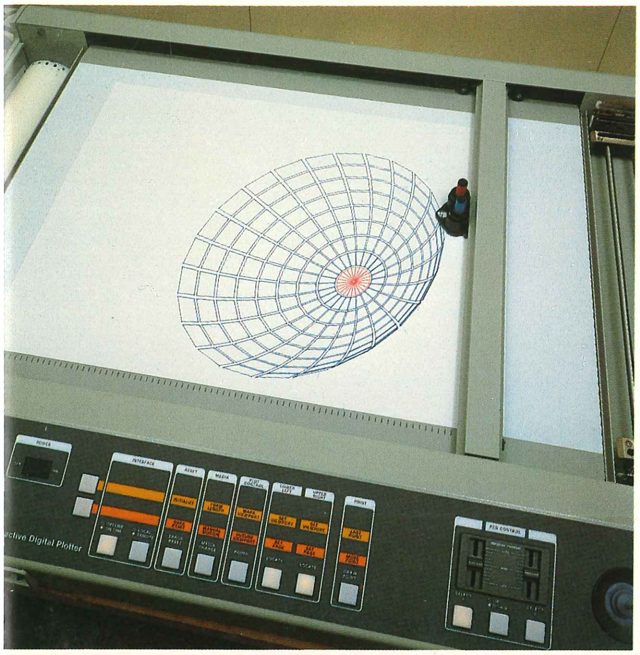
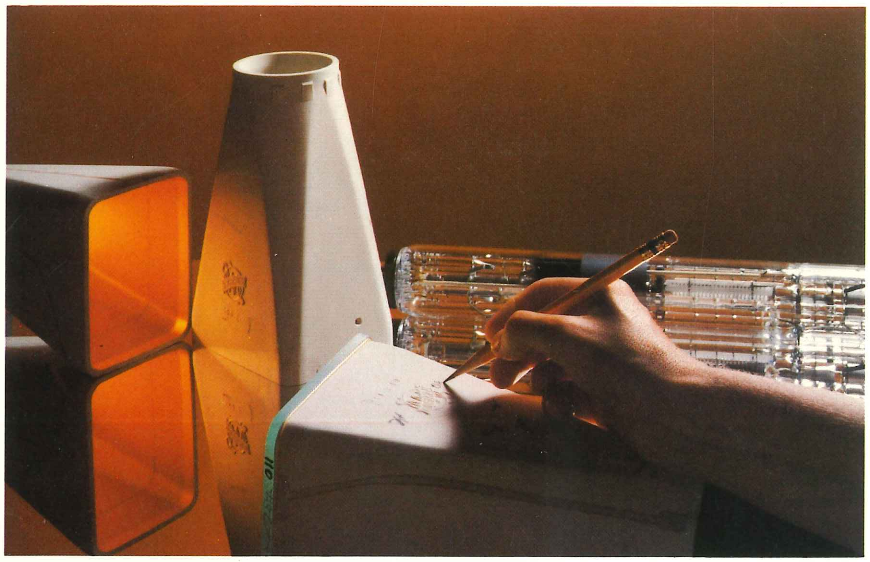
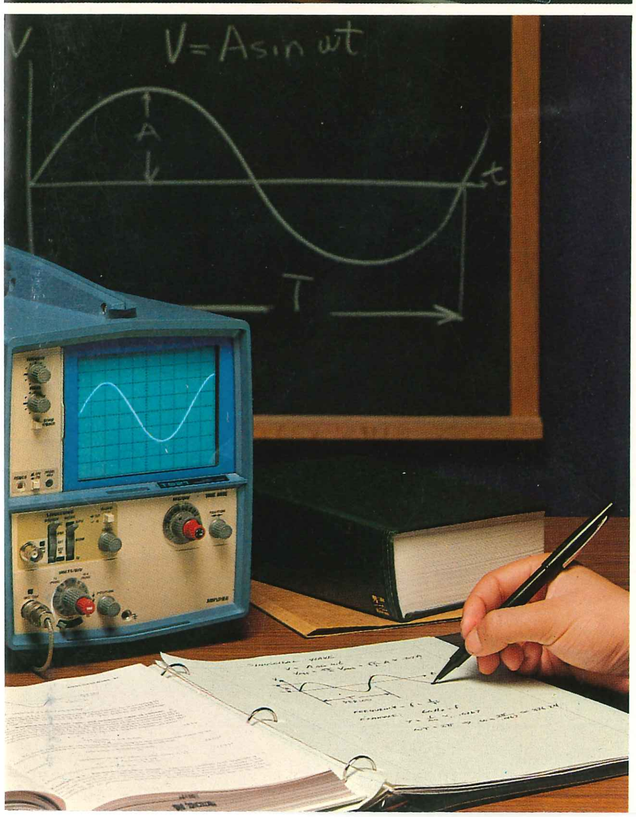
Digital Counter and Meter Concepts







Tektronix®
COMMITTED TO EXCELLENCE

TRAINING INFORMATION

Tektronix training programs are developed to assure customers maximum return on their investments. Several types of training programs meet that objective: formal classroom training; audiotapes on operation, circuit description, and calibration; videotapes on basic concepts, operation, and applications; and stand-alone multi-media training packages which combine printed materials with audiotapes and/or videotapes in a format designed for independent learning.

ORDERING INFORMATION

You may order additional copies of this booklet through your nearest Tektronix Field Office, listed inside the back cover. For more information regarding training classes, audiotapes, and training packages, request a copy of the current Customer Training Catalog from your local Tektronix Field Representative.

062-4799-00

Marketing Training
April 1980

Digital Counter and Meter Concepts

Tektronix®
COMMITTED TO EXCELLENCE

PREFACE

This booklet, when used with the two associated videotape recordings, will provide you with the basic principles of digital counter and meter operation. For maximum effectiveness this training package should be approached in the following order:

1. View the video tape *Digital Counter Concepts,* (Tektronix Part No. 068-0090-00).
2. Read Chapter 1 of this booklet, performing the Quizzes as encountered.
3. View the video tape *Digital Meter Concepts,* (Tektronix Part No. 068-0091-00).
4. Read Chapter 2 of this booklet, performing the Quizzes as encountered.

The videotapes greatly enhance the communication of this information; however, this training manual may be used alone.

After completing this program you should be able to:

A. State the order of events, at a block diagram level, which occur in either a digital counter or meter from the time the input signal is applied until the readout is displayed.

B. Select the proper operating mode when given a set of measurement parameters (e.g., what mode is used to measure the time between two pulses on a nonrepetitive digital signal).

C. Calculate the accuracy and resolution of a measurement when given the displayed readout, the instrument control settings, and the specified instrument accuracy.

D. Define the terminology associated with digital counters and meters.

LIST OF ILLUSTRATIONS

TABLE OF CONTENTS

CHAPTER 1
DIGITAL COUNTERS

In electronics we must be able to accurately measure signals for frequency and duration. Digital counters provide us the accuracy needed while offering a wide variety of measurement modes. Such modes as totalize, frequency, period, width, etc., may all be found in the same digital counter.

DIGITAL COUNTER CONCEPTS VIDEOTAPE QUIZ

View the videotape entitled *Digital Counter Concepts.* Answer the questions below and check your responses against the answer key which precedes the Glossary at the back of this book.

1. The Main Gate is called the heart of a digital counter because:
   a. the maximum counting limits of the counter are determined here.
   b. connections to the Main Gate determine the operating mode.
   c. Main Gate provides the clock reference.
   d. both a and c.

2. Overflow, a term associated with readout, indicates:
   a. the counter is in an incorrect mode.
   b. damage to the counter is imminent.
   c. the counting capabilities are exceeded.
   d. both a and c.

3. Readout resolution is equal to:
   a. one count of the least significant digit.
   b. one count of the most significant digit.
   c. ten counts of the least significant digit.
   d. ten counts of the most significant digit.

4. In the totalize mode, the total number of events are counted:
   a. with reference to time.
   b. without reference to time.
   c. with reference to one second.
   d. none of the above.

5. In the frequency mode, the total number of counted events occur:
   a. each second of time.
   b. each minute of time.
   c. without any reference to time.
   d. both a and b.

6. In the period mode (the inverse of frequency mode), the connections to the Main Gate are:
   a. removed.
   b. identical.
   c. reversed.
   d. not used.

___

7. The frequency ratio mode requires:
   a. two Amplifier and Shaper stages.
   b. two input signals.
   c. two Main Gate stages.
   d. both a and b.

8. Time interval measurements include:
   a. time A-to-B measurements.
   b. frequency ratio measurements.
   c. width measurements.
   d. both a and c.

___

9. The width mode measures the elapsed time between the selected trigger level on the starting slope and the same trigger level on the:
   a. next starting slope of the same polarity.
   b. opposite polarity, ending slope.
   c. same polarity on any starting slope.
   d. both a and b.

TOTALIZE MODE

The "totalize" or "events" mode is a basic counter mode where the total number of input events (or occurrences of a preselected transition) are counted *without* reference to time. For example, if you measure a 15-pulse signal burst in this mode, the resultant display will indicate "15". This readout is without reference to the signal frequency or time in which these 15 pulses occurred.

Figure 1-1 illustrates the operation of a digital counter in the totalize mode. The input signal is first either attenuated or amplified to the appropriate level in the Amplifier stage. Selected here via front-panel controls are trigger sensitivity, slope polarity, and input coupling. Then the Shaper conditions (shapes) the signal by modifying the rise and fall times, so that following circuitry will be properly driven. The shaped input signal is now applied to the Main Gate.

The Main Gate is a simple gate which, in this mode, opens or closes in response to either the manual gate signal or the external gate signal. When open, the Main Gate passes the shaped signal pulses through, counting them as they pass. Closing the Main Gate stops the count.

Signals which pass through the Main Gate accumulate (are totaled) in the Counter/Storage circuit which contains both decimal-counting and count-storing devices. The count is then passed to the Encoder which converts it to a signal which will drive the readout. The readout now displays the total number of events, cycles, or pulses which occurred while the Main Gate was open. Popular readout devices include light-emitting diodes, liquid crystal displays, and crt displays. The number of digits in the readout impose an upper limit on the totalized count.

When the count exceeds the maximum limit of the Counter/Storage devices, an overflow occurs. Overflow (sometimes referred to as overrange) may be indicated by a flashing readout display or by a special overflow indicator. When overflow occurs, the most significant digit will drop from the display. For example, in a seven-digit display counter, for an actual count of 10,000,000 the readout will indicate "0000000". Therefore, unless you know with certainty how many significant digits are not shown, and what these digits are, the overflow display is of little value.

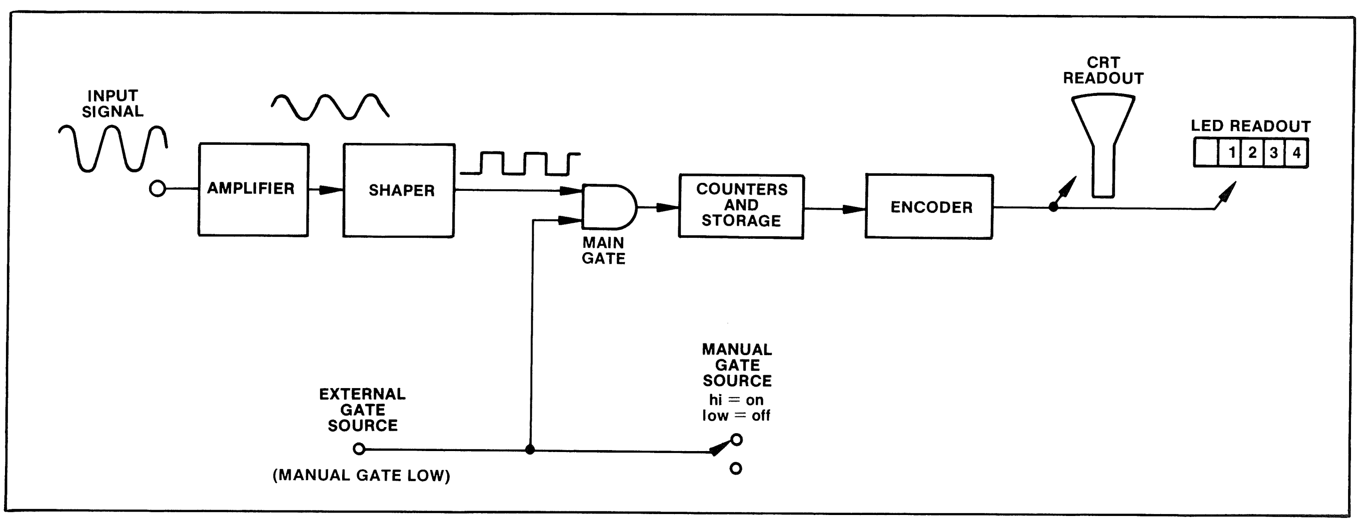


Figure 1-1. Basic block diagram of totalize mode.

TOTALIZE MODE QUIZ

Perform the following self test by responding to the questions. Then check your responses against the answer key which precedes the glossary at the back of this book.

---

1. The totalize mode counts the number of events occurring. An event is:
   a. a signal transition of selected polarity.
   b. any spike in the input signal.
   c. a specified dc level.
   d. both b and c.

---

2. The Amplifier and Shaper stages:
   a. attenuate the signal, if necessary.
   b. are basically an AND gate.
   c. amplify the signal as well as modify the rise and fall times.
   d. both a and c.

---

3. In the totalize mode, the Main Gate opens and closes in response to the:
   a. manual gate.
   b. external gate.
   c. input signal.
   d. both a and b.

---

4. The Main Gate passes the ______ in the totalize mode.
   a. clock pulses
   b. external gate signal
   c. overflow signal
   d. shaped input signal

5. The Counter/Storage stage is made up of devices that:
   a. store the count.
   b. count the events (in the totalize mode).
   c. convert the count to an analog signal.
   d. both a and b.

---

6. The Encoder converts the count signal to:
   a. a digital signal.
   b. binary coding.
   c. a signal which will drive the readout device(s).
   d. all of the above.

---

7. In the totalize mode, the readout depicts the total number of ______ that occurred while the Main Gate was open.
   a. events
   b. cycles
   c. pulses
   d. all of the above.

---

8. Overflow occurs when:
   a. the input signal is out-of-phase with the shaped signal.
   b. the counting capabilities of the counter are exceeded.
   c. both a and b.
   d. the input signal is of too high an amplitude.

FREQUENCY MEASUREMENTS

FREQUENCY MODE

A counter in the frequency mode operates similarly to one in the totalize mode, except now the count is directly referenced to one second of time. This is done by adding Clock and Gate Controller circuits (see Fig. 1-2) which provide a specific one-second time reference for the counter. All other stages operate as described for the totalize mode.

Precision time references are provided by the crystal-controlled oscillator of the Clock. These clock pulses are then divided down by the decade dividers of the Gate Controller stage to select the time the Main Gate is open. For example, with an input frequency of 1 MHz and a selected gating time of one second, one million pulses are passed through the Main Gate. This results in a readout of "1000000". If the gating time is changed to ten seconds, a count of "1000000.0" will be displayed. (This would cause an overflow condition on a seven-digit readout.)

FREQUENCY RATIO MODE

In the frequency ratio mode the frequency measurement is made between two input signals. Notice in Figure 1-3 that the Clock stage has been replaced with another input Amplifier and Shaper which provide the time reference for the count. For example, with a 1 MHz signal connected to the first input and a 100 kHz signal connected to the second input, the count would be "10". This is the ratio of 1 MHz to 100 kHz. A readout display of "MHz" or "kHz" should be ignored in this mode.

