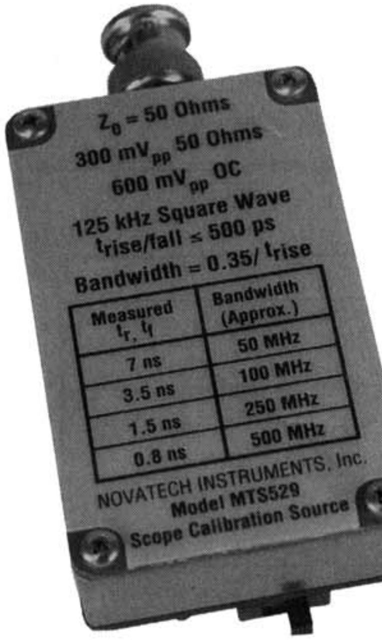
BUILD THE FAST PULSER SCOPE CALIBRATOR



Psst! Wanna buy a used oscilloscope? Checking out that bargin before you buy is now a snap with this handy, portable device.

STEVEN D. SWIFT

You're looking for a used oscilloscope at a ham fair and wonder if that $150 gem is really as good as the person at the table says it is. The trace lights up and the seller assures you it is "like new." What you need is something that will allow you to do a quick check of amplitude accuracy, sweep accuracy, and bandwidth. The Fast Pulser Scope Calibrator described here is a small, portable, battery-powered scope calibrator that meets those needs perfectly and costs less than one bad deal.

Testing a scope. Amplitude accuracy and calibration are both relatively simple to test. Any signal of a known amplitude will work well, including something as unsophisticated as a battery. Just apply the signal to the scope and count the number of divisions. If you have a way to generate one, a squarewave is even more useful as you get a direct indication of peak-to-peak amplitude that allows testing of AC-coupled circuits.

Time (or sweep) accuracy is easily tested by using a signal derived from a crystal oscillator, which will give better than 0.1% resolution and typically closer to 0.01%, depending on the crystal.

The most difficult parameter to measure is bandwidth. If you had a variable-frequency generator with a calibrated output, you could measure bandwidth by sweeping the input frequency until you reached the −3-dB point. Unfortunately, those instruments are not very portable. However, there is an easier way to determine bandwidth that is close enough for most purposes: apply a fast rise time pulse to the oscilloscope and observe the rise time of the displayed waveform.

To see how that works, let's say that a scope under test has the response curve of Fig. 1-a. Figure 1-b is a simple resistor-capacitor circuit that models that response curve.

If V_{in} is a fast pulse, V_{out} can be found with:

$$V_{out} = V_{in}(1 - e^{-t/RC})$$

where e is the exponential function, R is the resistance in ohms, C is the capacitance in farads, and t is the time in seconds after the pulse is applied. That output looks like the curve shown in Fig. 2. Figures 1-a and 2 were calculated using values of R and C to simulate an oscilloscope with a −3-dB rolloff at 100 MHz.

Rise time is the time for a signal to go from 10% of its final value to 90% of its final value. Those points are labeled as 10% and 90% in Fig. 2, with the final value of V_{in} normalized to one.

We need to find the rise time, so by using:

$$0.1 = (1 - e^{-t_{10}/RC})$$
$$\text{and } 0.9 = (1 - e^{-t_{90}/RC})$$

we solve for t_{10} and t_{90} using:

$$t_{10} = 0.1054\ RC$$
$$\text{and } t_{90} = 2.303\ RC$$

The final formula for the rise time becomes:

$$t_r = t_{90} - t_{10} = 2.198\ RC$$

Since the −3-dB bandwidth (BW) of a simple RC circuit is given by:

$$BW = 1/(2\pi RC)$$
$$\text{or } RC = 2\pi BW$$

With $\pi = 3.1416$, we substitute into the formula for t_r:

$$t_r = 0.35/BW$$
$$\text{or } BW = 0.35/t_r$$

That formula can also be used to approximate other circuits with a smooth rolloff that are more than just the simple RC type, as long as they do not suffer from excess peaking, which causes ringing. Figure 3 is a plot of the bandwidth versus rise time using that formula.

