TEKTRONIX®

AM 501
OPERATIONAL AMPLIFIER

INSTRUCTION MANUAL

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Serial Number ____________________

070-1616-00

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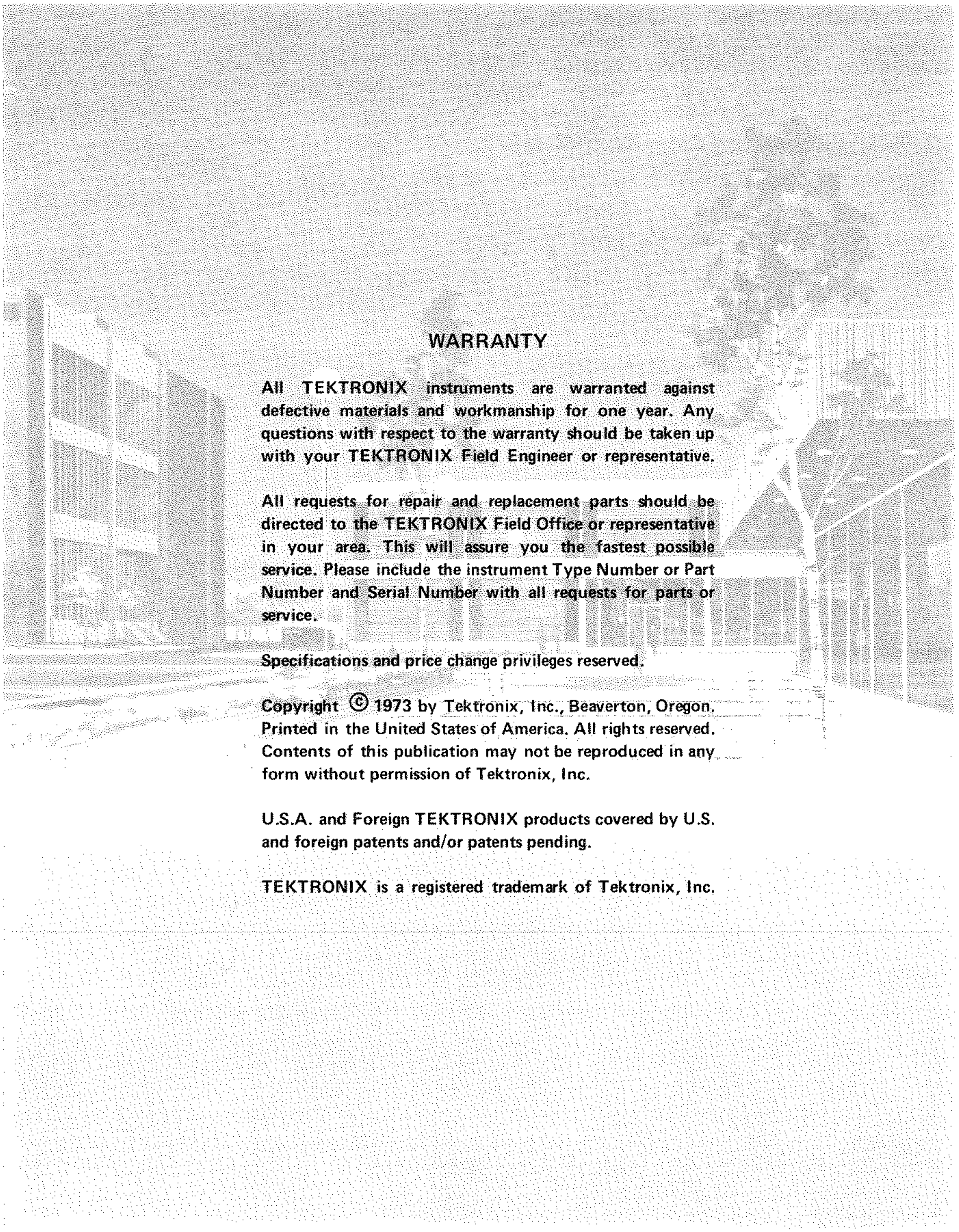

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All TEKTRONIX instruments are warranted against defective materials and workmanship for one year. Any questions with respect to the warranty should be taken up with your TEKTRONIX Field Engineer or representative.

All requests for repair and replacement parts should be directed to the TEKTRONIX Field Office or representative in your area. This will assure you the fastest possible service. Please include the instrument Type Number or Part Number and Serial Number with all requests for parts or service.

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OPERATING INSTRUCTIONS

INTRODUCTION

Instrument Description

The AM 501 is a high-power operational amplifier unit designed for use in the TM 500 series power modules. The unit has a wide output voltage swing centered at zero, high common-mode range, and a high slewing rate. The AM 501 has convenient front-panel access terminals for connection of feedback resistors to either input, or various input loading configurations. Internal pads on the circuit board permit permanent loading, feedback, or input component connections. A front-panel switch permits selective grounding of either BNC input or binding post connectors. The output may be taken from front-panel binding posts or a BNC connector.

Installation and Removal

The AM 501 is calibrated and ready for use when received. It operates in any compartment of a TM 500 series power module. See the power module instruction manual for line voltage requirements and power module operation. Fig. 1-1 shows the AM 501 installation and removal procedure.

CAUTION

Turn the Power Module off before inserting the plug-in; otherwise, damage may occur to the plug-in circuitry. Check that the AM 501 is fully inserted in the power module. Pull the PWR switch on the power module.

The Connectors and Adjustments foldout page in Section 3 gives a complete description of the front panel.