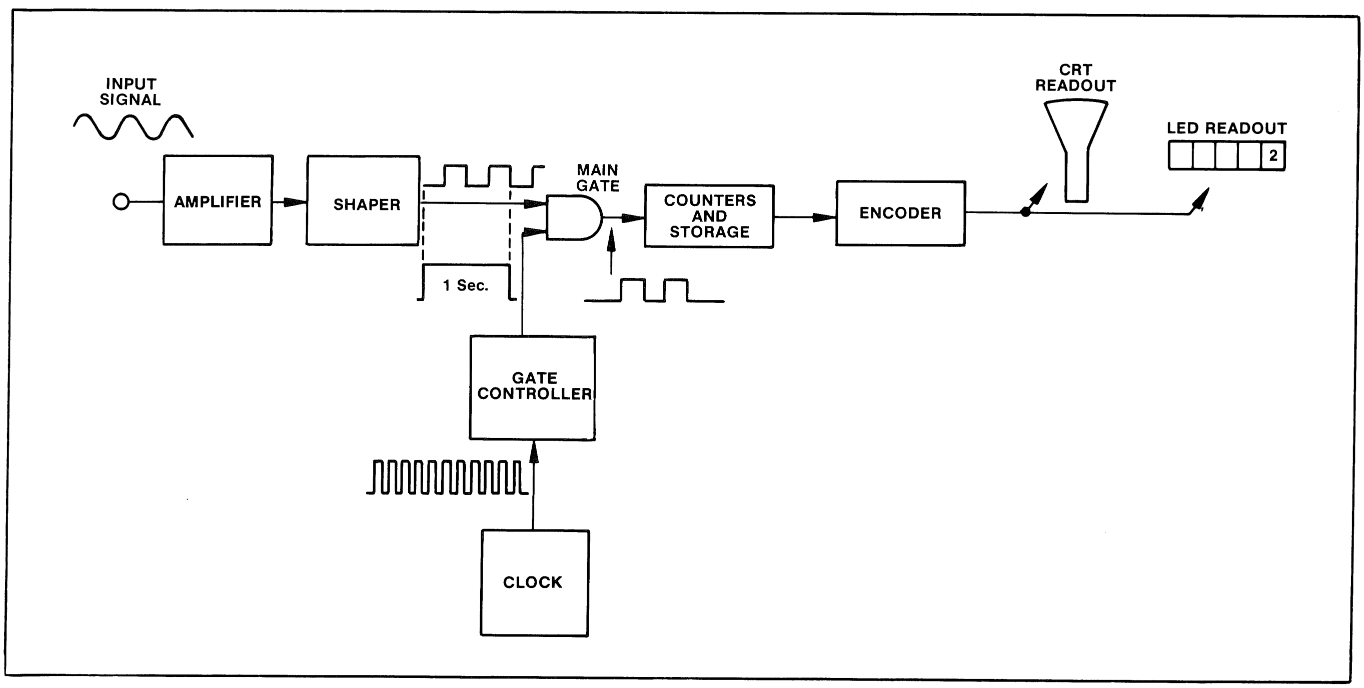


Figure 1-2. Basic frequency counter.

PRESCALE MODE

In the prescale mode the counter has a higher frequency-counting capability due to the addition of a divider before the Main Gate. However, for the count to be accurate, the gating time must also be divided. For a prescale factor of 10 (as shown in Figure 1-4), the gate control signal must be divided by 10. The Encoder is then adjusted for the decimal point to be in the correct position. A disadvantage with prescaling is the additional time needed to make a measurement.

RPM MODE

In the RPM (revolutions-per-minute) mode, the gating time is increased by a factor of six. Therefore, an original gating time of 10 seconds is now one minute (resulting in one count per minute).

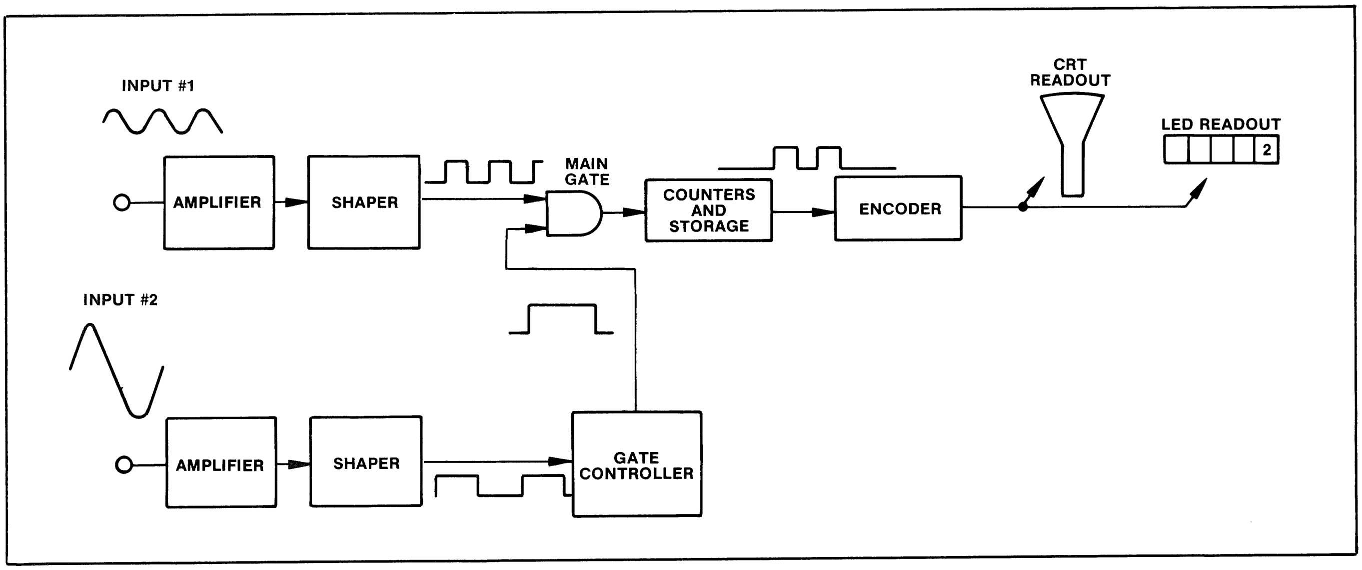


Figure 1-3. Basic frequency ratio counter.

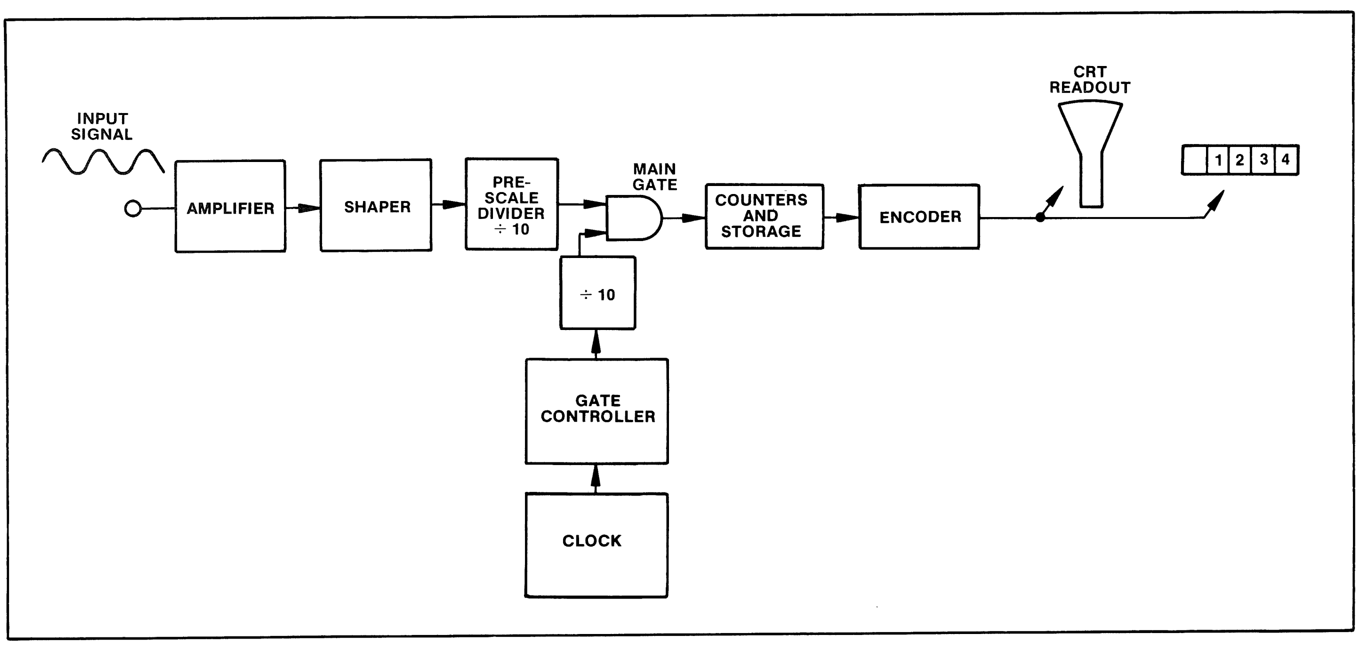


Figure 1-4. Basic prescale counter.

FREQUENCY MEASUREMENTS QUIZ

Perform the following self test by responding to the questions. Then check your responses against the answer key which precedes the glossary at the back of this book.

1. In the frequency mode the count is directly referenced to:
   a. a dc voltage.
   b. a ramp.
   c. time.
   d. 60 hertz.

2. The Clock provides the frequency counter a:
   a. very precise time reference.
   b. large count capability.
   c. floating decimal point.
   d. both a and c.

3. The Gate Controller divides down the clock signal to:
   a. attenuate the input signal.
   b. select the time the Main Gate is open.
   c. control the display intensity.
   d. all of the above.

4. A frequency ratio is between:
   a. the input signal and the clock signal.
   b. two input signals.
   c. a dc voltage and the input signal.
   d. none of the above.

5. With a 100 MHz signal applied to the first input and a 500 kHz signal applied to the second, the readout in the frequency ratio mode would be:
   a. 0.005.
   b. 2.
   c. 200.
   d. 5.

6. The correct units to be displayed for question 5 would be:
   a. kHz.
   b. MHz.
   c. picoseconds.
   d. none of the above.

7. A prescale counter is used when:
   a. measuring a very high frequency signal.
   b. measuring an input signal of many frequencies.
   c. measuring an input signal with very low amplitude.
   d. comparing two separate signals.

8. A disadvantage of the prescale counter is:
   a. the upper frequency limit.
   b. only allowing two input signals at a time.
   c. only measuring sinusoidal waveforms.
   d. the additional time required to make a measurement.

9. In the RPM mode the gate time is increased by a factor of six; therefore, the readout depicts:
   a. counts-per-second.
   b. counts-per-minute.
   c. counts-per-hour.
   d. counts-per-millisecond.

TIME MEASUREMENTS

PERIOD MODE

In the period mode, the time between two consecutive transitions of the same slope is counted. To do this the connections to the Main Gate are reversed from those previously described for the totalize or frequency modes. Now instead of the input signal being counted, the clock signal is counted (see Fig. 1-5). Since the input signal now controls the gating time, a Divide-By-Two stage is added to open the Main Gate for the period, not the pulse width, of the input signal. For example, if the input signal is 1 Hz and the clock is 1 ms, the counter will indicate "1000" for the number of clock pulses counted.

PERIOD AVERAGING MODE

The period averaging mode reduces random noise, the most serious source of error in period counts, by averaging these effects over time. By dividing the input signal before applying it to the Main Gate, the Main Gate is held open longer. This results in period averaging. For example, if the input is divided by ten, the Main Gate is held open ten times longer. Of course, the resulting count is ten times larger. (See Figure 1-6.) This mode increases the resolution and reduces the error by the averaging factor.

WIDTH MODE

In the width mode, the counter measures the time between two consecutive transitions of opposite slopes. (See Figure 1-7.) Starting slope and level are operator selected with front-panel controls. Unlike the period mode, the Divide-By-Two stage is not used in the width mode.

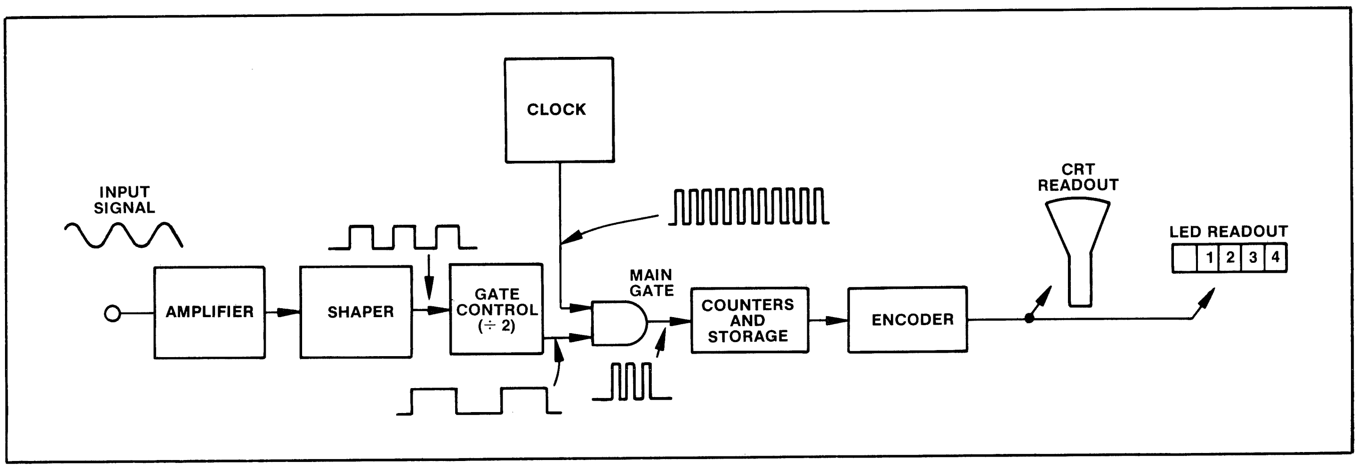


Figure 1-5. Basic period counter.

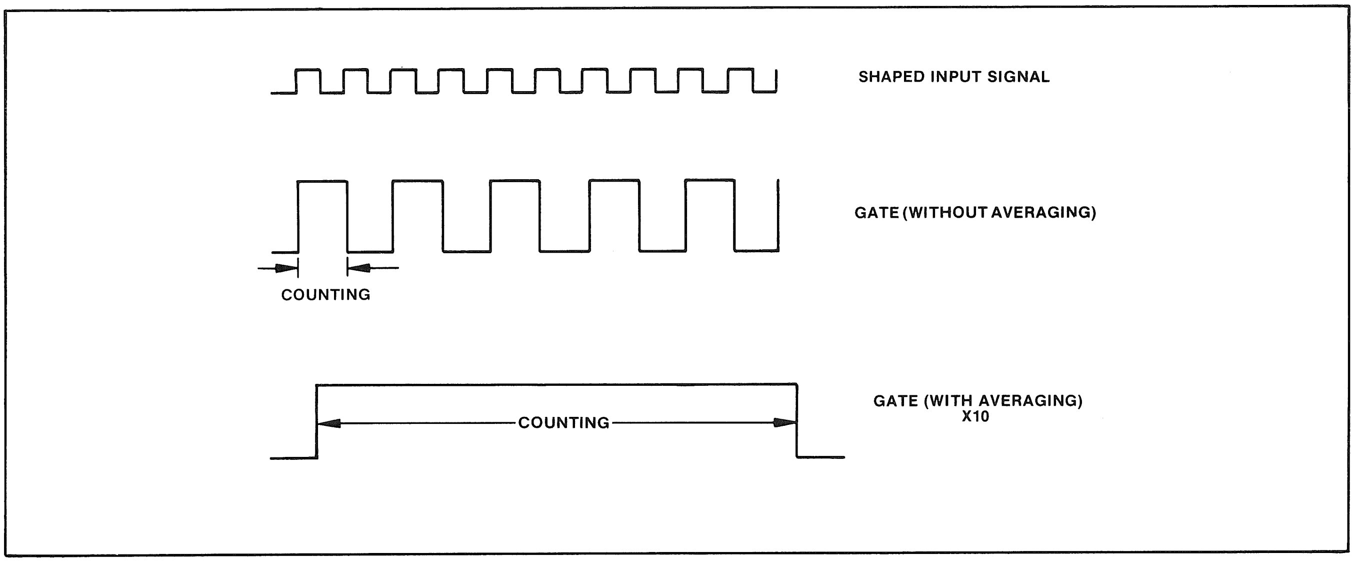


Figure 1-6. Comparing the input to the gate output in the period and period averaging modes.

