High impedance instrument probe features 100 MHz bandwidth

This probe will allow you to make CRO or frequency meter/timer measurements on high impedance circuits with waveforms having rise times as fast as three or four nanoseconds. Cost is well below commercial equivalents.

Jonathan Scott

MOST READERS would be aware that, when taking a measurement on electronic circuitry, the input impedance of the measuring instrument must be much greater than the impedance of the circuit to which it is attached, otherwise the accuracy of the measurement suffers. The input impedance of the majority of oscilloscopes is generally 1M with a parallel capacitance of between 20 pF and 40 pF. For a wide variety of applications this is perfectly adequate and will suffice for measurements of frequencies up to 5 MHz or so. The input impedance of the CRO falls with increasing frequency owing to the falling reactance of the input capacitance. For example, a capacitance of 30 pF — which may be made up of direct input capacitance plus cable capacitance — has a reactance of only 500 ohms at 10 MHz. The input capacitance also affects the rise time of the input — that is, the speed at which a 'step' input will rise from the 10% amplitude value to the 90% amplitude value.

The input impedance of an oscilloscope can be effectively raised, and the capacitance decreased, by using a 'step-down' probe. For example, a 'x10' probe will generally have an input impedance of 10M and a parallel capacitance of between 5 pF and 15 pF. While this improves the input impedance there are two trade-offs. Firstly, unless elaborate (and expensive) compensation is employed, the rise time is degraded, and secondly, maximum sensitivity is decreased by a factor of ten. As Murphy's law would have it, your CRO will run out of grunt just when you need it most.

Taking the situation with digital counter/timers, we find similar problems. Those that operate beyond 30 MHz or 50 MHz generally employ a prescaler with an input impedance of 50 ohms — which is perfectly all right if you're working on low impedance circuits and/or with high signal levels. But there are those occasions when you need a high impedance input and a fast (high frequency) rise time. As with the CRO, this is where your counter/timer runs out of grunt.

It's times like these you need . . . the ETI-156 instrument probe. This project is a x1 active instrument probe using a special buffer IC with an input impedance of typically 100 000 megohms! — that's 10^{11} ohms — a very low input capacitance of around four to five picofarads, a fast rise time (around three nanoseconds) and a bandwidth of 100 MHz. Output impedance is around 50 ohms and the device is capable of driving capacitive loads up to several thousand picofarads. Thus it is eminently suited for use with high speed, wide bandwidth oscilloscopes and digital frequency meter/timers at frequencies up to 100 MHz. Output impedance is close to 50 ohms and it is thus suited to drive both high impedance instrument inputs and low impedance inputs (which are generally 50 ohms).

