Service Scope

USEFUL INFORMATION FOR USERS OF TEKTRONIX INSTRUMENTS

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CURRENT MEASURING TECHNIQUES

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Introduction

Modern technology requires measurement capabilities in the fractional nanosecond (10^{-9} second) area. Diodes with switching times well under 100 picoseconds (10^{-12} second) and transistors with f_t (cut off frequency) of over 1000 Mc are presently available.

The sampling oscilloscope provides an excellent tool for the observation of these phenomena provided the signals are presented in a 50 Ω characteristic impedance system. However, it is very seldom that one can load a circuit with 50 Ω either in parallel or in series without disturbing it beyond use. Therefore, one has to provide means to extract the voltage and current waveforms from the circuit without disturbing the circuit to any great extent. The output of this device should present, to the sampling oscilloscope, an undistorted signal on a 50 Ω level.

In the case of voltage measurements, a good high frequency resistor (Ref. 1) may be selected. Provided it is placed in a proper environment, this type of series probe will perform rather well up to 1000 Mc. For the current waveforms, however, the solution is more complicated. Conventional current monitoring devices are restricted to relatively low frequencies either by basic limitations or by stray parameters. For example, the Hall potential in a Hall device is established in approximately 10^{-14} second. However, its inherent stray capacity and flux-linkage patterns prohibits its economical use above a few Mc.

The conventional current transformer with laminated core (Ref. 2) is useful up to a few kc. The tape wound version extends the frequency response and phase correlation to approximately 100 kc.

If the design of a current transformer is based on a TEM (Transverse Electromagnetic Mode) approach however, the basic frequency limitations are overcome and fractional nanosecond speeds can be achieved.

The TEM Current Transformer

A single turn circular winding is inserted in the space between the inner and outer conductor of a coaxial transmission line of impedance Z_0 (Figure 1). For simplicity only half of the lengthwise section is represented. The H (magnetic) field will terminate in a current sheath J in the circular winding.

(Curl H $= \dfrac{\partial D}{\partial t} + J$ since $\dfrac{\partial D}{\partial t} = 0$ inside the winding ∴ curl H = J.)

Also, since H is proportional to I, then $\oint J = I$ and a current I will flow in Z_1 for a single turn winding. At X_3 the current I in the single turn winding will

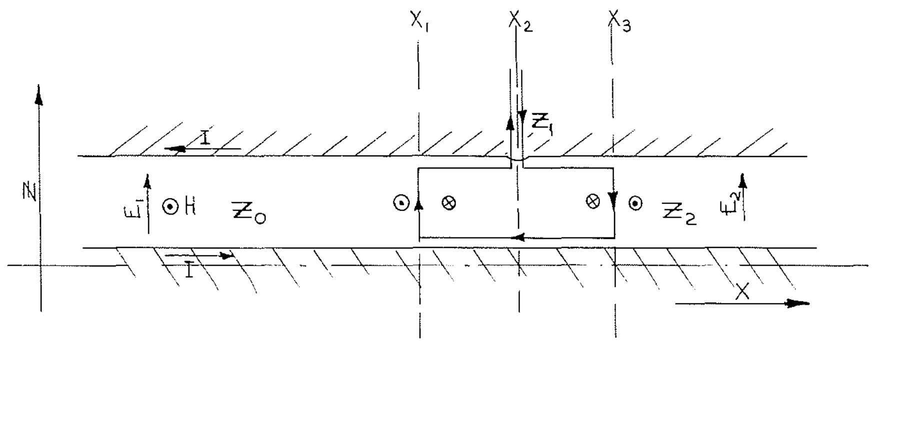


Figure 1. A single-turn winding inserted in the space between the inner and outer conductor of a coaxial transmission line of impedance Z_0.

regenerate H in equal magnitude and according to the principle of super-position $E_2 = E_1 - IZ_1$.

$$Z_o = \frac{E_1}{I} \; ; \; Z_2 = \frac{E_1 - IZ_1}{I} = Z_o - Z_1$$

indicating that the impedance Z_1 is effectively placed in series with Z_o. (Therefore, to maintain a first order matching, the ratio of the diameters of the inner and outer conductor past X_3 in the X direction should be reduced to be equal to Z_2.) A second order capacitive reflection occurs because the E field in going from X_1 to X_3 is confined between the inner conductor and the winding and between the outer conductor and the winding.

Neglecting the winding transit time, for an "n" turn winding $\oint J = I$ would still hold; however, I will be a current I/n per turn. The current through Z_1 is I/n and the series voltage drop reflected in the original E field is $\dfrac{\frac{I}{n}}{n} = \dfrac{I}{n^2}$

Therefore, $Z_2 =$

$$\frac{E_1 - \frac{I}{n^2} Z_1}{I} = Z_o - \frac{Z_1}{n^2}$$

The reflected impedance is proportional to $1/n^2$, similar to the conventional transformer. A true mathematical derivation of these results amounts to a double boundary value problem (Ref. 3 and 4) and is quite involved. However, this is not essential to achieve a basic understanding of the functioning of a TEM transformer.