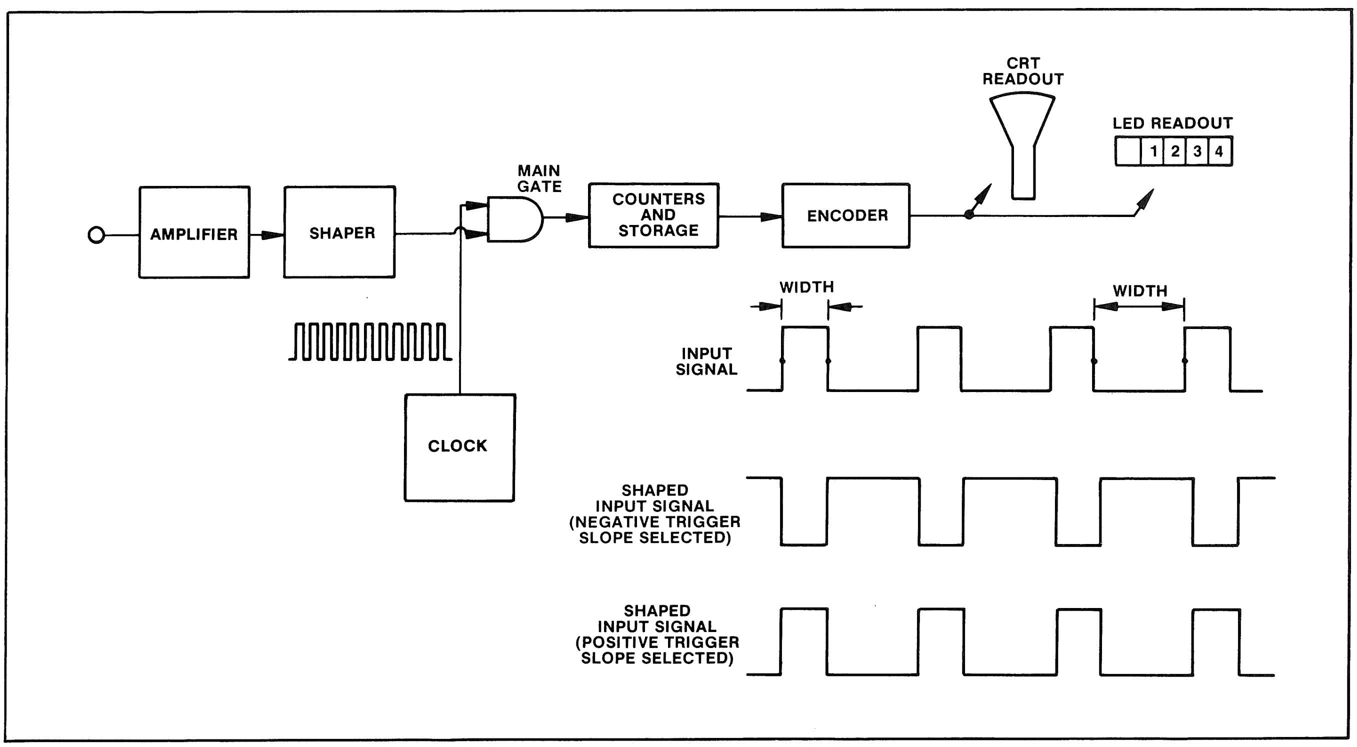


Figure 1-7. Basic width counter.

TIME A-TO-B MODE

In the time A-to-B mode, either the time from one point to another on the same signal, or from a point on one signal to a point on another signal, is measured by the counter. To do this a second input Amplifier and Shaper are added (see Fig. 1-8), and both shaped input signals are applied to the Gate Controller stage. This allows a selected point on the first channel (Event A in Fig. 1-8) to open the gate, and a selected point on the second channel (Event B) to close the gate. While the Main Gate is open the clock pulses are counted.

TIME-INTERVAL AVERAGING MODE

In time-interval averaging (either *width averaging* or *time A-to-B averaging)* the Main Gate is opened and closed numerous times. For example, to effect an average of 10, the Main Gate is opened and closed ten separate times. This reduces error due to noise, but not as effectively as period averaging. This is because each time the Main Gate opens and closes noise error may be introduced into the count. Resolution is increased in this mode, but it will not be as great as the averaging factor.

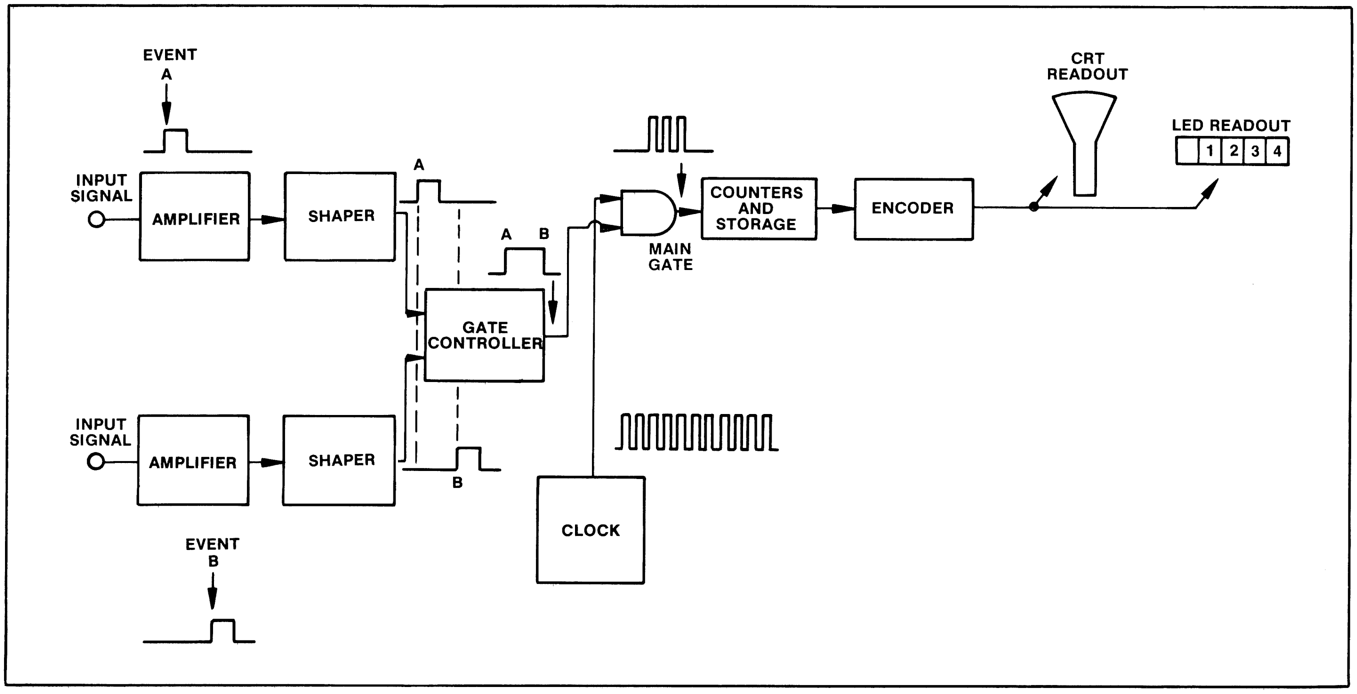


Figure 1-8. Basic diagram of the digital counter for the time A-to-B mode.

USE OF ARMING

With arming capability a counter can measure the time between two nonadjacent pulses. Figure 1-9 shows the proper placement of the arming inputs. In the example shown, the time is measured between the first and last pulses of the input burst. The A arming input is not used because the first pulse of the A input signal will set the gate control signal high. However, a disarming signal is applied to the B arming input so that only the last negative transition of the input burst will set the gate control signal low. This results in a gate control pulse width equal to the width of the input burst.

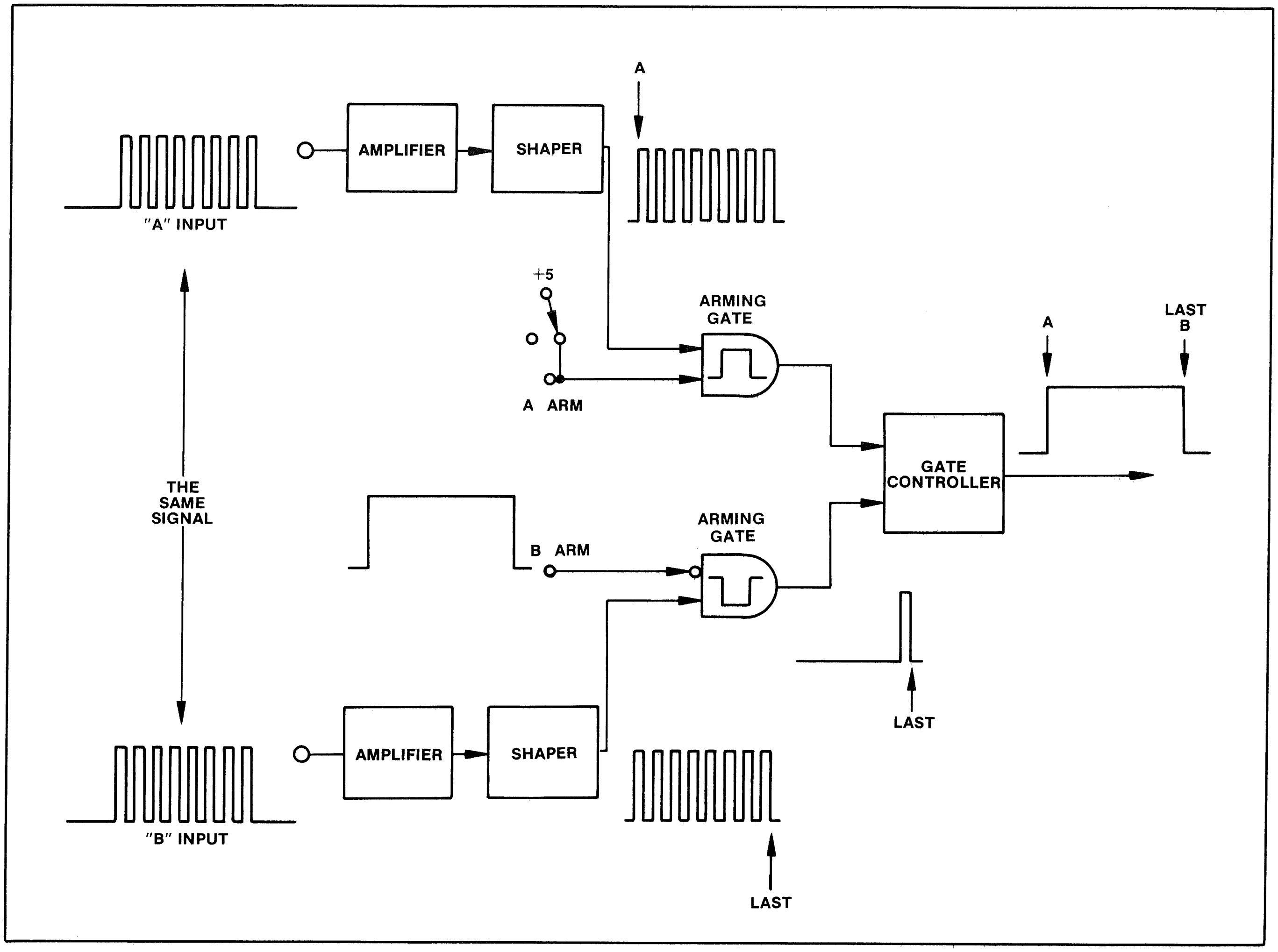


Figure 1-9. Basic diagram of counter with arming inputs.

TIME MEASUREMENTS QUIZ

Perform the following self test by responding to the questions. Then check your responses against the answer key which precedes the glossary at the back of this book.

---

1. In the period mode, the Main Gate passes and counts the:
   a. shaped input signal.
   b. arming signal.
   c. clock signal.
   d. disarming signal.

---

2. The time the Main Gate is open (in the period mode) is equal to the _____ of the input signal.
   a. period
   b. frequency
   c. width
   d. both a and c.

---

3. Period averaging is used primarily to:
   a. increase the upper frequency limit of the counter.
   b. measure the average frequency of two separate input signals.
   c. reduce the effect of random noise.
   d. both b and c.

---

4. Width mode measures the time between two consecutive transitions of:
   a. the same slope.
   b. opposite slopes.
   c. opposite polarities.
   d. both b and c.

5. In the time A-to-B mode, the time measured is between:
   a. consecutive positive transitions.
   b. a point on one input signal and a point on a second input signal.
   c. two points on the same input signal.
   d. both b and c.

---

6. For time-interval averaging the Main Gate will open and close:
   a. 10 times to average 10 times.
   b. one time to average 10 times.
   c. 100 times to average 100 times.
   d. both a and c.

---

7. The arming capability is used to measure:
   a. the width of a burst of pulses.
   b. the time between pulses in a nonrepetitive pulse train.
   c. all time A-to-B measurements.
   d. both a and b.

@ 4/80

DIGITAL DELAY

ANALOG VERSUS DIGITAL DELAY

For a long delay time, the analog ramp pickoff method of generating the delay is not recommended since analog jitter is then introduced. Also, the nonlinearity of the ramp used may cause inaccuracies. Therefore, one type of digital delay (either delay-by-time or delay-by-events) should be used to generate the long delays. For very short delays, however, the analog delay method may be superior.

DELAY-BY-TIME MODE

In the delay-by-time mode, the delay time between the input signal and the trigger is front-panel selectable. As shown in Figure 1-10, a transition of the input signal applied to the Delay Interval stage causes its output to go high. When the delay interval signal is high, clock pulses are passed through the Main Gate to the Preset Counter. The Preset Counter then counts down until, when zero is reached, a pulse is sent to reset the Delay Interval signal. The Preset Counter pulse is also sent to the Trigger Generator where the delayed trigger pulse is produced.

