Test equipment probes—Part I

By Vaughn D. Martin

As consumer electronics equipment becomes more technologically advanced, more sophisticated test equipment is required to service it. Oscilloscopes are being offered with greater bandwidth, digital storage capability, and other advanced features. Other types of test and diagnostic equipment such as logic analyzers and frequency counters are increasingly important in diagnostic procedures.

A piece of test equipment is only as good as the weakest link in the system. If the probes being used with a particular piece of test equipment for a particular task are not adequate, the result could be distorted results. And distorted test results could lead the technician in the wrong direction.

This four-part story will take an in-depth look at test equipment probes. Oscilloscope probes will be given the most attention, but the articles will also cover logic analyzer probes, a frequency counter delay equalizing probe, and even a TV/ video sync pod probe accessory.

The function of test equipment probes

Probes connect the measurement test points in a DUT (device under test) to the inputs of an oscilloscope or other test instrument. Achieving optimum system performance depends on selecting the proper probe. Connecting a scope and DUT with just wire, would not let you realize the full capabilities of your scope. But let's begin this article considering the characteristics of wire probes, then evolve into an ideal probe, step-by-step, examining all factors, including all design tradeoffs that affect probe performance.

Why not just use wire?

Why not just use a piece of wire as a probe? Good question. There are legitimate reasons for not using a piece of wire or, more correctly, two pieces of wire. Some low bandwidth scopes and special purpose plug-in amplifiers only provide bind-

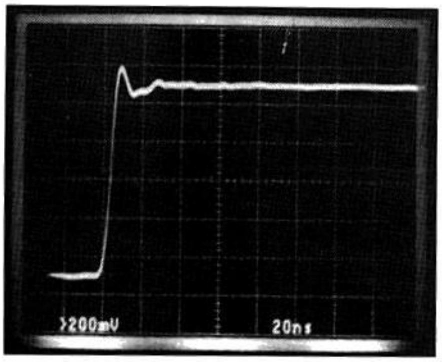


Figure 1. A signal from a 500Ω impedance with a 10MΩ, 10pF probe.

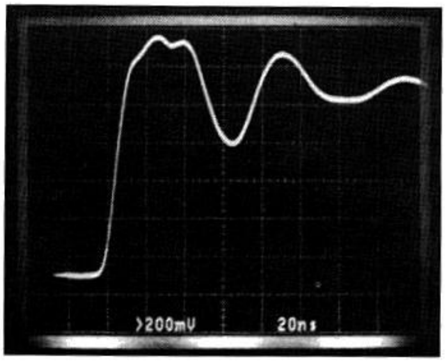
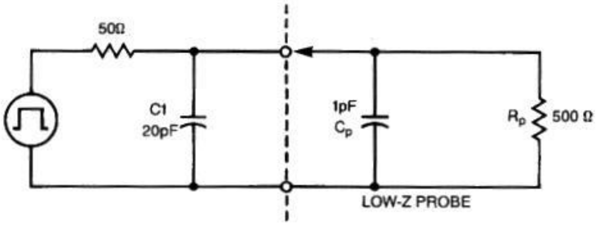


Figure 2. The same signal as in Figure 1 with a 2-meter-long probe. Note the effects of stray capacitance.

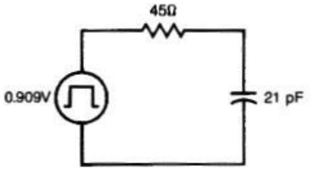
- If a low-R probe were used to measure the signal source, the probe loading circuit would change.
- In this instance R_p would not be 10 times greater than R1 and must be considered.



$V_0 = (500/(500 + 50)) \times V_{in} = .909 \times V_{in}$ (Voltage Divider with R_{source})

$R_{new} = R_{source} \parallel R_{probe} = 50 \parallel 500 = 45\ \Omega$

$C_{new} = C_{source} + C_{probe} = 21$ pF



$$\begin{aligned} tr &= 2.2 \times R_{new}C_{new} \\ &= 2.2 \times 45\ \Omega \times 21\ \text{pF} \\ &= 2.08\ \text{ns} \end{aligned}$$

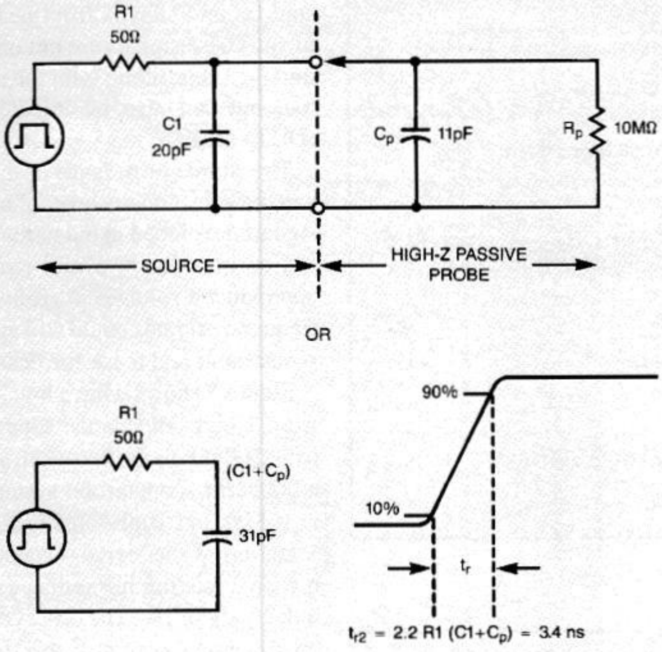
Faster than the risetime without the probe!

But, this decrease in risetime was "bought" at the expense of a loss of approximately 10% of the amplitude.

Figure 3. Loading effects of a low-Z probe.

Martin is Chief Engineer in the Automatic Test system Division at Kelly Air Force Base.

- If a typical passive probe is used to measure this signal, the probe's specified input capacitance and resistance is added to the circuit.



- Risetime was increased 55% by adding a 10 MΩ, 11 pF probe.
- There is no voltage divider action between R_{source} & R_{in} (probe). Hence amplitude measurement is 100% accurate.

Figure 4. Loading effects of a high-Z probe.

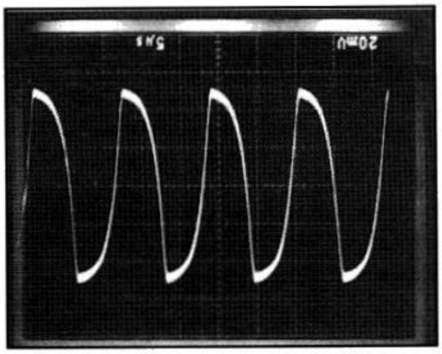


Figure 5. A low-level signal from a high-impedance source.

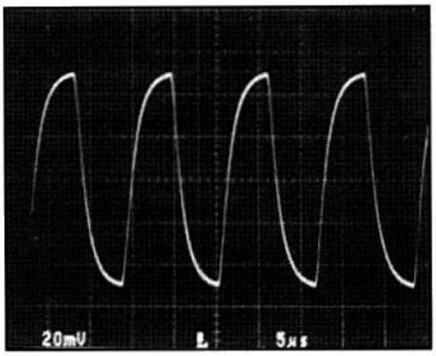


Figure 6. The same signal as in Figure 5 with the bandwidth limit (BW) switch engaged.

