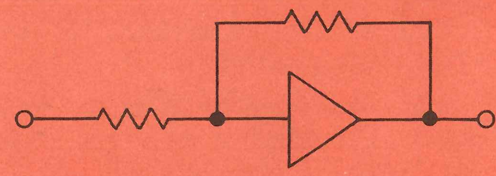
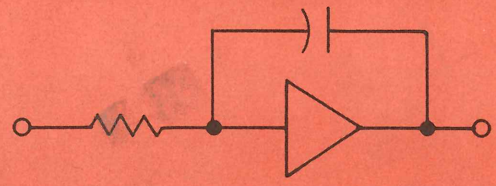
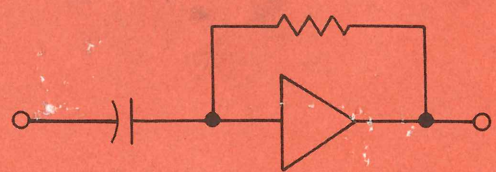
# TYPE O

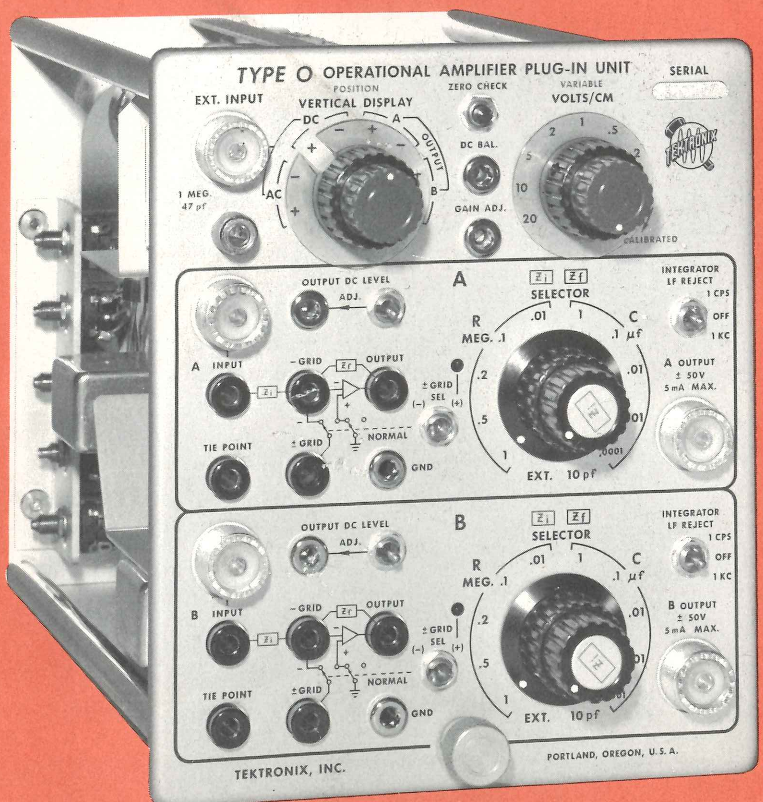
# OPERATIONAL AMPLIFIER

# PLUG-IN UNIT










## WHAT THE TYPE O WILL DO

The Tektronix Type O Operational Amplifier performs precise operations of integration, differentiation, function generation, and linear or nonlinear amplification. As the operation is performed, the results can be displayed by the oscilloscope in which the Type O is used or can be fed to other circuitry.

The Type O can be used with any Tektronix Type 530, 540, 550, or (with a Type 81 Adapter Unit) 580-Series Oscilloscope. In addition, through use of the Type 127, 132, or 133 Plug-In Power Supplies, the Type O can also be used for other purposes.

AMPLIFICATION

INTEGRATION

DIFFERENTIATION

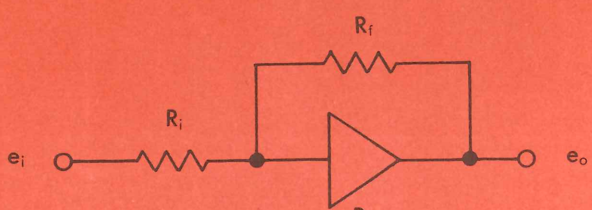
# BASIC CHARACTERISTICS AND OPERATIONS

The Type O contains two separate but identical operational amplifiers plus a vertical preamplifier. The vertical preamplifier monitors the output of either operational amplifier or can be used as an independent oscilloscope preamplifier.

Each operational amplifier is a high-gain inverting amplifier with selectable input and feedback impedances. The types of input and feedback impedances and their ratios determine the gain and type of operation.

Normally, resistors and capacitors are used as input and feedback impedances. Front-panel switches on the Type O allow selection from a wide range of internal precision resistors and capacitors. Provision is made for use of external input and feedback impedances. External components can be used independently or in combination with the internal resistor-capacitor combinations.