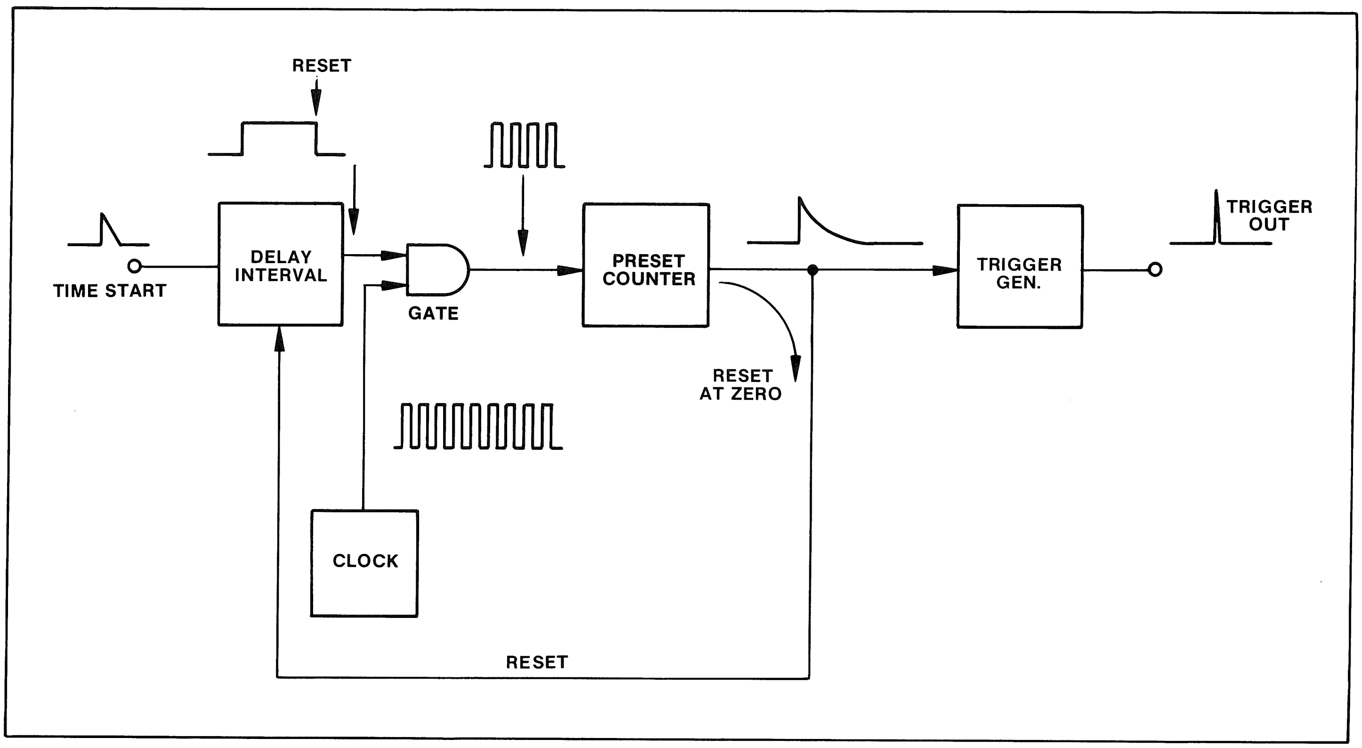


Figure 1-10. Basic diagram of delay-by-time circuits.

DELAY-BY-EVENTS MODE

In the delay-by-events mode, the number of events occurring between the input signal and the trigger is front-panel selectable. Input jitter is not a problem in this mode because the delay interval signal is synchronous with the jitter. The input signal (see Fig. 1-11) is first shaped and then applied to the Main Gate. When the signal applied to the Events Start input has a transition, the delay interval signal goes high, starting the counting process of the Preset Counter. The remaining circuitry operates as described for the delay-by-time mode, except that the trigger pulse occurs after a preselected number of events. The trigger pulse is only referenced to time if the external events are also.

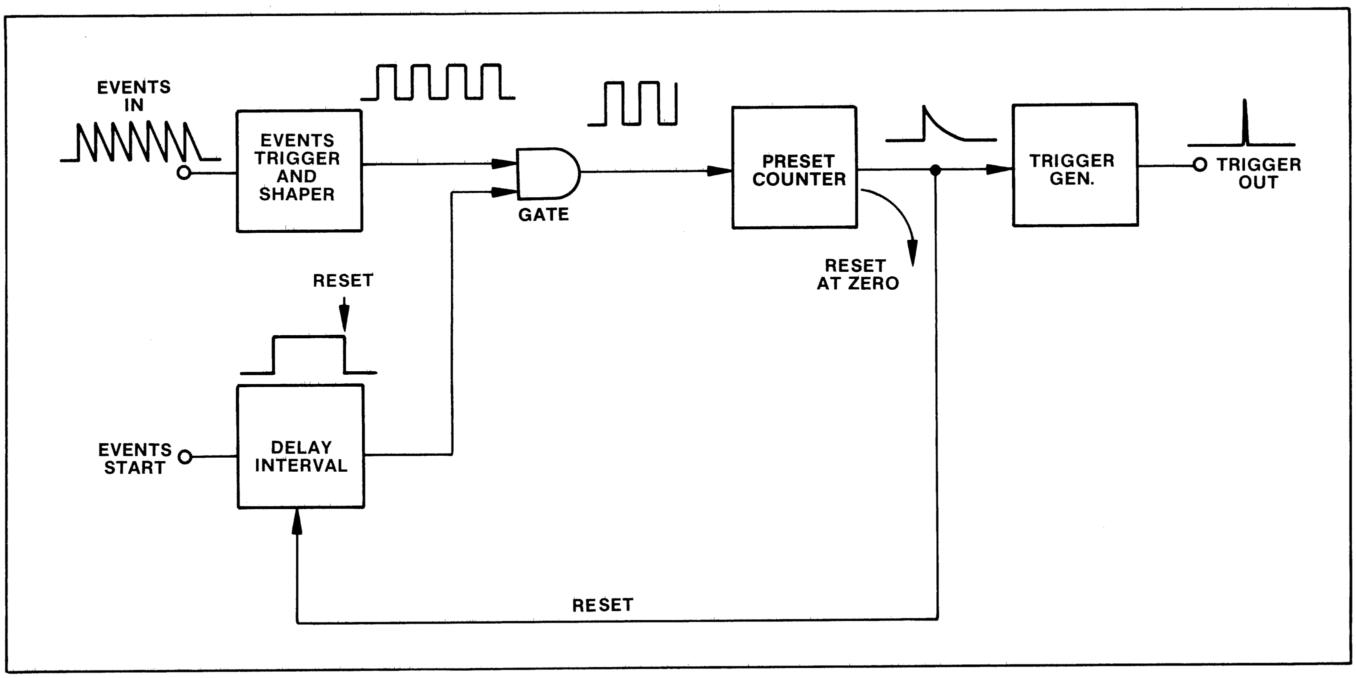


Figure 1-11. Basic diagram of delay-by-events circuits.

DIGITAL DELAY QUIZ

Perform the following self test by responding to the questions. Then check your responses against the answer key which precedes the glossary at the back of this book.

---

1. One advantage of digital delay over analog delay is:
   a. decrease jitter for short delays.
   b. increase jitter for long delays.
   c. decrease jitter for long delays.
   d. both a and c.

---

2. The digital delay method increases counter accuracy because:
   a. the ramp used is more linear.
   b. the ramp used is longer.
   c. the ramp is not used.
   d. both a and b.

---

3. The delay-by-time mode will:
   a. delay the input signal by a preselected amount of time.
   b. produce a trigger signal a preselected amount of time after the input signal.
   c. produce a trigger signal after a preselected number of events.
   d. both a and b.

4. The delayed trigger signal in the delay-by-events mode is:
   a. produced after a preselected number of events.
   b. produced after each input event.
   c. used to reset the delay interval.
   d. all of the above.

---

5. Jitter is not a problem in the delay-by-events mode because:
   a. the delayed trigger signal moves with the jitter on the input signal.
   b. an events signal does not have any jitter riding on it.
   c. the delay interval moves along with any jitter riding on the input signal.
   d. the events trigger is used to cancel the noise.

RESOLUTION AND ACCURACY

DISPLAY RESOLUTION

Usually, display resolution of a digital counter is stated as being equal to one count of the least significant digit. In frequency measurements, resolution refers to the least significant digit of readout. For all frequency modes but prescale, resolution is the reciprocal of the gate control signal. In time measurements, resolution is one count of the selected clock pulse.

RESOLUTION MULTIPLIER

For a count resolution better than 0.1 Hz, use a counter with a resolution multiplier. This type of counter has an additional internal oscillator which is phase-lock looped to the input signal. Therefore, if a X100 resolution multiplier is used with an input signal of 1 kHz, the resolution oscillator will be operating at 100 kHz. The counter will now count "1000000" in the same time "1000" would have been counted without the resolution multiplier. This has effectively increased the resolution of this counter 100 times.

COUNTER ACCURACY

Measurement accuracy for all modes, except time-interval averaging, is equal to the accuracy of the Clock plus the count ambiguity. Long-term accuracy should not be a problem with regular instrument calibration. Clock accuracy may be expressed in any of the following ways: "0.5×10^{-6}", "$0.5/10^{+6}$", "0.00005%", or "0.5 PPM".

When the input signal and the clock pulses are not synchronized, ± 1 count ambiguity may occur. This is, simply, when the counter displays one count more or less than the actual total count made. Count ambiguity may be expressed as:

$$\text{Count Ambiguity} = \frac{\text{displayed frequency}}{\text{total count}}$$

The total count is the number of counts made without reference to the decimal point. For example, if the readout displays "59.99998", the total count is "5999998".

Total accuracy of a counter is determined by combining all errors:

$$\text{Total Accuracy} = \text{count ambiguity} \pm (\text{clock accuracy} \times \text{the measurement})$$

For period averaging measurements, accuracy is calculated by dividing the total accuracy of the counter by the number of averages.

SIGNAL NOISE AND ACCURACY

Noise on the input signal may be counted as signal transitions by the counter, resulting in an incorrect count. This problem may be corrected in one of three ways: (1) The trigger slope or level can be adjusted to trigger the counter on a noise-free portion of the signal as shown in Figure 1-12. (2) The input signal can be externally conditioned to attenuate the noise (e.g., with filters or with an oscilloscope vertical preamplifier with bandwidth limiting). Refer to Figure 1-13. (3) The trigger sensitivity control can be used to attenuate both the input signal and the associated noise so that only the signal will pass through the hysteresis window. See Figure 1-14.

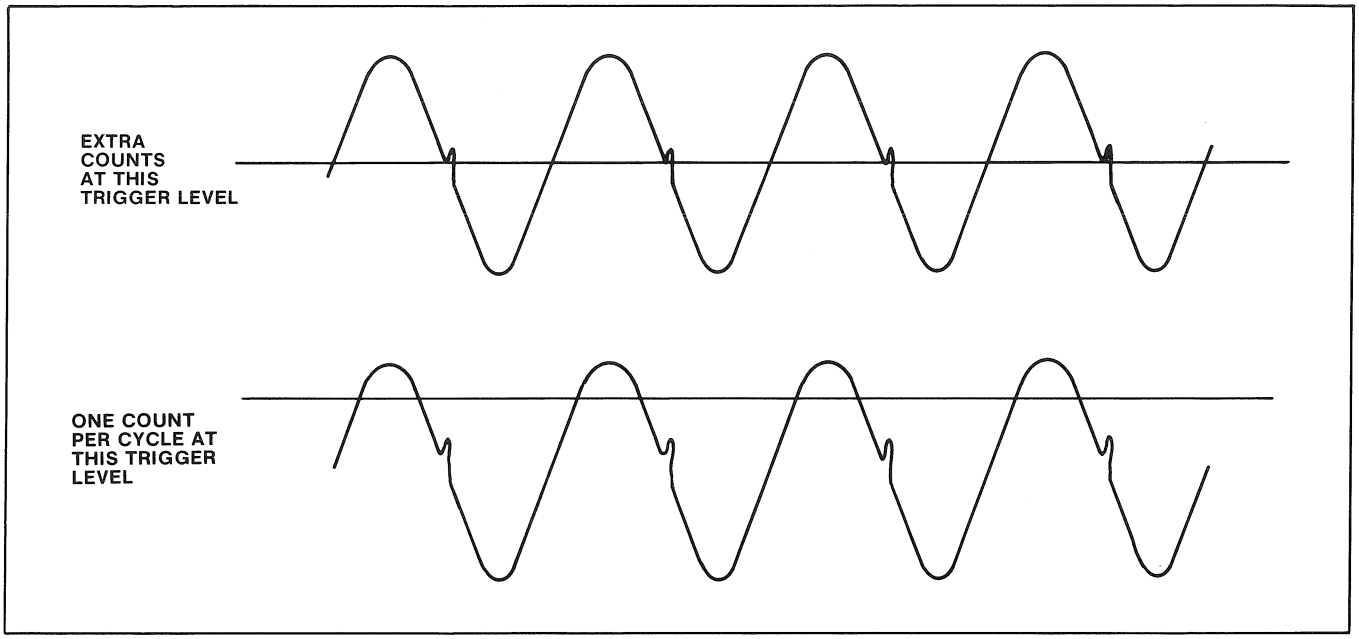


Figure 1-12. Example of noise reduction achieved by adjusting the trigger level.

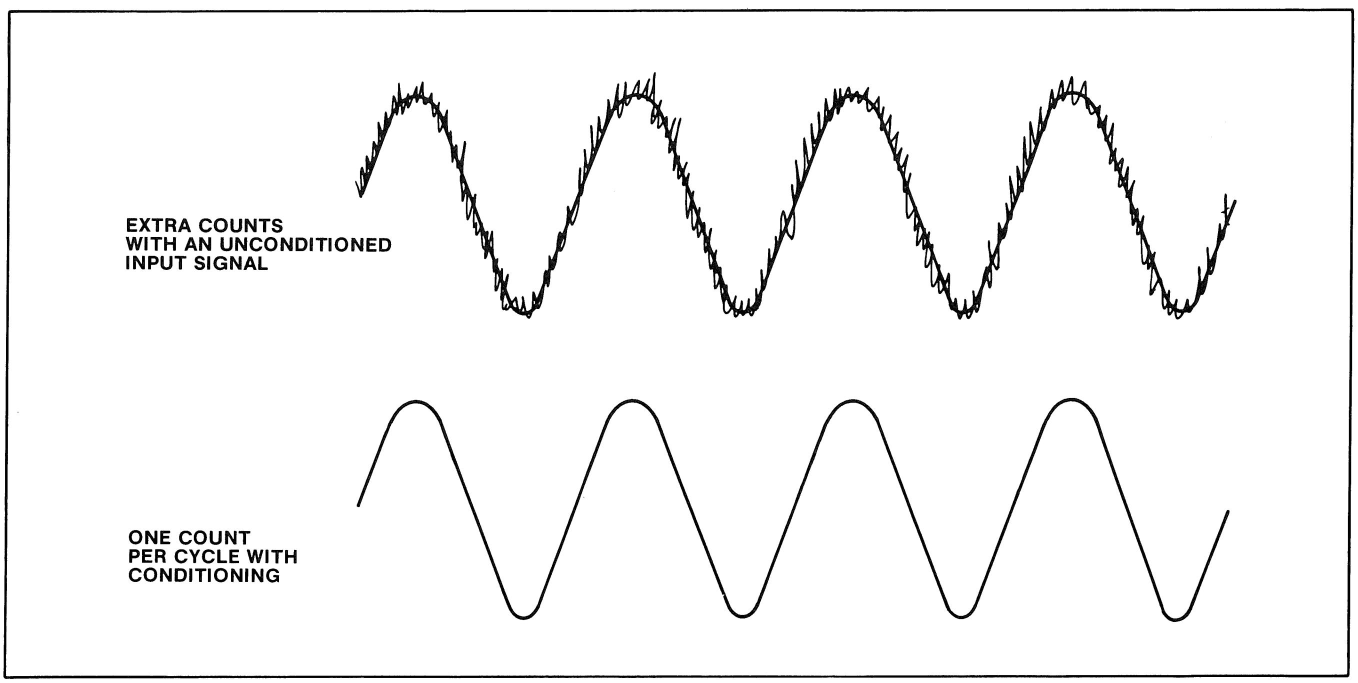


Figure 1-13. Example of noise reduction by conditioning the input signal.