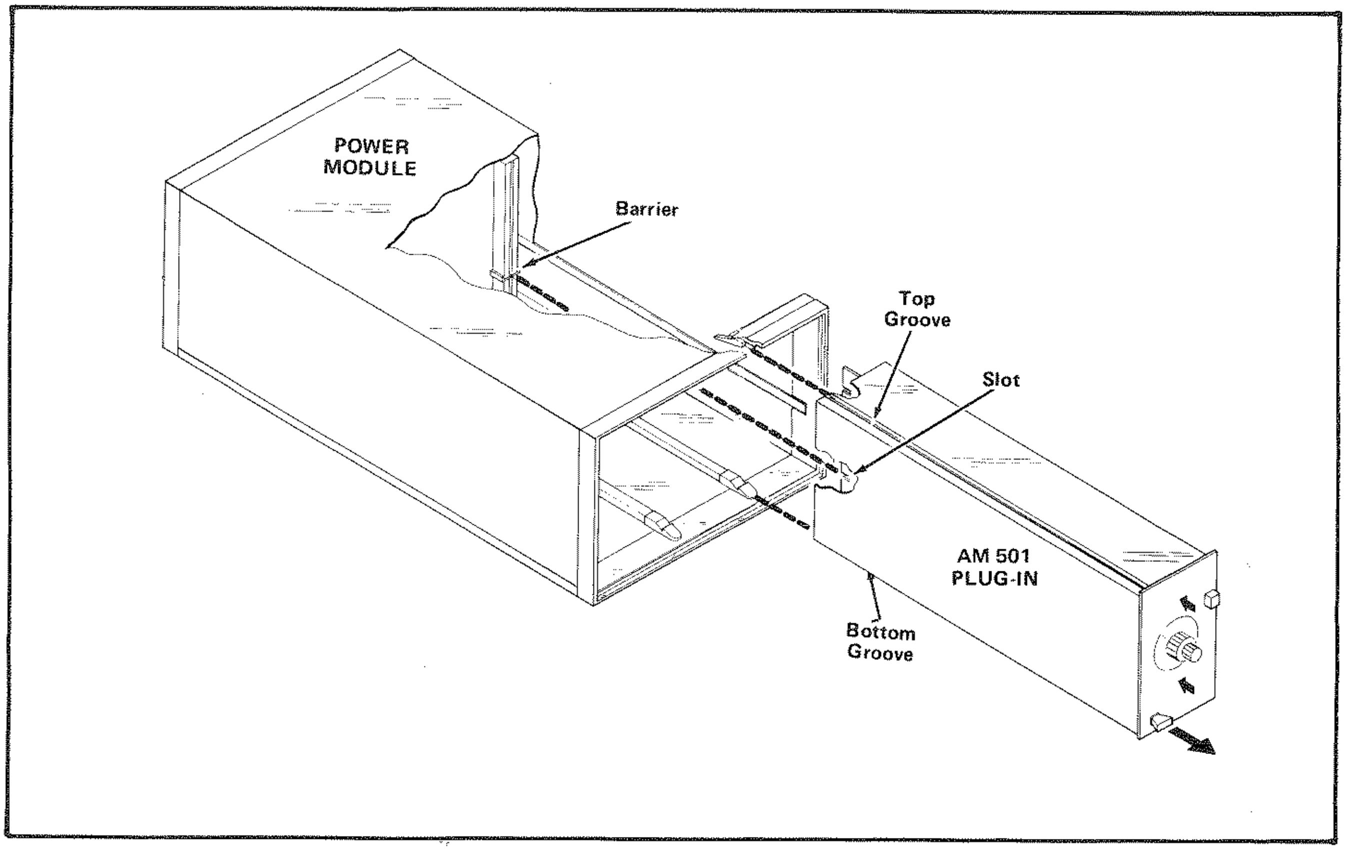


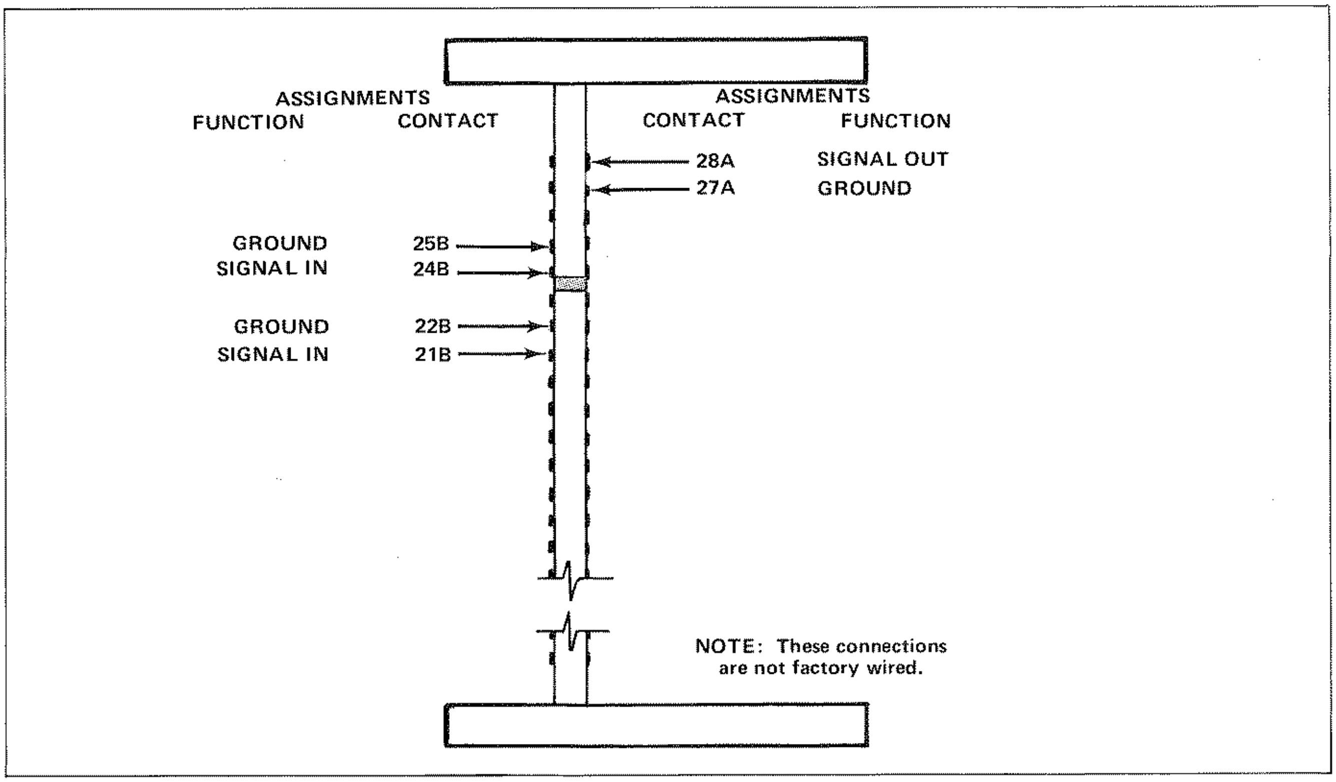
Fig. 1-1. AM 501 Installation and Removal.

BASIC OPERATION

Input, Output, and Feedback Connections

Make connections to the operational amplifier through the front-panel binding posts, the BNC connectors, or the rear interface connector. The rear interface connections are not factory wired. See Fig. 1-2 for suggested pin numbers and functions. Pads are provided on the circuit board for the pins shown.

A barrier inserted between pins 23 and 24 in the power module will allow the AM 501, and plug-ins compatible with it, to be inserted in that compartment. See the power module manual for more information.



NOTE: These connections are not factory wired.

Fig. 1-2. Input-Output assignments for plug-in rear interface connector contacts.

Fig. 1-3 shows pad layouts for internal component connections. Any combination of resistors, capacitors or other components may be soldered to the pads as required. Jumper from the Input, Output, and Ground connections, labeled on the board, to the appropriate pads. If necessary, remove the wires to the front-panel connections, and re-connect them to the pads.

If more than a foot or two of coaxial cable is used at the output, an isolation resistor equal to the cable impedance should be connected between the amplifier OUTPUT terminal and the center conductor of the coaxial cable to prevent ringing. This resistor may conveniently be connected between J175 (lower OUTPUT binding post) and J176 (OUTPUT BNC connector).

A transparent window with removable information slide is provided for noting the connections made to the AM 501. To remove the slide, grasp the sectioned sub-panel, on the right side of the instrument and pull. Attach a gummed label to the slide and draw on the label the connections made.

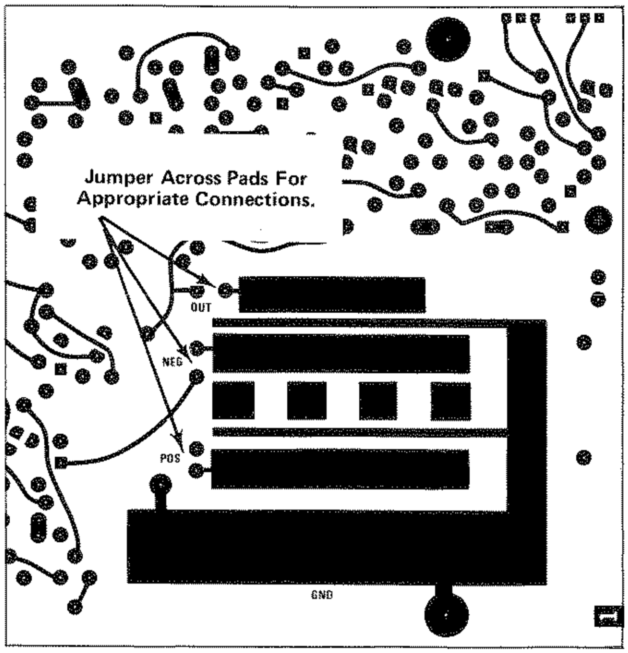


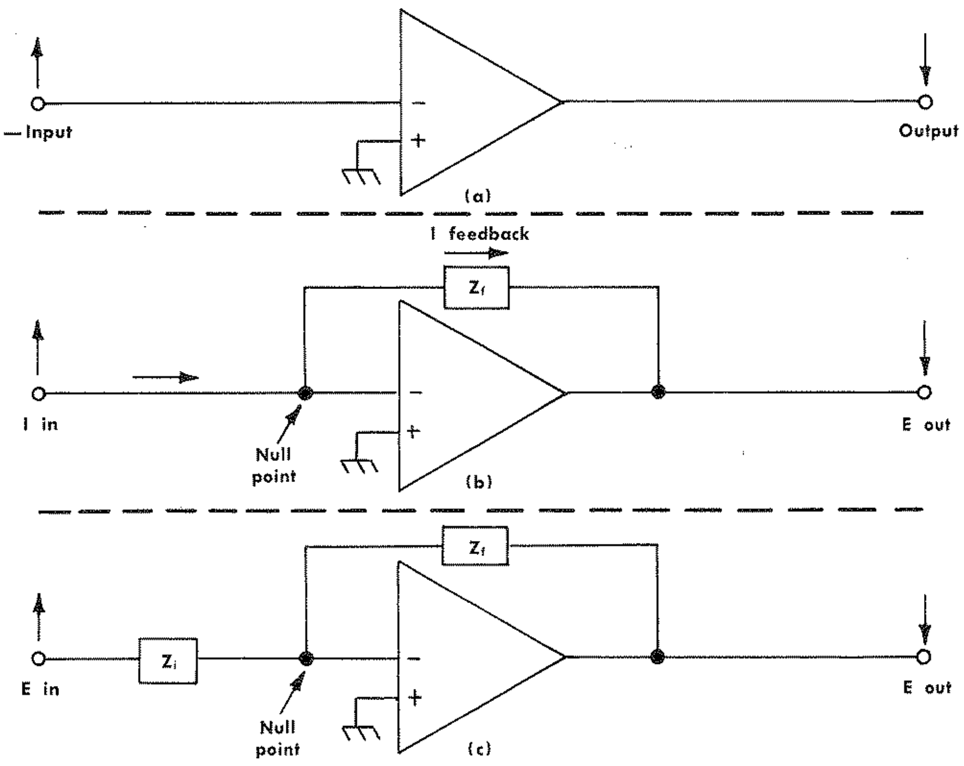
Fig. 1-3. Pad layouts for internal connections.

APPLICATION CONSIDERATIONS

Introduction

Operational amplifiers such as the AM 501 are useful in simulating a variety of circuits. They are used to add, subtract, differentiate, integrate, and amplify either linearly, or with controlled non-linear coefficients under signal conditions. By using semiconductors or other external active elements, operational amplifiers will perform compression, expansion, root and power functions, limiting, clipping, and fast-response logarithmic amplification.

The following text and illustrations will show some basic operational amplifier concepts and functions. The reader is referred to the many excellent books available concerning various uses and applications for operational amplifiers. See Fig. 1-4 for basic operational amplifier symbols.



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

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

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

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

Fig. 1-4. Conventional Operational Amplifier symbols.

Understanding Operational Amplifiers

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

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

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

Negative feedback (Z_f in Fig. 1-4B), from the output to the input of the amplifier, is obtained by connecting the output to the minus input through a resistor, capacitor, or a non-linear impedance device.

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

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

$$Z_i = \frac{Z_f}{A}$$

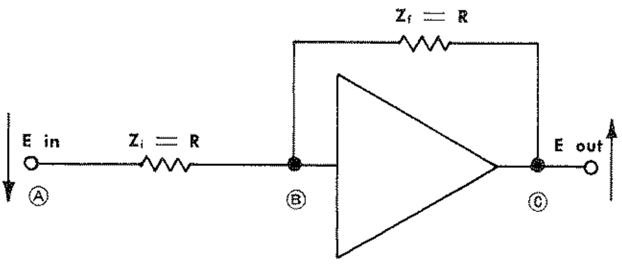
Current applied to the minus input tends to develop a voltage across the impedance of the feedback element and move the minus input away from ground. The output of the amplifier however, swings in the opposite direction and provides current to balance the input current. This effectively holds the minus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

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

Since most applications deal with voltage signals, an additional element called input impedance (Z_f) is used. This impedance in series with the minus input, converts that parameter of the input signal appearing as voltage into current. See Fig. 1-4C.

Gain

The current through Z_i is equal to the applied voltage at point A (Fig. 1-5) divided by the impedance of Z_i or E_{in}/Z_i. Previously, it was stated that this exact value of current must flow through Z_f to keep point B at ground potential. The voltage output at point C, therefore, must equal the current E_{in}/Z_i through Z_f multiplied by the impedance of Z_f. Since the output signal is the inverted input, it becomes $-E_{in}/Z_i \times Z_f$ and the voltage gain of the operational amplifier becomes E_{out}/E_{in} or $-Z_f/Z_i$.



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

Fig. 1-5. Operational Amplifier with resistors for both Z_i and Z_f.

Differentiation

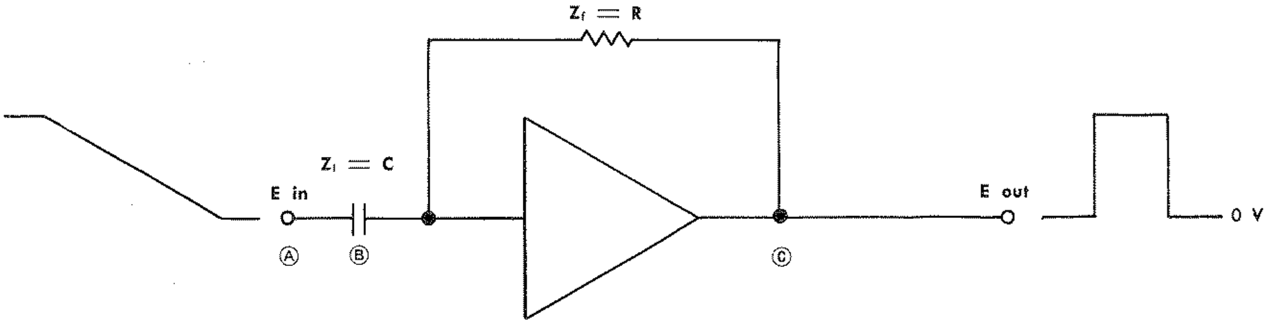
If Z_i is replaced with a capacitor (Fig. 1-6) the following action occurs.

