



TEKSCOPE

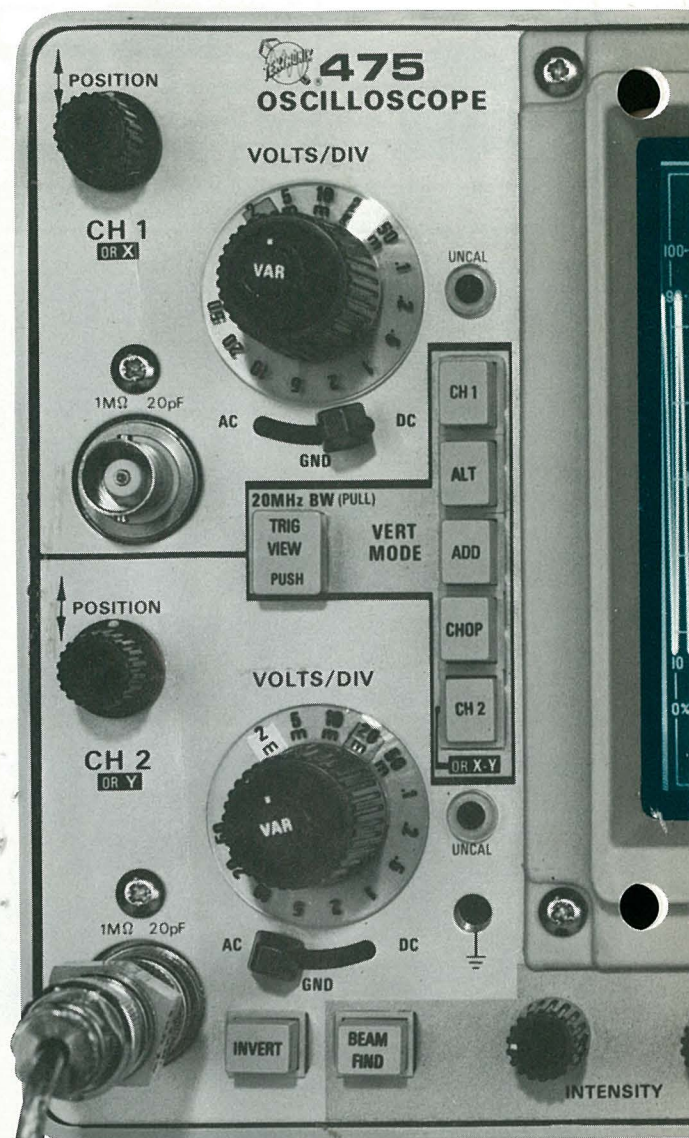
VOLUME 4

NUMBER 5

- THE NEW LOOK IN PORTABLES
- THE OSCILLOSCOPE CONTROLLED COUNTER
- DIFFERENTIAL AMPLIFIER TECHNIQUES
- SERVICING THE 432/434 OSCILLOSCOPES



the NEW LOOK in PORTABLES



We're living in a world that's on the go, and for the engineer on the go, the portable oscilloscope has become an essential part of his servicing equipment. Tektronix, Inc., the company that put performance in portability, now introduces two new portable instruments, the 465 and 475, to provide even more portable performance. Contrary to what you might expect, these instruments, including all of their new features, are available at a lower cost than any other comparable instrument.

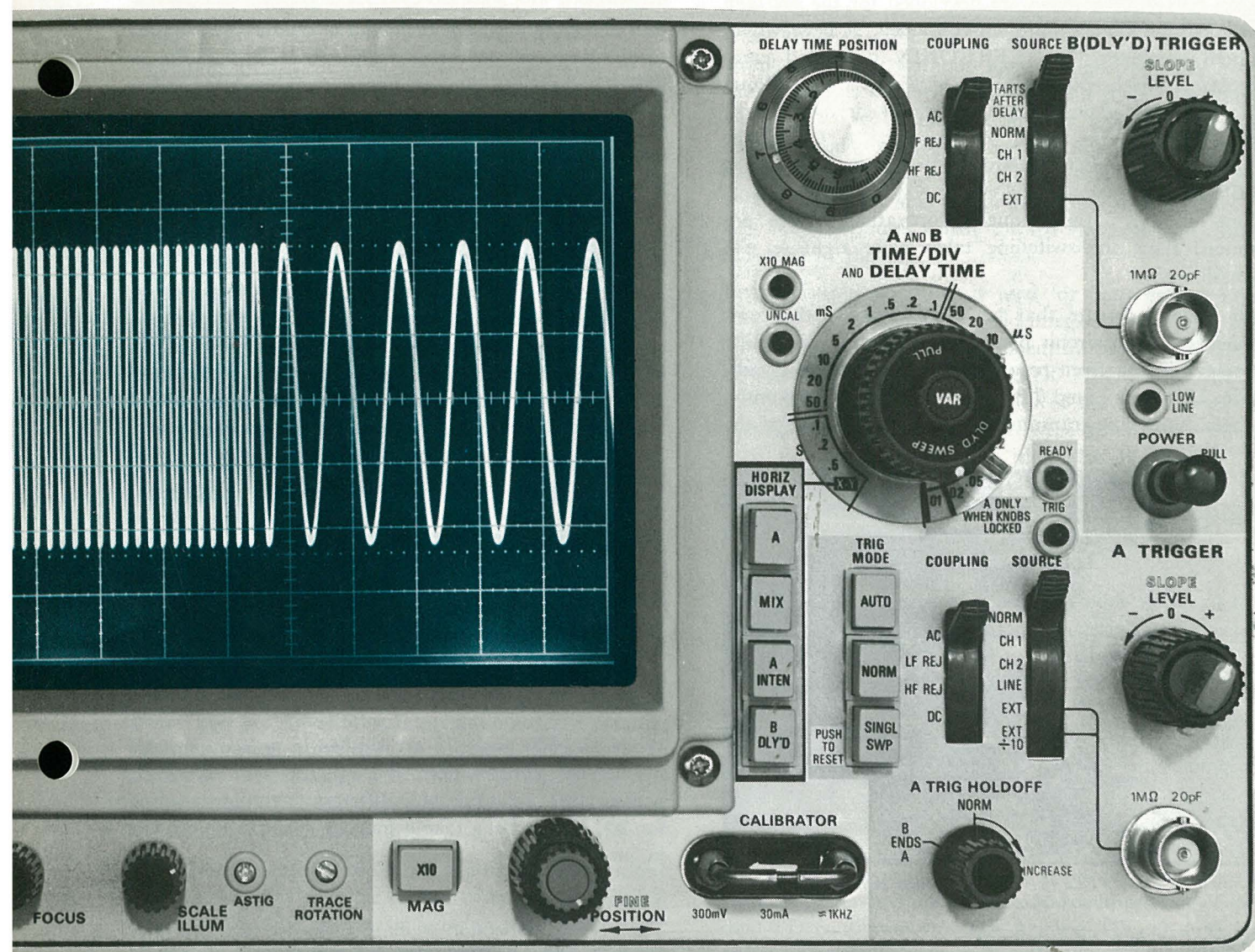
Pictured above (in full size) is the new look in portable oscilloscopes. Until now, portable scopes have been characterized by a small CRT located in the upper left hand corner of the front panel. The 465 and 475 feature

Cover: The new Tektronix 475 Portable Oscilloscope is shown in the cockpit of the Boeing 747. The big 8 x 10-cm screen, shown at top, makes waveform viewing easy.

a large 8 x 10 centimeter CRT located in the center of the front panel. This placement provides a natural division of the front-panel controls according to their functions: vertical controls are to the left, horizontal controls to the right, and display controls below the CRT.

Built From the Inside Out

In the past, buying a portable instrument often meant that, while you bought an instrument that packed a lot of performance into a small package, the components were likewise packed into a small area. As a result, most maintenance work had to be performed with the boards in the instrument and replacement of some sub-assemblies became a major task. Now, this is all changed. The 465 and 475 are literally built from the inside out. Central core of these instruments is a unique U-channel frame which cradles the CRT and its shield (see Fig. 1). This U-channel frame is secured to both the front and rear subpanels to form an extremely



rugged mechanical substructure. The circuit boards and electronic subassemblies are mounted to this U-channel frame. As a result, the mechanical parts which require little or no maintenance, are located in the less accessible center areas of the instrument while the important electronic components are easily accessible on the outside. The single piece cabinet completes the rugged mechanical package for the 465/475.

The circuit boards are easy to remove for service since they are located on the outside of the U-channel frame. External connections to the boards are made with quick-disconnect type connectors. The boards are designed to be self-contained; i.e., the switches, indicator lights, and variable controls associated with each board are mounted directly on the boards rather than on the chassis or on the front panel. Not only does this make the boards easier to remove, but it also reduces the number of interconnections necessary between boards and subassemblies, resulting in improved reliability.

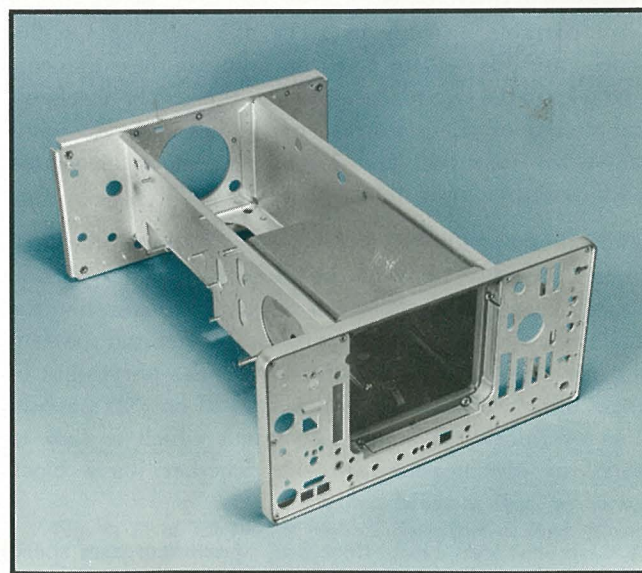


Fig. 1. U-channel frame provides strong central core for instruments.

Two new components were developed for the 465/475 to make the boards more self-contained. A new switch, which combines the TEKTRONIX developed cam-actuated switch with the action of a lever switch, allows the switching action in the horizontal circuits to take place right on the circuit board (Fig. 2). Called the "CLEVER" switch (Cam switch actuated by a LEVER), this really is a clever way to reduce front-panel clutter. High-frequency operation is also enhanced since the switching takes place right on the circuit board.

The second feature that helps to centralize the components on the circuit boards is a unique light piping system for the front-panel indicator lights. The indicator bulb is mounted directly on the circuit board and a plastic light pipe transmits the light to the plane of the front panel.

