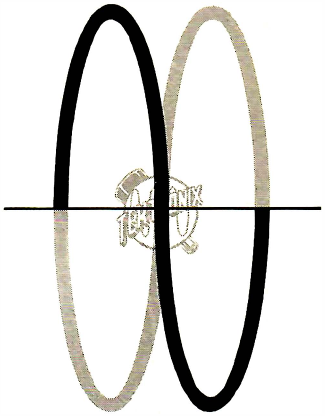
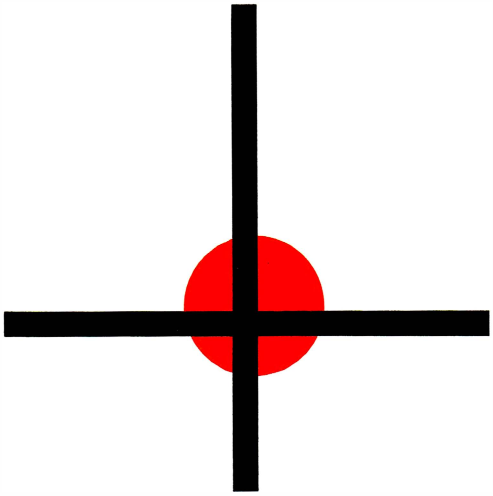
A PRIMER

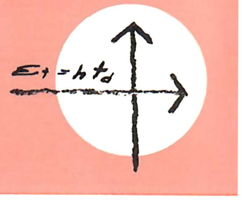
OF WAVEFORMS AND THEIR OSCILLOSCOPE DISPLAYS





Additional copies of this publication can be obtained from your Tektronix Field Engineer or Tektronix Representative, or from Tektronix, Inc., P.O. Box 500, Beaverton, Oregon. The price per copy is 50 cents. Request FIP-7851.

CONTENTS



FOREWORD

Workers in an increasing number of fields are faced with measurement problems that can be solved only by electronic means. Electronic tools become more valuable to the user who is willing to expend some effort in understanding their operation.

We at Tektronix assume a responsibility for providing materials to help everyone realize the greatest value from his oscilloscope. Our responsibility includes the development of training materials for technicians, engineers and physicists who have had limited experience in electronics. This booklet is a digest of those lecture notes that experience indicates have been most helpful to those making their first acquaintance with a laboratory-type oscilloscope. We hope you, too, will find it helpful. We welcome your comments on this booklet.

Fig. 1-a. Measuring elapsed time.

Fig. 1-b. Measuring voltage difference.

You, the interpreter . . .

INTERPRETING THE OSCILLOSCOPE DISPLAY

1

The display we get from a cathode-ray oscilloscope is ordinarily a graph (Fig 1-a) in which the instantaneous voltage of a wave is plotted against time. Elapsed time is indicated by horizontal distance, from left to right, across the cathode-ray-tube screen. The instantaneous voltage of the waveform we see is measured vertically on the screen.

To find the *elapsed time* between two points on the graph (such as points *A* and *B),* multiply the horizontal distance between these points in major graticule divisions by the setting of the TIME/DIV. control. This control sets the horizontal sweep rate of the oscilloscope. In Fig. 1-a, the distance between points *A* and *B* is 4.4 major divisions. If the TIME/DIV. control is set at 100 microseconds per division, then the elapsed time between points *A* and *B* must be 4.4 x 100=440 microseconds. In general,

Elapsed time

= horizontal distance in divisions
x TIME/DIV. setting

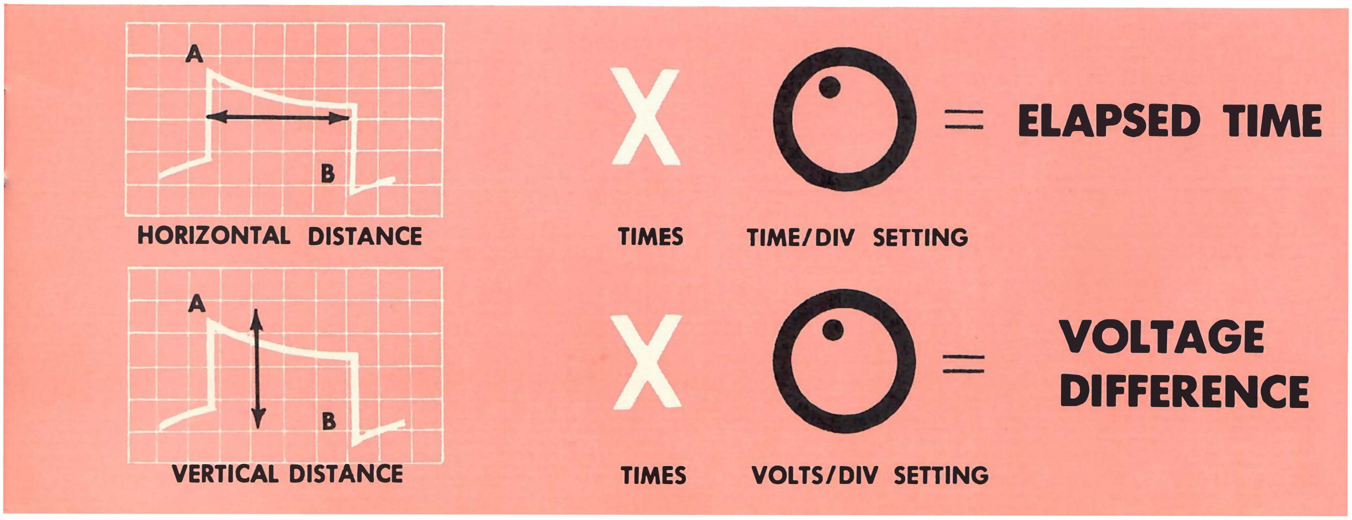
If a MULTIPLIER control is associated with the TIME/DIV. control, multiply the above result by the setting of the MULTIPLIER. If a MAGNIFIER is in operation, divide the result by the amount of magnification.

