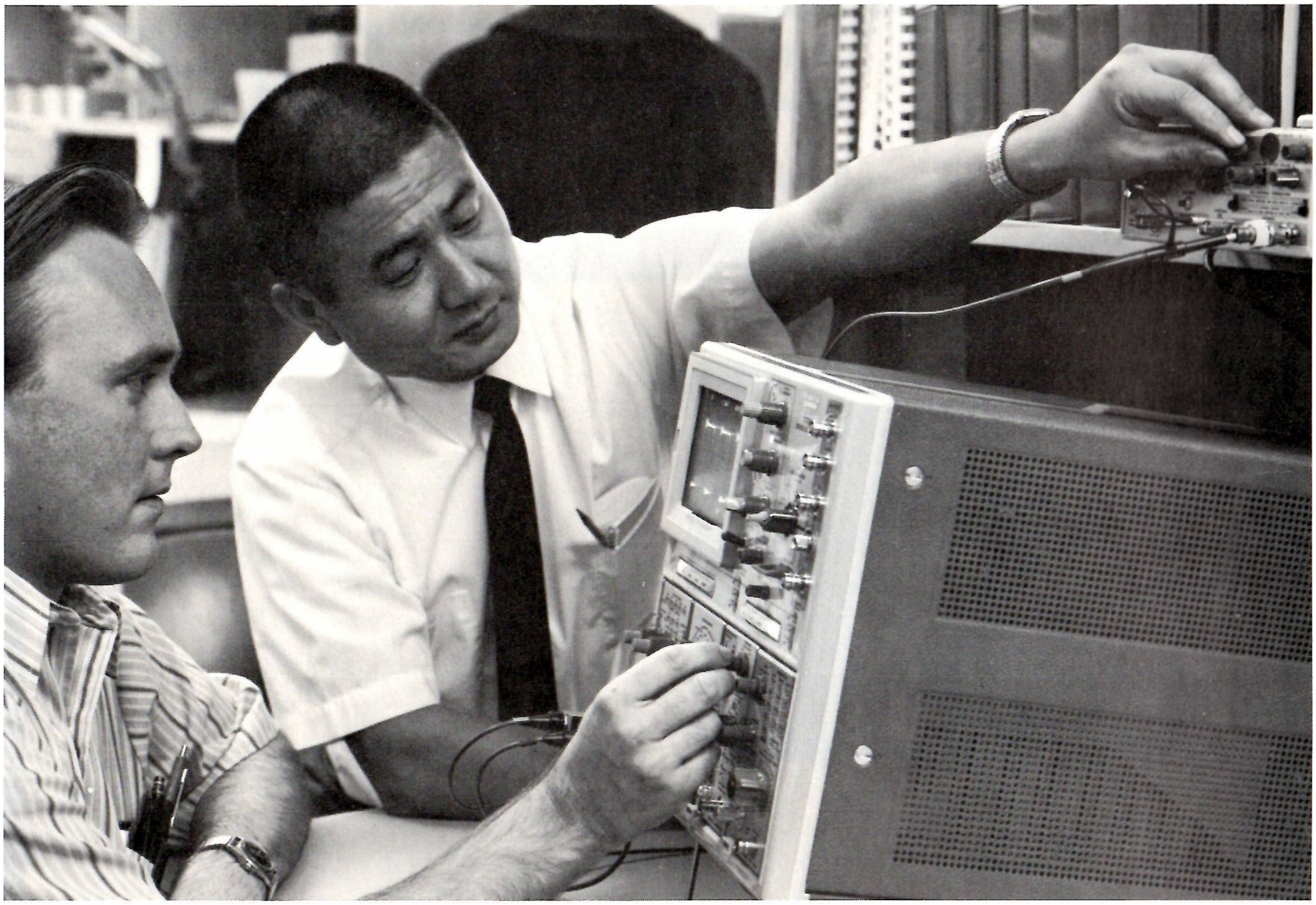


a new world of measurements for the oscilloscope

COVER—Two new plug-ins open the door to a world of measurements formerly outside the domain of the oscilloscope. The 7D14 Digital Counter plug-in directly-gated to 500 MHz and the 7D13 Digital Multimeter with temperature readout make the oscilloscope a more versatile measurement tool than ever before.