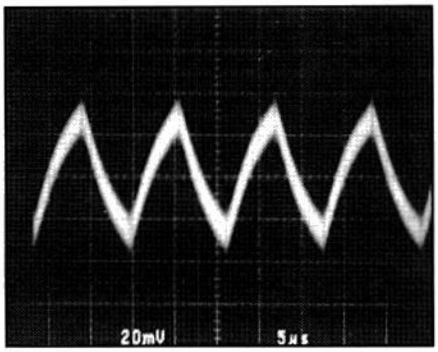


Figure 7. A "fuzzy" signal caused by use of a totally unshielded hookup wire for a probe.

ing post input terminals, a convenient means of attaching wires of various lengths.

DC levels associated with battery operated equipment could be measured. Low frequency (audio) signals from the same equipment and some high output transducers could also be examined. However, this type of connection should be kept away from line operated equipment for two basic reasons: safety and risk of equipment damage.

- Safety: Attachment of hookup wires to line-operated equipment could impose a physical safety hazard, either because the operator might come into contact with the hot side of the line itself, or with internally generated high voltages. In either case, the hookup wire offers you virtually no protection, either at the equipment source or at the scope's binding posts.
- Risk of equipment damage: Two unidentified hookup wires, one signal lead and one ground, could cause havoc in line-operated equipment. If the "ground" wire is attached to any elevated signal in line-operated equipment, various degrees of damage will result simply because both the scope and the equipment are (or should be) on the same three-wire outlet system, and short circuit continuity is completed through one common ground.

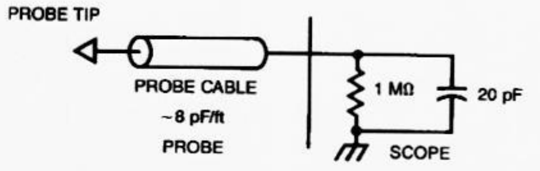
Circuit loading

Another reason that a straight piece of wire is not a desirable lead for an oscilloscope is that the oscilloscope might load the circuit to be tested, and therefore distort the measurements. The test equipment (scope and probe) presents a combination of resistance and capacitance to the circuit to which it is connected.

Without the benefit of using an attenuator (10X) probe, the loading on the (DUT) will be 1MΩ (the scope input resistance) and more than 15pF, which is the typical scope input capacitance, plus the stray capacitance of the hookup wire.

Figure 1 shows what a "real world" signal from a 500Ω impedance source looks like when loaded by a 10MΩ, 10pF probe: the scope/probe system is 300MHz, observed risetime is 6nsec.

Figure 2 shows the same signal when it is accessed by two two-meter lengths of hookup wire: loading is 1MΩ (the scope input resistance) and about 20pF (the scope input capacitance, plus the stray capacitance of the wires). Observed risetime has slowed to 10nsec and the transient response of the system has become unusable. Figures 3 and 4 show typical circuit loading for a low- Z and a hi-Z probe respectively (both to be explained shortly).



DISADVANTAGES:

- HIGH C_{in}

  $C_{in} = C_{scope} + C_{cable} = 20\text{ pF} + (8\text{pF/ft} \times 5\text{ ft}) = 60\text{ pF}$ (For a 1.5 m probe)

- LOW BANDWIDTH

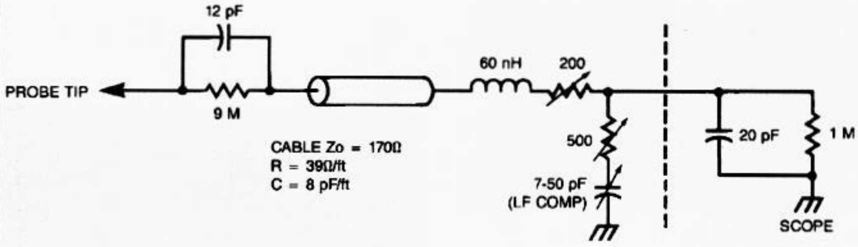
  R_{source} & C_{in} of the probe combine to form a low-pass filter. If R_{source} is only 100Ω, maximum BW will be equal to $1/(2\pi R_{source} C_{in})$ or only 26 MHz for this 1X probe.

ADVANTAGES:

- HIGH R_{in} (1 MΩ)
- GOOD FOR VIEWING LOW-FREQUENCY, LOW-AMPLITUDE SIGNALS

  (Like 60 Hz ripple on the output of a linear power supply.)

Figure 8. A typical 1X probe.



FOR LF COMP:

$R_{tip} \times C_{tip} = R_{scope} \times C_{tot}$

$9\text{ M} \times 12\text{ pF} = 1\text{ M} \times (C_{scope} + C_{cable} + C_{lf\ comp})$

where $C_{cable} = 8\text{ pF/ft} \times \text{cable length (ft)}$

CABLE TERMINATION NETWORK:

60 nH contributes inductive peaking

200 Ω is a first order high-freq termination for the cable

7-50 pF allows padding of C_{tot} for proper lf comp

500 Ω adjusts squareness of front corner

REDUCED LOADING:

$R_{in} = R_{tip} + R_{scope} = 9\text{ M}\Omega + 1\text{ M}\Omega = 10\text{ M}\Omega$

$C_{in} = C_{tip}$ in series with C_{tot}

$1/C_{in} = 1/C_{tip} - 1/C_{tot}$

C_{tip} places a limiting value on C_{in}
(for $C_{tip} = 12\text{ pF}$, $C_{in} \le 12\text{ pF}$)

This is less than C_{in} of the scope, and 49 pF less than the C_{in} of the 1X probe.

Figure 9. A typical 10X probe.

Susceptibility to external pickup

An unshielded piece of wire acts as an antenna for the pickup of internal fields, such as line frequency interference, electrical noise from fluorescent lamps, radio stations and signals from nearby equipment. These signals are not only injected into the scope along with the desired signal, but can also be injected into the (DUT) itself.

The source impedance of the DUT has a major effect on the level of interference signals developed in the wire. A very low source impedance would tend to shunt any induced voltages to ground, but high frequency signals could still appear at the scope input and mask the desired signal.

Figure 5 shows what a low level signal from a high impedance source (100mV from 100kΩ) looks like when accessed by a 300MHz scope/probe system; loading is 10MΩ and 10pF. This is a true representation of the signal, except the probe resistive loading has reduced the amplitude by about 1%. The observed high-frequency noise is part of the signal at the high impedance test point and would normally be removed by using the BW (bandwidth) limit button on the scope (see Figure 6).

If you were to look at the test point with those two pieces of wire, two things happen (Figure 6): the amplitude drops due to the increased resistive and capacitive loading, and noise is added to the signal because the hookup wire is completely unshielded (Figure 7). Most of the noise you see in the photo is line frequency interference from fluorescent lamps in the test area.

Probably the most annoying effect of using hookup wire to observe high frequency signals is its unpredictability. Any touching or rearrangement of the leads can produce different and nonrepeatable effects on the observed display.

