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JULY-AUGUST 1974

OSCILLOSCOPE PROBES & MEASUREMENT TECHNIQUES

by Chuck Donaldson

Historically, the oscilloscope has been used as a tool to make measurements of amplitude versus time over a rather broad frequency range. Since the display is completely visual, the capability of deriving a great deal of qualitative information, e.g. waveform shapes, perturbations, etc. as well as the quantitive values of amplitude and time, has caused the oscilloscope to become the engineer's "screwdriver". When a problem exists, or gross circuit characteristics are required, he has become accustomed to reaching for his scope, hooking it up to his circuit, and gathering information, without regard for such considerations as input and output impedances, rise times, etc. If a probe was required, the one which was mechanically most convenient was typically the one which would be used.

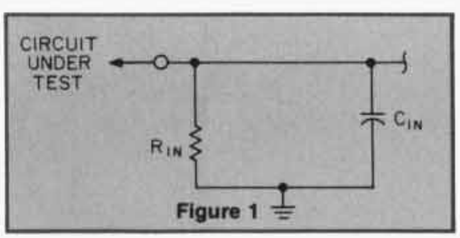


Figure 1

Divider Probes

Let's talk about how to make measurements with a typical general purpose scope-probe combination. Initially, we'll restrict the discussion to passive probes working into a high-impedance oscilloscope. In order to appreciate the problems involved, we might want to take a look at just what a probe is, and what it is intended to do. The input circuit of an oscilloscope has traditionally been a parallel RC circuit as shown in Figure 1. The advantage of this type of circuit is that R_{in} can be made high enough to present an insignificant load to many circuits (1 Megohm) while C_{in} can be held to a low enough value to maintain the desired system bandwidth. How does the probe affect the measurement? The simplest case is that of a 1:1 transfer probe where the probe simply looks like a small resistance (200 to 300 ohms) in series with the scope input, and a fairly large capacitance (approximately 37 to 55 pf) in shunt with the input of the oscilloscope. See Figure 2. The total magnitude of R remains essentially constant, but the new value of C presented to the circuit under test is $C_{probe} + C_{input}$, so we now have approximately 1 Megohm paralleled by 57 to 84 pf. This additional capacitance will translate into a loss of rise time and bandwidth. We can measurably improve the situation through use of a 10:1 divider probe, for those cases where the signal voltage is sufficient to drive the oscilloscope after the 10:1 division. A simplified circuit of this type of probe is shown in Figure 3. Looking into the probe tip, the circuit sees resistance of $R_{probe} + R_{input}$. Typically, this would be 9M ohms + 1M ohm. More importantly, note that the capacitors are in series and the effective capacitance is $\frac{(C_{comp}) \cdot (C_{input})}{C_{comp} + C_{input}}$.

Typically the circuit sees a shunt capacitance of about 10 pf!

While this is a very dramatic improvement, this concept can be carried only so far since passive probe capacitance cannot easily be reduced to zero, and there is certainly a point of voltage division which becomes impractical.

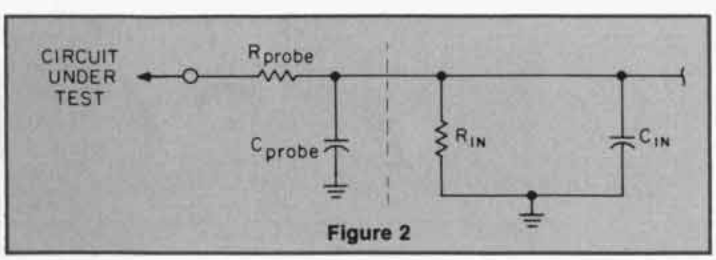


Figure 2

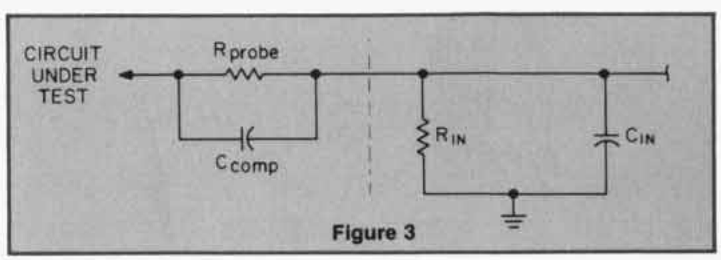
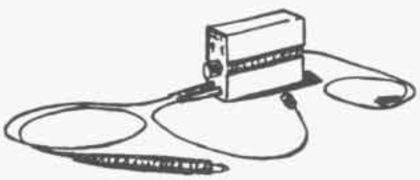


