Service Scope

USEFUL INFORMATION FOR USERS OF TEKTRONIX INSTRUMENTS

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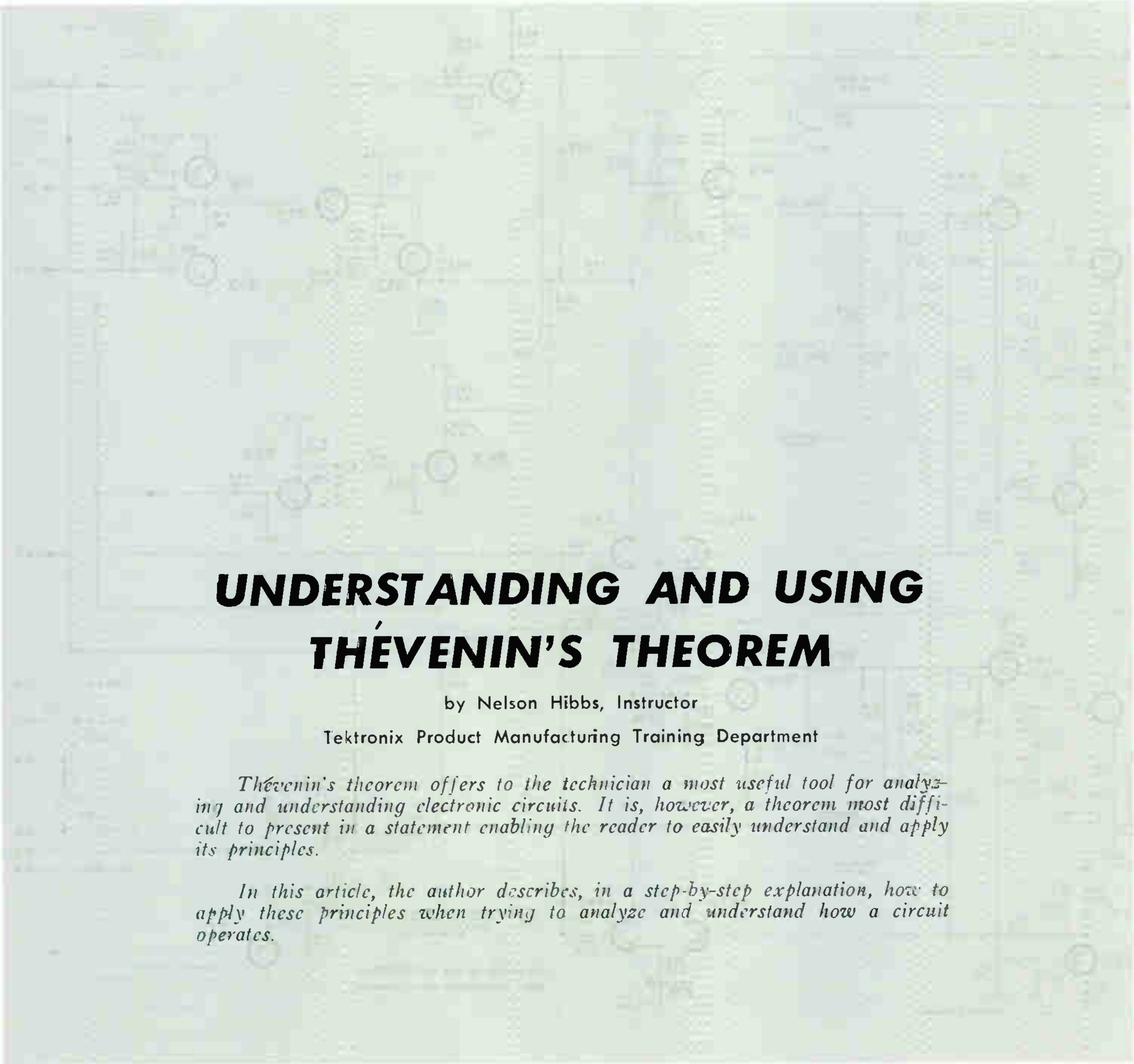

UNDERSTANDING AND USING THÉVENIN'S THEOREM

by Nelson Hibbs, Instructor

Tektronix Product Manufacturing Training Department

Thévenin's theorem offers to the technician a most useful tool for analyzing and understanding electronic circuits. It is, however, a theorem most difficult to present in a statement enabling the reader to easily understand and apply its principles.

In this article, the author describes, in a step-by-step explanation, how to apply these principles when trying to analyze and understand how a circuit operates.

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INTRODUCTION

Thévenin's theorem is one of the most useful extensions of Ohm's law ever devised. It is, however, a theorem most difficult to present in a statement that enables the reader to readily understand and easily apply its principles. For this reason perhaps, some college courses in electrical engineering do not delve into the theorem in any depth until in the senior year.

Once the electronics student or technician does understand Thévenin's theorem, he will find it a most useful tool for analyzing and understanding electronic circuits. The theorem is a general transformation which reduces any combination of active and passive circuit elements to a simple equivalent circuit consisting of a voltage source in series with an equivalent passive element. It is a general theorem applicable to all combinations of passive circuit elements.

With Thévenin's theorem, one can replace any portion of a circuit with a voltage source and an impedance in series, provided the portion replaced has only one pair of terminals. The voltage source in the Thévenin's equivalent circuit will have a value equal to the open circuit voltage appearing at the pair of terminals, and the series impedance will be the impedance that would be seen looking into the pair of terminals with all energy sources turned off and shorted.

