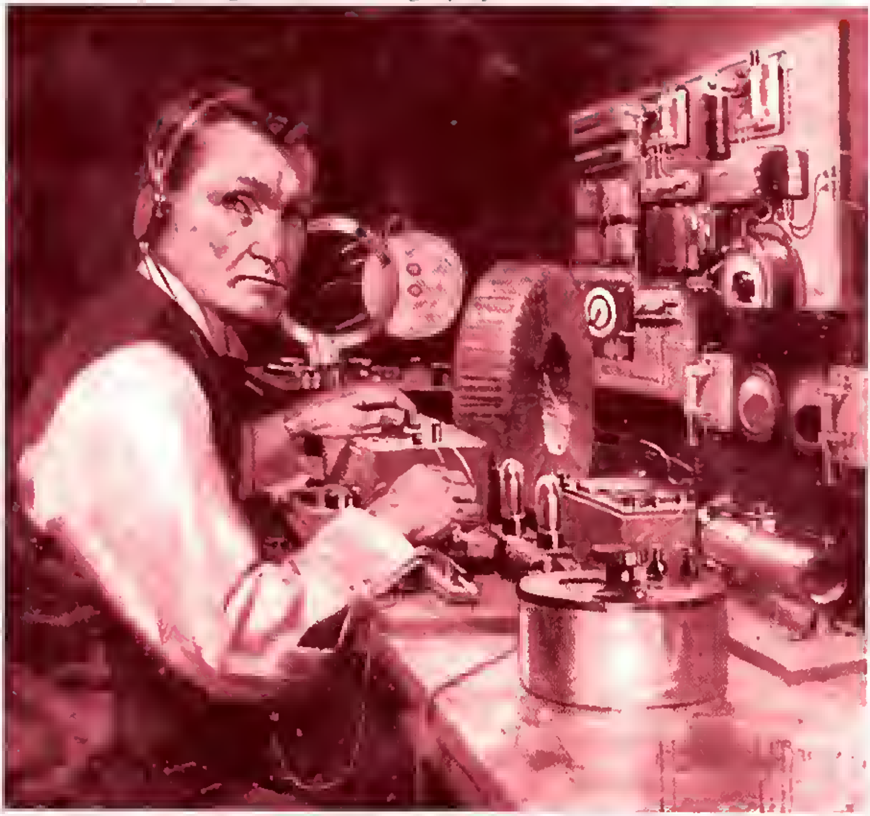
The Impoverished Radio EXPERIMENTER

Tricks, tips, and secrets to help the builder of simple radios and electrical gear achieve high performance at minimal cost!



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Build an Impedance Bridge, a One-Tube SW Receiver, a Headphone Amplifier, Old-Time Radio Cases, More!

EXPERIMENTER

Building an Impedance Bridge, Amplifier & more...

Since you can't see electricity or hold it in your hand, you have to have measurement equipment to act as your senses. I would never even attempt to build a radio without having a volt-ohmeter (VOM) and a grid-dip oscillator (GDO). These devices will allow you to determine if your tube or transistor is getting the correct voltages and current, to determine resistance and continuity, to determine the resonant frequency of a coil capacitor, and more.

There is a third piece of gear I've come to appreciate over the past few years, one I would never part with: an impedance bridge. With it you can measure capacitors of all kinds and most larger inductances such as power supply chokes, audio transformers, and rf chokes.

Sure, you can go out and buy fancy test gear. Used test gear is readily available, often at low prices. You never know if the cheap, used gear is functional, and even if it is, it often needs calibration – in other words, the measurements it now makes are no longer accurate.

Quality gear will cost you around a $100 on up to many thousands. But at least you can be sure it works well.

Since our goal here is to experiment on the cheap, we need to build a bridge to we can measure all the "garbage" we pick out of dumpsters in the alley or out of filthy cardboard boxes stashed beneath tables at fleamarkets or in basements. A simple, homemade bridge will allow us to recycle used components, and actually help us build many of our own components.

Building a bridge is a simple worthwhile investment that will yield huge dividends in a very short time.

What is a bridge?

Few people seem to know what a bridge is. No, not something that spans the river or something in your mouth. We're talking about an electrical comparison circuit that is ridiculously simple, yet can provide measurements of incredible accuracy and precision. In fact, the "big boys" at the standards laboratories in all countries have used bridges for decades for extremely precise comparison.

To understand how this amazing machine works, we need to understand the voltage divider circuit. It's easy. If you put two resistors in series with a battery, and measure the voltage across one of the resistors, the voltage you read will be proportional to the ratios of the resistances. In other words, if you put 12 volts across a pair of 5000 ohm resistances, you'll measure 6 volts across either resistor.

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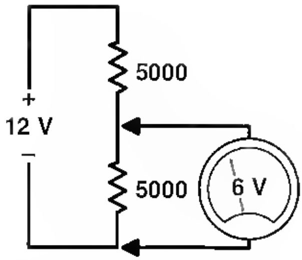
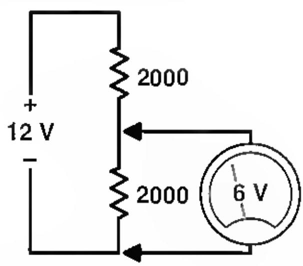


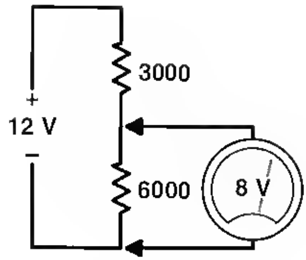
Why? Simple. Each resistor is half of the total resistance, isn't it? You should measure half the total voltage, 6 volts, across either resistor. That's because the same current flows through each resistor.

Another example: Let's suppose you put a pair of 2000 ohm resistors in series, and connected a 12 volt battery. What's the total resistance? 4000 ohms.



So either resistor represents half the total resistance. Therefore the voltage across either resistor will be half the input voltage whatever it might be. Put in 12 volts, and you'll get 6 across each resistor. Put in 10 volts, and you'll get 5. Put in 3 volts, and you'll get 1.5 volts. A pair of equal resistors will divide the input voltage in half. That's why it's called a voltage divider.

Another example: If we put a 6000 ohm resistor in series with an 3000 ohm resistor, what kind of voltages can we read? What's the total resistance? Easy: 3000 + 6000 = 9000 ohms.



If I put 12 volts across the pair and hook my voltmeter across the 6000 ohm resistor, I should read 8 volts. That's because 6000 was 2/3 of 9000 the last I heard, and if I figure right, 2/3 of 12 volts is 8 volts.

So how about the 3000 ohm resistor then? Well, 3000 is 1/3 of the total 9000 ohms, so I should measure 1/3 of 12, or 4 volts. And that makes sense. I should have 4 volts across one resistor and 8 volts across the other, giving a total of 12, which, lo and behold!, is exactly what we put in.

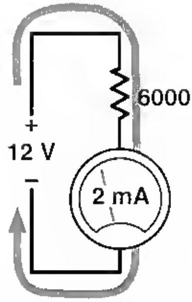
We can express this numerical mess with a simple formula:

Vout = (R individual/R total) x V in

Understand that, and you're well on your way to being an electrical engineer!

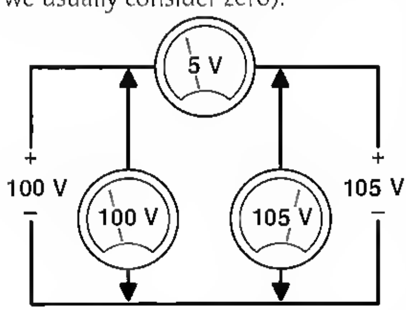
It's important to remember that current is the "stuff" of electricity. It flows through wires. To measure current we have to break open the circuit and insert a meter in series so that the current will flow through our meter.

In real life there's always something that gets in the way of current.



It just doesn't flow unless you put pressure behind it. The greater the hinderance, or impedance, or RESISTANCE, the greater the pressure, or VOLTAGE must be. Voltage always pushes current through a resistance. The higher the voltage, the more current flows. And that's Ohm's Law. Nothing more. Nothing less.

When it comes to measuring voltage, the pressure of electronics, we actually measure the difference in voltage between two points. If you put the negative lead (black) of your voltmeter on the chassis of your tube radio and the positive lead (red) on the plate and measure 90 volts, you have measured a difference of 90 volts between the plate and ground (which we usually consider zero).

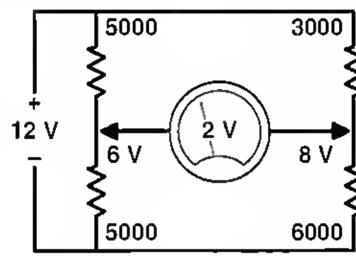


If you put each of the leads of your meter on the plates of two different tubes, each having 90 volts on them, your meter will read zero. Why? Because there is no DIFFERENCE. Both plates are at 90 volts. Voltmeters measure difference. If one lead was on a part of the circuit with 100 volts and the other on 105 volts, your meter would only read 5 volts. Really! That's the way it works.

And this concept is extremely important. Voltage is the pressure difference between two different points in the circuit.

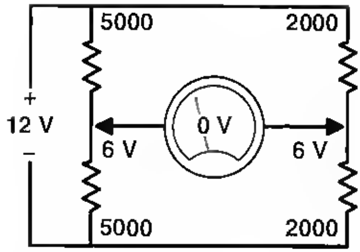
A Wheatstone Bridge

In 1831 Christie (so I've heard) hooked together two voltage divider circuits and was amused. Ten years later Wheatstone, realized that the simple circuit could used to make measurements, and ever since his name has been associated with the circuit.

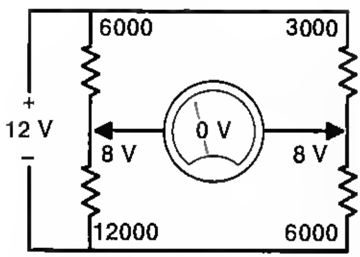


If we take our pair of 5000 ohm resistors and our 3000-6000 pair of resistors and hook them in parallel to the same 12 volts source, what will we find? As before, we'll read 6 volts across the lower 5000 ohm resistor, and 8 volts across the 6000 ohms resistor. If we bridge the two voltage dividers with a volt meter what will we read? If one point is at 8 and the other 6, the meter will read 2 – the difference.

Let's remove the 3000-6000 pair and replace it with the 2000-2000 pair. The middle point of the 5000 pair is the same 6 volts. And the junction of the 2000 pair is also 6 volts as before.



When we put a meter across the two points, we read zero volts because each point is at the same voltage. Notice that the left "leg" is made up of two identical resistors: 5000 ohms. And the right leg is also of identical 2000 ohm resistors.



Suppose we build a "bridge" with 6000 and 12000 resistors in the left leg, and 3000 ohm and 6000 ohm resistors in the right leg. What will the bridge voltmeter read? The ratio in the left leg is 12000 out of 18000 total, or 2/3. The ratio in the right leg is 6000 of 9000 total, or 2/3. The junction point in the middle of the left leg will be at 2/3 of 12 volts or 8, and the right leg will be at 2/3 of 12 or 8 also. The meter between the two points will read zero.

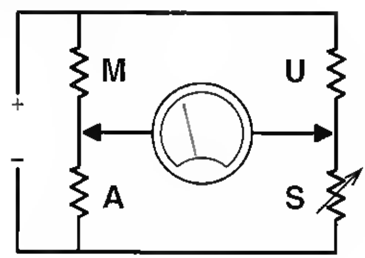
Extremely important conclusion: when the bridge meter is zero, the ratios of the resistors in the left leg and right leg are equal. The actual number of ohms, and the voltage applied to the circuit are of no importance. When the ratio of the resistances in each leg are identical, the bridge meter will read zero.

If we make one or more components of the bridge adjustable, we can force the bridge meter to drop to zero by making whatever adjustment is necessary so that the left and right ratios are equal. And that's the magic.

The meter that "bridges" the left and right legs is usually called a null detector. Its purpose is to indicate when the voltage difference, and thus the current flowing, is null, or nothing. In DC work a zero-center galvanometer is usually used.

A Comparison Machine

If the top resistor of the left leg is equal to bottom resistor, then the upper resistor of the right leg must equal the lower resistor if the null detector or galvanometer is to read zero. We can use this principle to build a comparison machine.



$$U = \frac{M}{A} \times S$$

If in this diagram, M is equal to A, and if we plug an unknown resistance into position U, the meter will read zero only when adjustable resistance S is equal to U. In effect we've compared S to U.

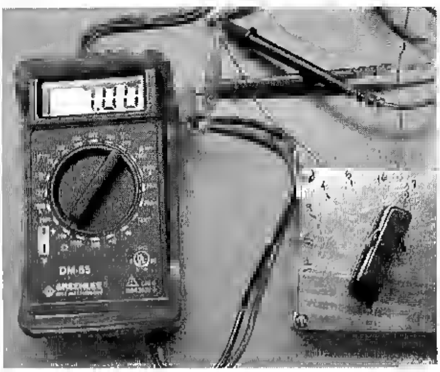
For example, if M=1000 and A=1000, and put an unknown resistor in to position U, we find that we can get the galvanometer to read zero

You MUST have a VOM

if you plan to build electronic gear of any consequence. I picked this one up at a local hardware store for $30. There was a $20 model, but its lowest resistance range was 0-2000 ohms, whereas this one had a bottom range of 0-200 ohms, and that's important if we're to use it in finding reasonably accurate resistors for bridge building.

Be sure to get a digital model. These machines have an internal battery to supply operational power. You can get cheaper VOM's with an analog meter, but they are not as accurate, and they suck power out of the circuit to make the meter needle move. And that can affect accuracy.

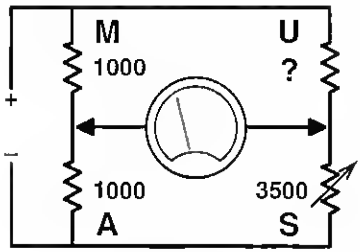
These modern solid-state cheapies suck almost no power out of the circuit under measurement and because of integrated circuits can be very accurate. This model is rated at ±1.5% accuracy on resistance scales. But I put the meter on an very accurate resistance box and found the maximum error was 1/2%, and even less than that on most ranges.



Here, a 10 kilohm pot with pointer knob has been mounted on an aluminum panel. A fine point Sharpie™ß marker is used to put calibration marks on the aluminum. Here, we see 7.00 kilohm has been located and marked on the panel as "7". I like Sharpie™ markers because the markings can be quickly and easily removed with a tissue moistened with lacquer thinner.

Here some homemade and commercial alligator clip jumper cables, a battery, and our calibrated pot are lashed together as a Wheatstone bridge. The VOM is used at the bridge, or null, meter. Here a 4700 ohm 5% carbon resistor reads 4.7 on the panel markings. That's only two significant digits, but that's about all any of us need for radio building.

when we adjust S to 3500 ohms.

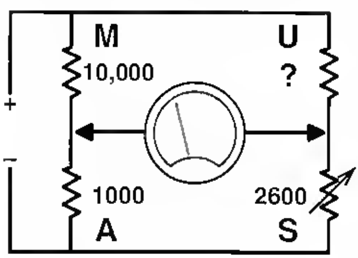


$$U = \frac{1000}{1000} \times 3500$$

$$U = 1 \times 3500 = 3500$$

We know that the unknown must be equal to 3500 ohms because the ratio of the right and left leg must be identical.

If we make M=10,000 and A=1,000, and if we get a zero reading on our galvanometer when adjustable resistor S (our resistance standard) reads 2600, then we know the unknown resistor must be 26,000 ohms.

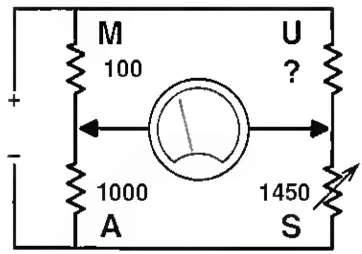


$$U = \frac{10{,}000}{1000} \times 2600$$

$$U = 10 \times 2600 = 26{,}000$$

Looking at the left leg, we see the upper resistor is now ten times greater than the lower leg. Since the same relationship must hold on the right side, the unknown must be ten times greater than our adjustable resistor, or 2,600 x 10 = 26,000 ohms.

By changing the M resistor by factors of ten, we can use the same adjustable resistor to measure resistances greater or smaller by factors of ten. That's why we call it a multiplier. If M=100 and A=1000 then the unknown will have to be one-tenth the adjustable resistor.



$$U = \frac{100}{1000} \times 1450$$

$$U = \frac{1}{10} \times 1450 = 145$$

What we have here is a classic Wheatstone bridge. If we make the adjustable resistor an extremely accurate and stable *variable* resistor, usually called a rheostat in the old days, we can measure resistances to a high degree of accuracy and precision.