To find the *voltage difference* between any two points on the graph, such as points *A* and *B,* multiply the vertical distance between these points in major graticule divisions by the setting of the VOLTS/DIV. control, which sets the vertical deflection factor or "sensitivity" of the oscilloscope. In Fig. 1-b, the vertical distance between points *A* and *B* is 3.6 divisions. If the VOLTS/DIV. control is set at 0.5 volt per division, then the voltage difference between points *A* and *B* must be 3.6 x 0.5=1.8 volts. In general,

Voltage difference

= vertical distance in divisions
x VOLTS/DIV. setting

The oscilloscope is also used to picture changes in quantities other than simply the voltages in electric circuits. If an electric *current* waveform is of interest, it is usually satisfactory to send the current through a small series resistor and to look at the voltage wave across the resistor with the oscilloscope. Other quantities such as temperatures, pressures, strains, speeds and accelerations can be translated into voltages by means of suitable transducers, and then viewed on the oscilloscope.



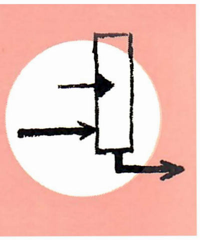


Fig. 2 is a block diagram of a typical oscilloscope, omitting power supplies. The waveform *(A)* to be observed is fed into the vertical-amplifier input. The calibrated VOLTS/DIV. control sets the gain of this amplifier. The push-pull output (*B* and C) of the vertical amplifier is fed through a delay line to the vertical-deflection plates of the cathode-ray tube. The purpose of the delay line is explained later on this page.

The time-base generator or "sweep generator" develops a sawtooth wave *(E)* that is used as a horizontal-deflection voltage. The rising or positive-going part of this sawtooth, called the "run-up" portion of the wave, is linear. That is, the waveform rises through a given number of volts during each unit of time. This rate of rise is set by the calibrated TIME/DIV. control. The sawtooth voltage is fed to the time-base amplifier. This amplifier includes a phase inverter so that the amplifier supplies two output sawtooth waveforms (G) and (*J*) simultaneously—one of them positive-going, like the input, and the other negative-going. The positive-going sawtooth is applied to the right-hand horizontal-deflection plate of the cathode-ray tube, and the negative-going sawtooth is applied to the left-hand deflection plate. As a result, the cathode-ray beam is swept horizontally to the right through a given number of graticule divisions during each unit of time—the sweep rate being controlled by the TIME/DIV. control.

In order to maintain a stable display on the cathode-ray-tube screen, each horizontal sweep must start at the same point on the waveform being displayed. To maintain a stable display, we feed a sample of the displayed waveform to a "trigger" circuit that gives a negative output voltage spike *(D)* at some selected point on the displayed waveform. This triggering spike is used to start the run-up portion of the time-base sawtooth. As far as the display is concerned, then, "triggering" can be taken as synonymous with the starting of the horizontal sweep of the trace at the left-hand side of the graticule.

A rectangular "unblanking" wave *(F)* derived from the time-base generator is applied to the grid of the cathode-ray tube. The duration of the positive part of this rectangular wave corresponds to the duration of the positive-going or run-up part of the time-base output, so that the beam is switched on during its left-to-right travel and is switched off during its right-to-left retrace.

In the case shown, the leading edge of the waveform being displayed is used to actuate the trigger circuit. Yet we may want to observe this leading edge on the screen—and the triggering and unblanking operations require a measurable time interval *P*, often about 0.15 microsecond. To permit us to see the leading edge, a delay Q of about 0.25 microsecond is introduced by the delay line in the vertical-deflection channel, after the point where the sample of the vertical signal is tapped off and fed to the trigger circuit.

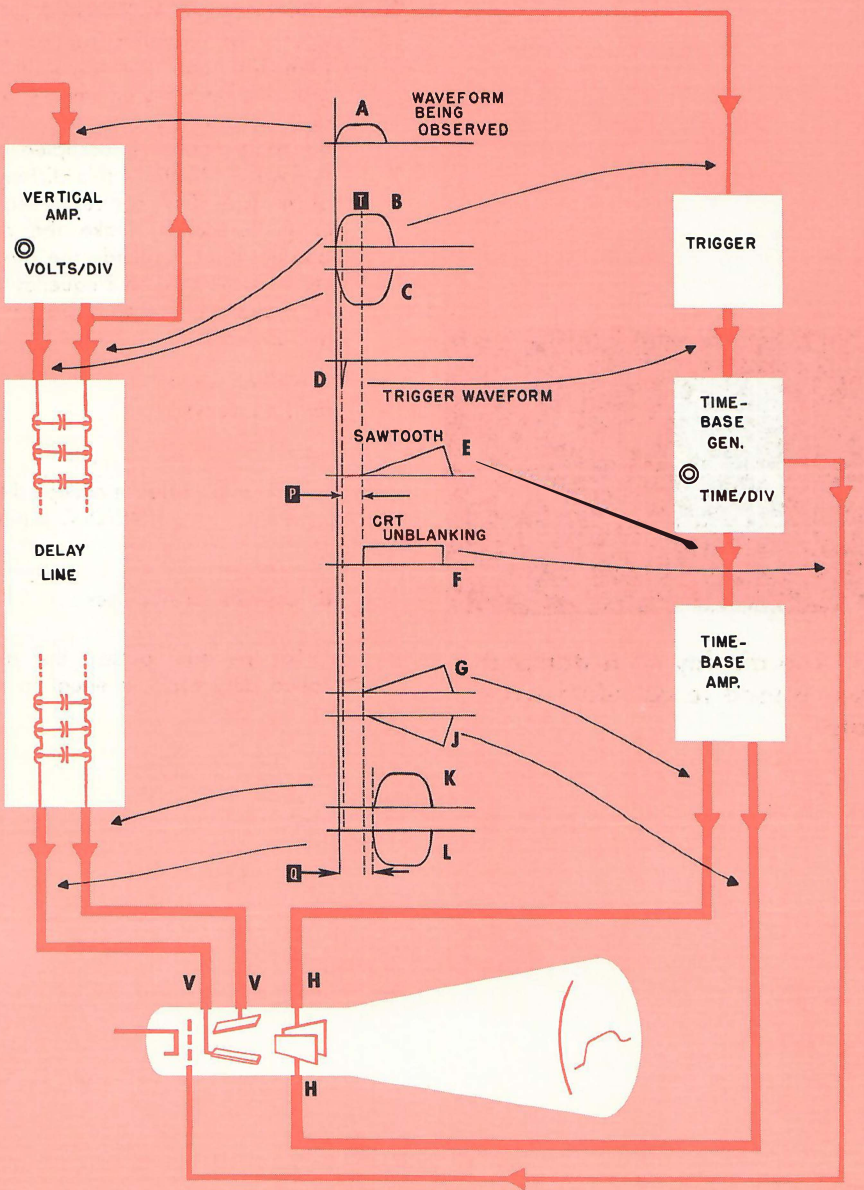
To summarize the purpose of the delay line, it is to retard the application of the observed waveform to the vertical-deflection plates until the trigger and time-base circuits have had an opportunity to get the unblanking and horizontal-sweep operations under way. In this way, we can view the entire desired waveform—even though the leading edge of that waveform was used to trigger the horizontal sweep.

