PRELIMINARY

INSTRUCTION MANUAL

TYPE O

This instruction manual is not complete and it may contain errors. We are sending it with your instrument so you will have something to use until the permanent manual is completed. Please put your name and address on the post card and mail it to us. We will send you a permanent manual just as soon as they are ready.

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TYPE O OPERATIONAL AMPLIFIER

Operating Instructions

General Information

The Type O Plug-In Unit is a versatile device; its applications are limited only by the imagination of the user. To realize the full potentialities of the unit, it is important that you 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.

INSTALLING THE PLUG-IN UNIT

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. When one of the 580-Series Oscilloscopes is used, the Type 81 Plug-In Adaptor 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.

OPERATING THE PREAMPLIFIER

The Type O Unit contains a vertical preamplifier which is used in much the same manner as the preamplifier 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) outputs of either of the two 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 preampliifer vertical deflection factor is controlled by the VOLTS/CM controls. Nine calibrated deflection factors from 0.05 to 20 volts per centimeter are provided. The VARIABLE VOLTS/CM 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 screen of the crt the VOLTS/CM controls are adjusted to give a convenient amount of vertical deflection.

External input signals to the vertical 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 you to display the information of interest while blocking the dc component. Ac coupling also permits you to observe ac information at high sensitivities without dc components deflecting the display off the crt.

Dc coupling must be used to look at very low frequency signals (the coupling circuit is 3 db down at approximately 3 cps). Dc coupling must also be used when you desire to measure the dc component of the input signal or to make 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. If you desire to ac couple the output of the operational amplifiers, you can 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 to 1 MEG., the VERTICAL DISPLAY switch to DC+, and the $\pm$GRID SEL switch to (—).

After inserting the plug-in unit in the oscilloscope and switching on the power, wait a few minutes for the instruments 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.

Adjusting the Output DC Level of the Operational Amplifiers

With no input signal to the operational amplifiers, the output dc level of the amplifiers should be zero volts. To insure that this condition exists, 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 volts.

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 vertical preamplifier. To do this, set the VOLTS/CM control to .5 and press the ZERO CHECK switch. (The ZERO CHECK switch disconnects all signals to the vertical preamplifier and permits the dc level of the preamplifier only to be displayed on the oscilloscope.) Then use the POSITION control to position the trace to a convenient horizontal graticule line. The zero input dc level of the vertical preamplifier then corresponds to this graticule line.

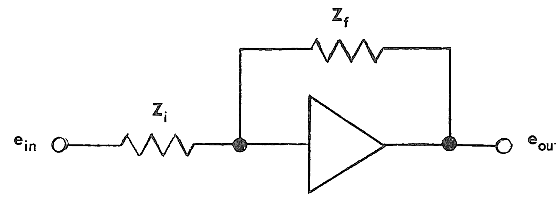
When the zero input level line of the vertical preamplifier has been determined, set the VERTICAL DISPLAY switch to A+. This connects the output of the A operational amplifier to the input of the vertical preamplifier. Place the OUTPUT DC LEVEL switch in the ADJ. position and hold it there. Set the ADJ. control to position the trace on the oscilloscope screen 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 held in the ADJ. position, the external circuit is disconnected 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, that you recognize any large amount of drift and noise as being 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.

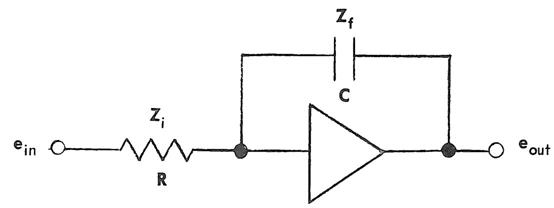
Feedback Controls

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 determines the gain of the feedback amplifier. In integration the feedback impedance is a capacitor while the input impedance is a resistor. In differentation the feedback impedance is a resistor while the input impedance is a capacitor. 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.

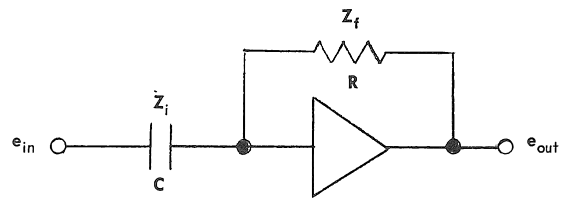
The front-panel controls labeled Z_i and Z_f select the input and feedback impedances from several possible internal values. External positions for these controls also permit connection of desired external values to the jacks on the front panel of the unit. Paralleling internal components with external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



(a) Amplification by a constant with polarity inversion.



