

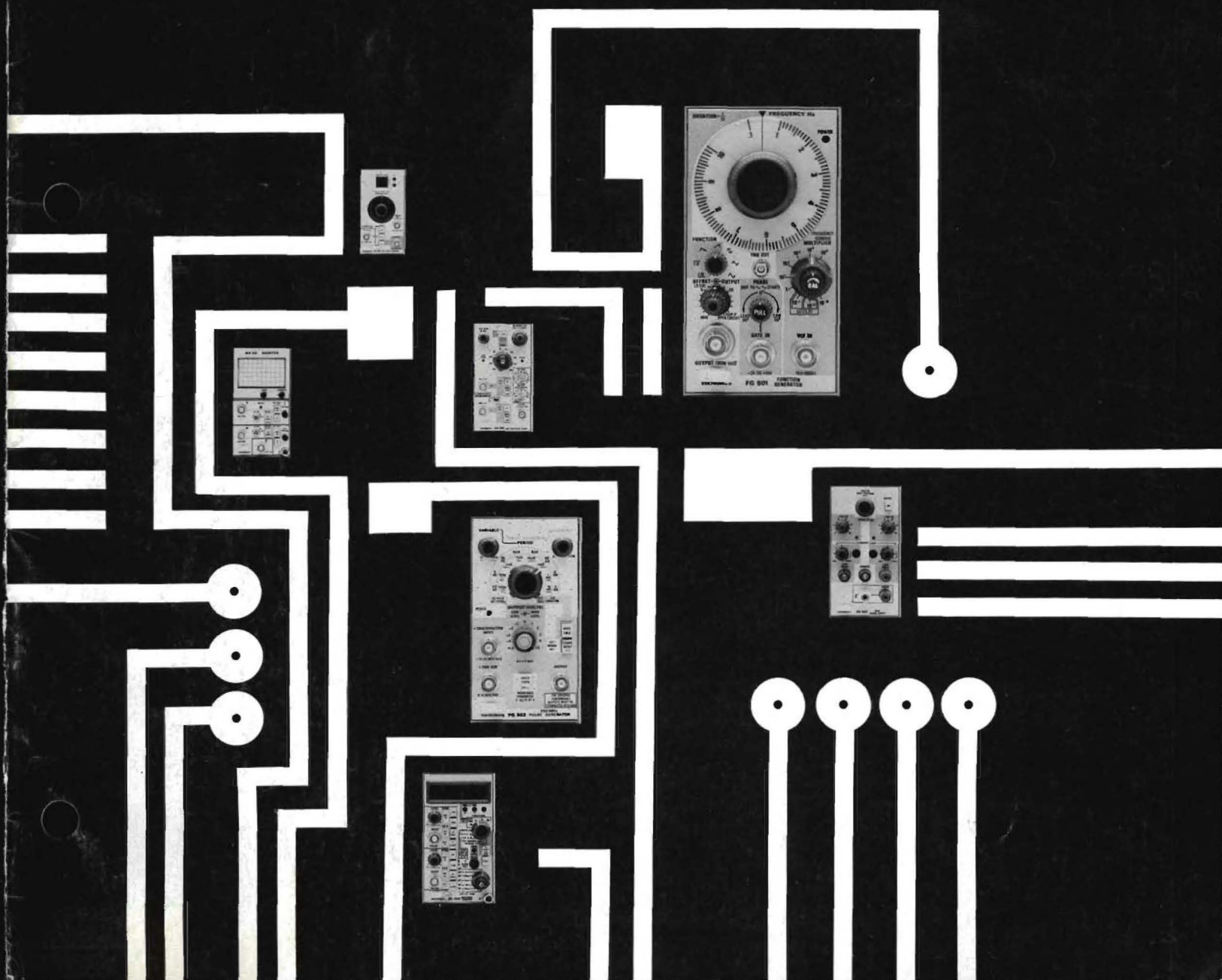


TEKTRONIX®
committed to
technical excellence

TEKSCOPE

Volume 5 Number 5

Sept/Oct 1973



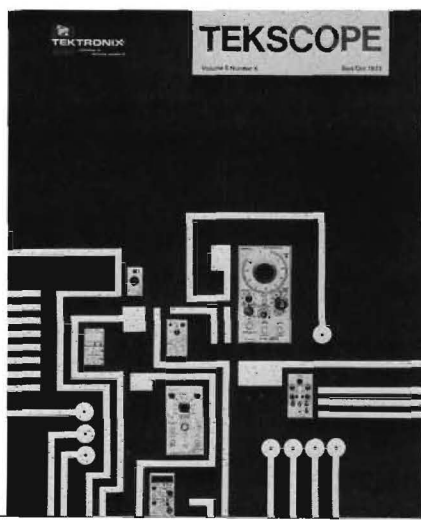
Customer Information from Tektronix, Inc.,
P.O. Box 500, Beaverton, Oregon 97005

Editor: Gordon Allison,

Ass't Editor: Dale Aufrecht,

Graphic Designer: Tom Jones

Cover: Some of the newest members of the TM 500 family are pictured on the front cover. It's a distinguished family that includes counters, multi-meters, power supplies, signal sources, signal processors, and CRT monitors, with more on the way.



Contents

- 3 **Philosophy of product design**
New product design is more than just an engineer's dream.
- 4 **A new approach to multi-functional instruments**
The time-tested plug-in approach yields multi-function operation with almost unlimited versatility.
- 8 **A new high speed pulser for logic testing**
A 250-MHz pulser that meets today's needs for logic testing, design and performance verification.
- 10 **A time mark generator with error-percentage readout**
Timing error is quickly and accurately measured with percent error displayed digitally.
- 12 **Operational amplifier applications**
An operational amplifier in instrument form serves as a versatile signal conditioner or interfacing device.
- 14 **A new 225-MHz Universal Counter/Timer**
Wide-band dual inputs and a 100-MHz clock rate are featured in a high performance plug-in counter.
- 17 **Verification or Calibration? A time saving decision**
The TM 500 Calibration Package takes the "cal lab" to the instrument site.



"Product planning and design must be guided by customer needs—immediate and anticipated."

Philosophy of product design

Undertaking the development of a new product line, or single product, should properly commence after the recognition of one or more user needs that currently are not being met; or, after determining that one or more of his present needs can be met better.

At Tektronix each person is encouraged, and expected, to participate in the initial planning of projects that he or she is likely to be involved in, to contribute ideas or information about these projects. To the degree that people involved in planning are able to correctly ascertain the potential customer's needs, sound judgment may be applied to the relative importance of many factors. These factors must be considered when defining what the product will be. Frequent interchanges with Tektronix Field Engineers and Field Service Technicians; visits directly with present and potential customers, industry forums and trade shows; technical journals and educational programs; all are valuable in enhancing the participants awareness of your needs.

Upon stating what is believed to be a good understanding of present or anticipated customer needs, I believe that all of the suggestions brought forward during the planning process can, and should, be weighed against their relative effects on the primary customer benefits. The decisions regarding these suggestions determine just how well this new product (or product line) will benefit YOU—the customer.

Customer benefits include performance capability, reliability, cost of acquisition, cost of maintenance, ease of operation, versatility, size and weight, appearance, inter-relationship with other equipment and assistance prior to, during and after purchase.

Almost every suggestion initially brought forward is to enhance, or improve, the possible customer benefits in one or more of these areas. Each suggestion needs to be carefully considered for possible detrimental effects in regard to *all* primary benefits. Judgment is applied as to whether any particular suggestion will be incorporated in the plan. This process, of necessity, involves compromises. The result is that some customers still may not have available, equipment which better suits their particular needs. Frequently variations in the form of options (or different models) will be planned and made available to better meet our original goal—providing equipment and service which could benefit you to a greater degree than previously possible. This process of suggesting, comparing and choosing must be continued by all those people involved with executing the plan since the numerous details also affect (favorably or unfavorably) many of the possible customer benefits.

In conclusion, I believe that if one wishes to provide you—the customer—with equipment and service which is better than that now available, one must "join hands" with capable people who have a similar desire. Then, we must work together to provide readily available avenues which encourage and assist the participants in the development of better understanding of your needs. At Tektronix we're striving to do just that.