Benefits of using probes

For starters, probes help minimize loading. To a certain extent, all probes load the DUT—the source of the signal you are measuring. Still, probes offer the best means of making the connections needed. A simple piece of wire, as we have just seen, would severely load the DUT. In fact, the DUT might stop functioning altogether.

Probes are designed to minimize loading. Passive, non-attenuating 1X probes

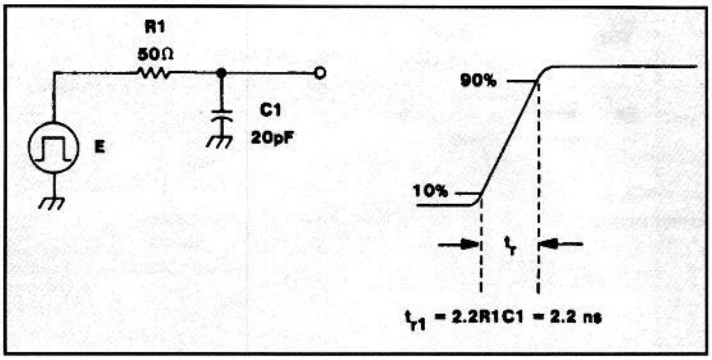


Figure 10. Internal source resistance and capacitance affect the equivalent circuit. At no time can the output risetime be faster than 2.2(RC) or 2.2nsec.

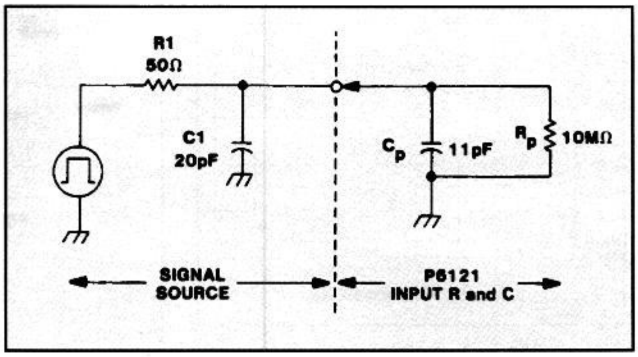


Figure 11. Adding the impedance characteristics of the probe to the circuit under test.

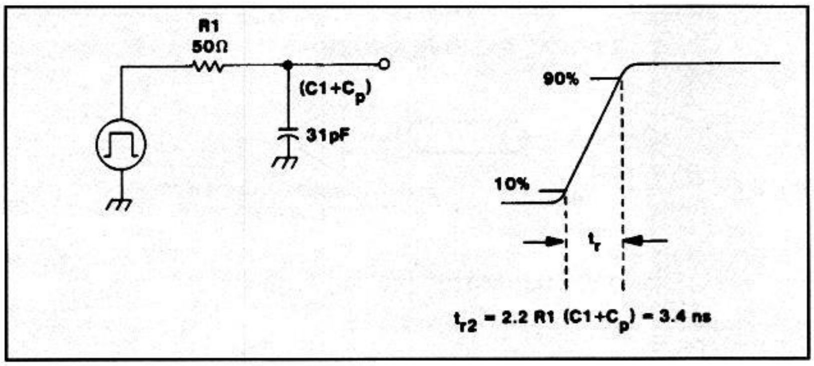


Figure 12. Observing how a probe affects risetime.

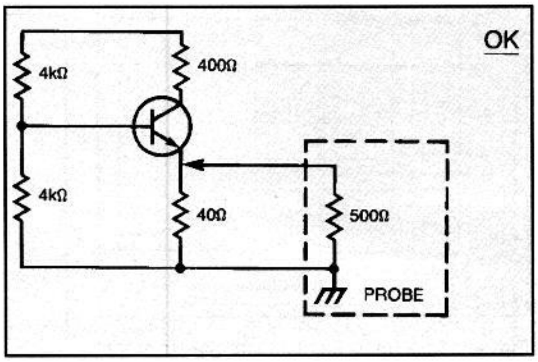


Figure 13. An example of when using a low-Z probe is appropriate.

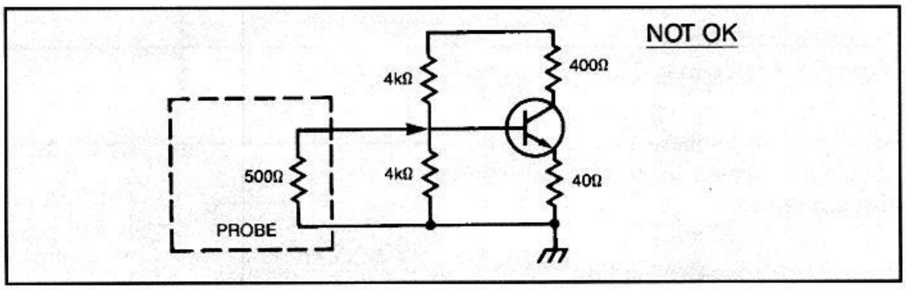


Figure 14. An example of when using a low-Z probe is not appropriate.

offer the highest capacitive loading of any probe type. Even passive 1X probes, however, are designed to keep loading as low as possible (Figure 8).

Probes extend a scope's signal amplitude handling capability. Besides reducing capacitive and resistive loading, a standard passive 10X (ten times attenuation) probe extends the on-screen viewability of signal amplitudes by a factor of ten (Figure 9).

A typical scope minimum sensitivity is 5V/division. Assuming an eight-division vertical graticule, a 1X probe (or a direct connection) would allow on-screen viewing of 40Vpp maximum. The standard 10X passive probe provides 400Vpp viewing. Following the same reasoning, a 100X probe should allow 4kV on-screen viewing. However, most 100X probes are rated at 1.5kV to limit power dissipation in the probe itself.

Check the specs

Bandwidth is the probe specification most users look at first, but plenty of other features also help to determine which probe is right for a given application. Circuit loading, signal aberrations, probe dynamic range, probe dimensions, environmental degradation and ground-path effects will all affect the probe selection process.

How probes affect measurement

Probes affect measurements by loading the circuit that you are examining. The loading effect is generally stated in terms of impedance at some specific frequency, and is made up of a combination of resistance and capacitance.

- Source impedance. Obviously, source impedance will have a large impact on the net effect of any specific probe loading. For example, a device under test with a near zero output impedance would not be affected in terms of amplitude or risetime to any significant degree by the use of a typical 10X passive probe. However, the same probe connected to a high impedance test point, such as the collector of a transistor, could affect the risetime and amplitude of the signal.
- Capacitive loading. To illustrate capacitive loading, let's take a pulse generator with a very fast risetime. If the initial risetime was assumed to be zero (tr = 0), the output tr of the generator would be limited by the associated resistance and capacitance of the generator. This *integration network* produces an output risetime equal to 2.2(RC). This limitation is derived from the universal time-constant curve of a capacitor.

Figure 10 shows the effect of source resistance and capacitance on the equivalent circuit. At no time can the output rise-

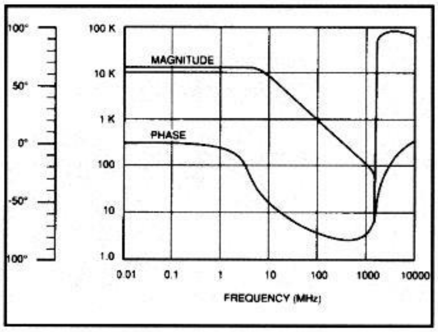


Figure 15a. An impedance vs frequency graph of an active probe.

