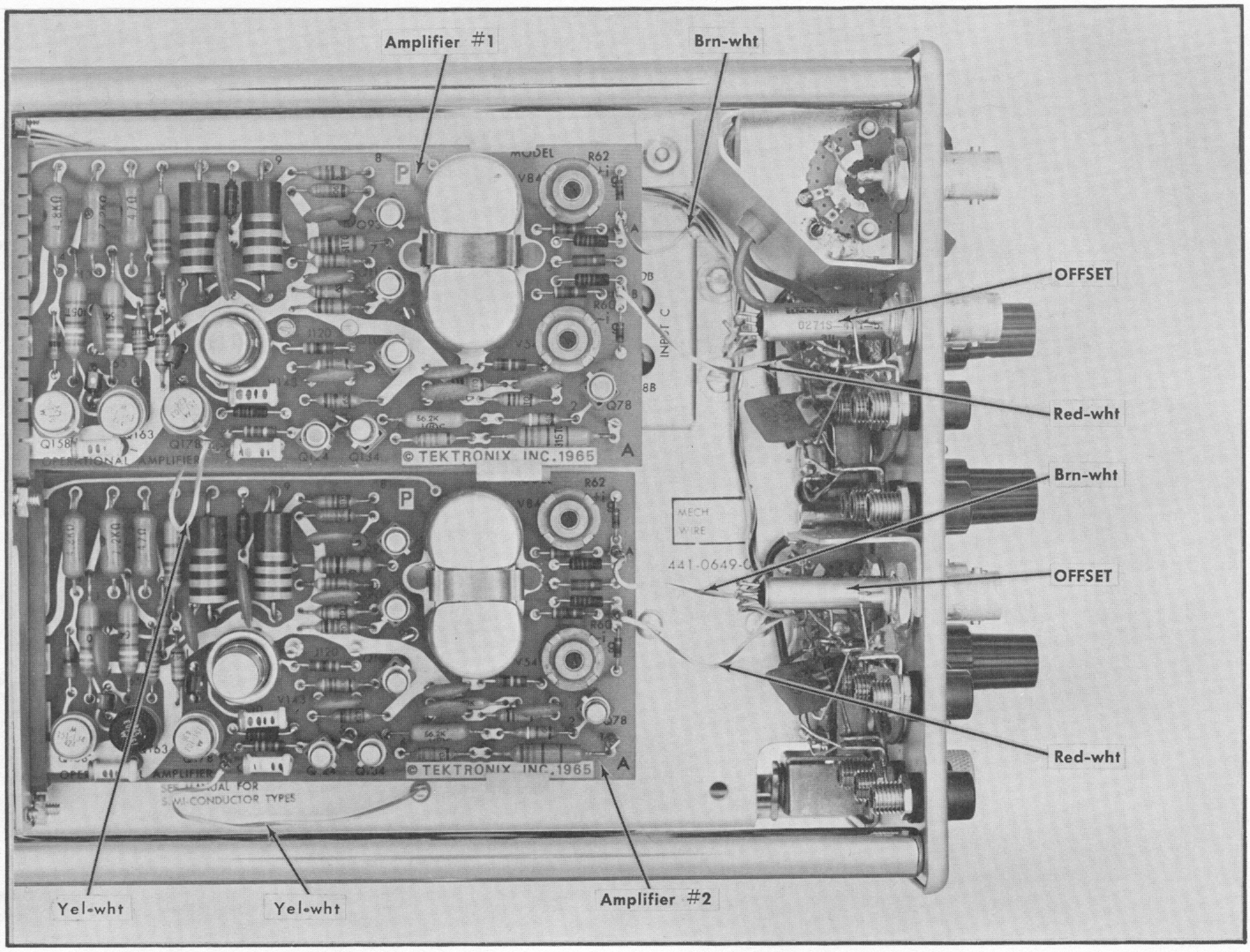



**Fig. 5-1. Operational Amplifier etched-circuit card.**

the bond between the etched wiring and the base material by charring the glass epoxy laminate.

The following technique is recommended to replace a component on an etched circuit board or card.

1. Remove the component by cutting the leads near the body. This frees the leads for individual unsoldering.

2. Grip the lead with needle-nose pliers. Apply the tip of the soldering iron to the connection at the back of the board, then pull gently to remove the lead.

3. When the lead comes out of the board it should leave a clean hole. If not, the hole should be cleaned by reheating the solder and placing a sharp object such as a toothpick or enameled wire into the hole to remove the old solder.

4. Clean the leads on the new component and bend them to the correct shape to fit into the holes. Insert the leads, making certain the component seats the same as the orginal part.

5. Apply the iron to the connection at the back of the board and apply only the amount of solder required to form a good electrical connection.

6. Check the front, or component side, of the board to insure that the solder has wicked through the plated hole.

NOTE

**Some components can be damaged by heat. If this is likely, connect a heat sink such as a pair of needle-nose pliers between the component and the connection before applying the soldering iron.**

7. Clip the excess lead that protrudes through the hole in the board.

8. If necessary, clean the area around the soldered connection with a flux-remover solvent to maintain good environmental characteristics.

When soldering metal terminals (e.g., switch terminals, potentiometers, etc.) ordinary 60/40 solder is satisfactory. The soldering iron should have a 40- to 75-watt rating with a $\frac{1}{8}$ inch wide chisel tip.

1. Apply only enough heat to make the solder flow freely and only enough solder to form a good electrical connection. (Excess solder may impair the operation of the circuit or cover a cold joint.)

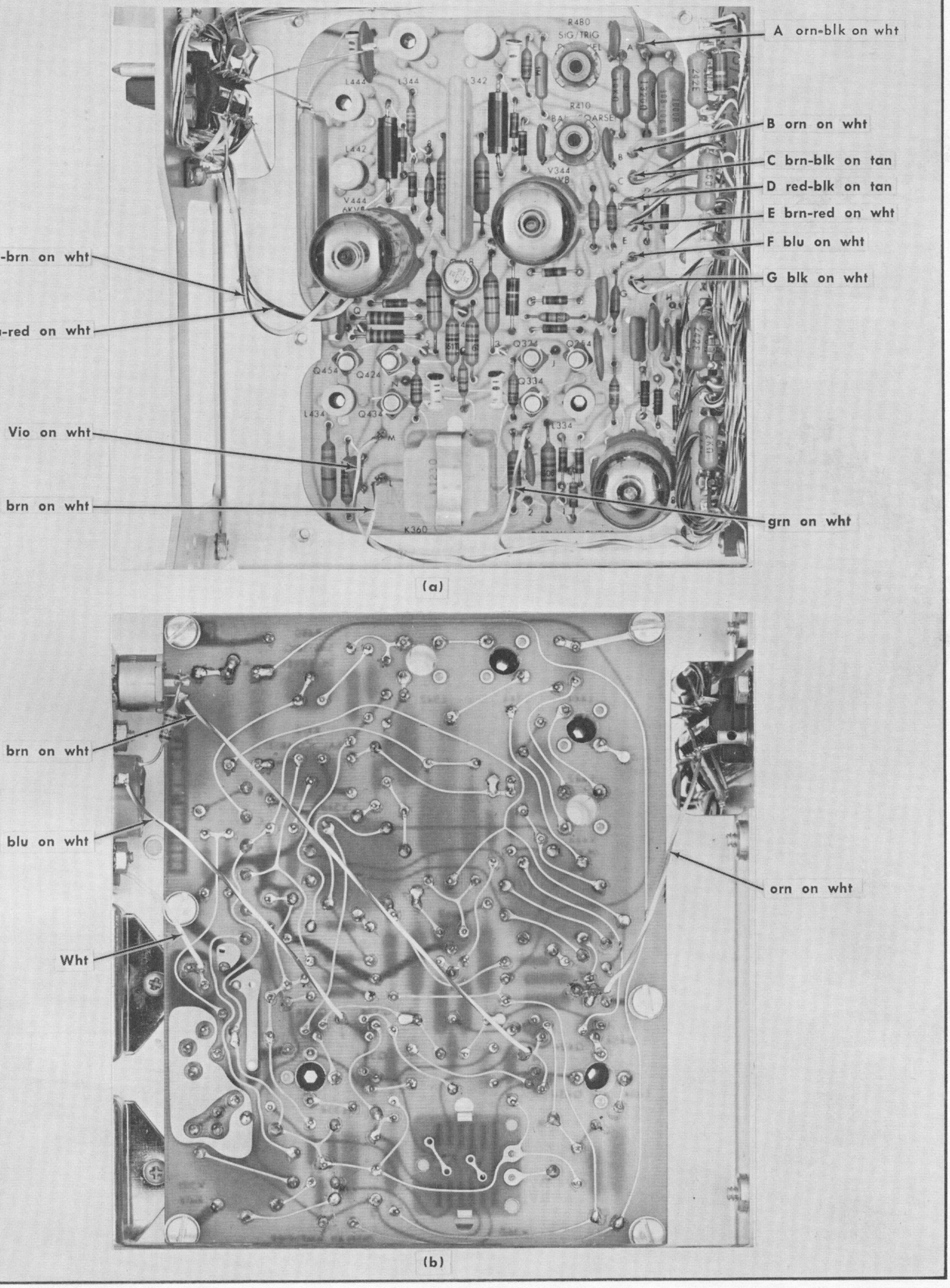



Fig. 5-2. Display Amplifier etched-circuit board. a. Component side. b. Back side.

2. Clip off excess wire that may extend past the solder connection and clean with flux-remover solvent.

## Etched Circuit Board Or Card Removal

The Operational Amplifier cards are the plug-in type and easily removed. This is accomplished by removing the three external wires from the pin connectors, then spreading the nylon clip retainers. The card can then be snapped free and gently pulled from the socket.

The Display Amplifier board is mounted with six screws. Disconnect the external wires from the pin connections. Unsolder the two leads to L344 and L444. See Fig. 5-2. Remove the 6 screws and lift out the board.

To replace the etched circuit boards, reverse the order of removal. Correct location of the external wires to the pin connectors is shown in Figs. 5-1 and 5-2. Replace the pin connectors so they mate correctly and do not become damaged.

## Switch Replacement

Individual wafers normally are not replaced in switch assemblies. Replacement switches may be ordered from Tektronix either unwired or with the associated wires and components attached. See the Parts Lists in Section 8 and 9.

When soldering leads to a switch, do not let solder flow around and beyond the terminal rivet as this may destroy the contact spring tension.

## Tubes and Transistors

Tubes and transistors should not be replaced unless actually defective. However, temporary substitution is an effective way to detect defective tubes or transistors. Before making the substitution, the circuit conditions should be checked to be certain that a replacement tube or transistor will not be damaged. In some cases, these checks will also show if the tube or transistor is at fault.

When circuit conditions have been checked, install a tube or transistor which is good and of the same type and check for proper operation. If the original tube or transistor is thus proved operative, return it to its original socket to avoid unnecessary recalibration.

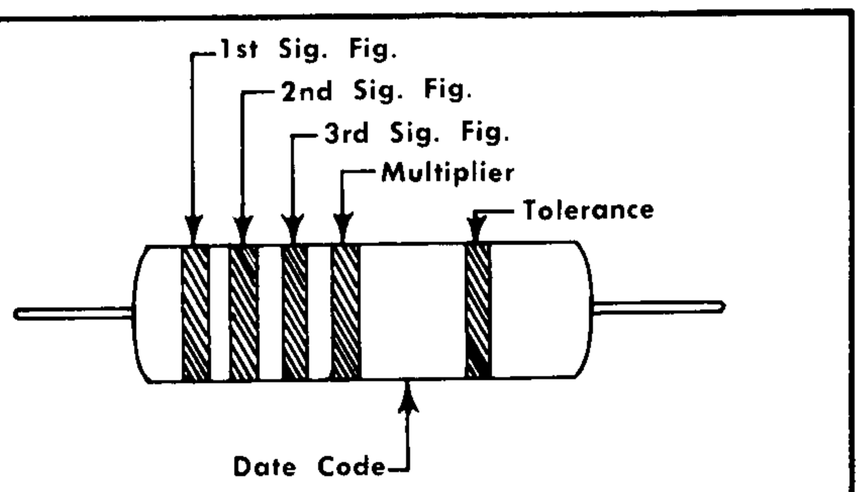
## Troubleshooting Aids

This manual and the instrument contain many features intended to speed and simplify maintenance. A block diagram which provides an overall picture of instrument operation is included with the diagrams in Section 10. The schematic diagrams give the circuit reference number for each electrical component as well as important operating voltages, signals, and conditions for the measurements.

The instrument contains a number of stable metal-film resistors identified by their gray background color and color coding. If a resistor has three significant figures and a multiplier, it will be EIA color coded. If it has four significant figures and a multiplier, the value will be printed on the resistor. For example, a 333-k resistor will be color coded, but a 333.5-k resistor will have its value printed on the resistor body. The color-coding sequence is shown in Fig. 5-3.

Fig. 5-4 identifies the polarity of the various diode types used in Tektronix instruments.

**In-Circuit Diode Checks.** In circuit diode checks may be performed with a voltmeter. A comparison check of the voltages on each side of the diode with the typical voltages listed on the diagram will help determine if the diode is faulty. Forward-to-back resistance ratios can be checked by referring to the schematic and pulling appropriate tubes or transistors to remove low resistance loops around the diode.




| Color | 1st Sig. Fig. | 2nd Sig. Fig. | 3rd Sig. Fig. | Multiplier | Tolerance (±) % |
|---|---|---|---|---|---|
| Black | 0 | 0 | 0 | 1 | — |
| Brown | 1 | 1 | 1 | 10 | 1 |
| Red | 2 | 2 | 2 | 100 | 2 |
| Orange | 3 | 3 | 3 | 1,000 | — |
| Yellow | 4 | 4 | 4 | 10,000 | — |
| Green | 5 | 5 | 5 | 100,000 | 0.50 |
| Blue | 6 | 6 | 6 | 1,000,000 | 0.25 |
| Violet | 7 | 7 | 7 | 10,000,000 | 0.10 |
| Gray | 8 | 8 | 8 | 100,000,000 | 0.05 |
| White | 9 | 9 | 9 | 1,000,000,000 | — |
| Gold | | | | 0.1 | 5 |
| Silver | | | | 0.01 | — |
| No Color | | | | | 10 |

**Fig. 5-3. Standard EIA color code for metal-film resistors.**

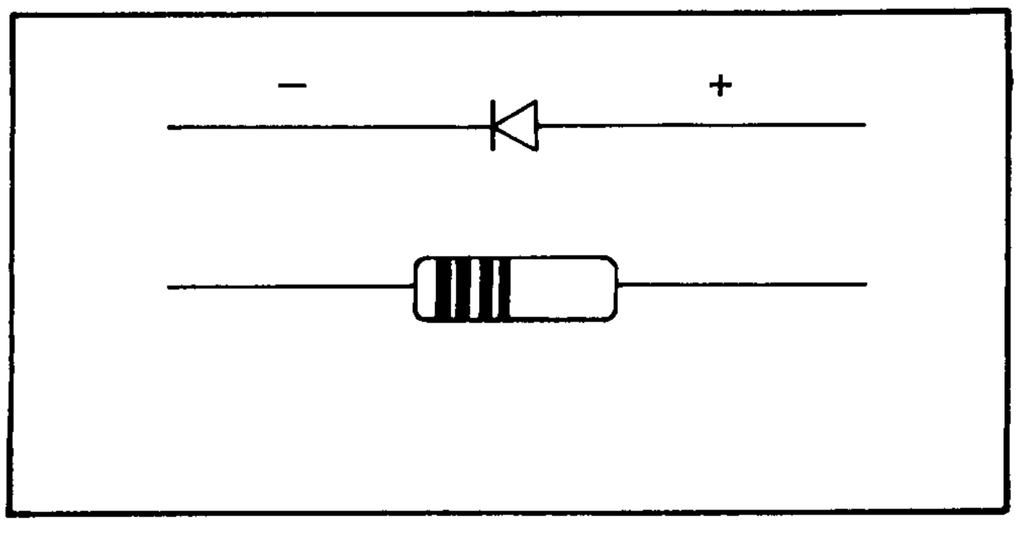



**Fig. 5-4. Diode polarities and color code of glass diodes used in Type 3A8.**

## General Troubleshooting

Attempt to isolate the trouble to a circuit by an operational and visual check. Verify that the apparent trouble is actually a malfunction within the Type 3A8, and not improper control settings or a malfunction of associated equiqment.

Operate the front-panel controls and note their effect on the trouble symptoms. Normal or abnormal operation of each control helps establish the nature of the trouble. Refer to Section 2 for the normal function of each control.

If the trouble cannot be isolated by front-panel checks, remove the side panel from the main frame oscilloscope. Check voltages against those shown on the diagrams in Section 10 of the manual. Use an accurate 20,000 ohms/volt, or better, dc voltmeter to measure voltages. Test points are numbered and accessible on the top of the card or etched circuit board. Refer to Figs. 5-5 and 5-6 for component identification.

Start with the power-supply connections, then proceed consecutively from test point to test point. Once the trouble is isolated to a circuit, refer to the circuit description in Section 4 for a description of the normal circuit operation.

CAUTION

**Use care when measuring voltages on live circuits. The small size and high density of components used in this instrument establishes a situation such that an inadvertent movement of the test probe or the use of oversized probes may short-circuit between components.**

The pin connectors used to connect the etched circuit boards to the instrument provide a unique method of circuit isolation. For example, operational amplifier cards may be exchanged, or with the power off, dc resistance measurements can be taken.

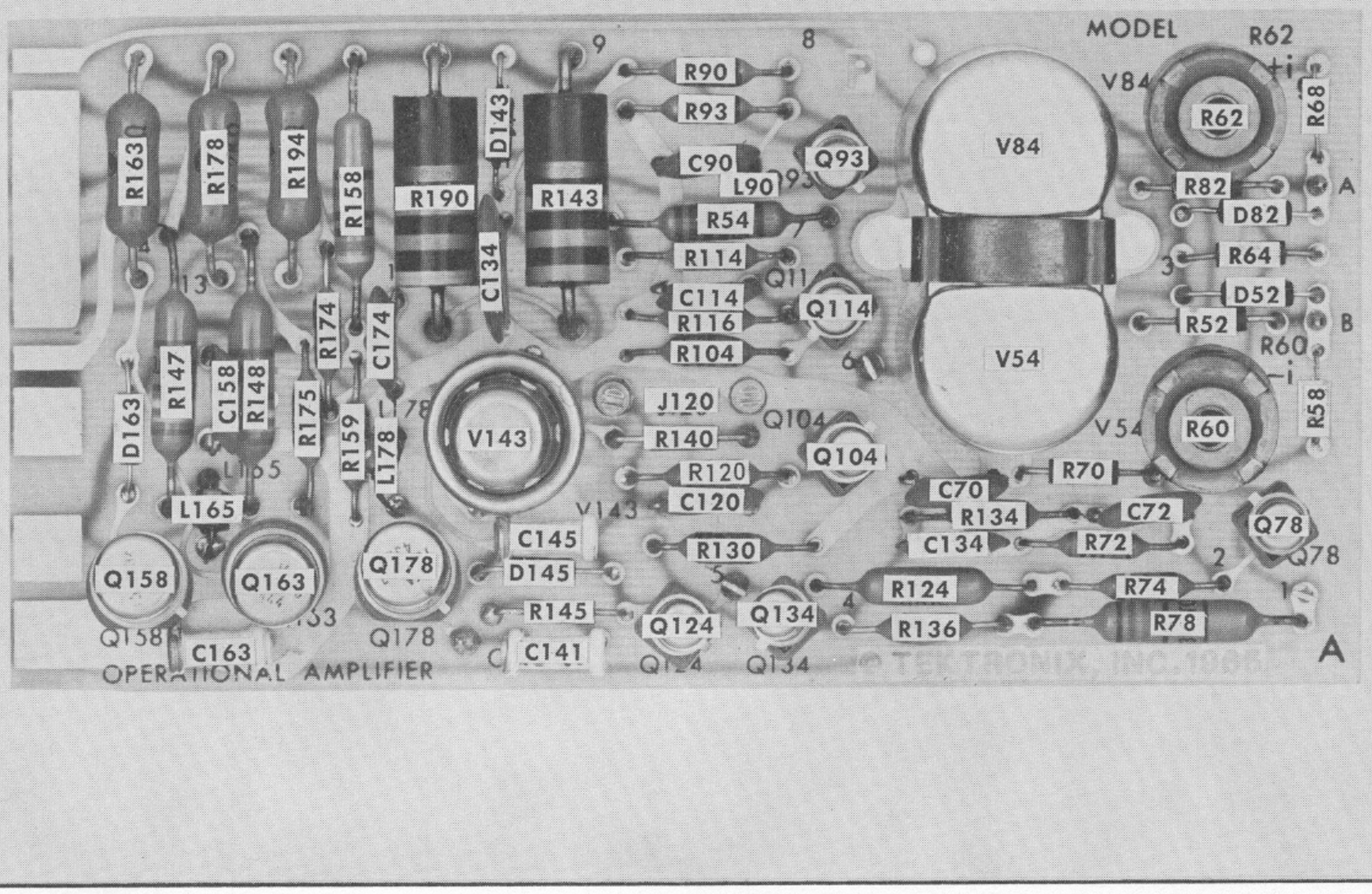



Fig. 5-5. Etched circuit boards Operational Amplifier.

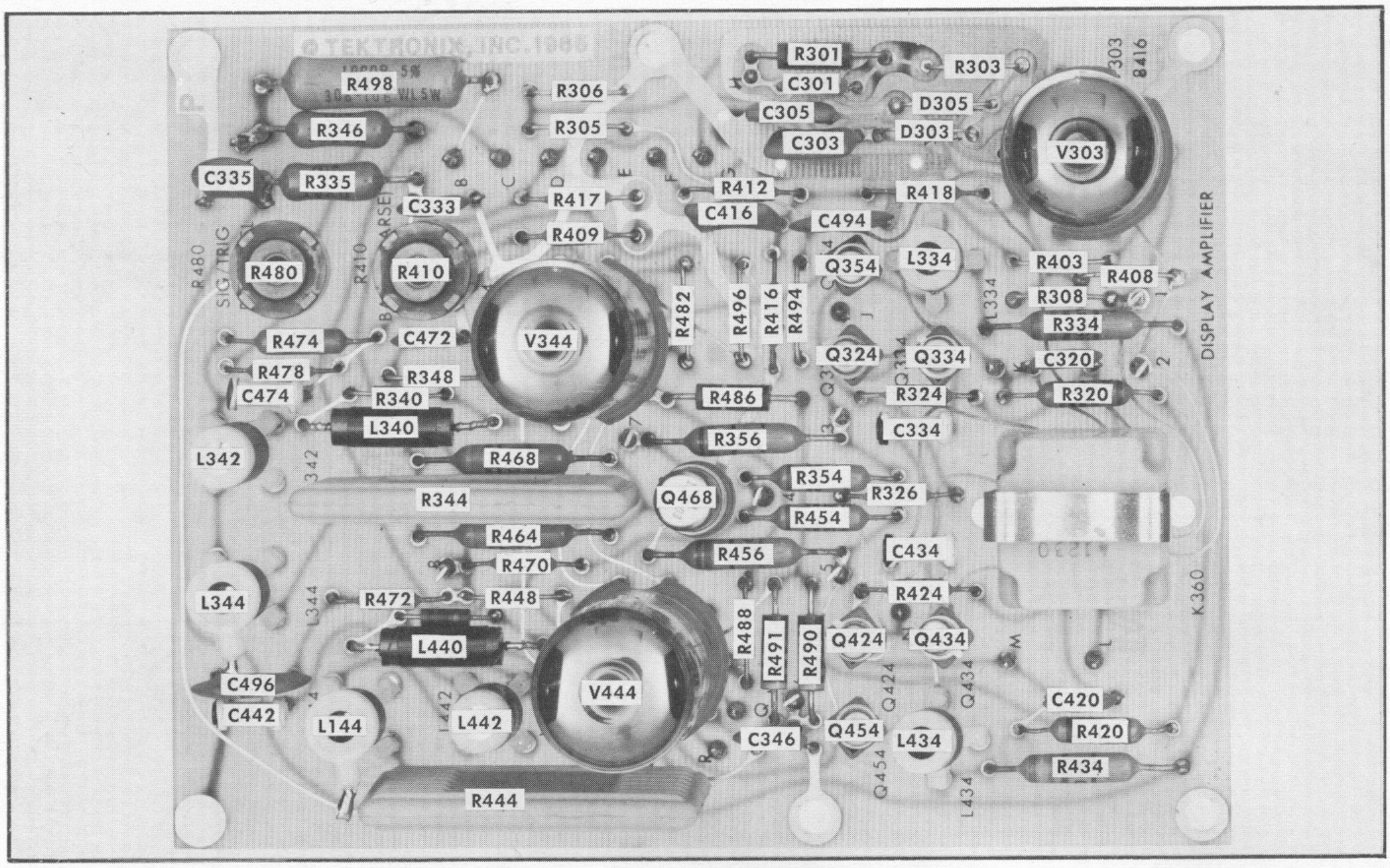



Fig. 5-6. Etched circuit boards Display Amplifier.

# SECTION 6

# PERFORMANCE CHECK

## Introduction

This performance check procedure is provided to check the operation of the Type 3A8. This procedure may be used for incoming inspection, instrument familiarization, reliability testing, calibration verification, etc.

Failure to meet the characteristics given in this procedure indicates that the instrument requires internal checks and/or adjustments. See the Calibration section of this Instruction Manual.

The following equipment is recommended for a complete performance check. Specifications given are the minimum necessary to perform this procedure. All equipment is assumed to be calibrated and operating within its specifications. If equipment is substituted, it must meet or exceed the specifications of the recommended equipment.

For the most accurate and convenient performance check, special calibration fixtures are available from Tektronix. Order by part number through your local Tektronix Field Office or representative.

1. Test oscilloscope. Tektronix 560-Series (except the 560), Type 561A recommended. The test oscilloscope square-wave transient adjustments must be correct.

**NOTE**

**Early production models of the 560-Series oscilloscopes were wired with the variable compensating capacitor for the vertical deflection plates connected from pin 21 of the plug-in connector to ground. In recent models, this capacitor is relocated across the vertical deflection plates (pin 21 to pin 17 of the plug-in connector). If the Type 3A8 does not meet bandpass or risetime specifications, it may be because the capacitance to ground from pin 17 is quite different from that at pin 21 to ground. This may occur even though the effective capacitance between pins 21 and 17 is correct. This is less likely where the variable compensating capacitor is connected between pins 17 and 21, and adjusted for correct deflection plate capacitance.**

**Adjust by using Tektronix Type 3M1 Crt Deflection Capacitance Normalizer Plug-In Unit and the instructions in the Calibration procedure of the oscilloscope manual.**

2. Time-base plug-ins used with the Tektronix Type 561A oscilloscope, Type 2B67, 3B1 thru 3B4 recommended.

3. Test oscilloscope with dc to 15 MHz br greater bandpass and 50 mV/cm maximum sensitivity. 540A or B-Series oscilloscope with the Type 1A1 Plug-In Unit and Tektronix P6006 Probe recommended.

4. Standard amplitude calibrator. Accuracy within 0.2% signal amplitude, 5 millivolts to 50 volts; output signal 1 kHz. Tektronix calibration fixture 067-0502-00 recommended.

5. Square-wave generator. Frequency 450 Hz to 400 kHz. Risetime less than 15 nanoseconds. Tektronix Type 106 Square-Wave Generator recommended.

6. Constant amplitude sinewave signal generator. Frequency 50 kHz and 350 kHz to 10 MHz, with an output impedance of 50 ohms. Tektronix Type 191 Constant Amplitude Signal Generator recommended.

7. Input time-constant standardizer, 47 $\mu$s with BNC connectors. Tektronix Part No. 011-0068-00.

8. Termination. Impedance, 50 ohm; with BNC connectors. Tektronix Part No. 011-0049-00.

9. 10× attenuator. Impedance, 50 ohm; with BNC connectors. Tektronix Part No. 011-0059-00.

10. Adapter, GR to BNC, female. Tektronix Part No. 017-0063-00.

11. Cable. Impedance, 50 ohm; type RG-58A/U; length, 42 inches; BNC connectors. Tektronix Part No. 012-0057-00.

12. Cable. Impedance, 50 ohm; type RG-58A/U; length, 18 inches; BNC connectors. Tektronix Part No. 012-0076-00.

13. Grid current checker. Tektronix Part No. 067-0507-00.

14. Test jig. 1 kHz LF Reject. Special. See Fig. 6-6.

15. Patch cord. Length, 18 inches; BNC to banana plug connectors. Tektronix Part. No. 012-0091-00.

16. Patch cord. Length, 18 inches; BNC to BNC connectors. Tektronix Part No. 012-0091-00.

17. Patch cord. Length, 6 inches; banana plug connectors. Tektronix Part No. 012-0028-00.

18. Resistor, 3.34 kΩ, 1%, ½ watt.

19. Capacitor, 1 $\mu$F, 100 V.

20. Double banana plug (three). General Radio Type 274-MB.

21. Screwdriver, ⅛ inch blade. Tektronix Part No. 003-0192-00.

## PERFORMANCE CHECK PROCEDURE

### General

In the following procedure, test equipment connections or control settings should not be changed except as noted. If only a partial check is desired, refer to the preceding step(s) for setup information.

The following procedure uses the equipment listed under Recommended Equipment. If substitute equipment is used, control settings or setup must be altered to meet the requirements of the equipment used.

### Preliminary Procedure

1. Install the Type 3A8 Unit in the vertical compartment of a 560-Series oscilloscope.

2. Set the Type 3A8 and Time-Base Plug-In Unit controls as follows:

**Type 3A8**

| | |
|---|---|
| Display Amplifier | |
| EXT-1-2 | EXT |
| AC-GND-DC | GND |
| NORM-INVERT | NORM |
| VOLTS/DIV | .02 |
| VARIABLE | CAL |
| POSITION | Midrange |
| Operation Amplifiers, 1 and 2 | |
| $Z_i$ | 1MΩ |
| $Z_f$ | 1MΩ |
| ± GRID SEL | (—) |
| ADJUST-NORM-∫LF REJ | NORM |

**Time-Base Plug-In Unit**

| | |
|---|---|
| Time/Div | 20 μSEC |
| Triggering | |
| Level | Auto or Freerun |
| Slope | (+) |
| Coupling | AC |
| Source | Int |

3 Apply power to the test equipment and the Type 3A8. Allow a minimum 15 minute warm-up period at 25° ±5°C, for equipment stabilization.

### 1. Check DC Balance

a. Requirement—Less than ±1 minor division trace shift with trace at horizontal graticule centerline as the NORM-INVERT switch is changed from NORM to INVERT.

b. Position the trace to the graticule centerline (zero reference level) with the input to the Display amplifier grounded.

c. Check—Change the NORM-INVERT switch to INVERT and check for trace shift. Should be less than 1 minor division.

d. If required, adjust the BAL adjustment for minimum trace shift as the NORM-INVERT switch is changed from NORM to INVERT.

NOTE

**Rapid switching between NORM and INVERT position may cause the balance point to drift. Allow a lag time between switch positions before the BAL adjustment is made.**

### 2. Check POSITION Control Range

a. Requirement—Sufficient range to deflect a full scale display beyond the top or bottom graticule line.

b. Apply a 50 kHz sine wave signal from the sine wave signal generator to the EXT input connector of the Type 3A8.

c. Set the AC-GND-DC switch to AC.

d. Adjust the time-base Level control for a stable display.

e. Adjust the signal generator output control for a full scale display amplitude.

f. Rotate the POSITION control full clockwise then full counterclockwise.

g. Check—Display should move off the graticule area in both the up (clockwise) and down (counterclockwise) direction.

h. Return the display to the center of the graticule area and remove the sine-wave generator signal.

### 3. Check VARIABLE Control Effect On Trace Position

a. Requirement—Trace shift due to VARIABLE control rotation should not exceed 1 major division when BAL is properly adjusted. See step 1.

b. Set time-base Time/Div switch to 1 mSEC and the Level control for a free-running trace.

c. Set the Type 3A8 NORM-INVERT switch to NORM.

d. Rotate the VARIABLE control through its range and note the amount of trace shift.

e. Check—Trace shift should not exceed 1 major division

f. Set VARIABLE control to CAL.

### 4. Check NORM-INVERT Balance

a. Requirement—Trace shift less than 2 minor divisions, with trace positioned at top or bottom graticule line, as the NORM-INVERT switch is changed from NORM to INVERT when BAL has been properly adjusted. See step 1.

b. Position the trace at the top graticule line.

c. Change the NORM-INVERT switch to INVERT and note trace shift.

d. Check—Trace shift not to exceed 2 minor divisions.

e. Position the trace to the bottom graticule line.

f. Change the NORM-INVERT switch to NORM and note trace shift.

g. Check—Trace shift not to exceed 2 minor divisions.

h. Position trace to the zero reference level.

### 5. Check Input Grid Current

a. Requirement—Trace shift due to input grid current not to exceed 2 minor divisions.

b. Switch the AC-GND-DC switch to DC and note amount of trace shift.

c. Check—Trace shift not to exceed 2 minor divisions.

## 6. Check Microphonics

a. Requirement—Excessive microphonics is a condition that can only be judged after a number of instruments have been compared under specific conditions. Microphonics due to light tapping with the finger on the front of the Type 3A8 is typically less than 1 major division.

b. Set the AC-GND-DC switch to GND.

c. Lightly tap the front panel of the Type 3A8 with the fingers and note amplitude of microphonics.

d. Check—Microphonics not to exceed 1 major division.

## 7. Check CAL Adjustment

a. Requirement—Vertical deflection sensitivity must adjust to .02 Volts/Div.

b. Apply the output from the standard amplitude calibrator through a 50-Ω cable to the Type 3A8 EXT Input connector.

c. Set the standard amplitude calibrator for a 0.1-volt square-wave output.

d. Set the Type 3A8 AC-GND-DC switch to DC.

e. Adjust the time-base Level control for a stable display.

f. Check—Crt display for 5 major divisions of amplitude (see Fig. 6-1). If necessary, adjust CAL for precisely 5 major divisions of amplitude.

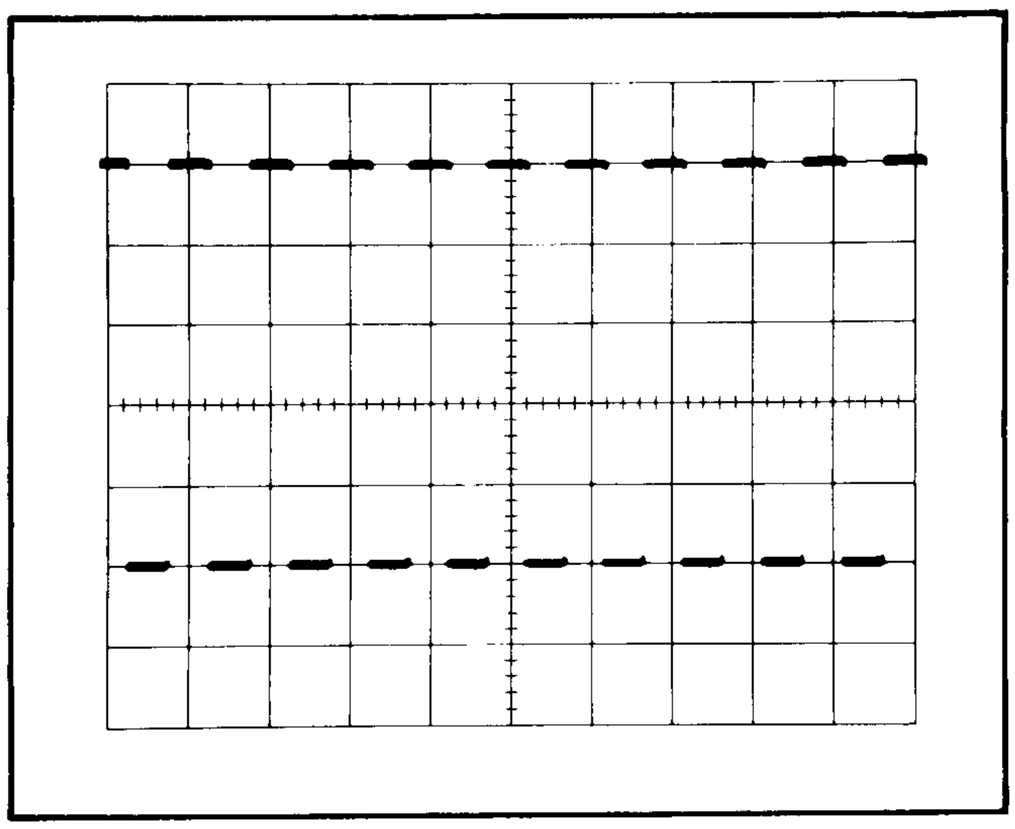


**Fig. 6-1. Typical crt display when making CAL adjustment.**

## 8. Check VOLTS/DIV Attenuator Accuracy

a. Requirement—Vertical deflection sensitivity within ±3% of the VOLTS/DIV attenuator indication.

b. Check—Using Table 6-1, for vertical deflection accuracy.