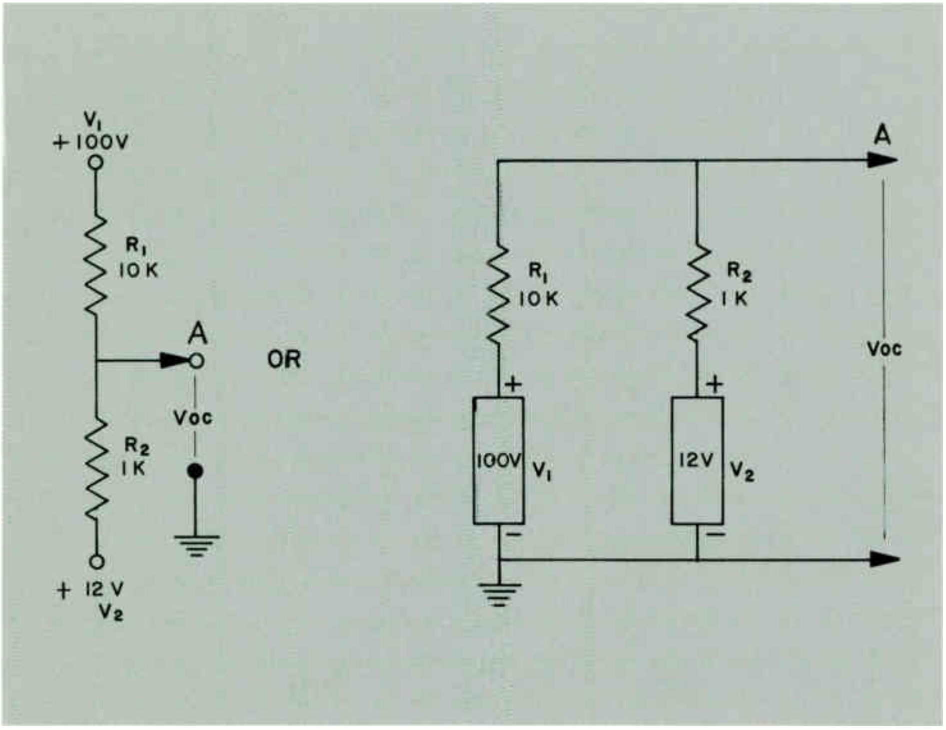

Figure 1. A simple circuit consisting of ideal voltage sources (no internal impedance) and resistors.

In this writer's opinion, one of the more understandable presentations of Thévenin's theorem is put forth by Phillip Cutler in his book "Electronic Circuit Analysis, Volume 1, Passive Networks".* On the bottom of page 18 Cutler writes, "1-5 Thévenin's Theorem. Thévenin's theorem states that any linear network of impedances and generators, if viewed from any two points in the network, can be replaced by an equivalent voltage source V_{oc} and by an equivalent impedance Z_{th} in series".

We will take a look at the mechanics by which this is achieved in a moment; but before we do, let us see what this presentation actually says.

Apparently the first thing we need is a linear network of impedances and generators. To keep it simple, we will use resistors for the impedances and good solid voltage supplies for the generators. Our circuit might then look like the circuit in Figure 1.

Cutler's statement of Thévenin's theorem next says we must view this circuit from two points in the network; let us select for these two points, the ground and common lead at point A. Next it tells us that Thévenin pointed out we can make a substitution for the complex network made up of a single voltage source (which he called V_{oc}) and a single series resistance (which he called Z_{th}).

Let us define V_{oc} and Z_{th}. Since ground is one point of reference and the common lead the other, V_{oc} becomes the voltage difference between these two points. Thus in the circuit in Figure 1,

$$I = \frac{V_1 - V_2}{R_1 + R_2}$$

$$V_{oc} = V_2 + I\ (R_2)$$

$$= V_2 + \frac{(V_1 - V_2)\ R_2}{R_1 + R_2}$$

$$V_{oc} = 12\text{ V} + \frac{88 \text{ x } 1\text{ k}}{10\text{ k} + 1\text{ k}} \text{ or } 20\text{ V.}$$

If we assume we are using ideal batteries for our "good solid voltage supplies" we will, of course, have zero impedance within the voltage sources. Looking back then into the circuit from our selected reference points, through the resistors to the zero impedance point, we will see an impedance made up of the parallel resistance of the two divider resistors and this impedance becomes Z_{th}. Thus in the circuit in Figure 1,

$$Z_{th} = \frac{10\text{ k x } 1\text{ k}}{10\text{ k} + 1\text{ k}} \text{ or .91 k ohms.}$$

According to Thévenin's theorem, these two units, V_{oc} and Z_{th}, will be seen in series when used as a substitute for our simple circuit, see Figure 2.

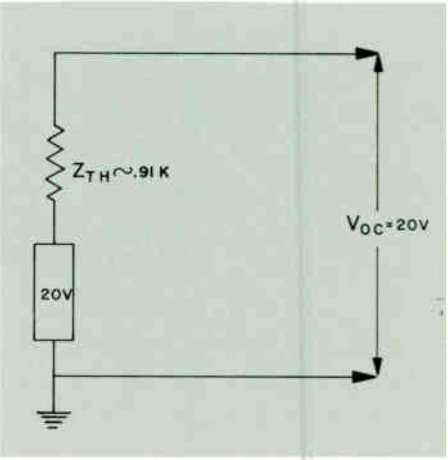

Figure 2. Thévenin's equivalent of the circuit in Figure 1.

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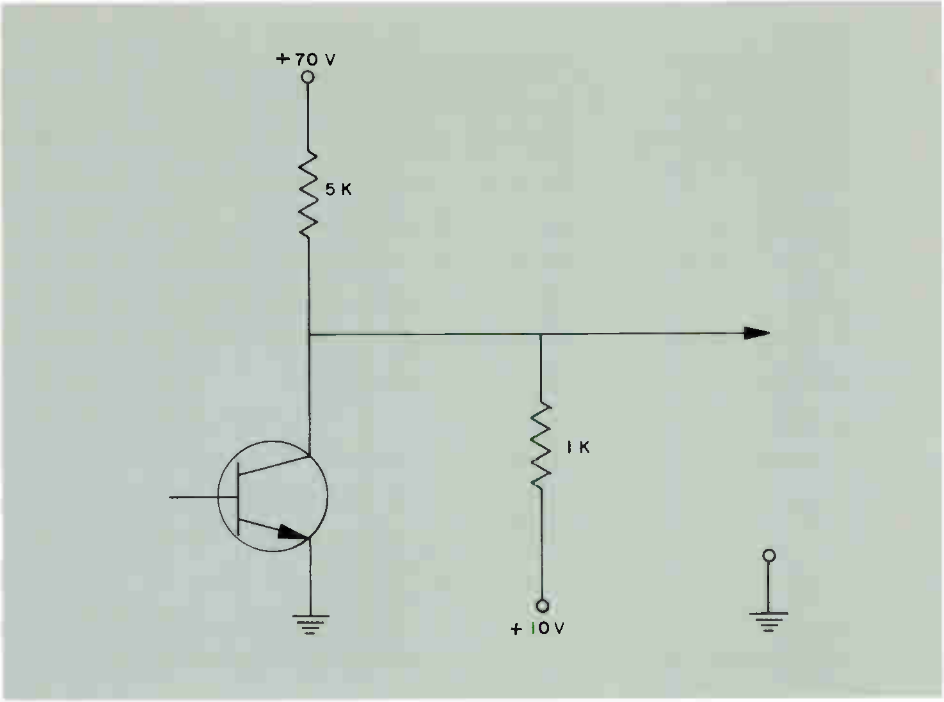


