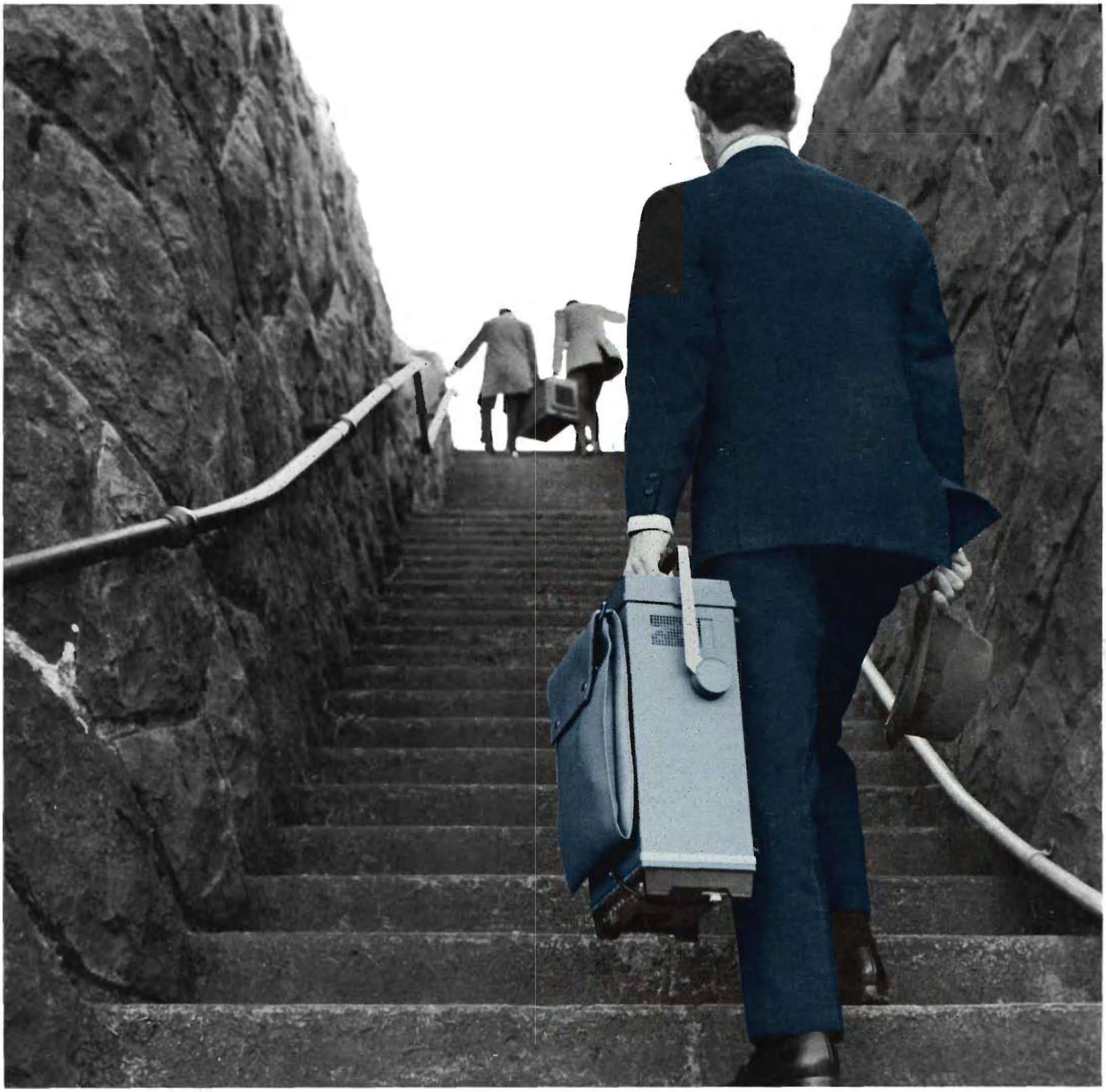
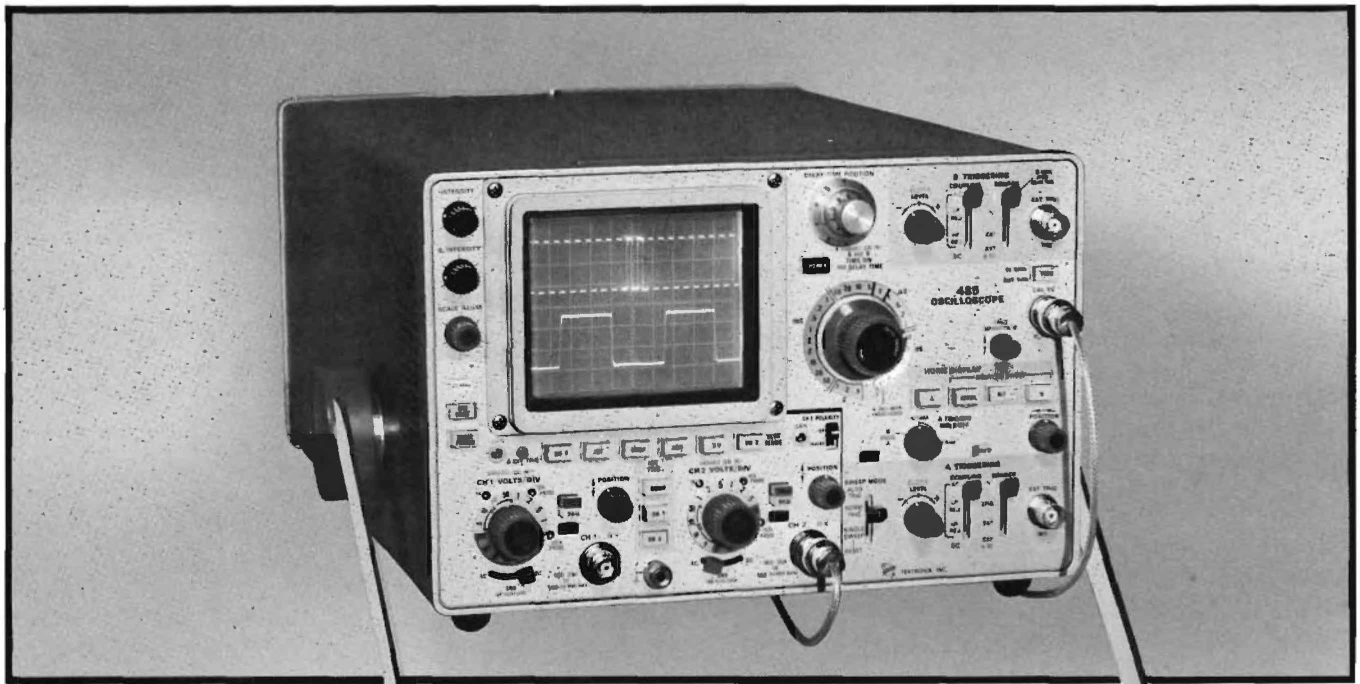
TEKSCOPE

MARCH 1972



A Nanosecond Portable Oscilloscope
A Review of Basic Counter Principles
A Potpourri of Servicing Aids



A Nanosecond Portable Oscilloscope

By Gene Andrews,
Engineering Project Manager

Nanosecond signals, limited to the laboratory environment yesterday, are appearing with increasing frequency in equipment delivered to customers today. The need to view and measure these signals in a "field" environment is upon us.

Responding to this need, the 485 offers greater bandwidth/sensitivity than any other real time oscilloscope available today, and in a portable package.

Weighing only 20½ pounds the 485 boasts 350-MHz bandwidth at 5 mV/div with a 50-ohm input impedance. Selectable input impedance permits you to easily switch to the traditional 1-megohm input for measuring power supplies and other high level signals. Bandwidth in the 1-megohm position is 250 MHz.

The wide bandwidth is complemented by a top sweep rate of 1 nanosecond/div with stable triggering to full bandwidth. A variable holdoff control permits viewing of complex waveforms such as digital words without multiple triggering.

Smaller and lighter than the world's most widely travelled oscilloscopes, the TEKTRONIX 453A and 454A, the 485 possesses all of the capability you have come to expect in portables, plus several new features. Dependability, dual trace, delaying sweep, automatic triggering, bright trace, X-Y . . . they're all there. In addition, you have an alternate sweep presentation that lets you view repetitive signals on both delaying and delayed sweeps at the same time. Automatic focusing keeps both traces sharp even though the individual intensity settings differ widely. Because of the infrequent need for adjustment, the focus and astigmatism controls have been relegated to the rear panel.

COVER—The new 485 Portable Oscilloscope makes the going easier whether the problem is a steep flight of stairs or a difficult measurement.

Much has been done to reduce operator error and speed measurement time. For example, light emitting diodes indicate the vertical deflection factor at the probe tip, automatically switching to accommodate X1, X10 or X100 probes. Push-away variable controls prevent measurement error caused by inadvertently leaving the control in an uncalibrated position.