**TABLE 6-1**

| Type 3A8 VOLTS/DIV Setting | Standard Amplitude Calibrator Output (Volts) | Vertical Deflection Major Divisions | Maximum For 3% Accuracy Minor Divisions |
|---|---|---|---|
| .02 | .1 | 5 | Adjusted |
| .05 | .2 | 4 | ±0.6 |
| .1 | .5 | 5 | ±0.75 |
| .2 | 1 | 5 | ±0.75 |
| .5 | 2 | 4 | ±0.6 |
| 1 | 5 | 5 | ±0.75 |
| 2 | 10 | 5 | ±0.75 |
| 5 | 20 | 4 | ±0.6 |
| 10 | 50 | 5 | ±0.75 |

## 9. Check VARIABLE Control Attenuation Range

a. Requirement—Attenuates display amplitude by a factor of at least 2.5:1 from calibrated setting. Checked at maximum calibrated attenuation.

b. Set the standard amplitude calibrator output to .1 volt.

c. Set the Type 3A8 VOLTS/DIV switch to .02. This should provide 5 division display amplitude.

d. Rotate the VARIABLE control for maximum attenuation, and check that amplitude is reduced to 2 divisions or less.

## 10. Check AC-GND-DC Coupling Switch Operation

a. Requirement—Correct signal coupling in each position.

b. Set the VARIABLE control to CAL and the AC-GND-DC switch to DC.

c. Set the standard amplitude calibrator for an output of 50 mV. (2.5 major divisions.)

d. Position the bottom of the display to the graticule centerline.

e. Set the AC-GND-DC switch to AC.

f. Check—Display waveform should move down and average about the centerline.

g. Set the AC-GND-DC switch to GND and time-base to free run.

h. Check—CRT display should be a straight line near the graticule centerline.

## 11. Check Vertical Deflection Linearity (Compression and Expansion)

a. Requirement—Compression or expansion should not exceed ±3% plus the linearity factor of the associated oscilloscope crt (typically ±1%).

b. Set AC-GND-DC switch to DC position and adjust time-base Level control for a stable display.

c. Position the top of the 50 mV waveform to the top horizontal graticule line, then position the bottom of the

waveform to the bottom horizontal graticule line. Note the compression or expansion of the display amplitude compared to its amplitude at the center of the graticule area.

d. Check—Compression or expansion compared to display amplitude at the center of the graticule area should not exceed ±3% (±0.75 minor division plus crt linearity factor).

## 12. Check VOLTS/DIV Compensation

a. Requirement—Optimum square-wave response with minimum rolloff, overshoot or tilt.

b. Set the Time/Div switch to .2 mSEC.

c. Apply the output of the square-wave generator (Type 106) to the Type 3A8 EXT Input connector through a GR to BNC adapter, 42 inch coaxial cable, 10× attenuator, 50 Ω termination and 47 μs input time constant standardizer.

d. Adjust the square-wave generator output for a signal amplitude of 5 major divisions at a frequency of 1 kHz.

e. Check— Square-wave display for less than 1.5 minor division rolloff, overshoot or tilt. See Fig. 6-2. Check display at each position of the VOLTS/DIV attenuator setting. Adjust the square-wave generator output to maintain 5 division signal amplitude. At the .2 VOLT/DIV position, remove the 10× attenuator. Remove the 50 Ω termination at the 2 VOLT/DIV position.

f. Remove the input signal from the square-wave generator.

## 13. Check High-Frequency Compensation

a. Requirement—Optimum square-wave response. Less than 2.5% rolloff and 3% or less overshoot.

b. Change to the following control settings:

| Type 3A8 | |
|---|---|
| VOLTS/DIV | .02 |
| **Time-Base Unit** | |
| Time/Div | 1 μSEC |
| Source | EXT |

c. Apply the fast rise + Output from the square-wave generator (Type 106) through the GR to BNC adapter, 18 inch coaxial cable and the 50 Ω termination to the Type 3A8 EXT Input connector.

d. Apply the Trigger Output from the square-wave generator (Type 106) to the EXT Input of the time-base plug-in unit.

e. Set the square-wave generator output frequency to approximately 300 kHz, then adjust the Amplitude control for a display amplitude of 4 major divisions on the crt graticule.

f. Adjust time-base Level control for a stable display.

g. Check—Crt display for optimum square-wave response (see Fig. 6-3). Less than ½ minor division rolloff (2.5%).

h. Switch the NORM-INVERT switch to INVERT.

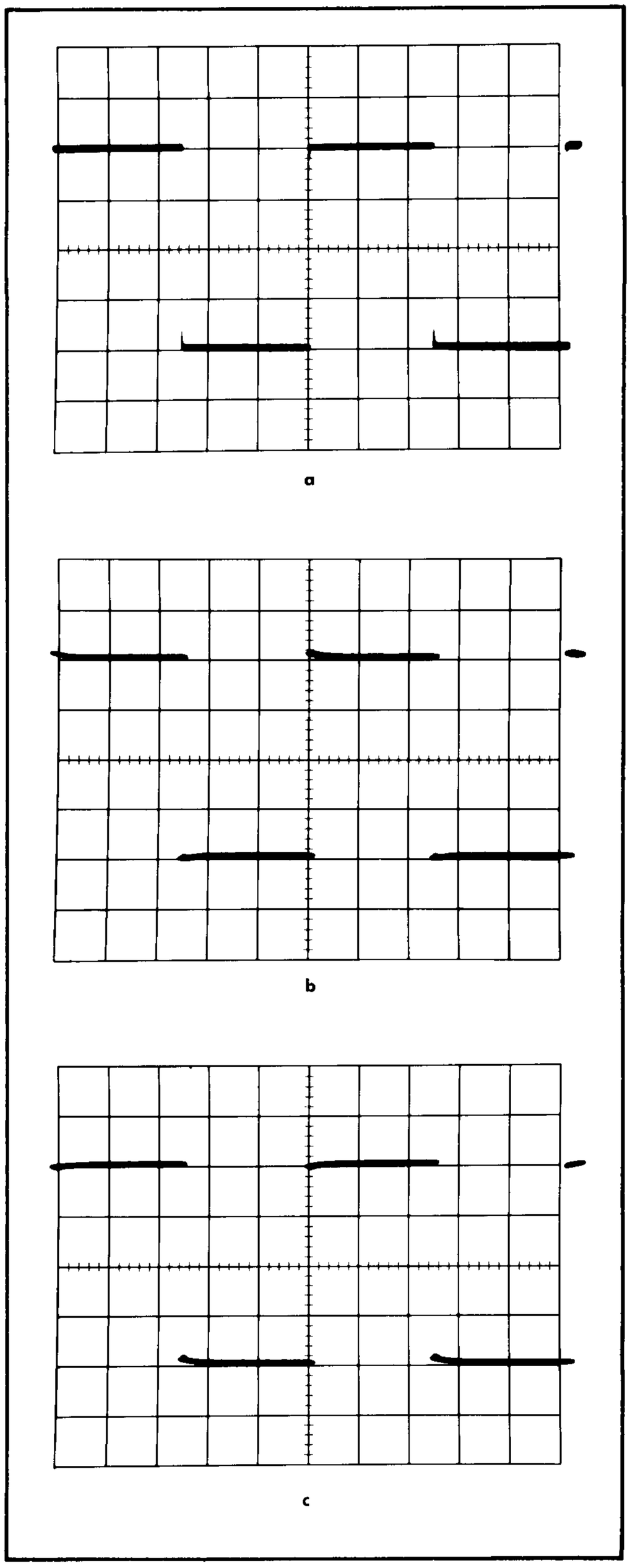



**Fig. 6-2. (a) Crt display of correct Volts/Div switch compensation and input time constant. (b) Input time constant too short (Input C too small). (c) Input time constant too long (Input C too large).**

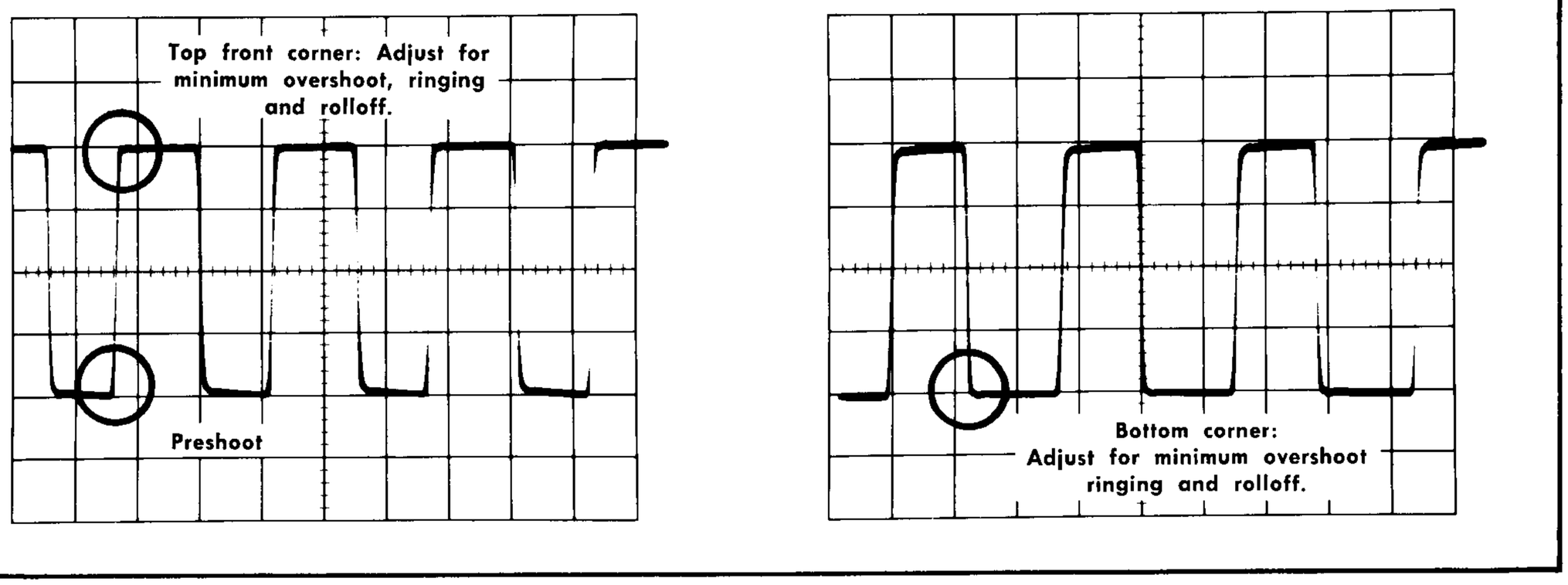



**Fig. 6-3. Waveform with correct high-frequency compensation. (a) Positive waveform showing top corner response. (b) Negative waveform showing bottom corner response.**

i. Check—Crt display for optimum square-wave response on the bottom corner. See Fig. 6-3. Less than ½ minor division rolloff.

j. Apply the fast rise — Output from the square-wave generator (Type 106) to the Type 3A8 EXT Input connector.

k. Check the display in both NORM and INVERT operation. Optimum square-wave response within the following tolerances: ½ minor division or less overshoot in the NORM position and 1.0 minor division or less overshoot in the INVERT position. In either NORM or INVERT position, ringing, hook or rolloff should be less than ½ minor division.

## 14. Check Risetime

a. Requirement—Risetime must be 100 nsec or less.

b. Reset the following controls to the following positions:

**Type 3A8**

| | |
|---|---|
| NORM-INVERT | NORM |

**Time-Base Unit**

| | |
|---|---|
| Time/Div | .2 μSEC |

c. Apply a 300 kHz signal from the + Output of the square-wave generator (Type 106) to the EXT Input connector of the Type 3A8.

d. Adjust time-base Level control for a stable display.

e. Measure the risetime from the 10% to the 90% points on the 4 major division display; see Fig. 6-4.

f. Check—Risetime must be 100 nsec. or less.

g. Remove the signal from the square-wave generator.

## 15. Check Bandwidth

a. Requirement—Display amplitude not more than 30% down at 3.5 MHz.

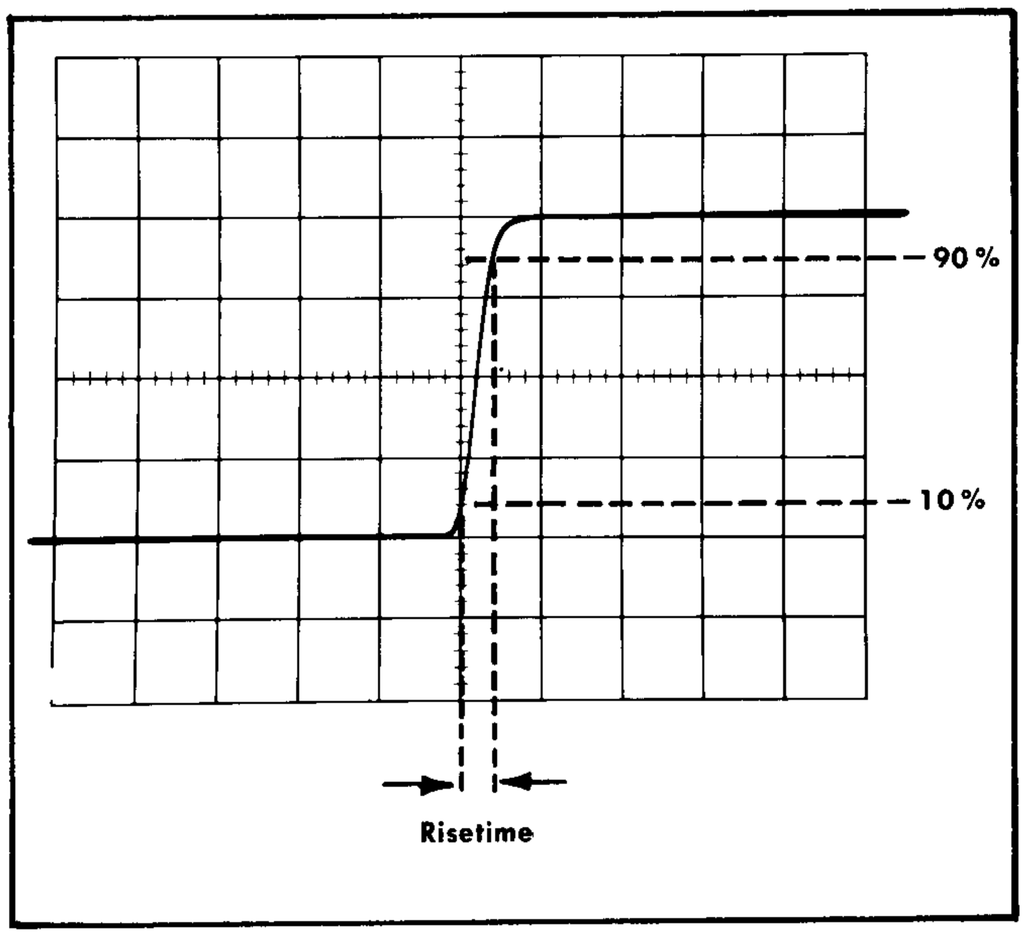



**Fig. 6-4. Measuring risetime.**

b. Change to the following control settings:

**Time-Base Unit**

| | |
|---|---|
| Time/Div | .1 mSEC |
| Source | Int. |
| Level | Free run or Auto |

c. Apply the output signal from the constant-amplitude signal generator (Type 191) to the EXT Input connector of the Type 3A8 through the GR to BNC adapter, 18 inch 50 Ω coaxial cable and 50 Ω termination.

d. Adjust time-base Level control for a stable display.

e. Adjust the output of the constant amplitude signal generator for a display amplitude of 4 major divisions at a frequency of 50 kHz.

f. Without changing the output amplitude, increase the constant amplitude signal generator frequency until the display amplitude is reduced to 2.8 major divisions. (Readjust time base Time/Div switch setting and Level control to maintain a stable display on the crt.)

g. Check—Frequency 3.5 MHz or higher.

h. Set the NORM-INVERT switch to INVERT and repeat the procedure to check bandwidth in INVERT operation.

i. Disconnect all test equipment.

This completes the performance check of the Display Amplifier.

## Operational Amplifier

Since the Operational Amplifiers are identical, the following performance check procedure is applicable to both. Check number 1 amplifier then change the Display Amplifier EXT-1-2 switch settings from 1 to 2 in all steps to check number 2 amplifier.

### 16. Check OFFSET (Output DC Level)

a. Requirement—Adjustable through zero.

b. Set input switch to GND position and position the trace to graticule center to establish a zero signal reference level.

c. Check the POSITION control and adjust if necessary; see Step 2.

d. Change the controls to the following settings:

| | |
|---|---|
| EXT-1-2 | 1 |
| VOLTS/DIV | 10 |
| ADJUST-NORM-LF REJ | ADJUST |

e. Position the trace to graticule center with the OFFSET adjustment.

f. Change the VOLTS/DIV switch setting to .1 in steps while adjusting the OFFSET each step, so as to position the trace to the graticule center.

NOTE

**Due to thermal lag, this adjustment will require time to stabilize. As the sensitivity of the deflection amplifier is increased, small changes in OFFSET adjustment will have increasing effect in the amount of trace movement. The final adjustment may drift around the zero reference trace position.**

g. Check—OFFSET must adjust trace through zero signal reference level.

h. Set ADJUST-NORM- LF REJ switch to NORM.

### 17. Check LF REJ for DC Rejection

a. Requirement—Trace should return to graticule center at each postion of $Z_f$.

b. Change to the following switch settings:

**Type 3A8**

| | |
|---|---|
| $Z_i$ | 1 MΩ |
| ADJUST-NORM-LF REJ | LF REJ |

**Time-Base Unit**

| | |
|---|---|
| Time/Div | 10 mSEC |

c. Position the trace vertically to the graticule centerline.

d. Switch $Z_f$ through all C positions.

e. Check—Trace may have ripple, but should return to the center horizontal graticule line at each 'C' position of $Z_f$.

f. Set ADJUST-NORM-LF REJ switch to NORM.

### 18. Check Grid Current

a. Requirement—Spot vertical movement not to exceed 2.5 major divisions in 5 seconds.

b. Change the following switch settings:

**Type 3A8**

| | |
|---|---|
| VOLTS/DIV | .1 |
| $Z_i$ | EXT |
| $Z_f$ | EXT |
| ± GRID SEL | (+) |

**Time Base Unit**

| | |
|---|---|
| Time/Div | 1 SEC (Decrease spot intensity to avoid burning phosphor on the crt screen) |
| Level | Free-run |

c. Plug the Grid Current Checker into the front-panel jacks.

d. As the free-running sweep moves the spot past a vertical graticule line, push the (—) Grid button on the Current Checker.

e. Check—Vertical movement of the spot should not be more than 2.5 major divisions in 5 major divisions or horizontal travel.

f. As the free-running sweep moves the spot past a vertical graticule line, push the (±) Grid button on the Grid Current Checker.

g. Check—Vertical movement of the spot should not be more than 2.5 major divisions in 5 major divisions of horizontal travel.

h. Remove the Grid Current Checker.

### 19. Check Open-Loop DC Gain

a. Requirement—Open-Loop DC gain must be 15,000 or more.

b. Change to the following switch settings:

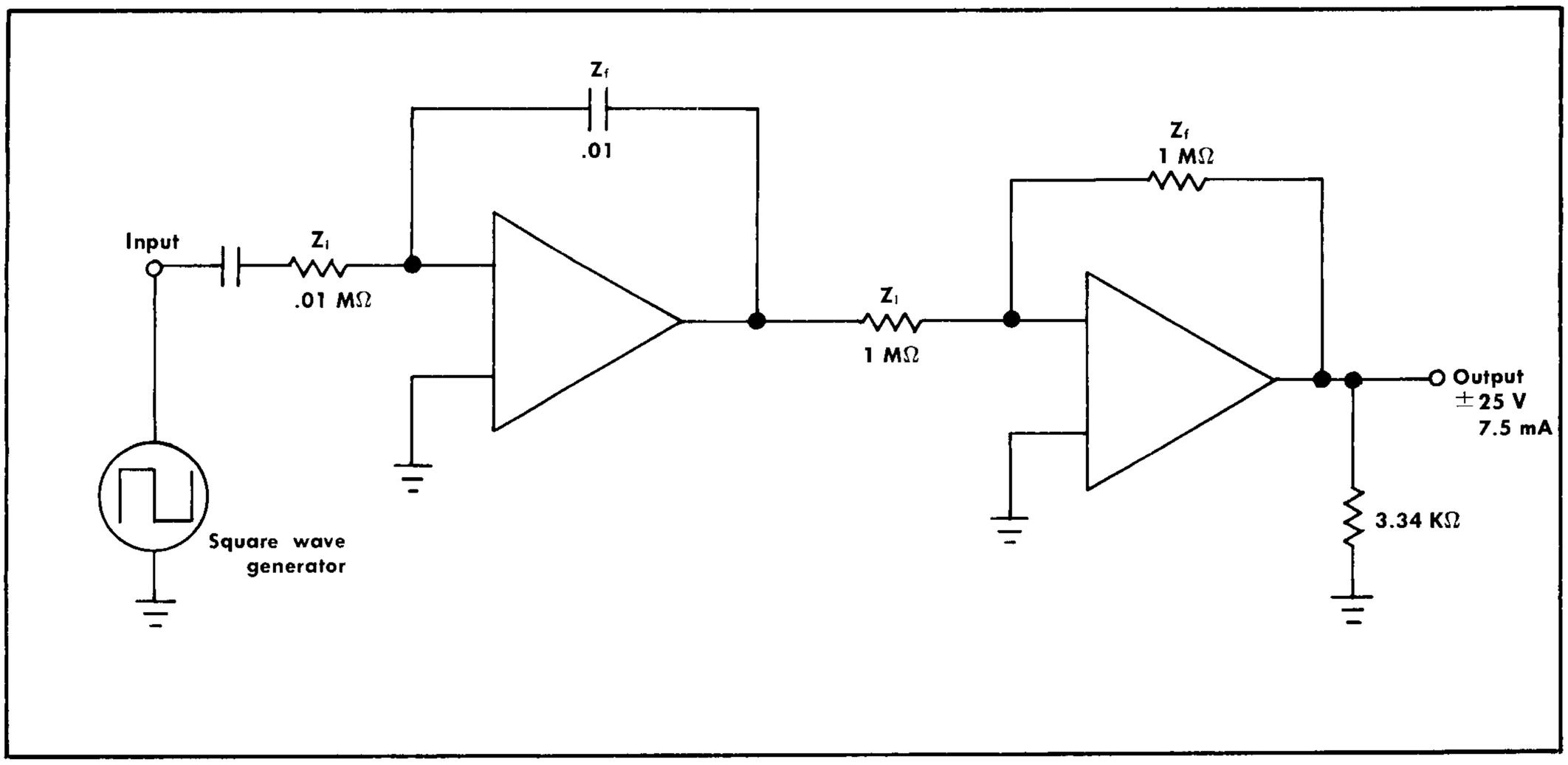



**Fig. 6-5. Operational amplifier connected to check output voltage and current specifications.**

**Type 3A8**

| | |
|---|---|
| VOLTS/DIV | 10 |
| $Z_i$ | 1 MΩ |
| $Z_f$ | 1 MΩ |
| ± GRID SEL | (—) |

**Time Base Unit**

| | |
|---|---|
| Time/Div | 5 ms |

c. Connect a shorting strap between the INPUT banana jack and the —GRID banana jack.

d. Apply 1 mV from the 560-Series oscilloscope Calibrator to the Operational Amplifier INPUT connector.

NOTE

**Signal frequency should be 60 Hz or less.**

e. Set $Z_f$ at EXT and check for at least 15 V peak-to-peak square-wave output. Adjust OFFSET if necessary to hold the display within amplifier limits.

f. Check—15 V ÷ 1 mV = Gain of 15,000.

g. Remove the shorting strap and set $Z_f$ switch to 1 MΩ.

## 20. Check Output Voltage and Current

NOTE

**This check requires one operational amplifier to drive the operational amplifier being checked.**

a. Requirement—Output ±25 V at 7.5 mA.

b. Change to the following switch settings:

**Type 3A8**

| | |
|---|---|
| EXT-1-2 | 2 |
| VOLTS/DIV | 10 |

**Driving Operational Amplifier**

| | |
|---|---|
| $Z_i$ | .01 MΩ |
| $Z_f$ | .01 μF |
| ± GRID SEL | (—) |
| ADJUST-NORM- LF REJ | LF REJ |

**Time-Base Unit**

| | |
|---|---|
| Time/Div | 1 mSEC |
| Level | Auto |

c. Apply the Hi Amplitude output from the square-wave generator (Type 106) through the GR to BNC adapter, 50 Ω termination, an 18-inch BNC to banana plug patch cord and 1.0 μF capacitor to the INPUT of the driving Operational Amplifier. Connect a banana plug patch cord as a ground strap between instruments.

d. Connect a 6-inch BNC to BNC patch cord between the output jack of the driving Operational Amplifier and the input jack of the Operational Amplifier under test. See Fig. 6-5.

e. Adjust the output of the square-wave generator for an output signal amplitude from the driving amplifier of 50 volts (5 major divisions) at an approximate frequency of 300 Hz. The output signal from the driving amplifier should be a triangular waveform with peaks at plus and minus 25 V.

f. Set the Type 3A8 EXT-1-2 switch to 1. Check for a display amplitude of ±25 V (5 major divisions) with no limiting at levels of ±25 V or less.

g. Connect the 3.34-kΩ resistor between the output jack and ground of the Operational Amplifier under check.

h. Check—Display amplitude should remain undistorted at ±25 V.

i. Disconnect all test equipment and test jigs.

## 21. Check $Z_i$ and $Z_f$ Resistor Components

a. Requirement—This check is a functional check on $Z_i$ and $Z_f$ component values. The high performance values of these components require a resistance or capacitance bridge to accurately check the component tolerances.

b. Change to the following switch settings:

**Type 3A8**

| | |
|---|---|
| VOLTS/DIV | .5 |
| $Z_i$ | .01 MΩ |
| $Z_f$ | .01 MΩ |
| ADJUST-NORM-LF REJ | LF REJ |

**Time Base Unit**

| | |
|---|---|
| Time/Div | .5 mSEC |

c. Apply the Hi Amplitude output from the square-wave generator (Type 106) through the GR to BNC adapter, 18-inch coaxial cable and 50 Ω termination to the Operational Amplifier INPUT connector.

d. Adjust the output and frequency of the square-wave generator (Type 106) for a 4 major division display of 1 kHz.

e. Check the operation of the $Z_i$ and $Z_f$ resistors according to Table 6-2.

**NOTE**

**Do not change the square-wave generator settings while checking $Z_i$ and $Z_f$ operation.**

**TABLE 6-2**

| Switch Setting | | | Amplitude Peak to Peak Major Divisions |
|---|---|---|---|
| $Z_i$ R MΩ | $Z_f$ R MΩ | VOLTS/DIV | |
| .01 | .01 | .5 | 4 |
| .1 | .1 | .5 | 4 |
| .2 | .2 | .5 | 4 |
| .5 | .5 | .5 | 4 |
| 1 | 1 | .5 | 4 |
| 1 | .5 | .5 | 5 |
| 1 | .2 | .1 | 4 |
| 1 | .1 | .05 | 4 |
| .2 | .01 | .02 | 5 |
| .01 | .1 | 5 | 4 |
| .1 | 1 | 5 | 4 |
| .2 | 1 | 2 | 5 |
| .5 | 1 | 1 | 4 |

## 22. Check $Z_i$ and $Z_f$ Capacitor Components

a. Change to the following control and switch settings:

**Type 3A8**

| | |
|---|---|
| VOLTS/DIV | .05 |
| Input Selector | 1 |
| DC-GND-AC | DC |
| NORM-INVERT | NORM |
| ADJUST-NORM-LF REJ | LF REJ |
| ± GRID SEL | (—) |
| $Z_i$ | 1 μF |
| $Z_f$ | 1 μF |

**Time Base Unit**

| | |
|---|---|
| Time/Div | .5 mSEC |

b. Apply a 1 kHz signal from the square-wave generator (Type 106) Hi Amplitude output through 18-inch coaxial cable, 10× attenuator and 50 Ω termination to the INPUT connector of the Operational Amplifier.

c. Adjust the output of the square-wave generator for a 4-division display. Adjust the time-base Level Control for a triggered display.

d. Check the operation of the $Z_i$ and $Z_f$ capacitors as per table 6-3.

Install the special reject board (see Fig. 6-6) and set the ADJUST-NORM-LF REJ switch to NORM.

Set $Z_i$ to .001 and $Z_f$ to 100 pF, then change the frequency of the square-wave generator (Type 106) to approximately 25 kHz. Readjust the output amplitude control of the square-wave generator to establish a 4-division display amplitude at a VOLTS/DIV setting of .5.

**TABLE 6-3**

| Switch settings | | | Amplitude Divisions |
|---|---|---|---|
| $Z_i$ (C) | $Z_f$ (C) | VOLTS/DIV | |
| 1 | 1 | .05 | 4 |
| .1 | .1 | .05 | 4 |
| .01 | .01 | .05 | 4 |
| .001 | .001 | .05 | 4 |
| 1 | .1 | .5 | 4 |
| .1 | .01 | .5 | 4 |
| .01 | .001 | .5 | 4 |
| .001 | 100 pF | .5 | 4 |

e. Check the operation of the 10 and 100 pF components as per table 6-4.

**TABLE 6-4**

| Switch settings | | | Amplitude Divisions |
|---|---|---|---|
| $Z_i$ (C) | $Z_f$ (C) | VOLTS/DIV | |
| 100 pF | 100 pF | .05 | 4 |
| 100 pF | 10 pF | .5 | 4 |
| 10 pF | 10 pF | .05 | 4 |

f. Remove the LF Reject circuit board and test equipment from the Type 3A8.

## 23. Check the Gain-Bandwidth Product (Open Loop)

a. Requirement— Open-loop gain-bandwidth product must be equal to or greater than 10 MHz.

Example:

$$\frac{\text{Measured amplitude}}{\text{Reference amplitude}} = \frac{\text{Actual Gain-Bandwidth Prod.}}{10\ \text{MHz}}$$

$$\frac{4.2\ \text{Cm}}{4\ \text{Cm}} = \frac{X}{10\ \text{MHz}}$$

$$X = 10.5\ \text{MHz}$$

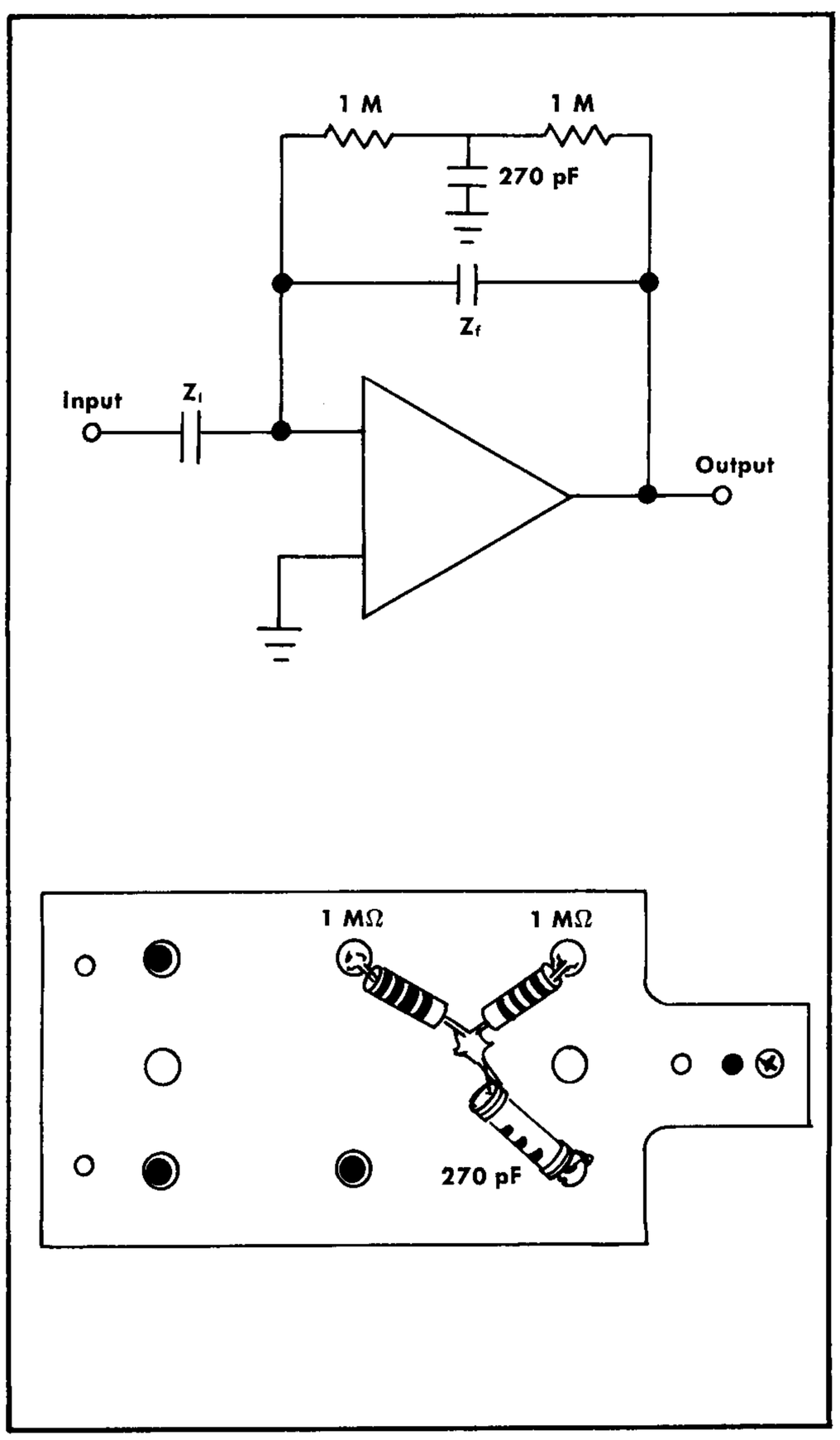



**Fig. 6-6. Test jig to check 10 and 100 pF $Z_i$ and $Z_f$ capacitors. (a) Circuit diagram approximate 1 kHz LF Reject jig. (b) Pictorial layout.**

b. Change to the following switch settings:

**Type 3A8**

| | |
|---|---|
| VOLTS/DIV | 10 |
| $Z_i$ | .001 $\mu$F |
| $Z_f$ | 1 MΩ |

**Time Base Unit**

| | |
|---|---|
| Time/Div | .2 mSEC |

c. Preset the constant amplitude signal generator (Type 191) as follows:

| | |
|---|---|
| Frequency Range | 8.2-18 MHz |
| Amplitude | 15 |
| Amplitude Range | 50-500 mV |

d. Preset the test oscilloscope (540-Series) controls as follows:

| | |
|---|---|
| Vertical Unit | |
| Volts/Div | .05 |
| Input Coupling | DC |
| Time-Base | |
| Time/cm | .2 $\mu$SEC |
| Triggering | |
| Mode | Auto |
| Coupling | AC |
| Source | Int |

e. Apply the Output of the Type 191 through a GR to BNC adapter, 18-inch coaxial cable and 50 Ω termination to the vertical Input connector of the test oscilloscope.

f. Adjust the Output and Frequency of the constant amplitude signal generator (Type 191) for a reference amplitude of 4 cm at 10 MHz on the test oscilloscope (200 mV with Volts/cm switch at .05).

g. Remove the signal cable from the vertical input of the test oscilloscope and apply the 10-MHz signal to the INPUT connector of the Operational Amplifier.

h. Connect a coaxial cable ($\leq$ 18-inch cable) from the OUTPUT connector of the Operational Amplifier to the vertical Input connector of the test oscilloscope.

i. Check—Test scope display must be 4 cm or greater in amplitude.

This completes the performance check of the Type 3A8. Disconnect all test equipment. If the instrument has met all performance requirements given in this procedure, it is correctly calibrated and within the specified tolerances.

# NOTES

# SECTION 7
# CALIBRATION

## Introduction

The following procedure should be used to calibrate the Type 3A8 Operational Amplifier Plug-In Unit. The instrument should not require frequent calibration, but occasional adjustments will be necessary when transistors, tubes and other components are changed. A periodic recalibration is desirable from the standpoint of preventive maintenance.

Apparent troubles in the instrument are occasionally the result of improper calibration of one or more circuits. Consequently, calibration checks should be an integral part of any troubleshooting procedure. Abnormal indications during calibration checks will often aid in isolating troubles to a definite circuit or stage.

In the instructions that follow, the steps are arranged in the proper sequence for a complete calibration of the unit. Each step contains the information required to make one check or adjustment or a series of related checks or adjustments. The steps are arranged to avoid unnecessary repetition of checks or adjustments.

## EQUIPMENT REQUIRED
### (see Fig. 7-1)

The following equipment or its equivalent is required to perform a complete calibration of the Type 3A8 Plug-In Unit. All test equipment is assumed to be correctly calibrated and operating within the original specifications. If equipment is substituted, it must meet or exceed the specifications of the recommended equipment. All calibration fixtures listed under Equipment Required can be obtained from Tektronix, Inc. Order by part number through your local Tektronix Field Office or representative.

1. Multimeter. Minimum sensitivity 20,000 ohms/volt.

2. Test oscilloscope. Tektronix 560-Series (except the 560), Type 561A recommended. The test oscilloscope square-wave transient adjustments must be correct.