Figure 3. Transistor with a split collector load.

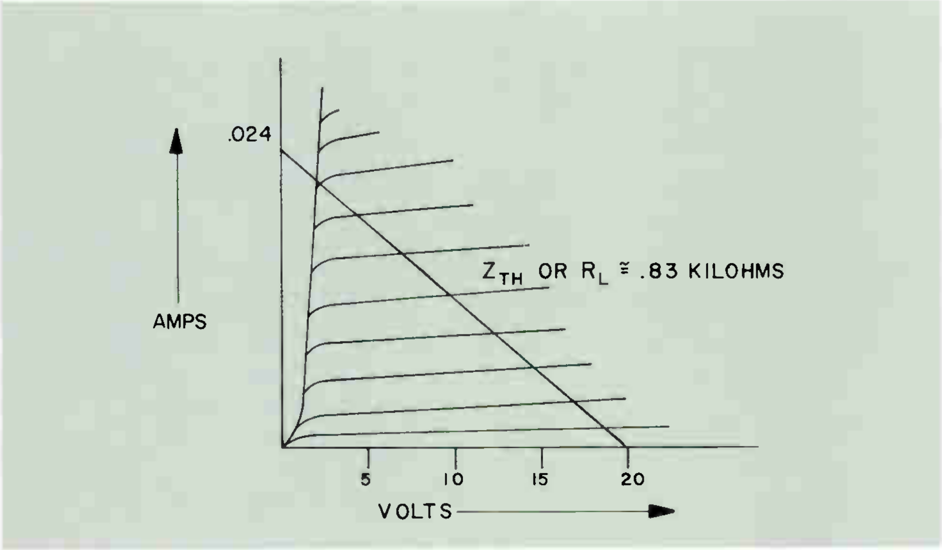


Figure 5. Load line drawn on the collector curves for the transistor in Figure 3 showing where the transistor is operating in that circuit.

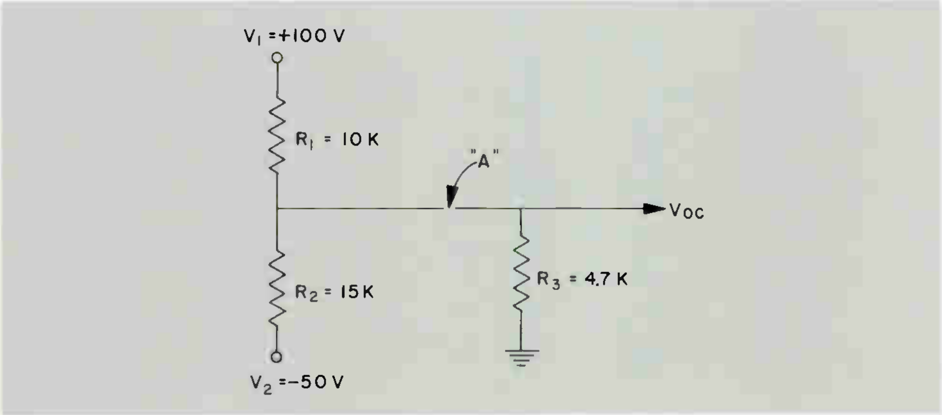


Figure 6. Illustration of a circuit a bit more complex than the one shown in Figure 1.

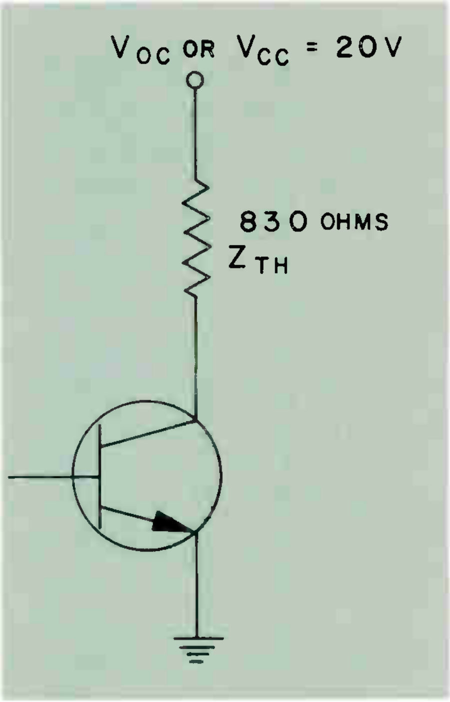


Figure 4. Thévenin's equivalent of the circuit in Figure 3.

Now let us put this idea into the practical framework of a real circuit.

Figure 3 shows a transistor with a split collector load. Let us assume we have the collector curves for this transistor and we would like to draw in the load line to obtain an idea of where the transistor is operating and how we can expect it to perform in this circuit. We now need to know what the effective V_{cc} is and how much resistance is in the actual effective R_L. Applying Thévenin's theorem, V_{cc} turns out to be the V_{oc} and R_L becomes the Z_{th} of the theorem, thus the Thévenin substitute for the circuit in Figure 3 would be the circuit shown in Figure 4. We can now draw in the load line for the transistor as shown in Figure 5.

