TEKTRONIX

Service Scope

USEFUL INFORMATION FOR USERS OF TEKTRONIX INSTRUMENTS

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INTRODUCTION TO OPERATIONAL AMPLIFIERS

Prepared by
Tektronix Field Information Department

Part 1.

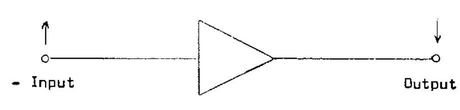
Functionally speaking, an operational amplifier is a device which, by means of negative feedback, is capable of processing a signal with a high degree of accuracy limited primarily only by the tolerances in the values of the passive elements used in the input and feedback networks.

Electronically, an operational amplifier is simply a high-gain amplifier designed to remain stable with large amounts of negative feedback from output to input.

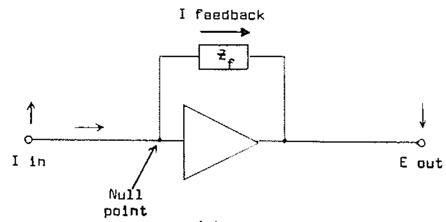
General-purpose operational amplifiers, useful for linear amplifications with precise values of gain, and for accurate integration and differentiation operations, have low output impedance and are DC-coupled, with the output DC level at ground potential.

The primary functions of the operational amplifier are achieved by means of negative feedback from the output to the input. This requires that the output be inverted (180° out of phase) with respect to the input. The conventional symbol for the operational amplifier is the triangle shown in Figure 1-a. The output is the apex of the triangle; the input is the side opposite the output. Negative feedback, through a resistor, capacitor, inductor, network or nonlinear impedance, designated "Z_f" is applied from the output to the input as shown in Figure 1-b. The input to which negative feedback is applied is generally termed "-input"* or "grid" (in the case of vacuum-tube operational amplifiers).

* The operational amplifiers of the Tektronix Type O Operational Amplifier also provide access to a non-inverting input. Uses of this "+input" or "+grid" are discussed later.



(a)



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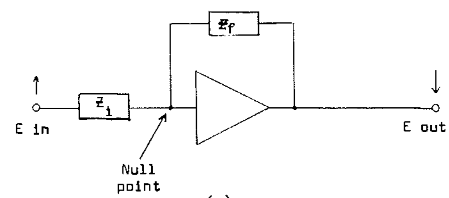


(c)

Figure 1. Conventional 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 negaative 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.

Operational Amplifier Seeks Voltage Null at —Input

An operational amplifier, using negative feedback, functions in the manner of a self-balancing bridge, providing through the feedback element whatever current is necessary to hold the —input at null (ground potential). See Figure 1-b. The output signal is a function of this current and the impedance of the feedback element.

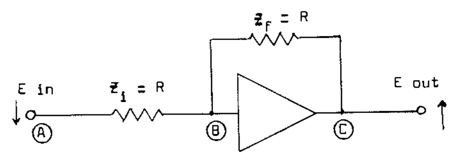
The —input, held to ground potential by the feedback current, appears as a very low impedance to any signal source. Using resistive feedback, for instance, the input appears to be the resistance of the feedback element, divided by the open-circuit gain of the operational amplifier.

If current is applied to the —input, it would tend to develop voltage across the impedance of feedback element, and move the —input away from ground potential. The output, however, swings in the opposite direction, providing current to balance the input current and hold the —input at ground. If the impedance of the feedback element is high, the output voltage must become quite high to provide enough current to balance even a small input current.

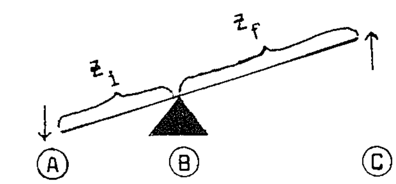
Input Element Z_i Converts Input Signal to Current

Since we more often have to deal with voltage rather than current signals, an additional element is used in most operational amplifier applications, designated "Z_i" (input impedance). This is an impedance placed in series with the —input, converting into *current* that parameter of the input signal which we want to appear as voltage at the output (Figure 1-c).

If Z_i and Z_f are both resistors (Figure 2), the operational amplifier becomes a simple voltage amplifier, the gain of which is $-Z_f/Z_i$.



(a)



(b)

Figure 2

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

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

Tektronix Instrument-Repair Facilities: There is a fully-equipped and properly-staffed Tektronix Instrument Repair Station near you. Ask your Field Engineer about Tektronix Instrument-Repair facilities.

Let's examine the mechanism by which this works. Referring again to Figure 2, we apply a voltage to point A, causing current to flow through Z_i. Were it not for the operational amplifier, this current would also flow through Z_f and to ground through the low impedance at point C, making Z_i and Z_f a voltage divider, and raising the voltage at point B. However, the operational amplifier operates to hold the voltage at point B (the —input) at ground potential. To do this, it must supply at point C a voltage which will cause a current to flow through Z_f which will just balance the current flowing through Z_i. When point B is thus held at ground potential, the voltage across Z_i is obviously equal to the applied voltage at A.

Output Voltage is Input Current X Impedance of Z_f

The current through Z_i is equal to the applied voltage at A divided by the impedance (in this case, resistance) of Z_i, or E_{in}/Z_i. This same value of current must flow through Z_f in order to keep point B at ground. The voltage at point C, then, must be E_{in}/Z_i (which is the value of the current in Z_f) multiplied by Z_f. The output is inverted (of opposite polarity) from the input, so we say that $E_{out} = (-E_{in})\left(\frac{Z_f}{Z_i}\right)$, and the voltage gain of this amplifier configuration is seen to be $\frac{-Z_f}{Z_i}$.