Oscilloscopes in the last twenty-five years have advanced from relatively simple indicating devices to sophisticated measurement tools used in nearly every segment of our society. However, the basic function of displaying waveforms for time and amplitude measurement has remained relatively unchanged.

Now, for the first time, the oscilloscope can measure voltage, current, resistance, temperature, and frequency, all digitally.

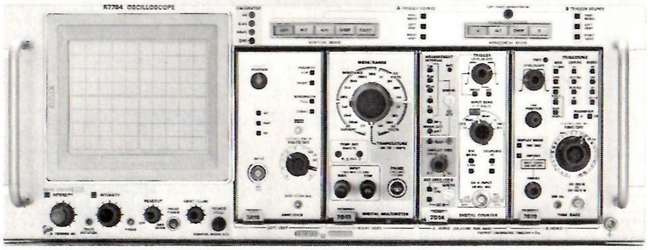
With the introduction of the 7D13 Digital Multimeter and the 7D14 Digital Counter plug-ins for the Tektronix 7000 Series, the oscilloscope assumes an entirely new role in the field of measurement.

Counters and digital multimeters are rapidly becoming necessities on the engineer's workbench. Integration of these capabilities into the oscilloscope provides an ideal answer to the space problem and, more important, offers many capabilities not available in stand-alone instruments.

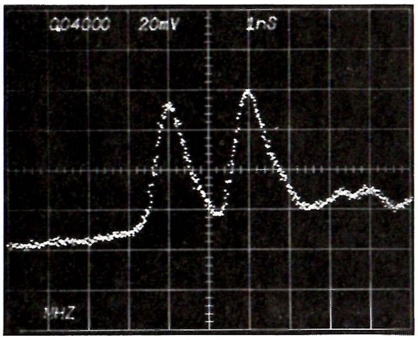
Hiro Moriyasu, Manager of Advanced Concept Development and Neil Robin, Project Engineer with primary responsibility for the 7D13 and 7D14 discuss operation of the 7D14 Digital Counter plug-in.

What are some of the advantages of marrying the digital counter, digital multimeter, and oscilloscope? Most obvious, of course, are savings in space and cost. For example, a 150 MHz oscilloscope complete with digital counter and digital multimeter use only 7" of rack height. A significant breakthrough for users where space is at a premium.

To you who record data on photos for your engineering handbook, another advantage readily apparent is the ability to display and photograph amplitude, time, frequency, temperature, and the wave shape all at the same time.



A 150 MHz oscilloscope, 500 MHz counter, and a digital multimeter, all in only 7" of rack space.



500 MHz direct-gated capability of the 7D14 is dramatically illustrated in this photo showing counting of a high-speed double pulse with a 20 kHz rep rate; a difficult, if not impossible measurement to make with most counters.

Signal conditioning is a must for many applications, and the wide range of vertical amplifier plug-ins available for the 7000 Series make excellent signal conditioners for the counter. With the 7D14 in either of the horizontal compartments, a signal connected to a vertical plug-in can be internally routed to the counter by the trigger source switches. In addition to conditioning the signal, this mode of operation lets you view the signal while counting, with minimum loading of the circuit under test.