**NOTE**

**Early production models of the 560-Series oscilloscopes were wired with the variable compensating capacitor for the vertical deflection plates connected from pin 21 of the plug-in connector to ground. More recent models have this capacitor relocated across the vertical deflection plates (pin 17 to pin 21 of the plug-in connector).**

**If the Type 3A8 does not meet bandpass or risetime specifications, it may be because capacitance to ground from pin 17 is quite different from that at pin 21 to ground, even though the effective capacitance between pin 17 and 21 is correct. This is less likely to occur where the variable compensating capacitor is connected between pins 17 and 21 and adjusted for correct deflection plate capacitance.**

**Adjust by using Tektronix Type 3M1 Crt Deflection Capacitance Normalizer Plug-In Unit and the instructions in the Calibration procedure of the oscilloscope manual.**

3. Time-base plug-in unit, used with the Tektronix Type 561A oscilloscope, Type 2B67, 3B1 thru 3B4 recommended.

4. Test oscilloscope with bandpass greater than 15 MHz. Type 540A or B series oscilloscope with the Type 1A1 Plug-In Unit and Tektronix P6006 Probe recommended.

5. Standard Amplitude Calibrator. Accuracy within 0.25%; signal amplitude, 5 millivolts to 50 volts; output signal 1 kHz. Tektronix calibration fixture 067-0502-00 recommended.

6. Square wave Generator. Frequency 450 Hz to 1 MHz. Risetime less than 15 nanoseconds. Tektronix Type 106 Square wave Generator recommended.

7. Constant Amplitude Signal Generator. Frequency 50 kHz and 350 kHz to above 10 MHz, with an output impedance of 50 ohms. Tektronix Type 191 Constant Amplitude Signal Generator recommended.

8. Input time-constant standardizer, 47 $\mu$s with BNC connectors. Tektronix Part No. 011-0068-00.

9. Grid current checker. Tektronix Part No. 067-0507-00.

10. Plug-in extension; for units in 560-Series oscilloscopes, Tektronix Part No. 013-0034-00.

11. 10× Attenuator. Impedance, 50 ohm; with BNC connectors. Tektronix Part No. 011-0059-00.

12. Termination. Impedance, 50 ohm; with BNC connectors. Tektronix Part No. 011-0049-00.

13. Cable. Impedance, 50 ohm; type RG-58A/U; length, 42 inches; BNC connectors. Tektronix Part No. 012-0057-00.

14. Cable. Impedance, 50 ohm; type RG-58A/U; length, 18 inches; BNC connectors. Tektronix Part No. 012-0076-00.

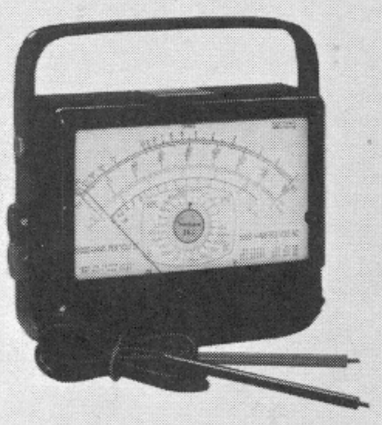
15. Patch cord. Length, 18 inches; BNC to BNC connectors. Tektronix Part No. 012-0087-00.

16. Patch cord. Length, 18 inches; BNC to banana plug connectors. Tektronix Part No. 012-0091-00.

17. Adapter, GR to BNC female. Tektronix Part No. 017-0063-00.

18. Double banana plug adapter (three). General Radio Type 274-MB.

19. Patch cord. Length, 18 inches; banana plug connectors. Tektronix Part No. 012-0031-00.



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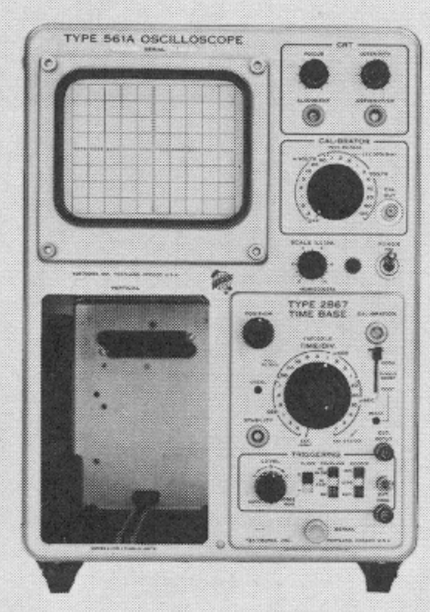


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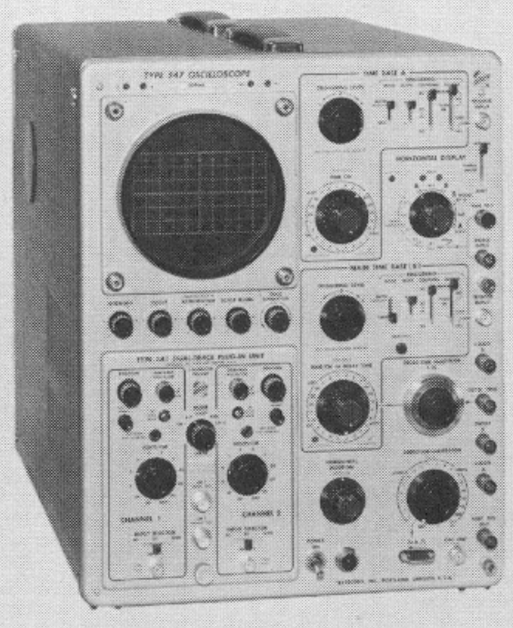


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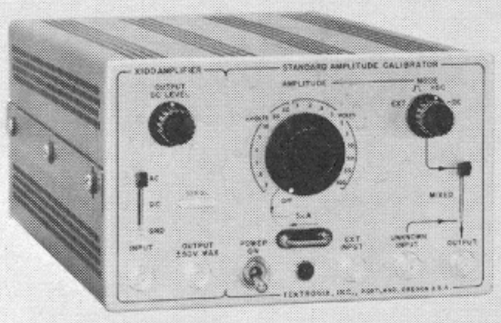


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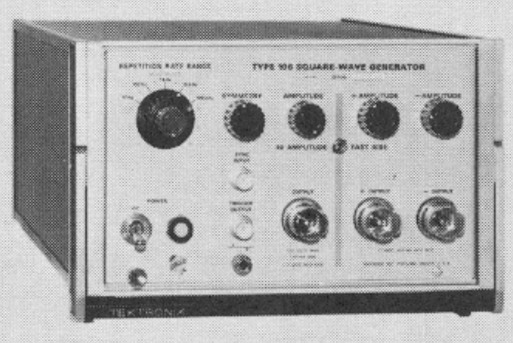


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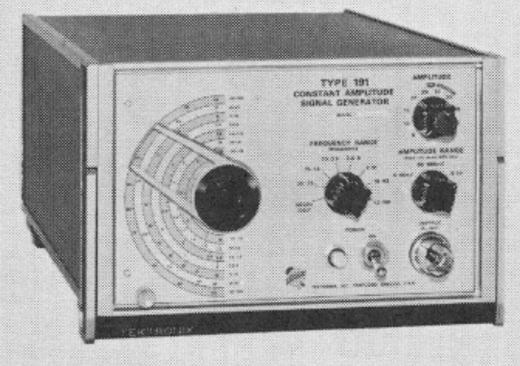


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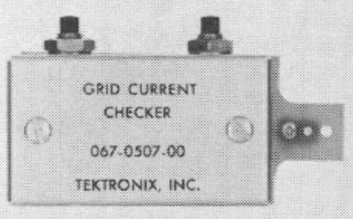


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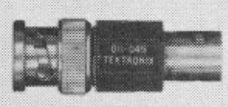


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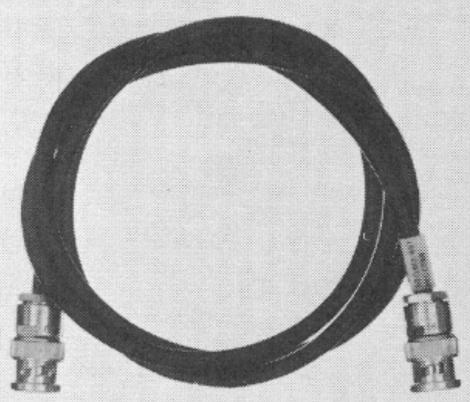

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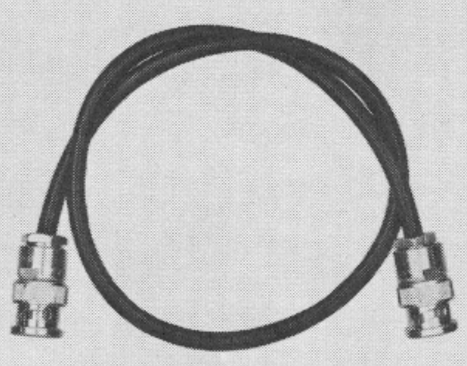

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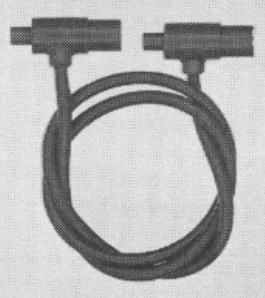

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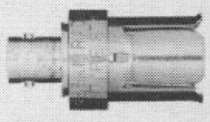

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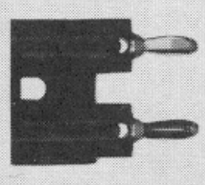

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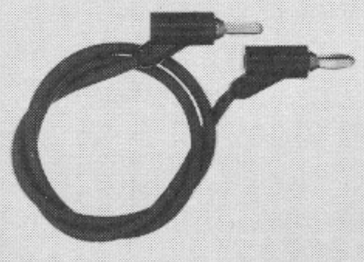

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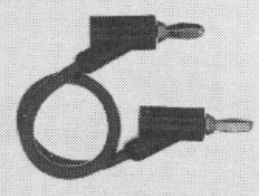


(20)

Fig. 7-1. Recommended calibration equipment.

20. Patch cord. Length, 6 inches; banana plug connectors. Tektronix Part No. 012-0028-00.

21. Resistor, 3.34 kΩ, 1%, ½ watt.

22. Capacitor, 1 μF, 100 V.

23. Adjustment tools (see Fig. 7-2).

| Description | Tektronix Part No. |
|---|---|
| a. Insulated screwdriver, 1½ inch shaft, non-metallic | 003-0000-00 |
| b. Screwdriver, 3 inch shaft | 003-0192-00 |
| c. Tuning rod, 5 inch | 003-0301-00 |

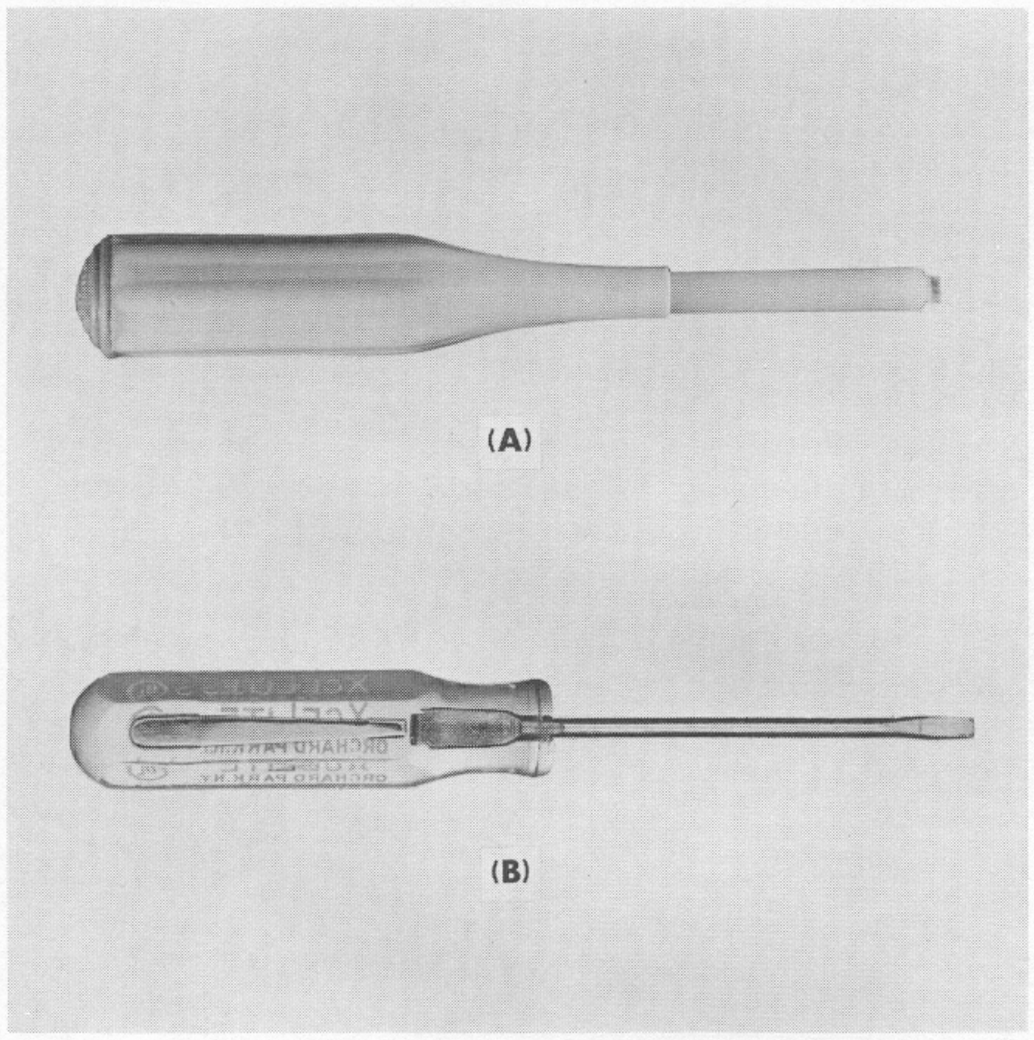



**Fig. 7-2. Recommended adjustment tools.**

## PRELIMINARY PROCEDURE

1. Remove the number 1 Operational Amplifier etched circuit card from the Type 3A8 to provide access to the attenuator adjustments.

CAUTION

**Keep loose pin connectors free from contact with voltage or signal points. There are no voltages on these wires, but the components connected to them could be damaged if excess voltage were applied.**

2. Install the Type 3A8 Unit in the vertical compartment of a 560-Series oscilloscope.

3. Remove the left side panel of the oscilloscope to expose test points and adjustments for the Type 3A8.

4. Apply power to the test equipment and the Type 3A8. Allow a minimum 15-minute warm-up period at 25°C. ±5°, for equipment stabilization.

## CALIBRATION RECORD AND INDEX

This abridged Calibration Procedure is provided to aid in checking the operation of the Type 3A8. It may be used as a calibration guide by the experienced calibrator, or it may be used as a calibration record. Since the step numbers and titles used here correspond to those used in the complete Calibration Procedure, the following procedure serves as an index to locate a step in the complete Calibration Procedure. Characteristics are those listed in the Characteristics section of the Instruction Manual.

Type 3A8 Serial No. _____

Calibration Date _____

☐ 1. Adjust DC Balance. Page 7-5.
No trace shift as NORM-INVERT switch is switched from NORM to INVERT position.

☐ 2. Check effect of VARIABLE control on trace position. Page 7-5.
Trace shift as the VARIABLE control is rotated should be less than 1 major division.

☐ 3. Check Grid Current. Page 7-6.
2 minor divisions or less trace shift due to grid current.

☐ 4. Check Microphonics. Page 7-6.
1 major division or less of microphonics

☐ 5. Adjust Cal. Page 7-7.
Correct signal amplitude as indicated by the VOLTS/DIV switch at the .02 position.

☐ 6. Check VOLTS/DIV Attenuator Accuracy. Page 7-7.
Waveform amplitude within ±3% of indicated switch position.

☐ 7. Check VARIABLE Control Attenuation Range. Page 7-7.
Range ratio 2.5:1 or more.

☐ 8. Check AC Coupling. Page 7-7.
Display averages around zero reference level.

☐ 9. Check Vertical Deflection Linearity (Compression and Expansion). Page 7-7.
Amplitude change due to compression or expansion must be within ±3% plus the linearity factor of the associated oscilloscope crt. (Typically ±1%).

☐ 10. Adjust DC Level of Trigger Signal Output and Check Trigger Output Amplitude. Page 7-8.
Adjusted for 0 volts ±0.2 volts, with trace centered. Trigger amplitude should be approximately 1 volt peak to peak with a low frequency 3 volts peak-to peak signal at pin 21 of rear connector plug.

☐ 11. Adjust Input Time-Constant and VOLTS/DIV Compensation. Page 7-9.
Adjust for optimum flat-top and front corner. Optimum square-wave response in all VOLTS/DIV positions.

☐ 12. Adjust High Frequency Compensation. Page 7-11.
Optimum response to 300 kHz fast-rise square-wave.

☐ 13. Check Risetime. Page 7-12.
Risetime to a fast-rise square-wave should be 100 ns or less.

☐ 14. Check Bandpass. Page 7-13.
DC to 3.5 MHz minimum.

**Operational Amplifiers**

☐ 15. Adjust OFFSET (Output DC Level). Page 7-14.
Position trace to zero reference level with OFFSET control.

☐ 16. Check LF REJ for DC Rejection. Page 7-14.
Trace should return to graticule center at each position of $Z_f$.

☐ 17. Adjust Grid Current. Page 7-15.
Minimum vertical spot velocity after each switch of the Grid Current Checker is opened.

☐ 18. Check Open-loop DC Gain. Page 7-17.
Gain 15,000 minimum.

☐ 19. Check Output Voltage and Current. Page 7-18.
Will drive 3.34 kΩ resistor at low frequencies to ±25 volts.

☐ 20. Check $Z_i$ and $Z_f$ Components. Page 7-19.
Operational check of correct function of $Z_i/Z_f$ combinations.

☐ 21. Adjust $Z_f$ 10 and 100 pF Variable Capacitors. Page 7-21.
Correct signal attenuation factor.

☐ 22. Adjust $Z_i$ 10 and 100 pF Variable Capacitors, Page 7-22.
Adjusted to correct attenuation factor.

☐ 23. Check Gain-Bandwidth Product (Open-loop). Page 7-25.
10 MHz minimum.

# CALIBRATION PROCEDURE

## General

In the following calibration procedure, a test equipment setup is shown for each major setup change. Complete control settings are listed beneath the picture. To aid in locating individual controls which have been changed during complete calibration, these control names are printed in bold type. If only a partial calibration is performed, start with the nearest setup preceding the desired portion.

NOTE

**When performing a complete recalibration, best performance will be provided if each adjustment is made to the exact setting, even if the Check is within the allowable tolerance.**

**The following procedure uses the equipment listed under Equipment Required. If substitute equipment is used, control settings or setup must be altered to meet the requirements of the equipment used.**

## NOTES

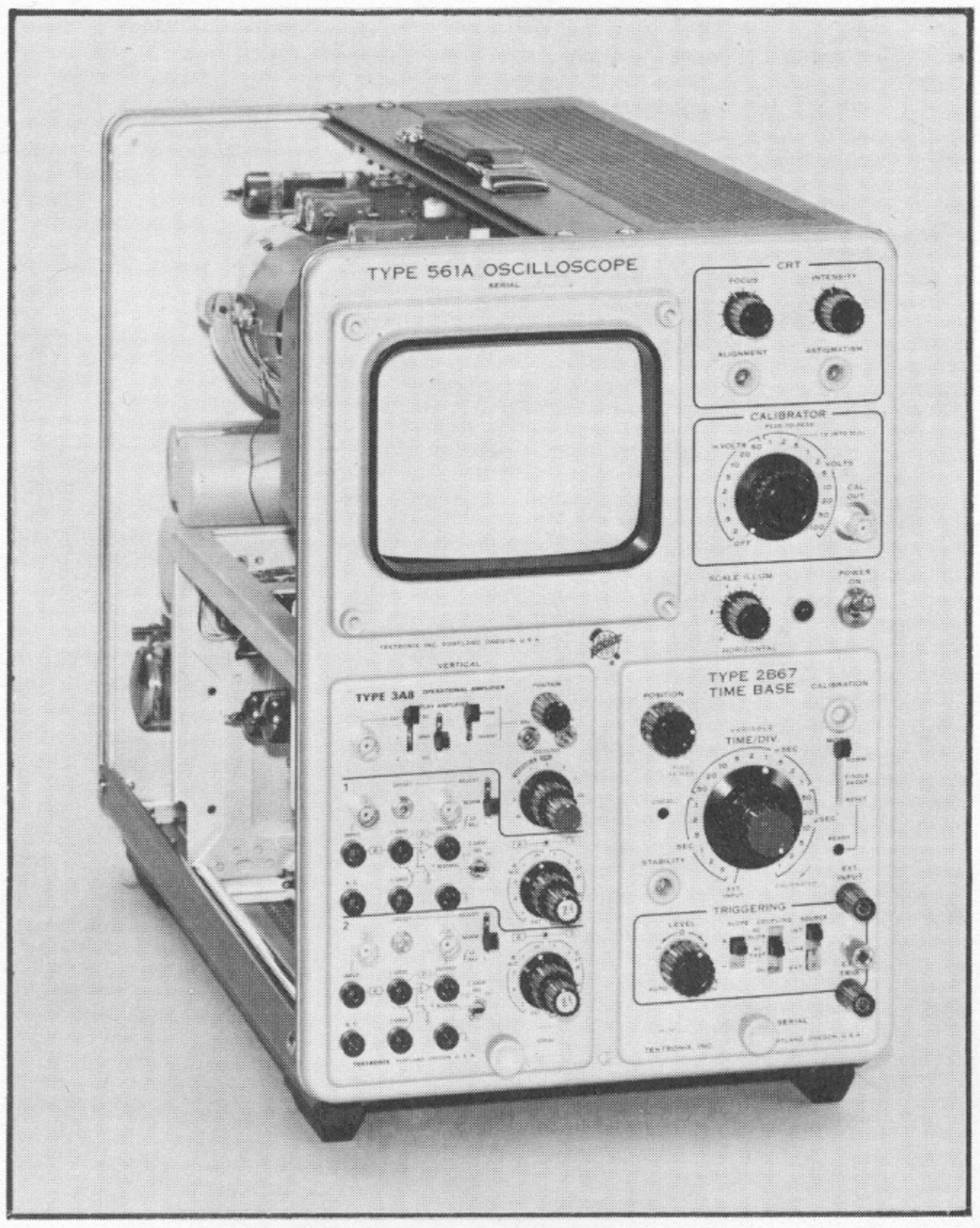



**Fig. 7-3. Initial test equipment setup for steps 1 through 5.**

## Type 3A8

Display Amplifier

| | |
|---|---|
| EXT-1-2 | EXT |
| AC-GND-DC | GND |
| NORM-INVERT | NORM |
| VOLTS/DIV | .02 |
| VARIABLE | CAL |
| POSITION | Midrange |
| BAL | Midrange |

Operational Amplifiers, 1 and 2

| | |
|---|---|
| $Z_i$ | 1 MΩ |
| $Z_f$ | 1 MΩ |
| ± GRID SEL | (—) |
| ADJUST-NORM-∫LF REJ | NORM |

**Time-Base Plug-In Unit**

| | |
|---|---|
| Time/Div | 1 mSEC |
| Triggering | |
| Level | Auto or Free-Run |
| Slope | + |
| Coupling | AC |
| Source | Int |

# DISPLAY AMPLIFIER

## 1. Adjust DC Balance

a. Test equipment setup is as shown in Fig. 7-3.

b. Position the trace to the graticule centerline, with the input to the Display Amplifier grounded. This trace position will be referred to as the zero signal reference level.

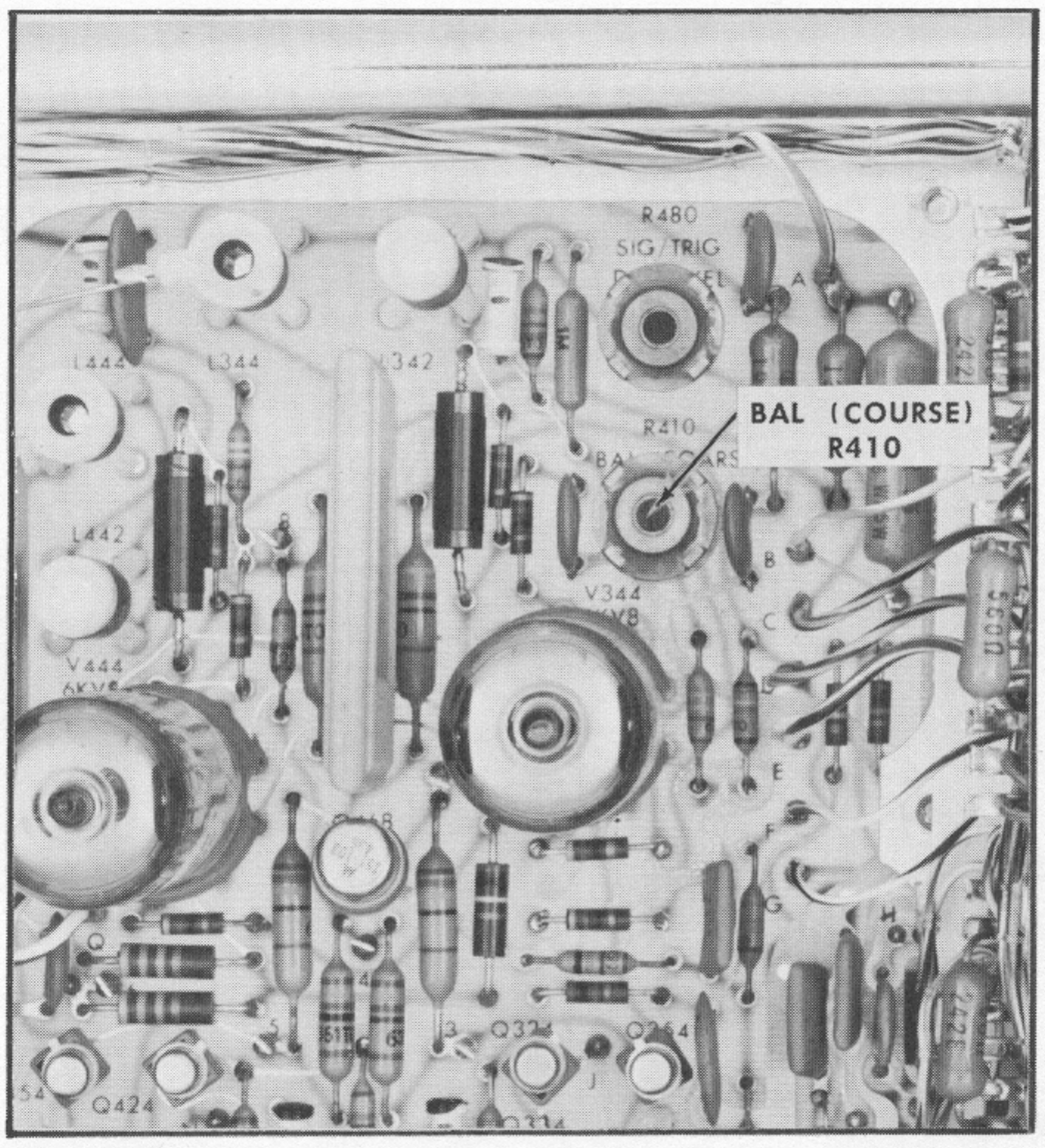



**Fig. 7-4. BAL (COARSE) Adjustment R410.**

c. Set the BAL (coarse) adjustment R410 (see Fig. 7-4) so there is less than 1 major division trace shift when the NORM-INVERT switch is alternated from NORM to INVERT position.

d. Set the front panel BAL adjustment R414 for minimum trace shift as the NORM-INVERT switch is alternated between the two positions.

NOTE

Rapid switching between NORM and INVERT position may cause balance point to drift. Allow a lag time between switch positions before the BAL adjustment is made.

## 2. Check VARIABLE Control Effect on Trace Position

a. Test equipment setup as shown in Fig. 7-3.

b. Rotate the VARIABLE control through its range and note the amount of trace shift.

c. Check—Trace shift should be less than 1 major division.

d. Select Q334 and Q434 for matched $V_{be}$, if imbalance is greater than 1 major division.

## 3. Check Input Grid Current

a. Test equipment setup is as shown in Fig. 7-3.

b. Switch AC-GND-DC switch to DC position and note the amount of trace shift.

c. Check—Trace shift not to exceed 2 minor divisions.

## 4. Check Microphonics

a. Excessive microphonics is a condition that can only be judged after a number of instruments have been compared under specific conditions. Microphonics due to light tapping with the finger on the front of the Type 3A8 is typically less than 1 major division.

b. Set AC-GND-DC switch to GND.

c. Lightly tap the front panel of the Type 3A8 with the fingers and note microphonic amplitude.

d. Check—Microphonics not to exceed 1 major division.

e. If microphonics are excessive, change the input tube V303 and repeat steps 1 through 3.

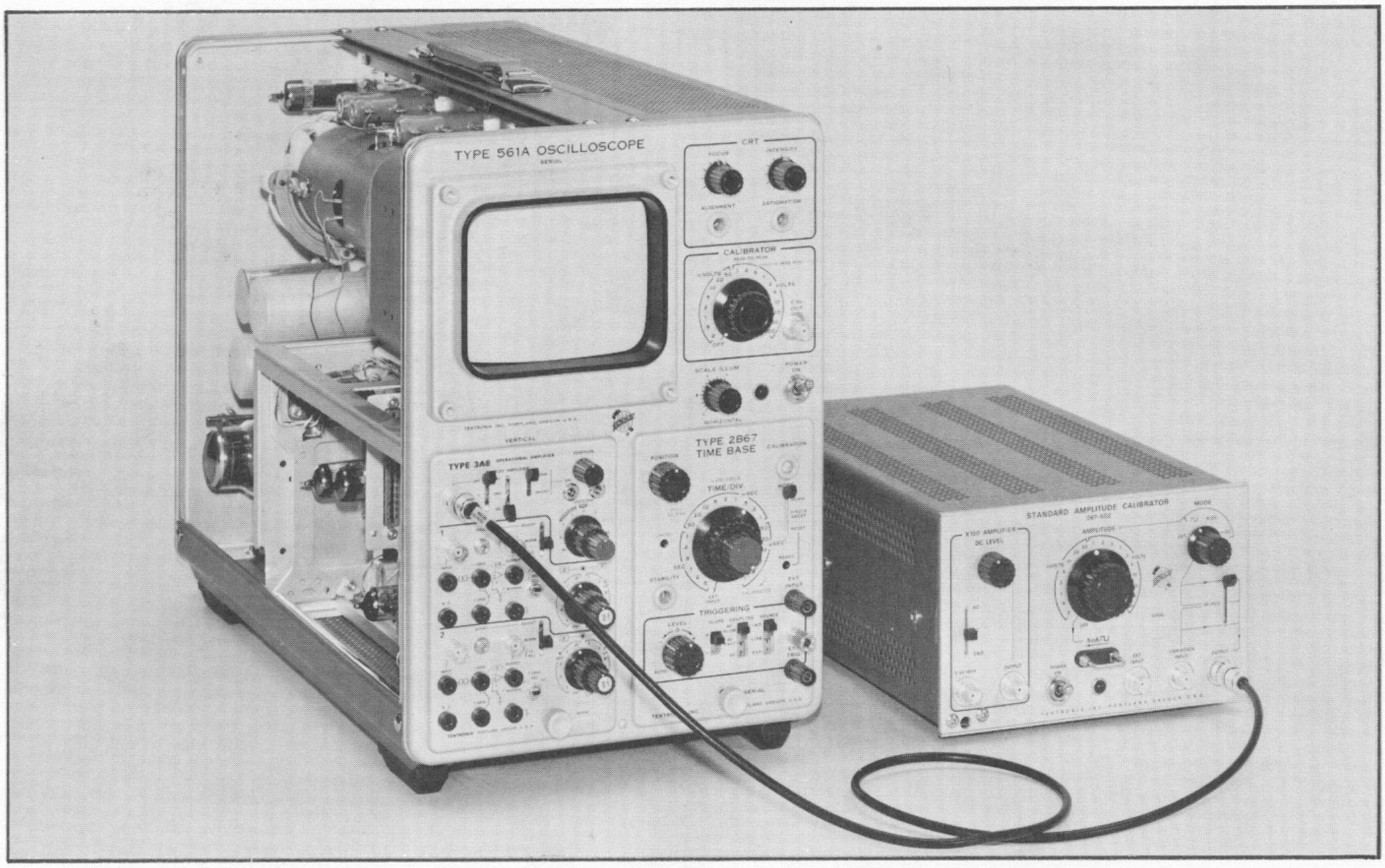



Fig. 7-5. Test equipment setup for steps 6 through 12.

### Type 3A8

| | |
|---|---|
| Display Amplifier | |
| EXT-1-2 | EXT |
| **AC-GND-DC** | **DC** |
| NORM-INVERT | NORM |
| VOLTS/DIV | .02 |
| VARIABLE | CAL |
| POSITION | Midrange |
| Operational Amplifiers, 1 and 2 | |
| $Z_i$ | 1 MΩ |
| $Z_f$ | 1 MΩ |
| ± GRID SEL | (—) |
| ADJUST-NORM∫LF REJ | NORM |

### Time-Base Plug-In Unit

| | |
|---|---|
| Time/Div | 1 mSEC |
| Triggering | |
| Level | Auto or Free-Run |
| Slope | + |
| Coupling | AC |
| Source | Int |

## 5. Adjust CAL (Basic sensitivity calibration) ❶

a. Test equipment setup is as shown in Fig. 7-5.

b. Apply a 0.1 volt signal from the Standard Amplitude Calibrator to the Type 3A8 EXT input connector.

c. Set the CAL adjustment R337, for an accurate signal amplitude of 5 major divisions. See Fig. 7-6.

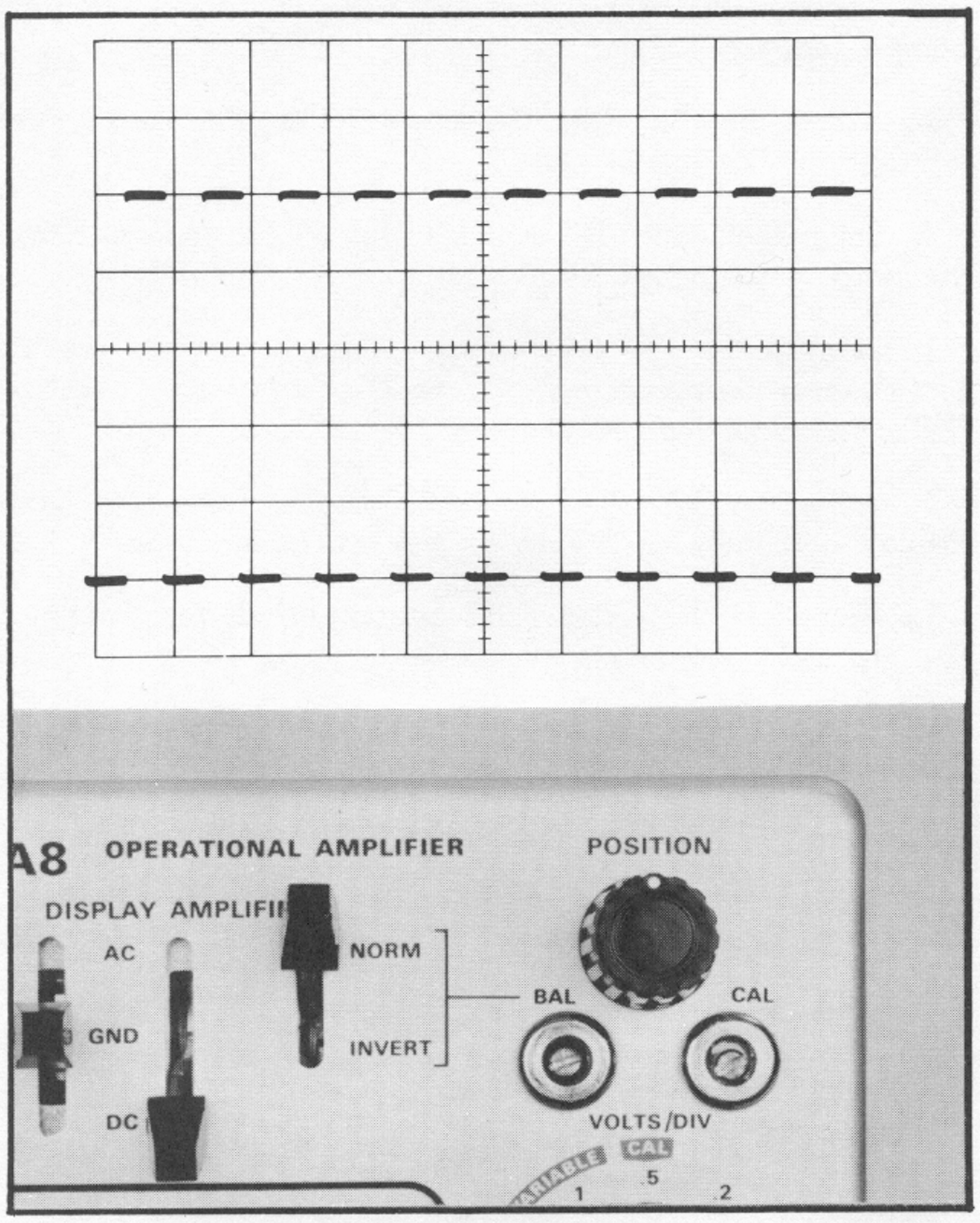



**Fig. 7-6. CAL adjustment set accurately to 20 mV/DIV.**

## 6. Check VOLTS/DIV Attenuator Accuracy

a. Test equipment setup as shown in Fig. 7-5.

b. Check—Using the VOLTS/DIV switch and standard Amplitude Calibrator settings given in Table 7-1, check that signal amplitude is within ±3% for each position of the VOLTS/DIV switch.