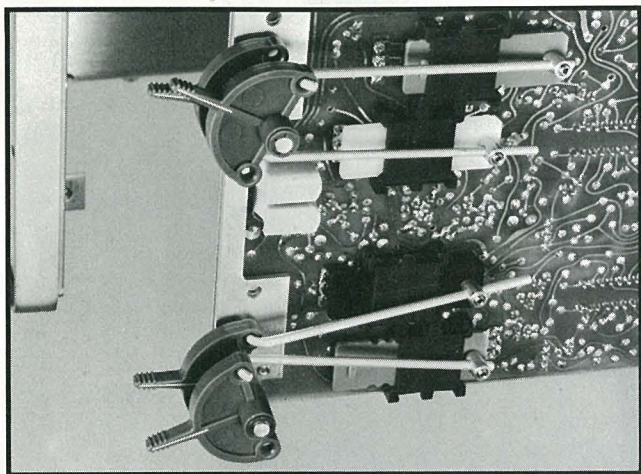


Fig. 2. New "CLEVER" switch keeps switching action on the circuit board.

Ready for Any Environment

We automatically associate extremes of environment with portable instruments. The 465 and 475 Oscilloscopes are designed to give you accurate measurements under extreme environmental conditions. The mechanical design of these instruments allows them to withstand the vibration and mechanical shock associated with portable measurements.

The cabinet of the 465 and 475 has a lower profile than many previous portable instruments. It also has a shorter carrying height which results from mounting the accessories in a pouch on top of the cabinet and shortening the carrying handle. Furthering the portability of these instruments is the light weight of only 23 pounds. The overall result is an instrument which is easy to carry to the measurement site, whether it's a block away or half-a-world away.

A variable-speed Hall-effect fan, which increases speed as the internal temperature rises, is used for cooling. This fan contributes to the improved accuracy of these

instruments and simplifies the circuitry needed to maintain accuracy over a wide range of operating temperatures. Reduced operating temperature also results in longer component life and improved reliability.

If your applications require an instrument with limited electromagnetic interference (EMI), the Option 4 version of the 465 and 475 is available which meets the EMI requirements of MIL-I-6181D.

At Home in the Lab Too

With these great qualifications as portable instruments, it's easy to overlook the capabilities of the 465 and 475 as laboratory oscilloscopes. The large screen display, wide bandwidth, and laboratory accuracy make these instruments the ideal oscilloscope for use on the workbench and their small size requires a minimum of space. The 14-stops on the handle allow you to set the instrument at any convenient viewing angle.

The Circuitry Makes the Difference

New circuit designs complement the new mechanical package of the 465 and 475 to provide all of the functions of the 453A and 454A, plus extended performance. Much of the cost savings that bring you more performance for fewer dollars are a result of these improved circuits.

While the 465 and 475 are similar in appearance and mechanical construction, the circuitry for 100 MHz performance is considerably different from that required for 200 MHz. Let's take a look at some of the circuits in more detail.

Vertical

The vertical deflection systems of the 465 and 475 have a bandwidth of 100 MHz and 200 MHz respectively. This in itself is quite outstanding when compared to the reduced cost of the instruments, and these bandwidths do not change even at maximum input sensitivity — 5 mV/div for the 465 and 2 mV/div for the 475. The two input channels of each instrument can be connected in a cascade mode with an external cable for an even greater sensitivity of 1 mV/div for the 465 and 400 μ V/div for the 475 (bandwidth reduced when cascaded).

Starting at the probe tips, you find a total vertical deflection system designed for each of these new instruments. The P6065 and P6075 probes were designed to provide full bandwidth operation for the 465 and 475 respectively. These probes feature a small, angled termination block at the front panel to minimize protrusion in front of the panel, and have a small probe tip for easy signal acquisition. Another feature is a ground button on the probe tip which allows you to disconnect the signal at the probe tip by just pressing a button.

At the same time a ground reference trace is displayed on the CRT screen (with DC coupling only).

The vertical deflection factor is indicated by a light behind the skirt of each VOLTS/DIV switch (lit only when a channel is being displayed). As a probe is added to the input, the indicator light automatically changes to reflect the actual deflection factor referenced to the probe tip (with recommended probes only). This feature, introduced by the TEKTRONIX CRT READ-OUT system, has quickly become a standard feature on oscilloscopes. This provides a real time savings when training new oscilloscope operators, and adds speed and confidence for the experienced operator. It also helps eliminate incorrect measurements caused by forgetting to take into account the probe attenuation factor or multiplying by 10 when we should be dividing.

The real changes in the vertical system are behind the front panel. The input coupling switch and the attenuator are built on the same circuit board using the TEKTRONIX-developed cam-actuated switch technique. This design provides a constant impedance transmission-line environment for the vertical signal, contributing much to the high-frequency operation of these instruments.

Signal attenuation is accomplished by plug-in attenuators (Fig. 3). These attenuators are built on a ceramic substrate using thick-film techniques. The variable capacitors, which compensate the input attenuators for optimum high-frequency operation, are an integral part of each plug-in attenuator unit.

The input amplifier of the 475 uses a new TEK-designed integrated circuit. Similar to the IC used in the vertical system of the 485¹, this IC includes an FET (field effect transistor) chip within the same 16-lead TO-8 package containing the amplifier chip. Overall gain of the vertical amplifier as well as variable deflection factor are determined within this IC by applying external DC voltages.

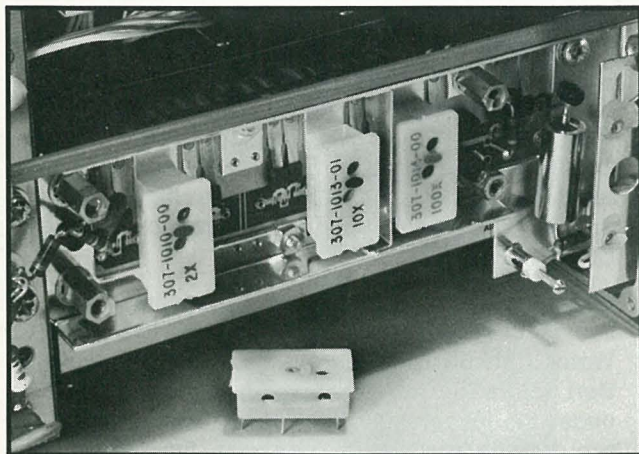


Fig. 3. Plug-in attenuator used for input attenuation (475 shown).

The 475 uses a newly developed IC channel switch to select the signal for display on the CRT. While providing switching without loss in high-frequency performance, this IC also provides output signals for channel 1 triggering, channel 2 triggering, channel 2 vertical output signal, and X signal for X-Y operation. By eliminating much of the critical circuitry and hand wiring necessary in a channel switch using discrete components, this IC contributes much toward the cost reductions achieved in the 475.

An IC output amplifier is used for both instruments. The 465 uses the single, hybrid integrated circuit which has become a standard component in many new instruments such as the TEKTRONIX 7704A, 7603, 7613, and 7623. The output amplifier of the 475 consists of two IC stages. The first stage is the same IC amplifier used for many functions in the TEKTRONIX 485. This stage drives an output IC which is very similar to the one used in the 465, but which has been changed slightly for improved high-frequency response.

A More Versatile Trigger

The 465 and 475 use a new dual tunnel diode (TD) trigger circuit for jitterless triggering to well beyond the upper bandwidth limit of each vertical system. Based on a TEKTRONIX patented concept, the trigger circuits of both instruments are similar except where special considerations must be made in the 475 due to the higher frequency signals involved. Fig. 4 shows a simple block diagram of the trigger circuit and explains the function of each block. With this trigger circuit, the sweep gate is produced directly from the incoming trigger signal without shaping as in previous trigger circuits. Jitter-free operation is largely the result of the dual-TD configuration. The Arming TD can only be triggered on the opposite half cycle preceding the trigger point and only after the holdoff has ended. Then it "arms" the Gating TD so it is ready to trigger at the exact trigger point selected by the front-panel trigger controls for a jitter-free sweep.

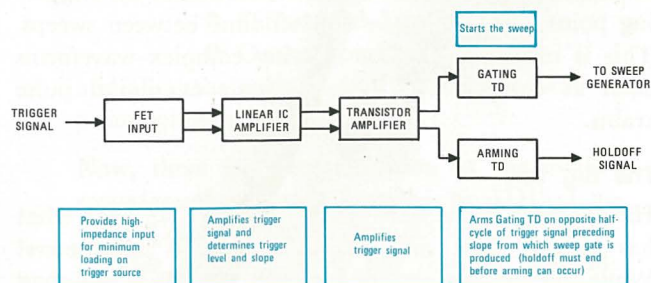


Fig. 4. Dual TD trigger circuit. Function of each block is shown in blue.

¹See "Three Technologies On One Chip Make a Broadband Amplifier", by John Addis, Tektronix, Inc., ELECTRONICS, June 5, 1972. pp. 103-107.

Basic arrangement of the triggering controls on these instruments is the same as the 453A and 454A. One important addition for the 465 and 475 is that CH 1 only, CH 2 only, or NORM triggering can be individually selected by the A and B TRIGGER SOURCE switches. Likewise an important deletion is the removal of the high-frequency stability control which is no longer required with the new jitterless trigger circuit. A TV sync separator circuit can be added to the 465, replacing the external $\div 10$ position. This optional circuit (Option 5) permits stable internal triggering from displayed composite video or composite sync waveforms.

These instruments also feature trigger view as pioneered on the 485 Oscilloscope. This permits you to view the external signal connected to the A trigger input by pressing a single button, eliminating the need to reset controls or disconnect leads just to display the trigger signal. Now you can easily check delays between the triggering point and the displayed signal.

An Accurate Time Base

Normal sweep accuracy of both the 465 and 475 is within 2% over the full 10 divisions of the CRT with magnified accuracy within 3%. Improvements have also been made in the differential delay measurement accuracy to provide measurements within 1%. Improved accuracy has been achieved in these instruments, along with lower cost, by careful minimization of all circuit tolerances which might lead to sweep errors; and through the use of components carefully matched to the circuit requirements.

Both the 465 and 475 offer faster sweeps than their predecessors. The 1 ns/div maximum sweep rate (X10 MAG on) of the 475 offers improved time resolution for those important high-frequency or fast-pulse measurements.

Horizontal modes for the 465/475 include both delayed and mixed sweep operation. Other features include a variable holdoff control to allow selection of the triggering point by varying the holdoff time between sweeps. This is most useful when viewing complex waveforms such as composite television signals or digital pulse trains.

The Big CRT

Hardly more needs to be said about the CRT than what has already been said—it's a full 8 x 10 centimeters! While the viewing area of the CRT is 55% larger than the 453A and 454A, the display is bright while retaining good photographic writing speed. This is achieved by the use of a new TEK-made, shaped scan-expansion mesh. Although use of this type of mesh in CRT's is not new, the techniques used in these instruments are advanced to the limits of the state-of-the-art.