Jerry Shannon

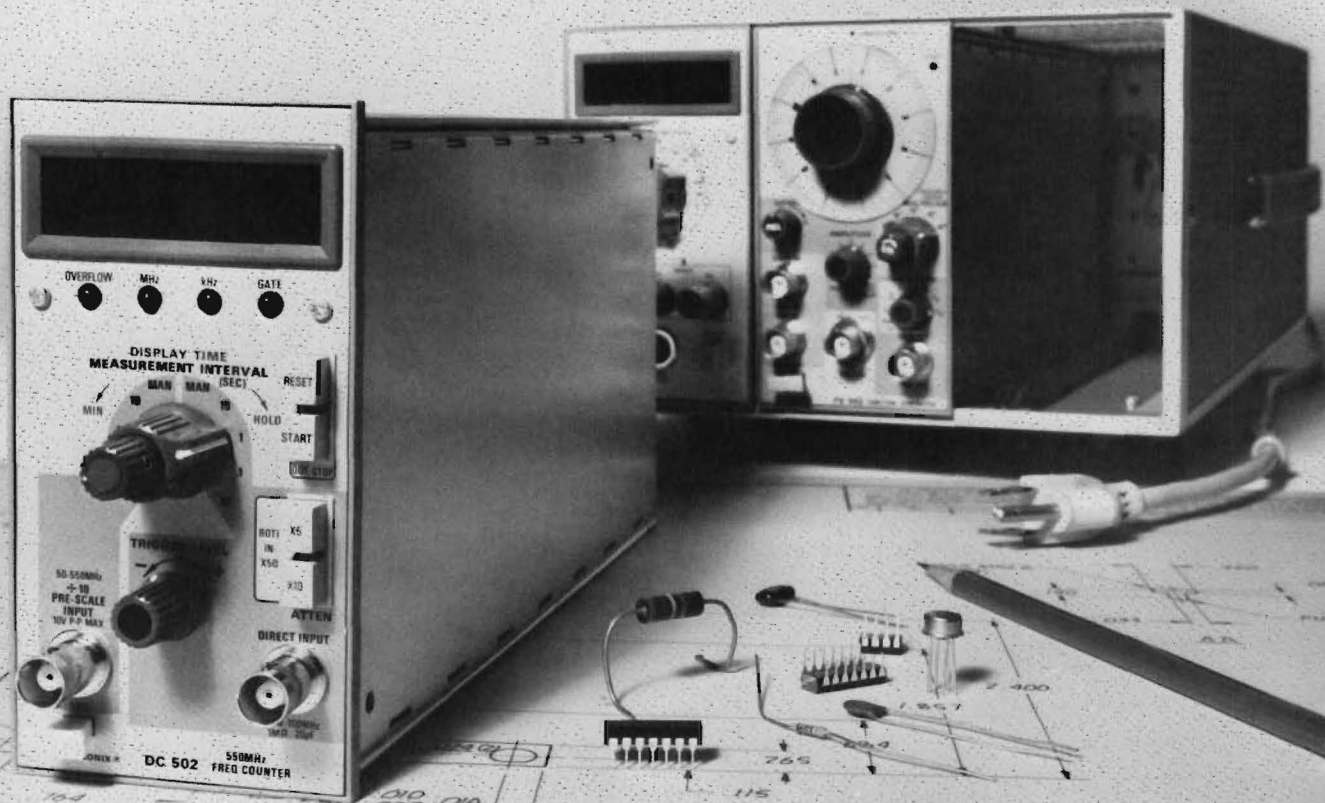
Engineering Program Manager



A new approach to multi-function instrumentation

"Ten instruments on a bench doesn't have to mean ten cabinets, ten line cords, ten power transformers . . ."

— Bob Metzler



General-purpose test and measurement equipment has traditionally been designed on a one-function-per-box basis. An audio oscillator was one physical entity, a voltmeter was a second, a counter was another, and so forth. Yet, in application, it is relatively rare when a single instrument suffices for a measurement.

A simple volt-ohm-milliammeter may do the job for a small appliance repairman, but the designer, tester, or troubleshooter of modern electronics equipment almost invariably needs multiple functions to satisfy his needs. One or more appropriate signal sources, amplitude measuring devices, frequency measuring devices, signal processors, and variable DC power supplies are frequently required.

An "eyeball estimate" of a typical engineering development laboratory at Tektronix leads to the conclusion that an average of ten instruments (usually not all powered up at one time) are found on a typical engineer's bench. This quantity of instrumentation, often with each instrument being of a different size, shape, and function, with various types of displays, leads to a degree of clutter and confusion which has been accepted as a "fact of life" for years.

Modern trends in technology have dramatically altered the pure electronics end of test and measurement equipment. The progression from vacuum tubes through discrete transistors to integrated circuits (especially large scale integration), has made instruments like counters and digital voltmeters practical, and has permitted size and cost reductions and performance improvements in older types of instruments. Modern digital display technology has permitted miniaturization and increased reliability. However, some portions of the instrument have not yielded similar size or cost reductions nor performance improvements. The tendency, therefore, has been for cabinets, handles, feet, power cords, power transformers, power supply filter capacitors, etc. to represent a larger and larger percentage of the instrument volume and cost.

Most major manufacturers of test and measurement equipment have responded in one of two fashions: they have either designed miniature single-function (traditional concept) instruments for field and portable use and stayed with more conventional packaging for bench use, or they have combined several instrument functions into one package to permit sharing the cost of a common housing, power supply, etc.

One of the shortcomings of combining two or more functions in one package is that often, displays and controls are shared in such a way that both functions cannot be used simultaneously. An example would be a combined counter and digital voltmeter. With only one display, one may count frequency or measure volt-

age, but not both at the same time. The more serious drawback of the permanently combined multi-function instrument, however, is the lack of ability to alter the configuration when measurement needs change. When a new project demands a different signal waveshape, or operation at a frequency outside the band originally covered, or requires a type of measurement not provided in the fixed multi-function instrument, the user has no choice but to begin stacking additional instruments on or alongside his no-longer-adequate multi-function box.

Another multi-function approach has been to package a basic portion of an instrument, such as the power supply and display, into one unit and then provide a variety of mating "front ends" of varying capabilities. This system provides flexibility in configuring an instrument and is advantageous from a manufacturer's inventory standpoint. But the resultant instrument is still essentially a stand-alone single-function instrument. If it does combine two functions into one "front end", the shared display still limits use to an either/or situation.

When the Tektronix engineering group, headed by Jerry Shannon, looked at the instrument field, the size and cost advantages of multi-function instruments were evident. These engineers had in their backgrounds the benefits of Tektronix' years of experience in designing and building plug-in oscilloscope systems whereby a basic display and mainframe can be configured into dozens of different packages for individual user requirements.

The concept that developed for the TM 500 was a modular, plug-in instrument line in which miniaturized instruments share a common power supply and cabinet, can be internally interconnected as desired for specific applications, but otherwise perform in a totally independent manner (like conventional stand-alone instruments) with no sharing of displays or controls. Instruments can be interchanged in a mainframe almost instantly for purposes of reconfiguring a group of test equipment.

Obsolescence is avoided since new instruments with different capabilities may be substituted whenever needed. Furthermore, test and measurement capability often may be increased by adding an instrument to an existing group rather than making a substitution. This permits a user to start with a limited system and expand it later, rather than being forced to foresee all possible future needs when initially buying test equipment.

An excellent example is found in function generators. With stand-alone single-function instruments, a user must decide before his original purchase whether

he will ever want sweep capabilities in his function generator. If he decides he will, he must buy a more expensive model with a built-in sawtooth generator. With the TEKTRONIX TM 500 modular system, however, one may purchase a function generator for manual use, and later add a ramp generator. With the ramp output connected to the function generator voltage-controlled-frequency (VCF) input within the cabinet, these two modules function as a self-contained sweep generator. An X-Y monitor can similarly be upgraded later to a calibrated time base Y-T oscilloscope by adding a ramp generator. Or, a digital voltmeter can become a digital differential-input millivoltmeter and microvoltmeter by adding the calibrated differential amplifier as a preamp.

A number of interesting features were developed as the TM 500 concept was carried forward into actual hardware design. One example is in the design of the mainframe power supplies and voltage regulators. A plug-in oscilloscope system typically has several complete voltage-regulated supplies in the mainframe; each has its output bussed to all plug-in compartments. This system is valid for oscilloscope systems, primarily because the plug-in outputs all interface with mainframe electronics at the same signal levels, and it is, therefore, easy to predefine adequate supply voltages. For a modular general-purpose instrumentation system, however, predefinition of supply voltages is nearly impossible. One instrument may need +15, -15, and +5 volt supplies for optimum operation, while another may require +20 and -6 volts. Predicting the specific requirements of next year's instruments is even more difficult.

Heat dissipation in voltage regulators is also a consideration warranting special attention in a modular system. Heat generated within a plug-in module cannot be carried outside the instrument as efficiently as from a mainframe location, due to additional thermal barriers, interfaces, greater path lengths, and less ventilation. The TM 500 Series solution was a combination of distributed power supplies and floating, raw AC windings. Filtered but unregulated DC at two potentials—+33.5 volts, and -33.5 volts—is bussed from its mainframe origin to each compartment. Two power transistors (one NPN and one PNP) per plug-in compartment, mounted on heatsinks, are located in the mainframe. Each instrument can thus regulate the plus and minus 33.5 voltages down to optimal levels with all significant dissipation occurring in the mainframe. A filtered +11.5 volt, 4-amp supply is also bussed to all compartments. Additionally, two floating 25-volt, RMS windings are available at each plug-in connector. They may be connected in series, parallel, or used independently by each plug-in.

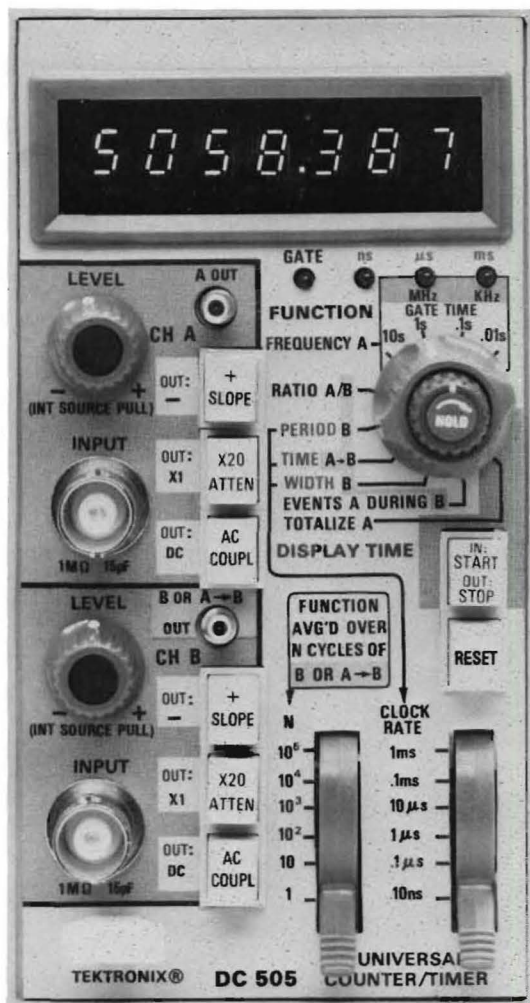
Panel design presents one of the most challenging and most important problems in miniature instrument design. Displays have shrunk in size, and integrated circuits are dramatically smaller than other devices to perform the same functions, but human fingers remain the same size. Combining all the necessary control functions and displays into the thirteen square inches of panel available, without compromising the human engineering aspects, requires real creativity.