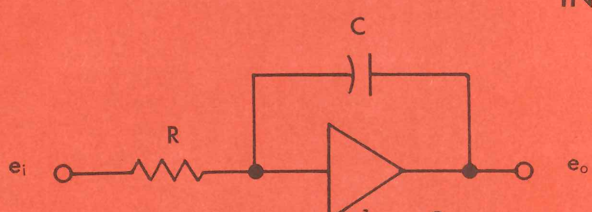
## AMPLIFICATION




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

Amplification of a signal is obtained by using resistors for the input and feedback impedances. Due to the high open-loop gain of the amplifier, the closed-loop gain is determined by the ratio of $R_f$ to $R_i$. In the Type O, various $R_i$ and $R_f$ values are selectable by front-panel switches. This provides convenient signal step-up or step-down operation, with low output impedances, to over 750 kc (Gain-Bandwidth product). Use of external high-frequency compensation extends the closed-loop gain-bandwidth product to 10 mc, or more.

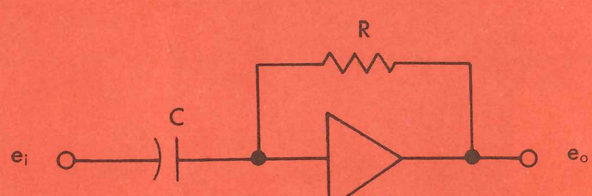
## INTEGRATION




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

Precise integration is obtained by placing a capacitor in the feedback loop. The integrating capacitors and resistors are selectable by front-panel switches. Typical applications include magnetic core B-H loop studies and finding the area under pulse waveforms.

## DIFFERENTIATION




$$e_o = -RC\frac{de_i}{dt}$$

Differentiation is accomplished by placing a capacitor in the input circuit. Capacitors of various values are selectable by front-panel switches. The unique characteristic of differentiation is its ability to extract higher-frequency waveform components. It can advantageously detect minute information such as noise, transients and slope changes.

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

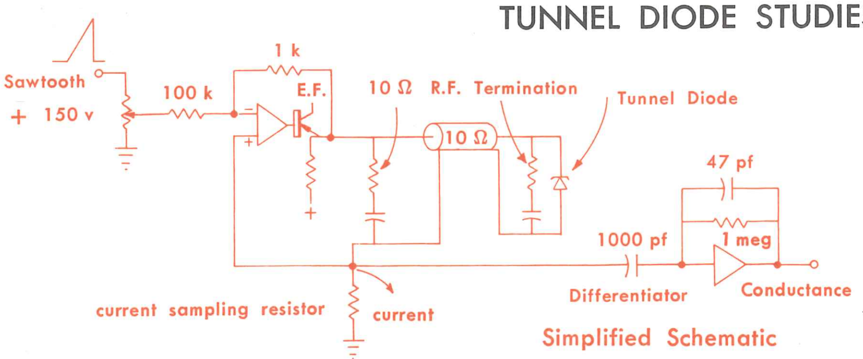
# A COMPLETELY FUNCTIONAL OPERATIONAL AMPLIFIER

## TYPICAL OPERATIONS AND APPLICATIONS *

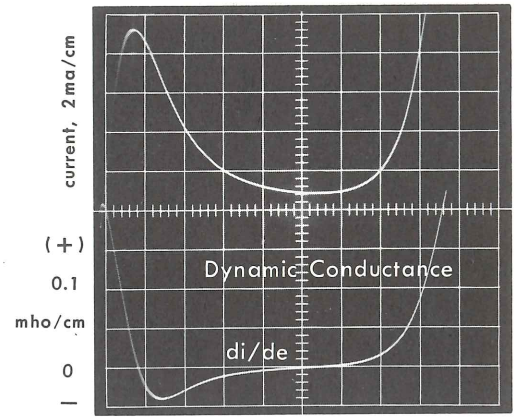
With the Type O, you can display the output of either operational amplifier—display both outputs simultaneously, using a dual-beam oscilloscope—feed the output of one of the operational amplifiers to the input of the other and display the resultant output—apply the output of either, or both, amplifiers to an external circuit.