Up to this point we really have not solved all basic limitations of the transformer, yet the preceding is essential for the understanding of the methods involved in solving them.

Outline of Limitations of Conventional TEM Transformer

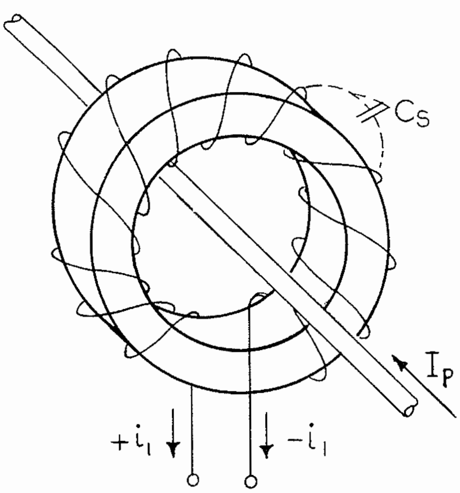


Figure 2. Twelve-turn transformer.

We have a transformer with one primary and n secondary turns (Figure 2). If we introduce a current step I in the primary winding, we will introduce a current step i_n at the *same* time and of equal magnitude in all n turns. The step i_n introduced in a particular turn will propagate in a transmission-line mode around the core in both directions and so will all steps in every turn. The resulting output waveforms at the secondary terminals of the transformer will, therefore, look like Figure 3 indicating a "push-pull" mode out-

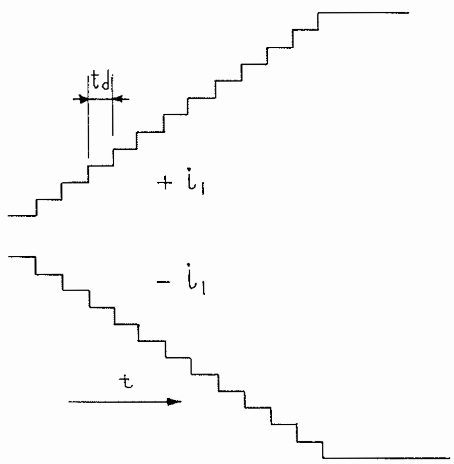


Figure 3. Output of twelve-turn transformer.

put. Here, then, we have the first basic limitation: the risetime of the output waveform will be approximately n times td, where td is the delay of one winding.

The second limitation of the conventional current transformer is the fact that there is a certain amount of stray capacitance (C_s) and inductance (L_s). This will form a distributed L-C circuit that will resonate at a frequency below $\dfrac{0.35}{n \times td}$ (equivalent 3-db point due to the first limitation) and, therefore, give a poor transient response especially when n is large.

Transmission Line Addition Technique

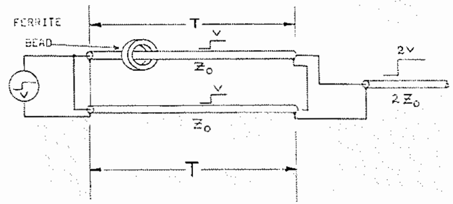


Figure 4. A step V, placed simultaneously on two Z_0 cables, adds the two steps to a 2V step into a $2Z_0$ cable.

In Figure 4, if a step V is placed simultaneously on the two Z_o cables, one can add these two steps to a 2 V step into a 2 Z_o cable, as shown. However, this will work only for a time equivalent to the double delay time (2T) in one Z_o cable because after that the generator will be shorted. One can extend this time span by placing an impedance in the short circuit loop — here done by means of a ferrite core (Refs. 6 and 7).