Naturally, the more complex linear networks will require a bit more figuring and will establish the reason for labeling Thévenin's voltage as V_{oc}, or open circuit voltage, rather than calling it the unloaded divider voltage or something else. However, as you have just seen, the figuring will involve only some very basic mathematics with which the electronic technician is (or should be) very familiar. There are other methods of analyzing complex linear circuits; but, they involve simultaneous equations which are time consuming; and, beyond the scope of this article.

As an example of a more complex circuit, let us consider the circuit in Figure 6. The procedure, when using Thévenin's theorem and analyzing a complex circuit, is to progressively apply the theorem to portions of the circuit until all elements of the

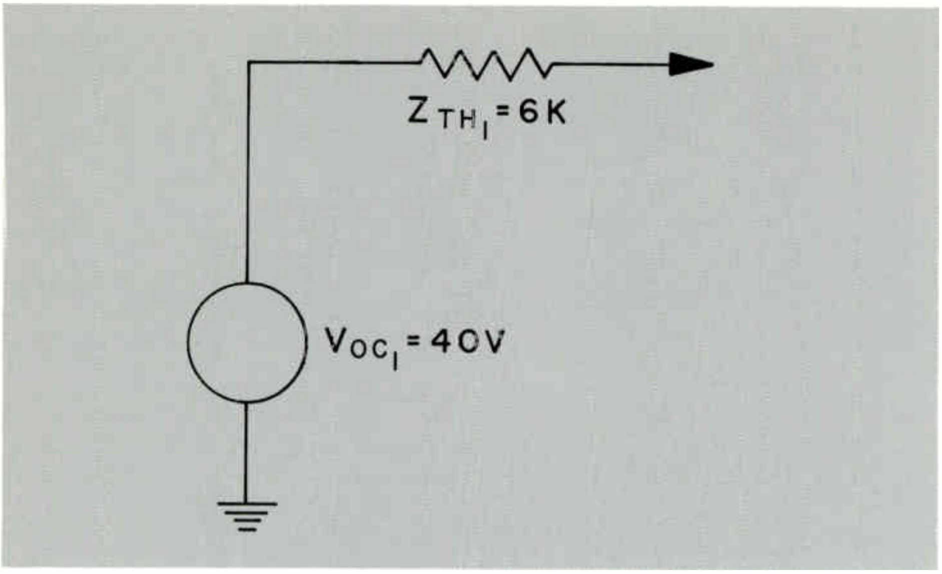


Figure 7. Thévenin's equivalent for that portion of the circuit in Figure 6 up to point "A".

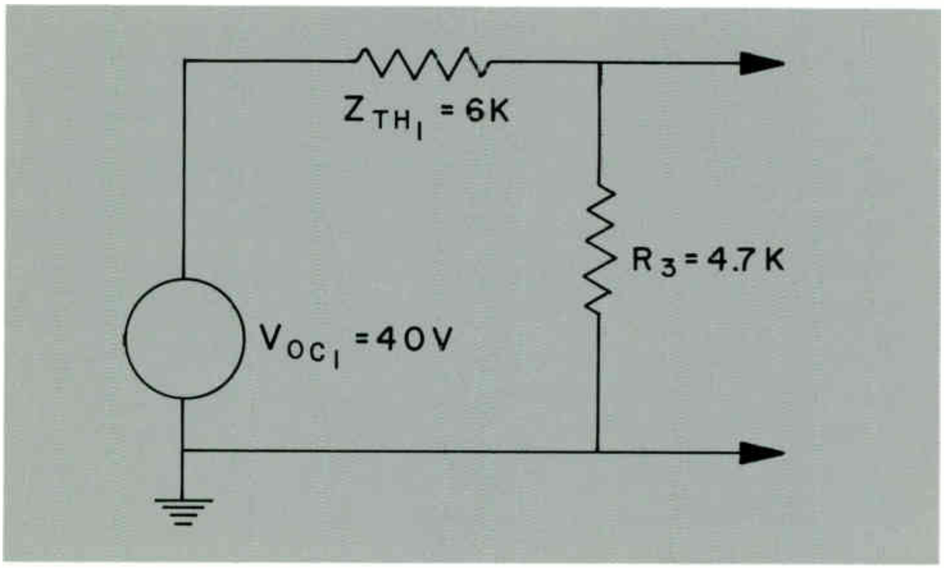


Figure 8. The circuit in Figure 6 redrawn with portion "A" replaced with the Thévenin equivalent.

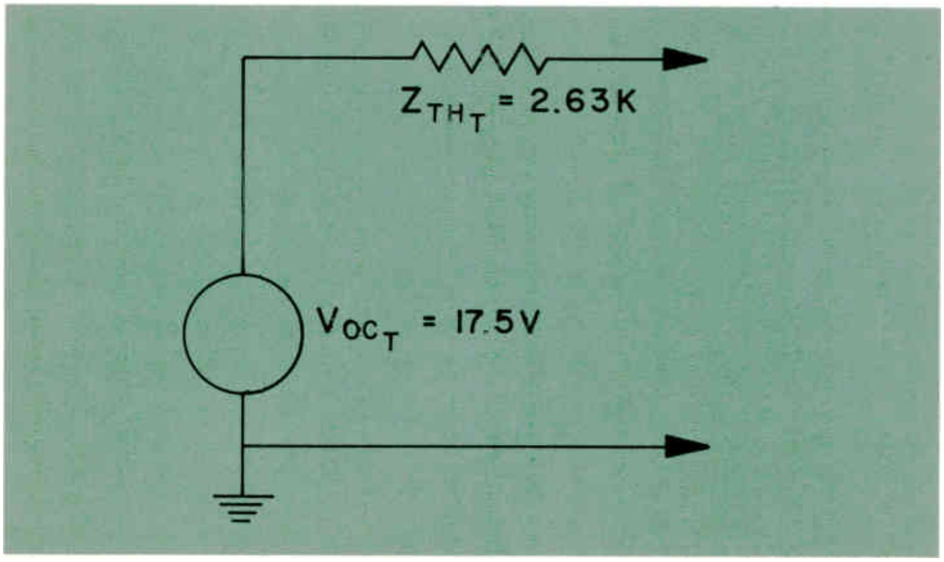


Figure 9. Thévenin's equivalent for the entire circuit in Figure 6.

circuit have been considered. If in Figure 6 then, we break the circuit at point "A", we can solve for V_{oc} and Z_{th} up to this point. In the interests of clarity, let us call the open-circuit voltage and impedance up to this point V_{oc_1} and Z_{th_1}, and the open circuit voltage and the impedance of the entire circuit V_{oc_t} and Z_{th_t}.