See-Saw Operation

As indicated in Figure 2-b, the operational amplifier with resistive input and feedback elements acts in see-saw fashion, the amplifier moving the output end of the see-saw in response to any motion of the input end, causing the system to pivot about an imaginary fulcrum, which is the "sensing point" (—input). The distance from the near end to the sensing point or fulcrum corresponds to the Z_i or input resistor, and the distance from the fulcrum to the far end corresponds to Z_f. The motion of the far end depends on the motion of the near end and the ratio of the two distances. This analogy suggests that the operational amplifier may be used to solve dynamic problems in mechanical engineering, and so it can. One of the principal uses of operational amplifiers has been in the rapid solution of complex mechanical or hydraulic problems by means of electronic analogs of mechanical or hydraulic systems: operational amplifiers are the basic components of an analog computer.

As may be expected, simple linear voltage amplification by precise gain factors is, though useful, not by any means the limit of the operational amplifier's capabilities.

Capacitor as Z_i Senses Rate-of-Change

Remembering that an operational amplifier with a resistor as a feedback element responds with an output voltage equal to the product of the input current and the feedback resistance, let's consider what happens if a capacitor is used instead of a resistor as Z_i (Figure 3).

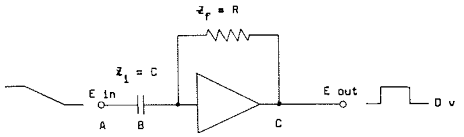


Figure 3.
Operational Amplifier as Differentiator. Output is proportional to *rate-of-change* of input voltage. $E_{out} = \frac{-dE_{in}}{dt} \times RC$.

The current through a capacitor is proportional to the *rate-of-change* of the voltage across the capacitor. A steady state DC voltage across a capacitor (assuming an "ideal" capacitor) passes no current through the capacitor, so no balancing current need be furnished by the output to hold the —input of the operational amplifier at ground. The output voltage then, is zero.

If the voltage at the input is changed, however, the *change* causes a current to flow through capacitor Z_i. The *amount* of current that flows is directly proportional to the capacitance of Z_i times the *rate of change* of the input voltage.

Let's assume that the potential at point A is +100 v DC, and that we change it smoothly to +95 v DC in five seconds. This represents a rate of change of one volt per second, the change taking place over a period of five seconds. If the value of Z_i is 1 μf, then, a current of —1 microampere will flow through Z_i for those 5 seconds.

The operational amplifier will cause an equal and opposite current to flow in Z_f. If we select a value of 1 megohm for Z_f, the one microampere current necessary to balance the circuit will require +1 v to appear at the output of the operational amplifier, during the time that 1 μa current flows through the capacitor.

This operation is *differentiation*: sensing the *rate-of-change* of an input voltage, and providing an output voltage proportional to that rate of change.

The actual relationship of output to input is this: $E_{out} = -\left(\frac{dE_{in}}{dt}\right)(RC)$, where the expression $\frac{dE_{in}}{dt}$ indicates the rate of change (in volts per second) of the input signal at any given instant, and R and C are Z_f and Z_i respectively.

In our example, we used a constant rate of change, and obtained a constant voltage level out. Had the rate been less even, the output signal would have demonstrated this dramatically with wide variations in amplitude. The differentiator senses both the rate and direction of change, and is very useful in detecting small variations of slope or discontinuities in waveforms.

Differentiator Has Rising Sine Wave Response Characteristic

In responding to sine-waves, the differentiator has a rising characteristic directly proportional to frequency, within its own bandwidth limitations (see Figure 7). The output voltage is equal to $(E_{in})\,(2\pi fRC)$, and the output waveform is shifted in phase by —90° from the input (the phase shift across the capacitor is actually +90°, but the output is inverted, shifting it another 180°).

Capacitor as Z_f Senses Input Amplitude and Duration

If we interchange the resistor and capacitor used for differentiation, and use a resistor for Z_i and a capacitor for Z_f (Figure 4) we obtain, as might be expected, the exact opposite characteristics from those obtained above. While in differentiation we obtained an output voltage proportional to the rate of change of the input, by swapping the resistor and capacitor, the output signal becomes a rate of change which is proportional to the input voltage.

This characteristic allows us to use the operational amplifier for integration, since the instantaneous value of output voltage at any time is a measure of both the amplitude and duration (up to that time) of the input signal — to be exact, a sum of all the amplitudes, multiplied by their durations, of the input waveform since the start of the measurement.

Here's how integration works: Let's assume the conditions of Figure 4 ($Z_i = 1$ meg, $Z_f = 1\ \mu$f), and an input signal level of zero volts. No current flows through Z_i, so the operational amplifier needs to supply no balancing current through Z_f. Suppose now we apply a DC voltage of —1 v to Z_i. This will cause a current of —1 μa to flow in Z_i, and the operational amplifier will seek to provide a balancing current through Z_f. To obtain a steady current of 1 μa through 1 μf, the operational amplifier will have to provide a continually rising voltage at the output, the rate of rise required being 1 volt per second. It will continue to provide this rate of rise until the input voltage is changed or the amplifier reaches its swing limit ("bottoms out"), or approaches its open-loop gain.

Now, this rate-of-rise, though helpful in understanding the mechanism by which the operational amplifier performs integration, is not the "answer" we seek from an integrator. The significant characteristics is the exact voltage level at a certain time, or after a certain interval.

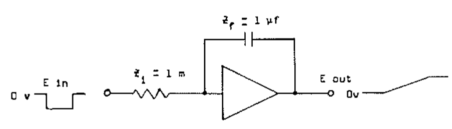


Figure 4.

Operational Amplifier as Integrator. Output rate of change is proportional to input voltage. $\frac{dE_{out}}{dt} = \frac{-E_{in}}{RC}$, 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*.

