INSTRUCTION MANUAL

TYPE O PLUG-IN UNIT

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070-323

CONTENTS

Warranty

Section 1 Characteristics

Section 2 Operating Instructions

Section 3 Applications

Section 4 Theory of Operational Amplifiers

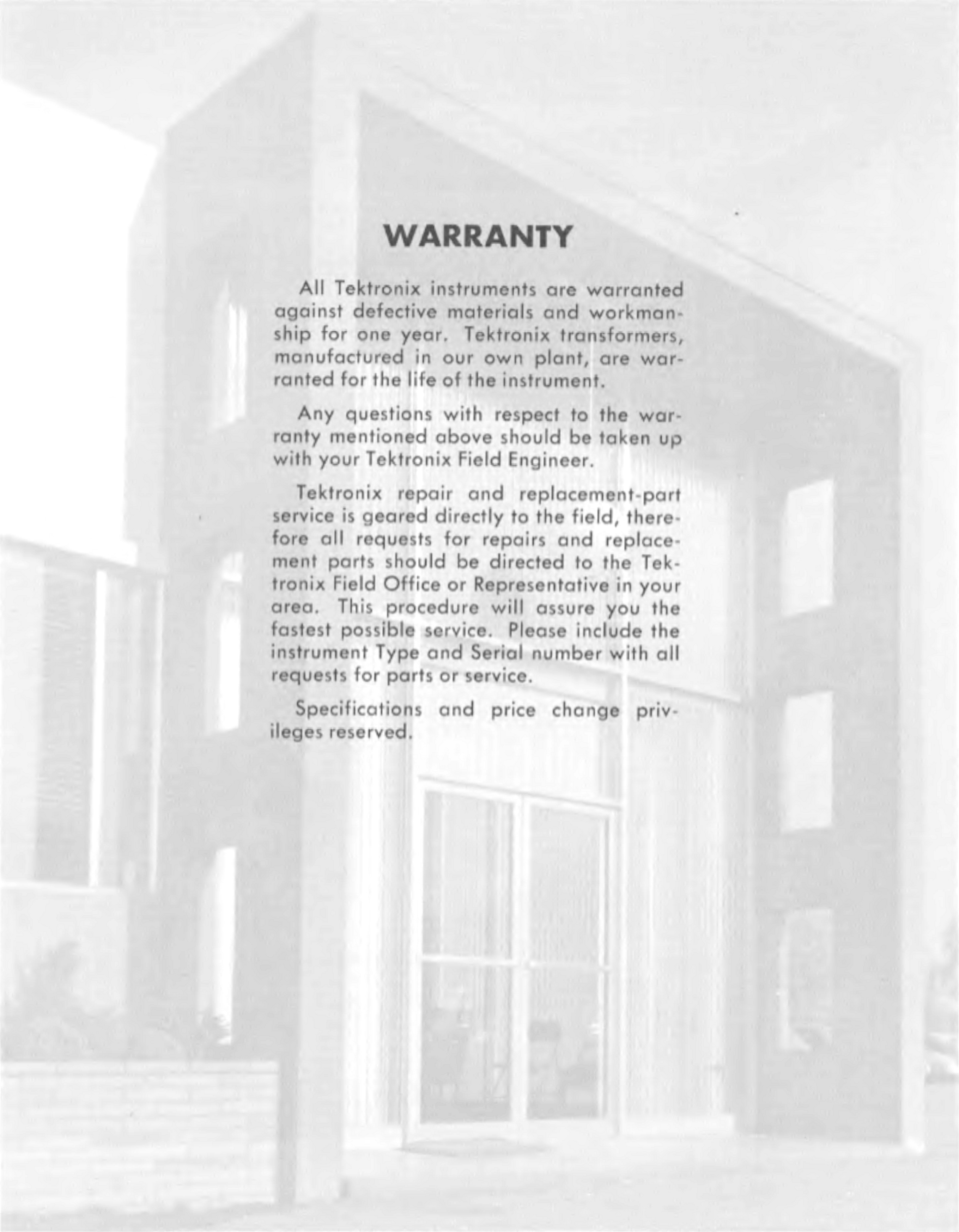
Section 5 Circuit Description

Section 6 Maintenance

Section 7 Calibration Procedure

Section 8 Accessories

Section 9 Parts List and Schematics



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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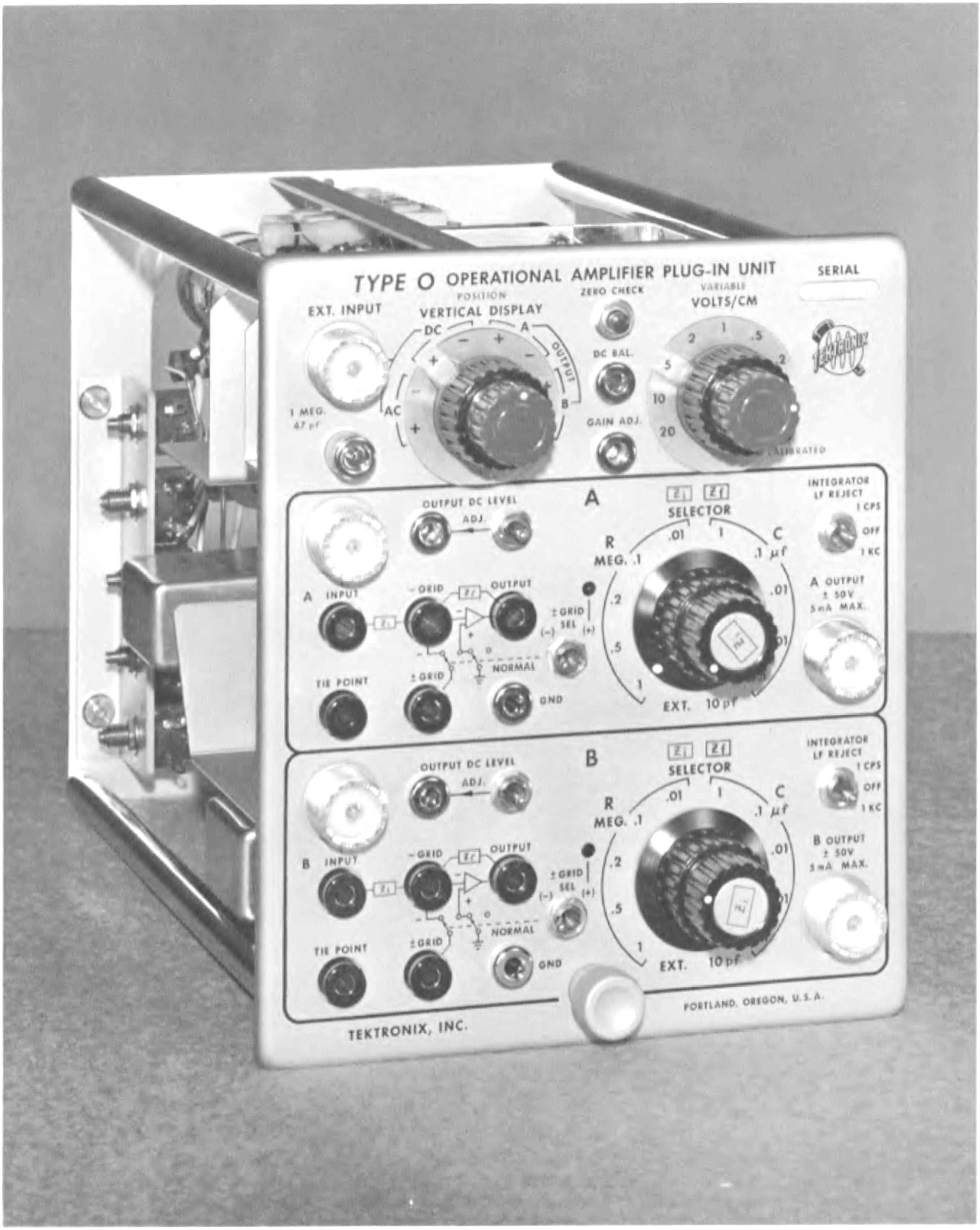
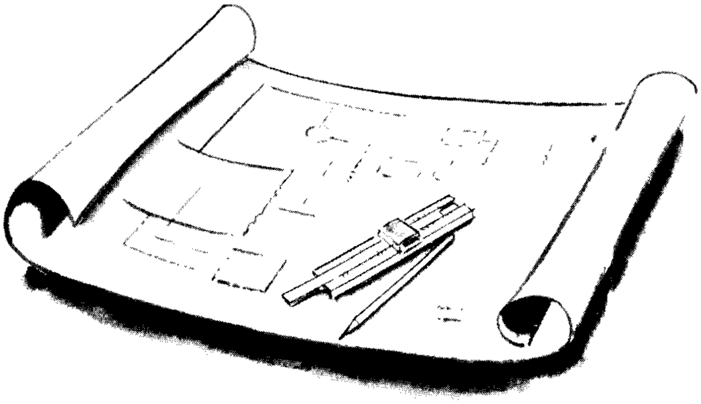

TYPE O OPERATIONAL AMPLIFIER PLUG-IN UNIT
SERIAL
EXT. INPUT
1 MEG. 47 pf
POSITION
VERTICAL DISPLAY
DC
AC
A
B
OUTPUT
ZERO CHECK
DC BAL.
GAIN ADJ.
VARIABLE
VOLTS/CM
CALIBRATED
TEKTRONIX
A
B
OUTPUT DC LEVEL
ADJ.
INPUT
-GRID
OUTPUT
±GRID
TIE POINT
NORMAL
GND
±GRID SEL
Zi Zf
SELECTOR
R MEG.
C µf
EXT.
10 pf
INTEGRATOR LF REJECT
1 CPS
OFF
1 KC
A OUTPUT ± 50V 5mA MAX.
B OUTPUT ± 50V 5mA MAX.
TEKTRONIX, INC.
PORTLAND, OREGON, U.S.A.



SECTION 1

CHARACTERISTICS

General Information

The Type O Operational Amplifier Plug-In Unit consists of essentially three parts: a vertical preamplifier and two operational amplifiers. The vertical preamplifier can be used either as an independent oscilloscope preamplifier or to monitor the output of either of the operational amplifiers.

The operational amplifiers can be used for applications involving integration, differentiation, amplification by a constant factor, summation, and phase inversion (as well as many others; see Section 3). The output of one operational amplifier can be applied to the input of the second for combined operations.

The Type O Unit can be used with any of the Tektronix 530-, 540-, or 550-Series Oscilloscopes. It can also be used with the 580-Series Oscilloscopes in conjunction with the Type 81 Plug-In Adapter. The Type O Unit can be used with other oscilloscopes and devices through use of the Types 127, 132, or 133 Plug-In Power Supplies.

Vertical Preamplifier

Bandpass

Dc to 14 mc (3 db) in Tektronix Type 530-Series Oscilloscopes (except Types 532 and 536).

Dc to 25 mc (3 db) in Tektronix Types 540- and 580-Series Oscilloscopes, and the Type 555.

Risetime

Approximately 25 nsec in Type 530-Series Oscilloscopes (except Types 532 and 536).

Approximately 14 nsec in Type 540- and 580-Series Oscilloscopes, and the Type 555.

Vertical Deflection Factors

Nine calibrated steps provided: 0.05, 0.1, 0.2, 0.5, 1, 2, 5, 10, and 20 volts per centimeter. A variable uncalibrated control provides for continuous adjustment from 0.05 to 50 volts per centimeter.

Input Characteristics

1 megohm paralleled by 47 pf.

Operational Amplifiers A and B

Open Loop Gain-Bandwidth Product

Approximately 15 mc. (Checked at 10 mc with 1-v input; see Chart 2-1.)

Open Loop DC Gain

Approximately 2500.

Output Range

±50 volts, ±5 ma.

Output Impedance, at Front-Panel OUTPUT Connectors

Approximately 30 Ω at 1 mc for compensated unity-gain amplifier.

Noise

Typically 0.5 mv peak-to-peak, referred to input. Approximately 3 mv peak-to-peak output noise.

Drift

Typically less than 10 mv per hour (after warmup), referred to input.

Grid Current

Less than 0.5 nanoampere for both + and — input grid. Adjustable to less than 0.15 nanoampere for + grid, and less than 0.3 nanoampere for — grid.

Input Impedance

Selected by front-panel control. Values contained internally are: 0.01, 0.1, 0.2, 0.5, and 1 megohm; 10 pf*, 0.0001*, 0.001, 0.01, 0.1 and 1 μf, at ±1% Other values may be connected externally.

Feedback Impedance

Same values and tolerances as the Input Impedances internally. Other values may be connected externally.

Signal Inputs

Signals may be connected to either the —grid (output inverted) or the +grid (output polarity same as input).

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* Individually adjustable.

Feedback

Provision is made for permitting either positive or negative feedback.

Integration Low-Frequency Rejection

A low-frequency rejection circuit is provided to prevent undesired integration of dc components and dc drift from forcing the oscilloscope trace off the crt. It is also possible to reject line-frequency pickup and other low-frequency noise. Rejection will occur at about 1 cps or about kc, depending on the setting of a front-panel control. The low-frequency rejection circuit may be switched in or out as desired.

Output DC Level

At ground potential. Output is adjusted to ground with a front-panel control.

Crosstalk Between Operational Amplifiers

Typically better than 300:1 under following conditions: Both Operational Amplifiers set for unity gain with Z_i Z_f 1 MEG, one amplifier driven with a capacitively-coupled oscilloscope Amplitude Calibrator signal of 100 volts (± 50-volt square wave of about 1-μsec risetime). Output of other amplifier will not exceed 330 mv.

Other Characteristics

Construction

Aluminum-alloy chassis with photo-etched anodized panel.

Weight

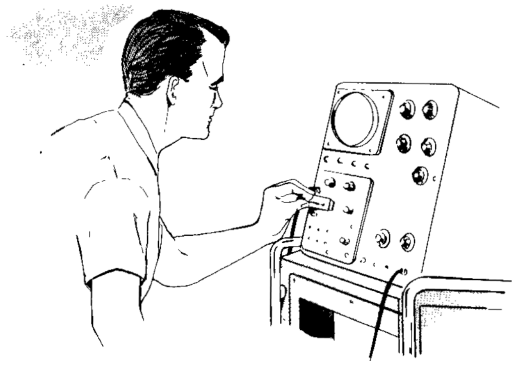
Approximately 5.5 pounds.

Accessories

2-Terminal Adapter Assemblies (013-048)

2-Terminal Shields (013-049)

2-Instruction Manuals (070-323)



SECTION 2

OPERATING INSTRUCTIONS

General Information

The Type O Plug-In Unit is a very versatile device. The number of applications for the unit is limited only by the imagination of the user. To realize the full potentialities of the unit, it is important for you to understand the operation and function of each control. Much of this understanding will come only as the result of actual use. This section provides the basic information you will require.

Typical application examples are included in this section of the manual to aid you in becoming acquainted with the unit. These examples provide set-up instructions for integration, differentiation, and amplification.

Connecting The Plug-In Unit To The Oscilloscope

The Type O Unit can be used with any of the Tektronix Type 530-, 540-, 550-, or 580-Series Oscilloscopes. In the Type 530-, 540-, or 550-Series Oscilloscopes, the plug-in unit need only be inserted in the plug-in compartment of the oscilloscope and the power switched on. If one of the 580-Series Oscilloscopes is used, the Type 81 Plug-In Adapter must be inserted into the plug-in compartment of the oscilloscope ahead of the plug-in unit. The plug-in unit can then be inserted into the compartment of the Type 81. The plug-in fastener knob should be turned until tight to insure that the plug-in unit makes good connection with the oscilloscope.

PREAMPLIFIER

The Type O Unit contains a vertical preamplifier which is used in much the same manner as the preamplifiers in other vertical plug-in units. The preamplifier can be used with or without the operational amplifiers. When the preamplifier is used alone, input signals are connected to the EXT. INPUT connector on the front panel.

The VERTICAL DISPLAY switch selects the input signal used by the preamplifier. Possible selections are (1) external signals applied to the EXT. INPUT connector, and (2) output of either of the operational amplifiers. The + or — sign at each position of the VERTICAL DISPLAY switch indicates whether the oscilloscope display is normal or inverted. In the — positions of the VERTICAL DISPLAY switch the input signal is inverted before being displayed.

The preamplifier vertical deflection factor is controlled by the VOLTS/CM switch. Nine calibrated deflection factors from 0.05 to 20 volts per centimeter are provided. The VARIABLE control allows uncalibrated deflection factors between ranges and gives a continuous range of deflection factors between 0.05 and approximately 50 volts per centimeter. With the desired signal displayed on the crt, the VOLTS/CM controls are adjusted to give a convenient amount of vertical deflection.

External input signals to the preamplifier may be either ac or dc coupled depending on the position of the VERTICAL DISPLAY switch. In many cases only the ac component of the input signal is of interest. In such cases, use of ac coupling allows the display of signal information while blocking the dc component. Ac coupling also permits observation of ac information at high sensitivities without dc components deflecting the display off the crt.

Dc coupling must be used to observe very low-frequency signals (the ac response is 3-db down at approximately 3 cps). Dc coupling must also be used when measuring the dc component of the input signal or making measurements which include the dc component.

Input signals may be displayed with or without inversion when using either ac or dc coupling.

Output signals from the two operational amplifiers are dc coupled through the VERTICAL DISPLAY switch to the preamplifier. To ac couple the output of an operational amplifier, connect a short jumper from the OUTPUT of the operational amplifier to the EXT. INPUT connector. Either of the AC positions of the VERTICAL DISPLAY switch can then be used.

First Time Operation

Initial operation of the Type O Unit requires that certain adjustments must be checked. Set both the A and B Operational Amplifier Z_i and Z_f controls at 1 MEG. Set the VERTICAL DISPLAY switch to +DC.

After inserting the plug-in unit in the oscilloscope and switching on the power, wait a few minutes for the instrument to warm up. Adjust the oscilloscope for a free-running sweep and, using the POSITION controls, position the trace on the crt. Set the intensity of the trace at a convenient level and adjust the oscilloscope FOCUS and ASTIGMATISM controls for a sharply focused trace.

OPERATIONAL AMPLIFIERS

With no input signal to the operational amplifiers, the output dc level of the amplifiers should be zero. To insure this condition, a check on the dc level should occasionally be made. The procedure is outlined in the following paragraph using the OUTPUT DC LEVEL switch in each amplifier. The OUTPUT DC LEVEL ADJ. control is used to set the output to zero.

In order to set or check the output dc level of the operational amplifiers, it is first necessary to determine the zero input dc level of the preamplifier. To do this, set the VOLTS/CM switch to .5 and press the ZERO CHECK switch. (The ZERO CHECK switch disconnects all signals to the preamplifier and permits only its dc level to be displayed on the crt.) Then use the POSITION control to position the trace to a convenient horizontal graticule line. The zero input dc level of the preamplifier then corresponds to this graticule line.

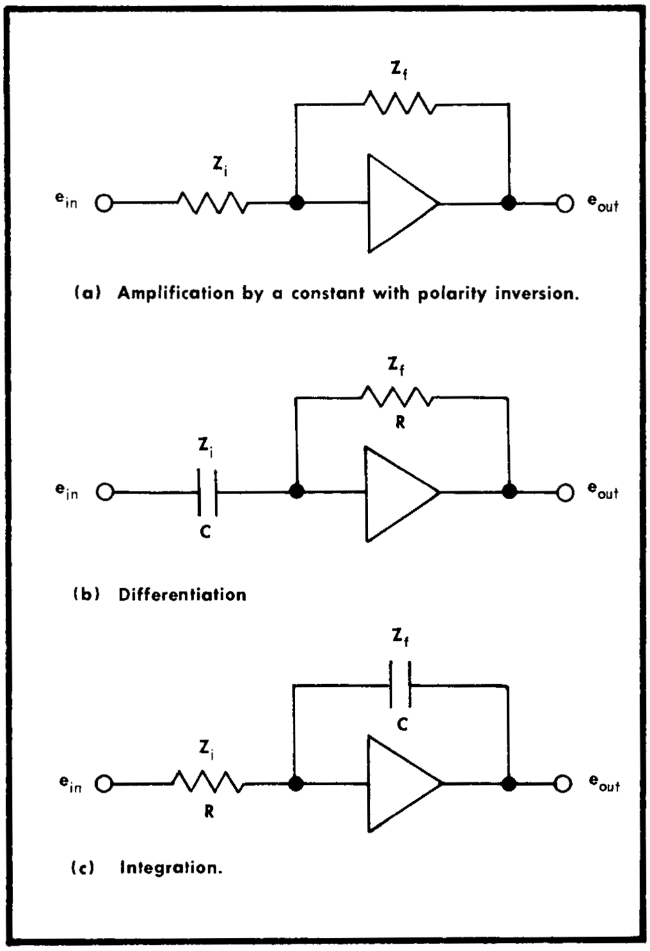
When the zero input dc level line of the preamplifier has been determined, set the VERTICAL DISPLAY switch to A+. This connects the output of the A operational amplifier to the input of the preamplifier. Place the OUTPUT DC LEVEL switch in the ADJ. position and hold it there. Set the ADJ. control to position the trace on the crt to the zero input dc level line previously determined. This sets the output level of the A operational amplifier at zero volts. When the OUTPUT DC LEVEL switch is pressed to the ADJ. position, the external circuit is disconnected, the input end of the Z_i component is grounded, and a gain of 100 is automatically provided in the operational amplifier. The 100× gain permits a more precise adjustment to be made. It is important, however, to recognize that any large amount of drift and noise is due to the extra gain.

Now set the VERTICAL DISPLAY switch to B+ and adjust the dc level at the output of the B operational amplifier in the same manner as for the A amplifier.

Feedback Controls

The most basic functions of an operational amplifier are those of amplification by a constant, integration, and differentiation. In amplification, both the input and feedback impedances are normally resistors (although capacitors or inductors can be used). The ratio of the feedback resistor to the input resistor detemines the gain of the feedback amplifier. In integration, the feedback impedance is a capacitor while the input impedance is a resistor. In differentiation, the input impedance is a capacitor while the feedback impedance is a resistor. In both integration and differentiation, the time constant of the feedback network determines the characteristics of the amplifier. The basic circuits for these three types of operations are shown in Fig. 2-1.

The front-panel controls labeled Z_i and Z_f select the input and feedback impedances from several possible internal values. External positions for these controls also permit connection of desired external values to the jacks on the front panel of the unit. Paralleling internal components with external components is practical; however, it is possible to perform any of the following basic operations using the internal values supplied with the unit.



(a) Amplification by a constant with polarity inversion.

(b) Differentiation

(c) Integration.

Fig. 2-1. The three most basic uses of an operational amplifier.

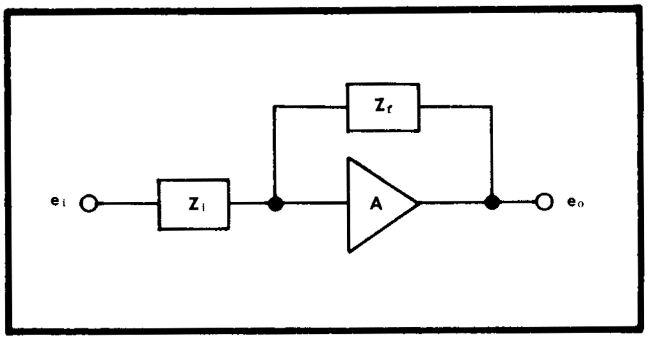


Fig. 2-2. Major terms used in general gain expression for an operational amplifier.

Operational Amplifier Gain

The gain of the operational amplifier with resistance input and feedback elements is the ratio of the feedback resistance to the input resistance: Gain = $-R_f/R$. This ratio is selected by means of the Z_i and Z_f SELECTOR controls or by externally mounted components. (See Fig. 2-2)

If the operational amplifier had infinite gain, the accuracy of the input and feedback resistors (to establish a given gain) would determine the accuracy of the gain ($-R_f/R_i$). However, the O Unit operational amplifier open-loop gain is 2500, not infinite, so a small error is introduced at higher closed-loop gain. When using internal input and feedback resistors, this error is internally compensated at ×50 and ×100 gain settings.

Error Factor

The gain of a feedback (operational) amplifier with finite gain may be expressed by the formula:

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

where e_o = output voltage, e_i = input voltage, Z_f = impedance of feedback component, Z_i = impedance of input component, and A = amplifier open-loop gain.

Since the first part of the formula ($-Z_f/Z_i$) corresponds to the expression for the closed-loop gain of an operational amplifier with infinite open-loop gain, the remainder of the formula is the Error Factor.

An example of the need for gain correction due to the Error Factor follows: If Z_i is set at .01 MEG and Z_f at 1 MEG, the gain would be —100 if the operational amplifier open-loop gain were infinite. Since the open-loop gain is 2500, the error for this example will be approximately 100/2500 or 4%.

A second example is with Z_i set at .01 MEG, and Z_f set at .5 MEG. The gain should be —50, but the error will be approximately 50/2500 or 2%.

To keep the feedback gain within the O Unit (using internally selected input and feedback resistances) to a tolerance of 3%, special precautions were taken with the Z_i and Z_f SELECTOR switches. The 3% gain tolerance is made up of a 1% limit due to the Error Factor and a 2% limit due to the 1% tolerance of the resistors. Therefore, the Z_i and Z_f switches have been wired to place a shunting resistor across the .01 MEG Z_i resistor when the Z_f control chooses a resistor that will give a gain error over 1%.

The schematic diagrams of the Operational Amplifiers show the .01 MEG Z_i resistors shunted with 240 k when the Z_f resistor is 1 MEG, and shunted with 510 k when the Z_f resistor is .5 MEG. The Z_i—Z_f switches do not shunt the .01 MEG Z_i resistor at any other time.

When using external input and feedback components it may be important to use the Error Factor to correct for gain errors.

Closed-Loop Gain-Bandwidth Characteristics of Operational Amplifiers

Open- and closed-loop gain-frequency characteristics of the Type O Unit Operational Amplifiers are shown in Chart 2-1. As mentioned in the Characteristics (Section 1), the Type O Operational Amplifiers have an open-loop gain-bandwidth product of approximately 15 mc. The open-loop gain-frequency characteristics set a maximum theoretical limit for the closed-loop characteristics. When using internal Z_i and Z_f resistors, the closed-loop bandwidth is always somewhat less that the theoretical limit due to wiring and stray capacitances.

Average closed-loop gain frequency characteristics in various closed-loop gain settings are shown in Chart 2-1. Since the individual Z_i and Z_f stray capacitances change with switch settings, the data presented in the chart may not fit all switch combinations for the same gain settings.

In a critical application, external capacitive compensation is recommended to reduce the effect of internal stray capacity and extend the closed-loop bandwidth.

Capacitive compensation is accomplished by placing external variable capacitors across the input and output resistors. With the oscilloscope Amplitude Calibrator signal applied to the input, the capacitors may be adjusted for optimum flat top response while observing the output waveform on the crt. Optimum response will be obtained when the time constant of the input circuit is equal to the time constant of the feedback circuit. Typical compensated unity-gain amplifier response is shown by the dotted line in Chart 2-1.

Sample Amplification Setup

1. Connect the output of the oscilloscope Amplitude Calibrator to the A INPUT connector on the front of the O Unit. Adjust the calibrator for a 1-volt signal.
2. Connect the output of the A operational amplifier to the preamplifier by setting the VERTICAL DISPLAY switch to A+.
3. Set the A GRID SEL switch to (—).
4. Adjust the A operational amplifier to give a gain of —1 by setting both the Z_i and Z_f controls to 1 MEG.
5. Set the VOLTS/CM switch to .5, VARIABLE control to CALIBRATED.

You should now have 2 centimeters of vertical deflection. Thus with 1 volt in, —1 volt out is obtained, resulting in a gain of —1. Note that whenever the Z_i and Z_f SELECTOR controls are both set to the same value of resistance, a gain of —1 is obtained.

Next set the VOLTS/CM switch to 5, Z_i to .1 MEG, and Z_f to 1 MEG. The ratio of Z_f to Z_i is 1/0.1 = 10, so a gain of —10 should be obtained. There should now be 2 centimeters of vertical deflection. This corresponds to an output of 10 volts. The gain is —10 as calculated. Try other settings of the Z_i and Z_f controls where the ratio of Z_f and Z_i is 10. You will see that in each case the gain of the amplifier is —10.

Differentiation

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 without loss of signal level.

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

$$e_o = -R_fC_i\frac{d}{dt}(e_i)$$

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 time constant and the rate at which the input voltage changes with respect to time.

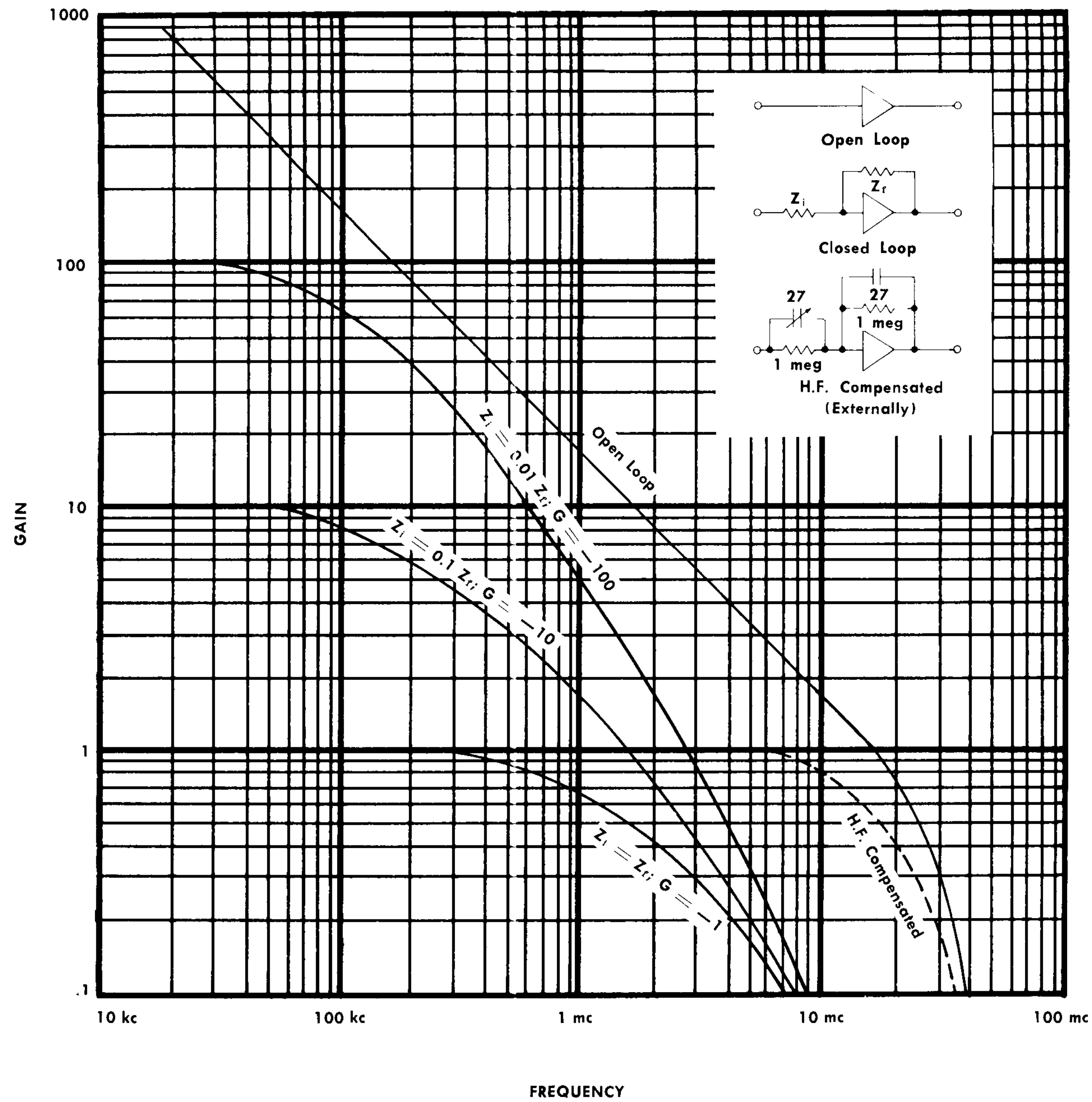


Chart 2-1. Average closed-loop and open-loop Gain-Frequency characteristics for the operational amplifiers. The dashed line indicates an example of external capacitance compensation extending the high-frequency performance.

A good starting point is to choose a time constant equal to the fastest risetime of the signal you are attempting to differentiate. The oscilloscope calibrator has approximately a 1-μsec risetime. Thus with the calibrator signal, an RC time of 1 μsec should be selected as a starting value. The VOLTS/CM switch can then be set to permit the display to be viewed. If necessary, the time constant can be changed to permit a better display. (Normally, the smaller values of capacitance will produce better results.)

Sample Differentiation Setup

1. Connect the oscilloscope Amplitude Calibrator to the A INPUT connector and adjust the calibrator for a 1-volt output.
2. Set the Z_i control to 10 pf and the Z_f control to 0.1 MEG. These values produce a time constant of 1 μsec.
3. Set the ± GRID SEL switch to (—).

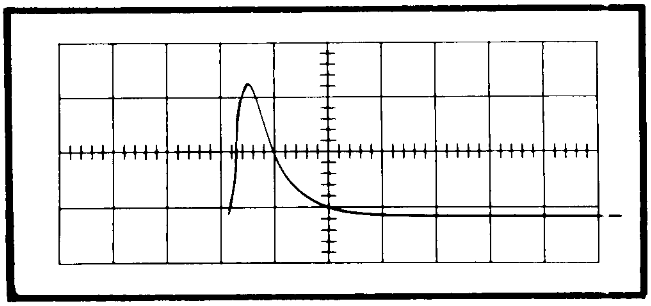


Fig. 2-3. Differentiated oscilloscope-calibrator signal; 1-µsec/cm sweep rate.

4. Set the VOLTS/CM switch to .5 and the Oscilloscope TIME/CM switch to 1 µSEC.

The display should be a differentiated waveform, as shown in Fig. 2-3.

Observe the effects of other RC combinations. It is important to use the lower capacitance values in order to minimize circuit loading. There will be minor differences in the waveforms obtained with various RC combinations. This is true even for simple RC differentiators that produce the same time constant.

Integration

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

$$e_o = -\frac{1}{R_iC_f}\int e_i\,dt.$$

The output voltage is inversely proportional to the time constant and directly proportional to the integral of the input voltage.

Sample Integration Setup

1. Connect the oscilloscope Amplitude Calibrator to the A INPUT connector and adjust the calibrator for a 1-volt output.
2. Set the Z_i control to 1 MEG, Z_f to .001 µf, and the INTEGRATOR LF REJECT switch to 1 CPS.
3. Set the ±GRID SEL switch to (—).
4. Set the VOLTS/CM switch to .2 and the oscilloscope TIME/CM switch to .5 mSEC.

The display should be on integrated calibrator signal, as shown in Fig. 2-4.

The time constant of the values chosen is 1 millisecond, the period of the Amplitude Calibrator waveform. Try other values of R and C which produce the same time constant. Then try other time constants to see the effect of changing the time constant.

With a good integrated calibrator waveform displayed, set the INTEGRATOR LF REJECT switch to OFF. The oscilloscope trace will probably deflect off the screen. If this happens, it is because of dc components in the input signal and/or inherent drift in the integrator. The 1 CPS position of the INTEGRATOR LF REJECT switch is used to prevent dc components and drift from being integrated. This allows ac components to be integrated while permitting the trace to remain on the screen. A 1 KC position of the INTEGRATOR LF REJECT switch is also provided. The 1 KC position permits elimination of low-frequency noise and power line hum pickup from integration in the medium- to high-frequency range.

Gain-Frequency Characteristics of Differentiator and Integrator

As stated in the Characteristics section, the Type O Operational Amplifiers have an open-loop gain-bandwidth product of 15 mc. This means the open-loop gain will drop from 2500 at low frequencies to unity at 15 mc.

It is also important to know the gain-frequency characteristics for both integration and differentiation. Chart 2-2 illustrates the gain-frequency characteristics for most Z_i and Z_f control settings for both integration and differentiation. This information can be used by the operator to avoid inaccurate measurements from erroneous waveforms due to gain-bandwidth limitations for each mode of operation.

Output Connections

Each of the three basic operational amplifier applications just described were employed by the oscilloscope crt. The Type O Unit front panel has two OUTPUT connectors, one of which is suited for coaxially connecting any application output signal to an external device.

The OUTPUT terminal located to the left of the Z_i-Z_f SELECTOR switches is available for connection of external feedback components that can augment the internal values of the Z_f selector switch. This OUTPUT connector is in parallel with the coaxial OUTPUT connector located to the right of the Z_i-Z_f SELECTOR switches. Either of these OUTPUT terminals can be used for external connection of one operational amplifier to the other operational amplifier INPUT. Or, the coaxial OUTPUT connector can be conveniently used to drive a 50 Ω coaxial cable to a fairly remote system requiring the use of one of the features of an O Unit operational amplifier. The output impedance is low enough to drive a 50 Ω coax with a reasonably good im-

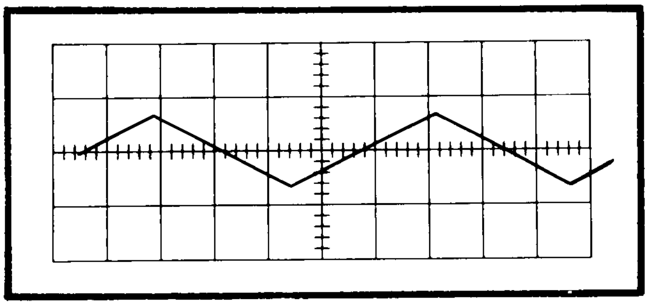


Fig. 2-4. Integrated oscilloscope-calibrator signal; 0.5-µsec/cm sweep rate.

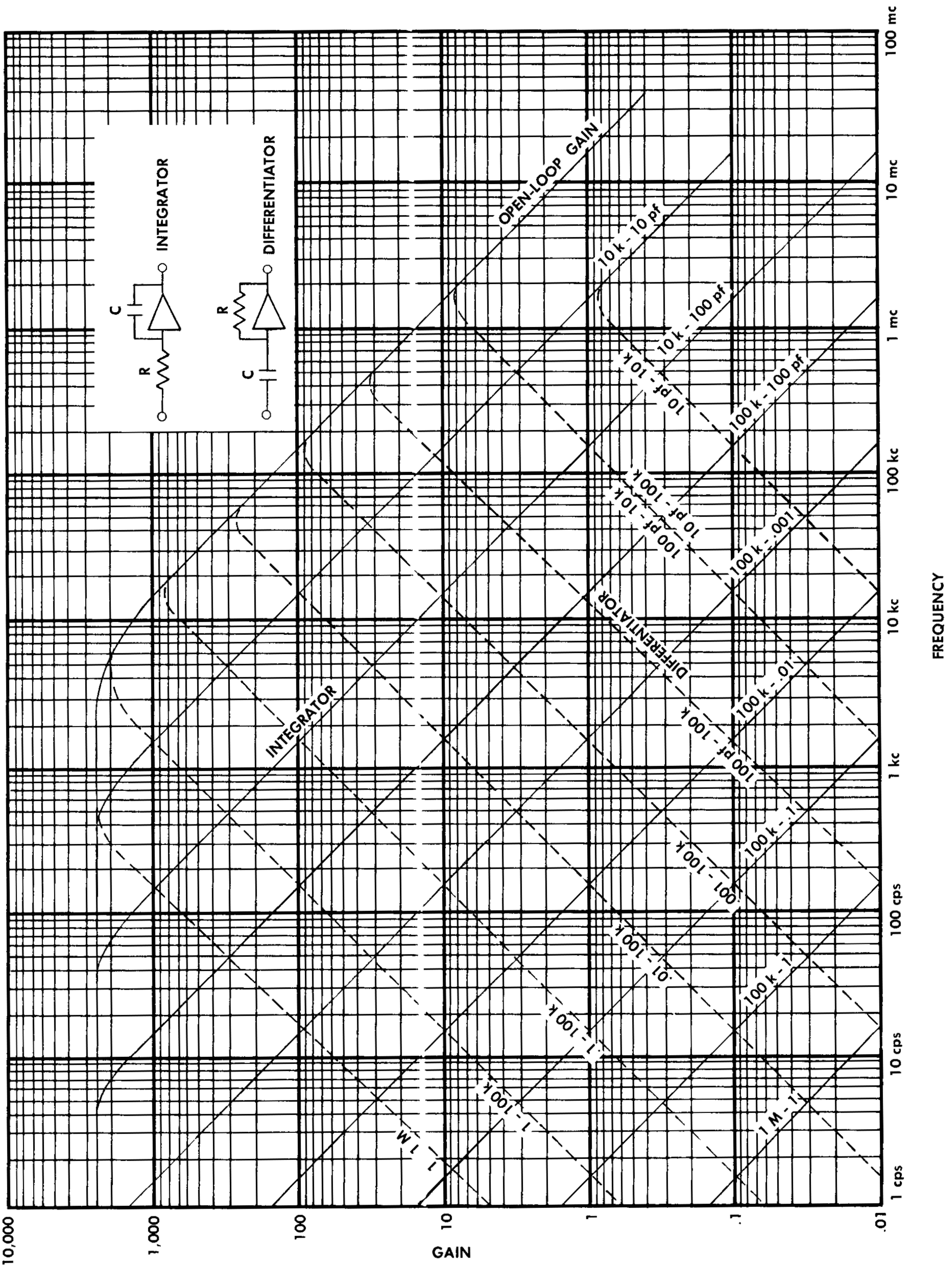


Chart 2-2. Average Gain-Frequency Characteristics for integration and differentiation.

pedance match throughout the frequency response limits of the operational amplifier.

Signal Connection Precautions

Certain precautions should be taken in connecting signals to the input of the operational amplifiers to assure good results. First, when dealing with low level signals it may frequently be necessary to use shielded leads in order to minimize stray pickup. This is particularly important when the unit is used for differentiation. High-frequency noise is particularly troublesome with differentiation since the output of the differentiator is proportional to frequency. Whether shielded leads are required for a particular application can usually be determined from the resulting oscilloscope display.

Precautions for connecting signals to the preamplifier are similar to those which must be observed for the operational amplifiers. When using only the preamplifier, avoid errors in readings by guarding against stray electric or magnetic coupling between circuits, particularly in the input signal leads. In general, unshielded leads of appreciable length are unsuited for this use. This is true even in the audio-frequency range. Shielded input cables are recommended for signal measurements when signals are obtained from a high-impedance source, or when leads are long. When shielded leads are used, the shields should be securely grounded to the chassis of both the signal source and the oscilloscope.