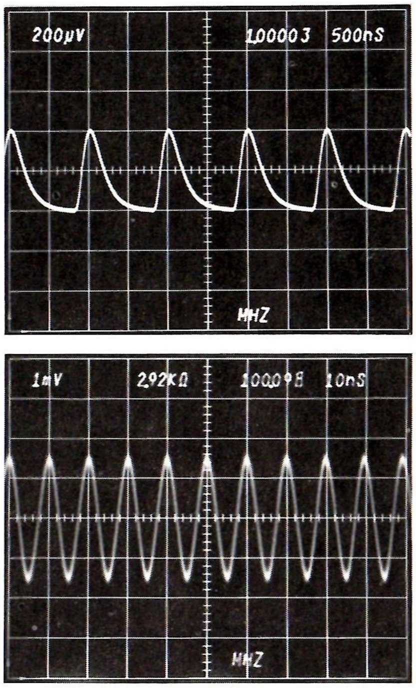
MINIMUM CIRCUIT LOADING

Circuit loading is given special attention in the 7D14. The wide frequency range of DC to 500 MHz, all directly-gated, calls for something other than just the 50-ohm input normally found on high-frequency counters. The 7D14 provides both 50-ohm and 1-megohm input impedances, and either may be AC or DC coupled. In addition, by using the vertical plug-ins as conditioners, the 7D14 Counter enjoys the same freedom from loading you've come to expect in oscilloscopes. The wide range of Tektronix probes, from FET's with high resistance and low capacitance to current probes with practically zero circuit loading, can be used to acquire the signal. Many of the probes can be used directly on the counter if attenuation of the signal can be tolerated. This leads us to another advantage of the counter/scope combination.

COUNTING LOW-LEVEL SIGNALS

Low-level signals are not among "the counted" for most counters today. The 100 mV P-P (35 mV RMS) sensitivity of the 7D14 is better than that of most counters. However, even signals in the microvolt region can readily be counted using the vertical plug-ins as conditioners. Pictured below is a 400 μV, 1 MHz signal being counted after conditioning by the 7A22 Differential Amplifier.

Low-level, high-frequency measurements beyond 150 MHz can easily be made using the 7A11 or 7A16 wideband plug-in amplifiers for conditioning. The photo showing a 3 mV, 100 MHz signal being counted, illustrates this unusual capability.

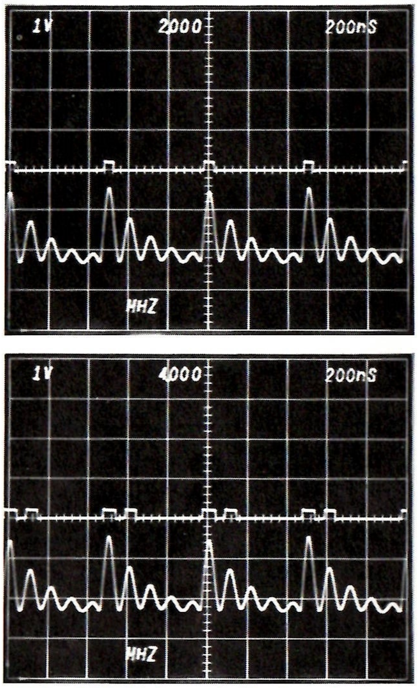


Signal conditioning using vertical amplifier plug-ins greatly expands the range of signals that can be counted. Top, a 400 μV, 1 MHz signal is counted using the 7A22 Differential Amplifier for conditioning. Bottom, 3 mV, 100 MHz signal is counted after conditioning by the 7A13 Differential Comparator Amplifier.

TRIGGER INDICATOR

One of the most difficult problems encountered when using conventional counters has been in determining just what the counter is counting. Noise peaks may trigger the counter or variations in signal level may cause an event to be missed. The 7D14 ends that uncertainty. Now we can see the same "shaped" input signal that the counter section actually sees.

The input signal passes through conditioning circuits in the 7D14. One of these is a Schmitt trigger which serves to reject noise and shape the input signal to the counter. The output of the Schmitt is a rectangular wave and drives the counter circuits. This makes it an ideal waveform to display on the CRT along with the input signal. With the 7D14 in a vertical plug-in compartment, we can view the Schmitt output. It can be displayed as a separate signal or "added" to the input signal to show precisely the portion being counted.



The value of the 7D14 trigger indicator when counting complex waveforms is apparent in these photos. The only change between the top and bottom photo was a slight adjustment of the counter's trigger level control.