The DC 505 Universal Counter is possibly the best example of the challenge, and the result. This counter measures frequency, period, ratio, time interval, pulse width, events A during B, and totalizes. Six choices of averaging factor are selectable in period, ratio, interval, width, and events A during B modes, and clock rate is selectable over five decades in period, interval, and width modes. Completely independent selection of clock rate and averaging factor is possible. Front-panel and rear-interface inputs are switch selectable for both A and B channels, display hold time is controllable, and both channels have selectable trigger polarity and adjustable trigger level. These controls plus two input jacks, gate output jacks, gate and unit indicators, and a seven-digit display are all combined into the 2.6" by 5" panel in a very usable manner.

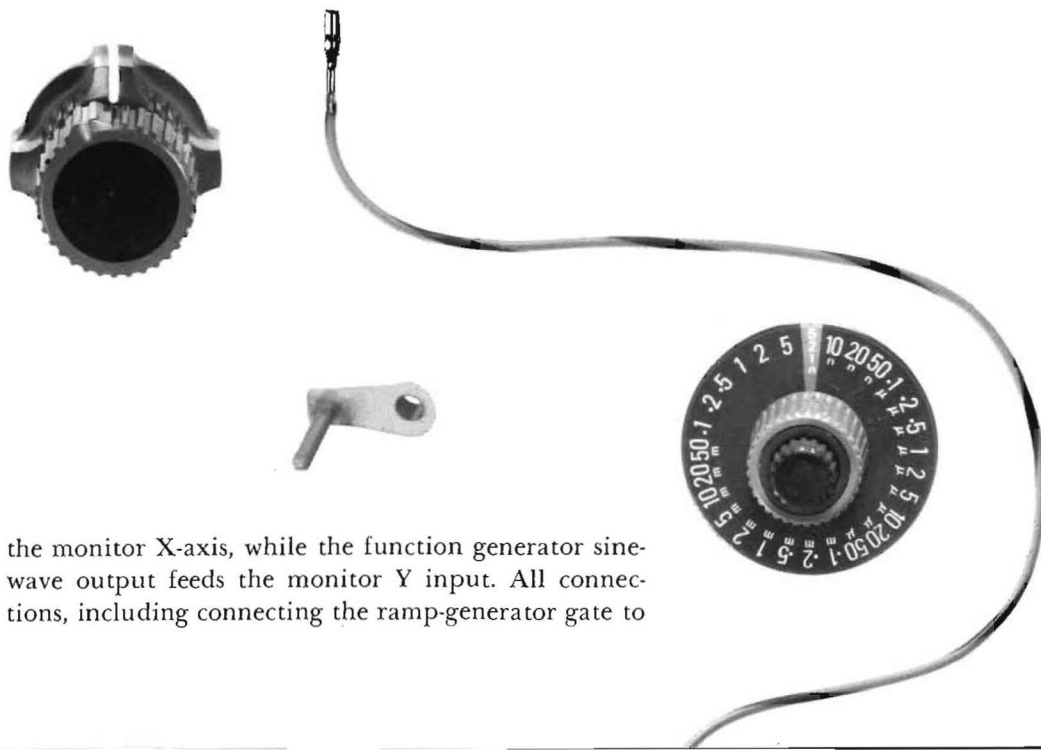
In other instruments, such as power supplies, where panel space is not at such a premium, it was possible to combine two or three supplies into one plug-in. For example, the PS 503 includes a fixed 5-volt at 1-amp regulated supply for digital logic, and separate plus and minus 0 to 20-volt supplies with independently adjustable current limiting.

In addition to the benefits of compactness and economy due to sharing of cabinet and power supply components, the modular TM 500 Series permits uncluttered, interconnected, portable, multi-instrument test sets with the internal-interconnect feature. Interconnecting of instruments is facilitated by an option available for the TM 503 Power Module which includes interconnect pins on the interface board at each instrument, a quantity of both shielded and unshielded jumpers, three rear-panel BNC connectors for user wiring for signal input and output, and a 50-pin connector and mating plug for user wiring to control lines, BCD outputs, etc. The internal jumpers may be connected for such simple applications as digital multimeter monitoring of a power supply, or counter monitoring of signal generator frequency.

More complex interconnections, still physically simple, permit the user to configure special-purpose test sets in one cabinet, with one handle and one power cord. One such example consists of an FG 502 11-MHz Function Generator, an MR 501 X-Y Monitor, and an



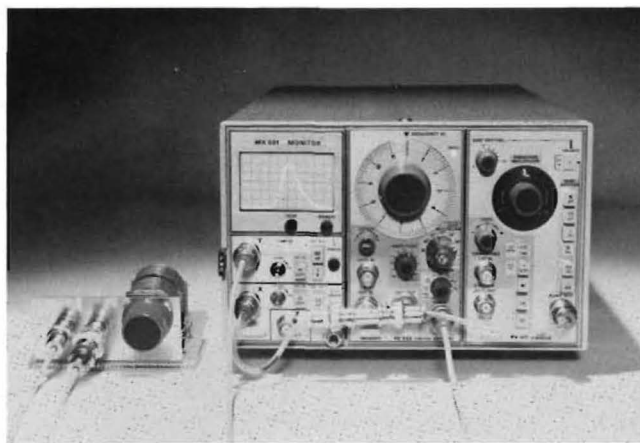
RG 501 Ramp Generator as a filter or IF transformer alignment test set. The ramp generator output simultaneously sweeps the function generator frequency and



the monitor X-axis, while the function generator sine-wave output feeds the monitor Y input. All connections, including connecting the ramp-generator gate to

the monitor Z-axis for retrace blanking, are made internally, and the only external cables necessary are those to the filter under test. The instruments and mainframe are still general-purpose in nature, and may be removed, interchanged, mixed, or matched rapidly into other configurations for other applications.

The TM 500 Series concept of modular instrumentation thus provides an optimum blending of the advantages of independent stand-alone operation with individual displays, and the benefits in size and cost reductions of modern multi-function instrumentation design and manufacturing technology. The added feature of internal interconnections results in increased versatility, less clutter, easier portability, and simpler operation.

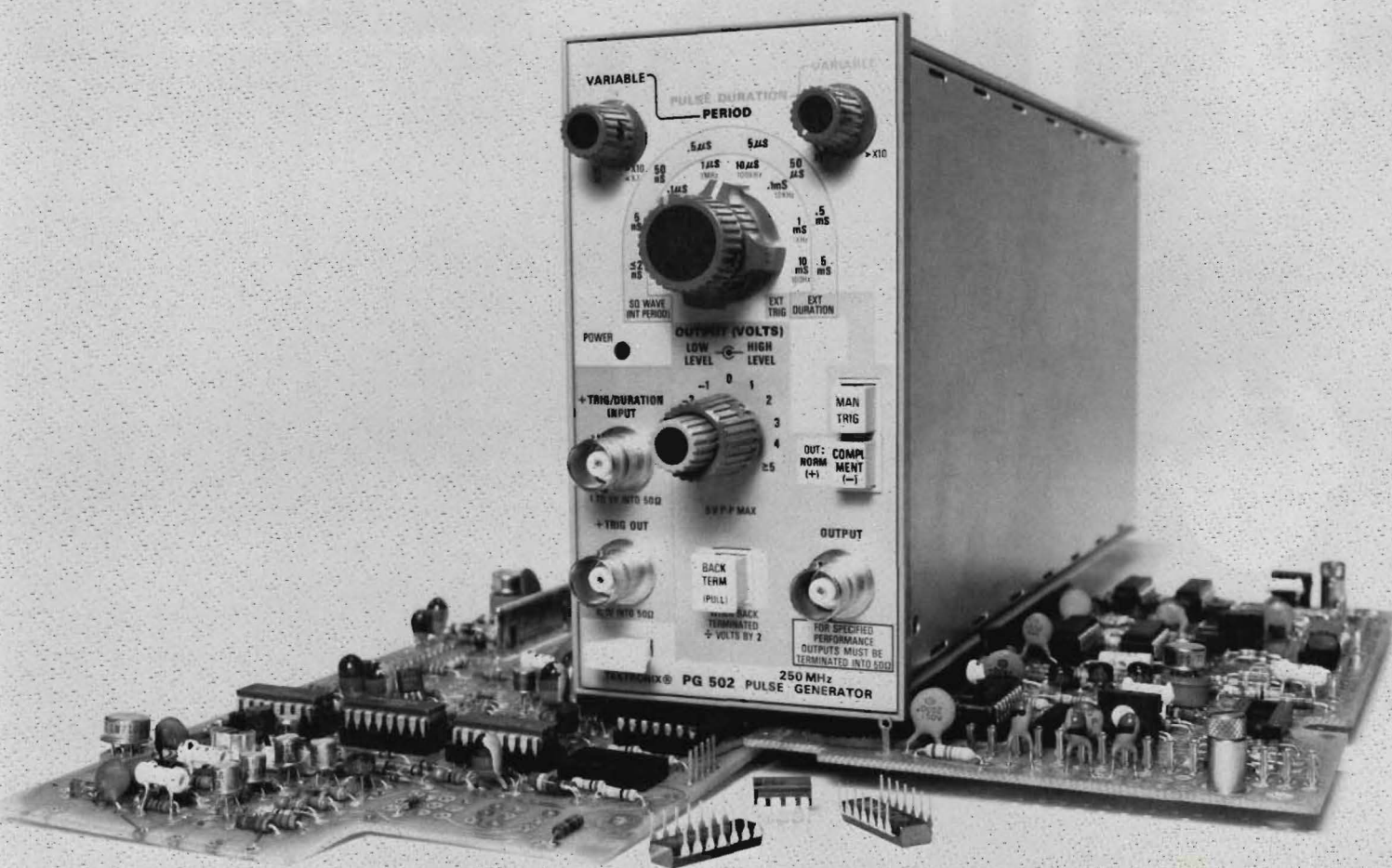




"Application-oriented instruments can save their users dollars, both initially and long term."— Mark Walker