If the rise time of the pulse is not fast compared to the rise time of the oscilloscope being tested, the scope's true rise time can be calculated by:

$$t_r(\text{scope}) = \sqrt{t_r(\text{observed})^2 - t_r(\text{pulse})^2}$$

For bandwidths up to 250 MHz, a pulse with a rise time t_r of < 640 picoseconds (0.64 nanoseconds) will cause less than a 10% error in the scope's bandwidth prediction. Figure 4 shows observed rise times on the scope's display versus actual rise times of the scope's circuitry as a function of the output rise time of the applied pulse.

Those calculations and figures apply to oscilloscopes with well-behaved responses as in Fig. 1-a. Poorly designed, misadjusted, or defective oscilloscopes will have overshoot,

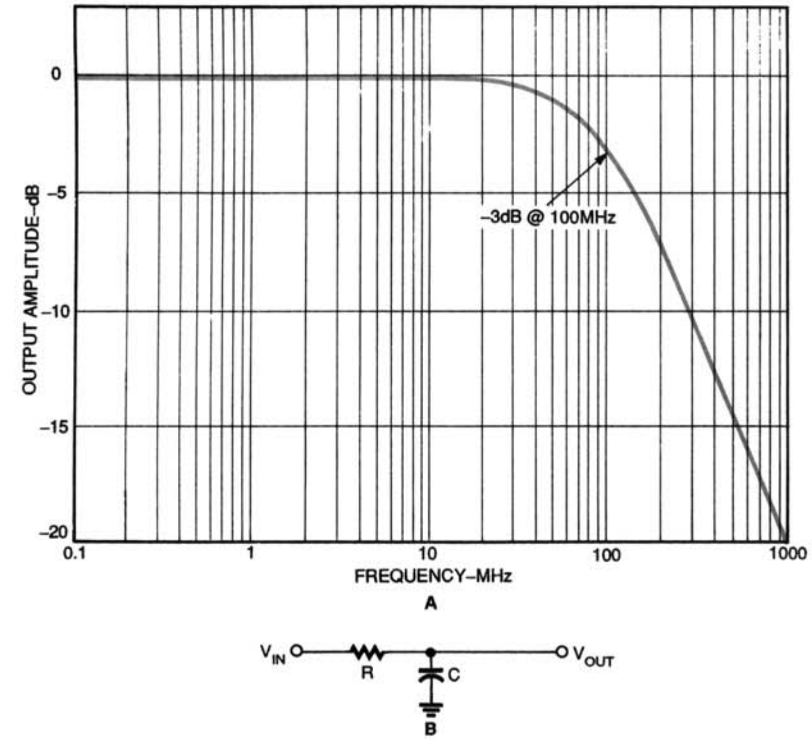


Fig. 1. The response curve of a typical oscilloscope (a) and a simple R-C circuit that simulates that response (b).