## 7. Check VARIABLE Control Attenuation Range

a. Test equipment setup as shown in Fig. 7-5.

b. Set the output of the Standard Amplitude Calibrator to .1 volt. This should provide a 5 division display amplitude.

c. Position the display to the center of the graticule area.

d. Rotate the VARIABLE control to maximum attenuation position.

e. Check—Display amplitude is 2 divisions or less (Attenuation ratio 2.5:1 or more).

**TABLE 7-1**

| Type 3A8 VOLTS/DIV Setting | Standard Amplitude Calibrator Output (Volts) | Vertical Deflection Major Divisions | Maximum Error For ±3% Accuracy Minor Divisions |
|---|---|---|---|
| .02 | .1 | 5 | Adjusted |
| .05 | .2 | 4 | ±0.6 |
| .1 | .5 | 5 | ±0.75 |
| .2 | 1 | 5 | ±0.75 |
| .5 | 2 | 4 | ±0.6 |
| 1 | 5 | 5 | ±0.75 |
| 2 | 10 | 5 | ±0.75 |
| 5 | 20 | 4 | ±0.6 |
| 10 | 50 | 5 | ±0.75 |

## 8. Check AC-GND-DC Coupling Switch Operation

a. Test equipment setup is as shown in Fig. 7-5.

b. Set the Standard Amplitude Calibrator for an output of 50 mV (2.5 major division display amplitude).

c. Position the bottom of the display to the graticule centerline and change the AC-GND-DC switch to AC.

d. Check—Display should move down and average about the graticule centerline.

e. Set the AC-GND-DC switch to GND position and the time-base triggering to free run.

f. Check—Crt display should be a straight line near the graticule centerline.

## 9. Check Vertical Deflection Linearity (Compression and Expansion)

a. Test equipment setup is as shown in Fig. 7-5.

b. Set the Standard Amplitude Calibrator for a 50 mV output and adjust the time-base Level control for a stable display.

c. Position the top of the 50 mV waveform to the top horizontal graticule line, then position the bottom of the waveform to the bottom horizontal graticule line. Note the compression or expansion of the display amplitude.

d. Check—Compression or expansion compared to display amplitude at the center of the graticule area should not exceed ±3% plus the linearity factor of the associated oscilloscope crt (typically ±1%).

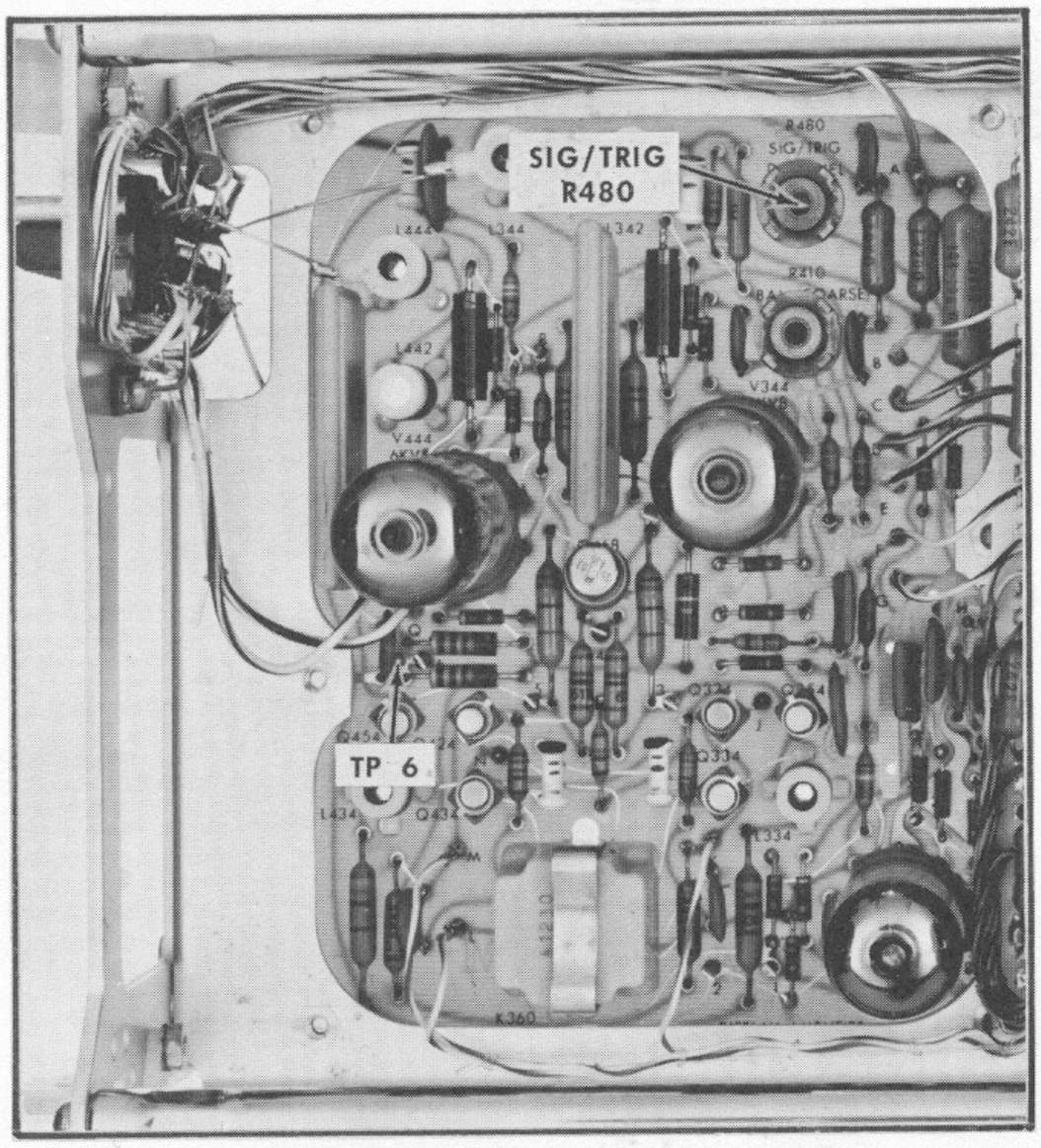



**Fig. 7-7. Test point 6 on Display Amplifier board, and Sig/Trig DC Level adjustment R480.**

## 10. Adjust DC Level of Trigger Signal Output and Check Trigger Output Amplitude ❶

a. Test equipment setup is as shown in Fig. 7-5.

b. Set the AC-GND-DC switch to GND position.

c. Position the trace to zero signal reference level (see step 1).

d. Connect the probe from the test oscilloscope to Test point 6 (see Fig. 7-7).

e. Adjust the Sig/Trig DC Level R480, for zero volts (allowed ± 0.2 volts).

f. Set the AC-GND-DC switch to the DC position and the Standard Amplitude Calibrator output to 10 mV.

g. Remove the test oscilloscope probe from Test Point 6 and connect the probe to pin 17 or 21 of J-11 (either vertical deflection plate lead to the crt).

h. Adjust the Type 3A8 VARIABLE control for a reference display amplitude of 3 volts on the test oscilloscope.

i. Reconnect the test oscilloscope probe to Test Point 6. See Fig. 7-7.

j. Check—Trigger amplitude should be approximately 1 volt in amplitude.

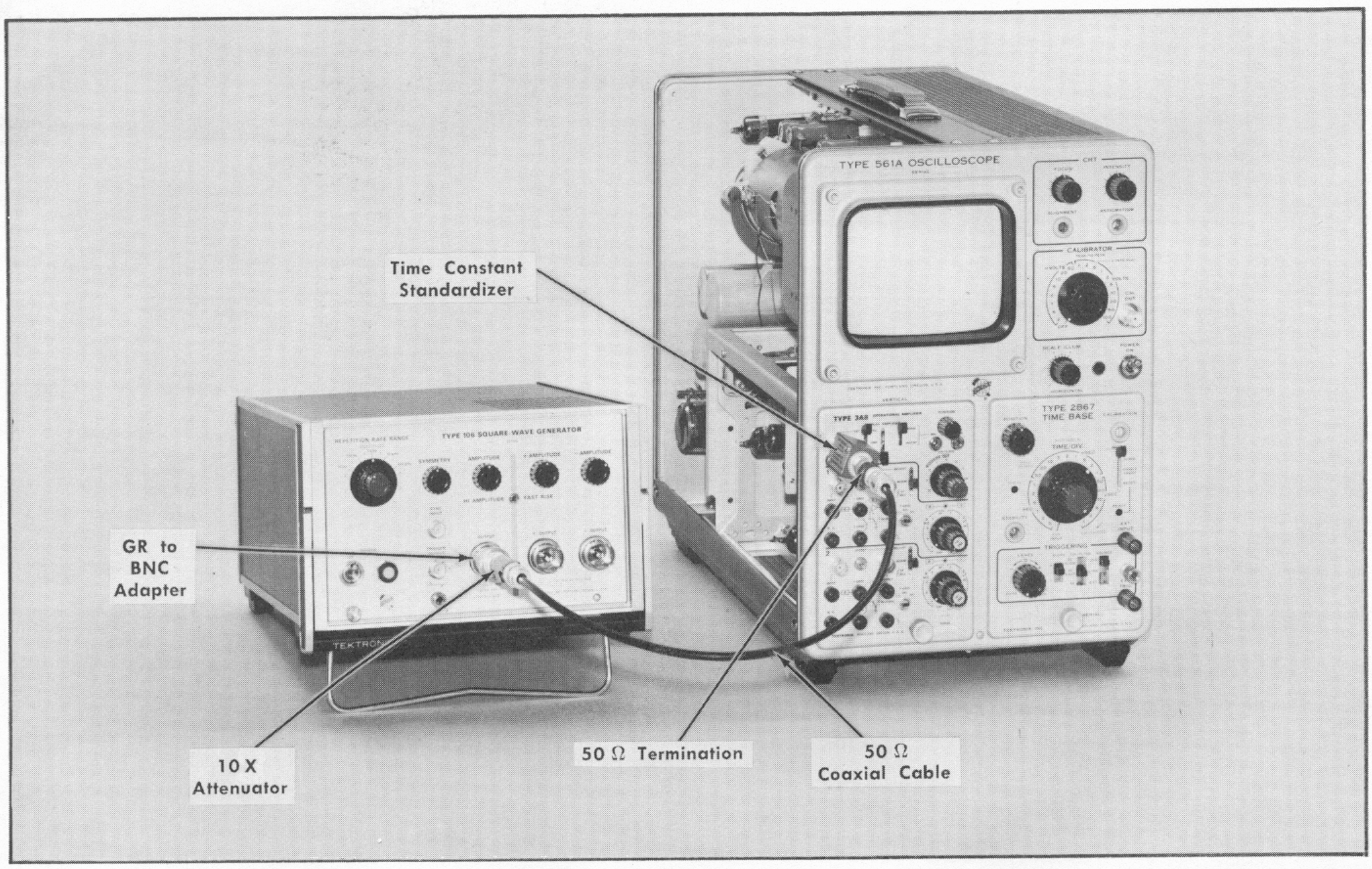



**Fig. 7-8. Test setup for step 11.**

**Type 3A8**

Display Ampifier

| | |
|---|---|
| EXT-1-2 | EXT |
| AC-GND-DC | DC |
| NORM-INVERT | NORM |
| VOLTS/DIV | .02 |
| VARIABLE | CAL |
| POSITION | Midrange |

Operational Amplifiers 1 and 2

| | |
|---|---|
| $Z_i$ | 1MΩ |
| $Z_f$ | 1MΩ |
| ± GRID SEL | (—) |
| ADJUST-NORM-∫LF REJ | NORM |

**Time-Base Plug-In Unit**

| | |
|---|---|
| **Time/Div** | **.2 mSEC** |
| Triggering | |
| Level | Auto or Free-Run |
| Slope | + |
| Coupling | AC |
| Source | Int |

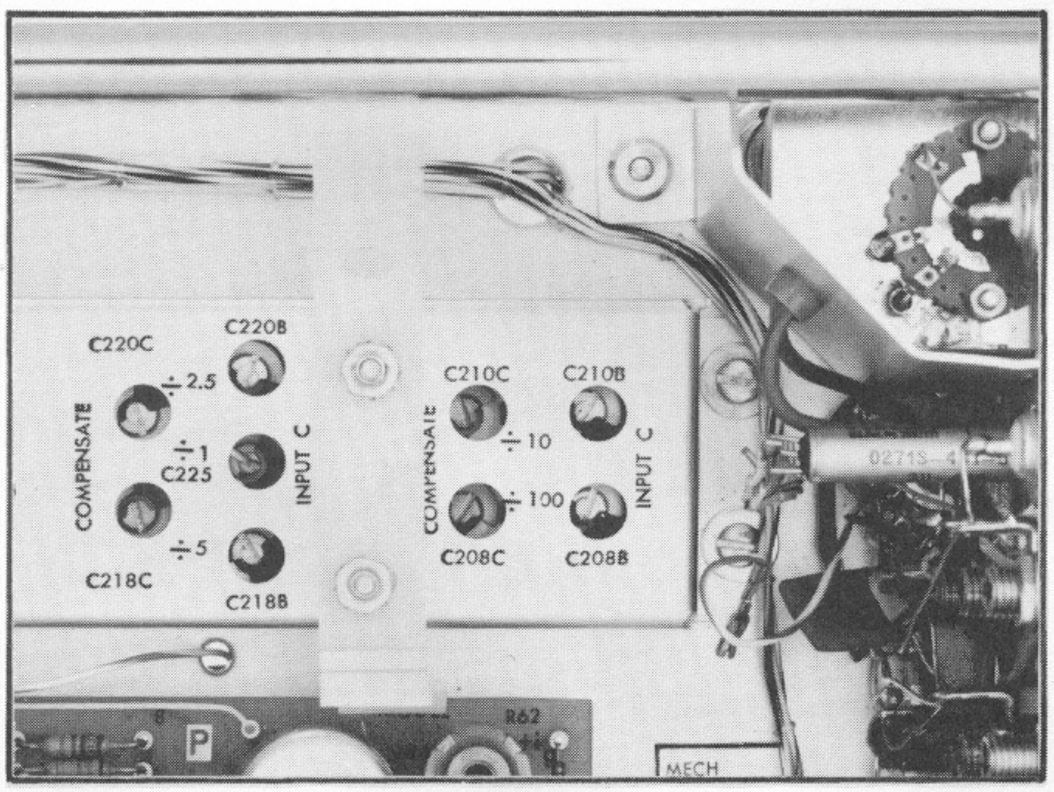



**Fig. 7-9. Input and compensating capacitors for VOLTS/DIV attenuator.**

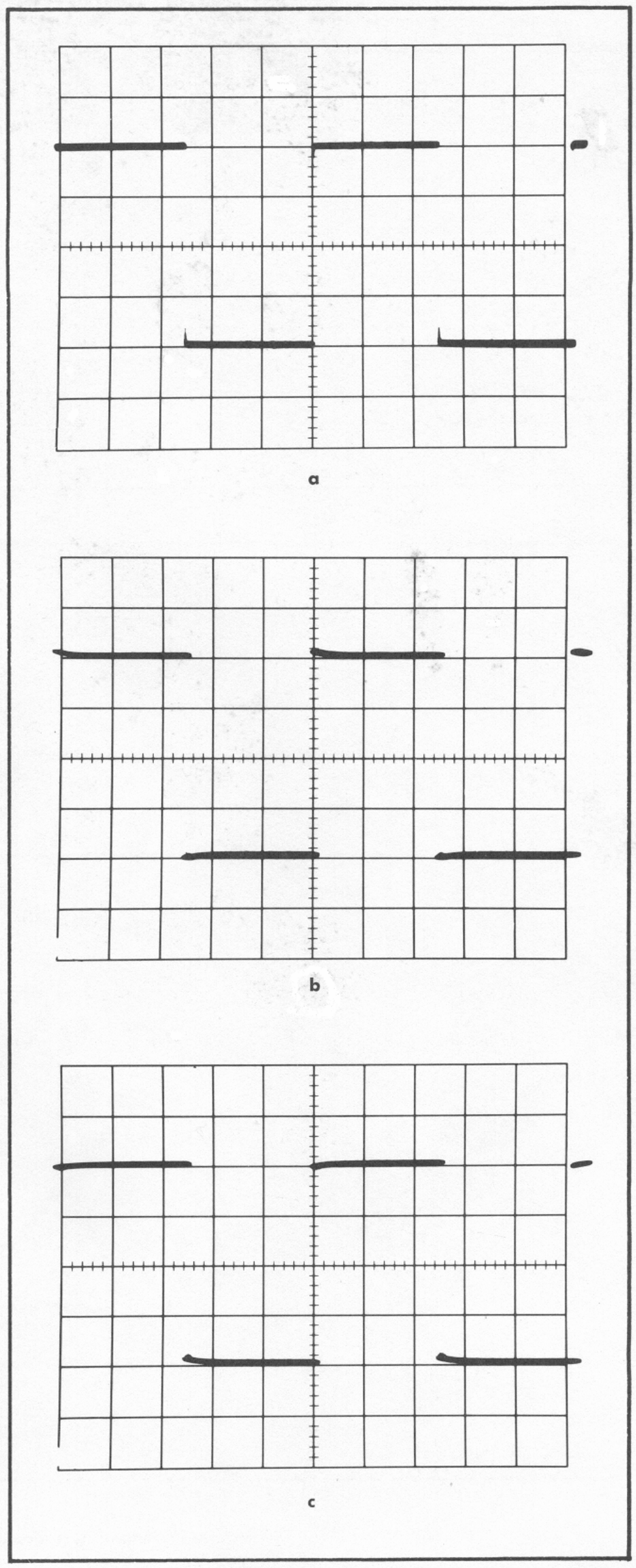



**Fig. 7-10. (a) Typical crt display showing correct compensation and input time constant. (b) Input time constant too short (Input C too small). (c) Input time constant too long (Input C too great).**

## 11. Adjust Input Time-Constant and VOLTS/DIV Compensation

a. Test equipment setup is as shown in Fig. 7-8.

**TABLE 7-2**

| VOLTS/DIV Setting | Ratio | Adjust for Optimum | |
|---|---|---|---|
| | | COM-PENSATE (Front Corner) | INPUT C (Flat Top) |
| .02 | ÷1 | | C225 |
| .05 | ÷2.5 | C220C | C220B |
| .1 | ÷5 | C218C | C218B |
| .2[1] | ÷10 | C210C | C210B |
| .5 | | Check | Check |
| 1 | | Check | Check |
| 2[2] | ÷100 | C208C | C208B |
| 5 | | Check | Check |
| 10 | | Check | Check |

b. Set the Square-Wave Generator (Type 106) frequency to 1 kHz and adjust the Hi-Amplitude output control for a 5 major division display. (See Fig. 7-9).

c. Adjust the Input C225 (see Fig. 7-9) for an optimum flat top display. See Fig. 7-10.

d. Check and if required, adjust the VOLTS/DIV capacitors as listed in Table 7-2. Maintain 5 major division display amplitude.

e. Check—Tilt or front corner rounding must be less than ±0.5% and rolloff or overshoot less than ±1%.

**[1]Remove the 10× attenuator to maintain 5 major division display amplitude.**

**[2]Remove the 50 Ω termination to maintain 5 major division display amplitude.**

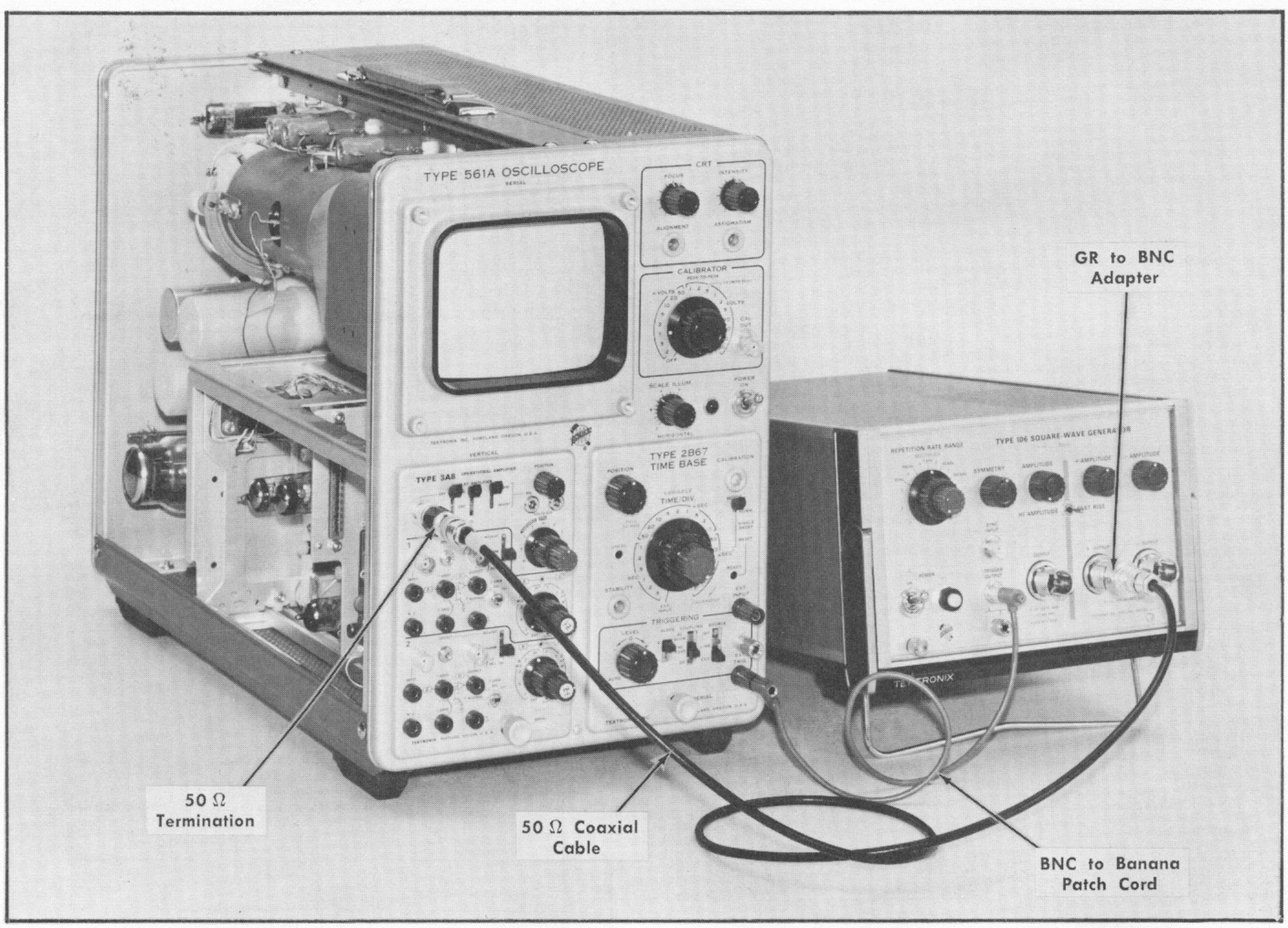



**Fig. 7-11. Initial test equipment setup for steps 12 and 13.**

**Type 3A8**

Display Amplifier

| | |
|---|---|
| EXT-1-2 | EXT |
| AC-GND-DC | DC |
| NORM-INVERT | NORM |
| VOLTS/DIV | .02 |
| VARIABLE | CAL |
| POSITION | Midrange |

Operational Amplifiers 1 and 2

| | |
|---|---|
| $Z_i$ | 1 MΩ |
| $Z_f$ | 1 MΩ |
| ± GRID SEL | (—) |
| ADJUST-NORM-∫LF REJ | NORM |

**Time-Base Plug-In Unit**

| | |
|---|---|
| **Time/Div** | **1 μSEC** |
| Triggering | |
| **Level** | **Stable display** |
| Slope | + |
| Coupling | AC |
| **Source** | **Ext** |

## 12. Adjust High Frequency Compensation ◐

a. Test equipment setup is as shown in Fig. 7-11.

b. Apply an approximately 300 kHz, fast-rise square-wave signal from the + Output of the Square-Wave Generator (Type 106) to the Type 3A8 and adjust the + Amplitude control for a display amplitude of 4 divisions.

c. Adjust time-base unit Triggering Level control for a stable display.

d. Adjust L334, L434, L344 and L444 for optimum top and bottom, leading corners of the display. See Fig. 7-12. L334 and L434 affect the corner of the square-wave display, while L344 and L444 affect a somewhat longer time constant. The coil adjustments will have an apparent interaction.

e. Set the NORM-INVERT switch to INVERT position.

f. Check the bottom corner of the square-wave for optimum square corner. See Fig. 7-12. Adjust coils if necessary.

g. Apply the fast-rise output from the Square-Wave Generator (Type 106) to the Type 3A8 and check the display in both NORM and INVERT operation.

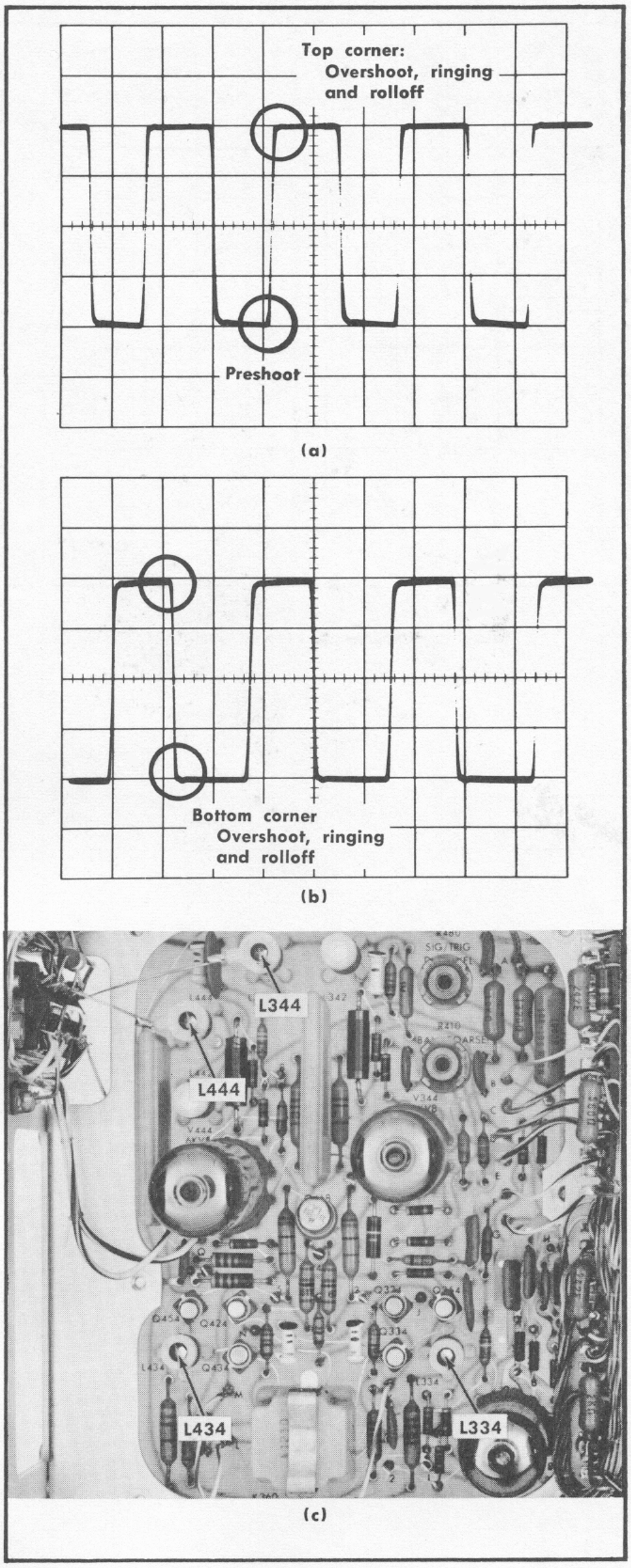



**Fig. 7-12. (a) Positive waveform showing top corner response. (b) Negative waveform showing bottom corner response. (c) Location of high frequency adjustments L334, L434, L344 and L444.**

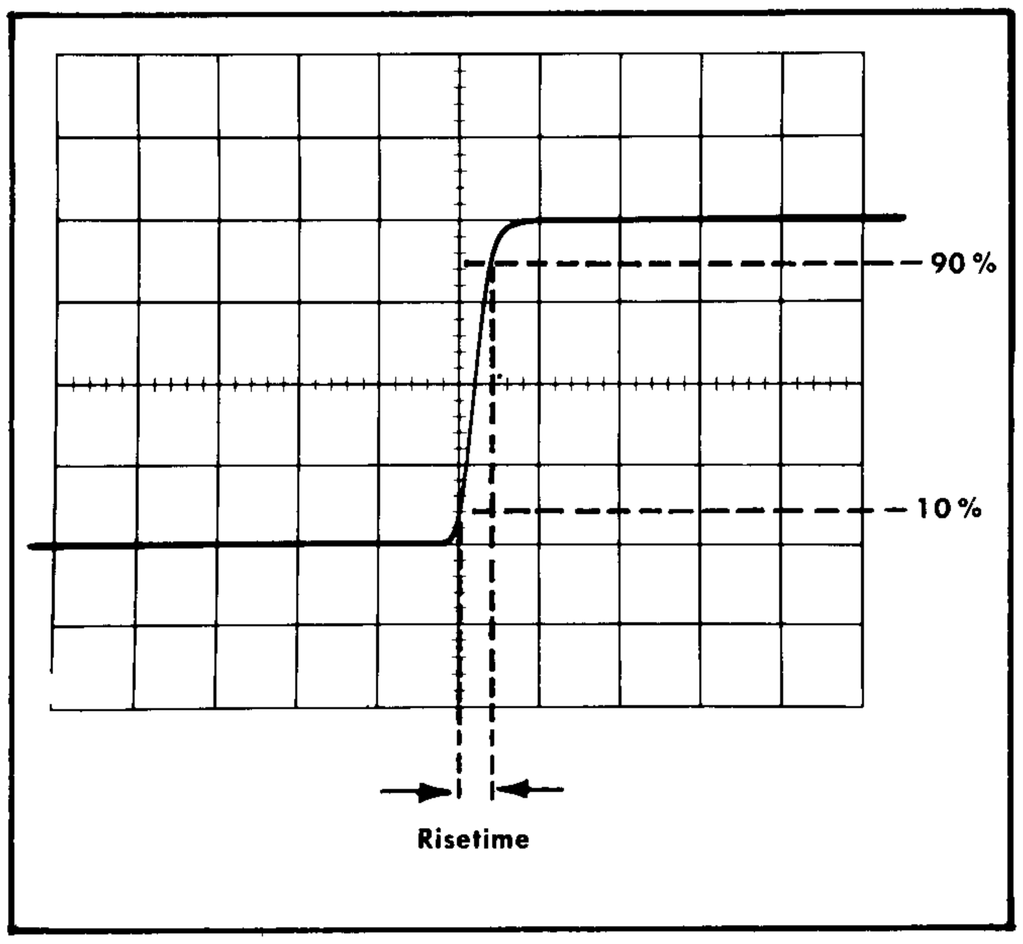



**Fig. 7-13. Measuring risetime of Display Amplifier ≤100 ns.**

h. Check 1% (0.2 minor div) or less overshoot in the NORM position and 3% (0.6 minor div.) or less overshoot in the INVERT position within the temperature range of 20 to 30°C. In either position of the NORM-INVERT switch, hook or rolloff should be less than 1%.

## 13. Check Risetime

a. Test equipment setup is as shown in Fig. 7-11.

b. Apply an approximately 300 kHz signal from the + Output of the Square-Wave Generator to the Type 3A8 and adjust the output for a display amplitude of 4 divisions.

c. Change the time-base Time/Div switch to the fastest available sweep rate. (If using Type 2B67, turn 5× Mag On). Adjust the Level control for a stable display.

d. Measure the pulse risetime from the 10 to 90% points on the 4 major division display. See Fig. 7-13.

e. Check—Risetime must be 100 ns or less.

f. If risetime is excessive, repeat step 12.

## NOTES

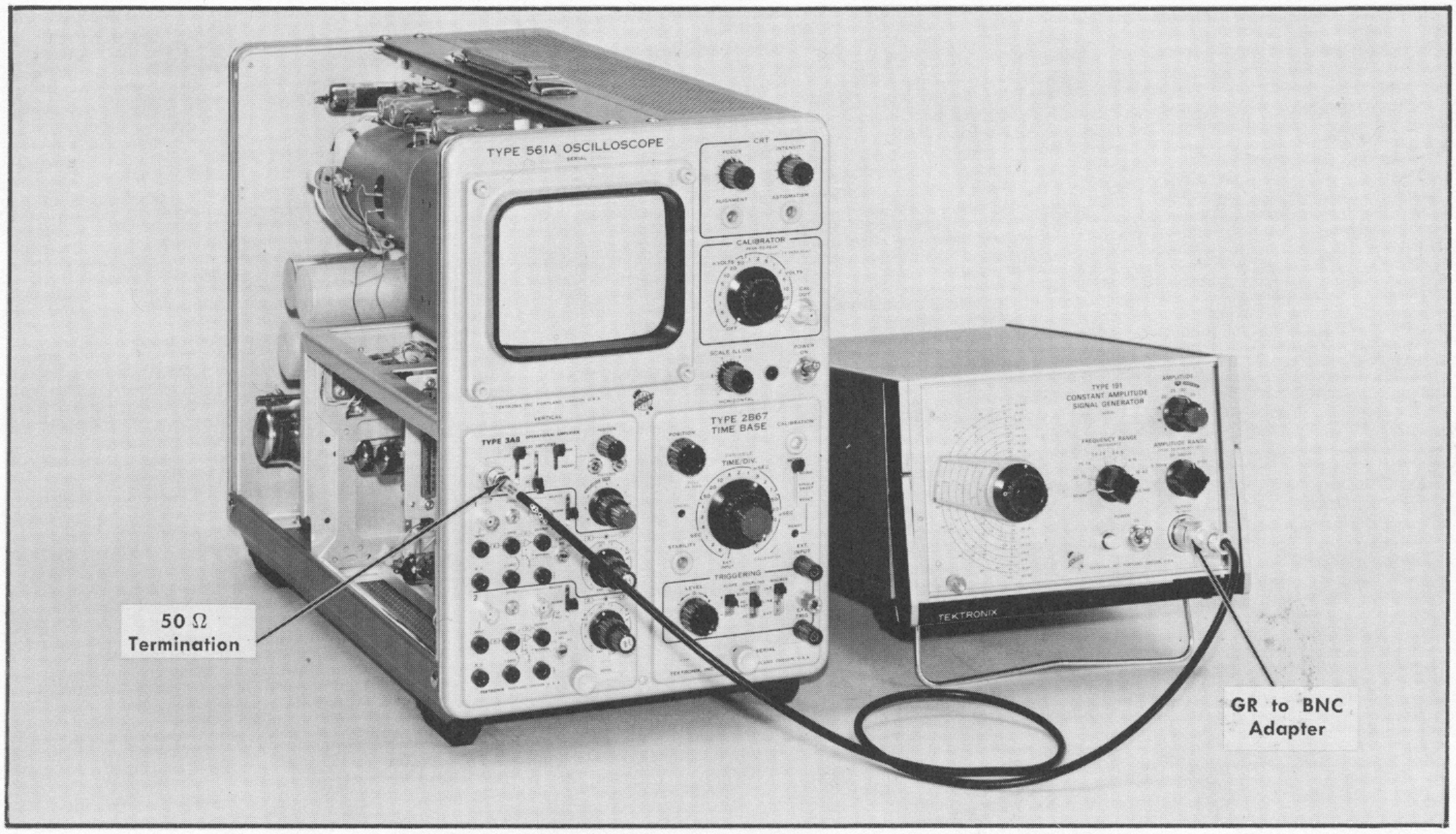



Fig. 7-14. Initial test setup for step 14.

### Type 3A8

Display Amplifier

| | |
|---|---|
| EXT-1-2 | EXT |
| AC-GND-DC | DC |
| NORM-INVERT | NORM |
| VOLTS/DIV | .02 |
| VARIABLE | CAL |
| POSITION | Midrange |

Operational Amplifiers 1 and 2

| | |
|---|---|
| $Z_i$ | 1 MΩ |
| $Z_f$ | 1 MΩ |
| ± GRID SEL | (—) |
| ADJUST-NORM-∫LF REJ | NORM |

**Time-Base Plug-In Unit**

| | |
|---|---|
| **Time/Div** | **.1 mSEC** |
| Triggering | |
| **Level** | **Auto or Free-Run** |
| Slope | + |
| Coupling | AC |
| **Source** | **Int** |

**Constant Amplitude Signal Generator**

**(Type 191)**

| | |
|---|---|
| **Frequency Range** | **50 kHz** |
| **Amplitude** | **5** |
| **Amplitude Range** | **50-500 mV** |

## 14. Check Bandpass

a. Test equipment setup is as shown in Fig. 7-14.

b. Apply a 50 kHz signal from the Constant Amplitude Signal Generator (Type 191) to the Type 3A8 and adjust the Variable Output control for a display with an amplitude of 4 major divisions.

c. Adjust the time-base Triggering Level control for a stable display.

d. Increase the frequency of the signal from the Constant Amplitude Signal Generator until the display amplitude has decreased to 2.8 divisions (30% down). Readjust the Level control if necessary to maintain stability in the display.

e. Check—Output frequency of the signal generator (Type 191) must be 3.5 MHz or higher.

f. Change the NORM-INVERT switch to INVERT and repeat the bandpass check for INVERT operation.

g. If bandpass is below 3.5 MHz, repeat Steps 12 and 13.

