Octopus Tester

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Date	Changes
May 2013	Second design. Function generator usage & sweeping. Using active circuitry.
17 Feb 2013	Minor edits.

Additions:

1. From a Lissajous figure for a C or L, figure out the impedance. A tilted ellipse will be the general component; I'd imagine a person could get reasonably good at estimating the tilt angle to about 10°. The tilt would be the real part of the impedance and the ellipse would be the reactance.
2. Use a staircase function to provide excitation to e.g. the gate of a FET while the Octopus sweeps the i(V) characteristic of the drain-source. The only real challenge will be to have an integer number of Octopus sweeps during each step of the staircase. This shouldn't be hard with modern DDS generators. Then you should get a family of curves for a particular device.
3. Use a Schmitt trigger chip to detect when the excitation voltage crosses a certain point and use that to toggle between two analog switch channels. This would allow one cycle of the excitation waveform from the suspect circuit to be displayed followed by a cycle from a known-good circuit. This would be a powerful comparison tool, as there'd be two waveforms when there was a difference between the circuits.
4. Practical experience will lead to the knowledge that power supplies are often the cause of problems in electronic equipment. Besides the initial visual inspection, clarifying the problem statement, and causing the failure to repeat, the first basic task should probably be to thoroughly check out a circuit's power supply circuits. At least verify that you have all the voltages required, that they're within 10% or 20% (your judgment call) of their specified values, and that there's no objectionable ripple or noise on the output. Since you have an Octopus, you also have a scope, so you can make these measurements quickly. While a DMM is certainly useful, I like to use a 10X/1X scope probe and turn on the scope's measuring function to measure waveform amplitude. This lets me see a number for DC voltages as well as see alternating signals.
5. Add a feature to be able to estimate ESR for big caps. Basic technique: look for caps that don't look like a dead short. Test at 10 or 100 kHz with 10 to 100 mA of current.
6. Question: do you learn anything new by using a triangle wave instead of a sine wave for excitation? The extra harmonics might be useful in telling you about the higher frequency performance. Of course, if you use a function generator and a transformer to float the Octopus, the high frequency roll-off of the transformer will cause an issue.
7. Comment that you can also switch to normal scope mode and look at the signals in the time domain.
8. Add in the feature AppNotes/Polarity_Sensing_Continuity_Tester.pdf, as it's simple to add and would increase the usefulness of the tester. Even better, add in an adjustable audible continuity tester.
   a) Actually, this leads to the design of a troubleshooting tool that would have Octopus abilities, an audible continuity tester, and an ESR tester all rolled into one device.
9. Show the troubleshooting of a simple DC power supply circuit. See page 9-1 (page 80 in the PDF) of the Huntron Tracker manual HTR-1005B1S-Operator.pdf. You can see the state

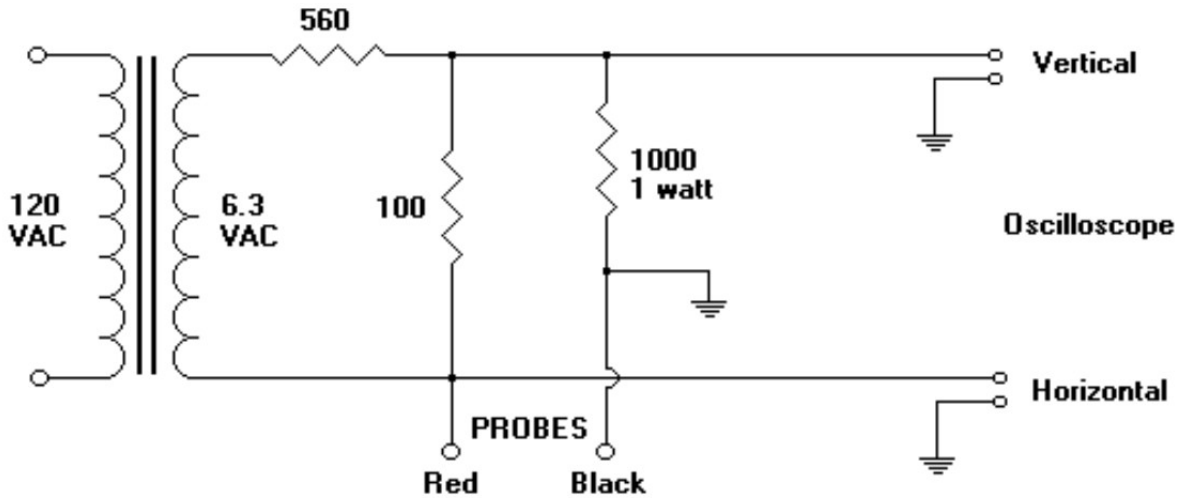
of the input power switch, fuse, and rectification diodes. Also show the effect of a blown filter cap. An advantage of this as an example is that the user can easily change the components (e.g., short or open a diode, short the capacitor, etc.) and see the composite effect. Make a point that a circuit designer can also include this information in the troubleshooting manual for the circuit and instruct the troubleshooter to use an Octopus with given characteristics.

10. Add a theory section that shows two sine waves for the current and voltage and their XY equivalent. In particular, discuss some simple AC theory that shows you can measure a reactive component's impedance using the Octopus.
11. With the right set-up, the octopus can be an effective continuity tester. Mine with the 5 V peak 1 mA setup shows a 100 Ω resistor as nearly a vertical line (short), but you can see the slope. A 10 kΩ resistor has a slope of 1/4 and a 100 kΩ resistor barely tilts the line off horizontal, so this i-V setting has a useful range of log 2 to 5 for resistance. Increasing the current to 100 mA would mean a 1 Ω to 1 kΩ range.
12. Set up the scope to allow you to switch quickly between the XY display and the two YT displays. Give some examples of the pairs of traces. This helps to give the user a feeling for what's actually going on.
13. Tip: if possible, keep the scope's channels DC-coupled. This will let you see any DC voltages that exist in the circuit when you're probing. Of course, there shouldn't be because you're doing this with the power off (right?), but a capacitor could still be charged.
14. Show pictures of typical transformer windings. These are interesting because they show core nonlinearities.
15. Show examples of a diode with a cap, inductor, series, parallel, etc. Make a catalog of waveforms with quantification so that it can be used later. Especially add the variable frequency ability with a function generator and extend the testing range.
16. Talk about fancier enhancements. For example, you could add a pot that would let you adjust the maximum short circuit current (include a fixed resistor to limit the maximum current). Calibrate the front panel with your ammeter.
17. Make the output a low voltage/low current (say, 1 Vpp and 1 mA) and you've got an in-circuit testing device that simply won't blow anything up.
18. Make the output 0.1 Vpp and 10 mApp and you've got a good continuity tester.
19. http://www.diyelectronicsprojects.com/2012/10/octopus-curve-tracer-circuit-diagram.html says: By placing the probes on a transistor's emitter and collector leads, then touching the base lead with your finger, you can observe the device's gain by seeing how much the curve changes.
20. If you don't have a suitable filament transformer, go to a second-hand store and get an AC wall wart. You can tell that it has an AC output because it will either say AC to AC, AC out, or give a tilde character (~) for the output. Look for an AC-output transformer with an output voltage of 3 to 6 V RMS. You can calculate the 0 to peak voltage by multiplying the RMS voltage by $\sqrt{2}$ and the peak-to-peak voltage by multiplying the RMS voltage by $2\sqrt{2}$.
    a) This could be a good excuse to take apart an old transformer and wind yourself one with multiple taps expressly for the use of the Octopus. This could be a good learning experience.
21. Use a function generator for the signal. A key requirement is you must make <u>sure</u> the circuit your testing is unpowered -- you don't want to accidentally fry your function generator.
22. It might be possible to build a small octopus setup with display and function generator with Arduino stuff.

Note: in this document, all AC voltages and currents are RMS values unless otherwise stated. I'll use the following abbreviations: RMS = root mean square, 0-pk = zero-to-peak, pp = peak-to-peak. Also note that I'm an electrical hobbyist, not an EE. I may have gotten something wrong, fuddled, or poorly stated. If so, please feel free to correct me at the above email address -- I'll appreciate it and subsequent readers will see better material.

Warning/disclaimer: this document talks about making connections to and using AC line voltages or other voltage sources. These voltages are in general hazardous, so this document is only intended to be used by people experienced in electronics, who understand the hazards, and know how to protect themselves from shocks or other hazards. I explicitly take no responsibility for how you use the information in this document; therefore, the information given is intended as reference information only.

Here's a useful Octopus from http://www.jammarcade.net/simple-component-tester-a-k-a-octopus-curve-tracer/ because it's designed to apply less than 1 Vrms and less than 1 mA to a load.



* All resistors in ohms and 1/2 watt unless otherwise indicated

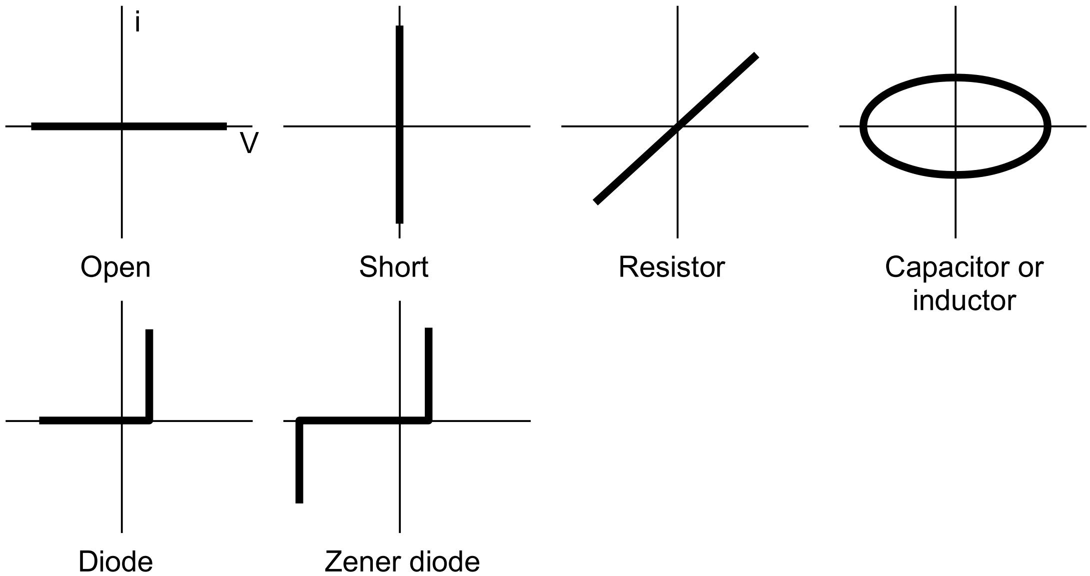
Introduction

If you have an oscilloscope and you like fixing electrical things, a useful tool you can build is the Octopus tester. It can be built from scrap stuff you may already have.

A simple Octopus test setup can be made from the crummiest oscilloscope available. All the scope needs to be able to do is to display one voltage on one axis with another voltage on the other axis (called XY mode). Since the test frequencies used are low (line frequency to perhaps 10 kHz), a low-bandwidth scope will work fine.

This device got its name from the leads running all over the bench when you cobble one together. You can do a web search on "Octopus tester" and you'll find lots of web pages with useful ideas.

So what exactly is it? The Octopus provides a current-limited AC voltage to apply to components and subcircuits. An oscilloscope is used to present the AC voltage applied to the component along the scope's horizontal axis and the current through the component on the vertical axis. This results in a current versus voltage plot for the component. Typical patterns seen on the scope are:



An advantage of the Octopus is that the circuit under test is unpowered. Thus, you won't be probing a circuit with potentially hazardous voltages present.

The patterns for the inductor and capacitor are Lissajous figures showing that the current leads or lags the voltage. The resistor, short, and open can also be considered Lissajous patterns (or limiting forms of them) but with no phase shift. In testing real circuits, you will often see combinations of these patterns. Here's one -- a signature of a diode in a sprinkler controller circuit:

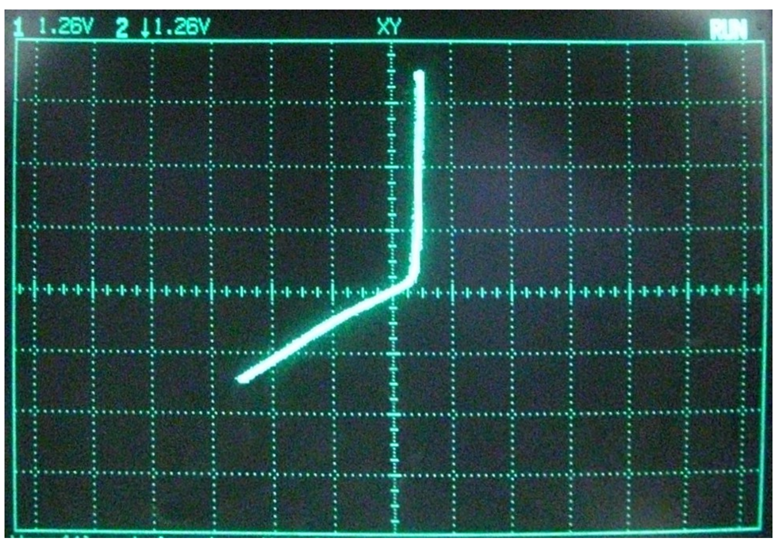


Figure 1

You can see the constant slope of a resistor in the circuit, then the point where the diode turns on at around half a volt (from the section *Diode and resistor*, we know this is a resistor in parallel with a diode). Interestingly, a resistor next to this one showed a similar figure except the diode turn-on came at 2.5 volts and the turn-on point moved to the right slowly, indicating a capacitor was charging. This is an example of a circuit giving a more complicated pattern than those illustrated above. **A powerful troubleshooting technique is to compare these patterns on a suspect or non-working circuit to the pattern from a working circuit**. If any differences are seen, you suspect something is wrong in that subcircuit.