Operation is simplified by single-function pushbuttons; just pressing one pushbutton switches you from Y-T operation to X-Y operation. And there is no need to reach frantically for the Intensity control. CRT beam current is automatically limited to prevent damage to the screen in every display mode.

A unique feature on the 485 is the ability to view the signal applied to the external trigger input, by means of a front panel pushbutton. This is a real time-saver when the external trigger signal is frequently used as a timing reference.

State-of-the-art performance at the front panel can only be achieved by state-of-the-art components and circuit design, coupled with the latest in manufacturing techniques. Let's look at each of these areas.

The CRT Circuit

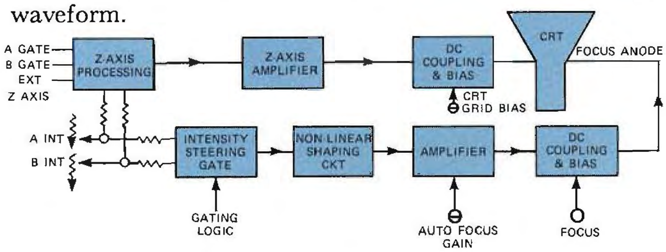
The CRT circuit produces the high voltage potentials and provides the control circuits necessary for the operation of the cathode ray tube. This section contains several innovations in circuitry that enhance the operation of the scope. Two examples are auto-focusing and beam current limiting.

Auto-Focus

Auto-focus is especially useful when viewing the delaying and delayed sweeps in the alternate mode. The focus voltage required is a function of the CRT control grid voltage or intensity setting. Since the two sweeps are normally set to different sweep rates, their respective intensity controls are set to different levels. The objective is to keep both traces in focus despite the difference in intensity settings.

In single-shot photography it is often necessary to take several trial shots to obtain the correct intensity for a good picture. With auto-focus the job is made easier because it is unnecessary to change the focus with each intensity setting.

A block diagram of the auto-focus circuit is shown below. The DC levels from both the main and B intensity controls are fed into a steering gate. Also fed into the steering gate is a gating waveform from the horizontal logic. During the blanking interval, when sweep switching takes place, the intensity levels are switched by the gating waveform.



Block diagram of the 485 auto-focus circuit.

From the steering gate the selected intensity level passes through a nonlinear shaping circuit. This circuit converts the linear intensity (CRT grid) voltage function to the nonlinear focus voltage required by the CRT. From the shaper it passes through an amplifier where the amplitude is set to match the focus function to the particular CRT. The final block before reaching the focus anode is the DC restorer circuit containing the FOCUS control located on the rear panel.

It is well to keep in mind that the purpose of the auto-focus circuit is to automatically change the focus voltage as the intensity level changes. It does not correct for defocusing caused by the geometry of the CRT and the deflection plates.[1]

CRT Beam Current Limiter

Most scope users have, at one time or another, unwittingly switched to an operating mode in which the beam was either stationary or moving slowly, with the intensity setting very high. The result was often a spot or line burned in the phosphor screen, accompanied by a sick feeling in the pit of the stomach.

Now we have a circuit in the 485 to prevent this happening. The CRT beam current is sensed at the low-potential end of the high-voltage multiplier. When the average beam current exceeds the level set by the maximum intensity adjustment (about 20 μA), a signal is fed to the Z-axis processing IC which limits the maximum Z-axis drive signal. For sweeps of 50 ms/div and slower and in the X-Y mode, average beam current is limited to 5 μA. Normal CRT operation includes instantaneous beam currents as high as 150 μA but a continuous value of 20 μA is adequate for applications such as a full-screen bright raster.

In the event there is a failure in the Z-axis system that causes the average beam current to exceed 30 μA, a back-up system automatically shuts down the power supply. After 100 to 300 ms the supply attempts to restart. If the overload is still present, the supply will cycle off and on until the trouble is cleared or the scope is turned off.

The CRT

The 485 CRT was developed concurrently with the 500-MHz 7904 CRT and uses a similar gun structure. The 8 x 10 division scan (0.8 cm/div) is accomplished by the unique construction of the vertical deflection plate structure. Each plate is a photo-etched box-like structure about 2.5 inches long. The design permits bending the structure to gradually increase the spacing between plates at the screen end. The structure is tuned by means of adjustable compensator plates to maintain a Z_O of 364 Ω within 1%. A dome-shaped mesh shields the deflection plate area from the high accelerating-anode potential and contributes a two-times deflection magnification.

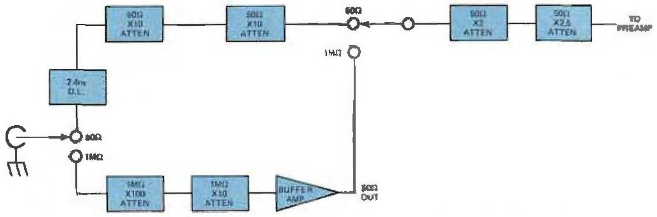
The 21 kV accelerating potential yields a writing speed in excess of 6 div/ns using a P11 phosphor and C-31 Camera with 10,000 speed film.

THE VERTICAL AMPLIFIER

Access to the vertical amplifier is through a single front panel BNC connector. Separate 50-ohm and 1-megohm signal paths are selected by a front panel push-button.

Note 1 Reference TEKTRONIX Circuit Concepts Book entitled "Cathode Ray Tubes".

The input switching relay also provides protection for the 50-ohm input by automatically disconnecting the input whenever a continuous signal exceeds 5 V RMS, or a pulse above 5 V exceeds 0.1 watt-second. A RESET light indicates overload has occurred. The input is easily reset by pressing the 50 Ω/1 MΩ input selector pushbutton.



Separate input paths for the 50 Ω and 1 MΩ inputs yield a low 1:1.2 VSWR.

The vertical amplifier uses nine IC's, all of the same type with the exception of the output stage. Both types are Tek-designed and manufactured. Innovation in packaging as well as circuit design contributes to the outstanding performance of these devices. The square lead arrangement of the M84AC package minimizes bondwire lengths and provides the optimum configuration for interfacing with the printed circuit board.

The M84AC is a multifunction device. It serves as an amplifier, polarity inversion switch and variable gain control. Basically it is a cascode amplifier. Connection to the base of the input amplifier is through a "T" coil arrangement partially formed by the bondwires of the device. This technique results in the input appearing as a 50-ohm load at all frequencies and a considerable increase in the bandwidth of the device is effected.

Two pairs of transistors form the output portion of the cascode amplifier. The DC voltage on the bases determines which pair conducts and, hence, the polarity of the output signal relative to the input. Variable gain control is achieved by allowing both pairs to conduct by a selected amount.

Bandwidth limiting in the stage driving the output amplifier is achieved using a similar technique. With the BW LIMIT switch in the FULL bandwidth position, one pair of output transistors passes the signal through a 50-ohm environment to the output stage. In the 20-MHz position, the signal is routed through the other pair of output transistors into a 2-pole, 12 dB/octave filter for signals above 20 MHz.

The output stage is a hybrid IC consisting of an "f_T doubler"[2] stage driving discrete transistors mounted on separate silicon chips. The output stage is housed in a TO-8 stud-mounted package with the integrated circuit chip mounted right on the stud for maximum heat transfer.

THE HORIZONTAL SYSTEM

Flexibility is the word best describing the horizontal system in the 485. Some of the features we've already mentioned briefly, such as stable triggering to full bandwidth and viewing of both delaying and delayed sweeps in an alternate sweep presentation. A single pushbutton puts the 485 in a calibrated X-Y mode with less than 3° phase shift to 5 MHz.

The top sweep rate of 1 ns/div is achieved without the use of the usual 10X magnifier. This results in improved linearity and timing accuracy for the fastest sweeps since the horizontal amplifier operates over a relatively small dynamic range. The amplifier circuitry is greatly simplified as the limiters and circuitry normally associated with the use of a magnifier are not needed.

Further simplification of the horizontal circuitry is effected through a unique scheme that uses a single time base generator to generate the 1, 2, 5 ns/div sweeps for both the main and delayed sweep functions.

Usually the main (delaying) sweep operates over the broadest range of sweep rates since this is the sweep used in the majority of applications. The delayed sweep normally does not include the slower sweep rates; however, the faster sweeps are needed for many applications. This means the horizontal system usually contains two time base generators capable of generating these fast sweeps.

In the 485 only the delayed sweep generator is used for the 1, 2 and 5 ns/div sweep rates. When operating in the Main Sweep Mode at these sweep rates, both Time/Div controls are locked together. The delayed sweep generator is automatically placed in a "zero delay" condition and starts immediately upon receiving a gate from the Main Trigger logic. In essence, it is being triggered by the Main Trigger and it is not apparent to the user that the displayed sweep is actually being generated by the delayed sweep generator.

Requiring only one time base to generate the fast sweeps results in an appreciable reduction in instrument cost. Maintenance expense is also reduced accordingly.