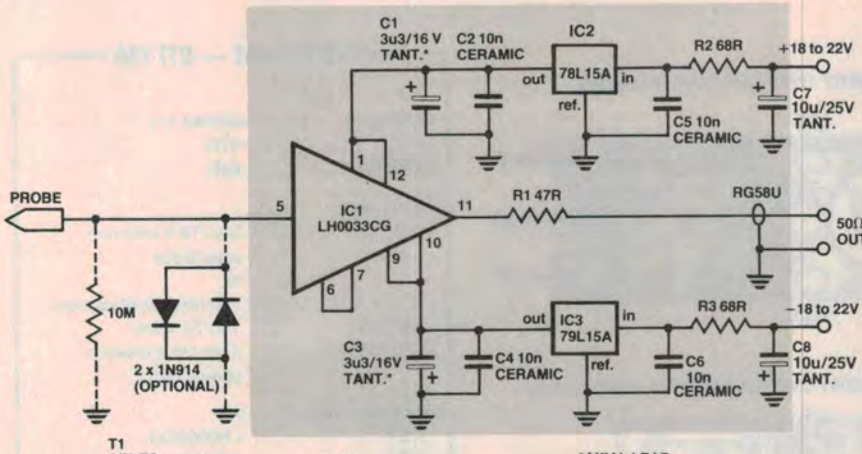
Design

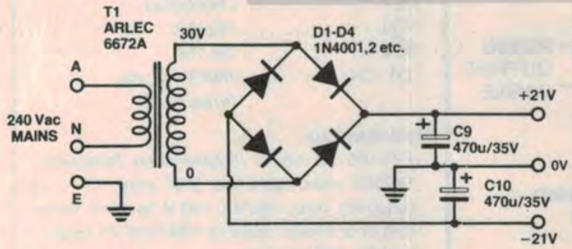
It's all done inside a special IC — an LH0033CG from National Semiconductors. This is described as a 'fast buffer amplifier'. (It has a companion designated LH0063, described as a 'damn fast buffer amplifier'!). The LH0033 is a direct-coupled FET-input voltage follower/buffer (gain ≈ 1) designed to provide high current drive at frequencies from dc to over 100 MHz. It will provide ±10 mA into 1k loads (±100 mA peak) at slew rates up to 1500 V/µs, and the chip exhibits excellent phase linearity up to 20 MHz. No offset voltage adjustment is required as the unit is constructed using specially selected FETs and is laser-trimmed during construction. Input is directly to the gate of a junction FET, operated as a source follower, driving a complementary output pair of bipolar transistors.

Regulated plus and minus supplies of 15 V each provide power to the IC. Low-power three-terminal regulators are

SPECIFICATIONS ETI-156 HIGH IMPEDANCE INSTRUMENT PROBE

Input impedance	10^9 to 10^{11} ohms (depends on construction)
Input capacitance	about 5 pF (depends on construction)
Maximum permissible input voltage	
***Hi-z load**	±15 V
***50 Ω load**	±10 V
Output impedance	50 to 55 Ω
Bandwidth	100 MHz
Rise time	better than 3.5 ns
Gain ***Hi-z load**	0.98
***50 Ω load**	0.49





*AXIAL LEAD SOLID TANTALUM CAPACITOR

NOTE: Capacitors C2 and C4 need to be ceramic chip (10n value) or ceramic disc or plate (1n value) capacitors. C5 and C6 need only be disc or plate ceramic. See 'Bypassing' over the page.

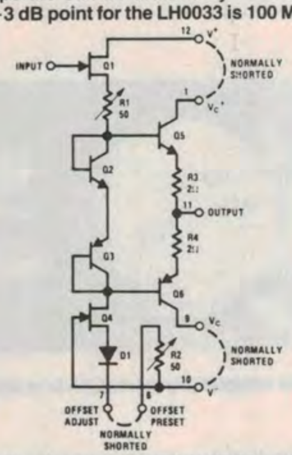
used to keep the unit compact. An external unregulated supply of between 18 and 22 volts at around 50 mA is required to power the probe.

The supply pins on the IC need to be well bypassed over a wide frequency range so that the IC can maintain its characteristics, and the construction has been specially arranged to achieve this. Axial lead solid tantalum capacitors are used to bypass the IC's supply pins at the lower frequencies, while low inductance ceramic capacitors are employed as bypasses for the higher frequencies. A double-sided fibreglass pc board is used to preserve the high frequency response and the high input impedance, and the layout is arranged

HOW IT WORKS ETI-156

This instrument probe employs a wideband hybrid voltage follower/buffer IC, the LH0033, with very close to unity gain, that features a very high input impedance and a low output impedance. It requires regulated, well-bypassed supply rails. Two three-terminal low power regulators provide plus-and-minus 15 V supplies from an unregulated input.