Integrator Holds Final Level Until Reset

Before the amplifier reaches its output limit, suppose we remove the input voltage to Z_i. The output does not return to ground, but remains at the level it reached just before the signal was removed. The rate of rise has stopped because the necessity for providing $+1\ \mu a$ through Z_f to maintain the null at the —input has been removed. With an ideal capacitor and amplifier, the output voltage would remain at the last level reached indefinitely, until an input signal of the opposite polarity were applied to Z_i, and a negative-going rate of change at the output were required to maintain the null at the —input.

If the positive input signal is greater than our original —1 volt, it will take less time for the output voltage to reach zero than it originally took to rise. If the positive signal is smaller, it will take more time.

The absolute output level of the integrator at the end of some interval is the sum of the products of all the voltages applied to Z_i since the output was at zero, times the durations of these voltages, that sum divided by —RC.

Interpreting Answers Obtained From Integrator

The mathematical expression for the output level reached in a given interval of time $(T_2 - T_1)$ is as follows:

$$E_{out} = \left(\frac{-1}{RC}\right) \int_{T_1}^{T_2} E_{in}\ dt$$

The integral sign indicates that the value to be used is the *sum* of all of the products (E_{in} X dt) shown, between the limits (T_1, T_2) noted. The expression "dt" indicates infinitely small increments of time.

It is not necessary, however, to understand and be able to manipulate expressions in integral calculus to understand and make use of an operational amplifier integrator.

The integrator provides a voltage output proportional to the net number of volt-seconds applied to the input. If the total volt-seconds of one polarity is equalled by those of the opposite polarity, the output level at the end of the selected interval will be zero. Let's look at some examples.

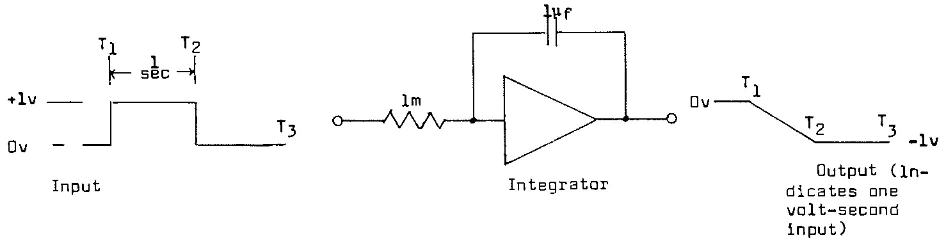


Figure 5.
Simple case of integrating 1-volt-second pulse. Integrator does not improve measurement accuracy in so simple a case.

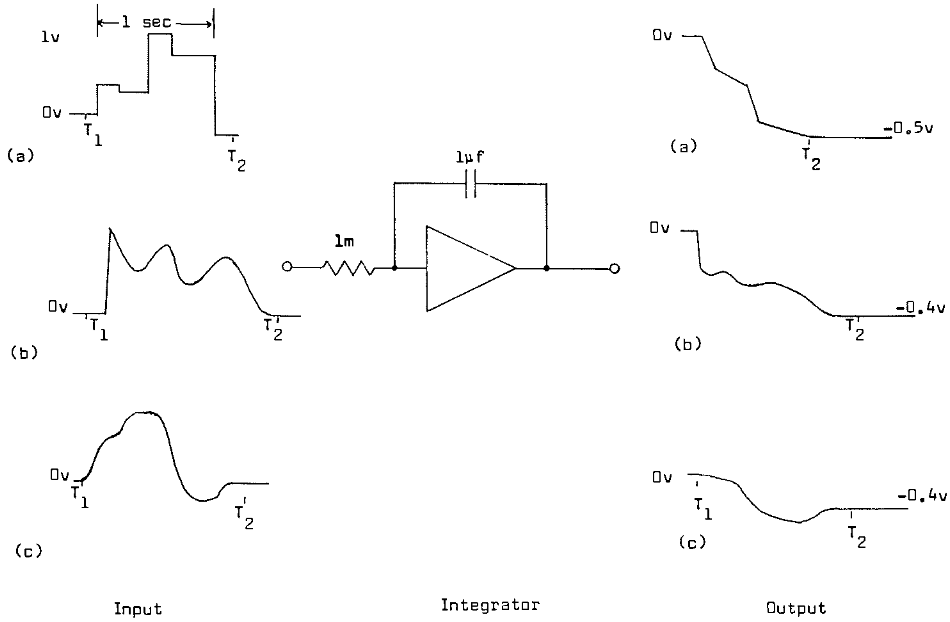


Figure 6.
Integrating more complex waveforms to determine "area under the curve" between T_1 and T_2. Note that in (c) the negative portion of the input waveform *reduces* the net integral.

Simple Example of Data From Integrator

First, we'll assume the signal we want to integrate is a simple one-volt positive pulse of one second duration (Figure 5). The sum of all voltages times durations between T_1 and T_2 is one volt-second. Using 1 megohm and 1 microfarad for Z_i and Z_f, the operational amplifier output will fall at the rate of one volt per second $\left(\frac{-E_{in}}{RC}\right)$ for one second, reaching —1 v when the pulse ends, and remaining at that level.

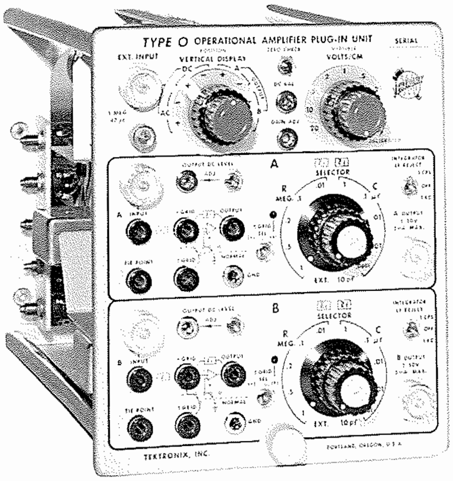
In reading this output level at T_2 we know that the input signal has amounted to 1 volt-second during the interval T_1 to T_2. Note also that a later observation, at T_3, gives the same answer, since E_{in} has been 0 between T_2 and T_3.