This completes the calibration of the Display Amplifier. Turn the power switch OFF and remove the Type 3A8. Replace the Operational Amplifier circuit card. Check for correct connections at the pins of both Operational Amplifier cards. See Maintenance section for correct pin connections. Pin A, white-brown wire. Pin B, white-red wire. Pin C, white-orange wire.

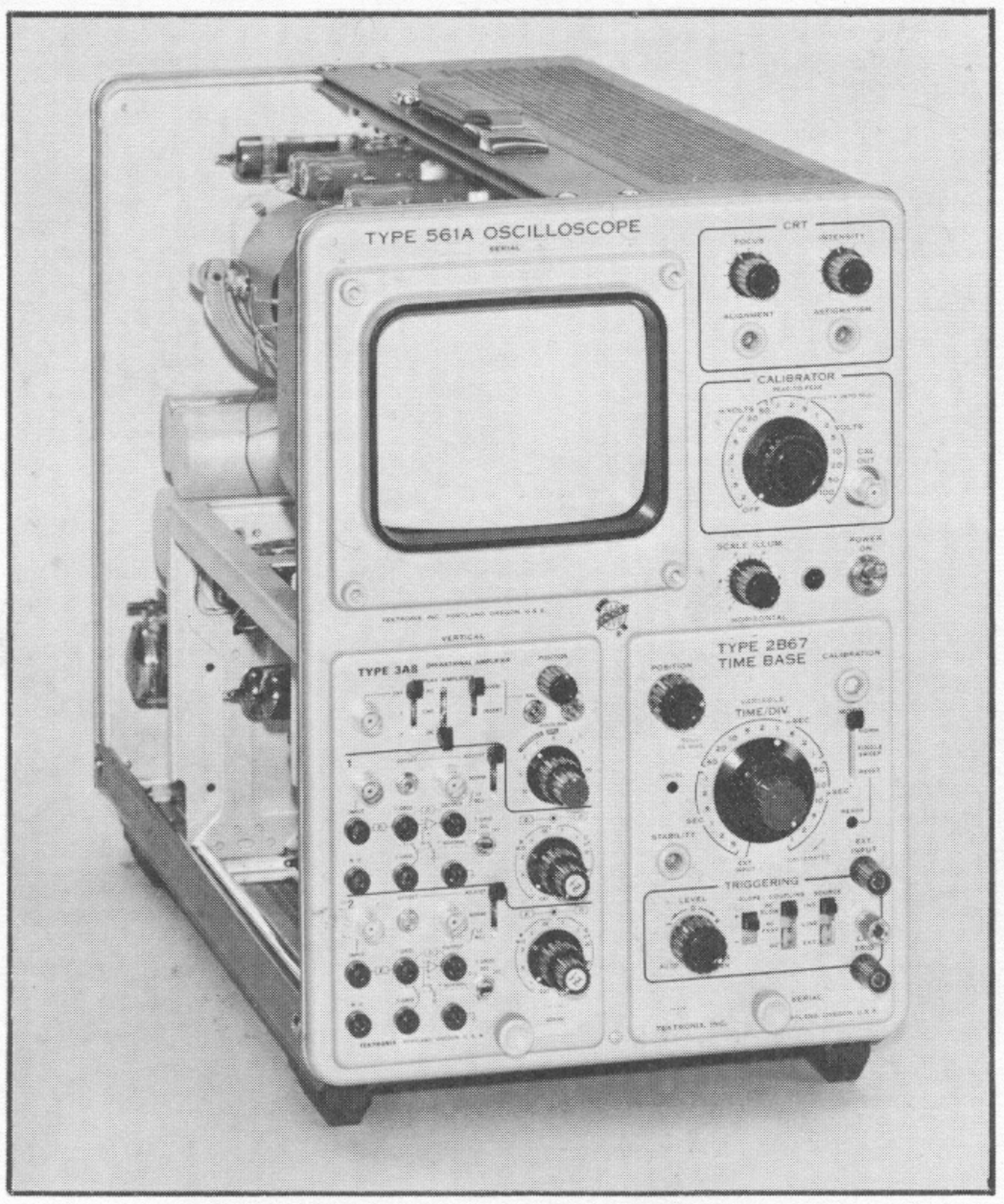



**Fig. 7-15. Initial test equipment setup for steps 15 and 16.**

**Type 3A8**

| | |
|---|---|
| Display Amplifier | |
| EXT-1-2 | 1 |
| **AC-GND-DC** | **GND** |
| NORM-INVERT | NORM |
| **VOLTS/DIV** | **1.0** |
| VARIABLE | CAL |
| POSITION | Midrange |
| Operational Amplifiers 1 and 2 | |
| **$Z_i$** | **.2 MΩ** |
| **$Z_f$** | **.01 MΩ** |
| ± GRID SEL | (—) |
| **ADJUST-NORM-∫LF REJ** | **ADJUST** |

**Time-Base Plug-In Unit**

| | |
|---|---|
| **Time/Div** | **1 mSEC** |
| Triggering | |
| Level | Auto or Free-Run |
| Slope | + |
| Coupling | AC |
| Source | Int |

## OPERATIONAL AMPLIFIERS

The 1 and 2 Operational Amplifiers are identical, therefore the calibration procedure is applicable to both although it is written for the number 1 amplifier. Calibrate number 1 amplifier then change the Display Amplifier EXT-1-2 switch settings from 1 to 2 in all setups for calibrating number 2 amplifier. Preliminary: After the power is applied, allow an initial 15 minutes warm-up period for the circuit to stabilize.

## 15. Adjust OFFSET (Output DC Level)

a. Test equipment setup is as shown in Fig. 7-15.

b. Position the trace to the zero reference trace position. See step 1.

c. Set the AC-GND-DC switch to DC position.

d. Adjust the OFFSET to position the trace to the zero reference level.

e. Increase the Display Amplifier sensitivity by changing the VOLTS/DIV switch setting to .1 in steps, adjusting the OFFSET each step to keep the trace near the zero reference level.

NOTE

Due to thermal lag, the amplifier will require time to stabilize after each adjustment. As the sensitivity of the amplifier is increased, small changes in OFFSET will have a marked effect in the amount of trace movement. After final adjustment, the output probably will move slowly back and forth through zero reference.

The ADJUST setting of the ADJUST-NORM-∫LF REJ switch provides a closed-loop gain of ×100. Thus, with a VOLTS/DIV switch setting of .02, one major division of the graticule corresponds to 200 μV referred to the Operational Amplifier input.

f. Set the ADJUST-NORM-∫LF REJ switch to NORM position.

## 16. Check ∫LF REJ for DC Rejection

a. Test equipment setup is as shown in Fig. 7-15.

b. Change to the following control settings:

**Type 3A8**

| | |
|---|---|
| AC-GND-DC | DC |
| VOLTS/DIV | .1 |
| ADJUST-NORM-∫LF REJ | ∫LF REJ |
| $Z_i$ | 1 MΩ |

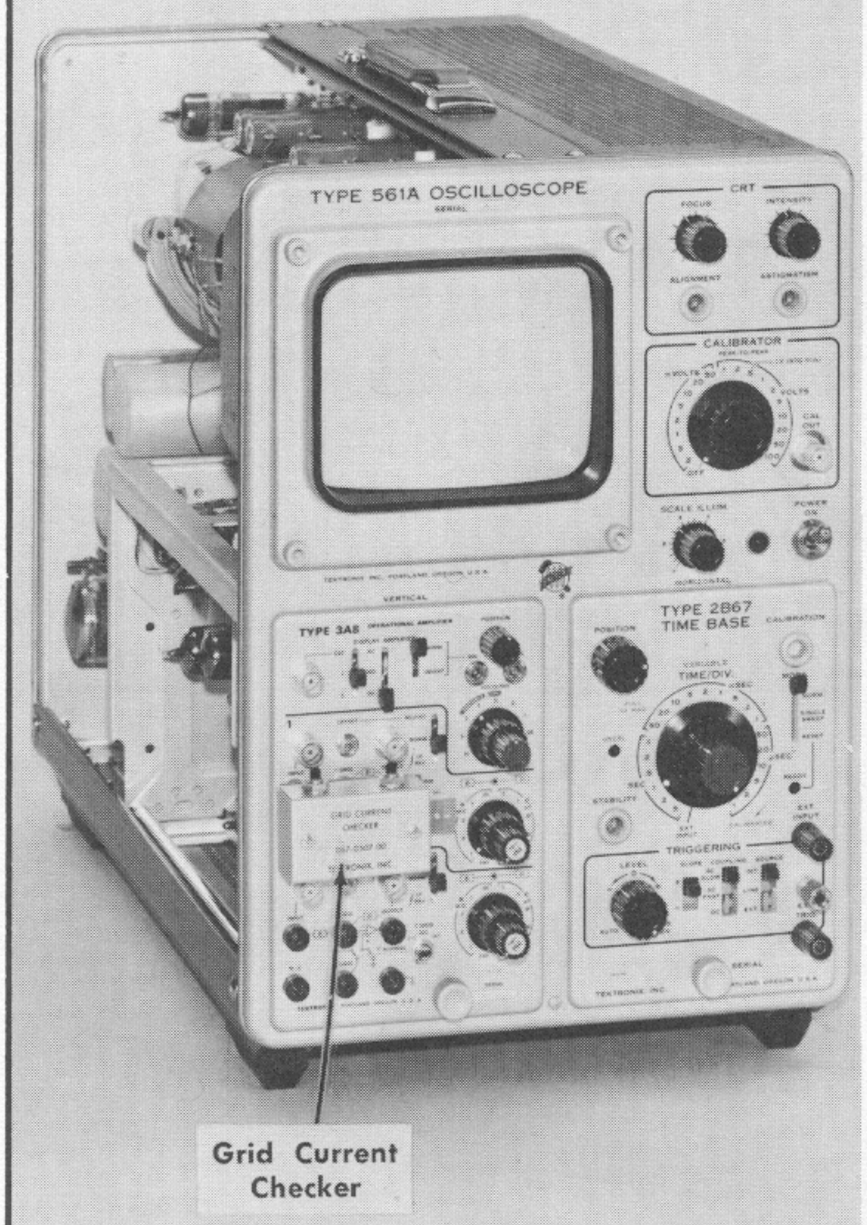
**Time Base Unit**

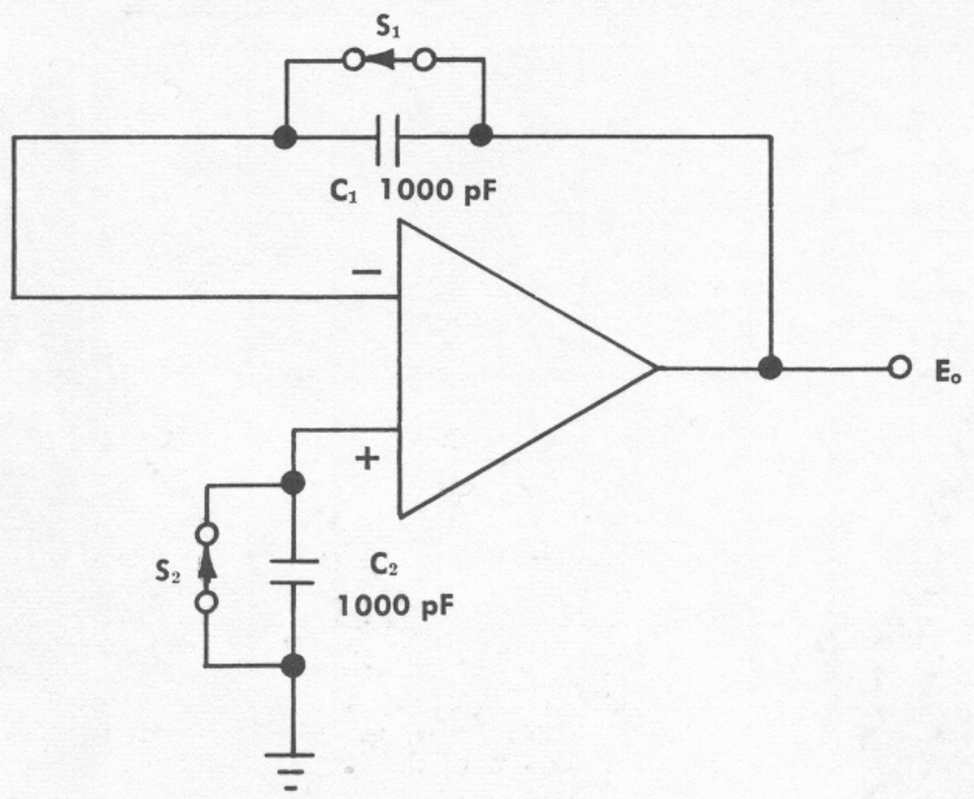
| | |
|---|---|
| Time/Div | 10 mSEC |

c. Position the trace to the center line of the graticule.

d. Switch $Z_f$ through all C positions.

e. Check—Trace should return to the center horizontal graticule line at each position of $Z_f$. (Trace may have ripple).




**Grid Current Calculations**

**With no external resistor between the minus grid and ground, and with a capacitor in the $Z_f$ position, the rate, polarity, and amount of change in amplifier output voltage indicates the grid current. The principle is valid for either the — grid or the + grid.**

**Grid current is measured by measuring the charge stored by a capacitor in a given time after the switch paralleling the capacitor is opened.**

$$q = Ce; \text{ then, with C constant, } \quad i = C\frac{de}{dt}, \text{ or } \quad i = C\frac{\Delta e}{\Delta t}.$$

**If C is 1000 pF ($10^{-9}$F) then $i = \frac{10^{-9}\,\Delta e}{\Delta t}$ — and dividing through by $10^{-12}$, pico-amperes $= \frac{10^{3}\,\Delta e}{\Delta t}$**

**If the capacitor voltage (after opening the switch) changes 0.25 V in 5 seconds, the current is 50 picoamperes.**

**Fig. 7-16. (a) Test setup for step 17. (b) Grid current calculations.**

## Type 3A8

| | |
|---|---|
| **Display Amplifier** | |
| EXT-1-2 | 1 |
| AC-GND-DC | DC |
| NORM-INVERT | NORM |
| **VOLTS/DIV** | **1** |
| VARIABLE | CAL |
| POSITION | Midrange |
| **Operational Amplifiers** | |
| **$Z_i$** | **EXT** |
| **$Z_f$** | **EXT** |
| **± GRID SEL** | **(+)** |
| **ADJUST-NORM-∫LF REJ** | **NORM** |
| **Time-Base Plug-In Unit** | |
| Time/Div | 1 SEC |
| **Triggering** | |
| Level | Auto or Free-Run |
| Slope | + |
| Coupling | AC |
| Source | Int |

CAUTION

**Decrease intensity to avoid burning the phosphor on the crt screen.**

## 17. Adjust Grid Current ❶

a. Test equipment setup is as shown in Fig. 7-16. Fig. 7-16b illustrates the circuit and method used to measure grid current.

NOTE

**Offset must be as near zero as possible when this adjustment is made.**

b. When the free-running sweep moves the spot past a vertical graticule line, push the — Grid button on the Grid Current Checker. The rate of spot movement vertically indicates the rate at which current charges the 1000 pF capacitor. The spot should not move vertically more than

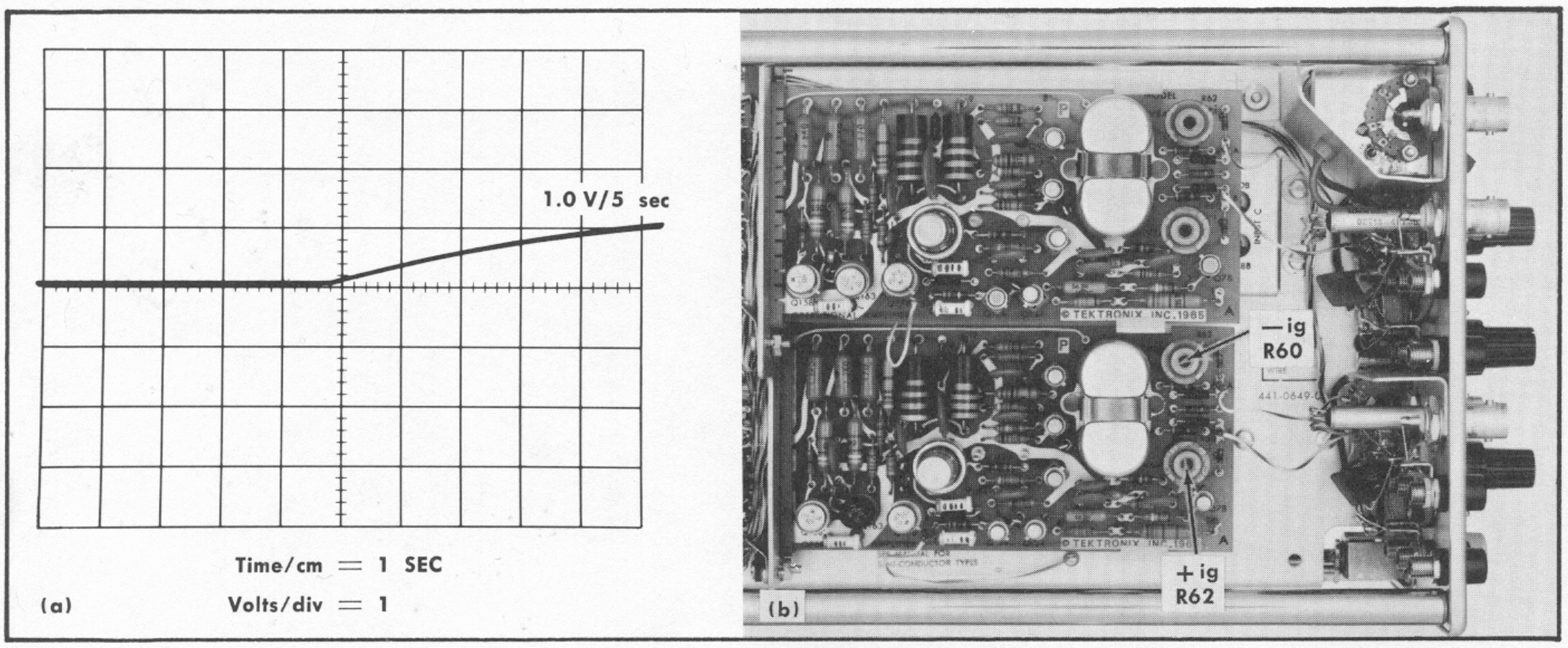



**Fig. 7-17. (a) Crt display, indicating rate at which grid current charges the 1000 pF capacitor. (b) Location of R60 and R61 + and — Grid current adjustments.**

2.5 major divisions in 5 major divisions of horizontal travel (0.25 V/5 seconds). See Fig. 7-17a.

c. Adjust the $-I_g$ adjustment R60 (see Fig. 7-17b) for minimum rate of vertical spot movement after the switch is opened.

d. As the free-running sweep moves the spot past the vertical graticule line, push the + Grid button on the Grid Current Checker. The spot should move vertically not more than 2.5 major divisions in 5 divisions of horizontal travel.

e. Adjust the $+ I_g$ adjustment R62 (see Fig. 7-17b) for minimum vertical rate of change after the switch is opened.

f. Remove the Grid Current Checker.

## NOTES

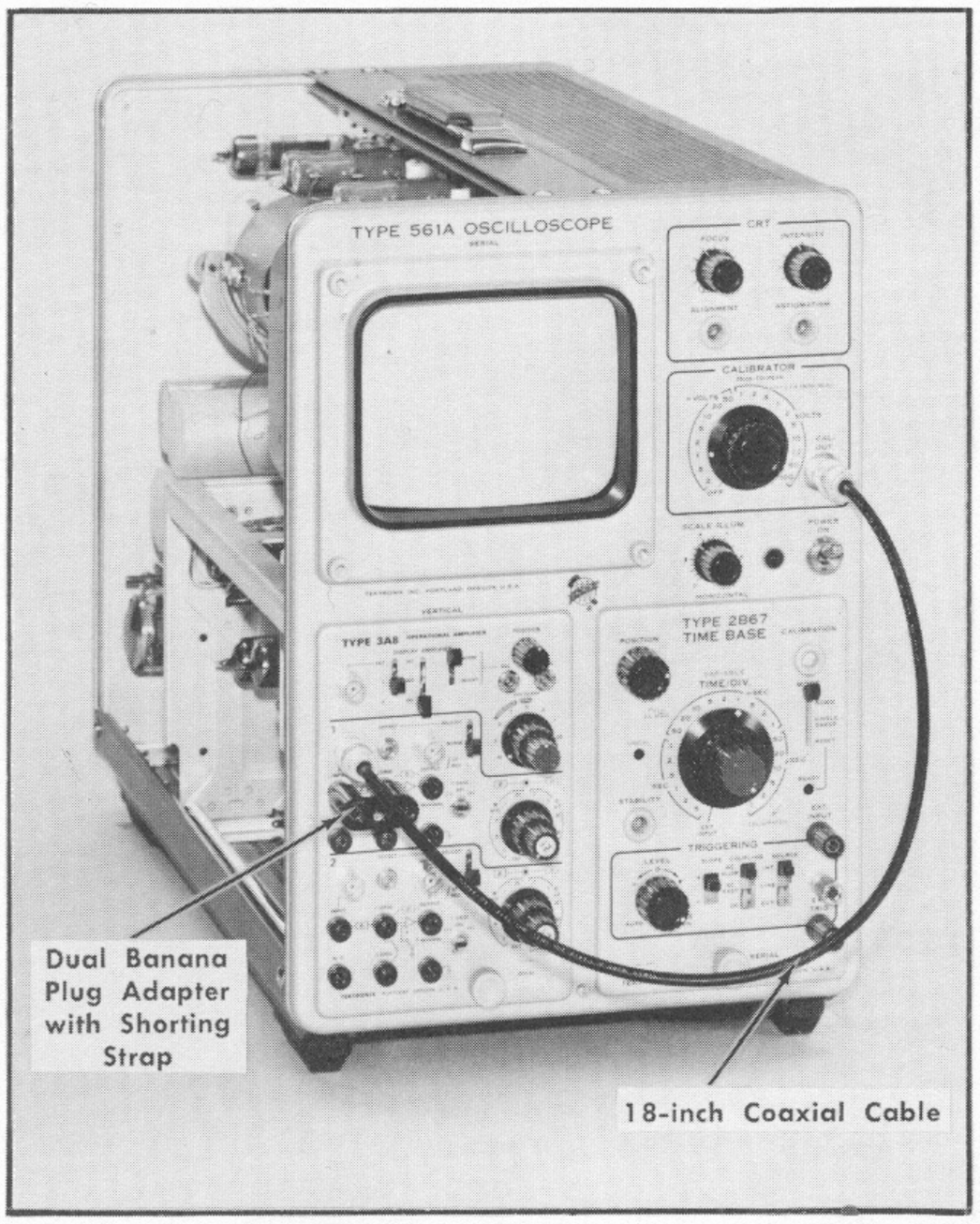



Fig. 7-18. Initial test equipment setup for step 18.

**Type 3A8**

| | |
|---|---|
| Display Amplifier | |
| EXT-1-2 | 1 |
| AC-GND-DC | DC |
| NORM-INVERT | NORM |
| **VOLTS/DIV** | **10** |
| VARIABLE | CAL |
| POSITION | Midrange |
| Operational Amplifiers | |
| **$Z_i$** | **1 MΩ** |
| **$Z_f$** | **1 MΩ** |
| **± GRID SEL** | **( — )** |
| ADJUST-NORM-$\int$LF REJ | NORM |

**Time-Base Plug-In Unit**

| | |
|---|---|
| **Time/Div** | **5 mSEC** |
| Triggering | |
| Level | Auto or Free-Run |
| Slope | + |
| Coupling | AC |
| Source | Int |

## 18. Check Open-loop DC Gain

a. Test equipment setup is as shown in Fig. 7-18.

b. Apply 1 mV from the oscilloscope Calibrator to the INPUT of the Operational Amplifier. (This signal must be 60 Hz or less for an effective check).

c. Set $Z_f$ switch to EXT position and check for a minimum 15 volt peak-to-peak display. Adjust OFFSET as required to hold the display within the amplifier limits.

**NOTES**

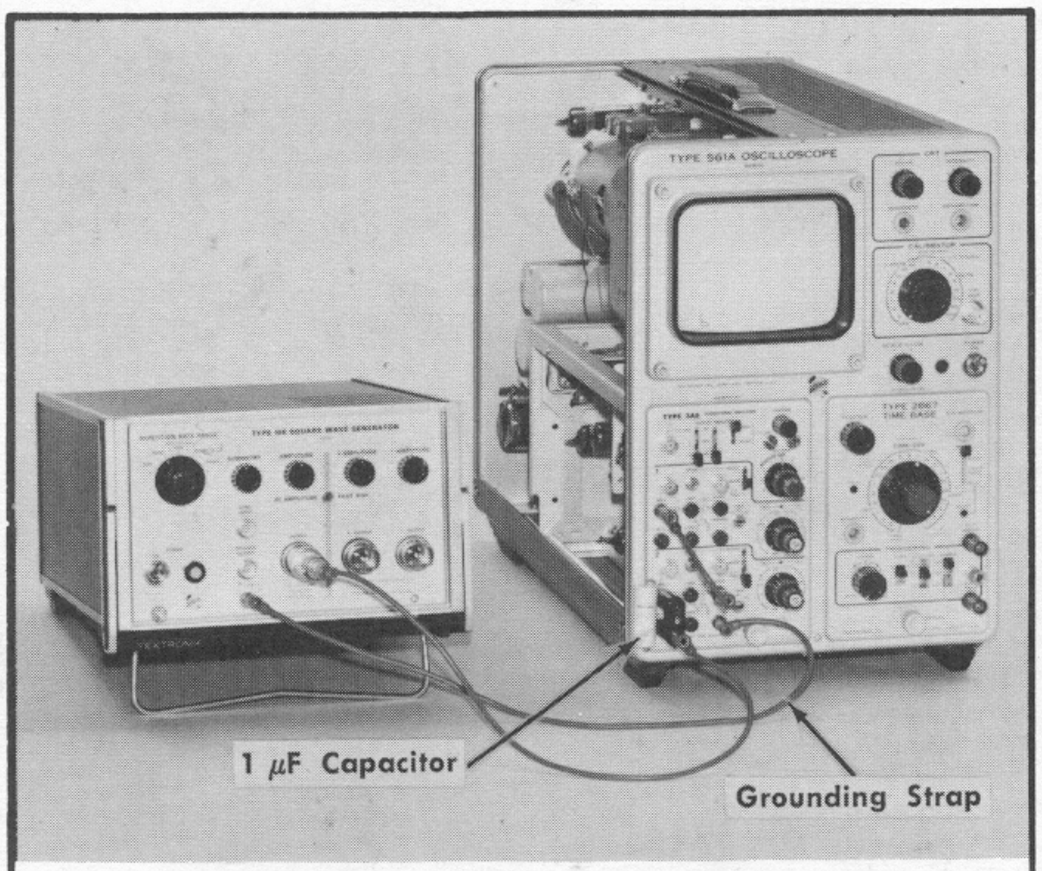



Fig. 7-19. (a) Test equipment setup for step 19. (b) ±25 volt output signal of No. 2 (1) Operational Amplifier.

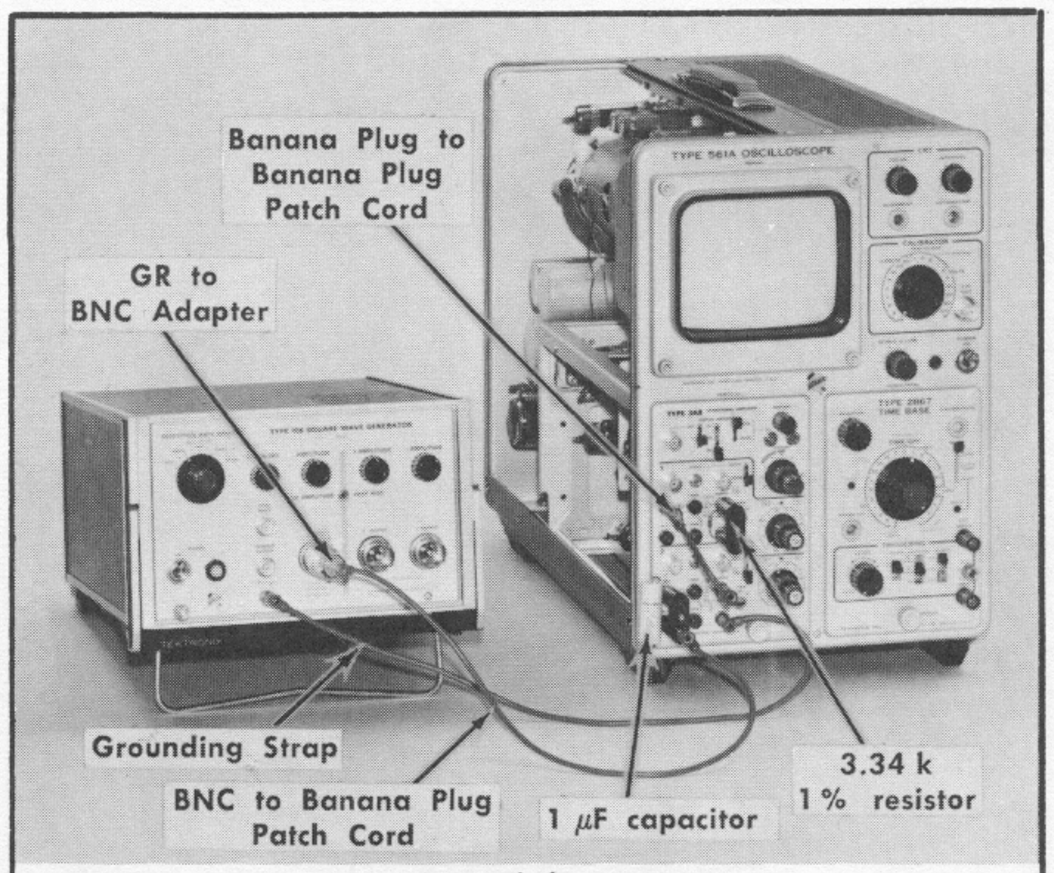



Fig. 7-20. (a) Test equipment setup to check output current. (b) Display amplitude of ±25 V when 3.34 kΩ resistor load is connected between amplifier output and ground. Should show no limiting.

## Type 3A8

| | | |
|---|---|---|
| Display Amplifier | | |
| **EXT-1-2** | **2** | |
| AC-GND-DC | DC | |
| NORM-INVERT | NORM | |
| VOLTS/DIV | 10 | |
| VARIABLE | CAL | |
| POSITION | Midrange | |
| Operational Amplifiers | 1 | 2 |
| **$Z_i$** | **1 MΩ** | **.01 MΩ** |
| **$Z_f$** | **1 MΩ** | **.001 μF** |
| **± GRID SEL** | — | — |
| **ADJUST-NORM ∫LF REJ** | **NORM** | **∫LF REJ** |
| **Time-Base Plug-In Unit** | | |
| **Time/Div** | **1 mSEC** | |
| Triggering | | |
| Level | Auto or Free-Run | |
| Slope | + | |
| Coupling | AC | |
| Source | Int | |

## 19. Check Output Voltage and Current

a. Test equipment setup is as shown in Fig. 7-19.

b. Apply an approximately 300 Hz signal from the Square-Wave Generator (Type 106) through the 1 μF coupling capacitor to the No. 2 Operational Amplifier input. Adjust the Hi Amplitude control for an output display amplitude of 5 major divisions (50 volts). See Fig. 7-19b.

c. Set the EXT-1-2 switch to 1 position and note that the display is 5 major divisions in amplitude (±25 volts).

d. Connect the 3.34 kΩ resistor from the OUTPUT of the number 1 Operational Amplifier to ground. See Fig. 20.

e. Check—Display amplitude should remain at ±25 volts; if clipping occurs, it should be above the ± 25 volt levels.

f. Disconnect all test fixtures and test equipment.

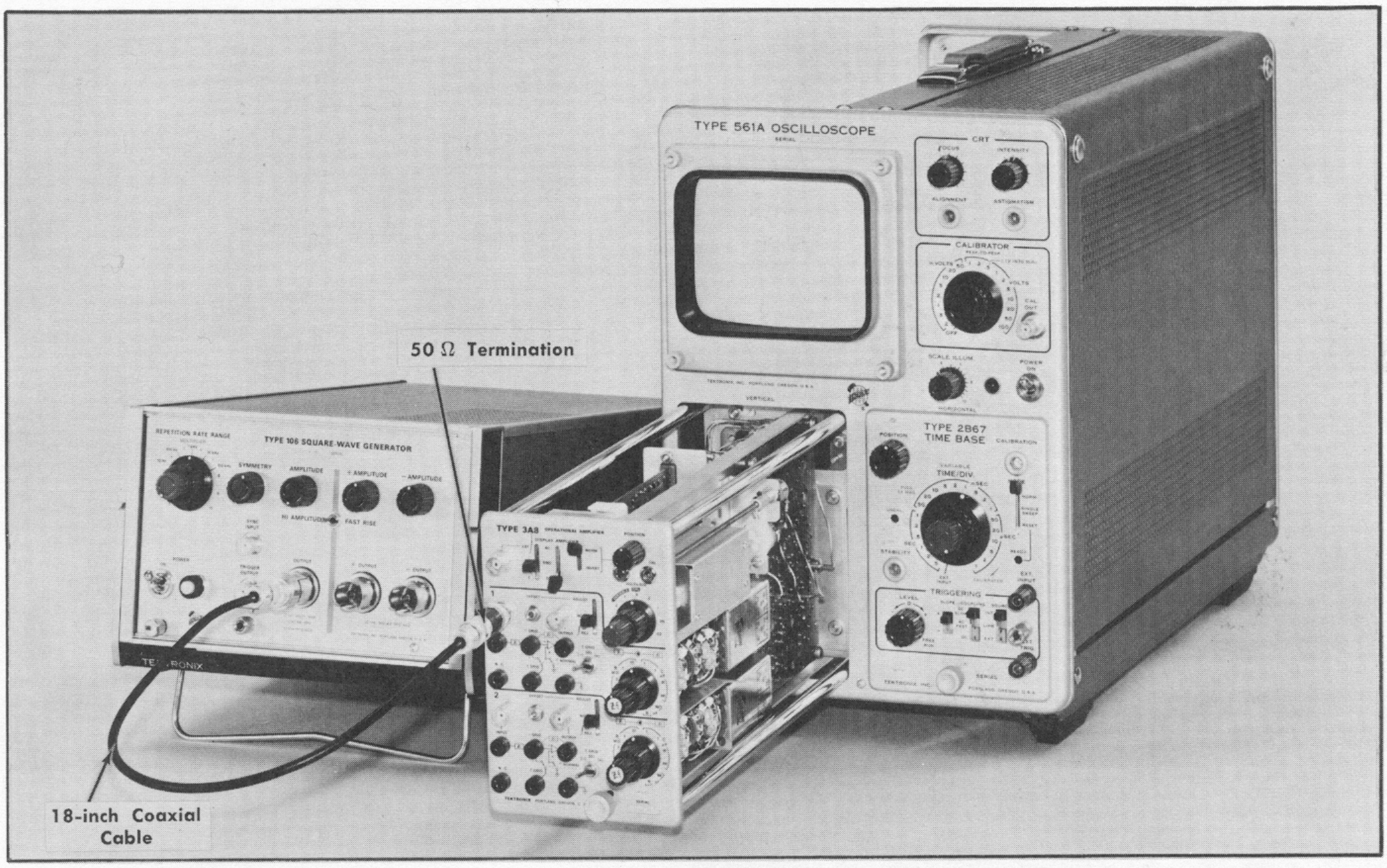



Fig. 7-21. Test equipment setup for step 20. Type 3A8 extended to calibrate $Z_i$, $Z_f$ 10 and 20 pF capacitors.

**Type 3A8**

Display Amplifier

| | |
|---|---|
| **EXT-1-2** | **1** |
| AC-GND-DC | DC |
| NORM-INVERT | NORM |
| **VOLTS/DIV** | **.5** |
| VARIABLE | CAL |
| POSITION | Midrange |

Operational Amplifier

| | |
|---|---|
| **$Z_i$** | **.01 MΩ** |
| **$Z_f$** | **.01 MΩ** |
| ± GRID SEL | $\overline{\int}$ |
| **ADJUST-NORM-$\int$LF REJ** | **$\int$LF REJ** |

**Time-Base Plug-In Unit**

| | |
|---|---|
| **Time/Div** | **.2 mSEC** |
| Triggering | |
| Level | Auto or Free-Run |
| Slope | + |
| Coupling | AC |
| Source | Int |

## 20. Check $Z_i$ and $Z_f$ Components

Turn the power off and insert the plug-in extension between the Type 3A8 and the blue-ribbon connector on the 560-Series oscilloscope. Turn the power switch on and allow a few minutes for the circuits to stabilize.

This check is a functional check of $Z_i$ and $Z_f$. Because of the high performance values of these components measurement accuracy is extremely complex.