If the delay line were not used, we would be able to see only that portion of the waveform following the instant designated as *(T)* in waveform *(A)*.

Fig. 2. Block diagram of the oscilloscope.

Behind the front panel . . .

THE OSCILLOSCOPE BLOCK DIAGRAM



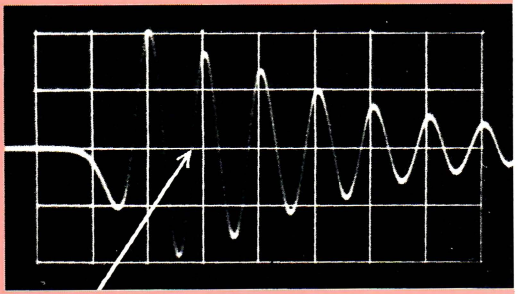


Fig. 3. The display of a damped sine wave used to calculate writing rate.

A. Pulse repetition rate

The quantity called pulse repetition rate (or pulse repetition frequency) for periodic pulses can be expressed as the number of pulses per unit of time. Examples: 10 pulses (or cycles) per second; 50 pulses (or cycles) per microsecond.

In using the oscilloscope to measure the frequency or repetition rate of a periodic waveform, first read the horizontal distance in major graticule divisions between corresponding points on two succeeding waves. This distance is the horizontal distance occupied by one cycle of the wave. Multiply this distance by the setting of the TIME/DIV. control in seconds, milliseconds or microseconds. Take the reciprocal of this product (that is, divide the product into 1). The result is the desired frequency or repetition rate in cycles per second, per millisecond or per microsecond:

$$\begin{array}{l}\text{Repetition rate} = \\ \text{(or frequency)}\end{array}$$

$$\frac{1}{\begin{array}{l}\text{horizontal distance occupied by one cycle} \\ \text{x TIME/DIV. setting}\end{array}}$$

B. Duty factor of pulses

For periodic pulses, the duty factor, often called *duty cycle*, is equal to the duration of a pulse multiplied by the pulse repetition rate (or divided by the period of the pulse). The pulse duration is the interval of time between the first and last instants at which the pulse voltage reaches some specified percentage of the peak voltage of the pulse. The duty factor is often expressed as a percentage. (Note that duty factor as here defined is essentially the ratio of "on" time to the total time for one cycle. This is different from another common use of the term "duty factor"—the ratio of average power to peak power. The two usages give equal values only in the case of rectangular pulses and certain other special pulses.)

C. On-off ratio

This is the ratio of "on" time of a pulse to the "off" time (between pulses).

D. Writing rate

The writing rate of which an oscilloscope is capable is usually taken to mean the maximum spot speed (usually in centimeters per microsecond) at which a satisfactory photograph can be made. For many purposes, a useful criterion is the writing rate for which the density of the photographic record is increased by 10 percent.

The maximum writing rate that can be observed depends not only on the responses of the horizontal- and vertical-deflection systems of the oscilloscope, and the characteristics of the cathode-ray tube, but also upon the photographic equipment and processes used.

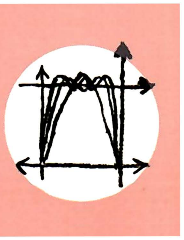
Fig. 3 shows one way in which writing rate can be calculated. Display a single trace of a damped sine wave whose frequency is such that the rapidly rising and falling portions of the first cycle or two fail to photograph. Determine the writing-rate capability of the oscilloscope as follows: Starting from the left, find the first rapidly rising or falling portion of the damped sine wave that is photographed in its entirety. Let *D* represent the vertical distance between the peaks that are connected by this portion. If *D* is three or more times as great as the horizontal distance occupied by one cycle, the writing rate in centimeters per microsecond is given closely by

$$R_w = 3.14\,Df$$

Eq. (4)

where *f* is the frequency of the damped wave in megacycles.

> **Note:** Although the writing rate is an important characteristic of the oscilloscope, it does not completely describe the ability of the oscilloscope to present detailed information. It is also important to consider the available resolution, in conjunction with screen size. It is convenient to present these latter data in terms of the number of spot widths contained in the length and in the height of the graticule.



It can be shown that a periodic nonsinusoidal wave is equivalent to the sum of:

1. A *fundamental* wave—that is, a sine wave whose frequency is equal to the frequency of the original nonsinusoidal wave.

2. And a series of *harmonics*—sine waves whose frequencies are whole numbers multiplied by the fundamental frequency.

The various sine waves just mentioned are called *components* of the original nonsinusoidal wave. With appropriate equipment, we could either *(a)* break down the original nonsinusoidal wave into its fundamental and harmonic sine-wave components, or *(b)* combine an appropriate set of sine waves to produce a desired nonsinusoidal waveform. We shall not concern ourselves here with actually performing either of these operations. But the fact that a sequence of periodic pulses is equivalent to an appropriate set of sine-wave components helps us to understand the problems of generating, amplifying, and displaying complicated waveforms.

If we were to reproduce a nonsinusoidal waveform by adding together the proper sine-wave components, each component sine wave would have to be correct in amplitude, frequency, and phase, in order that the given nonsinusoidal wave might be reproduced faithfully.

Because a nonsinusoidal wave is equivalent to a combination of two or more sine-wave components, we refer to a nonsinusoidal waveform as a *complex* waveform.