In broadband applications, it may be necessary to terminate signal cables to prevent ringing and standing waves in the cable. The termination is generally placed at the oscilloscope end of the cable, although some sources also require a termination at the source end.

As nearly as possible, simulate actual operating conditions in the equipment being tested by permitting it to work into a normal load.

Consider the effect of loading upon the signal source due to the input circuit of the preamplifier. The input impedance of the preamplifier is 1 megohm to ground, paralleled by 47 pf. With a few feet of shielded cable, the capacitance may well be 100 pf. Where the effects of these resistive and capacitive loads are not negligible, it may be necessary to use a probe to lessen their effect.

Use of Probes with the Type O Unit

Standard Tektronix probes can be used with the preamplifier of the Type O Unit. When used, the probes must be connected to the EXT. INPUT connector.

When probes with 10× or more attenuation are used, they must first be properly compensated for high-frequencies. This compensation is most easily accomplished using the oscilloscope Amplitude Calibrator signal.

To compensate the probe, first obtain a display of the calibrator signal on the crt. Then adjust the probe compensation control for the squarest possible corners on the displayed waveform. This condition results when the undershoot or overshoot has been reduced to a minimum.

The attenuation factor of the probe must be considered when measurements are made. The vertical deflection factor of the O Unit is effectively increased by the attenuation factor of the probe. When a 10× probe is used with a VOLTS/CM switch setting of 5, the actual deflection factor is 50 volts per centimeter.

Probes reduce both capacitive and resistive loading on the signal source. They also permit larger signals to be displayed than would otherwise be possible.

Attenuator probes are not normally used with the operational amplifiers, because of the variable input characteristics. A special case, however, is illustrated in Fig. 2-5. This application is used when it is necessary to obtain the signal from a high-impedance circuit and deliver it to a low-impedance load without attenuation. To permit the use of a 10× probe, the operational amplifier input must look like the input to the preamplifier; that is, 1 megohm paralleled by 47 pf.

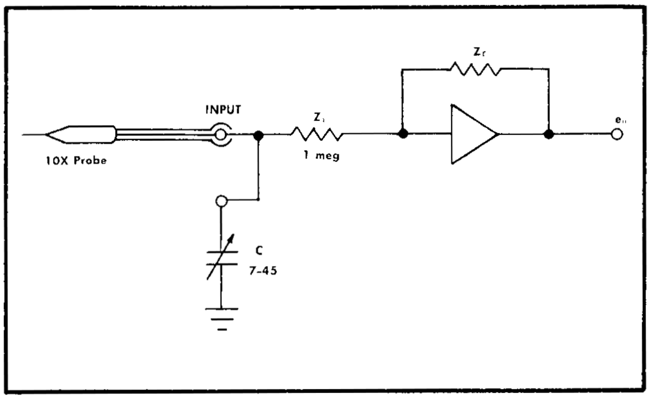


Fig. 2-5. Special case of a 10X probe used with an operational amplifier.

Fig. 2-5. shows an internally selected Z_i of 1 megohm, with an externally connected variable capacitor. By using an external feedback resistor (Z_f) of 10 megohms, the amplifier gain will be 10, although the probe attenuation of 10 makes the overall gain unity.

Using the oscilloscope Amplitude Calibrator, the external capacitor can be adjusted to compensate the system for optimum response (as explained earlier).

This system now appears as a dc-coupled 10-megohm probe, without attenuation, having a very low input impedance.

The OUTPUT connector can be coaxially connected to an external system requiring the low output impedance probe just described.

Connection of Signals to the ± GRID Jack

The ± GRID jack can be used to connect signals to either input grid of the operational amplifiers. When the ± GRID SEL switch is in the (—) position, signals connected to the ±GRID jack are applied to the —grid; when the ±GRID SEL switch is in the (+) position, signals connected to the +GRID jack are applied to the +grid. (Signals connected to the −GRID jack are always applied to the −grid, regardless of the ±GRID SEL switch setting.) Signals applied to the −grid are inverted at the output of the amplifier; signals applied to the +grid are not inverted.

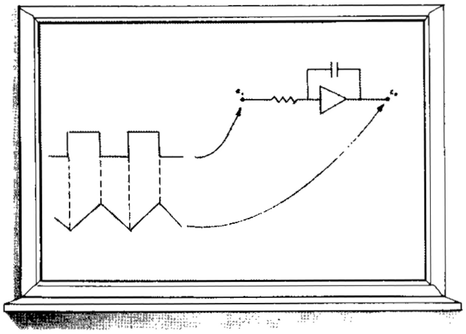
When using the +grid, both grids can be active, as in a differential amplifier. Three ways the −grid can be connected (when using the +grid) are: (a) 100% feedback from the output to the −grid; (b) −grid grounded; and (c) a feedback element connected from the output to the −grid. Each of the three −grid circuits affects the operational amplifier characteristics when driving the +grid. It is safe to say that when the ±GRID SEL switch is at +), both the − and + grid circuits must be planned and properly connected.

Input signals applied to either grid through either the −GRID or +GRID jacks bypass the internal input impedances and are therefore not affected by settings of the Z control.

Access to the +grid increases the versatility of the Type O Unit over conventional operational amplifiers and permits its use in certain applications where it could not otherwise be used. Thus external components can be used to provide positive rather than negative feedback to the operational amplifier. Some applications for using the + grid input to the operational amplifiers are described in the Applications section of this manual.

Connecting External Feedback Components

It will occasionally be necessary to mount external feedback components on the O Unit. This is necessary because of the limited number of components which may be mounted internally. A convenient means for mounting these parts is through the use of the adapter board received with your Type O Unit. The parts can easily be installed on the adapter board and the connectors can then be inserted in the jacks on the front panel of the O Unit. A shield should be placed over the adapter board to prevent stray signal pickup. The standard $^3/_4$" spacing of the jacks on the front panel of the O Unit also permits use of double banana plug connectors, such as General Radio Type 274-B. See the Accessories section of this manual for additional component mounting devices.



SECTION 3

APPLICATIONS

Operational Amplifiers

An operational amplifier is a very high-gain, direct-coupled amplifier having out-of-phase input-output characteristics (180° phase shift) which permits negative feedback. Since the open-loop gain of the amplifier is very high, closed-loop characteristics can be controlled by feedback components within the frequency and gain limits of the amplifier. (See Error Factor discussion on pages 2-3, and 4-1.)

The output level of the operational amplifiers is normally at dc ground so that two or more may be cascaded to perform successive operations.

Normally, resistors and capacitors are used as input and feedback components. By selecting proper feedback networks, many operations including linear amplification by a constant, summation of two or more signals, and integration and differentiation of voltage waveforms with respect to time, can be performed.

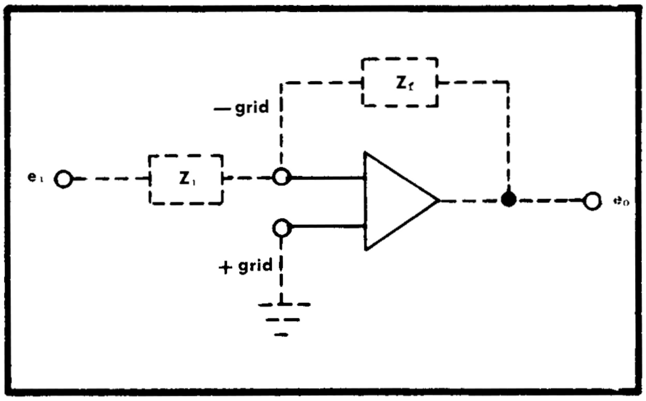


Fig. 3-1. Operational amplifier symbols.

A symbol frequently used for an amplifier is a triangle with the vertex pointing in the direction of signal flow (see Fig. 3-1). This symbol is used throughout the manual to represent the operational amplifiers. Note that Fig. 3-1 is drawn with both a + grid and a — grid. Signals applied to the — grid are inverted at the output, while signals applied to the + grid arrive at the output with the same polarity. The — grid is normally used in an operational amplifier because the inverted output permits the use of negative feedback through the Z_f feedback components. When not used, the + grid is grounded and will be omitted from diagrams.

The most basic form of an operational amplifier, illustrated in Fig. 3-2, is a time insensitive circuit that includes both negative and positive feedback. While many versions of the basic form can be used in time insensitive circuits, the four most common forms are: (1) an input voltage generates an output voltage; (2) an input voltage generates an output current; (3) an input current generates an output voltage; and (4) an input current generates an output current. These four basic Operational Amplifiers are illustrated in Fig. 3-3, and various forms appear in the applications that follow.

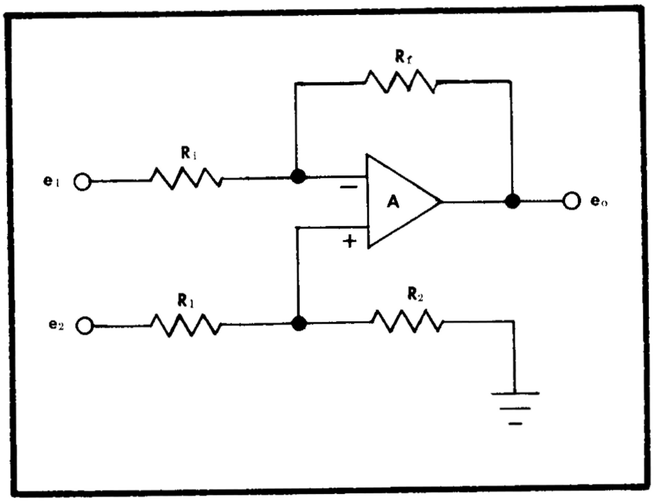


Fig. 3-2. Basic form of operational amplifier with both negative and positive active grids.

Virtual Ground

The dc level at the — grid input of an operational amplifier is very close to ground. When an input signal is applied, the signal tends to move the grid away from ground. However, the negative feedback from the output of the amplifier resists this tendency. The amount that the — grid voltage varies with a signal is dependent on the open-loop gain of the amplifier; the higher the gain, the less the — grid voltage varies. With the high open-loop gain normally encountered in an operational amplifier, the — grid voltage varies only slightly under closed-loop conditions. Therefore, it is convenient to assume that for all practical purposes the — grid voltage does not change with signal.

Since the — grid voltage remains essentially constant with input signal changes, it appears as though the — grid

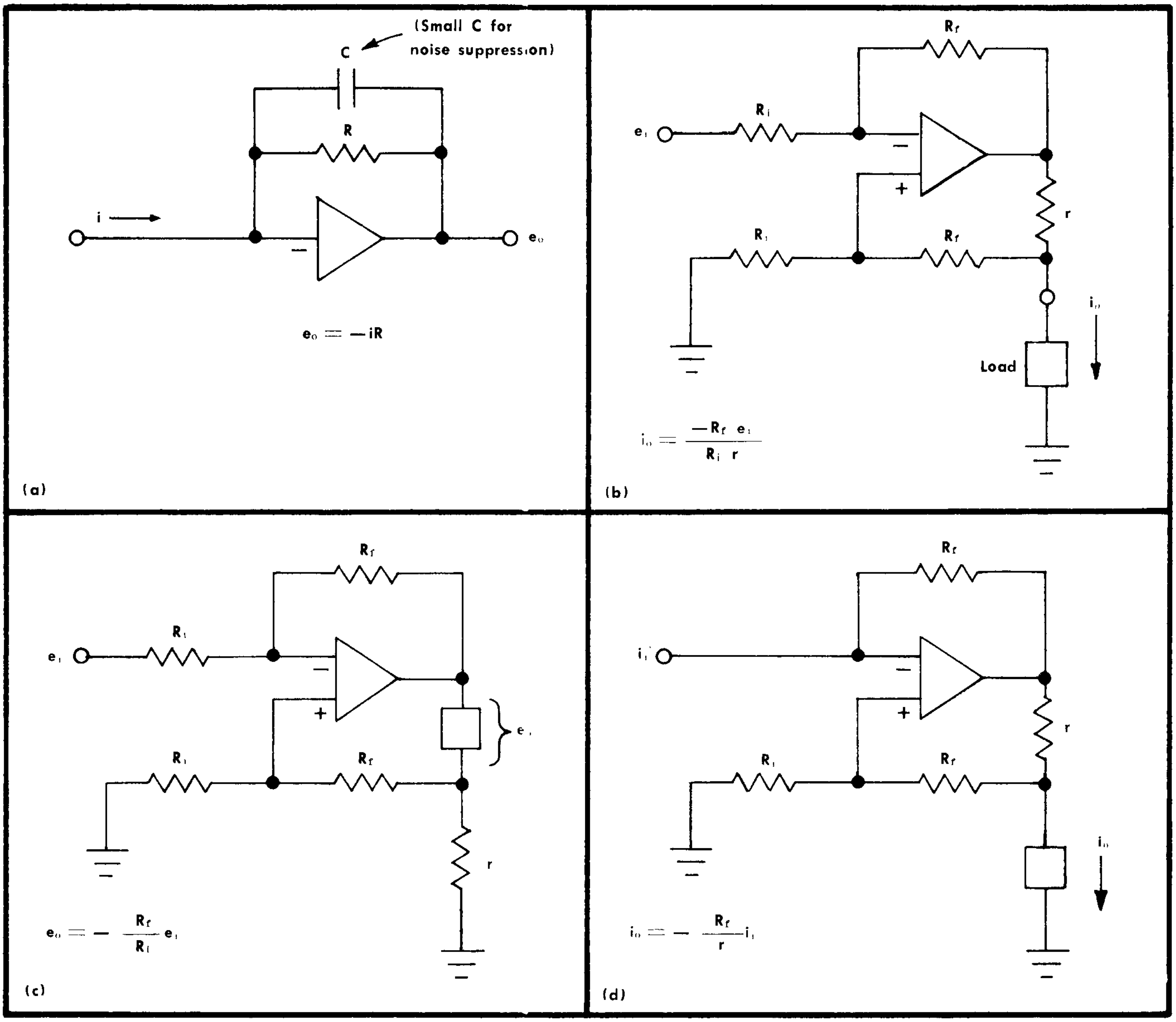


Fig. 3-3. Operational amplifiers in Voltage-Current conversions (a) $i_{in}/-e_{out}$; (b) $e_{in}/-i_{out}$; (c) $e_{in}/-e_{out}$; (d) $i_{in}/-i_{out}$.

is grounded. Thus, a virtual ground can be considered to exist at the — grid input. The word "virtual" is used to indicate that although the input of the amplifier appears to be grounded, it actually is not. Many equations for the functions performed by an operational amplifier can be most easily derived by use of the concept of a virtual ground.

It should also be noted that since a virtual ground exists at the — grid, the input impedance of the amplifier is essentially determined by the value of the Z_1 component.

Formulas and their derivation for finding the true input impedance at the — grid are presented in Section 4 of this manual.

TYPICAL APPLICATIONS

The remainder of this section explains typical applications for the O Unit operational amplifiers. The circuit for each application is shown, along with a brief discussion of the circuit and method of use. Most circuits are typical only, and not necessarily the only configurations that can be used. Modifications of these basic circuits may be employed to adapt the O Unit for individual needs.

The derivation of the equations relating to these applications will be found in Section 4. Equations indicating the operation of a particular circuit were derived assuming infinite open-loop amplifier gain. In most cases this assumption is quite good and calculations will be very close to conditions actually obtained. In practical applications it may be necessary to consider several factors such as open-loop and gain-frequency characteristics, stray capacity, and the output impedance of the signal source. The input impedance of the operational amplifier is really a combination of the signal source impedance and the impedance selected by the Z_i control. If the output impedance of the signal source is low, it can usually be ignored.

Applications Index

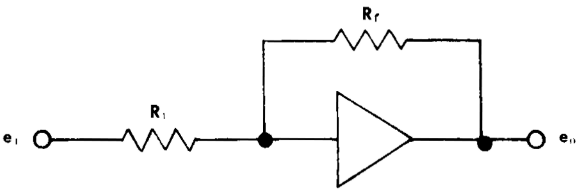
1. Amplification by a Constant
2. Integration
3. Differentiation
4. Summation
5. Unity-Gain Amplifier with High Input Impedance
6. High Input Impedance Amplifier
7. Subtractor and/or Difference Amplifier
8. Voltage to Current Converter
9. Voltage to Voltage Amplifier
10. Bandpass Amplifier
11. Flip-Flop Multivibrator
12. Logarithmic Amplifier
13. Logarithmic Amplifier (fast response)
14. Limiter Amplifier
15. Expansion Amplifier
16. Clipper Circuit
17. Frequency to Voltage Converter
18. Peak-Reading Amplifier
19. Very Low Current Measurements
20. Capacitance Measurements
21. Gated Amplifier
22. Gated Integrator
23. Stair-step Generator
24. Function Generator
25. Low-Frequency Sine Wave Generator
26. Segments Function Generator
27. CRT Arbitrary Function Generator
28. Displaying B-H Curves for Magnetic Materials

Description and Additional Information

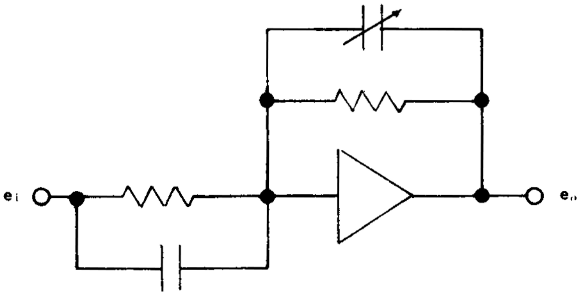
1. Amplification by a Constant

This circuit is useful for providing amplification by a desired constant. The closed-loop gain is determined by the feedback components within the frequency and gain limits of the amplifier. Either internal or external feedback components may be used to provide the desired constant gain.

The output of the amplifier in this configuration is inverted. This makes the amplifier useful as a sign changer, with or without amplification. Applications 5 and 6 show circuits which can be used if inversion of the input signal is not desired.



For low frequencies



Compensated for high frequencies

$$e_o = -\frac{R_f}{R_i} e_i$$

1. Amplification by a Constant

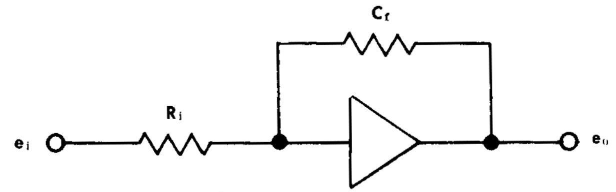
The circuit can be made to provide variable gain by replacing the feedback resistor with a potentiometer. As the potentiometer setting is changed, the gain of the amplifier will also change. Replacing R_f with a potentiometer will allow the input impedance of the amplifier to remain essentially constant while permitting the gain to be varied.

The fixed resistors may also be replaced by thermistors, photoresistors, or other variable-resistance elements. The gain will then be a function of the temperature, light level, or other variable.

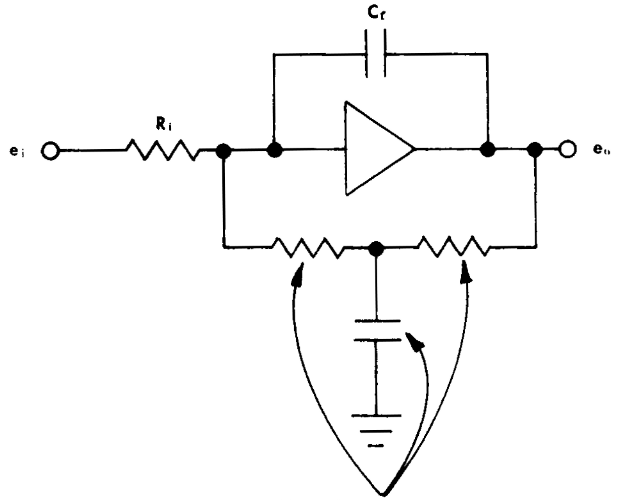
2. Integration

Integration of various signals can be accomplished by means of the Application 2 circuit. Feedback elements shown in the diagram may be selected from internal values or connected externally. The output voltage from the integrator is inversely proportional to the time constant of the feedback network and directly proportional to the integral of the input voltage. A good starting point in any integration application is to make the R_iC_f time constant approximately equal to the period of the signal to be integrated.

This basic circuit integrates not only the ac components of signals, but the dc components and drift as well. Integration of dc components or amplifier drift will cause the trace to gradually drift off the crt. To prevent this condition when integrating repetitive signals, an integration low-frequency rejection circuit is incorporated in each operational amplifier of the Type O Unit. This circuit prevents the integration of component signals with frequencies lower than approximately 1 cps or 1 kc, depending on the setting of the INTEGRATOR LF REJECT switch.

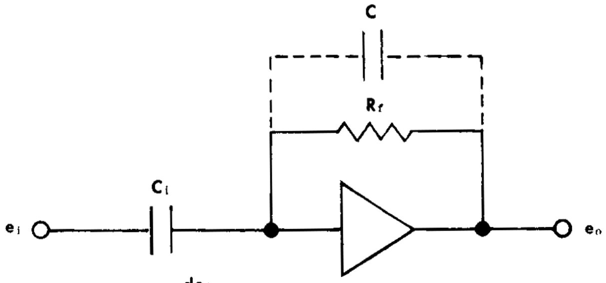


$$e_o = -\frac{1}{R_i C_f}\int e_i \, dt$$



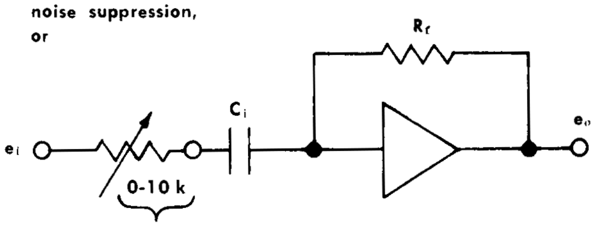
To reduce integration of low-frequency signals and/or drift.

2. Integration



$$e_o = -R_i C_f \frac{de_i}{dt}$$

Add $C = C_i/100$ for noise suppression, or



Alternate method of noise suppression

3. Differentiation

The integrator circuit can be used as a precision 90° phase shifter within the frequency limits of the amplifier. Sine waves applied to the input of the integrator are shifted in phase by exactly +90°.

In some applications it may be desirable to start and stop the integration at a known time interval. This type of integrator is discussed as the Gated Integrator, Application 22.

3. Differentiation

The output voltage of the differentiation circuit is inversely proportional to the feedback time constant and is directly proportional to the time rate of change of the input voltage. In practical applications, the R_fC_i time constant will have to be chosen somewhat on a trial and error basis to obtain a reasonable output level. A good starting point, however, is to make the time constant approximately equal to the risetime of the signal to be differentiated.

Differentiation permits slight changes in input slope to produce very significant changes in the output. An example of the usefulness of this feature would be in determining the linearity of a sweep-sawtooth waveform. Nonlinearity results from changes in the slope of the waveform. Therefore, if nonlinearity is present, the differentiated waveform indicates the points of nonlinearity quite clearly. Repetitive waveforms with a rise and fall of differing slopes can show erroneous waveforms. Under such conditions it is best to view the waveform using the oscilloscope SINGLE SWEEP mode.

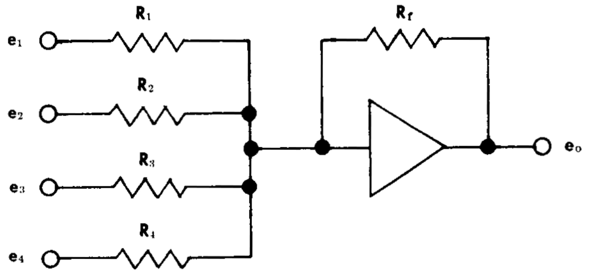
The output voltage of the differentiator is directly proportional to the frequency of the input signal (within the frequency limits of the circuit). This permits the differentiator to be used as a frequency to voltage converter. The frequency of an unknown signal can be determined by comparing the amplitude of the output voltage to that obtained using a known input frequency. The oscilloscope graticule can be calibrated, if desired, for frequency per centimeter. A constant-amplitude input signal must be used in this application, to prevent changes in amplitude from disturbing the measurement.

Differentiation of a sine wave results in a 90° phase shift at the output of the differentiator. The circuit can thus be used as a precision 90° phase shifter within its frequency limits. The output of the differentiator is shifted by —90° as opposed to +90° for the integrator circuit.

In general, differentiation accentuates high-frequency noise; if this is objectional, a noise suppression capacitor may be placed in the feedback circuit, or a resistor in the input circuit, to limit the high-frequency response above the signal frequency.

Conversely, in some applications a differentiator may be advantageously used to detect the presence of distortion or high-frequency noise in the signal. A differentiator can often detect hidden information that could not be detected in the original signal.

4. Summation



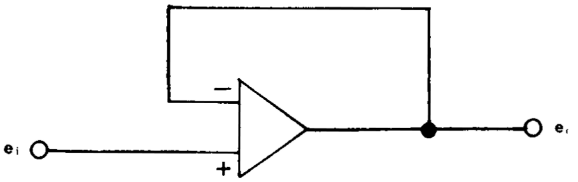
$$e_o = -\left(\frac{R_f}{R_1}e_1 + \frac{R_f}{R_2}e_2 + \frac{R_f}{R_3}e_3 + \frac{R_f}{R_4}e\right)$$

When $R_1 = R_2 = R_3 = R_4 = R_f$,
then $e_o = -(e_1 + e_2 + e_3 + e_4)$

4. Summation

Summation of a number of voltages can be accomplished with the Application 4 circuit. The feedback resistor R_f can be selected from internal values, however it will be necessary to provide external input resistors. When the values of all resistors are the same, the output of the amplifier is the inverted sum of all of the input voltages. By proper resistor selection, many input voltages can be amplified at the output, limited only by the ability of the output to swing either ±50 volts or ±5 ma.

5. Unity-Gain Amplifier with High Input Impedance



$e_o = e_i$

5. Unity-Gain Amplifier with High Input Impedance

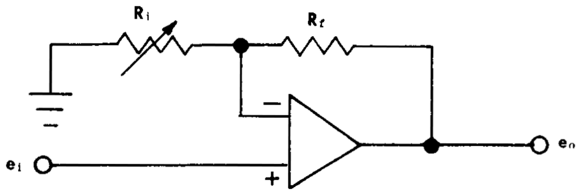
NOTE

The following method of determining input impedance signifies a concept only, and is not necessarily valid for all circuit configurations.

In this circuit, a gain of +1 is obtained. The input signal is applied directly to the +grid with feedback applied from the output to the −grid. Since the signal is applied directly to the +grid, and since there are no resistance elements between it and ground, the input impedance of the circuit is determined primarily by the grid current. This current is on the order of 0.3 nanoampere (see Characteristics Section) for signals of less than about ±10 volts; thus the input impedance is on the order of 10,000 megohms. For signals of ±1 v, the input impedance is on the order of 1000 megohms. This is, of course, the dc impedance. For ac signals, the shunt capacitance brings the impedance down to a much lower level. The input impedance varies with the input voltage (assuming $R_i = e_i/i_g$) since the grid current (i_g) remains relatively constant.

The feedback to the −grid insures a gain of 1 at the amplifier output.

6. High Input Impedance Amplifier



$$e_o = \frac{R_i + R_f}{R_i}\,e_i$$

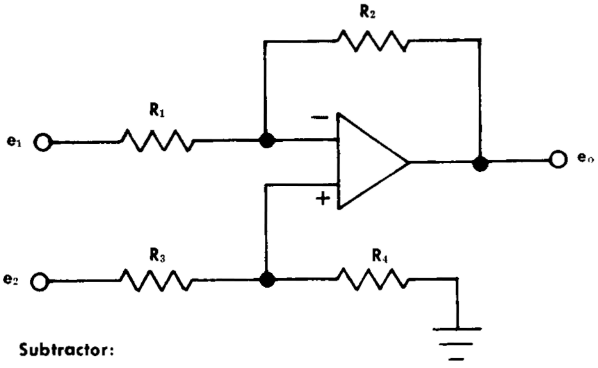
6. High Input Impedance Amplifier

The high input impedance feature of the previous circuit is combined with gain in this circuit. The gain is positive and is determined by the formula shown with the diagram.

In this circuit, the signal is again applied directly to the +grid with feedback from the output to the −grid. The amount of feedback is controlled by the values of R_i and R_f. Note that it is not possible to obtain a gain of less than one with this circuit.

Both R_i and R_f can be selected from internal values. If internal values are used, it will be necessary to externally ground the A INPUT connector in order to ground one end of R_i.

7. Subtractor and/or Difference Amplifier



Subtractor:

$$e_o = -\frac{R_2}{R_1}e_1 + \left[\frac{R_4}{R_3 + R_4}\right]\left[\frac{R_1 + R_2}{R_1}\right]e_2$$

Difference (special case)
When $R_1 = R_2 = R_3 = R_4$,
then $e_o = e_2 - e_1$

7. Subtractor and/or Difference Amplifier

One signal voltage can be subtracted from another through simultaneous application of signals to both grids of the amplifier, as shown in the preceding diagram. The signal applied to the − grid is subtracted from the signal applied to the +grid.

If the values of the resistors are not all the same, the gain of the amplifier for signals applied to the +grid is

$$\frac{R_1 + R_2}{R_1} \times \frac{R_4}{R_3 + R_4}.$$

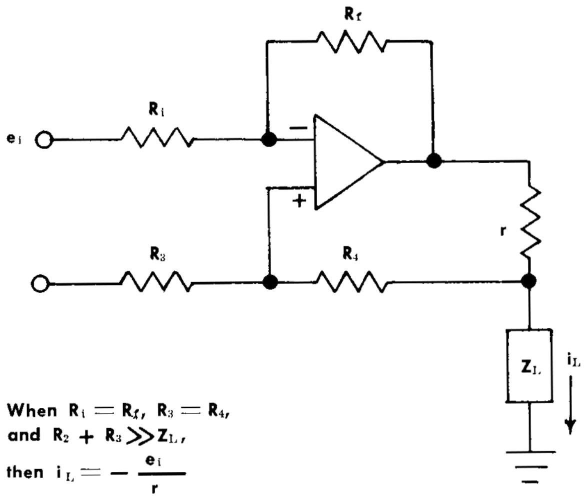
Gain of the amplifier for signals applied to the − grid is $-R_2/R_1$. Through use of these two equations, a desired amplification can be combined with the subtractive process shown by the generalized expression,

$$e_o = -\frac{R_2}{R_1} e_1 + \left(\frac{R_1 + R_2}{R_1}\right)\left(\frac{R_4}{R_3 + R_4}\right) e_2.$$

In this application, the amplifier is used essentially as a difference amplifier.

A difference amplifier may be operated with compensated frequency response by adding small variable capacitors across R_3 and R_4 of the preceding circuit. This permits balancing the time constants, extending the usable bandpass of the difference amplifier. In cases where all resistors are not equal, compensation for high frequencies may be accomplished by making all time constants equal.

8. Voltage to Current Converter (Transadmittance Amplifier)



When $R_1 = R_f$, $R_3 = R_4$, and $R_2 + R_3 \gg Z_L$, then $i_L = -\frac{e_1}{r}$

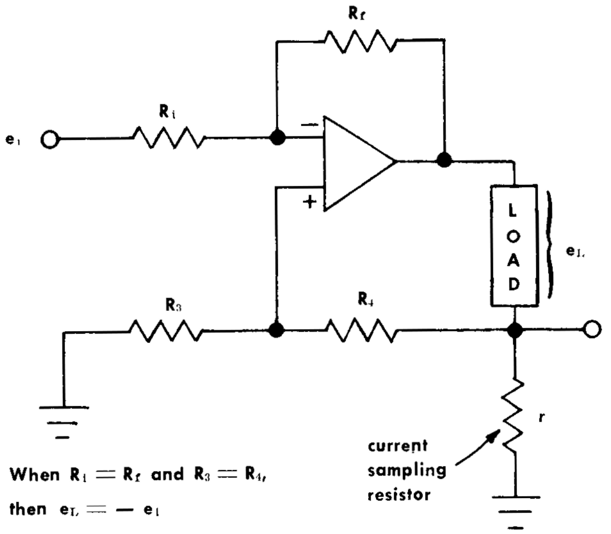
8. Voltage to Current Converter

This circuit can be used to supply a current to a load which is proportional to the voltage applied to the input of the amplifier. The current supplied to the load is relatively independent of the load characteristics. This circuit is essentially a current feedback amplifier. Load current is limited to ±5 ma.

A current sampling resistor is used to provide the feedback to the +grid. When $R_1 = R_f = R_3 = R_4$, the feedback maintains the voltage across r at a value $-R_f/R_i \times e_i$ regardless of the load. If a constant input voltage is applied to the input of the amplifier, the voltage across r also remains constant regardless of the load. If the voltage across r remains constant, the current through r must also remain constant. With R_3 and R_4 normally much higher than the load impedance, the current through the load must remain nearly constant regardless of its impedance.

The values of R_i, R_f, R_3, and R_4 should normally be the same (1 megohm for each is satisfactory). The current sampling resistor is then selected for the desired load currents. The current through the load $i_L = e_i/r$ milliamperes per volt of signal when r is expressed in kilohms. The value of r should be selected to limit the maximum current drawn from the operational amplifier to less than 5 ma.

9. Voltage to Voltage Amplifier (Voltage Gain Amplifier)



When $R_1 = R_f$ and $R_3 = R_4$, then $e_L = -e_1$

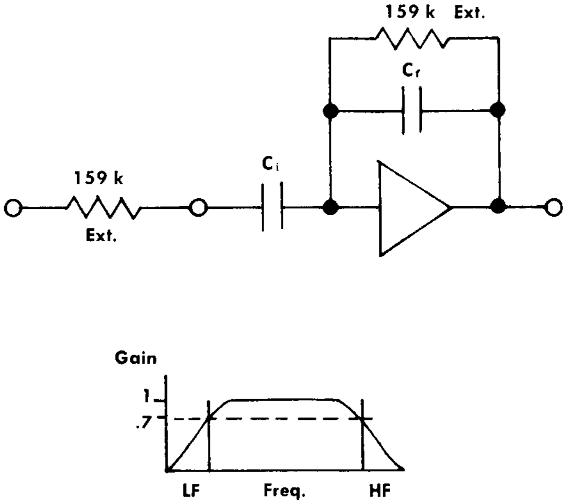
9. Voltage to Voltage Amplifier

This circuit is similar to the voltage to current converter described previously, except that the load is now placed where the current sampling resistor was in the previous circuit. With $R_i = R_f = R_3 = R_4$, the feedback to the + grid maintains the voltage across the load equal to minus the input voltage regardless of load (within the current limitations of the amplifier). Operation of the circuit is essentially the same as that of the voltage to current converter.

Since the voltage across the load is equal to the input voltage, sweeping the input voltage results in the voltage across the load also being swept. A voltage proportional to the current through the load can be obtained across r. The combination of the voltage across the load and the current through r can then be used to display the characteristic curves of devices such as tunnel diodes.

When using this circuit, care should be taken in adjusting the input voltage and/or load impedance so that the ±5 ma rating of the operational amplifier is not exceeded.

10. Bandpass Amplifier



10. Bandpass Amplifier

An operational amplifier can be applied as a bandpass amplifier with proper input and feedback elements. The adjacent circuit illustrates an example with only the addition of two external resistors. The C_i and C_f capacitors are internally chosen. The bandpass curve shown with the circuit illustrates an RC rolloff at each end of the bandpass with the signal amplitude dropping 6 db per octave. To make such a system guassian, with a rolloff of 12 db per octave after the 3 db down point, two bandpass amplifiers can be cascaded.

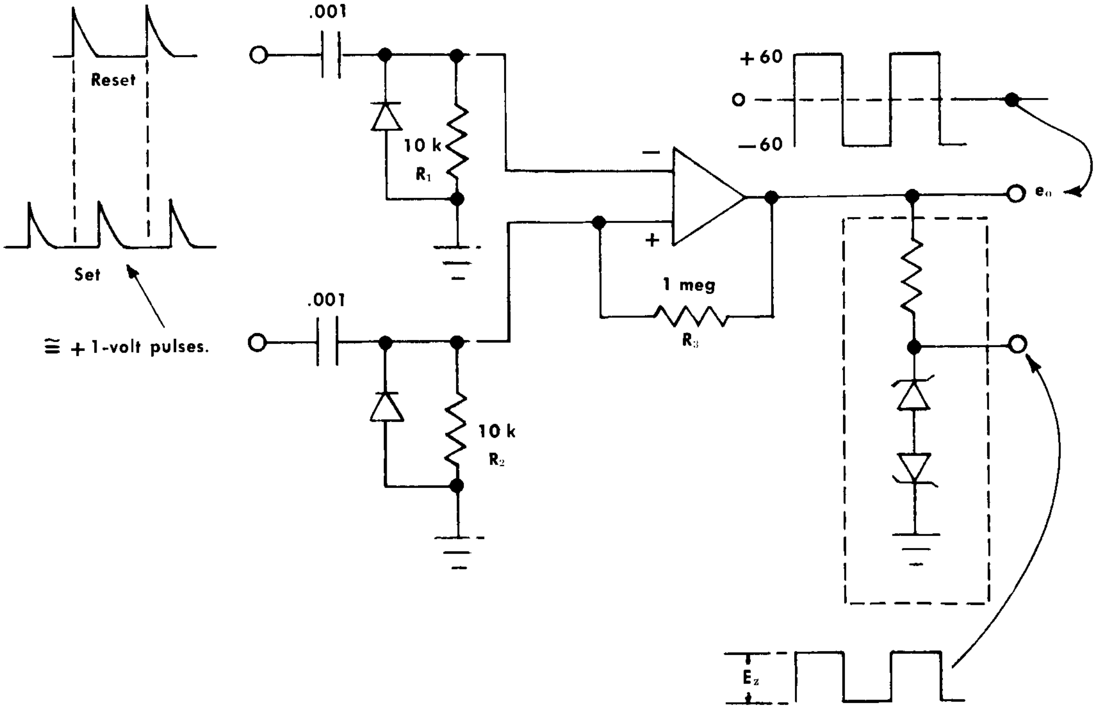
The principle of operation of the bandpass amplifier is that the input series R and C attenuate low frequencies, and the feedback parallel R and C attenuate high frequencies. The maximum gain, in the flat area of the frequency response curve, is unity with the following suggested values:

C_i and C_f, for —3-db frequency values, when external resistors are 159 k.

L. F.	C_i	*H. F.*	C_f
1 c	1 μf	100 kc	10 pf
10 c	.1 μf	10 kc	.0001 μf
100 c	.01 μf	1 kc	.001 μf
1 kc	.001 μf	100 c	.01 μf
10 kc	.0001 μf	10 c	.1 μf
100 kc	10 pf	1 c	1 μf

11. Flip-Flop Multivibrator

In the flip-flop multivibrator circuit, +1-volt or greater pulses are applied to both the + and — grids. When



11. Flip-Flop Multivibrator

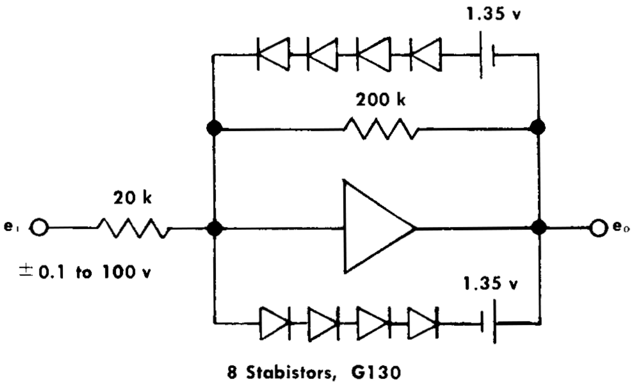
the multivibrator is flipped to one state of conduction by application of a pulse to one of the grids, it remains in that state of conduction until a positive pulse is applied to the other grid.

The output of the multivibrator is a series of positive and negative pulses approximately 50 volts in amplitude. This circuit is useful to approximately 10 kc. The sensitivity of the circuit can be changed to satisfy application requirements. The circuit can be made more sensitive by increasing the ratio of R_3 to R_2.

Waveforms shown on the circuit drawing as e_o are idealized. To obtain flat tops and bottoms on the output waveforms use a double Zener output circuit, as indicated by the dotted area below the e_o terminal.

12. Logarithmic Amplifier

In many applications it is desirable to have a device whose output is proportional to the logarithm of the input. However, a practical amplifier cannot give a true logarithmic response because of two primary limitations: (1) the logarithm of zero is —infinity, thus a true logarithmic amplifier would have an output of —infinity with zero input; (2) the logarithm of a negative number is not defined, therefore a true logarithmic amplifier could not accept negative input signals.



$$e_o = -[0.7 + (0.35 \log_{10} e_i)]$$

12. Logarithmic Amplifier

An approximate logarithmic output can be obtained from the indicated circuits; the relation between input and output is shown in the equation under the diagram.

The stabistors shown provide feedback which produces the logarithmic output response for input voltages between ±0.1 and ±100 volts.

13. Logarithmic Amplifier (fast response)

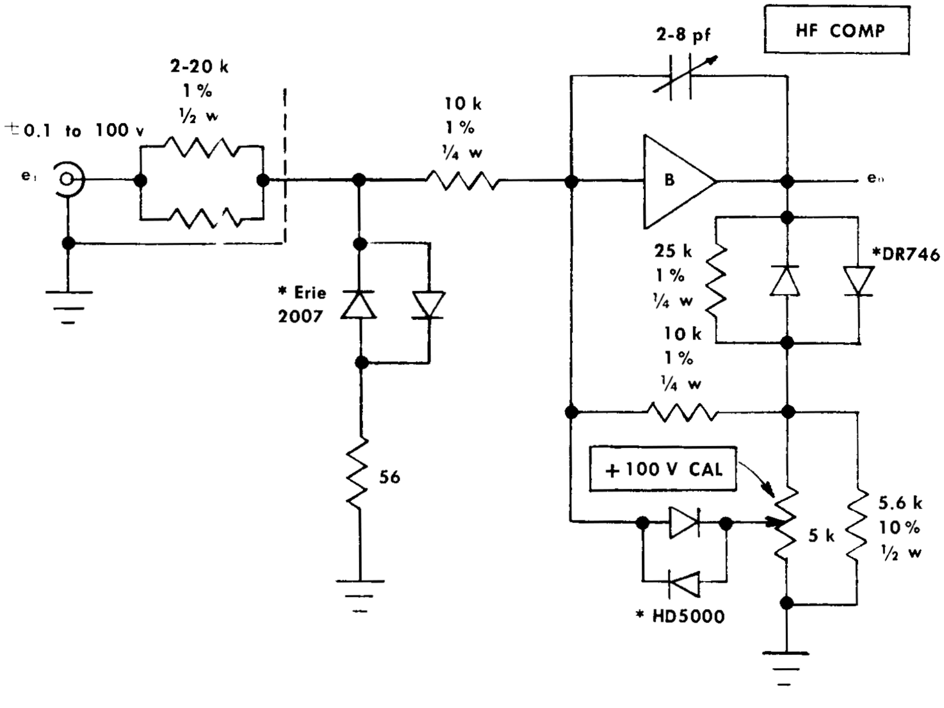
This circuit performs with a much faster logarithmic response than circuit 12. It operates to a higher frequency, employing high-frequency components and circuitry.