You typically hold two probes in your hands and methodically probe the parts of the circuit (always with the circuit's power off). You look up at the scope's display, mentally evaluate the pattern, then go to the next component. This is reasonably fast -- you might spend a second or so on each part. You can make these comparisons even if you don't have a schematic of the circuit. Most things I've had to troubleshoot I haven't had a schematic.

You can test circuits that are unable to be powered up because of some problem, such as a short or hazardous operation. For example, in the *Uses* section I mention how the Octopus quickly (in under a minute) determined whether a small heater was worth keeping or not by comparing it to a known-good heater. I did all the testing by just connecting the Octopus to the two leads of the heater's power cord. This comparison method of testing allows you to e.g. check a bunch of components quickly to make sure they're functioning correctly or are identical.

The basic test method of the Octopus was developed in the 1930's soon after the first commercial oscilloscopes appeared. A commercial instrument called the Huntron Tracker works on this principle and is still sold, but is priced out of reach of the typical hobbyist; they can change applied voltage range, currents, and frequencies, allowing you to test more components. However, a hobbyist can build an Octopus with minimal work and expense and it really wouldn't make sense to spend a bunch of money on a Huntron Tracker unless you see a way to get a return on your investment. If you have a function generator, then you can build an Octopus that can do most of what the Huntron Tracker can do, just not as quickly or conveniently.

Some analog oscilloscopes have an Octopus tester built into them -- one example is the B&K 2125A. You connect the probes, push a button, and start testing. It doesn't get any faster than that.

The method is sometimes called analog signature analysis. This contrasts to "digital signature analysis", which was made briefly popular by HP in the late 1970's with an instrument used to capture digital signatures from digital circuitry. However, it never became terribly popular as a troubleshooting technique because of the need to stimulate the circuitry in particular ways and the circuit to be tested had to be designed to be used with signature analysis (I've read it's still occasionally used in niche applications). But analog signature analysis is still used frequently for troubleshooting.

This document looks at two different incarnations of an Octopus tester: basic and generator. Both require only a transformer and a resistor.

1. **Basic**: a bare bones implementation using a transformer and a resistor.
    a) Parts needed: box, transformer, resistor, power switch, fuse, banana jacks and female BNC terminals.
    b) Basic single-frequency Octopus testing -- will handle many troubleshooting tasks.
2. **Generator**: an Octopus based on a function generator that can provide a sine wave.
    a) If the generator's output is floating, you only need a resistor (if not, you need a small transformer for isolation).
    b) Allows you to see frequency dependence, giving you more troubleshooting clues.
    c) If your function generator's output can be swept, adds a powerful capability.

If you have a function generator that you're willing to use when you're troubleshooting, then I recommend you build the Generator Octopus. One advantage is that you don't need to make it line-powered, meaning there won't be any potentially dangerous voltages inside the unit.

Finally, there are enhancements that you could make to an Octopus circuit using active circuitry:

- Add fixed test frequencies.
- Allow variable gain amplifiers to have adjustable current and voltage limits.
- Have two channels for a known-good circuit signal and a suspect circuit signal, allowing quick comparison.

Building an Octopus

Here's the basic circuit diagram for both models:

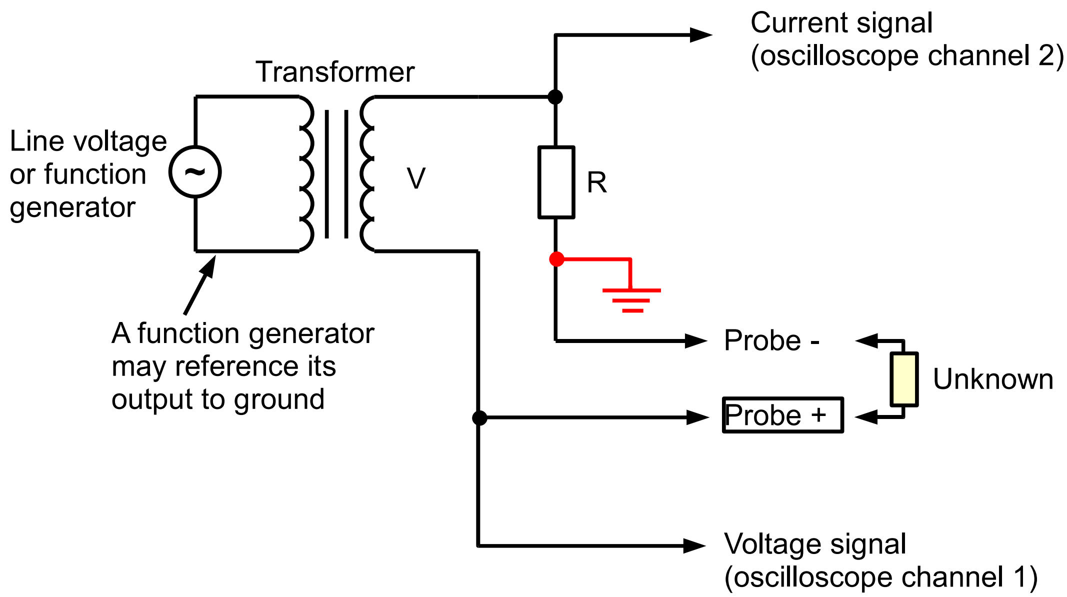


Figure 2

Basic model

The basic model is constructed using line power as shown in Figure 2. The transformer serves two purposes. First, if you're using line voltages, it steps down the line voltage to a more suitable value. Typical transformer step-down ratios used for Octopus testers can be 0.05 to 0.2 for 120 V line voltages. We'll discuss the second purpose in the next section.

The ground connection on the right is in red because it is important -- it's the reason the Octopus can be built with so few parts. You could construct an equivalent circuit for the secondary side of the Octopus in Figure 2 as

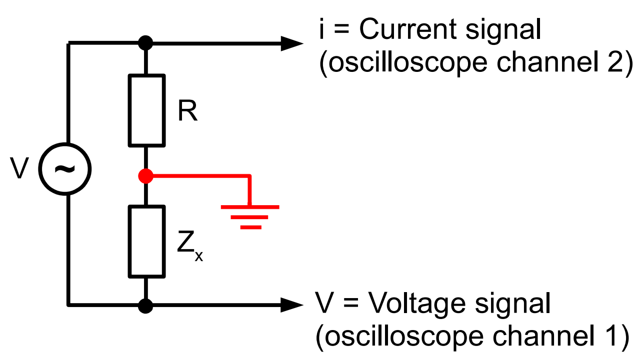


Figure 3

where Z_x is the circuit element being probed with the Octopus. Since the two connections to the oscilloscope are high impedances (1 MΩ), the equivalent circuit is essentially two impedances in series with a voltage source. The grounding point provides a reference potential that is the same as the oscilloscope's -- and, thus, the voltages measured by the oscilloscope represent the voltage across the circuit element Z_x (channel 1) and the current through circuit element Z_x (channel 2).

An important thing to note is that **the voltage V in Figure 3 is isolated from ground potential** (i.e., not referenced to it). It's referenced to the other leg of the transformer circuit. In an isolated circuit like Figure 3, you can connect any point of the circuit to a reference potential if desired and it doesn't change the circuit's behavior. If the oscilloscope's channels could take differential inputs, then this grounding wouldn't be important. However, since the scope's input channels are referenced to ground, the grounding connection as shown in Figure 3 is the key to the simplicity of the Octopus.

Important: This electrical isolation of the transformer is an important feature to prevent shocks. Note that some transformers (called autotransformers), such as Variacs, do not have such isolation and should not be used for this purpose. Use your DMM to measure the DC resistance between the primary and secondary sides of the transformer -- it should be unreadable or at least many MΩ. See *Variacs are not isolation transformers*.

If the output of the transformer is a sine wave of V volts, the circuit will apply a $2\sqrt{2}V$ peak-to-peak sine wave voltage across the unknown Z_x (or $\sqrt{2}V$ 0-pk). The resistor R is used to limit the current through the component Z_x being probed as well as provide the voltage representing the current through Z_x. The short-circuit current when Z_x is zero will be V/R. The short-circuit power dissipated by the resistor is V^2/R. These two relationships allow you to pick an appropriate value for R and its wattage rating.

Example: suppose I want my Octopus display to use four divisions horizontally and vertically. If I want each horizontal division to be 1 volt, then I'll be applying a 4 V 0-pk signal to the unknown Z_x. R is thus determined by the desired short-circuit current. Suppose I want the short-circuit current to be 4 mA 0-pk (or 1 mA per division). Then we calculate R to be (4 V)/(0.004 A) or 1 kΩ. When Z_x is zero, the voltage V will be across R and the dissipated power will be V^2/R or 16/1000 or 16 mW. An eighth-watt resistor would work fine.

In Figure 2, the voltage representing the current through the tested component will be 180° out of phase with the voltage across the component. This leads to current versus voltage plots that are reflected about the vertical axis compared to the usual up and to the right type of plot. You can use this plot as it is -- there's no loss of information in such a plot. However, this reversal is easy to fix -- just invert one of the scope channels and you'll see a more usual plot where a deflection to the right of the origin means a positive voltage and a deflection above the origin means a positive current.

A common transformer voltage used to be 6.3 V; these were used as filament heater voltages for tube-era equipment. You can use nearly any scrap transformer that has the desired ratio. You can also cascade two transformers to get the voltage you want. Use what you have on-hand. Don't forget wall-warts -- there are many that are AC output instead of DC and can thus make Octopus transformers. Check the stock of a local second-hand store -- many times they will have a large box of wall warts and only charge 50 cents or a dollar each.

For my first Octopus, I used a World War 2 era transformer that output 3.5 V. Since the 0-pk voltage was thus 5 V, this was convenient because my scope had 5 horizontal divisions to the left and right of the center of the screen, giving an easy-to-interpret 1 volt per division.

Fancier versions of the Octopus might include multiple transformer taps for different voltages and a switch to select different current-limiting resistors. A small Variac would be quite nice in combination with a step-down transformer to get an adjustable Octopus voltage.

Warning: make sure you don't use a Variac without a suitable transformer, as **a Variac doesn't provide the necessary isolation** a regular transformer does -- and you would definitely run a risk of getting a shock. See *Error: Reference source not found* for more details.

Another warning concerns the maximum voltage applied to the circuit under test. If you want to test transistors with your Octopus, be aware that around 5 volts is a maximum for the base to emitter voltage for typical transistors (read the datasheet). I had to learn this the hard way one day when testing a transistor and getting results that didn't make sense until I read the datasheet.

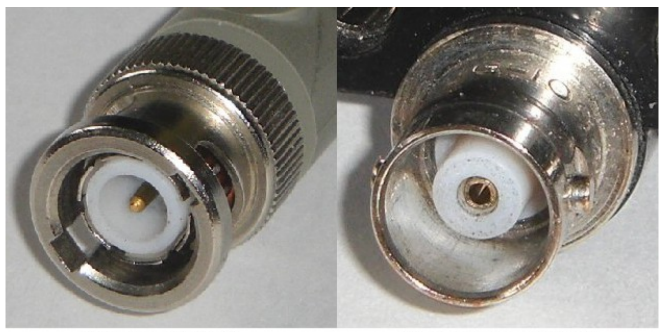
Function generator model

An advantage of using a function generator for an Octopus is that you can control the amplitude and frequency of the excitation voltage. Being able to adjust the voltage is useful because a) you can choose whether you want to turn semiconductor junctions on or not and b) you can safely test a sensitive circuit with low voltages. Being able to adjust the frequency is useful because you can get usable responses from a wider range of components/subcircuits.