As an example, Fig. 4 shows a sequence of periodic pulses having a rectangular or "square" waveform. Such a pulse sequence can be shown to be made up of a fundamental sine wave plus an infinite series of "odd" harmonic sine waves. That is, the pulse sequence is composed of the fundamental sine wave and only those harmonic sine waves whose frequencies are equal to the fundamental frequency multiplied by odd whole numbers. The amplitudes of the harmonics vary in inverse proportion to the frequencies of the harmonics. That is, the third harmonic is 1/3 as strong as the fundamental; the fifth harmonic is 1/5 as strong as the fundamental, etc. The way these sine-wave components can be combined to make up the original square-wave pulse sequence is suggested by Fig. 5.

It will be noted that the first few harmonics combine with the fundamental to provide an approach to an actual square wave. Additional harmonics, of higher frequencies, would *(a)* cause the leading edge of the wave to rise more rapidly, and *(b)* produce a sharper corner between the leading edge and the top of the wave. It would require an "infinite" range of harmonics to produce a truly vertical leading edge and an actual sharp corner, and this situation is physically impossible to produce. But waves can be generated that are very close to this ideal situation. (The same considerations apply to the falling edge of the waveform, and the following corner.)

Information regarding the amplitudes and phase relationships of the higher harmonics is, then, contained in the leading-edge steepness and in the sharpness of the corner.

If low-frequency components (fundamental and the first few harmonics) are not present in the proper amounts and in the correct phase relationships, the part of the square wave affected

Fig. 6. Illustrating low-frequency defects in square waves. In A, the low-frequency components have leading phase angles and are attenuated. In B, the low-frequency components have lagging phase angles and are accentuated.

A wealth of information . . .

INFORMATION CONTAINED IN A SQUARE WAVE

4

will be the flat top. Low-frequency defects will manifest themselves in the form of slope or general curvature in the top (Fig. 6). This situation is summarized in Fig. 7.

It is convenient to use square waves, rather than other forms of waves, for testing of equipment because the *nature* of a defect, rather than simply its presence, is suggested by the kind of distortion that occurs to a square wave. By observing square-wave response, we can tell whether the transmission of low or high frequencies is affected. This observation is not so well separated with regard to frequency if waves other than square waves are used.

If two linear devices give identical responses when square waves are fed into them, they can, in general, be expected to give responses similar to each other when other waveforms are fed into them.

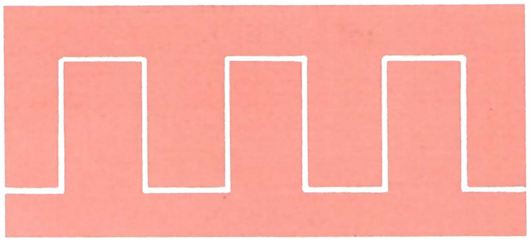


Fig. 4. Three cycles of a periodic rectangular wave (square wave).

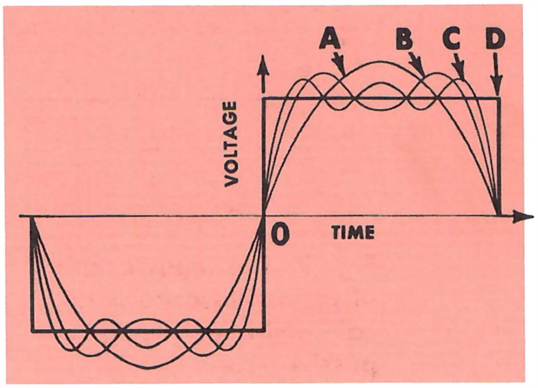


Fig. 5. Illustrating the addition of successively higher-order harmonics to a fundamental sine wave, to produce a close approximation of a square wave.

Waveform A is the fundamental sine wave. Waveform B shows the result of adding the third harmonic sine wave to the fundamental. Waveform C shows the effect of adding both the third and the fifth harmonics to the fundamental. Note that waveforms B and C show closer and closer approximations to the final square wave D.

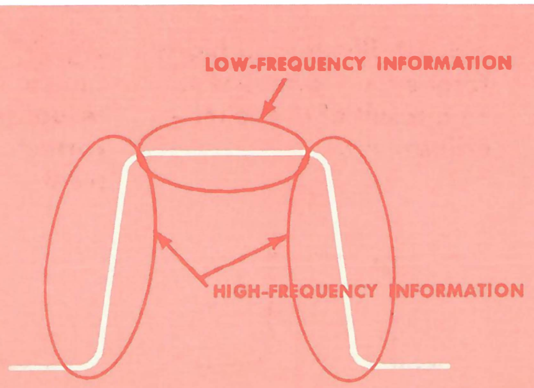


Fig. 7. A summary of the low- and high-frequency information found in a square wave.

The input circuit to the vertical amplifier of an oscilloscope can be simulated by a high resistance *R* shunted by a small shunt capacitance *C* (Fig. 8).

In some applications, even this high resistance and small capacitance can produce undesirable loading upon the circuit whose waveforms are being examined by means of the oscilloscope. This loading can cause our oscilloscope presentations to be different from the waveforms that would be present with the oscilloscope disconnected. One use of a passive probe is to reduce this resistive-capacitive loading on the circuit under investigation.

The probe includes a resistor R_P shunted by a capacitor C_P (Fig. 9). This combination is connected in series with the inner conductor of the cable to the oscilloscope input. The result is that when the probe is connected to the circuit under investigation, there is connected to that circuit a new effective loading capacitance smaller than the original capacitance *C* and a new effective loading resistance larger than the original resistance *R*. Thus the loading effect of the oscilloscope input circuit on the circuit under

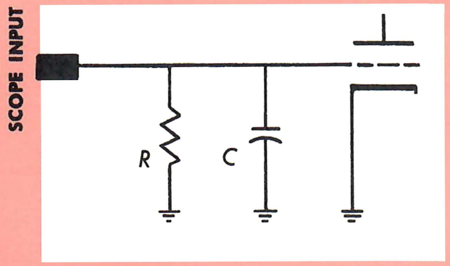


Fig. 8. The input circuit of an oscilloscope vertical amplifier.

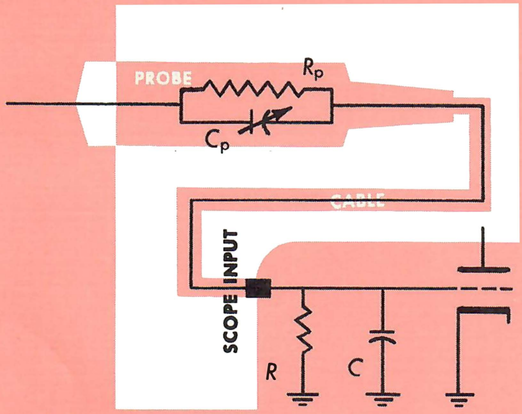


Fig. 9. The input circuit of an oscilloscope vertical amplifier using a passive probe.