Another important feature of the horizontal system is the capability of operating at up to 2-MHz rep rates on

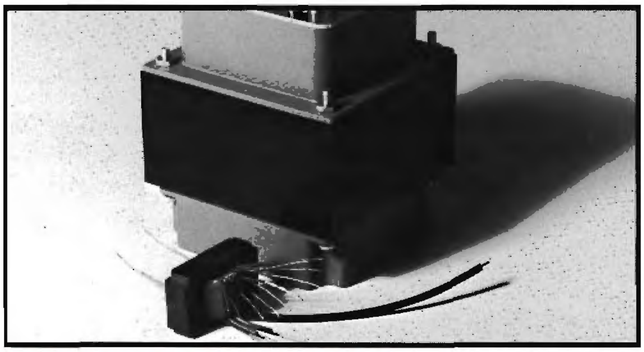
Note 2 See July TEKSCOPE "A Subnanosecond Realtime Oscilloscope".

the faster sweeps. This provides minimal loss of signal information and maximum display brightness.

THE POWER SUPPLY

The 485 uses a high-efficiency power supply; the type first used in the 7704 Oscilloscope[3]. Great strides have been made in reducing the complexity and physical size of such supplies. In the 485, total weight of the unit supplying both low and high voltages is only 2.8 pounds. Overall efficiency from line to regulated DC is 80%.

A single transformer weighing only 4 ounces and dissipating less than 2 watts powers the unit. The photo below shows its size in comparison to the power transformer used in the TEKTRONIX 547 Oscilloscope.



MECHANICAL CONSIDERATIONS

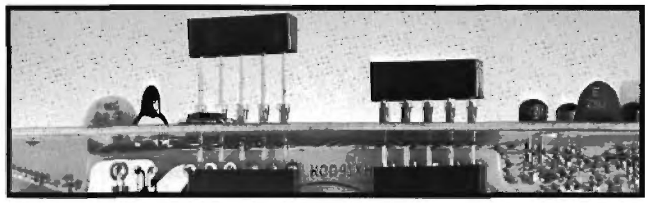
Mechanical design goals for the 485 were to produce a smaller, lighter package than the 453/454, with improved operating ease and serviceability. Close cooperation between the electrical and mechanical design groups resulted in significant achievement in each of these areas.

Some of the improvements in operating ease have already been noted, such as function changing by means of a single pushbutton, elimination of front panel controls through automatic focusing, and front panel indication of the deflection factor at the probe tip. Tektronix-developed cam switches provide smooth, easy operation for changing of sweep rates and vertical deflection factors.

Note 3 See March, 1971 TEKSCOPE.

The low 20½ pound weight is achieved by unitized construction which takes maximum structural advantage of all components. Overall dimensions of 20-5/8 x 12 x 6-9/16 inches make the 485 both narrower and shorter than other portables. It requires less bench space and is easier to carry.

Serviceability is a prime feature of the 485 design. A minimum number of printed circuit boards are used and a unique circuit board interconnection system practically eliminates cabling between boards.

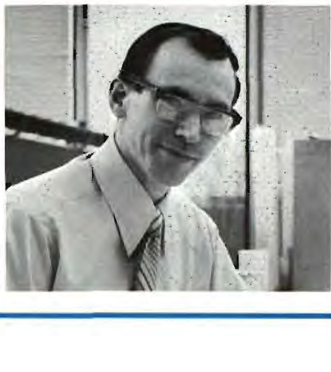


Since the 485 is expected to operate in widely differing environments, the cooling system employs a temperature sensing circuit which varies the air flow according to the ambient temperature. This insures minimum drift and maximum reliability.

Designed to meet the need for nanosecond measurements in a field environment, the truly remarkable capabilities of the 485 will undoubtedly find many applications in the laboratory and production areas as well.

ACKNOWLEDGEMENTS

A project of the magnitude of the 485 naturally involves many people. Here are some of the members of the talented team responsible for the 485. John Addis was project leader for the vertical section, assisted by Winthrop Gross. Glenn Bateman, Ron Peltola and Bob Firth designed the low and high impedance attenuators. Murlan Kaufman was project leader for the horizontal and logic systems and designed the trigger generator. Bob White designed the trigger amplifier and external trigger view circuits. Keith Taylor did the work on the fast sweeps, the horizontal and the Z-axis amplifiers. The excellent mechanical design was done by Tom Baker, Mark Anderson and Dave Curtis under the direction of Dick Duggan. Dick Troberg designed the high efficiency power supply system, contributing much to the low power and weight of the instrument. Vaughn Weidel, project coordinator, provided much valuable assistance including the unique board-interconnect design. Conrad Odenthal designed the high-performance 485 CRT. A great many other groups also made valuable contributions to the 485 project.



Gene Andrews—During his ten years at Tek, Gene has made many fine contributions to the product line. He began by working on the 10A2 amplifier, and was then responsible for the vertical amplifier design of the 453 Portable. He later was project engineer on the 647A/10A2A to bring this up to a 100-MHz instrument. When the 7000-Series was conceived he worked out the horizontal amplifier for the 7704 and designed the high-efficiency power supply for the unit; the first used in a TEKTRONIX laboratory oscilloscope.

Gene received his BSEE from Oregon State in 1954 and completed his M.S. at Stanford in 1956. For recreation he enjoys hiking with his wife and two teenagers in this great Northwest country.

a review of basic Counter Principles

By Ray Herzog, Assistant Program Supervisor

With the introduction of the 7D14 Digital Counter plug-in, Tektronix opened the door to the world of counter measurements for oscilloscope users. The convenience of having a digital counter as an integral part of the oscilloscope meant that, for the first time, many of you would be using this valuable tool to help solve your measurement problems.

As with any instrument, the more familiar one is with the basic operating principles of the counter, the better he can put it to use. To this end, we've prepared a review of basic counting principles and the common types of counters in use today.

BASIC COUNTER FUNCTIONS

Although there are many types of counters, all are basically designed to measure an unknown frequency or time by comparing it with a known frequency or time. Design differences account for variations in such areas as price, accuracy, and number of measurement modes. We will use the direct counting type of counter as a basis for our discussion of basic counter functions. Other types of counters will be mentioned later in the article.

In addition to a power supply and necessary switching circuitry, five main functions are essential to any counter. As shown in Figure 1 these are:

(1) Signal input conditioner
(2) Gate
(3) Gate control/Time base
(4) Decimal counting units (DCU's)
(5) Readout

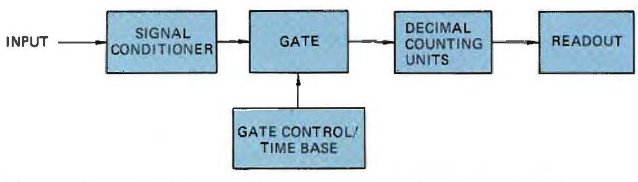


Fig. 1. Five main functions of an electronic counter.

The incoming signal to be counted, in going through the signal conditioner stage, receives the normal conditioning typical with any input stage: attenuation for large signals, amplification for weak signals, selection of coupling, impedance matching and so forth. But in addition to normal signal processing, the counter signal conditioner has another purpose; to transform the measured signal's waveform into a precisely shaped signal suitable for further counter functions. The conditioner, therefore, may also be referred to as a "shaper". The need for signal shaping arises from the fact that input signals, with varying shapes and amplitudes, are not suitable to drive the counting circuits.

Signal shaping is usually done with a Schmitt trigger circuit. Inherent with this Schmitt is a LEVEL/SLOPE control that selects the amplitude and slope on the signal where the counter is triggered. This control is much like that found on the conventional scope.

The conditioned signal is next passed through a gate for a time interval determined by another function—the Gate Control/Time Base. The gate is a "go/no go" device. How it is turned on and off via the control stage is basically determined by the operating mode. More will be said about the gate and its control later in the operating mode discussion.

Signal pulses from the gate, having been determined by the counting mode, are fed to the decimal counting units (DCU's). Here they are converted into a signal suitable to drive the readout. DCU's are usually flip-flops arranged to divide their input by 10; they drive the readout in binary coded decimal (BCD) form. The first DCU gives the "units" count, the second DCU, the "tens" count and so forth. And, as would be expected, the number of DCU's, as well as readout capacity, determines the magnitude of the displayed count. For example, eight DCU's and a corresponding number of readout units would give an 8-digit readout.

Readout, the last of the counter stages, provides a visual indication of the count. Typical readout devices include neon lamps, incandescent lamps, light emitting diodes, gas ionization tubes, and multi-segment/bar indicators. With the 7D14, readout is provided by the unique oscilloscope CRT readout. CRT readout gives an alphanumeric display of information on the CRT on a time-shared basis along with the analog waveform.

MODES OF OPERATION

The electronic counter is most often thought of as a device that totalizes (counts) input events. But this operation, in the totalize mode, is only one of seven common modes. A counter can also indicate an input signal's frequency or period, in frequency and period modes. It can compare two signals in the ratio mode. It can indicate the time between any two points on a waveform; when they represent an input signal's pulse width, the counter would be in a width mode. And finally, in the averaging mode, a counter can average the measurement reading over a number of periods or time intervals to give better resolution.