(b) Integration.



(c) Differentiation

Fig. 2-1. Three basic uses of an Operational Amplifier

OPERATIONAL AMPLIFIER GAIN

The gain of an operational amplifier can be controlled by selecting the feedback and input resistances. This portion of the Operating Instructions is included to give you some experience in operating the unit as well as a demonstration of how the method works. The Amplitude Calibrator of the oscilloscope provides a convenient signal source which will be used in the following setups.

The gain of the operational amplifier with feedback is the ratio of the feedback resistance to the input resistance: Gain $= -R_f/R_i$. This ratio is selected by means of the Z_i and Z_f controls or by externally mounted components.

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. Therefore, when using the internal input and feedback resistors to control the gain, there will always be a small error from the gain ratio.

Error Factor

A general expression for the gain of a feedback (operational) amplifier with less than infinite gain is:

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

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 ($-\frac{Z_f}{Z_i}$) is the same as the gain ratio ($-\frac{R_f}{R_i}$ for resistive components), the remainder of the formula is the Error Factor.

An example of the need for gain correction due to the Error Factor is: if R_i is set at .01 MEG. and R_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 R_i set at .01 MEG, and R_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 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. R_i resistor when the Z_f control chooses an R_f resistor that will give a gain error over 1%.

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

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. Adjust the A operational amplifier to give a gain of —1 by setting both the Z_i and Z_f controls to 1 MEG.
4. Now set the VOLTS/CM switch to .5.

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 controls are both set on the same value of resistance, a gain of —1 is obtained.

Next set the VOLTS/CM control 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 to 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:

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

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

A good starting point to chose is 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 control can then be set to permit the display to be viewed. If necessary, the RC time can be changed to permit a better display. (Normally, the smaller values of capacitance will produce better results.)

Sample Differentiation Setup

1. As an example of differentiation, connect the output of the calibrator to the A INPUT connector and adjust the calibrator output for 1 volt.
2. Use the Z_i control to select an input capacitance of 10 pf and the Z_f control to select a feedback resistance of 0.1 MEG. These values produce an RC time of 1 μsec.
3. Set the VOLTS/CM control to .5 and the TIME/CM control of the oscilloscope to 1 μSEC.

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

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

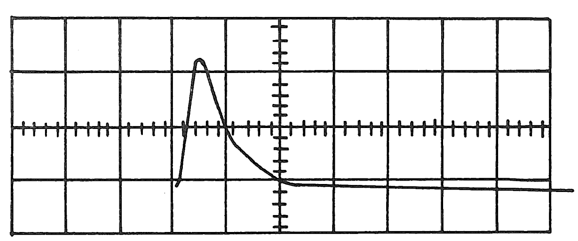


Fig. 2-2. Differentiated calibrator waveform; 1 μsec/cm sweep.

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 of the operational amplifier is given approximately by:

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

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 output of the oscilloscope calibrator to the A INPUT connector. 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 VOLTS/CM switch to .2 and the TIME/CM switch to .5 mSEC.
4. Position the display on the screen.

The display should be an integrated calibrator signal, such as shown in Fig. 2-3.

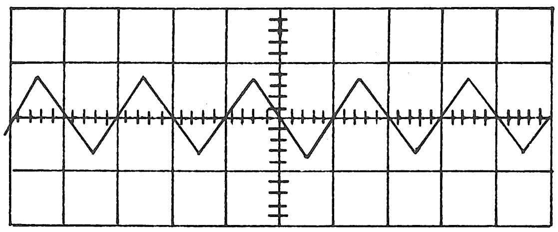


Fig. 2-3. Integrated calibrator waveform; 0.5 msec/cm sweep.

The time constant of the values chosen is 1 millisecond, the period of the 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 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 pickup from integration in the medium to high frequency range.

OPERATIONAL AMPLIFIER GAIN-BANDWIDTH LIMITS

As mentioned 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 megacycles.

It is also important to know the gain-bandwidth characteristics of the operational amplifiers for both integration and differentiation. Chart 2-1 illustrates the gain-bandwidth limitations 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.

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 due to stray electric or magnetic coupling between circuits, particularly in the input signal leads to the preamplifier. In general, unshielded leads of appreciable length are unsuited to 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 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. For example, the equipment should work into a normal load.