Figure 3

Active Probes

Active probing devices are the highest resistance/lowest capacitance probes available today. An active probe with a 10:1 divider can provide an input resistance of 1 Megohm shunted by about 1 pf of capacitance. These active probes are typically used with oscilloscopes that have vertical amplifiers with a 50 ohm input impedance.

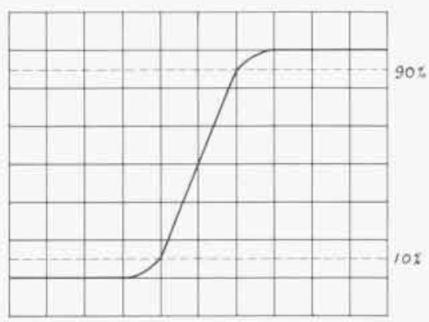


Active probes aren't usually thought of as general purpose probes, and because they are more expensive, more care needs to be taken in their use. Suffice is to say that when working at very high frequencies (above 300 MHz or so), there are different probes and techniques available to obtain more accurate results (e.g. sampling oscilloscopes).

Measurement Accuracy

Let's now consider measurement accuracy. Suppose you feed the output of a pulse generator through a probe to an oscilloscope. You adjust the scope time base for a fast sweep. (This is the typical setup for measurement of rise time). The result is the familiar rise-time waveform shown in Figure 4. If the time base is set for a sweep of 5 nanoseconds per division, what is the rise time of the generator's output pulse (ignoring any inherent scope inaccuracies)?

Figure 4. Pulse rise time is measured between the 10% and 90% points on the leading edge of oscilloscope trace. In this case, rise time is 10 ns.



Reading the CRT, you answer 10 ns. Right? Maybe yes, and maybe no.

Although 10 ns is the reading of the scope display, this value may not be the true rise time of the pulse. Ignoring scope inaccuracies, what other reason is there for suspecting that the measurement is not the real rise time?

Basically, when the pulse passes through the probe, the scope amplifier, and even the scope CRT, it suffers rise time deterioration. Thus, the displayed waveform doesn't represent the true, original signal.

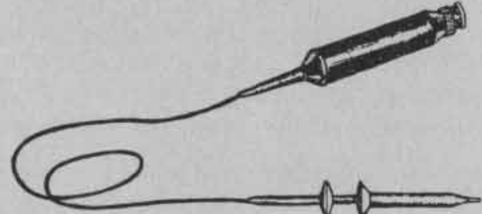
Although this is an unfortunate circumstance, it has one saving grace: it can be predicted. So if you erroneously said that the rise time in the example was 10 ns, it should be both interesting and informative to learn how to determine what the error might be.

True rise time can be determined by the use of the tongue-twisting formula known as the "square root of the sum of the squares." In mathematical terms:

$$T_{RG} = \sqrt{T_{RD}^2 - T_{RS}^2}$$

where T_{RG} = true signal generator rise time

It might be worthwhile to point out that even though the oscilloscope system is the engineer's "screwdriver", they need to be handled with more care than the normal screwdriver. This is particularly true for the probe. Many times a probe will be used to pull a 'scope around when it is on a cart.



It is sometimes dropped on the floor, stepped on or rolled over with a cart.

Probes are designed to be as rugged as possible, but many times they are abused. It turns out that a high-frequency passive probe is a fairly sophisticated piece of electronic equipment, even if it doesn't sound or look exciting. Electrically, there is a complex termination and compensation network at the base of the probe. The probe tip has the divider resistor (usually about 9M ohms) and another compensating capacitor. One of the toughest things to design and build well is the probe cable. To keep the input capacitance at the probe tip as low as possible, the cable must be very low capacitance. To accomplish this, a very small diameter center conductor must be used. The smaller the center conductor, the lower the capacitance, but also, the easier it is to break the center conductor. The typical diameter of a probe cable center conductor is 4 mils (about the size of a hair!). The point is that a probe should be handled with care, just as any precision measuring tool should be.