Bridges for Capacitors and Inductors

In a Wheatstone bridge we use steady voltages that cause steady currents to flow. Although here we have "nulled" our bridge so that our bridge voltmeter reads zero, we can more accurately say that we have zero current flow. Any tiny difference in voltage between the junctions in the left and right legs will cause a small current to flow. And to detect that current we use very sensitive ammeters, actually micro-ammeters, capable of measuring millionths of an ampere. These days we can use DC amplifiers and other fancy tricks to improve the sensitivity of galvanometers. So one way to think of how a bridge works is to say that two currents are being collided inside the galvanometer, one from the left leg and one from the right leg, and if they are equal and opposite in polarity, they will cancel. The meter will read zero. The bridge is in balance.

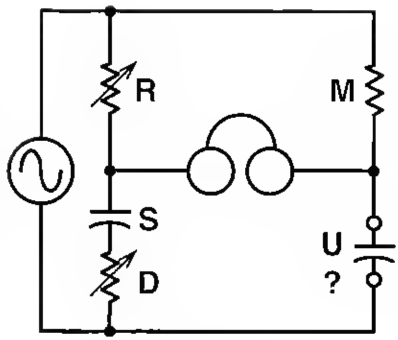
You can't measure capacitors or inductors with a Wheatstone bridge because when using DC, the perfect capacitor is an open circuit, and the perfect inductor is a dead short. If we use an audio tone to power our bridge, the capacitor starts to act like a large resistance, and inductor behaves like a low resistance. Exactly how the capacitor and inductor behave depends on frequency, and this is what we call reactance.

If the concept of impedance and its two components of resistance and reactance are a mystery to you, you really must understand the concept. It's the foundation of electronics. Trying to build radios or any electronic device without knowing the basic concepts of impedance is like trying repair an automobile without being able to tell the difference between the water pump and the differential. Almost any basic electronics and/or electricity book will discuss AC circuits and the concepts of impedance.

The Capacitance Comparison Bridge

With a multiplier resistor, and a variable resistor we can compare a capacitor against a known capacitance using a deSauty bridge. As you can see, the circuit is very simple. The upper impedance in each leg is a resistor, and the lower impedances are the capacitances: the standard and the unknown.

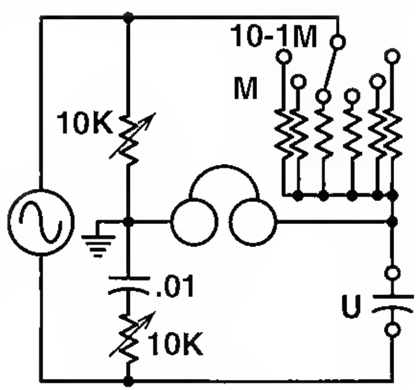
The actual ratio of each leg de-



$$U = \frac{R}{M} \times S$$

pends on the impedance of each capacitor which changes with frequency. Since both legs are supplied with the same AC signal, the impedances will change in unison. So it doesn't really matter whether we feed the capacitance bridge with an 800 cycle tone or a 1000 cycle tone. We'll get an accurate reading with either.

Variable resistor R is provided with a pointer knob and scale so that we can easily read its resistance, and thus the value of the unknown capacitor very easily. The multiplier resistor is a switched fixed resistor that together with the variable resistor pro-



$$U = \frac{R}{M} \times S$$

vides a ratio so that the standard capacitor can be compared against a wide range of unknown capacitors.

A practical capacitance bridge can be built with the following values. The main measurement resistor has a maximum resistance of 10 kilohms. The multiplier bank consists of six resistors with values from 10 ohms to 1 megohm giving multiplier ratios of from 1/100 to 1000. When used with the .01 standard capacitor, we can measure capacitors ranging from about 10 picofarad to 100 microfarad.

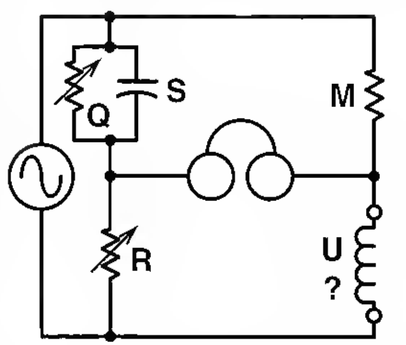
The mysterious 10 kilohm variable resistor in series with the .01 standard capacitor is needed to nullify imperfections in the capacitor being measured. All capacitors have some internal resistance resulting from less-than-perfect insulation. We usually think of this resistance as being in series with a perfect capacitor. A capacitor with air between its plates will have almost no loss which means the series resistance is almost nonexistent. Its dissipation (of energy, I suppose) is said to be very low or zero. An old tubular .01 mfd bypass capacitor from the 1940's made from aluminum foil insulated with leaky, inferior waxed paper may have exhibit 477 ohms of resistance. A .01 capacitor at 1000 cycles, the frequency most often used for measurements, has 15,916 ohms of reactance. The 477 ohms is 3% of the 15,916. Therefore we say the dissipation is 3%. A decent modern capacitor will have a dissipation of less than 1%.

If we use a standard .01 capacitor with very low series resistance we can artificially add series resistance to simulate almost any unknown capacitor we're likely to encounter. And we can estimate the quality of the unknown capacitor by noting how much of the 10 kilohm resistance we had to add in. If our dissipation (D) pot at balance is at or near zero, the unknown is very good quality. A high setting at balance shows the capacitor is not so good and perhaps should be discarded.

An Inductance Bridge

Capacitors and inductors are, in a sense, mirror images of one another. A capacitor is just a negative inductor, or vice versa. If we flop the left leg of our capacitance bridge, transposing the standard and the main measurement pot, we end up with a Maxwell bridge which allows us to measure low-Q inductances, which will be most of the inductances we encounter in radio building.

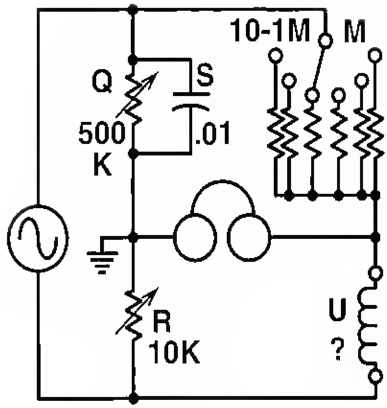
An inductor will exhibit series resistance just like the capacitor. The lower the resistance the better the



U = M x R x S

quality of the inductor, or Q. Higher resistance in an inductor means that it is less pure – that its Q is lower.

In the capacitance bridge we placed a 10 kilohm pot in series with a .01 standard, where zero resistance was desired. Here in the Maxwell bridge we put a very large variable resistor, Q, in parallel with the standard. A very high resistance around the standard indicates very low loss.



U = M x R x S

In measuring an inductor, we can estimate Q by noting how much Q resistance is needed to balance the bridge: high resistance means high Q, and vice versa.

Practical values for a Maxwell inductance bridge are the same as those for the capacitance bridge, except that the 10 kilohm dissipation pot in series must be replaced with 500 kilohm Q pot in parallel with the standard. With this circuit, most inductors from about 100 micro-henries to 100 henries can easily measured.

Building a Bridge

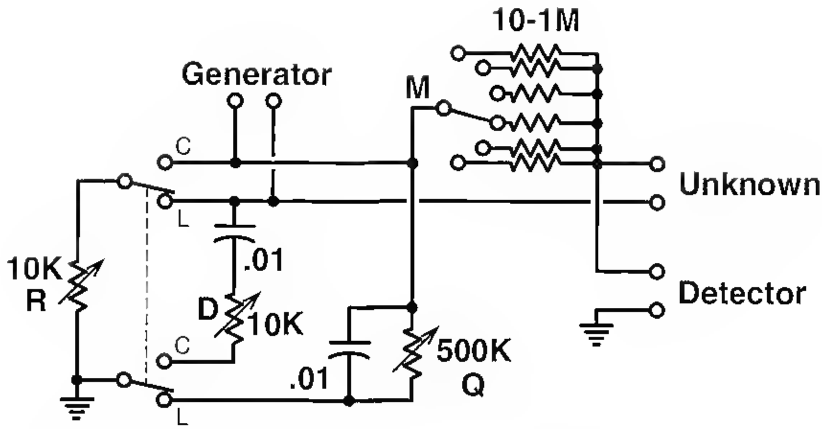
You can build either bridge circuit by itself, and it will work beautifully. But if you add a dpdt switch to the circuit, you can build both bridges in one common circuit and switch between capacitance bridge and inductance bridge instantly.

You'll need two 10 kilohm pots. You may already have them in your junk box. Measure their total resistances to be sure that the pot used as the main measurement pot, R, is at least 10,000 ohms. Not all are. I ordered by mail three new Asian-made pots for this demonstration project. The values I received were 10.2K, 11.1K, and 9.55K. You really should use a pot slightly over 10 kilohms. The 11.1k pot would work although the scale would be slightly compressed. The 9.55k pot is usable if a 470 ohm resistor is put in series with it, in which case the very lowest measurements are unusable. But that's not a hardship since that range is almost unreadable anyway. If the pot you get is between 9,000 and 9,500 ohms, you can put a 1,000 ohm resistor in series and use it. Anything less that 9,000 cannot be used as the main measurement pot. Instead, you can use it as the dissipation pot since this pot will usually be set somewhere near zero resistance most of the time.

The 10K pot is mounted on a panel, and a large pointer knob is attached. You then connect the pot to an accurate volt-ohmmeter (VOM) set on resistance scale. Next, you rotate the pot until the meter reads 1000 ohms, and make a mark on the panel with a permanent marker and label it one. You then do the same for 2000 ohms, and so one up to 10,000. Next, you go back and add a mark at 1500, 2500, and other "in between" settings.

After you have marked out the panel, that is, calibrated your pot, you should run your pot up to the 8 setting, for instance, and be sure that your VOM shows about 8000 ohms. Check various settings a number of times to be sure they're reliable. Sometimes a pot set on 5, for instance, will read 4500 on one test, and 5200 on the next. Such a pot is not accurately "resettable", and cannot be used here. Find another 10 kilohm pot.

The multiplier resistor is next problem to be tackled. You'll need a rotary switch with at least one pole and six positions. My switch came



from a fleamarket for a quarter. Brand new good quality plastic rotary switches are available for about $3.50 at this time.

You'll need one each of 10, 100, 1K, 10K, 100K and 1 Megohm resistors. That doesn't sound so difficult. But they must be accurate to 1%, and that means they're not common. If your VOM is accurate enough, and most modern digital meters are, you can go through your junk box and select common old carbon resistors that are within ±1%. For instance, 1% of 1,000 ohms is 10 ohms. You must have a resistor that is somewhere between 990 (ten ohms low) and 1010 (ten ohms high). Another way to figure the range is multiply the desired value by .99 on your calculator and by 1.01.

Caution: when measuring the 10, you need between 9.9 and 10.1 ohms, that's .1 ohm either way. But the resistance of your VOM leads can easily be .3 ohm which will destroy the accuracy of your measurement. Some high-quality VOMs have a "relative" setting to compensate for lead resistance. You may get by simply by shorting the probes together and reading the VOM reading is the so-called "short". You can subtract that "zero-reading" from your measurements to get a true indication of the resistance.

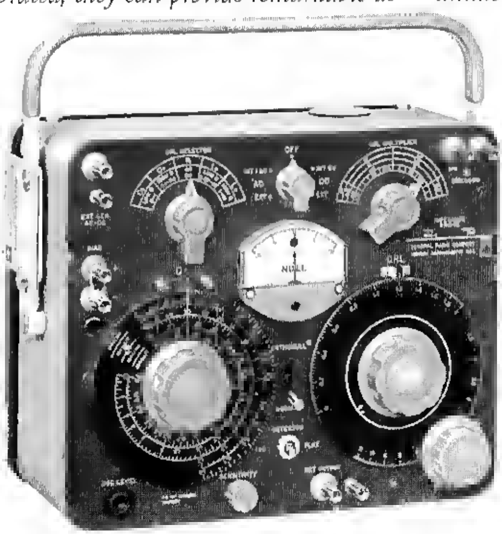
The easiest way is just buy the resistors. I get them from Mouser and Digi-key, but I'm sure 1% metal film resistors are available from other sources, too. They only cost 10¢ to 12¢ in single quantities. Geez... you can get 200 for $4.00, and take your pick of the very best if you're planning to build a super accurate bridge. Postage and handling on your order will cost far more than the resistors, but at least you'll know you're getting accurate multiplier resistors, and that's very important if you want accurate measurements.

The standard must be accurate, too. The easiest route is to order these from suppliers as well. I used a polyester capacitor which has low dissipation, a value known to ±2%, a voltage rating of 100 volts (more than enough), and best of all is less than 50¢ in single quantities. You'll need, two. I bought 10 for $3.00 and put the rest in the capacitor junk box for future projects.

Again, the pots here are cheap imports costing about $1.25 at this time. And only the value for the main calibrated pot, R, is at all critical.

You'll need three pairs binding posts of some kind. I used a standard 1/4" phone jack for the earphones. Since the panel of bridge is conducting aluminum and is at ground, a standard jack will work here. But you'll need two other pairs of connectors of some type which are insulated from the panel. I used standard binding posts mounted on industry-standard 3/4" centers to connect in the generator, our audio oscillator, and connect the unknown to the bridge.

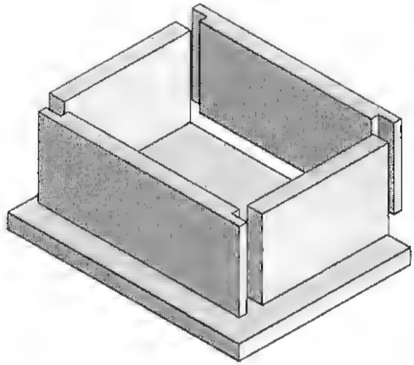
THE classic impedance bridge is the 650A first marketed by General Radio in 1933 and produced until 1959. It was the first self-contained bridge complete with a 1000 cycle tone provided by a quaint (by modern standards) battery-powered electromechanical oscillator called a microphone hummer. A meter was used as a null detector in measuring resistance, with headphones and the operator's ears being the detector for the measurement of capacitance and inductance. Accuracy was 1 to 2%. These bridges appear occasionally at flea markets and internet auction sites. Once calibrated, they can provide remarkable accuracy despite their age. Their greatest weakness is the hummer which had a tendency to age and get very sluggish (not unlike most of us).



(illustrations from old General Radio catalogs)

In 1959 the 650A was discontinued and a new, improved version, the 1650A, was introduced. Improvements included a transistorized tone generator, tuned detector with meter, expanded ranges, and a handy patented coupling mechanism called "Orthonull" which made measuring low Q inductances much easier. These 1% machines are still commonly available for between $50 and $150.

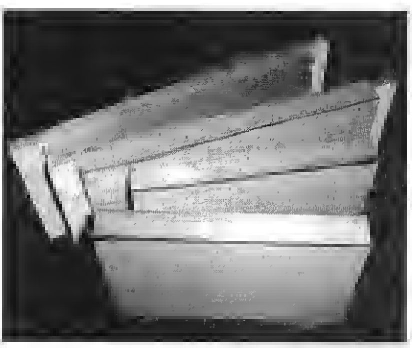
Building a Bridge Case



The old-time measurement equipment circuits were mounted on a flat Bakelite™ or aluminum panel and dropped into a hardwood box usually lined with copper foil. Thompson-Levering, Leeds & Northrup and General Radio produced beautiful cases of cherry, mahogany, oak, and walnut. Panels were usually painted classic black – the "only" color.

We can approximate the look of the old-time bridges, improve performance and make the bridge easier to use by mounting it in a case from common dimension lumber.

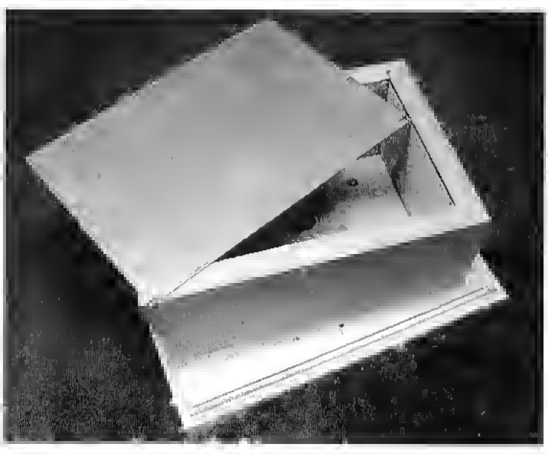
It's easy. You build a box from plain ol' dimension lumber using rabbet or butt joints that are glued and nailed. Douglas fir 1x4 lumber will work quite well. It's cheap and easy to work with hand tools. You can make it look fancy by adding decorative edges cut with a router mounted on a table. It's wood working at its simplest.



