The Impoverished Radio EXPERIMENTER

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

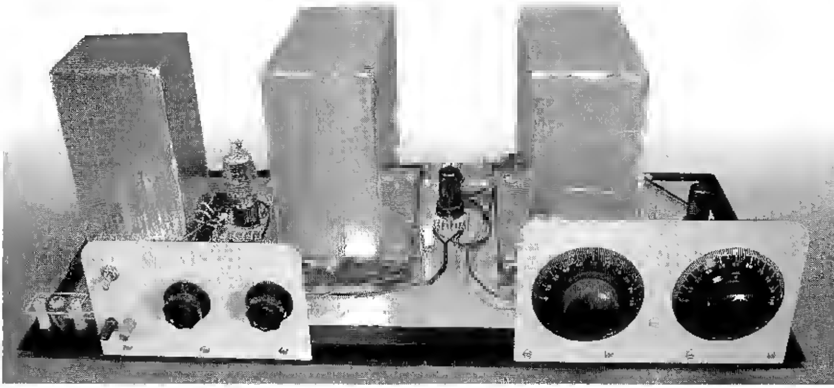
5

Build a Superhet Receiver!
Coil Winding Machine!
Simple Alignment Oscillator!
IF Transformers! More!

©2003 Lindsay Publications Inc

EXPERIMENTER

Building a simple, good quality three-tube superhet, & more!



It's time to build a superheterodyne receiver. But before you run off screaming into the sunset looking for a bed under which to hide, you must understand that a superhet does not need to be complex, expensive, or mysterious. In fact, the construction of the simple superhet shown here was no more difficult than the TRF regenerative receiver demonstrated in EXPERIMENTER 4.

This three tube machine may look difficult to build, but that lowly crystal set you built not long ago looked overwhelming in the beginning. Once you get this simple receiver working, you'll be saying to yourself "That wasn't any more complicated than anything else I've ever built. Why did I wait so long to build a superhet?"

The superhet we'll build here is anything but sophisticated. It certainly does not come close to the quality of receiver that can be built at home. And yet, this simple little receiver will outperform almost any regenerative receiver. There is no regeneration control needing constant adjustment. And the 5 khz selectivity of this superhet will seem razor-sharp compared to that of a regenerative.

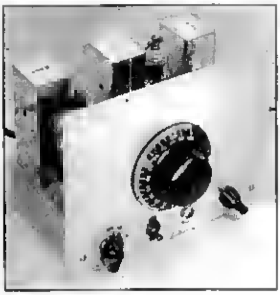
Unlike a regen, once you have this superhet receiver pulling in signals, you'll be able to modify and improve circuits, add new enhancements, and keep upgrading the receiver in the ways you want. There is not much you can do to significantly improve the regenerative. All the essential receiving functions are wrapped up in the one detector tube. Only when you sepa-

The Impoverished Radio Experimenter Volume 5
©2003 by Lindsay Publications Inc, Bradley IL 60901 • all rights reserved
many other unusual books are available – **www.lindsaybks.com**
ISBN 1-55918-293-8 2 3 4 5 6 7 8 9 0

rate the various functions into separate stages, can you improve the receiver. In other words, superhets not only outperform regeneratives, they also open up a whole new area of exploration and experimentation. And it's something in which you can certainly participate.

The Three-Tube Superhet

The original inspiration for the receiver shown in these pages was a receiver offered to readers of QST in the August 1938. Described was a battery-powered three-tube superhet receiver designed for portable and emergency work on lower frequency bands.



A 6K8 hexode-triode vacuum tube provided frequency conversion. The triode oscillated creating the local oscillator signal which mixed with the incoming signal off the antenna to create a new, amplified signal at 460 khz.

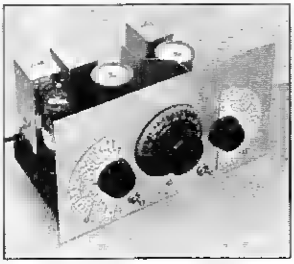
The newly manufactured signal which still carried the program information of interest, was fed to the input tank circuit of an intermediate frequency (IF) transformer. While the input tank circuit rang like a bell at 460 khz, the output tank circuit listened and also rang. Since both the input tank circuit and output tank circuits were carefully tuned to exactly the same frequency, the only signal going into the transformer that has any chance of coming out the other end was a signal in the vicinity of 460 khz. Signals significantly lower or higher than the 460 khz center frequency just didn't get through. In other words the IF transformer was a 460 kHz filter.