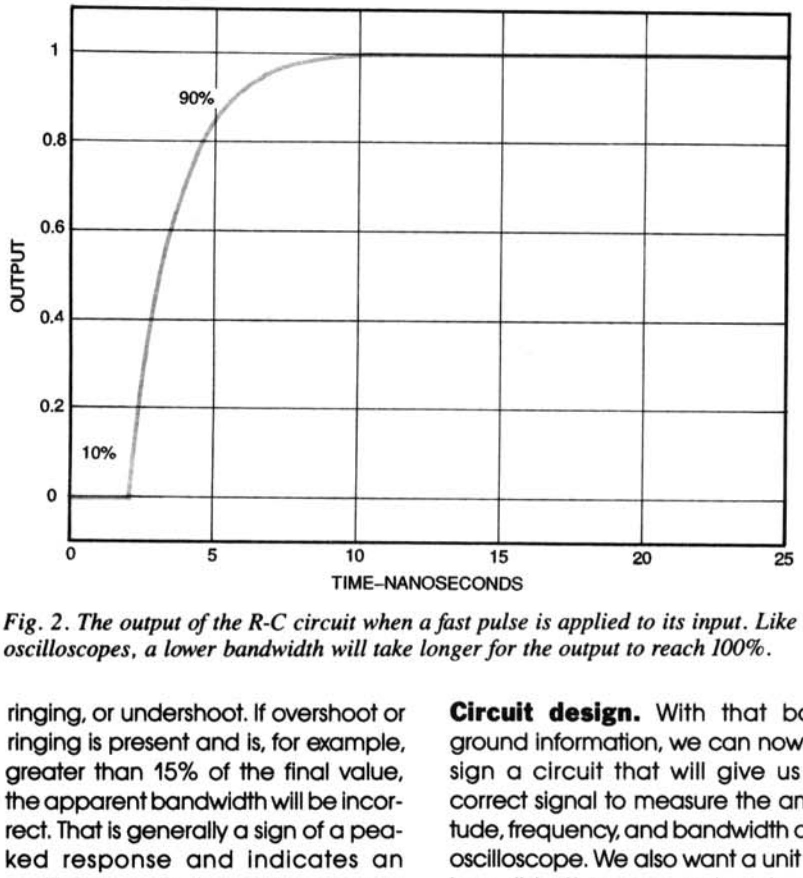


Fig. 2. The output of the R-C circuit when a fast pulse is applied to its input. Like oscilloscopes, a lower bandwidth will take longer for the output to reach 100%.

ringing, or undershoot. If overshoot or ringing is present and is, for example, greater than 15% of the final value, the apparent bandwidth will be incorrect. That is generally a sign of a peaked response and indicates an oscilloscope that may have some problems or be unsuitable for precision work.

Circuit design. With that background information, we can now design a circuit that will give us the correct signal to measure the amplitude, frequency, and bandwidth of an oscilloscope. We also want a unit that is small, battery-powered, and portable.

Since the bandwidth specification is going to be the most challenging, let's start there. We need to generate a fast pulse. In the past, the fastest devices available were tunnel diodes. Tektronix at one time made many different tunnel-diode pulsers, but those diodes are almost impossible to find. Fortunately, the need for high-speed digital circuitry has forced semiconductor manufacturers to generate special fast-logic families. One of those is Motorola's ECLips (*E*mitter *C*oupled *L*ogic *i*n *p*icoseconds). The devices specified have a maximum output rise time of 350 ps (0.35 ns): more than adequate for our purposes. We'll choose one of those devices for the fast part of the circuit.

A crystal-oscillator circuit ensures frequency accuracy, while the amplitude is set by choosing a version of the

PARTS LIST FOR THE FAS

RESISTORS

(All resistors are 1/10-watt, 1%, metal film, type 0805 surface mount, unless otherwise noted.)

R1, R2—82.5-ohm
R3, R4, R5, R9—124.0-ohm
R6, R7, R14—681.0-ohm
R8—1-megohm
R10, R11—100-ohms, 1 turn variable, surface mount (Panasonic EVM-1GSX30BXX or similar)
R12, R15, R18—27.4-ohm
R13—63.4-ohm
R16—49.9-ohm
R17, R19—0.0-ohm

CAPACITORS

C1, C2, C3, C4, C14, C16—10-µF, 6.3WVDC, tantalum, surface mount (3216 SM)
C5, C6, C7—.022-pF ceramic, surface mount (0805 SM)
C8, C9—470-µF, 6.3WVDC, high-frequency aluminum electrolytic (Panasonic ECA-0JFQ471 or similar)
C10, C11, C13, C15—22-pF ceramic, surface mount (0805 SM)
C12—220-pF ceramic, surface mount (0805 SM)

SEMICONDUCTORS

IC1—74HC4060M HCMOS oscillator/divider, SO-16 integrated circuit
IC2—MC100EL32D ECLips divide-by-2, SO-8 integrated circuit (Motorola)
IC3—MAX777CSA switching regulator, SO-8 integrated circuit (Maxim)
LED1—High brightness light-emitting diode, red

device for the fast part of the circuit whose output levels are both temperature and power-supply stable. The final overall block diagram is shown in Fig. 5.

Design details. Figure 6 shows the complete schematic. Refer to it and the block diagram during the discussion that follows.

A 74HC4060 HCMOS oscillator/divider integrated circuit (IC1) was chosen for generating the master clock because it includes the oscillator circuitry and dividers necessary for a precision crystal-controlled clock with a minimum of external components. Choosing that part lets us use an inexpensive 4-MHz crystal rather than a larger and more costly low-frequency crystal.