Consider the effect of loading upon the signal source due to the input circuit of the preamplifier. The input circuit of the O Unit 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, you may want to use a probe to lessen their effect.

USE OF PROBES WITH THE O UNIT

Standard Tektronix probes can be used with the preamplifier in the O Unit. When used, the probes must be connected to the EXT. INPUT connector which has an input impedance of 1 megohm paralleled by 47 pf. Probes cannot normally be used with the operational amplifiers because of their variable input characteristics.

When probes with 10× or more attenuation are used, they must first be properly compensated for high frequency attenuation. 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 screen of 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.

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

CONNECTION OF SIGNALS TO THE + GRID

The ± GRID jack on the front of each operational amplifier can be used to connect input signals to either of the input grids of the operational amplifiers. Signals connected to the — grid are inverted at the output of the amplifier. Signals applied to the + grid have the same polarity at the output. This is in agreement with standard operational amplifier uses.

Selection of either the + or — grid is made with the ± GRID SEL switch. When the ± GRID SEL switch is in the (+) position, signals may be applied simultaneously to both the + and — grids. In such an application, the signal to the — grid is connected to the — GRID jack and the signal to the + grid is connected to the + GRID jack. With the proper circuit, the operational amplifier can be used as a differential amplifier. Input signals applied to the — grid through either the — GRID or ± GRID jacks bypass the internal input impedances and are therefore not affected by settings of the Z_i control.

Access to the + grid increases the versatility of the 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.

CONNECTING EXTERNAL FEEDBACK COMPONENTS

It will occasionally be necessary for you to mount external feedback components on the O Unit. This is necessary because of the limited number of components which may be mounted internally. Perhaps the most convenient means of mounting these parts is through the use of adaptor boards and shields. The parts can easily be installed on the adaptor boards 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 adaptor 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-MB.