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

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

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

The actual relationship of output to input is: $E_{out} = -dE_{in}/dt \times RC$. The expression dE_{in}/dt, indicates the



Operational Amplifier as Differentiator. Output is proportional to rate-of-change of input voltage. $E\ out = (-RC)\frac{dE_{in}}{dt}$

Fig. 1-6. Operational Amplifier as a Differentiator.

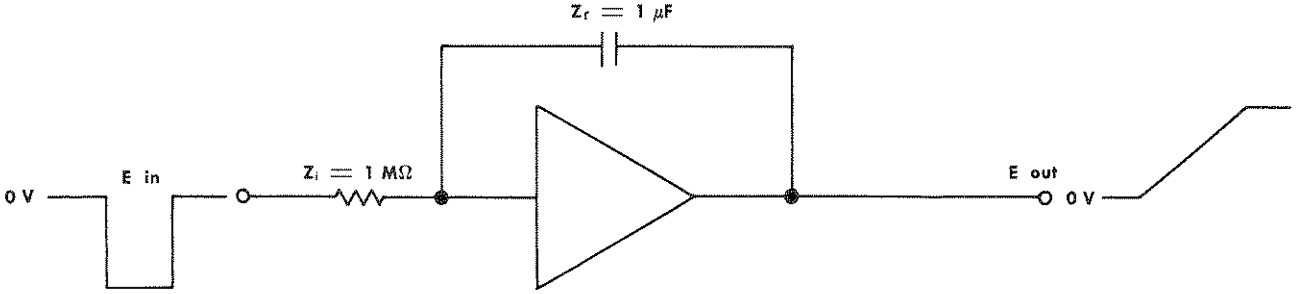
rate-of-change (in volt-seconds), of the input signal at any given instant while the R and C are the Z_f and Z_i respectively.

The example uses a constant rate of change, and a constant voltage output is obtained. If the rate of change is not constant, the output signal voltage shows this dramatically with wide variations in amplitude. The differentiator senses both rate and direction of change. It is a useful device for detecting small variations of slope or discontinuities in waveforms.

Integration

If the resistor and capacitor used for differentiation are interchanged (Fig. 1-7), the circuit characteristics are exactly opposite. The output signal becomes a rate-of-change that is proportional to the input voltage. This is integration, because the instantaneous value of the output voltage at any time is a measure of both amplitude and duration (up to that time) of the input signal.

The operational amplifier operates as an integrator in the following manner. Assume a Z_i of 1 MΩ Z_f of 1 µF and an



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

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

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

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

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

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

where E is the peak amplitude, (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.

Fig. 1-7. Operational Amplifier as an Integrator.

input signal of zero. With these conditions, no balancing current is required through Zf, so the output voltage remains at zero. Suppose that a −1 volt DC signal is applied to Zi. This will require a balancing current of 1 μA through Zf. To produce this 1 μA balancing current through a Zf of 1 μF, a continually rising voltage must be generated at the output, having a rate of rise equal to 1 volt per second. This rate of rise continues until the input voltage is changed or the amplifier reaches its swing limit.

If the input signal to Zi is removed before the amplifier reaches its output limit, the output voltage remains at the level reached when the signal was removed. The 1 μA current through Zf to balance or null the input is no longer required; therefore, under ideal conditions the output voltage remains at this level indefinitely, or until an input signal is again applied to Zi.

Absolute integrator output level, at the end of some interval of time, is the sum of the products of each voltage (applied to Zi) times the period of each applied voltage, divided by −RC. The mathematical expression of the output level in a given period from t_1 to t_2 is:

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

The integral sign ∫, indicates the summation of all the products (E_{in} X dt) shown between the time limits of t_1 and t_2. The expression dt represents infinitesimal increments of time.

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

Assume that an input signal for integration is a 1 volt positive pulse for a period of 1 second (Fig. 1-8). The sum of all voltage periods from $t_2 - t_1$ is one volt-second. With a Zi/Zf combination of 1 MΩ and 1 μF, the output voltage (E_o) will fall at a rate of 1 volt-second times E_{in}/RC for a period of 1 second. The output voltage will reach −1 volt at the end of the input pulse time period and remain at this level.

This is often referred to as taking the area under the curve, since the area under the waveform plotted against time (i.e., the area bounded by t_1, t_2, the amplitude of the waveform and the 0 line) is the number of volt-seconds involved. In addition, the instantaneous value of E_{out} at any time is proportional to the input volt-seconds to that selected time.

The preceding example used an RC of 1 ($1 \times 10^6 \times 10^{-6}$) and the numerical value of the output voltage at the end of the integrating period was the number of volt-seconds in the input waveform. Other values of R and C will require additional calculation to find the input volt-seconds. The

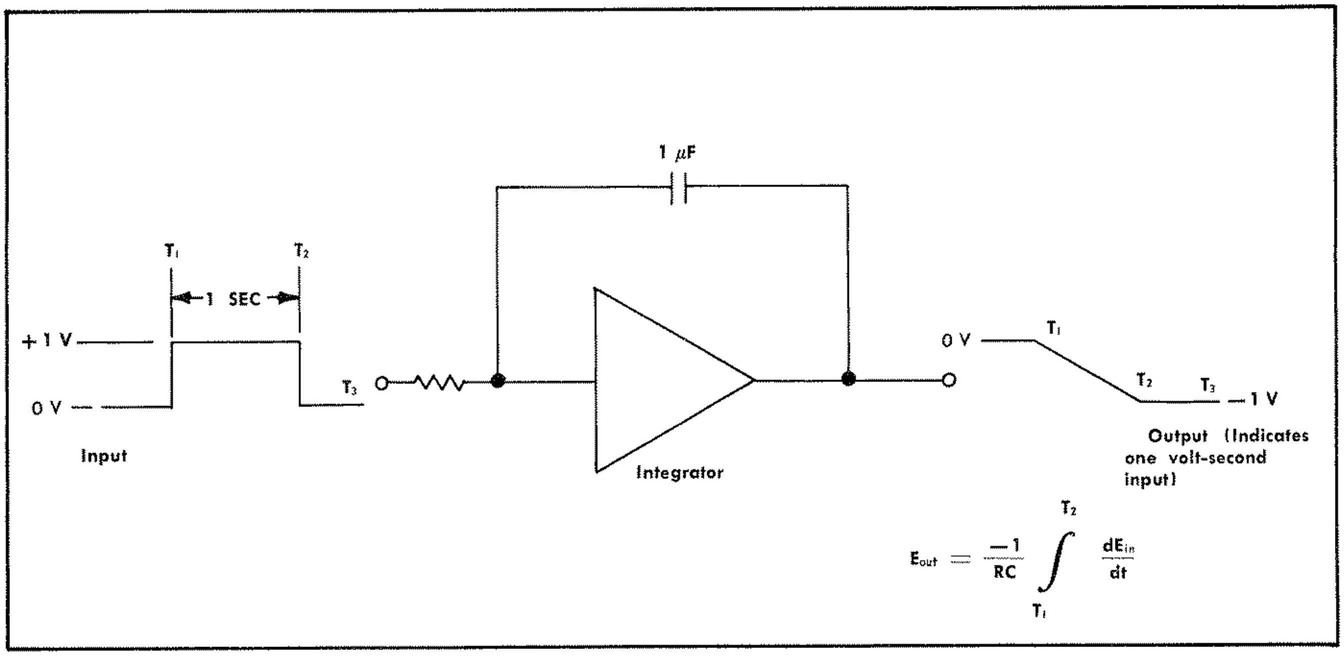


Fig. 1-8. Simple case of integrating 1 volt-second pulse. The integrator does not improve measurement accuracy in so simple a case.

output voltage must be multiplied by −RC. For example, if R is 200,000 Ω, C is 0.01 μF and the output after the selected period is −2.5 volts, then multiplying −2.5 by $2 \times 10^5 \times 1 \times 10^{-8}$ yields −5 mV/s. Due to the polarity reversal in the amplifier, it is necessary to multiply by −RC to obtain the proper sign in the answer.

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

Operational Amplifier Specifications and Limitations

The ideal operational amplifier would provide an infinite amount of gain, infinite input impedance and zero output impedance. With these ideal conditions, the operational amplifier could process signals with an accuracy that is limited only by the tolerances in the values of the passive elements in the input and feedback network. The practical amplifier has finite values for all three, which determine the limits of accuracy in all applications. Some of the prominent limitations are:

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

Open Loop Gain

The accuracy of all operations is ultimately limited by the open loop gain of the amplifier, which is a determinant of how close the amplifier holds the null at the minus input. The ideal amplifier (with infinite gain) would hold the null at exactly zero volts and the impedance would be exactly zero ohms. The practical amplifier having finite gain, does not quite null the minus input to zero ohms, but moves 1/A times the output voltage swing. (A = Open loop gain of the amplifier.) $E_{in} = E_{out}/A$. The input impedance, therefore, appears as the quantity $Z_f/(1 - A)$. See Fig. 1-9.

NOTE

The input impedance at the minus input is obtained by the following mathematical derivation:

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

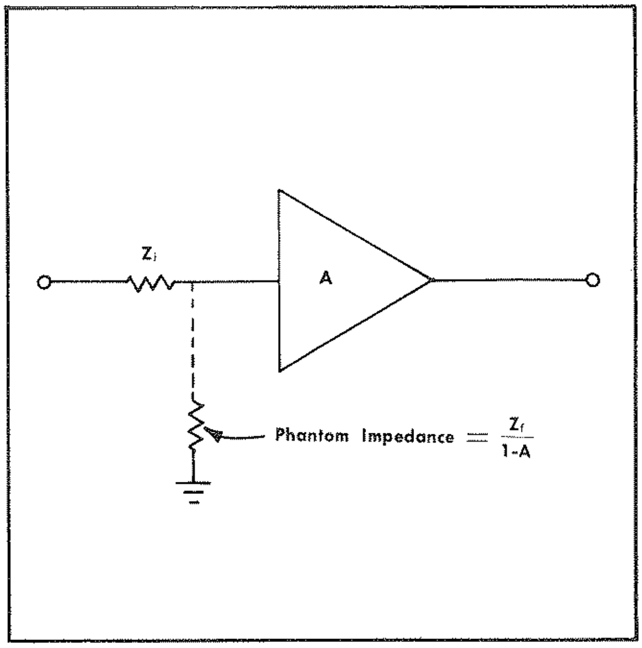


Fig. 1-9. Apparent impedance at the −input.