T_{RD} = displayed risetime

T_{RS} = oscilloscope/probe system risetime.

For a 50 MHz oscilloscope/probe combination, the risetime is 7 ns. Putting this into the formula, we get:

$$T_{RG} = \sqrt{10^2 - 7^2} = \sqrt{51} = 7.1 \text{ ns}$$

The actual risetime of the pulse generator is 7.1 ns, not 10 ns. The measurement was in error by about 41%.

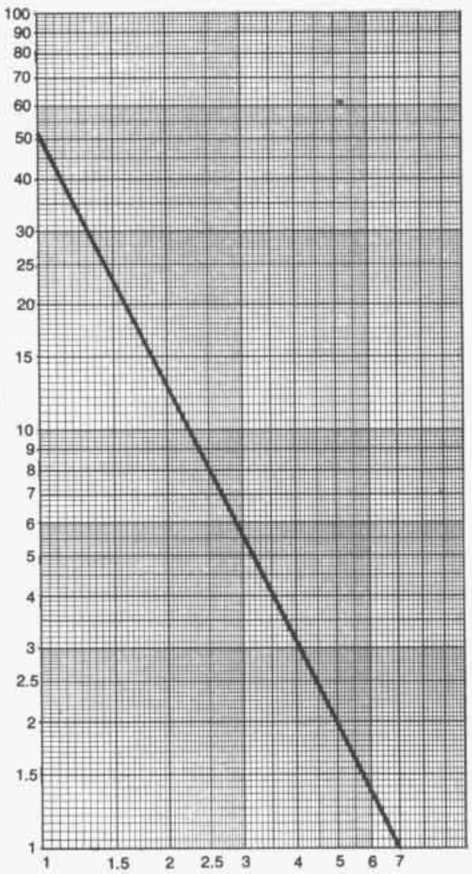


Figure 5. Measurement Error vs. Signal/ System Rise Time Ratio

It is important, therefore, to keep in mind that the displayed risetime is greater than the actual risetime.

The amount of error can be determined from the graph in Figure 5. Here, percent of error is plotted against the ratio of test system rise time over true signal risetime. As an example, suppose you are using a 100 MHz oscilloscope/probe combination that has a rise time of 3.5 ns. You are examining signals whose true risetimes are 10 ns. Ten divided by 3.5 is 2.9. Using Figure 5, the error is 6%.

Let's look at the problem another way. Suppose we want our measurements to be within 5%. What is the fastest risetime we could view on the CRT without going over 5% in error? Going to the 5% point on Figure 5, the ratio is 3.2. For our 3.5 ns system (T_{RS} = 3.5).

$$\frac{\text{True Signal Risetime}}{3.5 \text{ ns}} = 3.2$$

$$\text{True Signal Risetime} = (3.5)(3.2) = 11.2 \text{ ns.}$$

Rearranging our formula,

$$T_{RD} = \sqrt{T_{RG}^2 + T_{RS}^2} = \sqrt{11.2^2 + 3.5^2} = 11.7 \text{ ns}$$

Continued on Page 8

INPUT CAPACITANCE

The input capacitance of a scope is held to a value such that the desired system bandwidth can be maintained, assuming that system bandwidth is measured under certain conditions, specifically using a 50 ohm generator, terminated in 50 ohms, or equivalently a 25 ohm source impedance. While this is a perfectly valid method for specifying the bandwidth, it leads to false conclusions on the part of many users, namely that the scope bandwidth (or rise time) is independent of the way they make the measurement. How important is the input capacitance? If we were to draw a graph of resistance versus frequency, with capacitance as the variable parameter, we can easily determine the source resistance limits to achieve a desired frequency (or rise time) at specific values of capacitance. For example, if we wanted to operate from a 10K ohm source, and our scope input has 20 pf of capacitance, our bandwidth is less than 1 MHz! Or to state the problem a little differently, if we want to operate from a 10K ohm source and achieve a bandwidth of 100 MHz, we must limit our capacitance to 0.16 pf! See Figure A.