The amplifier is essentially logarithmic from ±0.1 volt to ±100 volts. It is not logarithmic with signals less than about ±0.08 volt.

When calibrated, the amplifier has a gain of 3 for very low-level signals. At a signal level just under 0.1 volt, the gain is approximately 1.4, and continues to drop logarithmically with increased signal.

Calibration is accomplished by using the oscilloscope AMPLITUDE CALIBRATOR and a Type 105 Square-Wave Generator with a 93 Ω cable and termination as signal sources.

1. Let the O Unit warm up for 10 to 15 minutes. Plug the logarithmic amplifier into the B operational amplifier.



* Matched pairs

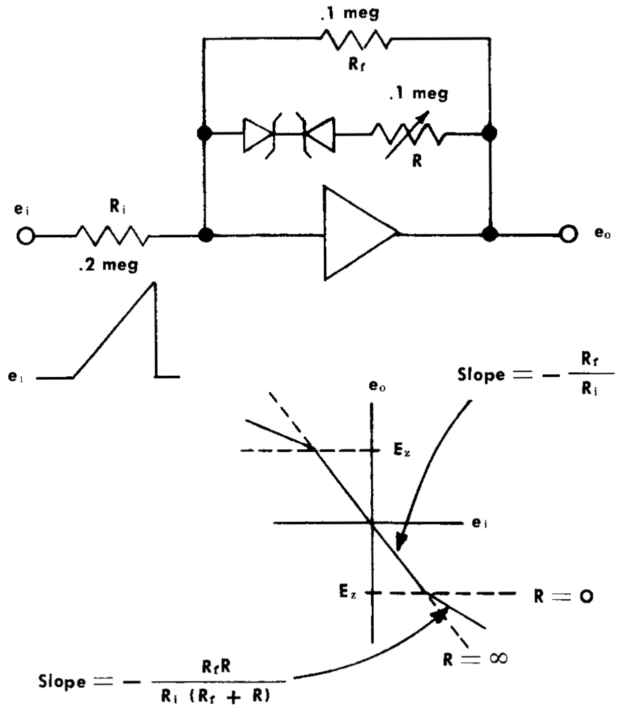
13. Logarithmic Amplifier (fast response)

2. Free run the sweep at about .5 mSEC/CM.
3. Set the VERTICAL DISPLAY switch to B—.
4. Place the Z_i and Z_f controls in the EXT. position.
5. Adjust the OUTPUT DC LEVEL to match the ZERO CHECK trace position.
6. Set the VOLTS/CM switch to .1 .
7. Connect a 1-volt calibrator signal to the input of the logarithmic amplifier.
8. Adjust the VARIABLE VOLTS/CM control for two centimeters of crt display. Recheck the OUTPUT DC LEVEL and ZERO CHECK to be sure the negative part of the display coincides with zero volts. (A little drift will alter the calibration for low level signals.)
9. Raise the calibrator signal to 100 volts. Adjust the 5-k potentiometer ±100 v CAL for a 4-centimeter crt display. The zero-volt part of the display may not return completely to zero in the time the calibrator remains at zero volts. Do not adjust the vertical POSITION control for the zero volt point while adjusting the ±100 v CAL potentiometer.
10. Repeat steps 7, 8 and 9 as necessary until the amplifier functions properly. Proper operation means a 0.1-volt calibrator signal will produce 1 centimeter of deflection; 1 volt will produce 2 centimeters; 10 volts will produce 3 centimeters; and 100 volts will produce 4 centimeters. A tolerance of ±0.5 mm can be expected.
11. Disconnect the calibrator signal and connect a 25 kc square wave from the Type 105 Square-Wave Generator to the input. Use a 93 Ω cable and a 93 Ω Termination Resistor and adjust the HF COMP capacitor for minimum spike at the leading edge of the square wave at about a 10-volt level. This adjustment will change with maximum signal amplitude, so it should be made at the maximum value of voltage the amplifier is expected to handle.
12. The amplifier is now calibrated. Always recheck the OUTPUT DC LEVEL against the ZERO CHECK trace position prior to any measurement.

Response-time of the logarithmic amplifier (the time to change 100% of a step signal amplitude) varies with the direction of change. The amplifier was originally designed to operate between 0.1 to 10 volts, therefore the response-time performance has been measured within these limits. Response-time when going from 0.1 volt to 10 volts is approximately 0.2 μsecond. Response-time when going from 10 volts to 0.1 volt is approximately 0.3 μsecond.

14. Limiter Amplifier

The limiter amplifier operates as a normal amplifier until the output reaches the Zener breakdown voltage of the diodes. When this occurs, the Zener diode places *R* in parallel with R_f, thereby increasing the negative feedback and decreasing the gain of the amplifier. By changing the setting of *R*, the gain of the amplifier after Zener breakdown can be controlled. The curve illustrates the input-output characteristics of the circuit.



14. Limiter Amplifier

The input and output voltages of an amplifier are related by the expression $e_o = Ge_i$, where e_o is the output voltage, G is the gain, and e_i is the input voltage. From this expression it can be seen that G is the slope of the curve. For voltages between the two Zener breakdown points, the gain (and the slope of the curve) is the usual expression $-R_f/R_i$. After the Zener breakdown, the effective feedback resistance is that of R_f and *R* in parallel. The gain (and slope) of the limited curve is

$$G = -\frac{R_f R}{R_i (R_f + R)}$$

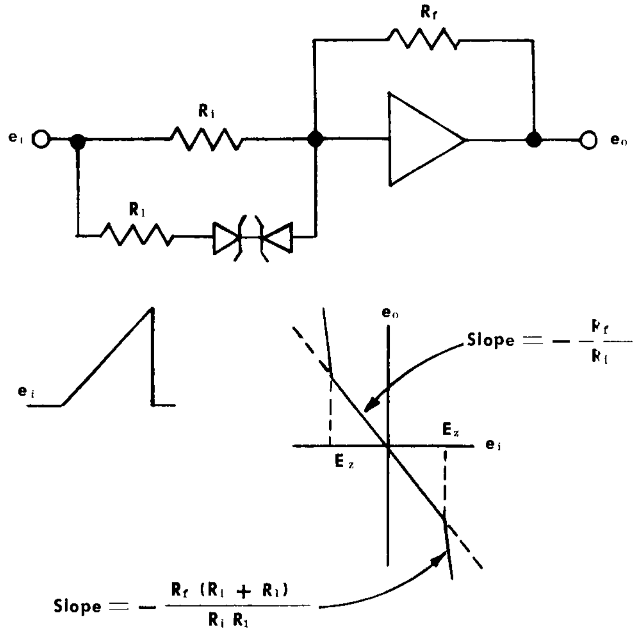
The slope of the limited curve can be varied between zero and $-R_f/R_i$ by varying the value of *R* between zero and infinity.

The purpose of the circuit is to limit the gain of the amplifier for output voltages greater than the Zener breakdown voltage. If *R* is reduced to zero, the output voltage is limited to the Zener breakdown voltage.

15. Expansion Amplifier

The expansion amplifier is similar in operation to the limiter amplifier of application 14. The primary difference in the two circuits is in the location of the back-to-back Zener diodes.

In this circuit, the gain of the amplifier is the usual $-R_f/R_i$ until the input voltage reaches the Zener breakdown level. When this occurs R_i is placed in parallel with R_i thereby increasing the gain of the amplifier for input voltages above this level.



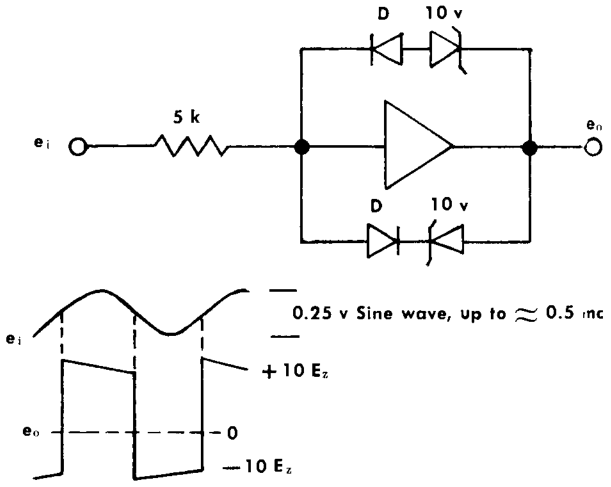
15. Expansion Amplifier

As mentioned previously, the gain of the amplifier (and thus the slope of the input-output curve) is $-R_f/R_i$ for input voltages below Zener breakdown. Above Zener breakdown the gain (and slope of the limited curve) is

$$G = -\frac{R_f(R_i + R_1)}{R_i R_1}$$

Input signals above the Zener breakdown voltage are effectively expanded by the amplifier. Signals below the Zener breakdown voltage are amplified in the normal manner.

16. Clipper Circuit



16. Clipper Circuit

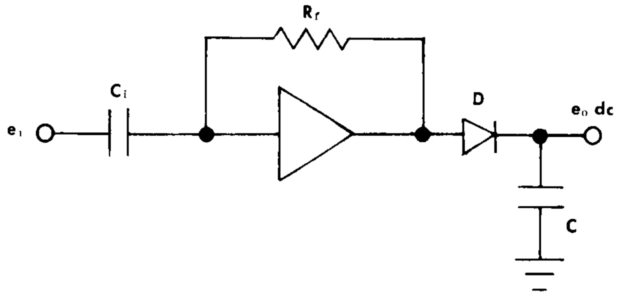
The clipper circuit is similar to the circuit shown in application 14 except that no feedback resistor is used. This means that the open-loop gain of the amplifier is obtained until the output reaches the Zener breakdown voltage. The output is then limited to the Zener breakdown voltage. The low-capacity signal diodes *D* disconnect each Zener during its forward voltage excursion to keep leakage feedback to a minimum.

The combination of the very high gain and clipping at the Zener breakdown voltage permits small amplitude sine waves to produce large amplitude square waves.

The example shows a gain of about 80 with clipping at the Zener level on both halves of each cycle.

17. Frequency to Voltage Converter

The frequency to voltage converter is essentially a differentiating circuit. The output of the differentiator in this circuit is rectified and used to charge a capacitor. Since the output of a differentiator is proportional to frequency, the capacitor charge is also proportional to frequency. A dc voltage is thus obtained which is proportional to frequency.



17. Frequency to Voltage Converter

It is important that the proper values of R_f and C_i are used in order to obtain best results from this circuit. Refer to Chart 2-2 for the proper values to use in the frequency range you wish to cover. Practical limits of performance are from approximately 1 cps to 1.5 mc, shown as several ranges in Chart 2-2.

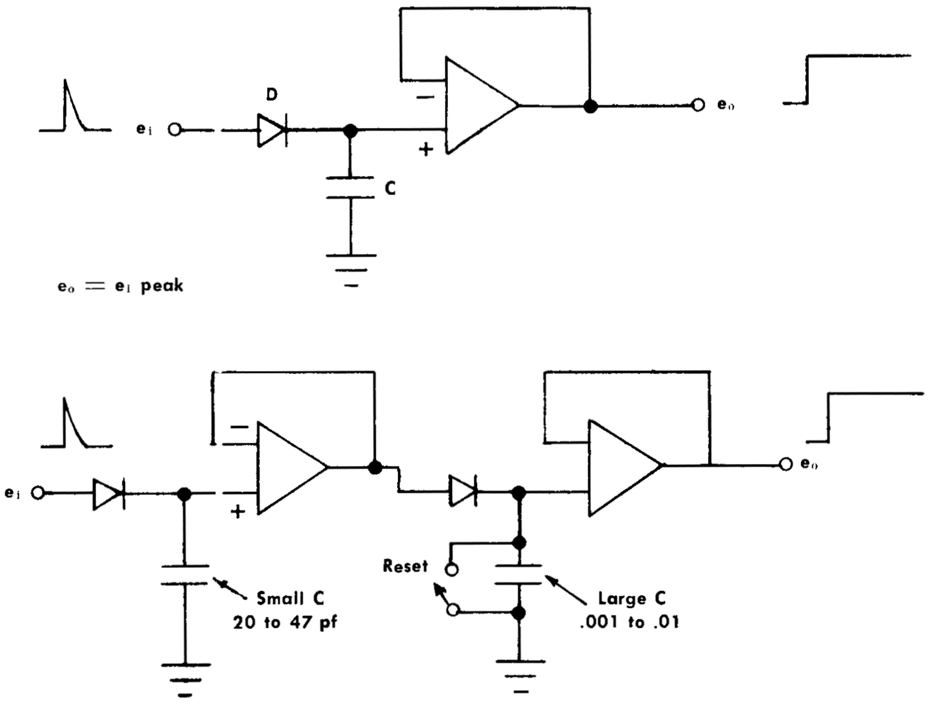
The diode *D* and capacitor C must both be selected to have high leakage resistance to permit maintaining the proper dc output voltage during the part of each cycle that *D* is not conducting in the forward direction.

18. Peak Reading Amplifier

In this circuit, advantage is taken of the high input impedance feature of the + grid. When a positive pulse is applied, the diode conducts, charging the capacitor to the peak voltage. Because of the high input impedance, the capacitor charge is retained for a relatively long period. The gain of the amplifier is unity under these conditions, so the output is equal to the peak voltage of the input pulse.

In order for the circuit to operate properly, the time constant of the source impedance and the capacitor to be charged must be short enough so that the capacitor can charge to the peak voltage in the time that the pulse remains at the peak. For this reason, the value of the capacitor should be as small as possible. The capacitor cannot be too small, however, or it will discharge too rapidly. A capacitor with very low leakage should be selected to prevent rapid loss of the charge. Also, the diode reverse current should be very low to prevent the capacitor charge from being lost too rapidly. The forward drop across some silicon diodes is great enough to prevent the capacitor from charging to the peak voltage.

In practice, two peak reading amplifiers can be cascaded to minimize input loading and extend peak memory time.



18. Peak-Reading Amplifier

19. Very Low Current Measurements

The output voltage of this circuit is proportional to the input current. The circuit can be used to measure very low currents, such as reverse current of semiconductor diodes, or the leakage current of capacitors.

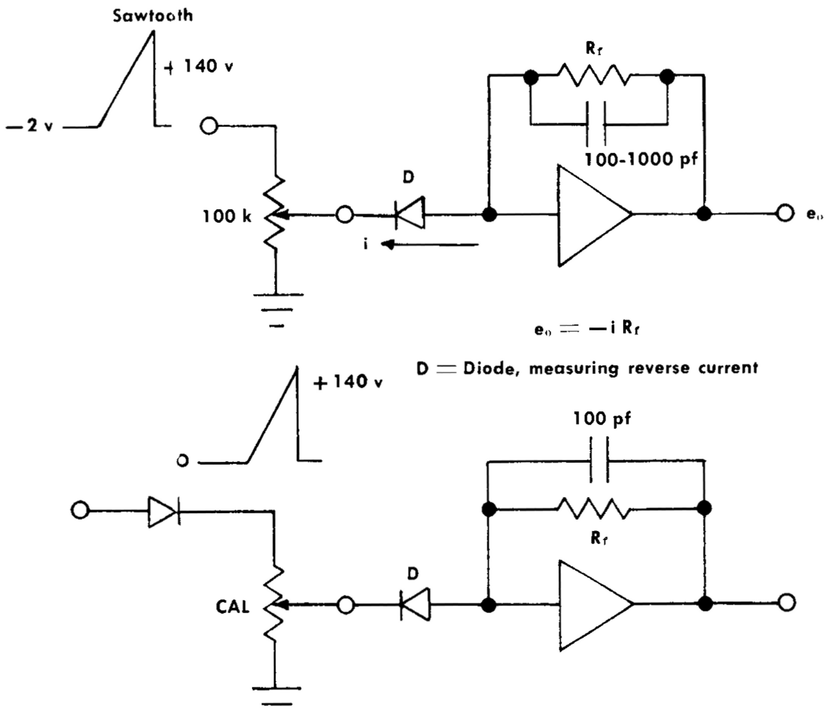
If R_f is 1 megohm, the output will change 1 volt per microampere input.

If R_f is 50 megohms (external resistor), the output will change 50 millivolts per nanoampere input.

The capacitor across R_f may be required to reduce output noise when the gain of the overall system is high.

A convenient voltage source for measuring diode reverse current is the oscilloscope SAWTOOTH OUT waveform.

The peak value of the sawtooth can be varied to suit the particular diode by means of a 100-k potentiometer. With



Silicon diode added to block negative sawtooth for very low current measurements.

19. Very Low Current Measurements

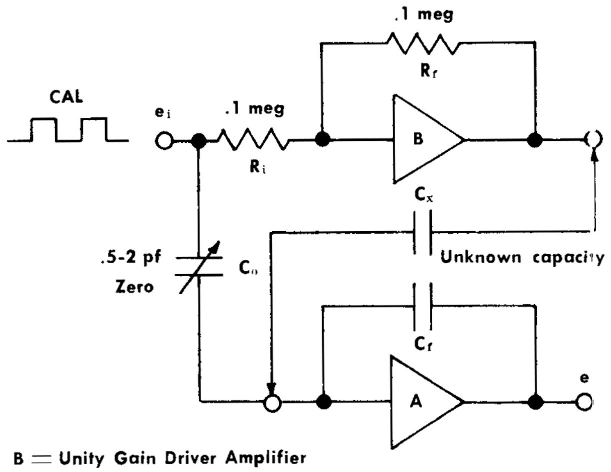
such a system, the horizontal display can be calibrated in volts per centimeter. Thus the exact voltage at which the diode reverse current exceeds a given value can be seen dynamically on the crt.

For very high sensitivities (the measurement of very low current) it may be necessary to shield the input and output circuits to eliminate hum pickup. The noise of the system can be reduced by placing a capacitor across the feedback resistor.

The oscilloscope sawtooth-out voltage usually contains a small negative offset when the crt spot is at rest. To prevent the diode being tested from going into forward conduction and saturating the amplifier, a silicon diode may be inserted between the sawtooth-out voltage and the potentiometer to block the negative offset voltage.

Capacitance of the added diode can affect the display at high sweep rates. To minimize the capacitance effect, slow sweep rates should be chosen for nanoampere current measurements. The oscilloscope single sweep feature may also be used to improve the display.

20. Capacitance Measurements



B = Unity Gain Driver Amplifier

C_0 = Stray capacitance balance when measuring 1-10 pf.

C_f = O Unit 1% Z_f capacitor

A: Use INTEGRATOR LF REJECT 1 CPS

20. Capacitance Measurements

The above circuit can be used to make accurate capacitance measurements by comparing the value of an unknown capacitor against one of the internal standard capacitors. The fixed internal capacitors are within 1% of the front-panel values. The two lowest value capacitors are adjusted during calibration. In the diagram, C_x is the unknown capacitance and C_f is the selected internal capacitor

Although resistors are normally used as the input and feedback components when an operational amplifier is used to provide amplification by a constant, capacitors may be used also. The gain of the amplifier with capacitors as the input and feedback elements is the ratio of the capacitive reactance of the feedback capacitor to the capacitive reactance of the input capacitor. The gain is therefore equal to $-C_x/C_f$. If a known input signal from the oscilloscope calibrator is applied to the amplifier, the gain can be determined by comparing the output displayed on the oscilloscope to the input signal. With the gain and C_f known, C_x can be calculated. This is the general method used.

Operational amplifier B is used as a unity gain driver for operational amplifier A. The low output impedance of amplifier B is necessary to obtain accurate measurements on large capacitors. The low output impedance permits charging C_x in less than one half the period of the calibrator waveform.

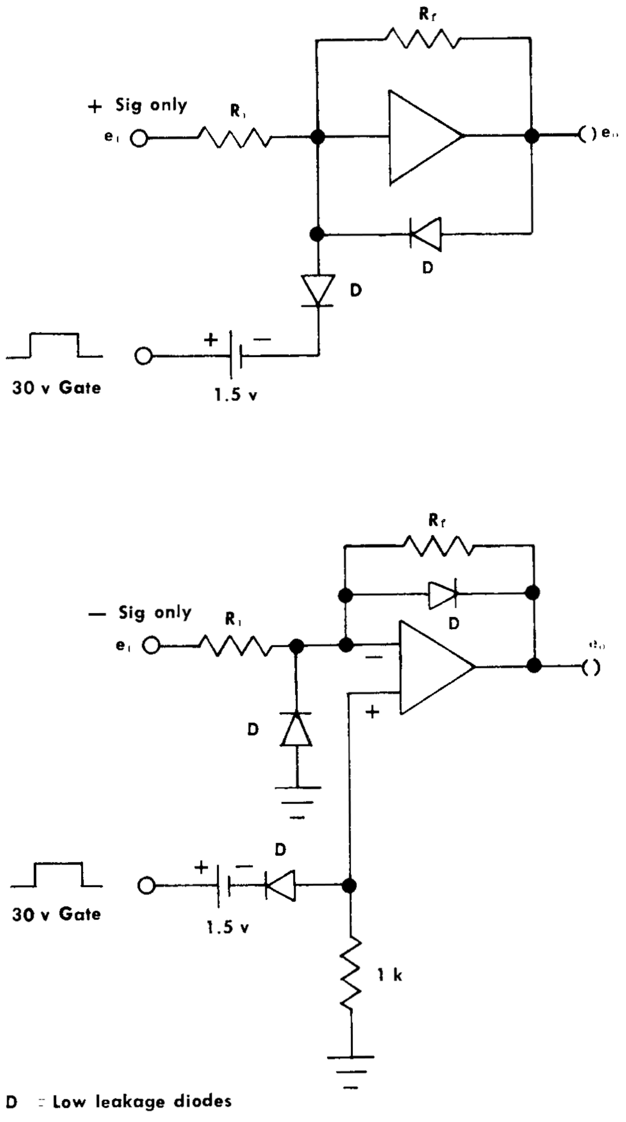
To make a capacitance measurement, proceed as follows:

1. Connect the circuit as shown in the diagram but do not connect C_x. Set the A Operational Amplifier Z_i switch to EXT.
2. Connect the output of the oscilloscope AMPLITUDE CALIBRATOR to the input of Operational Amplifier B and adjust the calibrator output voltage according to the following chart for the range of capacitance to be measured.
3. Set the VERTICAL DISPLAY switch to A+. Set the VOLTS/CM switch to .05. Connect any device which will be used to hold the unknown capacitor to the A INPUT and A — GRID connectors. If the capacitor to be measured is 10 pf or less, adjust C_o, the neutralizing capacitor, for the least amount of signal displayed on the crt. This neutralizes the stray capacitance between the input and A — GRID connectors.
4. Connect the amount of signal indicated below for the range of capacitance expected. Connect the capacitor to be measured and read the output of the amplifier displayed on the crt. Calculate the gain and the value of C_x. If C_x is equal to the value of the C_f switch setting, the display amplitude will be equal to the calibrator peak-to-peak voltage. If C_x is one half the value of the C_f switch setting, the display amplitude will then be one half the calibrator peak-to-peak voltage.

RANGE	CALIBRATOR SIGNAL	C_f SWITCH SETTING
0 — 10 μf	10 mv	.1
0 — 1 μf	.1 v	.1
0 — .1 μf	.1 v	.01
0 — .01 μf	.1 v	.001
0 — .001 μf	1 v	.001
0 — 100 pf	10 v	.001
0 — 10 pf	10 v	.0001

21. Gated Amplifier

It is possible to gate on and off an operational amplifier. The simplest form of this type of circuit would be to use a relay with contacts that short across the feedback component when the amplifier is to be turned off, but the speed of response is limited by the response of the relay used.



21. Gated Amplifier

The simple relay may be replaced by a diode gate that is turned on and off to gate off and on the operational amplifier.

The 30-volt gate indicated can be obtained from the 'B' sweep of a Tektronix dual-sweep oscilloscope, such as the Type 535A or 545A. The 1.5-volt battery biases diode *D* to conduction when there is no + GATE signal. With the arrival of the + GATE, diode *D* opens, permitting the amplifier to function.

The back resistance of the diode gate must be very high to prevent altering the amplifier performance. Also, its forward resistance must be low to permit firm clamping of the amplifier.

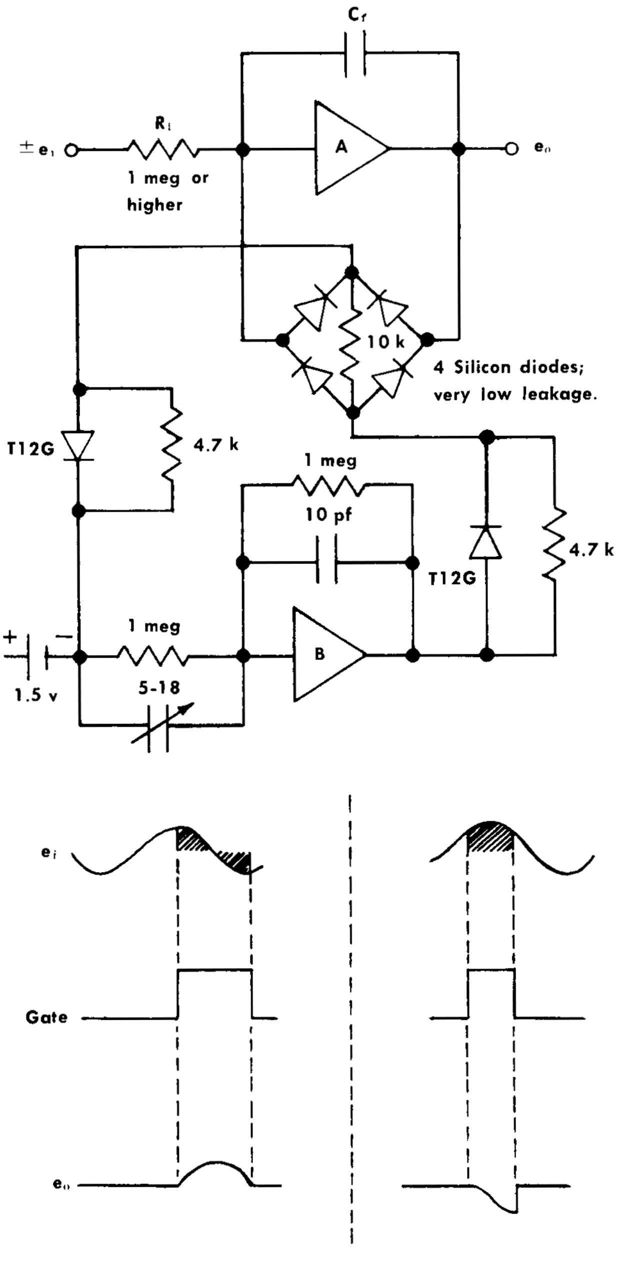
The gated amplifier illustrated here can accept only one polarity of signal. If the feedback capacitor of application 22 is replaced by a feedback resistor, a signal containing both positive and negative polarity can be gated.

22. Gated Integrator

This circuit is a modification of application 21.

The gated integrator can be used to integrate a signal over a specific time interval such as a portion of a sine wave or a small pulse that follows a large pulse. If a large pulse preceding a small pulse were to be integrated too, the area under the small pulse might not be easily resolved from the display.

By using a two-sweep oscilloscope, such as a Type 535A or Type 545A, the oscilloscope HORIZONTAL DISPLAY should first be set to 'B' INTENSIFIED BY 'A'. Adjust the two sweep rates and the DELAY-TIME MULTIPLIER dial so



22. Gated Integrator

the desired portion of the display is viewed by the 'A' sweep. Then, switching the HORIZONTAL DISPLAY switch to 'A' DEL'D BY 'B', the crt presentation will be that portion of the signal to be integrated. By using the + GATE A to turn on the integrator, the full crt display will then be the integral of the desired part of the original display.

If the waveform is of a recurrent nature, it may be necessary to use external triggering to the Time-Base B external TRIGGER INPUT. If the waveform is a single-shot type, the system described above will function correctly. In either case, it may be advantageous to read the operating instructions about the 'A' DEL'D BY 'B' mode of operation in the instruction manual for the oscilloscope used.

Integration of a repetitive waveform requires the use of the Type O Unit INTEGRATOR LF REJECT switch to keep the integrated waveform on the crt. By using a gated integrator, it is possible to integrate a signal plus any reasonable dc component associated with the signal. Under such conditions the LF REJECT switch would be OFF. By virtue of the shorted feedback element when there is no turn-on gate, the gated integrator is not subject to dc drift between gating periods. Therefore, it is possible to integrate essentially single-shot waveforms with a dc component included in the integral waveform.

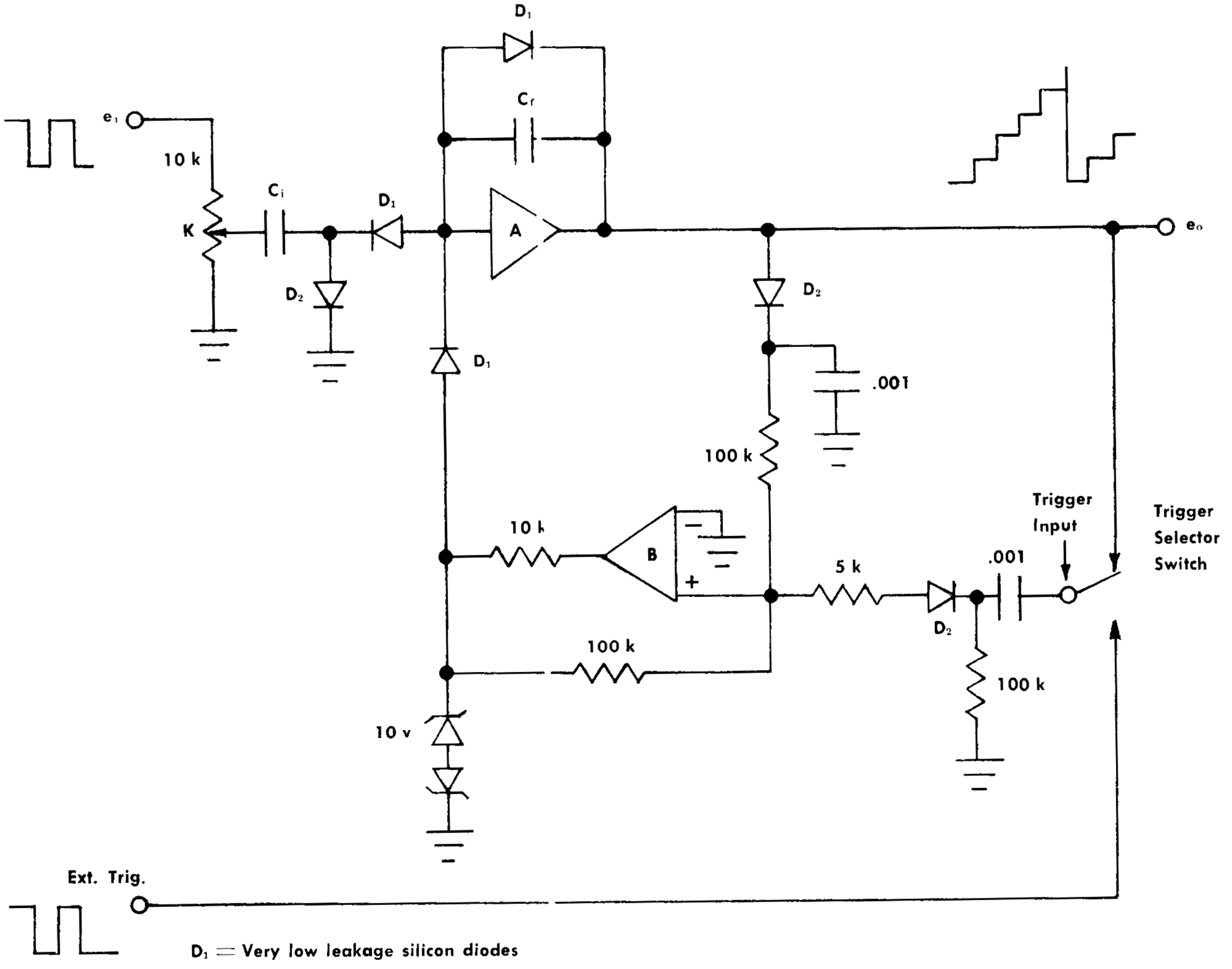
In any use of the gated integrator, refer to Chart 2-2 so that errors will not be made due to the gain-frequency limits of the operational amplifier integrator.

23. Stair-Step Generator

Another form of gated system is shown here with the B amplifier used as a multivibrator to gate an operational integrator. The integrator is fed a train of equal amplitude pulses via a 'Bucket' capacitor circuit to form a stair-step output waveform.

With e_i equal to the amplitude of the pulse feeding the operational integrator, the output amplitude per step is

$$e_o \text{ per step} = -\frac{K C_i}{C_f} e_i,$$



D_1 = Very low leakage silicon diodes

D_2 = Any signal diodes

23. Stair-step Generator

where K is the potentiometer setting (as a fraction of the pulse amplitude), C_i is the input capacitor, and C_f the feedback capacitor.

Diode coupling from the output stair-step to the + GRID of the B amplifier multivibrator assures the system will revert to zero output at the voltage of the back-to-back Zener diodes.

Once reverted to essentially zero output, a trigger pulse is required at the multivibrator + grid to open the gate again and permit another stair-step cycle. Thus the circuit can either produce a continuous series of stair-steps, or only one at a time, on the arrival of a single trigger. To make it repetitive, connect the output stair-step to the trigger input.

The maximum time per step (with good fidelity) is determined by the value of C_i. Two examples of maximum time limit per step, when C_f is a .01-μf capacitor, are: if $C_i = .001\ \mu f$, the maximum time per step is about 10 μseconds; if $C_i = 47$ pf, the maximum time per step is about 1 μsecond. The minimum time per step is limited by the impedance of the driving source at C_i, and by the bandwidth of the A amplifier.

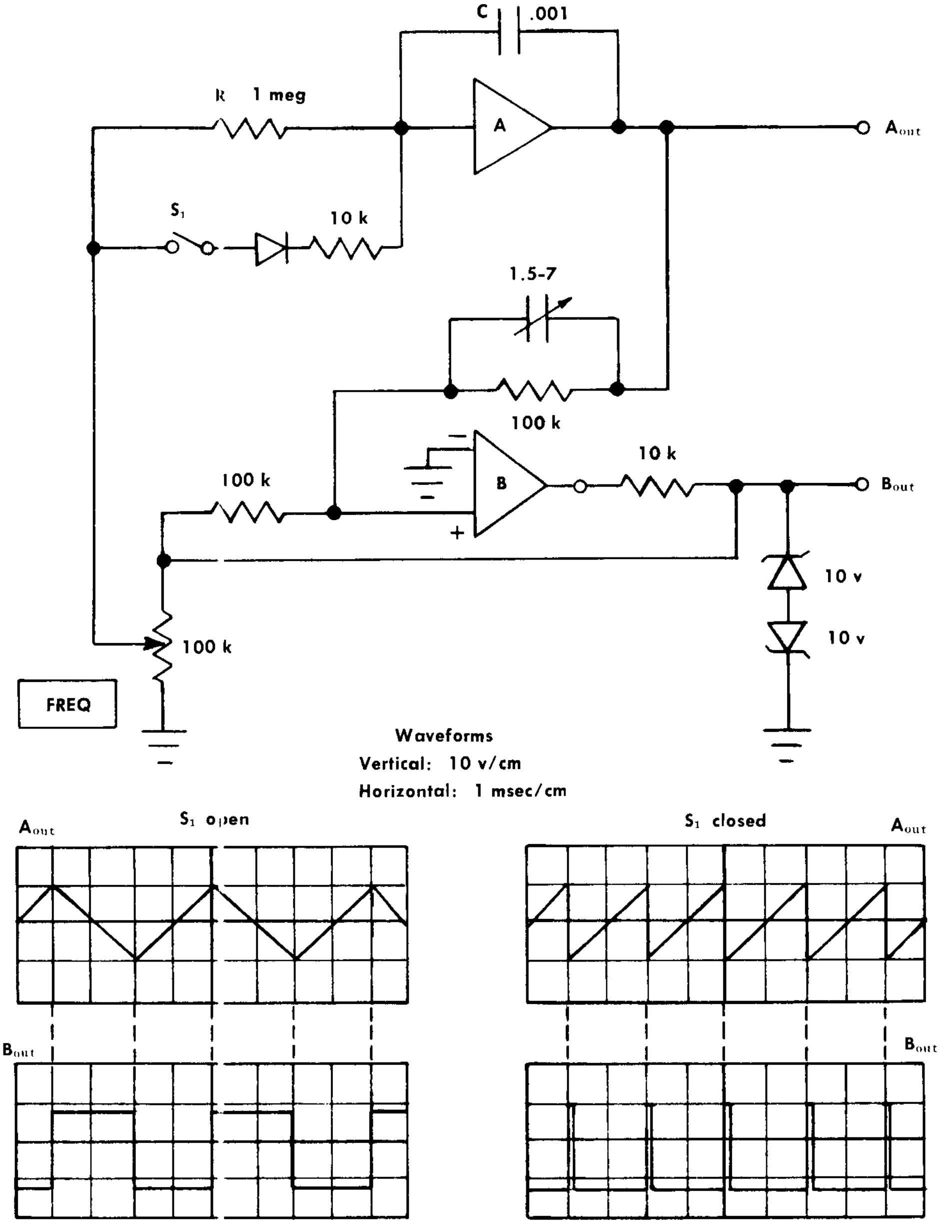
24. Function Generator

The function generator makes simultaneous use of both operational amplifiers. The A amplifier functions as an integrator while the B amplifier functions as a flip-flop multivibrator.

When the unit is switched on, the dc level at the output of the B amplifier is integrated by the A amplifier to form a linear ramp as shown by the waveform from the A output. When the ramp voltage reaches a certain level, it causes amplifier B to switch into its other state. The change in voltage at the output of B is integrated by A to form the remainder of the sawtooth from A. The output from A is again applied to B and causes B to switch to its original state after the output of A reaches the required level. This completes one cycle of operation. The cycle then repeats. The operation of the circuit can be compared in many respects to a simple relaxation oscillator.

The frequency of the output is determined by the time required for the voltage at the output of amplifier A to rise to the required switching level of B. This is determined by the value of *R* and *C*, and the setting of the *FREQ.* control. A nominal upper limit of 60 kc is possible without seriously changing the waveforms from those shown.

The output waveforms are modified by closing switch *S1*. This switch permits a diode to reduce the charging time for C in one direction only, changing the symmetrical ramp waveform to an unsymmetrical one as shown. This also affects the switching time of amplifier B and its duty cycle.



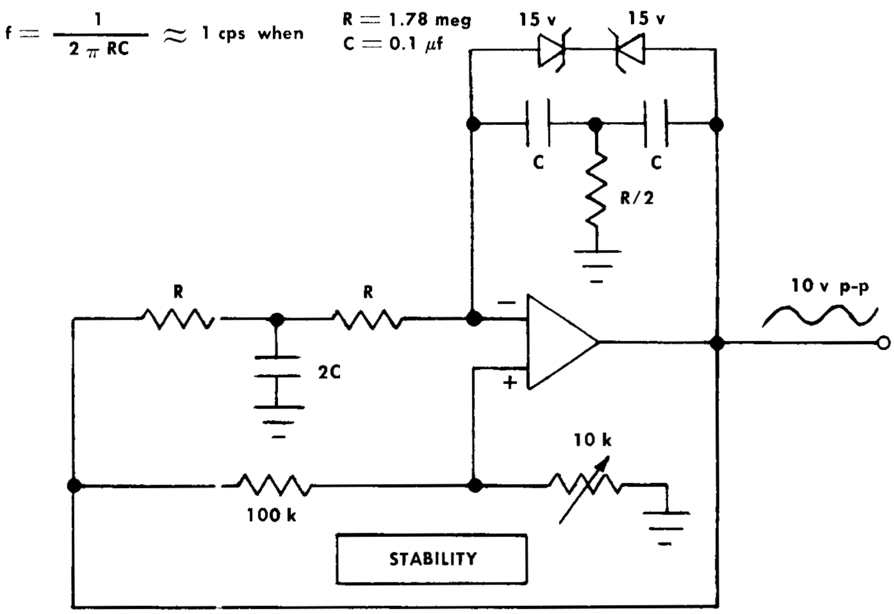
24. Function Generator

The back-to-back Zener diodes at the output of amplifier B square off the tops and bottoms of the waveforms and limit their amplitude, providing a square-wave output.

25. Low-Frequency Sine-Wave Generator

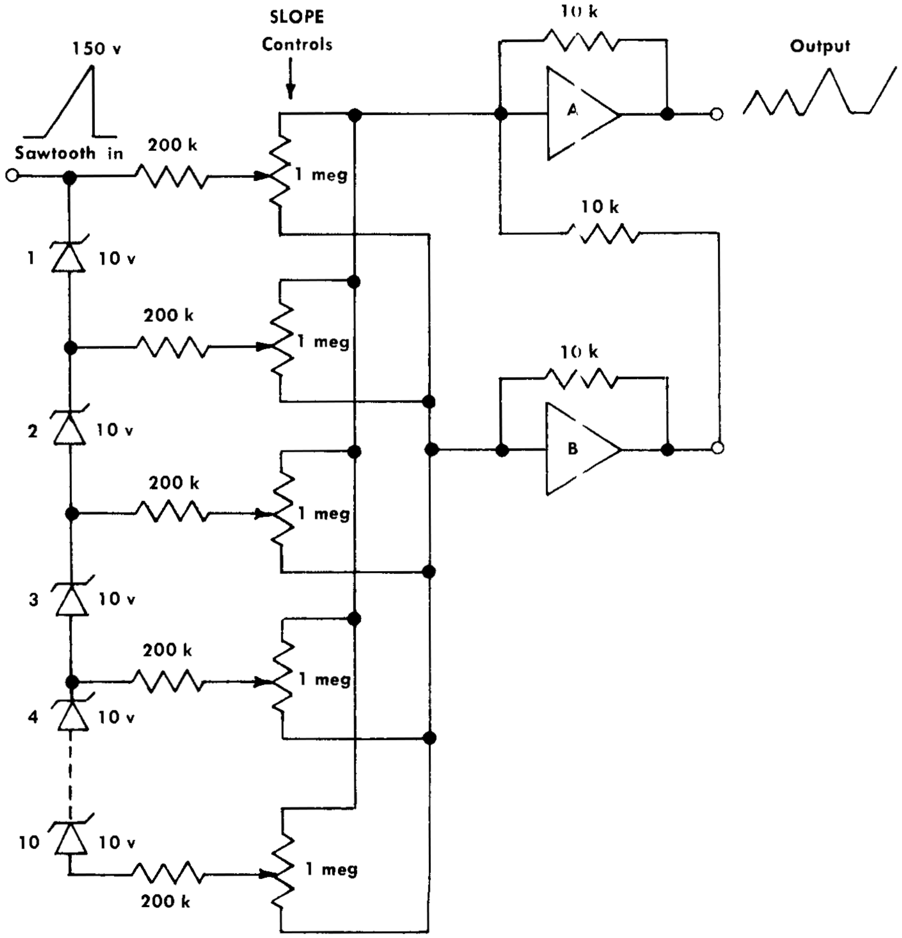
This circuit is a parallel-T oscillator. Feedback to the — grid becomes positive at the frequency indicated in the formula, while positive feedback is applied to the + grid at all frequencies. The amount of positive feedback to the + grid is sufficient to cause the amplifier to oscillate. In combination with the feedback to the — grid, feedback to the + grid can be used to stabilize the amplitude of oscillations.