EXTERNALLY-GATED MEASUREMENTS

Externally-gated measurements usually entail a lot of guesswork, especially when the signal to be counted is a burst. Using the 7D14 with delaying sweep plug-ins such as the 7B70/7B71 greatly simplifies these measurements.

The 7D14 is located in one of the vertical plug-in compartments and the sweeps are operated in the delaying time base mode. The signal to be measured is displayed with A time base while B time base intensifies the trace and provides the counter gate. We can set B gate (or delayed gate) to the desired width and position it anywhere along the displayed sweep. Thus, we can gate the counter for any portion of the display we choose.

Gating the counter with an external gate that coincides with the intensified portion of the trace offers many measurement possibilities. For example, measuring the duration of a ramp, time interval, counting events in a burst and the frequency in a burst are but a few of the measurements you can make using this technique.

COUNTING EVENTS IN BURST

To count the number of events in a burst, feed the burst signal into the counter Channel A input. Gate the counter externally with the delayed gate output from the scope and set the intensified portion of the sweep to bracket the burst to be counted. The counter readout displays the number of events occurring in the burst. Moving the intensified portion back and forth with the Delay Time Multiplier while observing that the counter readout remains steady will verify that all of the events in the burst are counted. This is particularly important when measuring bursts of 10 μs or shorter duration.

COUNTING FREQUENCY IN BURST

To count an unknown frequency in a burst, the setup is the same as above only the intensified portion is made shorter than burst width and positioned within the burst. The counter readout is noted. The width of the external gate, which corresponds to the intensified portion, is then measured by one of two methods.

The most accurate method is signal substitution. The burst signal is removed and a known reference frequency connected to the signal input. The counter readout is again noted. External gate duration is calculated by multiplying the number of reference frequency cycles counted, times the period of the reference frequency (Gate Width $= N_{ref} \times$ period). The burst frequency is then easily determined by dividing the number of burst cycles counted, by the gate width

$$\left(f_{burst} = \frac{N_{burst}}{\text{Gate Width}}\right).$$

The second method, though not as accurate, is somewhat simpler since it requires no external reference frequency. The external gate width is simply measured using the scope time base. Once the external gate width is measured, the frequency in the burst is calculated as before. The number of burst cycles counted is divided by the gate width

$$\left(f_{burst} = \frac{N_{burst}}{\text{Gate Width}}\right).$$

FREQUENCY COMPARISON

Frequency comparisons are commonly made by alternately feeding the two signals into the counter and noting the difference between the two readings. These measurements are made more quickly and accurately with the 7D14 using a dual-trace or differential plug-in to switch rapidly between the two signals. The 7A12, 7A13, and 7A22 are ideal for this application.

COUNTER READOUT

The 7D14 provides 8-digit readout on the CRT with leading zeros suppressed, that is, zeros leading the first major digit are not displayed. Accuracy of the counter is parts in 10^7. Why then 8-digit readout? There are a number of reasons: first, provision is made to drive the 7D14 with an external reference oscillator of greater accuracy and stability. This could easily yield measurement accuracy to the eighth place. Second, resolution; some measurements are best made using comparison techniques. Frequency difference is then of more importance than absolute frequency. The more resolution you have, the closer the two frequencies can be compared. Third, the 7D14 can be manually or externally gated for "totalizing" measurements. The 8-digit readout makes possible totalizing counts from 0 to 10^8.

7D13 DIGITAL MULTIMETER

Thus far we have discussed primarily the 7D14 Digital Counter. Now, let's take a look at the 7D13 plug-in Digital Multimeter.

The 7D13 brings several new measurement capabilities to the oscilloscope. We're accustomed to taking AC waveform measurements from the CRT, but seldom do we take DC measurements from it. Perhaps we forget the oscilloscope has that capability. More likely, we need better resolution than an oscilloscope trace provides, or we find a meter easier to read.

The 7D13 brings improved resolution and accuracy to oscilloscope measurements, plus the convenience of digital readout. In addition to measuring DC voltage, the 7D13 measures DC current, resistance, and temperature. The temperature mode is new to the digital multimeter field and brings a much-needed tool to the engineer's fingertips.