Solution to First Order Limitations

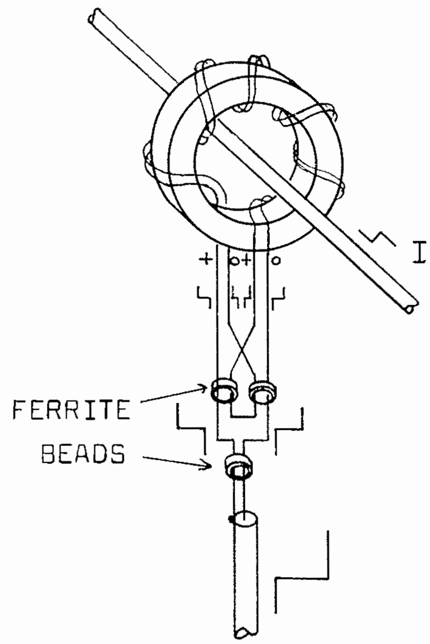
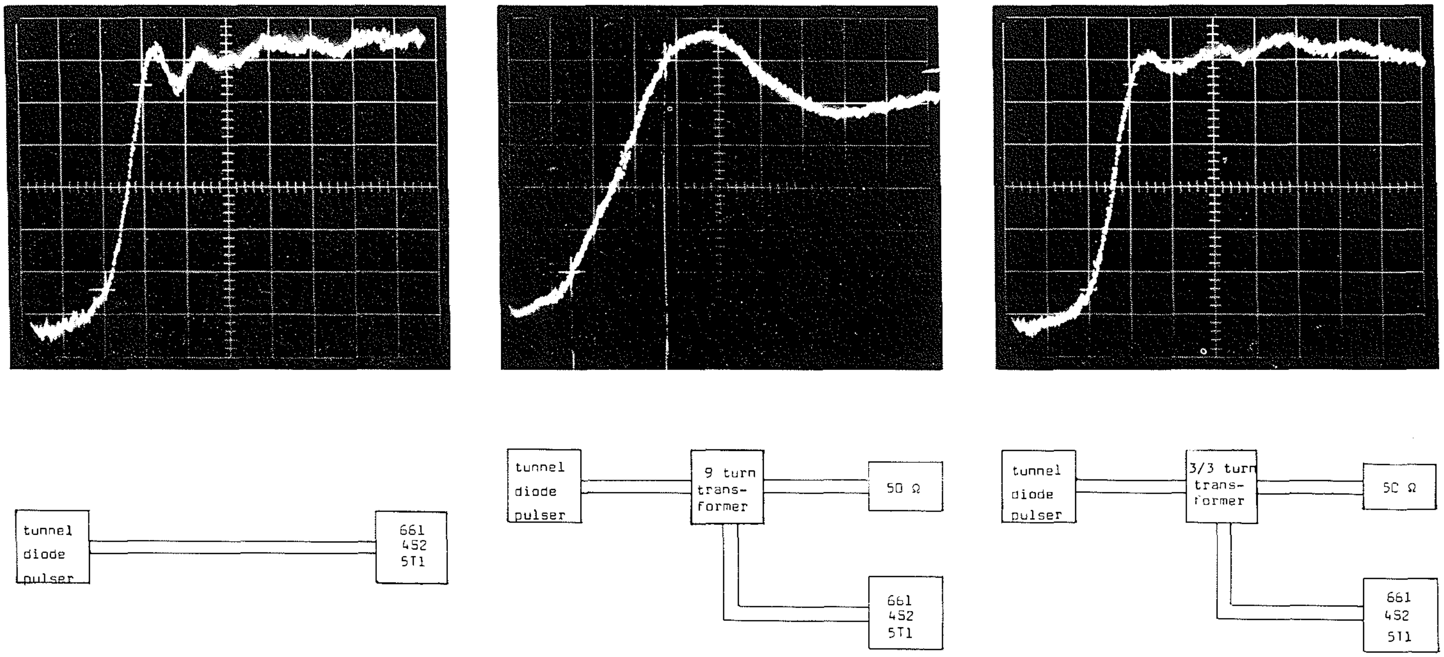


Figure 5. Twelve-turn bifilar winding.

In Figure 5, rather than wind an n turn single winding transformer, two windings each having $\frac{n}{2}$ turns have been wound bifilar, as shown. The four output voltages are then added and supply one single ended signal. The addition is performed with the transmission line addition technique. However, for practical reasons the wires are kept very short and, therefore, the double delay time (2T) is short. One depends mainly on the isolation provided by ferrite beads placed in the short circuit loop. Leads should be kept to the same length to assure time-coincident addition of the signals. By doing this we have achieved two improvements (Figure 6):

(a) The risetime of the output pulse, due to limitation one, has been reduced from n x td to n/2 x td. (This is not exact because the turns in this case will be slightly longer; therefore, td will be slightly greater. However, this effect is small.)



(a) Pulse direct to 4S2.

(b) Pulse coupled to 4S2 via a straight nine-turn transformer on a ½" dia. by ¼" core.

(c) Pulse coupled to 4S2 via 3 x 3-turn transformer on a ½" dia. by ¼" core [same core as used in (b)].

Figure 6. System used to obtain these waveform pictures: Tunnel diode pulser (≈30 psec risetime), Type 661 Sampling Oscilloscope with a Type 4S2 Dual-Trace Sampling Unit and a Type 5T1 Timing Unit, and a Type C-19 Camera. Sweep Time/cm: 0.2 nsec.

(b) The transient response, due to limitation two, has been improved due to the fact that the stray capacitance has been reduced since the two windings at every point on the core move in the same manner voltage-wise [fr (resonant frequency) proportional to $1/\sqrt{c}$] while the inductance and resistance stay essentially the same.

Note that at DC the two windings are in series. The output voltage is the same as that of a conventional n turn transformer. One can use multiple turns through the isolation beads to obtain a large time constant. Note also that one is not limited to 2 windings of n/2 turns per winding. One can use n windings of 1 turn per winding (as long as n/a is greater than 1 and a real number). The limitation is n windings of 1 turn per winding and there the risetime is equivalent to 1 x td or the total propagation time around the core, whichever is greater (Figure 7).

One can build a transformer with a large number of turns to get a long time constant, but at the same time one can get a very fast risetime and good transient response, as will be explained later.