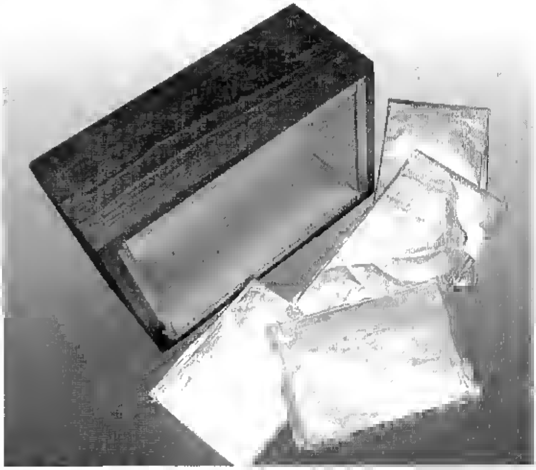
(left) Here, the four sides of the box with rabbet joints have been cut on a table saw from scrap lumber. You can do it by hand, too, although you may want to use butt joints which are not quite as strong.

This case has long sides of 10" and short sides of 6-1/4", which when assembled give a box of outside dimension of 7" x 10". Not much depth is needed so plain ol' 1x4 which actually measures 3/4" x 3-1/2" will work nicely.

(right) After the box is glued and nailed, a bottom board 8-1/2 x 11-1/2 was cut and "prettified" with a common ogee bit in the router. A 7x10 panel was cut from .050 aluminum. The bottom panel is held to the box with four common #6 x 1-1/2 wood screws, but is not glued.

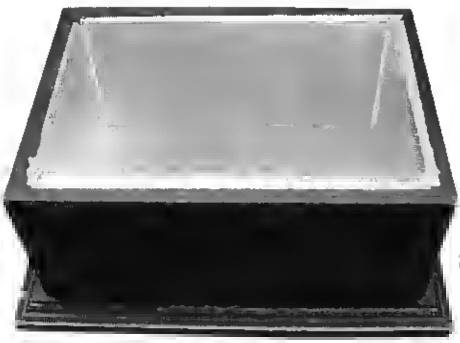


Next, the base plate and outside edges are painted with Rustoleum Satin Black spray paint. To get good results use satin black. Not gloss. Not flat. And not something that must be brushed on. After the first coat let it dry thoroughly, and sand lightly with very fine sandpaper to remove imperfections. Then give the parts three or four more coats of paint. When complete, you'll have a case with a beautiful satin sheen in classic black.



Next you have to install shielding. This is the electrical equivalent of soundproofing. You want your bridge to hear only the component being measured, not the outside world. You isolate your bridge by gluing kitchen aluminum foil to the insides of the box. It's easy, too. Cut a sheet for the bottom board, and four pieces for each of the inside walls of the box. Lightly crease the pieces so that you're sure they will assemble correctly. And make sure they overlap somewhat on all edges so that the shielding is complete.

To install the foil, layout a wide area of newspapers. I put them on the basement floor. Turn one foil panel over at a time, spray it with spray adhesive from an art supply store, and then quickly place the foil in place and rub it down. If done carefully, the foil goes down quickly and smoothly.

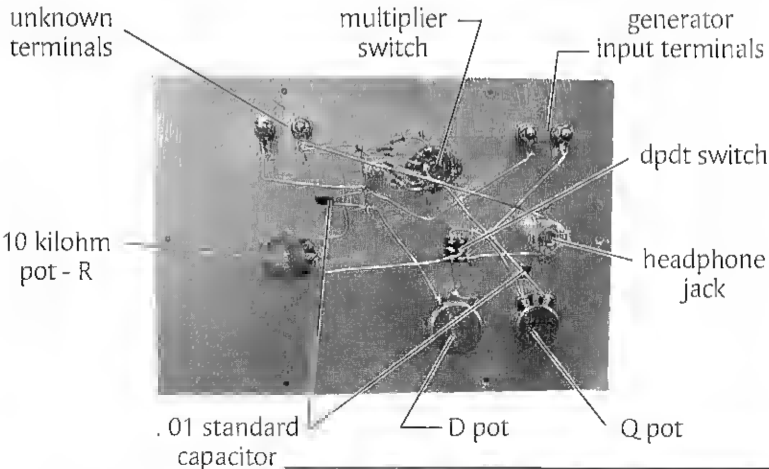


(above) The completed bridge case awaiting installation of the circuit. Large rubber feet are fastened to the underside of the bottom board with no. 6 screws so that the bridge won't easily slide across the table top.

(right) I use Elmer's Spray Adhesive. I got my can at a art supply store, but I would guess it's available elsewhere as well. A single can will provide enough adhesive to allow you to glue aluminum foil to all the houses in your neighborhood!

Mounting the Bridge Components

The bridge components are mounted to the 7x10 aluminum panel. The main measurement pot, R, should be mounted first with plenty of room to accommodate the calibration markings. Then other components can be mounted where convenient. Wiring was done with rigid #18 and #16 tinned bus wire. You can get by with common hookup wire so long as it doesn't flop around too much. In very sensitive bridges, which this is not, moving wires can be heard in the earphones as microphonic noise.



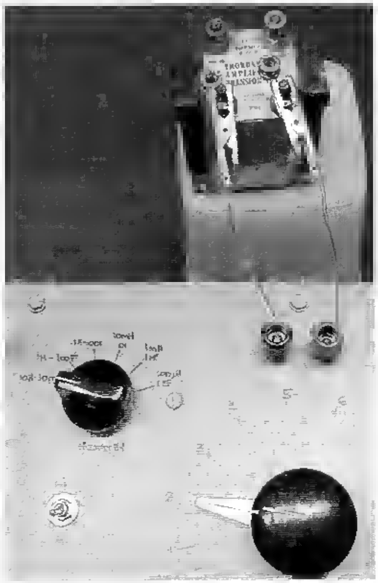
Legends for the multiplier switch are 10 Henry & 10 pfd for the 1 megohm position. The 10 ohm position at the other end of the switch will have legends of 100µh and 1 mfd. In between legends increase or decrease by a factor of ten. Thus if the main dial is half way between 3 and 4 when making a reading, and the multiplier legend is 1H & 100 pfd, the capacitor you are measuring has a value of 3.5 x 100 pfd, or 350 pfd.

After all components are test mounted on the bare aluminum panel, they are removed so that the panel can be given two to three thin coats of Rustoleum spray paint. The color used here is putty which looks good with the satin black case and will take legends carefully written on the panel with a fine point Sharpie™ marker. The large knob is a hamfest component, but the smaller knobs are available new from Mouser and other dealers.

Using the Bridge

You must feed an audio signal into the generator terminals of the bridge. I usually use a simple commercially built audio oscillator that I use for general test work. It puts out about 5 to 6 volts of signal at 1000 cycles, the usual test frequency, at low impedance. If you don't have a audio signal generator, you can build a simple one from a single IC chip as described elsewhere in this volume.

And you must have a detector. The "big boys" use high-gain tuned amplifiers whose output is rectified and fed to a meter. In other words these are audio amplifiers with enormous voltage gain, often as much as a million, and can pick out a narrow band of audio frequencies and exclude everything else. You can build one from integrated circuits, but for our simple bridge all you need are the high-impedance earphones you use on your crystal set or vacuum tube radio.



This ancient Thordarson interstage transformer from a flea market has a plate-side winding measuring about 20 henries: 2.0 on the dial times 10H on the multiplier switch.

Next, you connect the component to be measured to the "unknown" terminals. (Into the unknown terminals I usually insert lengths of no. 16 or 18 tinned bus wire to the ends of which alligator clips have been attached.)

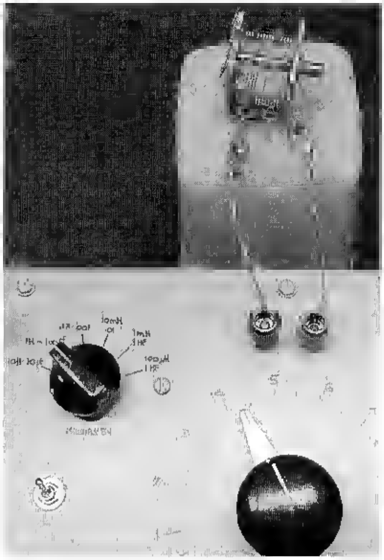
If you're testing an inductor, you must flip the dpdt switch to L to set up the Maxwell bridge. And make a guess as to the inductance. If you're measuring a power supply choke, you can set the multiplier switch to a high range such as 1 or even 10 Henry. Put the Q pot to its maximum setting.

If you're testing a capacitor, set the switch to C, and make a guess as to the proper multiplier switch setting. Put the D pot at its minimum setting.

Next put the pointer knob somewhere in the middle of the scale, about 5, and turn on the generator. You should hear a tone quite clearly. Your goal is make the tone go away.

Swing the pointer knob back and forth. You may find the volume of the tone drops somewhere around 2.5, for instance. In that case, you made a good first guess. But if you find the volume decreases as you run the pointer up to 10 and beyond, then you need to change the multiplier to the next higher range, and look for a null somewhere between 1 and 10. Or if the volume drops as you get below 1, then you need to drop the multiplier switch to the next lower range and search again.

Eventually, you should hear a decrease in the volume of the tone. If the decrease is dramatic, you have a sharp null. More likely, the decrease is gradual until the pointer reaches 2.5, for instance, and then increases again. You need to sharpen that null, so there can be no mistake as to its location. And that's what the Q and D controls do.



Here, a flea market variable capacitor is sitting on an upside down plastic food container (electrically inert). My measurement showed 430 pfd. I expected the usual 365 pfd, and thought there must be something wrong with the bridge. So I put the capacitor on a General Radio bridge of known accuracy (very expensive when new), and read 430 pfd!

If you're measuring a choke, and you find the volume decreases somewhat as you run the dial through 7, for instance, and then increases again, put the dial on 7 or as close as you can guess as to the point of minimum volume. Now adjust the Q pot down from it's maximum position. You should find that the volume decreases even more. Then adjust the main pointer knob. You may find that the minimum is now about 7.2. Then go back to the Q control and try to reduce the volume even more. As you go back and forth from one control to the other, you should be able to quickly zero in one very distinct setting where the tone provided from the generator disappears completely. At this point you read the number off the measuring dial, 7.3 let's say, and multiply it by the multiplier dial. If the multiplier is set on 10H, then your choke has a value of 7.3 times 10, or 73 henries.

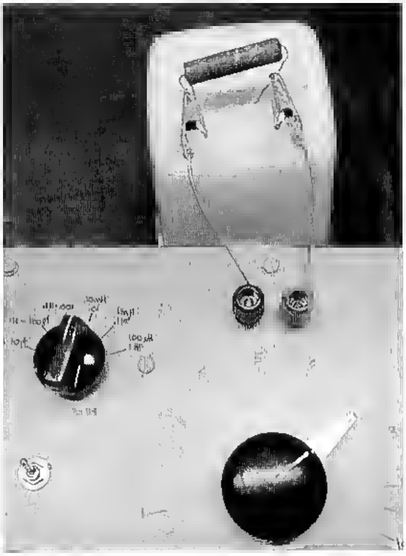
The same technique is used for capacitors. You look for an approximate null, that is a decrease in volume, when adjusting the main measuring resistor, R, and then try to reduce the volume even more with the D pot. Going back and forth will allow you to quickly locate a sharp null, from which you can read off the digits and multiply them by the setting on the range switch. You can estimate the quality of a capacitor or an inductor by noting the position of the Q or D control. If the D control is near zero, you know you have a capacitor with very little series resistance, or dissipation. If you have to run the control up to any great degree to get a sharp null, you know that there is quite a bit of leakage in your capacitor. You'll usually see this is capacitors salvaged from very old radios. Only one capacitor tested with this bridge, an old paper tubular, showed significant D.

But inductors are another thing. Almost every inductor I measured, whether was a 400µH tank coil, 2.5 mH RF choke, or 12 henry power supply choke, needed significant changes in the Q control to bring the bridge into balance. This is to be expected since inductors are dirty; they not only have lots of inductance, but they usually have lots of capacitance and resistance as well.

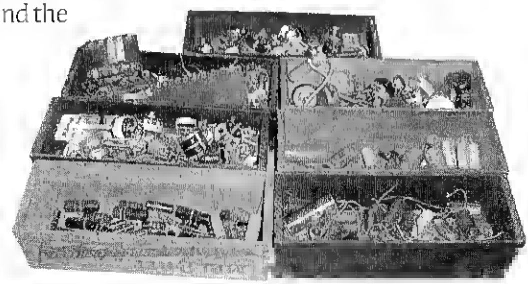
Two important points need to be

made concerning measurement of inductors. First, this bridge is for average inductors. If you try to measure a high-quality inductor having a high Q at 1000 cycles, you may not be able to get a sharp null. To measure such components you need a Hay inductance bridge circuit. Second, inductors having iron cores do not have a unique value of inductance. Their inductance changes depending on how powerful a tone you put into them. Try measuring a power supply choke with the lowest possible volume from your audio generator and note the reading. Then try it again with maximum volume. You'll get two different inductance readings. This change in inductance is non-linearity, and it creates distortion and harmonics in vacuum tube audio amplifiers and other circuits.

If you try to measure very small capacitors, such as 15 pfd, you'll have to measure the zero capacitance. The internal wiring of the bridge and the wires connecting the unknown to the bridge can have several picofarads of capacitance that will upset the accuracy of the measurement. What you can do is put a small capacitor, say 10 pfd, across the alligator clips leads which have been positioned close to the locations where they will be used. The unknown component is NOT connected. The bridge is balanced. You may read 14 pfd. Next, carefully connect the unknown capacitor without moving either of the leads to any great degree, and take another measurement. This time you may measure 29 pfd. Subtract the 14 pfd "zero capacitance" from the 29 pfd to get a true reading of 15 pfd. That's the amount capacitance from the unknown you added in parallel. Our little bridge is very primitive, but capable of remarkable results if we use it cleverly to get around its imperfections.



I searched through my junk box for an old tubular capacitor of poor quality. It took a while, but I found this .1 bypass. The actual capacitance was .074 and very high dissipation. After I shot this photo, the capacitor went into the garbage!



These wooden cheese boxes full of ancient components were purchased at a flea market for about $5. An impedance bridge can tell us if they are still usable – most are, but a few will be trashed.

Building More Precise Impedance Bridges

You can buy used General Radio bridges at flea markets, from dealers, and on internet auction sites. Other brands are available as well, but GR was the finest manufacture in its day. Bridges are no longer manufactured.

The old 650A and newer 1650 bridges are available from $50 to $150. The 1608, a 1/10% bridge is usually available for a bit more money. These massive industrial quality bridges are capable of the same performance today as when they left the factory decades ago once calibrated.

But you can build your own precise bridge capable of making comparisons between capacitors and inductors to degrees of precision to better than 1/100%. When you get to this level however, you must use shielding throughout the bridge, resistors that change very little with changes in temperature (low temperature coefficient), and you must use a Wagner ground to nullify errors that creep into measurements from external sources, and other precautions. It sounds really complicated, and it can be, but a homebrew precision bridge is more plumbing than electronics: mixtures of copper water pipe, bronze welding rod, porcelain and acrylic standoffs, flashing copper boxes and more.

If this kind of thing sounds interesting you need to learn more about measurement. Here are a few of the best sources I have found. You'll need to understand complex impedance, and you should brush up on complex algebra from high school.

Melville Stout – BASIC ELECTRICAL MEASUREMENTS – 2nd Edition
Prentice-Hall, 1950, 1960
–A great introduction to all types of meters and bridges for all types of electrical and magnetic measurements.

Hague – ALTERNATING CURRENT BRIDGE METHODS – 5th Edition
Pitman & Sons, London 1957
–The classic text on impedance bridges. A number editions can be found from the 1930's to 1957

Ivan Easton – IMPEDANCE BRIDGES ASSEMBLED FROM LABORATORY PARTS
General Radio Experimenter – a series of articles beginning in July 1941
–A great collection of how-to later reprinted by General Radio in a booklet. Aimed at electrical engineers. It will probably be confusing on the first or second reading, but Stout (above) can explain the missing parts.

Ferguson & Bartlett – MEASUREMENT OF CAPACITANCE IN TERMS OF RESISTANCE AND FREQUENCY – Bell System Technical Journal, July 1928
Millea & Ilie – A CLASS OF DOUBLE-BALANCE QUADRATURE BRIDGES...
Metrologia – Vol 5 No. 1, 1969
–Laboratory standard capacitors are expensive because they are unstable. Standard resistors on the other hand are very stable and quite inexpensive. With a quadrature or Wien bridge, you can measure capacitance against a resistance and a signal of known frequency and end up with an inexpensive laboratory standard capacitor. Sumthin' for nuthin'! (A trick few engineers know!)