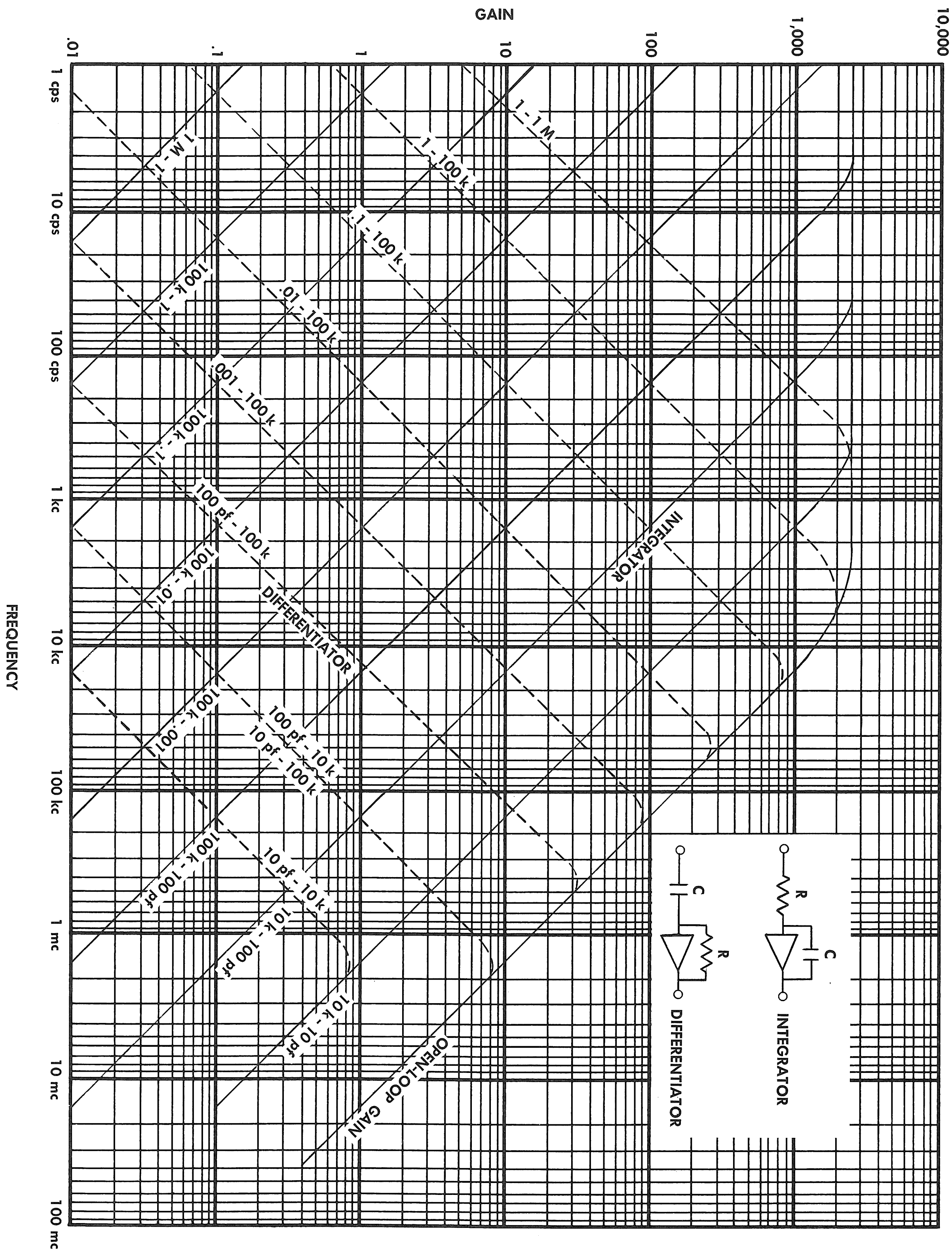