As an example, a small transformer I have has a winding with an inductance of about 4 mH. It looks like a dead short when tested with an Octopus at 60 Hz. At a higher frequency, it shows the characteristic elliptical shape. A 100 μF capacitor looks like a dead short at 1 kHz, but you can reduce the frequency to a few Hz and see the characteristic elliptical shape.

I would imagine that most function generators made today that are line-powered have their outputs referenced to ground. Here, "ground" means the power line safety ground. You'll have to use a transformer as in Figure 2 to use a ground-referenced generator.

Older generators (for example, the HP 200 models or my old Wavetek 144) may have their outputs floating. Floating means that the output is not connected to the safety ground. Practically, this means if you measure the resistance from the generator's output connections to ground, you'll measure effectively an open circuit. A ground-referenced function generator will measure a resistance of about an ohm or less between one of its output terminals (the outside of the female BNC connector) and the safety ground connection. Some manuals seem a bit confused about what a female BNC connector is. The sex is determined by the center conductor; see the following picture:



Male BNC **Female BNC**

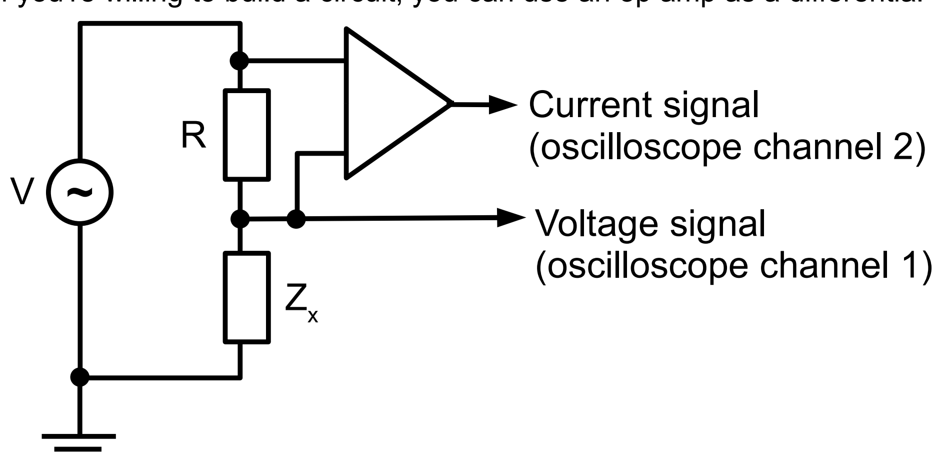
If you have a generator with a floating output, you can make your Octopus with one resistor R as per Figure 3. This is quite cool because it's so simple. If your generator is not floating, check the user's manual, as there may be a control or internal connection that lets you decide whether the output is floating or not (my Wavetek 144's manual tells you how to make an internal connection to reference the output to ground if you wish). One clue that a BNC output is or can be made floating is that it will be insulated from the chassis, usually by a visible clear or translucent-white insulator.

Another advantage of using a function generator as an Octopus tester is that you can use low frequencies in combination with a digital camera and an analog scope. By opening the shutter during the excitation waveform's period, you can capture a whole waveform. This allows you to use frequencies on the order of 1 Hz or less, which may prove useful in some cases (such as getting a Lissajous figure from a big capacitor). You may have to build a light shield for the camera to avoid the picture getting washed out from room light.

Other methods of using a ground-referenced function generator

While the use of a small 1:1 transformer in the configuration of Figure 2 is probably the most straightforward method of dealing with a ground-referenced generator, there are other methods.

Differential amplifier: If you're willing to build a circuit, you can use an op amp as a differential



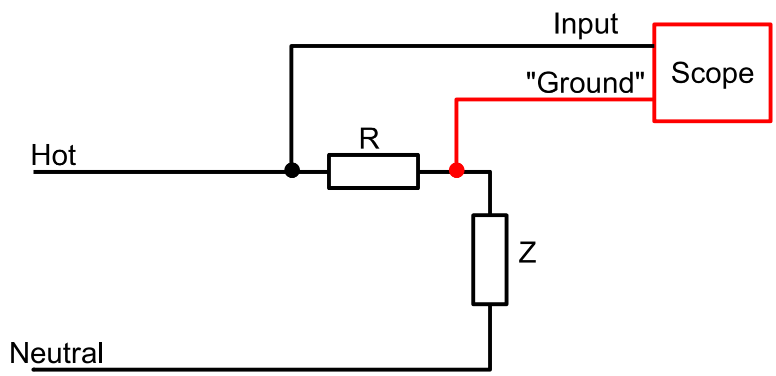
amplifier to measure the voltage across the current sense resistor and change it to a voltage referenced to ground:

You can change the gain of the amplifier to change the Octopus' full-scale current value (of course, you can do the same with the scope's input amplifier gain).

Floating: Experienced electrical people occasionally resort to floating an instrument. This means the instrument's case and chassis are not connected to safety ground. There are two common ways of doing this: using a 3-to-2 wire adapter or an isolation transformer. The 3-to-2 wire adapter disconnects the safety ground. The **risk of doing this is that an electrical fault in the instrument can put dangerous voltages on the exposed metal instrument surfaces and lead to a shock**. I've occasionally done this when there wasn't any other choice, but it's not recommended, especially for beginners.

One reason I don't like beginners floating scopes is that they might leave the scope floating -- when someone else uses the scope, they could **be unaware that a key safety feature was disabled**. Few scope users would think of checking that the scope was grounded properly (they'd just assume it was if it was plugged in). This could be an accident waiting to happen.

Here's the safety issue. If you were using a typical scope probe, you connect the grounded lead near where you're probing for a good signal return. One reason to float a scope is to let you connect this "ground" lead (which isn't grounded when the scope is floating) to one side of a resistor and the probe to the other side, letting you measure the voltage across the resistor. This e.g. lets you view the current waveform through the resistor. The danger is that this resistor could be on the "high side" of a circuit. By connecting the "ground" wire of the probe to the high side (suppose it's near 120 V line voltage), **you now have nearly 120 V on the outside of the scope's BNC connectors**. This is shown in the following figure -- suppose R is a relatively small resistance used to measure the current through the circuit with impedance Z. Then the "ground" wire of the scope probe, shown in red, is connected essentially to a voltage near the line voltage.



If you touch the metal outside of a BNC connector on this scope and an earth ground, **you're going to get a shock**. If you absolutely have to use this measurement method, then you should power the scope from a ground fault interrupter circuit to help protect against such a shock. Make sure you test the GFI to ensure it is working before making the measurement.

Years ago I occasionally needed to use this method and I was cautious with my setup. I'd have my wife in the room next to a switch that would cut off all power if something went wrong. I didn't make any connections with the power on -- I connected the probes with the power off, stood away from the circuit and the scope, and then powered things on. It worked well, but I later bought a differential amplifier, the proper tool for this type of measurement.

Isolation transformer: Another way to float an instrument is to power it from an isolation transformer. This is an accepted way of floating an instrument, but it's only for experienced technical people who know exactly what it does, why they're doing it, and what specific safety precautions need to be taken. This is also not recommended for beginners.

Battery operation: A battery-operated function generator could be an excellent choice for Octopus testing because it's already isolated from ground. You need to wire things carefully, however, as the scope connections will have the outer conductor of the BNC jack grounded (unless you're using a battery-operated scope). Thus, you'd want to insulate the BNC input jack used to input the generator's signal from the metal case of the container (or use a plastic box).

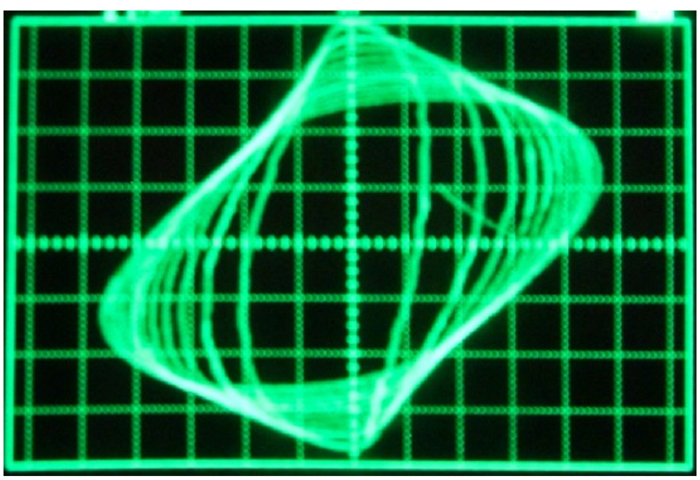
If you're only interested in Octopus testing at one or a few frequencies, you could construct an Octopus tester from a suitable wall-wart or battery, a quad op amp IC, and a handful of components. One op amp could be e.g. a Wien bridge oscillator, another could adjust the Octopus test voltage, and a third could amplify the voltage across the sense resistor. You'd have an op amp left over (one use could be a low battery comparator). Other advantages of battery operation are no power supply noise and you can use low-voltage components and batteries to limit the voltage applied to the circuit to be tested.

Using a sweep

A function generator that is capable of sweeping in frequency can provide another dimension of Octopus use: you can see the frequency-dependent behavior of the circuit you're probing without having to twiddle knobs or press buttons. You see the circuit's response change during the frequency sweep. You slow the generator's sweep time down to see more detail if you see something interesting.

While you can see more detail by slowing down the generator's sweep time, but there's a tension with being able to step from component to component quickly for troubleshooting. You can set the sweep time to 1/2 to 1 second for fast response, then adjust the generator's sweep time knob to look at things in more detail when you wish.

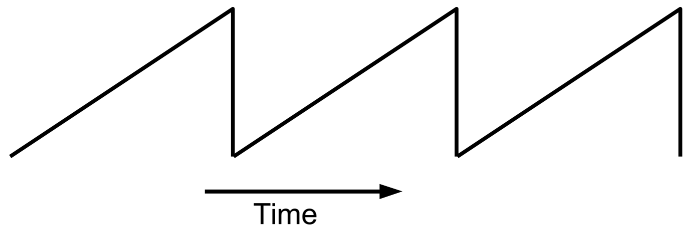
Here's an example. I used a B&K Precision 2542B-GEN scope's function generator to sweep a sine wave from 10 Hz to 100 Hz in 1 second. The circuit being tested with the Octopus was the two power cord conductors (hot and neutral) of a DC power supply. Here's a picture of the result taken with a long exposure (the camera was hand-held, so it's blurry):



You're seeing the primary winding of the power supply's transformer (and perhaps some of the secondary circuitry "reflected" into the primary). It was easy to identify as an inductor because the current dropped as the frequency increased which, in turn, is caused by the increasing reactance of the winding. You can also see the tilted ellipse, which is caused by the winding's DC resistance.

Some digital scopes' XY display will depend on the scope's sweep time setting; for other digital scopes the scope sweep time has no effect during XY display. If your scope's displayed pattern is affected by the scope's sweep time, experiment to find the most useful scope sweep speed for the chosen generator sweep speed.

If your function generator doesn't have the ability to sweep, you may be able to get a sweep effect if the generator supports FM modulation. For example, my old Wavetek 144 has a VCG (voltagecontrolled generator) port that can change the output frequency by a factor of 1000 depending on the applied DC voltage. You'd get the effect of a linear frequency sweep by applying a positive ramp (see following figure) waveform to the VCG port. This can also work with function generator chips with a VCO input such as the XR2206.



This could make a relatively inexpensive production inspection tool. You could build a circuit that would e.g. generate one cycle of a sine wave at selected test frequencies, then capture the composite test signal using the Octopus. There'd be one complete trace on the screen for each frequency.

Buy a commercial unit

If you have some disposable cash, you could buy yourself a Huntron Tracker. But most of us couldn't justify spending a few kilobucks unless there was a way we could earn money with it.

A revision of the present document in 2013 discussed a less expensive commercial Octopus for around $130, but the web site appears to be dead. It looked like a good tool, but obviously sales weren't enough.

If you know of more commercially-available units, let me know via email and I'll include them in this document. But a basic Octopus is so easy to make from a few parts that I suspect there's not much of a market for these more simplistic units. I'd imagine the reason people buy the Huntron Tracker is because it's an all-in-one unit that is up and running immediately, but they're so expensive that they're typically only purchased by people who can justify it as a business expense they'll recoup.

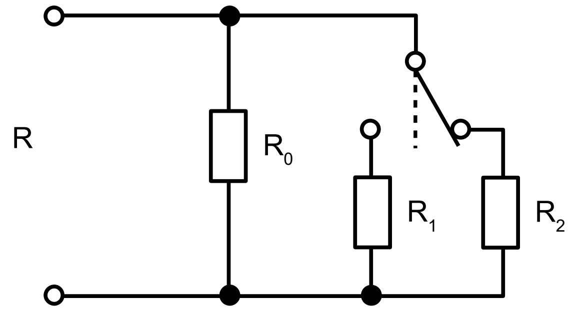
Octopus design

This section gives the details of the second Octopus unit I designed for myself. The first unit used a 6.3 V RMS filament transformer, but that transformer unfortunately had nonlinearities that affected the output shape and was pretty noisy.