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

$$\frac{\frac{E_{out}}{A}}{\frac{\frac{E_{out}}{A} - E_{out}}{Z_f}} \text{ or } \frac{Z_f}{1 - A}$$

If the voltage swing E_{out}/A is a significant fraction of the input signal E_{in}, or if the impedance $Z_f/(1 - A)$, is a significant fraction of Z_i, there will be a definite error in the output signal, which adds to the error introduced by the tolerances of the passive elements, Z_i and Z_f. The exact value of this error is:

$$1 - \frac{A}{A - 1 - \frac{Z_f}{Z_i}}$$

If the ratio of Z_f/Z_i is small and A is large, this error is not serious.

Shunt Impedance Across The Minus Input

The true impedance from the minus input to ground is $Z_f/(1 - A)$, and with large values of A, is a very low value, calculated as virtual ground. However, when A becomes small and Z_f becomes large, the shunt impedances (particularly capacitive reactance) can interfere with the operation. See Fig. 1-10.

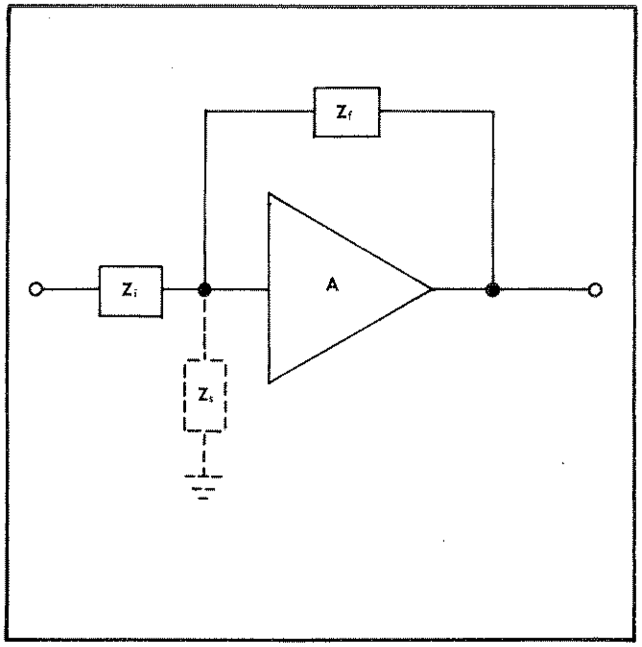


Fig. 1-10. Shunt Impedance across –input. Where Z_s is large compared to Z_i and Z_f, and open-loop gain A is high, effect of Z_s is negligible.

The general expression for the closed loop gain (discussed later in this text) of an operational amplifier,

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

, may be modified to show the effect of shunt impedance Z_s across the minus input:

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

keeping in mind that A is a negative number. As it becomes smaller, the effect of Z_s on accuracy becomes apparent and may become comparable to that of Z_f/Z_i.

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

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

Closed Loop Gain Accuracy For Amplification

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

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

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

has been reduced to:

$$\frac{-Z_f}{Z}\left[\frac{A}{A-1-\frac{Z_f}{Z_i}}\right]$$

It may also be written:

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

This more clearly shows the effect of A on accuracy.

Gain Bandwidth Product

The gain factor A, of the operational amplifier decreases with an increase in frequency; therefore, it is important to know the effective value of A for the frequencies in use.

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

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

It is well to note that except in the case of straight amplification (Fig. 1-10), the compensation introduces possible errors that must be recognized and considered in the interpretation of the results.

Accuracy With Capacitors Used For Zi Or Zf

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

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

$$e = \frac{1 - \frac{E_{out}}{E_{in}}}{1 - A} \text{, where A is the open-loop gain, and}$$

E_{out}/E_{in} is the actual voltage gain. Remember that both A and E_{out}/E_{in} are negative numbers. For example, when A is −10,000 and the observed E_{out}/E_{in} is −500, the error is 501/10,001 or 5.095%. The output, −500, then represents 94.905% of the correct value and the correct value is −500/0.94905, approximately −527.

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

$$\frac{\text{Max } E_{out}}{E_{in}} = 1 - e\,(1 - A)$$

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

Compensation For The Effect Of Stray Capacitance

Accuracy in high-speed operations will be affected by shunt capacitance (C_s), and by the distributed capacitance around Z_i and Z_f (Fig. 1-11). Their effect is more pronounced at higher frequencies where the effective value of A is low.

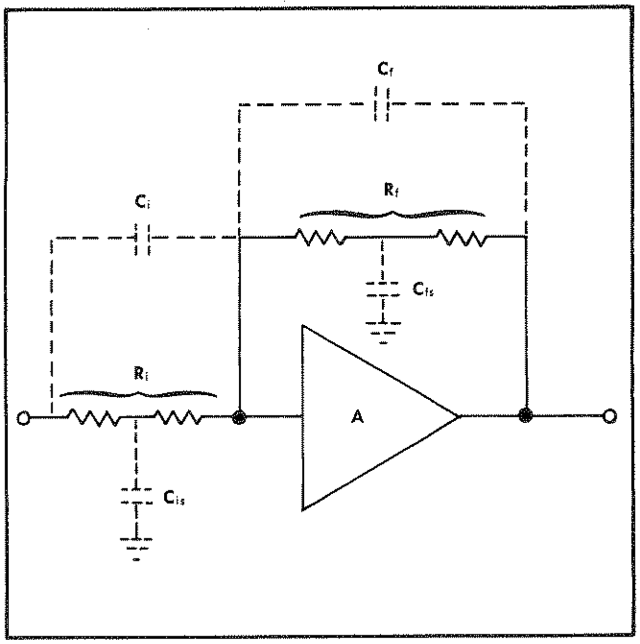


Fig. 1-11. Where Z_i or Z_f is a resistor, and particularly if a large (> 100 k) value, more serious errors may be caused by capacitance from the resistor body (highest impedance point) to ground, and, in the case of R_i during integration, end-to-end capacitance of R_i. Time constants involved in shunt capacitance C_{fs} and C_{is} are approximately RC/4.

Figs. 1-12 through 1-14 illustrate the corrections necessary to improve accuracy for each of the basic operations.

Errors Due To Signal Source Impedance

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

Compensated Differentiator

Without compensation, the differentiator may respond to a sudden change in dE_{in}/dt by overshoot, followed by sinusoidal ringing. This is because excess output voltage must be developed to charge the input capacitance via R_f, plus the distributed stray capacitance of R_f itself. Current is also required to obtain a null at the minus input. As soon as the stray capacitances are charged, excess current through R_f upsets the null, and the output must swing in the opposite direction to re-establish the null and discharge the capacitance associated with R_f. This produces the ringing. A small capacitance across R_f (Fig. 1-13) provides the

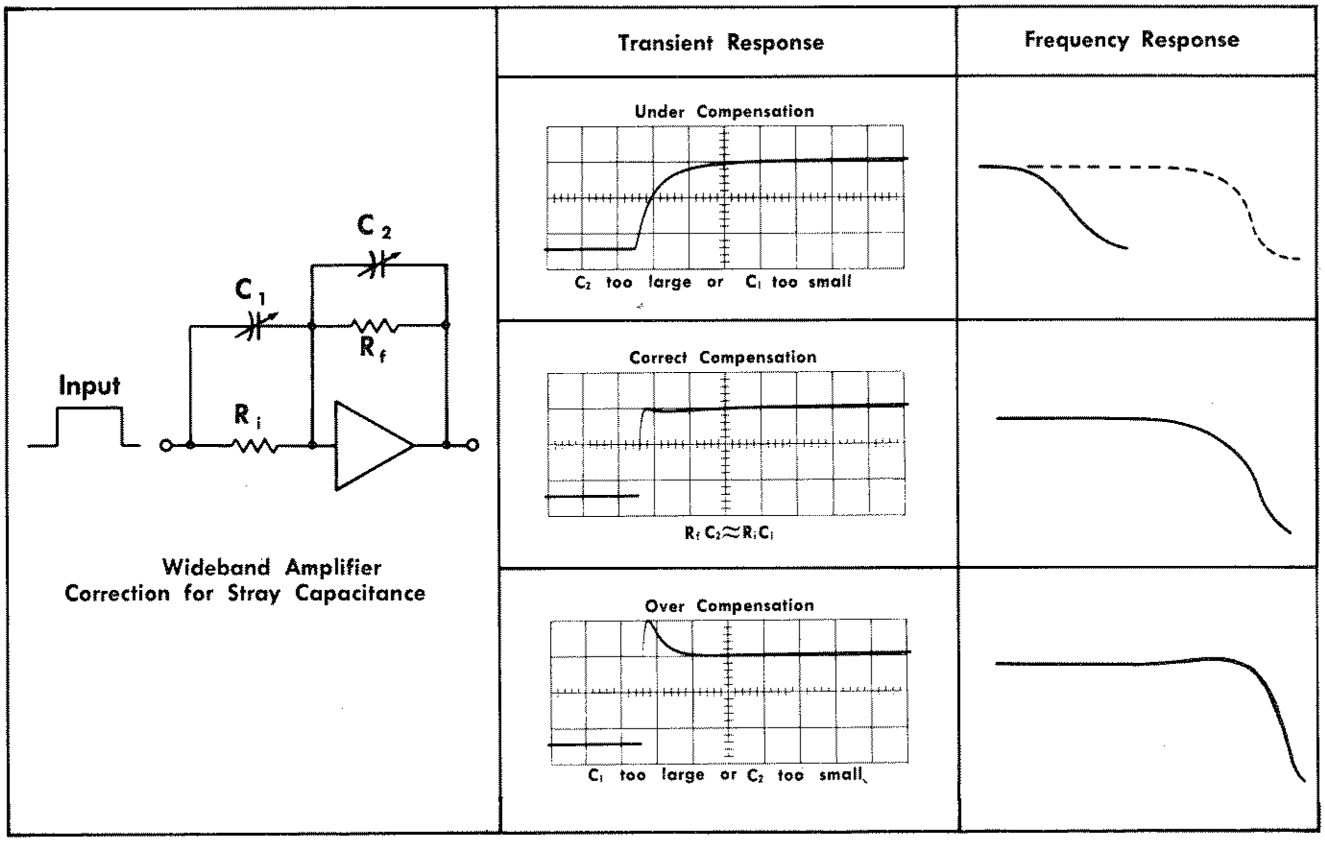


Fig. 1-12. Wideband Amplifier—Correction for stray capacitance.