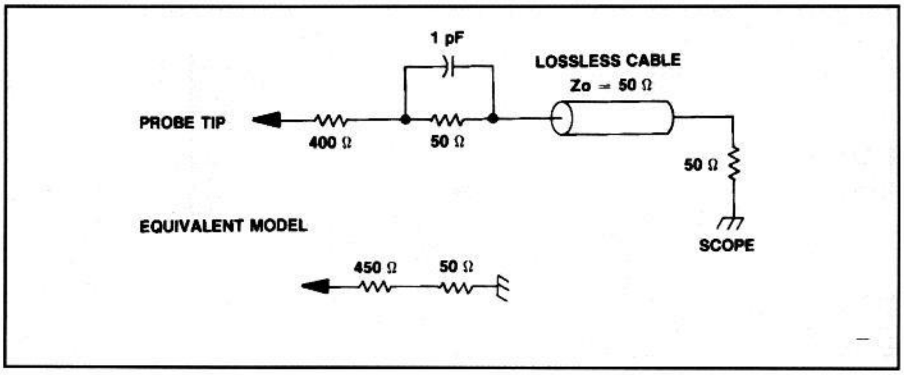


Figure 16. An illustration of how a low-Z probe offers low tip capacitance.

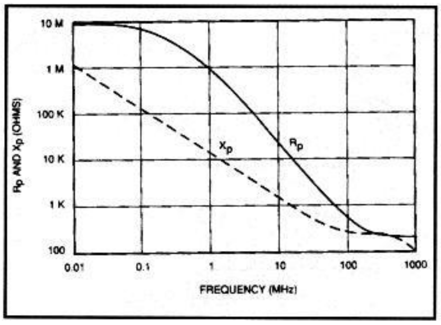


Figure 15b. An impedance vs frequency graph of a passive probe.

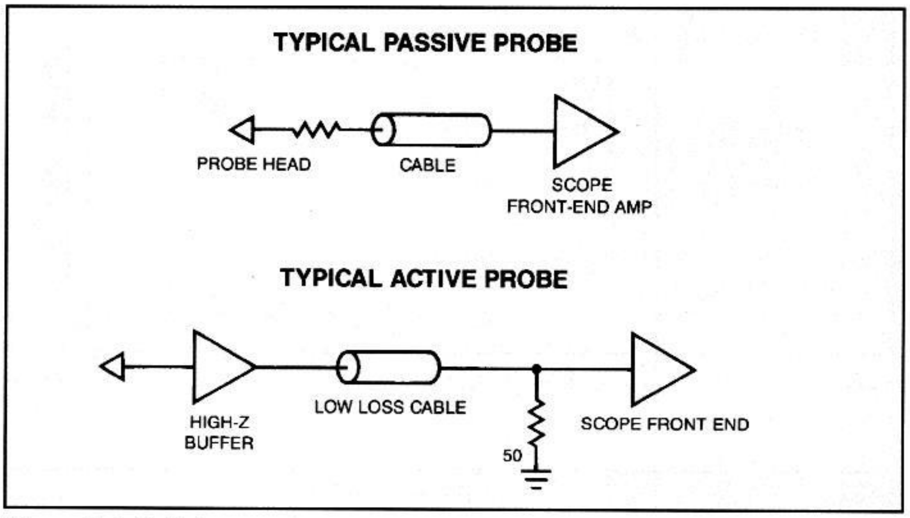


Figure 17. A block diagram of an active probe.

time be faster than 2.2(RC) or 2.2nsec.

If a typical probe were used to measure this signal, the probe's specified input capacitance and resistance would be added to the circuit as shown in Figure 11. Because the probe's 10MΩ resistance is much greater than the generator's 50Ω output resistance, it can be ignored.

Figure 12 shows the equivalent circuit of the generator and probe, applying the 2.2(RC) formula again. The actual risetime has slowed from 2.2nsec. to 3.4nsec.

Percentage change in risetime due to the added probe tip capacitance:

$$\% \text{ change} = [(tr_2-tr_1)/tr_1]\text{x}100$$
$$= [(3.4-2.2)/2.2]\text{x}100$$
$$= 55\%$$

Another way of estimating the effect of probe tip capacitance is to take the ratio of the probe tip capacitance (marked on the probe compensation box) to the known or estimated source capacitance.

Using the same values:

$$[C(\text{probe tip})/C_1]\text{x}100$$
$$= [11\text{pF}/20\text{pF}]\text{x}100 = 55\%$$

Any added capacitance slows the source risetime when using high impedance passive probes. In general, the greater the attenuation ratio, the lower the tip capacitance.

Capacitive loading

When probing continuous wave (CW) signals, the probe's capacitive reactance at the operating frequency must be taken into account. The total impedance as seen at the probe tip is designated Rp, and is a function of frequency. In addition to the capacitive and resistive elements, designed-in inductive elements serve to off-

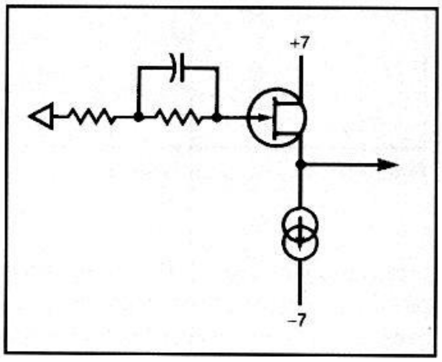


Figure 18. A typical FET front end of an active probe.

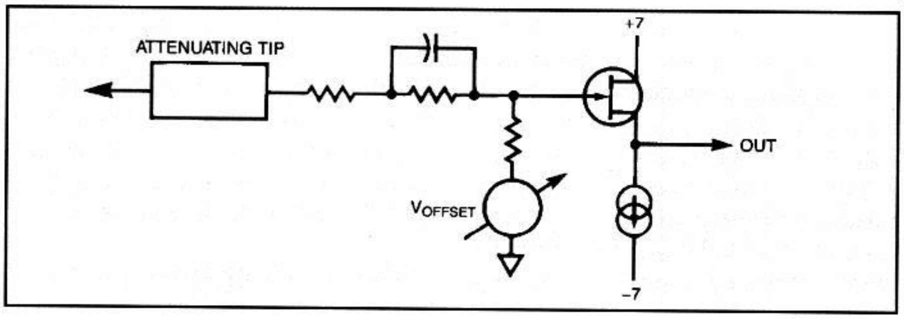


Figure 19. An improved front end of an active probe.