A Word to the Wise...

You will see General Radio decade resistance boxes and capacitance standards offered for sale at flea markets and on internet auction sites. You may get a good deal, or you may get less than you expected.

General Radio decade boxes use wire wound resistors on each step of each switch. Each resistor is actually a pair of wire-wound resistors wound in opposite directions on a mica card. This is done to neutralize the inductance that all wire wound resistors exhibit. For example, on each step of the 100 ohm decade is a mica card with two 200 ohm windings of manganin wire. The pair of 200 ohm windings in parallel gives 100 ohms with almost no inductance.

You may buy a decade box and put it on your ohmmeter to test it. The first 100 ohm step may read 100 ohms. The second 200 ohms. But the third instead of reading 300 ohms actually reads 400 ohms. What has happened is that one of the windings on the third step has opened – not shorted, but opened. You can repair the decade by soldering in a precision 200 ohm resistor (if you happen to have one) in parallel to bring the step down to 100 ohms. This kind of problem is usually the result of someone having abused the decade box.

If you intend to pursue precision measurements, you must remember that in 1948 electrical standards changed. Ohms got smaller; henries got smaller; farads got larger. All these changes are small, only .0495%, but they can easily be measured with good quality equipment. If you buy pre-1948 decade boxes and other standards, you must remember that they will be off calibration by at least 495 parts per million. See Basic Electrical Measurements by Stout for details.

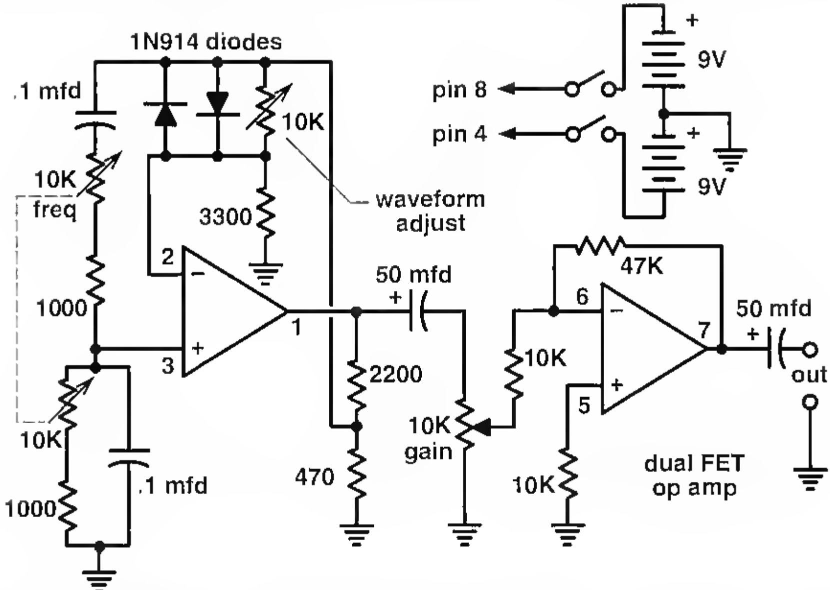
Capacitors suffer from another problem. Almost all capacitors age. For instance, I bought several type 509 standard capacitors for $3 each at a flea market. One was marked 2000 pfd ±.25%. That means the original value taking into consideration the 1948 change in standards was between 1994 and 2004 pfd. My precision measurements put it at 2014 pfd which makes is almost .75% high sixty years after manufacture.

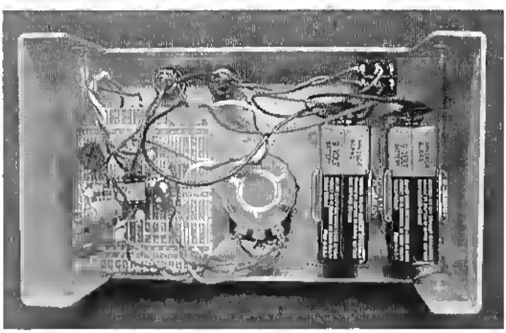
Early capacitors increased in value dramatically within the first ten years of manufacture. Be aware of that. I bought these old standards knowing they would be high, but that most of the aging had occurred, and that once measured, I could depend on them to be stable. I use them to check both homemade and commercial bridges.

The point is: don't buy old capacitance standards and trust them to be accurate. They most likely have changed value dramatically. Know what it is you're getting. Calibrating a bridge with an old standard will most likely result in having a bridge that reads low.

Building an Audio Oscillator

If you don't have an audio signal generator, you'll need to build a generator of some type capable of generating several volts of 1000 cycle power. Many simple oscillators can be used: phase-shift, LC resonant, twin-T and others. You need a sine-wave: a nice pure tone. A squarewave would probably work but is not desirable because a bridge can be balanced to make the 1000 cycle fundamental disappear, but the harmonics will still be there, making it difficult to find the null.



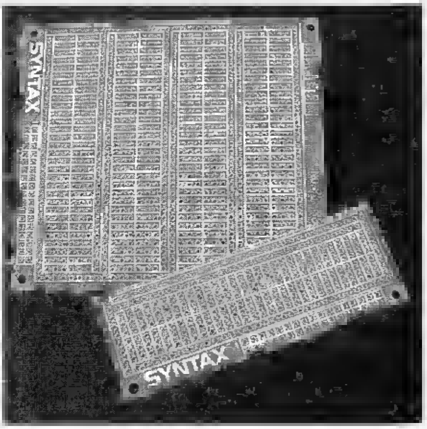


Here is a simple Wein bridge oscillator that tunes from 150 cycles to 1550 cycles and provides 8 volts output peak-to-peak, or about 2.8 volts rms. The first opamp is configured as a Wein-bridge using a ganged double 10K pot with 1K fixed resistors and .1 mfd capacitors to create the desired frequency. A pair of back-to-back silicon diodes (1N914s) are biased with another 10K pot to provide automatic gain control so that the output voltage stays more or less constant as frequency is changed.

The second opamp amplifies the sine-wave output of oscillator to provide maximum output when powered by a pair of 9 volt transistor radio batteries.

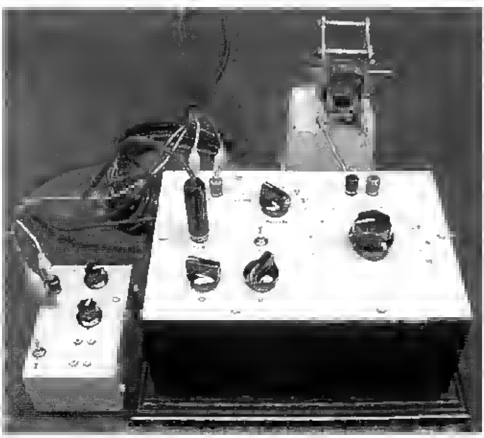
The only exotic component is the double 10K pot, but even it is readily available in electronics catalogs for a couple of dollars. Everything else is common, and can probably be found on old printed circuit boards from VCRs, answering machines, old computer equipment, and who knows what else.

The whole thing is built on a small piece of printed circuit board cut with tinsnips from a larger prototyping board having three-hole pads – that is, groups of three holes spaced .1 inch apart that are tied together with copper. This particular board I got some time ago from Circuit Specialists for a few dollars. One board provides all I need for several simple transistor circuits. The whole circuit is mounted inside a mini-box with the usual hardware.

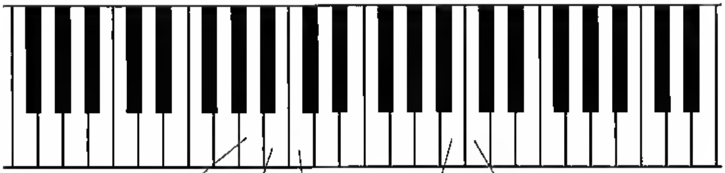


The only adjustment needed is to the diode biasing pot. Simply listen to the output tone in a pair of earphones and adjust the pot so that tone is as loud as it can get without distorting. You want a pure tone.

Both opamps are contained on the same chip. Here, I used a TL082 IC, but I'm sure a common LF353 or other FET opamp will work every bit as well. Pin outs should be the same. You should not have to spend more than 50¢ for the chip.



Here we have the audio oscillator feeding the bridge through alligator clip leads. Make or buy some. They're extremely handy to have. An ancient General Radio variable capacitor obtained for $3 at a hamfest recently is sitting on top of an overturned electrically-inert plastic food container. The bridge has been balanced and the oscillator shut off. The bridge is showing me that this is a 150 pfd model from the 1920's.



Impedance measurements are usually made at 1000 cycles per second (Htz). To calibrate the tone generator for your bridge, you simply use a frequency counter. They are a great convenience if you have one, but we can get by comparing the output of the generator with an accurately tuned piano.

Middle C, located in the middle of the keyboard has a frequency of 528 cycles. The C below that is one half or 264 cycles per second. The C above middle C is 1056 cycles (double). You can set your generator frequency control until the tone matches the B above middle C, which is 990 cycles, or 1% short of exactly 1000 cycles. If you're tone deaf and can't "carry a tune", you had better get someone to help you.

This is a simple technique, but is plenty accurate for our needs. Who needs a counter?

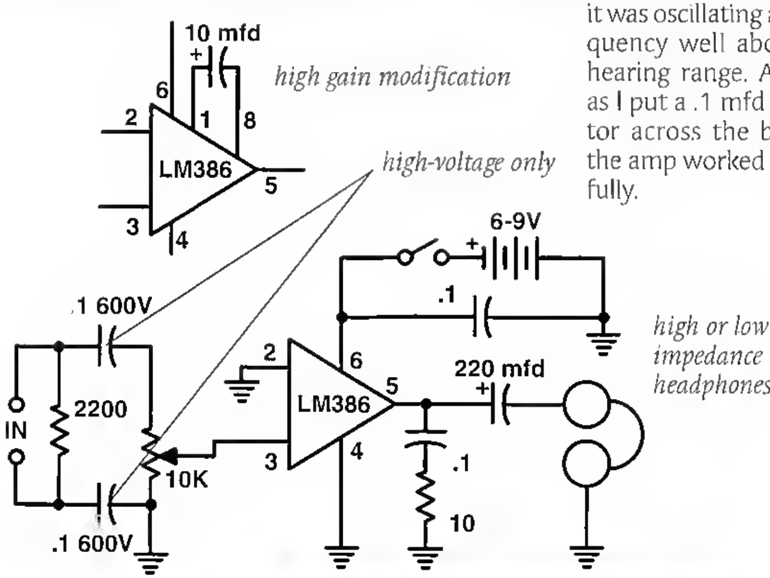
Building an Audio Amplifier

Our simple impedance bridge works only with high-impedance phones which can be somewhat difficult to find. And when used on the lowest capacitance/highest inductance setting, the internal impedance of the bridge is so high that a simple signal generator can't provide a tone loud enough to be comfortably heard.

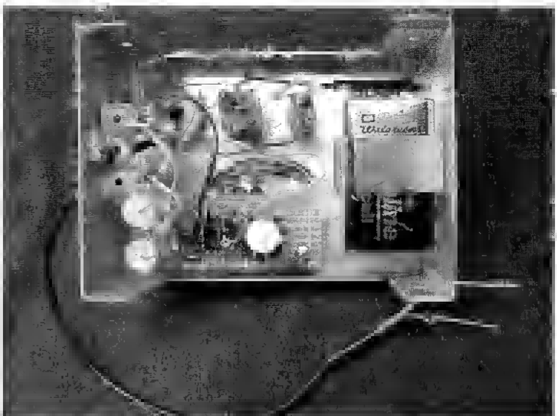
The solution to the problem is a simple audio amplifier built around a common, inexpensive LM386 integrated circuit. In this circuit, the outside world is connected across a 2200 ohms resistor which in turn is connected to the amplifier circuit through a pair of .1 mfd/ 630 volt capacitors. These caps let the audio signal into the solid-state electronics, but keep any high voltages out.

This very simple circuit provides a voltage gain of 20, and because the opamp output is low impedance, the amplifier can drive both high-impedance and low-impedance phones. Lo-Z phones (Walkman-type phones) are available almost anywhere for just a few dollars. Not only will you be able to use them here on your impedance bridge, but you can safely hook this circuit up to a regenerative receiver or a crystal set. In fact, when tested with the crystal receiver shown in Volume 1, I discovered AM signals all up and down the band almost impossible to hear before. And the gain makes measuring the smallest capacitors with the bridge far easier.

If you want even greater gain, you can put a 10 mfd capacitor across pins 1 and 8 as shown. That should give you a gain of about 200, but I've found 20 is plenty for my needs. At full comfortable volume, the amp draws only about 8 mA, well within the capability of an alkaline transistor radio battery. Note: in prototyping the circuit, I found my LM386 chip drawing almost 45 mA, but not amplifying! At least that's what I thought. In fact, it was oscillating at a frequency well above my hearing range. As soon as I put a .1 mfd capacitor across the battery, the amp worked beautifully.

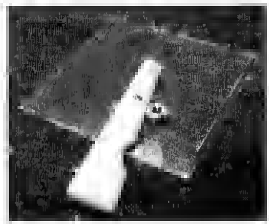


Be sure you use high voltage capacitors between your solid state circuit and the 2200 ohm resistor. And be sure there is no way the input leads can accidentally come in contact with the case or anything else. Some simple tube receivers put the phones in series with the high voltage supply. You don't want that voltage accidentally getting into the circuit and into you!



In this mini-box I mounted both a 1/4" and a 3.5mm miniature phone jack for the low impedance phones both of which are connected to the 220 capacitor. This is about as simple an electronic project as you'll ever build, and yet it's a very handy piece of gear to have.

Creating a Pointer for a Knob

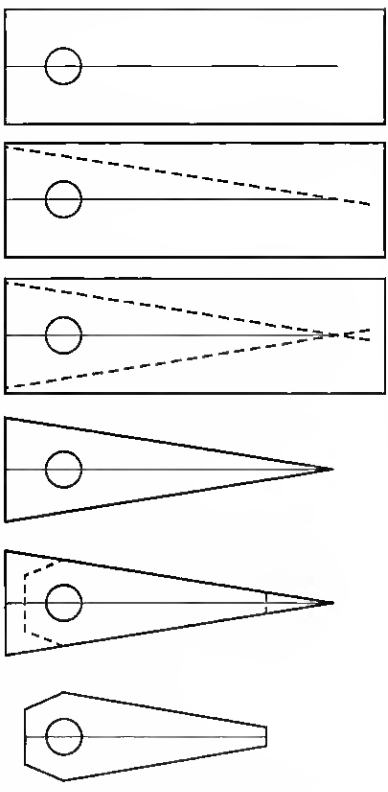


You can add a long transparent pointer to any knob quite simply. Acrylic plastic (Plexiglas or Lucite) is often used to replace broken windows. It is usually cut by scribing a deep groove and then snapping the sheet in two along the groove by flexing over the edge of table much like cutting glass. An inexpensive scribing tool costing no more than a dollar or two makes scribing very easy.

To make a pointer I use the scriber on the case of a CompactDisk. Among computer fanatics they're referred to as crystal cases. Regardless of what you call them, they're styrene plastic which can be attached to almost anything with almost any glue. The same cannot be said about other clear plastics.

I drill a 1/4" hole at one end of the plastic sheet, and using a small steel rule and fine carbide scriber or small nail I scribe a light line that will be the "hairline". On either side of that I scribe much deeper groove with the scribing tool. This forms a triangle that can easily be snapped out of the sheet.

Next, a series of smaller grooves are scribed to form a roughly semicir-



1. A 1/4" hole is carefully drilled at one end of a sheet of styrene.

2. Through the center of this hole a light line is scribed out about 2-1/4". This will be the "hairline"

3. Next, deep grooves are cut at an angle on either side of the "hairline", forming a triangle.

4. If the grooves are cut deeply enough, a triangle can be easily and cleanly snapped out of the styrene sheet.

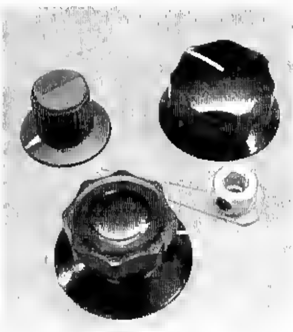
5. Three or more grooves are cut to create a semicircular path around the hole. And a groove is cut across the tip of the triangle about 1-3/4" from the center of the hole.

6. When the final unwanted pieces are snapped off, the edges of the pointer can be smoothed by laying a piece of fine sandpaper on a table top and carefully polishing them.