A new high speed pulser for logic testing

Did you know that many modern high-speed TTL flip flops will change division ratio when drive levels are changed? Or that the maximum toggle rate depends on the '0' drive level of most logic families? Or even that the ideal input drive levels may not be those supplied by the outputs of IC's from the same logic family? The list goes on and on, but these are some of the things we have found at Tektronix since a new high-speed pulse generator became available.



As the world-wide demand for logic components increases at astounding rates, so does the demand for higher speed, easier to use test and measurement equipment. Most measuring equipment has kept pace with the increased demands; but until now, logic-oriented pulse generators have fallen behind. There just are not many reasonably-priced high performance pulse generators available that will meet today's needs for logic testing, design, or performance verification.

Most conventional pulse generators allow their users to define a pulse with a pulse-amplitude control and a pulse baseline offset control. To properly drive a given logic device with these instruments, the proper value for pulse amplitude and offset must be calculated. Take, for example, driving a 7400 gate. To derive the required pulse amplitude, the low level value of +0.4 volts must be subtracted from the +2.4 volt high level, giving a pulse amplitude of +2 volts. Offset must then be set at +0.4 volts in order to properly approximate the signal out of an assumed preceding gate.

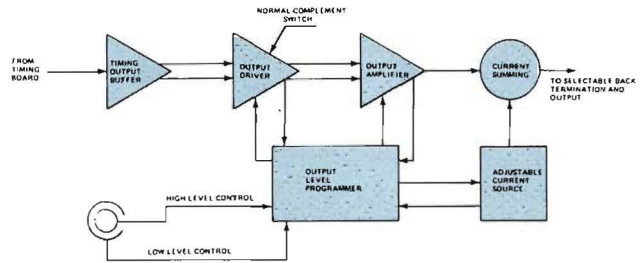
The setup so far is not difficult, however, attempt now to determine the effect of the low level on the performance of the gate, without changing the upper level. This requires duplicating the same set of calculations for every new low level, and necessitates resetting both amplitude and offset controls. This calculating and setting and recalculating and resetting process can even get worse when working with many ECL families.

The new TEKTRONIX PG 502 Pulse Generator was specifically engineered to satisfy just such measurement needs. This instrument, with a maximum frequency in excess of 250 MHz, has separately adjustable pulse high and low levels over a full 5-volt range. This means that any logic family powered within 5 volts of ground can be properly (and if desired, improperly) driven with up to 5 volts of pulse. This includes all of the very popular TTL families as well as faster ECL types. All pulse amplitude and offset combinations that are available with the amplitude/offset system are still available, but without the interaction that can make changes in just one level so difficult. Using the PG 502, thorough evaluation of effects due to changes in only upper or lower logic levels become as easy as turning a single knob. This allows many things to be uncovered that would otherwise go undetected—things like the problems mentioned in the opening paragraph of this article.

The PG 502 introduces this capability at the very high speeds necessary for today's world of logic. At the heart of the PG 502 output stage are two Tektronix-built integrated circuits. The driver IC, in addition to driving the output stage, has current-adjustable amplitude allowing optimum drive and therefore minimum


output pulse aberrations. This IC also allows convenient switching for the pulse "normal" or "complement" modes.

The second IC is mounted with the output transistor on a Tektronix-built hybrid circuit, allowing a clean high-speed interconnect for the subnanosecond risetime pulses present in this stage. The pulse leaving this stage is summed with a DC current controlled by the Output Level Programmer (as shown by block diagram, Fig. 1). From this summing mode the com-



ination pulse and DC current, representing the pulse high and low levels selected at the front panel, goes through the selectable back termination switch and on to the output. The back termination switch allows the generator to act essentially as a current source output calibrated into a 50 Ω load, or as a 50 Ω voltage source. However, note that when acting as a 50 Ω voltage source terminated into 50 Ω , the output high and low levels are reduced to one half. The total load on the generator in this position is 25 Ω .

The Output Level Programmer block takes the values of pulse high and low levels requested by the front panel controls and translates this information into the pulse amplitude to be delivered by the output amplifier, and the DC current to be summed with that amplitude to obtain the desired output levels. It also controls the driver so as to optimize the output signals. This Output Level Programmer block minimizes the time consuming setups typical of other instruments, whenever specific and adjustable upper and lower pulse levels are needed.

For pulse testing not requiring this much versatility, the TM 500 Series also includes the PG 501 which can drive all types of TTL logic up to 50 MHz with its ground-referenced outputs. 

A time mark generator with error-percentage readout

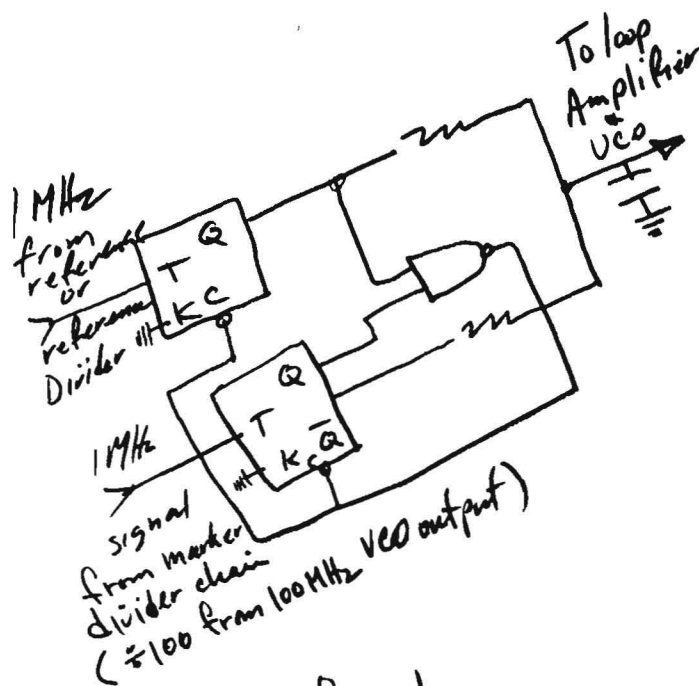


Fig. 1
Simple phase detector used
in TG 501 Time Mark Gen.

Ever since the introduction of calibrated test equipment, the need for calibration sources has been apparent. And every advance in instrumentation invokes a need for improved calibration equipment. More accurate voltmeters, faster-rising pulse generators, faster time mark generators and higher-frequency sinewave sources are essential for calibrating today's advanced instruments.

In 1952, Tektronix introduced the Type 180 Time Mark Generator for time base calibration. This instrument was rather bulky by today's standards, but did produce very usable time marks. These were counted down from a 1 MHz crystal source by using RC time constant circuits to achieve the desired divider ratio. This ratio was either divide-by-two or divide-by-five, resulting in outputs sequenced 1, 2, 5, 10, etc., from 1 μ sec to 5 seconds. Sinewave markers at 200 ns, 100 ns, and 50 ns were obtained by multiplying up from the 1 MHz reference.

With the Type 184, introduced in 1965, came smaller size, transistor and nuvistor circuitry, a 10 MHz crystal reference, and sinewave markers from 50 ns to 2 ns. Calibration needs were changing, supported by the maximum marker jump from 50 ns to 2 ns.

Then, in 1970, the Type 2901 Time Mark Generator was introduced. This instrument simply duplicated the basic Type 184 performance, but with one significant change. It introduced all-digital countdown circuitry using RTL logic, but retained the RF-type multipliers and the 10-MHz reference.

Now with the introduction of the TG 501 Time Mark Generator come several important changes, plus a new feature aimed at relieving much of the time-consuming chore involved in verifying today's equipment.

The TG 501 is only $\frac{1}{3}$ the size of its predecessor, has a 1 ns output sinewave, and a 100 MHz basic marker frequency. It can be driven externally by any lab standard at 1, 5, or 10 MHz. The timing of any marker 10 ns or slower can be varied over a limited range by a front panel control, with the deviation from the calibrated position displayed digitally in terms of percentage. This feature permits you to quickly and accurately determine time-base errors.