It should be noted that not all counters are capable of seven modes. The main factors that limit the total number of modes are price and type of counter. For some applications, all modes are not needed. The 7D14, for instance, has the totalize, frequency and ratio modes.

Totalize Mode

The discussion of counting modes will start with the simplest one, the totalize mode shown in Figure 2. When compared with Figure 1, it may readily be seen that the gate control/time base function is no more than a simple switch that turns the gate on and off in performing the totalize operation. Indeed, in totalizing an input signal, all that's necessary is to let the signal accumulate in the readout register. Thus, the gate is permitted to pass the signal for whatever time the totalizing is to occur.

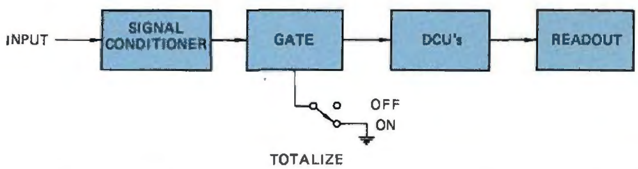


***Fig. 2.** In totalize mode, the gate is turned on for the time that the input signal is to be accumulated.*

In its simplest form, the gate's "on" time is controlled manually. In the 7D14 this switching is done with a double push-button, self-cancelling switch called MANUAL GATE/ON OFF. A count is started when the "ON" switch is pushed "in", and is ended when the "OFF" switch is pushed "in". Figure 3 shows this function, along with one other totalizing gating method; external control.

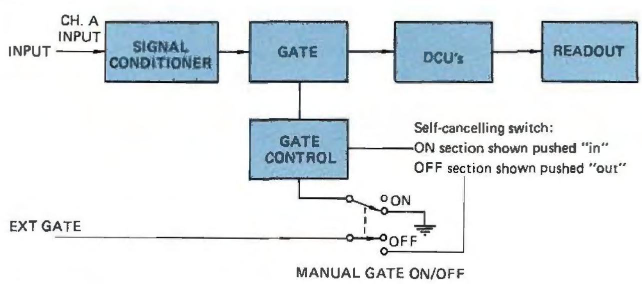


***Fig. 3.** Two methods for totalize mode gate control: Internal (manual) and external.*

Remote control of the gate may be obtained from an external control signal. When the MANUAL GATE "OFF" switch is pushed "in", the EXT GATE input is connected to the gate control circuitry, and this signal establishes the gate "on/off" time. When the external control signal is an accurate time base, precise gate control may be established.

In both of the above totalizing operations, the input signal will be totalized (counted) for as long as the gate is conducting.

Frequency Mode

When the gate is controlled by an accurate time interval, the counter is in the frequency mode. This is diagramed in Figure 4. In a way, the frequency mode is like the totalize mode in that the input signal is counted for the period of time that the gate is open. In fact, a comparison of the totalize mode in Figure 3 with the frequency mode in Figure 4 reveals that the only difference is the way in which the gate control is operated.

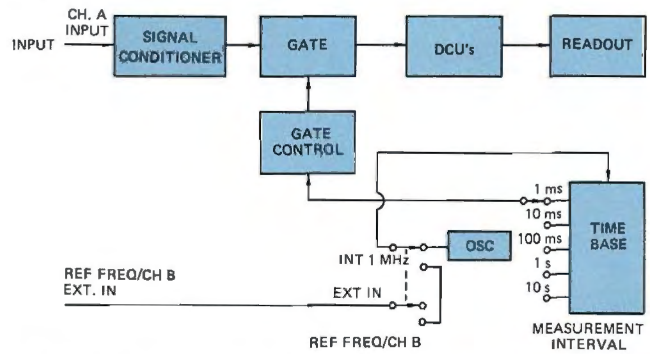


***Fig. 4.** Two methods for frequency mode gate control: internal time base and external.*

For frequency measurements, the counting time interval must be very accurate. Usually a reference oscillator in the counter provides the time interval. The 7D14 oscillator frequency of 5 MHz is divided down to a 1-MHz signal before being fed to the time base. The time base further divides the 1 MHz and from it derives time base intervals.

As Figure 4 shows, an external oscillator may also serve as the time base reference. For this operation, the external oscillator is applied to the REF FREQ/CH B EXT IN connector; from there it is routed via the EXT IN switch to the time base.

Ratio Mode

A third mode of operation is shown in Figure 5, in which the ratio of two input signals is displayed on the counter readout. The higher frequency signal is fed to the CH A INPUT connector and goes to the gate. The lower frequency signal is fed to the REF FREQ/CH B EXT IN connector. With the EXT IN switch pushed in, this signal is then routed to the time base. Here it is divided down and serves as the gate control signal.

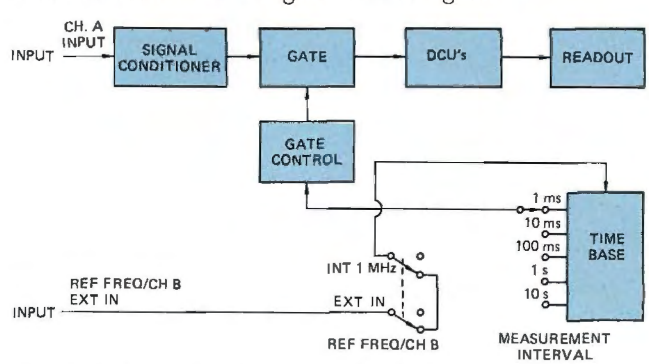


***Fig. 5.** Ratio mode gives the ratio of two input signals.*

In effect, what happens is that the lower frequency signal determines how long the gate is open, and thus, how long the gate passes the higher frequency signal from the CH A INPUT. The gate output, therefore, is the ratio of the two signals.

An example will serve to illustrate this. For convenience in understanding ratio action, both signals will be assumed to be equal. And the influence of the time base will be ignored for the moment. Let's say a 1 kHz signal is fed to the CH A INPUT and another 1 kHz signal is fed to the REF FREQ/CH B EXT IN connector. The gate would then be open for 1 ms (period of the 1 kHz signal). In this 1 ms time, the gate would pass 1 pulse of the CH A INPUT signal. Or, in other words, the ratio of the two signals, each 1 kHz, would be 1/1. This ratio would be displayed on the counter as 1. (The ratio denominator "1" is assumed in the readout.)

Now let's consider the effect of the time base on the above example. With the MEASUREMENT INTERVAL switch in the 1 ms position, the REF FREQ/CH B EXT IN signal would be divided by 1000. The gate would thus be open for a longer time than in the previous example. The result of the longer counting time is better resolution of the ratio measurement. This is shown on the readout in the form of significant decimal digits. The 1/1 ratio in our example would be displayed as 1.000 with the MEASUREMENT INTERVAL switch in the 1 ms position. In the 10 ms position, the displayed readout would be 1.0000, and for a 100 ms time interval, the readout would be 1.00000.

Period Mode

The period of a signal is the reciprocal of its frequency. As such, the measure of signal period might be expected to have a similar inverse relationship with its frequency measurement. And as shown in Figure 6, the period mode circuit is similar to that of the frequency mode (Figure 4)—with the exception of a reversal of the gate inputs.

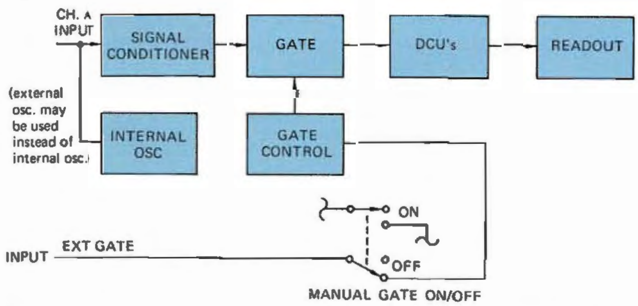


***Fig. 6.** In period mode, counter counts a reference oscillator signal during an input signal's period.*

In the period mode, the signal to be measured is fed to the gate control where it determines how long the gate is open. To the gate is also fed an accurate oscillator signal. The gate output, therefore, consists of pulses from the oscillator that represent the measured signal's period. For example, say the signal to be measured is 100 kHz (10 μs) and the reference oscillator is 1 MHz (1 μs). The gate would be open for 10 μs, and in this time would pass 10 pulses from the oscillator. These 10 pulses are then processed by the counter to provide a readout indicating a period of 10 μs.

Time-Interval Mode

The time-interval mode permits the counting of any number of events occuring between any two points on a waveform. This variable interval of measurement time is possible with a more elaborate gate than with other modes previously discussed. As evidenced in Figure 7,

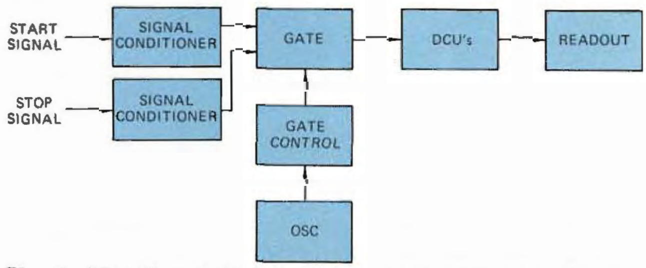


***Fig. 7.** "Start" and "stop" signals open and close the gate in the time-interval mode.*

the gate has three inputs: one from the gate control, and two from the signal conditioner stages—"start" and "stop" inputs.