The output of the oscillator is a stable sine wave with very low harmonic content. Output voltage is approximately 10 volts, peak-to-peak. The non-linear resistance of the back-to-back Zener diodes is used to limit the output amplitude and maintain good linearity.



$$f = \frac{1}{2\pi RC} \approx 1 \text{ cps when } R = 1.78 \text{ meg}, C = 0.1\ \mu f$$

25 Low-Frequency Sine Wave Generator



26. Segments Function Generator

26. Segments Function Generator

The simple segments function generator shown employs Zener diodes to determine the starting voltage of each segment, and 200-k potentiometers to control the slope of the segment after each Zener conducts.

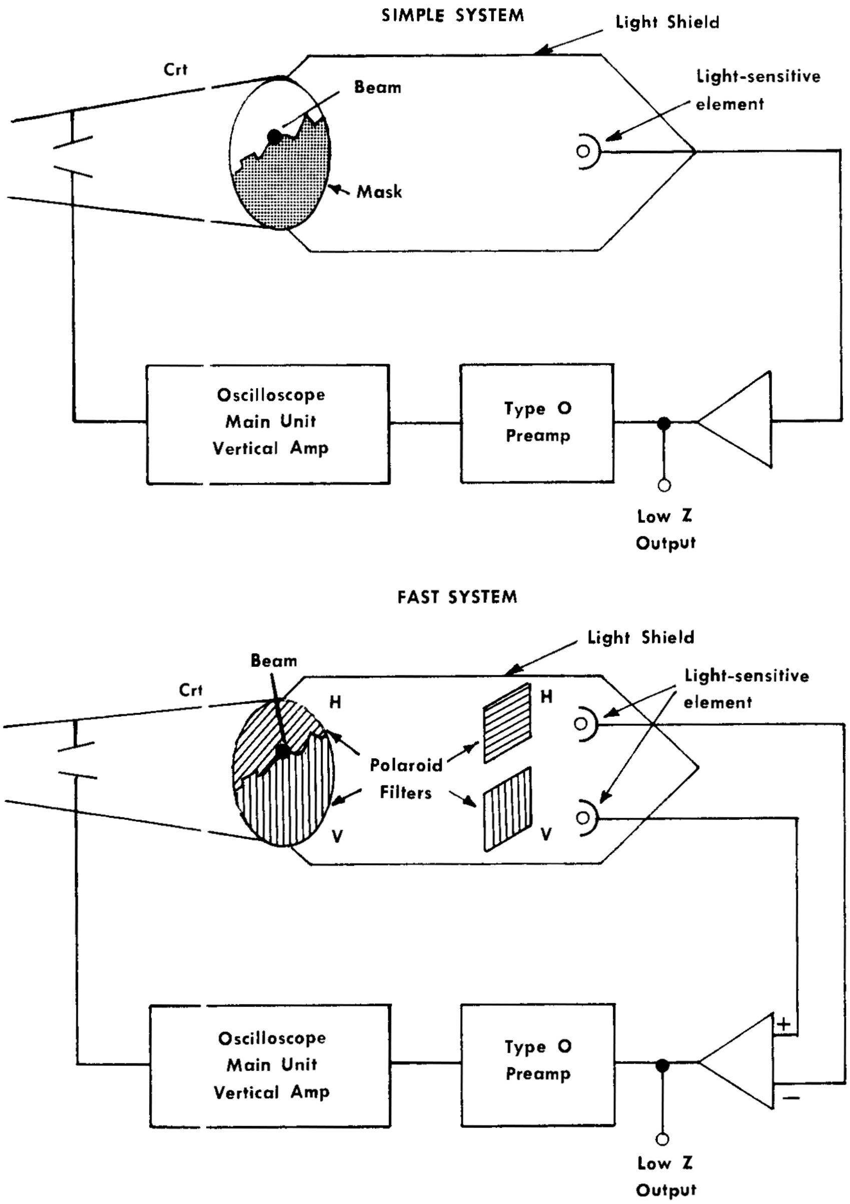
Many Tektronix oscilloscopes can provide the input signal from the SAWTOOTH OUT connector. The oscilloscope sweep generator therefore controls the waveform rate, either on a repetitive basis or on a manually- or externally-triggered single-shot basis.

27. CRT Function Generator

The top illustration shows the circuit and physical arrangement for a simple crt arbitrary function generator. A mask is placed over the face of the oscilloscope crt in the shape of the waveform to be generated. A light-sensitive element is then placed in front of the crt. The output of the high-gain operational amplifier is applied to the preamplifier to control the vertical position of the crt spot. The light-sensitive element is connected so that a bright display moves the spot down.

In operation, the crt spot is positioned (with the Positioning controls) to be just above the highest edge of the mask. If the spot then moves higher, the additional light reaching the phototube moves the spot down. If the spot moves down too far, the reduced light moves the spot back up. The net result is that the spot stays at the edge of the mask. As the spot is swept horizontally by the oscilloscope sweep circuit, it follows the edge of the mask, tracing out the pattern. The dc-coupled voltage from the operational amplifier OUTPUT connector is nearly an exact replica of the mask. Any type of arbitrary function waveform can be generated by cutting out the proper mask and placing it over the oscilloscope crt.

The simple crt function generator has upper rate limitations for the crt spot movement. These limitations are due to the response time of the light-sensing element, the bandwidth of the operational amplifier, and the type of phosphor and its light output. If a fast sweep rate is required, it may be necessary to undercut the mask at sharp corners. Experimental masks will lead to the correct shape to give the desired waveform output.



27. CRT Arbitrary Function Generator

A more sophisticated version of the crt function generator is shown in the lower illustration. This system uses two light-sensing elements and two sets of polaroid filters for differential operation. The response time of this system is greater than the simple system, with a limitation now including the oscilloscope delay line.

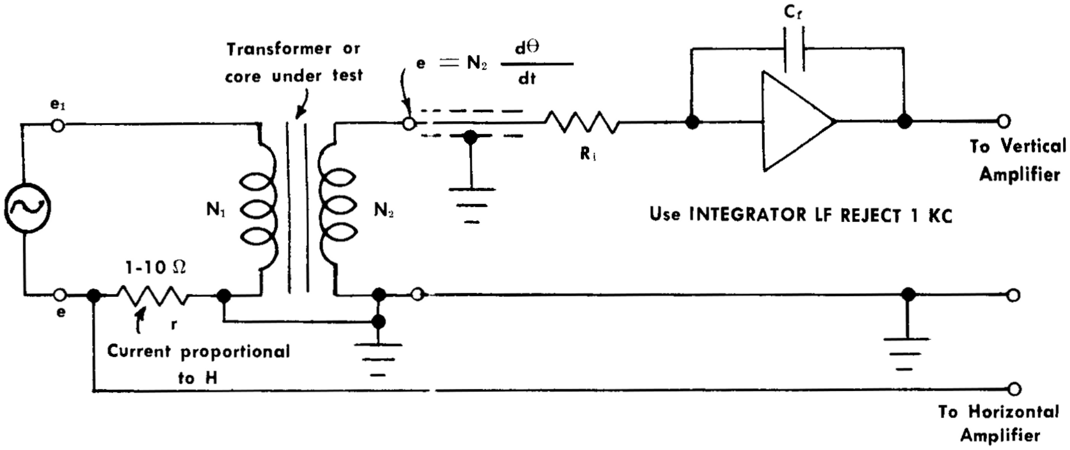
28. Displaying B-H Curves for Magnetic Materials

B-H curves for magnetic materials can be displayed using this circuit. A transformer is constructed using a core of the test material and the transformer is excited from the output of a variable autotransformer. The magnetic intensity *H* in the core is proportional to the current through the primary winding. The voltage across a current sampling resistor in the primary circuit is applied to the horizontal deflection system of the oscilloscope. Horizontal deflection on the oscilloscope is thus proportional to *H*.

The output voltage obtained from the secondary winding is proportional to the time rate of change of the flux. The transformer secondary voltage is applied to an integrator circuit which gives an output voltage proportional to the flux. The output of the integrator is applied to the preamplifier where it produces vertical deflection of the crt beam. Since the flux density *B* is equal to ϕ/A (where *A* is the cross sectional area of the core), the oscilloscope vertical deflection is also proportional to *B*.

The net result of the signals applied to the horizontal and vertical deflection systems is to produce patterns similar to those indicated. Vertical deflection is proportional to *B* and horizontal deflection is proportional to *H*.

If it is desired to determine qualitative measurements of a transformer core from the oscilloscope display, the proportionality constants relating the horizontal and vertical deflections to *H* and *B* must be determined (see page 4-4).



(a) Three levels of supply voltage to an inductor.

(c) Top: Normal B-H curve. Bottom: Small dc offset bias effect.

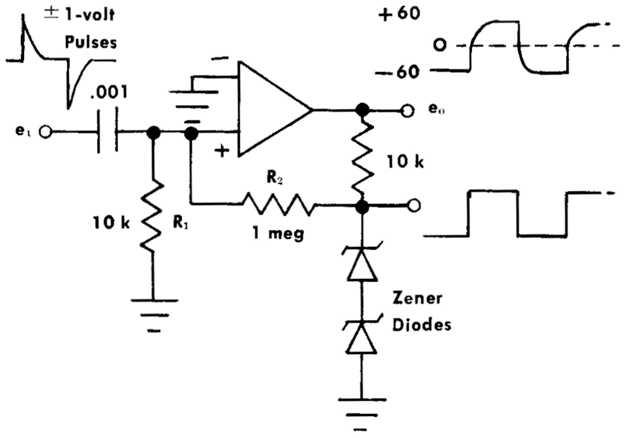
(b) Same inductor, indicating residual magnetism.

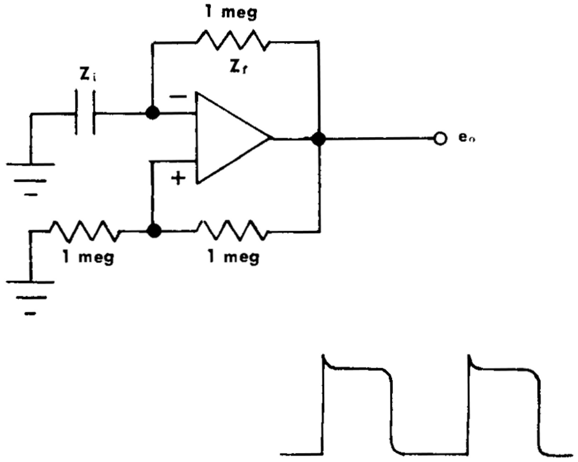
(d) Normal B-H curve compared with case of one shorted turn.

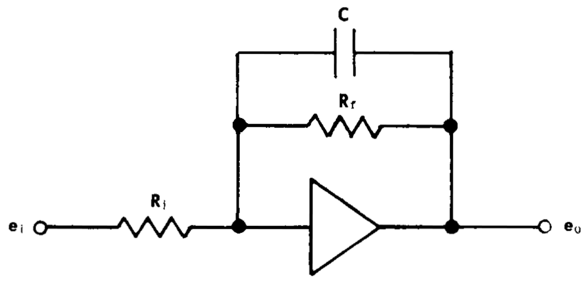
28. Displaying B-H Curves for Magnetic Materials

ADDITIONAL APPLICATIONS

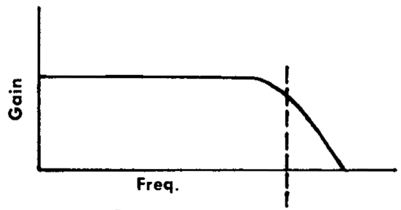
The following applications are in schematic form only, offering suggestions for other uses of the Type O Unit.



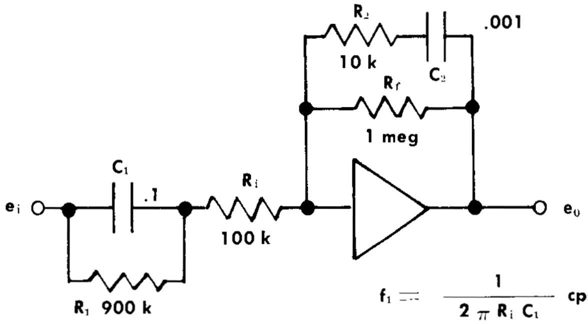




Gain $= -\frac{R_f}{R_i}$

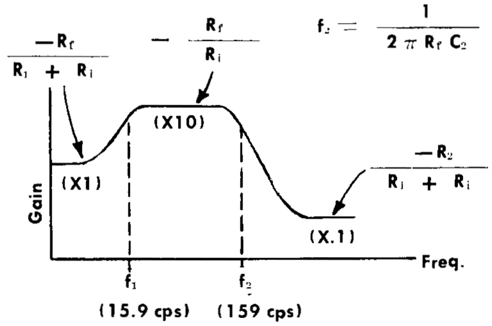


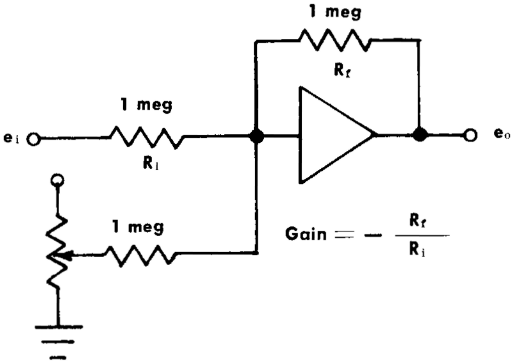
High-freq. Response $f_{hf} = \frac{1}{2\pi R_f C_f}$ cps



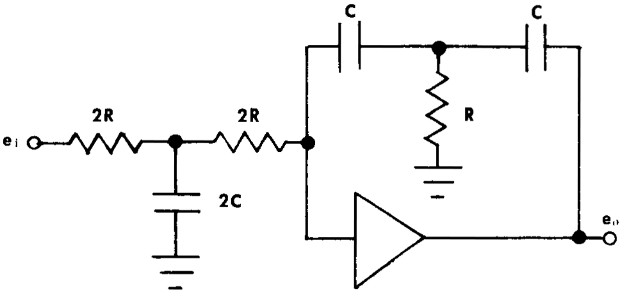
$f_1 = \frac{1}{2\pi R_i C_1}$ cps

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

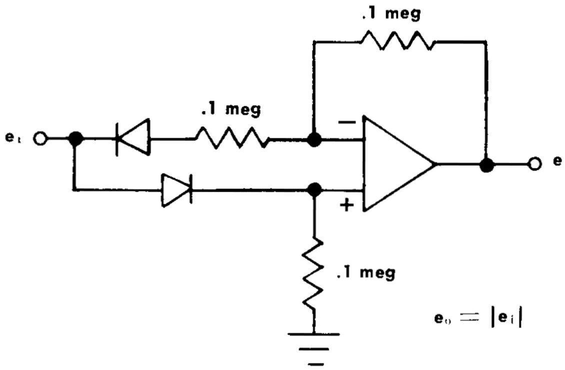




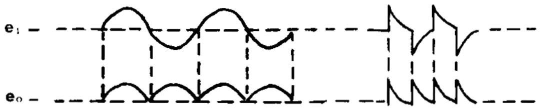
Gain $= -\frac{R_f}{R_i}$

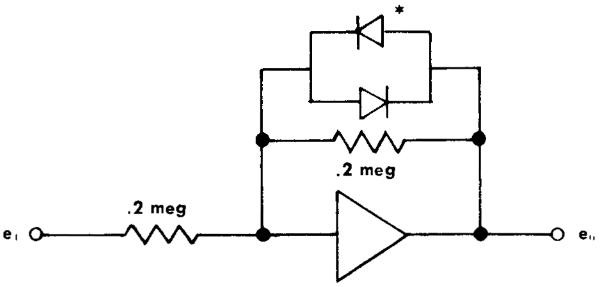


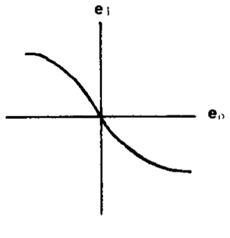
$e_o = -\frac{1}{4R^2C^2}\iint e_i \, dt \, dt$



$e_o = |e_i|$



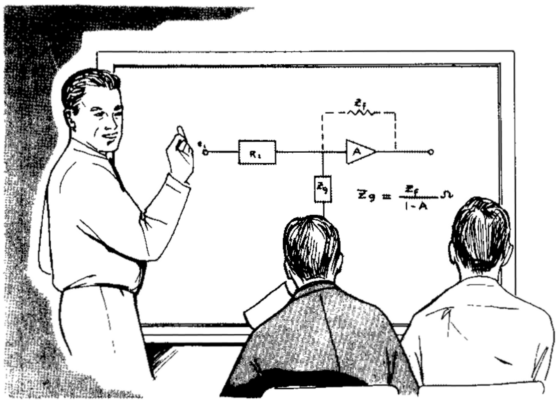




* Any signal diodes, such as T13G

SECTION 4

THEORY OF OPERATIONAL AMPLIFIERS



General

Information in this section of the manual is intended to provide some understanding of the theory of operational amplifiers. In addition, derivations presented in this section support some of the formulas that appear throughout other sections of this manual.

Operational Amplifier

An operational amplifier is basically a high-gain dc amplifier with feedback. The feedback elements selected permit the amplifier to perform various operations such as amplification by a constant factor, integration, differentiation, summation, etc. In conventional operational amplifiers, the feedback is negative. However, the operational amplifiers in the Type O Unit also permit positive feedback, thereby increasing the number of possible applications.

Generalized Feedback Arrangement

In the feedback operational amplifier shown in Fig 4-1, the summation of input and feedback currents is equal to zero at the input grid (assuming the input grid current is negligible), or

$$i_1 + i_2 = 0. \tag{1}$$

From Fig. 4-1 we find that

$$i_1 = \frac{e_i - e_g}{Z_i} \tag{2}$$

and $i_2 = \dfrac{e_o - e_g}{Z_f}$. (3)

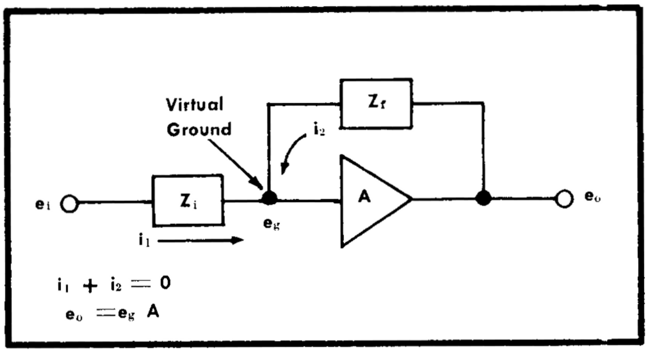


Fig. 4-1. Generalized feedback circuit.

Substituting these values for i_1 and i_2 into equation (1), we have

$$\frac{e_i - e_g}{Z_i} + \frac{e_o - e_g}{Z_f} = 0. \tag{4}$$

Since $e_g = e_o/A$ (where A is the open-loop gain), equation (4) becomes

$$\frac{e_i - \frac{e_o}{A}}{Z_i} + \frac{e_o - \frac{e_o}{A}}{Z_f} = 0. \tag{5}$$

Rewriting equation (5):

$$\frac{e_i}{Z_i} - \frac{e_o}{Z_i A} + \frac{e_o}{Z_f} - \frac{e_o}{Z_f A} = 0. \tag{5}$$

Then

$$e_o\left(\frac{1}{Z_f} - \frac{1}{Z_f A} - \frac{1}{Z_i A}\right) = -\frac{e_i}{Z_i}. \tag{6}$$

Solving for e_o:

$$e_o = -\frac{Z_f}{Z_i}\left[\frac{e_i}{1 - \frac{1}{A}\left(1 + \frac{Z_f}{Z_i}\right)}\right]. \tag{7}$$

The gain of a closed-loop amplifier is

$$G = \frac{e_o}{e_i} = -\frac{Z_f}{Z_i}\underbrace{\left[\frac{1}{1 - \frac{1}{A}\left(1 + \frac{Z_f}{Z_i}\right)}\right]}_{\text{Error Factor term.}} \tag{8}$$

Virtual Ground at the — Grid

(The concept of a virtual ground applies only when the +grid is grounded.)

An operational amplifier with negative feedback tends to maintain a very small voltage change at the — grid terminal. Insofar as circuit behavior is concerned, it will appear as if a very low impedance is placed between the — grid and ground; it is considered a "virtual ground".

To find the equivalent impedance at the — grid (Z_g) refer to Fig. 4-1 again, where $e_g = e_o/A$.

Assuming the — grid current to be negligible, the current entering the virtual ground terminal is equal to the current through Z_f:

$$i_2 = -\frac{e_g - e_o}{Z_f} = -\frac{\frac{e_o}{A} - e_o}{Z_f} \qquad (9)$$

and

$$i_1 = -i_2 = \frac{\frac{e_o}{A} - e_o}{Z_f}. \qquad (10)$$

The equivalent impedance looking into the — grid is obtained by dividing e_g by i_1, or

$$Z_g = \frac{e_g}{i_1} = \frac{\frac{e_o}{A}}{\frac{\frac{e_o}{A} - e_o}{Z_f}} = \frac{Z_f}{1 - A}. \qquad (11)$$

Fig. 4-1 can now be redrawn as Fig. 4-2, with the feedback resistor Z_f replaced by the equivalent resistance it creates, Z_g, as shown at the — grid terminal.

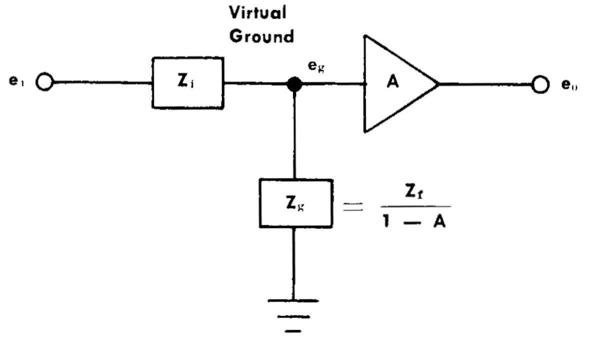


Fig. 4-2. Equivalent virtual ground impedance at the — grid.

Grid Current Calculations

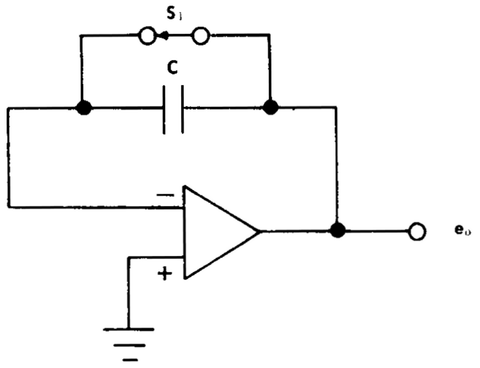
With no external resistor between the grid and ground, and with a capacitor in the Z_f position, the rate, polarity, and amount of change in amplifier output voltage determines the grid current. Fig. 4-3 illustrates a typical grid current measurement setup; the principle is valid for either the — grid or the + grid.

Grid current is measured by essentially measuring the charge stored by capacitor C in a given time after S_1 is opened.

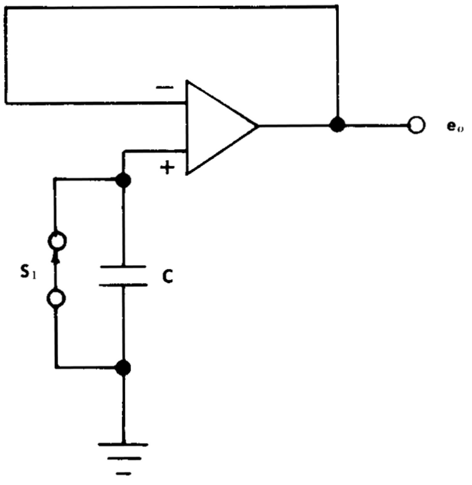
$q = Ce$; then, with C constant,

$$i = C\frac{de}{dt}, \text{ or} \qquad (12)$$

$$i = C\frac{\Delta e}{\Delta t}. \qquad (13)$$



(a) Measuring — GRID current.



(b) Measuring + GRID current.

Fig. 4-3. Typical grid current measurement circuits.

If C in Fig. 4-3 is .001 μf, then

$$i = 0.001 \times 10^{-6}\frac{\Delta e}{\Delta t} = \frac{\Delta e}{\Delta t} \text{ nanoamperes.}$$

If the capacitor voltage (after opening S_1) changes 2.5 volts in 5 seconds, the current is 0.5 nanoampere.

Combined Operations

The two operational amplifiers in the Type O Unit permit combined operations to be performed. For example, a signal can be amplified by a desired constant using one amplifier, and its output can be applied to the other for *integration or differentiation.*

Both operational amplifiers have zero input and output no-signal dc levels, permitting the amplifiers to be stacked. Stacking permits their operations to be combined, greatly increasing their applications.

FORMULA DERIVATION

The remainder of this section is used for the derivation of formulas employed in the Typical Applications portion of Section 3.

Amplification by a Constant

Application 1 shows an amplifier circuit. Both the input and feedback components are resistors. The concept of a virtual ground at the amplifier input is used in the following expression for the circuit gain.

The total current entering and leaving the junction at the — grid must be equal to zero. If we consider the grid current to be negligible (a good approximation of the actual case), then all current entering the junction through R_i must leave through R_f. The current through R_i must therefore be e_i/R_i. Because of the virtual ground at the — grid, the output from the amplifier is the voltage across R_f. The output voltage

$$e_o = -\frac{e_i}{R_i} R_f,$$

where the — sign results from the direction of the current through R_f. The gain of the amplifier is then

$$G = \frac{e_o}{e_i} = -\frac{R_f}{R_i}.$$

Thus, the gain depends only on the input and feedback resistances. The gain can therefore be controlled by adjusting the ratio of R_f to R_i. In a practical application, use the desired gain to find the ratio of R_f to R_i and then select appropriate values to give this ratio. In many cases you can obtain the required ratio by means of the internal Z_i and Z_f resistors. In other cases it will be necessary to use external resistors.

Integration

Application 2 shows an operational amplifier used for integration. The circuit is the same as for amplification except that R_f is replaced by a capacitor. Using the concept of the virtual ground, the current through R_i is found to be e_i/R_i. Assuming the grid current to be negligible, the current through R_i charges the feedback capacitor. The output of the amplifier is essentially the voltage across the capacitor, again because of the virtual ground at the grid of the amplifier. The voltage across the capacitor (and also the output voltage) is

$$e_o = -\frac{1}{C_f}\int i \, dt,$$

but since $i = e_i/R_i$, it can be written as

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

Thus, the output voltage of the amplifier is proportional to the integral of the input voltage. The proportionality constant $1/R_iC_f$ gives the scaling of the output voltage. In a practical application, the values of R_i and C_f must be chosen to provide a useful output. If the values of either or both R_i and C_f are decreased, the output of the integrator will increase. The value of R_i includes any internal resistance of the signal source and the virtual ground resistance at the input grid.

A good starting point in a practical problem is to let the R_iC_f product equal (approximately) the period of the waveform to be integrated. This choice generally results in a satisfactory output voltage.

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:

$$e_o = -\frac{1}{R_i C_f}\int E \sin \omega t \, dt$$

$$e_o = \frac{E}{R_i C_f \omega} \cos \omega t$$

where E is the peak amplitude, ω 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.

It should be noted that the output voltage is leading the input by exactly 90°. Thus the integrator can be used as a 90° phase shifter for sinusoidal input signals.

The gain of an integrator circuit as a function of frequency is determined by

$$G = \frac{e_o}{e_i} = \frac{\dfrac{E}{R_i C_f \omega}}{E} = \frac{1}{R_i C_f \omega} = \frac{1}{2\pi R_i C_f f}.$$

Differentiation

The circuit for differentiation is shown in application 3. The input component is a capacitor and the feedback component is a resistor. Since the — grid is at virtual ground, the current through the capacitor at the input is

$$i = C_i \frac{de_i}{dt}$$

The output voltage is the voltage across the feedback resistor:

$$e_o = -iR_f.$$

Substituting for i in the above equation:

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

The output voltage of the differentiation circuit shown in application 3 is directly proportional to frequency. This is apparent if we assume an input signal of the form $e_i = E \sin \omega t$. Substituting in the preceding equation for e_i:

$$e_o = -R_f C_i \frac{d}{dt}(E \sin \omega t)$$

$$e_o = -R_f C_i E \omega \cos \omega t.$$

The output voltage is thus proportional to frequency ($\omega = 2\pi f$) and is shifted 90° with respect to the input signal. This permits use of the differentiator as a 90° phase shifter and as a frequency-to-voltage converter as described in application 17.

Summation

Application 4 shows the circuit for a summing amplifier. Because of the virtual ground at the — grid, the current in the total R_i network is

$$i = \frac{e_1}{R_1} + \frac{e_2}{R_2} + \frac{e_3}{R_3} + \frac{e_4}{R_4} \dots + \frac{e_n}{R_n}.$$

The output voltage of the summing amplifier is obtained by multiplying R_f by the current through it.

$$e_o = -i R_f = -\left(\frac{R_f}{R_1} e_1 + \frac{R_f}{R_2} e_2 + \frac{R_f}{R_3} e_3 + \frac{R_f}{R_4} e_4 \dots + \frac{R_f}{R_n} e_n\right).$$

Any of the input voltages may be amplified by a constant before the summation is made. In the special case where

$$R_1 = R_2 = R_3 = R_4 = R_n = R_f$$

the equation reduces to

$$e_o = -(e_1 + e_2 + e_3 + e_4 \dots + e_n).$$

Displaying B-H Curves for Magnetic Materials

The circuit for displaying B-H curves for magnetic materials is illustrated as application 28. The magnetizing force H and the flux density B of a magnetic sample can be calculated from the following.

H: Magnetizing Force

The relation between H and the current in a magnetic core is given by

$$H = \frac{N_1 i}{l}$$

where H is the magnetizing force in ampere-turns per meter, N_1 is the number of turns in the primary winding, i is the primary current in amperes, and l is the mean length of the magnetic path in meters.

The voltage across the current sampling resistor is due to the primary current through it. This current is equal to e/r, where e is the voltage across r applied to the horizontal deflection system of the oscilloscope. Substituting for i in the equation:

$$H = \frac{N_1 e}{l r}.$$

The voltage e can be determined from the calibrated horizontal deflection factors of the oscilloscope. Since all other factors are known, H can then be determined.

The secondary voltage of the transformer e_2 is given by

$$e_2 = N_2 \frac{d\phi}{dt}$$

where N_2 is the number of secondary turns in the transformer, and $d\phi/dt$ is the time rate of change of flux. Since

$$d\phi = \frac{e_2}{N_2} dt,$$

$$\phi = \int \frac{e_2}{N_2} dt.$$

ϕ: Flux

If the secondary voltage of the transformer is applied to the O Unit integrator circuit, the output voltage from the integrator is

$$e_o = -\frac{1}{R_i C_f} \int e_2 \, dt.$$

It can be resolved from the preceding equations that

$$e_o = -\frac{N_2}{R_i C_f} \phi \text{ and}$$

$$\phi = -\frac{R_i C_f}{N_2} e_o.$$

The output voltage from the integrator circuit e_o can be measured from the oscilloscope display by means of the calibrated vertical deflection factors. Since all other factors are known, the flux can be calculated.

B: Flux Density

The flux density B is the total flux ϕ divided by the cross sectional area A, or $B = \phi/A$. The cross sectional area of the core can be determined from its physical dimensions. Substituting for ϕ in the preceding equation and solving for B:

$$B = -\frac{R_i C_f}{N_2 A} e_o.$$

It is therefore possible to determine both H and B from the oscilloscope display and the constants of the particular configuration.

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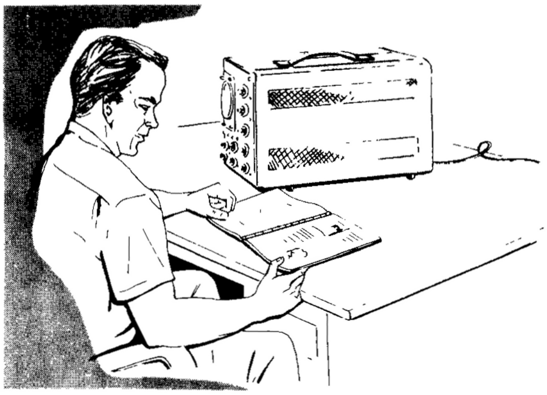
SECTION 5

CIRCUIT DESCRIPTION



General

This section of the manual describes the Type O Unit circuitry with reference to the block diagram and schematics in Section 9.

Block Diagram

The block diagram shows that the output of the two operational amplifiers and the external input signals are individually applied to the VERTICAL DISPLAY switch. The switch selects the desired input and applies it to a step attenuator. The attenuator reduces the signal to the required level before it is applied to the amplifier stages. The output of the amplifiers is then applied to the vertical amplifier of the oscilloscope.

Preamplifier

Input signals to the preamplifier are selected by the VERTICAL DISPLAY switch. Signals are then applied through the ZERO CHECK switch to the VOLTS/CM switch and its attenuator. The ZERO CHECK switch allows input signals to be quickly disconnected so that the zero-signal dc level of the preamplifier can be determined.

The VOLTS/CM switch attenuators are frequency-compensated voltage dividers that reduce the input signal amplitude to a level suitable for driving the grids of the input stage. Each attenuator presents an input impedance of 1 megohm paralleled by 47 pf, regardless of signal frequency. The frequency compensation is accomplished by a variable capacitor across the input resistor of each divider. The input capacitance is adjusted with a variable capacitor in parallel with both resistors of the divider. In the ×2 attenuator, for example, these capacitors are C6508C and C6508B, respectively.

No attenuator is used in the .05 position of the VOLTS/CM switch. The preamplifier input capacitance in this position is adjusted to 47 pf by means of either C6521 or C6541, depending on whether the VERTICAL DISPLAY switch is set to a + or — position.

Input signals from the attenuator are applied to the grid of either V6524 or V6544 depending on the setting of the VERTICAL DISPLAY switch. Positive-going signals applied to the grid of V6524 appear on the oscilloscope crt in the normal position. Positive-going signals applied to the grid of V6544 are inverted. Resistor R6518 prevents excessive input tube grid current if a large positive signal is applied to the input without attenuation. C6518 prevents R6518 from affecting the high-frequency response of the amplifier.

The input stage of the preamplifier, V6524 and V6544, is a cathode-coupled paraphase amplifier. The signal is applied to one grid, and the other grid is at ac ground at all times. Cathode coupling produces equal and opposite (push-pull) output signals. The VARIABLE control R6530 (concentric with the VOLTS/CM switch), varies the cathode degeneration and hence the stage gain. With the VARIABLE control at its detent position (minimum resistance), the GAIN ADJ. control R6536 is used to set the preamplifier maximum gain by varying the total cathode current.

The DC BAL. control R6533 permits an exact balance in dc cathode currents of V6524 and V6544. This prevents any change in dc voltage at the cathodes of V6524 and V6544 when the VARIABLE control is rotated. When the DC BAL. control is adjusted correctly, the crt trace will not shift vertically when the VARIABLE control is rotated.

The push-pull output of the paraphase amplifier is applied directly to the bases of output amplifier transistors, Q6564 and Q6574. The output amplifier is a difference amplifier with emitter coupling. The emitter-coupling network employs a time constant equal and opposite to the transistor thermal time constant, providing low-frequency gain stabilization. The collector circuits contain networks to improve the high-frequency response of the amplifier. L6564 and L6574 peaking coils are adjustable, permitting proper collector circuit compensation for the capacitance of the interconnecting plug and the oscilloscope main-unit vertical amplifier.

The preamplifier input capacitance is stabilized against changes in the setting of the VARIABLE VOLTS/CM control by neutralization from the collectors of Q6564 and Q6574 to the grids of V6524 and V6544. When a signal is applied to the grid of V6524, for example, the collector voltage of Q6564 changes in the same direction as the cathode of V6524. When the VARIABLE control is rotated, increasing its resistance, the signal voltage appearing at the cathode of V6524 will increase while the signal voltage appearing at the cathode of V6544 will decrease. When neutralizing capacitor C6574 is properly adjusted, the change in effective capacitance between the grid and cathode of V6524 will be offset by the opposite change in effective capacitance between the grid of V6524 and the collector of Q6564. The net result is that the effective input capacitance remains constant. The same effect is produced on the other side of the amplifier when the signal is applied to the grid of V6544.

Operational Amplifiers

Since the two operational amplifiers are identical, only the Amplifier A will be discussed.

Input signals to the operational amplifier are normally applied through the A INPUT connecter on the front panel of the unit. The signals are then connected through the input impedance selected by the Z_i SELECTOR switch to the grid of V5524. Or, the input signals may be applied directly to the grid through the — GRID connector (or the ± GRID connector, providing the ± GRID SEL switch is in the (—) position). Signals connected directly to the —GRID connector bypass the Z_i SELECTOR switch.

Tubes V5524 and V5534 comprise an input difference amplifier stage. Signals applied to the grid of V5524 (the —grid) are inverted at the A OUTPUT connector while signals applied to the grid of V5534 (the + grid) are not inverted. Signals applied to either grid are amplified and applied from the plate of V5524 to the bootstrap cathode follower V5543A. The polarity of the signal at the grid of V5543A depends upon the polarity of the input and on whether the signal is applied to the + or — grid.

The plate load resistors of V5524 are part of a bootstrap circuit driven by the cathode of V5543A through Zener diode D5528 and capacitor C5528. The bootstrap circuit makes the plate load resistors of V5524 appear larger than they actually are, and the supply voltage (+350 v) much higher than it actually is. This permits the plate voltage of V5524 to rise and fall with almost no change in plate current.

V5543A also drives the grid of the output cathode follower V5543B through Zener diode D5529 and capacitor C5529. Any voltage change at the cathode of V5543A is coupled to the grid of V5543B without attenuation. D5529 assures that the A OUTPUT connector voltage can be set at ground.

The open-loop gain of this system is less than 2500. To increase the gain, a small amount of positive feedback is applied from the A OUTPUT terminal to the cathodes of the input stage through R5547 and the OPEN LOOP GAIN A control R5548.

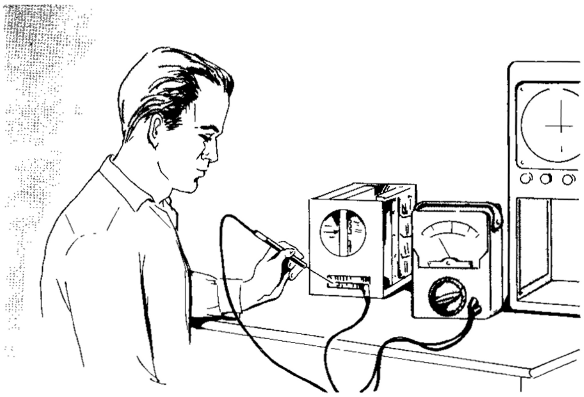
To assure that the A OUTPUT connector voltage can be set at ground, the screen voltage in the input stage is adjustable. The DC LEVEL RANGE A control (internal adjustment) and the front-panel OUTPUT DC LEVEL control permit the screen voltage of one of the input tubes to be raised while the screen voltage of the other tube is lowered. Thus the conduction of V5524 can be changed to suit the required ground level output voltage when there is no input signal.

The front-panel OUTPUT DC LEVEL ADJ. switch, SW5520, allows the output dc level of the operational amplifier to be adjusted to ground even when input circuits and signals are connected. SW5520 disconnects all input circuitry to the amplifier and switches in a feedback network that makes the operational amplifier gain 100. The 100× gain permits the operator to make the OUTPUT DC LEVEL adjustments with good display resolution.

A second form of screen voltage adjustment of the input tubes permits the selection of the amplifier operating conditions that are required for minimum grid current. Minimum grid current occurs when the operating bias of the input tubes is adjusted to the correct value. A limited adjustment range for the screen voltage of the input amplifier (an adjustment that changes both screen voltages equally), assures that the proper operating conditions for minimum grid current can be obtained. By adjustment of the GRID CURRENT A control, R5535, the input stage operating bias can be changed to the optimum value without appreciably affecting the system gain. Since the V5524 plate circuit is a bootstrap system, a change in the bias caused by a small change in the screen voltage will not significantly disturb the output dc level.

When an operational amplifier is connected for integration, normal amplifier drift and small dc components of the signal will also be integrated. The result is that the display will be slowly forced off the crt. To prevent this, a special feedback network can be switched in series with the integrator Z_f component. The special network is composed of R5514, R5515, C5514, and C5515. With the front-panel INTEGRATOR LF REJECT switch in either the 1 CPS or 1 KC position, any dc or low-frequency changes at the A OUTPUT connector are applied through the feedback network to the grid of V5524, restoring the trace position on the crt. The high-frequency components of the integrated signal are not fed back to the grid of V5524.

By means of the INTEGRATOR LF REJECT switch, the time constant of the feedback network can be selected. In the 1 CPS position, the time constant of the feedback network is about 1 second. Signals much above 1 cps are not fed back to the grid of V5524. In the 1 KC position, the time constant is about 1 millisecond. In this case signals much above 1 kc are not fed back to the grid of V5524. The 1 KC position can be used to prevent the integration of line-frequency hum pickup or other noises, while still permitting the integration of desired signals above 1 kc.



SECTION 6

MAINTENANCE

PREVENTIVE MAINTENANCE

Calibration

The Type O Plug-In Unit will not require frequent calibration. However, to insure that the unit is operating properly at all times we suggest that you check the calibration after each 500-hour period of operation (or every six months if the unit is used intermittently). A complete step-by-step procedure for calibrating the unit and checking its operation is given in the Calibration Section of this manual.

The accuracy of measurements made with the O Unit depends not only on the accuracy of calibration, but also on the calibration of the associated oscilloscope. It is important for the oscilloscope to be maintained in proper calibration.