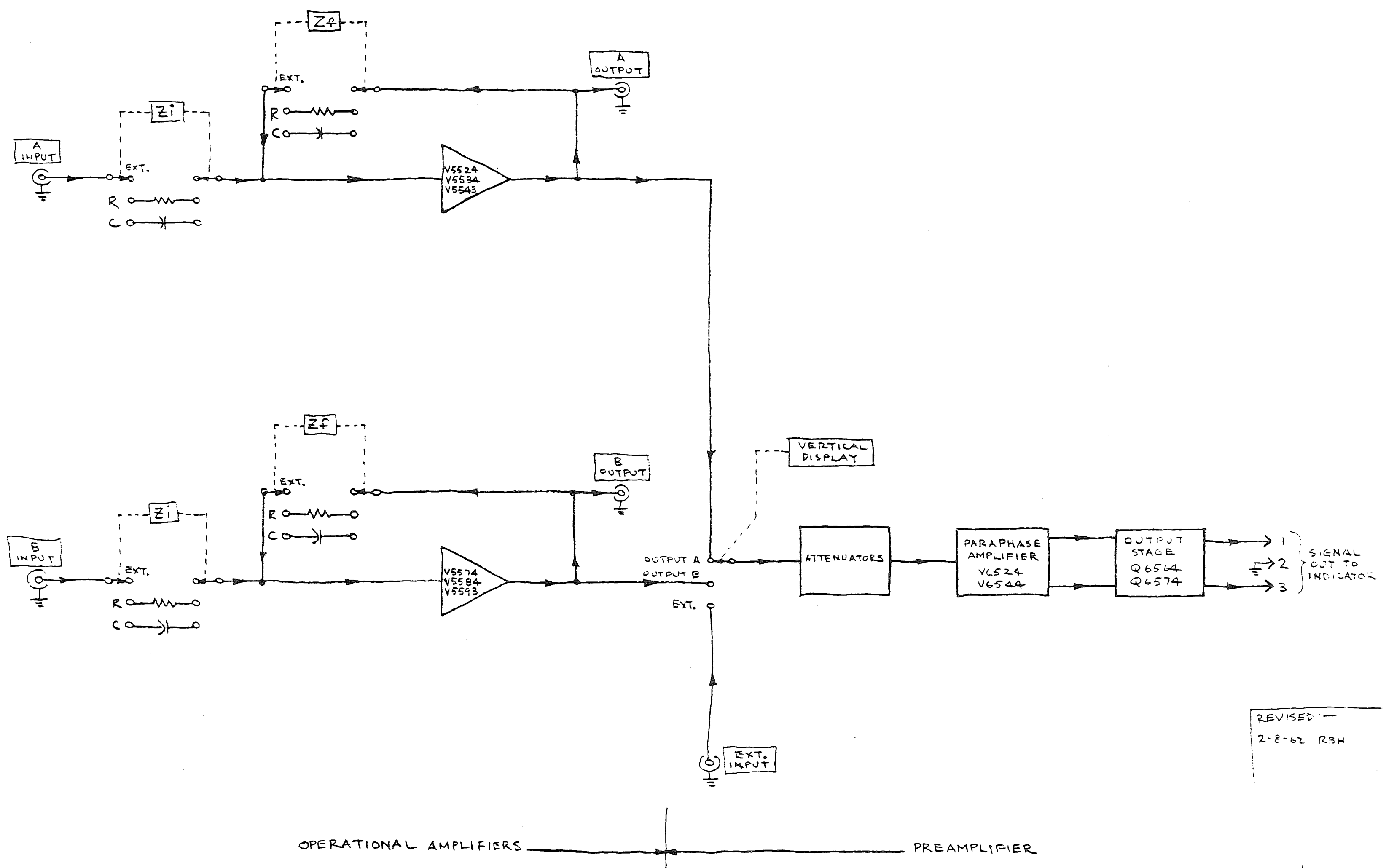