Because of this versatility, many combinations of the basic modes of operation are possible. This permits use of the Type O in a wide variety of applications such as:

### TUNNEL DIODE STUDIES



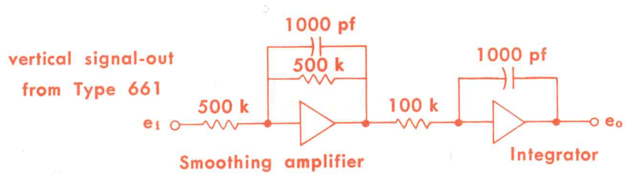

Simplified Schematic

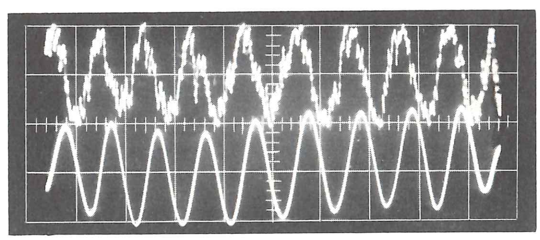



Voltage, 50 mv/cm

The Type O, with associated circuitry, can drive a tunnel diode with very low impedance. The diode is stabilized at high-frequencies by an R.F.-terminated jig, and thus may be driven by a very slow ramp-voltage. Linear drive of the tunnel diode allows differentiation of the current and obtainment of di/de curve.

### INTEGRATION OF SAMPLED DATA

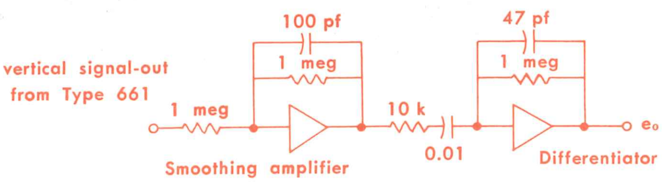


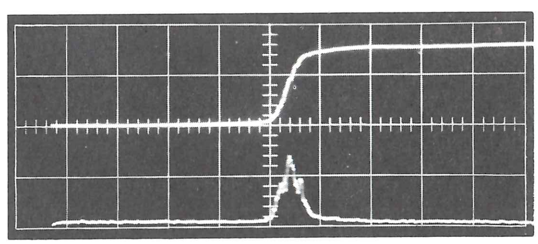



Sampling Sweep, 1 nsec/cm

It is possible to integrate repetitive signals to approximately 1 gigacycle using the vertical signal-out from a sampling oscilloscope such as the Tektronix Type 661. Sampled data contains many high-frequency components as well as the desired lower-frequency signals. In some operations it may be necessary to insert a smoothing amplifier before performing linear operations.

### DIFFERENTIATION OF SAMPLED DATA



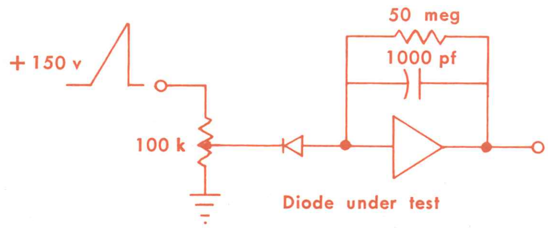
Sampling Sweep, 1 nsec/cm

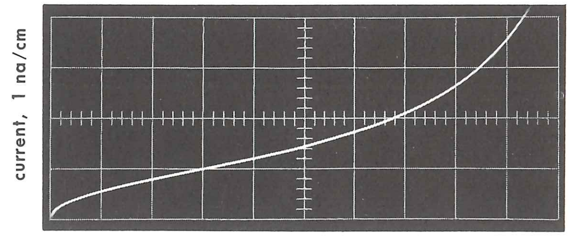
Differentiation of sampled signals can be performed after passing the sampled signal through a smoothing amplifier. An additional high-frequency limiting circuit is necessary in differentiation. It is possible to differentiate signals with nanosecond risetimes.

* Note: All multiple-trace photographs are double exposures.