The internal circuit of the LH0033 is shown below. Basically, it consists of a FET input stage (Q1), operated as a source follower. The other FET, Q4, provides a constant current source for the source bias of Q1, while Q2 and Q3 are connected as diodes and provide bias for the bases of Q5 and Q6. Resistors R1 and R2 are laser trimmed in manufacture so that the IC meets the offset voltage specification. As Q1 has a constant current source load, the input impedance at the gate of Q1 is very high indeed and the distortion of the stage is very low. The output of the source follower drives a complementary pair output stage, Q5-Q6. Thus the IC will have a very high input impedance, a very low output impedance and a gain very close to unity. With appropriate construction employed for the internal devices, the bandwidth over which the device will operate can be made very wide indeed. The −3 dB point for the LH0033 is 100 MHz.



As the device is direct-coupled, dc levels will be maintained between input and output.

Bypassing requirements for the IC's supply leads are explained elsewhere in the article.

To provide regulated plus-and-minus 15 V rails for the IC, two three-terminal regulators are employed, a 78L15A for the positive rail and a 79L15A for the negative rail. These can supply up to 100 mA and have a very low output impedance up to several hundred kilohertz, which is exploited for low frequency bypassing. Each supply rail requires an unregulated input of between 18 V and 22 V. Decoupling of the supply leads is provided by R2/C7 on the positive rail and R3/C8 on the negative rail. The input terminal of each regulator is bypassed to prevent instability.

As the input voltage is limited to a maximum equal to the supply rails (high impedance load), input protection may be added in applications where only low level signals are being examined. As shown in the main circuit, this protection consists of two 1N914 diodes connected back-to-back in parallel with a 10M resistor across the input. Signals above 1 V peak-to-peak will be clipped, preventing any damage to the IC. If very fast rise time signals are to be examined then better protection for the IC can be obtained by using hot-carrier diodes such as the HP 5082-2800 instead of the 1N914s.

SPECIFICATIONS LH0033

Absolute maximum ratings

Supply voltage	±40 V
Max. power dissipation	1.5 W
Input voltage	same as supplies
Continuous output current	±100 mA
Peak output current	±250 mA

dc characteristics (LH0033C/LH0033CG) — typical

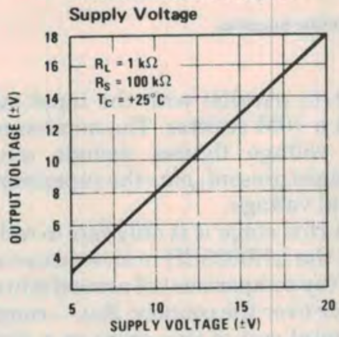
Output offset voltage	12 mV
Voltage gain	0.98
Input impedance	10^{11} ohms
Output impedance	6 ohms
Output voltage swing	±13 V
($V_S = \pm5$ V)	(6 V p-p)
Supply current	21 mA
($V_S = \pm15$ V)	
Power consumption	630 mW
($V_S = \pm15$ V)	

ac characteristics (LH0033C/LH0033CG) — typical

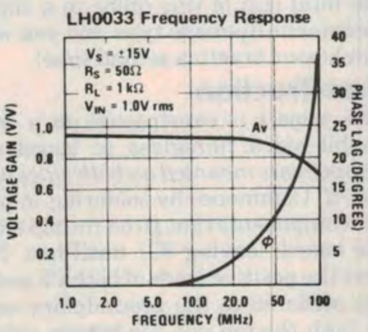
Slew rate ($V_{in} = \pm10$ V)	1400 V/µs
Bandwidth ($V_{in} = 1$ V_{rms})	100 MHz
Phase non-linearity (1 - 20 MHz)	2°
Rise time ($\Delta V_{in} = 0.5$ V)	3.2 ns
Propagation delay ($\Delta V_{in} = 0.5$ V)	1.5 ns
Harmonic distortion (f>1kHz)	<0.1%

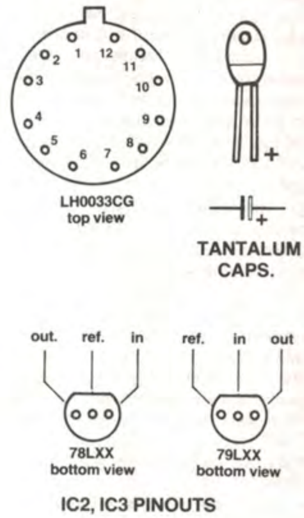
NOTE: Unless otherwise specified, these figures apply for +15 V applied to pins 1 and 12, −15 V to pins 9 and 10, and pin 6 shorted to pin 7. Specifications apply over temperature range between −25°C and +85°C; typical values shown are for a temperature of 25°C.