The gate control feeds an accurate oscillator frequency to the gate where it then gets counted for a time determined by the "start" and "stop" input. The "start" and "stop" points are selected by triggering levels on the input waveform.

In a way, the time-interval mode is like the period mode, i.e., counting is done during a given time. But with the selectable "start" and "stop" points, the time-interval mode can count for not only the signal's period, but less than or more than a given period.

Width Mode

The width mode is a type of time-interval mode wherein the measurement is that of the signal's width. Compared with the time-interval mode, the width mode would have a preset trigger and other circuitry to function on the signal slopes so that the effective "start" and "stop" points are those of the successive rising and falling slopes of the measured signal.

Averaging Mode

It is often desirable when making period, time-interval, or width measurements to be able to average the reading over a number of periods or time intervals to achieve better resolution and accuracy. This is done with the averaging mode.

Consider the period mode given in Figure 6: if the input signal fed to the EXT GATE connector were to be divided by 1000, then the count of the reference oscillator applied to CH A INPUT would be averaged for 1000 periods. As long as the total count does not exceed the capacity of the readouts, the resolution would effectively be increased 1000 times.

In a ratio measurement, averaging is done when the signal fed to CH B EXT IN is routed through the time base to the gate control. In the ratio mode example, the 1 kHz input to the time base would be extended 1000 times with the MEASUREMENT INTERVAL switch in the 1 ms position. (1 ms being 1/1000th of a second.)

TRIGGERING

Part of the signal conditioner function in Figure 1 is a trigger circuit that selects the signal level at which counting is to occur. You'll recall that the signal conditioner output is a series of shaped pulses, and this output is affected by a trigger LEVEL/SLOPE control.

Let's examine this more closely. Consider a Schmitt trigger circuit receiving a sinewave input signal as in Figure 8(a). Each time the signal level rises above and drops below the circuit's hysteresis window, a rectangular pulse is produced. This properly shaped pulse becomes the signal that eventually gets counted.

Why, it may be asked, convert the input signal to a pulse? Or, what is the purpose of the level control? It would appear from Figure 8(a) that the signal's peak could serve as a point to be counted; moreover, the hysteresis window, centered at the input zero level, seems to give a good output reference. So why the variable trigger and conversion?

Basically this—conversion provides a uniform signal suitable to drive the counting circuits; and a variable trigger permits errorless, noise free counting. Indeed, an important criterion for a counter is its accuracy. No discussion of counters would be complete without its mention. And so, let's see how counting accuracy is affected by triggering and other factors.

COUNTER ACCURACY

Three major factors affect the accuracy of counter measurements: (1) trigger errors; (2) time base stability; and (3) inherent count ambiguity. Trigger errors are a main source of inaccuracy in totalize, ratio, period, width, or time-interval measurements. Time base stability primarily affects frequency measurements, but is important for all others. And count ambiguity can affect all counter measurements.

Trigger Errors

As depicted in Figure 8, trigger errors can cause the shaped pulses out of the Schmitt circuit to be either: (1) too wide; or (2) too many. For instance, the first cycle in Figure 8(b) is noise free, and it produces a normal output pulse. However, noise on the second and third cycles triggers the Schmitt too soon, producing a wider output pulse; this too-wide-a pulse would cause an error in the ratio, period, width, or time-interval modes, but not in the totalize or frequency modes.

Noise on the fourth cycle goes through the hysteresis window and produces an output pulse. This extra pulse would show up as an error in all modes except frequency.

But notice what happens when the hystersis level is adjusted to be above the noise level as in Figure 8(c). Now the noise pulses don't go through the window and therefore cannot cause any erroneous trigger output!

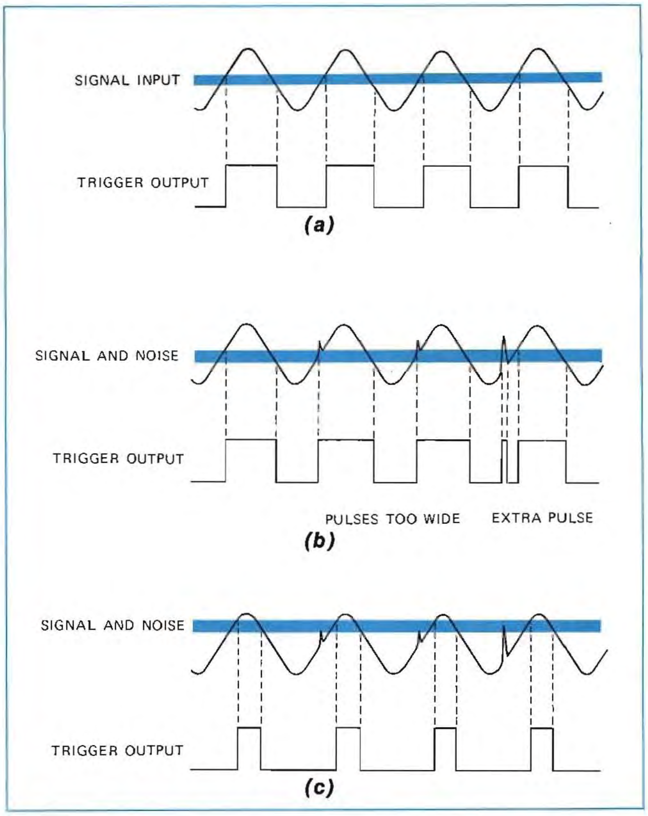


Fig. 8(a). Whenever input signal crosses hysteresis window (shaded area), an output pulse is produced. (b) Noise in input signal produces errors in output count. (c) Hysteresis level moved above noise level for noise-free count.

There is a compromise, however. Best operation comes with a trigger recognition point on the portion of the signal with the greatest slope (fastest rate of change in signal) and with as large an effective hysteresis window as possible.

Trigger error can be stated in two ways: (1) as a function of time; or (2) as a percent.

$$t \propto \frac{Vn}{Ss}$$

where t = time in which an error could occur, in seconds

Vn = peak-to-peak noise, in volts

Ss = slope of input signal at trigger point, in volts/second

This error time can be visualized as in Figure 9. When the trigger point is at the maximum slope, the time for possible error is the smallest. As the trigger level moves nearer to the top of the signal (where the slope is smallest), the time for any possible error increases. Trigger error expressed as a percent is:

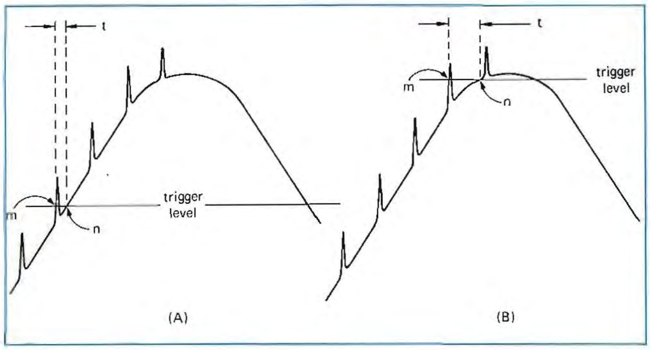


Fig. 9. *Trigger error, t, is smallest when triggering occurs on maximum slope.*

where % error = trigger error, figure of merit
t = error time, in seconds
T = time gate is open, in seconds

Quite often trigger error is specified as <0.3% divided by the number of periods taken (averaged). This percentage assumes certain conditions: sinewave input, signal amplitude equal to counter's sensitivity limit (usually 100 mV P-P), and signal-to-noise ratio of 40 dB.

In summarizing these two trigger error formulae it is clear that minimum error comes when—

- a count is made over a long time
- signal-to-noise ratio is high
- trigger point is on greatest signal slope

Time-Base Stability

The second major accuracy factor is time base stability. It primarily affects the frequency mode with both short-term and long-term stability contributing factors.

Long-term stability of the time base is affected by vibration, temperature, power supply voltage, and the oscillator crystal aging rate. Of these factors, the first three should be self-explanatory. Crystal aging, however, warrants further discussion.

Crystals have a slow variation in their resonant frequency with respect to time. This change or drift is predictable, with the greatest change taking place during the first 30 days. Specifications for crystal drift are usually given in parts per million per month; the 7D14, for instance, has a long term stability of 1 part in 10^7 per month.

Short-term stability is also affected by vibration, temperature, and power supply voltage; moreover, it is affected by crystal defects and inherent thermal noise of the oscillator. Short-term stability is usually specified as the frequency deviation for periods of seconds, or fractions of seconds. When longer periods are specified, the error is primarily a function of thermal noise.

Plus or Minus One-Count Ambiguity

The final accuracy factor to be discussed is the plus or minus one-count ambiguity. If the input signal is not synchronized with the gate operation, the resultant time difference can cause the total count to be either one count too great or one count too few.