The divide-by-16 output of IC1, at 250 kHz, is applied to a Motorola MC100EL32 divide-by-2 ECLips flip-flop (IC2), through level-shift and decoupling components C7, C15, and R6. Resistor R3 sets the input impedance seen by IC2 and divides the amplitude of IC1's output down to the ECLips input levels. The MC100EL32 has transition times of both outputs specified at less than 350 ps (0.35 ns) and temperature-compensated output levels. The divide-by-2 action of the device provides 125 kHz at approximately 800-mV p-p to the amplitude adjustment circuit and output stage.

The output of IC2 is terminated with loads consisting of resistor pairs R1/R4 and R2/R5. The values shown provide an equivalent load voltage of about −2 volts and a load impedance of 50 ohms. The output of IC2 is AC-coupled by capacitors C12, C13, C14, and C16 to an adjustable T-attenuator network. The various values of the coupling capacitors combine to transmit the fast rise time edges (C12 and C13)

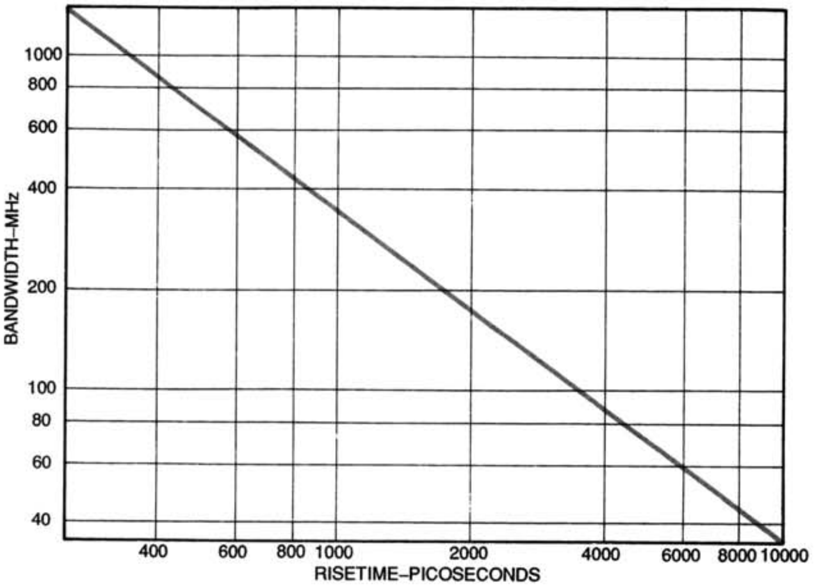


Fig. 3. The bandwidth of an oscilloscope can be found by observing how quickly the oscilloscope responds to a fast-rising input pulse. The quicker a scope responds to an input, the greater its bandwidth.

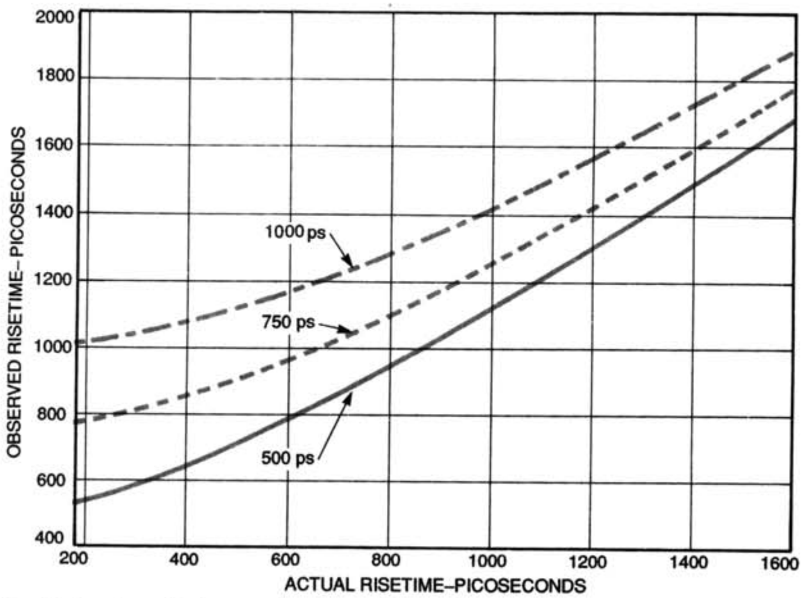


Fig. 4. A pulse with its own rise time will introduce additional error when measuring a scope's bandwidth. Keeping the pulse's rise time as short as possible will reduce such errors to an acceptable level.