The variable 10 and 100 pF capacitors are dynamically adjusted.

a. Test equipment setup is as shown in Fig. 7-21.

b. Apply a 1 kHz signal from the Square-Wave Generator (Type 106) and adjust the amplitude to produce a 4 major division display.

CAUTION

**Do not change the Square-Wave Generator (Type 106) output amplitude settings when checking the operation of the $Z_i$ and $Z_f$ components.**

c. Check—the operation of the $Z_i$ and $Z_f$ resistors according to Table 7-3.

**TABLE 7-3**

| Switch Setting | | | Amplitude Peak to Peak Major Divisions |
|---|---|---|---|
| $Z_i$ R MΩ | $Z_f$ R MΩ | VOLTS/DIV | |
| .01 | .01 | .5 | 4 |
| .1 | .1 | .5 | 4 |
| .2 | .2 | .5 | 4 |
| .5 | .5 | .5 | 4 |
| 1 | 1 | .5 | 4 |
| 1 | .5 | .2 | 5 |
| 1 | .2 | .1 | 4 |
| 1 | .1 | .05 | 4 |
| .2 | .01 | .02 | 5 |
| .01 | .1 | 5 | 4 |
| .1 | 1 | 5 | 4 |
| .2 | 1 | 2 | 5 |
| .5 | 1 | 1 | 4 |

**NOTES**

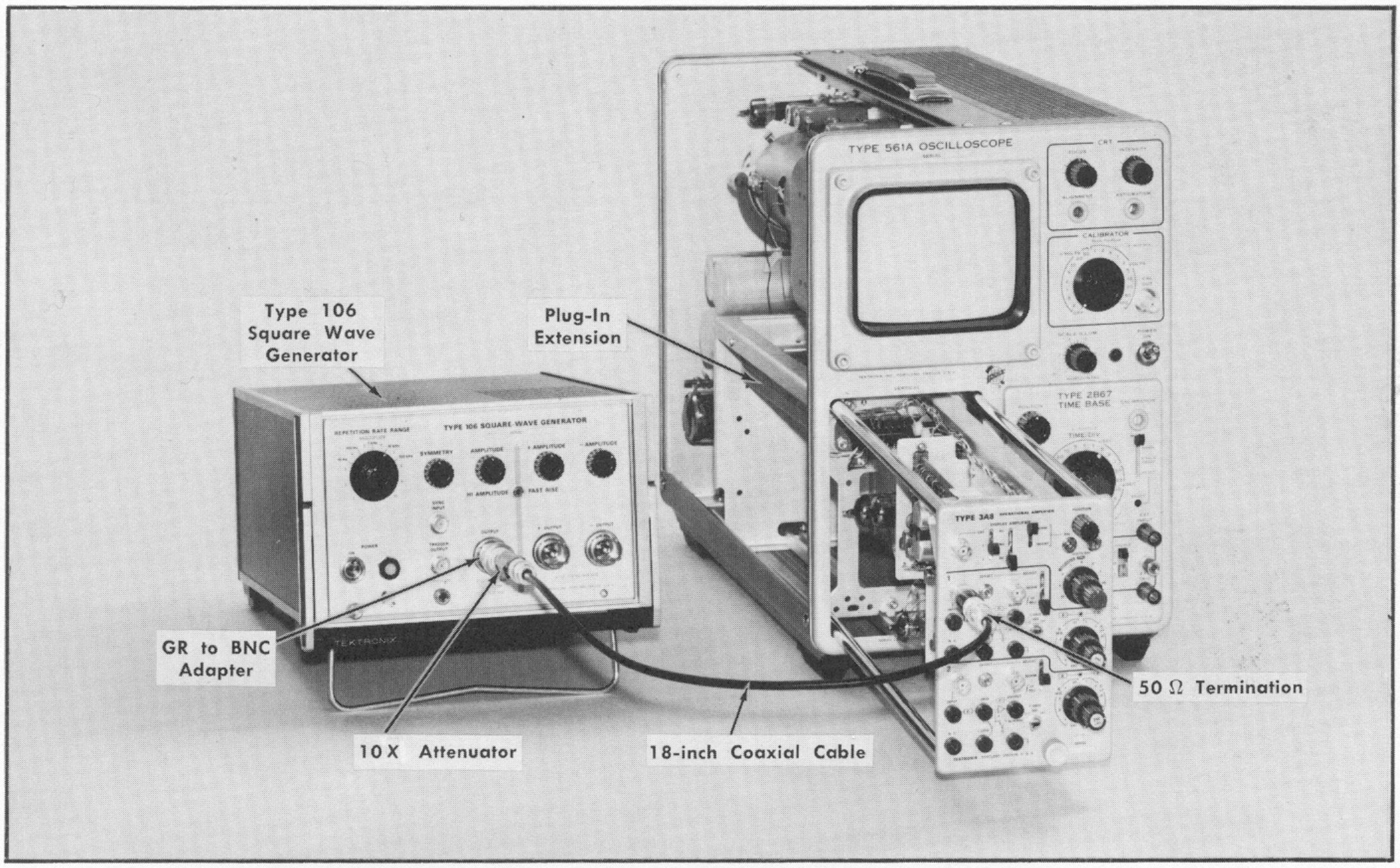



Fig. 7-22. Test equipment setup for steps 21 and 22.

| Type 3A8 | |
|---|---|
| Display Amplifier | |
| EXT-1-2 | 1 |
| AC-GND-DC | DC |
| NORM-INVERT | NORM |
| **VOLTS/DIV** | **.05** |
| VARIABLE | CAL |
| POSITION | Midrange |
| Operational Amplifier | |
| $Z_i$ | 1 μF |
| $Z_f$ | 1 μF |
| ± GRID SEL | (—) |
| ADJUST-NORM-∫LF REJ | ∫LF REJ |

| Time-Base Plug-In Unit | |
|---|---|
| **Time/Div** | **.5** |
| Triggering | |
| Level | Auto or Free-Run |
| Slope | + |
| Coupling | AC |
| Source | Int |

## 21. Check $Z_i$ and $Z_f$ Components

a. Test equipment setup is as shown in Fig. 7-22.

b. Apply an approximately 1 kHz signal from the Square-Wave Generator (Type 106) to the INPUT connector of the Operational Amplifier.

c. Adjust the Amplitude control of the Square-Wave Generator for a display amplitude of 4 divisions. Adjust the Time-Base Level control for a triggered display.

d. Check the operation of $Z_i$ and $Z_f$ capacitors according to table 7-4.

**TABLE 7-4**

| Switch Settings | | | |
|---|---|---|---|
| $Z_i$ (C) | $Z_f$ (C) | VOLTS/DIV | Amplitude |
| 1 | 1 | .05 | 4 |
| .1 | .1 | .05 | 4 |
| .01 | .01 | .05 | 4 |
| .001 | .001 | .05 | 4 |
| 1 | .1 | .5 | 4 |
| .1 | .01 | .5 | 4 |
| .01 | .001 | .5 | 4 |
| .001 | 100 pF | .5 | 4 |

## 22. Adjust the 100 pF $Z_i$ and $Z_f$ Capacitors ◐ Capacitors

a. Test equipment setup is as shown in Fig. 7-22.

b. Install a 1 kHz reject board (see Fig. 7-23).

c. Set $Z_i$ to .001 and $Z_f$ to .001, then change the frequency of the Square-Wave Generator (Type 106) to approximately 25 kHz.

d. Readjust the output amplitude control of the Square-Wave Generator to establish a 4 division display amplitude at a VOLTS/DIV setting of .1.

e. Set the VOLTS/DIV switch to 1 and $Z_f$ to 100 pF.

f. Adjust C16 for a signal amplitude of 4 major divisions. (See Fig. 7-24.)

g. Set the VOLTS/DIV switch to 10 and $Z_f$ to 10 pF.

h. Adjust C20 for a signal amplitude of 4 divisions.

i. Remove the 10× attenuator and change to the following switch settings:

| | |
|---|---|
| VOLTS/DIV | 2 |
| $Z_i$ | .001 μF |
| $Z_f$ | .001 μF |

i. Remove the 10× attenuator and change to the fol- Generator to establish the 4 division display amplitude.

k. Set the VOLTS/DIV switch to .2 and $Z_i$ to 100 pF.

l. Adjust C6 for a 4 division display.

m. Set the VOLTS/DIV switch to .02 and $Z_i$ to 10 pF.

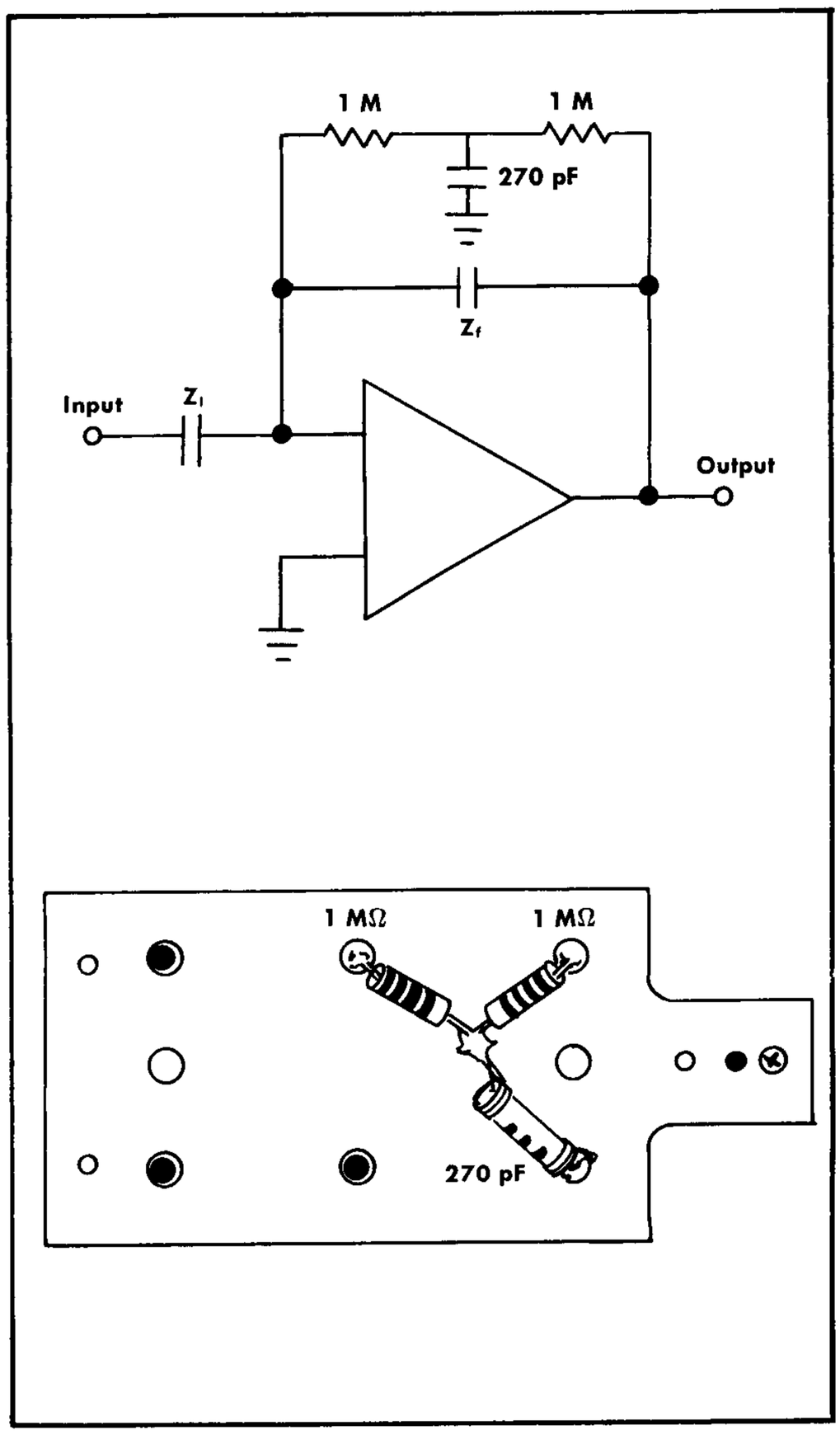
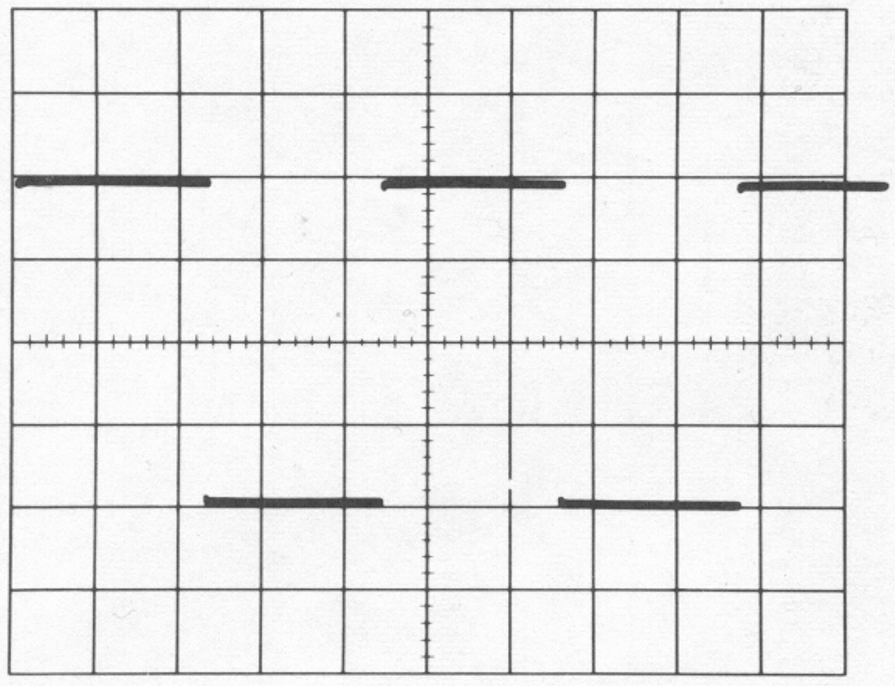



**Fig. 7-23. Test jig to check 10 and 100 pF $Z_i$, $Z_f$ capacitors. (a) Circuit diagram approximate 1 kHz LF Reject jig. (b) Pictorial layout.**

n. Adjust C10 for a 4 major division display amplitude.

o. Recheck adjustment of $Z_f$ and $Z_i$ capacitors.

p. Remove the plug-in extension, 1 kHz reject circuit and replace the Type 3A8 in the oscilloscope vertical compartment.



Time/Div = .2 mSEC

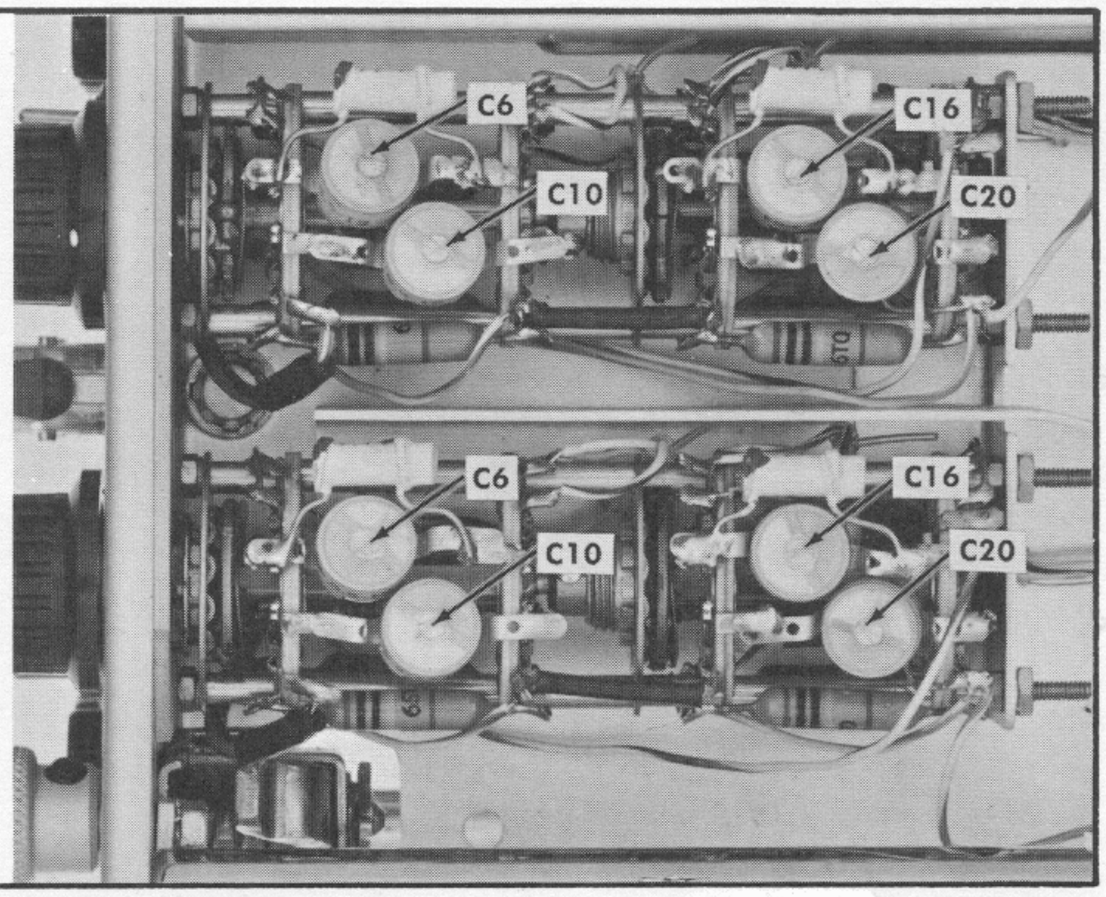



Fig. 7-24. (a) Typical 4 division display to adjust 10 and 100 pF capacitors. (b) Location of $Z_i$, $Z_t$ 10 and 20 pF variable capacitors.

## NOTES

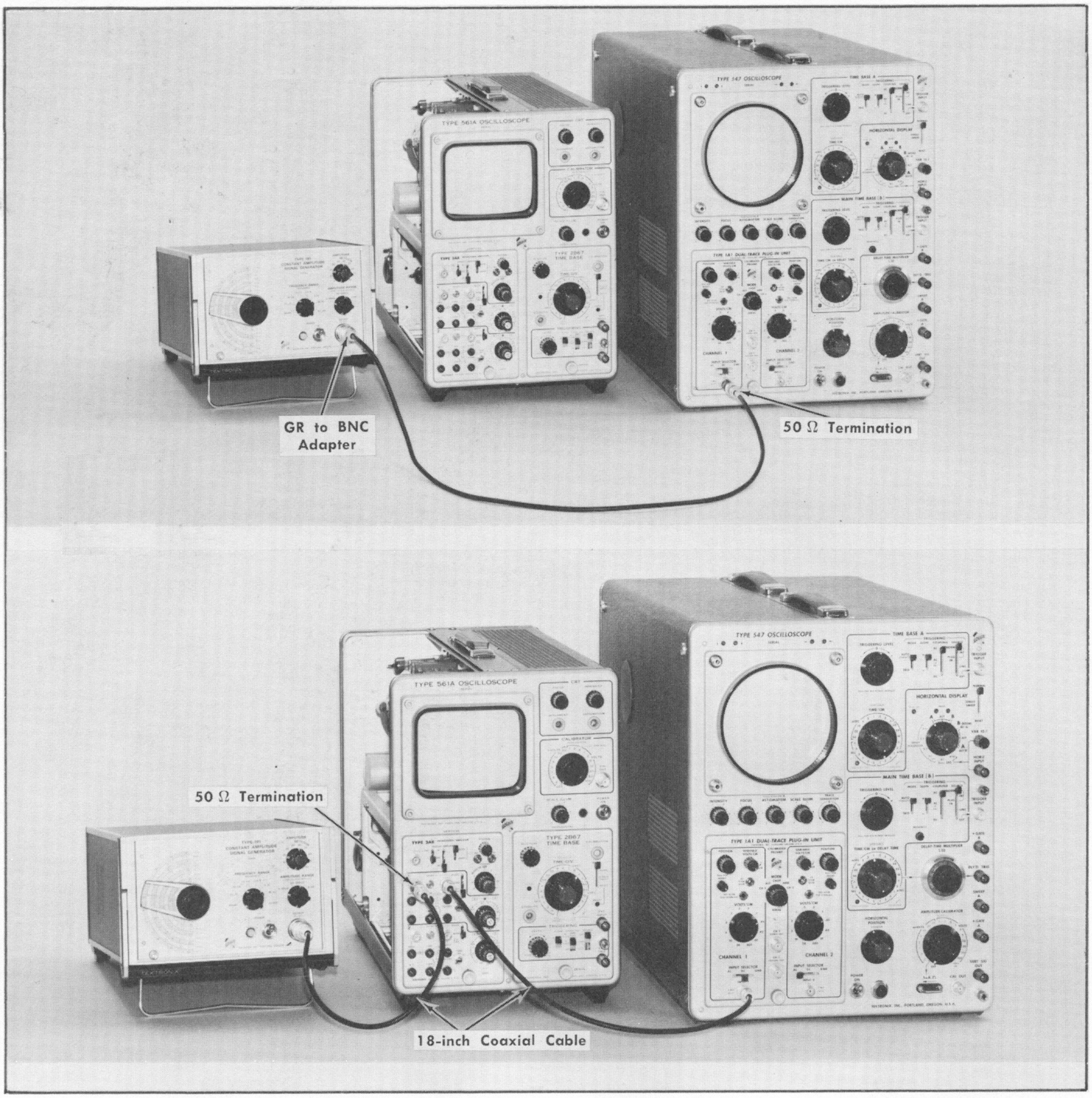



Fig. 7-25. Test equipment setup for step 23. (a) Initial setup to establish signal reference. (b) Setup to measure Type 3A8 gain bandwidth product.

| Type 3A8 | |
|---|---|
| Display Amplifier | |
| EXT-1-2 | 1 |
| AC-GND-DC | DC |
| NORM-INVERT | NORM |
| **VOLTS/DIV** | **10** |
| VARIABLE | CAL |
| POSITION | Midrange |
| Operational Amplifiers | |
| **$Z_i$** | **.001 $\mu$F** |
| **$Z_f$** | **1 M$\Omega$** |
| $\pm$ GRID SEL | (—) |
| **ADJUST-NORM-$\int$LF REJ** | **NORM** |

**Time-Base Plug-in Unit**

| | |
|---|---|
| **Time/Div** | **.2 mSEC** |
| Triggering | |
| Level | Auto or Free-Run |
| Slope | + |
| Coupling | AC |
| Source | Int |

**Constant Amplitude Signal Generator**

| | |
|---|---|
| Freq Range | 8.2-18 |
| Amplitude | 15 |
| Amplitude Range | 50-500 mV |

**Test Oscilloscope**

| | |
|---|---|
| Vertical Unit | |
| Volts/Div | .05 |
| Input AC-DC-GND | DC |

**Time-Base Unit**

| | |
|---|---|
| Time/Div | .2 μSEC |
| Triggering | |
| Mode | Auto |
| Coupling | AC |
| Source | Int |

## 23. Check Gain-Bandwidth Product (Open-loop)

a. Test equipment setup is as shown in Fig. 7-25a.

b. Adjust the Constant Amplitude Signal Generator (Type 191) output for a reference amplitude on the test oscilloscope of 4 major divisions at a frequency of 10 MHz. (200 mV with VOLTS/DIV switch set at .05.)

c. Remove the signal cable from the vertical input of the test oscilloscope and reconnect the signal to the INPUT connector of the Operational Amplifier.

d. Connect a coaxial cable (<18 inches) from the OUTPUT connector of the Operational Amplifier to the vertical input connector of the test oscilloscope. (See Fig. 7-25b.)

e. Check—Test oscilloscope display must be 4 divisions or greater in amplitude.

Example:

$$\frac{\text{Measured amplitude}}{\text{Reference amplitude}} = \frac{\text{Actual Gain-Bandwidth Prod.}}{10\ \text{MHz}}$$

$$\frac{4.2\ \text{Cm}}{4\ \text{Cm}} = \frac{X}{10\ \text{MHz}}$$

$$X = 10.5\ \text{MHz}$$

This completes the calibration of the Type 3A8 Operational Amplifier. Repeat the procedure to calibrate the second amplifier.

## NOTES

# NOTES

# ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| A or amp | amperes |
| AC or ac | alternating current |
| AF | audio frequency |
| $\alpha$ | alpha—common-base current amplification factor |
| AM | amplitude modulation |
| $\approx$ | approximately equal to |
| $\beta$ | beta—common-emitter current amplification factor |
| BHB | binding head brass |
| BHS | binding head steel |
| BNC | baby series "N" connector |
| $\times$ | by or times |
| C | carbon |
| C | capacitance |
| cap. | capacitor |
| cer | ceramic |
| cm | centimeter |
| comp | composition |
| conn | connector |
| $\sim$ | cycle |
| c/s or cps | cycles per second |
| CRT | cathode-ray tube |
| csk | countersunk |
| $\Delta$ | increment |
| dB | decibel |
| dBm | decibel referred to one milliwatt |
| DC or dc | direct current |
| DE | double end |
| $^\circ$ | degrees |
| $^\circ$C | degrees Celsius (degrees centigrade) |
| $^\circ$F | degrees Fahrenheit |
| $^\circ$K | degrees Kelvin |
| dia | diameter |
| $\div$ | divide by |
| div | division |
| EHF | extremely high frequency |
| elect. | electrolytic |
| EMC | electrolytic, metal cased |
| EMI | electromagnetic interference (see RFI) |
| EMT | electrolytic, metal tubular |
| $\varepsilon$ | epsilon—2.71828 or % of error |
| $\geq$ | equal to or greater than |
| $\leq$ | equal to or less than |
| ext | external |
| F or f | farad |
| F & I | focus and intensity |
| FHB | flat head brass |
| FHS | flat head steel |
| Fil HB | fillister head brass |
| Fil HS | fillister head steel |
| FM | frequency modulation |
| ft | feet or foot |
| G | giga or $10^9$ |
| g | acceleration due to gravity |
| Ge | germanium |
| GHz | gigahertz |
| GMV | guaranteed minimum value |
| GR | General Radio |
| $>$ | greater than |
| H or h | henry |
| h | height or high |
| hex. | hexagonal |
| HF | high frequency |
| HHB | hex head brass |
| HHS | hex head steel |
| HSB | hex socket brass |
| HSS | hex socket steel |
| HV | high voltage |
| Hz | hertz (cycles per second) |
| ID | inside diameter |
| IF | intermediate frequency |
| in. | inch or inches |
| incd | incandescent |
| $\infty$ | infinity |
| int | internal |
| $\int$ | integral |
| k | kilohms or kilo ($10^3$) |
| k $\Omega$ | kilohm |
| kc | kilocycle |
| kHz | kilohertz |
| L | inductance |
| $\lambda$ | lambda—wavelength |
| $\gg$ | large compared with |
| $<$ | less than |
| LF | low frequency |
| lg | length or long |
| LV | low voltage |
| M | mega or $10^6$ |
| m | milli or $10^{-3}$ |
| M$\Omega$ or meg | megohm |
| $\mu$ | micro or $10^{-6}$ |
| mc | megacycle |
| met. | metal |
| MHz | megahertz |
| mm | millimeter |
| ms | millisecond |
| — | minus |
| mtg hdw | mounting hardware |
| n | nano or $10^{-9}$ |
| no. or # | number |
| ns | nanosecond |
| OD | outside diameter |
| OHB | oval head brass |
| OHS | oval head steel |
| $\Omega$ | omega—ohms |
| $\omega$ | omega—angular frequency |
| p | pico or $10^{-12}$ |
| / | per |
| % | percent |
| PHB | pan head brass |
| $\phi$ | phi—phase angle |
| $\pi$ | pi—3.1416 |
| PHS | pan head steel |
| $+$ | plus |
| $\pm$ | plus or minus |
| PIV | peak inverse voltage |
| plstc | plastic |
| PMC | paper, metal cased |
| poly | polystyrene |
| prec | precision |
| PT | paper, tubular |
| PTM | paper or plastic, tubular, molded |
| pwr | power |
| Q | figure of merit |
| RC | resistance capacitance |
| RF | radio frequency |
| RFI | radio frequency interference (see EMI) |
| RHB | round head brass |
| $\rho$ | rho—resistivity |
| RHS | round head steel |
| r/min or rpm | revolutions per minute |
| RMS | root mean square |
| s or sec. | second |
| SE | single end |
| Si | silicon |
| SN or S/N | serial number |
| $\ll$ | small compared with |
| T | tera or $10^{12}$ |
| TC | temperature compensated |
| TD | tunnel diode |
| THB | truss head brass |
| $\theta$ | theta—angular phase displacement |
| thk | thick |
| THS | truss head steel |
| tub. | tubular |
| UHF | ultra high frequency |
| V | volt |
| VAC | volts, alternating current |
| var | variable |
| VDC | volts, direct current |
| VHF | very high frequency |
| VSWR | voltage standing wave ratio |
| W | watt |
| w | wide or width |
| w/ | with |
| w/o | without |
| WW | wire-wound |
| xmfr | transformer |

## PARTS ORDERING INFORMATION

Replacement parts are available from or through your local Tektronix, Inc. Field Office or representative.

Changes to Tektronix instruments are sometimes made to accommodate improved components as they become available, and to give you the benefit of the latest circuit improvements developed in our engineering department. It is therefore important, when ordering parts, to include the following information in your order: Part number, instrument type or number, serial or model number, and modification number if applicable.

If a part you have ordered has been replaced with a new or improved part, your local Tektronix, Inc. Field Office or representative will contact you concerning any change in part number.

## SPECIAL NOTES AND SYMBOLS

| | |
|---|---|
| ×000 | Part first added at this serial number |
| 00× | Part removed after this serial number |
| *000-0000-00 | Asterisk preceding Tektronix Part Number indicates manufactured by or for Tektronix, Inc., or reworked or checked components. |
| Use 000-0000-00 | Part number indicated is direct replacement. |
| ◐ | Screwdriver adjustment. |
| ▭ | Control, adjustment or connector. |

# SECTION 8
# ELECTRICAL PARTS LIST

Values are fixed unless marked Variable.

| Ckt. No. | Tektronix Part No. | Description | S/N Range |
|---|---|---|---|
| | | **Capacitors** | |
| Tolerance ±20% unless otherwise indicated. | | | |
| C4A, C4B, C4C, C4D | *291-0043-00 | 1 μF, 0.1 μF, 0.01 μF, 0.001 μF Timing Capacitor | |
| C4E, C4F, C4G, C4H | *291-0043-00 | 1 μF, 0.1 μF, 0.01 μF, 0.001 μF Timing Capacitor | |
| C6 | Use 281-0094-00 | 5.5-18 pF Cer Var | |
| C8 | 281-0646-00 | 88 pF Cer 500 V 5% | |
| C10 | Use 281-0094-00 | 5.5-18 pF Cer Var | |
| C15 | 281-0537-00 | 0.68 pF Cer 500 V | |
| C16 | Use 281-0094-00 | 5.5-18 pF Cer Var | |
| C17 | 281-0557-00 | 1.8 pF Cer 500 V | |
| C18 | 281-0646-00 | 88 pF Cer 500 V 5% | |
| C19 | 281-0503-00 | 8 pF Cer 500 V ±0.5 pF | |
| C20 | Use 281-0094-00 | 5.5-18 pF Cer Var | |
| C35 (2) | 283-0051-00 | 0.0033 μF Cer 100 V 5% | |
| C40 (2) | 283-0059-00 | 1 μF Cer 25 V +80%—20% | |
| C201 | *285-0657-01 | 0.1 μF PTM 600 V +5%—15% | |
| C204 | 281-0504-00 | 10 pF Cer 500 V 10% | |
| C208A | 281-0572-00 | 6.8 pF Cer 500 V ±0.5 pF | |
| C208B | 281-0103-00 | 1.8-13 pF Air Var | |
| C208C | 281-0100-00 | 1.4-7.3 pF Air Var | |
| C208E | 283-0541-00 | 500 pF Mica 500 V 10% | |
| C210A | 281-0504-00 | 10 pF Cer 500 V 10% | 100-219 |
| C210A | 281-0544-00 | 5.6 pF Cer 500 V 10% | 220-up |
| C210B | 281-0103-00 | 1.8-13 pF Air Var | |
| C210C | 281-0100-00 | 1.4-7.3 pF Air Var | 100-219 |
| C210C | 281-0103-00 | 1.8-13 pF Air Var | 220-up |
| C210E | 281-0504-00 | 10 pF Cer 500 V 10% | 100-219 |
| C210E | 281-0622-00 | 47 pF Cer 500 V 1% | 220-up |
| C218B | 281-0103-00 | 1.8-13 pF Air Var | |
| C218C | 281-0100-00 | 1.4-7.3 pF Air Var | |
| C218E | 281-0501-00 | 4.7 pF Cer 500 V ±1 pF | |
| C220B | 281-0103-00 | 1.8-13 pF Air Var | |
| C220C | 281-0103-00 | 1.8-13 pF Air Var | |
| C220D | 281-0501-00 | 4.7 pF Cer 500 V ±1 pF | |
| C225 | 281-0099-00 | 1.3-5.4 pF Air Var | |
| C301 | 283-0001-00 | 0.005 μF Cer 500 V | |
| C303 | 283-0059-00 | 1 μF Cer 25 V +80%—20% | |

## Capacitors *(Cont'd)*

| Ckt. No. | Tektronix Part No. | | Description | | S/N Range |
|---|---|---|---|---|---|
| C305 | 283-0059-00 | 1 μF | Cer | 25 V | +80%—20% |
| C320 | 283-0003-00 | 0.01 μF | Cer | 150 V | |
| C334 | 281-0529-00 | 1.5 pF | Cer | 500 V | ±0.25 pF |
| C335 | 283-0003-00 | 0.01 μF | Cer | 150 V | |
| C346 | 283-0003-00 | 0.01 μF | Cer | 150 V | |
| C416 | 283-0003-00 | 0.01 μF | Cer | 150 V | |
| C420 | 283-0003-00 | 0.01 μF | Cer | 150 V | |
| C434 | 281-0529-00 | 1.5 pF | Cer | 500 V | ±0.25 pF |
| C442 | 281-0547-00 | 2.7 pF | Cer | 500 V | 10% |
| C472 | 283-0003-00 | 0.01 μF | Cer | 150 V | |
| C474 | 281-0501-00 | 4.7 pF | Cer | 500 V | ±1 pF |
| C494 | 283-0079-00 | 0.01 μF | Cer | 250 V | |
| C495 | 283-0003-00 | 0.01 μF | Cer | 150 V | |
| C496 | 283-0092-00 | 0.03 μF | Cer | 200 V | +80%—20% |

## Diodes

| | | | |
|---|---|---|---|
| D303 | *152-0165-00 | Silicon | Selected from 1N3579 |
| D305 | *152-0165-00 | Silicon | Selected from 1N3579 |

## Connectors

| | | |
|---|---|---|
| J1 (2) | 131-0106-00 | Connector, chassis mtd, coaxial, 1 contact, female |
| J180 (2) | 131-0106-00 | Connector, chassis mtd, coaxial, 1 contact, female |
| J200 | 131-0106-00 | Connector, chassis mtd, coaxial, 1 contact, female |

## Relay

| | | |
|---|---|---|
| K360 | 148-0027-00 | 12 Vdc |

## Inductors

| | | | | |
|---|---|---|---|---|
| L334 | *114-0195-00 | 37-115 μH | Var | core 276-0511-00 |
| L340 | *108-0360-00 | 46 μH | | |
| L342 | *108-0361-00 | 50 μH | | |
| L344 | *114-0196-00 | 150-215 μH | Var | core 276-0540-00 |
| L434 | *114-0195-00 | 37-115 μH | Var | core 276-0511-00 |
| L440 | *108-0360-00 | 46 μH | | |
| L442 | *108-0361-00 | 50 μH | | |
| L444 | *114-0196-00 | 150-215 μH | Var | core 276-0540-00 |

## Transistors

| | | |
|---|---|---|
| Q324 | *151-0108-00 | Replaceable by 2N2501 |
| Q334 | 151-0184-00 | SM7744 |
| Q354 | *151-0108-00 | Replaceable by 2N2501 |
| Q424 | *151-0108-00 | Replaceable by 2N2501 |
| Q434 | 151-0184-00 | SM7744 |

## Transistors *(Cont'd)*

| Ckt. No. | Tektronix Part No. | Description | S/N Range |
|---|---|---|---|
| Q454 | *151-0108-00 | Replaceable by 2N2501 | |
| Q468 | *151-0103-00 | Replaceable by 2N2219 | |

## Resistors

Resistors are fixed, composition, ±10% unless otherwise indicated.