More Complex Cases

Now, take the more complicated case of the waveform in Figure 6-a. Its four voltage levels, of different duration, cause the integrator output to fall at four different rates, reaching a final level representing the total number of volt-seconds contained in the waveform. It should be apparent now that the integrator can measure the total volt-seconds contained in even the very complex waveform of Figure 6-b — something that would be difficult to measure by direct observation of the waveform. This type of operation is often referred to as "taking the area under the curve," since the area underneath a waveform plotted against time (i.e., the area bounded by T_1, T_2, the waveform and the line representing 0 volts) is the number of volt-seconds involved. Note, too, that we needn't wait for T_2 to obtain a reading: the instantaneous value of E_{out} at *any time* is proportional to the input volt-seconds up to that time.

Using Different Values of R and C

In the cases we've used for illustration, RC was 1 ($10^6 \times 10^{-6}$), and the numerical value of the output voltage at the end of the integrating interval was the number of volt-seconds in the input waveform. Using other values of R and C requires some additional calculation. To find the actual input volt-seconds, multiply the output voltage by (—RC). Example: R is 200 k, C is .01 μf and the output voltage after the selected interval is —2.5 volts. Multiplying —2.5 by $(-2 \times 10^5 \times 1 \times 10^{-8})$ gives us 5×10^{-3}, or 5 millivolt-seconds, positive polarity. Note that because of the polarity-reversal in the amplifier, we multiply by (—RC), to obtain the proper sign in the answer.



Measuring Ampere-Seconds (Coulombs)

To measure ampere-seconds, Z_i is omitted, and the current source is applied directly to the —input. The output level reached in a given time $(T_2 - T_1)$ is $\frac{-1}{C}\int_{T_1}^{T_2} I_{in}\,dt$.

Integrator Response to + and — Signals

If a waveform to be integrated contains both positive and negative polarity portions during the integrating interval, the output will be proportional to the *difference* between the volt-seconds of each polarity, the integrator being an averaging device. If it's desired to add the two polarities instead of allowing them to be subtracted, it is necessary to precede the integrator with an "absolute-value amplifier" (full wave rectifier) which inverts one of the polarities.

Necessity to "Reset" Integrator After T_2

The "integrating interval" (T_1 to T_2) has been mentioned several times. Because we frequently deal with repetitive signals; and continued integration of a waveform which is not perfectly symmetrical with respect to zero volts will eventually drive the operational amplifier to its output voltage limit, it's desirable to have some way of returning the output to zero at or after T_2, the end of the desired interval.

For slow work, a pushbutton which can be used to discharge Z_f manually is usually sufficient. Other circuits which may be used to perform this function automatically are shown in the applications section of the Type O-unit manual. Where the integrating interval is quite short, RC networks may be placed around Z_f to return the output level to 0 v through a time constant much longer (e.g., 100X) than the integrating interval.

In the Type O Unit, the "Integrator LF Reject" switch-positions perform this function whenever Z_f is set to a capacitive value.

Since the LF Reject circuit operates continually to return the integrator output to zero, it is necessary not only to keep the integrating interval short with respect to the LF Reject time-constant, but also to measure E_o before it has had a chance to decay, whenever these circuits are used. The value of resistors used in the circuit will also limit the maximum output obtainable for any given amplitude input (Max $\frac{E_{out}}{E_{in}} = \frac{R_r}{Z_i}$, where R_r is the resistance of the LF Reject circuit.

Reset or LF Reject Imperative When $Z_f = C$ is Small

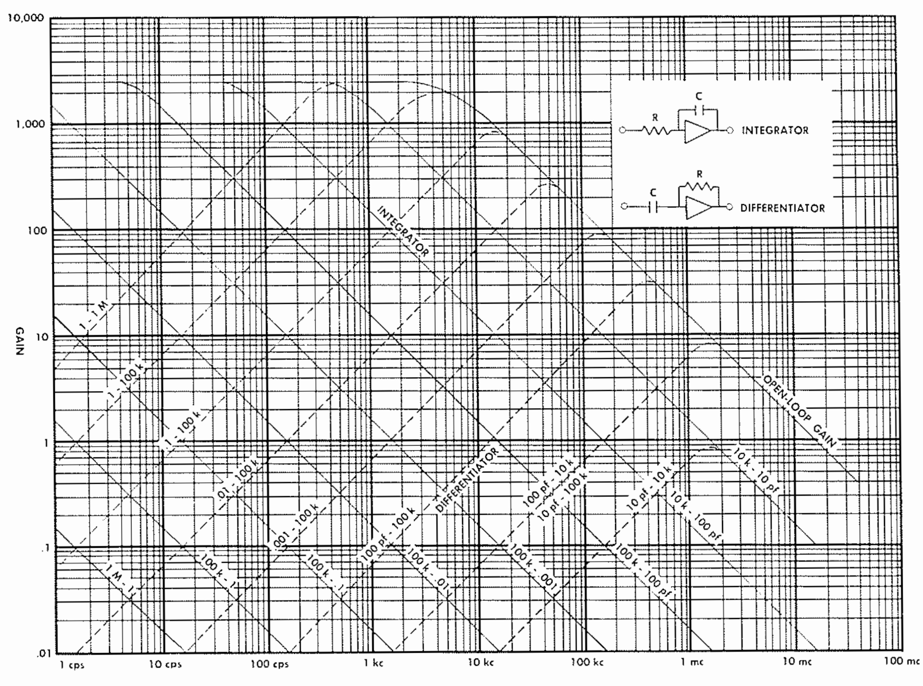
Use of resetting or LF reject circuits is usually imperative when small values of C are used for Z_f, since the small amount of grid current which flows in the —input grid even in the absence of an input signal is sufficient to cause a relatively rapid rise in output voltage as the operational amplifier tries to hold the —input null with balancing current through Z_f.