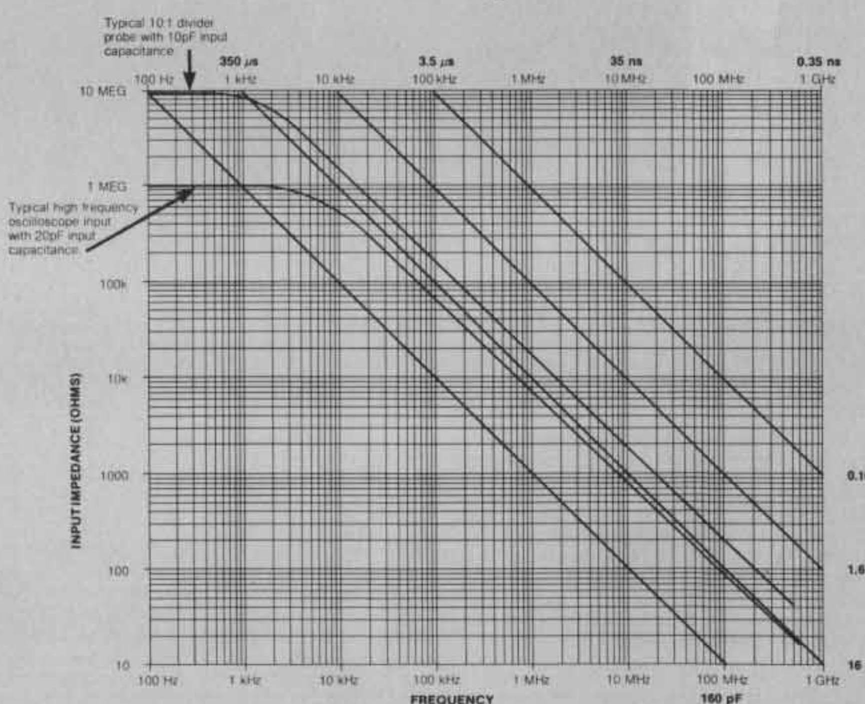


Figure A

READERS CORNER

Here's your chance to share your ideas and views with other *Bench Briefs* recipients. In Reader's Corner, we will print letters to the Editor, troubleshooting tips, modification information, and new tools and products that have made your job easier. In short, Reader's Corner will feature anything from readers that is of general interest to electronic service personnel.

If there is something you have to share with other *Bench Briefs* readers, let us hear from you.

ILLOGICAL LOGIC?

Dear Mr. Gasperini:

I expect that millions of your readers have already written to take issue with one portion of the solution offered to your Racing Quiz, but at the risk of some redundancy I'll add my complaint. While I agree that the solution you offer is the most straightforward, statement j does not really eliminate the American from coming in 4th place.

The statement reads, "The driver that finished in 4th place has a mother-in-law who is bigger than the American." While I am bigger than my mother-in-law and perhaps you are bigger than yours, contradictory instances abound. Therefore, an alternative solution would be the order "Italian, Englishman, Japanese, American, and German" for the Nationality column. The other two columns are unaffected.

Thanks for a useful (otherwise) publication.

Sincerely,

G.B. Rollman, Ph.D.
Associate Professor

A number of people did take issue with statement j. I've got a better quiz for a future issue. Watch for it.

Editor

Hewlett-Packard:

I would like to know if the plastic pushbuttons are available for your Model 241A oscillator.

The 241A oscillator we have was accidentally dropped into Lake Tanycomo and went into the grates where the water goes into one of our generators. We shut the machine down and our diver retrieved it. It was a little beat up on the outside but it works fine. We could use the top row of buttons—"off" and 1 through 9. The pushbutton switches themselves are OK.

Thank you,

Don Hargis
Communications
Empire District Electric Co.
Aurora, Missouri

Thanks for your letter on the 241A osc which went underwater into your generator grates. By the time you receive this, you should have a new set of pushbuttons and your oscillator should be back in A-1 shape.

It's always encouraging to receive letters such as yours and we took the liberty to pass it along to some of our service people and the design engineer. They all enjoyed it and the design engineer went off muttering something like "but I didn't DESIGN it to work underwater". Nevertheless, he was delighted to hear it still works.

Thanks for brightening our day.

Editor

Dear Sir:

After several years of using HP instruments while in the University and now in the field, this is the first time we have the possibility to read BB. We regularly receive the HP Journal and enjoy the articles on description of a new instrument, but we never smile as we did with BB; this is necessary to relax the strain after a day of hard work.