# TYPICAL APPLICATIONS

## VERY LOW CURRENT MEASUREMENTS

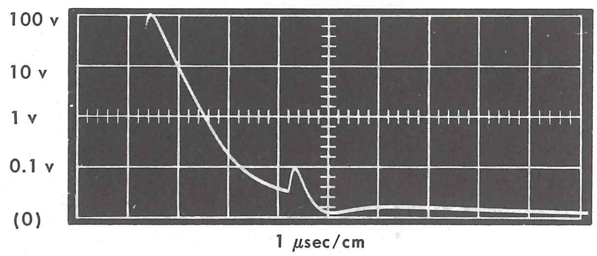


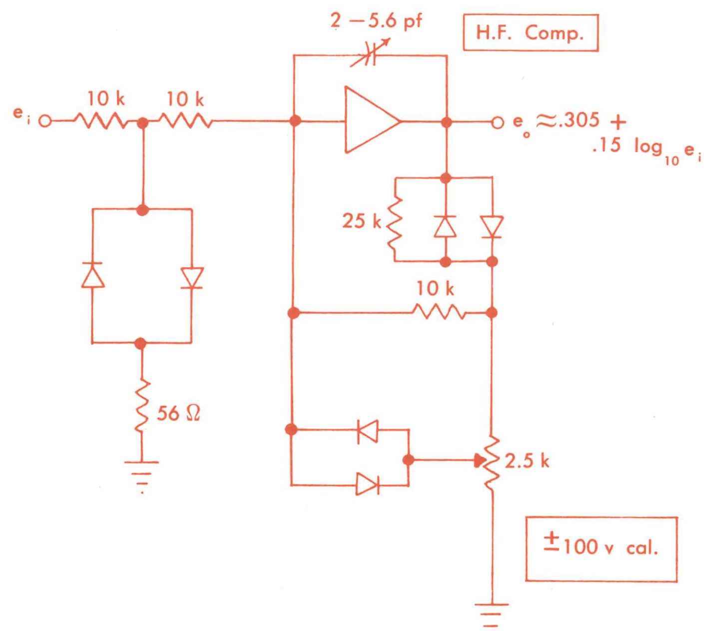




Reverse Voltage, 10 v/cm

Diode reverse-leakage current can be continuously plotted on the crt, using the oscilloscope sweep-sawtooth. Currents in the nanoampere region are easily displayed and measured.

## LOGARITHMIC AMPLIFICATION



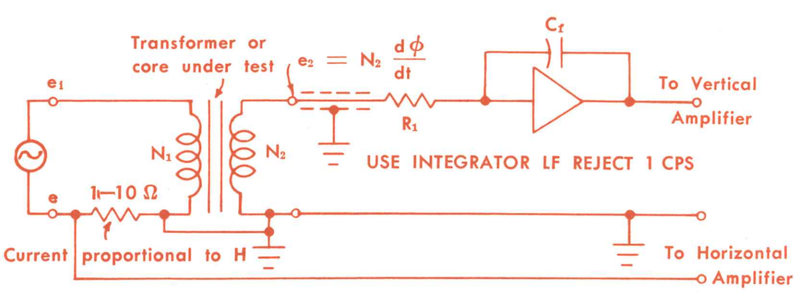



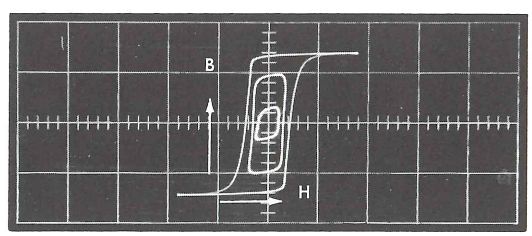

An advantage of a logarithmic amplifier is its ability to accept a wide range of signal levels without being overdriven.

Used as a logarithmic amplifier, the Type O allows the display and measurement of high-amplitude signals mixed with low-amplitude signals. An example of this type of composite signal is the waveforms resulting from an explosion or similar type shock.

Set up as shown in the diagram, the Type O accepts signals varying in amplitude from 0 to ± 100 volts. Many other nonlinear amplifier configurations are possible including square root, power function, symmetrical, etc.

## DISPLAYING B-H LOOP FOR MAGNETIC MATERIALS



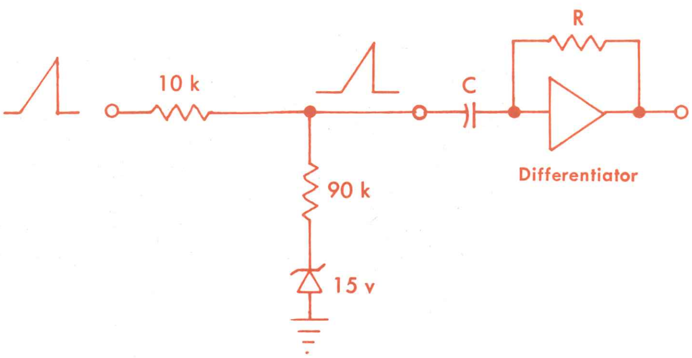

Three Levels of Supply Voltage to an Inductor

To study the magnetic properties of core materials, a B-H loop display is often employed. The Type O Unit can be used as an integrator to integrate the secondary voltage of a transformer to obtain a voltage proportional to flux $\phi$, or flux density, "B".

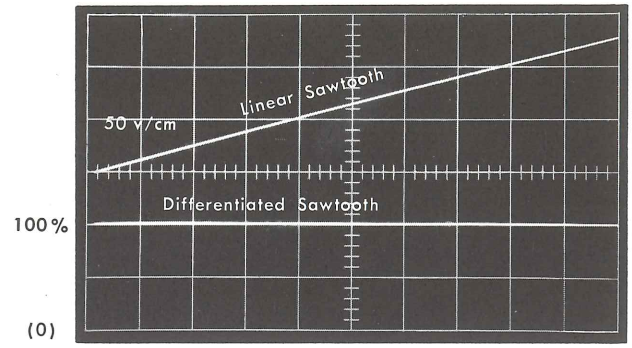
Since the primary current is proportional to the magnetizing force "H", when the voltage across the current-sampling resistor is applied to the Horizontal Input, B-H loops can be displayed.