Visual Inspection

Troubles can sometimes be found by a visual inspection of the unit. For this reason, you should perform a complete visual check every time the instrument is calibrated or repaired. Look for such defects as loose or broken connections, damaged connectors, improperly seated tubes, scorched or burned parts, broken terminal strips, etc. The remedy for these troubles is apparent, except for heat-damaged parts. Heat damage is often the result of other, less apparent trouble. It is essential for you to determine the cause of overheating before replacing damaged parts.

Tube Checks

Tube-tester checks on the tubes used in the Type O Unit are not recommended. Tube testers sometimes indicate a tube to be defective when that tube is operating satisfactorily in a circuit, or they may fail to indicate tube defects which affect the performance of the circuits. The criterion for usability of a tube is whether or not it works properly in the circuit. If it does not, then it should be replaced. Unnecessary replacement of tubes is not only expensive but may also result in needless recalibration of the instrument.

COMPONENT REPLACEMENT

General

The procedures for replacing most parts in the O Unit are easy. Detailed instructions for their removal are therefore not required. In some cases, however, additional information may help you. This information is contained in the following paragraphs. Because of the circuit configuration, it will be necessary to recalibrate portions of the circuit when certain parts are replaced. Refer to the Calibration Section of this manual.

Switches

Procedures for the removal of defective switches are, for the most part, obvious and only a normal amount of care is required. If a switch is removed, careful notation of the leads to the switch should be made to facilitate connecting the new switch. Photographs showing the location of parts on the switches are opposite the schematics in Section 9 of this manual.

Single wafers are not normally replaced on the switches used in the O Unit. If one wafer is defective, the entire switch should be replaced. Switches may be ordered from Tektronix either unwired or with the parts wired in place.

Soldering Precautions

In the production of Tektronix instruments a special silver-bearing solder is used to establish a bond to the ceramic terminal strips. This bond may be broken by repeated use of ordinary tin-lead solder, or by excessive heating of the terminal strip with a soldering iron. Occasional use of ordinary 60-40 solder will not break the bond unless excessive heat is applied.

If you are responsible for the maintenance of Tektronix instruments, it is advisable to have a stock of solder containing about 3% silver. This type of solder is used in printed circuitry, and is generally available locally. It may also be purchased from Tektronix in one-pound rolls; order by part number 251-514.

Because of the shape of the terminals of the ceramic terminal strips, we recommend a wedge-shaped tip on your soldering iron. These tips allow you to apply heat directly to the solder in the terminals. It is important to use as little heat as possible while producing a full-flow joint.

The proper technique for soldering components in place requires: (1) the use of long-nose pliers to hold the lead securely between the component and the point where heat is applied, allowing the pliers to serve as a heat sink; (2) the use of a hot iron for a short time; and (3) careful manipulation of the leads to prevent lead breakage. Use a 50- to 70-watt iron when working on ceramic strips.

Ceramic Terminal Strips

Damaged ceramic terminal strips are most easily removed by unsoldering all connections, then knocking the plastic yokes out of the chassis. This can be done by using a plastic or hard-rubber mallet to hit the ends of the yoke protruding through the chassis. If space limitations prohibit use of the mallet directly, a plastic rod can be used between the mallet and the yoke of the strip. When the two yokes supporting the strip have been knocked out of the chassis, the strip and yokes can be removed as a unit. The spacers will probably come out with the yokes; if not, they can be removed separately.

Another way of removing the terminal strip is to cut off the side of the yoke holding the strip with diagonal cutters. This permits the strip to be removed from a difficult area where a mallet cannot be used. The remainder of the yokes and the spacers can be pulled out separately. Since a replacement strip is supplied with yokes already attached, the old yokes need not be salvaged. However, the old spacers can probably be used again.

When the damaged strip and yoke assembly has been removed, place the spacers into the holes in the chassis. Then set the ends of the yoke pins into the spacers. Press or tap lightly directly above the yokes to drive the yoke pins down through the spacers. Be certain that the yoke pins are driven completely through the spacers. Then cut off the portion of the yoke pin protruding past the spacers. Fig. 6-1 shows how the ceramic strip parts fit together.

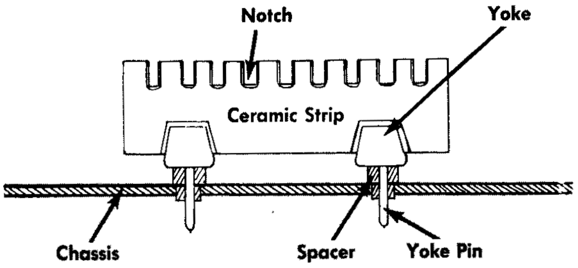


Fig. 6-1. The ceramic strip and its parts.

TROUBLESHOOTING

General Troubleshooting Information

This portion of the manual is intended to help you troubleshoot the Type O Unit in the event of trouble.

Since the Type O Unit derives all of its operating voltages from the oscilloscope, and depends on the oscilloscope for its display, you must be sure that the oscilloscope is not the cause of trouble. Trouble can usually be isolated to either the oscilloscope or plug-in unit by substituting another plug-in for the suspected one and checking for proper operation. Or you can insert the suspected O Unit in another oscilloscope and check for proper operation.

If trouble occurs in the Type O Unit, try to isolate it by quick operational and visual checks. First check the settings of all controls. Then operate the controls to see what effect, if any, they have on the trouble. The normal or abnormal operation of each control may help you to establish the trouble symptoms. (The cause of trouble which occurs only in certain positions of a control can usually be determined immediately from the trouble symptoms.)

After the trouble symptoms are established, look first for simple causes of trouble. Check to see that the pilot light of the oscilloscope is on, feel for any irregularities in the operation of the controls, listen for any unusual sound, see that the tube filaments are lit, and visually check the entire instrument. The type of trouble will generally indicate the checks to make.

In general, a troubleshooting procedure consists of two parts: circuit isolation and circuit troubleshooting. Since the Type O Unit is a relatively simple unit, divided into three independent circuits, it will be apparent which of the three is defective. After isolating the circuit, you can then troubleshoot in the circuit to find the cause of the trouble.

Table 6-1 lists troubles which can occur in the Type O Unit, the probable causes, and checks to make. The table is divided into two sections, the Preamplifier and the Operational Amplifiers. If trouble occurs, determine which section of Table 6-1 to use. Then try to identify the trouble with one of the steps in the table.

Most troubles will be caused by tube or semiconductor failures. Therefore, when trouble has been isolated to a circuit, the tubes and semiconductors in that circuit should be checked (by substitution). Be sure to return tubes and transistors found to be good to their original socket.

Switch wafers shown with the circuit diagrams are coded to indicate the position of the wafer on the switches. The number portion of the code refers to the wafer number on the switch assembly. Wafers are numbered from the front of the switch to the rear. The letters F and R indicate whether the front or the rear of the wafer is used to perform the particular switching function.

Test Points

Major test points in the unit are shown on the schematics and in Fig. 7-1. A test point is indicated by a number with a line indicating the location of the test point in the circuit. Test points are used as an aid in troubleshooting and calibrating the unit, and reference to these points is made in Table 6-1 and in the Calibration Procedure (Section 7 .

Voltage measurements, and the conditions under which they were obtained, are shown at many test points on the schematics.

Test points on the schematics are numbered consecutively starting with the diagram for the Preamplifier. Numbers increase from right to left across the page. The Operational Amplifiers have identical test points and voltages.

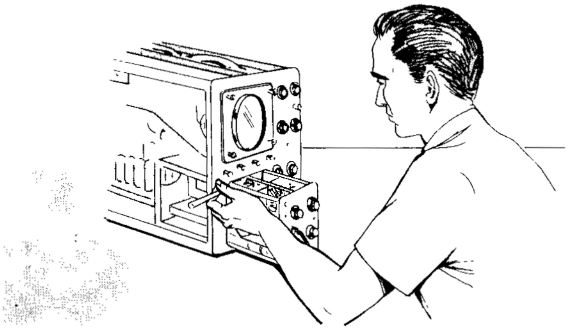
TABLE 6-1

TROUBLE	PROBABLE CAUSE	CHECKS TO MAKE
PREAMPLIFIER		
1. Gain of all signals low.	1. Front-panel GAIN ADJ. needs adjustment. 2. Oscilloscope vertical amplifier gain needs adjustment.	1. Check gain with the calibrator signal. 2. If unable to get enough gain, check the oscilloscope amplifier by using a Gain-Set Adapter between the plug-in unit and the oscilloscope.
2. Trace shifts vertically as VARIABLE control is rotated.	DC BAL. control needs adjustment.	Adjust the DC BAL. control until the trace does not move as the VARIABLE control is rotated.
3. Severe loss of gain and the vertical POSITION control works backward.	D6576 shorted.	D6576 should have 6.3 volts across it. If shorted, test points $\boxed{1}$ and $\boxed{3}$ will show higher than normal voltage.
4. When the unit is in a dual-sweep scope such as a 535A or 545A, noise is observed on trace when the B Sweep is running at 10 μSEC/CM.	C6539 open. C6576, C6582, C6584, C6586, C6588 or C6589 open.	Check C6539. Check all power-supply by-pass capacitors.
5. Noise on trace when both operational amplifiers are used as multivibrators at full 5-ma output.	Same as step 4.	Same as step 4.
6. Oscillations appear with signal near the top or bottom of the crt, but not in the center two centimeters.	C6564 or C6574 need adjustment.	See adjustment 10 in Calibration Procedure.
7. Tube heaters cold, oscilloscope +100-volt power supply out of regulation.	C6589 shorted. C6576 shorted.	If either C6589 or C6576 are shorted, look for damaged D6576, Q6564, Q6574, and tube heaters or resistors in oscilloscope that are in series with interconnecting plug terminal No. 15. Also look for burned resistors associated with Q6564 and Q6574.
OPERATIONAL AMPLIFIERS *		
1. Constant gain about half normal, and output voltage at about +25 volts.	D5529 (A) or D5579 (B) shorted. C5529 (A) or C5579 (B) shorted.	The Zener diodes should have from 95 to 105 volts across them. If shorted, replace, and check to see if R5523 (A) or R5573 (B) has been damaged. Replace if there is doubt. Check C5529 (A) or C5579 (B).
2. Overshoot of calibrator signal at unity gain with Z_i and Z_f both at 1 MEG. Output voltage about 3 or 4 volts negative.	D5528 (A) or D5578 (B) shorted. C5528 (A) or C5578 (B) shorted.	The Zener diodes should have from 95 to 105 volts across them. If shorted, replace, and check to see if R5523 (A) or R5573 (B) has been damaged. Replace if in doubt. Check C5528 (A) or C5578 (B).
3. Gain of operational amplifier low for high resistance values in constant-gain circuit. Gain is correct for low resistance values.	With internal feedback resistors: R5509, F and G (A), or R5559, F and G (B), open. With external feedback resistors: use Error Factor formula, page 4-1.	Check R5509, F and G (A). Check R5559, F and G (B).
4. Trace is shifted off crt from normal position. Can be returned to crt with vertical POSITION control. Operational Amplifier is very sensitive to external line-frequency interference.	+GRID SEL switch is in + position, and the + grid circuit is open.	Place +GRID SEL switch in (—) position, or ground + grid.

* (A) and (B) refer to the A and B circuits, respectively.

SECTION 7

CALIBRATION PROCEDURE



Introduction

The following procedure should be used to calibrate the Type O Operational Amplifier Plug-In Unit. The instrument should not require frequent calibration, but occasional adjustments will be necessary when tubes and other components are changed. Also, 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 precedure. 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

The following equipment or its equivalent is required to perform a complete calibration of the Type O Unit.

1. An accurate dc voltmeter with a sensitivity of 5000 ohms per volt or better.
2. An ohmmeter.
3. An oscilloscope having a bandpass of at least 30 mc in which to insert the Type O Unit during calibration, such as a Tektronix Type 541, 543, 543A, 545, or 545A. The test oscilloscope square-wave transient adjustments must be correct.
4. A constant-amplitude signal generator capable of generating sine waves of constant amplitude from 350 kc through 30 mc, with an output impedance of 50 ohms. Tektronix Type 190A or 190B recommended.
5. A variable frequency square-wave generator, capable of delivering at least six volts peak-to-peak output into a 25-ohm load (50-ohm system terminated with a 50-ohm load) at frequencies from 1 kc through 500 kc. Also it must be able to deliver at least 15 volts peak-to-peak into a 1-megohm load, at not greater than 600 ohms internal impedance. Risetime should be no longer than 13 nanoseconds into a 25-ohm load. Tektronix Type 105 Square-Wave Generator recommended.
6. A fast-rise square-wave generator capable of delivering about 0.2 volt peak-to-peak at about 450 kc into a 25-ohm load. Risetime must be no longer than 3 nanoseconds. Tektronix Type 107 Square-Wave Generator recommended.
7. A 47-picofarad Input Capacitance Standardizer, Tektronix Part Number 011-021.
8. A 6-inch plug-in extension, Tektronix Part Number 013-019.
9. A 50-ohm coaxial cable with UHF jack connectors on each end, such as the 42-inch length Tektronix cable, 012-001.
10. Two 50-ohm Termination Resistors fitted with one UHF jack and one UHF plug, such as the Tektronix 011-045 (replaces 011-001—either may be used).
11. If you do not have a Tektronix Type 107 Square-Wave Generator, the Type 105 can be used with the addition of a 50-ohm 10:1 T Attenuator, such as the Tektronix 011-031 (replaces 011-006, B52T10—either may be used).
12. Two 18-inch interconnecting leads with banana plugs on each end, similar to Tektronix Type PC-18R, 012-031.
13. Two 6-inch interconnecting leads with banana plugs on each end, similar to Tektronix Type PC-6B, 012-023.
14. A 10-k, 1%, ½-watt resistor.
15. A 27-ohm, 10%, 1-watt resistor.
16. A 0.001-μf, 5%, very low-leakage capacitor.
17. A SPST toggle switch.
18. Assorted alignment tools.

PRELIMINARY PROCEDURE

Make a complete visual check of the instrument. Be careful not to change any of the lead dress around the Z_i—Z_f SELECTOR switches.

Make resistance checks from each interconnecting plug terminal to ground. The resistance values should be approximately as listed in Table 7-1.

TABLE 7-1
INTERCONNECTING PLUG TERMINAL RESISTANCES TO GROUND

Pin Number	Resistance	Pin Number	Resistance
1	3.9 k	9	0.5 meg
2	0	10	1.5 k
3	3.9 k	11	10 k
4	Infinite	12	0.5 meg
5	Infinite	13	Infinite
6	Infinite	14	Infinite
7	Infinite	15	70 Ω
8	Infinite	16	Infinite

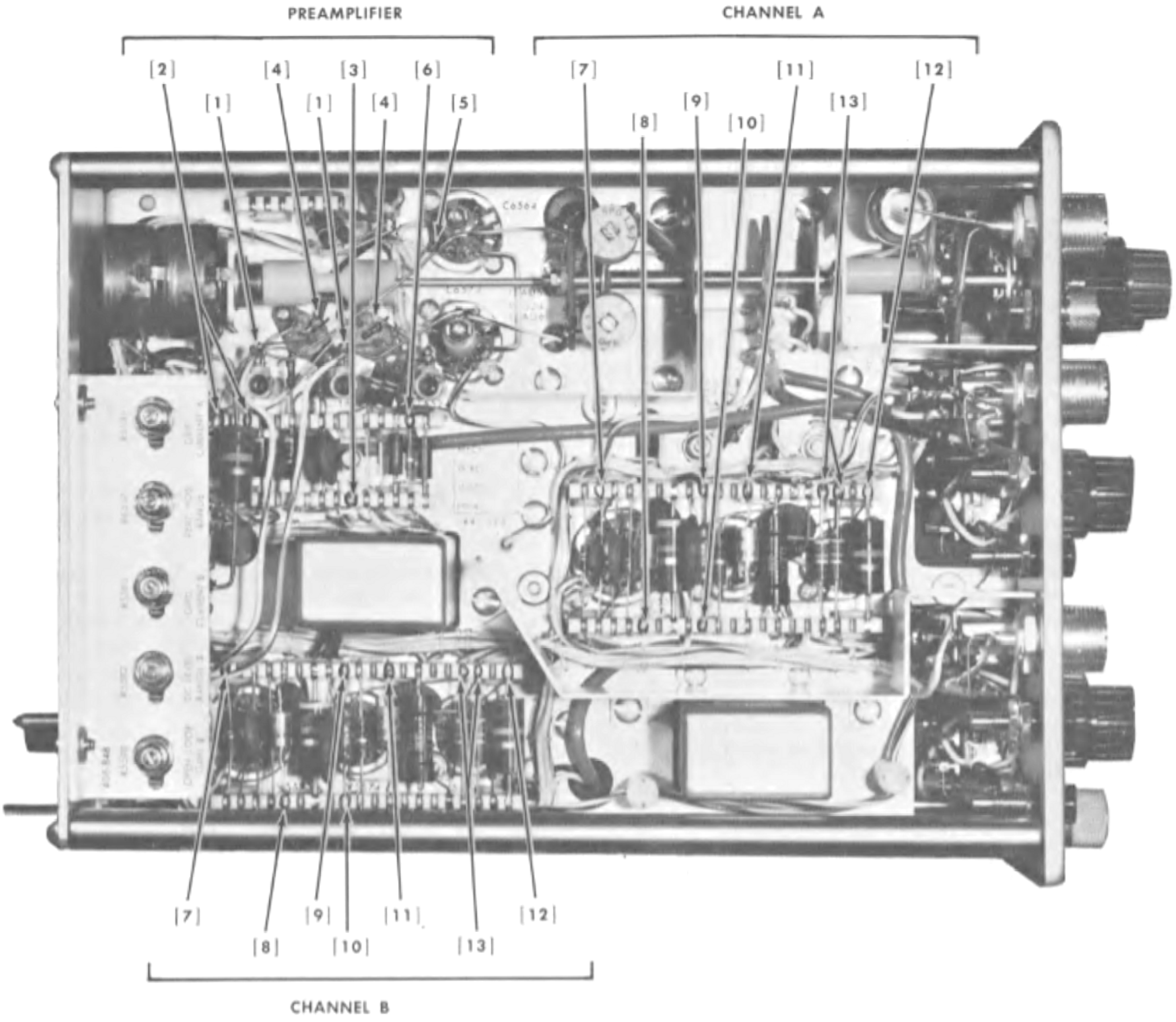


Fig. 7-1. Voltage test points. Test points are identified on schematics.

CHECK AND ADJUSTMENT PROCEDURE

Calibration of the Type O Unit requires that the line voltage be at the value indicated at the rear of the oscilloscope, near the power cord.

Install the Type O Unit in the oscilloscope and turn on the power. Let the instrument warm up for a few minutes.

Preamplifier

1. Set Front-Panel Controls

The oscilloscope controls should be set as follows, unless otherwise stated.

HORIZONTAL DISPLAY	INTERNAL SWEEP (Type 541) MAIN SWEEP NORMAL (Type 545) TIME BASE A (Type 545A) NORMAL (×1) (Type 543A)
TRIGGERING MODE	AUTOMATIC
TRIGGERING SLOPE	+INT
STABILITY	PRESET
TIME/CM	1 MILLISEC
MULTIPLIER	1 (Type 545)
SWEEP MAGNIFIER	OFF
INTENSITY	Counterclockwise

Set both Operational Amplifier controls as follows.

± GRID SEL	(—)
INTEGRATOR LF REJECT	OFF
Z_i SELECTOR	1 R MEG
Z_f SELECTOR	1 R MEG

Set the Preamplifier controls as follows.

POSITION	Midrange
VOLTS/CM	.05
VARIABLE	CALIBRATED (at detent)
VERTICAL DISPLAY	+DC

2. Locate Vertical-System Electrical Center

Turn the INTENSITY control clockwise to produce a visible trace. Remove the oscilloscope left side panel. Locate the vertical system electrical center by shorting between the two test points marked [1], Fig. 7-1, with the 27-ohm resistor. Record the trace position for future reference.

3. Preamplifier Dc Output Level

a. Adjust the trace position to the vertical system electrical center with the O Unit POSITION control.

b. The voltage at the output leads of the plug-in unit (test points [1]) must be between 65 and 70 volts above ground. The preferred value for the output voltage is +67 volts. If an output transistor is shorted, the output voltage will be near 72 volts for the lead connected to the shorted transistor.

4. Dc Balance

With the trace centered, adjust the DC BAL. control until there is no trace movement as the VARIABLE VOLTS/CM control is rotated.

5. Vertical Position Range

Set the O Unit POSITION control to midrange. Then adjust the VERT. POS. RANGE control, R6557, until the trace is at the previously determined electrical center. The VERT. POS. RANGE control is illustrated as (5), Fig. 7-2.

6. Check Input Tubes Grid Current

The grid current effect of the input tubes, V6524 and V6544, can be checked as follows.

a. Ground the EXT. INPUT connector with a short patch cord.

b. Make sure the VOLTS/CM switch is set to .05, and the VARIABLE control to CALIBRATED.

c. Switch the VERTICAL DISPLAY switch from + DC to — DC. The trace shift should be less than 1 mm. If the shift is more than 1 mm, replace V6524 and V6544. See the Parts List for proper replacements.

7. Check Input Tubes Microphonics

A light tap on the O Unit front panel should not produce microphonics of the short duration form greater than 2 mm, nor any prolonged ringing microphonics.

8. Gain Adjust

Set the VERTICAL DISPLAY switch to + DC, and apply a 1-volt signal from the oscilloscope AMPLITUDE CALIBRATOR to the EXT. INPUT connector. Adjust the GAIN ADJ. control for 2 cm of vertical deflection, centered about the graticule centerline. Be sure to measure from top to top or bottom to bottom on the trace, making certain the trace thickness does not become part of the amplitude.

9. Attenuator Tolerances

a. If the oscilloscope in which the Type O Unit is being calibrated is several years old, and if the attenuator (VOLTS/CM switch) 3% tolerance is important to you, it is advisable to check the accuracy of the AMPLITUDE CALIBRATOR before doing this step. Proceed by removing the pentode tube portion of the calibrator oscillator. Make certain the output cf is not in the same envelope. This will place the calibrator output cf at full conduction permitting the top of the output divider to rest at +100 volts. Using a precision voltmeter, such as a John Fluke or other infinite impedance voltmeter, adjust the CAL. ADJ. control until the voltage at the CAL. TEST POINT is precisely +100 volts. Then place the voltmeter in the CAL. OUT jack, and check each position of the AMPLITUDE CALIBRATOR switch for proper voltage. Tolerance for the individual voltages at each calibrator step is 3% for all Tektronix oscilloscopes listed for use when calibrating the Type O Unit.

Replace the calibrator tube.

b. Assuming the AMPLITUDE CALIBRATOR is operating properly, check the setting of the following O Unit controls.

VERTICAL DISPLAY	+DC
VARIABLE (VOLTS/CM)	CALIBRATED

c. Apply the AMPLITUDE CALIBRATOR signal to the EXT. INPUT connector and check for proper crt deflection as follows:

CALIBRATOR	VOLTS/CM	DEFLECTION
.1 VOLTS	.05	2 cm
.2 VOLTS	.1	2 cm
.5 VOLTS	.2	2.5 cm
1 VOLT	.5	2 cm
2 VOLTS	1	2 cm
5 VOLTS	2	2.5 cm
10 VOLTS	5	2 cm
20 VOLTS	10	2 cm
50 VOLTS	20	2.5 cm

d. Should any position of the VOLTS/CM switch produce a deflection more than 3% out of tolerance, it will be necessary to precisely bridge the resistors of the particular switch position. Replace one or both of them with correct value resistors.

10. Input Capacitance and Neutralizing Capacitors

Set the VOLTS/CM switch to .05 (VARIABLE to CALIBRATED) and connect the 47-pf Input Capacitance Standardizer (011-021) to the EXT. INPUT connector. Coaxially couple the Type 105 to the Standardizer through a 50-ohm Termination Resistor.

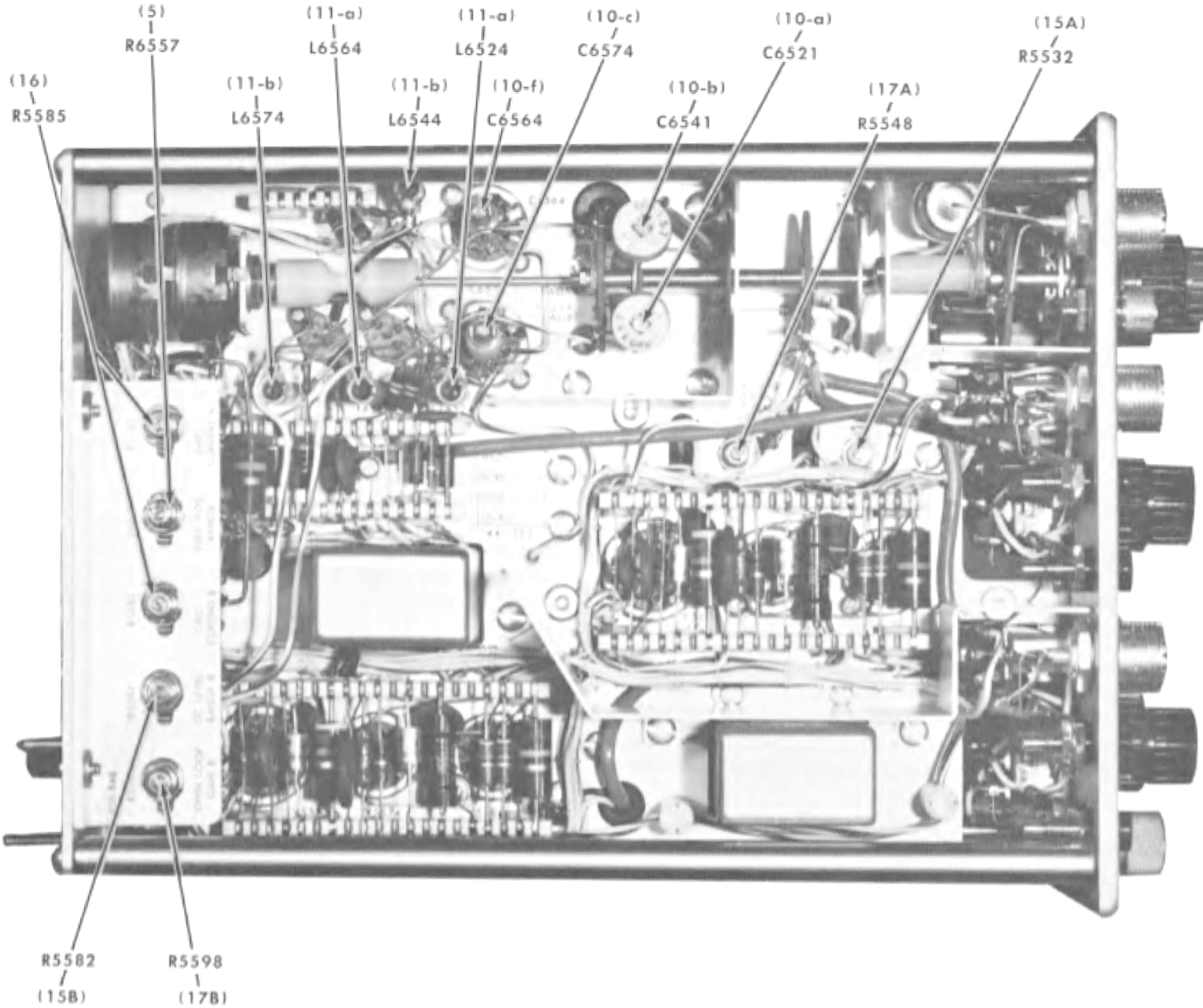


Fig. 7-2. Location of calibration adjustments. Numbers in parenthesis refer to steps in adjustment procedure.

Set the Type 105 to produce 1-kc square waves for a display amplitude of about 3.5 centimeters.

a. Adjust C6521 |(10-a), Fig. 7-2| for an optimum flat-top display.

b. Set the VERTICAL DISPLAY switch to — DC and adjust C6541 |(10-b), Fig. 7-2| for an optimum flat-top display.

c. Set the VERTICAL DISPLAY switch back to + DC and set the VARIABLE VOLTS/CM control for minimum gain. Increase the Type 105 output for 3.5 cm of crt display. Adjust C6574 |(10-c), Fig. 7-2| for an optimum flat-top display.

d. Return the VARIABLE control to the CALIBRATED position and lower the Type 105 output to 3.5 cm of crt display. It may be necessary to readjust C6521.

e. Work between C6521 and C6574 for best square-wave flat top at the two extremes of the VARIABLE control.

f. Repeat this procedure first with C6541 and then C6564 |(10-f), Fig. 7-2| with the VERTICAL DISPLAY switch at — DC.

11. High-Frequency Peaking

Set the O Unit front-panel controls as follows:

VERTICAL DISPLAY	+ DC
VOLTS/CM	.05
VARIABLE	CALIBRATED

With a 50-ohm cable terminated with a 50-ohm Termination Resistor, couple the Type 107 Square-Wave Generator

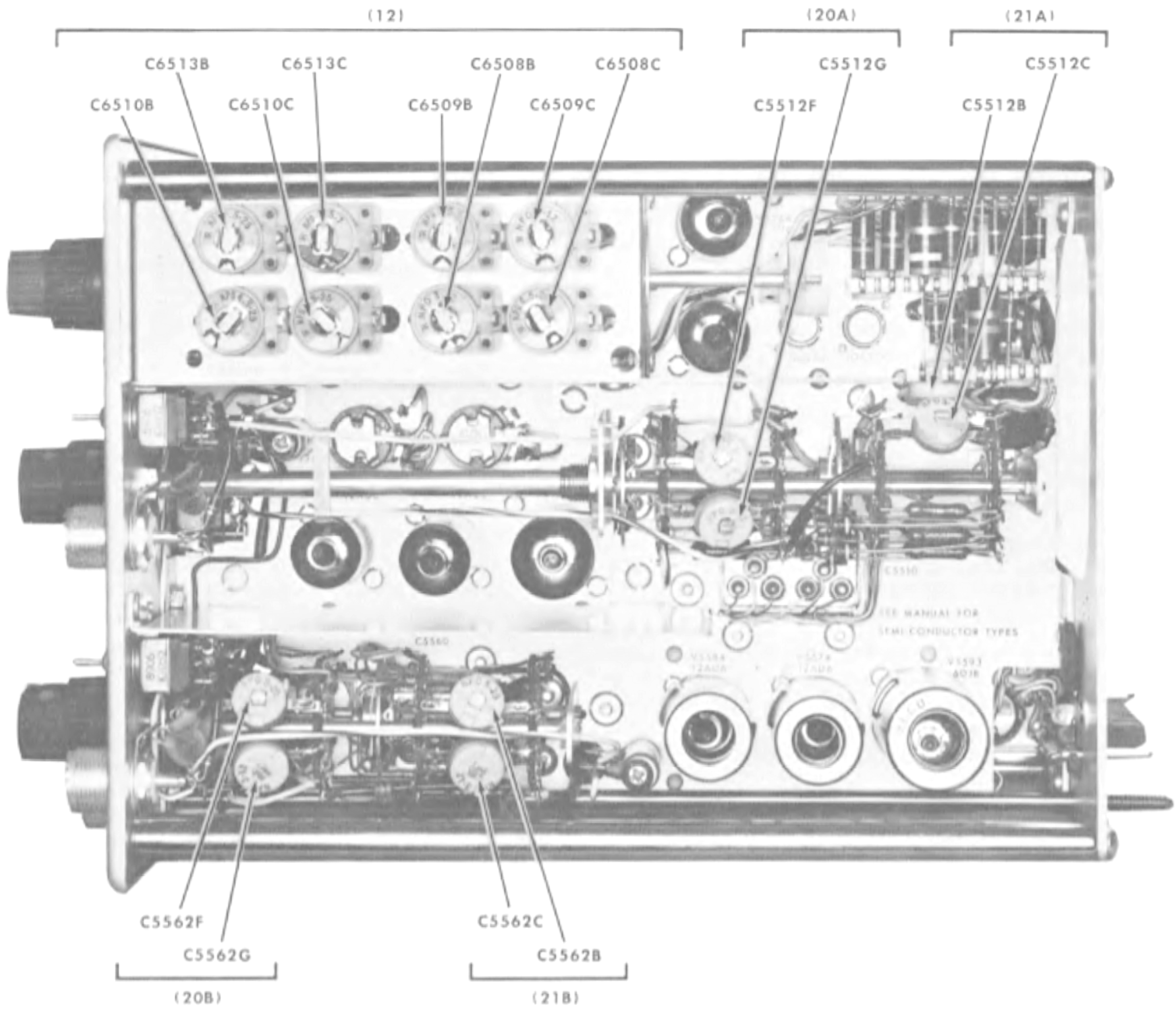


Fig. 7-3. Location of calibration adjustments. Numbers in parenthesis refer to steps in adjustment procedure.

signal to the EXT. INPUT connector of the O Unit. Set the Type 107 output at about 450 kc. Set the oscilloscope TIME/CM switch to present at least two cycles of the Type 107 signal.

a. Adjust L6524 and L6564 [(11-a), Fig. 7-2] for optimum waveform.

b. Set the VERTICAL DISPLAY switch to — DC and adjust L6544 and L6574 [(11-b), Fig. 7-2] for optimum waveform.

NOTE

If you do not have a Type 107 Square-Wave Generator, it is possible to make satisfactory adjustments of the O Unit high-frequency circuits by using a Type 105 Square-Wave Generator. It will be necessary to use a 50 Ω Termination at both ends of the cable, with a 10:1 T Attenuator between one Termination and the cable.

12. Attenuator Compensation

Turn off the oscilloscope. Insert a Plug-In Unit Extension (013-019) between the O Unit and the oscilloscope. Turn the power back on, and wait about two minutes before proceeding. Set the TIME/CM switch to .5 mSEC.

Check that the O Unit VERTICAL DISPLAY switch is at + DC, the VARIABLE control at CALIBRATED, and connect the 47-pf Input Capacitance Standardizer to the EXT. INPUT connector. Connect the Type 105 to the Capacitance Standardizer through a 50-ohm cable without a Termination Resistor or T Attenuator.

a. Adjust the Type 105 to produce 1-kc square waves, starting with the OUTPUT AMPLITUDE control at minimum. Through the following steps adjust the Type 105 to produce approximately 3.5 cm of display.

b. Set the VOLTS/CM switch as follows, and adjust the indicated capacitors. Adjust the "B" capacitors for optimum flat-top, and "C" capacitors for optimum square corners. See Fig. 7-3 (12).

VOLTS/CM	ADJUST
.1	C6508, B and C
.2	C6509, B and C
.5	C6510, B and C
5	C6513, B and C

13. Preamplifier Risetime

Turn off the oscilloscope. Remove the Plug-In Extension, and reinstall the O Unit in the oscilloscope. Turn the oscilloscope back on and wait about 5 minutes before proceeding.

Set the Type O Unit front-panel controls as follows:

VOLTS/CM	.05
VARIABLE	CALIBRATED
VERTICAL DISPLAY	+ DC

Set the oscilloscope TIME/CM switch to .1 μSEC, and turn on the 5× Sweep Magnifier. Set the TRIGGERING MODE switch to AC LF REJECT (AC FAST) and adjust the TRIGGERING LEVEL control for a stable display.

a. Connect the Type 107 to the EXT. INPUT connector through a 50-ohm cable terminated at the plug-in with a 50-ohm Termination Resistor. Set the Type 107 APPROXIMATE FREQUENCY control about ¼ turn from its .4 MC end. Set the amplitude for exactly 2 centimeters of display.

The risetime of the display, measured from the 10% to the 90% points of the rise, should be no greater than 14 nsec, and is typically less than 14 nsec (assuming the crt GEOMETRY is correctly adjusted).

b. If you do not have a Type 107, the Type 105 Square-Wave Generator can be used for the risetime measurement in the following manner.

Connect the Type 105 to the O Unit EXT. INPUT connector through a 50-ohm cable with a 50-ohm Termination Resistor at both ends, and a 10:1 T Attenuator between one termination and the cable. This will provide sufficient attenuation to permit proper risetime of the Type 105 output.

Set the Type 105 RANGE switch to 1 MC, and adjust its FREQUENCY control until the FREQUENCY meter reads 4.5 (or 450 kc). Adjust the OUTPUT AMPLITUDE control for exactly 2 centimeters of crt display.

The risetime of the display, measured from the 10% to the 90% points of the rise, should be no greater than 18 nsec, and typically less than 15 nsec.

14. Preamplifier Sine-Wave Frequency Response

Reset the oscilloscope contols as follows:

TRIGGERING MODE	AC +INT
TIME/CM	.1 MILLISEC
STABILITY	Fully clockwise

Set the O Unit Front-Panel Controls:

VOLTS/CM	.05
VARIABLE	CALIBRATED
VERTICAL DISPLAY	+ DC

Connect a 50-ohm Termination Resistor to the O Unit EXT. INPUT connector. Attach to it the Attenuator head of the Type 190 Constant-Amplitude Signal Generator. Set the Type 190 Attenuator switch to .5, and the OUTPUT AMPLITUDE control so the meter reads near 7. Set the RANGE SELECTOR switch to 50 KC (earlier instruments to 350 kc).

a. Observe the crt display, and adjust the Type 190 OUTPUT AMPLITUDE control for exactly 3 centimeters of display. The display should be a solid band, not a stable presentation of the Type 190 waveform. If a stable display appears, rotate the oscilloscope TRIGGERING LEVEL control fully clockwise.

b. Without touching any controls not mentioned, rotate the Type 190 RANGE SELECTOR switch to 21-50. Then slowly rotate the RANGE IN MEGACYCLES frequency knob to increase the frequency.

c. Observe the crt display, and stop rotating the Type 190 frequency control knob when the display has decreased in amplitude to 2.1 centimeters. This is the high frequency 3-db point. It should be no less than 25 mc, and it can be as much as 28 mc.

d. If the 3-db point falls appreciably above 31 mc, the O Unit high-frequency peaking adjustments have been over compensated and step 11 should be repeated.

This completes the calibration of the Preamplifier.

Operational Amplifiers

Since the A and B Operational Amplifiers are identical, except for component numbers and location, the following adjustment procedure is applicable to both. Only one amplifier should be adjusted at a time, however. If you start with Amplifier A, complete the entire procedure before starting Amplifier B.

15. Set O Unit Front-Panel Controls

VERTICAL DISPLAY	+A (for Amplifier A) +B (for Amplifier B)
VOLTS/CM	.5
VARIABLE	CALIBRATED
Z_i	1 MEG
Z_f	1 MEG
± GRID SEL	(−)
INTEGRATOR LF REJECT	OFF

Set the front-panel OUTPUT DC LEVEL adjustment to midrange.

a. Push the ZERO CHECK button and note the position of the trace. Release the ZERO CHECK button.

b. Push the OUTPUT DC LEVEL switch to the ADJ. position and hold it there while adjusting the DC LEVEL RANGE (R5532 for A, R5582 for B) to bring the trace near the position it occupied when the ZERO CHECK button was pushed. See Fig. 7-2, (15A) or (15B).

c. Alternately pushing the ZERO CHECK button and adjusting the front-panel OUTPUT DC LEVEL control, establish the trace at the position it occupies when the ZERO CHECK button is pushed. Any drift during this adjustment is due to the 100× gain when the OUTPUT DC LEVEL switch is in the ADJ. position.

16. Input Tubes + and — Grid Current

Refer to Fig. 4-3 and the accompanying discussion for the two circuits required to measure grid current in the Operational Amplifiers.

Set the oscilloscope controls as follows:

TIME/CM	1 SEC
STABILITY	Clockwise

The other controls remain as before.

Connect a 0.001-μf low-leakage capacitor and a SPST toggle switch for the + Grid circuit as shown in Fig. 4-3(b).

Set the O Unit front-panel controls as follows:

VERTICAL DISPLAY	+A +B
VOLTS/CM	1
VARIABLE	CALIBRATED
Z_i	EXT.
Z_f	EXT.
± GRID SEL	(+)
LF REJECT	OFF

a. + Grid

As the free-running sweep moves the spot past a vertical graticule line, open the toggle switch. The spot should not move vertically more than about $2\frac{1}{2}$ cm in 5 cm of horizontal travel. The amount of spot travel indicates the rate at which the current charges the 0.001-μf capacitor. The most stable grid current condition is when the spot moves upward. If the spot moves vertically more than $2\frac{1}{2}$ cm, adjust the GRID CURRENT control (R5535 for A, R5585 for B) to reduce the grid current and the spot travel. Typically, the vertical excursion should not exceed $\frac{3}{4}$ cm in 5 cm of horizontal travel.

The adjustment of + Grid current will affect the — Grid current.

b. — Grid

Reconnect the capacitor and toggle switch to measure the — Grid current as shown in Fig. 4-3(a). As the free-running sweep moves the spot past a vertical graticule line, open the toggle switch. The spot should not move vertically more than about $2\frac{1}{2}$ cm in 5 cm of horizontal travel. The most stable grid current condition is when the spot moves downward. If the spot moves vertically more than $2\frac{1}{2}$ cm (typically the vertical excursion should not exceed $1\frac{1}{2}$ cm), exchange the two input tubes. There is a chance that exchanging tubes will permit proper grid current limits. Recheck both the + Grid and the — Grid current after about 10 minutes warm-up.

In the grid current checks just described, two limits of spot travel were stated for each grid. This is because of the practical limits of 0.15 nanoampere for the + Grid and 0.3 nanoampere for the — Grid.

The final adjustment of the GRID CURRENT and OUTPUT DC LEVEL controls will probably interact. Therefore, after obtaining input tubes that are satisfactory for grid current, repeat steps 15 and 16.

17. Open Loop Gain

Set the oscilloscope controls for a stable, internally triggered display at .5 mSEC/CM.

Set the O Unit front-panel controls as follows:

VERTICAL DISPLAY	+A +B
VOLTS/CM	1
VARIABLE	CALIBRATED
Z_i	EXT.
Z_f	EXT.
± GRID SEL	(—)
INTEGRATOR LF REJECT	OFF

Apply a 1-millivolt signal from the AMPLITUDE CALIBRATOR to the — GRID jack.

a. Adjust the OPEN LOOP GAIN control (R5548 for A, R5598 for B) for a crt display of $2\frac{1}{2}$ cm. See Fig. 7-2, (17A) or (17B). It may be necessary to reposition the trace with the POSITION control or the OUTPUT DC LEVEL control during this adjustment. There will be some noise and instability in the crt display, but the adjustment can be made without difficulty.

b. This step can be used as a check on the condition of the input tubes. The OPEN LOOP GAIN control can increase the gain to at least 4000 (4 cm of deflection) if the tubes are operating properly. If the amplifier has been exhibiting drift problems, or if it is impossible to obtain a crt display greater than 4 cm, change the input tubes. See the Parts List for correct replacements.