Consider first the case where the input signal applied to the gate is synchronized with the gate control signal, as in Figure 10(a). The gate output will have the same number of pulses as its input, and thus there will be no error. But, as in Figure 10(b), when the two signals are not synchronized, the gate output could be either of two possible counts for a given input signal.

In accuracy specifications for a counter, the count ambiguity error may be given as $\frac{1}{\text{total no. of counts}}$.

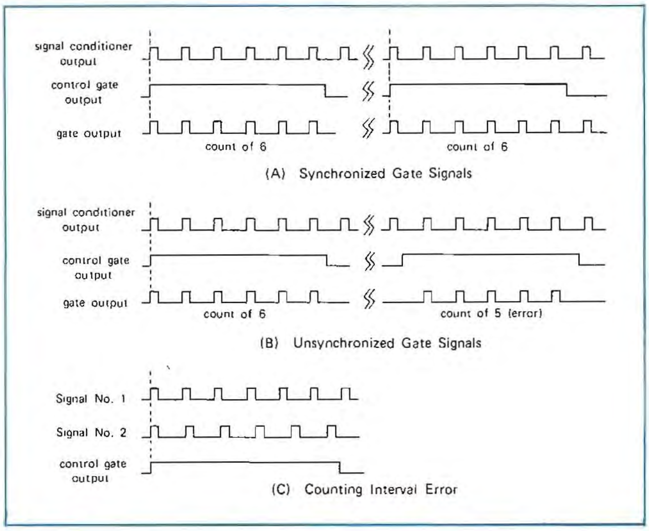


Fig. 10. *±1 count ambiguity gives **(a)** and **(b)** different counts for same input signal; or **(c)** same count for different input signals.*

Figure 10(c) depicts yet another ambiguous count situation where a change in the input test signal frequency would not be indicated in the gate output. Although signal number 2 has a slight frequency shift with respect to signal number 1, the gate output would still be six pulses for both signals. This undesirable effect can be minimized by using as long a counting interval as possible; or, in period or time-related measurements, by averaging. (If 100 counts were averaged, the ± count error will be only 1% as large as for a single period).

Count ambiguity for period or time-related modes can also be reduced by increasing the time base reference oscillator frequency. This effectively improves resolution and the ability to determine changes. If the oscillator frequency were increased, say, ten times, the count ambiguity would be decreased by a factor of ten.

REVIEW OF COUNTER TYPES

For consistency in presenting basic counter principles, this article has used one type of counter design throughout the discussion. To complete our study, let's now take a look at some other types of counters.

Prescaling Counter

The prescaling counter (shown in Figure 11) divides the input signal before it goes to the gate for subsequent counting. This design is economical. And with a frequency range from DC to 1 GHz, this type of counter is popular.

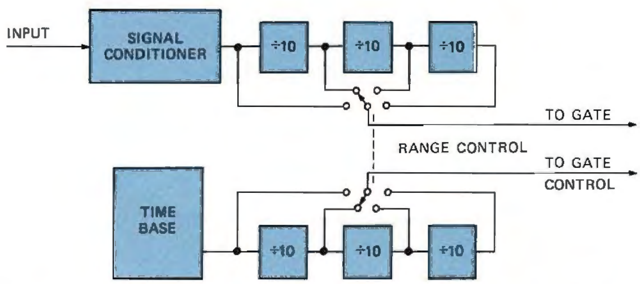


Fig. 11. Prescaling counter divides input signal and time base before further processing and counting.

On the other side of the pro's and con's for prescalers are such things as not being able to count a number smaller than the divider ratio, reduced resolution, and longer time to make as measurement. These three disadvantages arise from the necessity to divide the measurement interval by the same amount that the input is divided.

Heterodyne Converter Counter

The heterodyne converter counter mixes the input signal with a second frequency, and the difference frequency is then counted. The second frequency is usually derived from the counter reference oscillator, which drives a harmonic generator. The desired harmonic is then selected by a tuned filter or cavity, as shown in Figure 12.

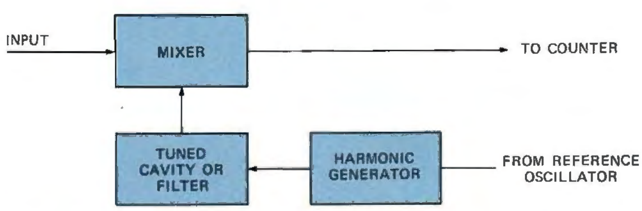


Fig. 12. Heterodyne converter converts a high input frequency to a lower frequency more suitable for counting.

Heterodyne counters provide a resolution of 1 Hz, and operate from DC up to 18 GHz. Their drawback comes from the operator having to use a conversion chart to determine the true input frequency from the readout frequency. And for accurate operation, the heterodyne counter works best with a sinewave input.

Manual Transfer Oscillator Counter (TO)

The manual transfer oscillator counter (TO) is somewhat like the heterodyne converter counter in that two signals are compared. But unlike the heterodyne unit with its fixed reference frequency, the transfer oscillator counter uses a variable frequency oscillator (VFO). The VFO frequency is harmonically related to the input signal being measured. In operation, the counter VFO frequency is counted, rather than the input signal's frequency. The correct VFO harmonic is determined by tuning the VFO and noting a zero beat in the meter stage shown in Figure 13. The counter readout is multiplied by the correct harmonic number to indicate the input signal frequency.

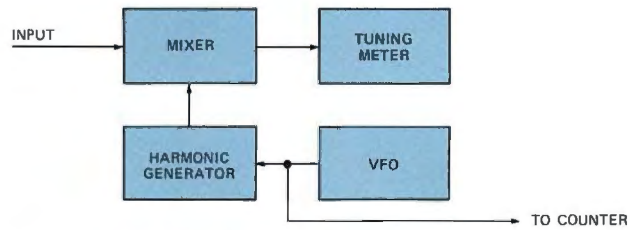


Fig. 13. Manual transfer oscillator counter measures its own oscillator frequency which is harmonically related to the input signal.

Two advantages of the transfer oscillator counter are: a very wide frequency range of 20 Hz to 40 GHz, and ability to measure pulsed signals as well as CW. Disadvantages include loss of resolution, longer measurement time, and the need for operator skill in the complex computation necessary for the harmonic calculation.

Preset Counter

The preset counter incorporates one or more dividers that can be used to preset limits for go/no go tests or to divide either the input or time base so that the readout is in engineering units (e.g., Feet/second, Parts/million.

Reversible Counter

The reversible counter permits the accumulation of a count which is proportional to two separate inputs or a single bipolar input.

Summary

Counters come in many sizes, shapes and capabilities; some perform many functions, some few. The basic principles of operation, however, are pretty much the same. Advances in components and packaging have dramatically reduced the physical size of counters. The TEKTRONIX 7D14 Digital Counter plug-in is an outstanding example of utilizing this reduction in size to expand the measurement horizon for both the oscilloscope and the counter.

NOTE: 7000-Series Application Notes on the 7D14 are available from Tektronix, Inc.

Editor's note: We have preempted the space normally devoted to TEKNIQUE to present this article in its entirety in this issue.

SERVICE SCOPE

A POTPOURRI OF SERVICING AIDS

By Charles Phillips
Factory Service Technician

Having the right tool for the job often makes the difference between a time-consuming frustrating task and a job quickly and expertly done. We would like to share with you some of the tools and other aids we find especially useful in our factory service center.

Thermal Shock Tools

In a previous issue we discussed using circuit cooler and a hair dryer as aids in locating intermittent or temperature sensitive components and connections. These tools will usually get you to the general area of the trouble, but the heat or coolant is applied over too large an area to identify the specific component. You can cool individual components by spraying a cotton swab with coolant and applying the tip of the swab to the suspect component. Conversely, you can heat individual components by applying the tip of a small (15 watt) soldering iron directly to the component. The soldering iron should be unplugged to prevent damage to the component caused by leakage voltage from the iron.

Incidentally, in selecting a spray coolant, choose one with a temperature rating of −50°C such as Miller-Stephenson MS-240. Coolants going down to −70°C may cause stress cracks to occur in the Polyphenylene Oxide (PPO) boards used in the vertical attenuator area. These boards are translucent in appearance and were selected for their extremely low dielectric loss.

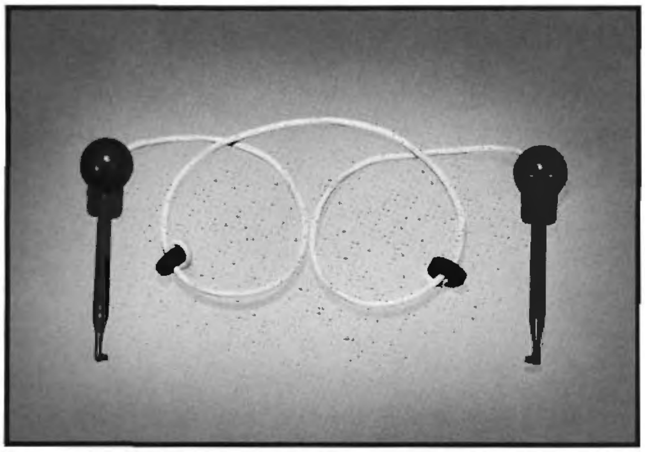
Test Leads and Cables

Test leads are like neckties in some respects. We usually have a lot of them hanging on the hook but find ourselves using a select few time after time while the rest just hang there in some degree of disarray. Here are some leads we've found to be especially useful.