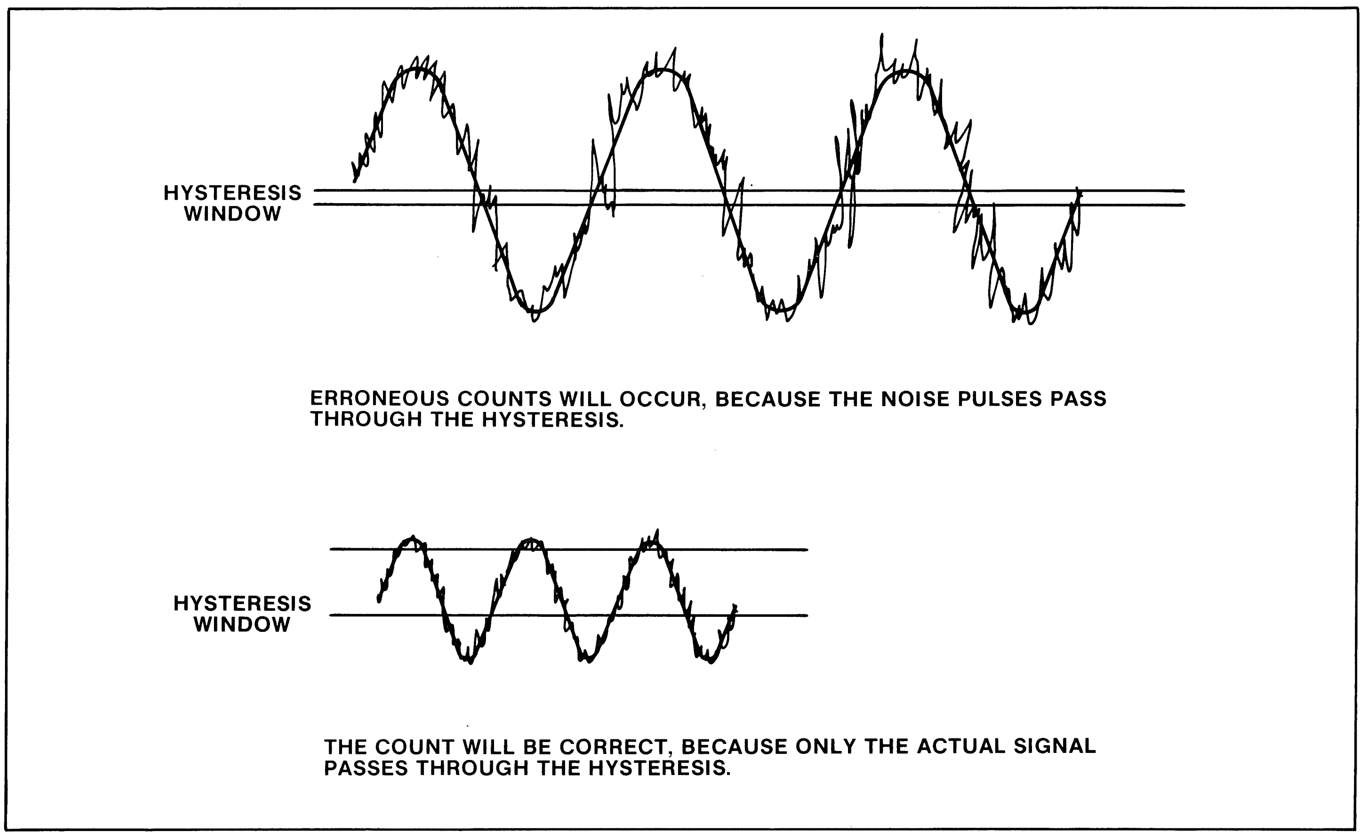


Figure 1-14. Example of noise reduction through signal attenuation.

RESOLUTION AND ACCURACY QUIZ

Perform the following self test by responding to the questions. Then check your responses against the answer key which precedes the glossary at the back of this book.

---

1. In frequency measurements the term resolution refers to:
   a. the most significant digit.
   b. the least significant digit.
   c. all of the digits.
   d. none of the digits.

---

2. In frequency measurements the resolution is the reciprocal of the:
   a. shaped input signal.
   b. encoded signal.
   c. clock frequency.
   d. gate control signal.

---

3. If the gate control signal is 10 milliseconds wide, the resolution of the counter is:
   a. 0.1 Hz.
   b. 1 Hz.
   c. 10 Hz.
   d. 100 Hz.

---

4. Resolution equals:
   a. one count of the least significant digit.
   b. ten counts of the least significant digit.
   c. one count of the most significant digit.
   d. ten counts of the most significant digit.

---

5. When a resolution better than 0.1 Hz is required:
   a. use a prescale counter.
   b. use averaging modes.
   c. use a resolution multiplier.
   d. increase the input frequency.

6. Measurement accuracy of a digital counter (except in the time-interval averaging mode) is equal to:
   a. clock accuracy.
   b. ± 1 count ambiguity.
   c. the reciprocal of the gate control signal.
   d. the clock accuracy and the count ambiguity combined.

---

7. Count ambiguity is caused by:
   a. the instability of the readout devices.
   b. noise.
   c. instability of the gate control signal.
   d. the input signal not synchronized with the clock signal.

---

8. If the display reads "588.99998", the total count is:
   a. 58899998
   b. .58899998
   c. 588.99998
   d. none of the above.

---

9. Noise riding on the input signal can be eliminated by:
   a. adjusting the trigger slope and level of the counter.
   b. externally conditioning the signal to reduce the noise.
   c. using the trigger sensitivity to attenuate both the input signal and the noise.
   d. all of the above.

CHAPTER 2
DIGITAL METERS

The heart of a digital multimeter is a dc voltmeter which converts a dc voltage to a decimal number display. Five basic techniques are available for the analog-to-digital conversion:

1. Single-ramp conversion.
2. Voltage-to-frequency integration.
3. Modified dual-slope integration.
4. Null balance.
5. Successive approximation.

The type of conversion used determines the meter's accuracy, noise immunity, and measurement speed. Measurements other than dc voltage may be made by adding circuitry prior to the dc voltage.

DIGITAL METER CONCEPTS
VIDEOTAPE QUIZ

View the videotape entitled *Digital Meter Concepts.* Answer the questions below and check your responses against the answer key which precedes the Glossary at the back of this book.

---

1. The heart of a digital multimeter is:
   a. a dc voltmeter.
   b. an ac voltmeter.
   c. a front-end converter.
   d. none of the above.

2. The AC-to-DC Converter added before the dc voltmeter stage of an average-responding ac voltmeter consists of a:
   a. diode.
   b. capacitor.
   c. diode in parallel with the input.
   d. both a and b.

3. A digital ac voltmeter responds to the average level of the input voltage and is calibrated to display:
   a. the average value of the input voltage.
   b. the peak-to-peak value of the input voltage.
   c. the RMS value (for sine waves only).
   d. both a and c.

   ____

4. A true RMS voltmeter is capable of measuring the RMS value of:
   a. square and sine waves.
   b. sine waves only.
   c. all waveshapes.
   d. high-frequency signals only.

   ____

5. The Ohms Converter added prior to the dc-voltmeter stage for resistance measurements contains a:
   a. constant voltage source.
   b. series of precision resistors.
   c. constant current source.
   d. 0.1 ohm resistor.

6. The Current-to-Voltage Converter used for making current measurements contains a:
   a. constant voltage source.
   b. constant current source.
   c. 0.1 ohm resistor.
   d. both b and c.

   ____

7. A _____ may be used as a temperature probe.
   a. platinum resistor
   b. NPN transistor
   c. 0.1 ohm resistor
   d. both a and b

   ____

8. A half digit of readout may display:
   a. the numeral 1.
   b. a zero.
   c. nothing.
   d. all of the above.

   ____

9. Count ambiguity equals:
   a. ± one count of the least significant digit.
   b. ± one count of the most significant digit.
   c. one count.
   d. none of the above.

DC VOLTAGE MEASUREMENTS

Most digital voltmeters today use the modified dual-slope integration method of conversion, which is simply an extension of the single-ramp conversion method discussed here. Figure 2-1 shows the basic block diagram of a single-ramp digital voltmeter.

The dc input voltage applied to the Comparator is compared with the ramp from the Ramp Generator. When the ramp reaches the level of the input voltage, the Comparator produces an output pulse.

When the ramp is sent to the Comparator, the Ramp Generator also sends a pulse to start the Clock. The Clock Generator then produces clock pulses until the output pulse from the Comparator stops the Clock Generator. The clock pulses are now counted and converted to a decimal equivalent which is displayed on the readout devices.

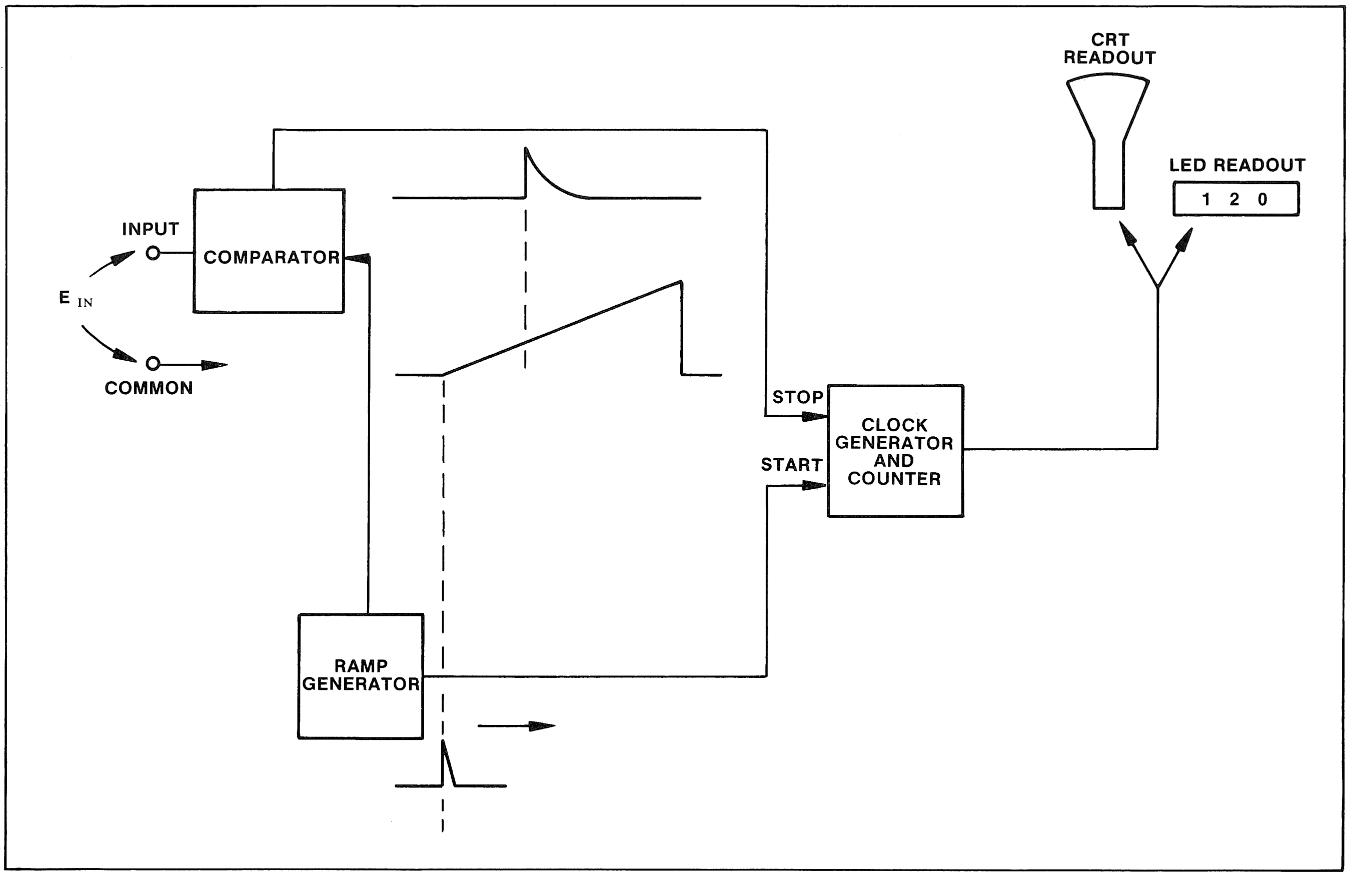


Figure 2-1. Single-ramp digital voltmeter.

Readout devices may include light-emitting diodes, liquid crystal displays, or a crt display. The readout of a digital meter may consist of from 3½ to 7 or more digits. A 4½-digit display means that four digits are capable of displaying the numerals "0" through "9"; the ½ indicates that the most significant digit is only capable of displaying the numerals "0" or "1." In most readouts with ½ digit capability, only the "1" will be displayed; the "0" will be blanked.

As in digital counters, resolution of a digital multimeter is equal to one count of the readout's least significant digit. However, because digital meters usually have fewer readout digits than counters, the value of the meter's least significant digit is greater. For example, if the readout displays "1.5462 V" the resolution is 0.0001 volt; however, if the readout displays "1.34 V", the resolution is only 0.01 volt. Therefore, as the number of digits in the readout decreases, so does resolution.

The decreased number of readout digits also results in a greater effect of count ambiguity on the measurement accuracy of the digital meter. Accuracy for a digital dc voltmeter is expressed as:

Accuracy = ±0.1% X displayed readout
+ count ambiguity

(The ±0.1% in the above formula is the manufacturer's specification for the short-term stability of the meter's clock and may vary between meters.)

To calculate the accuracy of a displayed readout of "1.765 V" on a digital dc voltmeter using the above formula:

Accuracy = ± (0.1% X 1.765 V) + 1 count
= ± (0.001765 V) + 1 count
= ± (0.001765 V) + 0.001 V
= ± 0.002765 V

DC VOLTAGE MEASUREMENTS QUIZ

Perform the following self test by responding to the questions. Then check your responses against the answer key which precedes the glossary at the back of this book.

---

1. The heart of a digital multimeter is:
   a. the Clock Generator.
   b. the readout.
   c. the DC Voltmeter.
   d. the Comparator.

---

2. The basic function of a dc voltmeter is to:
   a. change a dc voltage to an ac voltage.
   b. measure ohms.
   c. rectify an ac voltage.
   d. convert a dc voltage to a decimal display.

---

3. The Comparator compares:
   a. the input voltage to the Comparator output.
   b. the input voltage with a ramp.
   c. two dc voltages on one input signal with each other.
   d. one dc voltage input to another dc voltage input.

---

4. The Ramp Generator produces:
   a. a pulse to turn on the Clock Generator.
   b. a pulse to turn off the Clock Generator.
   c. a ramp which is sent to the Comparator.
   d. both a and c.

---

5. The output from the Comparator:
   a. turns on the Clock Generator.
   b. turns off the Clock Generator.
   c. moves the decimal point in the readout.
   d. both b and c.

---

6. The term "½ digit" means that:
   a. the least significant readout digit can be a 1 or a 0.
   b. the most significant readout digit can display numbers from 0 to 5.
   c. the most significant readout digit can display numbers from 5 to 9.
   d. the most significant readout digit can be a 1, 0, or blank.

---

7. If the number of digits in the readout is decreased, the resolution is:
   a. increased.
   b. decreased.
   c. the same.
   d. unknown.