Thus:

$$V_{oc_1} = V_2 + \frac{(V_1 - V_2)\ R_2}{R_1 + R_2}$$

$$= -50\text{ V} + \frac{[100\text{ V} - (-50\text{ V})]\ 15\text{ k}}{15\text{ k} + 10\text{ k}}$$

$$= -50\text{ V} + \frac{150\text{ V} \times 15\text{ k}}{25\text{ k}}$$

$$= -50 + 90\text{ V}$$

$$= 40\text{ V}$$

$$Z_{th_1} = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$= \frac{15\text{ k} \times 10\text{ k}}{15\text{ k} + 10\text{ k}}$$

$$= \frac{150\text{ k}}{25\text{ k}}$$

$$= 6\text{ k}$$

The Thévenin equivalent then, for that portion of the circuit in Figure 6 up to point "A", is the one shown in Figure 7.

We can now redraw the circuit in Figure 6, replacing that portion of the circuit up to point "A" with its Thévenin equivalent. This gives us the circuit shown in Figure 8. We can now apply Thévenin's theorem to this circuit and obtain our original objective; ie, a complete analysis of the circuit in Figure 6.

Thus:

$$V_{oc_t} = \frac{V_{oc_1} \times 417\text{ k}}{Z_{th_1} + 4.7\text{ k}}$$

$$= \frac{40\text{ V} \times 4.7\text{ k}}{6\text{ k} + 4.7\text{ k}}$$

$$= 17.5\text{ V}$$

$$Z_{th_t} = \frac{Z_{th_1} \times R_3}{Z_{th_1} + R_3}$$

$$= \frac{6\text{ k} \times 4.7\text{ k}}{6\text{ k} + 4.7\text{ k}}$$

$$= 2.63\text{ K}$$

The open circuit voltage (V_{oc}) and the impedance (Z_{th}) then for the circuit in Figure 6 is 17.5 V and 2.6 k, respectively, and the Thévenin equivalent circuit is the one shown in Figure 9.

From the foregoing, it should be apparent that in analyzing complicated circuits we open the circuit so that we consider only two supplies and their resistances at a time. Look at the circuit in Figure 10. Here we would open the circuit at point "A", take V_1 and R_1 and V_2 and R_2 and simplify them into one voltage supply and its series resistance. To this we would add the next supply and its series resistance, apply the procedure of Thévenin and find this new equivalent, and so on, until we had simplified the entire circuit.

It is not difficult to use Thévenin's theorem once you understand it. We hope that in this article we have given you a better understanding of the theorem and a new tool for circuit analysis.

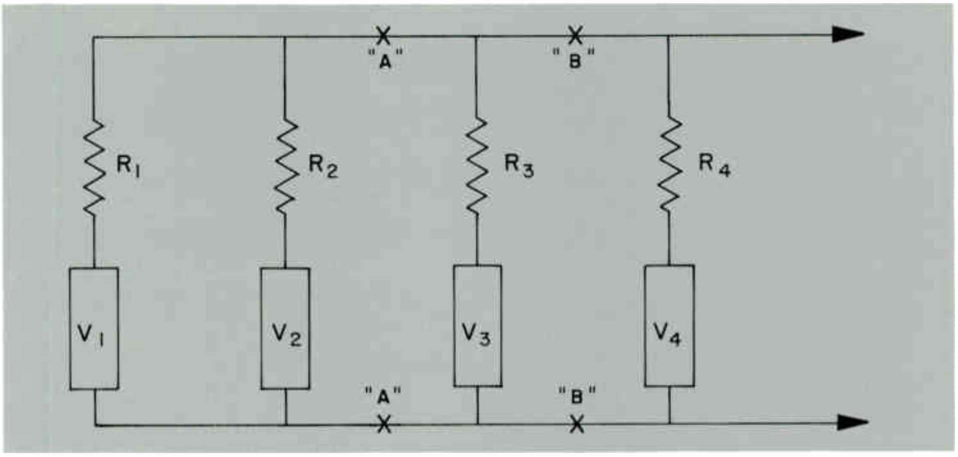
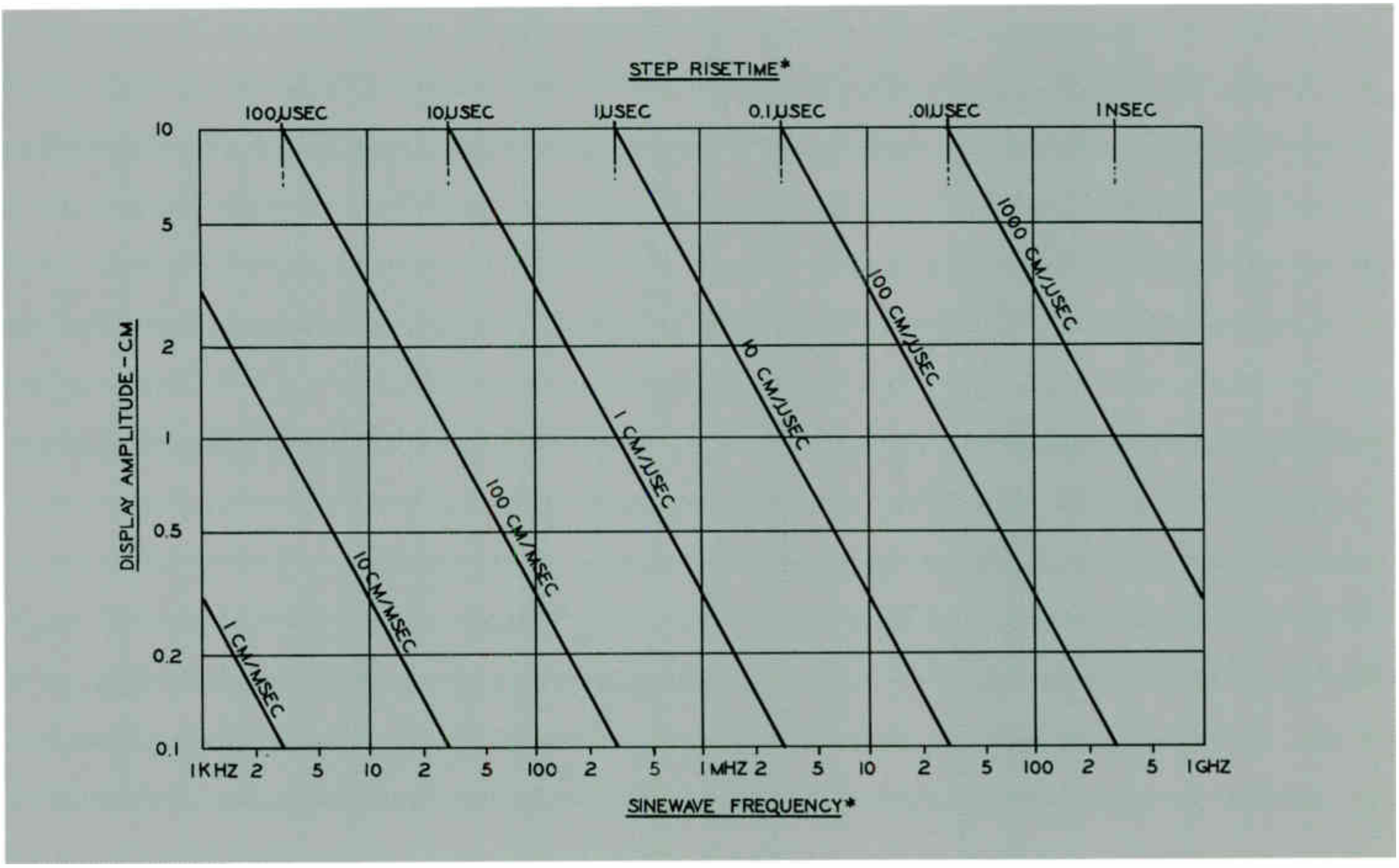