PULSER SCOPE CALIBRATOR

ADDITIONAL PARTS AND MATERIALS

J1—BNC male connector (Kings KC-79-59 or similar)

L1—100µH, 0.41-amp rated coil, surface mount (TOKO 636CY-101M or similar)

S1—SPDT miniature switch (Mouser 10SP018 or similar)

XTAL1—4-MHz AT-strip crystal, surface mount

B1—Batteries, 3-volts, see text

Printed-circuit board, case, cover, battery holder (Digi-Key BH2AA), 4-40 x ¼-inch Phillips pan head screws

Note: The following items are available from: Novatech Instruments, Inc., 1530 Eastlake Avenue East, Suite 303, Seattle, WA 98102; e-mail: novatech@eskimo.com, URL: http://www.eskimo.com/~ntsales: Key Parts kit (includes J1, IC1, IC2, IC3, printed circuit board, case, and cover) (order MTS529-K), $50. Circuit Board only (order MTS529-B), $10. Completely assembled and tested Scope Calibrator (order MTS529), $125. Please add $5 for USA shipping and $10 for overseas shipping by U.S. Postal Service. These are special prices and are valid only for six months. Please mention this article when you mail payment. WA residents must add 8.2% sales tax. Please mail a check drawn on a bank with a branch in the U.S. or a money order. Sorry, phone orders and charge cards are not accepted.

while preventing droop at the 125-kHz base frequency (C14 and C16).

The output T-attenuator allows adjustment of open-circuit voltage level (R10) and output impedance (R11). Levels of 600-mV p-p open circuited and 300-mV p-p into 50 ohms were chosen to correspond to 6 divisions on an oscilloscope with a high-impedance input set to 100-mV-per-division, or 50-mV-per-division if the scope's input impedance is 50 ohms. That output is applied to a male BNC connector, which allows direct connection to the oscilloscope under test without using cables or adapters. The parasitic inductance of the output stage is kept small by the use of surface-mounted components. Even with that precaution, the output stage degrades the rise time to approximately 500 ps (0.5 ns). That rise time is adequate for testing oscilloscopes to 250 MHz with less than 10% error without using the correction formula or Fig. 4.

A switching power supply (IC3 and its associated components) was chosen to generate the required power for the circuit. The −5V supply needed to supply power to IC1 and IC2 is generated by IC3, a MAX777CSA switching regulator. Using two AA alkaline cells will supply power for almost 4 hours of continuous operation, and keep the project compact. Various types and sizes of batteries were tested with the power supply and it was found that 2 AA alkaline cells provide excellent performance without being very expensive.

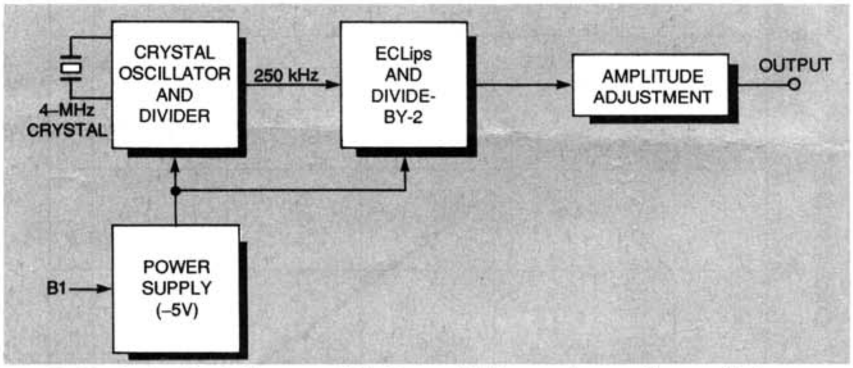


Fig. 5. Here's the block diagram of the Scope Calibrator. A crystal-controlled oscillator coupled with ECLips-based technology make for an accurate, reliable design.