I decided my second Octopus would use a function generator for the excitation voltage so that I could adjust the amplitude and frequency if I wished and utilize lower-distortion sine waves. I also wanted to be able to sweep the frequency.

I decided that I would use 4 volt zero-to-peak excitation voltages as my normal operating point. In conjunction with this voltage, I wanted to have current limits of 0.4, 4, and 40 mA. The reason for choosing multiples of 4 is because the scopes I use typically have four divisions vertically on either side of 0. With this design, one division horizontally will then be 1 volt and one division vertically will be 0.1, 1, or 10 mA. This makes for convenient measurements.

I don't have a handy 3-position rotary switch, so I decided to use a center-off single-pole double-throw switch to select the desired current level. This is done in the following way:



Here's how to select the needed resistors. Since the peak voltage is 4 V and the three maximum currents are 0.4, 4, and 40 mA peak, we need R to be 10 kΩ, 1 kΩ, and 100 Ω, respectively.

Since the equivalent resistance of two resistors in parallel is always less than either of the resistors[1], we need to pick R_0 as the 10 kΩ resistor. Thus, the center-off position of the switch will be 0.4 mA. Assuming R_1 is for the R = 1 kΩ case, we solve for R_1 from

$$\frac{1}{1000\ \Omega} = \frac{1}{10000\ \Omega} + \frac{1}{R_1}$$

giving R_1 as 1111 Ω. Similarly, we get 111.1 Ω for R_2.

At 40 mA, most of the current will be through R_2, so the power dissipated in R_2 is slightly less than $0.04^2(111.1)$ or 178 mW, so R_2 should be a 1/4 W resistor.

For this design, I would worry about accidentally applying more than 4 V 0-pk with a function generator. The maximum output that can be gotten from my function generator is a measured 95 mA 0-pk across a 111.1 Ω load. This implies a maximum power dissipation of $(0.095\text{ A})^2(111.1\ \Omega)$ or 1 W. Since I don't have a 111.1 Ω 1 W resistor, I'll use four 444.4 Ω resistors in parallel.

Sine wave amplitudes

Note these relationships are only true for sine waves.

Let $V = A\sin(\omega t + \delta)$ be the general form of a sine wave where t is time and the other three variables are constants.

For a sine wave, the following numbers are often used to characterize the amplitude:

A = Volts zero to peak: this is the usual mathematical definition of the amplitude..

V_{pp} = Volts peak to peak: This value is often measured on a scope and is 2*A*.

V_{rms} = Volts RMS: measures the equivalent heating power of the waveform and is

$$V_{rns} = \frac{A}{\sqrt{2}} = \frac{V_{pp}}{2\sqrt{2}}$$

Design of next Octopus

Key features:

- Function generator input. Also allows for a transformer connection to be made for 60 Hz testing.
- I would still like, if possible, to have a 4 V 0-pk 50 to 100 Hz signal.
- Current levels of 0.4, 4, or 40 mA 0-pk.
- Two simultaneous, identical outputs for known-good circuit and suspect circuit comparisons. Be able to switch between them rapidly for a flicker display.

1 Let x and y be the resistances. The parallel resistance is x(y/(x + y)) and y/(x + y) is strictly less than 1 if x and y are greater than zero.

- High purity sine wave excitations so that any nonlinearities seen are due to the item being tested, not the excitation circuitry.
- Use a wall wart internally for power & safety. Use 7812 voltage regulators. Use ±12 V DC supplies.

The desire to have two identical outputs implies that it would be best to use an op amp to measure currents and buffer the generator's signal. Since that means there'd be a wall wart providing power, it also means that a chip could be used to generate sine waves. Then there could be two pots on the control panel to control frequency (1 Hz to 10 kHz) and one to control amplitude.

See pg 13 of the LM324 data sheet about how to ground reference a current signal.

Would it be possible to alternately display one period of the suspect circuit and one of the known-good circuit? This would result in two curves on the screen and would allow immediate comparison between the two circuits. This could be done by e.g. using a Schmitt trigger to toggle an analog switch.

Build a tool that combines the following features:

- Octopus tester.
- Audible continuity tester.
- Audio tracer

Since I'll probably be using it with the 2542B-GEN scope, tailor the design to benefit from the scope/generator.

An ESR tester could also easily be made if the scope and generator were being used.

Controls

1. Switches
   a) Power on/off: single toggle switch.
   b) Signal: internal/external (internal means the internal oscillator, external means a function generator).
   c) Function: audio tracer or continuity tester
2. Pots
   a) Test frequency 1 Hz to 10 kHz
   b) Amplitude 0 to e.g 10 V 0-pk
   c) Audio amplifier gain
3. Indicators
   a) LED for power on
4. Jacks
   a) BNC female for V to scope
   b) BNC female for i to scope
   c) BNC female for function generator input
   d) Dual banana jacks for probes
   e) BNC female for probes
   f) BNC female for audio output
   g) Dual banana jacks for audio output

Huntron Tracker 1005B

This is from a scanned manual found on the web that dates from probably the late 1970's (Huntron has been making trackers since 1976). The specs were:

Excitation 80 Hz sine wave

Low range: 20 V peak-to-peak open circuit (7 V RMS), 170 mA peak-to-peak short circuit current

Medium range: 40 V peak-to-peak open circuit (14 V RMS), 0.7 mA peak-to-peak short circuit current

High range: 120 V peak-to-peak open circuit (42.4 V RMS), 0.8 mA peak-to-peak short circuit current

This is a good manual to read through because it covers the testing of different devices. It also demonstrates that a better tester would include higher voltage ranges to allow tests of more devices.

Using the tool

The Octopus tester is straightforward to use. Here's the procedure I use:

1. Connect the voltage output BNC terminal to channel 1 on the scope.
2. Connect the current output BNC terminal to channel 2 on the scope.
3. Set the Octopus to 3.5 V RMS output (5 V 0-pk).
4. Set the scope to XY mode. (With my digital scope, just recall one of the setup registers.)
5. Plug the probes into the box.
6. Power on the tester.
7. You'll see a horizontal line on the scope. Set channel 1's gain to 1 V/div so that the line extends from -5 to +5 major divisions. Adjust position to center the line about the vertical axis.
8. Short the leads together to get a vertical line. Set channel 2's gain to 1.24 V/div so that the line extends from -4 to +4 major divisions. Adjust position to center the line about the horizontal axis.
9. Start probing a circuit. Make sure the power to the circuit under test is off and that all capacitors are discharged.

I usually leave the scope's channels DC-coupled. If you use AC-coupling, you may see waveform shifts.

I keep the red probe in my right hand and the black probe (which is connected to ground) in my left hand. This lets me see the polarity of semiconductor junctions. Most LEDs will usually light up faintly at 1 mA, so you can see that they work and identify the anode immediately.

Quantitative measurements

The scope picture allows you to make quantitative measurements if you know what the channel gains are. One of the advantages of a digital scope is that you can store the instrument setup in a register and have the scope set up for Octopus measurements quickly.

> It's not hard with an analog scope either. As long as you know the peak voltage and current (measure them), you can use the variable gain knobs to set an appropriate deflection on the screen (set the voltage with the probes open and the current with the probes shorted).

For example, on my HP digital scope, I use 960 mV/div for the voltage (horizontal) gain and 1.20 V/div for the current (vertical) gain. This gives me on the screen 1 V/div for voltage and 1/4 mA/div for current.

You can estimate what kinds of resistances you can distinguish. I'll use my unit as an example. The 0 to full scale deflection of current is 1 mA RMS or 1.4 mA 0-to-peak and the 0 to full scale deflection of voltage represents 5 V 0-pk.

Let's suppose I can detect a vertical deflection of 1/16th of a division. Since there are 4 vertical divisions, this means I can detect 1/64th of full scale, or 22 μA. A nearly-horizontal line with this slope would thus represent (5 V)/(22 μA) = 230 kΩ. Actual measurements show I can do a bit better than this -- I can see a 500 kΩ resistance by rapidly touching the probe to the resistor and then disconnecting it. This is similar to how astronomers detect movement in heavily-populated starfield pictures -- they rapidly exchange the two pictures and any differences show up as something flickering.

For a low resistance, the calculation is similar. The change in voltage will be 1/16th of a division; since there are 5 divisions, this is 1/80th of the range. Thus, the minimum detectable resistance is on the order of (5 V/80)/(1.4 mA) or 45 Ω. When I compared a low resistance to a dead short using the flicker method just mentioned, I could see a 10 Ω resistance.

By using a transformer that provides multiple voltage taps and different current-limiting resistors, you can extend the measurement ranges and sensitivity of the Octopus.

A third parameter to vary is the excitation voltage's frequency. This is most easily done by using a function generator (see the *Function generator model* section).

Continuity tester

You can use the Octopus tester as a continuity tester, especially if you're willing to increase the allowed current a bit or decrease the applied voltage.

This could be a good argument for having a separate setting where you'd apply a voltage of, say, 1 V 0-pk and use a current limit of 100 mA 0-pk to help you measure lower resistances. The resistor in Figure 2 would need to be 1/0.01 = 100 Ω. A resistor with a 1 W rating would be needed (2 W would be better).

Using the same arguments as in the previous section, the resistance sensitivity would be about (1 V/80)/(100 mA) or 1/8th of an Ω. Now you're in the area where lead resistances are important and 4 wire Kelvin measurements are required if you're using a DMM.

At 1 V and 100 mA, the maximum resistance you could detect would be about (1 V)/(0.1 A/64) or 640 Ω.

If there are 5 divisions from 0 to peak voltage horizontally and 4 divisions from 0 to peak current vertically, you can see a line at 45° to the axes would represent a resistance of $(1\ \text{V}/5)/(0.1\ \text{A}/4)$ or 8 Ω.

In other words, you'll be able to measure resistances from roughly 1 Ω to 500 Ω. This makes a useful continuity tester.

If you examine Figure 2, you'll see that the probe leads' resistances contribute to the overall load resistance being driven by the transformer's output voltage. My test leads have a resistance of 33 mΩ per lead (they're 18 gauge wire). For a 1 Ω load, this increases the measured resistance by about 6%. If you want more accurate low resistance measurements, switch to lower resistance probes. But I doubt this would be worth the effort -- if you want accurate resistance measurements, use an appropriate multimeter.

Standards box

I haven't done this yet, but I'd like to some day. If your Octopus has multiple voltage/current levels, it would be handy to have a small box with terminals on it that let you access various components. For example, you could put 10 Ω, 100 Ω, 1 kΩ, 10 kΩ, and 100 kΩ resistors in the box to allow you to estimate a resistance's order of magnitude. The box could also contain a selection of capacitors, inductors, and semiconductors. A quick probe would let you compare these known components to an unknown component and check that the Octopus is working correctly.

If each component's leads were connected to a quick-connect terminal (examples are the

Fahnestock spring connectors used to connect transformers to model train tracks or the push and insert connectors on stereos), then you could use some stripped connecting wires to connect the components in various configurations to see how a composite circuit behaves or to test out a hypothesis about what's causing a particular behavior.

Another construction method I've used is to solder the discrete components with leads to nails pounded into a chunk of plywood. This is cheap and easy to construct and works well for casual bench standards.

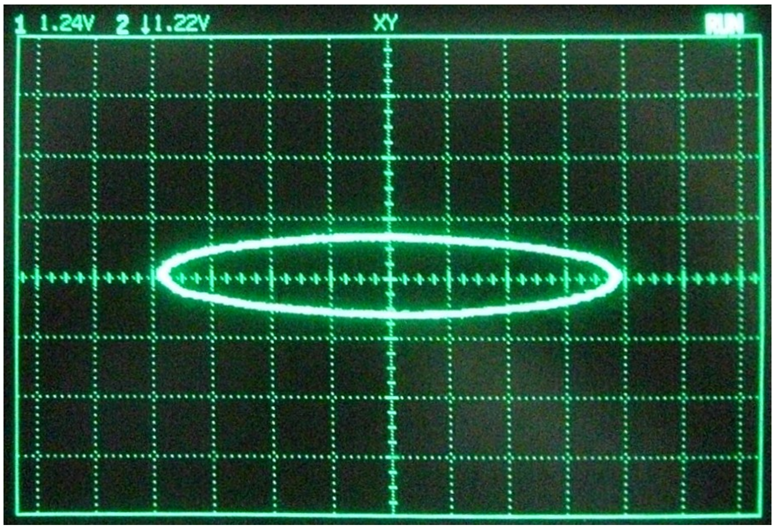
Uses

The Octopus is good for fast characterization and troubleshooting. Since I typically use it with my digital scope, I have the setup information stored in the scope's internal registers. I recall the instrument setup, connect two BNC cables to the scope's channels 1 and 2, connect the two probes, turn the Octopus on, and I'm up and running. Only a scope like the B&K 2125 with the built-in Octopus tester is faster.