THE TEMPERATURE SENSOR PROBE

The heart of the temperature sensor probe is an ordinary silicon npn transistor mounted in the tip of the probe. It is a characteristic of solid-state devices that the voltage across a forward-biased p-n junction is temperature dependent. It is this voltage that we use to measure temperature. There are, however, drawbacks to measuring the junction voltage (V_{be}) directly. V_{be} is not a perfectly linear function of temperature and varies from one device to another. This presents problems in measurement accuracy and, more important, in providing replacement sensors.

There is a solution to these problems. If, instead of using a constant collector current, the current is varied between a fairly high value, I_{c1}, and a fairly low value, I_{c2}, with resultant base voltages, V_{be1} and V_{be2}, we find that the base-voltage excursion (ΔV_{be}) has much-improved linearity and is proportional to absolute temperature.

The relationship between collector current, base-emitter voltage, and temperature is shown by the equation:

$$\Delta V_{be} = V_{be1} - V_{be2} = \frac{kT}{q} \ln \frac{I_{c1}}{I_{c2}}$$

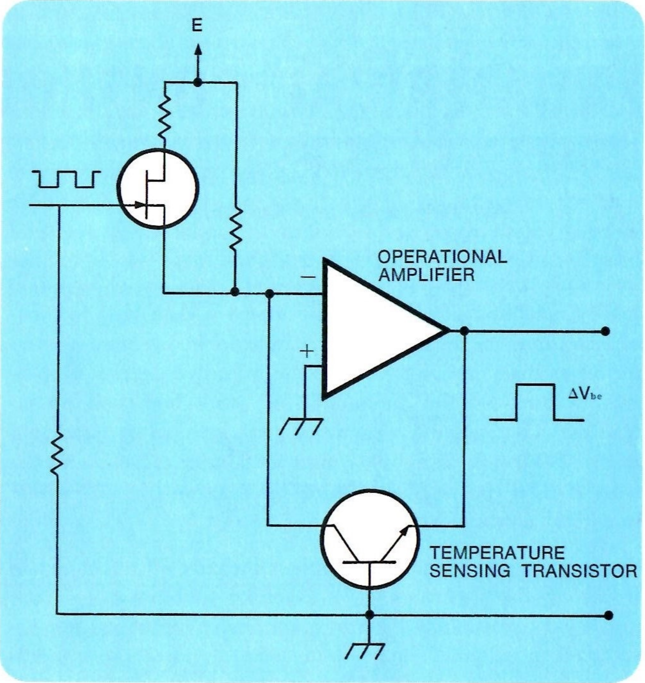
where k is Boltzmann's constant, q is the electron charge and T is temperature. Differentiation of this voltage excursion, ΔV_{be}, gives its temperature coefficient:

$$\frac{d}{dT}(\Delta V_{be}) = \frac{k}{q} \ln \frac{I_{c1}}{I_{c2}}$$

Using the switched-collector technique and measuring ΔV_{be} as the indicator of temperature change, we achieve improved linearity in temperature measurements and ease of interchangeability of the transducer transistor or probe tip.

Pictured is the basic circuit used in achieving the change in base-emitter voltage for a given change in collector current. The sensor transistor is connected in the feedback loop of an operational amplifier with the collector at the input, emitter connected to the output, and the base grounded. For a given current input, the output of the operational amplifier forward biases the emitter-base junction of the transistor to the level necessary to maintain the input collector current.

The ratio of the two levels of collector current is set at about 100:1, giving the base-emitter voltage a sensitivity to temperature of slightly less than 0.4 mV/°C.



Simplified circuit for achieving improved linearity by switching collector current and measuring ΔV_{be} as indicator of temperature change.

ELEVATED INPUT CAPABILITY

Another valuable feature of the 7D13 is the ability to float the input circuit up to 1.5 kV above chassis ground. This gives us considerable flexibility in measuring parameters that have a high common-mode voltage. The temperature probe shares this capability and can take temperatures of components elevated to 1.5 kV.