Construction details. To maintain the high-speed performance of the instrument, the circuit board used consists mostly of a solid copper ground plane, with just enough area cleared away for the components. Other than a few pads and holes, the whole solder side of the circuit board is also a ground plane. Please note that if you plan to make your own boards from the artwork, the minimum trace width used is 8 mils (0.2 mm) which may cause etching difficulties. Note also that the back side ground plane is important for correct operation, so the feedthrough holes must be connected.

The parts placement diagram for the project is shown in Fig. 7. Since we

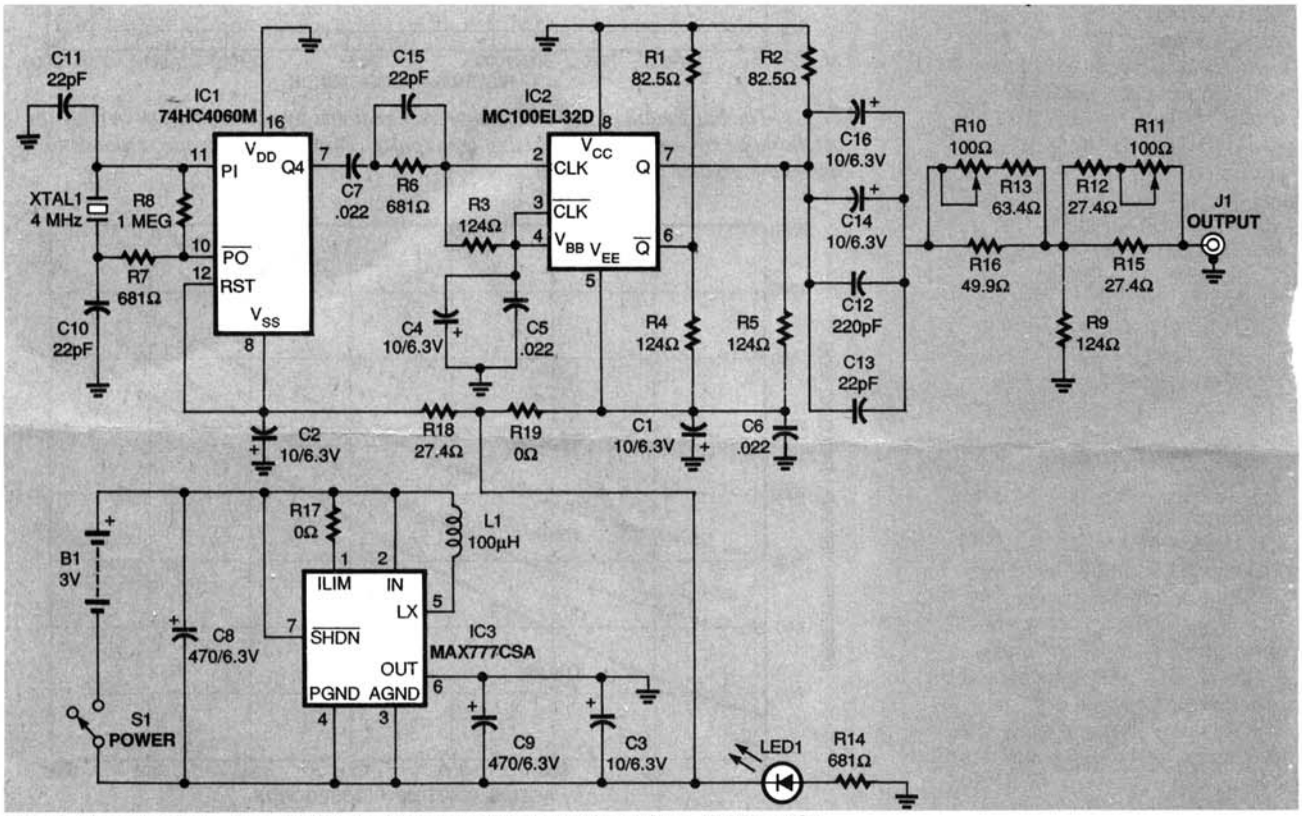


Fig. 6. The complete schematic for the Scope Calibrator is shown here. A Motorola MC100EL32D divide-by-2 ECLips flip-flop produces a signal unaffected by changes in temperature or supply voltage.