CHART 2-1

Average Gain-Bandwidth limits for Type O Unit Operational Amplifiers for both Integration and Differentiation.



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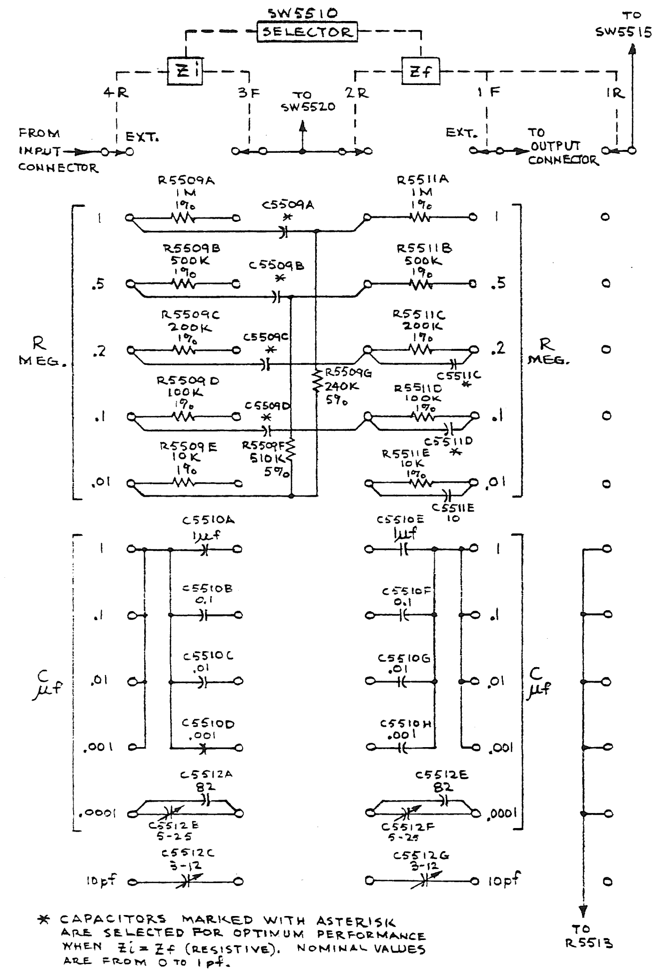
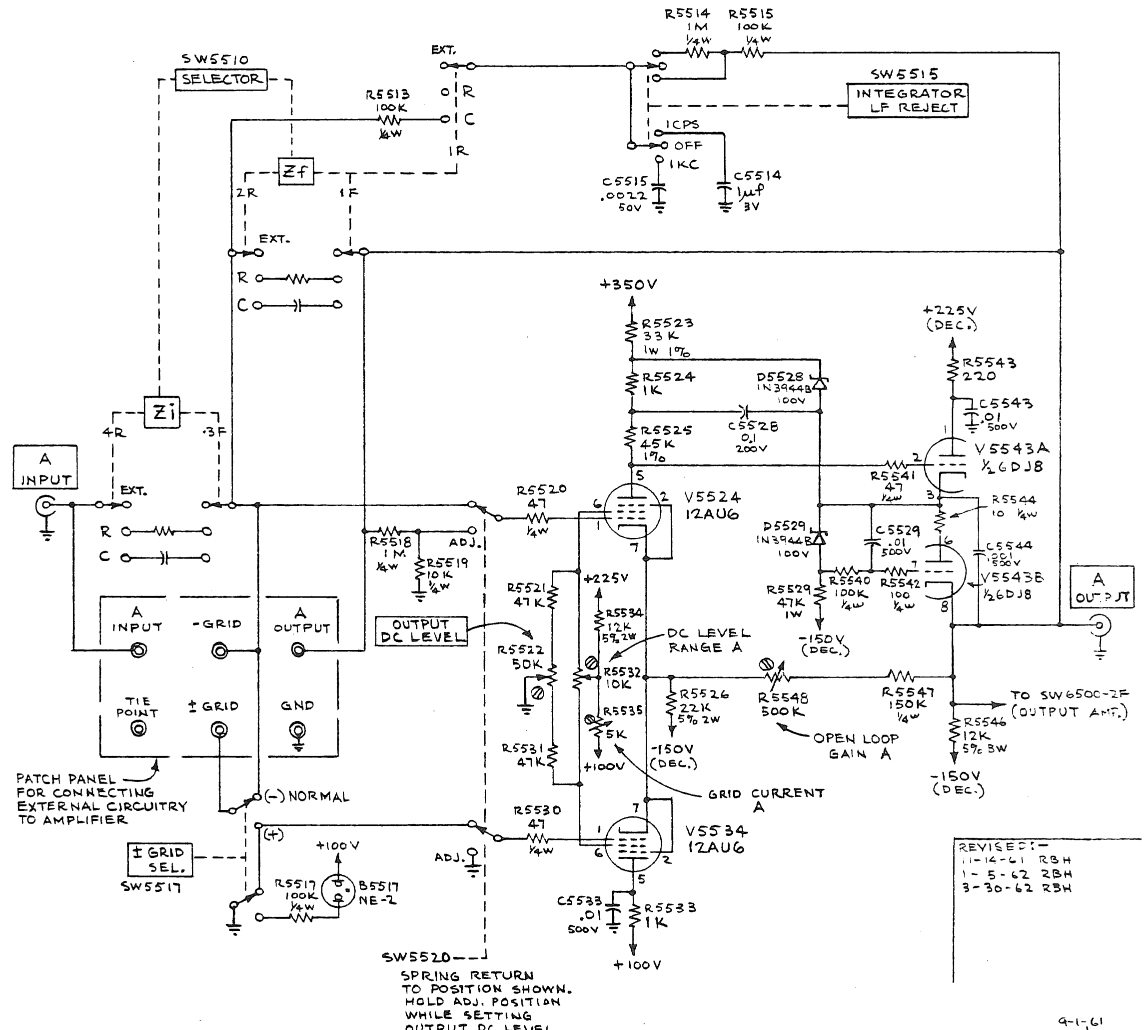
TYPE O PLUG-IN UNIT