From the output side of the first IF transformer the signal entered the grid of a 6K7 variable-mu pentode, also known as a super-control or remote-cutoff. The job of this tube was to dramatically amplify the 460 khz and feed it to the next IF transformer for even more filtration. By the time the signal exited the output of the second IF transformer, only signals in the range of 457 to 463 khz were left standing. Every other frequency had been eliminated.

Next, the highly refined signal was fed into one of the grids of a dual-triode 6C8 where it was detected, that is, the information was stripped off the 460 kHz carrier frequency. No grid-leak pair was used in the grid lead to bias the tube. That wouldn't work well. Instead, a cathode resistor developed a constant bias using the current supplied by the power supply. This was known as "plate detection". In addition, the triode also provided amplification of the audio signal that was stripped from the 460 khz carrier. High impedance earphones inserted into the B+ lead to the triode plate converted the output current into sound.

If the signal being received was CW (Morse code), no tone would be heard until another signal from the beat frequency oscillator (BFO) was mixed in. The other triode of the 6C8 pair was configured as a Hartley oscillator that created a signal just above or just below the carrier frequency. For instance, you could set the BFO to produce a 460.7 khz signal. Some of that leaked into the detector side of the tube to mix with 460 khz to create a tone that was equal to the difference of the two signals. In this case, 460.7 minus 460 leaves .7 khz or 700 cycles. Every time the transmitter was keyed, a carrier was transmitted, and a 700 cycle tone appeared in your earphones.

These days, a BFO is essential if you want to receive single sideband signals (SSB), which amateurs weren't using in 1938. AM signals provide a powerful carrier against which the sidebands are compared (if you want to think of it that way.) SSB signals have no carrier supplied, so the receiver must supply its own, and that's the job of the BFO. Technically speaking, the plate detector is not the best type of detector for SSB, but you can install a product detector in one of your future superhets if SSB is your first love.



An improved version of the August '38 circuit appeared in the 1942 Radio Amateur's Handbook and was still in there at least as late as 1946. The IF transformers were replaced by 1600 khz models to improve high frequency performance by eliminating unwanted signals (improved image rejection) and the 6K7 was replaced by the new 6SK7.

The control grid in the 6K7 was attached to the cap on the top of the tube. Minor changes in construction later allowed the grid lead to be brought out to the base. Instead of having leads coming out of both end of the tube, all leads came out of the same end, resulting it being called a "single-ended tube." To denote this the letter "S" was added, giving 6SK7. These tubes are very similar, but the 6SK7 provides about 50% more transconductance (the grid has improved "hearing") making it more sensitive. The Handbook receiver also provided a circuit for a 6F6 power amplifier should you want to drive a loudspeaker (assuming you have an adequate power supply.)

Parts for the superhet we're building are no more difficult to find than those for a regenerative receiver. In fact, about the only parts no longer being manufactured are the tubes and the variable capacitors. You can buy inexpensive trimmer capacitors, plastic octal tube sockets, resistors, bypass capacitors and so on. Most parts can be found in junked "boat anchors" that no one wants any longer. You don't even need IF transformers. You can wind your own.

This receiver has four stages, so if you approach building the machine with the attitude that you're building four one-tube radios that are then hooked together, you may find the project less formidable. If you find yourself saying, "That's too complicated. I could never build that," then you've already consigned yourself to failure. And I don't want to hear that. The world already has too many people with self-defeating attitudes. This is a project that you CAN build. And you'll find when you start using it, that it certainly was worth building. So get started now.

Our Superhet

In building this simple demonstration superhet, I assumed we would use octal tubes plugged into relay sockets mounted on a pine breadboard just like so many of our other receivers. And I assumed that you don't have IF transformers in your junk box. If you have a pair on the same frequency, use them. But you'll still need to fabricate a BFO coil and a coil for the alignment oscillator, so perhaps you should consider winding all the coils for your first receiver.