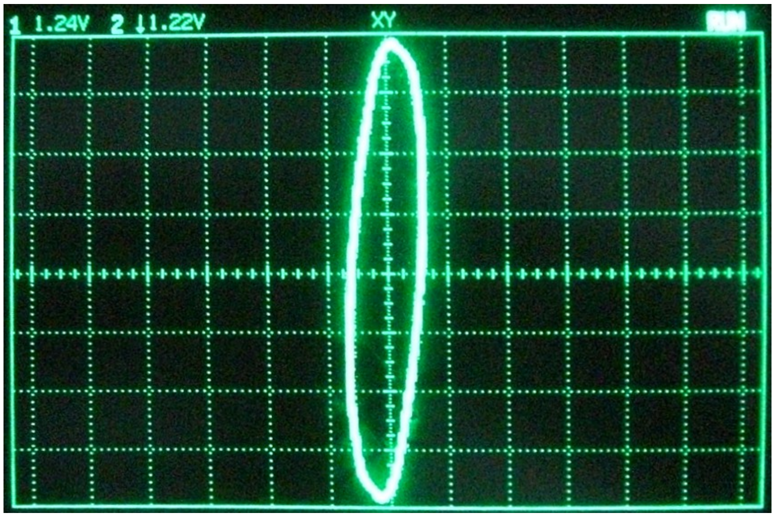
Sample traces

Here are some sample traces. The horizontal gain was set at 1.25 V/div and the vertical gain was 250 μA/div. After taking these pictures, I realized it made more sense to set the horizontal gain to 1 V/div; this gives me almost 5 divisions on either side of zero -- and makes it easier to read off voltages. When I use the 7 Vrms output, I set the horizontal gain to 2 V/div.

Here's a 100 nF capacitor:

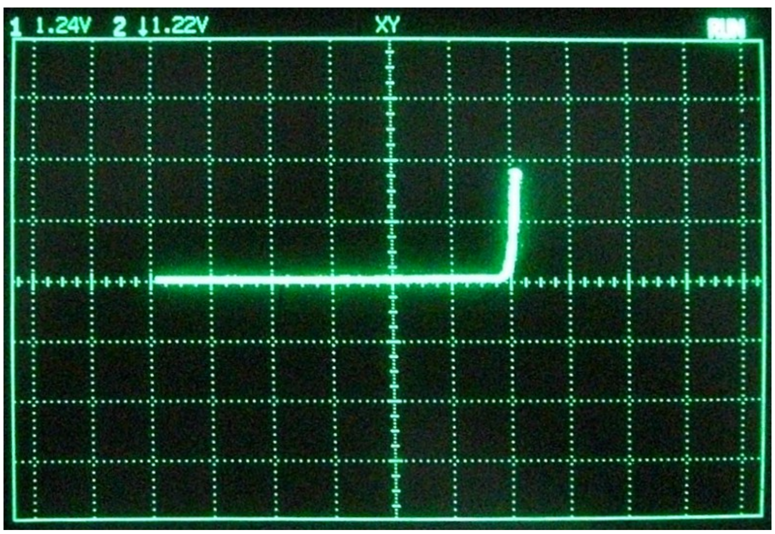


A 520 mH inductance (part of a transformer):



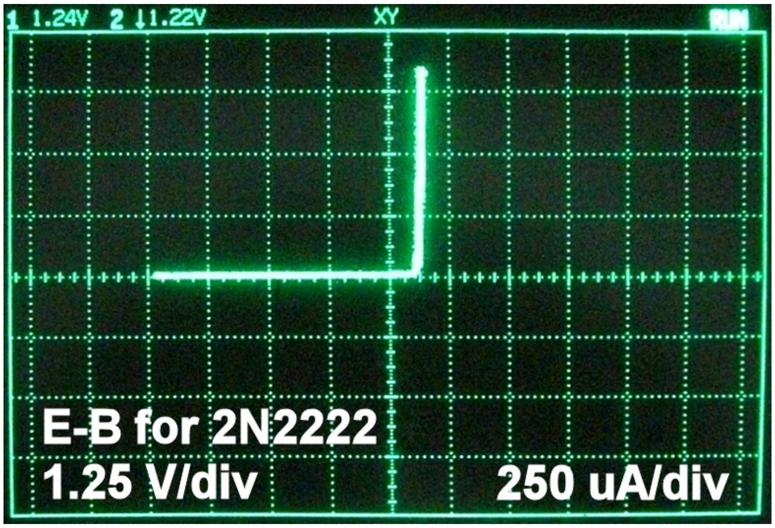
Note there's a slight lean to the right of the ellipse; this is because of the transformer's winding resistance. From the slope, I'd estimate it to be on the order of 50 Ω; it was 45 Ω when measured with a DMM. This implies something you might want to do: measure the slopes of the lines from 10 Ω, 100 Ω, 1 kΩ , etc. resistors and paste the results somewhere handy. This will help you in estimating an unknown resistance.

A blue LED with a DMM-measured forward voltage of 2.55 V:

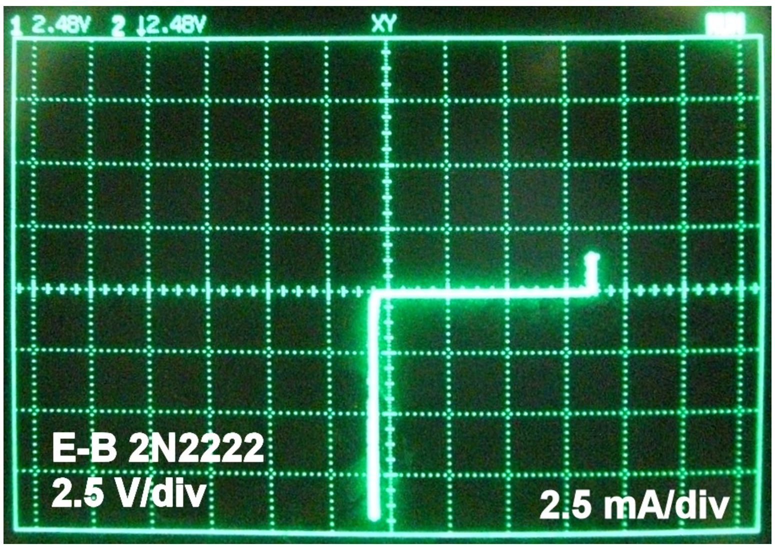


Note the knee of the curve at 2 div or 2.5 V.

Here's a 2N2222 transistor. The first picture is the emitter-base junction:



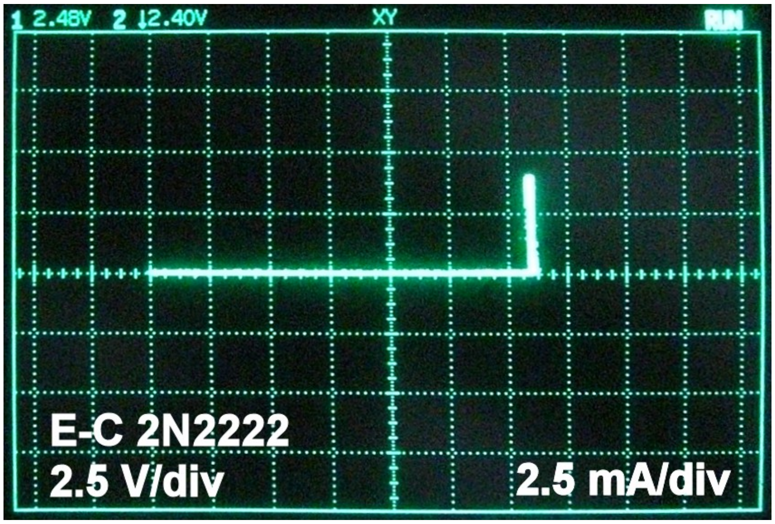
The manuals will tell you that this trace should look like a zener diode. Here's a trace with the 10 V zero-to-peak stimulation:



The leads were reversed from the previous picture. In addition, the current in the vertical direction should really be 2.6 mA/div because the current was measured at 10.6 mA, but 2.5 mA is a little easier to remember.

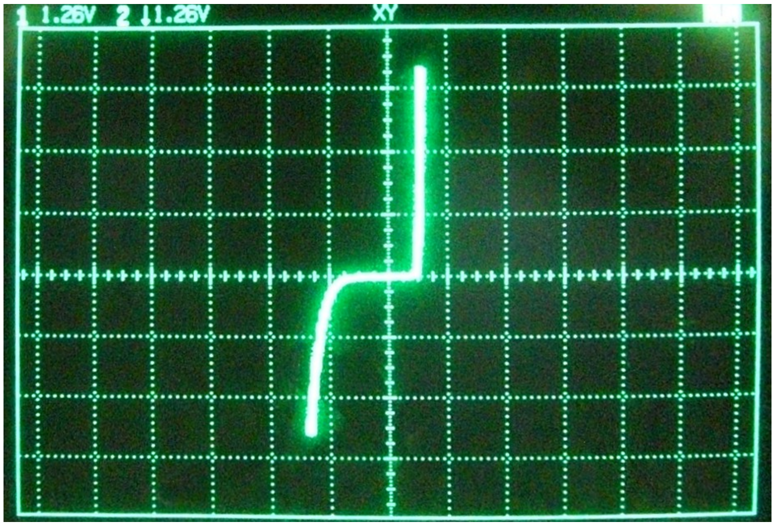
Because you can identify the polarities of the signals, you can identify the leads and the polarity of an unknown bipolar transistor.

Here's the emitter-collector with the Octopus changed to 7 Vrms:



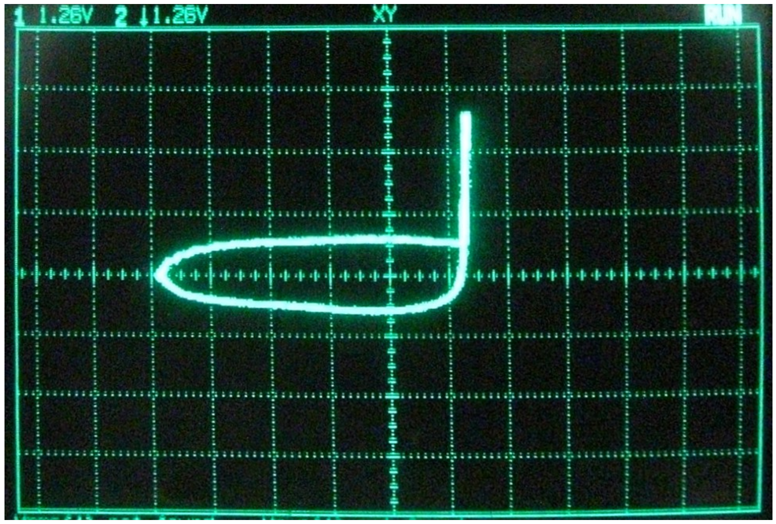
Apparently Huntron made a model that was sold by Tektronix called the TR201. It was without a display, as the typical Tektronix user would already have a scope. It came with a manual (Tektronix part number 071-0114-01) that explains the details of using such a tool. If you're interested in building your own Octopus, it will probably be worth your time finding a copy.

Here's a 3.3 V 1 W zener diode:



The zener was labeled by the seller as 3.3 V, but it's only reaching about 1.5 V for its reverse breakdown voltage.

As a last example, here's the signature of a 100 nF capacitor in parallel with a red LED:



I mentally call this a "golf club" because it looks like a golf putter. It demonstrates a composite signal that can be seen when testing real circuits. The display is a Lissajous figure of a capacitor "interrupted" by the conduction of the diode at about 1.75 V. The low resistance of the diode masks the reactance of the capacitor.

Comments on scopes

The type of scope you use with the Octopus could have an impact on its usability. I've used some digital scopes that have some limitations in XY display mode. For example, some scopes limit the maximum gain in the X direction. This limits the amount of screen space you can use (I like to set the scope up to use as much screen space as I can). You may also find the sweep speed is important, as it controls the sampling rate. If the sampling speed is too fast, you may only see a partial waveform on the screen. This is easily fixed by decreasing the sweep speed.

An advantage of a digital scope is that you may be able to average out random noise. This can be a big help on small signals. However, it can also decrease the responsiveness of the Octopus tool unless you can increase the test frequency. My older digital scope won't allow this averaging in XY mode.

If you're going to set up a dedicated scope for Octopus testing, I'd recommend using a cheap analog scope. You'll get the display you want and there won't be any surprises like you might have with a digital scope. On the other hand, most of us hobbyists have only one scope and want to use it for multiple things. I still prefer a digital scope for general-purpose lab use and I'll live with any minor annoyances. If I was going to do a lot of troubleshooting, I'd probably want to find a used analog scope to use exclusively with the Octopus tester.