18. Output Voltage and Current

Set the O Unit front-panel controls as follows:

VERTICAL DISPLAY	+A +B
VOLTS/CM	20
VARIABLE	CALIBRATED
Z_i	1 MEG
Z_f	1 MEG
± GRID SEL	(—)
INTEGRATOR LF REJECT	OFF

a. Apply a 50-volt signal from the AMPLITUDE CALIBRATOR to the INPUT connector. There should be $2\frac{1}{2}$ cm of crt display.

b. Connect a 10-k, 1%, $\frac{1}{2}$-watt resistor between the OUTPUT jack and ground. The display should remain at $2\frac{1}{2}$ cm. Remove the resistor. This checks the minus output voltage and current capability.

c. With an unterminated coax cable, connect the Type 105 OUTPUT connector to the Operational Amplifier INPUT connector.

d. Set the Type 105 to produce 1-kc square waves, and adjust the output amplitude for $2\frac{1}{2}$ cm of display.

e. Connect the 10-k, 1%, $\frac{1}{2}$-watt resistor between the O Unit OUTPUT jack and ground. The display should remain at $2\frac{1}{2}$ cm. Remove the resistor. This checks the plus output voltage and current capability.

f. In either case, if the output voltage or current is less than called for, it will be necessary to make repairs. Replace V5543 for A, or V5593 for B. If this does not correct the deficiency, check the drop across the two 100-volt Zener diodes (D5528 and D5529 for A, D5578 and D5579 for B).

19. Z_i and Z_f Components

This step checks the tolerance of the resistors and capacitors in the Z_i—Z_f circuit.

Set the O Unit front-panel controls as follows:

VERTICAL DISPLAY	+A +B
VOLTS/CM	2
VARIABLE	CALIBRATED
Z_i	.01 MEG
Z_f	.1 MEG
± GRID SEL	(—)
INTEGRATOR LF REJECT	1 CPS

Connect a 50-ohm Termination Resistor to the INPUT connector. Apply a 1-kc signal from the Type 105 to the Termination through a 50-ohm cable. Adjust the Type 105 OUTPUT AMPLITUDE control for a crt display of 4 cm.

a. Switch the Z_i and Z_f knobs as follows, and check for the corresponding deflection.

Z_i	Z_f	Defl.
.1 MEG	.1 MEG	0.4 cm
.01 MEG	.01 MEG	0.4 cm
.1 MEG	.2 MEG	0.8 cm
.1 MEG	.5 MEG	2 cm
.1 MEG	1 MEG	4 cm
.2 MEG	1 MEG	2 cm
.5 MEG	1 MEG	0.8 cm
1 MEG	1 MEG	0.4 cm

b. Without changing the Type 105 output, set Z_i to 1 μf. There should be 4 cm of crt display.

Switch the Z_i and Z_f knobs as follows, and check for the corresponding deflection.

Z_i	Z_f	Defl.
.1 μf	.01 μf	4 cm
.01 μf	.001 μf	4 cm
.001 μf	.001 μf	0.4 cm
.01 μf	.01 μf	0.4 cm
.1 μf	.1 μf	0.4 cm
1 μf	1 μf	0.4 cm

20. Variable Z_i .0001-μf and 10-pf Capacitors

Turn off the oscilloscope and insert the Plug-In Extension between the Type O Unit and the oscilloscope. Turn the power back on and wait for about two minutes. Adjust the OUTPUT DC LEVEL before proceeding.

Set the oscilloscope TIME/CM switch to 1 μSEC.

Set the O Unit front-panel controls as follows:

VERTICAL DISPLAY	+AC
VOLTS/CM	.05
VARIABLE	CALIBRATED
Z_i	.01 MEG
Z_f	.001 μf
± GRID SEL	(—)
INTEGRATOR LF REJECT	1 KC

Connect a short patch cord between the OUTPUT jack and the EXT. INPUT connector.

With a coaxial cable, connect the Type 107 Square-Wave Generator to the INPUT connector. Do not use a Termination.

a. Set the Type 107 APPROXIMATE FREQUENCY control fully counterclockwise. Turn the APPROXIMATE AMPLITUDE control fully clockwise. There should now be about a 2-cm display of an integrated square wave, as illustrated in Fig. 7-4. Set the Type 107 APPROXIMATE AMPLITUDE control and/or the O Unit VARIABLE control for 2 cm of deflection, disregarding overshoot. (If you cannot obtain 2 cm of display, replace the Type 107 output 6AU6 tube with a 6AK5.)

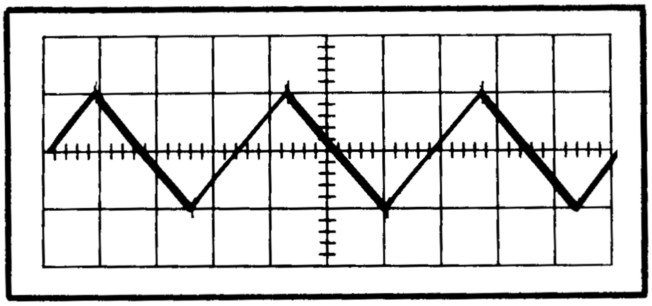


Fig. 7-4. Waveform discussed in step 20-a. Integrated 400-kc (approx.) square wave from a Tektronix Type 107 Square-Wave Generator.

b. Switch the O Unit VOLTS/CM control to .5, and the Z_f control to .0001 μf. Adjust C5512F for A or C5562F for B. See Fig. 7-3, (20A) or (20B). The waveform should be free from overshoot, as shown in Fig. 7-5. Adjust C5512F for A or C5562F or B until the tips (top and bottom) of the waveform are exactly 2 cm in amplitude.

c. Switch the O Unit VOLTS/CM control to 5, and the Z_f control to 10 pf. Adjust C5512G for A or C5562G for B until the tips of the display are exactly two centimeters in amplitude.

NOTE

If you do not have a Type 107 Square-Wave Generator, you may use the Type 105 at a frequency of about 100 kc. Use a 50 Ω Termination at the plug-in end of a 50 Ω coax cable, and a 1-μf, 100-volt capacitor between the Termination and the INPUT connector. Under these conditions, the three positions of the VOLTS/CM switch should be .2, 2, and 20, respectively.

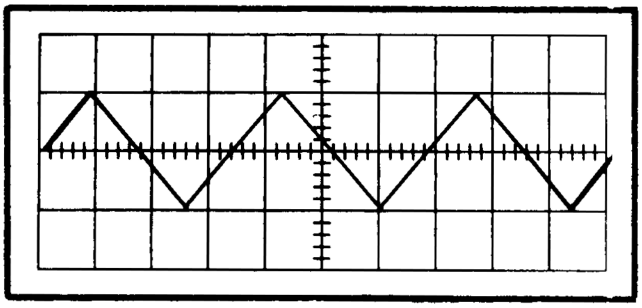


Fig. 7-5. Waveform discussed in step 20-b. Shows display when calibrating C5512F or C5562F.

21. Variable Z_f .0001-μf and 10-pf Capacitors

Connect either the Type 107 directly to the INPUT connector, or the Type 105 through a 50-ohm Termination Resistor to the INPUT connector. Set the Type 107 output frequency at .4 MC, or the Type 105 output frequency at about 100 kc.

Ignore any high overshoot on the display and read only the flat portion of the waveform during these adjustments, as illustrated in Fig. 7-6.

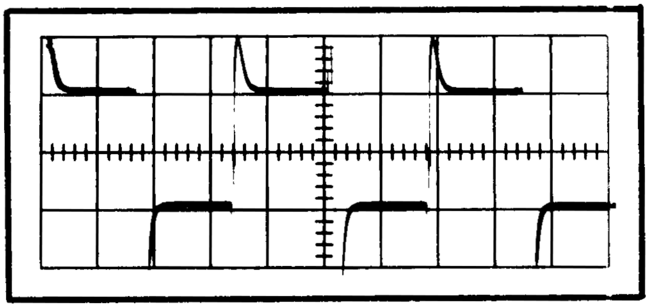


Fig. 7-6. Waveform discussed in step 21. Shows display when calibrating variable Z_f capacitors.

Set the O Unit front-panel controls as follows.

VERTICAL DISPLAY	+A +B
VOLTS/CM	.05 (107)—.5 (105)
VARIABLE	CALIBRATED
Z_i	.001 μf
Z_f	.01 μf
± GRID SEL	(—)
INTEGRATOR LF REJECT	1 KC

a. Check the adjustment of the OUTPUT DC LEVEL before proceeding.

b. Set the crt amplitude to be exactly 2 cm between flat portions of the waveform.

c. Switch the Z_i and Z_f controls simultaneously to the next smaller capacitance... Z_i to .0001 μf and Z_f to .001 μf.

d. Adjust C5512B for A or C5562B for B for exactly 2 cm of display. See Fig. 7-3, (21A) or (21B).

e. Switch the Z_i and Z_f controls simultaneously to the next smaller capacitance... Z_i to 10 pf and Z_f to .0001 μf.

f. Adjust C5512C for A or C5562C for B for exactly 2 cm of display.

22. Gain—Bandwidth Product

Turn off the oscilloscope, remove the Plug-In Extension, and replace the O Unit in the oscilloscope. Turn on the power and wait a few minutes. Adjust the OUTPUT DC LEVEL before proceeding.

Set the O Unit front-panel controls as follows:

VERTICAL DISPLAY	+DC
VOLTS/CM	.5
VARIABLE	CALIBRATED
Z_i	1 uf
Z_f	10 pf
± GRID SEL	(—)
INTEGRATOR LF REJECT	1 KC

a. Attach a 50-ohm Termination to the output of the Type 190 Constant-Amplitude Signal Generator Attenuator head. Connect the 50-ohm Termination to the O Unit EXT. INPUT connector. Set the Type 190 RANGE SELECTOR to 50 KC (to .35-.75 on earlier models) and the frequency control dial to 50 KC (350 kc on earlier models). Adjust the Type 190 output for 2 cm of crt display.

b. Remove the Type 190 output (and termination) from the EXT. INPUT connector and switch its RANGE SELECTOR switch to 9-21. Then connect the Type 190 (and Termination) to the A or B INPUT connector.

c. Change the VERTICAL DISPLAY to +A or +B. There should be much more than 2 cm of display. Increase the frequency of the Type 190 slowly until the amplitude is just 2 cm. In case there is an unstable ripple on the top and bottom edges of the display, make your measurement between the average values of the ripple. The Type 190 should now be at or above 15 mc.

SECTION 8

ACCESSORIES

The Type O Operational Amplifier Plug-In Unit will fit many measurement applications and systems through use of standard and special accessories listed in this section. Accessories should be ordered by type or part number through your local Tektronix Field Office.

PLUG-IN EXTENSION

Calibration of the Type O Plug-In Unit requires the use of the EP 54 Plug-In Extension.

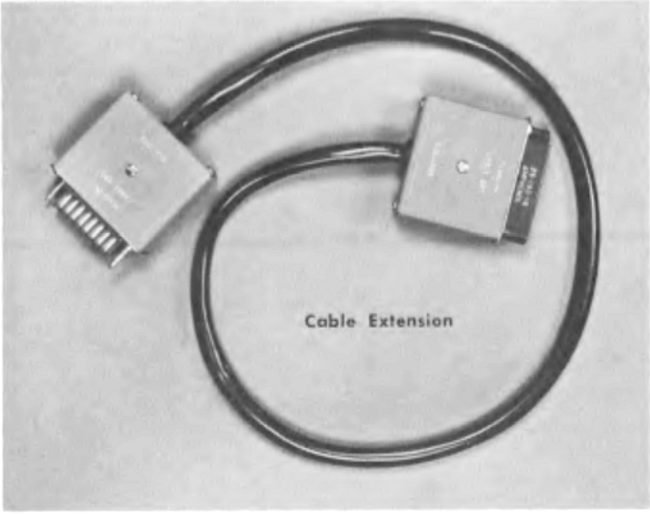
Order Part Number 013-019

EP 54 Extension

PLUG-IN CABLE EXTENSION

Provides easy access to the interior of the Type O Plug-In Unit during maintenance (cannot be used for calibration).

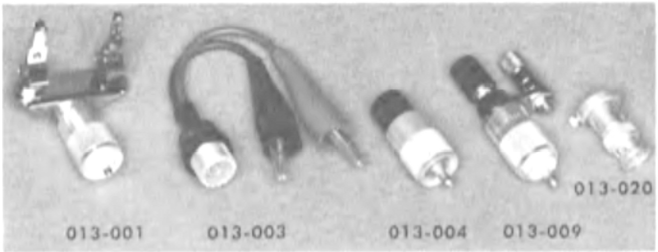
Order Part Number 012-038

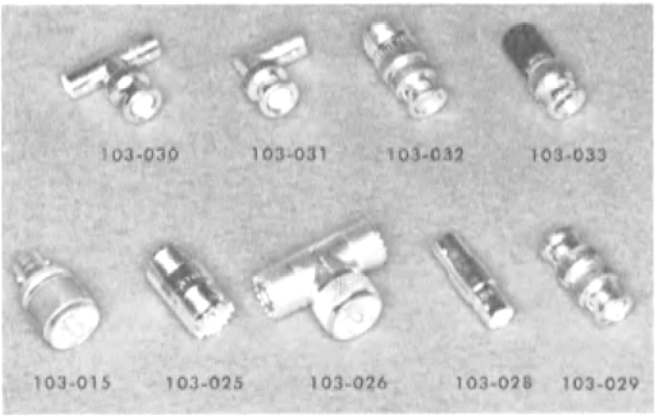


Cable Extension

COAXIAL CONNECTOR ADAPTERS

Some electronic equipment is designed with coaxial connectors different from those provided on Tektronix oscilloscopes. Tables 8-1 and 8-2 list adapters that permit joining many of the modern connector styles to your Tektronix signal amplifier. Also, the adapters may be used to mate other systems using dissimilar coaxial connectors.





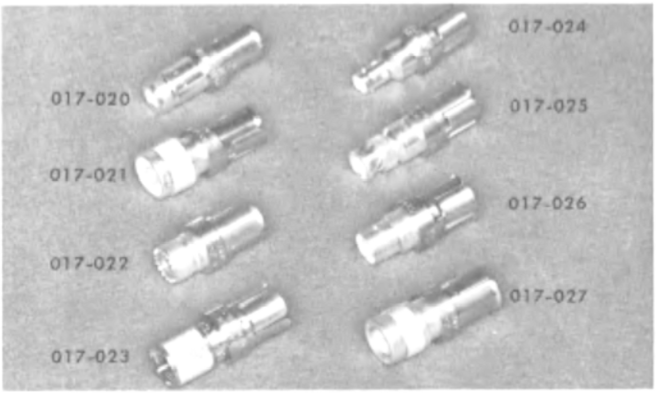


TABLE 8-1
COAXIAL CONNECTOR ADAPTERS

Description	Part Number
Component test fixture. Intended for use with Type 130 L-C Meter. Fitted with UHF Plug.	013-001
Clip leads fitted with UHF Jack.	013-003
Single Binding Post fitted with UHF Plug.	013-004
Dual Binding Post fitted with UHF Plug.	013-009
P6000 Probe Adapter. Fitting, BNC Plug.*	013-020
BNC Jack to UHF Plug. Fits BNC Plug and UHF Jack.	103-015
UHF Coupling. Jack on each end. Fits UHF Plug on each end.	103-025
UHF T Connector. Fits one UHF Jack to two UHF Plugs.	103-026
UHF Elbow. Fits UHF Jack to UHF Plug. (Not shown)	103-027
BNC Coupling. Jack on each end. Fits BNC Plug on each end.	103-028
BNC Coupling. Plug on each end. Fits BNC Jack on each end.	103-029
BNC T Connector. Fits one BNC Jack to two BNC Plugs.	103-030
BNC Elbow. Fits BNC Jack to BNC Plug.	103-031
BNC Plug to UHF Jack. Fits BNC Jack and UHF Plug.	103-032
Single Binding Post fitted with BNC Jack.	103-033

* The BNC Probe Adapter permits connecting a BNC coaxial system to any P6000 or P6017 series probe. If cable requires termination, see Table 8-5 for proper BNC termination unit. Items of Tables 8-1 and 8-2 permit a probe to be fitted to almost any coaxial system.

TABLE 8-2
50 Ω GR TYPE 874-Q ADAPTERS

Description *	Part Number
Type 874 Connector and Type N Jack. (GR Type 874-QNJ) Fits Type N Plug.	017-020
Type 874 Connector and Type N Plug. (GR Type 874-QNP) Fits Type N Jack.	017-021
Type 874 Connector and Type UHF Jack. (GR Type 874-QUJ) Fits Type UHF Plug.	017-022
Type 874 Connector and Type UHF Plug. (GR Type 874-QUP) Fits Type UHF Jack.	017-023
Type 874 Connector and Type BNC Jack. (GR Type 874-QBJ) Fits Type BNC Plug.	017-024
Type 874 Connector and Type BNC Plug. (GR Type 874-QBP) Fits Type BNC Jack.	017-025
Type 874 Connector and Type C Jack. (GR Type 874-QCJ) Fits Type C Plug.	017-026
Type 874 Connector and Type C Plug. (GR Type 874-QCP) Fits Type C Jack.	017-027

* Typical vswr for two connectors, paired, to 2000 megacycles: Type BNC, less than 1.07; Type N and Type C, less than 1.04.

COAXIAL CABLES

Coaxial cables with several connector styles are listed in Table 8-3. (Signals take nominally 5 nsec to pass through 40" of 50-ohm cable.)

TABLE 8-3
COAXIAL CABLES

Description	Part Number
Two UHF Plug Connectors. 50 Ω nominal impedance. 42" long. RG-58A/U.	012-001
Two UHF Plug Connectors. 75 Ω nominal impedance. 42" long. RG-59A/U.	012-002
Two UHF Plug Connectors. 93 Ω nominal impedance. 42" long. RG-62A/U.	012-003
Two UHF Plug Connectors. 93 Ω nominal impedance terminated with 93 Ω, ½-watt resistor in unpainted end. 42" long.	012-005
Two UHF Plug Connectors. 170 Ω nominal impedance. 42" long.	012-006
Two UHF Plug Connectors. 170 Ω nominal impedance. 60" long.	012-034
Two BNC Plug Connectors. 50 Ω nominal impedance. 42" long. RG-58A/U.	012-057
Two GR 874 Connectors. 50 Ω nominal impedance. 80", 10-nsec delay. RG-58A/U.	017-501
Two GR 874 Connectors. 50 Ω nominal impedance. 40", 5-nsec delay. RG-8A/U.	017-502
One GR 874 Connector, other end pigtail. 50 Ω nominal impedance. 8", 1-nsec delay. RG-58A/U.	017-503
Two GR 874 Connectors. 50 Ω nominal impedance. 160", 20-nsec delay. RG-8A/U.	017-504
Two GR 874 Connectors. 50 Ω nominal impedance. 16", 2-nsec delay. RG-58A/U.	017-505

INTERCONNECTING LEADS

Several types of interconnecting leads are listed in Table 8-4. These are valuable when patching between circuits or between panel connectors of Tektronix oscilloscopes.

TABLE 8-4
INTERCONNECTING LEADS

Description	Part Number
Type W130B. Black, 30" flexible output lead with banana plug at one end and alligator clip at other.	012-014
Type W130R. Same as Type W130B except colored red.	012-015
Type PC-6B. Black, 6" flexible cord with combination plug and jack banana-type connectors on each end.	012-023
Type PC-6R. Same as Type PC-6B except colored red.	012-024
Type PC-18R. Similar to Type PC-6B except 18" long and colored red.	012-031
Type W531B. Black, 6" flexible cord with plug banana-type connectors on each end.	012-028
Type W531R. Same as Type W531B except colored red.	012-029

INPUT CAPACITANCE STANDARDIZER

Standardization of the Type O Unit Preamplifier input capacitance is important when exchanging attenuator probes between units. The overall amplifier attenuator plus probe frequency response is degraded if all input time constants are not equal. Standardizer for 1-megohm, 47-pf input plug-in units, 4× attenuation.

Order Part Number 011-021

47-pf Input Capacitance Standardizer

HIGH FREQUENCY BNC CONNECTOR TERMINATIONS AND ATTENUATORS

Tektronix offers a series of terminating resistors and attenuators, having a BNC Plug on one end and a BNC Jack on the other. The attenuators have a vswr of less than 1.1, when properly terminated, to 100 megacycles. Table 8-5 lists the BNC group.

Any of the BNC terminations and attenuators may be used with Tektronix oscilloscopes by adding the proper adapter (listed in Table 8-1). For example, to adapt a BNC Plug to a UHF Jack, select part number 103-015.

It is often necessary to terminate a coaxial system when connecting it to the input of an oscilloscope. Proper termination with a resistance equal to the cable characteristic impedance will prevent signal reflections and avoid measurement errors.

If the signal requires attenuation at the oscilloscope input, a 10:1 T attenuator of the correct impedance can be used. However, a T attenuator alone is not a correct cable termination and must be followed by the proper termination resistor.

Observe the power rating stamped on the case of the terminations and attenuators. Power dissipation in excess of the rating may destroy the resistance element inside the unit. Replacement resistor part numbers are included in Table 8-5. If the resistors are damaged, the unit disassembly can be accomplished simply by unscrewing first the jack end, and then the plug end. Place the new resistors in the unit maintaining the same spacing and lead length.

TABLE 8-5
BNC TO BNC COAXIAL TERMINATIONS AND ATTENUATORS

Fittings: One BNC Plug — One BNC Jack

Description	Part Number	
50 Ω Cable Termination, ½ watt.	Unit: Element:	010-313 1,319-019
50 Ω 10:1 T Attenuator, ½ watt.	Unit: Elements:	010-314 1,318-026 1,318-027 1,319-020
75 Ω Cable Termination, ½ watt.	Unit: Element:	010-315 1,319-021
75 Ω 10:1 T Attenuator, ½ watt.	Unit: Elements:	010-316 1,318-028 1,318-029 1,319-022
93 Ω Cable Termination, ½ watt.	Unit: Element:	010-317 1,319-023
93 Ω 10:1 T Attenuator, ½ watt.	Unit: Elements:	010-318 1,318-030 1,318-031 1,319-024
50 Ω to 75 Ω Minimum Loss L Attenuator, 1 watt.	Unit: Elements:	010-319 1,319-025 1,319-026
50 Ω to 93 Ω Minimum Loss L Attenuator, 1 watt.	Unit: Elements:	010-320 1,319-027 1,319-030

010-313 Thru 010-320

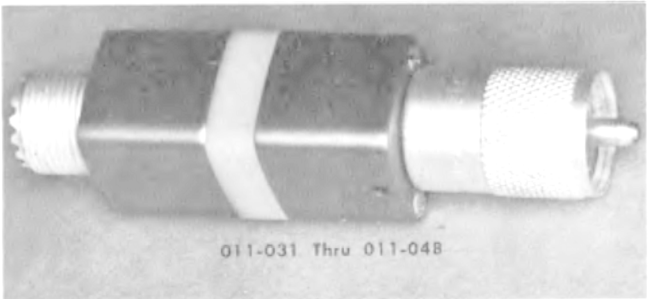
UHF SYSTEM ATTENUATORS AND TERMINATIONS

When working with UHF coaxial systems in the range of 100 megacycles and below, the attenuators listed in Table 8-6 will function properly when terminated with a termination resistor of the same value. Termination resistors listed in Table 8-7 will also perform to 100 mc except where noted.

TABLE 8-6
UHF SYSTEM ATTENUATORS

Fittings: One UHF Plug — One UHF Jack

Description	Part Numbers
50 Ω 10:1 T Attenuator, 1.5 watts.	Unit: 011-031 Elements: 2, 310-138 2, 319-048
50 Ω 5:1 T Attenuator, 1.5 watts.	Unit: 011-032 Elements: 2, 310-039 2, 319-049
75 Ω 10:1 T Attenuator, 1.5 watts.	Unit: 011-033 Elements: 1, 310-135 2, 319-045 1, 309-363
75 Ω 5:1 T Attenuator, 1.5 watts.	Unit: 011-034 Elements: 1, 310-134 2, 319-044 1, 309-362
93 Ω 10:1 T Attenuator 1.5 watts.	Unit: 011-035 Elements: 1, 310-137 2, 319-047 1, 309-365
93 Ω 5:1 T Attenuator, 1.5 watts.	Unit: 011-036 Elements: 1, 310-136 2, 310-046 1, 309-364
50 Ω to 75 Ω Minimum Loss Attenuator.	Unit: 011-041 Replaces: 011-004 Elements: 1, 310-140 2, 309-366
50 Ω to 93 Ω Minimum Loss Attenuator.	Unit: 011-042 Replaces: 011-014 Elements: 1, 310-141 2, 309-367
50 Ω to 170 Ω Minimum Loss Attenuator.	Unit: 011-043 Replaces: 011-005 Elements: 1, 309-368 2, 319-050



011-031 Thru 011-048

Replacement resistance elements are listed with the units. To disassemble, remove the four screws from the plug end, unsolder the lead in the plug center conductor and remove the plug. Then the jack can be removed with the resistors attached. Place the new resistors in the unit maintaining the same spacing and lead length.

TABLE 8-7
UHF SYSTEM TERMINATIONS

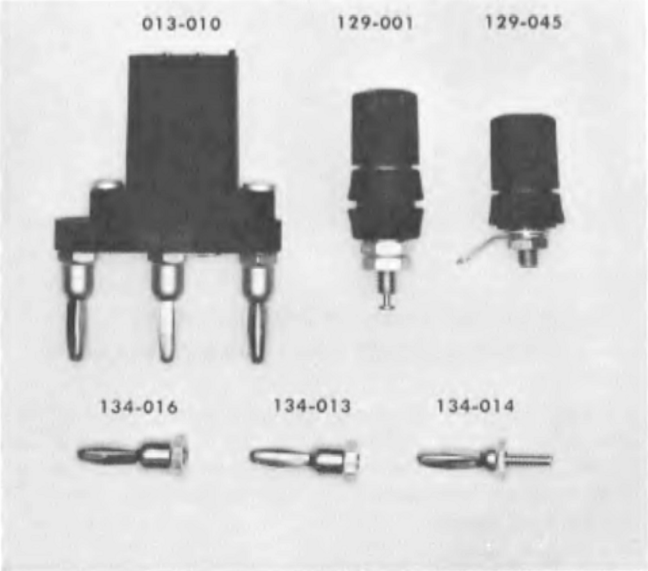
Fittings: One UHF Plug — One UHF Jack

Description	Part Numbers
50 Ω Termination Resistor, 1.5 watts	Unit: 011-045 Replaces: 011-001 Elements: 2, 309-372
75 Ω Termination Resistor, 1.5 watts	Unit: 011-046 Replaces: 011-007 Elements: 2, 309-374
93 Ω Termination Resistor, 1.5 watts	Unit: 011-047 Replaces: 011-011 Elements: 2, 309-374
170 Ω Termination Resistor, 0.5 watt 1.25 vswr at 30 mc.	Unit: 011-048 Replaces: 011-016 Elements: 1, 309-360

COMPONENT MOUNTING FIXTURE

Easy connection of external components with long leads can be accomplished through the use of the three-terminal adapter illustrated here. The adapter can be plugged into two Type O Unit front-panel terminals by removing one of the banana pins. Large components can be strapped to the adapter slide for easy mounting and short leads. There is room for four adapters on the front panel of the Type O Unit.

Order Part Number 013-010



ADDITIONAL MOUNTING ACCESSORIES

Banana Plugs

To make permanent forms of any of the application circuits for the Type O Unit, ordinary banana plugs can be mounted on a small insulated board for component mounting. Banana plugs with 6-32 tapped threads in the mounting end are available for this purpose.

Order Part Number 134-013

Banana plugs with a $^{3}/_{8}$-inch long threaded 6-32 bolt in the mounting end are also available for component mounting board use.

Order Part Number 134-014

Banana plugs with 10-32 tapped threads in the mounting end can be used on the bolt end of five-way binding posts listed next.

Order Part Number 134-016

Five-Way Binding Posts

Occasionally it is convenient to mount external components on the Type O Unit without an insulated board.

The two five-way binding post assemblies listed here can be used for component mounting by attaching a banana plug with appropriate threads (134-016 above). Thus, individual components can be mounted between two five-way binding posts.

Five-way binding post, short, without mounting bushing, but with one 10-32 nut and one solder lug.

Order Part Number 129-045

Five-way binding post, full size, with mounting bushing and two 10-32 nuts.

Order Part Number 129-001

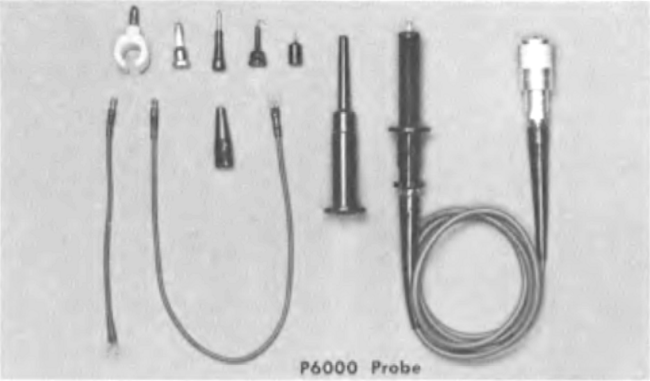
PROBES

The most common method of connecting signals to an oscilloscope vertical amplifier is to use a probe of appropriate attenuation. An attenuator probe significantly reduces the loading on the circuit being measured below the loading value of the signal amplifier input terminals. An attenuator probe can be used effectively on either a standard 1-megohm input amplifier, or a Sampling System 50-ohm signal amplifier.

P6000 Low-Capacitance High-Performance Probe

The P6000 Probe preserves the transient response of Tektronix fast-rise dc to 30-megacycle oscilloscopes. The probe is free of overshoot and ringing and has uniform frequency response. It is easy to handle, of rugged construction, and light in weight. Compensation is accomplished by the rotation of a tubular nose section capacitor; no tools are necessary.

Average bandpass characteristics show the P6000 Probe to be down between 0 and 1.2 db at 30 megacycles. Risetime of probe (measured with a Tektronix Type 541 Oscilloscope with Type K Plug-In Unit): 12 to 14 nanoseconds.



P6000 Probe

Voltage derating with frequencies above 10 megacycles must be observed when using the P6000 Probe. The probe will operate at 600 volts peak-to-peak to 10 mc, dropping to 375 volts peak-to-peak at 15 mc, 260 volts peak-to-peak at 20 mc, and 100 volts peak-to-peak at 30 mc.

Physical dimensions of the probe body are $^{7}/_{16}$ inch in diameter and $3^{5}/_{8}$ inches long without the tip. Cable length is 42 inches.

Accessories include five interchangeable tips—straight, hooked, pincher, spring and banana. A 5-inch and a 12-inch ground lead are also included.

P6017-Series Probes

The P6017-series of probes preserves the transient response of Tektronix 30-megacycle, 1-megohm input resistance instruments. The 42-inch cable length P6017 and P6022 Probes provides uniform amplitude response with no overshoot or ringing. Average bandpass characteristics show the P6017 and P6022 Probes, with 42-inch cables, to be down between 0 and 1 db at 30 megacycles. 12-foot cables reduce bandpass to 3 db down between 16 and 20 megacycles.

Voltage derating with frequency for all but the 12-foot cable length probes must be observed. The 42-inch length P6017 and P6022 will operate at 600 volts peak-to-peak to

P6017 Probe

TABLE 8-8
PROBE SPECIFICATIONS

Probe and Connector	Cable Length	Atten. Ratio	Input Impedance			Voltage Rating (Max.) †	Part Number	
			Resistance Meg Ω	Capacitance—pf Min. *	Max. **		UHF	BNC
P6000-UHF	42-inch	10	10	11.5	14.5	600	010-020	
P6017-UHF P6022-BNC	42-inch	10	10	14	14	600	010-038	010-064
	6 foot	10	10	17	17	600	010-056	010-066
	9 foot	10	10	20	20	600	010-057	010-067
	12 foot	10	10	23	23	600	010-058	010-068
P6027-UHF P6028-BNC	42 inch	1	1	67	94	600	010-070	010-074
	6 foot	1	1	94	120	600	010-071	010-075
	9 foot	1	1	120	147	600	010-072	010-076
	12 foot	1	1	146	173	600	010-073	010-077
P6002-UHF P6005-BNC	42 inch	100	9.1	2.5	2.8	2000	010-024	010-029
	6 foot	100	9.1	2.8	3.25	2000	010-034	010-050
	9 foot	100	9.1	3.5	4.0	2000	010-043	010-051
	12 foot	100	9.1	3.8	4.0	2000	010-044	010-052

* When connected to instruments with 20-pf input capacitance.

** When connected to instruments with input capacitance up to 50 pf.

† See derating information.

1.5 mc, dropping to 400 volts peak-to-peak at 3 mc, 200 volts peak-to-peak at 6 mc, 135 volts peak-to-peak at 10 mc, and 90 volts peak-to-peak at 30 mc.

Four interchangeable tips—spring, hooked, pincher, and banana tip—are included with the probe. A 12-inch ground lead is also included.

100X Probes

Probes having an attenuation ratio of 100 are also listed in Table 8-8. These probes are provided in the event you require very small capacitive loading when measuring signals of high impedance, or if it is necessary to measure voltages higher than 600 volts. They will perform with uniform amplitude response without overshoot or ringing on any 30-mc signal amplifier. No voltage vs frequency derating is necessary.

Physical dimensions of the probe body are 7/16 inch in diameter and 3⅝ inches in length without the tip. The standard cable length is 42 inches.

Four interchangeable tips—spring, hooked, BNC, and banana tip—are included with the probe. A 5-inch and a 12-inch ground lead are also included.

P6013 High Voltage Probe

The P6013 High Voltage Probe provides a means of observing waveforms of high amplitude. Voltage rating for dc and pulses is ±12 kv with proper derating above 100 kc.

Attenuation Ratio—1000.

Frequency Response—Dc to over 30 mc with proper derating.

Input Impedance—100 megohms and 3 pf.

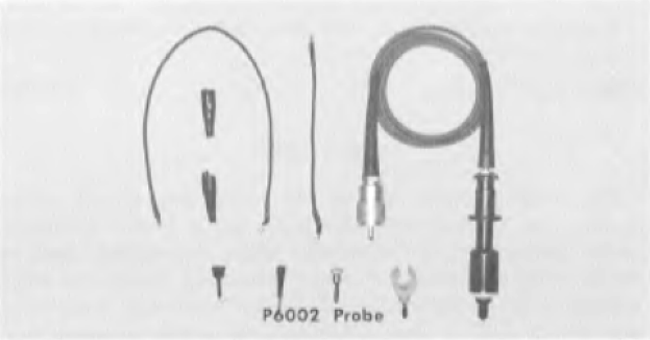
Voltage vs Frequency Derating—±12 kv to 100 kc, dropping to ±5 kv at 1 mc, ±1.5 kv at 10 mc, and ±500 volts at 30 mc.

A compensating box at the oscilloscope end of the probe cable enables the P6013 to be properly compensated to any oscilloscope having an input resistance of one megohm and a capacitance of 20 to 47 pf. The probe introduces no ringing or overshoot.

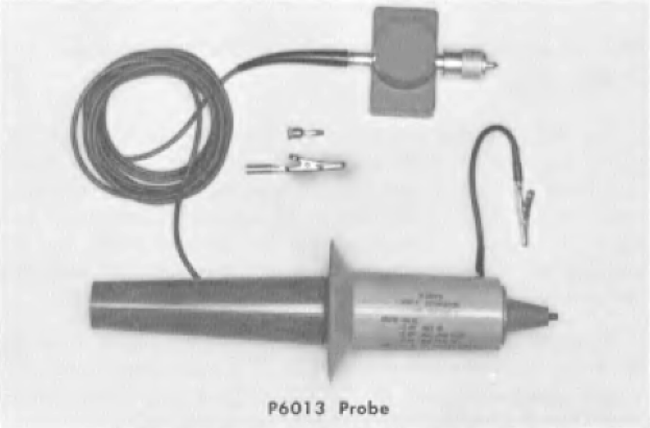
Probe body length is 12 inches, coaxial cable length is 10 feet (up to 25 feet on special order).

Accessories include 2 banana-plug tips, an alligator-clip assembly, and an attached 7½-inch ground lead.

Order Part Number (10-ft cable) 010-106



P6002 Probe



P6013 Probe

P500CF Cathode-Follower Probe

The P500CF Probe presents low capacitance with minimum attenuation. Input impedance is 40 megohms paralleled by 4 pf. Gain: 0.8 to 0.85. Input to probe is ac-coupled, limiting its low-frequency response to 5 cps. Amplitude distortion is less than 3% on unidirectional signals to 5 volts. 10× attenuator head is included with probe, and should be used on signals exceeding a few volts to minimize amplitude distortion. With the attenuator head attached, the probe input impedance is approximately 10 megohms paralleled by 2 pf. Probe output level is 11 v positive, making it necessary to use the ac-coupled position of the oscilloscope AC-DC switch. Probe cable is 42" long.

Order Part Number 010-105

P500CF Probe

Type 128 Probe Power Supply

Probe power supply for the P500CF Cathode-Follower Probe. The Type 128 supplies the necessary plate and heater voltages for one or two probes, making it possible to use cathode-follower probes with signal amplifiers not equipped with a probe-power outlet.

DC Output Voltages—+120 v regulated, at 25 ma; two +6.3 v unregulated, at 150 ma.

Voltage Ripple—+120 v supply, not more than 5 mv peak-to-peak; +6.3 v supplies, not more than 75 mv peak-to-peak.

Power Requirements—105 to 125 v or 210 to 250 v, 50 to 60 cycles, 25 watts using two P500CF Probes.

Dimensions—4¾" wide, 7¾" high, 9" overall depth.

Weight—6 lbs.

Type 128

P6016 AC Current Probe System

The P6016 Current Probe with the Type 131 Current Probe Amplifier or the Passive Termination constitute an ac current detecting system for use with any oscilloscope. The system provides accurate displays for observation and measurement of ac current waveforms. Current range extends from less than one milliampere to 15 amperes.

Use of the Current Probe and Amplifier system with any signal amplifier having less than a 22-mc bandwidth will result in an upper-frequency limit similar to that of the amplifier used; this will be less than the upper-frequency limit of the probe system alone.

The long narrow shape and convenient thumb control make the P6016 Curent Probe easy to use. Just place the probe slot over the conductor and close the slide with your thumb—no direct electrical connection is required. Wiping action keeps core surfaces clean. Loading introduced is so slight that it can almost always be disregarded. For increased sensitivity, loop the conductor through the probe slot two or three times.

Order Part Number (Probe only) 010-037

P6016 Probe and Type 131 Amplifier

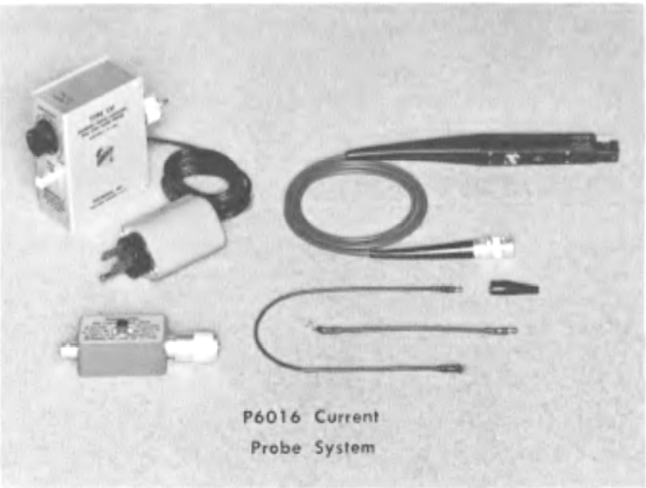
Sensitivity (with 50 mv/div oscilloscope input)—1 ma/div to 1 amp/div in 10 steps. Variable sensitivity control on oscilloscope provides continuous uncalibrated adjustment.

Frequency Range (with 30-mc oscilloscope)—3 db down at 50 cps and approximately 17 mc.

Risetime—20 nsec.

Saturation Ratings—DC, 0.5 amp; AC, 15 amps peak-to-peak decreasing to 8 amps at 400 cps, 400 ma at 50 cps.

Order Part Number (Probe & Type 131) 015-030



P6016 Current Probe System

P6016 Probe and Passive Termination

Sensitivity—2 ma/mv and 10 ma/mv.

Frequency Range (with 30-mc oscilloscope)—3 db down at 850 cps (2 ma/mv), 230 cps (10 ma/mv), and 20 megacycles.

Risetime—18 nsec.

Saturation Ratings—DC, 0.5 amp; AC at 2 ma/mv, 15 amps peak-to-peak decreasing to 8 amps at 1.5 kc, 4 amps at 850 cps; at 10 ma/mv, 15 amps peak-to-peak decreasing to 5 amps at 400 cps, 2.5 amps at 230 cps.

Order Part Number (Probe & Termination) 011-044

CAMERAS

Type C-12 Camera

Interchangeable Lens—Lens easily changed by loosening two adjustable locknuts. Lenses available are f/1.5, f/1.9, and f/4.5. Object-to-image ratios include 1:1, 1:0.9, 1:0.7, 1:0.5.

Interchangeable Back—Accepts all standard Graflok accessories. Backs may be interchanged without refocusing.

Binocular Viewing—Orthogonal and undistorted over full 8 × 10 cm area.

Hinge Mounting—Camera swings away from crt for full visibility, lifts easily out of hinge fittings.

Rotation and Sliding Backs—Rotation through 90° steps. Horizontal or vertical movements of back through five positions.

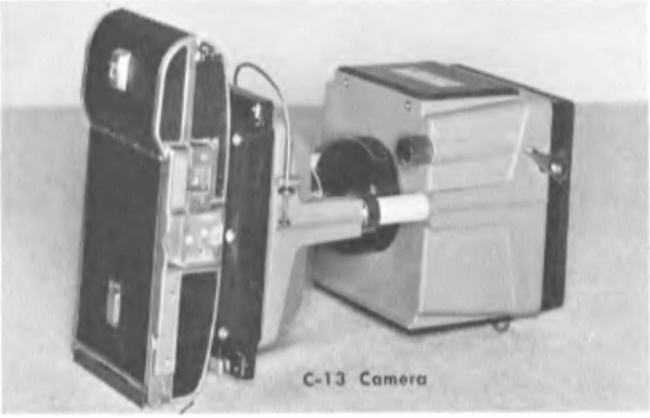
Standard C-12 Camera shipped with f/1.9 Oscillo-Raptar lens having 1:0.9 object-to-image ratio, focusing 4 × 5 Graflok back, and Polaroid roll-film back.