Core Material

Unless a core with a permeability >1 is inserted inside the windings, the transformer action is limited to the double transit time

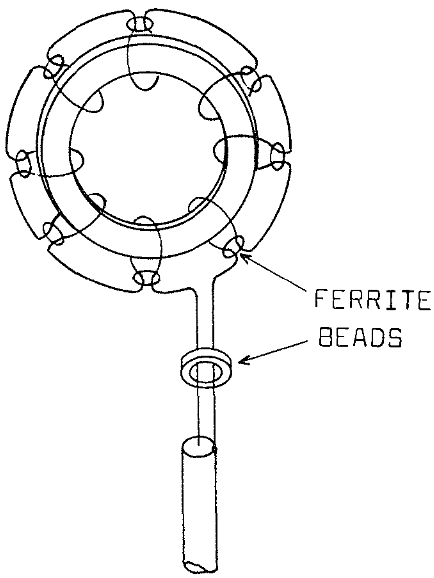


Figure 7. Eight-turn multifilar winding.

of the winding. To extend this time usually for high frequency applications a ferrite core material (Ref. 5) is used. Ferrites are sintered materials, generally of a basically spinel crystalline structure consisting of $MOFe_2O_3$ where M can be of any of the following elements: Co, Ni, Mn, Cu, Mg, Zn, Cd.

Generally the low permeability ferrites have a high resistivity and the high permeability ferrites a low resistivity. Therefore, the high permeability ferrites have higher loss than the low permeability versions. Some typical high frequency ferrite materials are:

		Permeability	*Rho* (Ω *cm*)
Ferroxcube	104	200-250	$>10^5$
	102	250-400	400-600
	101	300-700	250-450
Kearfott	MN30	4,000-6,000	300
	MN60	5,000-10,000	250

The Design of a TEM Current Transformer

In order to design a high speed current transformer, one has to consider several factors; transformer ratio, risetime, low frequency time constant, space available, impedance level, etc. The lumped constant equivalent circuit is represented in Figure 8. Here $R_1 = R_o n^2$; $L = L_o n^2$

R_o is assumed to be a constant proportional to the core losses and expressed in ohms/turn². In practice, however, one might have to use a different R_o for high frequency (and low frequency) calculations depending on material and bandwidth. The values given by the ferrite manufacturers generally refer to the low-frequency losses of the material. They have no consistent

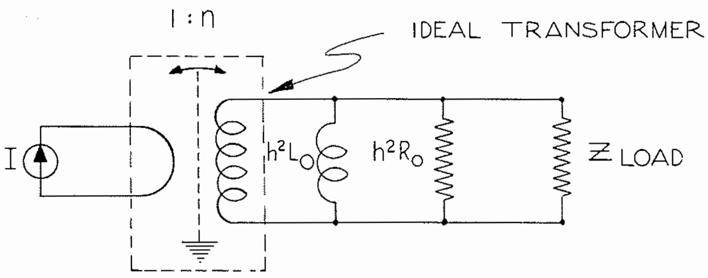


Figure 8. Lumped-constant equivalent circuit of a current transformer.

correlation with the frequency values of R_o. Therefore, these need to be measured for individual materials. Values vary from 20 Ω/n^2 to >500 Ω/n^2 depending on core material and dimensions.

L_o is a constant proportional to the permeability of the core, the cross section and the magnetic length. For a cylindrical core with outer diameter D, inner diameter d and length t, the inductance/turn² can be estimated by: $L_o = 0.2\ \mu t \ln D/d \times 10^{-8}$ $\mu H/n^2$

Z_{in} = the transformed impedance.

The low frequency cut-off is determined by the L/R time constant.

The response will be 3-db down if: $\omega L = 2\pi f L = R$, where R is the total resistance R_p in parallel with L.

$$R_p = \frac{n^2 R_o R_L}{n^2 R_o + R_L}$$

$$f_{3db} = \frac{R_p}{2\pi L} = \frac{R_p}{2\pi n^2 L_o}$$

At this point there will be a 45° phase shift through the transformer.

If accuracy of 1% is required in the transfer ratio, the low frequency response will be limited to a higher frequency. It can be readily verified that:

$$f_{1\%} = \frac{R_p}{.282\pi L_o n^2}$$

The phase shift will be approximately 8.1° at this frequency. If a maximum phase shift of 1° is required the lower frequency response should be limited to a still higher frequency. By performing the necessary calculations one finds:

$$f_{\theta=1^\circ} = \frac{R_p}{.0349\pi L_o n^2}$$

As a practical example, a transformer with a low frequency 3-db point of 10 kc will have a 1% amplitude accuracy above 70 kc and less than 1° phase shift above 570 kc.

From the low frequency point of view it is desirable to have a large number of turns to make L and R_1 large. As previously shown, this limits the risetime.

By splitting the winding into several multifilar turns, as previously outlined, one can maintain the risetime for high speed operation and still have a large L and long time constant since at low frequencies the turns appear in series. The transformer may be used for current measuring purposes as well as for matching two points of different impedance levels. In either case, the transmission line will have a voltage waveform as well since the characteristic impedance is always greater than zero. In order to prevent capacitive coupling of the voltage waveform, the transformer has to be well shielded by a ground plane between the center conductor and the transformer. A perfect shield is not feasible, since this would amount to a shorted turn on the transformer. However, satisfactory shielding can practically be achieved by leaving a narrow gap in the shield.