Various magnetic characteristics can be studied such as core saturation current, residual magnetism, dc offset bias, or shorted turn in winding.

## ANALYSIS OF LINEARITY

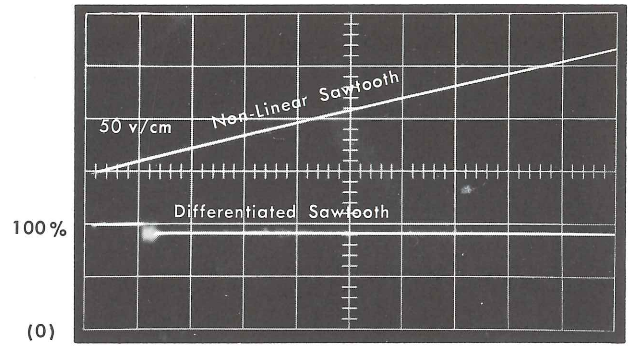



Simulated Non-linearity




.2 v/cm

Linear Sweep 1 msec/cm




Differentiated Waveform Showing 10% Non-Linearity (also detects Zener noise)

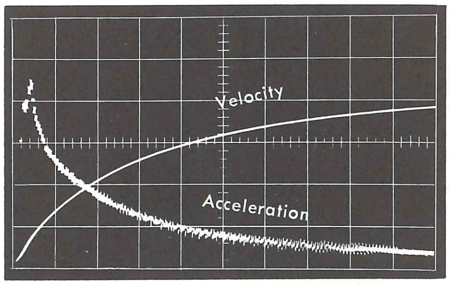
With the O Unit, you can detect and measure non-linearity of motion. Transducer output from the source being measured, in the form of a ramp (sawtooth) waveform, is differentiated and then displayed on the associated oscilloscope.

Measurements of non-linearity can be accurately made. Typical applications are measurements of acceleration, rotation, linearity of amplifiers, or circuits.

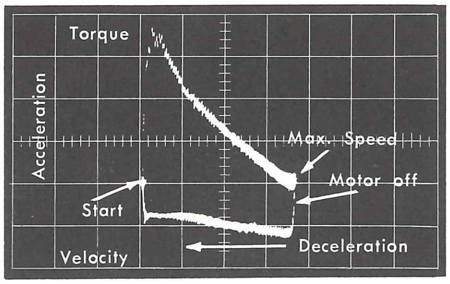
In the example shown, a non-linear sawtooth with a 10% change of slope was generated to simulate non-linear motion.

The degree of non-linearity can be read directly from the oscilloscope display.

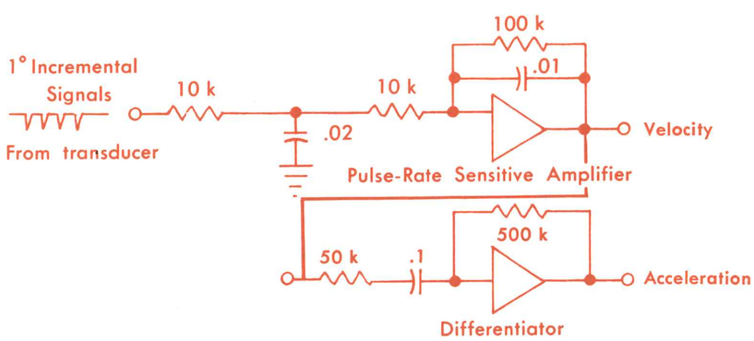
## ROTATIONAL ANALYSIS




Velocity (1 cm equivalent to 200 rad/sec)
Acceleration (1 cm equivalent to 2000 rad/sec$^2$)




Velocity (1 cm equivalent to 200 rad/sec)
Acceleration (1 cm equivalent to 2000 rad/sec$^2$)



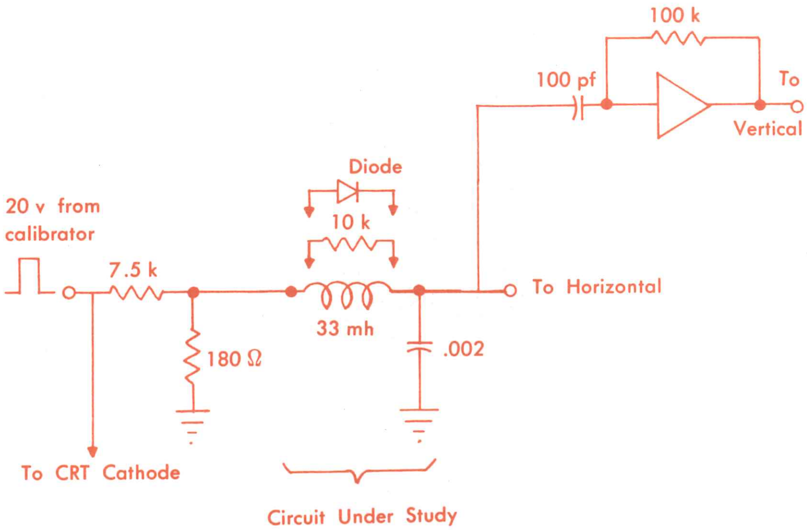

The Type O can be used to great advantage in the analysis of velocity, acceleration, speed, and torque of rotating machinery such as electric motors.