C-12 Camera

Type C-13 Camera

Same style as the C-12 except that it does not have the binocular viewing feature. Standard lens supplied with the C-13 Camera is an f/4.5 Oscillo-Amaton which has an object-to-image ratio of 1:0.7. Other lenses currently available from Tektronix will fit the C-13.

Other features of the C-13 Camera are similar to those of the C-12.


C-13 Camera

Type C-19 Camera

Same style as the C-12 Camera except that it is constructed without a beam-splitting mirror to permit maximum light from the oscilloscope screen to reach the camera lens. This feature in conjunction with the fast f/1.5 lens supplied with the camera make the C-19 particularly suitable for applications requiring extremely high writing rates. Other lenses currently available from Tektronix may be used with the C-19.

Binocular viewing of a 5 cm high by 10 cm wide screen area permits the oscilloscope display to be observed while being photographed.


C-19 Camera

Other features of the C-19 Camera are similar to those of the C-12.

AUXILIARY DEVICES

Type 105 Square-Wave Generator

Risetime—13 nsec, with 50-ohm termination.

Frequency Range—25 cycles to 1 mc, continuously variable.

Frequency Meter—Direct reading, accurate within 3% of full scale.

Output Amplitude—0 to 100 v maximum, 0 to 15 v across 93-ohm load.

Type 105

Type 107 Square-Wave Generator

Risetime—Less than 3 nsec, with 50-ohm internal termination.

Frequency Range—400 kc to 1 mc, uncalibrated.

Output Amplitude—0.1 v to 0.5 v, with 50-ohm terminated cable.

Type 107

Type 130 L-C Meter

Guard Voltage—Permits measuring an unknown capacitance while eliminating the effects of other capacitances from the measurements.

Five Ranges—Microhenries: 0 to 3, 10, 30, 100, 300. Picofarads: 0 to 3, 10, 30, 100, 300.

Accuracy—Within 3% of full scale.

Type 130

Type 132 Plug-In Unit Power Supply

Ideal for using Plug-In Units with or without an oscilloscope.

Frequency Response and Risetime—Dc to 15 mc, 23 nsec, when used with a Tektronix Type K or Type L Plug-In Unit and terminated in 50 ohms.

Gain—The push-pull gain is 10 when the Plug-In sensitivity is 50 mv/cm, and the unit is terminated in 93 ohms. Gain is approximately 5 when terminated in 50 ohms.

Output Terminals—Push-pull or single-ended + or − outputs are available at front-panel terminals.

Type 132

Dual-Trace Operation—Convenient back-panel jacks and switching arrangement permit use of Plug-In Unit alternate and chopped modes with chopped transient blanking.

Power Supply—Electronically regulated. Provides correct voltages for the internal amplifier and any Tektronix Type A to Z Plug-In Unit.

Type 133 Plug-In Unit Power Supply

(Not illustrated; similar in size and appearance to Type 132.) Ideal for using Plug-In Units to drive a pen recorder.

Frequency Response—Dc to 100 kc.

Gain—10, single-ended output.

Output—±5 volts into a high impedance; 1.5 amperes short circuited. Output impedance is 2 ohms.

Phase Inversion—An internal switch permits phase inversion of the signal.

Monitor Jack—A front-panel monitor jack permits observing the output with an oscilloscope without switching cables.

Dual-Trace Operation—Back-panel jacks and switching permit use of the alternate mode of operation when using the Tektronix Type CA Dual-Trace Plug-In Unit.

Power Supply—Electronically regulated.

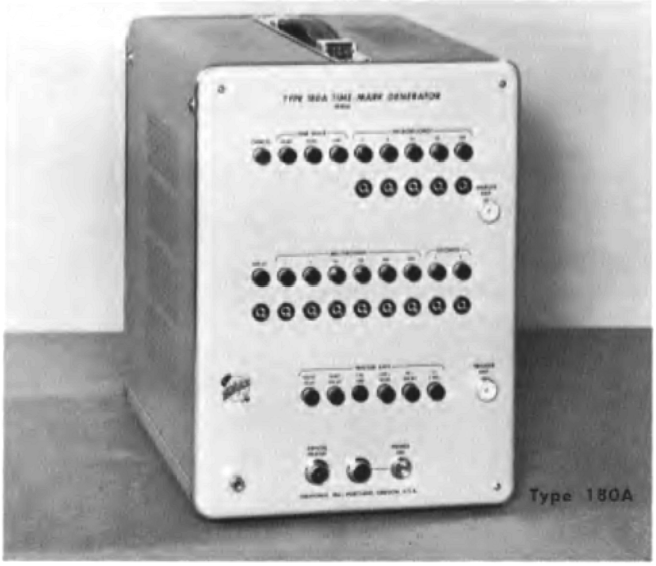
Type 180A Time-Mark Generator

Time-Marks—1, 5, 10, 50, 100, 500 μsec; 1, 5, 10, 100, 500 msec; 1, 5 seconds.

Three Sine-Wave Frequencies—5 mc, 10 mc, and 50 mc.

Six Trigger-Rate Frequencies—1, 10, 100 cycles and 1, 10, 100 kc.

Temperature-Stabilized Crystal—Provides stability of 3 ppm over 24-hour period.



Type 180A

Type 181 Time-Mark Generator

Time-Marks—1, 10, 100, 1000, and 10,000 μsec, plus 10-mc sine wave.

1-Mc Crystal Controlled Oscillator—Accurate within 0.3%.

Type 181

Type 190B Constant-Amplitude Signal Generator

Output Frequency—350 kc to 50 mc, continuously variable, 50-kc reference signal.

Output Amplitude—40 mv to 10 v peak-to-peak, continuously adjustable.

Amplitude Variation—Less than 2% from 50 kc to 30 mc; less than 5% from 30 mc to 50 mc.

Harmonic Content—Typically less than 5%.

Type 190B

Type 1121 Amplifier

Voltage Gain—100 with 9 calibrated attenuator steps to provide net gain from 100 to 0.2.

Frequency Response—5 cycles to 17 mc, decreasing slightly with increase in attenuator setting.

Risetime—21 nsec.

Maximum Output Voltage—±1 v in terminated 93-ohm cable.

RECALIBRATION TOOLS

The tools shown are handy, and in some cases necessary, for the recalibration of Tektronix instruments. All of the tools except the assembly 003-007 are available through most radio and electronic parts suppliers.

003-001 Jaco No. 125 insulated screwdriver with 7" shank and metal bit. This tool is useful for hard-to-reach adjustments.

003-000 Jaco No. 125 insulated screwdriver. This tool is similar to 003-001 but has a 1½" shank.

003-003 Walsco No. 2519 insulated alignment tool. This double-ended tool is useful for adjusting variable inductors.

003-004 Walsco No. 2503, ¼" insulated hexagonal wrench. This tool is useful for tightening variable inductor lock nuts.

003-006 (Not pictured) Insulated alignment tool suitable for adjusting small capacitors.

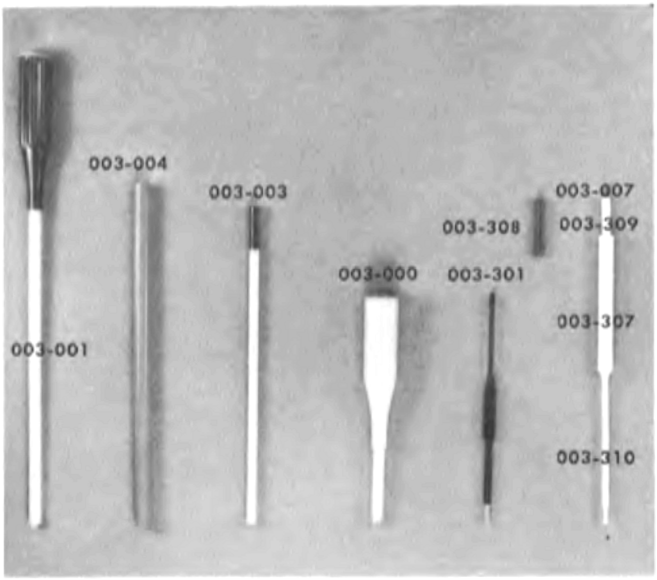
003-007 Tektronix recalibration tool assembly. This 4-unit tool assembly provides most of the necessary tools for adjusting variable inductors in Tektronix instruments.

003-301 Walsco No. 2543 double-ended 0.1" hexagonal wrench. This tool is useful for adjusting variable inductors with hexagonal cores.

Alignment tool kit: Contains the following tools.

003-001	003-004	003-308
003-000	003-006	003-309
003-003	003-307	003-310

Order Part Number (for kit) 003-500



NOTICE

If you have measurement situations that do not respond to the conventional attack, call Tektronix at your local Field Office. The composite experience of 350 man-years of Field Engineering, solving problems similar to yours, is available to you as a Tektronix Customer. The Field Engineer responsible for your area is always looking for a new challenge.

SECTION 9

PARTS LIST and SCHEMATICS

ABBREVIATIONS

Cer.	Ceramic	p	Pico, or 10^{-12}
Comp.	Composition	PMC	Paper, metal cased
EMC	Electrolytic, metal cased	Poly.	Polystyrene
EMT	Electrolytic, metal tubular	Prec.	Precision
f	Farad	PT	Paper, tubular
F & I	Focus and Intensity	PTM	Paper, tubular, moulded
G	Giga, or 10^9	S/N	Serial number
GMV	Guaranteed minimum value	T	Turns
h	Henry	TD	Toroid
K or k	Kilohms, or kilo (10^3)	Tub.	Tubular
M or meg	Megohms, or mega (10^6)	v	Working volts DC
μ	Micro, or 10^{-6}	Var.	Variable
m	Milli, or 10^{-3}	w	Watt
n	Nano, or 10^{-9}	w/	With
Ω	Ohm	WW	Wire-wound

SPECIAL NOTES AND SYMBOLS

X000 Part first added at this serial number.

000X Part removed after this serial number.

*000-000 Asterisk preceding Tektronix Part Number indicates manufactured by or for Tektronix, also reworked or checked components.

Use 000-000 Part number indicated is direct replacement.

HOW TO ORDER PARTS

Replacement parts are available from or through your local Tektronix Field Office.

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 including any suffix, instrument type, serial number, and modification number if applicable.

If a part you have ordered has been replaced with a new or improved part, your local Field Office will contact you concerning any change in part number.

ELECTRICAL PARTS LIST

Values are fixed unless marked variable.

Bulbs

Ckt. No.	Tektronix Part No.	Description	S/N Range
B5517	150-002	Neon, Type NE-2	
B5567	150-002	Neon, Type NE-2	

Capacitors

Tolerance ±20% unless otherwise indicated.
Tolerance of all electrolytic capacitors are as follows (with exceptions):

3 v — 50 v = −10% — +250%
51 v — 350 v = −10% — +100%
351 v — 450 v = −10% — +50%

C5509A †		Selected				
C5509B †		Selected				
C5509C †		Selected				
C5509D †		Selected				
C5510A	*291-033	1 µf		Z_i — Z_f Series		±1%
C5510B		.1 µf				
C5510C		.01 µf				
C5510D		.001 µf				
C5510E		1 µf				
C5510F		.1 µf				
C5510G		.01 µf				
C5510H		.001 µf				
C5511C †		Selected				
C5511D †		Selected				
C5511E	281-504	10 pf	Cer.		500 v	10%
C5512A	281-528	82 pf	Cer.		500 v	10%
C5512B	281-048	5-25 pf	Cer.	Var.		
C5512C	281-031	3-12 pf	Cer.	Var.		
C5512E	281-528	82 pf	Cer.		500 v	10%
C5512F	281-048	5-25 pf	Cer.	Var.		
C5512G	281-031	3-12 pf	Cer.	Var.		
C5514	283-017	1 µf	Disc Type		3 v	
C5515	283-028	.0022 µf	Disc Type		50 v	
C5528	283-057	.1 µf	Disc Type		200 v	
C5529	283-002	.01 µf	Disc Type		500 v	
C5533	283-002	.01 µf	Disc Type		500 v	
C5543	283-002	.01 µf	Disc Type		500 v	
C5544	283-000	.001 µf	Disc Type		500 v	
C5559A †		Selected				
C5559B †		Selected				
C5559C †		Selected				
C5559D †		Selected				

† These capacitors are installed when necessary for optimum performance. Nominal values are from 0 to 1 pf.

Capacitors *(continued)*

C5560A	*291-033	1 µf	Z_i — Z_f Series			±1%	
C5560B		.1 µf					
C5560C		.01 µf					
C5560D		.001 µf					
C5560E		1 µf					
C5560F		.1 µf					
C5560G		.01 µf					
C5560H		.001 µf					
C5561C †				Selected			
C5561D †				Selected			
C5561E	281-504	10 pf	Cer.		500 v	10%	
C5562A	281-528	82 pf	Cer.		500 v	10%	
C5562B	281-048	5-25 pf	Cer.	Var.			
C5562C	281-031	3-12 pf	Cer.	Var.			
C5562E	281-528	82 pf	Cer.		500 v	10%	
C5562F	281-048	5-25 pf	Cer.	Var.			
C5562G	281-031	3-12 pf	Cer.	Var.			
C5564	283-017	1 µf	Disc Type		3 v		
C5565	283-028	.0022 µf	Disc Type		50 v		
C5578	283-057	.1 µf	Disc Type		200 v		
C5579	283-002	.01 µf	Disc Type		500 v		
C5583	283-002	.01 µf	Disc Type		500 v		
C5593	283-002	.01 µf	Disc Type		500 v		
C5594	283-000	.001 µf	Disc Type		500 v		
C6501	*285-556	.1 µf	PTM		600 v		
C6507	281-543	270 pf	Cer.		500 v	10%	
C6508	281-007	3-12 pf	Cer.	Var.			
C6508C	281-010	4.5-25 pf	Cer.	Var.			
C6508D	281-501	4.7 pf	Cer.				
C6509B	281-010	4.5-25 pf	Cer.	Var.			
C6509C	281-007	3-12 pf	Cer.	Var.			
C6510B	281-010	4.5-25 pf	Cer.	Var.			
C6510C	281-010	4.5-25 pf	Cer.	Var.			
C6510E	283-508	150 pf	Mica		500 v	10%	
C6513A	281-505	12 pf	Cer.		500 v	10%	
C6513B	281-010	4.5-25 pf	Cer.	Var.			
C6513C	281-005	1.5-7 pf	Cer.	Var.			
C6513E	283-543	250 pf	Mica		500 v	5%	
C6518	283-002	.01 µf	Disc Type		500 v		
C6519	283-002	.01 µf	Disc Type		500 v		
C6521	281-034	1.5-7 pf	Cer.	Var.			
C6523	283-023	.1 µf	Disc Type		10 v		x105-up
C6539	290-164	1 µf	EMT		150 v		
C6541	281-034	1.5-7 pf	Cer.	Var.			
C6564	281-027	.7-3 pf	Tub.	Var.			
C6565	283-028	.0022 µf	Disc Type		50 v		
C6574	281-027	.7-3 pf	Tub.	Var.			
C6576	283-002	.01 µf	Disc Type		500 v		
C6579	283-004	.02 µf	Disc Type		150 v		
C6582	283-002	.01 µf	Disc Type		500 v		
C6584	283-002	.01 µf	Disc Type		500 v		
C6586	283-002	.01 µf	Disc Type		500 v		
C6589	283-012	.1 µf	Disc Type		100 v		

† These capacitors are installed when necessary for optimum performance. Normal values are from 0 to 1 pf.

Diodes

Ckt. No.	Tektronix Part No.	Description					S/N Range
D5528	152-087	Zener IN3044B			100 v		
D5529	152-087	Zener IN3044B			100 v		
D5578	152-087	Zener IN3044B			100 v		
D5579	152-087	Zener IN3044B			100 v		
D6576	152-016	Zener RT6			6.3 v		

Inductors

L6524	*114-149	.2-.325 μh		Var.			
L6544	*144-149	.2-.325 μh		Var.			
L6564	*114-043	.5-1 μh		Var.			
L6574	*114-043	.5-1 μh		Var.			

Resistors

Resistors are fixed, composition, ±10% unless otherwise indicated.

R5509A	309-148	1 meg	½ w		Prec.	1%	
R5509B	309-140	500 k	½ w		Prec.	1%	
R5509C	309-051	200 k	½ w		Prec.	1%	
R5509D	309-260	100 k	½ w		Prec.	1%	
R5509E	309-100	10 k	½ w		Prec.	1%	
R5509F	301-514	510 k	½ w			5%	
R5509G	301-244	240 k	½ w			5%	
R5511A	309-148	1 meg	½ w		Prec.	1%	
R5511B	309-140	500 k	½ w		Prec.	1%	
R5511C	309-051	200 k	½ w		Prec.	1%	
R5511D	309-260	100 k	½ w		Prec.	1%	
R5511E	309-100	10 k	½ w		Prec.	1%	
R5513	316-104	100 k	¼ w				
R5514	316-105	1 meg	¼ w				
R5515	316-104	100 k	¼ w				
R5517	316-104	100 k	¼ w				
R5518	316-105	1 meg	¼ w				
R5519	316-103	10 k	¼ w				
R5520	316-470	47 Ω	¼ w				
R5521	302-473	47 k	½ w				
R5522	311-164	50 k		Var.		OUTPUT DC LEVEL	
R5523	310-070	33 k	1 w		Prec.	1%	
R5524	302-102	1 k	½ w				
R5525	309-354	45 k	½ w		Prec.	1%	
R5526	305-223	22 k	2 w			5%	
R5529	Use 306-473	47 k	2 w				
R5530	316-470	47 Ω	¼ w				
R5531	302-473	47 k	½ w				
R5532	311-153	10 k		Var.		DC LEVEL RANGE	
R5533	302-102	1 k	½ w				
R5534	305-123	12 k	2 w			5%	x155-up
R5535	311-171	5 k		Var.			x155-up
R5540	316-104	100 k	¼ w				
R5541	316-470	47 Ω	¼ w				
R5542	316-101	110 Ω	¼ w				
R5543	302-221	220 Ω	½ w				
R5544	315-100	10 Ω	¼ w			5%	

Resistors *(continued)*

Ckt. No.	Tektronix Part No.	Description					S/N Range
R5546	308-069	12 k	8 w		WW	5%	
R5547	316-154	150 k	¼ w				
R5548	311-068	500 k		Var.		OPEN LOOP GAIN	
R5559A	309-148	1 meg	½ w		Prec.	1%	
R5559B	309-140	500 k	½ w		Prec.	1%	
R5559C	309-051	200 k	½ w		Prec.	1%	
R5559D	309-260	100 k	½ w		Prec.	1%	
R5559E	309-100	10 k	½ w		Prec.	1%	
R5559F	301-514	510 k	½ w			5%	
R5559G	301-244	240 k	½ w			5%	
R5561A	309-148	1 meg	½ w		Prec.	1%	
R5561B	309-140	500 k	½ w		Prec.	1%	
R5561C	309-051	200 k	½ w		Prec.	1%	
R5561D	309-260	100 k	½ w		Prec.	1%	
R5561E	309-100	10 k	½ w		Prec.	1%	
R5563	316-104	100 k	¼ w				
R5564	316-105	1 meg	¼ w				
R5565	316-104	100 k	¼ w				
R5567	316-104	100 k	¼ w				
R5568	316-105	1 meg	¼ w				
R5569	316-103	10 k	¼ w				
R5570	316-470	47 Ω	¼ w				
R5571	302-473	47 k	½ w				
R5572	311-164	50 k		Var.		OUTPUT DC LEVEL	
R5573	310-070	33 k	1 w		Prec.	1%	
R5574	302-102	1 k	½ w				
R5575	309-354	45 k	½ w		Prec.	1%	
R5576	305-223	22 k	2 w			5%	
R5579	Use 306-473	47 k	2 w				
R5580	316-470	47 Ω	¼ w				
R5581	302-473	47 k	½ w				
R5582	311-153	10 k		Var.		DC LEVEL RANGE	
R5583	302-102	1 k	½ w				
R5584	305-123	12 k	2 w			5%	x155-up
R5585	311-171	5 k		Var.			x155-up
R5590	316-104	100 k	¼ w				
R5591	316-470	47 Ω	¼ w				
R5592	316-101	100 Ω	¼ w				
R5593	302-221	220 Ω	½ w				
R5594	315-100	100 Ω	¼ w			5%	
R5596	308-069	12 k	8 w		WW	5%	
R5597	316-154	150 k	¼ w				
R5598	311-068	500 k		Var.		OPEN LOOP GAIN	
R6502	302-220	22 Ω	½ w				
R6507	302-220	22 Ω	½ w				
R6508C	309-140	500 k	½ w		Prec.	1%	
R6508C	309-148	1 meg	½ w		Prec.	1%	
R6509C	309-141	750 k	½ w		Prec.	1%	
R6509E	309-139	333 k	½ w		Prec.	1%	
R6510C	309-142	900 k	½ w		Prec.	1%	

Resistors *(continued)*

Ckt. No.	Tektronix Part No.	Description					S/N Range
R6510E	309-138	111 k	½ w		Prec.	1%	
R6513C	309-145	990 k	½ w		Prec.	1%	
R6513E	309-135	10.1 k	½ w		Prec.	1%	
R6516	302-270	27 Ω	½ w				
R6517	309-148	1 meg	½ w		Prec.	1%	
R6518	316-104	100 k	¼ w				
R6519	316-334	330 k	¼ w				
R6520	*308-141	1 Ω	½ w		WW	5%	x105-up
R6521	316-470	47 Ω	¼ w				
R6522	316-221	220 Ω	¼ w				x105-up
R6523	316-560	56 Ω	¼ w				101-104
	*308-141	1 Ω	½ w		WW	5%	105-up
R6524	318-083	200 Ω	⅛ w				
R6530	*311-259	710 Ω		Var.	WW	VARIABLE VOLTS/CM	
R6531	303-153	15 k	1 w			5%	
R6532	303-153	15 k	1 w			5%	
R6533	311-171	5 k		Var.		DC BAL.	
R6536	311-300	5 k	2 w	Var.		GAIN ADJ.	
R6538	306-103	10 k	2 w				
R6539	302-562	5.6 k	½ w				
R6541	316-470	47 Ω	¼ w				
R6544	318-083	200 Ω	⅛ w		Prec.	1%	
R6550	311-028	2x100 k	2 w	Var.		POSITION	
R6551	302-104	100 k	½ w				
R6552	302-104	100 k	½ w				
R6556	302-104	100 k	½ w				
R6557	311-301	100 k	2 w	Var.		VERT. POS. RANGE	101-154
	311-088	100 k	0.2 w	Var.			155-up
R6558	302-104	100 k	½ w				
R6563	302-392	3.9 k	½ w				
R6564	318-083	200 Ω	⅛ w		Prec.	1%	
R6565	307-023	4.7 Ω	½ w				
R6568	319-050	119 Ω	¼ w		Prec.	1%	
R6569	301-912	9.1 k	½ w			5%	
R6573	302-392	3.9 k	½ w				
R6574	318-083	200 Ω	⅛ w		Prec.	1%	
R6575	307-023	4.7 Ω	½ w				
R6575	306-392	3.9 k	2 w				
R6579	301-912	9.1 k	½ w			5%	
R6580	304-152	1.5 k	1 w				
R6582	302-101	100 Ω	½ w				
R6586	302-101	100 Ω	½ w				

Switches

	Unwired	Wired		
SW5510	*260-430	*262-424	Rotary	SELECTOR A
SW5515	260-396		Toggle	INTEGRATOR LF REJECT A
SW5517	260-398		Toggle	GRID SEL
SW5520	260-397		Toggle	DC LEVEL ADJ A
SW5560	*260-431	*262-425	Rotary	SELECTOR B

Switches *(continued)*

Ckt. No.	Tektronix Part No. Unwired	Tektronix Part No. Wired	Description		S/N Range
SW5565	260-396		Toggle	INTEGRATOR LF REJECT B	
SW5567	260-398		Toggle	GRID SEL	
SW5570	260-397		Toggle	DC LEVEL ADJ B	
SW6500	*260-432	*262-423	Rotary	VERTICAL DISPLAY	
SW6502	260-248		Push Button	ZERO CHECK	
SW6510	*260-428	*262-426	Rotary	VOLTS/CM	

Transistors

Ckt. No.	Tektronix Part No.	Description
Q6564	151-067	2N1143
Q6574	151-067	2N1143

Electron Tubes

Ckt. No.	Tektronix Part No.	Description
V5524 V5534 †	*157-050	12AU6
V5543	154-187	6DJ8
V5574 V5584 †	*157-050	12AU6
V5593	154-187	6DJ8
V6524 V6544 †	*157-050	12AU6

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† Selected pair. Furnished as a unit.

MECHANICAL PARTS LIST

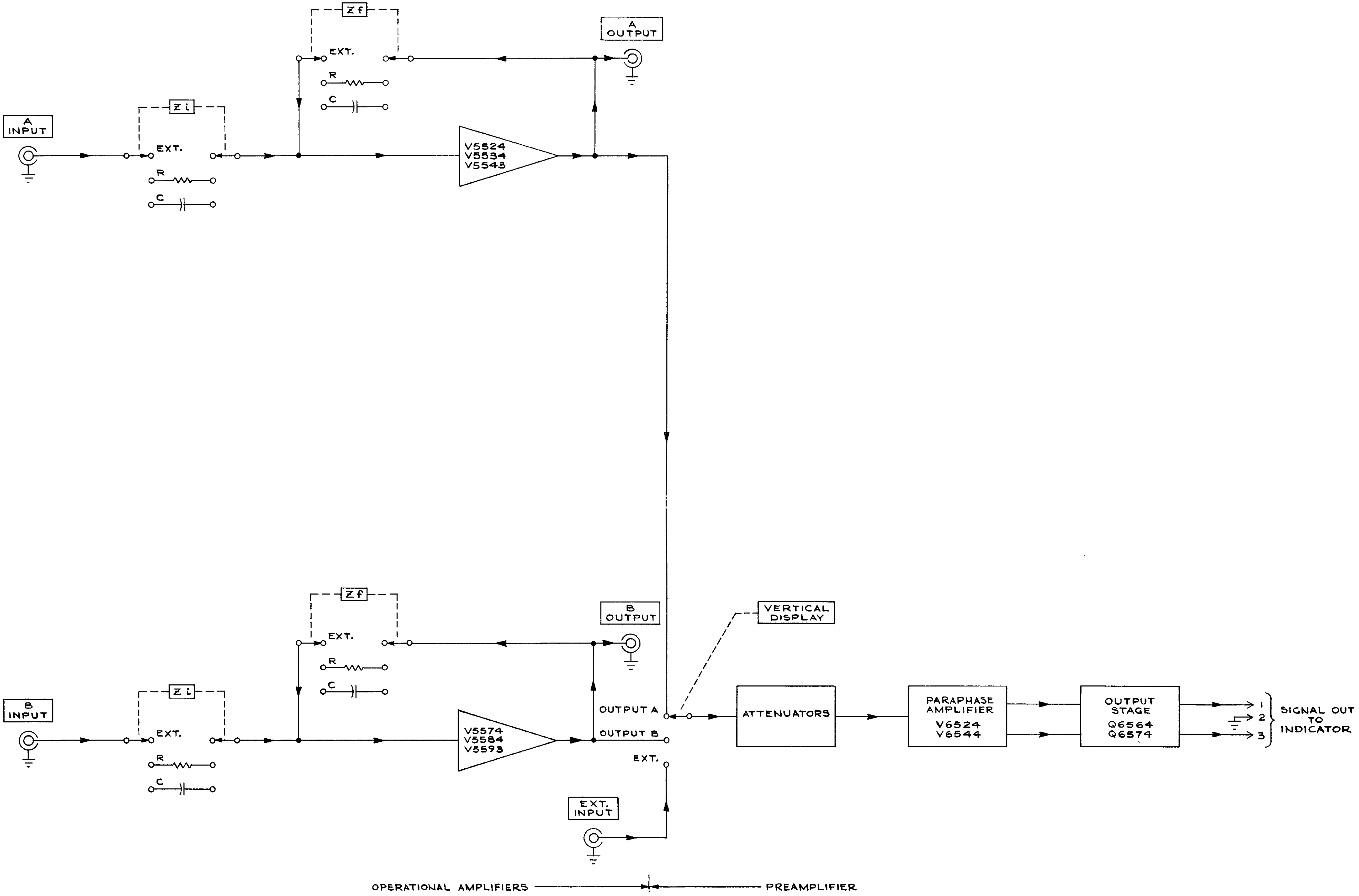
		Tektronix Part Number
Adapter, terminal adapter ass'y		013-048
Adapter, terminal shield		013-049
Bracket, switch end		406-720
Bracket, pot, $.063 \times 1\frac{5}{16} \times \frac{1}{2} \times \frac{7}{8}$		406-722
Bracket, atten.		406-723
Bracket, selector switch		406-724
Bracket, cap. mtg. s.s. for "O"		406-725
Bracket, pot, $.080 \times 2\frac{3}{4} \times 1\frac{1}{4} \times \frac{1}{2}$	S/N 101-154	406-796
Bracket, pot, $.080 \times 3\frac{7}{8} \times 1\frac{1}{4}$	S/N 155-up	406-848
Bushing, banana jack		358-054
Cable, harness, chassis	S/N 101-154	179-635
Cable, harness, chassis	S/N 155-up	179-671
Cable, harness, "A" selector switch		179-636
Cable, harness, "B" selector switch		179-637
Chassis		441-395
Clamp, cable, $\frac{1}{2}$ plastic		343-006
Clamp, CRT		344-047
Connector, chassis mt., 16 contact, male		131-071
Connector, chassis mt., 1 contact, female		131-081
Coupling, flexible, ass'y		376-024
Eyelet, tapered barrel		210-601
Grommet, rubber $\frac{1}{4}$		348-002
Grommet, rubber $\frac{5}{16}$		348-003
Grommet, rubber $\frac{3}{8}$		348-004
Grommet, rubber $\frac{3}{4}$		348-006
Grommet, poly $\frac{1}{4}$		348-031
Holder, neon bulb holder		352-008
Knob, large black 1.225 w/$\frac{1}{4}$ hole thru		366-029
Knob, small red, .694 w/$\frac{1}{8}$ hole part way		366-031
Knob, indicator ass'y		366-087
Knob, plug-in securing		366-125
Knob, small black ass'y		366-132

Mechanical Parts List *(continued)*

	Tektronix Part Number
Lockwasher, int., #4	210-004
Lockwasher, int., #6	210-006
Lockwasher, int., 1/4	210-011
Lockwasher, int., pot, 3/8 × 1/2	210-012
Lockwasher, int., 1/4	210-046
Lug, solder, SE6, w/2 wire holes	210-202
Lug, solder, pot, plain, 3/8	210-207
Lug, solder, 1/4" hole	210-223
Lug, ground, .025 × 15/16	210-241
Nut, hex, 4-40 × 3/16	210-406
Nut, hex, 6-32 × 1/4	210-407
Nut, hex, 3/8-32 × 1/2	210-413
Nut, hex 1/4-28 × 3/8 × 3/32	210-455
Nut, keps, 6-32 × 5/16	210-457
Nut, hex, 1/4-32 × 3/8 × 3/32 (mini-pot)	210-465
Nut, hex, 1/4-32 × 5/16 × 19/32 (mini-pot)	210-471
Nut, hex, 6-32 × 5/16 × .194 (5-10 w/resistor mtg.)	210-478
Nut, hex, 1/4-40 × 5/16	210-562
Panel, front	333-662
Plate, sub panel	387-226
Plate, front sub panel	387-463
Post, binding ass'y	129-053
Ring, retaining	354-025
Rod, extension	384-146
Rod, frame	384-508
Rod, securing	384-510
Rod, cap. mtg. post, 1" × 5/16	384-596
Rod, nylon, 5/16 × 3/4	385-013
Rod, delrin, 5/16 × 15/16	385-135
Screw, 4-40 × 3/16 BHS	211-007
Screw, 4-40 × 1/4 BHS	211-008
Screw, 4-40 × 1 FHS	211-031

Mechanical Parts List *(continued)*

	Tektronix Part Number
Screw, 4-40 × $\frac{5}{16}$ PAN HS w/lockwasher	211-033
Screw, 4-40 × $\frac{1}{2}$ BH nylon	211-036
Screw, 2-56 × $\frac{5}{16}$ RHS, PHILLIPS	211-057
Screw, 6-32 × $\frac{1}{4}$ BHS	211-504
Screw, 6-32 × $\frac{5}{16}$ BHS	211-507
Screw, 6-32 × $1\frac{1}{2}$ RHS, PHILLIPS	211-553
Screw, 8-32 × $\frac{1}{2}$ RHS, PHILLIPS	212-044
Screw, 4-40 × $\frac{1}{4}$ PHS, threadcutting, PHILLIPS	213-035
Screw, 6-32 × $\frac{3}{8}$ TRUSS HS threadcutting, PHILLIPS	213-041
Screw, 5-32 × $\frac{3}{16}$ PAN HS threadcutting, PHILLIPS	213-044
Shield, socket, STS 129, .770±.005	337-004
Shield, socket, STS 179, $\frac{29}{32}$	337-005
Shield, tube, SHT 7-56 $\frac{7}{8}$ w/spring, $1\frac{3}{4}$ hi	337-007
Shield, tube, SHT 9-62, $1\frac{1}{32}$ w/spring, $1\frac{15}{16}$ hi	337-008
Shield, A&B channels	337-460
Shield, rear switch	337-461
Shield, vert. display switch, front	337-462
Shield, attn. switch, .040 × $2\frac{23}{32}$ × $4\frac{11}{16}$ × $\frac{3}{8}$	337-463
Shield, attn. switch, .040 × $1\frac{1}{2}$ × $1\frac{7}{8}$	337-464
Shield, B selector switch	337-494
Socket, 7 pin, UHF, miniature	136-071
Socket, 9 pin, UHF, miniature	136-072
Socket, 4 pin, transistor	136-095
Socket, banana jack ass'y w/black cap	136-106
Spacer, nylon, $\frac{5}{16}$, for ceramic strip	361-009
Strip, ceramic, $\frac{7}{16}$ × 20 notches	124-145
Strip, ceramic, $\frac{7}{16}$ × 16 notches	124-146
Strip, ceramic, $\frac{7}{16}$ × 13 notches	124-147
Strip, ceramic, $\frac{7}{16}$ × 9 notches	124-148
Strip, ceramic, $\frac{7}{16}$ × 7 notches	124-149
Tag, s/n insert	334-679
Washer, steel, .390 × $\frac{9}{16}$ × .020	210-840
Washer, steel, .093 × $\frac{9}{32}$ × .020	210-850
Washer, poly, .190 × $\frac{7}{16}$ × $\frac{1}{32}$	210-894
Washer, black nylon, $\frac{3}{8}$ × 1/10	210-895
Washer, steel, $\frac{1}{4}$ × $\frac{3}{8}$ × .0206	210-940

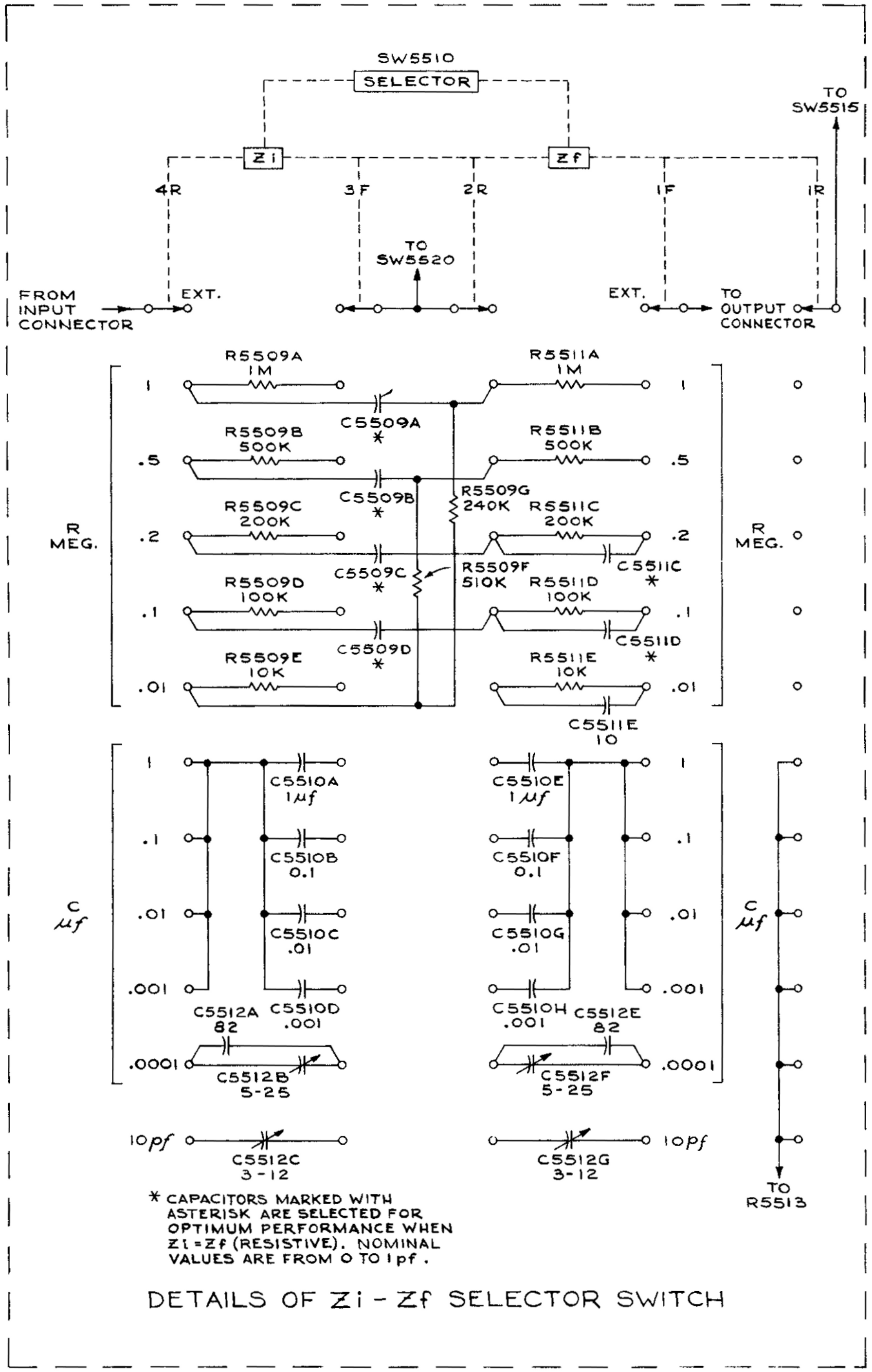


MRH
2-19-62

TYPE O PLUG-IN UNIT

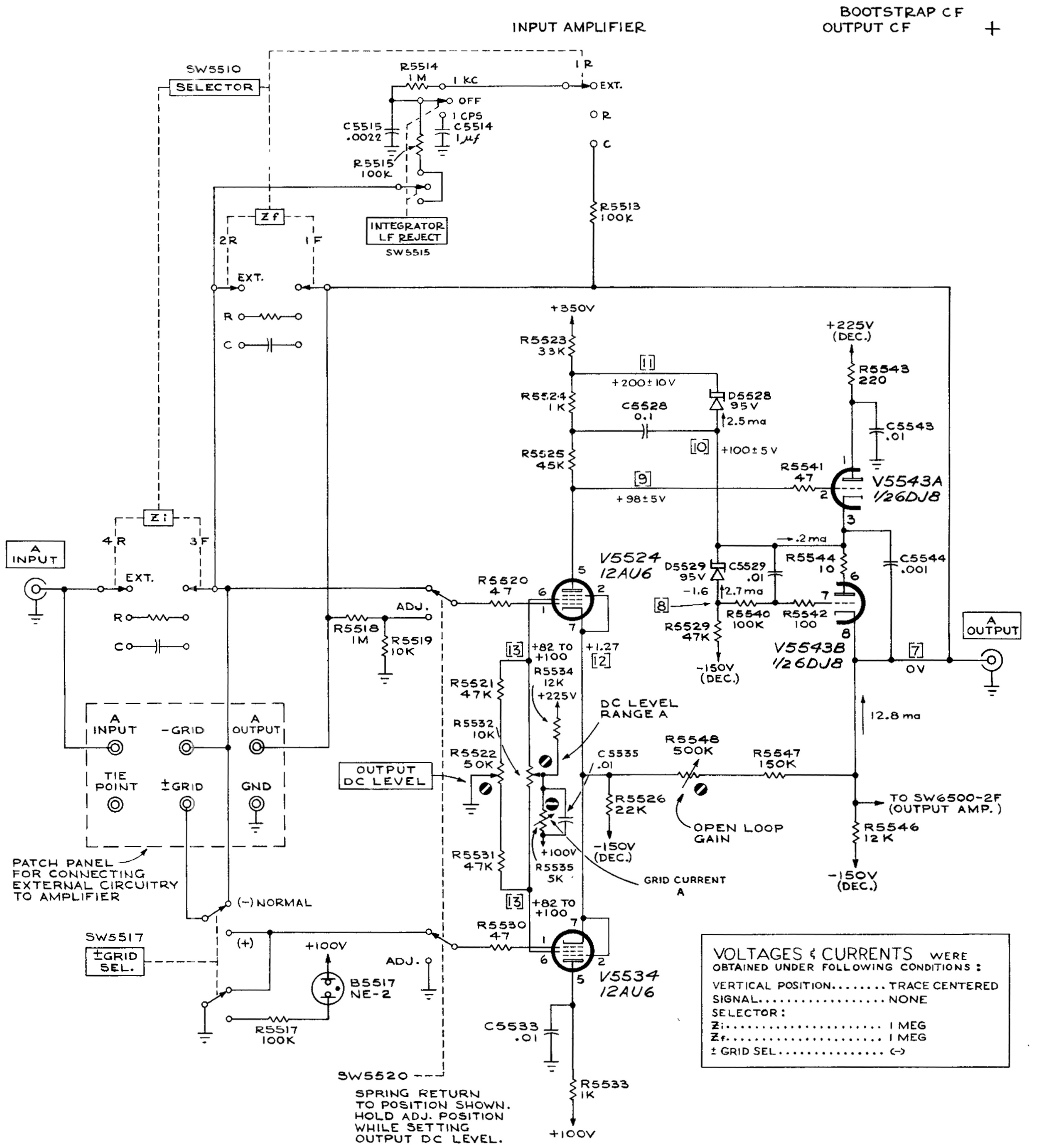
A

BLOCK DIAGRAM



* CAPACITORS MARKED WITH ASTERISK ARE SELECTED FOR OPTIMUM PERFORMANCE WHEN Zi = Zf (RESISTIVE). NOMINAL VALUES ARE FROM 0 TO 1 pf.