LH0033 Output Voltage vs Supply Voltage



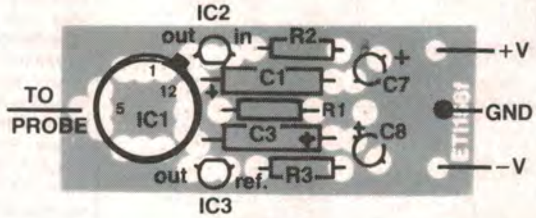
LH0033 Frequency Response



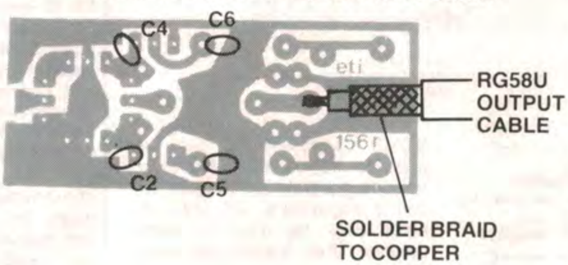


IC2, IC3 PINOUTS

COMPONENT OVERLAY, TOP OF BOARD



COMPONENT OVERLAY, BOTTOM OF BOARD



The completed pc board, prior to assembly in the probe housing.

PARTS LIST — ETI 156

Resistors all ½W, 5%
- R1 .... 47R
- R2, R3 .... 68R

Capacitors
- C1, C3 .... 3u3/16 V solid tant. axial leads, or
- C2, 4, 5, 6 .... 10n ceramic block caps.
- C7, C8 .... 10u/25 V tant.
- C9, C10 .... 470u/35 V electros (if required)

Semiconductors
- IC1 .... LH0033CG
- IC2 .... 78L15A
- IC3 .... 79L15A
- D1 - D4 .... 1N4001, 2, etc. (if required)

Miscellaneous

ETI-156 pc board (double-sided fibreglass); RG58U coax cable and BNC plug; T1 — (if required) Arlec 6672A 240 V to 30 V transformer or similar; optional 10M/½W 5% resistor and 2 x 1N914 diodes; wire; probe housing — Jabel type PH3T or similar.

Price estimate

We estimate the cost of purchasing all the components for this project will be in the range:

$48 - $55

Note that this is an **estimate** only and **not** a recommended price. A variety of factors may affect the price of a project, such as — quality of components purchased, type of pc board (fibreglass or phenolic base), type of front panel supplied (if used), etc — whether bought as separate components or made up as a kit.

to permit direct connection to the probe tip and provide low input capacitance.

However, the presence of the pc board substrate will degrade the input impedance, surprisingly enough, and you can drill out the area of board immediately beneath pin 5 of the IC and solder the pin directly to the probe tip. For those who wish to go 'all the way' (as Frank Sinatra sings), the plastic insulation of the probe tip can be replaced with a similar piece of Teflon — if you can afford it and have access to a lathe.

The maximum input voltage permissible, when driving a high impedance load, is plus or minus 15 volts. When driving a 50 ohm load, maximum input voltage permissible is only plus or minus 10 volts (limited by maximum output current). No input protection has been included. However, if you are only working with circuits where voltages are no greater than about 1 V peak-to-peak, protection can be added by putting two diodes back-to-back in parallel with the input, along with a 10M resistor. The maximum input voltage figures include any dc voltages present, *plus* the superimposed signal voltage.