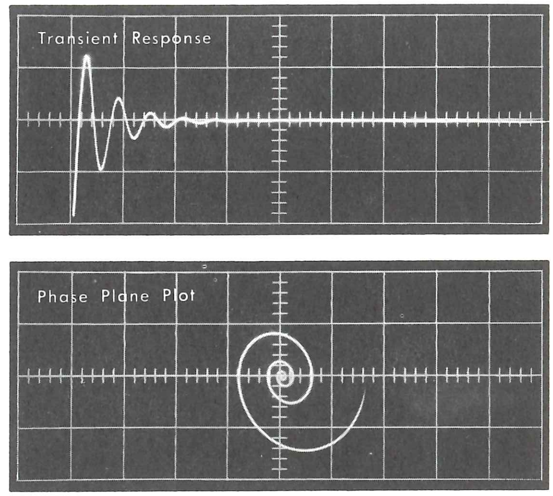
In the example shown, the Type O, used as a pulse-rate sensitive amplifier, converts 1° incremental signals from a transducer to angular velocity. It then differentiates the velocity waveform to obtain the acceleration.

The speed-torque plot is obtained by an X-Y display of the velocity and acceleration waveforms.

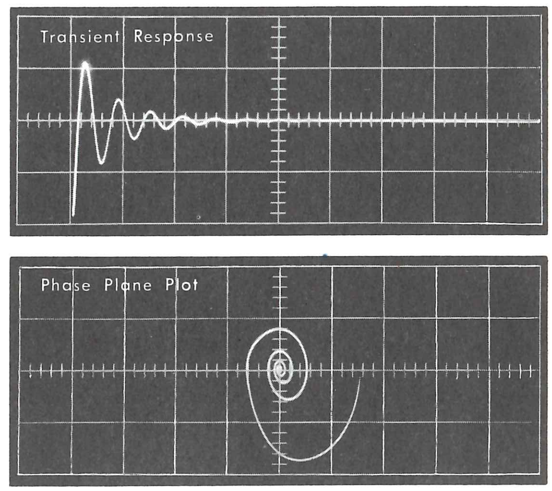
# TYPICAL APPLICATIONS

## PHASE PLANE PLOT



10 k Damping



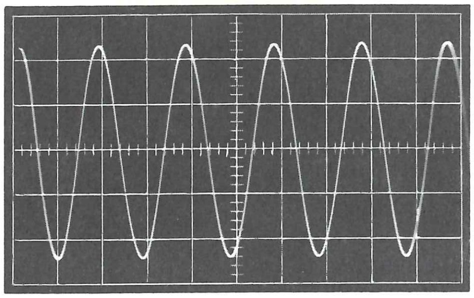
Diode Damping

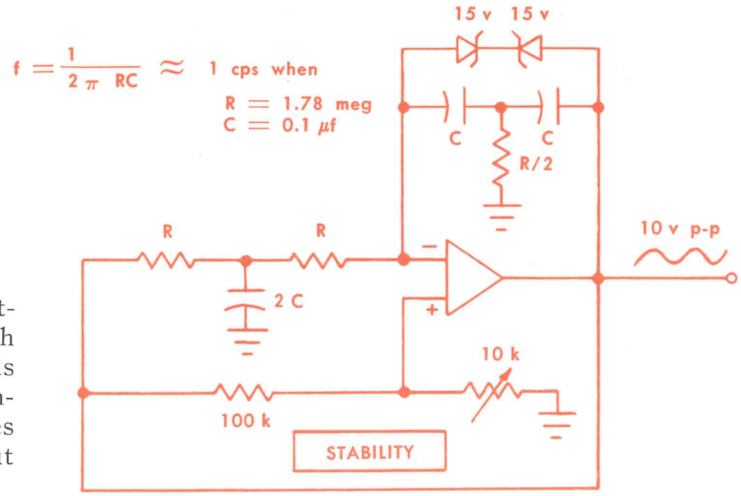
In studying system stability of control systems or feedback systems, transient response is often employed. If a non-linear element is involved in a system, stability criteria usually becomes quite complex, and analysis is normally limited to linear approximations.