The versatile TG 501 is made possible by several advances in technology. The standard internal reference frequency is 1 MHz (a 5 MHz reference with greater stability is available). This signal is conditioned at 1 MHz and fed to one side of a phase detector fabricated from a dual TTL flip flop and a single gate (see Fig. 1). The output of the detector drives an amplifier (to increase loop gain), which in turn drives the 100-MHz voltage-controlled oscillator. The output of the oscillator is then buffered and shaped to produce the 10 ns markers. It is also divided down by two for the 20 ns markers and by five for 50 ns. Between 50 ns and 100 ns the transition is made from emitter coupled logic to TTL where the divide-by-two and divide-by-five circuits are again repeated, giving .1 μ s, .2 μ s, or .5 μ s markers. The .5 μ s markers are fed to a divide-by-two circuit with the 1 MHz result fed to the other side of the phase comparator. This closes the phase lock loop and insures a stable reference at 100 MHz.

Previous time mark generators repeated the 1, 2, 5 sequencing all the way to their longest marker output; not so with the TG 501. The last divide-by-two or divide-by-five employed gave the .2 μ s and the .5 μ s markers described above. The remainder of the countdown chain uses only divide-by-ten stages. By simply calling up the desired unit (1, 2, or 5) and the correct power of 10 (10^0 to 10^{-7}), the chain produces the correct marker. This system greatly reduces the amount of logic needed and the switching complexity necessary to pro-

I'm interested in learning more about the TM 500 Series Test and Measurement instruments.

☐ Send me the new 12-page, full color brochure and spec sheets.

☐ Have your Field Engineer call to arrange for a demonstration.

Name _____

Title _____

Company _____

Address _____

City _____ State _____ Zip _____

BUSINESS REPLY MAIL

No postage necessary if mailed in the United States

Postage will be paid by

TEKTRONIX, INC.

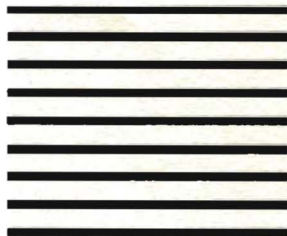
P.O. Box 500

Beaverton, Oregon 97005

FIRST CLASS

PERMIT NO. 61

BEAVERTON, OREGON



duce any marker. The output amplifier even has three values of input impedance which are selected together with the 1, 2, or 5 lines. This produces constant duty cycle markers over the entire 1, 2, 5 range with only one marker-shaping capacitor per decade.

The timing-error readout circuitry also introduces some unique techniques. To change marker timing it is only necessary to change the reference frequency fed into the phase detector, by the desired percentage. The phase lock loop will change the 100-MHz reference by exactly the same percentage, and since all markers are directly derived from this reference, all markers will change by exactly the same percentage. To accomplish this, a front-panel-controlled variable oscillator is inserted in place of the crystal reference as the drive for the phase lock loop. To obtain an accurate digital reading of the percentage of error, it is necessary to produce a signal whose frequency can be counted and read directly in percent. A Type D flip flop is used as a digital mixer to give the difference frequency between the variable reference and the crystal or external reference. For a 1% change in timing, the 1-MHz frequency will change 10,000 cycles. By counting the 10^4 bit and the 10^3 bit this reading would be 1.0%. To display this reading introduces counter error of ± 1 digit in the last, or the 0.1% digit. By also counting the 10^2 bit and using it to round off the 10^3 bit as displayed, this counting error is reduced by 10 times, yielding a very accurate indication of timing error. This is shown in Fig. 2.

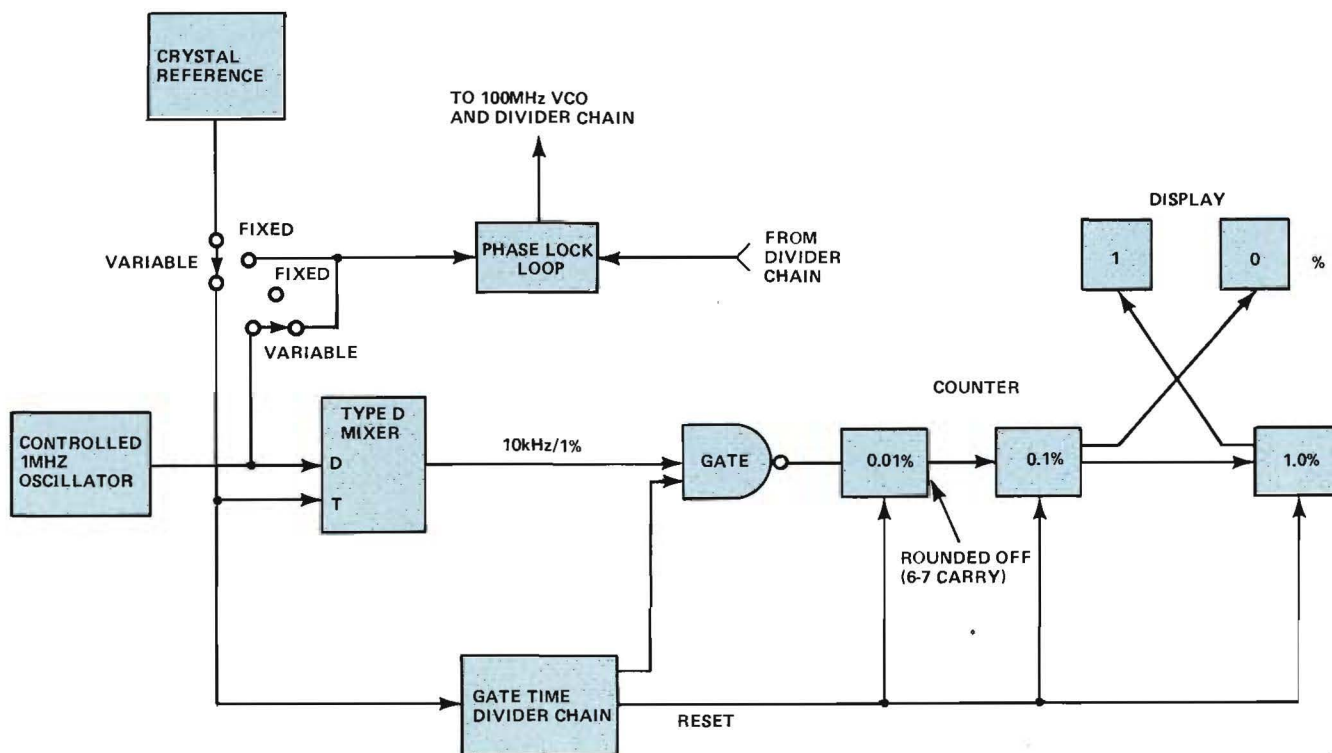
Since timing, when in error, can be either fast or slow, it is necessary to indicate the direction of error on

the digital readout. This is done by again using a simple phase detector like that shown in Fig. 1. Since the detector output indicates direction of frequency difference by its output voltage level, the signal that is faster is easily determined. The fast LED is lit when the variable sequence oscillator is above the crystal reference in frequency. All pertinent information is therefore read out when the TG 501 is used in the variable timing mode, with the entire readout going dark when the unit is operated in the calibrated position.

Another point in the design of this instrument deals with the main phase lock loop for marker generation. If this loop should fail for any reason, it would be possible to have markers generated which were not, in fact, locked to the reference source. To prevent this condition from occurring, the out-of-lock conditions of the loop are monitored. If lock is lost, the instrument output is automatically disconnected, indicating the need for servicing.

On the high end, sinewave markers of 5, 2, and 1 ns are generated. These markers are generated by taking the outputs from the RF-type multipliers and filtering them through comb-type filters. These filters are printed directly on the circuit board, and are used to eliminate both the harmonics and subharmonics which are generated in the multiplying process. This technique allows good filtering characteristics, requires little volume, and gives consistent filtering results. All markers are at 1 volt P-P amplitude up to 2 ns, with the separate 1-ns output delivering 0.5 volt P-P into a 50 Ω load.

For application of the TG 501 and other new calibration aids, see Service Scope in this issue.



Teknique

Operational amplifier applications



"Good design combined with simplicity, flexibility and reliability yields a high return on your instrument investment."

— Warren Collier

Although op-amps in a variety of physical forms are usually thought of as components buried within an instrument or system block, there are many applications where a free-standing op-amp can serve as a signal conditioner or interfacing device.

We've just added this valuable tool to the TEKTRONIX TM 500 Test and Measurement family. The AM 501 is an operational amplifier packaged and configured for use as an instrument. You can readily define the characteristics of the AM 501 to suit your particular application, through convenient front panel connectors, or you can install the feedback components inside the unit if desired.

The AM 501 features high input impedance, a slew rate of at least $50 \text{ V}/\mu\text{s}$ and output range of ± 40 volts and ± 50 mA. It can withstand input voltage as high as 80 volts. These broad performance characteristics make the AM 501 well suited for a wide range of analog processing applications.