I started out using the 6K8 as the frequency converter. But I just couldn't get it to oscillate reliably. None of the 6K8's in my tube collection would oscillate reliably regardless of the changes made to component values and coil windings. I suspect that the problem lies in long lead lengths necessary on a breadboard. So I gave up on the 6K8 and used the more modern 6SA7 pentagrid converter which has never failed me. In addition, I used a 6SK7 for an IF amplifier tube, and same 6C8 tube described in both articles. These three tubes are available inexpensively new, in the box. And they're readily available used at giveaway prices.

The first step in designing the receiver was to choose the desired frequency band: 80 meter amateur band - 3.5 mhz to 4 mhz. Next, you must choose your IF frequency. Since we're building our own IF transformers, we want a low frequency so that we have good selectivity, but not so low that images become a problem. I chose 400 khz.

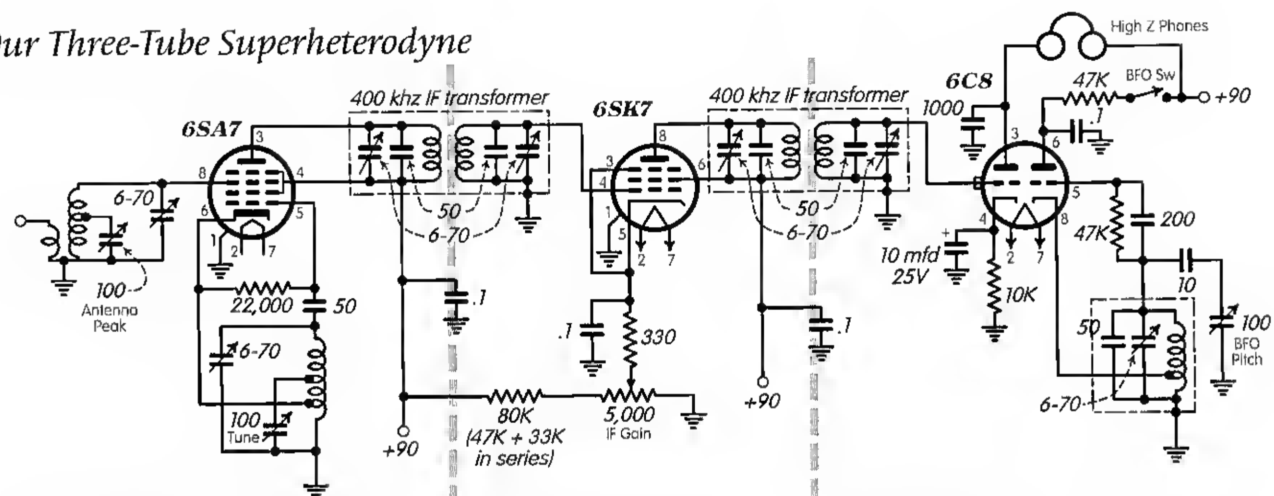
That means we'll a resonant tank circuit that tunes from 3.5 to 4 for the antenna lead feeding the 6SA7. The oscillator has to tune a range higher than the incoming signal by 400 khz (.4 mhz) so that when the desired signal is mixed with the local oscillator signal, the different of 400 khz will get through the IF transformers. That means that the resonant circuit in the local oscillator area of the 6SA7 must tune from 3.5 +.4 or 3.9 mc to 4.0 + .4 or 4.4 mc. And that's about all the design decisions we'll have to make. And believe it or not winding the two coils for 3.5-4 and 3.9-4.4 is the most difficult part of building the whole receiver.

The IF transformers are created by winding 360 turns of #30 enameled wire onto cardboard tubes extracted from rolls of kitchen plastic wrap. Six coils are created. Four are used in the two IF transformers. The other two coils are provided with a tap near the ground end so that they can be used in the BFO oscillator and in the transistor alignment oscillator needed. Winding these coils can be difficult unless you first build a very simple coil winder. Using it, high-quality coils can be wound very rapidly without failure.

Once the coils are glued to a small square of thin plywood they get mounted on a larger baseboard and surrounded by shielding – "the can". To get the job done as quickly and inexpensively as possible, the cans are fabricated from corrugated cardboard, Elmer's glue, spray adhesive, and kitchen aluminum foil. And I'm hear to tell you that despite how primitive they may be, these IF transformers really do perform very well.