---

8. Count ambiguity is _____ of a factor on the accuracy of a digital meter than for a digital counter because the number of readout digits is typically _____
   a. more — increased.
   b. less — decreased.
   c. more — decreased.
   d. less — increased.

---

9. The accuracy of a meter reading "2.60 V" with a specified accuracy of "0.1% of the reading ± 1 count" is:
   a. 0.126 volts.
   b. 0.0126 volts.
   c. 0.16 volts.
   d. 0.26 volts.

AC VOLTAGE MEASUREMENTS

A digital ac voltmeter is essentially just a digital dc voltmeter with additional circuitry to convert the ac input voltage to a dc voltage. Figure 2-2 diagrams a basic ac voltmeter.

The ac input voltage is converted to a dc voltage by the rectifier and filter within the AC-to-DC Converter stage. The rectified and filtered input voltage is then a dc voltage which can be measured by the internal dc voltmeter. The readout display represents the effective value, or RMS value, of the applied sine wave.

RMS (root-mean-square) is the effective value of a varying voltage (i.e., the value which would produce the same power loss if a continuous voltage were applied to a pure resistance). For sine waves, the RMS voltage equals 0.707 times the peak voltage. For waveforms other than sine waves, RMS must be measured with a "true RMS meter".

A true RMS meter will measure the RMS voltage of any waveform because of the True RMS Converter added to the ac voltmeter. The True RMS Converters are usually one of the following basic types:

1. Thermocouples.
2. Thermopiles.
3. Squaring circuits.

Limitations associated with true RMS meters include the Crest Factor and the Form Factor. Crest Factor is the ratio of peak voltage to the RMS value (with the dc component removed) and is a specification of the True RMS Converter. If the Crest Factor of the input signal exceeds the amount specified for the meter, an erroneous reading will occur. Form Factor, like Crest Factor, will result in an erroneous reading if the specification is exceeded. Form Factor is a measure of ac to dc within the signal, and is expressed as the RMS value divided by the average value.

Gain or loss through an electronic system is expressed in decibels (dB). A dB equals one-tenth of a bel, or one-tenth of a power of ten. Therefore 50 dB equals 5 bels or 10^5. So if an amplifier has a gain of 50 dB, the output power is 10^5 times greater than the input power.

When decibels are referenced to one milliwatt, the power ratio term of "dBm" is used. To calculate the dBm of a system:

$$\text{dBm} = 10\text{LOG}\ \frac{\text{Input Power}}{\text{1 milliwatt}}$$

To determine the decibels/volt (dBV) use the following:

$$\text{dBV} = 20\text{LOG}\ \frac{\text{Input Voltage}}{\text{1 volt}}$$

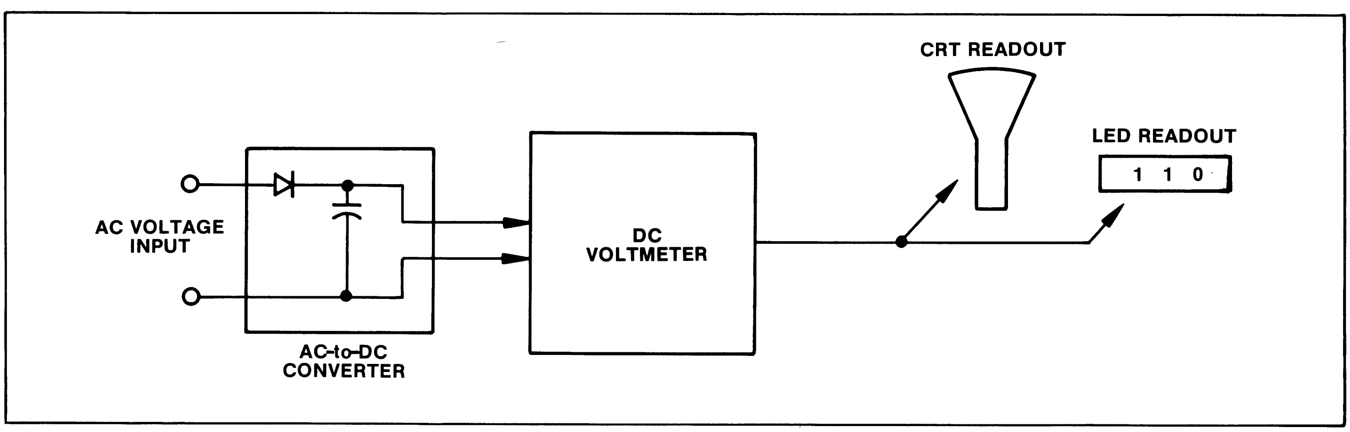


Figure 2-2. Digital ac voltmeter.

AC VOLTAGE MEASUREMENTS QUIZ

Perform the following self test by responding to the questions. Then check your responses against the answer key which precedes the glossary at the back of this book.

1. To measure ac voltages, the input signal is first _____ then measured by the dc voltmeter.
   a. rectified,
   b. filtered,
   c. digitized,
   d. both a and b.

2. The RMS voltage of a sine wave is equal to:
   a. 2 times the peak value.
   b. the square root of 0.707.
   c. 0.707 times the peak voltage.
   d. both a and c.

3. True RMS is the RMS value of a:
   a. sine wave only.
   b. square wave only.
   c. ramp only.
   d. any waveshape.

4. Crest Factor is the ratio of:
   a. peak voltage to the RMS value.
   b. peak-to-peak voltage to the RMS value.
   c. duty factor to the Form Factor.
   d. peak voltage to peak-to-peak voltage.

5. Form Factor is the ratio of:
   a. Crest Factor to the RMS value.
   b. input power to output power.
   c. ac to dc present on the input signal.
   d. both a and b.

6. 30 dB is equal to:
   a. 10^{-3}.
   b. 10^{3}.
   c. 100.
   d. 10,000.

7. A dBm is a power expression referring to one:
   a. millivolt.
   b. watt.
   c. volt.
   d. milliwatt.

8. A dBV is a power expression referring to one:
   a. millivolt.
   b. watt.
   c. volt.
   d. millwatt.

OTHER METER MEASUREMENTS

CURRENT MEASUREMENTS

To measure current, a Current-to-Voltage Converter is added between the input and the internal dc voltmeter. This Current-to-Voltage Converter usually consists of a 0.1-ohm precision resistor placed in series with the input current. If the input is a direct current (dc), the dc voltage drop produced across the precision resistor is then measured by the internal dc voltmeter and displayed on the readout in units of amperes. (Refer to Figure 2-3 for a block diagram of a DC Current meter.)

When the input is an alternating current (ac), the ac voltage produced across the precision resistor must be converted to dc before the internal dc voltmeter can measure it. Therefore, for ac current measurements an AC-to-DC Converter is added to the meter following the Current-to-Voltage Converter. (See Fig. 2-4.) The dc voltage can then be measured and the value of the ac input current displayed.

The impedance of the circuit under test must be considered when making current measurements. Usually this impedance is sufficiently large to not be affected by the addition of 0.1 ohm. However, if the circuit under test has very low impedance, then the additional resistance from the meter will cause enough of a current reduction to result in inaccurate readings.

RESISTANCE MEASUREMENTS

By adding an Ohms Converter before the internal dc voltmeter, the digital multimeter can now measure the resistance. The Ohms Converter (see Fig. 2-5) is a constant current source which supplies a known current through the device under test. The voltage drop created across the unknown resistance is now measured by the internal dc voltmeter. The readout then displays the resistance value in units of ohms.

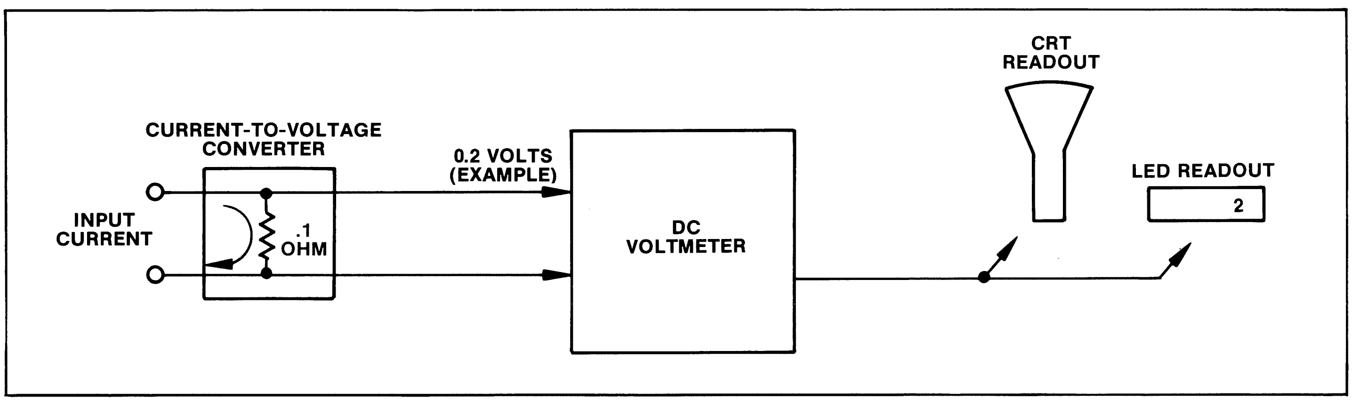


Figure 2-3. DC current meter.

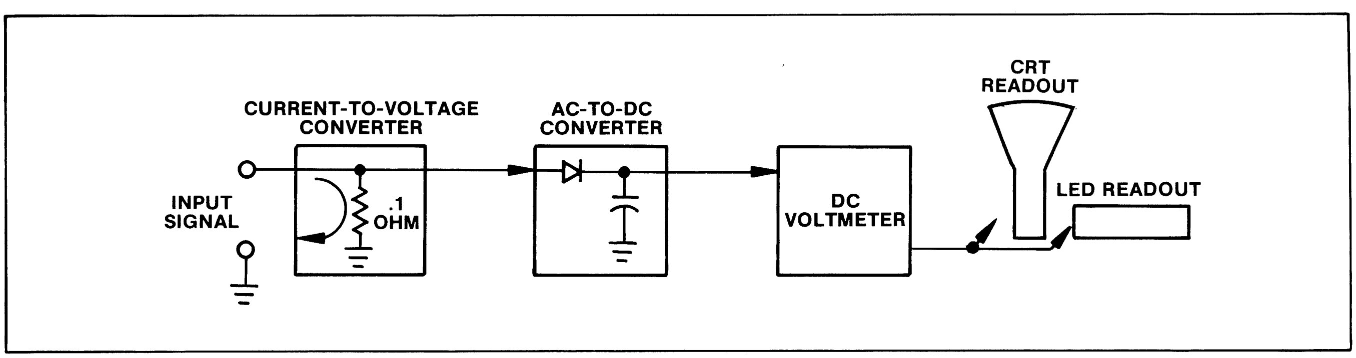


Figure 2-4. AC current meter.

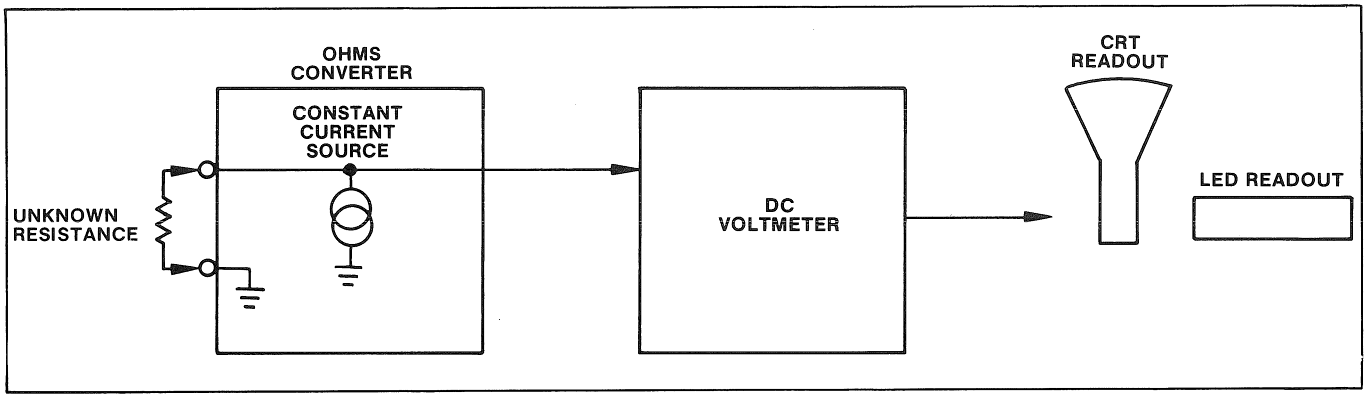


Figure 2-5. Resistance meter.

TEMPERATURE MEASUREMENTS

Temperature measurements are made by converting the input temperature to an equivalent dc voltage. Two methods of conversion are available: (1) Using an NPN Transistor Probe with a Temperature Converter as shown in Figure 2-6, or (2) using a Platinum Resistor Probe with an Ohms Converter as shown in Figure 2-7.

The first method operates on the principle that a change in temperature at the base-emitter junction of a bipolar transistor produces a corresponding change in the junction voltage. The resulting change in base-emitter voltage is then applied to the Temperature Converter where the voltage is properly scaled to be read in degrees by the internal dc voltmeter. Most temperature meters will read either in degrees Fahrenheit or degrees Celsius, as front-panel selected.

The second method of measuring temperature operates on the principle that as the temperature changes, so will the resistance of the platinum resistor. The resistance of the platinum resistor is then changed to a dc voltage by the Ohms Converter. Again, this voltage is measured by the dc voltmeter and displayed on the readout to indicate degrees.

SAMPLE-AND-HOLD

"Sample-and-Hold" refers to the way some digital meters can sample a particular point of the input signal and hold that voltage long enough to measure it. These voltage readings are made with reference to ground. Some sample-and-hold meters can measure the voltage between two particular points of the input signal, providing a useful difference reading of the two selected points.

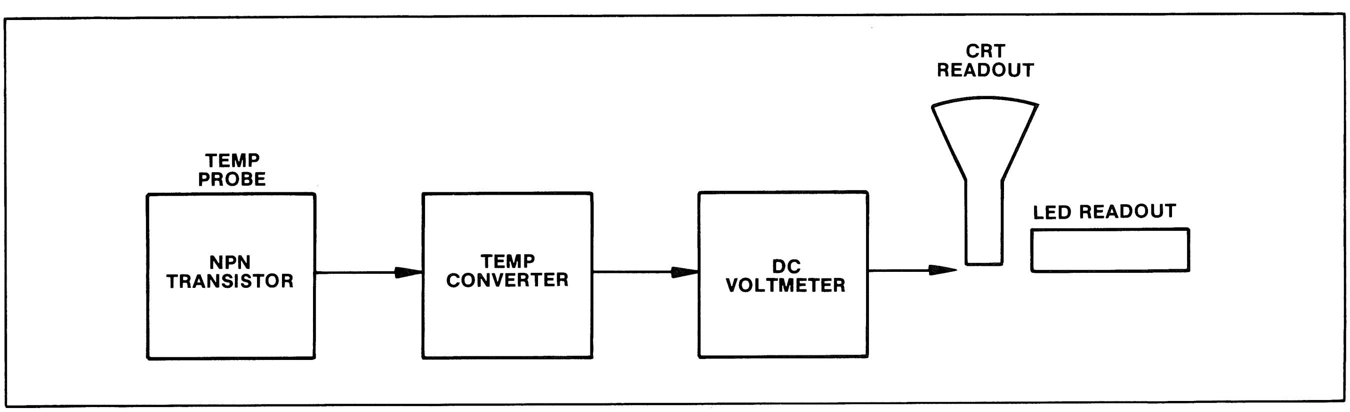


Figure 2-6. Temperature meter with an NPN transistor probe.