Power Supply

The 465 and 475 are powered by a conventional electronically regulated power supply. The supply features an IC error amplifier and, in keeping with the compactness of other circuits in the instruments, the supply occupies very little space in relation to previous instruments. A low-line voltage circuit monitors the unregulated source voltage and, if it drops below a level which will provide accurate instrument operation, the LOW LINE light on the front panel comes on to alert the instrument user. This circuit senses low line voltage due to both low RMS line voltage or low peak-to-peak voltage because of sinewave distortion.

A new addition in power capability for these instruments is operation from either a free-standing battery-powered inverter or a battery pack which attaches directly to the instrument for a truly portable oscilloscope. In the latter mode, an inverter board is added inside the instrument and permits the additional flexibility of operation from an external DC voltage.

Summary

The 465 and 475 Oscilloscopes provide performance in the tradition established by such outstanding TEKTRONIX portable instruments as the 453A and 454A Oscilloscopes. Improving upon instruments which have been accepted as the standard of excellence for portable measurements is difficult. However, the designers of the 465 and 475 Oscilloscopes have met this challenge by providing you the most performance for the lowest price of any wide bandwidth portable oscilloscope available today!

ACKNOWLEDGMENTS

Initial product planning and project coordination was provided by Leon Orchard. The mechanical design team for the 465 and 475, headed by Bob Rossman, was: Neal Broadbent, Bob Leith, Len McCracken, Bob Smesrud, Ilmars Smiltins, and Bob Twigg. Ken Holland and Bill Mark provided the attenuator design while Bob Johnson designed the P6065 and P6075 probes. Low-voltage power supply for the 465/475 was by George Ermini, and Dennis Braatz designed the high-voltage supply. Connie Wilson and Gary Nelson did the CRT development.

Electrical design team assisting R. Michael Johnson in development of the 465 was: Frank DeWater, Pete Janowitz, Dave Laib, Al Schamel, and Bert tenKate. Corresponding group for the 475 under the leadership of Jim Hinze was: Jim Godwin, Les Larson, Steve Tosh, and Jim Woo.

THE OSCILLOSCOPE CONTROLLED COUNTER

by NEIL A. ROBIN — Project leader.

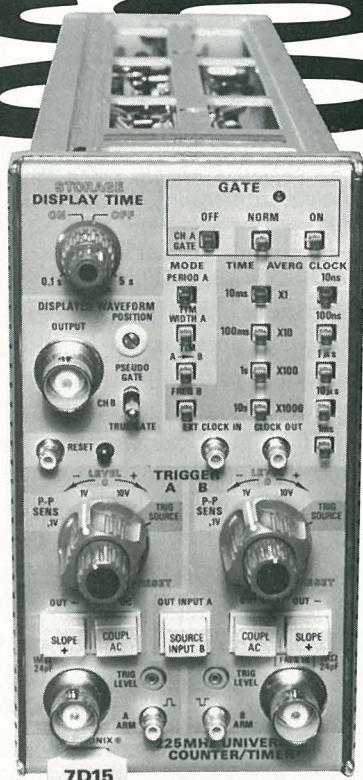
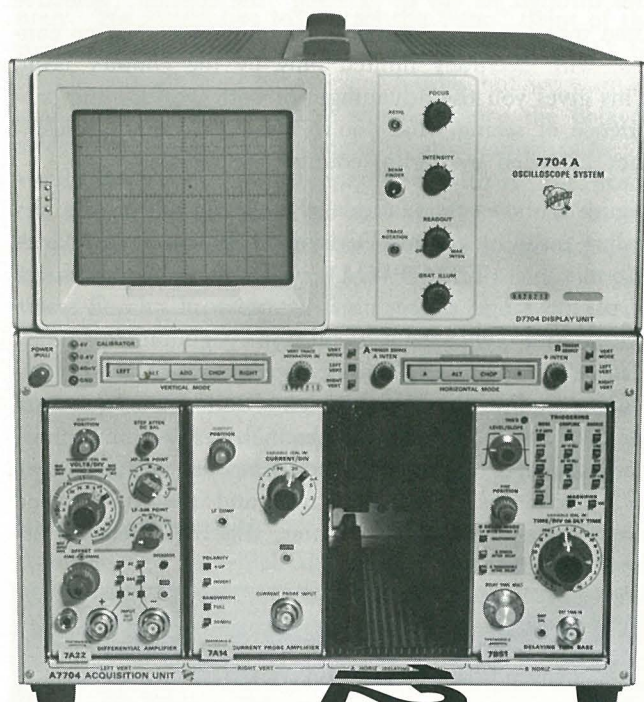
How many times have you made a digital time interval measurement and wished you could see exactly where you were triggering? Most counters have no visual triggering aid. By designing them into an oscilloscope, this problem is solved. Carried further—the signals from the scope can be used to control the counter for new and previously difficult measurements.

About two years ago a unique change was made in digital frequency counters.¹ For the first time one could be plugged directly into an oscilloscope, sharing its power supply and CRT READOUT. The first member in this family, the 7D14 Digital Frequency Counter, has been a success. Its top frequency (525 MHz direct count), is a key factor, of course; but probably more importantly, the scope offers certain features to the counter that really make sense; namely, being able to display what the trigger circuit "sees", and the ability to precondition the signal via the vertical amplifiers of the scope before it is routed to the counter. Some of the input possibilities this creates are:

- 10 μ V sensitivity
- Differential input
- Current probe input

and all at the push of a switch when the appropriate plug-in is used!

Now, there is a new addition to the oscilloscope/counter plug-in family—the 7D15 Universal Counter/Timer. The 7D15 is a 225-MHz counter offering all of the features normally found in Universal Counter/Timers (UCT's) plus some new ones that are unique to the oscilloscope/counter combination. These include "selective" time and frequency measurements, and "arming" capability in both Time Interval Measurement (TIM) and Period modes.



Counter Signals Displayed

To facilitate these measurements a number of display features are provided in the counter. When the 7D15 is plugged into a vertical position in the scope mainframe a selection of three signals from the counter can be displayed:

1. Channel B—The conditioned signal derived from the output of the Channel B shaper circuit.
2. True Gate—The main gate waveform. Its rep-rate is a function of the DISPLAY TIME setting.
3. Pseudo Gate—The output of the free-running gate flip-flop from which the True Gate is derived. It is a high rep-rate replica of the True Gate.

These signals are also available from a jack on the counter front panel.

In time measurement modes the "pseudo gate" is the most frequently used. Normally, the counter is limited to a few readings/second to permit the operator to observe the digital results; however, the duty cycle is very low for a CRT type of display. The "pseudo gate" provides a high rep-rate signal to give you a brighter CRT display.

Having these display features in the 7D15 allows you to easily make timing/frequency measurements that were pure guesswork before. You can appreciate this capability when you need to measure a signal that has "ringing" or reflections from poor termination associated with it (See Fig. 1).

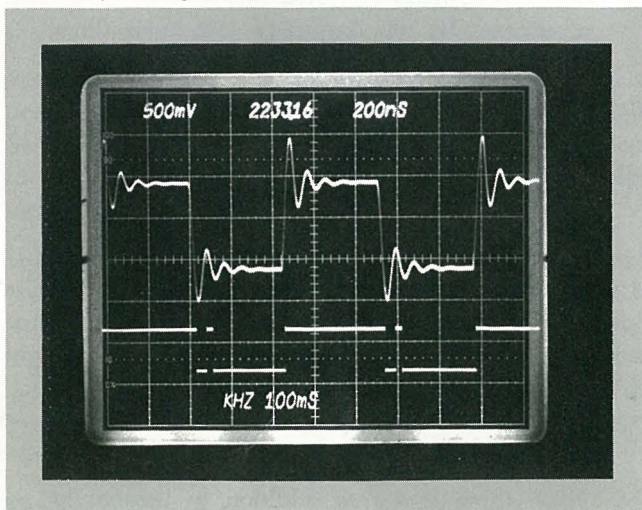


Fig. 1. Incorrect trigger level setting is readily determined by viewing the signal from the CH B shaper circuit (lower trace). Note extra narrow pulse.

Arming

In addition to the display features, the 7D15 makes use of certain signals such as the DELAYED GATE and SAWTOOTH OUT, which are normally available on TEKTRONIX oscilloscope mainframes. The DELAYED GATE is valuable, creating many possibili-

ties through its use in "arming" the counter. Selective time measurements are possible under oscilloscope control with accuracy limited only by the counter itself. This gives you the advantages of both worlds—the confidence of seeing what you're measuring and the accuracy afforded by digital counter techniques.

Figure 2 shows an example of how the width of a signaling pulse in a Time Division Multiplex/Pulse Width Modulation (TDM/PWM) system can be measured. First, the scope triggering is set up to display a stable trace, and synchronized at the beginning of each "frame". A "frame" is one complete cycle of the multiplexing equipment. Now imagine that a time measurement of the third pulse, or channel, in the communication system is required. By adjusting the delayed sweep to a position as shown in Figure 2 and using the delayed sweep gate to arm the counter, this measurement becomes feasible.

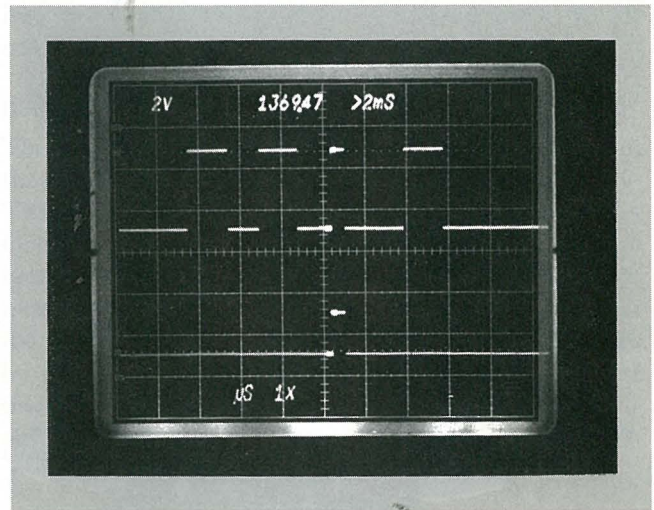


Fig. 2. Selective arming using the delayed gate makes it possible to measure individual pulses in a TDM/PWM system.

If the counter is plugged into a vertical position in the scope mainframe, the trigger points can be observed. It is not always necessary to be in a vertical slot, however, because an output jack on the counter front panel also provides this signal. A patch cord from the counter to an available vertical channel will provide display. Care must be used here when working with very fast sweep speeds because misleading information can result from the additional delays created by the patch cord. With the counter display presented along with the signal, it becomes obvious if the arming is not functioning at the appropriate time.