Fig. 10. Illustrating high-frequency attenuation as a result of probe misadjustment.

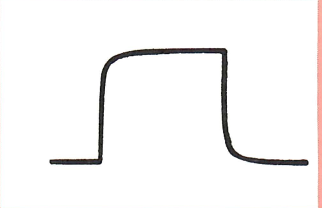


Fig. 11. Illustrating optimum high-frequency response as a result of correct probe adjustment.

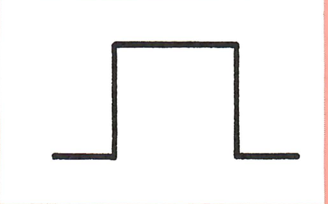
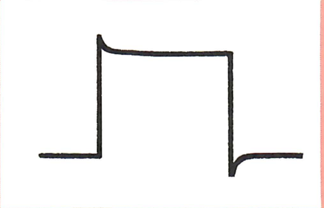


Fig. 12. Illustrating accentuated high-frequency response as a result of probe misadjustment.



investigation is reduced through the use of the probe.

The probe is marked with the new effective shunt resistance and capacitance placed across the circuit under investigation when the probe is used.

A second effect of the probe is to reduce the amount of signal voltage applied directly to the oscilloscope input connection for a given amount of original signal voltage. This reduction occurs because of the voltage-divider action of R_P and R. This effect is taken into account in the "attenuation ratio" marked on the probe. Thus if the probe is marked "10X ATTEN." you have to multiply all oscilloscope voltage indications by 10.

Now suppose we are using an oscilloscope equipped with a probe to look at a square wave. If the probe capacitor C_P were absent, or if C_P were too small, some of the high-frequency components of the square wave would be by-passed around the oscilloscope input terminals by the input capacitance C. Thus the steepness of the leading edge of the displayed square wave would be reduced (Fig. 10).

If we adjust the probe capacitor C_P to the correct value, a compensating amount of high-frequency information will be bypassed around the probe resistor R_P to make up for the loss through C, and the leading edge of the displayed square wave will be restored to its original steepness (Fig. 11). But if we make C_P *too* large, we over-compensate the high-frequency response of the circuit and apply too much high-frequency information to the oscilloscope input connection. This results in an overshoot in the displayed waveform that was not present in the original (Fig. 12). You can adjust C_P to its correct value by using the probe to display the square wave generated by the voltage calibrator that is a part of your oscilloscope. Adjust for the flattest top in the displayed waveform (Fig. 11).

Serious errors might be introduced into your observations if you fail to check this adjustment regularly. In particular, the probe adjustment must be checked whenever you use the probe with an oscilloscope or a plug-in preamplifier whose input capacitance is different from of the instrument with which the probe was previously used.

It is desirable to be able to express in numbers the steepness of the leading edge of a square wave. This need brings us to the concept of the risetime of a wave, which is customarily taken as the time required for the leading edge to rise from 10% of the peak value of the wave to 90% of the peak value (Fig. 14).

Risetime has sometimes been taken as the interval required for the leading edge to rise from 5% of the peak value to 95% of the peak value. If this, or any other definition different from that given in the paragraph above, is intended, the intended definition should be stated along with the risetime value.

The risetime of a device that transmits or displays waveforms is taken as the risetime of the output (or displayed) waveform if the device were driven with a theoretically perfect square wave. In practice, we use an input square wave whose risetime is much less than the risetime of the device being tested.

It is of interest to know the effect upon the risetime of an output wave if a theoretically perfect square wave were transmitted through two or more devices in cascade. Suppose that device *A*, operating alone, has a risetime T_{RA}; and suppose that device *B*, operating alone, has a risetime T_{RB}. If a theoretically perfect square wave were fed into the two devices in cascade, the risetime T_R of the output wave would be approximately

$$T_R = (T_{RA}^2 + T_{RB}^2)^{1/2}$$

T_R is therefore the risetime of the cascade combination of devices *A* and *B*.

As an example, if a theoretically perfect square wave is fed into an amplifier whose risetime is 3 microseconds, and if the output of this amplifier is fed into a second amplifier whose risetime is 4 microseconds, the risetime of the output from the second amplifier will be about 5 microseconds.

Suppose we want to amplify or to display some given waveform. Also, suppose we want the risetime of the output or displayed waveform to be the same as that of the input waveform, within some given tolerance. Figure 14, calculated from Eq. (5), tells us how good our amplifier or oscilloscope must be, with respect to risetime, to get this result. For example, Fig. 14 shows us that if we wanted to observe the risetime of a waveform whose risetime is 0.04 microsecond, we would need an oscilloscope whose risetime is not more than 0.01 microsecond if the error in the observation is to be kept less than 3%.

In cases where three or more risetimes are to be combined, it is only necessary to include all of them in a root-sum-square method like that of the above equation.

Now suppose we want to measure the risetime T_{RM} of some amplifier or other device. Let the risetime of the square-wave generator we are using be T_{RG}, and let the risetime of our oscilloscope be T_{RO}. If the risetime of the waveform displayed on the oscilloscope is T_{RD}, then a modification of Eq. (5) tells us that the amplifier risetime we are measuring is

$$T_{RM} = (T_{RD}^2 - T_{RG}^2 - T_{RO}^2)^{1/2}$$

In practice, it is not usually convenient to determine separately the actual operating risetime T_{RG} of the generator or the actual operating risetime T_{RO} of the oscilloscope. We now describe a risetime-measurement technique that takes into account the composite effects of these risetimes.

For best results, use a generator and an oscilloscope whose risetimes are appreciably shorter than the risetime of the device under test. Use a square-wave generator whose output waveform is essentially free from overshoot (see Sec. 8 of this publication). Furthermore, the accuracy of the measurement might suffer if either the oscilloscope or the device under test has appreciable overshoot, say, more than 2 or possibly 3 percent.