References

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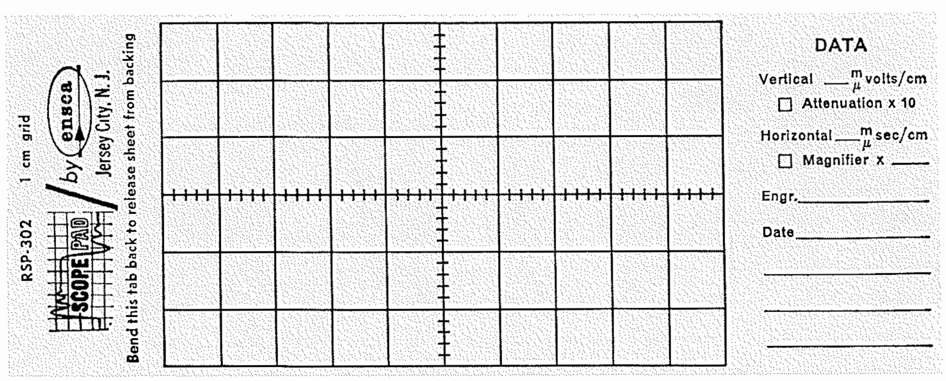
7. Lewis - Wells, MILLIMICROSECOND PULSE TECHNIQUES, Pergamon Press

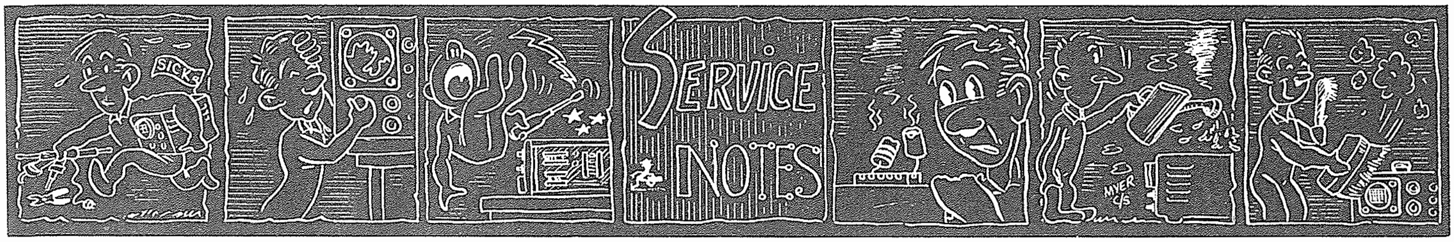
RECORDING WAVEFORMS WITHOUT A CAMERA

If you wanted to make a record of a repetitive waveform displayed on the crt of an oscilloscope and you didn't have a camera, you could stand back with easel and pen, hold up your thumb in Rembrandt-style and sketch away. Or, you could place a sheet of translucent paper over the face of the crt and trace the waveform. The difficulty here, of course, is trying to hold the paper firmly in place and at the same time make the tracing.

One solution to this problem is to use a sheet of "Scope Pad". This is a unique product manufactured and distributed by Ensca, Inc., P. O. Box 253, New York, New York 10023.

"Scope Pad" consists of twenty, translucent, adhesive-backed sheets ruled with a graticule-line grid. At the side of each sheet are spaces for time and amplitude data.





SHORTING PROBLEMS DURING TROUBLE SHOOTING

Chuck Miller of our Field Training group calls our attention to a serious problem that can exist when attempting to trouble-shoot an instrument incorporating high-density (tightly-notched) ceramic strips—see Figure 1.

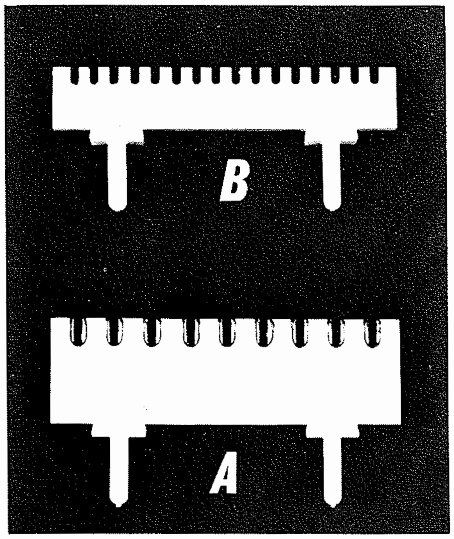


Figure 1. These two ceromic strips are the same length. The conventional strip (a) contains 9 notches, the high-density strip (b) contains 16 notches.

If, in this trouble-shooting, the probe employed uses a large tip—the old-style double-pincher tip for example—the danger exists of shorting out components and possibly destroying expensive transistors, diodes, etc.

A way to minimize this problem is to use the newer and thinner pincher tip (Tektronix Part Number 013-071—see Figure 2). This blade-like, single-pincher tip offers a greater margin of safety against the shorting out of components in crowded areas and the improved pincher tip has greater holding ability. The thin blade design causes a minimum of component displacement during trouble-shooting and facilitates checking difficult-to-reach test points.