At this stage it is only fair to tell you that the LH0033CG is an expensive device (by comparison) at around $30 or so apiece over the counter. But — compare the total cost of this probe to a similar commercially-made type and you won't catch your breath a second time!

Construction

The project is constructed on a small double-sided fibreglass pc board *with components mounted on both sides of the board.* Commence by soldering in place the components that go on the top side of the board, leaving IC1 until last. Note that the positive leads of both C3 and C8 are soldered to the groundplane areas on both the top and the bottom sides of the board. Take care with the orientation of the tantalum capacitors, as well as IC2 and IC3. Having done that, solder C2, C4, C5 and C6 to the bottom side of the board. Now you can install IC1. Watch the orientation — the tag on the can points toward the 'out' pin of IC2. You will have to juggle the legs a little. Push the can as far down on the board as you're able; its base should sit no more than 3 mm from the board.

Now that you have everything in place, *check it all.* It seems pretty simple, but Murphy's law will ensure that the simplest things have the highest stuff-up rates!

All's well? — now you attach the output coax cable to the underside of the board, plus the dc input and ground (0 V) wires. *But* — before you do, slip the output end piece of the probe case over the cable and supply wires, push it down about 150 mm or so and then slip the case of the probe case down the wires. This saves slipping them over the other end of the whole business and sliding them all the way to the probe.

The probe tip can be attached and

soldered in place last of all. Now you can screw it all together and attach the appropriate plugs to the other end of the cable and supply wires.

With the construction completed, you can power up and try it out. Note that the transformer suggested in our power supply is but one of many suitable types. Any transformer that will deliver at least 26 Vac at a load of about 50 mA will suffice. Alternatively, any dual-polarity dc supply having an output between 18 and 22 volts at 250 mA will power the probe.

Notes

When using the probe to drive a 50 ohm load, the pulse response can be improved if you wish by a simple modification. Apply a fast rise time square wave to the input and observe the output on a wideband (50 MHz to 100 MHz) CRO. The rise time can be optimised by paralleling small-value ceramic capacitors across R1 — tack them in place on the underside of the board.

Always take care that you don't exceed the input voltage limitation; LH0033s are expensive.

BYPASSING

SUPPLY LEAD BYPASSING is important in order that the LH0033 can operate correctly over the full bandwidth from dc to 100 MHz. To ensure this, the bypassing has been specially arranged and the techniques employed are probably unfamiliar to many readers.

The output circuit signal return path for the IC is via the ground and the two supply rails. Any significant impedance in series with this path (or paths) will subtract signal from the output load. Thus, the supply rail bypassing has to present an impedance which is a *fraction* (like one-tenth or better) that of the minimum output load impedance. Here, the minimum output load is about 100 ohms (R1 + 50 ohms instrument input impedance) and the supply bypassing impedance should ideally be less than 10 ohms across the frequency range.

The bypassing on each supply rail to the IC leads here takes advantage of the characteristics of three separate components to cover three sections of the frequency range.

From dc to around 100 kHz, each three-terminal regulator (IC2, IC3) has an output impedance well below one ohm, rising to four or five ohms at 1 MHz, as shown in Figure 1. The two tantalum capacitors, C1 and C3, then take over.

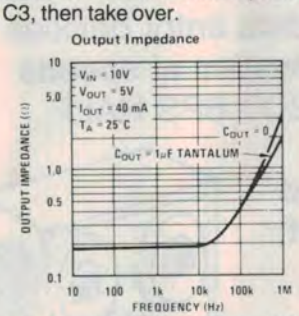


Figure 1. **Output impedance characteristic of a three-terminal regulator.**

Solid tantalum capacitors have a characteristic impedance that falls with frequency according to its value, which then 'flattens out' in the region around 500 kHz — 1 MHz, rising to a few ohms around 10 MHz, as can be seen in Figure 2. Thus, C1 and C3 serve as effective bypasses across the range from around 100 kHz to around 10 MHz. Axial lead tantalum capacitors were chosen as their construction exhibits the slowest impedance rise following the minimum impedance value.