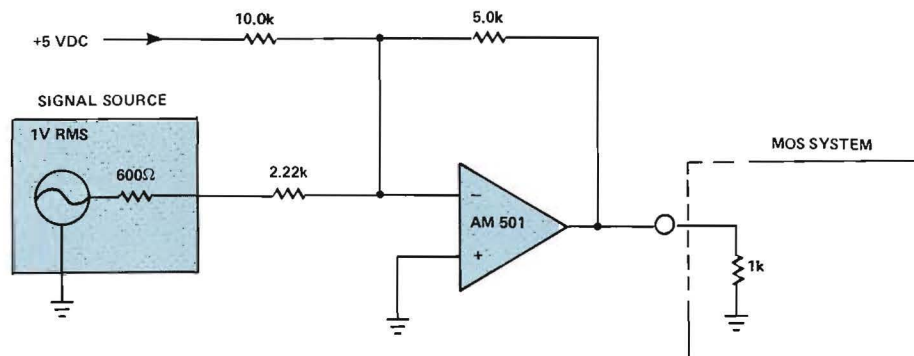
Before detailing a few very specific types of interfacing applications, it may be well to list the general kinds of things an op-amp can do, utilizing the classic feedback configurations. The op-amp can act as:

1. A buffer stage with nearly ideal follower characteristics.
 - A. Output is in phase with input.
 - B. Gain is unity, within a close tolerance; no adjustment required.
 - C. Input impedance is high; output impedance is low.
2. A voltage amplifier capable of a wide range of accurate and arbitrary gain factors.
 - A. If amplification is in phase, the input impedance may be kept very high; this configuration is best suited to a single input signal.
 - B. If used as an inverting amplifier, input impedance will be lower, but many AC and/or DC voltages may be summed, with almost no interaction. Also, the gain factor for each input may be different.
3. A precision differentiator, producing a well-defined output voltage which is proportional to the rate-of-change of the input signal.
4. A precision integrator, producing an output signal which has a well-defined rate-of-change proportional to the input voltage.
5. A Schmitt trigger with well-defined and easily adjusted hysteresis.

In addition to performing each function separately, several op-amps may be interconnected to perform more complex functions. For example, using one AM 501 as an integrator, and a second as a Schmitt trigger, triangle and ramp waveforms of unusual linearity may be generated.

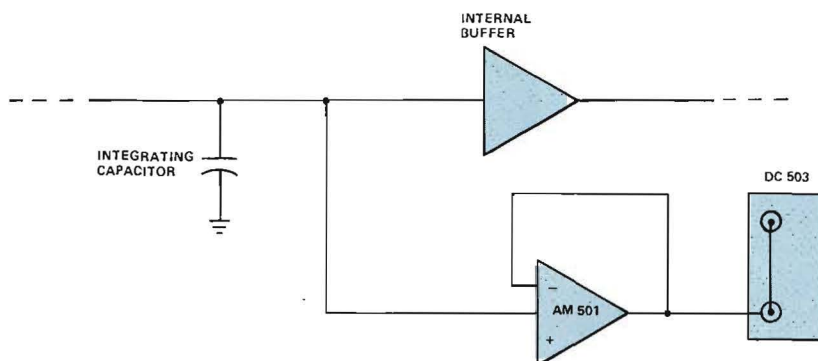
In summary, any time you want to change the amplitude, invert the phase (or polarity), and transform the impedance or shift the DC level of a low-frequency signal, one or more op-amps will do the job for you. Additionally, they can be used to operate on the derivative or integral of the input signal. The main limitations are that very high gains or very low input levels are not suitable, high speed signals are generally not suitable, and because of the op-amp's "slew rate" characteristics, bandwidth and risetime depend on signal amplitude. On the positive side, accuracy and stability are excellent, and there is very little offset between input and output DC level, except as intentionally introduced.

To proceed with more specific application examples, consider the following interface problems and their op-amp solutions:



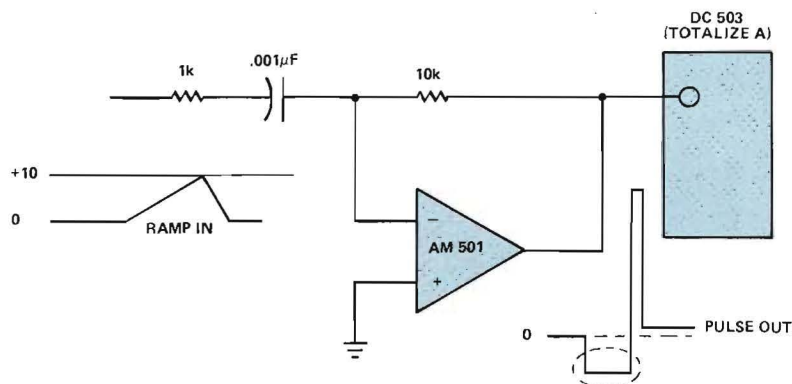
Problem 1.—A sinewave source needs to be clocked into an MOS system. The amplitude is insufficient (one volt RMS behind 600 Ω) and the DC level is wrong (centered at ground). The signal has to swing between zero and at least five volts minus.

Solution—Interface the signal with an AM 501 connected as a summing amplifier. Introduce the necessary offset by summing the signal with a DC voltage from a power supply.



Problem 2. You want to connect the signal on an integrating capacitor to a time-interval meter (TIM). The signal amplitude is several volts, and only a few nanoamps of load current can be tolerated; the one megohm input impedance of the TIM is too low. The circuit under test has an internal buffer, but it shifts the DC level to an unsuitable value. Capacitive coupling will introduce signal aberration or excessive load current.

Solution—Interface the signal with an AM 501 connected as a follower. Input current is less than one nanoamp at room temperature; output signal is nearly identical to input signal.



Problem 3. A system generates ramps at random intervals. The ramps are of uniform amplitude, but are of two different durations. You want to count the number of fast ramps only, which occur in one hour. Both ramps have a 10 V amplitude; the slow ramp has a duration of 50 μsec and the fast ramp lasts 10 μsec .

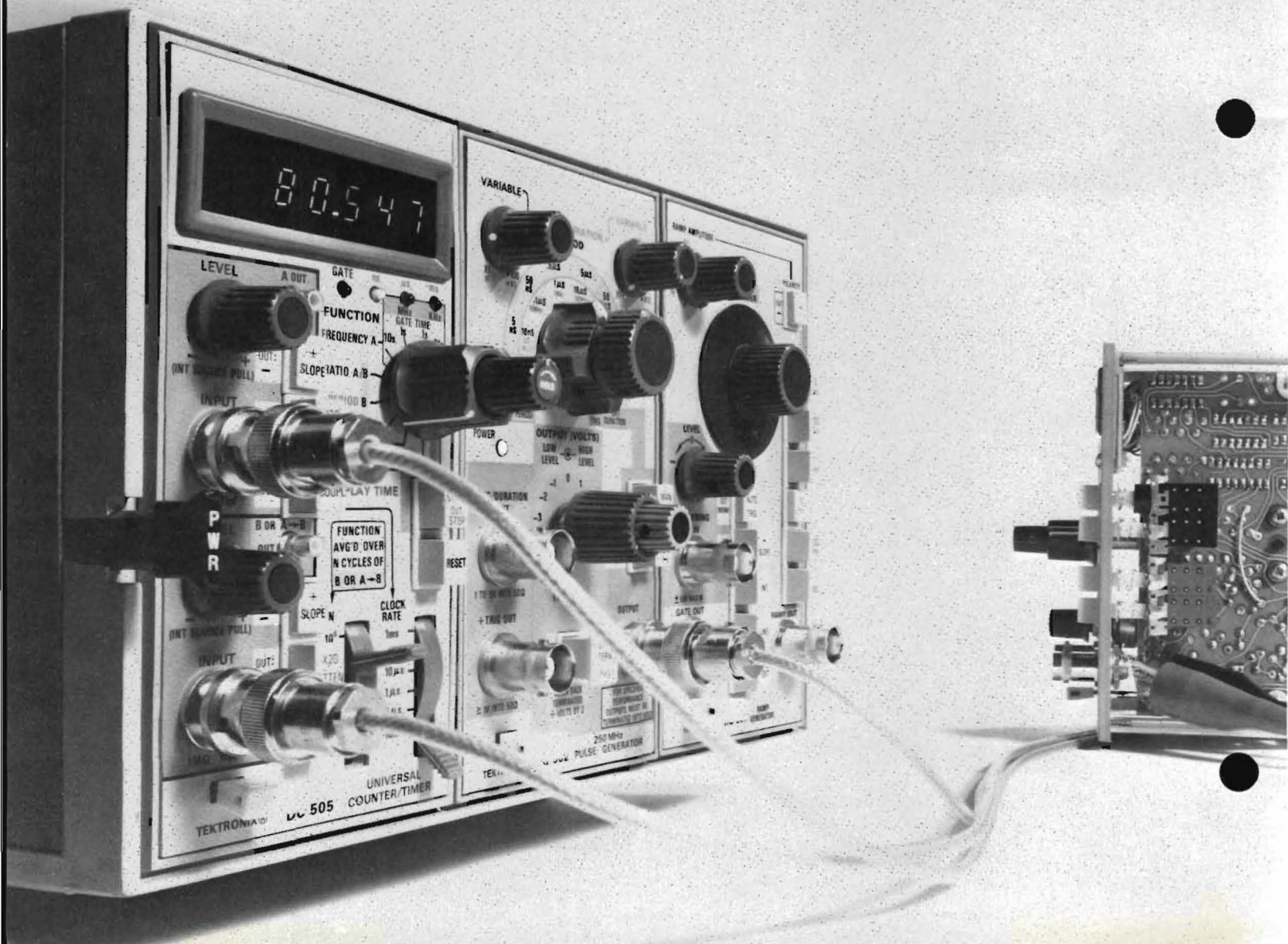
Solution—Using the AM 501, differentiate the ramps so that only the fast ramp generates an output voltage adequate to trigger the counter.



"Today's IC's let the counter designer concentrate on application-oriented instruments."

— Jim Geddes

A new 225-MHz Universal Counter/Timer



A 100-MHz clock rate for high resolution single-shot measurements of interval and period, time interval averaging for still better resolution, two identical input channels permitting measurements on extremely narrow pulses, independent selection of clock rate and averaging factor, and a new capability called EVENTS A DURING B: these are some of the outstanding features of the new DC 505 225-MHz Universal Counter Timer. This high performance counter adds important new measurement capabilities to the TEKTRONIX TM 500 Series of test and measurement equipment.