This newer pincher tip is designed to be used with the following Tektronix probes:

P6000	P6004	P6008	P6023
P6001	P6005	P6009	P6027
P6002	P6006	P6017	P6028
P6003	P6007	P6022	

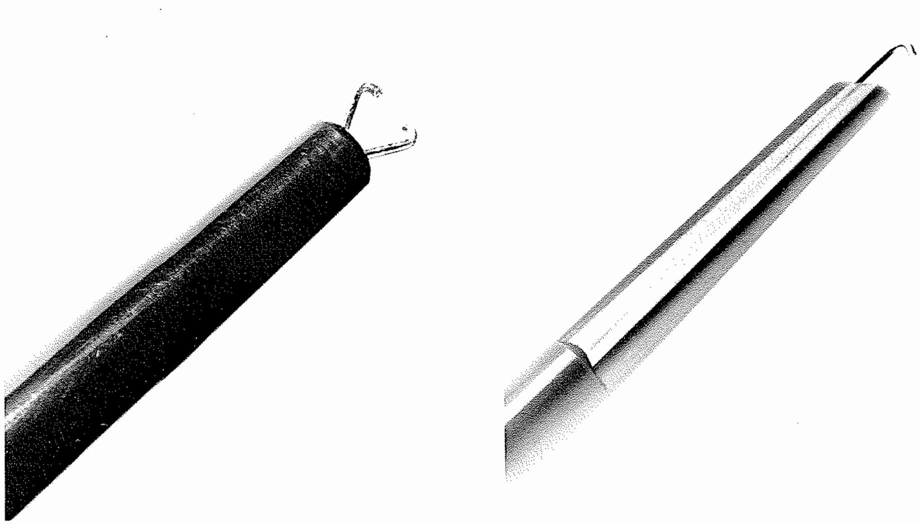


Figure 2. A comparison of the older double-pincher tip (left) and the new thin-blade, single-pincher tip (right). Both shown with pincher extended.

TYPE 575 TRANSISTOR CURVE TRACER — PEAK-VOLTS AUTO-TRANSFORMER IMPROVEMENT

Here is a service that if performed on the Peak-Volts autotransformer (T701 in the collector-sweep schematic) will improve its operation at low collector voltage when the HORIZONTAL VOLTS/DIV control is set to the 0.01 collector-volts position.

Prior to this service the PEAK VOLTS control will not turn down past around 5 cm of volts with the HORIZONTAL VOLTS/DIV control in the 0.01 position. After the service it will turn down to 2 cm of volts and the operation down to and up from this position will be very smooth.

The service consists of lowering the minimum voltage output of the autotransformer, T701. To do this, loosen the screw holding the rotational limit stops and adjust the stops so that counter-clockwise rotation can be made down to the last one or two windings. *Care must be exercised not to allow the contact to run off the end of the windings* as damage could result.

PLASTIC LIGHT SHIELD FOR RECTANGULAR CRT's

A plastic light shield, similar to that used in Tektronix instruments with 5″ round crt's, is available for Tektronix instruments with 5″ rectangular crt's.

The shield is designed to block any entrance of light onto the phosphor via the space between the crt shield and the front panel. Light escaping through this space can prove bothersome in some oscilloscope photography applications.

Designed specifically for the Type RM-561, the shield is equally useful in other Tektronix instruments employing a rectangular glass crt—the Type 567, Type RM567, Type 527, Type RM527 and the Type 561A MOD210C or 210E. This shield is not needed with the ceramic crt since light is shielded by the ceramic envelope and rubber boot.

Tektronix part number of the new light shield is 337-586. Order through your local Tektronix Field Office or your Tektronix Field Engineer.

POWER CONNECTOR BREAKAGE—PREVENTIVE MAINTENANCE

Breakage of the 3-wire power connector on instruments employing a detachable 3-conductor power cord can occur when the instruments are tilted or lifted from the front with the power cord connected.

This breakage can be prevented by recessing the power connector as shown in Figure 3.

Parts needed:

Qty.	Item	Tektronix Part No.
1	aluminum spacer	361-012
2	1¼", 6-32 screw	211-545
2	6-32 Keps nut	210-457