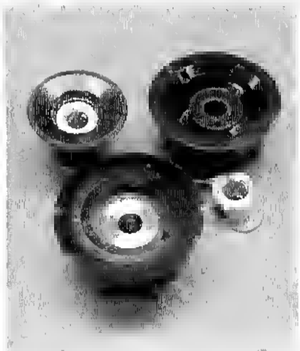
cular pattern around the 1/4" hole. And the tip of the triangle is squared off. The rough edges are cleaned up by rubbing them against fine sandpaper.

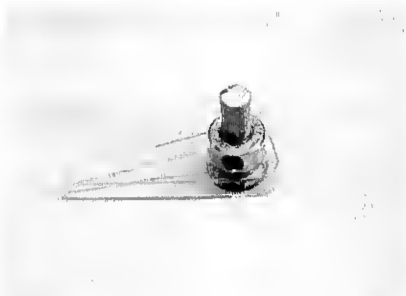
The pointer is completed by either gluing it to the skirt of a knob or to a hardware-store-variety shaft collar. As a last step, a black Crayola is rubbed into the hairline groove to blacken it. Excess Crayola is easily removed with a tissue.

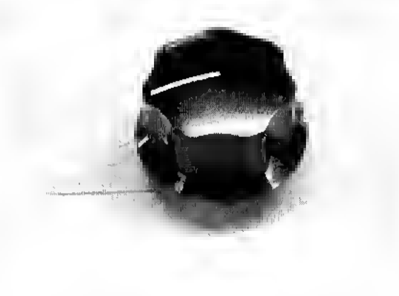
(left) Clamp a 1/4" shaft in a vise and put a shaft collar in position. Put a little SuperGlue on the collar, and slide the pointer down onto the collar. (right) Slide another collar down and tighten it to hold the pointer in place while the glue sets up. It would be very wise to lubricate the shaft with something oily to prevent everything from being glued together should excess glue ooze out of the joints onto the shaft!



(left) Different knobs will dictate how the pointer is to be mounted. (right) The bottom knob has a wide flat skirt to which the the pointer can be glued directly. The top knobs have recesses below their skirts requiring that the pointer be glued to a 1/4" shaft collar.







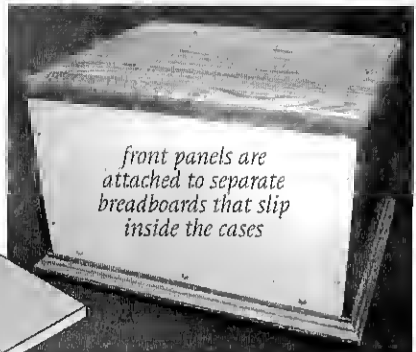
Using a shaft collar requires that the potentiometer or capacitor have a shaft length of about 3/4". Imported pots with long aluminum shafts can be purchased inexpensively. It's a simple matter to clamp the tip of the shaft in a vise and quickly cut it down to the required size with a hacksaw. Obviously, the longer you make the clear plastic pointer, the finer you can read off dial legends. But that also means you'll need a lot more panel space.

Old Time Radio Cabinets

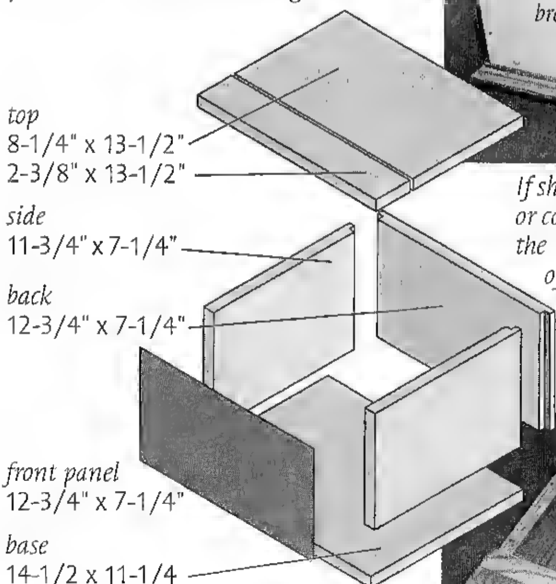
If you plan to build old-time radios or want to make a modern radio look old-time, then you need to put it in a wooden cabinet. I've seen some people build really fine receiver and transmitter circuits and then mount the electronics in a cabinet that looked like it had been in a train wreck. It doesn't have to be that way. If you have a nicely working radio, that's the cake. So put some frosting on it with a nice cabinet.

What I show you here are two cabinets that I fabricated. And the reason I present them here is that *these are my very first attempts* at cabinet building. If I can produce something that looks as nice as this, anyone experienced in wood working should be able to build something far better.

I had an old table saw – just a cheapie. The motor mount cracked and a jury rigged repair didn't work very well. So I finally bought a better table saw (far more than what is needed for these cases) and a run-of-the-mill router mounted in a homemade router table. These two cabinets were built in order to learn how to use the new equipment. As you can see I've haven't yet put radios in them yet.



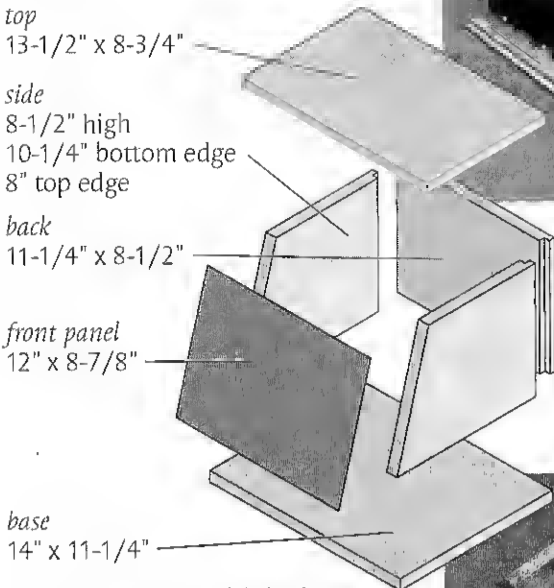
front panels are attached to separate breadboards that slip inside the cases



This brute is built from one inch oak dimension lumber, meaning that all thicknesses are 3/4" and that the completed case weighs far more than it should. A walnut oil stain was applied followed by several coats of urethane varnish.

If shielding is needed, aluminum or copper foil could be attached to the inside of the case. A number of holes in the back panel allow heat from tubes to escape, or at least that's the plan.

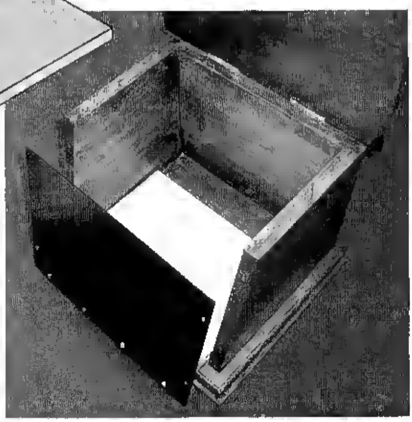
If you need ideas for cabinet designs, look through old radio magazines including QST (on CD-ROM) for ads from various manufacturers. You can take the dimensions given and add a little imagination to come up with case as good as the electronics it contains!



This roomy case is also built from dimension lumber, aspen if I recall correctly, finished in a gel stain (which I found to be a pain) and more urethane varnish. There are no ventilation holes yet.

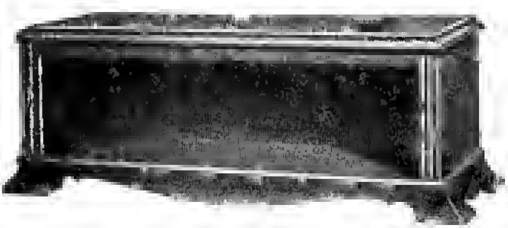
This case is modeled after a 1925 Standardyne Multivalve Radio. You could mount two large dials on the satin black .062 aluminum front panel, and could put at least two tubes inside. The hinged lids on these old cabinets allow for the changing of plug-in coils. You could put a complete solid-state QRP station in a box with this along with lead-acid batteries and tell people you're communicating with Tesla!

The dimensions I used here were dictated by the lumber sizes available in local home improvement chain stores. If you choose to make your own joined panels or use plywood, you can make almost size cabinet. How about a fine walnut cabinet designed to hold a rack panel painted in classic black crackle? You can do it. It really isn't that difficult.



The top of this case was beautified by using a vertical panel raising bit on three edges. Since the bit has to remove a lot of wood, small amounts were removed in multiple passes on the router table. Other decorative edges where routed with a standard ogee bit. There are scores of bits to choose from. Each will create a cabinet with it's own individual personality.

For Quality **CORBETTS CABINETS** For Quality



OUR NEW MODEL "T"

Price List:

Size	Mahogany any finish	Walnut or Mahogany	Size	Mahogany any finish	Walnut or Mahogany	Size	Mahogany any finish	Walnut or Mahogany
7x10-8	$6.55	$8.20	7x20-8	$10.70	$13.35	8x30-8	$13.70	$17.10
7x12-8	7.00	8.75	7x28-8	11.80	14.70	7x18-10	10.20	11.55
7x14-8	7.50	9.40	7x30-8	12.75	15.85	7x21-10	10.90	13.25
7x18-8	8.55	9.50	7x27-9	11.85	14.80	7x24-10	11.70	14.65
7x21-8	9.30	11.50	8x24-8	11.10	13.90	7x26-10	12.65	15.80
7x24-8	10.10	12.60	8x26-8	11.70	14.65	7x30-10	13.30	16.65

SHIPPING CHARGES PREPAID

Our Model "T" cabinet is unquestionably superior to anything offered in design and finish and is backed by our guarantee to please. It is equipped with full length piano hinge and lid stay. Carefully hand rubbed piano finish. Accurately made of best kiln dried lumber and well packed for shipment.

MOUNTING BOARDS—10 to 18 in., 40c; 21 to 26 in., 50c; 28 to 30 in., 60c each.

WRITE FOR BOOKLET offering best values in radio furniture.

Set manufacturers inquiries solicited for special cabinets for any receiving or sending apparatus.

LIBERAL F. O. B. FACTORY DISCOUNTS to Dealers on all orders.

CORBETT CABINET MFG. COMPANY
St. Marys, Pa.

If you work wood or you know someone who does, then building really fine cabinets is within your grasp. It appears that 5/8" thick stock was preferred for cabinets, and to produce that you may need a planer.

(left) an advertisement from the July 1925 issue of QST (below) another ad from the September 1925 QST

In the mid-1920's radio was the cutting edge technology that everyone was excited about, not unlike the recent computer/internet craze, or the CB radio craze of the 1970's.

A Radio Cabinet of Beauty and Elegance Direct to You at Lowest Cost

Lid splined both ends to prevent warping.
Nickeled piano hinge.
Nickeled lid support of artistic design.
Anti-vibration cushion feet (not visible in cut).
Edges of lid moulded to match bottom.
Shipped securely packed in strong carton.
Prompt shipment.

	Hardwood, Rubbed Mahogany Finish	Solid Black American Walnut
7 x 18 x 7½ or 10 in. deep	$3.50	$6.00
7 x 24 x 7½ or 10 in. deep	4.00	5.50
7 x 26 x 7½ or 10 in. deep	4.75	6.25
7 x 28 x 7½ or 10 in. deep	5.50	7.00
7 x 30 x 7½ or 10 in. deep	0.00	8.00

CASH WITH ORDER or C. O. D. if ¼ of price is sent with order.

Prices F. O. B. Hickory, N. C. Order express shipment, often cheaper than mail and much safer from damage.

FREE WITH EACH CABINET, a glued-up stock non-warping ½-inch BASEBOARD.

Free Catalogue.

The Southern Toy Company, Inc.
Dept. T **Hickory, North Carolina**

Measuring Unknown Transformers and Chokes

A bridge is useful for measuring unknown transformers and chokes. Old regenerative receivers often used a tetrode, also called a screen-grid tube, or a pentode as a detector. These more complicated tubes have far greater plate resistance than triodes. To get the maximum gain out of any tube requires that you put a load impedance on the plate at least as great as the plate resistance. So when it comes to getting the maximum audio from a tetrode or pentode regenerative detector, you need a very high impedance at audio frequency. And that means you'll want a large inductance which will easily let through direct current to power the tube but will not let audio frequencies through.

For instance the old 24A screen-grid tube, still quite common and inexpensive used, has a plate resistance of 600,000 ohms. Maximum voltage gain, μ, is calculated by multiplying the transconductance, g_m times plate resistance. For the 24A

$$\mu = 1050\ \mu\text{mho} \times .6\ \text{megohm} = 630$$

To get 90% of that voltage gain (not power gain) from the tube, you would need a load impedance of about 9 times the .6 megohm, or 5.4 megohms. How big a choke would we need to provide 5.4 megohms of reactance at 1000 cycles per second (htz).

We can take the standard formula for inductive reactance...

$$X_L = 2\pi f L$$

where

f = frequency
in cycles per second (htz)
L = inductance in henries

$$2\pi = 6.283$$

We rearrange the formula so that we can calculate inductance...

$$L = \frac{X_L}{2\pi f}$$

and we plug in the numbers to find

$$L = \frac{5.4\ \text{megohm}}{6.283 \times 1000} = 859\ \text{henries}$$

We need an inductor of 859 henries!

I have a 500 henry "audio reactor", a fancy term for audio choke, manufactured by United Transformer Corporation years ago, but that's the biggest I've ever found. If I were to use it on a 24A, I would get a voltage gain of about 529, or 84% of what the tube is capable of delivering under ideal conditions.

This simple theory about loading tubes tells us why incredibly large inductors were used in the plate circuits of the tetrode and pentode regenerative detectors. Finding such chokes is very difficult. You may have to wind one using #40 or #42 wire on a core salvaged from an old power transformer. There are many articles for winding transformers in old radio magazines and ARRL handbooks, including THOSE GREAT OLD HANDBOOK RECEIVERS published by Lindsay Publications. True, the instructions are for power transformers and filter chokes, but the basic construction principles are the same, and the process is actually easier, because you can scramble wind as many turns in the space allowed. There is little need to be neat. As an experiment, I once wound several thousand turns of #32 wire on an old transformer core and ended up with 45 henries. Doubling the number turns would have increased the inductance by a factor of not 2, but 4, or would have given 180 henries.

Your bridge will measure chokes up to about 100 henries. Beyond that your bridge, and most commercial bridges, start to have trouble.

So how big a choke would we need to get 90% of the maximum voltage gain available from a 27 triode, a contemporary with the 24A? Multiply the plate resistance of 9000 ohms by 9, and you get 81,000 ohms. Plug that into the formula used above...

$$L = \frac{81{,}000}{6.283 \times 1000}$$

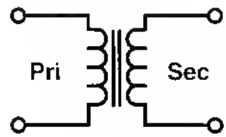
$$= 13 \text{ henries}$$

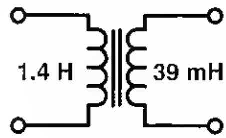
and we get an inductance of about 13 henries. And the voltage gain? Multiply the transconductance, gm, of 1000 µohm x .009 megohm plate resistance, and you get 9. But we're only getting 90%, or a voltage gain of 8. Just eight.

The message is simple. To get maximum performance from the fewest number of tubes in a regenerative receiver, use a tetrode or pentode and hang the largest choke you can find or wind on the plate. In our example here, a loaded 24A could give us a gain of about 529 versus 8 for the 27 triode.

Your impedance bridge can be used to test output transformers designed for audio amps, interstage transformers, even blocking oscillators from old tube televisions to see what kind of a load they can provide.

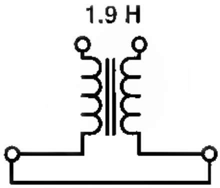
You can start by using your ohmmeter to match up pairs of wires connected to the primary and secondary. Output transformers and audio transformers are usually color coded as are power transformers.

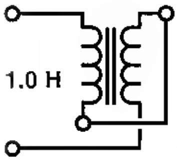




Next measure the inductance of the primary and the secondary and record the results. For example, here I measured a junk box audio transformer and found the primary to have 1.4 Henries of inductance and secondary having only 39 mH, which is equivalent to .039 Henry. Dividing 1.4 by .039 gives about 36 which is the impedance ratio of the transformer. Take the square root of thirty six, which is 6, and you have the turns ratio. You could use this as a 6:1 interstage transformer.

You can double check your results by connecting one of the primary leads to one of the secondary leads and measuring the inductance across the remaining two leads. Doing that on our test transformer gives 1.9 Henry. Then you use the same primary lead and connect it to the other second lead, and again measure. This time we get 1.0 H. In the first connection the magnetic fields created aid one another. In the second connection the magnetic fields "buck" one another, and therefore produce a lower inductance.