| | | | | | | |
|---|---|---|---|---|---|---|
| R1 | 323-0481-00 | 1 MΩ | ½ W | | Prec | 1% |
| R3 | 323-0452-00 | 499 kΩ | ½ W | | Prec | 1% |
| R5 | 323-0414-00 | 200 kΩ | ½ W | | Prec | 1% |
| R7 | 323-0385-00 | 100 kΩ | ½ W | | Prec | 1% |
| R9 | 323-0289-00 | 10 kΩ | ½ W | | Prec | 1% |
| R10 | 323-0481-00 | 1 MΩ | ½ W | | Prec | 1% |
| R13 | 323-0452-00 | 499 kΩ | ½ W | | Prec | 1% |
| R15 | 323-0414-00 | 200 kΩ | ½ W | | Prec | 1% |
| R17 | 323-0385-00 | 100 kΩ | ½ W | | Prec | 1% |
| R19 | 323-0289-00 | 10 kΩ | ½ W | | Prec | 1% |
| R21 | 315-0470-00 | 47 Ω | ¼ W | | | 5% |
| R30 | 315-0105-00 | 1 MΩ | ¼ W | | | 5% |
| R35 (2) | 315-0105-00 | 1 MΩ | ¼ W | | | 5% |
| R38 (2) | 315-0103-00 | 10 kΩ | ¼ W | | | 5% |
| R40 (2) | 315-0104-00 | 100 kΩ | ¼ W | | | 5% |
| R192(2) | 311-0444-00 | 5 Ω | | Var | | |
| R201 | 315-0105-00 | 1 MΩ | ¼ W | | | 5% |
| R208C | 322-0624-00 | 990 kΩ | ¼ W | | Prec | 1% |
| R208E | 321-0614-00 | 10.1 kΩ | ⅛ W | | Prec | 1% |
| R210C | 322-0621-00 | 900 kΩ | ¼ W | | Prec | 1% |
| R210E | 321-0617-00 | 111 kΩ | ⅛ W | | Prec | ½% |
| R218C | 322-0620-00 | 800 kΩ | ¼ W | | Prec | 1% |
| R218E | 321-0618-00 | 250 kΩ | ⅛ W | | Prec | 1% |
| R220C | 322-0643-00 | 600 kΩ | ¼ W | | Prec | 1% |
| R220E | 322-0644-00 | 666.6 kΩ | ¼ W | | Prec | 1% |
| R215 | 317-0270-00 | 27 Ω | 1/10 W | | | 5% |
| R225 | 323-0481-00 | 1 MΩ | ½ W | | Prec | 1% |
| R301 | 301-0105-00 | 1 MΩ | ½ W | | | 5% |
| R303 | 315-0621-00 | 620 Ω | ¼ W | | | 5% |
| R305 | 315-0124-00 | 120 kΩ | ¼ W | | | 5% |
| R306 | 315-0123-00 | 12 kΩ | ¼ W | | | 5% |
| R308 | 315-0332-00 | 3.3 kΩ | ¼ W | | | 5% |
| R320 | 322-0414-00 | 200 kΩ | ¼ W | | Prec | 1% |
| R324 | 321-0227-00 | 2.26 kΩ | ⅛ W | | Prec | 1% |
| R326 | 321-0209-00 | 1.47 kΩ | ⅛ W | | Prec | 1% |
| R332 | 311-0310-00 | 5 kΩ | | Var | (Selected) | |
| R334 | 323-0245-00 | 3.48 kΩ | ½ W | | Prec | 1% |
| R335 | 308-0301-00 | 10 kΩ | 3 W | | WW | 1% |
| R337 | 311-0169-00 | 100 Ω | | Var | | |
| R339 | 321-0060-00 | 41.2 Ω | ⅛ W | | Prec | 1% |

## Resistors *(Cont'd)*

| Ckt. No. | Tektronix Part No. | Description | | | | S/N Range |
|---|---|---|---|---|---|---|
| R340 | 315-0162-00 | 1.6 kΩ | ¼ W | | 5% | |
| R344 | *310-0625-00 | 3.5 kΩ | 8 W | Prec | 1% | |
| R346 | 308-0253-00 | 1.32 kΩ | 3 W | WW | 5% | |
| R348 | 315-0470-00 | 47 Ω | ¼ W | | 5% | |
| R354 | 322-0123-00 | 187 Ω | ¼ W | Prec | 1% | |
| R356 | 323-0174-00 | 634 Ω | ½ W | Prec | 1% | |
| R403 | 315-0470-00 | 47 Ω | ¼ W | | 5% | |
| R408 | 315-0332-00 | 3.3 kΩ | ¼ W | | 5% | |
| R409 | 321-0452-00 | 499 kΩ | ⅛ W | Prec | 1% | |
| R410 | 311-0465-00 | 100 kΩ | Var | | | |
| R412 | 321-0437-00 | 348 kΩ | ⅛ W | Prec | 1% | |
| R414 | 311-0467-00 | 100 kΩ | Var | | | |
| R416 | 321-0280-00 | 8.06 kΩ | ⅛ W | Prec | 1% | |
| R417 | 321-0394-00 | 124 kΩ | ⅛ W | Prec | 1% | |
| R418 | 321-0407-00 | 169 kΩ | ⅛ W | Prec | 1% | |
| R420 | 322-0414-00 | 200 kΩ | ¼ W | Prec | 1% | |
| R424 | 321-0227-00 | 2.26 kΩ | ⅛ W | Prec | 1% | |
| R434 | 323-0245-00 | 3.48 kΩ | ½ W | Prec | 1% | |
| R437 | 311-0565-00 | 215 Ω | Var | | | |
| R440 | 315-0162-00 | 1.6 kΩ | ¼ W | | 5% | |
| R444 | *310-0625-00 | 3.5 Ω | 8 W | Prec | 1% | |
| R448 | 315-0470-00 | 47 Ω | ¼ W | | 5% | |
| R454 | 322-0123-00 | 187 Ω | ¼ W | Prec | 1% | |
| R456 | 323-0174-00 | 634 Ω | ½ W | Prec | 1% | |
| R464 | 323-0163-00 | 487 Ω | ½ W | Prec | 1% | |
| R468 | 323-0163-00 | 487 Ω | ½ W | Prec | 1% | |
| R470 | 321-0327-00 | 24.9 kΩ | ⅛ W | Prec | 1% | |
| R472 | 321-0452-00 | 499 kΩ | ⅛ W | Prec | 1% | |
| R474 | 322-0481-00 | 1 MΩ | ¼ W | Prec | 1% | |
| R478 | 321-0451-00 | 487 kΩ | ⅛ W | Prec | 1% | |
| R480 | 311-0465-00 | 100 kΩ | Var | | | |
| R482 | 315-0470-00 | 47 Ω | ¼ W | | 5% | |
| R486 | 301-0104-00 | 100 kΩ | ½ W | | 5% | |
| R488 | 315-0470-00 | 47 Ω | ¼ W | | 5% | |
| R490 | 301-0433-00 | 43 kΩ | ½ W | | 5% | |
| R491 | 301-0433-00 | 43 kΩ | ½ W | | 5% | |
| R494 | 315-0101-00 | 100 Ω | ¼ W | | 5% | |
| R496 | 315-0470-00 | 47 Ω | ¼ W | | 5% | |
| R498 | 308-0106-00 | 1 kΩ | 5 W | WW | 5% | |
| R500 | 308-0298-00 | 560 Ω | 3 W | WW | 5% | |
| R501 | 301-0301-00 | 300 Ω | ½ W | | 5% | |
| R502 | 308-0298-00 | 560 Ω | 3 W | WW | 5% | |
| R511 | 308-0291-00 | 2 kΩ | 3 W | WW | 5% | |
| R512 | 308-0298-00 | 560 Ω | 3 W | WW | 5% | |
| R520 | 308-0281-00 | 1.8 kΩ | 3 W | WW | 5% | |

## Switches

| Ckt. No. | Tektronix Part No. Unwired | Wired | Description | | S/N Range |
|---|---|---|---|---|---|
| SW10A | 260-0734-00 | *262-0739-00 | Rotary | $Z_i$ | |
| SW10B | 260-0734-00 | *262-0739-00 | Rotary | $Z_f$ | |
| SW30 (2) | 260-0642-00 | | Toggle | ± GRID SEL | |
| SW40 (2) | 260-0732-00 | | Lever | ADJUST NORM<br>LF REJ | |
| SW200 | 260-0730-00 | | Lever | EXT 1 2 | |
| SW205 | 260-0600-00 | | Lever | AC GND DC | |
| SW210 | 260-0733-00 | Use *262-0740-01 | Rotary | VOLTS/DIV | |
| SW350 | 260-0731-00 | | Lever | NORM INVERT | |

## Electron Tubes

| | | | | | |
|---|---|---|---|---|---|
| V303 | 154-0413-00 | 8416 | | | 100-319 |
| V303 | *157-0116-00 | 8416 | Checked | | 320-up |
| V344 | 154-0497-00 | 6KV8 | | | |
| V444 | 154-0497-00 | 6KV8 | | | |

# OPERATIONAL AMPLIFIER CARDS (2)

| Ckt. No. | Tektronix Part No. | Description | Model No. |
|---|---|---|---|
| | *670-0087-00 | Complete Card | |

## Capacitors

Tolerance ±20% unless otherwise indicated.

| | | | | | |
|---|---|---|---|---|---|
| C70 | 283-0003-00 | 0.01 μF | Cer | 150 V | |
| C72 | 283-0003-00 | 0.01 μF | Cer | 150 V | |
| C90 | 283-0003-00 | 0.01 μF | Cer | 150 V | |
| C114 | 283-0003-00 | 0.01 μF | Cer | 150 V | |
| C120 | 283-0003-00 | 0.01 μF | Cer | 150 V | |
| C134 | 283-0003-00 | 0.01 μF | Cer | 150 V | |
| C141 | 281-0630-00 | 390 pF | Cer | 500 V | 5% |
| C143 | 283-0079-00 | 0.01 μF | Cer | 250 V | |
| C145 | 281-0552-00 | 25 pF | Cer | 500 V | |
| C158 | 283-0003-00 | 0.01 μF | Cer | 150 V | |
| C163 | 281-0543-00 | 270 pF | Cer | 500 V | 10% |
| C174 | 283-0003-00 | 0.01 μF | Cer | 150 V | |

## Diodes

| | | | |
|---|---|---|---|
| D52 | *152-0165-00 | Silicon | Selected from 1N3579 |
| D82 | *152-0165-00 | Silicon | Selected from 1N3579 |
| D143 | *152-0107-00 | Silicon | Replaceable by 1N647 |
| D145 | *151-0165-00 | Silicon | Selected from 1N3579 |
| D163 | 152-0141-00 | Silicon | 1N3605 |

## Inductors

| | | |
|---|---|---|
| L90 | 276-0507-00 | Core, Ferramic Suppressor |
| L165 | Use *120-0402-00 | Toroid, 3 turns single |
| L178 | Use *120-0402-00 | Toroid, 3 turns single |

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## Operational Amplifier Cards (2) *(Cont'd)*

### Transistors

| Ckt. No. | Tektronix Part No. | Description | Model No. |
|---|---|---|---|
| Q78 | 152-0184-00 | SM7744 | |
| Q93 | 151-0184-00 | SM7744 | |
| Q104 | *151-0133-00 | Selected from 2N3251 | |
| Q114 | *151-0108-00 | Replaceable by 2N2501 | |
| Q124 | 151-0184-00 | SM7744 | |
| Q134 | *151-0133-00 | Selected from 2N3251 | |
| Q158 | *151-0134-00 | Replaceable by 2N2905 | |
| Q163 | *151-0121-00 | Selected from 2N3118 | |
| Q178 | *151-0150-00 | 2N3440 | |

### Resistors

Resistors are fixed, composition, ±10% unless otherwise indicated.

| | | | | | |
|---|---|---|---|---|---|
| R52 | 315-0470-00 | 47 Ω | ¼ W | | 5% |
| R54 | 322-0306-00 | 15 kΩ | ½ W | Prec | 1% |
| R58 | 317-0107-00 | 100 MΩ | ⅛ W | | |
| R60 | 311-0462-00 | 1 kΩ | Var | | |
| R62 | 311-0462-00 | 1 kΩ | Var | | |
| R64 | 315-0391-00 | 390 Ω | ¼ W | | 5% |
| R68 | 317-0107-00 | 100 MΩ | ⅛ W | | 5% |
| R70 | 315-0104-00 | 100 kΩ | ¼ W | | 5% |
| R72 | 321-0370-00 | 69.8 kΩ | ⅛ W | Prec | 1% |
| R74 | 321-0335-00 | 30.1 kΩ | ⅛ W | Prec | 1% |
| R78 | 323-0313-00 | 17.8 kΩ | ½ W | Prec | 1% |
| R82 | 315-0470-00 | 47 Ω | ¼ W | | 5% |
| R90 | 321-0355-00 | 48.7 kΩ | ⅛ W | Prec | 1% |
| R93 | 321-0374-00 | 76.8 kΩ | ⅛ W | Prec | 1% |
| R104 | 321-0431-00 | 301 kΩ | ⅛ W | Prec | 1% |
| R114 | 321-0384-00 | 97.6 kΩ | ⅛ W | Prec | 1% |
| R116 | 321-0403-00 | 154 kΩ | ⅛ W | Prec | 1% |
| R120 | 321-0354-00 | 47.5 kΩ | ⅛ W | Prec | 1% |
| R124 | 322-0361-00 | 56.2 kΩ | ¼ W | Prec | 1% |
| R130 | 321-0393-00 | 121 kΩ | ⅛ W | Prec | 1% |
| R134 | 321-0389-00 | 110 kΩ | ⅛ W | Prec | 1% |
| R136 | 321-0419-00 | 226 kΩ | ⅛ W | Prec | 1% |
| R140 | 315-0330-00 | 33 Ω | ¼ W | | 5% |
| R141 | 315-0331-00 | 330 Ω | ¼ W | | 5% |
| R143 | 305-0333-00 | 33 kΩ | 2 W | | 5% |
| R147 | 323-0367-00 | 64.9 kΩ | ½ W | Prec | 1% |
| R148 | 323-0367-00 | 64.9 kΩ | ½ W | Prec | 1% |
| R158 | 323-0355-00 | 48.7 kΩ | ½ W | Prec | 1% |
| R159 | 321-0304-00 | 14.3 kΩ | ⅛ W | Prec | 1% |
| R163 | 308-0390-00 | 4.8 kΩ | 3 W | WW | 5% |
| R174 | 321-0308-00 | 15.8 kΩ | ⅛ W | Prec | 1% |

## Operational Amplifier Cards (2) *(Cont'd)*

### Resistors *(Cont'd)*

| Ckt. No. | Tektronix Part No. | | Description | | | Model No. |
|---|---|---|---|---|---|---|
| R175 | 321-0371-00 | 71.5 kΩ | 1/8 W | Prec | 1% | |
| R178 | 308-0391-00 | 7.2 kΩ | 3 W | WW | 5% | |
| R190 | 305-0433-00 | 43 kΩ | 2 W | | 5% | |
| R194 | 308-0388-00 | 47 Ω | 3 W | WW | 5% | |

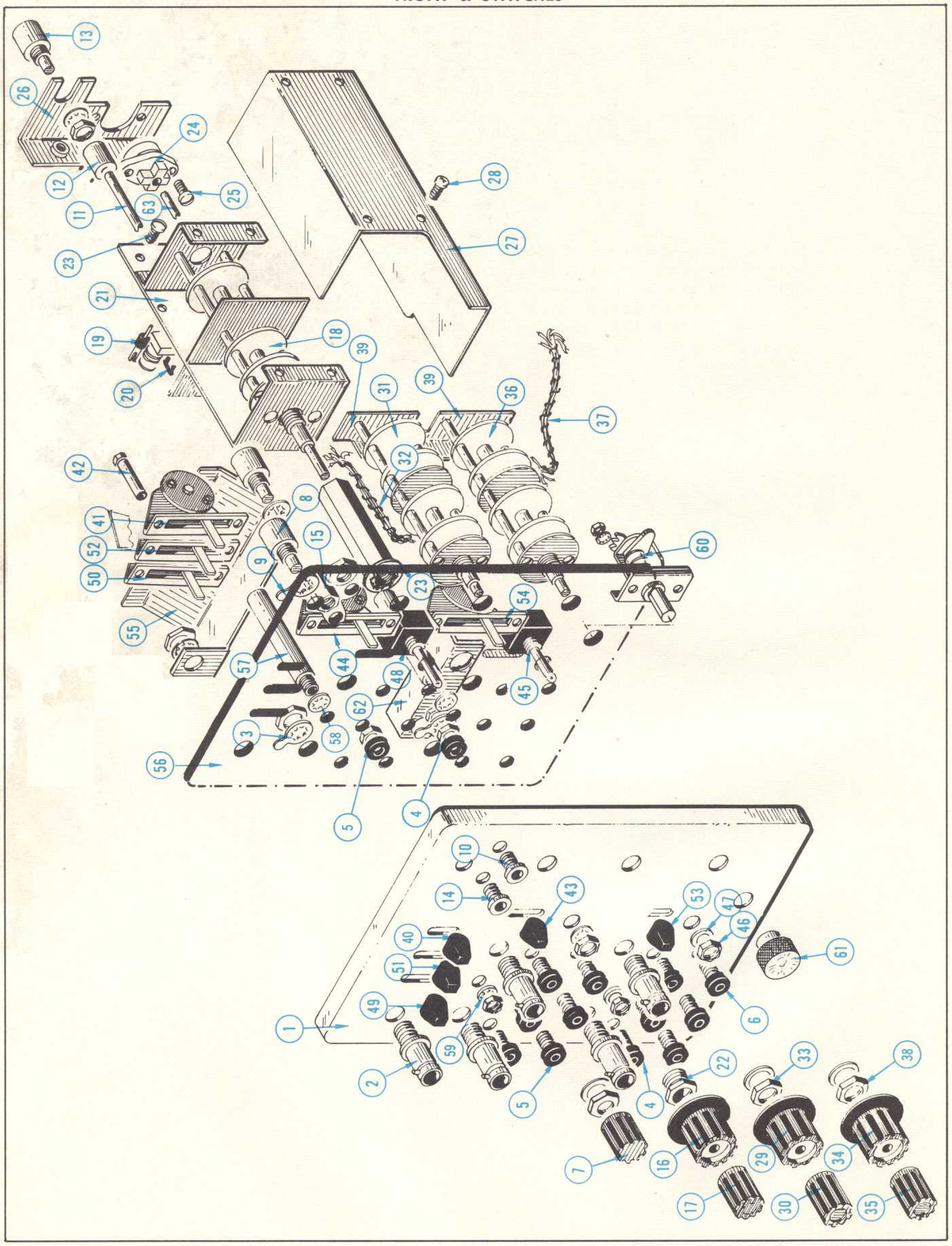
### Electron Tubes

| | | | | |
|---|---|---|---|---|
| V54, V84 | *157-0110-00 | 7586 | Selected (1 pair) | |
| V143 | 154-0323-00 | 6CW4 | | |

# SECTION 9
# MECHANICAL PARTS LIST

A list of abbreviations and special symbols in use throughout this manual will be found immediately preceding the Electrical Parts List, Section 8. Abbreviations and symbols used in this manual are based on or taken directly from IEEE Standard 260 "Standard Symbols for Units", MIL-STD-12B and other standards of the electronics industry. Parts ordering information is also located immediately preceding Section 8.

## FRONT & SWITCHES



## FRONT & SWITCHES

| REF. NO. | PART NO. | SERIAL/MODEL NO. EFF. | SERIAL/MODEL NO. DISC. | QTY. | DESCRIPTION |
|---|---|---|---|---|---|
| 1 | 333-0915-00 | | | 1 | PANEL, front |
| 2 | 131-0106-00 | | | 5 | CONNECTOR, coaxial, 1 contact, BNC |
| 3 | 210-0255-00 | | | 4 | LUG, solder, 3/8 inch |
| 4 | 136-0140-00 | | | 8 | SOCKET, banana jack |
| | - - - - - - | | | - | mounting hardware for each: (not included w/socket) |
| | 210-0895-00 | | | 1 | WASHER, insulating, black plastic |
| | 210-0465-00 | | | 2 | NUT, hex., 1/4-32 x 3/8 x 3/32 inch |
| | 210-0269-00 | | | 1 | LUG, terminal, non-locking |
| 5 | 136-0140-00 | | | 2 | SOCKET, banana jack |
| | - - - - - - | | | - | mounting hardware for each: (not included w/socket) |
| | 210-0895-00 | | | 1 | WASHER, insulating, black plastic |
| | 210-0465-00 | | | 1 | NUT, hex., 1/4-32 x 3/8 x 3/32 inch |
| 6 | 136-0140-00 | | | 2 | SOCKET, banana jack |
| | - - - - - - | | | - | mounting hardware for each: (not included w/socket) |
| | 210-0046-00 | | | 1 | LOCKWASHER, internal, 1/4 ID x 0.400 inch OD (not shown) |
| | 210-0269-00 | | | 1 | LUG, terminal, non-locking (not shown) |
| | 210-0465-00 | | | 1 | NUT, hex., 1/4-32 x 3/8 x 3/32 inch (not shown) |
| 7 | 366-0153-00 | | | 1 | KNOB, charcoal—POSITION |
| | - - - - - - | | | - | knob includes: |
| | 213-0005-00 | | | 1 | SCREW, set, 8-32 x 1/8 inch, HSS |
| 8 | - - - - - - | | | 2 | RESISTOR, variable |
| | - - - - - - | | | - | mounting hardware: (not included w/resistor) |
| | 210-0583-00 | | | 1 | NUT, hex., 1/4-32 x 5/16 inch |
| | 210-0940-00 | | | 1 | WASHER, flat, 1/4 ID x 3/8 inch OD |
| 9 | 210-0223-00 | | | 1 | LUG, solder, 1/4 ID x 7/16 inch OD, SE |
| 10 | 358-0054-00 | | | 1 | BUSHING, banana jack, 1/4-32 x 13/32 inch |
| | - - - - - - | | | - | mounting hardware: (not included w/bushing) |
| | 210-0465-00 | | | 1 | NUT, hex., 1/4-32 x 3/8 x 3/32 inch |
| | 348-0031-00 | | | 1 | GROMMET, plastic, 3/32 ID x 1/4 inch OD |
| 11 | 384-0376-00 | | | 1 | ROD, extension, 6.300 inches long |
| | - - - - - - | | | - | mounting hardware: (not included w/rod) |
| 12 | 376-0029-00 | | | 1 | COUPLING, rod, 1/4 inch diameter |
| | - - - - - - | | | - | coupling includes: |
| | 213-0075-00 | | | 2 | SCREW, set, 6-32 x 3/32 inch, HSS |
| 13 | - - - - - - | | | 1 | RESISTOR, variable |
| | - - - - - - | | | - | mounting hardware: (not included w/resistor) |
| | 210-0940-00 | | | 1 | WASHER, flat, 1/4 ID x 3/8 inch OD |
| | 210-0465-00 | | | 1 | NUT, hex., 1/4-32 x 3/8 x 3/32 inch |
| 14 | 358-0054-00 | | | 1 | BUSHING, banana jack, 1/4-32 x 13/32 inch |
| | - - - - - - | | | - | mounting hardware: (not included w/bushing) |
| 15 | 210-0471-00 | | | 1 | NUT, hex., 1/4-32 x 5/16 x 19/32 inch |
| | 210-0046-00 | | | 1 | LOCKWASHER, internal, 1/4 ID x 0.400 inch OD (not shown) |
| 16 | 366-0250-00 | | | 1 | KNOB, charcoal—VOLTS/DIV |
| | - - - - - - | | | - | knob includes: |
| | 213-0004-00 | | | 1 | SCREW, set, 6-32 x 3/16 inch, HSS |

## FRONT & SWITCHES *(Cont'd)*

| REF. NO. | PART NO. | SERIAL/MODEL NO. EFF. | SERIAL/MODEL NO. DISC. | QTY. | DESCRIPTION |
|---|---|---|---|---|---|
| 17 | 366-0189-00 | | | 1 | KNOB, red—VARIABLE-CAL |
| | - - - - - - | | | - | knob includes: |
| | 213-0020-00 | | | 1 | SCREW, set, 6-32 x 1/8 inch, HSS |
| 18 | 262-0740-00 | 100 | 219 | 1 | SWITCH, wired—VOLTS/DIV |
| | 262-0740-01 | 220 | | 1 | SWITCH, wired—VOLTS/DIV |
| | - - - - - - | | | - | switch includes: |
| | 260-0733-00 | | | 1 | SWITCH, unwired—VOLTS/DIV |
| | 210-0001-00 | | | 2 | LOCKWASHER, internal, #2 |
| | 211-0007-00 | | | 2 | SCREW, 4-40 x 3/16 inch, PHS, phillips |
| | 210-0405-00 | | | 2 | NUT, hex., 2-56 x 3/16 inch |
| | 337-0783-00 | | | 1 | SHIELD, attenuator |
| | 358-0241-00 | | | 10 | BUSHING, terminal |
| | 361-0101-00 | | | 1 | SPACER, attenuator switch |
| | 407-0191-00 | | | 1 | BRACKET, attenuator switch |
| 19 | 131-0344-00 | | | 10 | CONNECTOR, bifurcated feed-thru |
| 20 | 214-0456-00 | | | 9 | FASTENER, trimmer |
| 21 | 441-0650-00 | | | 1 | CHASSIS, attenuator |
| | - - - - - - | | | - | mounting hardware: (not included w/switch) |
| 22 | 358-0029-00 | | | 1 | BUSHING, hex., 3/8-32 x 13/32 inch |
| 23 | 210-0840-00 | | | 1 | WASHER, flat, 0.390 ID x 9/16 inch OD |
| | 211-0008-00 | | | 2 | SCREW, 4-40 x 1/4 inch, PHS, phillips |
| | 210-0851-00 | | | 2 | WASHER, flat, 0.119 ID x 3/8 inch OD |
| 24 | - - - - - - | | | 1 | RESISTOR, variable |
| | - - - - - - | | | - | mounting hardware: (not included w/resistor) |
| 25 | 211-0097-00 | | | 2 | SCREW, 4-40 x 5/16 inch, BHS |
| | 210-0586-00 | | | 2 | NUT, keps, 4-40 x 1/4 inch (not shown) |
| 26 | 407-0189-00 | | | 1 | BRACKET, switch |
| | - - - - - - | | | - | mounting hardware: (not included w/bracket) |
| | 211-0008-00 | | | 2 | SCREW, 4-40 x 1/4 inch, PHS, phillips (not shown) |
| | 210-0850-00 | | | 2 | WASHER, flat, 0.093 ID x 9/32 inch OD |
| 27 | 337-0784-00 | | | 1 | SHIELD, aluminum, attenuator, right side |
| | - - - - - - | | | - | mounting hardware: (not included w/shield) |
| 28 | 213-0055-00 | | | 4 | SCREW, thread forming, 2-32 x 3/16 inch, PHS, phillips |
| 29 | 366-0250-00 | | | 1 | KNOB, charcoal—Zi (1) |
| | - - - - - - | | | - | knob includes: |
| | 213-0004-00 | | | 1 | SCREW, set, 6-32 x 3/16 inch, HSS |
| 30 | 366-0153-02 | | | 1 | KNOB, charcoal—Zf (1) |
| | - - - - - - | | | - | knob includes: |
| | 213-0020-00 | | | 1 | SCREW, set, 6-32 x 1/8 inch, HSS |
| 31 | 262-0739-00 | | | 1 | SWITCH, wired—Zi-Zf (1) |
| | - - - - - - | | | - | switch includes: |
| | 260-0734-00 | | | 1 | SWITCH, unwired—Zi-Zf (1) |
| 32 | 179-1009-00 | | | 1 | CABLE HARNESS, switch (1) |
| | - - - - - - | | | - | mounting hardware: (not included w/switch) |
| 33 | 210-0413-00 | | | 1 | NUT, hex., 3/8-32 x 1/2 inch |
| | 210-0840-00 | | | 1 | WASHER, flat, 0.390 ID x 9/16 inch OD |
| 34 | 366-0250-00 | | | 1 | KNOB, charcoal—Zi (1) |
| | - - - - - - | | | - | knob includes: |
| | 213-0004-00 | | | 1 | SCREW, set, 6-32 x 3/16 inch, HSS |

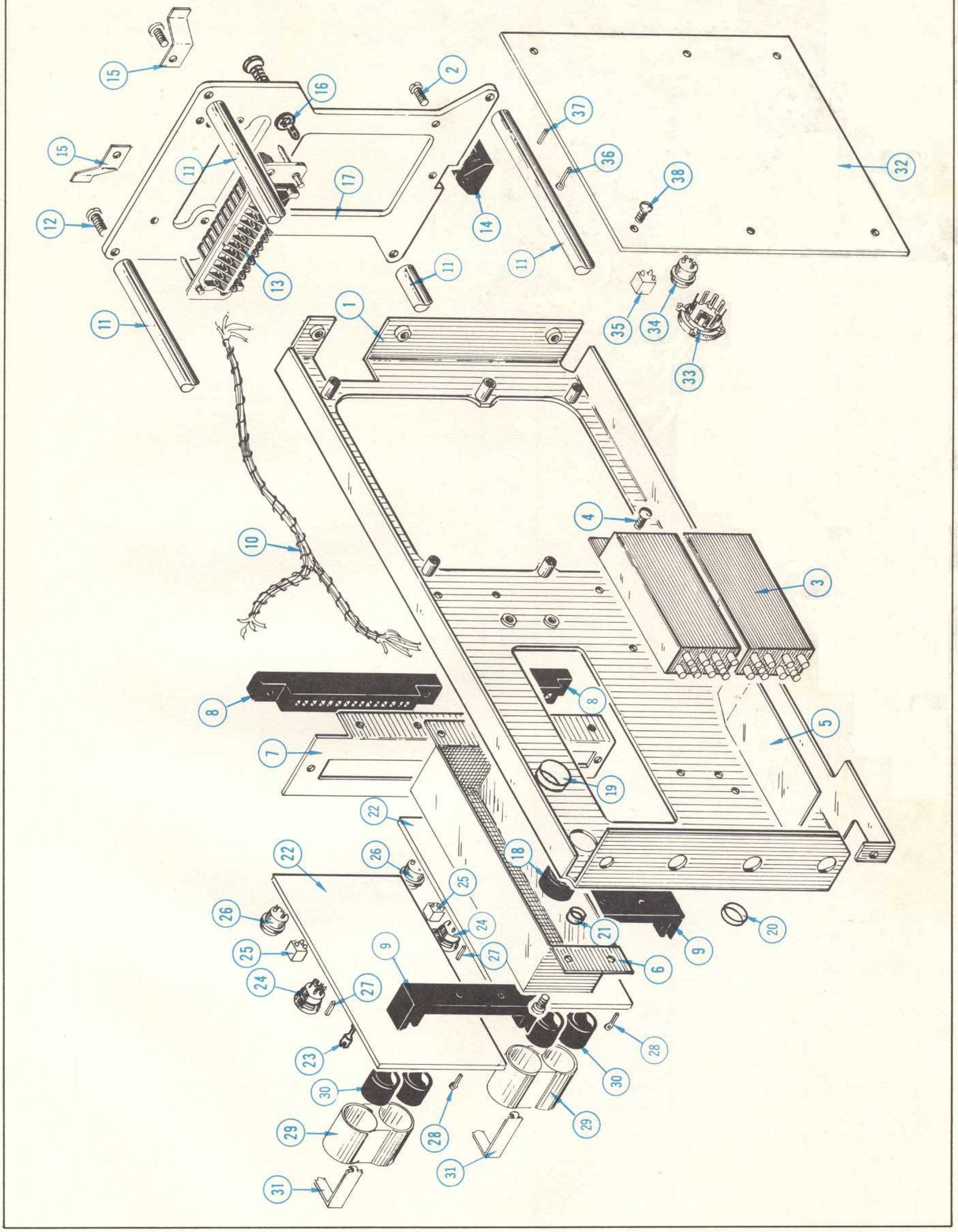
## FRONT & SWITCHES *(Cont'd)*

| REF. NO. | PART NO. | SERIAL/MODEL NO. EFF. | SERIAL/MODEL NO. DISC. | QTY. | DESCRIPTION |
|---|---|---|---|---|---|
| 35 | 366-0153-02 | | | 1 | KNOB, charcoal—Zf (2) |
| | - - - - - - | | | - | knob includes: |
| | 213-0020-00 | | | 1 | SCREW, set, 6-32 x 1/8 inch, HSS |
| 36 | 262-0739-00 | | | 1 | SWITCH, wired—Zi-Zf (2) |
| | - - - - - - | | | - | switch includes: |
| | 260-0734-00 | | | 1 | SWITCH, unwired—Zi-Zf (2) |
| 37 | 179-1009-00 | | | 1 | CABLE HARNESS, switch, (2) |
| | - - - - - - | | | - | mounting hardware: (not included w/switch) |
| 38 | 210-0413-00 | | | 1 | NUT, hex., 3/8-32 x 1/2 inch |
| | 210-0840-00 | | | 1 | WASHER, flat, 0.390 ID x 9/16 inch OD |
| 39 | 407-0188-00 | | | 1 | BRACKET, switch |
| | - - - - - - | | | - | mounting hardware: (not included w/bracket) |
| | 211-0008-00 | | | 2 | SCREW, 4-40 x 1/4 inch, PHS, phillips, (not shown) |
| | 210-0851-00 | | | 2 | WASHER, steel, 0.119 ID x 3/8 inch OD (not shown) |
| | 210-0001-00 | | | 4 | LOCKWASHER, internal, #2 (not shown) |
| | 210-0405-00 | | | 4 | NUT, hex., 2-56 x 3/16 inch (not shown) |
| 40 | 366-0215-01 | | | 1 | KNOB, charcoal—Display Amplifier NORM-INVERT |
| 41 | 260-0731-00 | | | 1 | SWITCH, unwired—Display Amplifier NORM-INVERT |
| | - - - - - - | | | - | mounting hardware: (not included w/switch) |
| 42 | 220-0413-00 | | | 2 | NUT, hex., 3/8-32 x 1/2 inch |
| | 166-0418-00 | | | 1 | TUBE, electrical shield |
| 43 | 366-0215-01 | | | 1 | KNOB, charcoal—ADJUST-NORM-∫ LF REJ (1) |
| 44 | 260-0732-00 | | | 1 | SWITCH, unwired—ADJUST-NORM-∫ LF REJ (1) |
| | - - - - - - | | | - | mounting hardware: (not included w/switch) |
| | 220-0413-00 | | | 2 | NUT, hex., 3/8-32 x 1/2 inch (not shown) |
| 45 | 260-0642-00 | | | 1 | SWITCH, unwired—±GRID SEL (2) |
| | - - - - - - | | | - | mounting hardware: (not included w/switch) |
| 46 | 210-0562-00 | | | 2 | NUT, hex., 1/4-40 x 5/16 inch |
| 47 | 210-0940-00 | | | 1 | WASHER, flat, 1/4 ID x 3/8 inch OD |
| | 210-0046-00 | | | 1 | LOCKWASHER, internal, 1/4 ID x 0.400 inch OD (not shown) |
| 48 | 260-0642-00 | | | 1 | SWITCH, unwired—±GRID SEL (1) |
| | - - - - - - | | | - | mounting hardware: (not included w/switch) |
| | 210-0562-00 | | | 2 | NUT, hex., 1/4-40 x 5/16 inch |
| | 210-0940-00 | | | 1 | WASHER, flat, 1/4 ID x 3/8 inch OD |
| | 210-0046-00 | | | 1 | LOCKWASHER, internal, 1/4 ID x 0.400 inch OD |
| 49 | 366-0215-01 | | | 1 | KNOB, charcoal—Display Amplifier 1-2 |
| 50 | 260-0730-00 | | | 1 | SWITCH, unwired—Display Amplifier 1-2 |
| | - - - - - - | | | - | mounting hardware: (not included w/switch) |
| | 220-0413-00 | | | 2 | NUT, hex., 3/8-32 x 1/2 inch (not shown) |
| 51 | 366-0215-01 | | | 1 | KNOB, charcoal—Display Amplifier AC-GND-DC |
| 52 | 260-0600-00 | | | 1 | SWITCH, unwired—Display Amplifier AC-GND-DC |
| | - - - - - - | | | - | mounting hardware: (not included w/switch) |
| | 220-0413-00 | | | 2 | NUT, hex., 3/8-32 x 1/2 inch (not shown) |
| 53 | 366-0215-01 | | | 1 | KNOB, charcoal—ADJUST-NORM-∫ LF REJ (2) |
| 54 | 260-0732-00 | | | 1 | SWITCH, unwired—ADJUST-NORM-∫ LF REJ (2) |
| | - - - - - - | | | - | mounting hardware: (not included w/switch) |
| | 220-0413-00 | | | 2 | NUT, hex., 3/8-32 x 1/2 inch (not shown) |

## FRONT & SWITCHES *(Cont'd)*

| REF. NO. | PART NO. | SERIAL/MODEL NO. EFF. | SERIAL/MODEL NO. DISC. | QTY. | DESCRIPTION |
|---|---|---|---|---|---|
| 55 | 337-0779-00 | | | 1 | SHIELD, aluminum, display selector |
| | - - - - - - | | | - | mounting hardware: (not included w/shield) |
| | 211-0008-00 | | | 1 | SCREW, 4-40 x 1/4 inch, PHS, phillips, (not shown) |
| | 210-0851-00 | | | 1 | WASHER, flat, 0.119 ID x 3/8 inch OD (not shown) |
| 56 | 386-0237-00 | | | 1 | PLATE, sub-panel, front |
| 57 | - - - - - - | | | 1 | RESISTOR, variable |
| | - - - - - - | | | - | mounting hardware for each: (not included w/resistor) |
| 58 | 210-0971-00 | | | 1 | WASHER, flat, 0.219 ID x 0.350 inch OD |
| | 210-0020-00 | | | 1 | LOCKWASHER, internal, #12 |
| 59 | 210-0467-00 | | | 1 | NUT, hex., 12-28 x 5/16 inch |
| 60 | 214-0052-00 | | | 1 | FASTENER, pawl right, w/stop |
| | - - - - - - | | | - | mounting hardware: (not included w/fastener) |
| | 210-0004-00 | | | 2 | LOCKWASHER, internal, #4 |
| | 210-0406-00 | | | 2 | NUT, hex., 4-40 x 3/16 inch |
| 61 | 366-0109-00 | | | 1 | KNOB, aluminum, plug-in securing |
| | - - - - - - | | | - | knob includes: |
| | 213-0005-00 | | | 1 | SCREW, set, 8-32 x 1/8 inch, HSS |
| 62 | 337-0794-00 | | | 1 | SHIELD, aluminum, terminal |
| 63 | 384-0384-00 | | | 1 | ROD, extension, 1/8 OD x 8.1 inches long |