Daniel Grekoff
Technical Manager
AVIATRONIC SAC
Buenos Aires, Argentina

NEW VIDEO TAPES

Two new video tapes are available that will be of interest to service personnel.

BASIC OSCILLOSCOPE MEASUREMENTS

(90030—#820) 23 minutes. Color. A basic introduction to oscilloscopes for use by electronics students and technicians who want to learn how to use an oscilloscope for measuring. This elementary program takes a brief look at oscilloscope block diagrams, front panel operation, the variables of voltage and time that an oscilloscope measures, typical oscilloscope measurements using divider probes, AC and DC coupling, triggered sweep, dual-channel X-Y mode, and TV sync. This single-concept, tutorial style program also includes a self-scoring quiz.

7040 FAMILY X-Y RECORDERS, SERVICE

(90210—) 30 minutes. Demonstrates to service technicians and engineers the similarities between the five-instrument 7040 family of sophisticated X-Y recorders, to save time and effort in service situations. The program offers a brief introduction to each instrument in the line, then proceeds to a demonstration of electrical calibration, a discussion on troubleshooting, and a look at practical mechanical maintenance and cleaning procedures.

To obtain more details or to place an order, please contact your local HP office.

8690B FREQUENCY RESPONSE

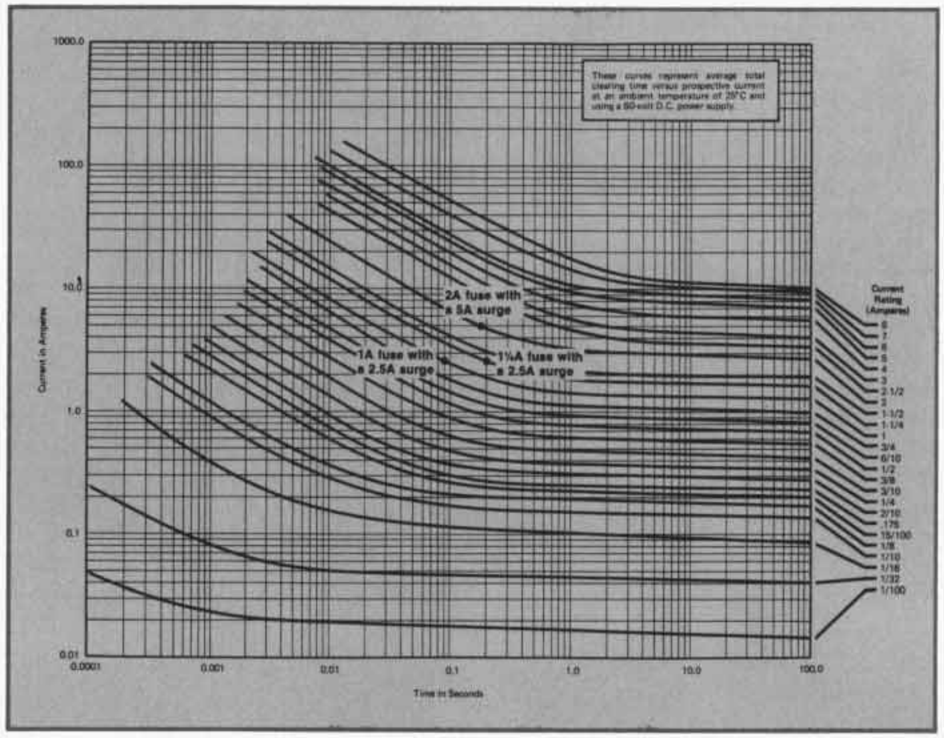
If you find that an 8690B that you are repairing has limited frequency response, you might check the protection circuit A4A5. If this limiting circuit has a failure, it will limit the input much earlier than it should. This limits the maximum helix voltage available, which in turn limits the output frequency.

LINE FUSE SIZE

Ever wonder why an instrument that requires a 2 Amp fuse for 110V operation needs a 1¼ amp fuse at 220V? Intuition might indicate that half the current would flow at 220V and therefore a 1 Amp fuse should suffice. Why the difference? One way of determining fuse size is to pick the smallest rated fuse that will blow neither at turn-on nor at steady state. For 220V operation, the value determined is reduced by 50% since the primary circuit current flow is only half.