BLOCK DIAGRAM



DETAILS OF Zi - Zf SELECTOR SWITCH



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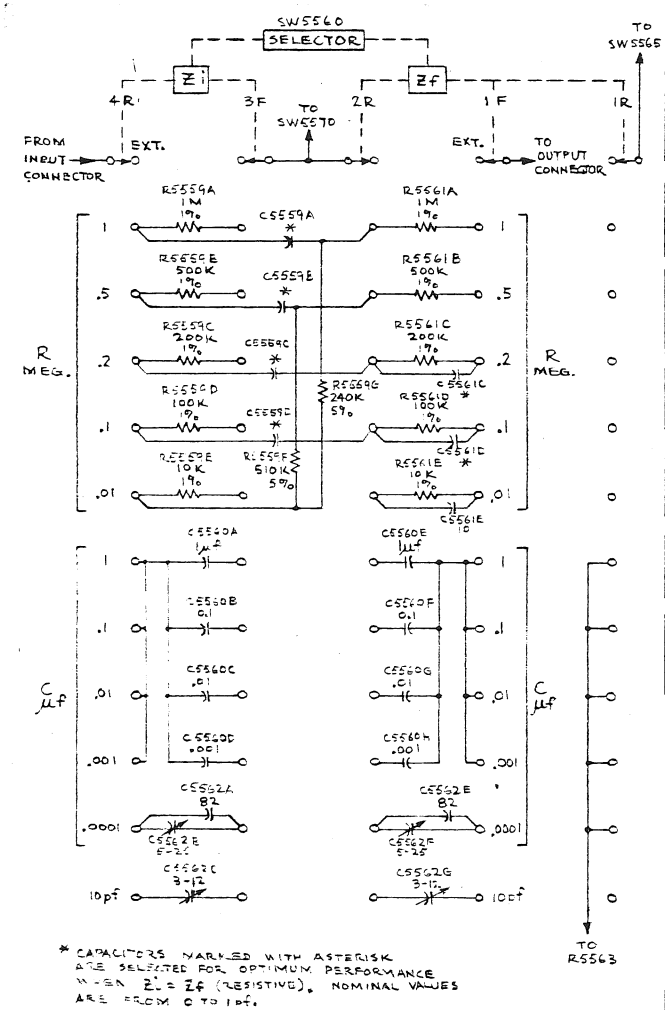
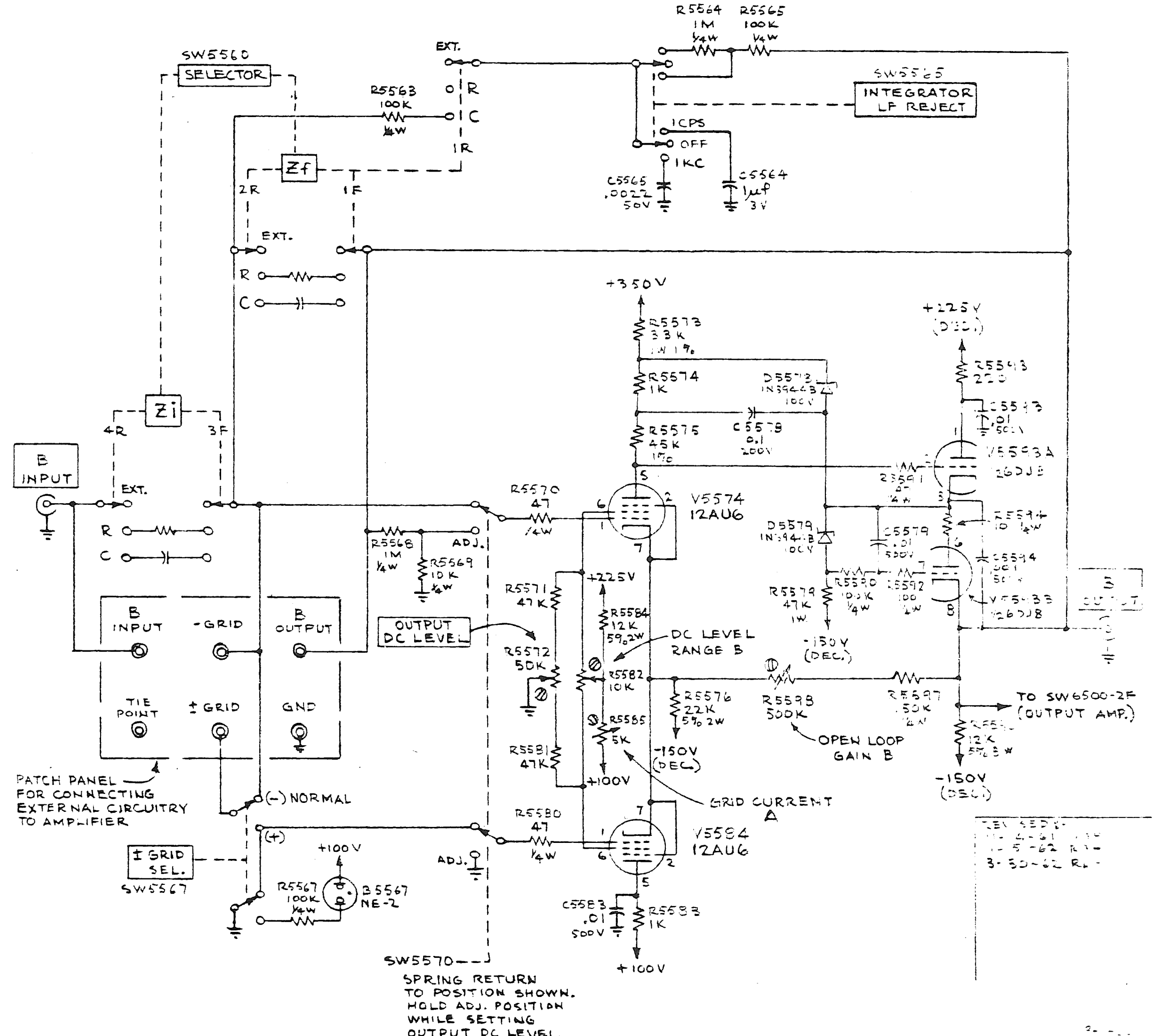
CHANNEL A OPERATIONAL AMPLIFIER