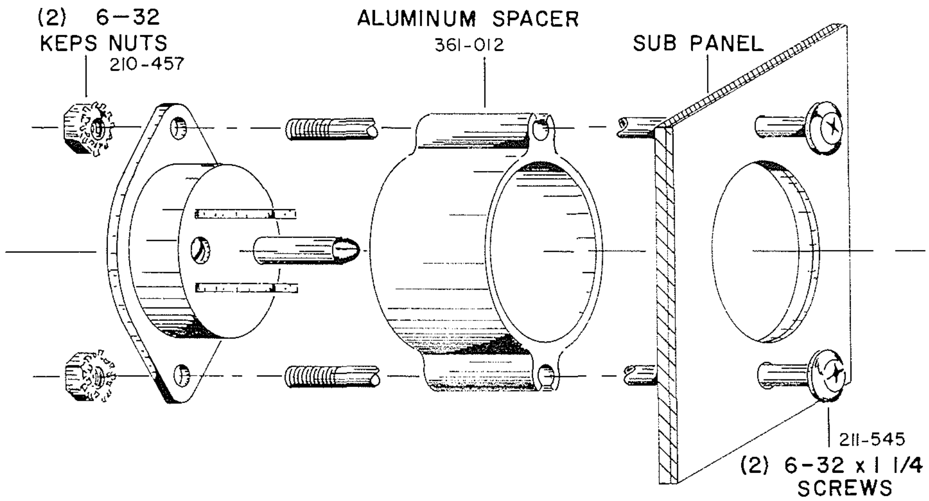


Fig. 3. Pictured instructions for recessing the 3-wire connector on instruments using a detachable, 3-conductor power cord.

TYPE 527 AND TYPE RM527 WAVEFORM MONITOR—VOLTAGE STRESS ON 6EW6 TUBES DURING TURN-ON

When the Type 527 or Type RM527 Waveform Monitor is first turned on, V444 and V544 (6EW6 tubes in the two-stage, push-pull input amplifier) are subjected to quite a voltage stress. This stress can cause excessive cathode deterioration which, in turn, will cause the tube to become gassy. Under this condition the input amplifier will not perform properly and the 6EW6 tubes in the input amplifier are doomed to early failure.

A simple modification to overcome this problem consists of replacing the 0.01 μf/47 k RC network in the grid circuit of both V444 and V544 with a 1N3605 diode (Tektronix Part Number 152-141)—See Figure 4. After the modification, R440, the 47 ohm parasitic resistor will connect directly from the rear wafer of the RESPONSE switch to pin 1 of V444 and the new diode will connect between pin 1 and 2 of V444. Be sure the cathode of the diode connects to pin 2. Repeat these changes in the grid circuit of V544 and the modification is complete.

Gassy 6EW6 tubes in the V444 and V544 positions cause hook and tilt in the displayed waveform. This malfunction is most apparent when viewing the vertical blanking pulse portion of the transmitted composite-video signal. To determine whether the fault is in the transmitted signal or in the Waveform Monitor, position the vertical-blanking-pulse waveform near either the top or bottom of the crt. This increases the current through either V444 or V544, and if they are gassy the hook and tilt will be much more pronounced.

If there is no appreciable change in hook or tilt, V444 and V544 are probably all right and the difficulty is most likely in the transmitted signal.

Type 527's with serial numbers above 744 and Type RM527's with serial numbers above 1189 have this modification installed at the factory. Also, the following serially numbered instruments were modified out of sequence:

Type 527:

645	724 through 726
646	739
674	

Type RM527:

730 through 732	1066
889	1071 through 1074
908	1097
980	1116
997	1121
1020	1122
1035	1138 through 1141
1036	1143 through 1145
1038	1147 through 1159
1042	1162 through 1188

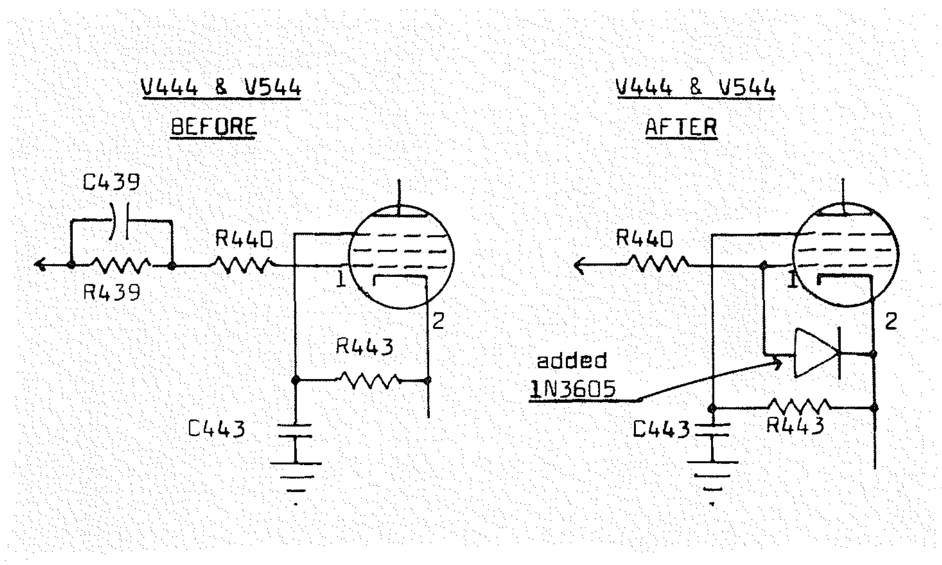


Figure 4. "Before" and "After" schematic for replacing the 0.01 μf/47 k RC network, in the grid circuit of both V444 and V544, with 1N3605 diodes.

USED INSTRUMENTS FOR SALE

1 Type 513D Oscilloscope, s/n 1672 with new crt. Ray Case, 8146 Matilija, Panorama City, California, phone 780-0322. Price: $350.