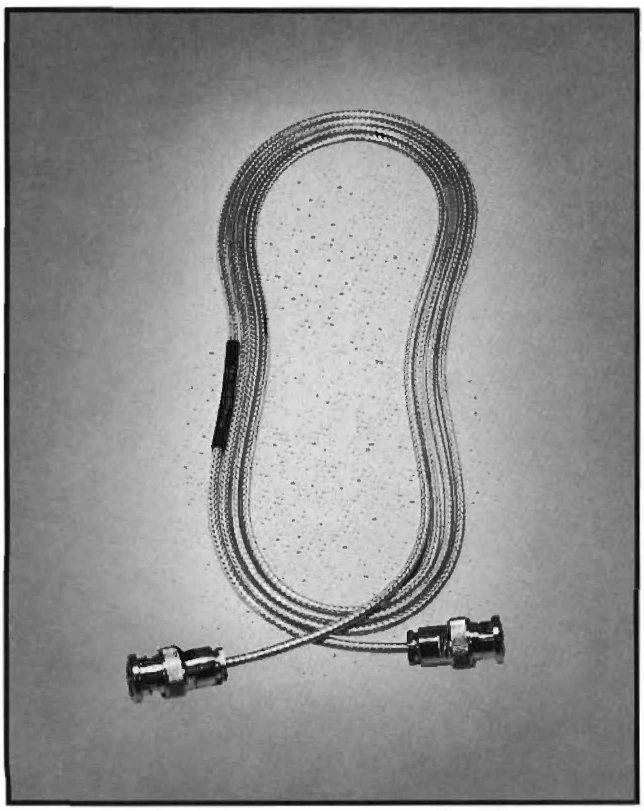
Pictured at upper right is a hybrid set of test leads consisting of Triplett or (Simpson) meter leads with Tektronix probe tips installed on the probing end. These are handy to connect onto closely spaced components without shorting between them.

The photo at right shows what you will need, in addition to the basic meter leads, to build them. The small rubber grommet serves to hold the lead securely in the probe body when the rear set screw is tightened.

To facilitate fastening the stranded lead to the nose portion of the probe body, solder a short piece of solid wire to the lead (a straightened standard paper clip works well). This simplifies threading the lead through the probe body and provides a good solid contact against which to tighten the forward set screw. Clip off the excess solid wire protruding from the probe nose. All of the needed parts may be ordered from your Tektronix Field Office using the part numbers shown in the photo.



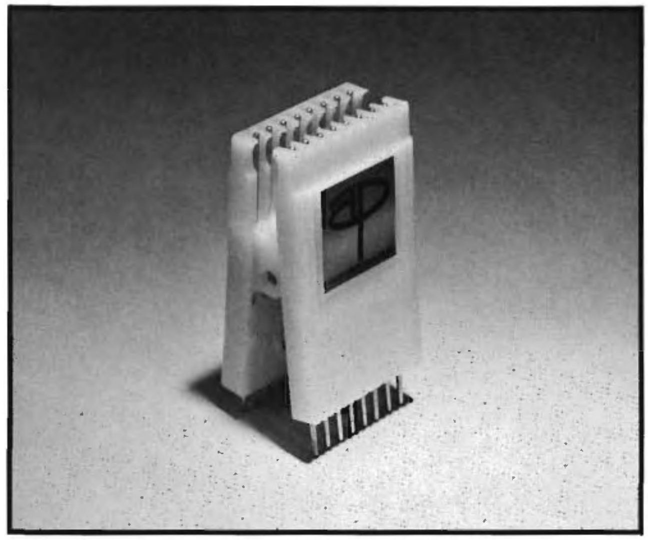
Another type of lead that is very useful is shown above. It's designed primarily for locating unbalanced stages in push-pull amplifiers but it is so convenient you'll find many occasions to use it. The small ferrite beads prevent the lead from causing oscillations when connected to high gain circuits. The assembly is available from Tektronix under part number 003-0507-00 or you can build your own leads to a length best suited to your purpose. The clips carry the designation X-100 and are manufactured by E-Z Hook, Division of Tektest, Inc., P. O. Box 1405, Arcadia, Calif. 91006.



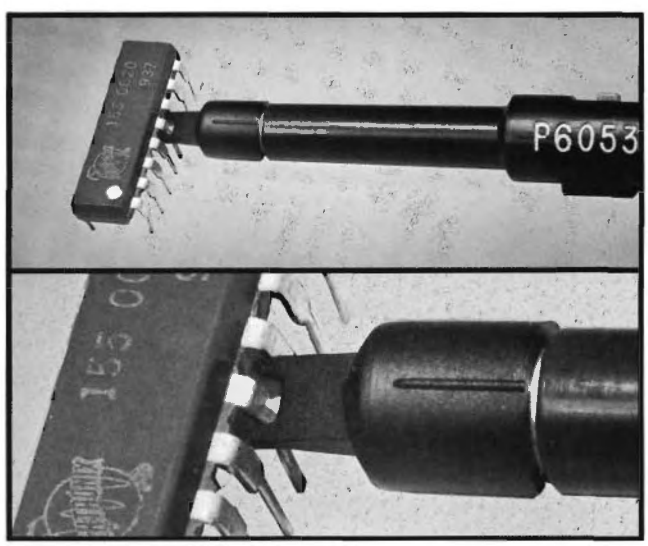
Pictured above is a six-foot 50-ohm cable that is much smaller in diameter and more flexible than RG-58 cable and, hence, easier to use. The Tektronix part number is 012-0113-00.

Other Miscellaneous Tools

In the June 1970 issue of TEKSCOPE we introduced you to the integrated circuit test clip shown below but failed to give you adequate ordering information. The unit clips over a 16-pin dual-in-line package and provides accessible test points. It is also useful in removing the IC from sockets and boards. The 0.3-inch size (#923700) fits most IC's, with a 0.5-inch size (#923-702) available for wider packages. The clip is manufactured by AP Inc., 72 Corwin Dr., Painesville, Ohio 44077.



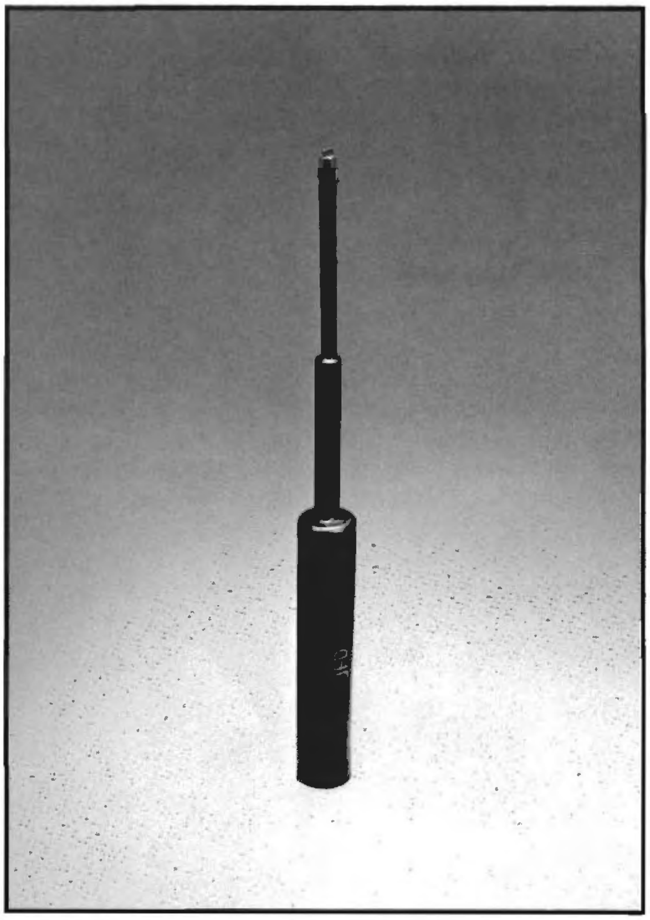
While we're discussing making readings on IC pins we should mention a new probe tip designed specifically for this function. It slips over the bayonet tip of TEKTRONIX miniature probes and covers the exposed ground sleeve. The tip guides itself squarely into firm contact with one pin of the IC at a time without danger of shorting to adjacent pins. You'll find it good for a variety of other probing jobs where leads are close together, as in much of the transistor circuitry. The Tektronix part number is 015-0201-00.



Another handy tool around the bench is the angle tweezers shown being used to remove leads from the CRT neck pins. Much less pressure is applied to the pin as compared to using long-nosed pliers for this function, thereby reducing the likelihood of damage. The tweezers also may be used to remove IC's from their sockets by placing the tips between the IC and the socket and using a gentle prying action.