Two input channels are characteristic of universal counters, in contrast to the single inputs found on simpler frequency counters. But there is something special about the two inputs on the DC 505. Typically, the B channel of a counter has much less bandwidth than the A channel. The TEKTRONIX DC 503 is representative of this with a 10-MHz B channel and a 100-MHz A channel. The new DC 505 boasts a 225-MHz bandwidth in both channel A and B.

In making time interval and pulse width measurements, channel A starts the counter and channel B stops it. With a wide bandwidth in both channels, the DC 505 permits interval and width measurements on much narrower pulses than most other instruments. For example, an instrument with a 10-MHz stop channel is typically limited to 100-ns minimum-width pulses. The DC 505 can make interval (TIME A \rightarrow B) measurements on signals as narrow as 5 nanoseconds.

Pulse Width Measurements

Pulse width can be measured on any universal counter with a TIME A \rightarrow B capability by using a "tee" connector and two cables to feed the signal to A and B inputs simultaneously. One channel's controls are then set to trigger on the leading edge, the other on the trailing edge, and the width measurement is made. Some instruments provide some simplification by a switch which parallels both channels to one input jack. This eliminates the need for the "tee" connector, but the input impedance is still cut in half. In either case (and in all TIME A \rightarrow B measurements), any mismatch in propagation delay through the two channels adds to the measurement error.

The DC 505 provides simpler operation, more accuracy, and narrower pulse capability by its WIDTH B mode. The unknown pulse is connected to the B channel with one cable, where it sees the full 1 Megohm input resistance. Triggering level is set by one control and no channel match error (mismatched propagation delay) occurs since the B channel both starts and stops the measurement. The stop automatically results when the signal passes through the selected trigger level again, with the opposite polarity to that selected by the front

panel SLOPE switch. Since less circuitry is involved in the path in WIDTH mode, the DC 505 can make measurements on pulses as narrow as 2 nanoseconds (absolute accuracy will be ± 3 nanoseconds).

Time Interval Measurements

The need for better accuracy and (particularly) better resolution of time interval measurements is one of the significant trends in counter applications. Range determination by radar and lasers, determination of time of flight of sub-molecular particles, and propagation delay through logic circuits are only a few of the important areas where improved time interval resolution is desirable.

Resolution on a single-shot time interval measurement is determined strictly by the clock rate; a 1-MHz clock gives 1 microsecond resolution, 10 MHz gives 100 nanoseconds, and so forth. The quartz crystals used as the time bases in virtually all modern counters operate somewhere between 1 MHz and 10 MHz since achievable stability is optimized there. The DC 505 has a 1-MHz crystal standard or an optional 5-MHz temperature-compensated crystal with divide-by-five circuitry to provide a 1-MHz output. This 1-MHz signal is then multiplied to 100 MHz using a phase locked loop, yielding a 10 nanosecond resolution for single-shot measurements.

While the 10 nanosecond clock period and resultant resolution limitation is essentially the state-of-the-art for single-shot measurements, large improvements are achievable through averaging techniques when the interval to be measured is repetitive. The resulting improvement in resolution is a factor of $1/\sqrt{N}$ where N is the averaging factor; so 10,000-times averaging with the 10 nanosecond clock produces a minimum of 100-picosecond resolution, unless the counter clock and the external pulse rate are synchronous (see below).

Internal averaging, unlike period averaging, is a statistical process. A thorough mathematical analysis of the process, including confidence levels in the displayed results, is beyond the scope of this discussion; but one important potential limitation in the interval averaging process should be noted. The improvement in resolution occurs only when the counter clock and the repetition rate of the interval being averaged are not harmonically related. If the rep rate of the system being measured is adjustable, a good test is to make the averaged interval measurement at several different rates. The answers should agree unless a synchronous counter-clock and system-clock situation exists at one of the rates.

Absolute Accuracy of Time Interval

Absolute accuracy in time interval measurements is a function of four factors: resolution, time base error,

triggering error, and channel delay mismatch. When making single-shot measurements of intervals less than about one millisecond, resolution is normally the largest contributor to error. Time base error with the temperature-compensated Option 1 time base will virtually never be a factor in interval measurements. Triggering error and channel delay mismatch, lumped together, will not exceed 6 nanoseconds on fast rise and fall pulses where interval measurement is commonly used.

Since time-interval averaging can reduce the ± 1 count resolution ambiguity from 10 nanoseconds (assuming the fastest clock rate) to 100 picoseconds, the ultimate absolute accuracy when averaging becomes limited by the triggering and channel mismatch errors. External cables of finite length must be used for any measurement, so the overall channel mismatch error consists of both internal mismatch in the instrument (2 nanoseconds maximum) and mismatch in the electrical length of the external cables. For any given instrument the internal mismatch will be constant and could be calibrated out of the system by trimming the proper external cable length while measuring an accurately known interval. The ± 4 nanosecond triggering error, thus, is the accuracy limit in time interval averaging measurements.


Independent Rate and Averaging Factor

A unique feature of the DC 505 is the completely independent selection of clock rate and averaging factor. Clock rates are selectable from 10 nanoseconds (100 MHz) through 1 millisecond (1 kHz), and averaging factors from 1 (single shot) through 10^5 . For most interval, width, or period measurements of relatively clean, stable signals, one would normally select the fastest clock rate and an averaging factor limited either by display overflow or the length of time the operator is willing to wait for an answer. With noisy or jittering signals, the operator may wish to deliberately select a large averaging factor. If the duration of the interval (or width or period) being measured is such that the value of averaging factor selected results in display overflow, a slower clock rate may be chosen. This useful operating feature led to an unusual circuit requirement within the counter. Since the location of the decimal point and the units indicators (ns, μ s, ms) depend on both clock rate and averaging factor, they could not be controlled in the usual simple fashion by contacts on a rotary function selector switch. The solution to the problem was a simple discrete-transistor read-only memory (ROM) in the form of a 6 X 7 matrix.

EVENTS A DURING B Mode

In addition to the unusual characteristics already discussed and the fairly conventional modes of opera-

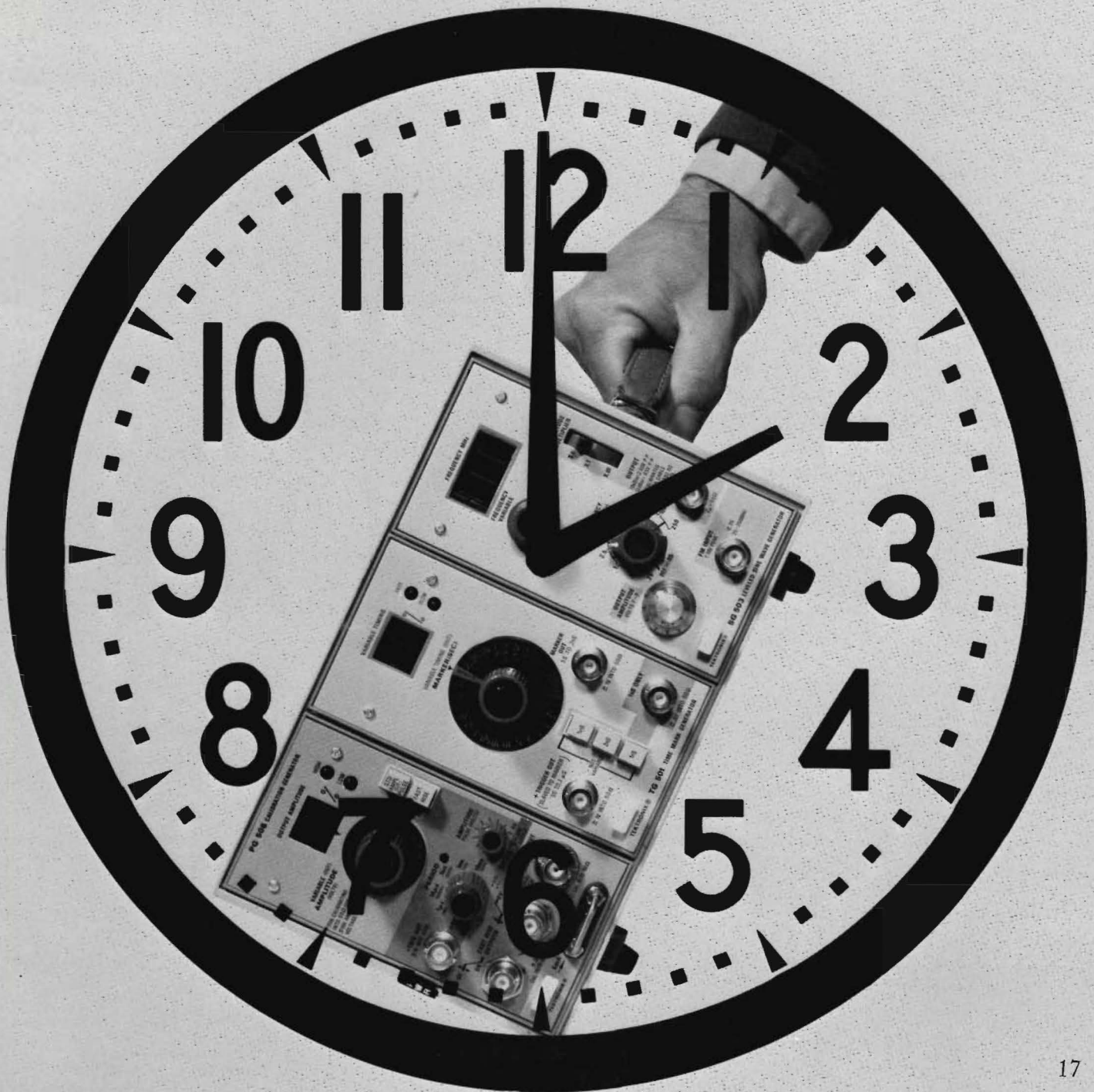
tion like frequency, totalize, period, and ratio, a new functional capability called EVENTS A DURING B exists in the DC 505. The display will show the number of events appearing at the A input during the width of a pulse at the B input. This feature can be selected over a range of 1 to 10^5 B input pulses by means of the averaging factor switch. Direct verification of the division ratio of counters on a single-shot basis can be made using this mode of operation. It would also be useful for counting computer clock pulses occurring during some operation, or could be used simply as a remotely-gated totalize function.