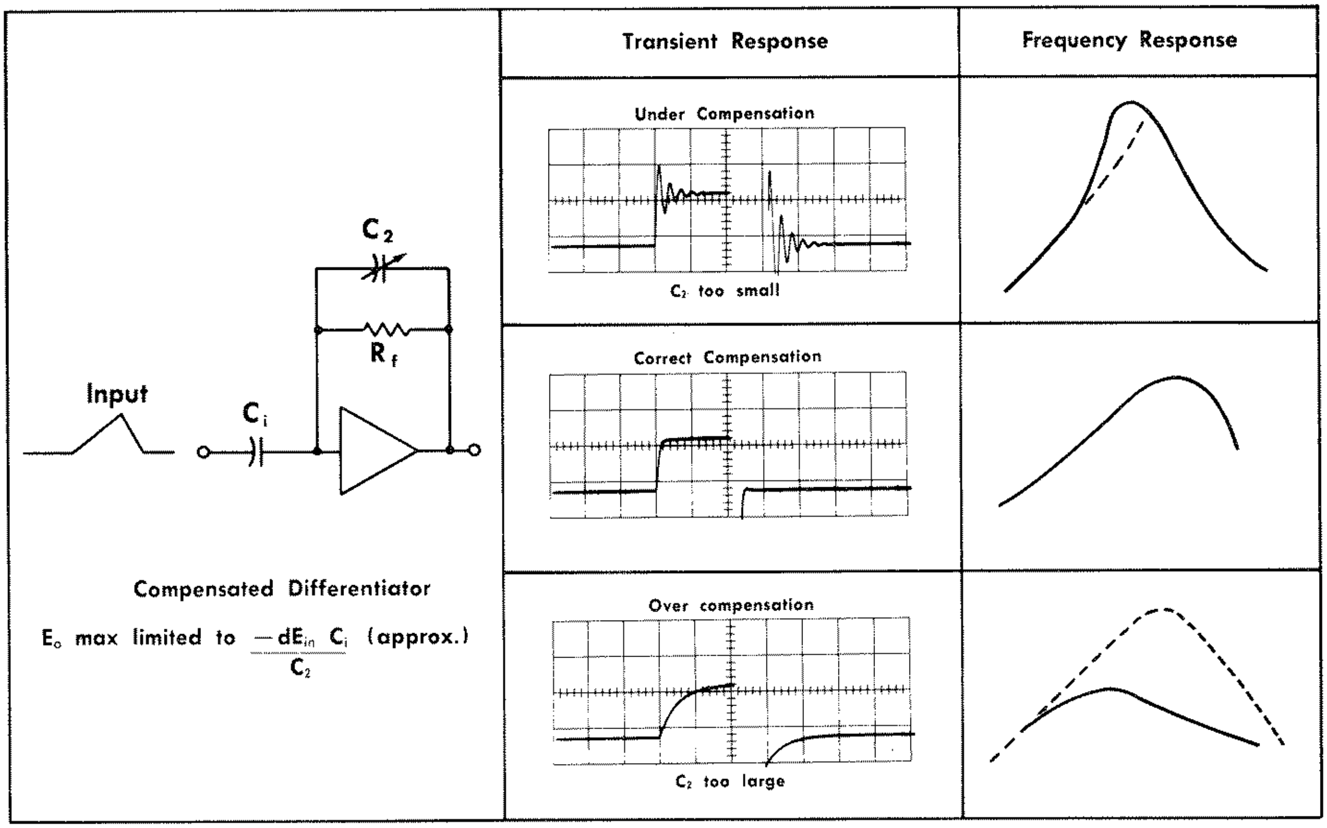


Fig. 1-13. Compensated differentiator. E_O max limited to $\frac{-dE_{in}\,C_i}{C_2}$ (approximate).

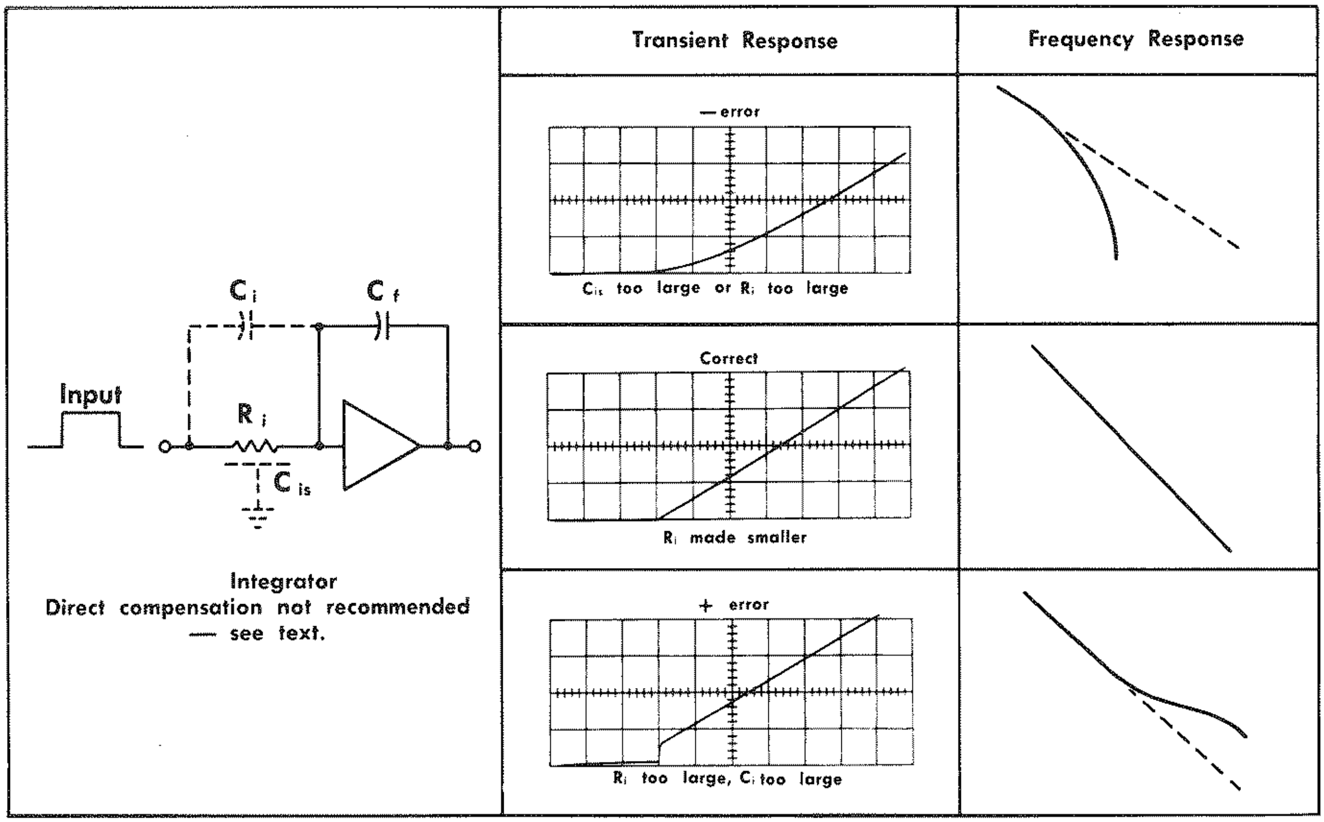


Fig. 1-14. Integrator—direct compensation not recommended.

current needed to establish the null at the start of the waveform without having to develop excess voltage across R_f.

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

Integrator Compensation

Compensation to integrate fast-rise input signals is not recommended. The added components introduce more stray capacitance. It is recommended that smaller values of R_i and a larger C_f be used to maintain the same time constant. This is limited by how much loading the signal source can tolerate when R_i is reduced.

Using Standard Waveforms For Comparison

The use of a standard waveform (pulses and ramps) with known parameters is of considerable help in adjusting compensation and ensuring best accuracy for critical measurements near the limits of the instrument capabilities. Selection of time and amplitude parameters close to those of waveforms to be measured gives best assurance against possible system errors.

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

For slow work, a pushbutton switch that can discharge Z_f manually is usually sufficient. When the integrating interval is quite short compared to the signal period (low duty factor), RC networks may be placed around Z_f to return the output level to 0 volts through a time constant much longer (e.g., 100X) than the integrating interval.

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

Practical Circuits

Figs. 1-15 through 1-19 show several practical circuit applications for the AM 501. These circuits illustrate the many possible uses for the AM 501.

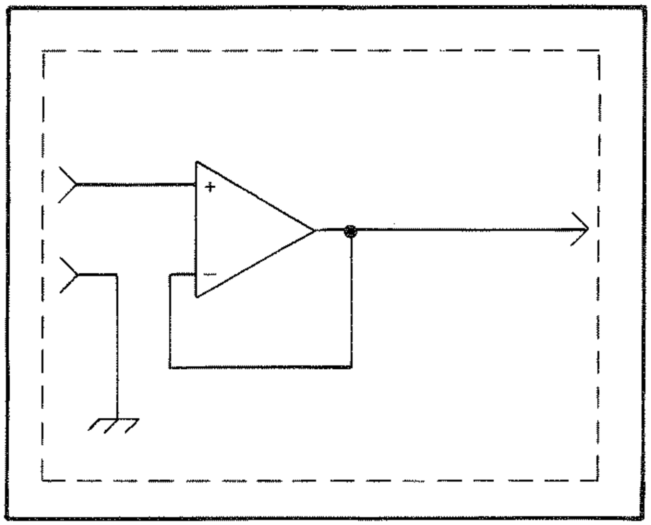


Fig. 1-15. X1 Non-inverting amplifier (follower).

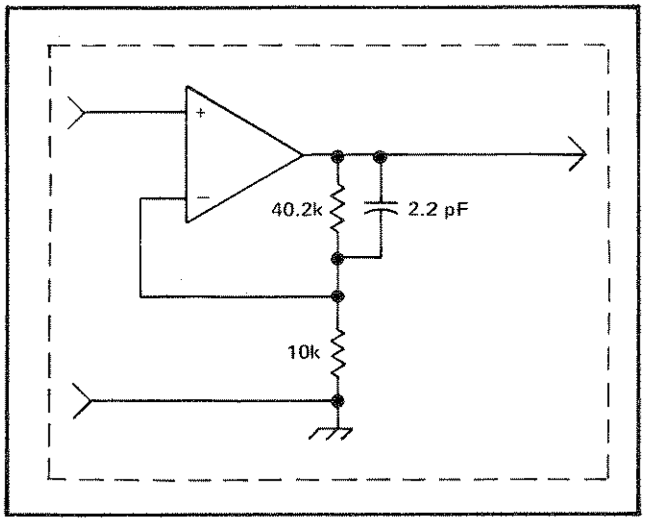


Fig. 1-16. X5 Non-inverting amplifier.