1 Type 317 Oscilloscope, s/n 346. Instrument like new. Will sacrifice for $500. Mr. Rising, 53 Hundreds Circle, Wellesley Hills, Massachusetts. Telephone: Area Code 617, 235-0385.

1 Type 535 Oscilloscope, s/n 6095 with a Type 53/54C Plug-In Unit, s/n 9668. Price: $1200. R. L. Bennett, Todd-AO Corporation, 1021 Seward Street, Hollywood, California. Phone: HO 3-1136.

1 Type 511AD Oscilloscope, s/n 4718 with P510 Attenuator Probe. Recently repaired, modified and recalibrated at Tektronix Repair Center. R. J. France, Control Science Corporation, 5150 Duke Street, Alexandria, Virginia.

1 Type 502 Oscilloscope, s/n 4211 and 2 Type 122 Preamplifiers, s/n's 5494 and 5495. Instruments have seen little use. C. R. Smith, President, Capital Sales Ltd., P. O. Box 266, Fredericton, New Brunswick.

1 Type 81 Plug-In Adapter (for use with Type 580 Series Oscilloscopes). New, never used. Dalmo Victor, Belmont, California, Attention: Mr. Wells.

1 Type 532 Oscilloscope, s/n 5100; 1 Type 53G Plug-In Unit, s/n 100 and 1 cart. Mr. Richardson, N.J.E. Corporation, 20 Boright Avenue, Kenilworth, New Jersey.

1 Type 67 Plug-In Unit, s/n 2596. Never used. In original packing. Mr. Leo Katz, Electronics Laboratory, Notre Dame Hospital, 1560 Sherbrooke Street East, Montreal 24, Quebec, Canada. Telephone 525-6363 — Local 576.

1 Type 190A, s/n 6048; and 1 Type 190B, s/n 6952 Constant-Amplitude Signal Generators. A. Samuelson, Electric Service Systems, 5555 Old Highway 5, Minneapolis 24, Minnesota. Telephone: 941-2200.

1 Type 517, s/n 508, High Speed Oscilloscope. For sale, lease or rent. Recently overhauled by Tektronix, Inc. Michael J. Haddad, Surface-Air Electronics, 138 Nevada Street, El Segundo, California. Telephone SP2-1469.

1 Type 82 Plug-In Unit, s/n 2307. Joel Backer, Magnetic Research Corporation, 3160 West El Segundo Boulevard, Hawthorne, California. Telephone: OS 5-1171.

1 Type 513D Oscilloscope, s/n 691. Price: $450. Donald Fleischer, 503 Tennis Avenue, Ambler, Pennsylvania. Telephone: MI 6-0580.

1 Type 502 MOD104 Oscilloscope, s/n 2840. Dr. Peckham, Eye Research Foundation, 8710 Old Georgetown Road, Bethesda, Maryland. Phone: 301-656-1527.

USED INSTRUMENTS WANTED

1 Type 310 Oscilloscope. E. C. Webb, Lakewood Manufacturing, 25100 Detroit, Westlake, Ohio. Telephone: Area 216-TR1-5000.

1 Type 321 Oscilloscope, John Sumner, 728 N. Sawtelle, Tucson, Arizona.

1 Type 515 or Type 515A Oscilloscope. William Macoughtry, Code 536, NASA, Goddard Space Flight Center, Greenbelt, Maryland.

1 Type 524AD Oscilloscope. H. Holland, H. W. H. Electronic Service, 7217 Gulf Boulevard, St. Petersburg Beach, Florida.

1 Type 310, 316 or 515 Oscilloscope. $225 maximum. George Reeves, 4273 W. Oak Avenue, Fullerton, California.

Mr. John Bowser of the Smith Corona Corporation at 301 N. Michigan Street, Chicago, Illinois, reports the theft of a Type 310A Oscilloscope, s/n 17926. The instrument disappeared from the car of one of their servicemen while it was parked in the back of their office building. Mr. Bowser would appreciate hearing from any of our readers who have any information on the whereabouts of this instrument.

Another car prowl, this one also in Chicago, produced a Type 516 MOD 108B for the vandals. Serial number of this instrument is 1930 and it is the property of the General Electric Company, 840 S. Canal Street, Chicago, Illinois. The theft occurred on Tuesday, November 26, 1963, while the car was parked outside their building. Information on the location of this instrument should be relayed to Mr. O. Nickerson of the General Electric Company at the address noted above.

This last report of a missing instrument concerns one that disappeared on January 1, 1963 and has just been called to our attention.

This oscilloscope, a Type 310A, s/n 012960, belongs to Huyck Systems located on Wolf Hill Road in Huntington, Long Island, New York.

Mr. Al Richert of Huyck Systems tells us that the oscilloscope was at Lockheed in Burbank, California at the time of its disappearance and he asks our readers in that area to be on the lookout for it.

Mr. Richert is the man to contact if you have any information about this oscilloscope.

Service Scope

USEFUL INFORMATION FOR

USERS OF TEKTRONIX INSTRUMENTS

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