Response of Integrator to Sine Waves

For sine waves, the gain of the integrator varies inversely with frequency, the actual gain being $\frac{-1}{2\pi fRC}$, except as limited by the open-loop gain (at low frequencies) and the open-loop gain-bandwidth product at high frequencies (see Figure 7). At low frequencies, the gain becomes less than the formula would indicate, the effect becoming noticeable at the point where the formula indicates a gain of approximately 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°.

Editor's note: The second (and concluding) part of this article will appear in the April '63 issue of SERVICE SCOPE. This second part will discourse on the + input, a feature of some operational amplifiers. It will also discuss limitations of operational amplifiers, chief of which are:

1. *Open-loop Gain*
2. *Gain-bandwidth product.*
3. *Grid current (primarily of concern during integration).*
4. *Output-current and voltage capability.*
5. *Signal-source impedance.*



Average Gain-Frequency characteristics for integration and differentiation.

Figure 7.

ANODE-CONNECTOR ARCING IN THE TYPE 507 OSCILLOSCOPE

In the December '62 issue of SERVICE SCOPE we suggested a cure for arcing at the anode connector in the Type 507 Oscilloscope. In a good many instances this cure proved effective. However, under difficult environmental conditions, arcing may persist. Humidity, altitude, temperature and other atmospheric conditions can contribute to the proclivity of the Type 507 toward arcing. This tendency stems from the 20 kv present at the anode connector of this instrument.

Happily, we can now offer a more effective solution to this problem. A new anode connector, developed recently by our Instrument Manufacturing Staff Engineers, exhibits a remarkable ability to resist arcing. Tested under severe environmental conditions this connector, in almost every instance, eliminated or drastically reduced anode-connector arcing.

Type 507's with serial numbers above 418 have this new anode connector installed at the factory. Type 507's with serial numbers 418 and under will readily accept it. A word of caution here: The silicon rubber cover of the new connector, although highly resistant to arcing is a very easily damaged material. It is quite tender, and care must be exercised when installing and connecting the connector. Avoid the use of sharp pointed or edged tools. A hole through the silicon rubber covering destroys the effectiveness of the connector.

The Tektronix part number for this new connector is 131-238. Price is $2.50. Order through your local Tektronix Field Office or Field Engineer.

SERVICE HINTS

DIODE REPLACEMENT IN TYPE 503, RM503, 504 AND RM504 OSCILLOSCOPES

Do not use "off-the-shelf" diodes when replacing the rectifier diodes (D652, D662, D672 and D682) in the power supplies of these instruments. If you will refer to the power supply schematic for any of these instruments you will notice that V620 (a 6DQ6A tube), the primary of transformer T620, and part of the secondary of T620 form an Armstrong oscillator circuit to drive T620 at about 25 kc. Recovery time, therefore, becomes an important consideration in selecting these rectifier diodes.

Not all types of power diodes nor all the diodes of any one type have the short recovery time required in this application. Diodes must be checked and only those with the required short recovery time selected. Tektronix part numbers 153-007 and 153-008 are such selected diodes. You may order these from your local Tektronix Field Office or Field Engineer. For D652 specify part number 153-008 and for D662, D672 or D682 specify part number 153-007.

TYPE 321 OSCILLOSCOPE SWEEP FAILURE AT 10/MSEC AND SLOWER SWEEP RANGES

"No Sweep" at the 10 msec/cm and slower sweep ranges in the Type 321 Oscilloscope generally indicates failure of holdoff capacitor C180A, a 2 μf, 25 volt electrolytic capacitor. Investigation indicates that a certain brand of capacitor which we formerly used in this application will not give reliable service in this circuit. Should you experience a failure of C180A in your Type 321 Oscilloscope, replace it with a Sprague 2 μf, 25 volt electrolytic capacitor — Tektronix part number 290-121.

TYPE 575 TRANSISTOR CHARACTERISTIC-CURVE TRACER AND LONG-LEAD TRANSISTORS

A confusing failure can occur when using the Type 575 Transistor-Curve Tracer to check long-lead transistors. The trouble may appear to be a failure of the base step generator in the Type 575. If you encounter this difficulty, check the long-lead transistor receptacle before you blame the Type 575. Occasionally the receptacle will open up internally at the emitter connection and cause the Type 575 to exhibit symptoms indicating failure of the base step generator.

TYPE 585 OSCILLOSCOPE FUSE FAILURE

Experience in the field reveals that, in some areas, operators of the Type 585 Oscilloscopes are experiencing excessive fuse failure; particularly when using the Type 82 Dual-Trace or Type 84 Test Plug-In Units.

Prior to the advent of these two plug-in units, the Type 585 used a 6 amp fast-blow fuse. The current demands of the two newcomers are a bit higher than those of previously designed plug-in units intended for use with the Type 585. At start-up time or at high line voltage a Type 585/82 (or 84) combination can draw enough current to exceed the limitations of the 6 amp fast-blow fuse. However, the design of the Type 585 is such that you may safely substitute a 7 amp slow-blow fuse for the original 6 amp fuse. This will minimize the chances of interruption due to fuse failure.

TYPE 585 Oscilloscope with serial numbers above 4108 are equipped with a 7 amp slow-blow fuse at the factory.

USED INSTRUMENTS FOR SALE

1 Type 514D Oscilloscope, s/n 1135. In excellent condition. Lawrence Gevins, Electronic Instruments for Research, 4135 Hayward Avenue, Baltimore, Maryland.

* * *

1 RM31A Oscilloscope, s/n 1807. Harry Buckalter, Applied Systems Corporation, 925 East Meadow Drive, Palo Alto, California.