The risetime-measurement method is as follows:

1. Observe the risetime of the square-wave output of the generator directly on the oscilloscope. For this measurement, terminate the generator with a load resistance and shunt capacitance (including the input capacitance of the oscilloscope or probe) equal to the load resistance and shunt capacitance provided by the input circuit of the device you are going to test. We call this equivalent risetime of the generator and oscilloscope together T_{RE}.

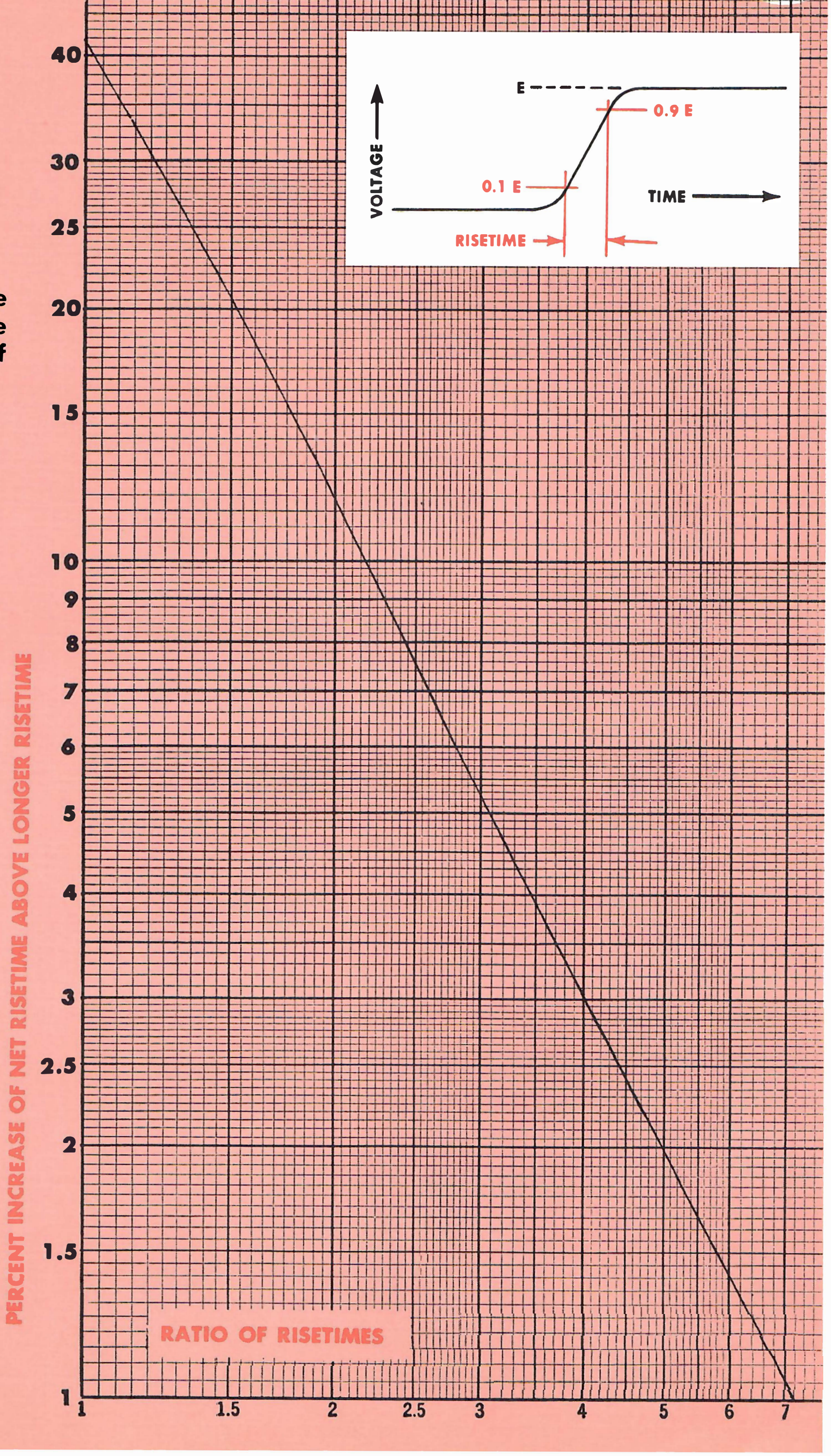
2. Drive the device under test with the output of the square-wave generator. Observe on the oscilloscope the risetime of the output waveform of the device under test. For this observation, terminate the device under test with a load (including the input impedance of the oscilloscope) whose characteristics are similar to those of the load into which the device normally operates. We call this displayed risetime T_{RD}.

3. Compute the actual risetime T_{RM} of the device under test from the relation

$$T_{RM} = (T_{RD}^2 - T_{RE}^2)^{1/2}$$

SQUARE-WAVE RISETIMES

Fig. 14. Percent increase in the risetime above the risetime of the slower of two cascaded devices.



A measure of performance . . .

FREQUENCY–RESPONSE CURVES

7

Fig. 15 shows a possible frequency-response curve for an amplifier. The solid curve indicates the response of a direct-coupled amplifier, and goes down to 0 cycles (dc). The dotted curve shows the response of an ac-coupled amplifier.

The 3-db-down frequencies, where the output voltage falls to 70% of the mid-frequency output voltage, are indicated. In what follows, we shall consider principally cases where the amplifier response goes down to zero cycles or to quite low frequencies. In these cases, the upper 3-db-down frequency is the 3-db bandwidth of the amplifier, quite accurately.

For best (shortest) risetime without overshoot, the high-frequency response should theoretically roll off according to a curve known as a "gaussian" curve. A rule-of-thumb in approximating this curve is: The output voltage should be close to 12 db down at twice the 3-db-down frequency.

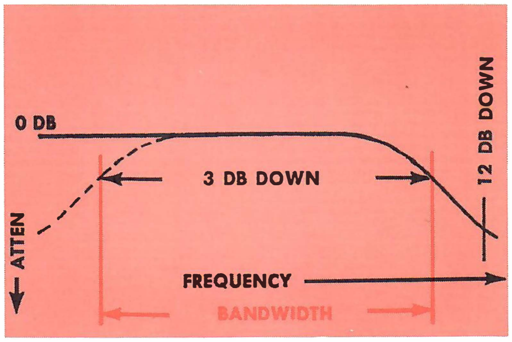


Fig. 15. Frequency–response curve.