It should be noted that channel A of the counter is armed on a positive signal or logic "1", while channel B has reversed logic or is armed when the arming input is at a low state. The reason is simple. The use of arming may involve more than one signal to be measured

and we may not wish to stop the measurement immediately. We would like to control the "stop" point of the measurement as well as the "start". This would be simple enough from an external source, but we want to make the most of available signals. Since the delayed sweep gate signal is a single positive-going pulse, it would be nice to have compatibility with it. By reversing the "stop" arming logic and placing a "tee" in the circuit, the counter effectively will not accept a "stop" command until the delayed gate has returned to a low state; hence, the width of the delayed gate controls the "stop" point. The advantages of having this "control" should be obvious for many uses and particularly in complex communications systems or radar ranging where multiple returns could confuse ordinary time-measurement equipment without selective "stop" arming.

Burst Measurements

Another area in which this feature can be valuable is in "burst" measurements. Often the frequency of a tone burst signal is unknown and it is desirable to measure it. There is specialized equipment available to do this, but it is far more expensive than the equipment described here. With "arming" and "display capability" designed into a counter, tone burst measurements become easy.

The signal is first displayed as a stable trace on the CRT face. Then with the delayed sweep gate, the counter is "armed" during one of the burst intervals. Either a Period or Frequency measurement can be made. If the burst is at least 11 milliseconds long, a Frequency mode measurement would probably be preferred. Shorter bursts than this would require using the Period mode, and then calculating the frequency.

All of the averaging possibilities still apply as long as the length of the measurement does not overlap the burst zone of the signal. Having the display of the counter response next to the signal display is very handy to determine this. It also makes it possible to start the measurement later than the first pulse, or to end it sooner than the last pulse of the burst. This can often be desirable, as the beginning and end of the signal may have a certain amount of distortion due to the keying equipment generating the pulse.

Time Interval Averaging

Another feature rarely found in digital counters is "Time Interval Averaging". A distinction must be made between "Period Averaging", which is also included in the design, and "T.I. Averaging". A Period Averaging measurement is one in which the counter gate is simply opened for a predetermined number of cycles of the input signal while the internal clock is counted. As the number increases, improved average resolution occurs,

plus the effect of noise becomes less significant. In general, by averaging over many cycles, greater accuracy and resolution can be obtained at the expense of time. Period Averaging is found in the majority of Universal Counters.

"T. I. Averaging", on the other hand, opens and closes the counter gate a preselected number of times. This mode allows an improvement in accuracy of a T. I. measurement by greater than ten times. With a 10-ns clock, it is possible to obtain accuracies of 1 ns. For example, assume the T. I. to be measured equals 11 ns and we make the measurement and total the results 1000 times. A 10-ns clock is used. It's clear that 1.1 pulses of the clock will occur during the interval, so over 1000 measurements you might expect to see 1100 counts recorded. Of course, the counter cannot record a fractional count, so sometimes it will register 1 count and sometimes 2 counts, depending on the timing between the "clock" and the repetition frequency of the interval to be measured. For a pure random distribution, 10% of the time you would expect to see 2 pulses and 90% of the time, 1 pulse. In practice, the probability distribution function of the timing relation of the two signals is variable and gating errors must also be considered.

Overall, the improvement due to T. I. averaging is not as great as might first appear. For the majority of applications, an improvement in accuracy and resolution of at least ten times is common. The greatest hazard is pure synchronization between the signals; the answer will be very steady but the results will be wrong. Anything short of pure synchronization, however, will usually be quite acceptable, particularly when 1000 averages are made. Figure 3 shows the graphical representation of the above example. To calculate the standard deviation with so many variables becomes nearly impossible and definitely beyond the scope of this article.

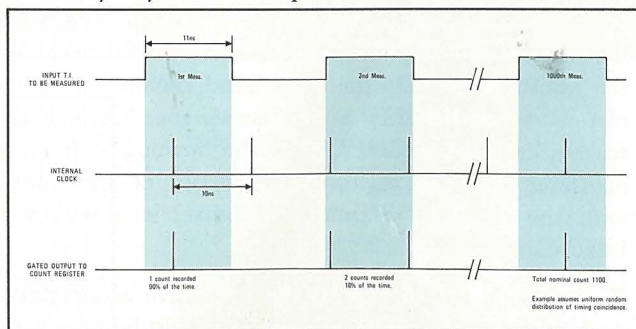


Fig. 3. Time Interval Averaging allows an improvement in accuracy of a T.I. measurement by greater than ten times.

10-ns Clock

Incorporated in the design of the 7D15 is an expansion of the normal 1- μ sec clock. It doesn't take much intuition to realize that the accuracy of a short-time measurement is limited by the clock resolution. Care must

be exercised whenever we talk of ultimate accuracies, as many factors, such as noise, can have a significant contribution. But generally speaking, for short intervals, the ± 1 count ambiguity is the limiting factor. It stands to reason that having a faster clock will reduce the significance of this error; hence a 100-MHz signal is provided.

To obtain this signal and still have it as accurate as the basic crystal oscillator time base, requires some form of frequency multiplication. A phase-locked loop was chosen here. This method has significant advantages over the old-fashioned tuned-circuit variety in production, for example, only one simple adjustment!

Accuracy—Counter vs Oscilloscope

A question that is often brought up when someone tries to make a time measurement is, "Can I get greater accuracy using an oscilloscope trace and observing the time under question, or using a digital method (such as the 7D15), to obtain the answer?" Most oscilloscope sweeps have a timing accuracy of about $\pm 4\%$ over the temperature range discussed here and over a nominal scan width.² This, of course, assumes that the sweep rate is fast enough to resolve 4% errors. The type of measurement makes a difference so we'll assume a "Period Average" first. From accuracy equations for the 7D15 in "Period Averaging" mode, with 10-ns clock, X1000 averages, 90 days between oscillator calibration, and a 4% accuracy limit under normal logic noise conditions, the answer is found to be:³

For periods greater than 10 ns use the digital counter.

For less than 10 ns, use the oscilloscope.

And if the same approach is used for T. I. Averaging:

For T. I.'s greater than 50 ns, use the digital counter.

For less than 50 ns, use the oscilloscope.

These, of course, are very general "rules of thumb". The oscilloscope can become the better method when the noise level is high because the human eye can average the results better. On the other hand, oscilloscope traces can have non-linearity at fast sweep speeds which can further limit the accuracy. With the "arming" capability, anything that can be displayed should be measurable with the counter, assuming of course, it is within its basic capability.

Figures 4, 5, and 6 express the respective accuracies of each of the three major modes. It should be noted that these errors are expressed in terms of frequency and time, rather than as a percentage. It is felt this may be more useful to the operator. The operator's manual has expressions for both.

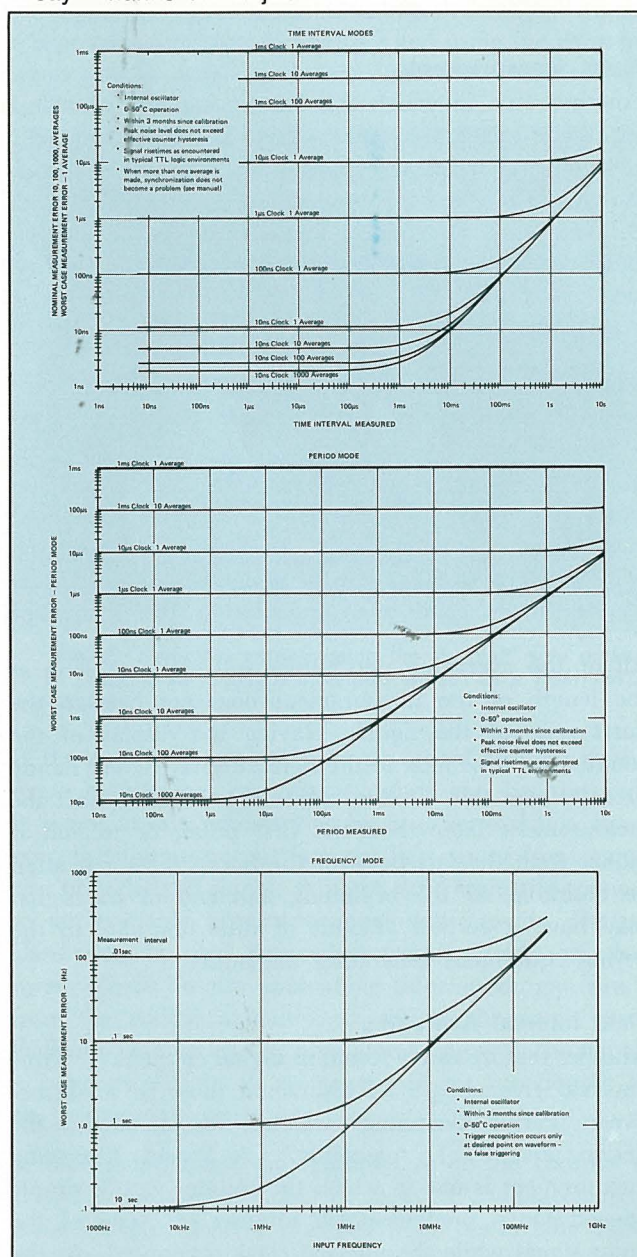
Summary

The integration of the oscilloscope and digital counter into one measuring instrument makes possible measurements that neither instrument could conveniently per-

form alone. The 7D15 Universal Counter/Timer is the newest addition to an expanding digital plug-in family for the TEKTRONIX 7000-Series Oscilloscopes. The list also includes the 7D13 Digital Multimeter, 7D14 Digital Frequency Counter and the 7D11 Digital Delay Generator.

ACKNOWLEDGMENTS

The performance of the 7D15 could never have been achieved in such a compact package without the use of five Tektronix-manufactured integrated circuits. At least 100 people played some role in bringing the 7D15 into production. It would be impossible to give all of them credit here. I know of no better way than to simply say—thanks for a job well done . . . !



Figs. 4, 5, 6. Graphs show accuracy of the 7D15 in various modes.

7D15 Abbreviated Specifications

Crystal Oscillator—Accuracy: Within 0.5 ppm (0°C to +50°C ambient). Long term drift: 1 part or less in 10^7 per month. Oscillator is temperature compensated, no warm up is required.

Clock Out (time mark) selectable on front panel 10 ns, 100 ns, 1 μ sec, 10 μ sec, 1 msec, compatible with TTL logic or will drive 50 Ω load to +0.5 volts.