* * *

1 Type 517A Oscilloscope, s/n not given but instrument is said to be one year old. Jim Shaw, Amelco, Inc., 12964 Panama Street, Los Angeles 66, California.

* * *

1 Type 535 Oscilloscope, s/n 368. Earl Dahlin, Tally Register Corporation, 1310 Mercer Street, Seattle, Washington.

* * *

1 Type 561 Oscilloscope, s/n 577. Fred Proctor, Proctor and Associates, Box 471, Bellevue, Washington.

* * *

1 Type 503 Oscilloscope, s/n not given but instrument is approximately two years old. Dr. Siegfried Lindena, Electrosolids, 12740 San Fernando Road North, Sylmar, Calif.

* * *

1 Type 524D Oscilloscope, s/n 1799. Has just had a complete overhaul. Joel Naive, 2758 Bordeaux, La Jolla, California. Phone: GL 4-1314.

* * *

1 Type 502 Oscilloscope, s/n 3146. M. Lipshutz, Cofax Electronics, 537 Commerce Street, Franklin Lakes, New Jersey. Phone: FE. 7-6177.

* * *

1 Type M Plug-In Preamplifier, s/n 206. Used very little. Dr. Ralph Waniek, Advanced Kinetics, 1231 Victoria Street, Costa Mesa, California.

* * *

1 Type 53/54C Plug-In Preamplifier, s/n 20261. Price: $175.00. 1 Type RM181 Time-Mark Generator with crystal oven, s/n 1034. Price: $195.00. 1 Tektronix Cradle Mount for rack mounting a Type 503 Oscilloscope. Price: $20.00. Joseph M. Edelman, M.D., 4550 North Boulevard, 204 Medical Center, Baton Rouge 6, Louisiana.

1 Type 535A Oscilloscope with a Type CA Plug-In Preamplifier, s/n not given but owner says instrument is in new condition. Ross Farmer, 3675 Westwood Boulevard, Los Angeles 34, California. Phone: VErmont 8-4753.

* * *

1 Type 514AD Oscilloscope, s/n not given. Engineering Associates, 434 Patterson Road, Dayton 19, Ohio. Attn: C. C. Littell, Jr.

* * *

1 Type 53/54H Plug-In Preamplifier, s/n 1198. Blake Lloyd, Engineer, Engineering Test Department, Metcom, Inc., 76 Lafayette Street, Salem, Massachusetts.

* * *

1 Type E Plug-In Preamplifier, s/n 003376. Used about one year. Bertram Wellman, Instrumentation Laboratory, Dartmouth Medical School, Hanover, New Hampshire.

* * *

1 Type M Plug-In Preamplifier, s/n 206, (very low mileage). Dr. Ralph Waniek, Advanced Kinetics, 1231 Victoria Street, Costa Mesa, California.

Intercontinental Electronics, located on Shames Drive in Westbury, New York, has asked us to report their Type 524D Oscilloscope, serial number 651, as missing and presumably stolen. They ask that anyone with information regarding this instrument contact them, either by mail at the above address or by telephone. Their phone number is 334-8300 in Westbury, New York.

* * *

The Wisconsin Air National Guard, either through theft or misplacement, suffered the loss of a Type 545A Oscilloscope, serial number 10661, and a Type 53/54K Plug-In Preamplifier, serial number 7048. These instruments disappeared from the air base on November 30, 1962.

Information concerning this oscilloscope and plug-in should be directed to Major Paul H. Poberezny, Chief of Maintenance, Wisconsin Air National Guard, General Mitchell Field, 4840 South Howell Avenue, Milwaukee 7, Wisconsin, Attn: BMO.

USED INSTRUMENTS WANTED

1 Type 310 or Type 310A Oscilloscope. Leo L. Stachowski, P. O. Box 703, Newark, Ohio.

* * *

1 — 3" or 5" oscilloscope. Must have a triggered sweep. Condition of instrument not important, except that it must be repairable. Will pay up to $300.00 for the right instrument. Contact: John M. Hicks, 329 South Avenue, Pittsburgh, Pennsylvania.

* * *

1 Type 524D Oscilloscope. T. Jorgenson, KXLY Television, West 315 Sprague Avenue, Spokane 4, Washington.

* * *

1 Type 310A Oscilloscope. Joe Marie, Bronson Instruments, 1643 Lee Road, Room 9, Cleveland 18, Ohio. Phone: 216-321-9339.

* * *

1 Type 503 or Type 504 Oscilloscope. Dr. James Nicol, Cyronetics Corporation, Northwest Industrial Park, Burlington, Massachusetts.

6AG7 TUBE PROBLEMS

Recent reports from our Field Engineers contain a number of complaints regarding 6AG7 tubes. Drift, compression, microphonics, interface and hum are the offensive characteristics complained against. These complaints are supported and reinforced in the regular reports of our plant calibration personnel. Because of this, we requested an evaluation of 6AG7 tubes by our Material Evaluation Group. The results indicate that the greatest problems are drift and compression, which appear to be related and the result of the same defect—a weak or inactive cathode.

Fortunately, heating the cathode will in most cases activate (or reactivate) it. This heating of the cathode is done by raising the filament voltage to 18 volts for a period of about 30 seconds, with the other tube elements floating or the tube biased below cut-off. After the tube cools to normal temperature it is ready for use. Some tubes may require two or more such treatments.