If we take the original individual inductances and find their square roots, we get:

$\sqrt{1.4} = 1.183$
$\sqrt{.039} = .197$

If we add these together and square the result, we get

$1.183 + .197 = 1.38$
$1.38^2 = 1.9$

which is what we measured with the windings connected so that the fields aided one another.

Subtracting the two roots, and then squaring gives:

$1.183 - .197 = .986$
$.986^2 = .97$

And here, the .97 is about 1.0 which is what we measured when the fields bucked one another.

I get a kick out of the adherents to the vacuum tube stereo religion who believe that tubes sound better than transistors. One the main reasons tube cannot match solid state amplifiers is because of the need for output transformers to match tube plate impedances to speaker impedances. Transformers, being built with iron, are notoriously "dirty." A couple of problems result from a reduction of incremental inductance and from poor coefficients of coupling between windings. It's beyond the scope of this simple booklet, but if you have a precise and accurate bridge you can quickly measure incremental inductance and coupling. In fact you can wind your own audio frequency transformers and test them for performance.

Most often I'll dig through the junk box and find an output transformer. They are usually easy to spot. The primary has two heavy plastic or cloth covered leads, and secondary is usually two heavy leads with only enamel insulation. I just measure the inductance of each winding and divide to get impedance ratio. For instance, the primary might be 2.4 Henry and the secondary might be 3.5 mH (or .0035 H). Dividing 2.4 by .0035 gives about 686. If the secondary is connected to an 8 ohm speaker, the primary will see 8 x 686 or 5488 ohms. So this transformer could be used on an audio output tube that needs a 5500 ohm load (as stated in a tube manual) like an octal 6V6, or its miniature equivalent, the 6AQ5.

You can judge power capacity by size. Even a small transformer that fits in the palm of your hand will handle several watts. The larger the transformer and the more it weighs, the more power it can handle.

Trick: You can connect the primary and secondary windings of an interstage transformer to aid one another, and get a choke with far greater inductance than merely the total of the two inductances. (Like the 1.9 measurement above). Sometimes inductances can be quite large.

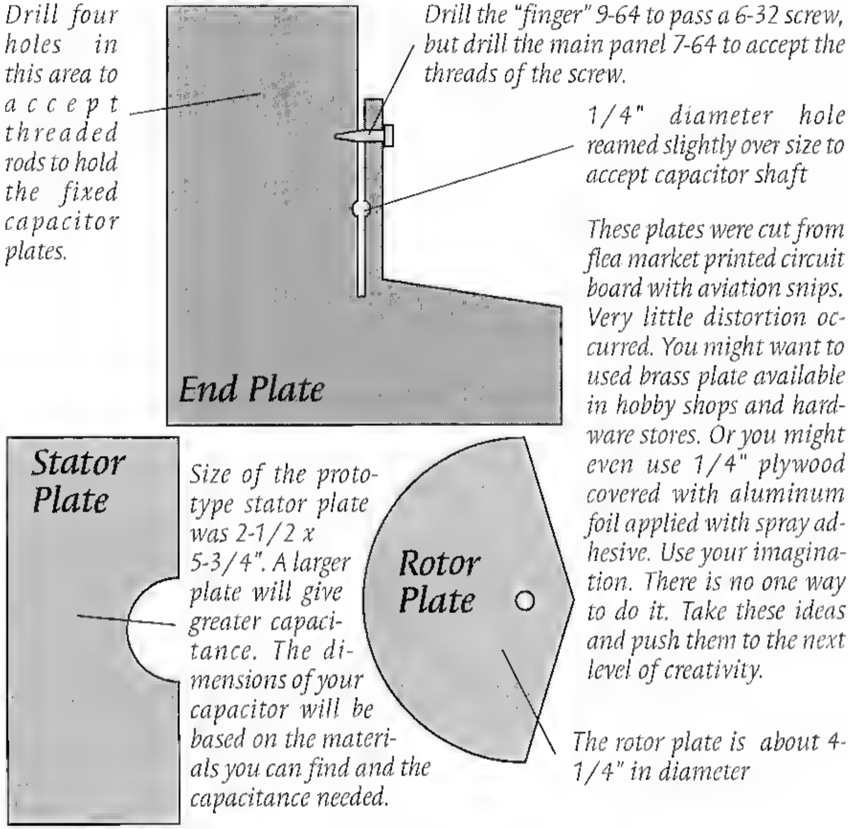
Building a Variable Capacitor and a Receiver Around It

Once you have an impedance bridge, you can build a variable capacitor and measure it. And from that you can build a radio that will tune the band of frequencies you desire.

Here I built a simple variable capacitor with four stator plates of about 2-1/2 x 5-3/4 in size, and three rotor plates about 4-1/4" in diameter. Each plate was cut from small pieces of single-sided glass-epoxy printed circuit board that were glued to 1/4" shaft collars with "super-glue." If you choose to duplicate this technique thoroughly clean both the shaft collar and the plastic side of the pc board so that you get a strong joint. Shaft collars can be very expensive if purchased in a hardware store, but if you can get them from an industrial supplier, they can be had for not much more than 50¢ each. The shaft collars position the plate on a standard 1/4" rod (hardware store material), and keep the plane of the plate at right angles to the shaft, so that as you rotate the shaft the moving plates don't touch the fixed plates at some point – something that can be difficult to achieve.

Stator plates are mounted on 10-32 threaded rod from the hardware store and positioned with 10-32 nuts to give sufficient clearance for the rotor plates. You can maximize capacitance, of course, by bring fixed plates as close to the rotor plates as possible. Or you can increase capacitance by adding additional fixed and rotating plates.

The end plates are fabricated from 1/2" thick oak. The bearing hole for the 1/4" shaft is roughly reamed out a little oversize. The slit together with the adjustment screw allow the



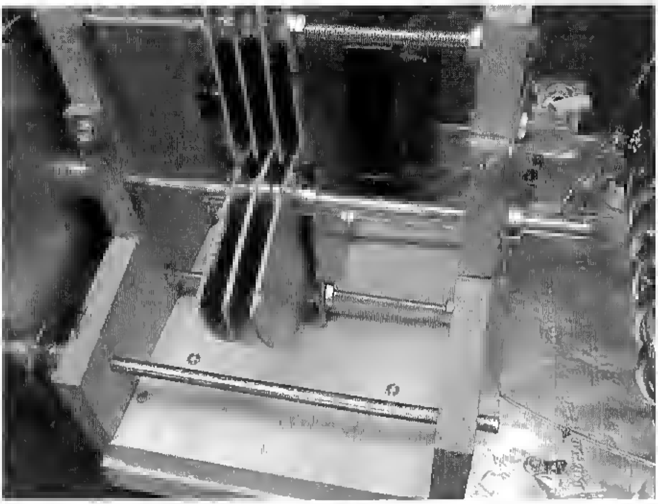
bearing to be adjusted to a degree that the shaft turns smoothly but without backlash or "slop." It's a very primitive bearing, but it works very well.

If you build a capacitor similar to this one, you'll get best results if you clamp all the stator plates and wooden end plates together and drill them as one unit with a drill press. Doing so will ensure that all holes line up and the whole assembly goes together without tears and profanity!

The slow-motion dial drive used on this capacitor was described in Vol 2 of this series and works remarkably well.

Once the capacitor was built and operating smoothly, it was put on the bridge and measured. The first step was to hook up leads from the bridge to the capacitor terminals. Then one lead was disconnected but left dangling very near the terminal. Next a 27 pfd 5% capacitor soldered to alligator clips was put across the leads, and the bridge balanced. The reading was about 32, telling me that all the wiring inside and outside was adding 5 pfd to any reading. Then the 27 pfd cap was removed and the dangling lead reconnected to the variable capacitor terminal.

With the plates fully meshed I measured about 97 pfd, and with the plates completely unmeshed, the reading was about 37 pfd. Subtracting the 5 pfd from both readings told me that the homemade capacitor

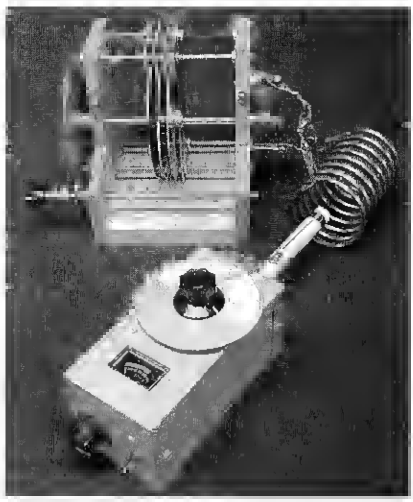


(left) Another view of the prototype variable capacitor mounted on a breadboared covered aluminum foil

(below) Checking the frequency range of the coil and the homemade capacitor.

would change from about 32 pfd to 92 pfd. That's an awfully high minimum capacitance, but when you consider the way the unit is built and its size, that's not unusual.

The next step was to take this reading and using the formula given in Vol 2 (page 39), I found that to tune in shortwave stations in the vicinity of 10 mHtz, I would need a 1.5 µh coil and a fixed capacitor of about 85 pfd across the variable. Digging through the junk box turned up a huge old coil wound from 1/4" copper tubing about 2-3/4" in diameter that had been wound for experiments with self-excited transmitter designs from the 20's. The grid dip oscillator (Vol 2) and a 100 pfd capacitor soldered to alligator clips, I began to look for a dip with the capacitor clipped across various numbers of turns. The formula for resonance (Vol 2 - formula 2 page 23) told me that I should see a dip at 13 mHz when the capacitor was across 1.5 µh. A dip at a lower frequency would mean too many turns. A dip at a higher frequency would indicate that the capacitor was not across enough turns.



As it turned out, six turns came in with a dip somewhat below 13 mHz meaning that I had slightly more inductance than I needed. I cut the coil at six turns, drilled a 9/64" hole in the loose end to accept a 6-32 screw. Next the coil was clipped the variable capacitor and the 100 pfd added as well. The maximum and minimum resonant frequencies where measured with the gdo, and both came in a little bit low – from about 8.5 to just over

10 mHz. But that's okay because the 100 pfd is really too high and when changed to something less in the final assembly, the frequency will come up.

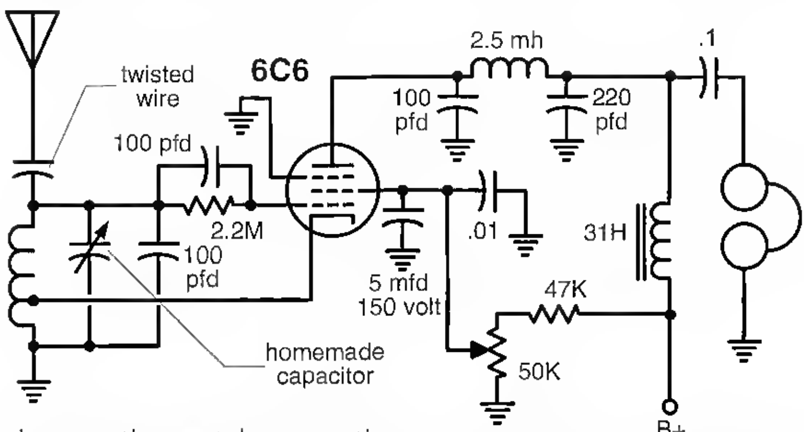
When I mounted the old porcelain standoffs from my collection of old parts to the baseboard, I spaced them a little further apart than the distance between the coil mounting holes. Then I stretched the coil apart a little to mount it, and in doing so, slightly reduced the inductance.

When the variable capacitor, coil and padding capacitor were mounted on a pine breadboard, the gdo was again used to check the frequency range. This time I got a range from 9.3 to 11.3. A 2 mHz range is a bit too much, but at least I could tune shortwave broadcast stations, WWV time station, and the 30 meter ham band. So all that was left was to a build more-or-less standard regenerative receiver.

A One Tube Regenerative Receiver

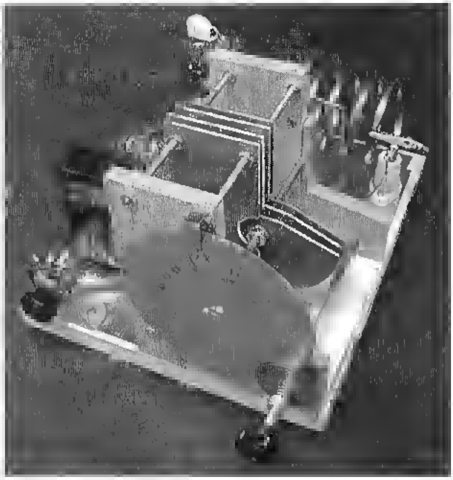
Once a tank circuit for the wavelength desired has been built, the process of building a one-tube regenerative receiver around it is relatively easy. Because the tank coil is so large and the turns so far apart, a large alligator clip can be used to tap into the ground end of the coil to provide feedback. As a result, a Hartley-type regen was called for.

Digging through the tube box turned up a 6C6 sharp-cutoff pentode. This tube has a 6.3 volt AC filament and uses the old 6 prong tube base from the early 30's. The 6D6 "super-control" pentode would work as well,



A demonstration one-tube regenerative receiver using a 6C6 sharp-cutoff pentode (or valve of your choice). Only the tank values as discussed are critical. The rest are not. Try to use something close to 47K and 50K values used in supplying the screen grid with voltage. Values too large will not allow adequate current to flow. Values too low could pull down the B+ supply and/or the heavy current draw could burn the pot and/or resistor. (Details on parts, allowable parts substitutions, sources, power supplies, adjustment, etc can be found in How to Build Your First Vacuum Tube Regenerative Receiver *by T.J. Lindsay - Lindsay Publications 1997)*

A pointer was mounted on one of the capacitor plate rods, and frequencies marked on the aluminum drive dial with a Sharpie™ fine-point marker. The marks can easily be removed with lacquer thinner. The control to the left is the regeneration pot, and to the right is the tuning control.



perhaps better. But you're not obligated to use these early tubes. You can use tubes having grid caps and octal bases like the 6K7 or 6J7, or their single-ended equivalents (no grid cap), 6SK7 and 6SJ7. And you'll find many miniatures that will work like the 6AU6 (extremely common), 6BC5, 6CB6, and on and on.

Digging through the junk box turned up a pi-wound RF choke, and a quick check on the impedance bridge confirmed it was 2.5 mH – just what we need. And digging through a bunch of unmarked hamfest transformers turned up a few with values of 2, 3 and 10 Henries. Unfortunately the largest choke in the junk box measured 31 Henries. What is really needed on the plate of the pentode is more like 310 Henries, but this one would have to do.

The remainder of the components were standard, common, and cheap. The whole thing was soldered together quite quickly, and B+ from the power supply (Experimenter Vol 1 pg 40) was connected in along with filament power. When the cathode of the 6C6 was connected to the coil at a point just a fraction of a turn above ground, and the pot controlling the screen grid voltage was brought up, the tube came to life. Using the grid dip meter as a signal source, I took a marker and put frequency marks on

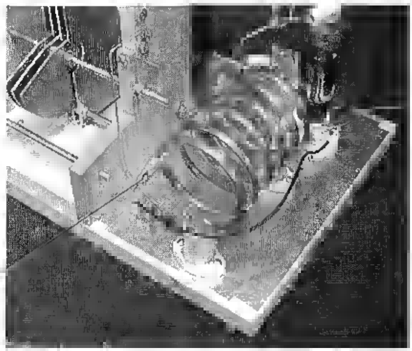
The tank coil was mounted on old porcelain standoffs, but wooden dowels, plastic blocks, or even old medicine vials would work. The tube is seated in a porcelain breadboard socket from the 1930's. They're very difficult to find. If you use an octal tube, such as a 6SK7, you can use a brand-new plastic octal relay socket with screw terminals (Experimenter Vol 1 pg 47). The breadboard is common pine with rubber feet attached on the under side, while the business side is covered with kitchen aluminum foil to act as a ground plane.

the aluminum dial drive disk.

Probably the best way to feed the antenna signal into the tank circuit is with a separate winding. But since I was in a hurry, and this is only a demonstration project, I took about eight inches of hook up wire and tightly twisted about 2 inches together. One end was soldered to the "hot" end of the tank coil, and the other end was connected to a long wire antenna. The loop formed by the twisting was clipped with wire cutters. That left the antenna connected to the receiver through the tiny amount of capacitance of the twisted wires and nothing more. How much capacitance? That might make for an interesting test of the bridge. An educated guess says somewhere between 1 and 3 pfd.