DETAILS OF Zi - Zf SELECTOR SWITCH



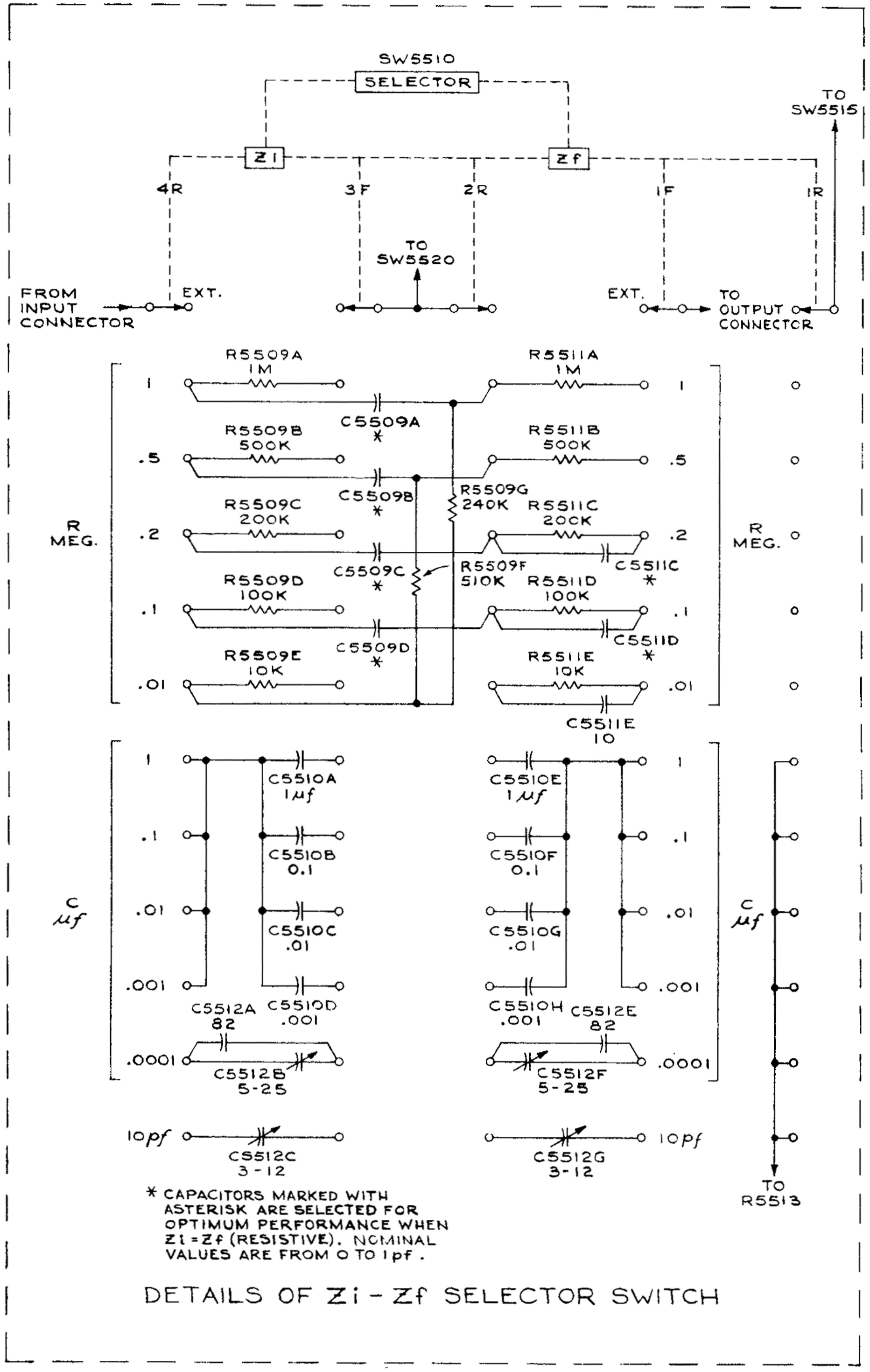
VOLTAGES & CURRENTS WERE OBTAINED UNDER FOLLOWING CONDITIONS:

VERTICAL POSITION........TRACE CENTERED
SIGNAL..................NONE
SELECTOR:
Zi......................1 MEG
Zf......................1 MEG
± GRID SEL..............(-)

MRH
7-16-62

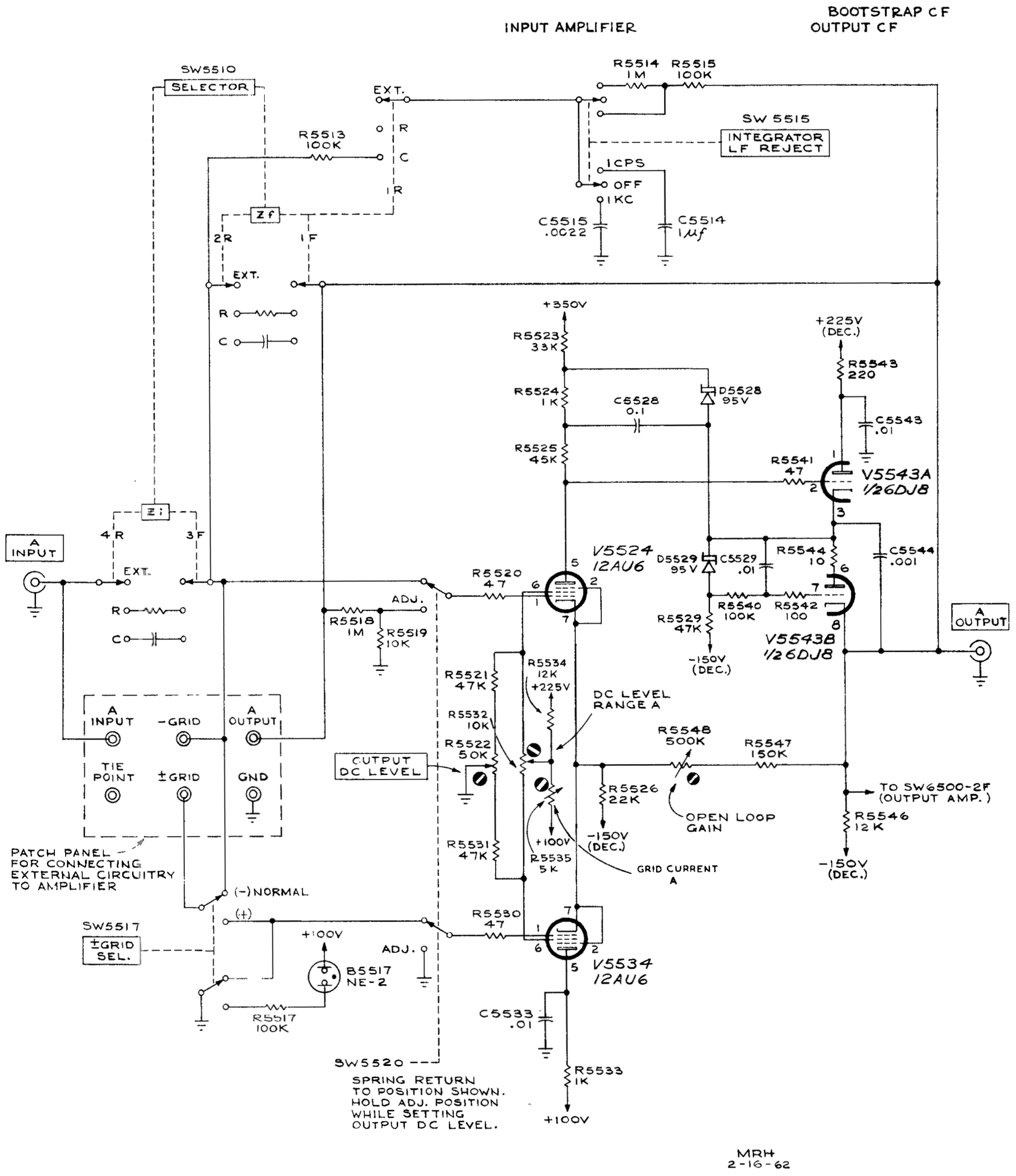
CHANNEL A
OPERATIONAL AMPLIFIER

EFF. S/N 319 & UP



* CAPACITORS MARKED WITH ASTERISK ARE SELECTED FOR OPTIMUM PERFORMANCE WHEN Zi = Zf (RESISTIVE). NOMINAL VALUES ARE FROM 0 TO 1pf.

DETAILS OF Zi - Zf SELECTOR SWITCH

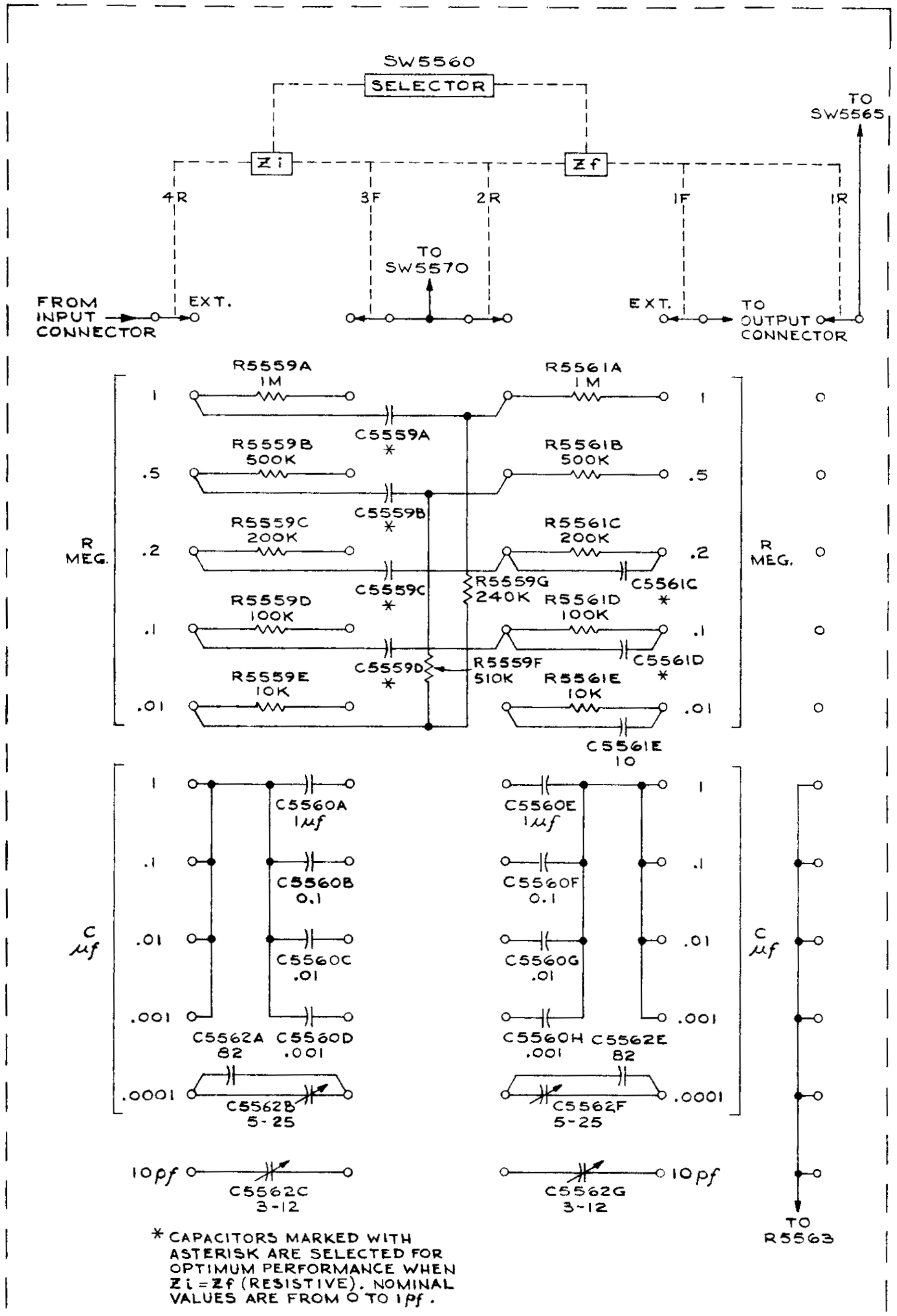


MRH
2-16-62

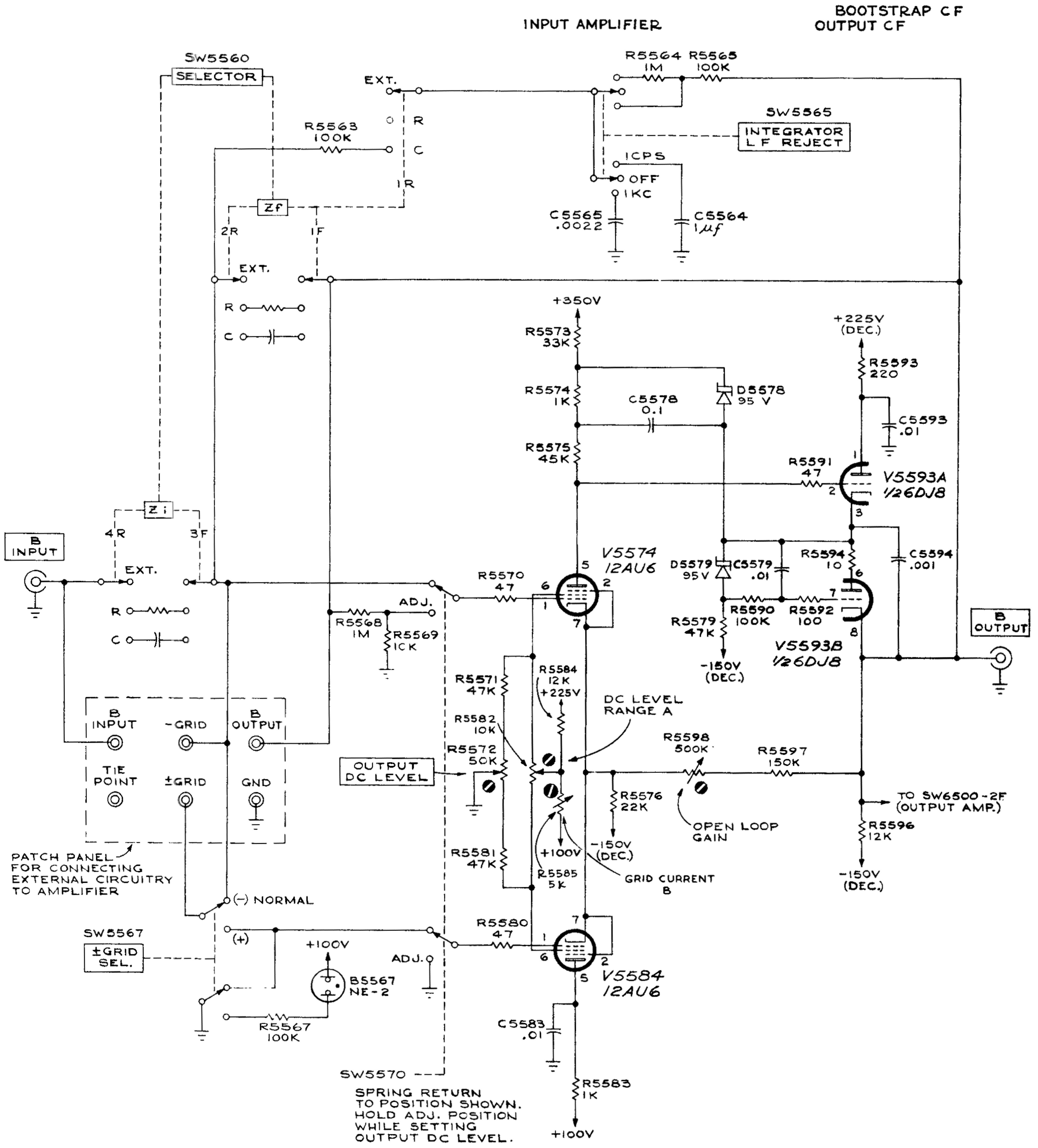
TYPE O PLUG-IN UNIT

A1

CHANNEL A
OPERATIONAL AMPLIFIER
EFF. S/N 101-318



DETAILS OF Zi-Zf SELECTOR SWITCH



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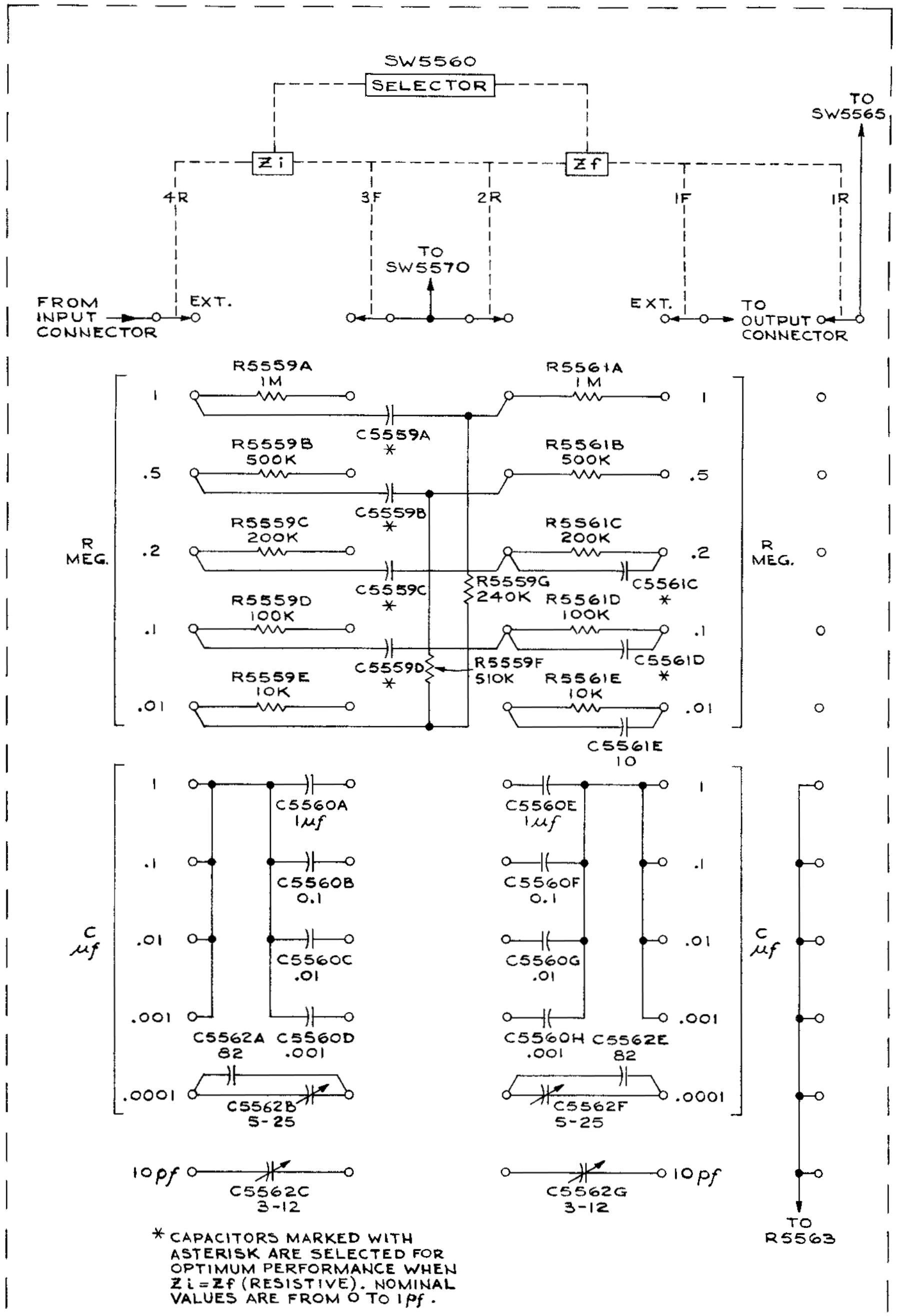
11-22-61

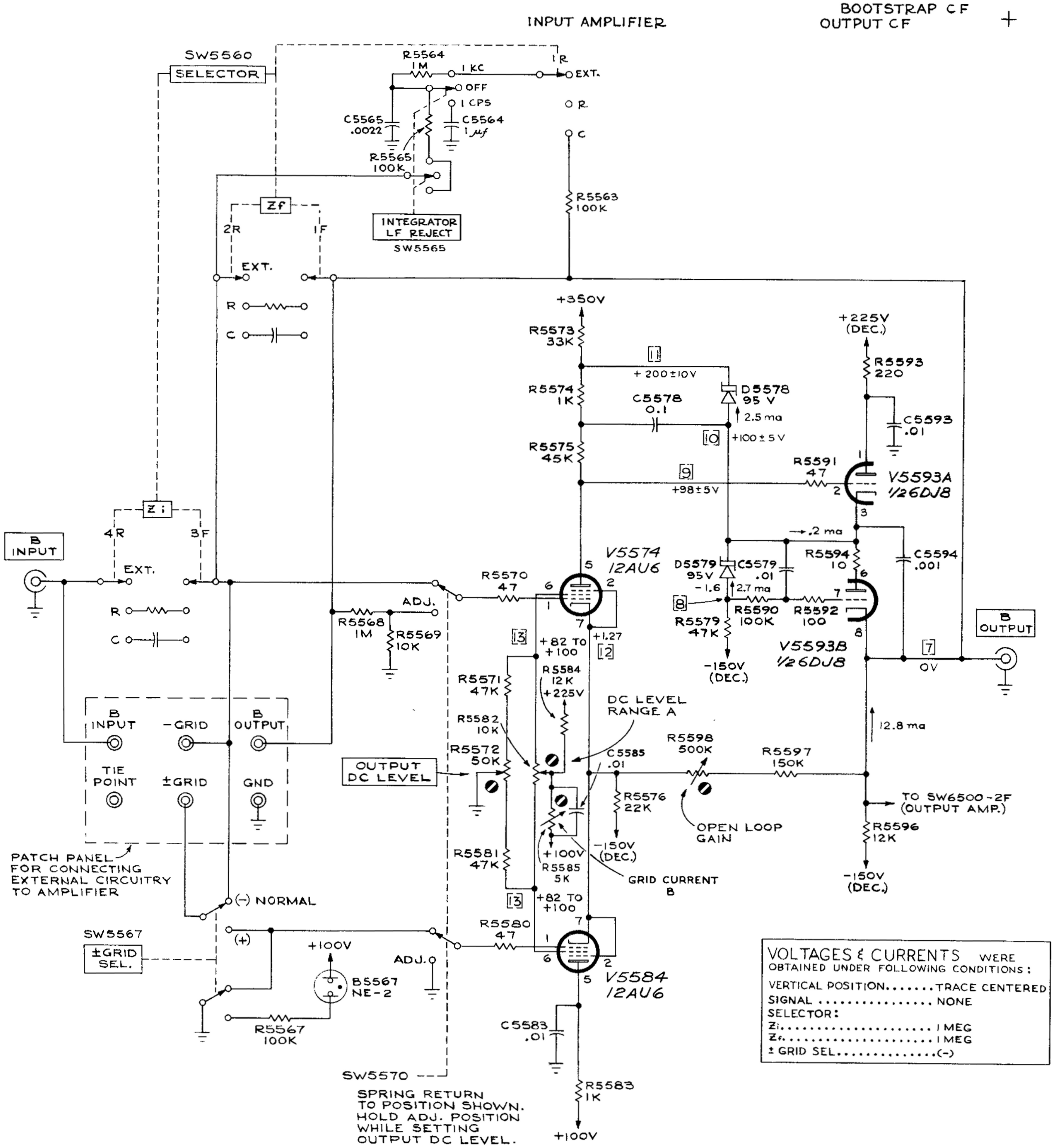
CHANNEL B
OPERATIONAL AMPLIFIER

EFF. S/N 101-318



* CAPACITORS MARKED WITH ASTERISK ARE SELECTED FOR OPTIMUM PERFORMANCE WHEN Zi = Zf (RESISTIVE). NOMINAL VALUES ARE FROM 0 TO 1pf.

DETAILS OF Zi-Zf SELECTOR SWITCH

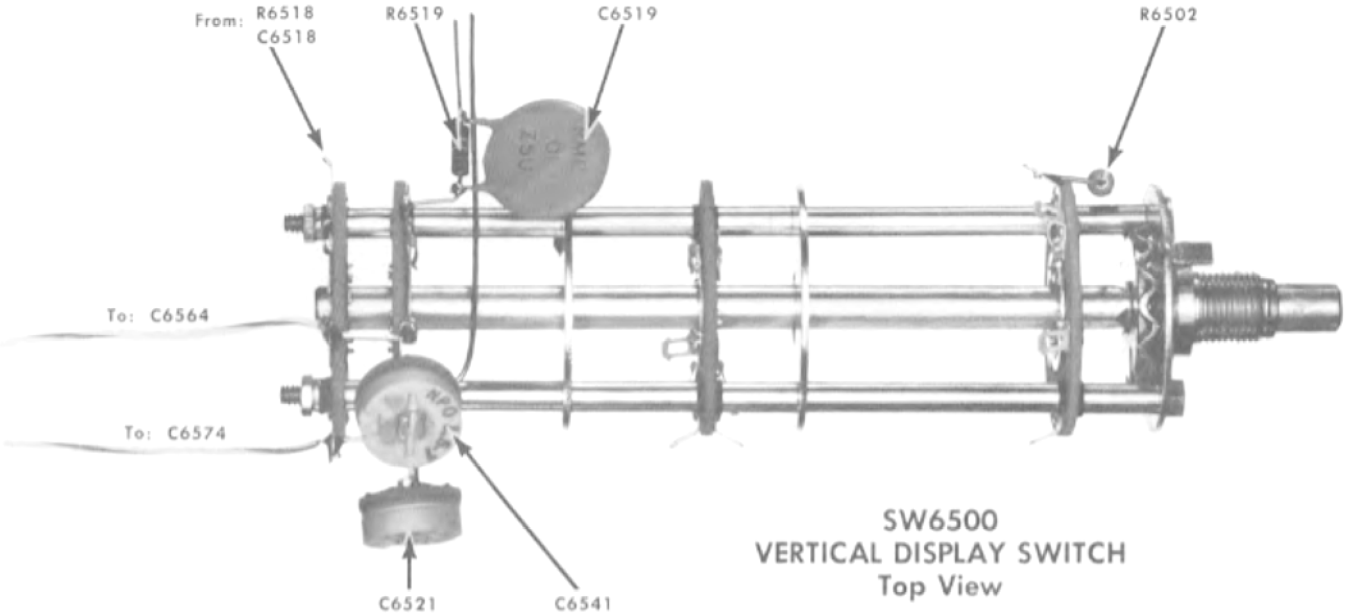


VOLTAGES & CURRENTS WERE OBTAINED UNDER FOLLOWING CONDITIONS:

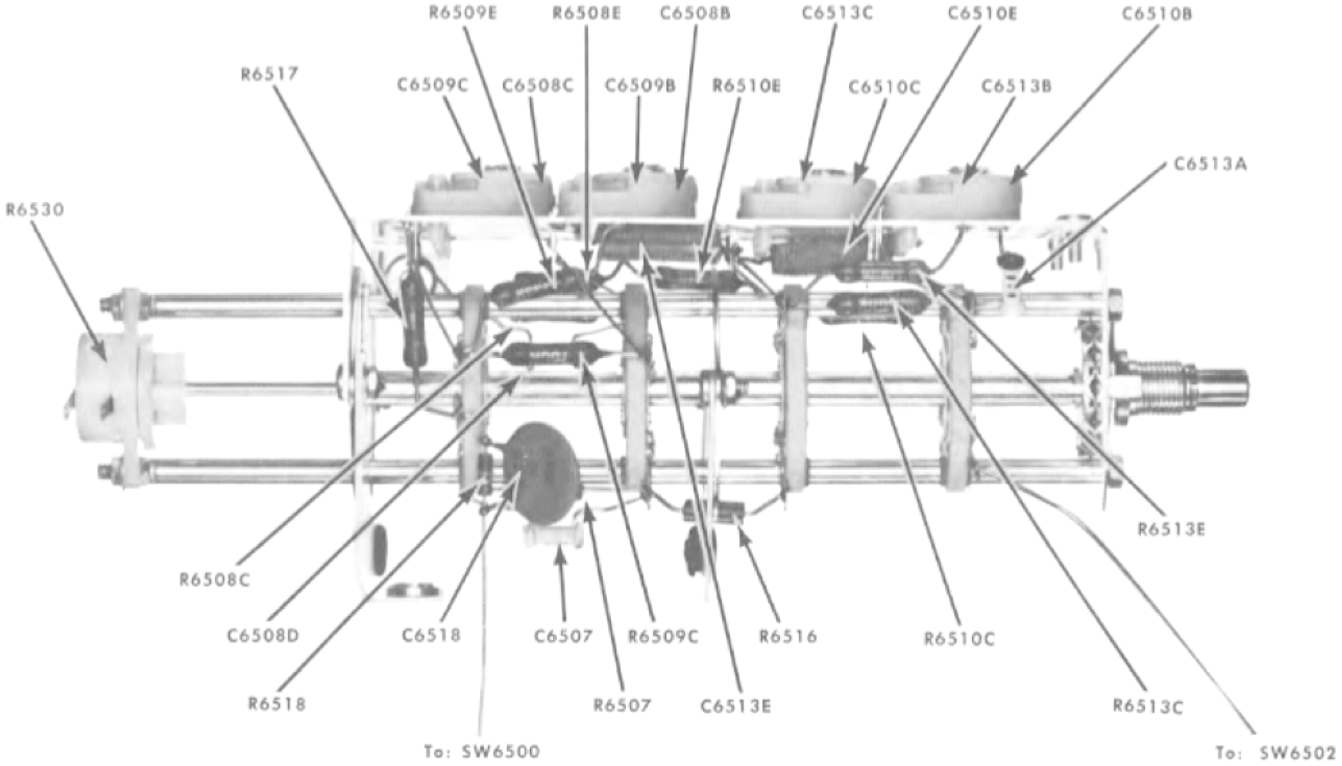
VERTICAL POSITION.......TRACE CENTERED
SIGNAL .... NONE
SELECTOR:
Zi..................... 1 MEG
Zf..................... 1 MEG
± GRID SEL..............(-)

MRH
7-22-62

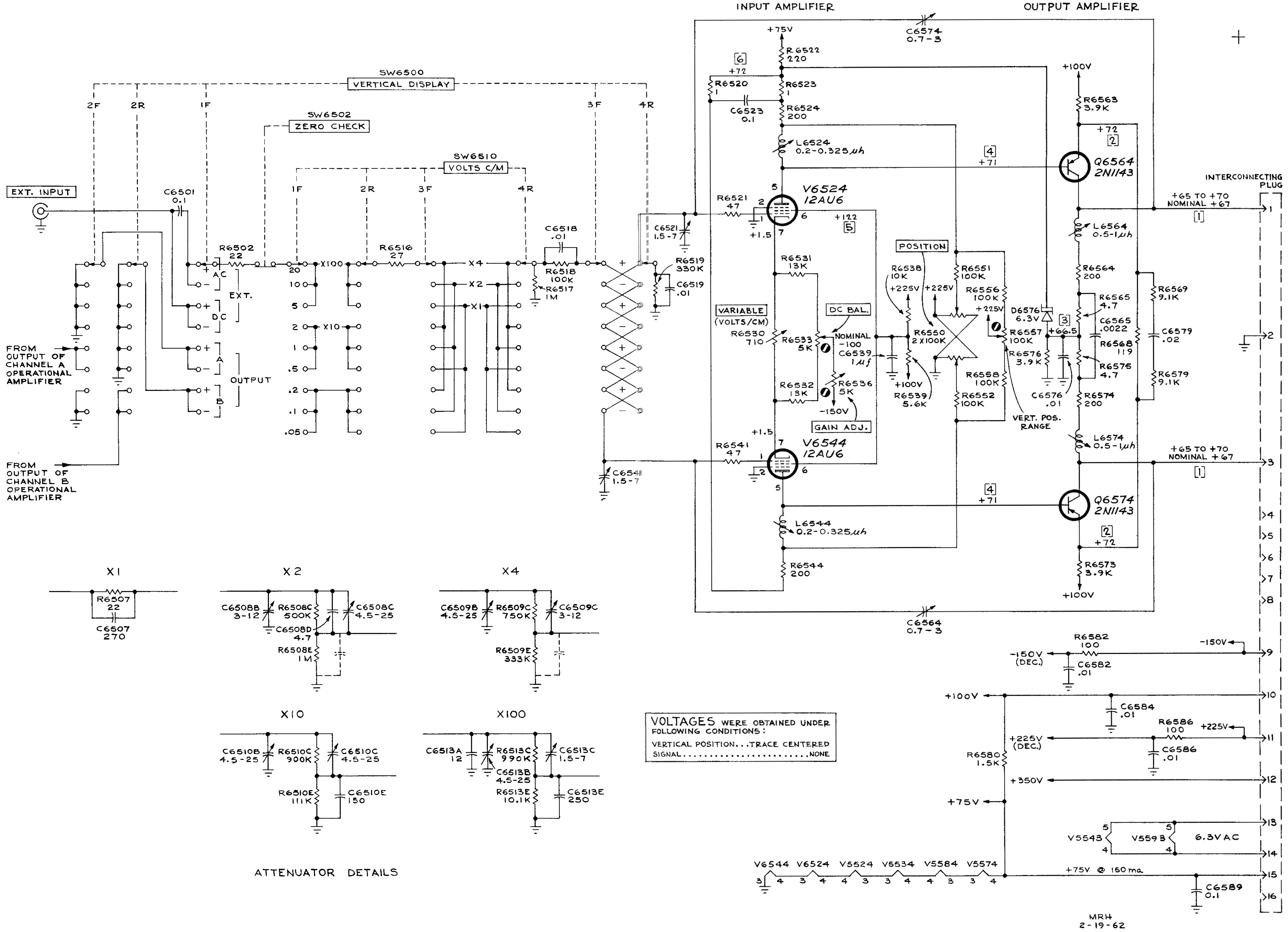
CHANNEL B
OPERATIONAL AMPLIFIER
EFF. S/N 319 UP



SW6500
VERTICAL DISPLAY SWITCH
Top View



SW6510
VOLTS/CM SWITCH
Top View



ATTENUATOR DETAILS

VOLTAGES WERE OBTAINED UNDER FOLLOWING CONDITIONS:
VERTICAL POSITION...TRACE CENTERED
SIGNAL........................NONE

MRH
2-19-62

PREAMPLIFIER

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.

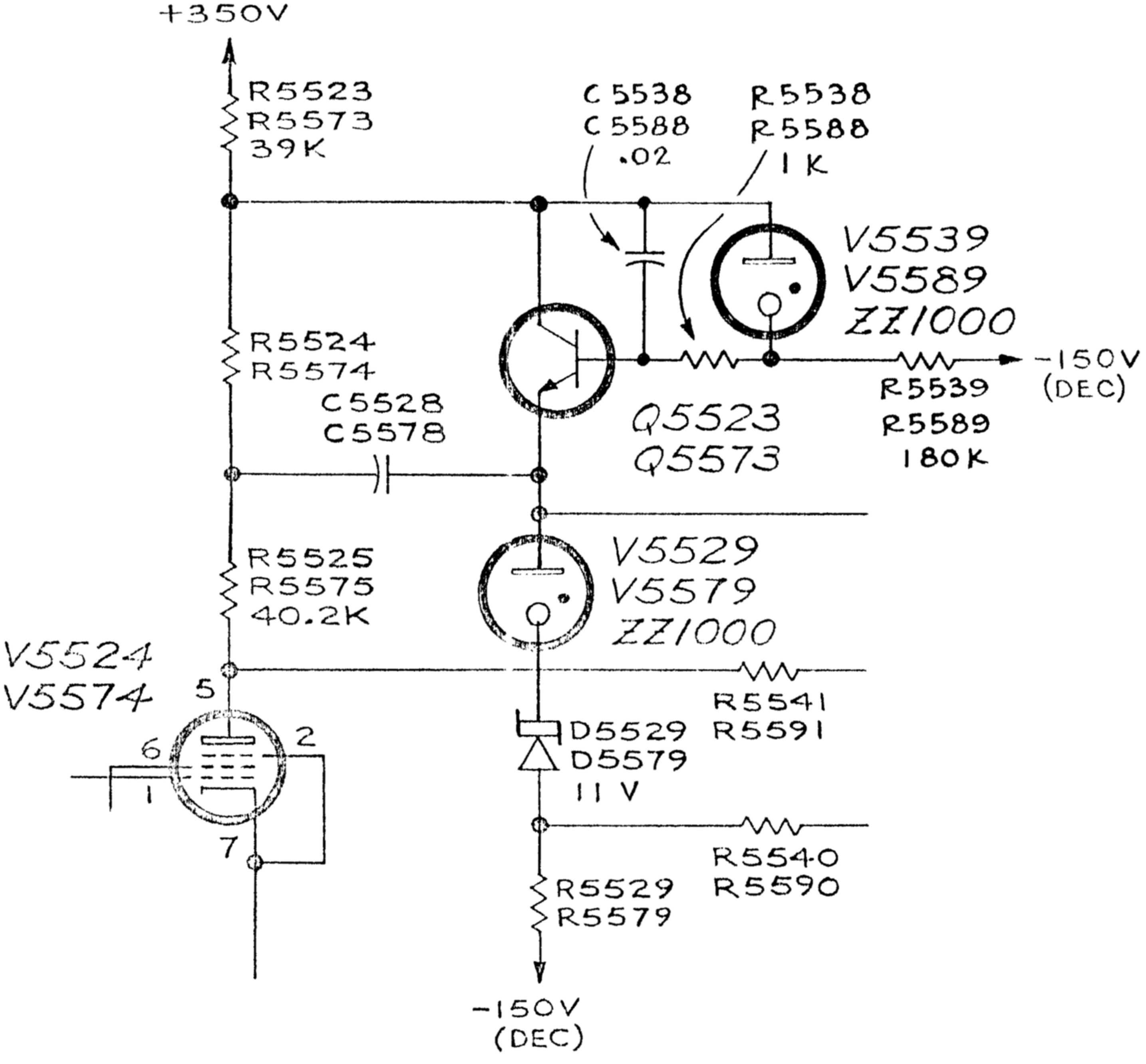
TYPE O PLUG-IN
MOD 6490 - Tent S/N 850 (1)

V6524 V6544	Change to	12AU6	Selected Pair	157-077

TYPE O PLUG-IN (49)
Mod 6115 Tent S/N 814

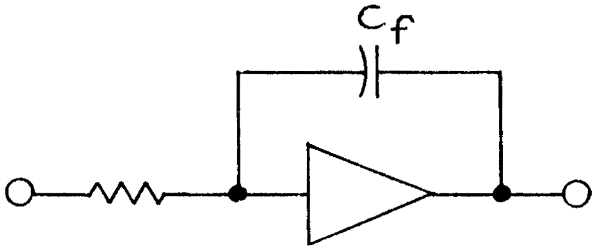
R5521, R5571	Change to	45k	1/2w	1%	309-354
R5523, R5573	Change to	39k	2w	5%	305-393
R5525, R5575	Change to	40.2k	1/2w	Prec.	323-347
R5526, R5576	Change to	22k	7w	1%	308-241
R5531, R5581	Change to	45k	1/2w	1%	309-354
R5539, R5589	Add	180k	1w	10%	304-184
R5538, R5588	Add	1k	1/4w	5%	315-102
V5529, V5539	Add	ZZ1000	Vacuum Diode		154-370
V5579, V5589	Add	ZZ1000	Vacuum Diode		154-370
D5529, D5579	Change to	Zener	1/4w	11v	152-055
Q5523, Q5573	Add	Transistor NPN Planar			151-096
C5538, C5588	Add	.02	Cer	150v	283-004

as per schematic attached



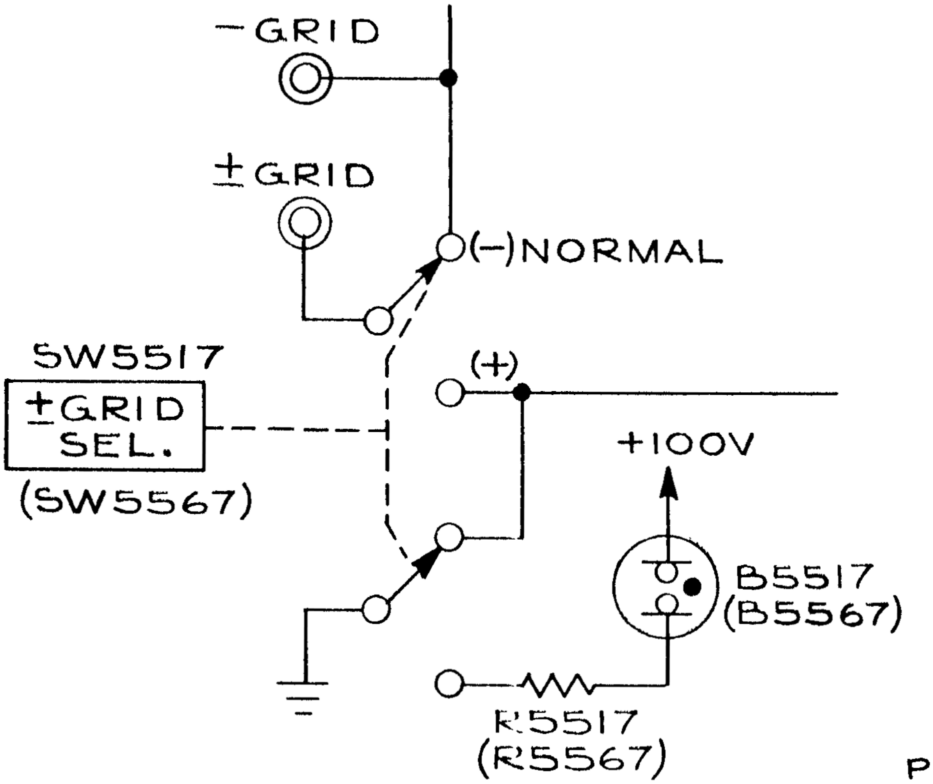
PART. DIAG. TYPE "O"
CHAN. A & CHAN. B AMPS.

Page 3-4, Fig. 2 upper diagram should appear as follows:



Page 3-18, Fig. 28 Schematic diagram should read: "Use integrator LF reject 1 cps" instead of "use integrator LF reject 1 kc."

Channel "A" and "B" operational amplifier schematics, all S/N ranges, SW5517 and SW5567 should appear as follows:



PLM
9-62

PART. DIAG. CHAN. A & CHAN. B
OP. AMPS.