The heating or reactivation of the cathode can be readily accomplished on the Tektronix Type 570 Characteristic Curve Tracer. Here is the recommended procedure for this application:

Procedure for Reactivating 6AG7 Cathodes

Set up the Type 570 as follows:

I. Plate Sweep Block
   A. PEAK VOLTS to 200 v
   B. SERIES LOAD to 300 Ω

II. Operating Voltage Block
   A. HEATER to 6.3 v
      1. VARIABLE (red knob) to 10 o'clock (will be adjusted later)
   B. + DC to 200 v
      1. VARIABLE (red knob) to 12 o'clock (will be adjusted later)
   C. —DC, counter clockwise

III. POWER
   A. MAINto OFF
   B. TEST to OFF

IV. TEST POSITION to OFF

V. Voltmeter Block
   A. RANGE DC VOLTS to 350
   B. INDICATION to +DC

VI. Grid Step Generator Block
   A. STEPS/SEC to left 120
      1. STEPS/FAMILY (red knob) to 12 o'clock
   B. VOLTS/STEP to .5
      1. START ADJUST (red knob), counter clockwise.

VII. CRT Display Block
   A. VERTICAL MA/DIV. (black) to 5
      1. Red knob to plate
   B. HORIZONTAL VOLTS/DIV (black) to 20
      1. Red knob to plate
   C. POSITIONING
      1. VERTICAL to mid range
      2. HORIZONTAL to mid range

VIII. Install 8-pin octal-socket adapter plate
   A. Patch pins 1 & 5 to "K" on test panel
   B. Patch pins 2 & 7 to HEATER jacks
   C. Patch pin 4 to GRID A jack
   D. Patch pin 6 to +DC jack
   E. Patch pin 8 to "P" jack

IX. Install 6AG7 tube and turn on MAIN POWER. Position crt spot to lower left hand corner of graticule.
   A. Turn on TEST POWER switch and note a horizontal trace of about 10 divisions.
   B. Switch TEST POSITION switch to GRID A and note a family of curves (see Figure 1).

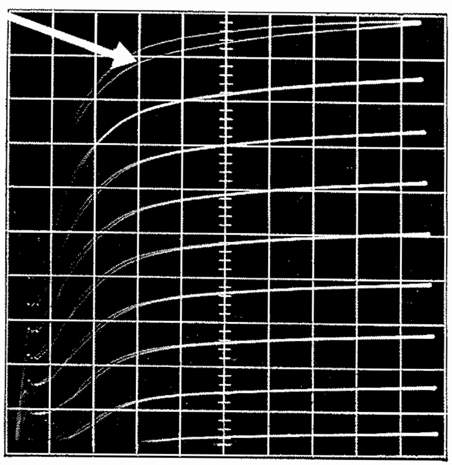


Figure 1
6AG7's with weak or inactive cathodes will show excessive retrace lines (see arrow) on the top member of a family of curves.

   C. Switch the INDICATION control to HTR and adjust the VARIABLE (concentric with the HEATER control and located in the Operating Voltages Block) to give an 80% reading on the Type 570's Volts-DC-and-Heater-Volts meter. Switch the INDICATION control back to +DC and adjust the VARIABLE (concentric to the +DC control and located in the Operating Voltages Block) to give a reading of 150 v on the 350 v scale of the Type 570's Volts-DC-and-Heater-Volts meter.

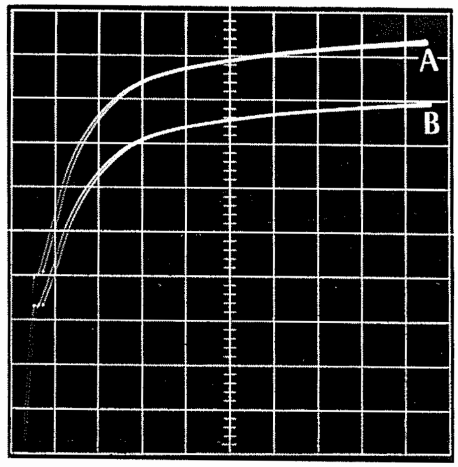


Figure 2
Waveform photo (double exposure) showing the E_p — I_g curve of o 6AG7 with a weak or inactive cathode; (A) at the instant after depressing the ZERO BIAS button and (B) at the point of maximum deflection change during depression of the button.

   D. While observing the top curve push the ZERO BIAS button and observe the deflection change (if any). If this change is greater than one minor division on the graticule, proceed as follows:
      1. Set TEST POSITION switch to OFF.
      2. Set POWER, TEST switch to OFF.
      3. Disconnect the leads from +DC and "P" (on test panel).
      4. Reset POWER, TEST switch to ON and turn HEATER control to 25 and leave there for 25 seconds (reactiviating time).
      5. Turn HEATER control back to 6.3 and wait 15 seconds.
      6. Set POWER, MAIN switch to OFF and reconnect leads disconnected in Step 3 above.
      7. Set both POWER switches, MAIN and TEST, to ON.

8. Set TEST POSITION switch to GRID A. After warm up make check again as in Step IX, D. There should be no change in plate current now. However, if there still is a change, repeat Steps 1 through 8 above and this time increase the reactivating time to 45 seconds. If, after this second attempt, the tube still exhibits an excessive deflection change when the ZERO BIAS button is depressed, it is probably beyond redemption and should be discarded.

In Part 4 of D, under Step IX, of this procedure the load on the filament transformer of the Type 570 is sufficient to drop the heater voltage applied to the 6AG7 to about 17.5 volts. Because of this load we recommend that only one 6AG7 be processed at a time.

THE TYPE 130 L-C METER AND THE S-30 DELTA STANDARDS

Some *Questions and Answers*

Question: In measuring the inductance of a coil with a Type 130 L-C Meter, I can increase inductance by inserting a core into the coil, but only up to a point, then the meter indication suddenly drops to zero. What is wrong?

Answer: Core losses. Many types of cores are suitable only for low frequency use, and show considerable loss (low Q) at the 120-140 kc measurement frequency of the Type 130 L-C. Core loss shows up as effective series resistance. The Type 130 L-C manual (Tektronix part number 070-231, page 2-4) provides correction tables for L measurements with *known* series resistance up to 40 ohms. When series resistance reaches about 75 ohms, the Q of the entire variable oscillator tank circuit has dropped to a level beneath that required to sustain oscillation, and the meter circuit—unable to follow a "difference" frequency of 140 kc—ceases to function. Therefore, do not rely on the Type 130 to measure coils which owe most of their inductance to their cores, particularly where the core material is intended for low-frequency use. The Type 130 is intended primarily for measuring coils having high Q at 120-140 kc.