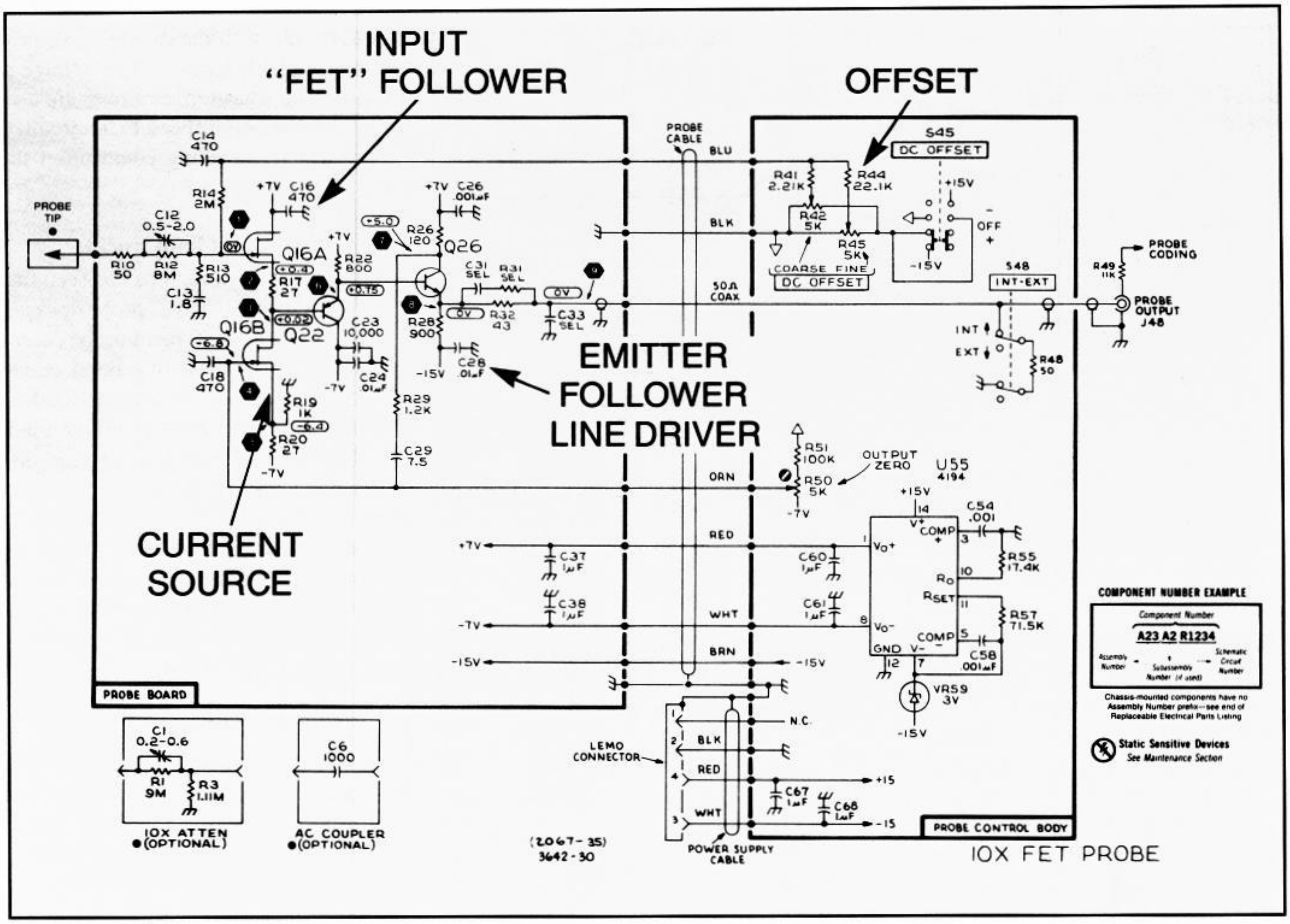


Figure 20. A schematic of a commercially-available active probe.

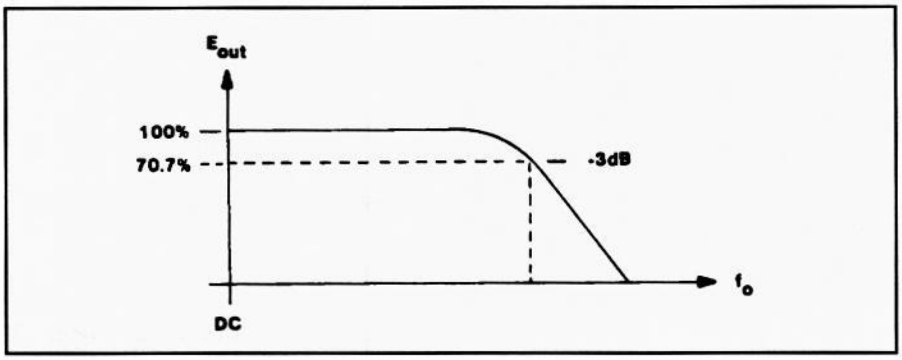


Figure 21. A typical response of an oscilloscope system.

set the pure capacitive loading to some degree. Figures 13 and 14 show uses of low-Z probes.

Curves showing typical input impedance vs frequency, or typical Xp and Rp vs frequency are included in most probe instruction manuals. Figure 15A shows the typical input impedance and phase relationship vs frequency of one active probe. Note the 10kΩ input impedance is maintained to almost 10MHz by careful design of the associated resistive, capacitive and inductive elements.

Figure 15B shows a plot of Xp and Rp vs frequency for a typical 10MΩ passive probe. The dotted line (Xp) shows capacitive reactance vs frequency. The total loading is again offset by careful design of the associated R, C and L elements.

If you do not already have access to the information and need a worst-case guide to probe loading, use this formula:

$$Xp = 1/2\pi FC,$$ where

Xp = capacitive reactance in Ω
F = operating frequency
C = probe tip capacitance

For example, a standard passive 10MΩ probe would have a tip capacitive reactance (Xp) of about 290Ω at 50MHz.

Depending, of course, on the source impedance, this loading could have a major effect on the signal amplitude (by simple divider action), and even on the operation of the circuit being measured.

Resistive loading

For all practical purposes, a 10X, 10MΩ passive probe has little effect on today's circuitry in terms of resistive loading. However, they do carry a tradeoff in terms of relatively high capacitive loading previously discussed.

Low-Z passive probes

A "low Z" passive probe offers very low tip capacitance at the expense of very high resistive loading. A typical 10X "50Ω" probe has an input C of about 1pF and a resistive loading of 500Ω. Figure