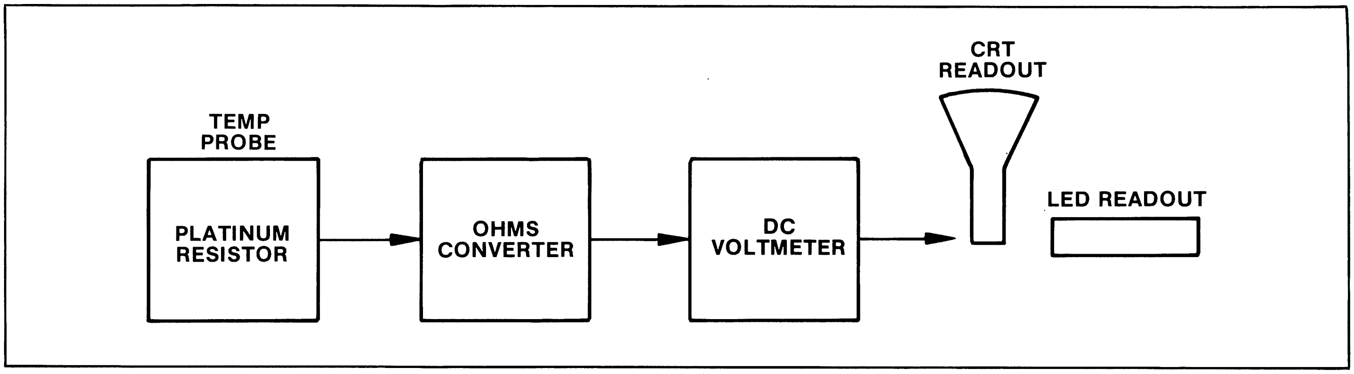


Figure 2-7. Temperature meter with a platinum resistor probe.

OTHER METER MEASUREMENTS QUIZ

Perform the following self test by responding to the questions. Then check your responses against the answer key which precedes the glossary at the back of this book.

1. The Current-to-Voltage Converter of a dc current meter consists of a:
   a. constant current source.
   b. precision resistor.
   c. platinum resistor.
   d. both a and b.

2. To measure alternating current, an ______ is added to the stages of a dc current meter.
   a. AC-to-DC Current Converter.
   b. AC Current-to-DC Voltage Converter.
   c. AC Voltage-to-DC Voltage Converter.
   d. AC Voltage-to-DC Current Converter.

3. Loading the circuit under test is a problem in a current measurement when the:
   a. source impedance is very high.
   b. source voltage is low.
   c. source impedance is very low.
   d. both b and c.

4. An Ohms Converter consists of a:
   a. constant current source.
   b. precision resistor.
   c. voltage source.
   d. rectifier.

5. A temperature meter probe:
   a. produces a resistance change proportional to temperature.
   b. converts degrees Fahrenheit to degrees Celsius.
   c. produces a voltage change proportional to temperature.
   d. both a and c.

6. A sample-and-hold meter is useful when measuring the:
   a. voltage between two points on a waveform.
   b. current at a specific point on a waveform.
   c. voltage at a specific point on a waveform.
   d. both a and c.

ANSWER KEY

FOR DIGITAL COUNTER CONCEPTS VIDEOTAPE QUIZ

1. (b) The Main Gate is the heart of the counter because it passes either the shaped input signal or a clock pulse, depending upon the selected operating mode.

2. (c) When the maximum counting capacity of the internal count storage devices are exceeded, an overflow condition occurs.

3. (a) The right-most digit of the readout is the "least significant digit". One count of the least significant digit will determine the readout resolution for the counter.

4. (b) In the totalize mode the count is made without reference to any internal or external clock. Only the total number of events are counted.

5. (a) The reference time for frequency measurements is one second. This reference, derived from the Clock circuit, is the time in which counting actually occurs.

6. (c) By reversing the connections to the Main Gate the signal will equal the period of the input signal.

7. (d) The counter requires two input signals to make a frequency ratio. Therefore, the counter also needs two Amplifier and Shaper stages to properly condition both signals.

8. (d) Both width and time A-to-B measurements are "time interval measurements" since they both measure the time between two specific points on a waveform.

9. (a) The pulse width should always be measured between two identical points on the waveform.

FOR TOTALIZE MODE QUIZ

1. (a) The transition polarity is front-panel selectable and is actually accomplished in the Shaper stage.

2. (d) Basically, the Shaper conditions the input signal so that it may pass through the Main Gate and be counted. Because input signals will vary, the Amplifier may be either an attenuator or an amplifier depending upon the applied signal.

3. (d) A high level must be applied to the bottom Main Gate input in order for the Main Gate to pass signals. This high can be applied from within the counter (the manual gate), or from an outside source (the external gate).

4. (d) The shaped input signal is connected to the upper input of the Main Gate. When the lower input goes high, the Main Gate will pass the shaped input signal for counting.

5. (d) The Counter/Storage stage first stores, then counts, the transitions from the Main Gate. This function is not mode dependent.

6. (c) The Encoder is a digital-to-analog converter which converts the digital count into an analog signal voltage which can drive the readout device(s).

7. (d) Since the counter responds to specific preselected transitions in the totalized mode, all answers are correct. The resultant count can be with reference to the total number of pulses or cycles, both of which are events.

8. (b) The size of the count-storing devices in the Counter/Storage stage is limited. Therefore, when a count larger than this limit occurs, the capacity of the counter is exceeded and an overflow occurs. The overflow is usually indicated with the readout.

FOR FREQUENCY MEASUREMENTS QUIZ

1. (c) Since frequency is the number of times a periodic phenomenon recurs in a specific unit of time, the count is made with reference to an accurate time source.

2. (a) The Clock contains a crystal-controlled oscillator, which is a very precise time reference.

3. (b) The time the Main Gate is held open must be adjustable in order to measure a variety of signals with optimum resolution.

4. (b) Two separate input signals are applied to the counter at the same time. The readout displays the ratio between these two signal frequencies.

5. (c) The ratio of 100 MHz to 500 kHz is 200.

6. (d) In a ratio, the value given is not related to any unit of measure.

7. (a) A prescale counter contains a divider which reduces the high-frequency signals to a frequency which can be handled by the counter.

8. (d) In a prescale counter, the gate control signal must be increased so that a very high count can be made; therefore, the elapsed time for making the measurement is significantly increased.

9. (b) In the frequency mode, the gate time is such that the count is referenced to one second; therefore, when this is increased by a factor of six, the count is now referenced to one minute.

FOR TIME MEASUREMENTS QUIZ

1. (c) In the period mode, the Main Gate is held open by the shaped input signal while the clock pulses are passed and counted. The total number of clock pulses are then converted into a value which equals the period of the input signal.

2. (a) The clock pulses passed through the Main Gate are converted to a value equal to the period of the input signal.

3. (c) Noise on the signal to be measured can cause an erroneous count. By averaging the input signal, the effects of noise are nullified.

4. (d) The terms "opposite slope" and "opposite polarities" are synonymous and are both correct answers. They both refer to the same portion of a waveform.

5. (d) The way in which the time A-to-B mode is used, either to measure between two points on the same waveform or between two points on separate waveforms, depends upon the manner in which the input signals are applied to the counter.

6. (d)The Main Gate will open and close once for every time an average is made in the time-interval averaging mode.

7. (d) By arming the counter, certain pulses which would normally be triggered on are ignored. The counter now triggers on pulses only when "armed" to do so. This allows the counter to count the time between pulses in a nonrepetitive pulse train, or the width of a burst of pulses.

FOR DIGITAL DELAY QUIZ

1. (c) In an analog delay method, the delay is accomplished by the use of a ramp which has a certain amount of nonlinearity. For long delays this nonlinearity will introduce jitter. The digital delay method does not use a ramp; therefore, jitter is not a problem.

2. (c) The nonlinearity of the ramp used for analog delays is a major contributor to the inaccuracy of an analog counter.

3. (b) The trigger pulse produced in the delay-by-time mode occurs a preselected amount of time following the input signal.

4. (a) The trigger pulse produced in the delay-by-events mode occurs after a certain number of preselected events.

5. (c) The delay interval signal moves in conjunction with the jitter on the input signal effectively canceling the jitter.

FOR RESOLUTION AND ACCURACY QUIZ

1. (b) Resolution is the least significant digit, also the right-most digit of the readout.

2. (d) The gate control signal, also referred to as the measurement interval, is front-panel selectable by the operator. The reciprocal of the gate control signal equals the resolution for frequency measurements (except prescale).

3. (d) 100 Hz is the reciprocal of the gate control signal.

4. (a) Resolution is equal to one count of the smallest unit the counter can measure, or one count of the least significant digit.

5. (c) A resolution multiplier increases the resolution of a counter past 0.1 Hz without significantly increasing the time required to make a measurement.

6. (d) To determine measurement accuracy, the accuracy of the Clock must be combined with the count ambiguity.

7. (d) Count ambiguity is an error resulting from the input signal occurring either before or after the clock signal.

8. (a) The total count is the total number of counts made without reference to the decimal point position.

9. (d) The effects of noise are reduced by: (1) Conditioning the signal externally, (2) adjusting the trigger level and slope of the counter, and (3) adjusting the trigger sensitivity to reduce both the input signal and the noise.

FOR DIGITAL METER CONCEPTS VIDEOTAPE QUIZ

1. (a) All digital multimeter measurements are made with a dc voltmeter having differing types of front-end circuitry added to convert the input signal into a measurable dc voltage.

2. (d) An ac voltage is converted into a dc voltage by a rectifier consisting of a diode and a capacitor.

3. (c) For sine waves, the readout displays the square root of the average of the squares of the input signal. For any other waveshape the reading is inaccurate.

4. (c) A true RMS voltmeter contains additional circuitry to allow the input of any waveshape (within limits) for accurate RMS readings.

5. (c) The constant current source produces a voltage across the unknown resistance which is then converted into a resistance reading.

6. (c) A typical value for the precision resistor is 0.1 ohm. This precision resistor then develops a voltage from the applied current which can be measured by the internal dc voltmeter.

7. (d) Temperature probes may consist of either an NPN transistor or a platinum resistor. Both types of probe work well, however, the platinum resistor is more linear with respect to temperature changes.

8. (d) The half digit is in respect to the most significant digit of the meter readout. Depending upon the specific meter used, this digit will display a 1, 0, or be blank.

FOR DC VOLTAGE MEASUREMENTS QUIZ

1. (c) All digital multimeter measurements are made with a dc voltmeter with differing types of front-end circuitry to convert the specific input to a dc voltage.

2. (d) The decimal display represents the dc voltage applied to the input of the digital dc voltmeter.

3. (b) The input voltage is compared to a specific dc level of the ramp.

4. (d) The Ramp Generator produces a ramp for the Comparator and a pulse to start the Clock Generator.

5. (b) The Comparator's output is used to stop the counting process by turning off the Clock Generator.

6. (d) Depending upon the type of meter used, the most significant digit may be a 1, 0, or blank.

7. (b) Decreasing the number of readout digits will decrease the resolution by decreasing the number of digits to the right of the decimal.

8. (c) Digital meters typically have fewer readout digits; therefore, count ambiguity is a more significant factor in accuracy since the value of one count will be larger.

9. (b) "0.1% of reading" equals 0.0026 volt; "1 count" equals 0.01 volt; therefore the accuracy equals 0.0126 volt.

FOR AC VOLTAGE MEASUREMENTS QUIZ

1. (d) The ac input voltage must be converted into a dc voltage through rectifying and filtering so that the internal dc voltmeter can measure it. The readout of the digital ac voltmeter will then display a value equal to the ac input voltage.

2. (c) 0.707 is the square root of the average of the squares of a sine wave only.

3. (d) The true RMS meter can measure the RMS value of any waveshape due to the True RMS Converter inside the meter.

4. (a) Crest Factor is a ratio of peak (one half the peak-to-peak) voltage to the RMS value of the input signal (with the dc component removed).

5. (c) Form Factor is a ratio of the ac component to the dc component of the input signal and is a limitation in making true RMS measurements.

6. (b) 30 dB is equal to 10^3 or 1000.

7. (d) dBm is an expression of power referenced to one milliwatt.

8. (c) dBV is an expression of voltage referenced to one volt.

FOR OTHER METER MEASUREMENTS QUIZ

1. (b) The precision resistor produces a voltage when current is passed through it. This voltage is then measured by the internal dc voltmeter. The displayed readout will reflect the input current.

2. (c) The ac current through the precision resistor produces an ac voltage which must be converted to a dc voltage before the internal dc voltmeter can measure it.

3. (c) Low source impedance can cause the measurement to be inaccurate due to the reduction in current caused by the probe.

4. (a) The constant current source supplies current for the unknown resistance which, in turn, creates a voltage which can then be measured.

5. (d) A resistance change proportional to temperature is produced by the Platinum Resistor Probe, and a voltage change proportional to temperature is produced by the NPN Transistor Probe.

6. (d) The voltage between any two points (dc levels) or any one point and ground can be measured with the sample-and-hold meter.

APPENDIX A—GLOSSARY

arming
A mode to block or pass signals through a channel in a counter; usually used when making complex time measurements.

average voltage
The sum of instantaneous voltages in a half-cycle waveshape divided by the number of instantaneous voltages in a sine wave. The average voltage is equal to 0.637 X peak voltage.

clock pulse
A signal used for system synchronization or timing.

± 1 count ambiguity
The error in the value of a counter or meter's least significant digit used to calculate overall measurement accuracy.

crest factor
The ratio of peak voltage to RMS voltage, with the dc component removed. Crest factor affects the True RMS measurements.

dB
Abbreviation for decibel. A standard unit for expressing transmission gain or loss and relative power levels. 1 dB equals one-tenth of a bel.

dBm
A power unit used when one milliwatt is the reference level.

dBV
A power unit used when one volt is the reference level.

duty factor
The ratio of time a waveform is high (on) to the time a waveform is low (off).

encoder
A device which converts digital information into analog information.

events
A voltage transition which triggers a count.

fall time
Time during which a pulse is decreasing from 90% to 10% of maximum amplitude.

filter
A selective network of resistors or capacitors offering little opposition to certain frequencies while blocking or attenuating other frequencies.

form factor
A ratio of how much ac voltage is present compared to the dc voltage present.

frequency
Recurrences of a periodic phenomenon in a unit of time, expressed in Hertz, when unit of time is one second.

hysterisis
The sensitivity of the trigger circuit of a digital counter or meter.

least significant digit
The digit with the lowest weighting in a number, usually the right-most digit.

LED
Abbreviation for Light-Emitting Diode. Usually a PN junction which emits light when forward biased.

liquid crystal
A liquid used for numerical displays which forms a crystalline structure when a voltage is applied.

overflow
A condition where the counting capabilities of a digital counter or meter are exceeded. In digital counters, overflow may be used to increase resolution.

peak-to-peak voltage
Voltage difference between the maximum positive and negative voltages of a waveform.

peak voltage
The maximum value present in a varying voltage signal. This value may be either positive or negative.

period
Time required for one complete cycle of a repetitive series of events.

power
A measure of the rate at which work is done; usually measured in watts or decibels.

rectifier
A device used to convert alternating current into direct current.

reset
Changing a digital system from one logic level to the other.

resolution
The smallest unit that can be measured, usually equal to one count of the least significant digit in digital counters and meters.

rise time
Time required for the leading edge of a pulse to rise from the 10% amplitude point to the 90% point.