Arming Inputs—Input R and C: 10 k Ω and 20 pF. Sensitivity Arm "A": Logical "1" $\geq +0.5$ V, Logical "0" $\leq +0.2$ V. Sensitivity Arm "B": Logical "1" ≤ 0.2 V, Logical "0" $\geq +0.5$ V.

Inputs Channel A and B

Sensitivity: 100 mV, 1 V, 10 V peak-to-peak
Input: 1 Megohm, 22 pF
Freq. Range: DC—225 MHz

Trigger Source Input:

Sensitivity: 0.5 divisions 5 Hz to 50 MHz derated above 50 MHz
Range: DC—225 MHz

Readout: 8 digits plus decimal point, legend, and miscellaneous data.

Displayed Waveform: Front panel switch selects pseudo gate, true gate, or Channel B Schmitt trigger for display on CRT when instrument is placed in vertical plug-in position.

External Clock In:

Sensitivity: 0.8 V peak-to-peak, 30 - 70% duty cycle
Freq. Range: 20 Hz to 5 MHz AC coupled

Trigger Level and Slope Adjust—Channel A and Channel B

Range: In 100 mV sensitivity position; +0.5 V to -0.5 V. Effectively scaled up in higher ranges. Preset 0 volt position also provided.
Slope: Positive or negative, selectable for each channel.

Monitor: Pin jack provides for monitoring of trigger level on each channel.

Programming: In preset position, allows for insertion of externally supplied voltage to set-up trigger level.

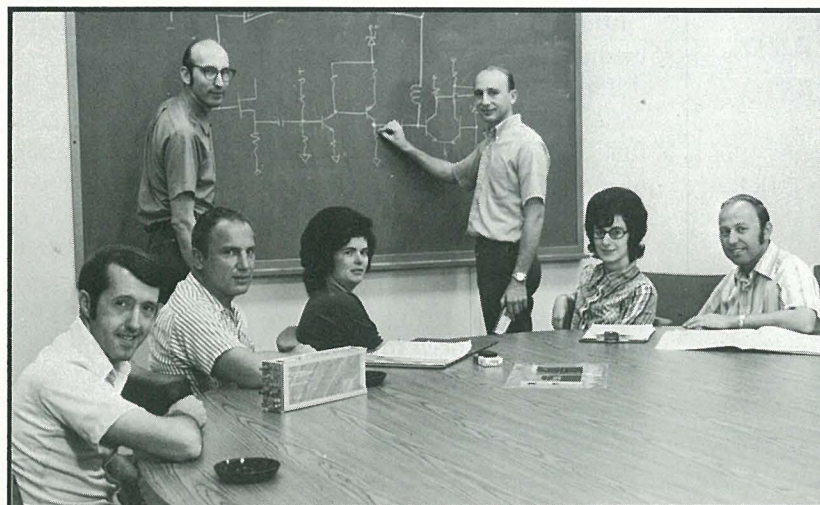
Display Storage Switch—A front panel switch is provided to disable readout storage for events counting, etc.

7D15 Features

MODE	RANGE	AVERAGING	RESOLUTION (Max)	ACCURACY
Frequency	DC-225 MHz	X1	0.1 Hz	See Figures 4, 5, 6 ↓
Period & Period Averaging	10 ns-10 ⁵ sec	X1, X10, X100, X1000	10 picosec.	
TIM & TIM Averaging Width CH A Start CH A/ Stop CH B	6 ns-10 ⁵ sec	X1, X10, X100, X1000	0.1 ns usable	
Frequency Ratio	10 ⁻⁷ to 10 ⁴	—	10 ⁻⁷	
Manual Stop Watch	0-10 ⁵ sec	—	10 ns (1 ms practical)	
Totalize (Electrical or Manual Control)	0-10 ⁸ counts	—	1 count	

References

1. TEKSCOPE January 1971, page 2-5.
2. Certain techniques can improve this, such as suggested on page 12, TEKSCOPE, August 1970. Generally, they must be done with care and take time to verify.
3. Refer to 7D15 Operating Manual for detailed discussion.



Some of the key people involved with the 7D15 are, left to right: Gary Burgess, Industrial Design; John Vrvilo, Mfg. Test and Calibration; Joan Sanderson, Mfg.-Engrg. Contact; Helene Albright, Prototype Support; Andy Anderson, Etched Circuit Board Design; Roger McCoy, Electrical and I. C. Design; and Art Metz, Electrical Design.



TEKNIQUE

by FRED BECKETT, engineer



A PRACTICAL APPROACH TO DIFFERENTIAL AMPLIFIERS AND MEASUREMENTS

This is the first in a series of articles on the characteristics and use of differential amplifiers. This article discusses the basic structure of the differential amplifier and its ability to reject common-mode signals.

Introduction

It is difficult to hear a whisper when a jet airplane is taking off or to see a star when the sun is shining brightly. It is equally difficult to measure small electrical signals in the presence of signals many times their size. We sometimes need to measure such signals and, fortunately, techniques and instruments have been developed to enable us to do so. This type of measurement is called a "differential measurement".

In order to get a clear picture of differential measurements we need to gain an understanding of such terms as "common mode" and "common mode rejection ratio" associated with these measurements. Before discussing these terms, however, we must first understand the basic structure of our measuring equipment, namely the differential amplifier, probes, and interconnecting cables, so the first part of this series will be devoted to this cause. Next, the various measurement techniques used to make correct differential measurements will be discussed in some detail; and, finally, we will investigate "guarded" measurements.

PART 1

THE DIFFERENTIAL AMPLIFIER AND COMMON-MODE REJECTION RATIO

When considering differential measurements, the term "Common-Mode Rejection Ratio" (CMRR) is the most meaningful specification in terms of absolute measurement accuracy. The ability of a differential measuring system to reject common-mode signals is a "figure of merit". We usually refer this specification to the actual measuring device (normally the differential amplifier) but it is well to remember that we cannot isolate this specification to the differential amplifier alone. We must consider ALL components of our system, which includes the source of the measurement itself.

Let's begin by discussing the differential amplifier itself in terms of common-mode and common-mode rejection ratio, then look at the input attenuators, probes and interconnecting cables, and finally, what effect the signal source has on our measurement.

The Differential Amplifier

All linear amplifiers, no matter what form they take, have one thing in common: the signal which is applied across the input terminals is amplified "gain times". Or, stated another way, an amplifier will amplify "gain times the difference between the input terminals". This statement is of prime importance since it will form the basis of all our early discussions. The above statement contains two fundamental truths about linear amplifiers:

1. The amplified output voltage (E_{out}) of an amplifier can be described as:

$$E_{out} = A_v (E_{in(1)} - E_{in(2)})$$

Where $E_{in(1)}$ and $E_{in(2)}$ are the input terminal voltages.

2. The gain (A_v) of an amplifier is fixed and independent of external parameters.

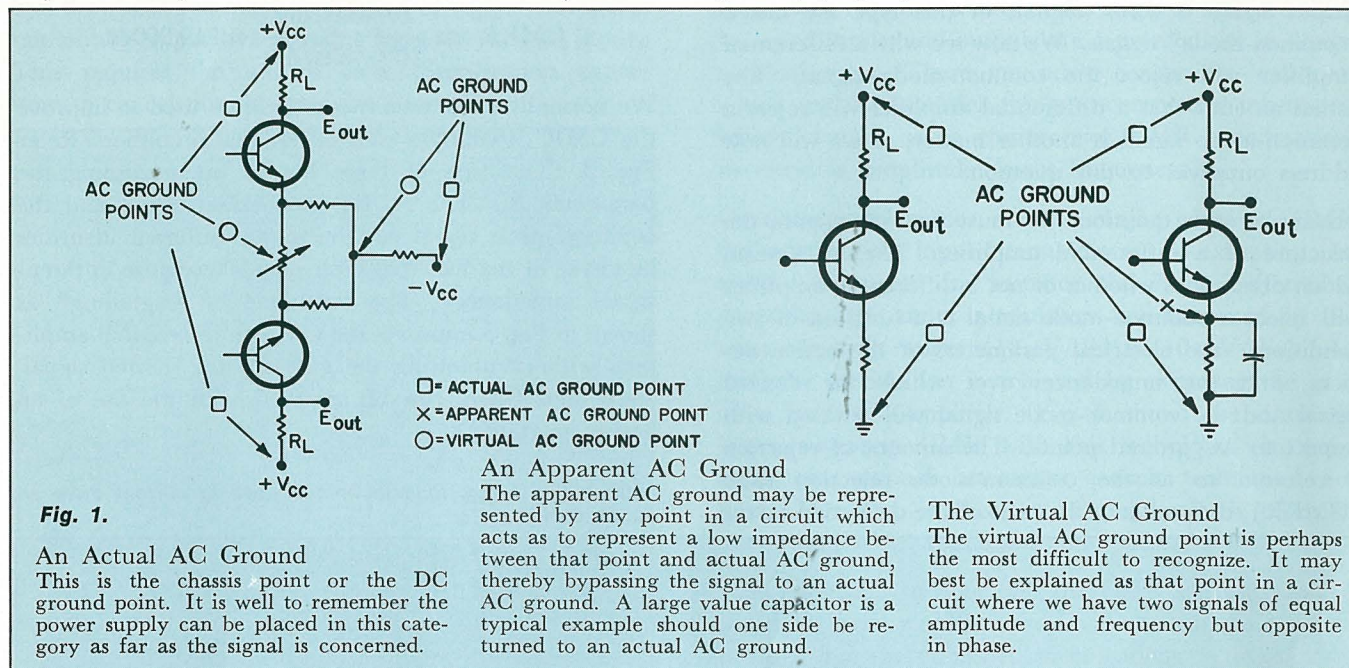
As simple as this statement appears to be, we cannot describe any differential amplifier or measurement without recognizing this fact and its implications.

The word "differential" is an adaptation of the word "difference". Strictly speaking, differential is an incremental finite difference between two quantities. So— a differential amplifier is a difference amplifier. But, by definition, so are all linear amplifiers, therefore, we must first ask ourselves, "What makes the differential family of amplifiers stand apart from other types?" To answer this question, we must first look at the basic concepts of the differential family. There are two forms in this family of amplifiers, namely the paraphase type and the push-pull. The only basic difference is that the paraphase has one input referenced to a fixed potential. The paraphase configuration is used for converting a single-ended drive to a push-pull drive. Since one side is tied to a fixed reference, we cannot use it in a true difference configuration in the strict sense, so for the moment we will turn

our attention to the push-pull type and use this form to describe a differential amplifier. However, the paraphase amplifier is the basic form of the differential comparator, a technique in differential measurement described later on in this series.