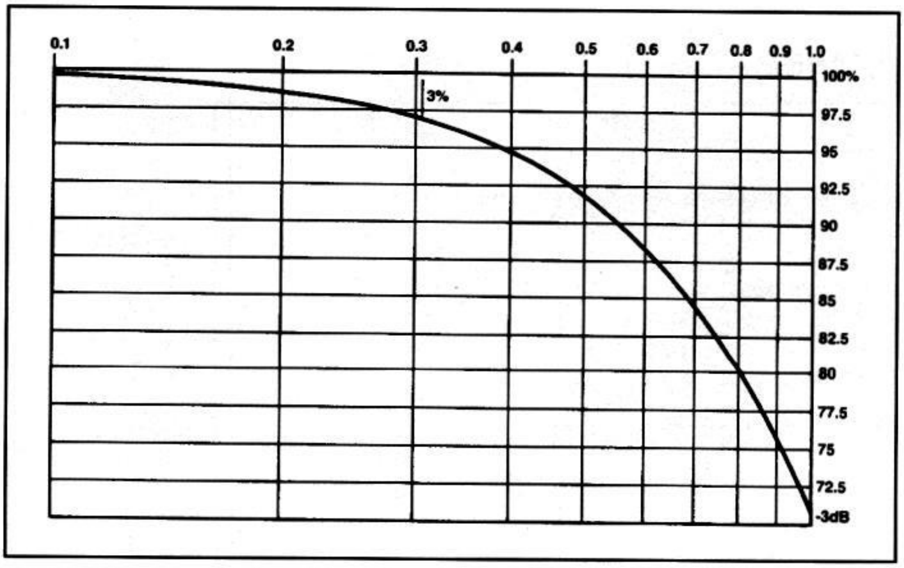
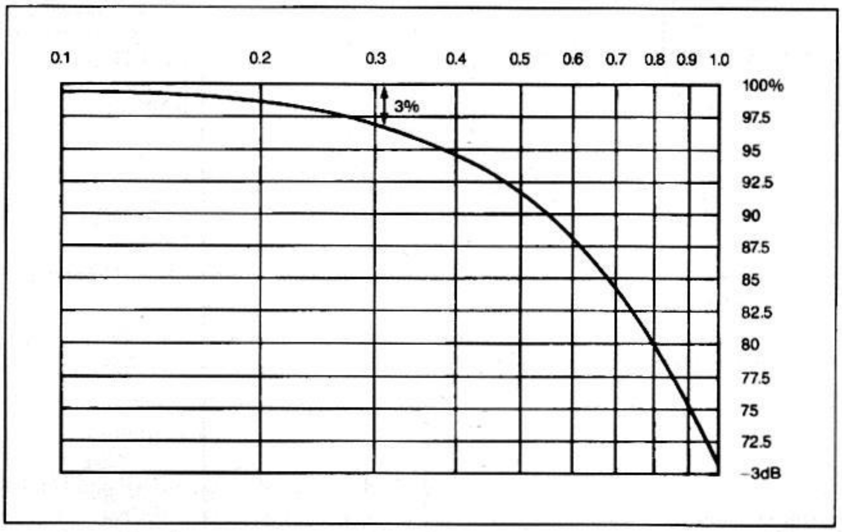


Figure 22. An expanded view of the -3dB area of an oscilloscope system.



Amplitude accuracy degraded to −3% at only 0.3 of normalized bandwidth. Therefore, a 350 MHz system is 3% accurate to only (.3)(350 MHz) = 105 MHz.

Figure 23. Amplitude accuracy vs normalized frequency.

16 shows the circuit and equivalent model of this type of probe.

This configuration shows a high frequency 10X voltage divider because, from transmission line theory, all that the 450Ω tip resistor sees looking into the cable is a pure 50Ω resistance, no C or L component. No low frequency compensation is necessary because it is not a capacitive divider.

Low Z probes are typically high bandwidth (up to 3.5GHz and risetimes up to 100ps) and are best suited for making risetime and transit-time measurements. They can, however, affect the pulse amplitude by simple resistive divider action between the source and the load (probe).

Because of its resistive loading effects, this type of probe performs best on 50Ω or lower impedance circuits under test. These probes operate into 50Ω scope inputs only. They are typically teamed up with fast (500MHz to 1GHz) real time scopes or with scopes employing the sampling principle.

Bias-offset probes

A bias/offset probe is a special kind of low-Z design with the capability of providing a variable bias or offset voltage at the probe tip. Bias/Offset probes are useful for probing high speed ECL circuitry, where resistive loading could upset the operating point.

The best of both worlds

From the foregoing, it can be seen that the totally "non-invasive" probe does not exist. However, one type of probe comes close: the active probe. In general, active probes provide low resistance loading (10MΩ) with very low capacitive loading (1pF to 2pF). They do have trade-offs in terms of limited dynamic range, but under the right conditions, offer the best of both worlds (Figures 17, 18, 19 and 20: a block diagram, the front end of such a probe, an improved front end and a schematic of an actual commercially available active probe, respectively).

Bandwidth

Bandwidth is the range of frequencies between the two points on an amplitude versus frequency curve where the amplitude of the signal is down 3dB from a starting (reference) level. Figure 21 shows a typical response curve of an oscilloscope system. Scope vertical amplifiers are designed for a Gaussian roll-off at the high end. With this type of response, risetime is approximately related to bandwidth by the following equation:

Tr=0.35/Bandwidth

or, Risetime = 350/Bandwidth(MHz)

Note the measurement system is 3dB (30%) down in amplitude accuracy at the specified bandwidth limit. Figure 22 shows an expanded portion of the -3dB area. The horizontal scale shows the input frequency derating factor necessary to obtain accuracies better than 30% for a specific bandwidth scope.

For example, with no derating, a "100 MHz" scope will have up to a 30% amplitude error at 100MHz (1.0 on the graph). If amplitude accuracy is to be better than 3%, the input frequency must be limited to about 30MHz (100 MHz/3).

For making amplitude measurements within 3% at a specific frequency, choose a scope with at least four times the specified bandwidth, as a general rule of thumb (Figure 23).

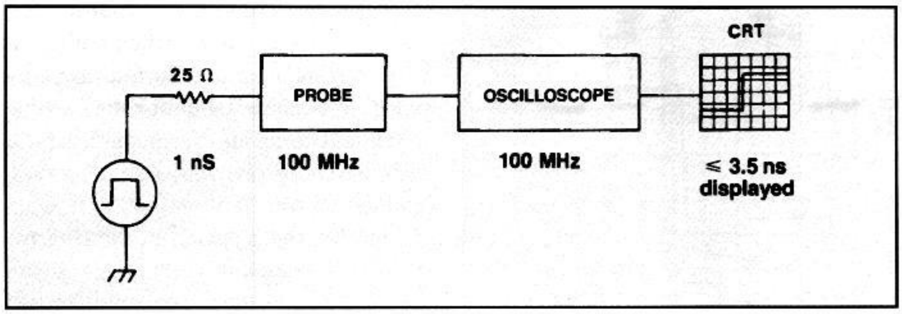


Figure 24. An equivalent circuit of a typical test setup.

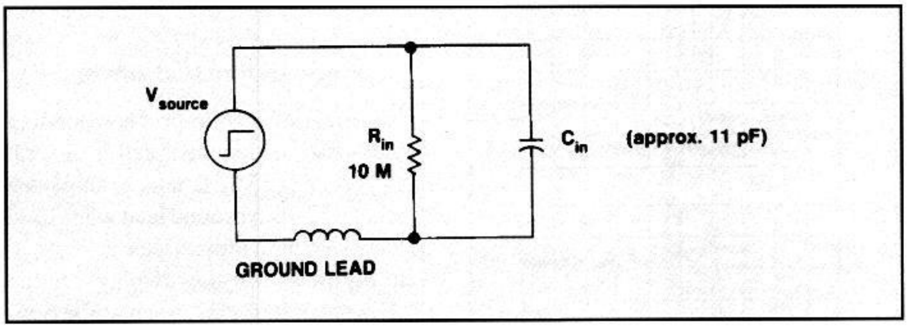


Figure 25. Effects of ground lead inductance.