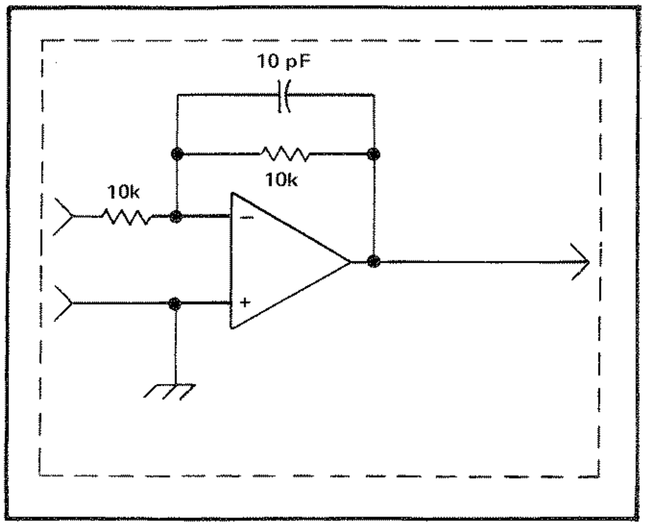


Fig. 1-17. X1 Inverting amplifier.

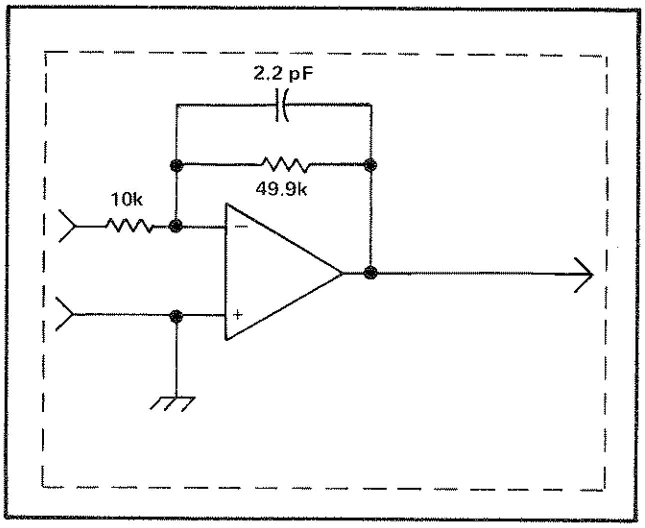
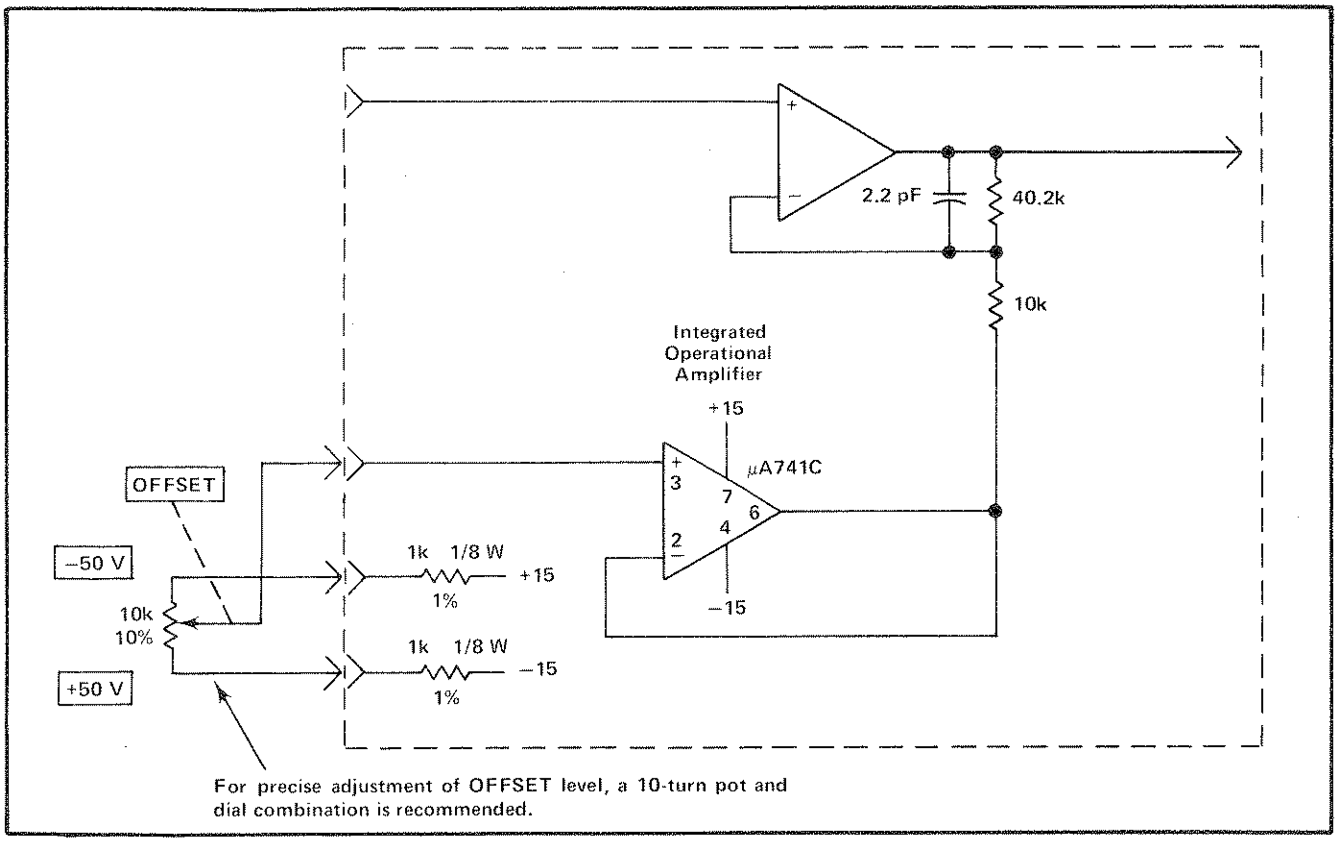


Fig. 1-18. X5 Inverting amplifier.



For precise adjustment of OFFSET level, a 10-turn pot and dial combination is recommended.

Fig. 1-19. X5 Amplifier with offset.

SPECIFICATIONS

Performance Conditions

The electrical characteristics are valid only if the AM 501 is calibrated at an ambient temperature between +20°C and +30°C and operated between 0°C and +50°C.

GAIN:

Open Loop: ⩾10,000 into an 800 Ω load.

COMMON MODE REJECTION RATIO:

⩾10,000 to 1 at 60 Hz.

UNITY GAIN BANDWIDTH:

⩾5 MHz into an 800 Ω load.

INPUT:

Maximum Safe Differential Input Voltage: 80 V.

Common Mode Input Voltage Range: ±40 V.

Input Leakage Current: < 500 pA at 25°C, < 2.0 nA at 50°C.

Equivalent Input Drift: ⩽ 100 μV/°C.

Equivalent Input Noise: ⩽ 10 μV RMS.

SLEW RATE:

⩾50 V/μs into an 800 Ω load.

OUTPUT:

Voltage Range: ⩾ ±40 V.

Current Limit: ⩾ ±50 mA.

Power Consumption: 8 watts

SUPPLEMENTAL INFORMATION:

Power Supplies:

DC Voltages: ± 49.6 V to ± 49.8 V

Ripple: < 5 mV measured with a 5 MHz bandwidth oscilloscope.

THEORY OF OPERATION

General

The AM 501 is a feedback amplifier having low output impedance, high overall gain, high output voltage and current capabilities and excellent stability.

The high gain section of the amplifier consists of the input FETs and current sources, and the output current sources. The output current sources serve as high impedance loads for the FETs. The gain is $G_m R_o$, where G_m is the transconductance of the input FETs and R_o is the impedance of the feedback amplifiers used as signal current sources at the output.

The output stage is a unity-gain amplifier having a very high input impedance and low output impedance. The output stage is capable of ±40 volts at approximately 50 mA.

Input Amplifier

The input FETs use a conventional current source, Q125, that provides a constant current, determined by the divider R101, R102, R126 and VR126.

The source-to-drain voltage of the input FETs is maintained at a constant value by VR110 and Q110, so that even though the common-mode input level may change, the FET characteristics remain constant.

CR100 and R100 provide impedance at the drain of Q120 A (plus input) equivalent to the impedance at the drain of Q120B (minus input).

Q105 is the current source for VR110. Q125 provides about 6 mA and Q105 needs about 2 mA. This leaves about 4 mA for Q120. Thus, when Q120 is balanced, 2 mA flows through each side of Q120.

VR126, R101, R102, R105, R125, and R126 set a relationship between current sources Q105 and Q125 so that any current change in one is matched by an equal change in the other. This keeps the total current in Q120 constant, and thus maintains amplifier stability with temperature and supply voltage variations.

The 2 mA flowing through Q120A also flows through common-base stage Q100, providing 2 mA to the controlled signal current source, Q130 and Q135.

The same condition exists in the Q115-Q140 side of the amplifier, which supplies 2 mA through Q140 to Q145 and Q150.

Differences in characteristics of the active components are balanced out using the Offset Null control, R122.

Q130 and Q135, and their counterparts, Q145 and Q150, act as signal current sources. Any voltage change at the base of Q135 causes equal current changes in Q130A and Q130B, since they are matched transistors. The same is true for Q145, Q150A and Q150B. Although the current through Q135 is fairly insensitive to collector voltage, slightly more current will flow through Q135 and Q130B when Q135's collector is more negative. This increased current passing through Q130B causes equally increased current flow in Q130A, making its collector go more positive and reducing the additional current through Q135. Again, the identical action takes place in Q145 and Q150, only the polarities are different. Thus, for a given signal current change at the base of Q135 and Q145, the output current at the collectors of Q135 and Q145 changes proportionally. This current change is nearly independent of the voltage at the collectors of Q135 and Q145. The drains of the input FETs see an effective load impedance of approximately 10 MΩ. This configuration also provides a single voltage amplification point, and a single RC amplitude vs. frequency rolloff characteristic. These factors are necessary to prevent oscillation when using 100% feedback.

CR130 and CR135 (CR140-CR145) prevent saturation of Q135 (Q145) when full differential voltage is applied at the input.