Figure 10. When using Thévenin's theorem to analyze a complicated circuit, open the circuit so that only two supplies and their associated resistors are considered at a time.

WRITING SPEED IN PRACTICAL TERMS



*If the principal spot velocity component is vertical. This chart was computed for 10-90% risetime displayed at about 55° angle from the horizontal and for sinewaves having a peak to peak amplitude about 3X the width of one cycle, to minimize the effect of the spot velocity vector introduced by the time-base.

HOW TO USE THE CHART

Use any two factors to find the third.

Example 1: Determine what oscilloscope/camera system is required to photograph, on a single-shot basis, a display of 100 MHz sinewaves on 6 cm high.

Reading up from 100 MHz and across from 6 cm, we find the intersection to be somewhat beyond 1000 cm/µs diagonal. If the fastest recording system available has a single-shot writing speed of 300 cm/µs, it becomes evident from the chart that the maximum amplitude of 100 MHz sinewaves that can be fully recorded is about 1 cm. Larger amplitudes may record at the peaks, but not at the "zero" crossing.

Example 2: A storage oscilloscope having a single-shot writing speed of 1 cm/µs is to be used to display a single transient having a risetime of 200 ns. What is the maximum amplitude that will allow the entire leading edge to be stored?

Reading down from 0.2 µs (note that 0.2 µs would be to the *left* of 0.1 µs) to intersect with the 1 cm/s line, we find that about 2 mm is the maximum 100% amplitude that will assure storage of the 10-90% risetime with a single sweep. However, if gaps in the trace are allowable, a larger amplitude may be attempted.

SERVICE NOTES

TYPE W HIGH-GAIN DIFFERENTIAL COMPARATOR UNIT—CALIBRATION INFORMATION

Some confusion exists concerning Step 6 of the calibration procedure, Adjust DC Level R280, on page 5-3 in the Type W Unit's Instruction Manual. In step "a," you are instructed to connect a VOM between the emitter and connector leads of Q184. The problem is that the manual fails to point out that there is a test point installed in the ceramic strip nearest the amphenol connector in the Type W Unit and this test point is at the emitter lead of Q184. Some in attempting to perform this step are mistakenly connecting to the top of R281. Trying to adjust for 6 volts differential between this point and the collector of Q184 will lead to frustration. The reading will never be less than approximately 9 volts. The required reading must be made directly between the emitter and collector leads of Q184. Figure 1 shows a view through the rear panel of the Type W Unit. The points to which the VOM must be connected when adjusting the DC level of R280 are clearly identified.

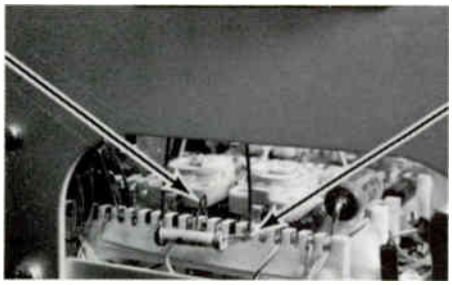
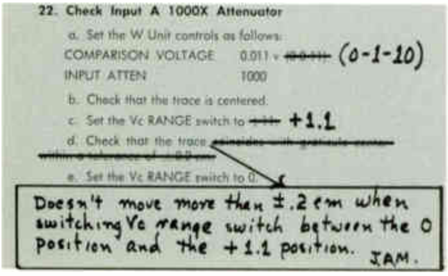


Figure 1. Arrows indicate the points to which the VOM must be connected when adjusting the DC level of R280.

We also call your attention to a correction to Step 22, Check Input A 1000X Attenuator, on page 5-8 of the calibration procedure of the Type W Unit. Change the information in your manual to agree with the following:



22. Check Input A 1000X Attenuator

a. Set the W Unit controls as follows:

COMPARISON VOLTAGE 0.011 v ~~[illegible]~~ (0-1-10)

INPUT ATTEN 1000

b. Check that the trace is centered.

c. Set the Vc RANGE switch to ~~[illegible]~~ +1.1

d. Check that the trace ~~[illegible]~~

e. Set the Vc RANGE switch to 0.