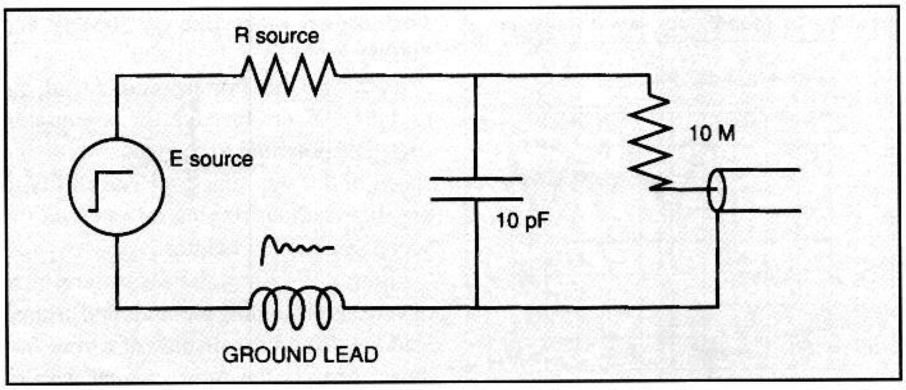


Figure 26. An equivalent circuit of a typical passive probe connected to a source, including ground lead inductance.

Probe bandwidth

All probes are ranked by bandwidth, just as scopes or amplifiers are. To determine the risetime of the scope/probe system, apply the square root of the sum of the squares formula. This formula states:

$$T_r = \sqrt{(Tr^2 \text{ displayed} - Tr^2 \text{ source})}$$

Passive probes do not follow this rule and should not be included in the square root of the sum of the squares formula. Most manufacturers provide a probe bandwidth ranking system specifying the bandwidth (frequency range) over which the probe performs within its specified limits. These limits include: total aberrations, risetime and swept bandwidth.

Both the source and the measurement system should be specified when checking probe specifications. In general, a "100 MHz" probe provides 100MHz performance (-3dB) when used on a compatible 100MHz scope. That is, it provides full scope bandwidth at the probe tip. However, not all probe/scope systems can follow this general rule.

Test methods

As with all specifications, matching test methods must be employed to obtain specified performance. With bandwidth and risetime measurements, it is essential to connect the probe to a properly terminated source. One manufacturer, for example, specifies a 50Ω source terminated in 50Ω, making this a 25Ω source impedance. Furthermore, the probe must be connected to the source via a proper probe tip to BNC adapter (Figure 24).

Scope bandwidth at the probe tip?

Most manufacturers of general purpose oscilloscopes with standard accessory probes in the package, promise and deliver the advertised scope bandwidth at the probe tip.

However, not all high performance scopes can offer this performance even when used with their recommended passive probes. This is because even the highest impedance passive probes are limited to about 300MHz to 350MHz, while still meeting their other specifications. This performance is only obtainable under strictly controlled, and industry recognized conditions; which states that the signal must originate from a 50Ω back-terminated source (25Ω), and the probe must be connected to the source by a probe tip to BNC (or other) adapter.

This method ensures the shortest ground path and necessary low impedance to drive the probe's input capacitance, and to provide the specified bandwidth at the signal acquisition point—the probe tip. Real-world signals rarely originate from 25Ω sources, so less than optimum transient response and bandwidth should be expected when measuring higher impedance circuits.

How ground leads affect measurements

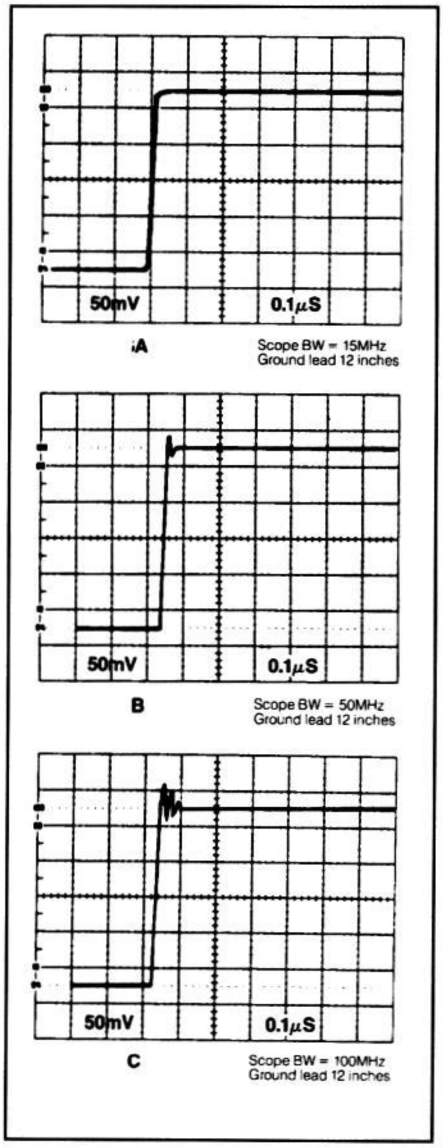
A ground lead is a wire providing a local ground-return path when you are measuring any signal. An inadequate ground lead (one that is too long or too high in inductance) can reduce the fidelity of the high-frequency portion of the displayed signal (Figure 25).

What grounding system to use

When making any measurement, some form of ground path is required to make a basic two-terminal connection to the DUT. If you want to check the presence or absence of signals from low-frequency equipment, and if the equipment is line-powered and plugged into the same outlet system as the scope, then the common 3-wire ground system provides the signal ground return. This indirect route adds inductance in the signal path. It can also produce ringing and noise on the displayed signal and is not recommended.

When making any kind of absolute measurement, such as amplitude, risetime or time delay, you should use the shortest grounding path possible, consistent with the need to move the probe among test points. The ultimate grounding system is an in-circuit ECB- (etched circuit board) to-probe-tip adapter. You can purchase these for miniature, compact or subminiature probe configurations.

Figure 26 shows an equivalent circuit of a typical passive probe connected to a source. The ground lead L and C form a series resonant circuit with only 10MΩ for damping. When hit with a pulse, it will ring. Also, excessive L in the ground lead will limit the charging current to C, the probe's capacitance, limiting the risetime.