## CHASSIS & FRAME



## CHASSIS & FRAME

| REF. NO. | PART NO. | SERIAL/MODEL NO. EFF. | SERIAL/MODEL NO. DISC. | QTY. | DESCRIPTION |
|---|---|---|---|---|---|
| 1 | 441-0649-00 | | | 1 | CHASSIS |
| | - - - - - - | | | - | mounting hardware: (not included w/chassis) |
| 2 | 211-0507-00 | | | 3 | SCREW, 6-32 x 5/16 inch, PHS |
| | 210-0586-00 | | | 1 | NUT, keps, 4-40 x 1/4 inch (not shown) |
| 3 | - - - - - - | | | 2 | CAPACITOR |
| | - - - - - - | | | - | mounting hardware for each: (not included w/capacitor) |
| 4 | 211-0008-00 | | | 1 | SCREW, 4-40 x 1/4 inch, PHS, phillips |
| | 210-0586-00 | | | 1 | NUT, keps, 4-40 x 1/4 inch (not shown) |
| 5 | 337-0780-00 | | | 1 | SHIELD, aluminum, Zi-Zf |
| | - - - - - - | | | - | mounting hardware: (not included w/shield) |
| | 210-0586-00 | | | 1 | NUT, keps, 4-40 x 1/4 inch (not shown) |
| | 210-0851-00 | | | 2 | WASHER, flat, 0.119 ID x 3/8 inch OD (not shown) |
| 6 | 337-0785-00 | | | 1 | SHIELD, aluminum, attenuator, left side |
| | - - - - - - | | | - | mounting hardware: (not included w/shield) |
| | 211-0008-00 | | | 4 | SCREW, 4-40 x 1/4 inch, PHS, phillips |
| | 210-0851-00 | | | 4 | WASHER, flat, 0.119 ID x 3/8 inch OD (not shown) |
| 7 | 407-0190-00 | | | 1 | BRACKET, aluminum, connector |
| | - - - - - - | | | - | mounting hardware: (not included w/bracket) |
| | 213-0044-00 | | | 2 | SCREW, thread forming, 5/32 x 3/16 inch, PHS, phillips (not shown) |
| | 211-0008-00 | | | 4 | SCREW, 4-40 x 1/4 inch, PHS, phillips (not shown) |
| | 210-0201-00 | | | 2 | LUG, solder, SE #4 (not shown) |
| 8 | 131-0327-00 | | | 2 | CONNECTOR, 30 pin |
| | - - - - - - | | | - | mounting hardware for each: (not included w/connector) |
| | 211-0014-00 | | | 2 | SCREW, 4-40 x 1/2 inch, PHS, phillips (not shown) |
| | 210-0586-00 | | | 2 | NUT, keps, 4-40 x 1/4 inch (not shown) |
| 9 | 352-0092-00 | | | 2 | HOLDER, delrin, circuit board |
| | - - - - - - | | | - | mounting hardware for each: (not included w/holder) |
| | 210-0586-00 | | | 2 | NUT, keps, 4-40 x 1/4 inch (not shown) |
| 10 | 179-1008-00 | | | 1 | CABLE HARNESS, chassis |
| | - - - - - - | | | - | cable harness includes: |
| | 131-0371-00 | | | 12 | CONNECTOR, pin |
| 11 | 384-0615-00 | | | 4 | ROD, spacer, 12 1/4 inches x 3/8 inch diameter |
| | - - - - - - | | | - | mounting hardware for each: (not included w/rod) |
| 12 | 212-0044-00 | | | 1 | SCREW, 8-32 x 1/2 inch, RHS, phillips |
| 13 | 131-0149-00 | | | 1 | CONNECTOR, 24 pin |
| | - - - - - - | | | - | mounting hardware: (not included w/connector) |
| | 211-0008-00 | 100 | 319 | 2 | SCREW, 4-40 x 1/4 inch, PHS |
| | 211-0008-00 | 320 | | 1 | SCREW, 4-40 x 1/4 inch, PHS |
| | 211-0097-00 | 320 | | 1 | SCREW, 4-40 x 5/16 inch, PHS |
| | 210-0201-00 | X320 | | 1 | LUG, solder, SE #4 |
| | 210-0586-00 | | | 2 | NUT, keps, 4-40 x 1/4 inch (not shown) |

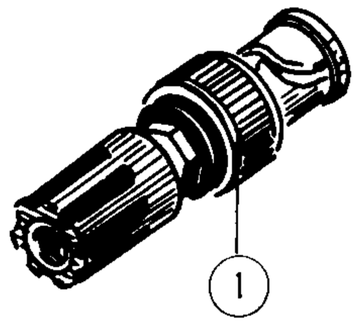


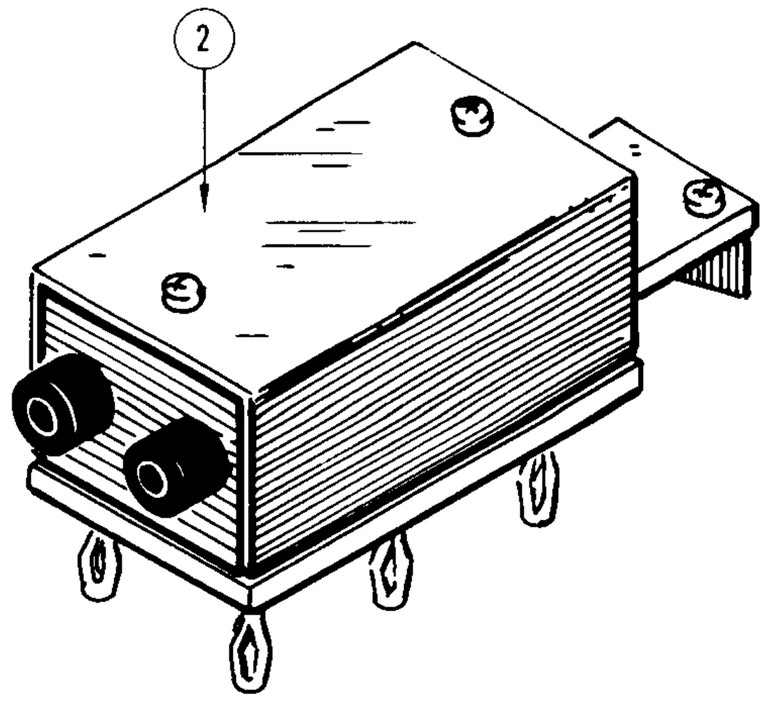
®

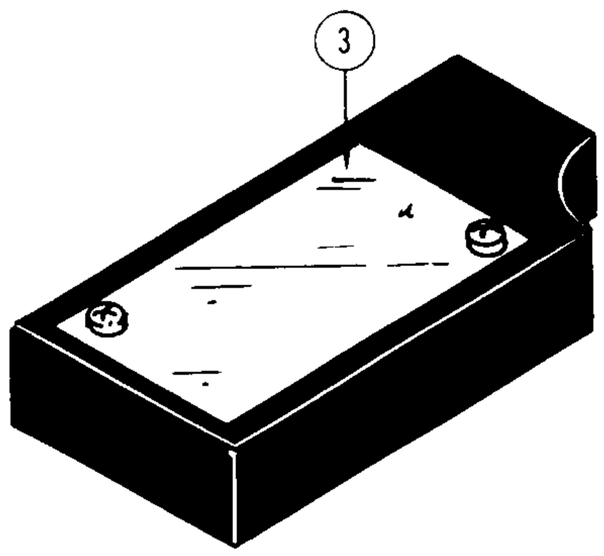
## CHASSIS & FRAME *(Cont'd)*

| REF. NO. | PART NO. | SERIAL/MODEL NO. EFF. | SERIAL/MODEL NO. DISC. | QTY. | DESCRIPTION |
|---|---|---|---|---|---|
| 14 | 351-0037-00 | | | 1 | GUIDE, plug-in, delrin, $\frac{5}{8}$ x $\frac{13}{16}$ inch |
| | - - - - - - | | | - | mounting hardware: (not included w/guide) |
| | 211-0013-00 | | | 1 | SCREW, 4-40 x $\frac{3}{8}$ inch, RHS, phillips |
| | 210-0586-00 | | | 1 | NUT, keps, 4-40 x $\frac{1}{4}$ inch (not shown) |
| 15 | 214-0276-00 | | | 2 | SPRING, ground, $\frac{1}{2}$ x $1\frac{1}{16}$ inches |
| | - - - - - - | | | - | mounting hardware for each: (not included w/spring) |
| | 211-0507-00 | | | 1 | SCREW, 6-32 x $\frac{5}{16}$ inch, PHS |
| | 210-0457-00 | | | 1 | NUT, keps, 6-32 x $\frac{5}{16}$ inch (not shown) |
| 16 | 210-0202-00 | | | 1 | LUG, solder, SE #6, w/2 wire holes |
| | - - - - - - | | | - | mounting hardware: (not included w/lug) |
| | 211-0504-00 | | | 1 | SCREW, 6-32 x $\frac{1}{4}$ inch, PHS, phillips |
| | 210-0407-00 | | | 1 | NUT, hex, 6-32 x $\frac{1}{4}$ inch (not shown) |
| 17 | 387-0647-00 | | | 1 | PLATE, aluminum, rear |
| 18 | 354-0068-00 | | | 1 | RING, securing, plastic, $\frac{1}{2}$ ID x $\frac{9}{16}$ inch OD |
| 19 | 348-0056-00 | | | 1 | GROMMET, delrin, $\frac{3}{8}$ inch diameter |
| 20 | 348-0055-00 | | | 3 | GROMMET, delrin, $\frac{1}{4}$ inch diameter |
| 21 | 348-0031-00 | | | 4 | GROMMET, plastic, $\frac{3}{32}$ inch diameter |
| 22 | 670-0087-00 | | | 2 | ASSEMBLY, Operational Amplifier, circuit card |
| | - - - - - - | | | - | each assembly includes: |
| 23 | 131-0285-00 | | | 2 | CONNECTOR, slotted terminal lug |
| 24 | 136-0125-00 | | | 3 | SOCKET, nuvistor, 5 pin |
| 25 | 136-0220-00 | | | 6 | SOCKET, transistor, 3 pin |
| 26 | 136-0183-00 | | | 3 | SOCKET, transistor, 3 pin |
| | 388-0676-00 | | | 1 | CARD, circuit |
| | - - - - - - | | | - | card includes: |
| 27 | 214-0506-00 | | | 3 | PIN, connector, straight |
| 28 | 214-0579-00 | | | 3 | PIN, test point |
| 29 | 200-0640-01 | | | 2 | COVER, heat stabilizer |
| 30 | 377-0103-00 | | | 4 | INSERT, heat stabilizer |
| 31 | 344-0121-00 | | | 2 | CLIP, spring, clamp |
| 32 | 670-0088-00 | | | 1 | ASSEMBLY, Display Amplifier, circuit board |
| | - - - - - - | | | - | assembly includes: |
| 33 | 136-0228-00 | | | 3 | SOCKET, nuvistor, 9 pin |
| 34 | 136-0183-00 | | | 1 | SOCKET, transistor, 3 pin |
| 35 | 136-0220-00 | | | 6 | SOCKET, transistor, 3 pin |
| | 388-0675-00 | | | 1 | BOARD, circuit |
| | - - - - - - | | | - | board includes: |
| 36 | 214-0579-00 | | | 8 | PIN, test point |
| 37 | 214-0506-00 | | | 16 | PIN, connector, straight |
| | - - - - - - | | | - | mounting hardware: (not included w/assembly) |
| 38 | 211-0601-00 | | | 6 | SCREW, sems 6-32 x $\frac{5}{16}$ inch, PHB, phillips |

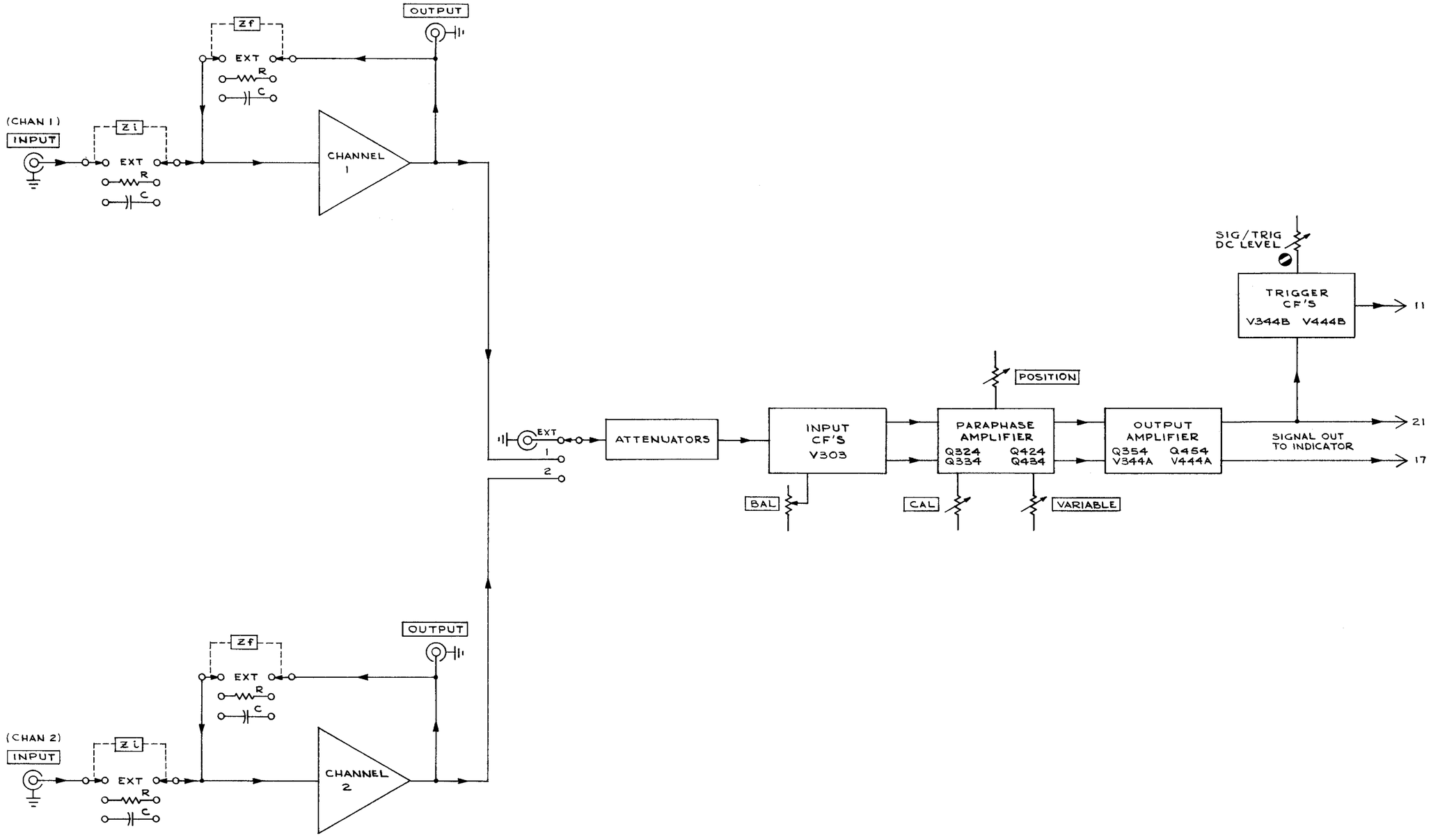
## ACCESSORIES

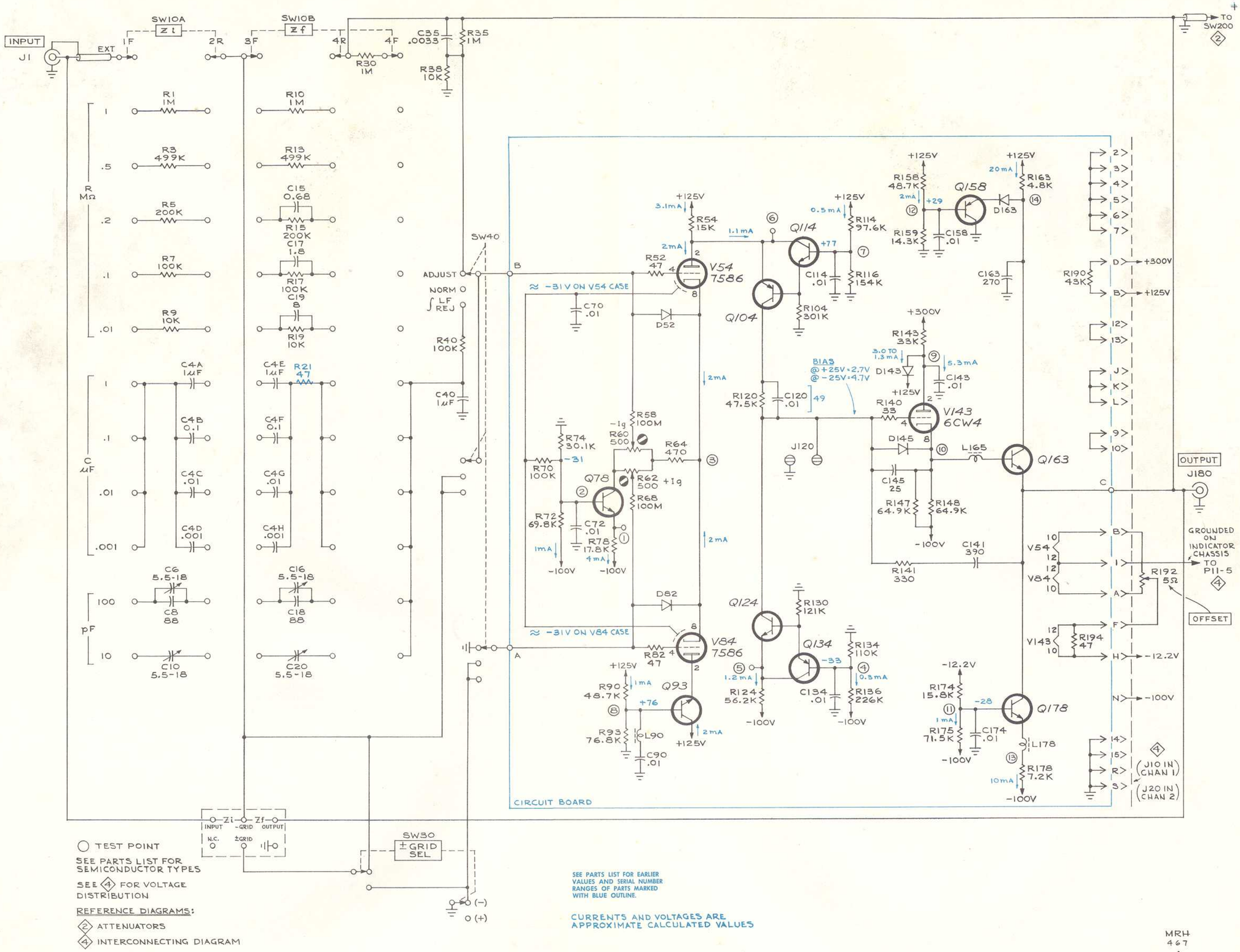



| REF. NO. | PART NO. | SERIAL/MODEL NO. EFF. | SERIAL/MODEL NO. DISC. | QTY. | DESCRIPTION |
|---|---|---|---|---|---|
| 1 | 103-0033-00 | | | 2 | ADAPTER, BNC to binding post |
| 2 | 013-0048-01 | | | 2 | ASSEMBLY, terminal adapter |
| 3 | 013-0049-01 | | | 2 | SHIELD, terminal adapter |
| | 070-0507-00 | | | 2 | MANUAL, instruction (not shown) |


(CHAN 1)
INPUT
Zi
EXT
R
C
Zf
EXT
R
C
OUTPUT
CHANNEL 1
(CHAN 2)
INPUT
Zi
EXT
R
C
Zf
EXT
R
C
OUTPUT
CHANNEL 2
EXT
1
2
ATTENUATORS
INPUT CF'S V303
BAL
POSITION
PARAPHASE AMPLIFIER
Q324 Q424
Q334 Q434
CAL
VARIABLE
OUTPUT AMPLIFIER
Q354 Q454
V344A V444A
SIG/TRIG DC LEVEL
TRIGGER CF'S
V344B V444B
11
21
SIGNAL OUT TO INDICATOR
17




○ TEST POINT

SEE PARTS LIST FOR SEMICONDUCTOR TYPES

SEE ④ FOR VOLTAGE DISTRIBUTION

REFERENCE DIAGRAMS:

② ATTENUATORS

④ INTERCONNECTING DIAGRAM

SEE PARTS LIST FOR EARLIER VALUES AND SERIAL NUMBER RANGES OF PARTS MARKED WITH BLUE OUTLINE.

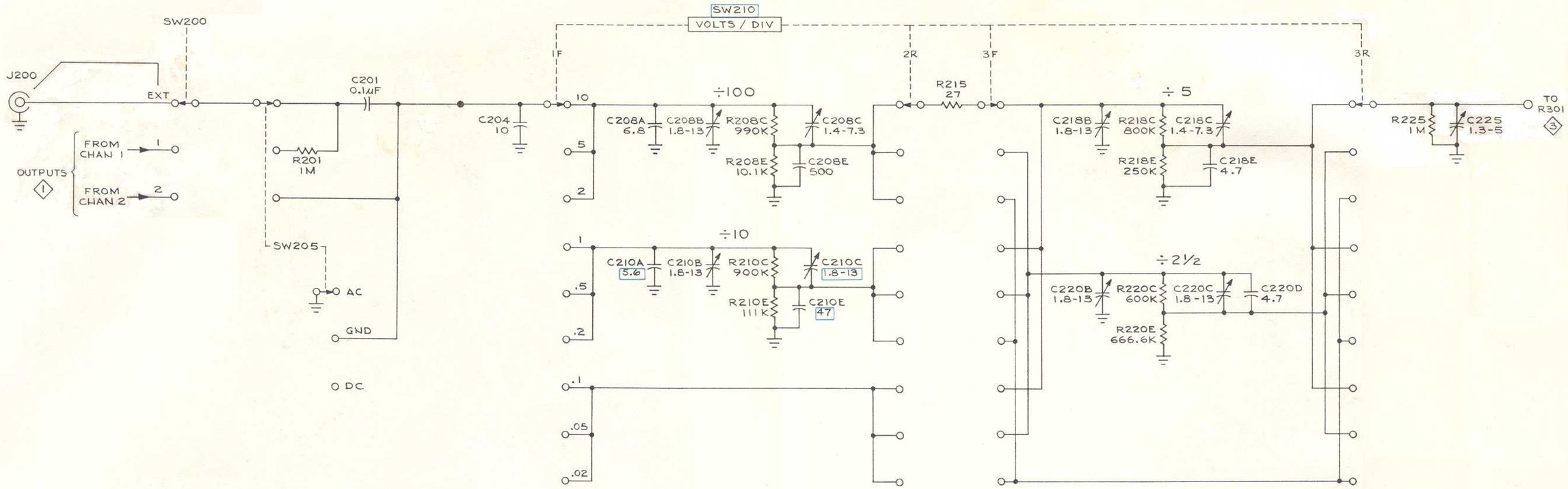
CURRENTS AND VOLTAGES ARE APPROXIMATE CALCULATED VALUES

MRH
467

# OPERATIONAL AMPLIFIER ① CHANNEL 1 OR 2

TYPE 3A8 OPERATIONAL AMPLIFIER

B




REFERENCE DIAGRAMS:

(1) OPERATIONAL AMPLIFIER

(3) DISPLAY AMPLIFIER

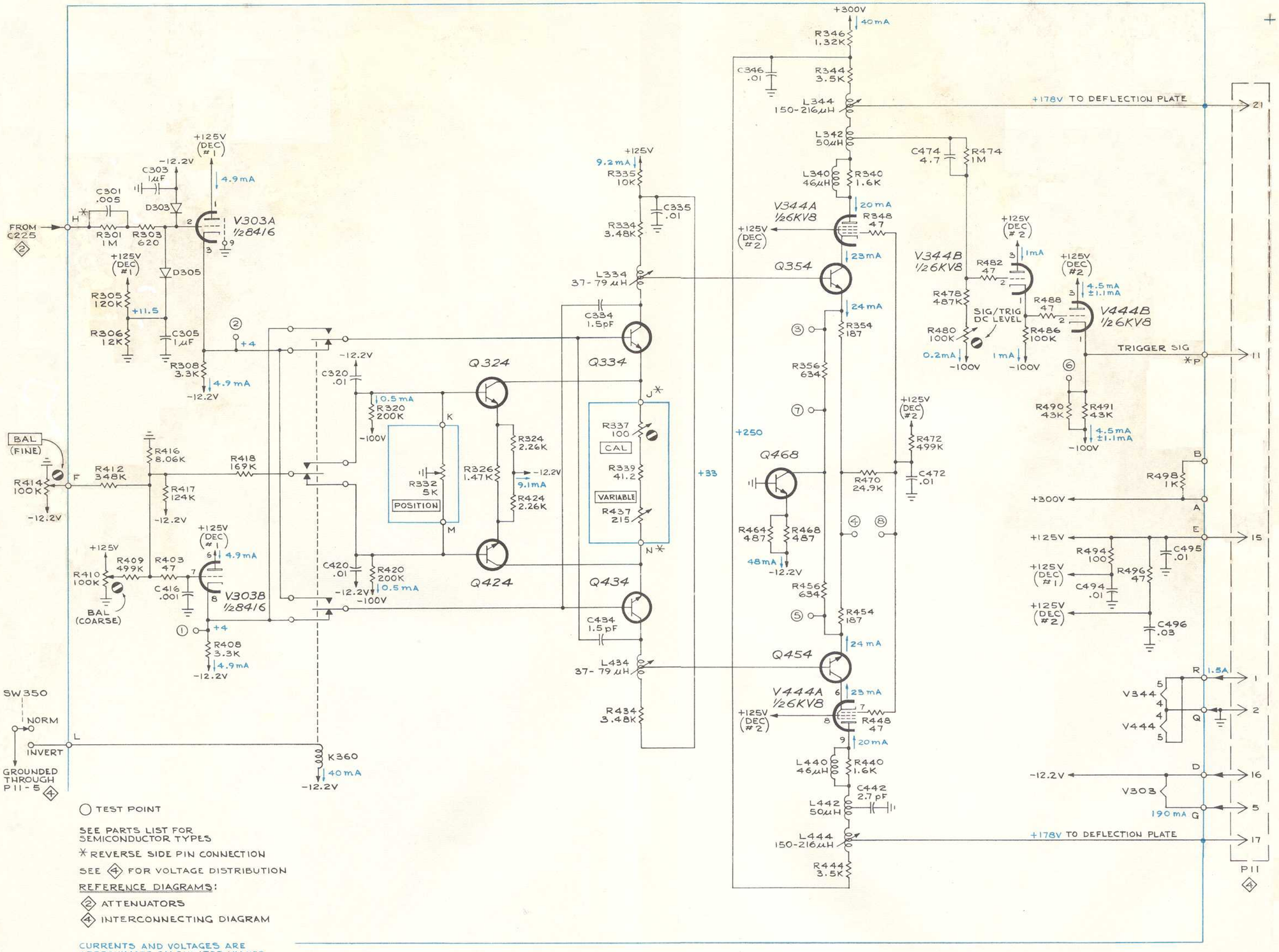
TYPE 3A8 OPERATIONAL AMPLIFIER

B

SEE PARTS LIST FOR EARLIER VALUES AND SERIAL NUMBER RANGES OF PARTS MARKED WITH BLUE OUTLINE.

MRH
466

ATTENUATORS (2)




○ TEST POINT

SEE PARTS LIST FOR SEMICONDUCTOR TYPES

* REVERSE SIDE PIN CONNECTION

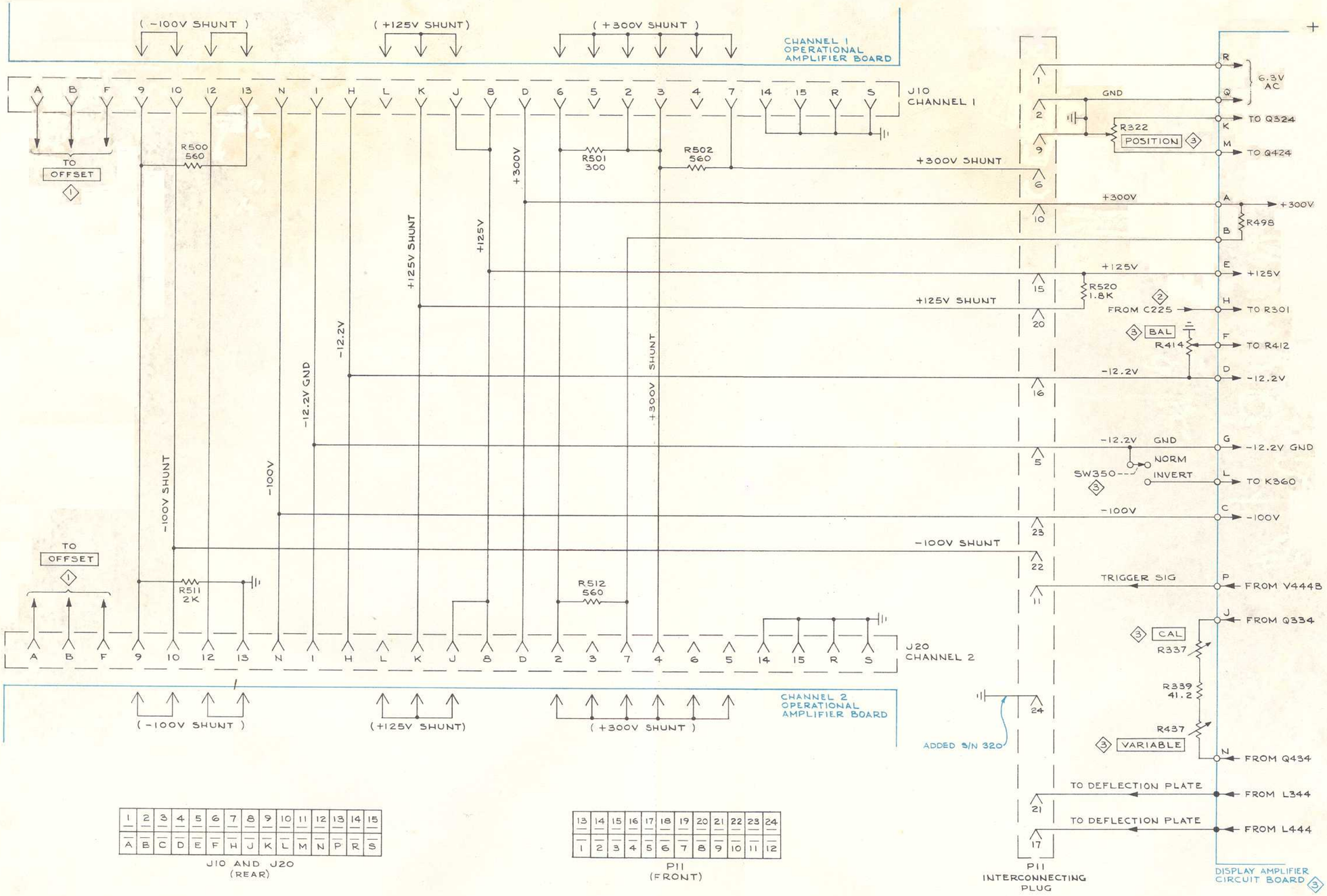
SEE 4 FOR VOLTAGE DISTRIBUTION

REFERENCE DIAGRAMS:

2 ATTENUATORS

4 INTERCONNECTING DIAGRAM

CURRENTS AND VOLTAGES ARE APPROXIMATE CALCULATED VALUES




| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | B | C | D | E | F | H | J | K | L | M | N | P | R | S |

J10 AND J20 (REAR)

| 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |

P11 (FRONT)

REFERENCE DIAGRAMS:

① OPERATIONAL AMPLIFIER
② ATTENUATORS
③ DISPLAY AMPLIFIER

## MANUAL CHANGE INFORMATION

At Tektronix, we continually strive to keep up with latest electronic developments by adding circuit and component improvements to our instruments as soon as they are developed and tested.

Sometimes, due to printing and shipping requirements, we can't get these changes immediately into printed manuals. Hence, your manual may contain new change information on following pages. If it does not, your manual is correct as printed.

TYPE 3A8

## TEXT CORRECTIONS

Section 1 Characteristics

Page 1-1 AC LF Response

CHANGE: ≥2 Hz @ -3 dB

TO: ≤2 Hz @ -3 dB

Page 1-1 VARIABLE VOLTS/DIV Range

CHANGE: ≤ 2.5:1

TO: ≥ 2.5:1

Page 1-2 Closed loop Gain-Bandwidth product, etc.

CHANGE: 250 kHz minimum, uncompensated (to -30% point).

TO: 50 kHz minimum, uncompensated (to -30% point).

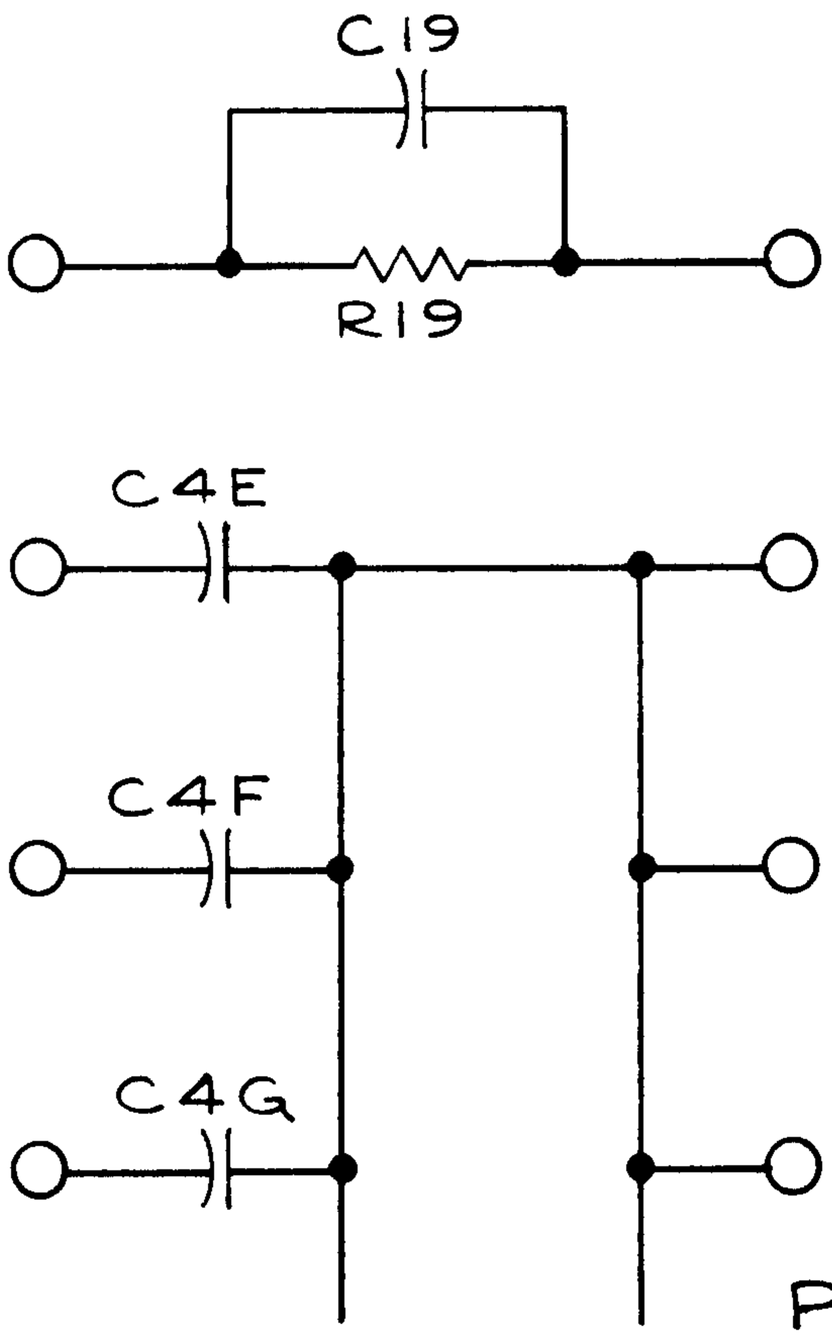
TYPE 3A8 TENT SN 420

## PARTS LIST CORRECTION

REMOVE:

| | | | | |
|---|---|---|---|---|
| R21 | 315-0470-00 | 47 Ω | 1/4 w | 5 % |

## SCHEMATIC CORRECTION




PARTIAL
OPERATIONAL AMPLIFIER
CHANNEL 1 OR 2

M11,960/167