A convenient relationship . . .

THE RELATION BETWEEN RISETIME AND BANDWIDTH

8

In Sec. 3, we found that the steepness of the leading edge of a square wave (its risetime, in effect) contained an indication of the presence, in proper amplitude and phase, of high-frequency components. For equipment having not more than 2 or 3 percent of "overshoot" (discussed later in this section), the relation between the upper 3-db-down frequency B in megacycles and the risetime T_R in microseconds is approximately

$$BT_R = K \qquad \text{Eq. (6)}$$

where K is a constant that depends upon the amount of high-frequency compensation in the amplifier. For less than 3 percent of overshoot, K is equal to 0.35. The above equation may be written in two other forms:

$$T_R = \frac{K}{B} \qquad \text{and} \qquad B = \frac{K}{T_R}$$

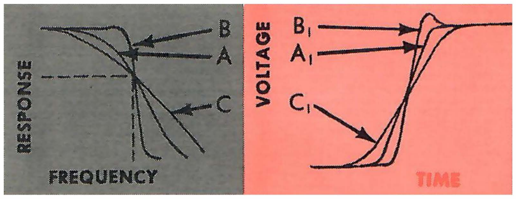


Fig. 16. Effects of high-frequency compensation on square waves.

As an example, if the 3-db-down frequency of an amplifier is 10 megacycles, its approximate risetime should be $T_R = K/B = 0.035$ microsecond.

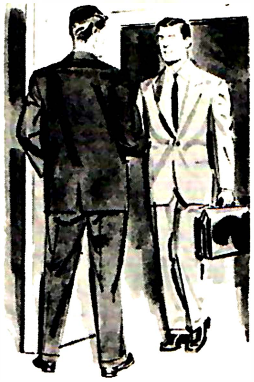
The effects on the square-wave response caused by various degrees of amplifier high-frequency compensation are indicated in Fig. 16. Curve A shows the frequency response of an amplifier that has been adjusted for approximately a gaussian roll-off. Curve A_1 shows the resulting optimum square-wave response of this amplifier—the fastest rise without overshoot.

Now consider a second amplifier whose high-frequency response was originally less than that of the amplifier treated in Curve A. Curve B shows the effect of the use of excessive high-frequency compensation in the design or adjustment of the amplifier to bring the upper 3-db-down frequency of this second amplifier up to that of the one treated in Curve A. Note that the frequency response falls off more steeply than it should, and that the associated square-wave response (Curve B_1) has overshoot and possibly ringing. (Ringing is damped oscillation at approximately the cut-off frequency, appearing along the top of the wave.)

Curve C shows what happens to the frequency response when insufficient high-frequency compensation is used. This curve falls off more slowly than it should. The corresponding square-wave response (Curve C_1) indicates that an undue amount of time is required for the wave to rise through the last several percent of the leading edge. Increased high-frequency compensation would reduce the risetime of this amplifier.

TEKTRONIX FIELD SERVICES

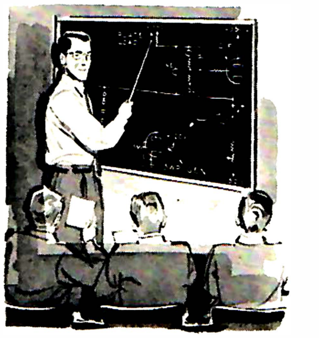
Tektronix Customers are urged to take advantage of the many field services available to them through Tektronix Field-Engineering Offices, Engineering Representatives, and Overseas Engineering Organizations. Some of these services are described below.



Ordering—There are many types of oscilloscopes, each designed for a specific application area. Your Field Engineer can help you select the one best suited to your present and future needs, and he will be happy to arrange a demonstration of the instrument.....in your application if you so desire.

If you are a Purchasing Agent or Buyer, your Field Engineer or his secretary can help you with information on prices, terms, shipping estimates, and best method of transportation on instruments, accessories, and replacement parts.

Operation—Your Tektronix Oscilloscope can be most useful to you when you are familiar with all control functions. Your Field Engineer will be glad to demonstrate the use of your instrument in various applications to help you become more familiar with its operation. If your instrument is to be used by several engineers, your Field Engineer will be happy to conduct informal classes on its operation in your laboratory.



Maintenance—Tektronix willingly assumes much of the responsibility for continued efficient operation of the instruments it manufactures. If you should experience a stubborn maintenance problem, your Field Engineer will gladly help you isolate the cause. Often a telephone discussion with him will help you get your instrument back into operation with minimum delay. If yours is a large laboratory, your Field Engineer can be of service to your maintenance engineers by conducting informal classes on test and calibration procedures, trouble-shooting techniques, and general maintenance.

If you are responsible for the maintenance of a large quantity of Tektronix Instruments, ask your Field Engineer about the free factory training course in maintenance and calibration.

Applications—Perhaps the answers you need in a specific application can be obtained faster and easier through use of your Tektronix Oscilloscope. Your Field Engineer can help you find out, and if use of your oscilloscope is indicated, help you with procedures. He may also be able to suggest many time-saving uses for your oscilloscope in routine checks and measurements.

Instrument Reconditioning—An older Tektronix Oscilloscope, properly reconditioned, can give you many additional years of service. Your Field Engineer will gladly explain the advantages and limitations of instrument reconditioning, and make the necessary arrangements if you decide in favor of it.

Nearly all major repair and recalibration jobs can be performed at a nearby Field Maintenance Center. Ask your Field Engineer about this at-cost service to Tektronix customers.

Communications— Your Field Engineer is a valuable communication link between you and the factory. He knows the exact person to contact in each circumstance, and he can reach that person fast and easily. Let him help speed your communications with the factory on any problem related to your Tektronix Instruments.

TEKTRONIX, INC.