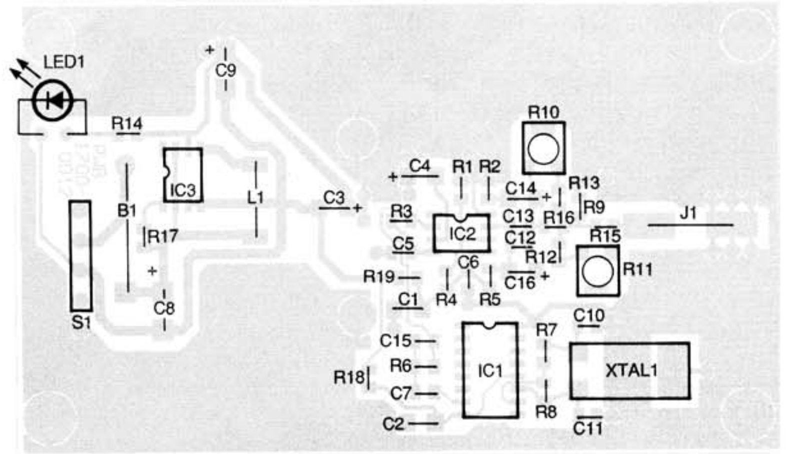
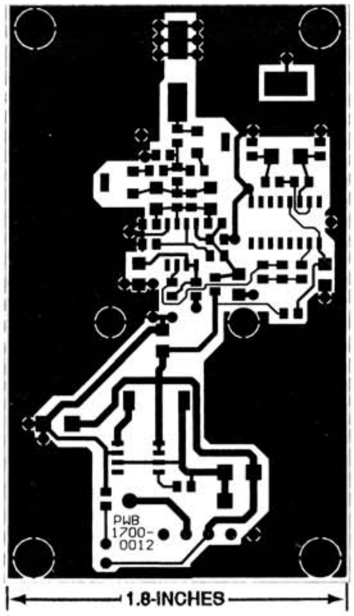
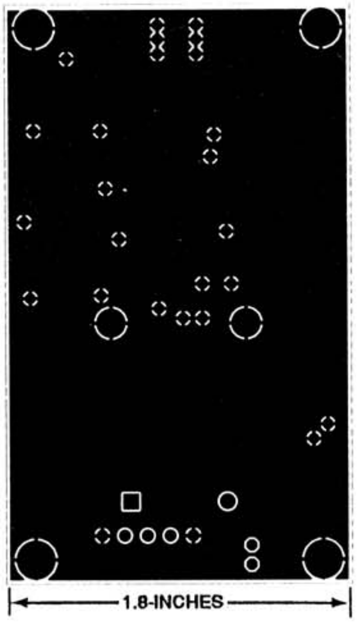


Fig. 7. Use this parts placement when building the Scope Calibrator. Surface-mount technology helps keep parasitic inductance to a minimum, as well as maintain a small physical size to the finished unit.



Here's the foil pattern for the component ide of the Scope Calibrator printed circuit board. If you decide to etch your own board, take care that the narrow traces don't break apart during the etching process.



Here's the foil pattern for the solder side of the printed circuit board. Connecting the ground planes on both sides of the board to each other is important for proper operation.

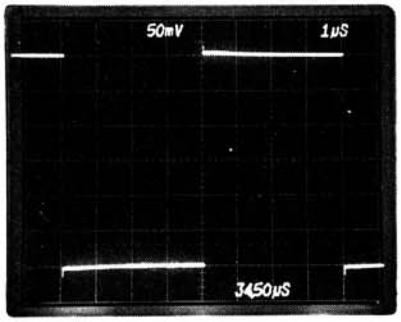


Fig. 8. Here we're testing the sweep speed and amplitude of an oscilloscope. You should count 8 divisions when the sweep is set to 1-μs/division.