VR135 and VR140 limit the voltage at the common output point, preventing saturation in the output amplifier. CR137 is a voltage-dropping diode used to compensate for inequality in junction drops from side to side in the output amplifier.

No harm can be done to the input, even if the input drive is maximum (+40 V and −40 V). The range of the amplifier will have been exceeded (it will be locked up at one end), but as the gate-to-drain breakdown of Q120 is reached, current limiting diode CR120 (CR124) limits the input current to 1 mA, protecting the FET. Below this point, CR120 (CR124) behaves as a low value resistor, approximately 1 to 2 KΩ.

C118 and R119 prevent oscillation at the higher frequency limits. C116 improves the slewing rate during high common-mode voltage swings. The bandwidth may be reduced, if desired, by the addition of capacitance at Points 1 and 2. See the Controls, Connectors and Adjustments foldout for locations.

Output Amplifier

The Output Amplifier is a unity-gain voltage-follower impedance-transforming amplifier.

Q170 is an emitter follower, having a current source from Q165, feeding two successive emitter followers, Q172 and Q175.

Q180 is an emitter follower, having a current source from Q190, feeding a unity-gain feedback amplifier, Q182 and Q185.

The algebraic sum of the diode and base-emitter drops around the loop, starting at the collector of Q185 (the emitter of Q182) and progressing clockwise to the emitter of Q175, is slightly greater than zero. These voltage drops are impressed across R175 and R185 to fix the standing current in the output transistors.

With the input FET gates tied together, the output voltage (at the junction of R175-R185) is zero.

R168 and R193 are part of a current-limiting circuit. As the load current increases to a value near the limit, the drop across R168 causes CR165 to turn on, taking emitter current from the current source, Q165. When the load current reaches its limit, enough current is diverted from Q165 to shut Q170 off and prevent the output from moving any further positive.

The same current limiting occurs in the other direction (negative swing at the output). R193 senses the load current, CR190 turns on, taking current from Q190 and preventing the negative driving signal from driving the output too far negative.

CR175 and CR185 prevent Q170 and Q180 from reaching base-emitter reverse breakdown during conditions of output overload or short circuit.

CR175 and R186 prevent oscillation when the output is capacitively loaded.

Power Supply

CR10 (a bridge) rectifies 25 V AC from the power module. This voltage is added to the +33.5 V DC from the power module to provide raw DC for the regulated +49 V DC. The +33.5 V is applied to pin 7 (Vcc) of the operational amplifier, U10. The plus input is referenced by VR50. The output voltage is sensed through R30 to the minus input of U10. VR20 allows U10 to operate near ground while controlling the current through Q10. R10 sets the output voltage. If the output voltage decreases, pin 2 of U10 goes negative, causing pin 6 to go positive. This action increases the current flow through Q10 to the load, bringing the voltage across the load to its original value. If the current through Q10 becomes excessive, the voltage dropped across R50 will turn Q20 on. As the current increases, Q20 will finally turn Q10 off, thus limiting the current. CR60 serves as a protective diode preventing the positive power bus from going below ground.

The −49 V supply operates nearly the same as the +49 V supply. 25 V AC is bridge rectified by CR12 and added to −33.5 V DC from the power module. VR52 references the negative input of U20, an operational amplifier. The −49 V is adjusted by R12, connected to the plus input of U20. If the load on the −49 V supply increases, the voltage will go more positive. This causes pin 3 of U20 to move in the positive direction through R32 and R12. Pin 6 of U20 goes positive, increasing conduction in Q12, restoring the −49 V and causing equilibrium at pins 2 and 3 of U20. If the load on the −49 V supply increases to the point of causing the voltage drop across R52 to turn Q22 on, pin 3 of U20 will go negative causing the base of Q12 to go negative. This reduces the current to the load to within safe limits.

REPLACEABLE ELECTRICAL PARTS

PARTS ORDERING INFORMATION

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

Changes to Tektronix instruments are sometimes made to accommodate improved components as they become available, and to give you the benefit of the latest circuit improvements developed in our engineering department. It is therefore important, when ordering parts, to include the following information in your order: Part number, instrument type or number, serial number, and modification number if applicable.

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

Change information, if any, is located at the rear of this manual.

SPECIAL NOTES AND SYMBOLS

X000	Part first added at this serial number
00X	Part removed after this serial number

ITEM NAME

In the Parts List, an Item Name is separated from the description by a colon (:). Because of space limitations, an Item Name may sometimes appear as incomplete. For further Item Name identification, the U.S. Federal Cataloging Handbook H6-1 can be utilized where possible.

ABBREVIATIONS

ACTR	ACTUATOR	PLSTC	PLASTIC
ASSY	ASSEMBLY	QTZ	QUARTZ
CAP	CAPACITOR	RECP	RECEPTACLE
CER	CERAMIC	RES	RESISTOR
CKT	CIRCUIT	RF	RADIO FREQUENCY
COMP	COMPOSITION	SEL	SELECTED
CONN	CONNECTOR	SEMICOND	SEMICONDUCTOR
ELCTLT	ELECTROLYTIC	SENS	SENSITIVE
ELEC	ELECTRICAL	VAR	VARIABLE
INCAND	INCANDESCENT	WW	WIREWOUND
LED	LIGHT EMITTING DIODE	XFMR	TRANSFORMER
NONWIR	NON WIREWOUND	XTAL	CRYSTAL

CROSS INDEX MFR. CODE NUMBER TO MANUFACTURER

MFR.CODE	MANUFACTURER	ADDRESS	CITY,STATE,ZIP
01121	Allen-Bradley Co.	1201 2nd St. South	Milwaukee, WI 53204
04713	Motorola, Inc., Semiconductor Products Div.	5005 E. McDowell Rd.	Phoenix, AZ 85036
07263	Fairchild Semiconductor, A Div. of Fairchild Camera and Instrument Corp.	464 Ellis St.	Mountain View, CA 94042
07910	Teledyne Semiconductor	12515 Chadron Ave.	Hawthorne, CA 90250
09353	C and K Components, Inc.	103 Morse Street	Watertown, MA 02172
12040	National Semiconductor Corp.	Commerce Drive	Danbury, CT 06810
15818	Teledyne Semiconductor	1300 Terra Bella Ave.	Mountain View, CA 94040
24931	Specialty Connector Co., Inc.	3560 Madison Ave.	Indianapolis, IN 46227
56289	Sprague Electric Co.		North Adams, MA 01247
58474	Superior Electric Co., The	383 Middle St.	Bristol, CT 06010
71744	Chicago Miniature Lamp Works	4433 Ravenswood Ave.	Chicago, IL 60640
72982	Erie Technological Products, Inc.	644 W. 12th St.	Erie, PA 16512
73138	Beckman Instruments, Inc., Helipot Div.	2500 Harbor Blvd.	Fullerton, CA 92634
75042	TRW Electronic Components, IRC Fixed Resistors, Philadelphia Division	401 N. Broad St.	Philadelphia, PA 19108
80009	Tektronix, Inc.	P. O. Box 500	Beaverton, OR 97077
80740	Beckman Instruments, Inc.	2500 Harbor Blvd.	Fullerton, CA 92634
81483	International Rectifier Corp.	9220 Sunset Blvd.	Los Angeles, CA 90069

Ckt No.	Tektronix Part No.	Serial/Model No.		Name & Description	Mfr Code	Mfr Part Number
		Eff	Dscont			
A1	670-2958-00			CKT BOARD ASSY:--MAIN	80009	670-2958-00
C10	290-0324-00			CAP.,FXD,ELCTLT:750UF,+75-10%,40V	56289	39D757G040HJ4
C12	290-0324-00			CAP.,FXD,ELCTLT:750UF,+75-10%,40V	56289	39D757G040HJ4
C20	290-0194-00			CAP.,FXD,ELCTLT:10UF,+50-10%,100V	56289	30D106F100DC4
C22	290-0194-00			CAP.,FXD,ELCTLT:10UF,+50-10%,100V	56289	30D106F100DC4
C100	283-0000-00			CAP.,FXD,CER DI:0.001UF,+100-0%,500V	72982	831-516E102P
C105	283-0000-00			CAP.,FXD,CER DI:0.001UF,+100-0%,500V	72982	831-516E102P
C116	281-0628-00			CAP.,FXD,CER DI:15PF,5%,600V	72982	301-000C0G0150G
C118	281-0504-00			CAP.,FXD,CER DI:10PF,+/-1PF,500V	72982	301-000C0G0100F
C125	283-0000-00			CAP.,FXD,CER DI:0.001UF,+100-0%,500V	72982	831-516E102P
C165	281-0504-00			CAP.,FXD,CER DI:10PF,+/-1PF,500V	72982	301-000C0G0100F
C167	281-0549-00			CAP.,FXD,CER DI:68PF,10%,500V	72982	301-000U2J0680K
C175	283-0032-00			CAP.,FXD,CER DI:470PF,5%,500V	72982	831-500Z5D471J
C190	281-0504-00			CAP.,FXD,CER DI:10PF,+/-1PF,500V	72982	301-000C0G0100F
C192	281-0549-00			CAP.,FXD,CER DI:68PF,10%,500V	72982	301-000U2J0680K
CR10	152-0488-00			SEMICOND DEVICE:SILICON,200V,1500MA	80009	152-0488-00
CR12	152-0488-00			SEMICOND DEVICE:SILICON,200V,1500MA	80009	152-0488-00
CR60	152-0107-00			SEMICOND DEVICE:SILICON,375V,400MA	80009	152-0107-00
CR62	152-0107-00			SEMICOND DEVICE:SILICON,375V,400MA	80009	152-0107-00
CR100	152-0141-02			SEMICOND DEVICE:SILICON,30V,150MA	07910	1N4152
CR120	152-0460-00			SEMICOND DEVICE:100V,1MA	04713	IN5298
CR124	152-0460-00			SEMICOND DEVICE:100V,1MA	04713	IN5298
CR130	152-0141-02			SEMICOND DEVICE:SILICON,30V,150MA	07910	1N4152
CR135	152-0061-00			SEMICOND DEVICE:SILICON,175V,100MA	80009	152-0061-00
CR137	152-0141-02			SEMICOND DEVICE:SILICON,30V,150MA	07910	1N4152
CR140	152-0061-00			SEMICOND DEVICE:SILICON,175V,100MA	80009	152-0061-00
CR145	152-0141-02			SEMICOND DEVICE:SILICON,30V,150MA	07910	1N4152
CR165	152-0141-02			SEMICOND DEVICE:SILICON,30V,150MA	07910	1N4152
CR175	152-0141-02			SEMICOND DEVICE:SILICON,30V,150MA	07910	1N4152
CR185	152-0141-02			SEMICOND DEVICE:SILICON,30V,150MA	07910	1N4152
CR190	152-0141-02			SEMICOND DEVICE:SILICON,30V,150MA	07910	1N4152
DS80	150-0109-00			LAMP,INCAND:18V,26MA	71744	CM7220
J118	131-0955-00			CONNECTOR,RCPT,:BNC,FEMALE	24931	28JR200-1
J119	129-0064-01			POST,BDG,ELEC:RED,5-WAY MINIATURE	58474	BB10167G2BX
J120	129-0064-01			POST,BDG,ELEC:RED,5-WAY MINIATURE	58474	BB10167G2BX
J123	131-0955-00			CONNECTOR,RCPT,:BNC,FEMALE	24931	28JR200-1
J124	129-0064-02			POST,BDG,ELEC:WHITE,5-WAY,MINIATURE	58474	DF21WTC
J125	129-0064-02			POST,BDG,ELEC:WHITE,5-WAY,MINIATURE	58474	DF21WTC
J174	129-0064-00			POST,BDG,ELEC:CHARCOAL,5-WAY MINIATURE	58474	BINP BB10167G13T
J175	131-0955-00			CONNECTOR,RCPT,:BNC,FEMALE	24931	28JR200-1
J176	129-0064-00			POST,BDG,ELEC:CHARCOAL,5-WAY MINIATURE	58474	BINP BB10167G13T
Q10	151-0436-00			TRANSISTOR:SILICON,NPN	80009	151-0436-00
Q12	151-0436-00			TRANSISTOR:SILICON,NPN	80009	151-0436-00
Q20	151-0347-00			TRANSISTOR:SILICON,NPN	80009	151-0347-00
Q22	151-0347-00			TRANSISTOR:SILICON,NPN	80009	151-0347-00
Q100	151-0279-00			TRANSISTOR:SILICON,NPN	07263	S25381
Q105	151-0350-00			TRANSISTOR:SILICON,PNP	07263	2N5401
Q110	151-0279-00			TRANSISTOR:SILICON,NPN	07263	S25381
Q115A,B	151-0261-00			TRANSISTOR:SILICON,PNP,DUAL	12040	NS7410
Q120A,B	151-1010-00			TRANSISTOR:SILICON,JFE,DUAL	15818	SU2115
Q125	151-0279-00			TRANSISTOR:SILICON,NPN	07263	S25381
Q130A,B	151-0261-00			TRANSISTOR:SILICON,PNP,DUAL	12040	NS7410