Tektronix, Inc., an Oregon Corporation, Home Office & Factory, P. O. Box 500, Beaverton, Oregon 97005
Telephone: (503) 644-0161 TWX—503-291-6805 Telex: 036-691 Cable: TEKTRONIX

FIELD ENGINEERING OFFICES

ALABAMA
Huntsvi
Telex 05-9422 ... Telephone: (205)881-2912

ARIZONA
Phoenix... 7045 E. Camelback Road, Scottsdale 85251...Telex 066-701 .... Telephone: (602)946-4273
Tucson Area: Enterprise 383

CALIFORNIA
San Diego... 3045 Rosecrans Street, San Diego 92110...Telex 069-525 .... Telephone: (714)222-0384

Los Angeles Area
● *Orange*... 1722 E. Rose Avenue, Orange 92667...Telex 06-78812 .... Telephone: (714)633-3450
Pasadena... 1194 East Walnut Street, Pasadena 91106...TWX: 213-449-1151...Telex 06-74397
Telephone (213)449-2164
From Los Angeles telephones call: 681-0201
● *Van Nuys*... 16930 Sherman Way, Van Nuys 91406...Telex 74396 .... Telephone: (213)-987-2600
From Los Angeles telephones: 873-6868
Island of Oahu, Hawaii Area: ENterprise 5-700

San Francisco Bay Area
Walnut Creek... 1709 Mt. Diablo Blvd., Walnut Creek 94596...Telex 033-644 .... Telephone: (415) 935-6101
From Oakland, Berkeley, Richmond, Albany and San Leandro: 254-5353
● *Palo Alto*... 3944 Fabian Way, Palo Alto 94303...Telex 033-911 .... Telephone: (415)326-8500

COLORADO
Denver... 2120 South Ash Street, Denver 80222...Telex 045-662 .... Telephone: (303)757-1249
Salt Lake Area: Zenith 381

FLORIDA
● Orlando... 205 East Colonial Drive, Orlando 32801...Telex 056-515 ...... Telephone: (305)GArden 5-3483
(also serves Puerto Rico) From The Cape Kennedy Area: 636-0343

GEORGIA
● Atlanta... 467 Armour Circle, N.E., Atlanta 30324...Telex 05-42233 .... Telephone: (404)873-5708

ILLINOIS
● Chicago... 400 Higgins
119 East Ogden Avenue, Suite 111, Hinsdale 60521 .. Telex 02-53694 .. Telephone: (312)325-3050

INDIANA
Indi
Telephone: (317)LIberty 6-2408

KANSAS
Kansas City... 5845 Horton, Suite 6, Mission 66202...Telex 04-2321 ...... Telephone: (913)HEdrick 2-1003
St. Louis Area: ENterprise 6510

MARYLAND
● Baltimore... 1045 Taylor Avenue, Towson 21204...Telex 087-804 .... Telephone: (301)825-9000
From Harrisburg, Lancaster and York Area call ENterprise 1-0631

MASSACHUSETTS
● Boston... 244 Second Avenue, Waltham 02154...Telex 094-6301 .... Telephone: (617)894-4550

MICHIGAN
● Detroit... 27308 Southfield Road, P. O. Box 37, Lathrup Village 48037
Telex 023-400 ... Telephone: (313)ELgin

MINNESOTA
Minneapolis... Suite 115, 7515 Wayzata Boulevard, Minneapolis 55426
Telex 029-699..Telephone: (612) 545-2581

NEW MEXICO
● Albuquerque... 1258 Ortiz Drive, S.E., Albuquerque 87108...Telex 074-621 .... Telephone: (505)268-3373
Southern New Mexico Area: Enterprise 678

NEW YORK
Buffalo... 965 Maryvale Drive, Buffalo 14225... Telex 091-385 .... Telephone: (716) 633-7861
● Endicott... 3214 Watson Blvd., Endwell 13763...Telex 093-796 .... Telephone: (607)PIoneer 8-8291
● Poughkeepsie... 12 Raymond Ave.,
● Syracuse... East Molloy Road & Pickard Drive, P.O. Box 155, Syracuse 13211
Telex 093-739 .... Telephone:

New York City Area
● *New York City and Long Island*... 125 Mineola Avenue, Roslyn Heights, L. I.,
Telex: ROSN 01-26446 .... Telephone (516)HT 4-2300
● *Northern N.J.* ... 400 Chestnut Street, Union, New Jersey 07083...Telex 01-26344 .. Telephone: (201)688-2222
Hudson River Valley, Westchester County, Connecticut... 144 Morgan Street, Stamford, Connecticut 06905
Telex 096-5917 ...... Telephone: (203)DAvis 5-3817

NORTH CAROLINA
● Greensboro... 1011 Homeland Avenue, Greensboro 27405...Telex 057-417 .... Telephone: (919)274-4647

OHIO
Cleveland... 5562 Pearl Road, Suite 101, Cleveland 44129...Telex 098-5217 ...... Telephone: (216)884-6558
Columbus... 12 West Selby Blvd., Suite
Telex: WOGN 024-684 ... Telephone: (614)888-4040
Dayton...3309 Office Park Drive, Dayton 45439...Telex 02-8825 .... Telephone: (513)293-4175

PENNSYLVANIA
● Philadelphia... 126 Presidential Blvd. North, Bala-Cynwyd 19004...Telex 083-4218
Telephone: (215)TEnnyson 9-3111
Pittsburgh... 3834 Northern Pike, Monroeville 15146...Telex 086-761 .... Telephone: (412)351-3345

Central Pennsylvania
North Central Area — contact our Endicott, New York Office
South Central Area — contact our Baltimore, Maryland Office

TEXAS
● Dallas... 2600 Stemmons Freeway, Suite 162, Dallas 75207...Telex 073-2217
Telephone: (214)MElrose 1-4560
Houston... 3723 Westheimer, Suite H, Houston 77027...Telex 077-494 ... Telephone: (713)MOhawk 7-8301
Austin Area: ENterprise 3093
New Orleans, Louisiana Area: WX 3093

WASHINGTON
Seattle... 236 S.W. 153rd St., Seattle 98166...Telex 032-488 .... Telephone: (206)CHerry 3-2494
From Portland, Corvallis, Eugene (Oregon): Commerce 9369
From Pullman, Richland, Spokane, Yakima: Zenith 9369

WASHINGTON, D.C.
● Washington, D.C.... 4205 Evergreen Lane, Annandale, Virginia 22003...TWX: 703-256-8902...Telex 089-515
Telephone: (703) 256-6700
Norfolk, Portsmouth, and Hampton, Virginia Area: Enterprise 741

● Also Repair Center

Area Code Numbers are in parenthesis preceding telephone number.