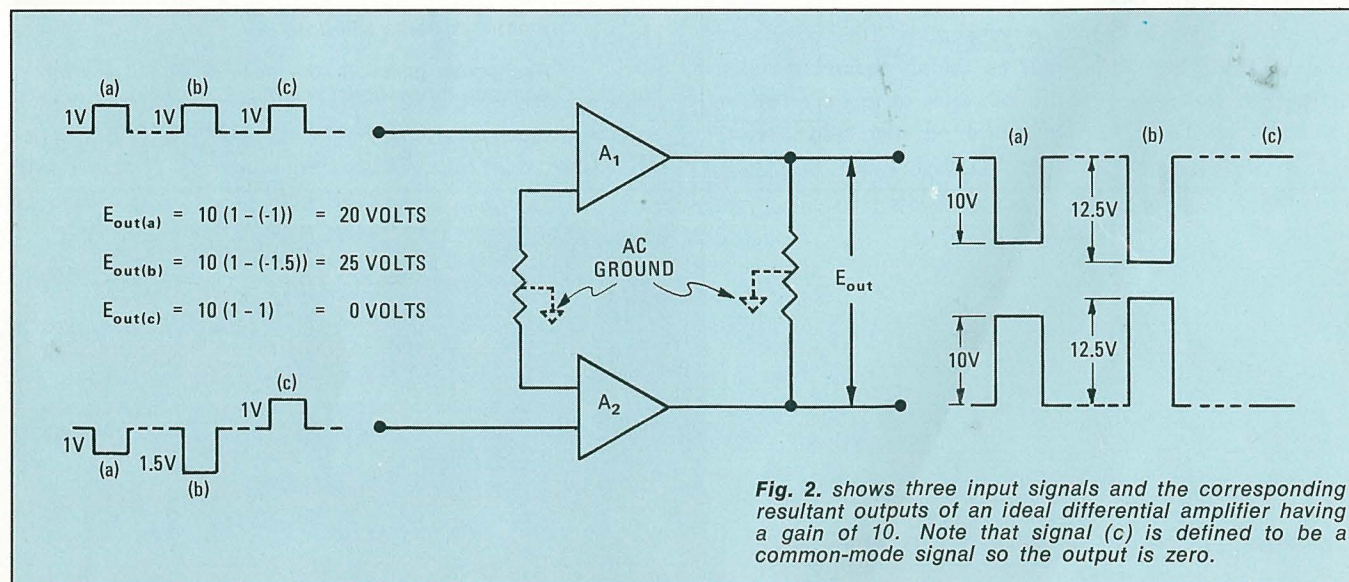
Let us reflect for a moment and see if the differential amplifier family meets our basic definition of any linear

amplifier. We may think of a differential amplifier as two single-ended amplifiers placed back to back. We need to recognize the existence of AC ground points and remember that the input and output voltages will develop across impedances connected to those AC ground points. We normally encounter three types of AC ground, (Fig. 1).



There are some interesting facts we should note about Figure 2. Let us assume that the gain of A_1 and A_2 is, say, 10. Remember this gain is fixed. We normally refer to a gain in the differential configurations as being from side to side or measured from the output of A_1 to the output of A_2 . The voltage we would expect to measure side to side will be "gain times the difference between the input terminals".

The phrase, "difference between the input terminals" implies both amplitude and phase, since this difference is the graphical addition of the two signals appearing at the input terminals of A_1 and A_2 . Looking at signal (a) we see two equal input voltages of opposite polarity which result in an output voltage 10 times their difference. With signal (b) we have two input voltages of opposite polarity but unequal in amplitude. The output



voltage is again 10 times their difference, but note that the output signal is balanced. Thus we see that push-pull amplifiers tend to correct unbalanced signal drives. Moving along to signal (c) we have two equal input voltages of the same polarity or phase. Since both inputs are of the same amplitude and phase there is no difference signal developed across the input, hence the output signal is zero. Signals of this type are called "common-mode" signals. We now see why a differential amplifier will reject the common-mode signal. The actual amount that a differential amplifier will reject a common-mode signal is another matter, so we will now address ourselves to this question.

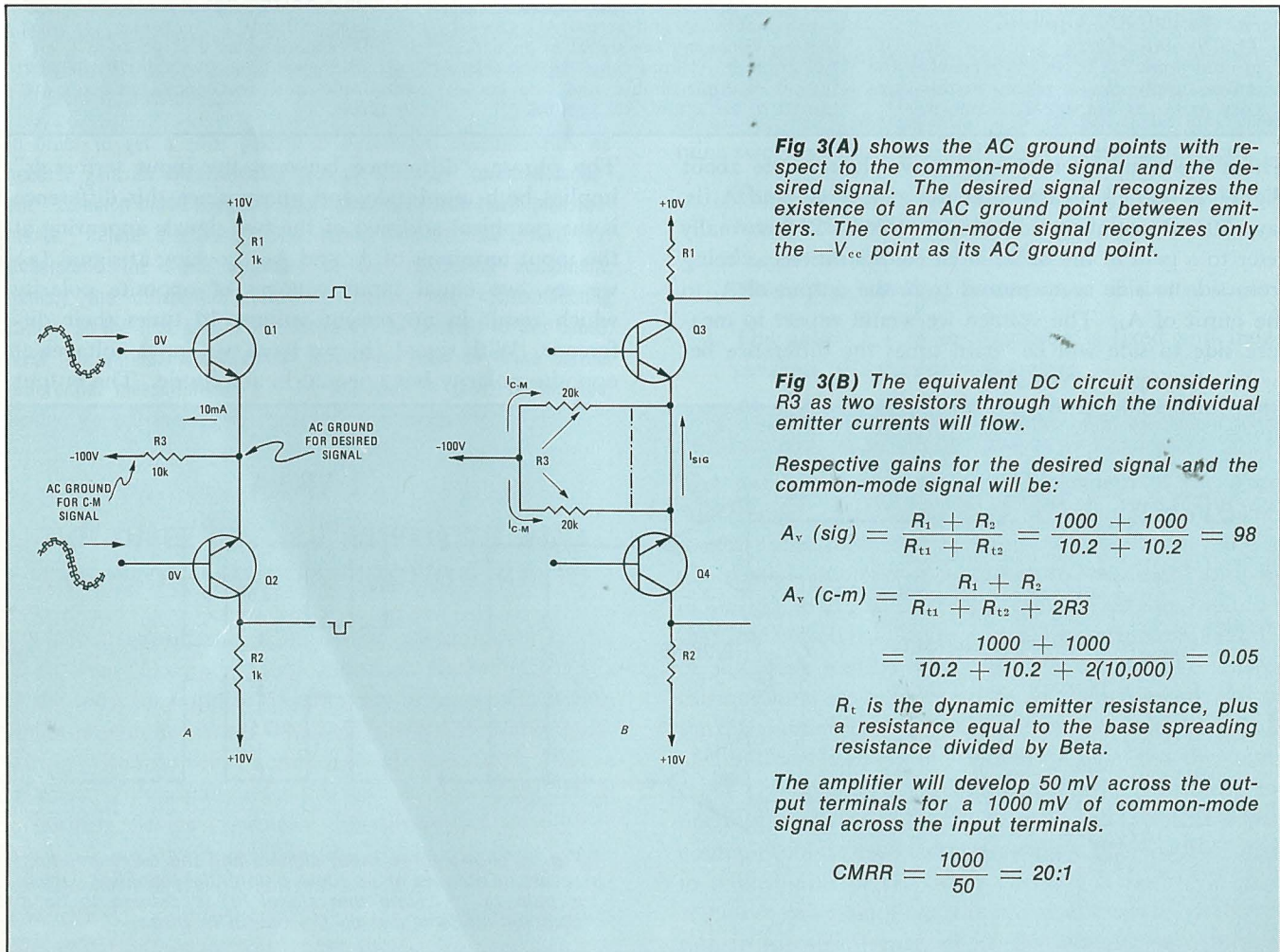
To answer this question, we must first investigate the structure of a differential amplifier. The mechanism which determines whether or not a differential amplifier will reject a common-mode signal is a function of two conditions: the electrical parameters of the active devices, and the impedances over which the desired signal and the common-mode signal will develop with respect to AC ground points. The amount of rejection is referred to as the common-mode rejection ratio (CMRR), defined as: "the ratio of the deflection factor

for a common-mode signal to the deflection factor for a differential signal applied to a balanced current input". (IEEE Standard Dictionary of Electrical & Electronic Terms.) So, if we measure, say, one millivolt/div across the output of a differential amplifier and 10 volts/div across its input terminals, the CMRR will be 10000:1, i.e.,

$$\text{CMRR} = \frac{10 \text{ volts/div}}{10^{-3} \text{ volts/div}} = 10,000:1$$

We normally encounter two techniques used to improve the CMR capabilities of a differential amplifier. Refer Fig. 3. The first of these lies in understanding the parameter A_v . The A_v for the desired signal and the common-mode signal is two entirely different identities by virtue of the fact that both signals recognize different signal impedances. The technique of longtailing* as shown in Fig. 3 improves the CMR in differential amplifiers without upsetting the gain for the desired signal. Very high CMR can be achieved with the use of an active longtail.

*Longtailing refers to a technique used to current drive an active device.



We also encounter the technique of the “floating power supply”. Refer Fig. 4. The power supply for the input amplifier, and the input amplifier, move an equal amount to the common-mode voltage, maintaining a constant operating characteristic of the input amplifier. This results in unchanged outputs which mean that the common-mode signal is rejected. The technique has one drawback inasmuch as the power supply introduces undesirable capacitive coupling between the two inputs. This requires the use of cross-neutralization capacitors to cancel out the cross-coupling effect.

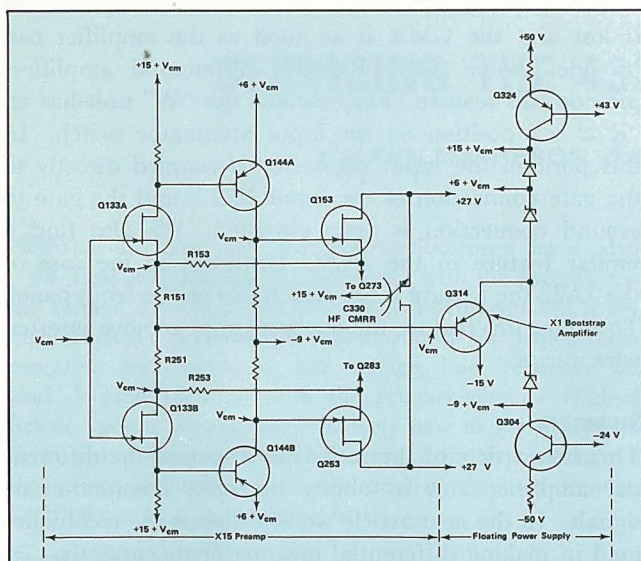


Fig 4. This is a simplified schematic of the 7A22 Differential Amplifier showing the X15 input preamplifier and its floating power supply. CMR is achieved by the common-mode signal which appears at the input, being bootstrapped via Q314 to the preamplifier's power supply. The net result is that the floating power supply will move with the common-mode signal. Essentially no changes in voltage or current levels will occur as a result of the common-mode signal. Further, any common-mode signals due to lack of symmetry within the amplifier, or noise components, will be dealt with similarly.