Ckt No.	Tektronix Part No.	Serial/Model No.		Name & Description	Mfr Code	Mfr Part Number
		Eff	Dscont			
Q135	151-0228-00			TRANSISTOR:SILICON,PNP,SEL FROM 2N4888	07263	S21862
Q140	151-0228-00			TRANSISTOR:SILICON,PNP,SEL FROM 2N4888	07263	S21862
Q145	151-0279-00			TRANSISTOR:SILICON,NPN	07263	S25381
Q150A,B	151-0232-00			TRANSISTOR:SILICON,NPN,DUAL	12040	NS7348
Q165	151-0350-00			TRANSISTOR:SILICON,PNP	07263	2N5401
Q170	151-0188-00			TRANSISTOR:SILICON,PNP	04713	2N3906
Q172	151-0347-00			TRANSISTOR:SILICON,NPN	80009	151-0347-00
Q175	151-0311-01			TRANSISTOR:SILICON,NPN	04713	MJE340
Q180	151-0190-00			TRANSISTOR:SILICON,NPN	04713	2N3904
Q182	151-0350-00			TRANSISTOR:SILICON,PNP	07263	2N5401
Q185	151-0311-01			TRANSISTOR:SILICON,NPN	04713	MJE340
Q190	151-0347-00			TRANSISTOR:SILICON,NPN	80009	151-0347-00
R5	304-0272-00			RES.,FXD,COMP:2.7 OHM,10%,1W	01121	GB2721
R7	304-0272-00			RES.,FXD,COMP:2.7 OHM,10%,1W	01121	GB2721
R10	311-1562-00			RES.,VAR,NONWIR:2K OHM,20%,0.50W	73138	91A-20000M
R12	311-1562-00			RES.,VAR,NONWIR:2K OHM,20%,0.50W	73138	91A-20000M
R20	321-0266-00			RES.,FXD,FILM:5.76K OHM,1%,0.125W	75042	CEATO-5761F
R22	321-0266-00			RES.,FXD,FILM:5.76K OHM,1%,0.125W	75042	CEATO-5761F
R30	321-0355-00			RES.,FXD,FILM:48.7K OHM,1%,0.125W	75042	CEATO-4872F
R32	321-0355-00			RES.,FXD,FILM:48.7K OHM,1%,0.125W	75042	CEATO-4872F
R35	301-0562-00			RES.,FXD,COMP:5.6K OHM,5%,0.50W	01121	EB5625
R37	301-0622-00			RES.,FXD,COMP:6.2K OHM,5%,0.50W	01121	EB6225
R38	315-0473-00			RES.,FXD,COMP:47K OHM,5%,0.25W	01121	CB4735
R40	315-0302-00			RES.,FXD,COMP:3K OHM,5%,0.25W	01121	CB3025
R42	315-0151-00			RES.,FXD,COMP:150 OHM,5%,0.25W	01121	CB1515
R50	307-0107-00			RES.,FXD,COMP:5.6 OHM,5%,0.25W	01121	CB56G5
R52	307-0103-00			RES.,FXD,COMP:2.7 OHM,5%,0.25W	01121	CB27G5
R80	303-0122-00			RES.,FXD,COMP:1.2K OHM,5%,1W	01121	GB1225
R100	321-0168-00			RES.,FXD,FILM:549 OHM,1%,0.125W	75042	CEATO-5490F
R101	321-0212-00			RES.,FXD,FILM:1.58K OHM,1%,0.125W	75042	CEATO-1581F
R102	323-0352-00			RES.,FXD,FILM:45.3K OHM,1%,0.50W	75042	CECTO-4532F
R105	321-0202-00			RES.,FXD,FILM:1.24K OHM,1%,0.125W	75042	CEATO-1241F
R115	321-0164-00			RES.,FXD,FILM:499 OHM,1%,0.125W	75042	CEATO-4990F
R116	321-0164-00			RES.,FXD,FILM:499 OHM,1%,0.125W	75042	CEATO-4990F
R119	316-0102-00			RES.,FXD,COMP:1K OHM,10%,0.25W	01121	CB1021
R120	321-0289-00			RES.,FXD,FILM:10K OHM,1%,0.125W	75042	CEATO-1002F
R122	311-0607-00			RES.,VAR,NONWIR:10K OHM,10%,0.50W	80740	62-59-3
R124	321-0289-00			RES.,FXD,FILM:10K OHM,1%,0.125W	75042	CEATO-1002F
R125	321-0202-00			RES.,FXD,FILM:1.24K OHM,1%,0.125W	75042	CEATO-1241F
R126	321-0212-00			RES.,FXD,FILM:1.58K OHM,1%,0.125W	75042	CEATO-1581F
R130	321-0164-00			RES.,FXD,FILM:499 OHM,1%,0.125W	75042	CEATO-4990F
R132	321-0164-00			RES.,FXD,FILM:499 OHM,1%,0.125W	75042	CEATO-4990F
R150	321-0164-00			RES.,FXD,FILM:499 OHM,1%,0.125W	75042	CEATO-4990F
R152	321-0164-00			RES.,FXD,FILM:499 OHM,1%,0.125W	75042	CEATO-4990F
R165	315-0302-00			RES.,FXD,COMP:3K OHM,5%,0.25W	01121	CB3025
R167	315-0242-00			RES.,FXD,COMP:2.4K OHM,5%,0.25W	01121	CB2425
R168	315-0510-00			RES.,FXD,COMP:51 OHM,5%,0.25W	01121	CB5105
R170	315-0913-00			RES.,FXD,COMP:91K OHM,5%,0.25W	01121	CB9135
R171	316-0183-00			RES.,FXD,COMP:18K OHM,10%,0.25W	01121	CB1831
R172	316-0681-00			RES.,FXD,COMP:680 OHM,10%,0.25W	01121	CB6811
R175	316-0220-00			RES.,FXD,COMP:22 OHM,10%,0.25W	01121	CB2201
R183	316-0331-00			RES.,FXD,COMP:330 OHM,10%,0.25W	01121	CB3311
R185	316-0220-00			RES.,FXD,COMP:22 OHM,10%,0.25W	01121	CB2201
R186	316-0471-00			RES.,FXD,COMP:470 OHM,10%,0.25W	01121	CB4711

Ckt No.	Tektronix Part No.	Serial/Model No. Eff	Dscont	Name & Description	Mfr Code	Mfr Part Number
R190	315-0302-00			RES.,FXD,COMP:3K OHM,5%,0.25W	01121	CB3025
R192	315-0242-00			RES.,FXD,COMP:2.4K OHM,5%,0.25W	01121	CB2425
R193	315-0510-00			RES.,FXD,COMP:51 OHM,5%,0.25W	01121	CB5105
S120	260-1206-00			SWITCH,TOGGLE:SPDT,5A,115VAC CENTER OFF	09353	7103SYZ
U10	156-0067-00			MICROCIRCUIT,LI:OPERATIONAL AMPLIFIER	80009	156-0067-00
U20	156-0067-00			MICROCIRCUIT,LI:OPERATIONAL AMPLIFIER	80009	156-0067-00
VR20	152-0283-00			SEMICOND DEVICE:ZENER,0.4W,43V,5%	04713	1N976B
VR22	152-0255-00	B010100	B029999	SEMICOND DEVICE:ZENER,0.4W,51V,5%	04713	1N978B
VR22	152-0283-00	B030000		SEMICOND DEVICE:ZENER,0.4W,43V,5%	04713	1N976B
VR50	152-0461-00			SEMICOND DEVICE:ZENER,0.4W,6.2V,5%	04713	1N821
VR52	152-0461-00			SEMICOND DEVICE:ZENER,0.4W,6.2V,5%	04713	1N821
VR110	152-0175-00			SEMICOND DEVICE:ZENER,0.4W,5.6V,5%	04713	1N752A
VR126	152-0195-00			SEMICOND DEVICE:ZENER,0.4W,5.1V,5%	81483	69-6512
VR135	152-0195-00			SEMICOND DEVICE:ZENER,0.4W,5.1V,5%	81483	69-6512
VR140	152-0175-00			SEMICOND DEVICE:ZENER,0.4W,5.6V,5%	04713	1N752A