All the foreign broadcast stations just below 10 mHz were heard speaking in every conceivable language. WWV came in on 10 mHz after dark. And just above that with careful tuning could be heard the CW (morse code) amateur stations in the 30 meter band. The receiver was drawing about 10 mA at 144 volts, and was going into regeneration with about 14 volts on the screen grid. The values you measure will be somewhat different depending on the pentode you choose, but they should be fairly close as long as you use a receiving pentode and not some high-power transmitting tube.

Audio output with this single tube receiver was not strong, but the volume was greater than I had expected. But! Hooking up the little solid state

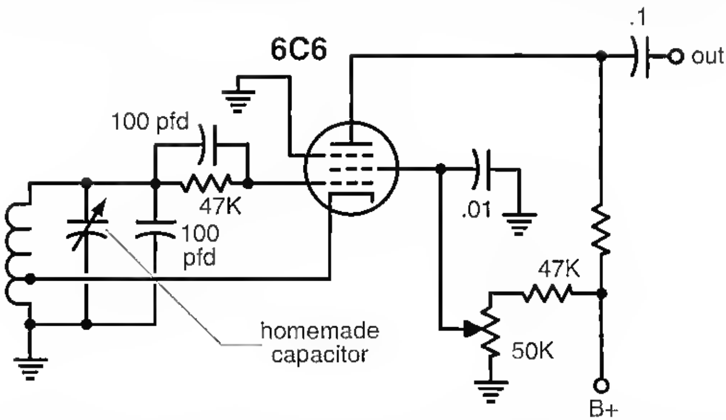


amp gave extra gain, and stations could easily be heard using both high and low impedance 'phones. The homemade capacitor tuned surprisingly smoothly and without the contact noise that I thought might be present. All in all it was a nice little receiver, that could easily have been adjusted and rebuilt to become an impressive show-stopper for your technologically-ignorant in-laws and neighbors! With some imagination you could turn this into "Frankenstein's Radio" with the gigantic capacitor, copper tubing coil, large glass tube with grid cap, and other strange (at least to them) components. (Careful! You might be labeled a Mad Scientist!)

Conversion to a Utility Oscillator

If you strip away from a regenerative receiver the circuitry that extracts the detected audio signal, you end up with an oscillator. After the receiver was tested and photographed for this booklet, the chokes and other parts were removed. The circuit you see here is a basic Hartley oscillator. When the screen voltage is brought up, this unit starts providing a signal at the frequency determined by the tank circuit.The tank circuit here, of course, is resonates around 10 mHz, but it could be changed to lower values with a coil having a greater number of turns, and a capacitor with more plates.

An oscillator like this has all kinds of uses. You can use it as a local oscillator or BFO in that superheterodyne you're going to build. Or if you used the proper tank circuit, you can use this as the signal generator you'll need to align that superhet. This can be the BFO in a vacuum tube direct conversion receiver (which first appeared in the 20's). Or you could use this as the VFO for a low-power transmitter, but only if the tank components are solidly mounted to prevent drift and microphonic modulation of the signal. In other words, this simple circuit can be very useful to you, the experimenter.



Other Capacitors You Can Build

from Voice of the Crystal *(left) a block of three homemade fixed capacitors ready for wiring into an experimental circuit (below) the "guts" of the capacitor, that is, what is actually concealed inside each tube*

Now that you have an impedance bridge, you can experiment with making your own paper capacitors for use as bypass capacitors. You might want to stack metal foil between glass plates to create small RF capacitors for use at high voltages. All you need are two metal plates separated by an insulator. As you build you can take notes on dimensions used, and then use the bridge to see how much capacitance you managed to create. With a little tinkering you should be able to create a wide variety of useful devices.

You can get a good estimate of the capacitance you can obtain from a homemade capacitor by using this formula.

$$C_{(pfd)} = \frac{.225 \times K \times A \times (n-1)}{d}$$

Where–

C is capacitance in picofarads
- .001 mfd = 1000 pfd
- .01 mfd = 10,000 pfd

K is the dielectric constant
- (the quality of insulation between plates) – see the table below

A is the surface area of one plate in square inches

n is the total number of plates in the capacitor

d is the distance between plates in inches

Dielectric Constants

Insulator	K
Air	1
Glass	10
Mica	6-9
brown paper	2.6
styrene plastic	2.6
wax	5-6

Pete Friedrichs in his 1999 gem of a book, Voice of the Crystal, will show you how he built both fixed and variable capacitors. You'll also find plans, hints and tips on building crystal detectors, variable inductors, and headphones. After he built the components, Pete, an engineer, used a professional bridge to determine their values. You have that valuable piece of equipment now, so there should be very little to hold you back!

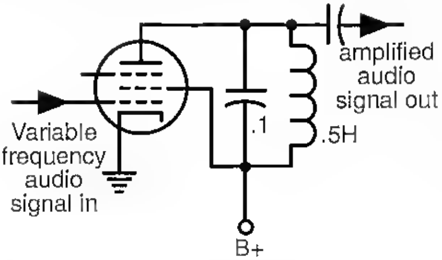
(photographs provided by the author)

Experimenting with Tuned Audio Filters

You can use your impedance bridge to easily measure unknown electronic components with a reasonable degree of accuracy. Many new fields of exploration open up to you. One worth looking into is audio filtration.

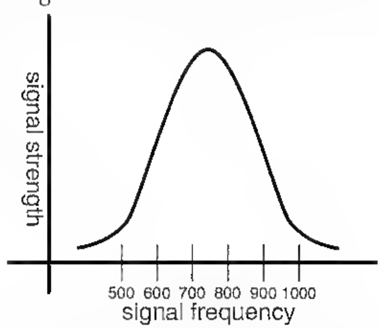
Regenerative receivers are wonderfully simple radios, but they lack selectivity. Signals from all over the band come flooding in, and if you're an amateur radio operator trying to copy code, you'll be overwhelmed by the number of signals in your earphones. You can greatly improve selectivity and eliminate the vast majority of signals that are of no interest by passing the audio through a passive filter tuned to one particular frequency. Only the code signal tuned to a certain pitch will be allowed through the filter into the audio amplifier.

The earliest filters were merely LC circuits used as loads on the plates of tubes, especially pentodes. The tuned circuit would let DC through from the power supply into the plate with little loss. But the AC would see an almost open circuit at one particular frequency. Audio signals at any other pitch would not see much of an obstacle and the signal would flow into the B+ supply and be lost. An audio tone coming out of the detector of the correct pitch would "see" such an enormous barrier, that the signal could not flow to the supply but instead was forced to go into the grid of the following audio stage. (This explanation is not quite right, technically speaking, but it is close.)



This little prototype amplifier was built to demonstrate the possibilities. It uses a 6SK7 pentode followed by a 6C5 triode. Both are 6.3 volt filament metal tubes. Others can be used. You could use 2.5 volt filament tubes like a 58 and 56, or miniatures like a 6AU6 and a 6C4, or many others.

At about 150 volts, the 6SK7 has a plate resistance of about 120,000 ohms, while the 6C5 has a plate resistance of only 10,000 ohms. The reason is that the screen grid literally shields or screens the grid from the plate, and that causes the plate resistance to dramatically increase. Both tubes have about the same transconductance, that is, sensitivity to the signal voltage on control grid. Both generate about the same amount of change in plate current for a given amount of change in signal voltage. But because maximum obtainable voltage from a tube can be calculated by multiplying the transconductance by the plate resistance, it should be obvious in this case, that because the 6SK7 has twelve times more plate re-



sistance, it could potentially deliver twelve times more voltage gain, or about 240.

But there's a catch. Always a catch. The only way you can get maximum power gain from any tube is by providing a plate load equivalent to the plate resistance. (Power gain is not exactly the same as voltage gain.) This is a form of impedance matching. If you want to get maximum power and signal quality out of your stereo amplifier, you must put four ohm speakers on the amplifier's four ohm output. Did you ever try to pull away from a stoplight in third gear? You won't get very far until you match the engine impedance to the rear wheel impedance with a mechanical transformer called a transmission by shifting into low gear. The same principle applies to the vacuum tube.

For triodes you can easily put a 10,000 ohm resistor on the plate and connect it up to 250 volts to get a reasonable plate current flowing. But some tubes like the 6AU6 can have a million ohms of plate resistance. You can put a million ohm resistor on the plate in order to load it optimally, but you'll have to use several thousand volts of B+ to get just a few milliamps of plate current to flow. Not too practical. In other words, it's very difficult to get maximum voltage gain from a pentode because it's difficult to devise a very high high impedance for the AC signal which at the same time is a low impedance for DC. About the only circuit that comes close is a tank circuit because at resonance a parallel tuned circuit is almost an open circuit – a very high impedance. This is why you see IF transformers hung on the plates of pentodes. When you see a pentode detector in a regenerative receiver, you'll see a gigantic choke coupling the detector to the audio stage, so that load impedance at audio frequency will be very high, loading the plate and thereby producing more gain from the detector. (Much smaller inductances can be used, with the loss in gain made up by an additional audio stage if necessary.)

Your little filter is a simple resonant circuit made up of a small choke or one of the windings of a small audio transformer. Dig through your junk box, and find aone. Next, measure the inductance of the windings, and that's where your impedance bridge comes to the rescue. Here, for instance, I measured about .46 H across one of the windings.

Next, you must calculate how much capacitance to put across it in order to get it to resonate at somewhere between 600 and a 1000 cycles. From Experimenter Vol 2, page 23, formula 2, we have...

$$C = \frac{25{,}330}{f^2 L}$$

for L in μH, C in pfd, f in mHtz

This formula is set up for small values of L and C for use in radio frequency circuits. It also works for other combinations of components...

$$C = \frac{25{,}330}{f^2 L}$$

for L in H, C in mfd, f in Htz

Let's assume that 800 Htz is the audio frequency that we want to amplify to the greatest degree, and .5 Henries which is approximately what our audio choke measures, we get...

$$C = \frac{25{,}330}{f^2 L} = \frac{25{,}330}{(800)^2 \times .5} = .08 \text{ mfd}$$

Since .08 mfd is a nonstandard

value, we can round up to .1, and use formula one from page 23 of Volume 2...

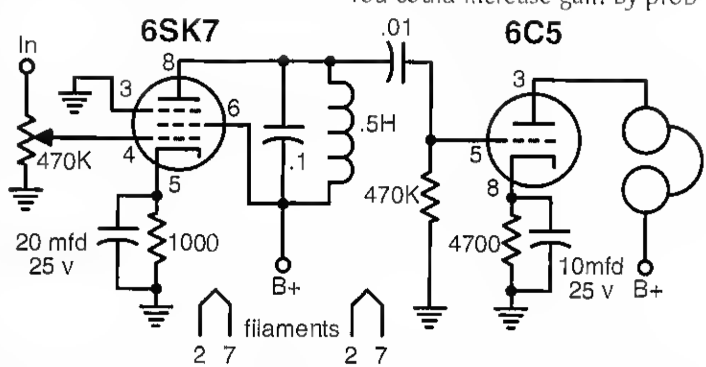
$$f = \frac{159}{\sqrt{LC}} = \frac{159}{\sqrt{.5 \times .1}} = 711 \text{ Htz}$$

The calculated value of 711 Htz is in the ball park. So the values we have chosen will do the job.

Next, you dig through the junk box looking for a .1 mfd capacitor. Locate more than one if you can. And measure each one with your bridge. You may find most have increased in value over the years, but perhaps you'll find one that's a little bit low, say .08. The exact value really isn't that critical as long as it is close, and your bridge will tell you just how close you are.

Building a Tuned Amplifier

All that's left is to build the circuit, put power to it and test it. You can feed audio from your bridge oscillator into the amplifier to see if it really does amplify more at about 750 cycles than it does at other frequencies. Hooked into the audio chain of a simple receiver, this amplifier will help eliminate unwanted code signals. You tune your receiver until the signal you want is louder than all the rest.

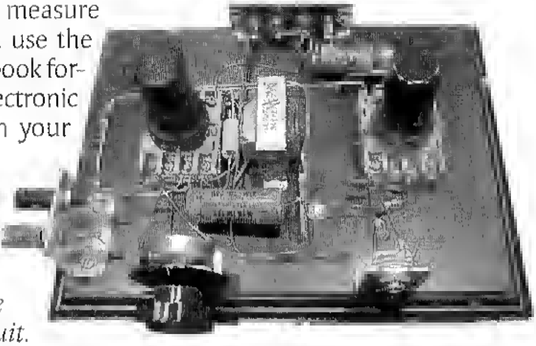


The simple, test amplifier here was not as selective as it could be when supplied with 150 volts of B+ from our homebrew power supply (page 40 Vol 1). I found plenty of power gain, about 6000, but voltage gain was not much more than 5. That means the amplifier did not increase the volume as much as we would like, but the volume available easily drove 2000 ohm headphones. If you wanted to hang this on a regenerative receiver, you need to get more gain out of it, or add another audio stage.

You could increase gain by probably increasing plate voltage to +250, and perhaps by modifying cathode bias values somewhat. This circuit is worth experimenting with. Check early QST's and other amateur radio magazines, and you'll find examples of regenerative receivers with peaked amplifiers.

But I must say, the one audio filter that has given the best performance is the two-pole filter built from 88mH telephone toroids, and commonly used in direct conversion receivers designed and built in the 1970's by DeMaw, Hargrove and others. Check old QST's and ARRL publications.

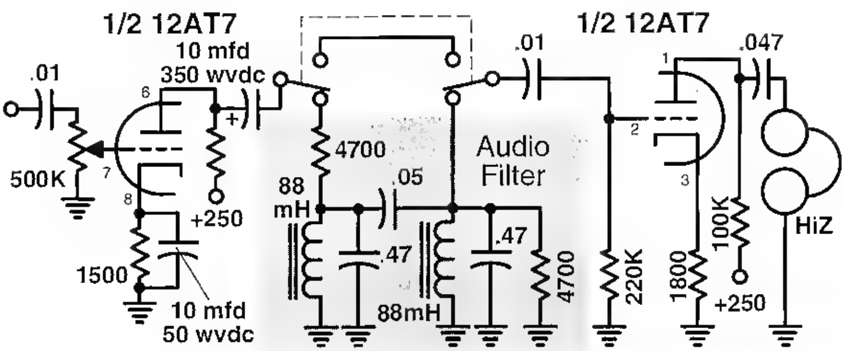
With a bridge, you can measure components accurately and use the values you measure in cookbook formulas or in computerized electronic design programs to design your own audio filters.



Two modern plastic octal relay sockets hold a pentode (left) and the triode. Between the tubes is the audio choke that forms the resonant circuit. Power terminals are to the rear, with audio input at the left, and a 1/4" phone jack output to headphones is to the right front. Left front is the volume control.

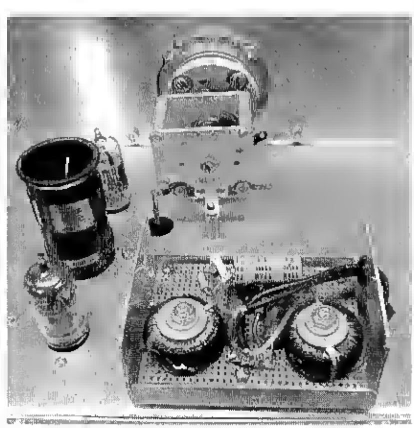
The amplifier is mounted on a small piece of 3/4" pine board run quickly through a router to add a decorative edge followed by several coats of satin black.

High Performance Audio Filter

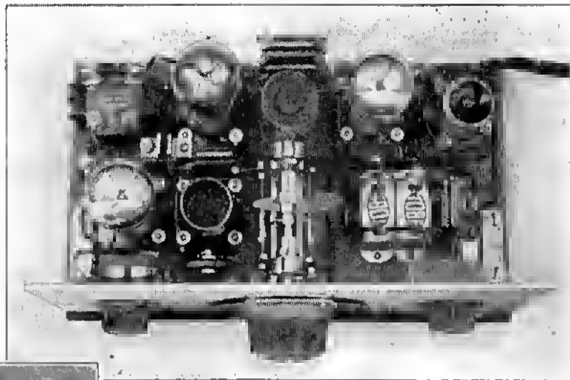


(above) This two stage audio amplifier follows a 6AU6 regenerative detector and delivers remarkably good performance: high gain and sharp selectivity. The 4700 ohm resistors in the filter are needed to get the proper bandpass shape. This passive circuit was lifted from Solid State Design for the Radio Amateur *by Hayward & DeMaw ARRL 1986*

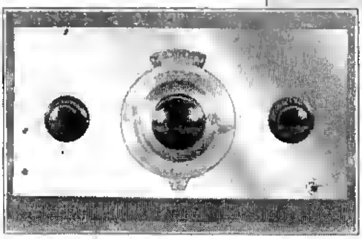
(right) filter with cover removed as part of two tube receiver. These 88mH chokes were used to neutralize capacitance in telephone cables, and are still available on the surplus market.