CMR vs Frequency

CMR is usually given in terms of a ratio or expressed in terms of decibels. It also has another parameter—frequency. You should be aware of the fact that CMR

specifications are normally given with reference to a specific frequency. Reactive components upset the symmetry throughout the measuring system and therefore have a marked effect on CMR as you might expect. We must remember that any shift in phase of a common-mode signal on either input or output terminals of a differential amplifier stage cancels or modifies the common-mode rejection ability of the stage, so symmetrically balanced inputs and outputs are a prerequisite in design considerations. There are other constraints, many of which are based on such things as component tolerances, which compel us to compromise CMR specifications in terms of amplitude versus frequency.

Component tolerances are the major cause of CMR degradation; the input attenuators are no exception. In some instruments, for instance the 7A22 Differential Amplifier, the input attenuators are not used in the most sensitive ranges (10 μ V/div to 10 mV/div). In this case attenuation is achieved by switching the gain of a feedback amplifier. Fig. 5 shows the dramatic improvement in CMR with this technique. In some cases conventional attenuator switch techniques are used. However, in these cases great care is taken to match and select attenuator components.

It is important to note that the CMR specifications of the differential amplifier are fixed and can be assumed to be within the published specifications. The majority of problems encountered meeting CMR conditions start with the methods used to connect the differential amplifier to the measurement source.

Probes and Interconnecting Cables

The majority of applications will dictate the use of a probe. Probes and the interconnecting cables invariably introduce degradation of the CMR. Normally this area will be the limiting factor. We usually refer to this overall reduction in CMR due to probes and interconnecting cables as the “apparent CMR”. Care must be taken to select identical probes and, if possible, probes that can be optimized for CMR such as the P6055 or the P6046 Differential Probe/Amplifier.

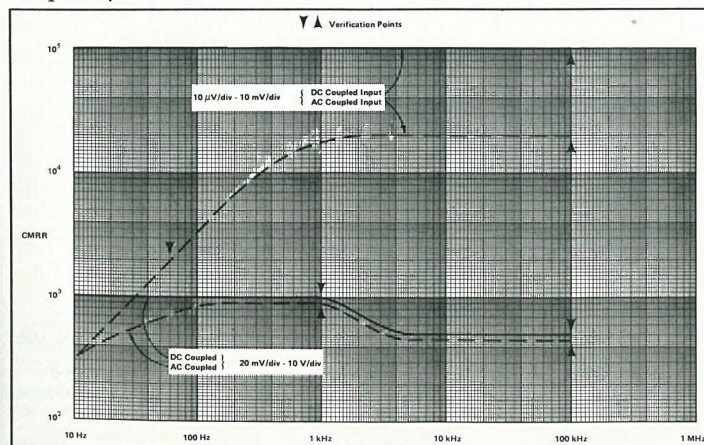
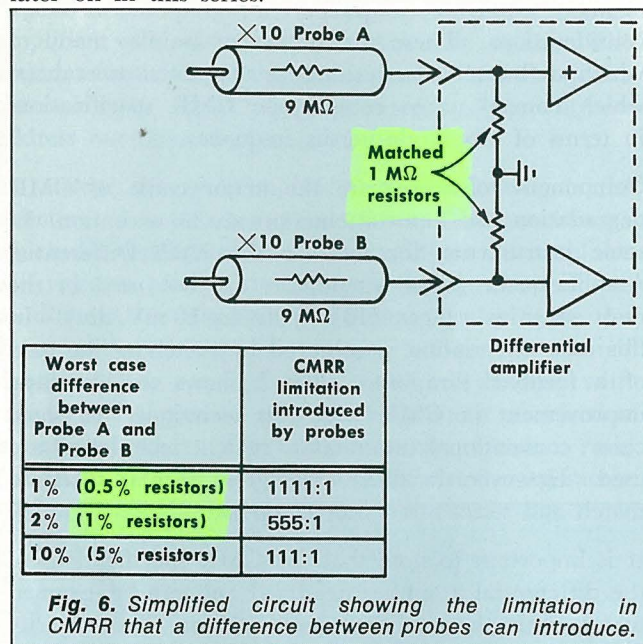


Fig. 5. CMRR vs. Frequency for signals not exceeding Common-Mode Signal Range.

Fig. 6 is a simplified circuit showing the limitation in CMR that a difference between attenuator probes can introduce. If the application requires direct connection from the source of measurement to the differential amplifier, the same rules for CMR compatibility apply, namely symmetry in all respects. Input connection practices for differential amplifiers will be dealt with later on in this series.



Source Impedance

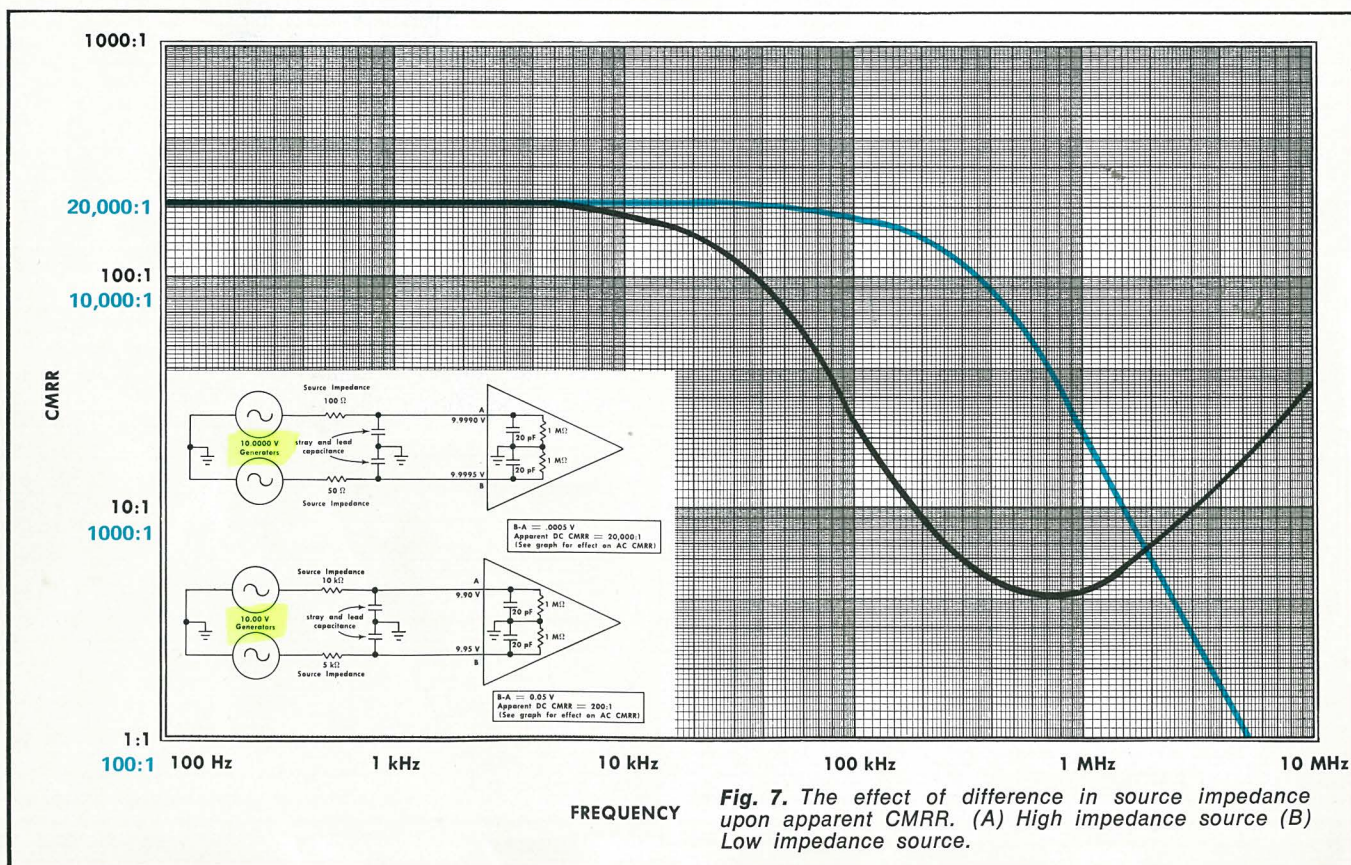
We will now consider the case where the two inputs to a differential amplifier are connected to circuits which do not have the same source impedance. If the source impedances are different (and in reality they probably will be) the apparent CMR will be lower even though the voltages from both sources are the same.

Let's examine the effects of unbalanced source impedance on CMR for two different conditions. See Fig. 7.

If we remove the 1 MΩ resistors none of the input signal is lost and the CMR is as good as the amplifier can provide. Some TEKTRONIX differential amplifiers provide this feature. For example the "W" unit has an " $R \approx \infty$ " position on the input attenuator switch. In this position the input connector is coupled directly to the gate connection of the input FET's and the gate to ground connection is open circuited. We also find a similar feature in the 7A22. However, in the case of the 7A22 the feature is not switchable on the front panel. To utilize this feature the operator must remove internal wire straps.

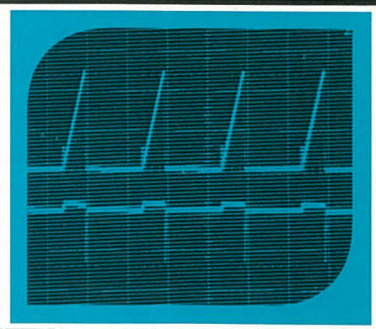
Summary

This first article of the series has discussed the differential amplifier and its ability to reject common-mode signals. In the next article we will discuss the techniques used in making differential measurements correctly.





SERVICE SCOPE



SERVICING THE 432/434 OSCILLOSCOPES

by KEN MATHESON, *product service technician*

The 432 and 434 Portable Oscilloscopes have identical performance characteristics with the exception of the storage feature in the 434. Both instruments use a new high-efficiency low-voltage power supply in which compensation for changes in line voltage, line frequency and load demand takes place in the primary circuit. High-efficiency power supplies are relatively new to the instrument field and present a somewhat more difficult challenge to the service technician than conventional regulated supplies. Let's take a look at this area first.