By the way, if you're not aware of the technique, your scope and function generator make a good tool for quickly and safely determining transformer winding ratios and phasing. Here's the voltage output of the transformer I use in my Octopus:

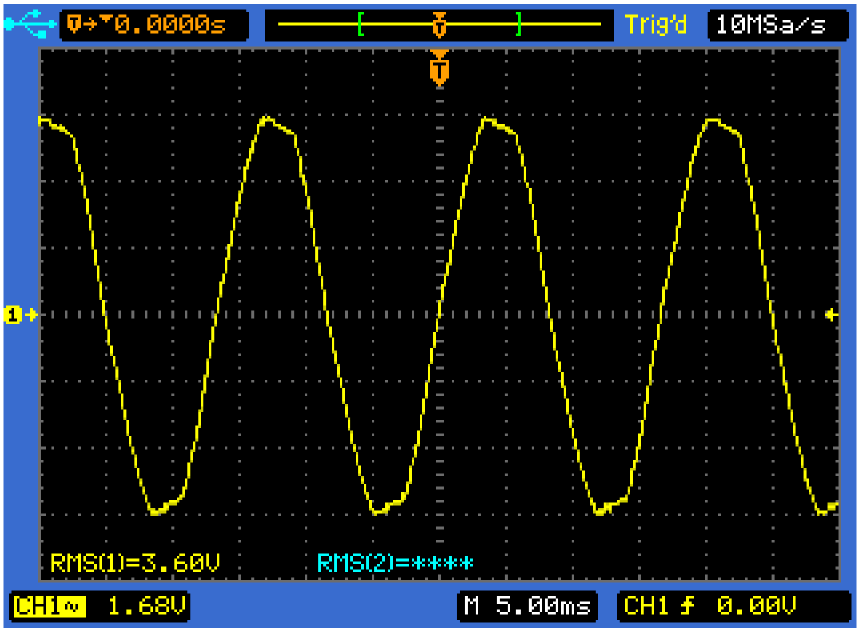


Figure 4

You can see that it's not a very good sine wave. This leads to noticeable distortion in the Lissajous figures for inductors and capacitors.

You'll have to decide if such distortion is important to you. For quick troubleshooting it can be ignored, but for more careful work where you want to be both qualitatively and quantitatively correct, it can lead to errors or uncertainty. The Octopus tester sometimes shows nonlinearities in traces from transformers and inductors with ferromagnetic cores -- and you might not want these confounded with the Octopus' nonlinearities. Thus, it may be worth your time to select a transformer that provides a sine wave with suitably-low distortion. Or, build an excitation circuit without the nonlinearities in a transformer.

Other examples of use

Identification of relay terminals

With a set of probes, an easy thing to do with the Octopus is to quickly identify the pins of a relay. The coil pins show up unequivocally as an inductor. Once you've identified the coil, you can then identify the NC and NO contacts by powering the relay coil. For example, I have a PCB relay that's sealed in an opaque container and there are no markings for the pins; the model number contains "12V", leading me to believe it's a 12 volt relay. I identified the coil leads, then measured the resistance between these leads at 123 Ω. For 12 V, that would put the DC current at about 0.1 A. I measured it at 90 mA when 12 V was applied and this actuated the relay correctly. Using the Octopus, I then identified the common, NO, and NC terminals. While I could have done this identification with an ohmmeter, the Octopus has the advantage of unambiguously identifying the coil through its elliptical signature.

Checking out a line-powered device

Another quick use during troubleshooting is when you have a line-powered device that doesn't operate. The first check is to put the Octopus on the power line plug's conductors (of course, the plug isn't plugged into the wall) and operate the power switch. If the device has a transformer, then you should see the signature of the primary winding of that transformer and possibly some of the secondary circuitry (e.g., the diode(s) of the power supply's rectifier). If there's no movement, you know there's a problem in the power supply end. An open, for example, might be indicating a blown fuse.

Compare to known-good

A powerful use of the Octopus is to compare a known-good item to a suspect one. I have a line-powered heater that I use in my computer room in the winter. I stopped using it one winter because it started smelling like something was burning. Fortunately, we had another identical heater. A quick comparison of the two heaters by putting the Octopus' leads on the power cord showed that the 5 position switch (Off, Fan, Lo, Med, Hi) had distinct problems. The fan motor winding's elliptical shape wasn't seen in the fan position and the other positions had bad noise problems (the good fan just showed low resistances). The ellipse from the fan on the good unit told me that the thermostat was working because as I turned it, the ellipse changed to a horizontal line (an open circuit). The comparison in the other positions told me the switch had gone bad, so I salvaged parts and tossed the rest out. Note this didn't require me knowing anything about how the device worked (although I had a good idea of how it was constructed, as it was a simple device). Most importantly, the **total troubleshooting time was under a minute**.

Sometimes you naturally have a good item to compare to. One situation that comes to mind is a multiple channel stereo amplifier where at least one channel works. Then you can compare test points in one channel to corresponding test points in the working channel. I've read that experienced people can usually find the problem component in 5 or 10 minutes with this technique.

Identifying power leads

On the sprinkler controller board mentioned above, there were three CD4051 CMOS 16 pin DIP chips that are 8 channel MUX chips. Each chip had a decoupling capacitor dedicated to it and it was easy to identify the power leads of the chip because they had the same signature as the decoupling capacitor. Of course, this could be verified by consulting a data sheet, but the point is that the Octopus can give you clues about things without knowing the circuit. Another feature of the Octopus is that I could put the probe on one pin of the IC, then drag it along the pins on the other side of the chip to see the variations in behavior. The point is that these are fast tests and can help you spot out-of-the-ordinary behavior -- especially if you know what the ordinary behavior should look like.

Summary

The Octopus tester applies a current-limited AC voltage to a component or circuit and plots this voltage against the current through the component on an oscilloscope set to XY mode operation. Since our brains are fast at recognizing patterns, the Octopus test patterns can characterize the behavior of a circuit or component. Comparing a circuit's behavior to a known-good circuit can tell you whether the suspect circuit is working correctly. Since you only need to look at the scope for a second or two, you can test lots of components and circuits quickly to help you troubleshoot non-working circuits.

Since things are non-powered, you can test components in-circuit. Depending on the design of your Octopus, this may or may not turn on semiconductor junctions.

If you have an oscilloscope and you occasionally need to troubleshoot electrical things, building a simple Octopus circuit will make a lot of sense -- they are cheap to build and easy to use. With a DMM and an Octopus in your set of tools, you can troubleshoot many electrical problems.

Characterization

Note: in the following, 0-to-peak was used for voltage and RMS for current. They really should be the same measure.

With 1 V/div horizontal and 0.25 mA vertical, the following slopes are gotten for various components. The deflection is total width or total height in divisions.

Resistors

R, kΩ	Vert	Horiz	Slope
0.9	3	1	3
0.65	4	1	4
1.7	3	2	1.5
2.7	2	2	1
4	3	2	1.5
7.8	2	3	0.67
10.6	1	4	0.25

Capacitors (X is reactance at 60 Hz)

C, μF	Vert	Horiz	Ratio	X, Ω
10	8	0.8	10	265
1	6	6	1	2653
0.1	1	5	0.2	2.65E+4
0.01	0.25	5	0.05	2.65E+5

Note that a 100 μF cap pretty much looks like a short at 60 Hz.

Inductors

L, H	Vert	Horiz	Slope	X, Ω
3	7.2	3.5	2.06	1131
2.39	5	6.2	0.81	901
0.87	4.8	2	2.4	328

If the ratio for the capacitors and inductors gives the same information as the resistor's slope, then the 0.1 μF capacitor ought to have about the same ratio as a 10 kΩ resistor -- and they are. The 0.87 H inductor ought to be near a 300 ohm resistor. A 300 Ω resistor has a height of about 7.2 and a width of about 0.7, giving a ratio of around 10. So the correlation isn't great, but it's somewhat indicative, as when the ratio goes up, the resistance/reactance goes down for resistors and capacitors.

Exercise 1: A potpourri of circuit elements

In this exercise, we make some connections with various components and use the Octopus to record the resulting current versus voltage waveform. Then we try to reason out the behavior we see. While I will give a number of examples here, you may want to construct a more encyclopedic set of examples in your lab notebook. This is worth your time, as you'll then have actual traces on known-good components. This lets you both qualitatively identify an unknown component or circuit behavior along with being able to quantify the difference between a good part and the part you're measuring.

Diode and resistor

Here are the Octopus traces of a 2400 ohm resistor and a 1N914 diode:

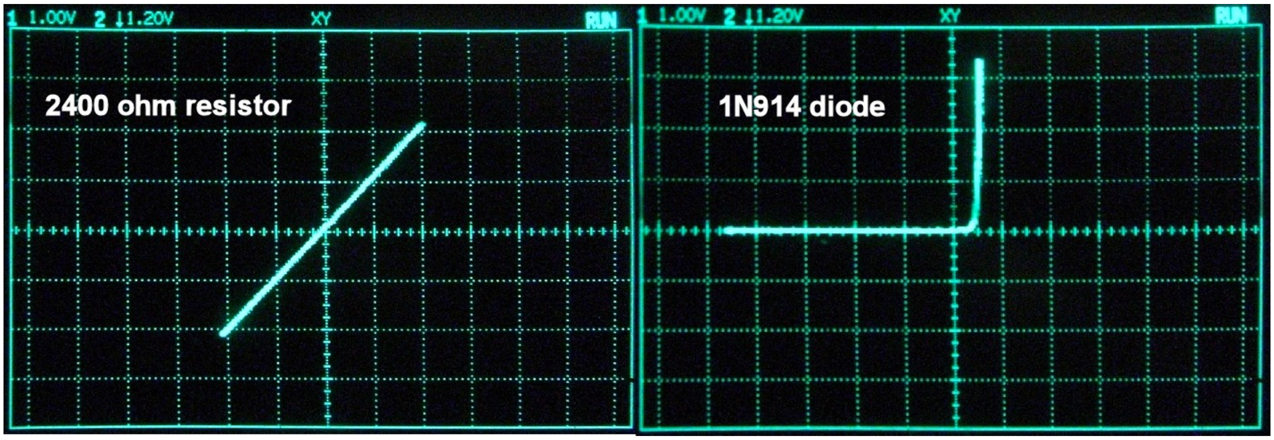


Figure 5

Here's the trace across the composite circuit:

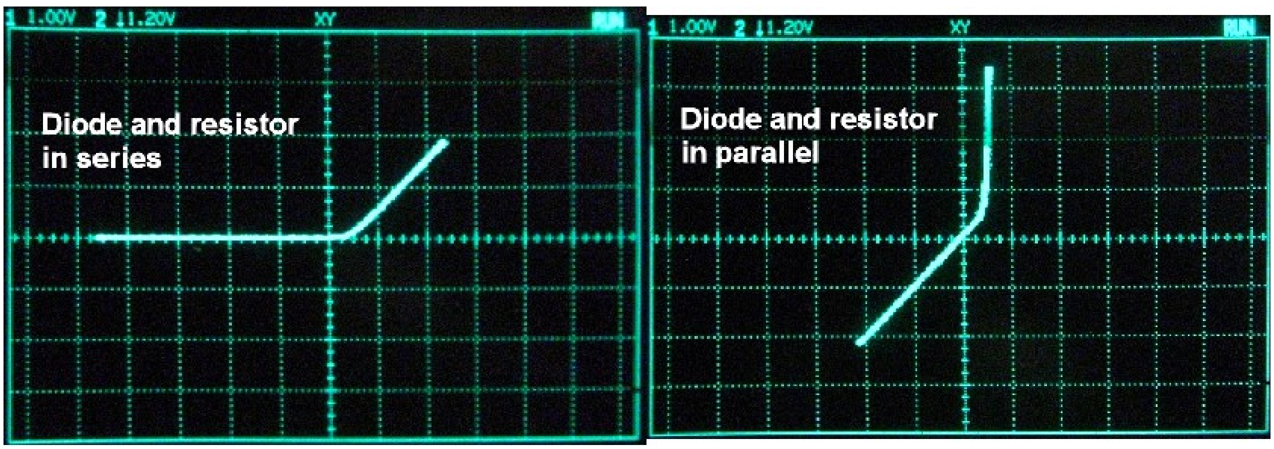


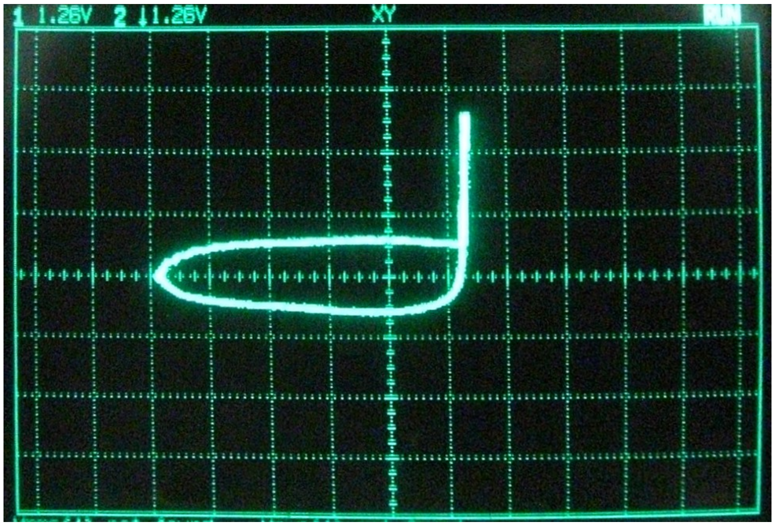
Figure 6

It's not hard to see why the composite behaviors occur. For the diode and resistor in series, a negative voltage results in no current because the diode blocks it. After a positive voltage is larger than the turn-on voltage of the diode (about 0.5 V), the diode looks like a small resistance, so the resistor's behavior determines the composite behavior and thus you see the up and to the right slope.