The first step is to build the simple transistor alignment oscillator so that you can use it to test each stage as you build. Actual construction starts by building circuits around each of the three tubes, and connecting them together with the IF transformers. I started with the 6C8 BFO-detector stage and worked forward toward the pentagrid frequency converter. You can test each tube as you go along to be sure it works before going onto the next stage. By the time you get to adjusting the front end tank circuits, you'll know that the rest of the radio is working well.

Our Three-Tube Superheterodyne



Frequency Converter Stage

A tuned circuit picks a particular frequency off the antenna wire and feeds it to the mixer grid. Another tuned circuit generates a signal 400 khz above the desired frequency. The two mix and create two new frequencies, one of which is 400 khz which is fed to the IF transformer.

IF Amplifier Stage

The weak 400 khz signal coming through the IF transformer is dramatically amplified by this pentode. A pot in the cathode lead allows reduction of gain to prevent overloading.

Detector Stage

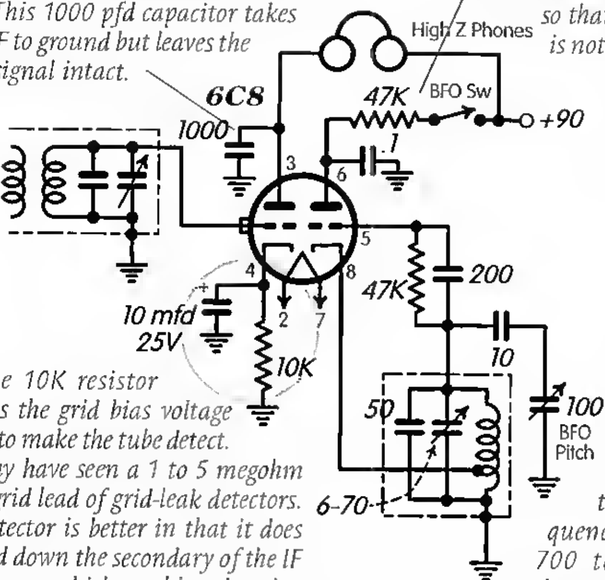
One of the two triodes inside this tube "detects" the 400 khz signal into an audio signal and amplifies it for headphones. The other triode serves as an oscillator to create a tone for Morse code (CW) or single-sideband (SSB) reception.

Detector Stage

The left side of this double tube is the real radio. Everything else in the receiver is there to make it perform better.

Some of the 400 khz signal will come through the tube and appear on the plate. This 1000 pfd capacitor takes most RF to ground but leaves the audio signal intact.

The 47K resistor dramatically reduces the 90 volts down to less than 40 so that the BFO signal is not so strong that it overwhelms the RF we want to detect.



The 10K resistor develops the grid bias voltage needed to make the tube detect. You may have seen a 1 to 5 megohm in the grid lead of grid-leak detectors. This detector is better in that it does not load down the secondary of the IF transformer which would undermine selectivity. A cathode resistor is the hallmark of a plate detector.

This tube does double service. It detects the RF and then amplifies the resulting audio frequency. Since the 10K resistor undermines audio gain, the damage can be undone and the gain restored by putting a large capacitor around the resistor which acts as a dead short at audio frequencies.

The 10 pfd capacitors in series with the 100 pfd variable adjusts the BFO frequency so that it is 700 to 1500 cycles above or below 400 khz. When the BFO signal mixes with RF in the detector side of the tube, an audio tone is created. No direct connection is necessary between the BFO and detector. Signal will "leak" from one side of the tube to other.

You almost always find grid-leak biasing in the oscillators used in classic tube superheterodynes – for a very important reason. The resistor with capacitor in parallel with it together with the grid and cathode of the tube convert some of the incoming RF into a DC voltage that makes the grid a few volts negative with respect to the cathode. The stronger the incoming signal, the more negative the bias, and the less capable the tube is of amplifying. When there is no signal coming in, the grid is relatively positive and the tube amplifies as hard as it can.