RMS
Abbreviation for Root-Mean-Square which is the square root of the average of the squares of the values of a periodic quantity taken throughout one complete period of a sine wave.

shaper
A stage within certain digital counters and meters whose function is to condition a waveform to meet certain requirements.

TIM
Abbreviation for time-interval measurement taken between two points on a waveform which are not necessarily on the same slope and level.

Time A-to-B
Time measurement between point A and point B on the same or on a different waveform.

total count
The total number of counts needed to make a measurement.

totalize
A digital counter mode used to count the total number of events on a signal.

transition
The instance of changing from one state (such as a positive voltage) to a second stage (such as a negative voltage).

True RMS
The RMS value of *any* waveform.

width
The time from a rising slope to the next falling slope, or from a falling slope to the next rising slope on a waveform.

ASIA, AUSTRALIA, CENTRAL & SOUTH AMERICA, JAPAN

ARGENTINA
Coasin S.A.
Buenos Aires
Phone: 52-3185, 51-9363
Cordoba
Phone: 51-3037

AUSTRALIA
Tektronix Australia Pty. Limited
Sydney
Phone: 888-7066
Adelaide
Phone: 223-2811
Melbourne
Phone: 818-0594
Perth
Phone: 325-4198
Brisbane, Queensland
Phone: 394-1560
Canberra
Australian (Capital) Territories
Phone: 82-3587

BOLIVIA
Coasin Bolivia S.R.L.
La Paz
Phone: 40962

BRAZIL
Tektronix Industria e Comercio Ltda.
Sao Paulo
Phone: 813-3011
Rio de Janeiro
Phone: 266-5364, 286-6946

CHILE
Equipos Industriales S.A.C.I.
Santiago
Phone: 716-882, 382-942

CHINA, PEOPLES REPUBLIC OF
Tektronix Export Marketing
USA
Phone: (503) 644-0161

COLOMBIA
Selectronica Ltda.
Bogota
Phone: 632874, 422376

COSTA RICA
Electro-Implex, S.A.
San Jose
Phone: 21-59-54

ECUADOR
Proteco Coasin Cia Ltda.
Quito
Phone: 52-6759, 52-9684

EL SALVADOR
Electronica Cuscatleca, S.A. de C.V.
San Salvador
Phone: 22-0297

HONG KONG
Gilman & Co. Ltd.
Electrical/Electronic Dept.
Causeway Bay
Phone: 5-794266

INDIA
Hinditron Services Private Ltd.
Bombay
Phone 81 13 16/81 53 44
Bangalore
Phone: 33139

INDONESIA
P.T. Dwi Tunggal Jaya Sakti
Jakarta
Phone: 367390-9, 356801-5, 358801-5

JAPAN
Sony/Tektronix Corporation
Tokyo
Phone: 448-4611 (Area 03/Tokyo)
Tokyo
Phone: 710-8141 (Area 03/Tokyo)
Osaka-shi
Phone: 312-2751 (Area 06/Osaka)
Nagoya
Phone: 581-3548 (Area 052/Nagoya)

KOREA
M-C International (Korea) Ltd.
Seoul
Phone: (56) 6131 thru 6138

MALAYSIA
Mecomb Malaysia Sdn. Bhd.
Petaling Jaya, Selangor
Phone: 773455

MEXICO
Tecnicos Argostal, S.A.
Mexico City
Phone: 515-85-80
Monterrey, N.L.
Phone: 51-13-60
Guadalajara, Jal.
Phone: 17-26-46, 17-78-12

NEW ZEALAND
W. & K. McLean Ltd.
Auckland
Phone: 587-037
Wellington
Phone: 851-450

PAKISTAN
Pak-Land Corporation
Karachi
Phone: 437315, 438084

PANAMA
Executive Marketing Corp.
Panama
Phone: 64-9354, 64-9851

PERU
Importaciones y Representaciones Electronicas S.A. (IRE Ingenieros)
Lima
Phone: 28-86-50

PHILIPPINES
Philippine Electronic Industries, Inc.
Makati, Rizal
Phone: 87-99-26, 87-99-27, 87-99-28

SINGAPORE
Mechanical & Combustion Engineering Co. Pte. Ltd.
Singapore
Phone: 647151

SRI LANKA
Maurice Roche Limited
Colombo
Phone: 25846, 25847, 25848

SURINAM
Wong Sang Tsoi & Co.
Paramaribo
Phone: 73511, 75187, 72154, 76369

TAIWAN
Heighten Trading Co. Ltd.
Taipei
Phone: 551-916

THAILAND
G. Simon Radio Company Ltd.
Bangkok
Phone: 30991-3

URUGUAY
Coasin Uruguaya S.R.L.
Montevideo
Phone: 91-79-78

VENEZUELA
Equilab, C.A.
Caracas
Phone: 283.1166 (5 lines)

Areas Not Listed, Contact:
Tektronix, Inc.
Beaverton, Oregon
Phone: (503) 644-0161

CANADA

CANADA
Tektronix Canada Inc.
Barrie, Ontario
Phone: (705) 737-2700
(Montreal)
Pointe Claire, Quebec
Phone: (514) 697-5340
Calgary, Alberta
Phone: (403) 230-1836
Edmonton, Alberta
Phone: (403) 434-9466
Ottawa, Ontario
Phone: (613) 225-2850
(Vancouver)
Burnaby, B.C.
Phone: (604) 438-4321
Winnipeg, Manitoba
Phone: (204) 632-4447, 632-4448
(Halifax)
Dartmouth, Nova Scotia
Phone: (902) 469-9476

Canadian Areas Not Listed, Contact:
Tektronix Canada Limited
Barrie, Ontario
Phone: (705) 737-2700

AFRICA, EUROPE, MIDDLE EAST

ALGERIA
Measurelec
Algiers
Phone: 61.50.99 and 61.50.24 (Algiers)

ANGOLA
Tecnidata
Representacoes Tecnicas e Electronica Aplicada Lda.
Luanda
Phone: 32025-32309

AUSTRIA
Rohde & Schwarz-Tektronix Ges.m.b.H.
Vienna
Phone: Vienna 62 61 41

BELGIUM
Tektronix nv/sa
Bruxelles
Phone: 02/720.80.20

BULGARIA
Rohde & Schwarz-Tektronix Ges.m.b.H.
Vienna, Austria
Phone: Vienna 62 61 41

CZECHOSLOVAKIA
Rohde & Schwarz-Tektronix Ges.m.b.H.
Vienna, Austria
Phone: Vienna 62 61 41

DENMARK
Tektronix A/S
Herlev
Phone: (02) 84 56 22

EAST AFRICA (Kenya, Tanzania and Uganda)
Engineering & Sales Co., Ltd.
Nairobi, Kenya
Phone: 26815

EGYPT
Giza Systems Engineering Company
Cairo
Phone: 841200, 849399, 849200

FEDERAL REPUBLIC OF GERMANY
Rohde & Schwarz Handels Ges.m.b.H.
Berlin
Phone: (030) 3 41 40 36
Rohde & Schwarz Vertriebs Ges.m.b.H.
Hamburg
Phone: (040) 38 01 91
Karlsruhe
Phone: (0721) 2 79 81
Koln
Phone: (0221) 77 22-1
Munchen
Phone: (089) 41 62-1
Nurnberg
Phone: (0911) 6 48 81
Stuttgart
Phone: (0711) 72 20 39

FINLAND
Tektronix O/Y
Helsinki
Phone: 90-722 400

FRANCE
TEKTRONIX
Orsay
Phone: 907 78 27
Lyon
Phone: (78) 76.40.03
Aix-en-Provence
Phone: (42) 59 24 66
Rennes
Phone: (99) 51 21 16
Strasbourg
Phone: (88) 39 49 35
Toulouse
Phone: (61) 40 24 50

GREECE
Marios Dalleggio Representations
Athens
Phone: 710.669

HUNGARY
Rohde & Schwarz-Tektronix Ges.m.b.H.
Vienna, Austria
Phone: Vienna 62 61 41

ICELAND
Kristjan O. Skagfjord Ltd.
Reykjavik
Phone: 24120

IRAN
Irantronics Company Ltd.
Tehran
Phone: 828294, 831564, 836466, 834459

IRAQ
Al Manar Engineering WLL
Baghdad
Phone: 60992 or 8880333

ISRAEL
Eastronics Ltd.
Tel Aviv
Phone: 475151

ITALY
Tektronix S.p.A.
Milano
Phone: 8466440/8466446
Roma
Phone:
Torino
Phone: 330143/372163

IVORY COAST
SITEL
Abidjan 01
Phone: 353600 or 353502

JORDAN
TAREQ Scientific Bureau
Amman
Phone: 42333

KUWAIT
TAREQ Company
Phone: 436100 & 436045

LEBANON
Projects S.A.L.
Beirut
Phone: 331680

MOROCCO
SCRM
Casablanca
Phone: 27 69 11

THE NETHERLANDS
Tektronix Holland N.V.
Badhoevedorp
Phone: 02968-1456

NORWAY
Tektronix Norge A/S
Oslo
Phone: 02-212855

POLAND
Rohde & Schwarz-Tektronix Ges.m.b.H.
Vienna, Austria
Phone: Vienna 62 61 41

PORTUGAL
Equipamentos de Laboratorio Lda.
Lisbon
Phone: 574984
574159

REPUBLIC OF SOUTH AFRICA
Protea Physical & Nuclear Instrumentation (Pty.) Ltd.
Transvaal
Phone: (27 11) 786-3647
Paardeneiland (Cape Town Branch)
Phone: 51-3247
Durban
Phone: 39-1100

ROMANIA
Rohde & Schwarz-Tektronix Ges.m.b.H.
Vienna, Austria
Phone: Vienna 62 61 41

SAUDI ARABIA
Electronic Equipment Marketing Co. Ltd.
Riyadh
Phone: 32700, 37023

SPAIN
Tektronix Espanola S.A.
Barcelona
Phone: (93) 330-2008
Madrid
Phone: (91) 404-1011

SUDAN
Cine & Photo Supply Company (CPSC)
Khartoum
Phone: 75162, 76943 and 42478

SWEDEN
Tektronix AB
Solna
Phone: 08/83 00 80
Gothenburg
Phone: 031/42 70 35

SWITZERLAND
Tektronix International A.G.
Zug
Phone: 042 21 91.92

SYRIA
General Trading Company
Damascus
Phone: 114807, 224170, 559108

TURKEY
Erkman Elektronik Aletler
Istanbul
Phone: 44 15 46/44 76 51

TUNISIA
EL ESLEK
Tunis
Phone: 244372

UNITED KINGDOM
Tektronix U.K. Limited
Harpenden
Phone: Harpenden 63141, 61251
Manchester
Phone: 061-224-0446
Livingston
Phone: Livingston 32766

USSR
Rohde & Schwarz-Tektronix Ges.m.b.H.
Vienna, Austria
Phone: Vienna 62 61 41

YUGOSLAVIA
Rohde & Schwarz-Tektronix Ges.m.b.H.
Vienna, Austria
Phone: Vienna 62 61 41

ZAMBIA
Baird and Tatlock (Zambia) Ltd.
Lusaka
Phone: 75315/6
Ndola
Phone: 3522 & 2253/4/6

Eastern European Countries Not Listed, Contact:
Rohde & Schwarz-Tektronix Ges.m.b.H.
Vienna, Austria
Phone: Vienna 62 61 41

Other Area Not Listed, Contact:
Tektronix Limited
Guernsey, Channel Islands
Phone: Guernsey 35781

UNITED STATES

U.S.A.
Tektronix, Inc.
Beaverton, Oregon
Phone: (503) 644-0161
(800) 547-1512
Oregon only (800) 644-9051

FIELD OFFICES

ALABAMA
Huntsville
Phone: (205) 881-2912

ARIZONA
Phoenix
Phone: (602) 268-8861

CALIFORNIA
(Concord)
Pleasant Hills
Phone: (415) 932-4949
(415) 932-4722
From Oakland: (415) 254-5353
Irvine
Phone: (714) 556-8080-89
(213) 778-5225, 26
(Los Angeles)
Woodland Hills
Phone: (213) 999-1711
San Diego
Phone: (714) 292-7330
Santa Clara
Phone: (408) 496-0800

COLORADO
(Denver)
Englewood
Phone: (303) 773-1011

CONNECTICUT
Milford
Phone: (203) 877-1494

FLORIDA
Fort Lauderdale
Phone: (305) 731-1220
Also serves Puerto Rico and U.S. Virgin Islands
From Miami: 947-6053
Orlando
Phone: (305) 894-3911
From the Cape Kennedy Area: 636-0343
Pensacola
Phone: (904) 476-1897

GEORGIA
(Atlanta)
Norcross
Phone: (404) 449-4770

HAWAII
Honolulu Service Center
EMC Corporation
Phone: (808) 847-1138

ILLINOIS
(Chicago)
Rolling Meadows
Phone: (312) 259-7580

INDIANA
Indianapolis
Phone: (317) 545-2351

KANSAS
(Kansas City)
Overland Park
Phone: (913) 341-3344

LOUISIANA
(New Orleans)
Kenner
Phone: (504) 466-4445

MARYLAND
(Baltimore)
Lutherville
Phone: (301) 321-7000
Rockville
Phone: (301) 948-7151

MASSACHUSETTS
(Boston)
Lexington
Phone: (617) 861-6800

MICHIGAN
(Detroit)
Farmington
Phone: (313) 478-5200

MINNESOTA
St. Paul
Phone: (612) 484-8571

MISSOURI
(St. Louis)
Hazelwood
Phone: (314) 731-4696

NEW JERSEY
Woodbridge
Phone: (201) 636-8616

NEW MEXICO
Albuquerque
Phone: (505) 265-5541

NEW YORK
(Albany)
Albany
Phone: (518) 458-7291
(Long Island)
Woodbury, L.I.
Phone: (516) 364-9060
(212) 895-9215
Poughkeepsie
Phone: (914) 454-7540
Rochester
Phone: (716) 244-2600
(Syracuse)
North Syracuse
Phone: (315) 455-6661
From New York: (800) 962-1095

NORTH CAROLINA
Raleigh
Phone: (919) 782-5624

OHIO
(Cleveland)
Middleburg Heights
Phone: (216) 243-8500
Dayton
Phone: (513) 859-3681

OKLAHOMA
Oklahoma City
Phone: (405) 848-3361

OREGON
(Portland)
Tigard
Phone: (503) 620-9100
Factory Service Center
Tektronix Industrial Park
Beaverton
Phone: (503) 644-0161
(800) 547-1512
Oregon only (800) 644-9051

PENNSYLVANIA
(Philadelphia)
Blue Bell
Phone: (215) 825-6400
Pittsburgh
Phone: (412) 244-9800

TENNESSEE
Knoxville
Phone: (615) 690-6422

TEXAS
Dallas
Phone: (214) 233-7791
Houston
Phone: (713) 933-3000
San Antonio
Phone: (512) 434-4334

UTAH
Salt Lake City
Phone: (801) 486-1091

VIRGINIA
Hampton
Phone: (804) 874-0099

WASHINGTON
Kent
Phone: (206) 575-0180

TEKTRONIX WORLDWIDE MARKETING CENTERS

U.S.A.
Tektronix, Inc.
U.S. Marketing
Beaverton, Oregon
Phone: (503) 644-0161
(800) 547-1512
Oregon only (800) 644-9051

AFRICA, EUROPE, MIDDLE EAST
Tektronix International Inc.
European Marketing Centre
Amstelveen, The Netherlands

AMERICAS/PACIFIC (Asia, Australia, Central & South America, Japan)
Tektronix, Inc.
Export Marketing
Beaverton, Oregon
Phone: (503) 644-0161
(800) 547-1512
Oregon only (800) 644-9051