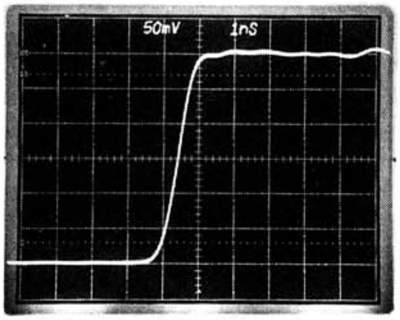


Fig. 9. Here we're testing the rise time of an oscilloscope. Measure the time it takes for the signal to rise from 10% to 90%, then use the chart in Fig. 3 to find the scope's bandwidth.

want a small sized instrument and the circuit has very high speed signals that require RF-design techniques, surface-mount components were chosen for the project. The small parts allow for optimized circuit specifications while reducing performance-degrading parasitic signals. They also allowed the complete project (less the batteries) to be enclosed in a 1.8-by 3-inch metal case.

Unfortunately, those small components make the assembly of the project rather difficult. If you have never handled SMT devices, you might want to look back at "Surface Mount Technology" in the November, 1987 issue of **Radio-Electronics**, or "A Hobbyist's Guide to Surface-Mount Technology" in the January, 1995 issue of **Popular Electronics** and first try some of the simple projects there. An assembled and tested Calibrator is also available from the source given in the Parts List.

The Scope Calibrator only needs calibration for amplitude. The basic accuracy of the crystal and the rise time are fixed by the design used and need not be calibrated. The easiest and most accurate way to calibrate the unit is to use a wideband (>200 kHz) AC rms voltmeter. With just the voltmeter load, adjust R10 for a reading of 300-mV rms (the rms value of an AC-coupled square wave is equal to one-half its peak-to-peak value). Now apply the squarewave output to the voltmeter through a 50-ohm feedthrough termination. Adjust R11 for 150-mV RMS. That sets the output impedance equal to your load, so the accuracy of your 50-ohm load determines the accuracy of your Fast Pulser calibrator.

Do not use test leads or cables as the signal will be degraded by overshoot and ringing. Use a direct connection to the meter, such as a BNC to banana-plug adapter. The assembled and tested unit is calibrated using a 1-MHz bandwidth rms meter and a ±1% 50-ohm load.

Applications. The Scope Calibrator is easy to use. Simply switch it on and connect the BNC output to the input channel of an oscilloscope under test. If the scope has a high input impedance (1 megohm is typical), set the vertical scale on the scope to 100-mV/division. If the scope has a 50-

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ohm input impedance, or if you have applied the signal through a 50-ohm feedthrough termination, set the scope to 50-mV/division. You should see 6 divisions of amplitude as shown in Fig. 8 (Fig. 8 and 9 are scope photos from a 500 MHz Tektronix 7904 oscilloscope with a 7A19 vertical amplifier). Using only the flat parts of the waveform, ignore any leading or falling edge aberrations when measuring amplitude.

To test sweep accuracy, set the horizontal sweep speed of the scope to 1 µs/division. You should see 8 divisions as shown in the photo of Fig. 8. The best possible accuracy is obtained by centering the signal on the screen and measuring from the center point of the waveform.

To measure the approximate bandwidth, set the sweep speed to the fastest rate and adjust the triggering so the complete rising edge of the waveform is visible as shown in Fig. 9. If that is not possible, it is likely that the scope under test does not have a vertical-amplifier delay line, which should be considered a serious deficiency. Ignore the amplitude of any ringing or overshoot, and measure the rise time by noting the time to go from 10% to 90% of the waveform amplitude. Some scopes have that precalibrated on the screen using either 5 or 6 divisions for 100%. If your scope has a 6 division scale for 100%, just use the variable vertical scaling commonly available to adjust the waveform to 5 divisions. Otherwise, just measure from 0.6 divisions to 5.4 divisions. That gives the rise time of the scope and the pulser combined. If the observed rise time is small (<1.5 ns), then use Fig. 4 or the formula to correct for actual rise time (use a nominal 0.5 ns for the pulse output rise time). Remember that the bandwidth is found from:

$$BW = 0.35/t_r$$

The total ringing or overshoot should be less than approximately 15% of the signal's final value. Ringing beyond that value might indicate problems with the vertical amplifier such as a peaked response, miscalibration, or faulty components. Ω