For the diode and resistor in parallel, the resistor conducts a negative current for negative voltage. The resistor's behavior dominates until the diode turns on at 0.5 V, at which point the diode's behavior dominates.

Diode and capacitor

Here's an Octopus trace of a 100 nF capacitor in parallel with a 1N914 diode:

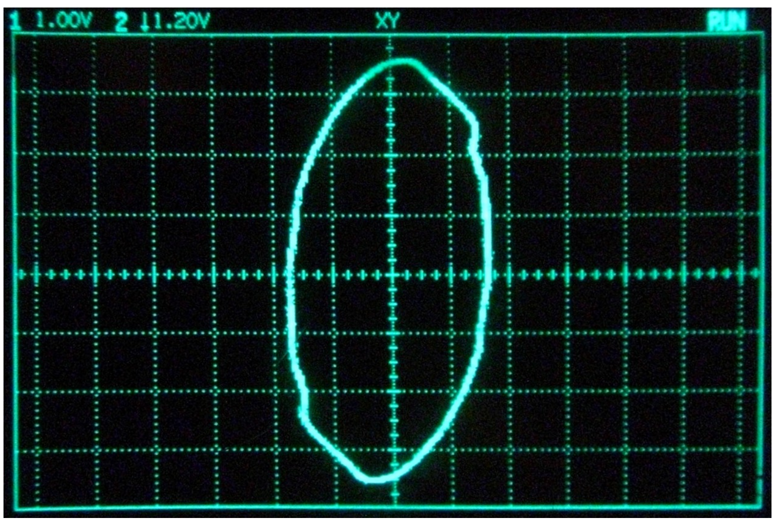


It's clear that when the diode starts conducting it overwhelms the effect of the capacitor.

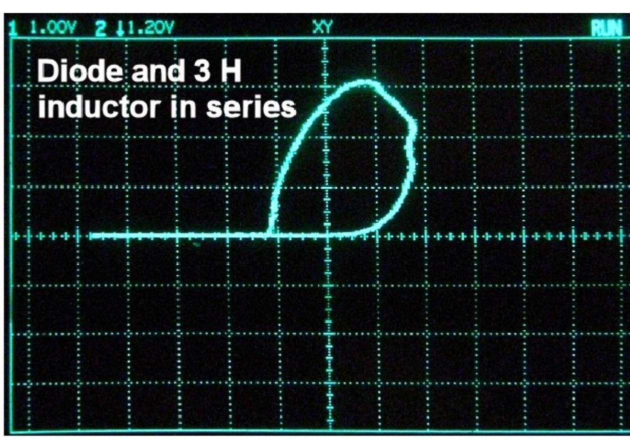
Question: knowing about the behavior of capacitors and diodes, why do you think I didn't bother displaying the trace of a diode in series with a capacitor?

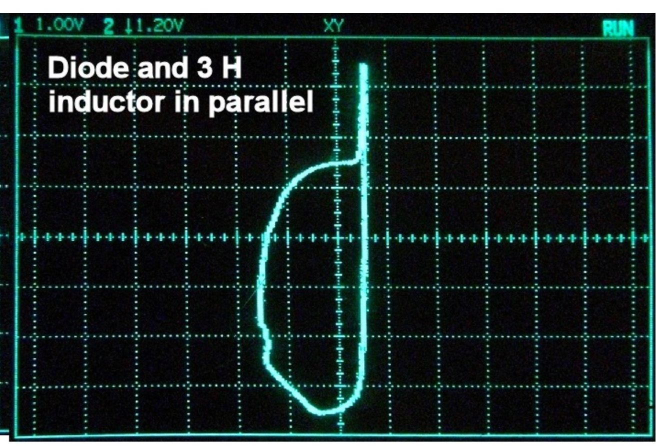
Diode and inductor

A 3 H inductor gave the following trace:



Here's the trace when combined with a 1N914 diode:





The bends in the side of the ellipse are due to the nonlinearities of the transformer I used in my first

Octopus (see Figure 4).

Exercise 2: Troubleshooting a power supply

In this exercise, we build a simple power supply circuit and examine its behavior with the Octopus for both normal operation and when a component fails.

This exercise is worth doing for a couple of reasons. First, power supply problems are responsible for many real-world problems in equipment, so it's worth getting to know how to troubleshoot one, even if you don't have a schematic. Second, this exercise allows you to experimentally simulate various component failures and see the result on the Octopus traces at various points in the circuit. This will give you insight because you'll be able to know both what you should see and what you'll see when something's wrong. An additional advantage is that you can probably build up the test circuit from parts in your junk box.

> A key thing to do is to carefully document what you do and see in this exercise in your lab notebook. You will likely find this information valuable at some point in the future.

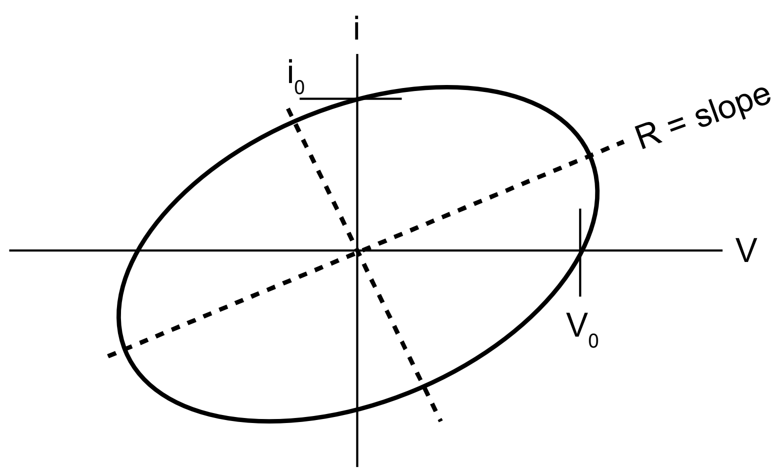
I'll call the sample power supply we make here the DUT, which is "device under test".

Here's the circuit you should build to make a simulated power supply. Use whatever parts you have on hand; if possible, build a real supply that you can actually power up and get a DC voltage from.

xx Show circuit

Check primary side: The Octopus is a good tool for this. Unplug the power cord from the wall and connect the Octopus to the two hot leads or the hot and neutral leads (ignore the safety ground connection). With the power switch to the DUT off, you should see an open circuit. Turn on the power switch and you should see the ellipse of the primary winding of the transformer. If you continue to see an open circuit, then your first suspects are that either the power switch is bad or the fuse is blown or missing.

It's good practice to record the Octopus test frequency and the numerical magnitudes of the transformer primary's signature:



The slope estimates the DC resistance of the winding and i_0 and V_0 characterize the impedance. These numbers can be written in your lab notebook and used later for troubleshooting when needed.

To check the power switch: Put the Octopus probes across the switch and operate the switch. It should go from open to short.

To check the fuse: Put the probes across the fuse; it should indicate a short. If the fuse is open, you've probably found the failure symptom, but now you need to ask why the fuse is blown. Something caused too much current to flow in the primary side of the transformer. The cause is likely to be a short somewhere. You can find a short in the primary side by replacing the fuse and looking for the transformer's primary side ellipse. Connect a temporary wire that simulates a short of the input voltage to ground. How does this change the Octopus trace? Once again, you see some advantages of using the Octopus:

- You don't need to do this testing with line power applied.
- You don't have to blow another fuse.

To check the transformer: If you've seen the ellipse from the inductance of the transformer's primary winding(s), then you may want to check the isolation between the primary windings and the secondary windings. Place one probe on the primary side and probe each of the secondary connections. You should see an open circuit for all of these. If you don't, then you might be looking at an autotransformer or there could be an internal short in the transformer. A quick resistance check with a DMM will tell you more.

> This winding isolation test is easier to make with a DMM that includes a nS conductance range or is capable of measuring high resistances. With my Fluke 83, I probe the primary's two wires on the conductance test and it will read OL for "overload" -- this means a high conductance (i.e., a low resistance). Then for the insulation resistance between windings, it should read low numbers. A transformer I tested read 0.5 to 1.0 nS (or, equivalently, 1 to 2 GΩ) between the windings.

Transformer secondary: If you put the Octopus probes on the transformer's secondary, you'll theoretically see the signature of the secondary's inductance, the output power circuitry's signature, and perhaps any load connected to it.

Diode bridge: The rectification of the transformer's secondary voltage is done by the diodes, which is usually a half-wave or full-wave bridge. For a full-wave bridge, you should see the usual diode signature, but at twice the normal diode drop (about 1.2 V for silicon diodes). And the negative-going part of the waveform will also be two diode drops; the negative waveform will be reflected about the origin (i.e., reflected about the V axis, then reflected about the i axis).

Filter capacitor: You will probably see a vertical line (dead short) when you probe the capacitor. If you have the ability to change the frequency, set it to 1 to 10 Hz to see if you can see the capacitor's ellipse. This is also a good time to short out the capacitor and see how that affects the signature of the secondary's trace, as well as removing the capacitor from the circuit.

Voltage regulator: The results you see will depend on the circuit element used.

Output load: You should test at various places in the secondary circuit with the output open, shorted, and with a typical load connected.

Appendixes

Transformer ratio and phase

An oscilloscope and function generator can be used to determine the ratio and phasing of a transformer's windings.

Here's one way to do it. Put the scope in XY mode and use a function generator to apply a low voltage sine wave (say, 1 V RMS at about line frequency) to the primary winding of the transformer. Most transformers are probably of the type used to step down the line voltage to a smaller value, but you should estimate from the winding resistances and estimated or measured wire size the approximate turns ratio. You don't want to be applying a voltage to a transformer with a large ratio and accidentally connect things so that there could be a hazardous voltage on exposed conductors.

Put the applied voltage on the horizontal channel and the transformer's secondary's output voltage on the vertical channel. You should then see a straight line. With a digital scope, adjust the vertical gain until the slope of the line is either +1 or -1. Then divide the two channels' gains (i.e., voltage per division settings) to get the transformer's winding ratio. With an analog scope, adjust the calibrated gains to make the slope near +1 or -1 and figure the transformer ratio in a similar manner. Make sure that either both scope channels are inverted or both are not inverted -- otherwise, you'll get the phasing wrong if you're not aware of the inversion.

When the slope of the line is positive, the positive leads from the scope identify the wires in the primary and secondary that are in phase. Conversely, a negative slope means the opposite.

If you only want to measure a transformer's ratio, it's probably faster using a DMM to measure the voltages. Use a sine wave; then an average-responding meter will measure the transformer ratio accurately, as long as you're within the DMM's bandwidth.

> Actually, you can make measurements outside the bandwidth of the DMM because what you're interested in is the ratio. This should still work outside the DMM's bandwidth as long as the DMM's response is linear. I've used my Fluke DMM at 10 times its rated bandwidth for this purpose (and it checked exactly with a more capable meter.

Instead of using the XY plot, you can display the two sine waves on the screen at once. When using the B&K 2542B-GEN scope, I put the function generator's output on channel 1 and the transformer's secondary's response on channel 2. I set the scope's measurement feature to measure the peak-to-peak voltage on both channels 1 and 2. Then I use the channels' gain fine adjust to make the two sine waves lie on top of each other (this lets me see any phase differences between the primary and secondary; there's usually a few degrees of phase shift between the windings, especially at frequencies at or above 10 kHz). When I've adjusted the two waveforms to use up all of the screen vertically, I divide the two peak-to-peak voltage measurements to get the transformer's ratio. This is also a convenient time to adjust the frequency to see how the voltages change as a function of frequency. I also use averaging to average out the random noise. Since this method works pretty quickly, I write the winding ratio(s) on a piece of white vinyl tape and stick it to the transformer so I can find a transformer I want in a box of them later.