The DC 505 packs an amazing amount of measurement capability and flexibility into one TM 500 module. In conjunction with other instruments like the PG 502 250-MHz pulse generator, the DM 501 $4\frac{1}{2}$ -digit multimeter, and a Tektronix high performance oscilloscope, it provides an extremely powerful tool for work in modern digital and high frequency systems. 

Servicescope

Verification or Calibration? A time-saving decision

With the announcement of the TM 500 "Cal Package", a powerful new tool is available to instrument calibration personnel to reduce the cost and improve the accuracy of oscilloscope calibration. The key to improvement lies in on-site verification rather than full, and often unnecessary, calibration in the metrology lab.



To properly contrast the improvements available, let's first consider typical calibration practices now in use. In many facilities, procedures for calibration of test instruments involve physically collecting the instruments from their usage points and transporting them to the metrology lab. This collection and transportation involves the risk of physical damage in handling and the loss of use of the instrument for at least a few days. The instruments are, of course, turned off during transportation and while awaiting calibration. They thus are cooled down and then warmed up again in the calibration facility. If the time allowed for thermal stabilization in the cal lab is inadequate, if the lab ambient temperature is different than that at the usage point, or if the room ambient is the same but the immediate thermal environment is different (as when a normally rackmounted instrument is removed from a factory test station and calibrated on an open bench), a less than ideal situation prevails. While the instrument is normally specified for operation over a reasonably wide temperature range, best accuracy is achieved if the thermal environments are identical for calibration and actual use.

Following the stabilization period, the instrument performance is usually verified before calibration takes place. This practice is particularly useful in determining whether calibration intervals should be lengthened or shortened. With conventional calibration equipment, verification requires both visual interpolation and calculation. The calibration technician sets his time mark generator or standard amplitude calibrator to the appropriate range and reads the deviation of the resultant display from the scope graticule divisions. Interpolation is generally necessary, so both subjective judgment and possible parallax errors can become significant factors. The technician then calculates, by longhand, slide rule or other means, the percentage deviation of the instrument from exact accuracy.

Even if the deviation is within specifications, verification is typically followed by full recalibration. In this procedure, the technician feeds the standard calibrating signal (time marks or amplitude) to the oscilloscope and "tweaks" the appropriate controls until the display is exactly aligned with the proper graticule divisions.

Finally, appropriate record keeping is done, and a new calibration sticker is affixed to the instrument.

Now let's consider a new approach using the TM 500 oscilloscope "Cal Package". The package typically consists of the TG 501 Time Mark Generator, the PG 506 Calibration Generator, and either an SG 503 or SG 504 Leveled Sinewave Generator, all contained in a TM 503 Power Module.

With this highly portable calibration system, verification moves from the cal lab to the user's work site. The calibration technician carries the TM 503 with instruments (approximate weight, 18 pounds) to the oscilloscope and powers up the Cal Package. The oscilloscope is neither turned off nor moved.

If the time base is to be checked first, a cable connection from the oscilloscope input is made to the TG 501, and the scope time base and TG 501 are set to corresponding ranges. With the time-variable knob on the TG 501 set to its outer position, the technician turns the knob until the time marks exactly align with the graticule and then reads the scope timing error in percent fast or slow, from the two-digit readout on the TG 501 front panel. Other ranges can be verified just as rapidly, with the deviation percentages recorded by the technician if that is part of the established procedures. No interpolation is required, no computations are necessary, and the entire operation takes place with the oscilloscope in its normal environment.

Vertical sensitivity verification is done in a virtually identical fashion using the PG 506 Calibration Generator. The two-digit readout on the PG 506 panel indicates percentage deviation of the generator output, high or low, from the switch-indicated (standard range) value. High generator output, when adjusted for square-wave alignment with the graticule, corresponds to low oscilloscope sensitivity and vice-versa. This contrasts to the Time Mark Generator case, where a fast generator and fast time base correspond.

The key parameters of vertical and horizontal accuracy have thus been verified "on location" in a matter of minutes. The bandwidth can be quickly checked with the SG 503 or SG 504, as appropriate for the instrument bandwidth. If all parameters have been verified as falling within acceptable deviations from perfect accuracy, the technician can re-sticker the oscilloscope, unplug his TM 503, and move on to the next location. No unnecessary recalibration needs to take place, and the instrument is ready for use in less time than a typical coffee break, rather than being shut down for hours. If a parameter was outside spec but within "tweak-in" range, both the TG 501 and PG 506 can function as normal fixed calibration sources simply by pushing the variable knob in. The digital readout is then disabled and the generator output is set only by the indicator-range switch.

With verification and minor calibration performed at the user's site, the metrology lab, as far as oscilloscopes are concerned, now becomes only a place for troubleshooting and repairing instruments which have actually failed.

You who are familiar with earlier generations of Tektronix oscilloscope calibration instruments will find the TG 501 Time Mark Generator similar to the 2901, with operation extended to one nanosecond (1 GHz) and the error readout feature added; however, the TG 501 does not permit "stacking" (combined operation of two markers to create time marks at two different rates). The PG 506 Calibration Generator combines the features of the 106 Pulse Generator and the Standard Amplitude Calibrator. The SG 503 Leveled Sinewave Generator is functionally similar to the 191, but extends coverage to 250 MHz and provides frequency readout by a built-in autoranging 3-digit

counter rather than a dial with attendant problems of accidentally reading the wrong range. It also replaces the 067-0532-00 Calibration Fixture. The SG 504 functionally replaces the upper portion of the range of the 067-0532-00 and extends coverage to 1050 MHz.



The TM 500 Series

Test and Measurement Instruments

SIGNAL GENERATORS

FG 501 Function generator; 0.001 Hz to 1 MHz, five waveforms

FG 502 Function generator; 0.1 Hz to 11 MHz, 25 ns rise and fall, five waveforms

PG 501 Pulse generator; 5 Hz to 50 MHz, 3.5 ns rise and fall

PG 502 Pulse generator; 250 MHz, 1 ns rise and fall, independently controllable logic 1 and 0 levels

PG 505 Pulse generator; 100 kHz, 80-V floating output, independently variable rise and fall times

PG 506 Pulse generator; 0.5 ns rise time output, 60 V output, and voltage calibrated output for oscilloscope calibration (measures amplitude errors with 0.1% resolution over error range of $\pm 7.5\%$)

RG 501 Ramp generator; 10- μ s-to-10-s ramp, with four scope-type trigger controls

SG 502 RC oscillator; 5 Hz to 500 kHz, sine and squarewaves, 0.1% distortion

SG 503 Sinewave oscillator; 250 kHz to 250 MHz, 50-kHz reference output

SG 504 Sinewave oscillator; 245 MHz to 1,050 MHz, 50 kHz reference

TG 501 Time-mark generator; 1-ns-to-5-s markers, measures timing errors with resolution within 0.1% over timing-error range of $\pm 7.5\%$

DIGITAL MULTIMETERS

DM 501 4½-digit multimeter; voltage accuracy to within 0.1% with temperature-measuring capability

DIGITAL COUNTERS

DC 501 Seven-digit, 110-MHz counter and totalizer

DC 502 Similar to DC 501 with $\div 10$ pre-scaler for counting to 550 MHz

DC 503 Seven-digit, 100-MHz universal counter with dual channels

DC 505 Seven-digit universal counter, 225 MHz on both channels

POWER SUPPLIES

(all also provide + 5 volts, referenced to ground)

PS 501 Floating output of 0 to 20 V, 0 to 400 mA

PS 501-1 PS 501 with 10-turn-potentiometer readout

PS 501-2 PS 501 with dual-range meter readout

PS 502 Dual-tracking supply ± 10 to ± 20 V or 20 to 40 V

PS 503 Dual supply, 0 to ± 20 V or 0 to 40 V

MAINFRAMES

TM 501 Powers one module from standard line voltage

TM 503 Powers three modules; dual rackmount kit available

MOBILE TEST STATIONS

203 Option 1 SCOPE-MOBILE® Cart mounts TM 503, stores four modules

204 Option 1 SCOPE-MOBILE® Cart mounts TM 503, stores five modules

SIGNAL PROCESSORS

AM 501 High-power, high-voltage op amp; 5-MHz bandwidth, 50 V/microsecond slew rate into 800-ohm load

AM 502 Dc-coupled, high-gain differential amplifier; 1 to 100,000 gain, dc-to-1-MHz bandwidth, selectable—3 dB points

CRT MONITOR

MR 501 X-Y monitor; 10 mV to 10 V per division, dc-to-2-MHz bandwidth (RG 501 also converts MR 501 to oscilloscope)