A Typical 1920's Regenerative Receiver with Peaked Amplifier



This receiver from the November 1928 issue of QST, also reprinted in the 1929 ARRL Handbook shows readers the "new" 1929 receiver hookups.



Here we find 201A triodes used with the brand new 222 tetrodes. The resonant circuit used to peak the amplifier is located between the third and fourth tubes.

(This receiver can be found in THOSE GREAT OLD HANDBOOK RECEIVERS *reprinted by Lindsay Publications Inc)*

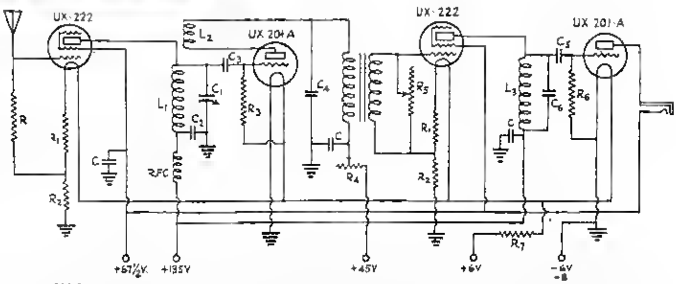


FIG. 2. THE WIRING OF THE FOUR-TUBE RECEIVER

The under surface of the wooden base-board is covered with thin sheet copper to which all the "ground" leads are run. This construction is preferable to placing the copper on the upper surface where it introduces difficulties in the insulation of components from it.

C —1-µfd. by-pass condensers.
C1—Plug-in midget tuning condensers.
C2—4000-µµfd. fixed condenser. (see comment below).
C3—100-µµfd. grid condenser.
C4—2,000-µµfd. by-pass condenser.
C5—6000-µµfd. audio grid condenser.
C6—.01-µfd. audio tuning condenser (experiment necessary)
R —10,000-ohm gridleak-type resistor.
R1—10-ohm Yaxley fixed filament resistor.
R2—5-ohm Yaxley fixed filament resistor.
R3—6 megohm gridleak.
R4—50,000-ohm Frost variable resistor.
R5—200,000-ohm Frost variable resistor for volume control.
R6—8-megohm gridleak.
R7—Filament ballast resistor for .75 amperes.
L1, L2—Tuning inductance and tickler wound on plug-in coil form.
L3—The secondary winding of a Ford ignition coil—core and primary removed.
R.F.C.—Receiver-type short-wave choke.

Some difficulty may be had in adjusting the tickler turns due to "dead-spots". It is suggested that the capacity of C2 be varied if any such trouble is experienced. The use of a filament rheostat is made unnecessary by the incorporation of a ballast resistor. It is, of course, possible to use a fixed resistor or a rheostat in its place. Though a number of "grounds" are indicated on the diagram it should not be thought that these are "grounds" of the water-pipe variety. They merely indicate connections to the panel or copper sub-base. Ordinarily, no external ground is used.

A Better Power Supply

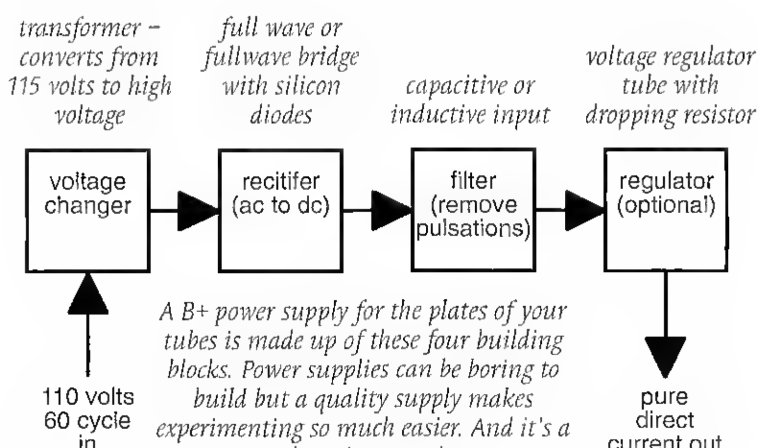
It's time to start scrounging for parts to build a better power supply. The small supply we built in Volume One, was intended for simple one and two tube experimental circuits that needed very little current. It will power a simple two tube receiver quite nicely. But we need to be thinking about building a more complicated receiver and perhaps a simple low power transmitter for the amateur bands, or perhaps a simple transmitter to broadcast your awful singing voice through your AM radio. We will need 250 volts at 100 mA (25 watts) and maybe more and 6.3 volts at 2 amps or more.

The "best" way, I think, is to buy an old piece of multi-tube electronic junk at a flea market or hamfest, and remove the power supply components. What you have for just a few dollars are the most difficult parts to obtain, and therefore most expensive these days.

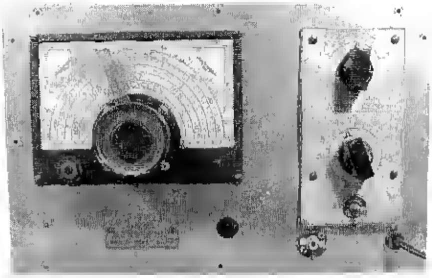
You will need a power transformer, a two or three henry choke or better yet a pair of chokes if come across them, a pair of 450 volt tubular electrolytic capacitors and a bunch of big, old power resistors that can generate a lot of heat without burning out. And you should pick up a copy of an old ARRL RADIO AMATEUR'S HANDBOOK from the 40's, 50's or 60's.

If you really intend to experiment with tubes seriously, you should consider building my favorite type of supply. It's actually two supplies in one. Inside one box is a large 6.3 volt transformer that delivers several amps to power filaments, and there is a B+ supply with a variable transformer on the transformer primary so that it can provide any DC voltage from 0 to 300 or more volts to the tube plates. And because the supply is variable you need meters on the output side.

Regardless, of what avenue you pursue, the place to start is with the chapter on power supplies in a RADIO AMATEUR'S HANDBOOK. There you will get a detailed discussion on types of rectification, filtration, and regulation. The more you learn and understand about power supplies the more successful you will be in adapting some piece of junk you found in the alley to your experimenting needs.



A B+ power supply for the plates of your tubes is made up of these four building blocks. Power supplies can be boring to build but a quality supply makes experimenting so much easier. And it's a great learning experience.



I bought this filthy signal generator a couple of years ago at a hamfest for $5 because I wanted the old National dial drive. But not only did I get a great dial drive that cleaned up nicely, I got a nice little power supply, a great 25 pfd variable capacitor, and lots of hard-to-find hardware like universal joints and panel bearings.

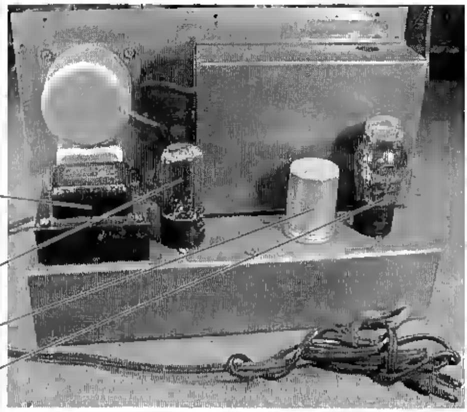
After you become familiar with power supplies (read the old Handbooks), you'll know in an instant what you're looking at when you remove the case.

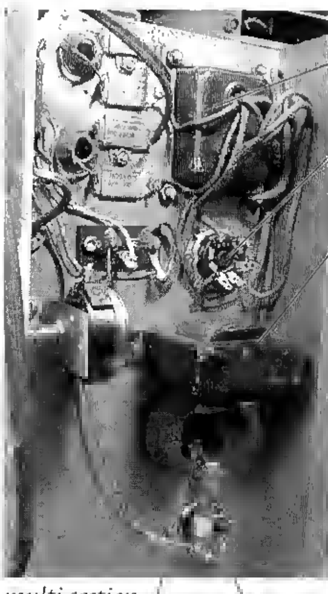
power transformer

rectifier tube

multi-section capacitor

regulator tube





power transformer

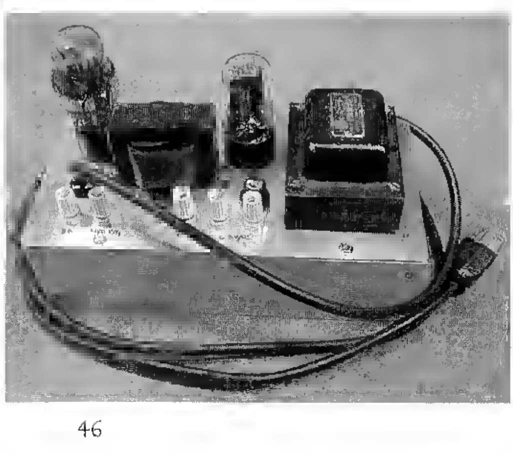
rectifier tube

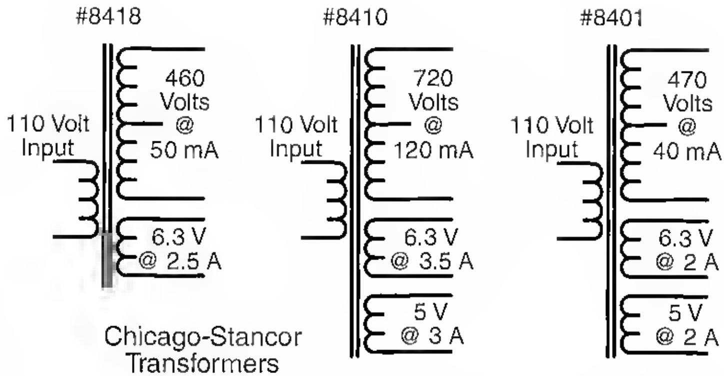
choke

multi-section capacitor

regulator tube

Trace the circuit, and remove the components. You then mount them on a new chassis, using a new 3-wire power cord and new tubular electrolytic capacitors. Be sure to fuse the primary for 1 amp or so, and add the types of binding posts or terminals you're like the best. This supply can easily power a three or four tube radio.





These are typical power transformers from the 1960's when vacuum tubes where on their way out the door. A 460 volt secondary, for instance, can deliver 460 volts to the filter section if you use a full-wave bridge like that in the small supply described in Volume One. If you use a full-wave rectifier for which this transformer was intended, you'll get 230 volts out. If you use a vacuum tube rectifier, the output voltage will be less than if you use modern silicon diodes which are so much better.

Power supplies can be confusing because we talk about AC rms voltage, and not peak voltage. For instance, Americans can pull 115 volts from a wall outlet. But it's not really 115 volts at all. It's really 325 volts peak-to-peak! If you put 230 volts (rms) into a capacitive input filter (see a Handbook), you'll find that you actually get more than 230 volts out because the input capacitor wants to charge up to the peak voltage which can be 325 volts at 120 cycles! (Getting exactly the voltage you need and want from a homebrew power supply can be hard to predict.)

A Wide Voltage Range Supply

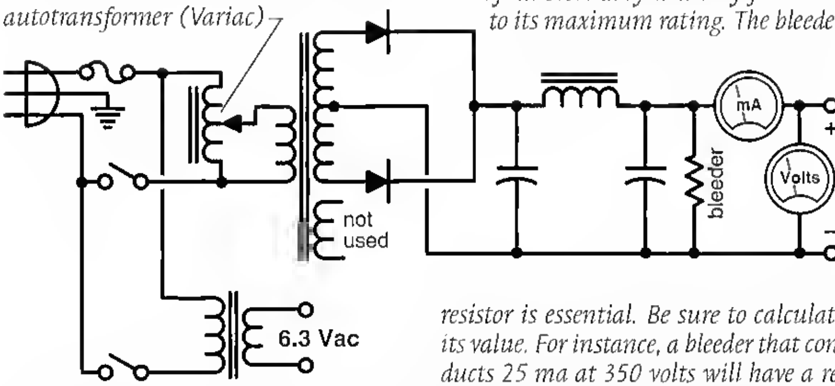
An inexpensive 3 amp autotransformer (Variac) on the primary of an old television transformer will give you a very versatile power supply. Only the center-tapped high-voltage winding is used. A pair of 1000 PIV 1 amp silicon diodes efficiently rectify the AC and then feed the pulsating DC to the capacitive input filter. I usually use 50 or 100 mfd 450 volt electrolytic capacitors, and a heavy choke with 2 to 10 henries. A physically large choke with low inductance is wound to handle heavy current. And a safety bleeder is never omitted. A milliammeter in series with the output lead will show plate current being drawn, while a voltmeter across the output terminals

A variac supply that powers an experimental eleven tube superhet receiver (to the left).

will show the voltage being delivered.

A separately switched 6.3 volt transformer NOT controlled by the Variac provides ample filament power.

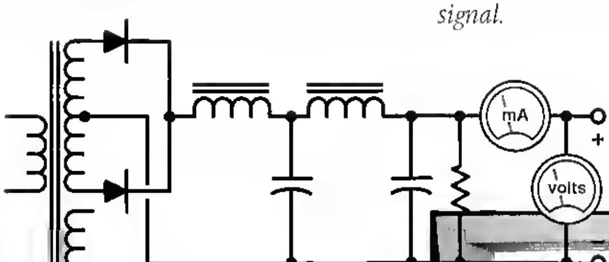
A Variac autotransformer can be put in series with the primary of a B+ transformer so that the input voltage can varied from zero to 115 volts. The voltage out of the secondary will vary from zero to its maximum rating. The bleeder resistor is essential. Be sure to calculate its value. For instance, a bleeder that conducts 25 ma at 350 volts will have a resistance of 350/25 or 14 kohms. But it will have to be at least 9 watts (350 x .025=8.75) and preferably much larger.



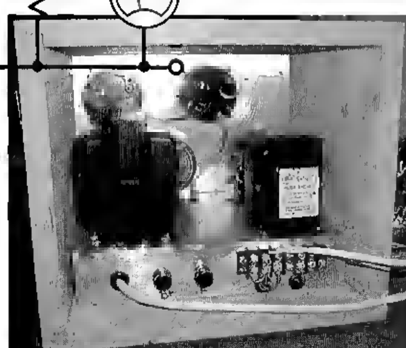
Be sure your filament transformer is NOT in series with the variac. You do NOT want the 6.3 filament voltage to change as you adjust the variac.

Separate switches allow you to heat up the tube filaments before applying B+ to the plates. Or when experimenting, you can shut off the B+ and safely make circuit changes while letting the tubes stay warm by leaving the filament supply on.

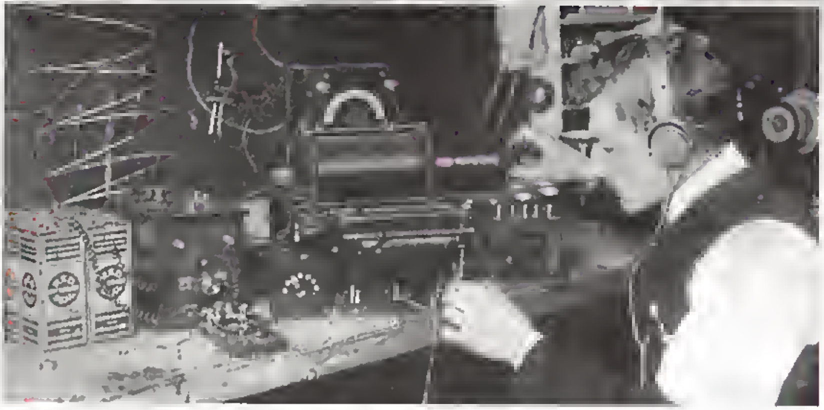
A capacitive input filter (above) does not provide very good voltage regulation. In other words, as you draw more current from the power supply the output voltage drops noticeably. For a receiver this is usually not a big problem. For a code transmitter (CW) it can create a poor signal.



(above) A choke-input filter provides quite good voltage regulation by preventing the voltage from rising by smoothing out the effect of the first capacitor in the filter. I use this on QRP transmitters. (right) Back side of the variac power supply built from huge old hamfest transformers and chokes.



YOU can build old-time radios!



Vacuum tubes are to the electronics industry what steam locomotives are to the railroading industry: hot, inefficient maintenance headaches. But like a steam locomotive, a tube has a simple fascinating charm that no high-tech chip can match.

You must try building a simple radio with tubes! It's easy, and it's cheap. (And don't tell me that doesn't appeal to you...) Do you remember the excitement when you built your first crystal set? This is even better.

Here you get tips, tricks, hints and details on building components and test equipment that will help you to put your radio on the shortwave frequencies you desire and carefully tune in the station you want.

Here you'll discover a simple technology that few people seem to know ever existed! But *you'll* know...

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