Doesn't move more than ±.2 cm when switching Vc range switch between the 0 position and the +1.1 position. JAM.

TYPE 422 OSCILLOSCOPE WITH BATTERY PACK — BATTERY PACK VOLTAGE CHECK

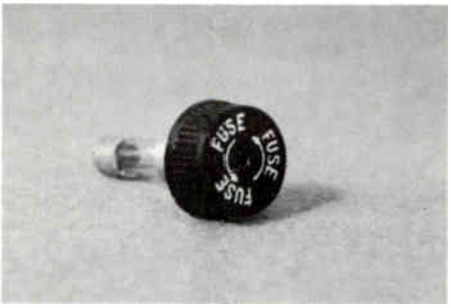


Figure 2. Type 422 Oscilloscope 3-ampere fuse holder with the thin-shell back pierced to allow insertion of a VTVM lead.

Here is a simple method for checking, under normal load conditions, the charge remaining in the battery pack of a Type 422 Oscilloscope.

First modify the 3-ampere fuse holder by piercing a hole thru the thin-shell back (see Figure 2). The thin-shell is composed of a plastic material and quite easily pierced with a metal scribe. To check the battery voltage, turn the POWER MODE switch to the INT BATT. position, turn the front panel POWER switch to ON, and insert one lead of a VTVM in the hole pierced in the 3-ampere fuse holder and connect the other lead to ground.

This method allows an accurate check of battery-pack voltage without removing the pack or power supply from the instrument.

TYPE 527 AND TYPE RM527 WAVEFORM MONITORS — USE WITH A GENERAL ELECTRIC TYPE TV83 DEMODULATOR

The following information concerns Type 527 and Type RM527 Television Waveform Monitors located in television transmitter installations, and then, only when they are used in conjunction with a General Electric Type TV83 Demodulator to monitor percent of modulation.

The flag pulse produced by the TV83 Demodulator will charge the coupling capacitor (C29) in the Type 527 and Type RM527 to a greater-than-normal value. This overcharge will exist for about 2 ms. While it exists, the over-charge will deactivate the Trigger and DC Restorer circuits in the Type 527 and Type RM527. During this period, the black level of the waveform under observation will be displaced about 30 IRE units above or below its normal level.

The solution to the problem is:

1. In the Sweep Trigger circuit of the Type 527 or Type RM527, remove the cathode lead of D32 (a 6061 diode) from ground.
2. Connect the cathode lead of a second 6061 diode (Tektronix part number 152-0061-00) to the cathode lead of D32.
3. Connect the cathode lead of the new diode to ground.
4. Install a 560 k ½ W, resistor (Tektronix part number 315-0564-00) between the junction of the two diodes and the —140 V supply.

(Figure 4 is a partial schematic showing the above four steps.)

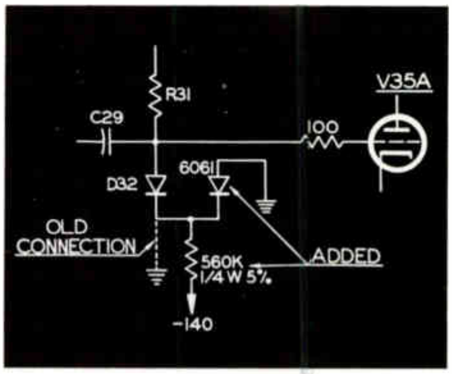


Figure 3.

5. In the DC Restorer portion of the Vertical Amplifier circuit, change the capacitor, C582, from a 100 pF to a 0.0033 μF capacitor (Tektronix part number 283-0051-00).

If the instrument you are concerned with is a Type 527 with a serial number below 745, or a Type RM527 with a serial number below 1190, we suggest you consult your Tektronix Field Engineer before attempting the above improvements.

BENT BNC CONNECTORS

Occasionally a female BNC connector will encounter an impact and become bent so it is no longer round. Often you can avoid the tedious and time-consuming job of replacing this damaged connector. If the connector is not too badly bent, the driver end of an Excellite #6, 3/16" nut driver makes an excellent tool for straightening it. The driver has just the right outside dimension to allow its insertion in the connector. After insertion, a little judicious wobbling will generally return the connector to a usable condition.

USED INSTRUMENTS FOR SALE

1—Type 80 Vertical Plug-In Unit, sn 3468; 1—Type D Plug-In Unit, sn 10641. Contact: Mr. Fred Morelli, Fabri-Tek, Inc., 705 Keller Avenue South, Amery, Wisconsin 54001.

1—Type 127 Power Supply, sn 1168; 2—Type E Plug-In Units, sn 4827 and 4829. Contact: Dr. S. C. Wang, Columbia University, Pharmacology Department, 630 West 168 Street, New York 1, New York. Telephone: 212—579-3577.

1—Type 132 Power Supply; 1—Type O Operational Amplifier. Contact: Dr. Neil Moore, Comparative Cardio Vascular Studies Unit, Philadelphia, Pennsylvania 19104. Telephone: 594-8897.

1—Type 310A Oscilloscope, sn 017388. Instrument is four years old and in very good condition. Contact: Mr. Bernard Burton, 4-Star Television, 4030 Radford Avenue, Studio City, California. Telephone: 213—766-4151, ext. 385.

1—Type 503 Oscilloscope, sn 5042, still new. Price: $550.00. Contact: Mr. William Larsen or Mr. Donald Ball, Ilg. Elec. Ventilating, 2850 N. Pulaski, Chicago, Illinois. Telephone: 312—KI 5-1520.

1—Type 514AD Oscilloscope with flat tube. Instrument is in good condition. Offers requested. Contact: Mr. Charles C. Littell, Jr., Engineering Associates, 434 Patterson Road, Dayton, Ohio 45419.

1—Type 531A Oscilloscope, sn 025602; 1—Type CA Plug-In Unit, sn 063558. Instruments are two years old and in very good condition. Contact: Mr. Cox, F. Clair Morgan Company, 1831 W. 9 Street, Los Angeles, California 90006. Telephone: 213—DU 7-3301.