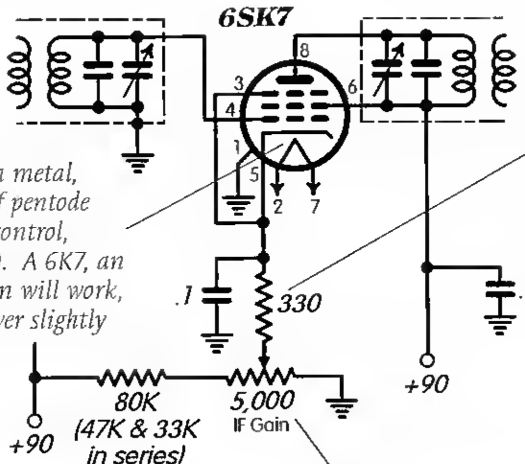
When you first turn on the power to the oscillator, it is not oscillating. No signal. No bias. Heavy conduction. That's like hitting a bell with a hammer. The oscillation starts, and now the grid leak has a signal that it can use to create negative bias and scale back the tube conduction to a reasonable level. In other words, using grid-leak bias in an oscillator is an almost foolproof way of assuring instant start-up when power is first applied.

IF Amplifier Stage

The IF amplifier dramatically increases the power level of the 400 khz signal passing through so that the detector can properly detect it and develop an easily heard audio signal in the earphones.

You might get by with 470 here. Or put a 220 in series with a 100 to get 320. Or solder a 1000 in parallel with a 470 to get 320. That should be close enough.

The 6SK7 is a metal, remote-cutoff pentode (aka: super-control, variable-mu). A 6K7, an earlier version will work, but will deliver slightly less gain.



Changes the bias on the tube grid which changes the gain of the tube. Translation: this is a volume control.

To operate properly, a tube usually must be "biased." From 1 to 10 volts of direct current must be applied to the grid so that alternating current (400 khz here) is amplified without distortion. Current flows from plate to cathode, through the cathode resistor to ground which makes the cathode a bit more positive by a few volts than the ground. Or said another way, the ground is a bit more negative than the cathode. If you tie the grid to ground, you can say, by extension, that the grid is also a bit more negative than the cathode. If you want to check the bias on the grid of a tube, merely measure the voltage developed across the cathode resistor from cathode to ground. That will be the grid bias voltage as well.

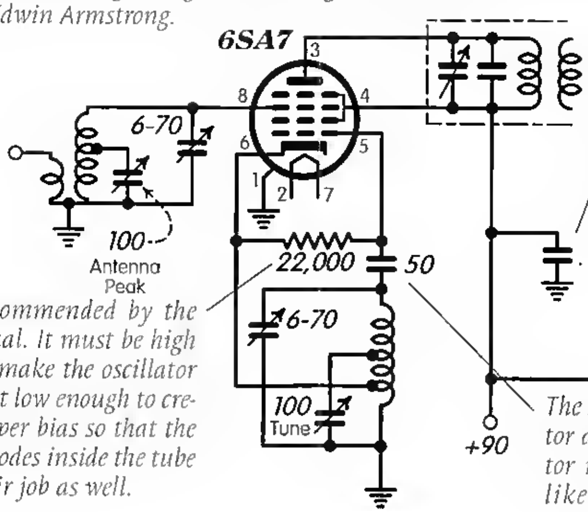
The biasing concept is a bit confusing until you straighten out in your mind the fact that a tube is doing two separate things at once: moving direct current around through some components, and moving alternating current around through often entirely different components.

In this circuit an 80K ohm resistor (47k in series with a 33K) in series with a 5000 ohm pot modifies the bias voltage over a wide range to control the gain of this variable-gain pentode. The 5K pot and 80K resistor add up to 85K. Don't use much less than 85K total. A 10K pot will work here, but a 1K pot won't give much control over volume.

The .1 mfd capacitors shown are necessary to siphon off any RF to ground, thereby keeping the DC in those portions of the circuit clean and pure. You might get by with .01, and probably .05, but .1 mfd is preferred.

Frequency Converter Stage

So far we have a nice little receiver for 400 khz. Who cares? The signal we want is at 3885 khz. What are we going to do? Simple. Change 3885 (or any other frequency) into 400 khz. This stage brings the 3885 signal we want down to 400 khz. Ah! the genius of Edwin Armstrong.



Another "purifying" capacitor – literally a sewer for unwanted signals

22K is recommended by the tube manual. It must be high enough to make the oscillator operate, but low enough to create the proper bias so that the other electrodes inside the tube will do their job as well.

The 50 pfd capacitor and 22K resistor may not look like the typical grid-leak pair, but they ARE a grid-leak pair.