TYPE O PLUG-IN UNIT

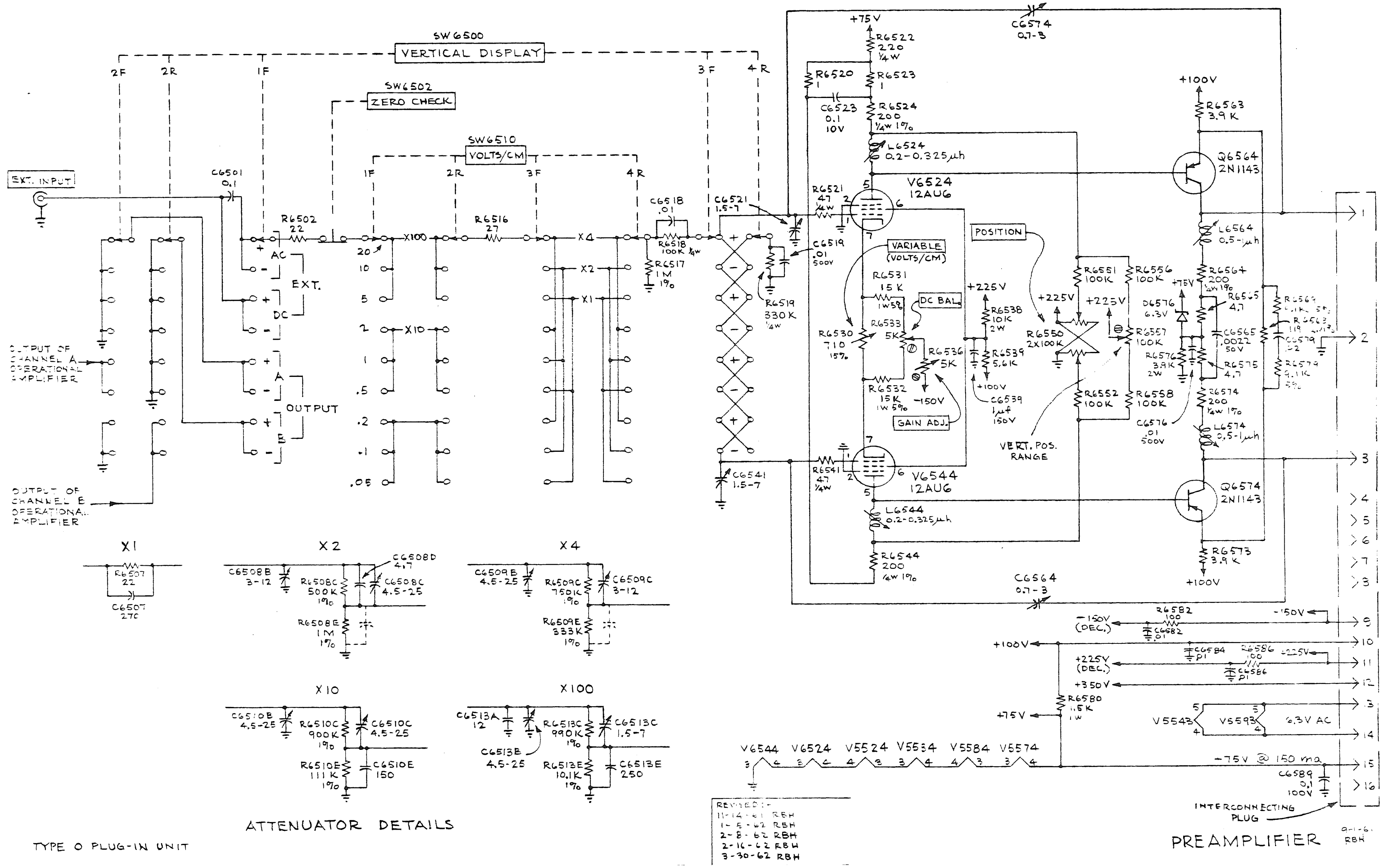


DETAILS OF Zi - Zf SELECTOR SWITCH



TYPE O PLUG-IN UNIT

CHANNEL 3
OPERATIONAL AMPLIFIER



ATTENUATOR DETAILS

PREAMPLIFIER

TYPE O PLUG-IN UNIT