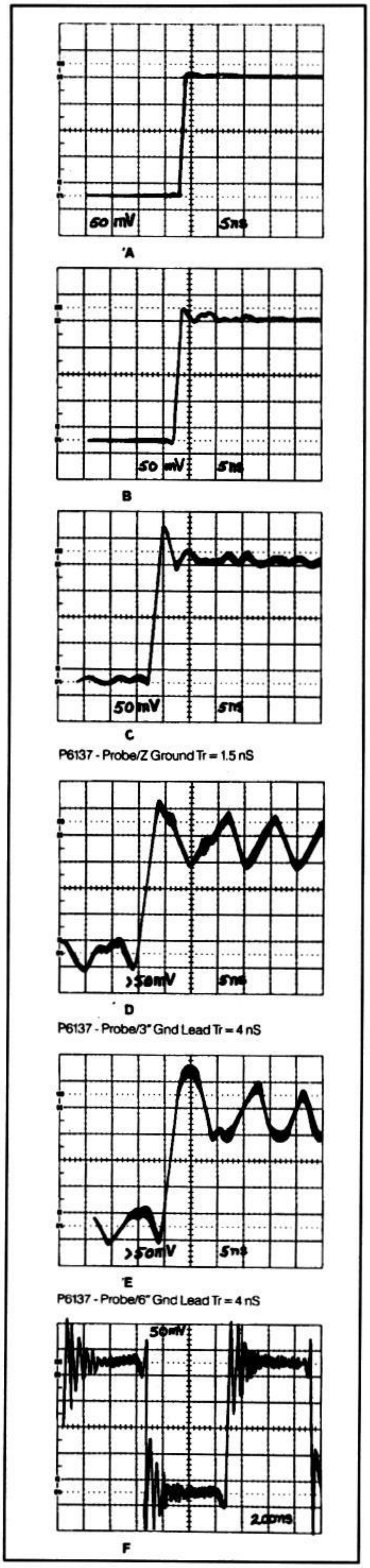
Scope BW = 15MHz
Ground lead 12 inches

Scope BW = 50MHz
Ground lead 12 inches

Scope BW = 100MHz
Ground lead 12 inches

Figure 27. Effects of ground lead inductance on oscilloscopes of various bandwidths. A. BW = 15MHz and ground lead = 12 inches. B. BW = 50MHz and ground lead = 12 inches. C. BW = 100MHz and ground lead = 12 inches.

Figure 28. An optimal impedance match, minimizing ground lead effects. ➤



P6137 - Probe/Z Ground Tr = 1.5 nS

P6137 - Probe/3" Gnd Lead Tr = 4 nS

P6137 - Probe/6" Gnd Lead Tr = 4 nS

Without going into the mathematics, an 11pF passive probe with a 6-inch ground lead would ring at about 140MHz when excited by a fast pulse. As the ring frequency increases, it tends to get outside the passband of the scope and is greatly attenuated. To increase the ring frequency, use the shortest ground lead possible and use a probe with the lowest input C.

Probe ground lead effects

The effect of inappropriate grounding methods can be demonstrated in several ways. Figures 27A, B and C show the effect of a 12-inch ground lead when used on various bandwidth scopes.

In Figure 27A, the display on the 15MHz scope looks OK because the ringing aberrations are beyond the passband of the instrument and are greatly attenuated. Figures 27B and C show what the same signal looks like on 50MHz and 100MHz scopes.

Even with the shortest ground lead, the probe-DUT interface has the potential to ring. The potential to ring depends on the speed of the step function. The ability to see the resultant ringing depends on the scope system bandwidth.

Figures 28A through F show the effects of various grounding methods and ground lead lengths on the display of a very fast pulse. This is the most critical way of looking at ground lead effects: we used a fast pulse, with a risetime of about 70ps and a fast (400MHz) scope with a matching probe.

Figure 28A shows the input pulse under optimum conditions when using 50Ω coax cable. The scope has an input impedance of 50Ω, the cable is 50Ω, and the source impedance is 50Ω. Displayed risetime is 1nsec.

Figure 28B shows the same signal when using the scope-probe combination under the most optimum conditions. A BNC to probe adapter or an in-circuit test jack provides a coaxial ground that surrounds the probe ground ring. This system provides the shortest probe ground connection available, displayed risetime is 1 nsec.

Part II examines how the design and type of probe affects your measurements.

Details, details, details

When thinking about the equipment we use every day, we tend to take certain items for granted. We tend to think about some things as commodity items, and give little thought to their selection, use and care. But every part of a system, at least a high performance system, has to be carefully designed and manufactured, and users should be attentive to their selection and care.

Take for example, the automobile. Most of us really don't think a great deal about the tires on the car. They're just black rubber things that have to go on the wheels, and that occasionally go flat and have to be replaced.

And when the car isn't going very fast, or won't be driven for a long period of time, or won't be going around corners very quickly, and when it isn't too hot out, and the surface of the road is in good shape, and when it isn't raining, and when there isn't several inches of rain on the roadway, or when there isn't snow, or ice on the road, the *quality* of the tires is not of major importance.

But in general, a tire is doing a lot of things that we really don't realize as we drive down the road. For example, as the tire rolls, the part of the tire that rolls to the bottom becomes flat. As that flat part rolls around toward the top, it becomes round again. That action causes the tire to be constantly flexing. That flexing generates heat that the tire must be designed to deal with. And the faster the car is driven, the greater the heat buildup in the tire.

As you turn a corner, the tire has a tendency to roll, so that if it weren't designed to be stiff enough the tread would roll away from the direction of travel and you'd be riding on the sidewall, and, of course, you'd lose traction. In cases of extreme cornering speeds and inadequate stiffness, the tire would roll right off the rim.

The dangers of hydroplaning in the wet, or losing traction in the snow are pretty obvious. Properly designed tire treads minimize those problems.

And yet, for the most part, most drivers take those tires for granted—until a tire that was of inadequate quality for the type of driving fails, perhaps catastrophically.

Test equipment accessories are sometimes taken for granted

It's pretty much the same with test equipment probes. Most of us who are technical can get pretty excited over a new oscilloscope or DMM that offers some new measurement features, or improved accuracy, or increased ease of use. But when we're thinking about all of those wonderful features, how often do we think about the probes that come with the unit.

We buy the unit without giving any thought to the probes. If we think about it at all, we generally simply expect that the manufacturer will provide probes that are adequate to the tasks that the product is designed to perform. And, that's a pretty good assumption. Test equipment manufacturers know what their products can do and provide an adequate set of probes with the product.

But most things wear out, or break, or become damaged. And test probes have a tendency to do that. They hang there on the bench where they can come into contact with a hot soldering iron. They're subjected to abuse by the technicians who use them. They become abraded by sharp edges on the bench or the equipment they're used to probe. They're dropped, or things are dropped on them.

When the test probes become damaged, they're replaced. Unfortunately, they're not always replaced with test probes of the quality of the originals. Service centers should know the requirements of the products they're testing in order to know the quality of probes they need.

For example, in order to look at digital signals, the probes need to be able to conduct a wide range of frequencies to the oscilloscope inputs. Square corners such as you see on digital signals contain, theoretically, sinewaves of an infinite number of frequencies, including those of many times the frequency of the square wave signal. If the probes attenuate the higher frequency components, the signal will be rounded, giving a distorted rendition of the signal.

A system is only as good as its weakest link

The same principle holds in just about every aspect of life, even, for example, in the worlds of culture and entertainment. Have you ever been to a movie or a play in which all of the parts were played by competent, believable actors, except for one part that was played by someone who was just not very good or seriously miscast. The level of the overall performance is basically set by the performance of that poorest of the performers.

The same is true of a musical performance. Whether you're listening to a symphony, a rock band or a singing group, if one of the musicians or singers is a little flat you're going to hear it and the level of that sound will set the grade that you'll give that group.

Attention to detail

The only way to be sure that your test equipment will give you the accuracy you need to troubleshoot a product, the only way that you can be sure that your tools will do the job you need them to do, the only way you can be sure that everyone in your organization is contributing positively to the mission of the organization is to know what needs to be done, what level of performance you want or need in getting that mission accomplished, and to select every piece of equipment, every accessory, and especially every individual so that the lowest level of each is of a quality at least as good as the performance that you wish to achieve.

Nils Conrad Persson