Power Supply

For a quick review of high-efficiency supplies . . . they are basically DC to DC converters. The line voltage is rectified and filtered and used to power an inverter that runs at approximately 25 kHz. The inverter drives the primary of the power transformer supplying the necessary secondary voltages. Regulation is usually accomplished by controlling the frequency at which the inverter runs, thereby controlling the energy applied to the primary. In some high-efficiency supplies further regulation takes place in the secondary circuitry. In the 432/434, only primary regulation is used. Variations in line voltage are compensated for by changing the duration of "on" time of the current driver, while variations in load are handled by changing the repetition of the "on" time.

Now let's take a look at troubleshooting the supply. There are two items you will find useful: a power line isolation transformer and a current probe such as the TEKTRONIX P6021. The primary power supply circuit common and guard box are elevated to line potential. The isolation transformer reduces the shock hazard and allows grounding the power supply common for troubleshooting. The current probe is a convenient means of viewing the current waveforms associated with the current driver, Q1080.

Suppose we undertake to troubleshoot a supply that won't stay up. Your ears may provide the first clue. If you listen closely you may hear a short burst of 12 kHz signal repeated about every ten seconds. This indicates a probable short

in one of the secondary supplies. What's happening is that when you turn the instrument on, the start circuit will try to start the inverter. The inverter will run at a frequency of 12 kHz for one second. At this point the start circuit turns off and, because of the shorted secondary supply, the inverter cannot produce adequate power to keep running and shuts down. After ten seconds the start circuit tries to start the inverter again and the cycle repeats itself. The signal you hear is the transformer core responding to those one-second bursts of 12 kHz energy. When the supply is operating normally it runs at 25 kHz, well above the audible range.

If the supply won't come up and it isn't evident what the problem is, the first step is to measure the +50 V bus on R1034 (10 k Ω to Common). Pulling Q1025 in the start circuit will allow the +50 V to stay up unless pulled down by a short on the primary board. A note of caution: much supply protection is removed with Q1025 out of the circuit. The supply should be left on only long enough to take a measurement, then shut down while you plan your next step.

The second step should be to check the waveform at the collector of Q1064. If okay, check the waveform at the collector of Q1065 and then at the base of Q1080 (TP1080).

Next, check the -5 VDC supply at the anode of CR1095. Other points to check are the collector of Q1078 for proper turn off pulse and TP1094 for proper damper waveform.

If the primary waveforms look good, pulling Q1040 will open the regulator circuit. If this shows no change, measuring the secondary supplies to ground and to each other may be useful.

Disconnecting secondary loads is helpful sometimes, however, the high voltage leads should not be lifted as this removes the discharge path and arcing may result. A shock hazard also exists.

Here are some common symptoms you may observe as you troubleshoot the supply:

- (a) With R1074 (Current Sense) set around mid-range sharp spikes on Q1080 collector voltage and current waveforms each time supply tries to turn on indicates a shorted secondary. This can be a grounded supply, a shorted rectifier diode on secondary boards, a shorted capacitor or diode on the high voltage section of the transformer, or a shorted transformer winding. A grounded power supply may also cause a flat collector waveform (Q1080) instead of high positive peaks.

To measure Q1080 collector current, insert both the gray/violet and gray/yellow wires to P102 in the current probe. This way the zener string current subtracts from the current in the gray/yellow wire to leave only Q1080 collector current.

- (b) If Q1080 collector current is around 6 A with no control by R1074, the turn-off circuit from the secondary winding of T1080, through Q1075 and Q1078, to the base of Q1080 is not functioning. However, if the current waveform rises sharply, a short may exist in the collector circuit of Q1080 through T1080 or the diode string (CR1084, VR1084 & VR1085).

Q1080 base current can also be checked with the current probe (the gray/green wire to P101). Reverse current turn-off spike should be greater than 1 A peak.

- (c) With Q1080 peak collector current set around 2 A to 2.5 A and period near 40 μ s, the -15 V adjust pot should have control of primary. If adjustment of R1122 has no effect, an open in the feedback loop from the regulator (U1130) through Q1138, Q1150, T1150 and Q1040 is likely.

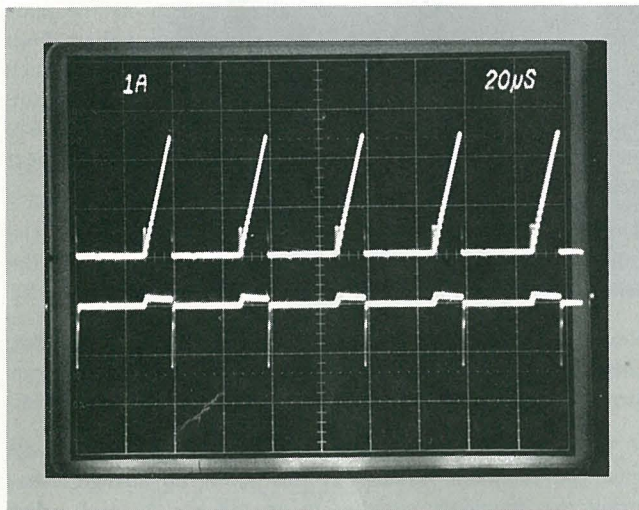


Fig. 1. The current waveforms at the collector (upper trace) and the base (lower trace) of Q1080.

High Voltage Supply

The high voltage is supplied from the same transformer that drives the low-voltage supplies. It is the only supply that uses secondary regulation. Since the 432 and 434 use mono-accelerator CRT's the supply is relatively simple.

When troubleshooting the high voltage supply, measurement of the 0 to +800 V supply (P121 pin 1) and the -4100 V supply (P128 pin 1) is a good place to begin. The 0-800 V reading depends on the line voltage, intensity settings and other factors but is nominally 200-500 volts. You should use the 1200 V scale on a standard multimeter (20,000 ohms per volt) to measure the 0-800 V supply to prevent loading the supply.

If the high voltage is too high it may relate directly to the positive supply. A grounded positive supply or shorted transistor may hold the positive supply down, pushing the negative supply more negative. If the High Voltage Adjust cannot be set to -3940, the thick-film resistors may have changed value.

If the high voltage is grounded momentarily or arced through a low-range meter setting several components may be damaged. In some early instruments arcing from C990 to the thick film resistor R962 has occurred. Typical component failures caused by shorting or arcing are CR926, CR928, CR931, CR935, Q925, Q989, Q990, Q995 and U940.

Because of the high voltage encountered, another common problem is diode leakage caused by low back resistance. Diodes should be checked on the highest resistance range and if any leakage at all is indicated, replace the diodes.

The Z-Axis

To begin troubleshooting Z-axis problems, measure the waveform at TP924 using your test scope with a X10 probe. Voltage baseline should be about +9 V and peak-to-peak voltage should vary with the intensity control from zero to about 105 V and carry the unblanking waveforms. If the signal is not present at TP924 check back through the operational amplifier and U940A. Inputs to the Z-axis can be at fault, especially the chopped blanking input.

If the waveform at TP924 is normal, check the CRT filament voltage; C1199 and CR1199 could have failed or you may have a defective CRT filament. Also check to insure that the sweep is running and the vertical is centered.

If everything looks normal here, the problem is in the high-voltage section or the DC restorer (Q924, Q925, etc.). Check the signal to pin 127-1 from the secondary power supply, then at the emitters of Q924 and Q925. These or diodes CR924 and CR925 may be faulty.

Here are some common symptoms you may encounter:

- Short bright trace at slower sweep speeds and full trace at the fastest sweep speeds. This is usually the DC restorer circuit.
- Intensity limit at slower sweep speeds doesn't work. Caused by shorted VR944.
- Bright spot or bright section of trace. Caused by diode leakage of CR926 or CR928.
- Excessive trace modulation. Some modulation at low intensity levels is normal. If it seems excessive, check Q925, CR931 or CR935.

Vertical Amplifier

The vertical circuitry is relatively easy to troubleshoot using the standard technique of starting at the output and working back to the source of the problem. One difference you will note is that lifting the collector leads of output transistors Q530 and Q580 doesn't center the trace as you would expect. Instead, the vertical plates rise to +115 V and attract the CRT beam current. This is due to no post deflection anodes. You will also notice that if one vertical lead to the CRT is open, varying the voltage on the other plate does not drive the trace off-screen; it stays pretty close to the center.

The most common problem experienced in the vertical is U210 or U310 failing. If either IC fails, the trace is deflected off-screen.

Trigger, Sweep, Horizontal

Troubleshooting the trigger is pretty much a matter of signal tracing and voltage measurements. No persistent problems have been experienced in this area.

The sweep circuit is best analyzed by checking for proper voltages and waveforms. The instruction manual contains some twenty-three waveforms for the sweep circuit. The best point to start is to check the voltage at TP678 to see if tunnel diode CR678 is in the high or low state. If it is in the high state the sweep should be running. It is fairly easy to signal trace from that point to determine where a malfunction is occurring.

The horizontal section is also straightforward and should not be difficult to troubleshoot. Linearity problems are usually diode related. Gain problems can usually be traced to resistor changes with a cam switch contact occasionally causing problems.

Summary

The 432 and 434 are relatively trouble free and easy to service, the most difficult areas being the high-efficiency power supply and Z-axis circuitry. We hope this article makes these areas easier to service.

Tektronix or its distributors will be participating in the following exhibitions in the International Marketing area during September and October:

On-line 72	London, U.K.	Sept 4 - 7
International Broadcasting Convention	London, U.K.	Sept 4 - 8
Interimpulse	Moscow, USSR	Sept 5 - 17
Brno International Fair	Brno, CSSR	Sept 8 - 17
Scientific Materials INSA	Lyons, France	Sept 19 - 22
1972 Electronics Show	Tokyo, Japan	Sept 21 - 27
SICOB	Paris, France	Sept 21 - 30
Electronics Components Fairex	Amsterdam, Netherlands	Sept 25 - 29
Physicists Convention	Wiesbaden, W. Germany	Sept 25 - 30
Electronics Promotion Fairex	Coventry, U.K.	Sept 26 - 28
Elektronik 1972	Copenhagen, Denmark	Sept 30 - Oct 6
Instruments & Mattekunik	Stockholm, Sweden	Oct 2 - 7
Electronics Promotion Group	Southampton, U.K.	Oct 4 - 6
Ljubljana Electronics Fair	Ljubljana, Yugoslavia	Oct 10 - 14
International Fair	Bucharest, Rumania	Oct 15 - 24
U.S. Industrial and Scientific Equip. Exhib.	Taiwan	Oct 16 - 21
Instrumento Expo-72	Buenos Aires, Argentina	Oct 16 - 20
Phirama	Marseilles, France	Oct 23 - 27
Advanced Office Equipment Exhibition	Caracas, Venezuela	Oct 24 - 28
Sonimag	Barcelona, Spain	Oct —

EXHIBITIONS



TEKSCOPE

Volume 4

Number 5

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MEDICINE

PROCESS CONTROL

the
613



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