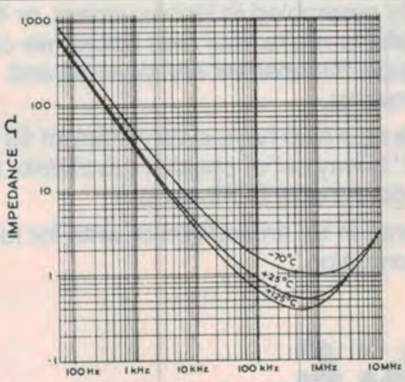


Figure 2. **Impedance characteristic of axial lead solid tantalum capacitors.**

To provide bypassing over the decade from 10 MHz to 100 MHz, capacitors C2

Figure 3. **Ceramic chip capacitors — shown about actual size. They have no leads, just plated end pads for connections.**

and C4 have been specially chosen and positioned on the pc board. For the prototype, 'chip' ceramic capacitors were used. These tiny, 'naked' chips of ceramic with a capacitor embedded in them are probably the most effective bypass capacitors made. The leads and physical construction of all capacitors form an inductance which is effectively in series with the capacitance of the component. The combined effect forms a series resonant circuit, the frequency of which (that is, the self-resonant frequency of the component) is mainly dependent on the length of the connecting leads, the particular construction of the capacitor and the way in which it is mounted. Ceramic chip capacitors, being a tiny block with connecting pads or surfaces on each end, have extremely low values of series inductance and thus very high self-resonant frequencies — see Figure 4. Now, any value of chip capacitor between 1n and 10n can be used for C2 and C4. The self-resonant frequency of a 1n chip capacitor is somewhat above 100 MHz (as per Figure 4), but that of a 10n chip is between 40 MHz and 50 MHz. Now, this isn't a problem, for the chip's impedance falls with frequency as usual until near the self-resonant frequency where it falls rapidly, reaching a minimum at the self-resonant frequency. Above that frequency its impedance rises again, but is still low enough for effective bypassing.

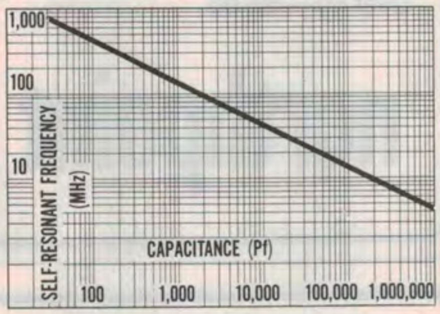


Figure 4. **The self-resonant frequency versus capacitance of a typical ceramic chip capacitor.**

Ordinary ceramic disc and plate capacitors behave in much the same way. The self-resonant frequency of a typical 5 mm diameter disc or 5 mm square plate capacitor depends on the lead length, as shown in Figure 5. Thus, you could use 470 pF or 1000 pF (1n) capacitors of this type for C2 and C4, provided you installed them on the underside of the board with *absolute minimum lead length*. More information on this subject can be obtained from "Self Resonance in Capacitors" by Roger Harrison, ETI March 1978, page 80.

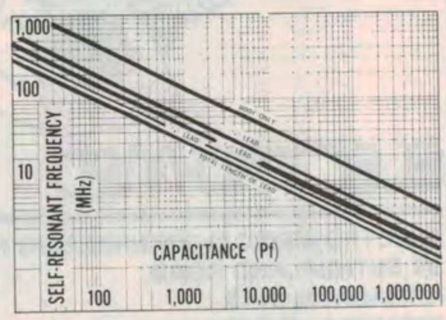


Figure 5. **The self-resonant frequency versus capacitance of a typical 5 mm disc or plate ceramic capacitor with differing lead lengths (from lower curve, up — 25 mm lead length, 22 mm, 13 mm, 6 mm and none).**