1—Type 575 Oscilloscope, sn 009427. The oscilloscope is in excellent condition, is 10 months old and used very little. Will accept best offer. Contact: Mr. Bob Fisher, Buyer, Preston Scientific, 805 E. Cerritos, Anaheim, California 92805. Telephone: 776-6400.

Nuclear Data is offering the following instruments for sale. The equipment is in good condition. Contact: Mr. George Bryson, Production Control Manager, Nuclear Data, Inc., 100 W. Golf Road, P. O. Box 451, Palatine, Illinois 60067. Telephone: 312—529-4600.

Type	Price
Type 133 Power Supply	
sn 437	$300
sn 432	300
sn 478	300
sn 441	300
sn 485	300
sn 477	300
sn 488	300
sn 439	300
sn 536	300
sn 486	300
sn 440	300
sn 537	300
sn 443	300
sn 634	300
sn 532	300
sn 476 (never used)	350
sn 479 (never used)	350
sn 480 (never used)	350
sn 442 (never used)	350
sn 364 (never used)	350
Type E Plug-In Unit	
sn 6296	95
sn 6043	95
sn 6323	95
sn 6330	95
sn 6322	95
sn 5665	95
sn 6020	95
sn 6044	95
Type T Plug-In Unit	
sn 3121	120
sn 3229	120
sn 3094	120
sn 3116	120
sn 3120	120
sn 3092	120
sn 3095	120
sn 3452 (never used)	150
sn 3453 (never used)	150
sn 3454 (never used)	150

1—C12 Oscilloscope Camera, sn 007550. As is, $125.00. Camera has an Ilex f/1.9 lens and Polaroid flat-pack back. The lens shutter is stuck half way open and the entire camera assembly needs cleaning. A factory reconditioning job will make this a good serviceable camera at a total cost considerably under that of a new one. Contact: Mr. John LeBeau, Machine Dynamics Company, 660 S. Arroyo Parkway, Pasadena, California 91101. Telephone: 213—661-2547.

1—Type 543A Oscilloscope, sn 4065. Excellent condition. Price $950.00. Contact: Mr. Art Bone, WJRT-TV, 2302 Lapeer Road, Flint, Michigan 48503. Phone: 313—239-6611.

1—Type 585A Sweep Delay Oscilloscope, sn 10457; 1—Type 82 Dual-Trace Plug-In Unit, sn 7446; 2—P6028 High Impedance Probes; 1—5" round polarized viewing hood. These instruments were purchased new in November, 1965. Make offer. Contact: Mr. Irwin H. Franzel, Autotronics, Inc., Ridgefield, New Jersey. Phone: 201—943-7163.

MISSING INSTRUMENTS

1—Type 310A Oscilloscope, sn 20218. The instrument was last seen at Scientific Analysis Research, Santa Barbara, California. Contact: Mr. Herb Fischer, Instrument Laboratory, Control Data Corp., 4201 N. Lexington Avenue, St. Paul, Minnesota 55112. Telephone: 612—631-0531, ext. 2298.

1—Type 310A Oscilloscope, sn 14532. It is presumed that this unit was stolen on June 30, 1966. Contact: Mr. Al Kuscher, 1118 Market Street, Philadelphia, Pennsylvania. Telephone: 215—LO 4-0101, ext. 257.

1—Type 316 Oscilloscope, sn 102. Instrument disappeared from Precision Instruments Co. It had a calibration sticker with "G58" on it. Contact: Mr. Don McCaskey, Precision Instruments Company, 3170 Porter Drive, Palo Alto, California. Telephone: 415—321-5615.

1—Type 422 Portable Oscilloscope, sn 1858, which was removed from a car in New York City on July 13, 1966. Contact: Mr. Clyde Cornwell, The Ampex Corp., 75 Commerce Way, Hackensack, New Jersey.

1—Type 422 Portable Oscilloscope, sn 3252, was apparently stolen about July 18, 1966. Contact: National Cash Register Company, 452 Delaware Avenue, Buffalo, New York.

1—Type 516 Oscilloscope, sn 2919. The instrument is believed to have been stolen about July 4, 1966. Contact: Mr. C. E. Batchelder, General Electric Company, 3 Penn Center Plaza, Philadelphia, Pennsylvania. Telephone: 215—LO 8-1800.

1—Type 545B Oscilloscope, sn 4790, disappeared on August 8, 1966, still in its original carton. Contact: Radio Corporation of America, Security Office, Camden, New Jersey.

The following are Tektronix, Inc. owned instruments. They were removed from a Field Engineer's car the night of July 19, 1966, in Baltimore.

Type	sn
549	137
564	7213
453	4245
422/125B	3565
1A1	3443
1L20	235
3A1	9531
3B4	121
C-30	158
Repair Kit	
Miscellaneous connectors.	

USED INSTRUMENTS WANTED

1—Type 524AD, Type 525, Type 527, or Type 529 Television Oscilloscope or Waveform Monitor. Will consider any of the above instruments, but prefer one that has recently been through a Tektronix, Inc. Service Center. Contact: Mr. Steve Little, Audio Visual Center, University of Oregon, Eugene, Oregon. Telephone: 503—342-1141, ext. 2361 or 2362.

1—Type 516 in good condition. Contact: Mr. Henry Stukas, 4446 N. Lowell, Chicago, Illinois. Telephone: 312—545-5977.

1—Type 541A, Type 543A, Type 543B, Type 544, Type 545A, Type 545B, or Type 546 Oscilloscope. With or without a Type L, Type K, or Type CA Plug-In Unit. Please state condition, serial number, and price. Contact John Cone, 775 South Madison, Pasadena, California 91106. Telephone: 213—SY2-5271.

FOR SALE OR TRADE

2—Type 123 Preamplifier Units; 1—Type LM Frequency Meter. Contact: Mr. Gus Winston, 227 Marine Way, Pacifica, California. Telephone: 415—355-6610.

Service Scope

USEFUL INFORMATION FOR

USERS OF TEKTRONIX INSTRUMENTS

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