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

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

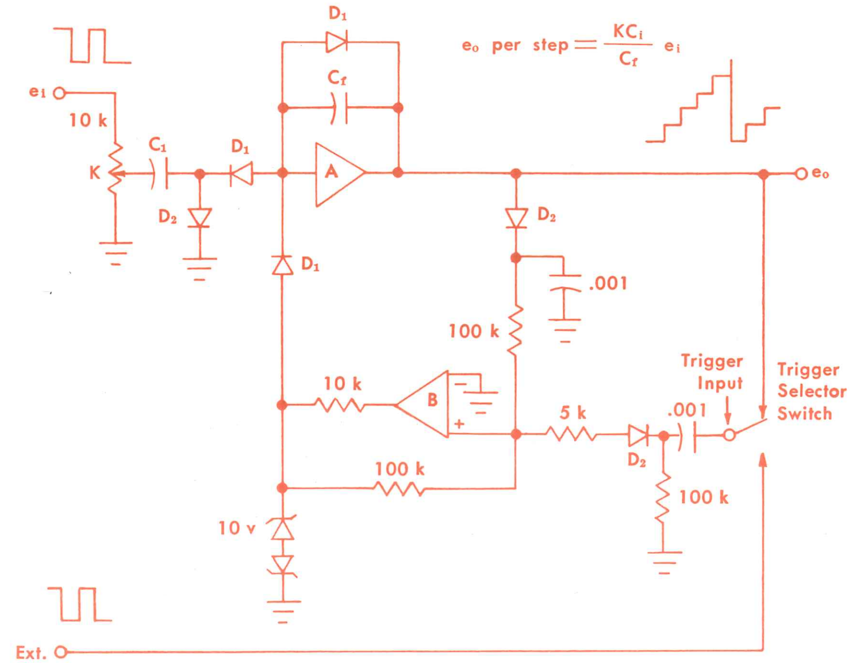
## LOW-FREQUENCY SINE-WAVE GENERATOR


Low frequency Sine-wave

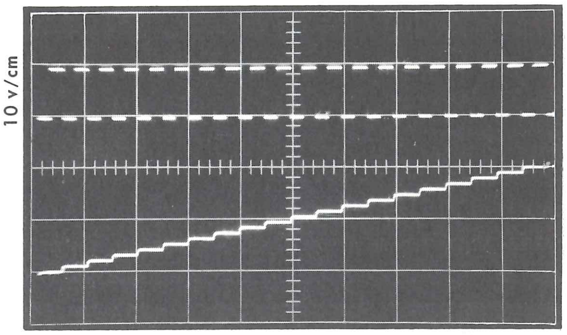



This circuit is a parallel-T oscillator. The output of the oscillator is a stable sine wave with very low harmonic content. Output voltage is approximately 10 volts, peak-to-peak. The non-linear resistance of the back-to-back Zener diodes in the negative feedback loop controls the output amplitude and maintains good stability.

## STAIR-STEP GENERATOR




$D_1$ = very low leakage silicon diodes
$D_2$ = Any signal diodes

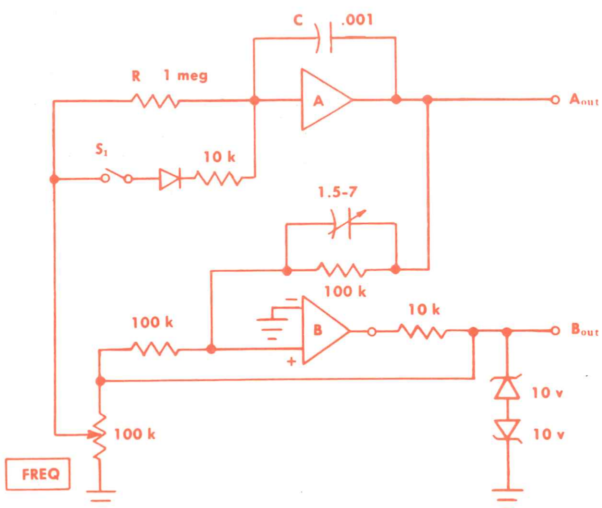



STAIR-STEP Generator 5 v/cm   Sweep 2 msec/cm

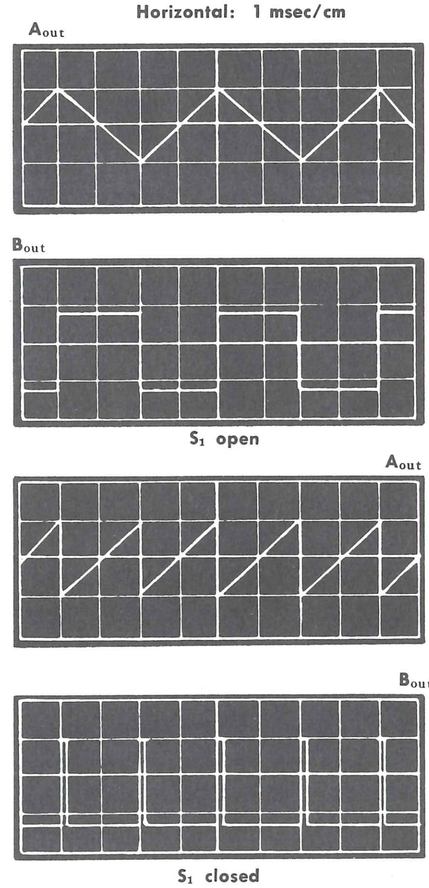
This arrangement provides a convenient laboratory stair-step generator useful in applications such as pulse rate count down, transistor base drive, or pulse controlled time base.