Another phasing technique uses a DC power supply or a battery to phase the transformer's windings. Current limit the supply or battery to the 10-100 mA range and then apply the voltage to the primary winding while measuring the secondary winding's output with the DMM or scope. When you apply the voltage, you should see the DMM's reading jump in the positive or negative direction. The direction of the initial jump tells you the phasing. If you're using a scope, you'll probably want to make sure you're triggering on the correct event with the correct slope, as there will be lots of "contact bounce".   This measurement is a case where a center-zero analog meter would be quite handy to see the initial deflection (in the old days, sensitive galvanometers in applications like Wheatstone bridges were used with a momentary connection to see the direction of deflection in the process of balancing the bridge).

Variacs are not isolation transformers

Both the isolation and voltage-reduction capabilities of a transformer are needed for making an Octopus. Some folks may not appreciate that the typical Variac (adjustable autotransformer) doesn't provide the requisite isolation. While this should be obvious from the typical schematic representation of a Variac, it may not be a deep-enough statement to get one to really believe it. A simple, safe experiment can be done with a Variac that will demonstrate to you that it can have dangerous line voltages on it if you attempted to use it as the basis of an Octopus tester. You'll need a Variac and a digital multimeter. A function generator is optional.

To demonstrate this, let's start with a typical transformer:

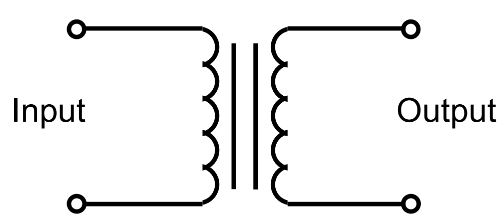


Figure 7

An input AC voltage on the left side produces the expected output voltage on the right side, taking into account the voltage ratio of the windings.

Now, suppose we made the following connection:

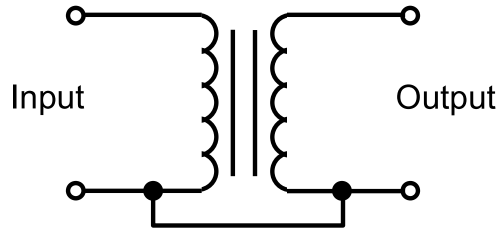


Figure 8

Can you predict what the effect is on the operation of the input and output circuitry?

In fact, all we've done is to cause the input and output voltages to have a common reference potential. Without knowing more about the input and output circuitry, it's not possible to state whether there will be any practical effect of this connection. Practically, however, there should be little effect except perhaps at performance extremes.

In fact, Figure 8 is electrically equivalent to a Variac (measure one with an ohmmeter to convince yourself). Now let's look at the hazards such a connection can create when used with line voltages.

Here's the transformer of Figure 8 connected to a typical US 120 VAC line voltage:

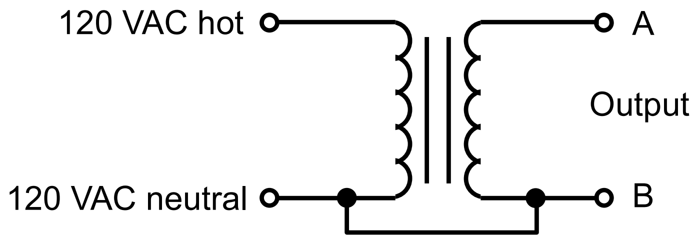


Figure 9

Since the 120 VAC neutral is typically at or within 1 or 2 volts of ground potential, this works fine and provides an output voltage referenced to ground.

Now, let's look at the case when the line voltage connections are reversed:

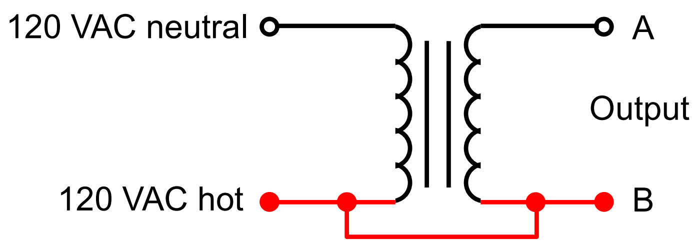


Figure 10

The red lines show that the 120 VAC hot line is connected to the output circuit directly. If you naively assumed that this autotransformer isolated you from the AC line voltages, you can see that you'd be wrong. If you touched a portion of the output circuit that is connected to the red line and also touched a grounded point, you'd get a shock. This is the basic reason that autotransformers are not suitable for isolation.

> You may ask how this reversal of connections happens. It can happen if someone uses an unpolarized two-prong plug. It can also happen when someone wiring a polarized plug makes a mistake and accidentally reverses the leads. Regardless of the cause, you can see that it's a definite shock hazard.
>
> NOTE: a GFI outlet is a nice safety device to have on such a circuit. If it's working correctly and this reversed-lead situation occurred where you touched terminal B and ground at the

same time, the GFI would protect you from a shock by disconnecting the power.

If you were using 240 VAC with both of the input lines being "hot", then you'd have the same situation, regardless of the polarity of the connection to the input of the autotransformer.

To experimentally convince yourself of the lack of an autotransformer's isolation, the simplest thing is to measure the DC resistance between the terminals with your digital multimeter. If you want to simulate things so they behave like the 120 VAC US circuit, you can use a ground-referenced function generator. First connect the generator as shown in Figure 9 and use your DMM to measure AC voltages with respect to ground[2]. You'll measure the function generator's output multiplied by the autotransformer's voltage ratio on the output A connection with respect to ground. Note it's with respect to ground because the ground connection is made between the two windings.

Reverse the function generator's connections so you have the situation in Figure 10. Now you'll measure the full output of the function generator when you measure terminal B with respect to ground. If you imagine the function generator could output normal line voltage, then you'd get a shock if you touched terminal B and then a ground connection with another part of your body.

A more subtle shock hazard exists in Figure 9. If the Variac is turned down so that the ratio is small, the output voltage is small. However, turn the Variac up and the output voltage can equal and exceed the line voltage. Thus, if you touched terminal A and then a ground connection with another part of your body, you'll get a shock.

The conclusion is inescapable: **a Variac provides no isolation safety regardless of how it's connected**.

References

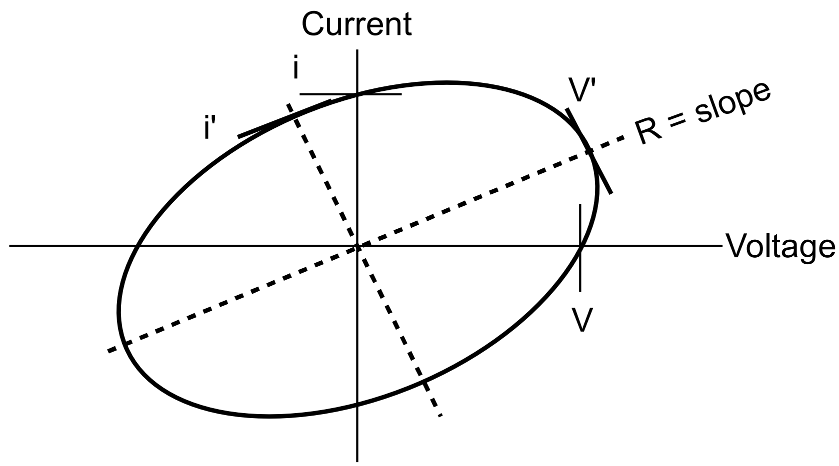
steber This is a curve tracer that uses a PC sound card. G. Steber, http://www.eevblog.com/forum/beginners/dirt-cheap-and-simple-scope-based-component-tester-curve-tracer/?action=dlattach;attach=25495, http://www.eevblog.com/forum/beginners/dirt-cheap-and-simple-scope-based-component-tester-curve-tracer/?action=dlattach;attach=25496, http://www.eevblog.com/forum/beginners/dirt-cheap-and-simple-scope-based-component-tester-curve-tracer/?action=dlattach;attach=25497

Lissajous to impedance

The idea is to convert a C or L octopus signal to impedance. Having a good source of sine waves from a function generator up to 100's of kHz would allow useful characterizations of impedance.

I need to understand the relationship between an Octopus trace and a part's impedance.

2 Make sure you connect the function generator to the primary side of the Variac so that you don't step up the function generator's output.



Questions:

Is the magnitude of the impedance V'/i' or V/i?

How is the slope R related to the impedance?

A non-tilted Lissajous figure has the parametric equations represented by the phasors

$$\boldsymbol{V} = V_0 \boldsymbol{e}^{j0} \text{ and } \boldsymbol{i} = i_0 \boldsymbol{e}^{j\delta}$$

Dresser Systems, Inc. Transformer

This is a nicely-made transformer salvaged from a 1970's Ithaco lock-in amplifier. The transformer's bottom is stamped with 14 Feb 1973, the model number is JP6392, and the serial number is 359702. The manufacturer's name is SIE Engineered Transformers, apparently part of Dresser Systems, Inc., Houston, Texas.

There are three Teflon-insulated (and shielded) windings coming out the top:

- A: Long white: BLK and WHT
- B: Long white with ORN tape: BLK and WHT
- C: Short white: BLK, WHT, and RED

I have found the hand-held LCR meters quite useful because they will measure impedance. The B&K Precision 879A is handy because it has two banana jacks to plug test leads into and the impedance of the leads can be corrected for with an open/short compensation. This meter lets you measure the impedance at 100 Hz, 1 kHz, and 10 kHz.

Using the B&K 879B, I measured the following properties at 1 kHz (DCR measured with HP 3456A):

Winding	**L_s, mH**	**Q**	**Z, kΩ**	**θ, °**	**4-w DCR, Ω**
A	799	3.13	5.05	77.8	37.7
B	793	3.36	5.69	71.8	34.1
C:BLK/WHT	40.8	1.16	0.34	49.7	0.85
C:BLK/RED	143.6	1.42	1.05	56.4	1.78
C:WHT/RED	41.4	1.16	0.34	49.3	0.95

I also measured the 1 kHz impedance between the windings:

Winding	**Z, kΩ**	**θ, °**
A to B	250	-88
A to C	1114	-87
B to C	1058	-87

Clearly, A and B can be used as an isolation transformer, which should fit the need of an Octopus.

Note these windings also have shields, so careful construction may mean reduced noise. The Octopus showed they had nearly identical elliptical patterns.

The C:BLK/WHT and C:WHT/RED windings are also clearly equal and the DCR measurements indicate it's a center-tapped winding.

The inductances predict the following voltage ratios:

A:B is 1:1

A:C for BLK/RED is 0.424, for non-center-tapped the ratio should be 0.226.

Using a 100 Hz sine wave set to 5 V RMS on winding A, I measured 4.93 V RMS on winding B. Thus, these two windings can be used as an isolation transformer.

Here are the voltage ratios for A:B and A:C:BLK/RED as a function of frequency (measured by an HP 3400A RMS voltmeter by setting the function generator generator to 1 V RMS):

	Voltage ratio	
Frequency, kHz	**A:B**	**A:C**
0.01	0.984	0.328
0.1	0.993	0.329
1	0.997	0.329
10	1.012	0.330
50	1.66	0.41
100	Res.	0.842

The ratio from winding B went into resonance at 90 kHz. The measurements indicate that the A:B isolation winding should only be used up to about 10 kHz.

Scrounging parts

If you're a new electrical hobbyist, you may find it hard to find the parts you need to build things. You can of course buy new stuff, but the costs can add up fairly quickly; if you're on a budget, you'll want to find cheaper stuff.

If you can get your hands on older test equipment from the 1960's to 1980's, you can often find a number of useful components that can be removed and stashed away for future use. My personal favorites are old HP "boat anchors". You can find this stuff in as-is or nonworking shape online, but the heavy stuff can cost $50 to $100 to ship.

Here are some of the things I've acquired from scrap stuff:

- A World War 2 era radar display gave lots of plated brass screws, 10 to 25 W pots, knobs, switches, and other hardware. This stuff was the finest that could be made and most of it is working perfectly 75 years later.
- Some HP analog instruments contain analog meters that HP built and calibrated in-house. These make wonderful instrument meters and microbalances.
- I always salvage as much wire as possible from HP instruments because HP used very good wire that's usually tinned and a dream to solder. There usually are also numerous pots and knobs worth salvaging.
- A 1960's HP differential voltmeter gave me a rather large set of precision 0.01% resistors and I use those as my lab standards.
- A 1970's era Ithaco lock-in amplifier gave me lots of 10-turn pots and dials, switches, trimmer resistors, etc.
- These instruments usually have lots of sheet aluminum which is worth salvaging and using for other shop projects.

The cost for salvaging this stuff will be your time to take things apart. As this is something that doesn't have to be done all at once, I do it is spurts at my leisure. Sometimes a particularly fine component will get stuck in your brain and you'll have to find a use for it.