Another convenient tool for removing IC's is a soldering aid such as the Hytron SH20A. It is slightly modified by filing down the sides of the flattened portion of the tip to extend the narrow portion. The tip is then curved to about a 45° angle so it can be used as a lever in the fashion described for the tweezers.

Almost as profuse as the test leads we collect are the trimmer tools in our tool box, most of them with damaged tips. We've found the J.F.D. production tool number 7104-5, while rather expensive (about five dollars), to be very durable. If you can't find it at your local supplier it can be ordered from Tektronix under part number 003-0666-00.



These are just a few of the tools and other items that we've found useful in doing the service job better and more efficiently. We trust you will find them as useful.

INSTRUMENTS FOR SALE

453, $1600. Used very little. FLM Industries, Maywood, Ill. (312) 345-6991, Mr. Lonberger.

545/CA/D/G/L/Scopecart, $1000. Wm. Erickson, 1273 Montevideo Ave., Placentia, Calif. 92670 (714) 524-2852.

502, $900. Used very little. Mergenthaler Linotype Co., 531 Plymouth Ct., Chicago, Ill. 60605. (312) 427-3121.

Sale or trade 453, $1100. Mr. L. R. Beam, 1705 Devonshire Rd., Sacramento, Calif. 95825. (915) 482-4321.

422, $1000. Exc cond. Mr. Frank Hayes, Red Hill Rd., Middletown, N. J. 07748. (201) 671-0271.

535A/B/Cart, $1000. Bill Vichiconti, Precision Multiple Controls, 231 Greenwood Ave., Midland Pk., N. J. (201) 444-8410.

524AD. Mr. Charles C. Yamamoto, C & E Radio of Hawaii, Inc., 1651 Ala Moana Blvd., Honolulu, Hi. 96813.

D54 w/2 Tek P6006 Probes, used less than 10 hrs. $550. (214) 348-6919.

545/CA/Scopemobile, access. $1200. D, $100. Dr. T. Perera, Barnard Coll. 76 Claremont, N. Y. C., N. Y. 10027.

453, 2-P6010, 2-P6028 Probes. Make offer. Barry Noll, FAMCO Machine Co., 3100 Sheridan Rd., Kenosha, Wi. 53140. (414) 654-3516.

Type 661, 4S1, 5T3, 109, 292, & 291. (617) 275-9200, Ext. 307.

502A, recond. 4/8/70 (New CRT) $700. Parko Electronics, 1540 S. Lyon, Santa Ana, Calif. 92705. (714) 547-0184.

RM529, $400. Stacey's Electronics, 1 Tibbett St., Natick, Mass. 01760. (617) 653-5822.

535A/CA. Bob Duke, 13526 Pyramid Dr., Dallas, Tex. 75234. (214) 241-2888.

547/1A4/Scope Cart & Access, $1800 or best offer. Metrology Inc., 126 No. Jackson Ave., Hopkins, Minn. (612) 935-4436.

545B/CA, best offer over $1500. Bates Aviation, Hawthorne, Calif. Jim Laver, (213) 675-4405.

CA, dual trace amp., $200. Univ. of Tenn. at Chattanooga. Dept. of Biology 37401. (615) 755-4221, Dr. Durham.

503. Mr. Daniel Baugh, 1835 Cutler Dr., Apt. A, Tempe, Ariz. 85281.

504, $275. Ron Stanley, Aero Devices, 2993 Los Feliz Dr., Thousand Oaks, Calif. 91360. (805) 495-1219.

543B/1A4 w/Scope Cart, $1800. Mr. Chas. Kroh (609) 424-3910.

535/C/E/L/N/P/T/Z, $1500 or best offer. Spare CRT & Scope cart. Harvey E. Smith, P. O. Box 2985D, Pasadena, Calif. 91106.

511AD with 121 Amplifier. Both for $250. Fred Chambers, 11 Locustwood Blvd., Elmont, N. Y. 11003.

For sale or trade for 2 or 3-series plug-ins: 3T2, 3S2, 2-S3's. Mr. John Forster, MIT Branch P. O. P. O. Box 48, Cambridge, Ma., 02139. (617) 876-1579.

561A/3A6/3B3, $1000. Ex. cond. Robert Harp, 166 Merrill Ave., Sierra Madre, Calif. 91024. (213) 355-4365.

531A/CA w/202-1. Joe Soltan, Dow Jones & Co., 1325 Lakeside Ave., Cleveland, Ohio, 4414. (216) 241-5183, Ext. 24.

Pulse Generator, Mod. 163, New, $95 postpaid. Bob Duke, 13526 Pyramid Dr., Dallas, Tex. 75234. (214) 241-2888.

Recond. type Z $225. Richard H. Cook II, Teletek Enterprises, P. O. Box 118, Carmichael, Calif. 95608. (916) 635-1773.

316 w/Scope cart, 10x and 2x probes, $600. I. R. Compton, Comptronics, 3220 16th Ave. West, Seattle, Wa. 98119. (206) AT 4-4842.

515A, $425. Mr. Israeley, JSH Electronics Co., 8549 Higuera St., Culver City, Calif. 90230. (213) 870-4616.

545A/CA, $400 for comb. Merle Smith, General Electric, 212 N. Vignes St., Los Angeles, Calif. 90051. (213) 625-7381.

661/5T1A/2-4S1's, $1800 or trade for 453 or 2-422's. Salient Electronics, Inc., Rexford, N.Y. 12148. (518) 393-4590.

53/54B, $50. Scott Howell, Mobilscope, Inc., 17734 1/2 Sherman Way, Reseda, Calif. 91335. (213) 342-5111.

561A/3A6/2B67/2A63. Used very little, $995. Mr. Bill Wiernsing, 125 Northview Rd., Ithaca, N. Y. 14850. (607) 272-3723.

B plug-in $40; 107 $60. Walt Sonnenstuhl, Energy Systems, 3180 Hanover, Palo Alto, Calif. 94303. (415) 493-3900, Ext. 222.

422, 20 hrs. use, $1200. Scope Cart $60. Ed Jevec, Canton, Ohio (216) 456-2851.

TLS53, 524AD, R527. Ken Durkee, Lafayette School Dist. (415) 284-7011.

575 Mod 122C Curve Tracer, 4 yrs. old—best offer. Joe Bookee, Rancho Los Amigos Hosp., 7601 Imperial Hwy., Downey, Calif. 90242. (213) 869-4521, Ext. 2122.

545A/H/L/M/Scopemobile, $850. Jim Underwood, 3615 Wilbur Ave., Huntsville, Ala. 35810, (205) 852-6153.

162 Waveform Gen. Layton Industries, Inc., 542 E. Squantum St., N. Quincy, Mass. 02171. (617) 773-9790.

516; Dustcover; Polaroid Viewer; 2/P6006 Probes, $800. Mr. Krandel Jr., (516) 825-6436.

564/3A72/2B67 w/probes $950. Mike Breen Univ. of Calif. LBL, Bldg. 14, Berkeley, Calif. 94720. (415) 525-3033.

(8) 519's from $1800 to $3000. 561B/3S2/3T2 & (2) S-2 Heads (never used) $2500. (4) C-27 Cameras from $250 to $400. C-40 Camera $275. Plug-ins; S $50, 82 $325, 80 $42. Mr. Henry W. McLarey (617) 271-6181.

543, 53/54K. Exc. cond. A. Blanck, Box 162 Rutherford, N. J. 07070. (201) 933-2091.

422. Allen Hahn, 3144 Black Swan Dr., Shawnee, Kan. 66216. (913) 362-5300, X 133.

611 Mod 162C. Syntex Medical Instr. 3401 Hillview Rd., Palo Alto, Calif. 94304.

INSTRUMENTS WANTED

Used 202-1 or 202-2 scope cart. Ronald B. Tipton, Testronic Dev. Lab., P. O. Drawer H, Las Cruces, N. M. 88001. (505) 382-5574.

1S1, Optitron, Inc., 1645 Sepulveda Blvd., Torrance, Calif. 90501. (213) 530-2811.

Real Time Tek scope with 15 to 30 MHz BW. Will trade 575 curve tracer. Bill McCarthy, 47 Tor Rd., Wappingers Falls, N.Y. 12590. (914) 297-7738.

5T3, 4S1, 4S2A, 4S3 in any condition. Bill Cordaro, 5 Rich Dr., Wappingers Falls, N. Y. 12590. (914) 297-7895.

Type L Plug-in, Gordon A. Hammers, Muir Industries Inc., 24 Thing Road, Tecate, Calif. 92080. (714) 478-5694.

P170CF Probe & B170A Attenuator for 517. Dr. Marshall Siegel, 211 Liberty St., Bloomfield, N. J. 07003. (201) 748-9000 Ext. 838.

TEKSCOPE

Volume 4 Number 2 March 1972

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Editor: Gordon Allison Graphic Designer: Tom Jones For regular receipt of TEKSCOPE contact your local field engineer.

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