Question: I understand that a S-30 Delta Standards can be "certified," traceable to N.B.S. Is this right?

Answer: Yes. On an order for a new S-30, simply request a certificate of traceable calibration. There is no extra charge; but, allow extra time.

Question: Why can't L15 (300 μh) in the S-30 be measured on a bridge?

Answer: Actually, L15 could be calibrated on a bridge *if* you had a bridge which operated at 120-140 kc. Most bridges at 1 kc, however, and most "Q" meters don't provide drive frequencies below 1 Mc. Since L15 has a powdered-iron core, its inductance at 120-140 kc will not be quite the same as its inductance at 1 kc or 1 Mc. In addition, shunt capacitance across L15, representing perhaps 1/3 of 1% of L15's admittance at 140 kc, will throw a measurement at 1 Mc off by about 20%.

Question: How does the "Inductance Standardizer," mentioned in the Type 130 L-C manual, work? Isn't it "circular calibration" to use the Type 130 to check its own standard?

Answer: The Type 130 L-C is used only as a frequency source and null indicator for adjustment of L15 in the S-30. The actual scale calibration of the Type 130 is not important. What is important is that the Type 130's fixed oscillator be within frequency tolerance (± ½ kc or ± 0.35%).

The inductance standardizer circuit consists of two circuits: a capacitor which is resonant at 140 kc with 300 μh, and a resistor which has the same resistance as the series-resonant circuit of 4310 pf and L15 where they are resonant at 140 kc.

The Type 130 is first adjusted so that the variable oscillator produces just 140 kc (zero beat with the fixed oscillator) in the 300 μh position when looking into a circuit which appears to be a (nearly) pure resistance of 7.5 ohms at 140 kc.

The Type 130 is then connected to the series circuit of 4310 pf and L15. If this circuit is resonant at 140 kc, the Type 130 meter reads "zero."

If L15's value is too high, the series circuit presents an inductive reactance to the Type 130, forcing the variable oscillator frequency down and causing the meter to read upscale. If L15's value is too low, the inductance standardizer appears as a capacitive reactance (negative inductance) in series with the inductance of the variable oscillator tank coil, forcing the variable oscillator frequency up. Since the meter circuitry reads only the "difference" between the fixed and variable oscillator frequencies, without regard to which is higher, an increase in variable oscillator frequency also reads upscale on the meter.

The 100 to 400 μh inductor across the input to the inductance standardizer is there to complete the oscillator's dc grid return, which is blocked by the 4310 pf capacitor. Since it is in the circuit both during the zeroing operation and during L15 standardization, its small reactive effect across the 7.5 ohm circuit (its reactance is 90-350 ohms at 140 kc) has no material effect on the operation. A low-value resistor here would swamp the null, so an inductor is used.

Question: The 130 L-C manual says to use 2% components in constructing the inductance standardizer. Will a standardizer, so constructed, be adequate to hold 1% calibration of L15?

Answer: No! 2% components will assure calibration to only within about 3%. The 4310 pf capacitor should be made up of stable, low-loss units (such as silvered micas) bridged out to ±½%, or closer at 1 kc or—preferably—140 kc. Tolerance on the 7.5 ohm resistor is not critcal. The inductor can be any convenient value between 100 and 400 μh.

Question: I'm piping the multivibrator output from the Type 130 L-C into a highly accurate frequency counter in order to obtain 0.01% resolution and 0.1% accuracy. The Type 130 seems to drift considerably with temperature and line voltage. Can I put a 140 kc crystal into the fixed oscillator circuit?

Answer: You can, but you'll wish you hadn't. The two oscillators (fixed and variable) in the Type 130 use identical transformers and component types so they will be self-compensating. Tie one of them down "solid" and you increase thermal sensitivity and drift by a factor of seven or more.

We designed the Type 130 L-C as a 3% device. With *careful*—and we repeat, *careful*—calibration it will give 1% (of full scale) accuracy. No part of its circuitry is so far overdesigned as to permit reliance on it to provide greater accuracy than the meter gives. We do not represent the Type 130 L-C to operate except as a self-contained "system."

Question: I'm experiencing some difficulty in measuring capacitance in a small relay assembly on my bench. Even though I keep it away from all metal objects, "guard" all unwanted contacts and use the P93C probe, I obtain two different C readings between points X and Y, depending upon which side I ground. What's going on?

Answer: The surface of your bench may be slightly conductive, thus forming a grounded capacitor "plate" which will have more capacitance to the larger or less isolated contact. Try slipping your Type 130 L-C manual under the relay. If this improves your measurements, you may want to build an insulated platform on which to make your more critical measurements; or, you might consider putting the relay into a guarded enclosure.

A CORRECTION

Ye Olde Editor misquoted the author, Paul Thompson, twice in the article "New Trigger-Circuit Adjustment Method," which appeared in the December issue of SERVICE SCOPE. In step 3 of the article, "TRIGGER LEVEL control" should read "TRIGGER SENSITIVITY control." In step 10 the second sentence should read "Set the AMPLITUDE CALIBRATOR to .2 VOLTS and connect the CAL. OUT to the EXT. TRIG. input and to the vertical INPUT."

If you tried this method and ran into trouble, give it another whirl. These corrections will probably clear up the difficulty.

Service Scope

USEFUL INFORMATION FOR

USERS OF TEKTRONIX INSTRUMENTS

Tektronix, Inc.
P. O. Box 500
Beaverton, Oregon