Amplifier A operates as a pulse integrator and amplifier B functions as a bistable comparator. Through use of the trigger selector switch, the circuit can operate in either a repetitive or triggered mode.

## SQUARE, TRIANGLE, SAWTOOTH AND PULSE GENERATOR




**Waveforms**
**Vertical: 10 v/cm**
**Horizontal: 1 msec/cm**




This 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.

The frequency of the output is determined by the value of R and C, and the setting of the FREQ. control. Frequency range of from 0.01 cps up to 50 kc is possible through selection of Freq. Multiplier capacitors without seriously distorting waveforms.

The output waveforms are modified by closing switch $S_1$. This 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.

# TYPE O OPERATIONAL AMPLIFIER

## CHARACTERISTICS

### TWO OPERATIONAL AMPLIFIERS

Both amplifiers have identical characteristics, and separate, but identical facilities for controlling the various operations.

**OPEN-LOOP GAIN-BANDWIDTH PRODUCT**—15 mc, or greater.

**CLOSED-LOOP GAIN-BANDWIDTH PRODUCT**—To 750 kc, with internal input and feedback resistors. To 10 mc, with external compensation.

**OPEN-LOOP DC GAIN**—2500, minimum. With external input and feedback components, the system gain is governed by the ratio of feedback to input values.

$$\text{Type O System Gain} = \frac{Z_f}{Z_i + \frac{Z_i + Z_f}{2500}}$$

**OUTPUT RANGE**— ± 50 v, ± 5 ma.

**OUTPUT DC LEVEL**—Adjustable to ground potential by a front-panel control.

**OUTPUT IMPEDANCE**—Approximately 30 Ω at 1 mc for compensated, unity-gain amplifier.

**NOISE**—Less than 0.5 mv, peak-to-peak, referred to input. Approximately 3 mv, peak-to-peak, output noise.

**SELECTABLE FEEDBACK IMPEDANCES**—A front-panel switch allows selection of the following resistors and capacitors: 0.01, 0.1, 0.2, 0.5, and 1 megohm; 10 pf, 100 pf, 0.001, 0.01, 0.1, and 1 μfd. All values are ±1%, except the 10 pf and 100 pf, which are adjustable.

**SELECTABLE INPUT IMPEDANCES**—A front-panel switch allows selection from a set of resistors and capacitors within the same range of values as the feedback impedances. Where $\frac{R_f}{R_i}$ is 50 or more, $R_i$ is automatically shunted with gain-correcting resistor to preserve gain accuracy.

**FEEDBACK**—Facilities provide for either positive or negative feedback.

**CROSSTALK**—Voltage rejection (with 1 kc square wave) is at least 300:1 from one operational amplifier to the other.

**DRIFT**—Typically less than 10 mv/hour referred to input (after warm-up).

**LOW-FREQUENCY REJECTION**—For integration of repetitive signals, a low-frequency rejection circuit prevents undesired integration of dc components, and also prevents dc drift from forcing the oscilloscope trace off the crt. It is possible to reject line-frequency pick-up and other low-frequency noise. A front-panel control permits rejection at either 1 cps or 1 kc (approx). The rejection circuit can be switched in or out as desired.

### VERTICAL PREAMPLIFIER

(Frequency specifications are at 3 db down)

**PASSBAND AND RISETIME**—DC to 25 mc, 14 nsec, in Tektronix Type 540A-Series Oscilloscopes. DC to 14 mc, 25 nsec, in Tektronix Type 530A-Series Oscilloscopes.

**CALIBRATED SENSITIVITY**—0.05 v/cm to 20 v/cm in nine steps. 1-2-5 sequence. Accuracy is within 3% of panel-reading on all ranges after adjustment on any one range. Variable (uncalibrated) between steps and to 50 v/cm.

**INPUT IMPEDANCE**—1 megohm paralleled by 47 pf.

**SWITCHING FACILITIES**—Permit the vertical preamplifier to be used as an independent oscilloscope preampifier or in conjunction with the operational amplifiers.

TYPE O UNIT — U. S. Sales Price, f.o.b. Beaverton, Oregon — $475

**For a demonstration—
please call your Tektronix Field Engineer.**

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