This does not work in general because of surge current at turn-on.

A 2 Amp fuse will tolerate a 5 Amp surge for about 180 ms. Refer to the fuse chart. Let's assume that our instrument has a 5 Amp surge for 120 ms when operating on 110V line. OK so far. This fuse will probably be selected for 110V operation, assuming that the steady-state current is below 2 Amp (and assuming other tests are passed). In selecting a fuse for 220V operation, we note that we still have a 120 ms surge, but now it is 2.5 Amps.



HP recommends that an exact replacement be obtained for fuses. This chart is presented only as an aid in understanding how fuse sizes are selected during product design. (Chart Courtesy of Littlefuse, Incorporated)

Looking at a fuse chart, we find that we would be in trouble with a 1 Amp fuse because it will blow after 90 ms with our 2.5 Amp surge. The next largest fuse size, 1¼ Amp, tolerates a 2.5 Amp surge for about 200 ms. Therefore this one is specified by the design engineer.

When replacing fuses, be sure to use the exact replacement listed in your HP operating and service manual. This will ensure that optimum protection is obtained.

ATTENTION 419A USERS

Some older model 419's may have a POTENTIONAL SHOCK HAZARD. A kit to increase operator safety may be obtained from your nearest HP office at no cost. Ask for HP Part Number 00419-69500.

An ohmmeter may be used to determine if your instrument needs this modification.

1. With all power removed from the 419A and with the line switch off, connect one ohmmeter lead to the - (minus) INPUT terminal.
2. Set the ohmmeter on the 1K ohm range.
3. Connect the other ohmmeter lead to the set screws on the NULL pot, ZERO pot, and RANGE switch one at a time and note the readings.
4. The ohmmeter should indicate infinity. If it instead shows continuity, it is recommended that the modification be installed.

The modification takes about one half hour to perform and Service Note 419A-7 (included in kit) gives step-by-step instruction. Contact your HP office for further information.

8690 SERVICE TIPS

If you find that A8R5 or R8 are badly burned in an 8690, check for these two possible problems. First, check to see if A1C2 is shorted (this capacitor is in parallel with A1R17 on the modulation board in the RF plug-in). A second possibility is that the BWO is drawing excessive current.

Also, if you find an A4C47 failure, this may be caused by failure in A1Q1, Q2 or CR1 in the 8707. A solution here is to replace the transistors with HP Part No. 1854-0079 instead of 1854-0232.

"...call your local HP office..."

That's a phrase frequently seen in HP publications. It appears with shipping instructions, parts ordering information and service literature. That phrase reminds you to call your local HP office if you need help. But to do that you must know where to find your local HP office. As HP continues to grow, many offices find themselves outgrowing their facilities and moving to larger quarters. Occasionally an additional office is added to serve an area. These changes may mean that an HP office is now more conveniently located for you.

Although many HP manuals and other publications contain a complete list of HP offices, the list may not be completely current since it is revised only when the publication is reprinted.

To make sure that you can easily locate your local HP office to obtain the service you have come to expect of Hewlett-Packard, here's an up-to-date listing of field offices for all areas of the world.

An arrowhead (▶) by the office serving your area indicates that there has been a change in address or telephone number, etc. during the past year. It may be helpful to note the new information and to pass it along to others in your facility also.

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Continued on Page 8

COLO SPRGS

SHERWOOD PAUL M

Oscilloscope Probes

Continued from Page 3

Anytime the displayed risetime is less than 11.7 ns, our measurement is in error by greater than 5% (unless we calculate it out). As you can see, making accurate measurements with a probe and oscilloscope isn't quite as simple as it first appears especially at high frequencies. The day is gone when you just hang your probe in a circuit and assume that it won't load your circuit and that the reading you are getting is accurate. With a little knowledge about your probe, oscilloscope, and the circuits you are probing, you can make accurate measurements with a minimum disturbance to the circuit.

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Chuck is a graduate of the University of Colorado with a BSEE and a degree in General Business; he has been with HP for 9 years. Like many people in Colorado, Chuck enjoys skiing in the many ski areas in the Colorado area. Chuck is married and has four children.

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