The 6SA7 is a pentagrid converter that appeared about 1938. Pin 4 is connected to a pair of screen grids (shielding grids – Brits say screening, Yanks say shielding). The cathode and the grid closest to it (pin 4) together with one of the screen grids form a triode that is connected up as a Hartley oscillator with grid-leak biasing. The screen grids act as a plate. It's a very simple oscillator, but it works very well.

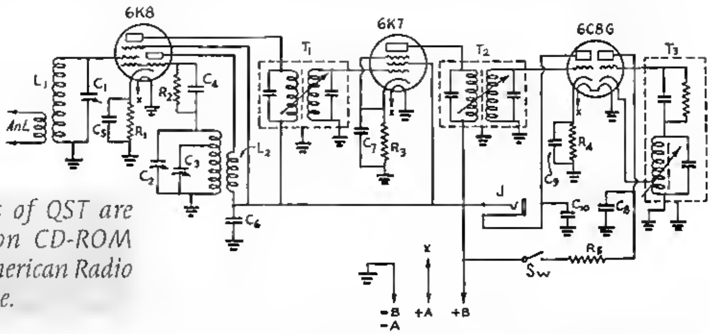
Another grid buried between the screen grids (pin 8) brings RF in off the antenna where it mixes with the signal created by the oscillator. In the collision of these two signals, two additional new signals are created: the sum and the difference. If we collide 3885 from the antenna with 4285 from the oscillator, the sum will be 8170, and the difference will be 400. When these two signals, together with the original signals, are pumped into the 400 khz IF transformers which are essentially deaf to anything but 400 khz, three signals get lost in never-never land, and only the 400 khz signal comes waltzing out the other side and into the lap of the IF amplifier tube.

It should be apparent that we need to create a tank circuit to resonate at the desired frequency and hook it to pin 8. It will help select only the signal we're interested in, and keep everything else out. And we need to create a tapped tank circuit that is 400 khz higher than the desired signal for use in the oscillator.

There really isn't much more to it than that. The only complexity is in winding the coil, but creating the tank circuits will be discussed shortly. And that's not difficult, either. We discussed that in detail in EXPERIMENTER VOL 2.

The Original Source of Inspiration

This receiver for emergency and portable radio communication appeared in the August 1938 issue of QST, and League handbooks for the next several years.

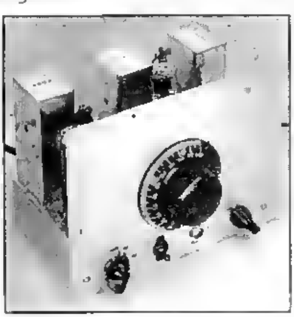


back issues of QST are available on CD-ROM from the American Radio Relay League.

FIG. 1—CIRCUIT DIAGRAM OF THE PORTABLE 3-TUBE SUPERHET

C_1, C_2—100-μμfd. midget variable (Hammarlund HF-100).
C_3—35-μμfd. variable (Hammarlund MC-35-S).
C_4—100-μμfd. midget mica.
C_5-C_8, inc.—0.1-μfd. paper.
C_9—10-μfd. 25-volt electrolytic.
C_{10}—0.005-μfd. mica.
R_1—300 ohms, ½-watt.
R_2—50,000 ohms, ½-watt.
R_3—500 ohms, ½-watt.
R_4—10,000 ohms, ½-watt.
R_5—50,000 ohms, ½-watt.
T_1, T_2—460-kc. permeability-tuned i.f. transformer, interstage type (Sickles 6504).
T_3—460-kc. permeability-tuned b.o. transformer (Sickles 6577).
Sw—S.p.s.t. toggle switch.
J—Open-circuit jack.

The value of amateur radio was driven home during the devastating floods along the Ohio River Valley in January 1937 (see QST April 1937 for details) when other lines of communication were destroyed. Suddenly amateurs realized they needed better emergency radio equipment, and this simple receiver was the first step in that direction.



THREE-TUBE SUPERHET FOR PORTABLE EMERGENCY USE

Filaments are heated by a 6-volt storage battery; "B" power is from one or two blocks of "B" batteries. The set is designed for the 1.75-, 3.5- and 7-Mc. bands.

When this appeared, about the only receiver any amateur would dare try to build was a regenerative. If he was courageous, he might even put an RF amplifier stage on it to create a TRF like we did in Vol 4. What the inimitable George Grammer, Asst Technical Editor for QST, did was to shoot down amateurs' excuses against trying to build something new, and definitely better.

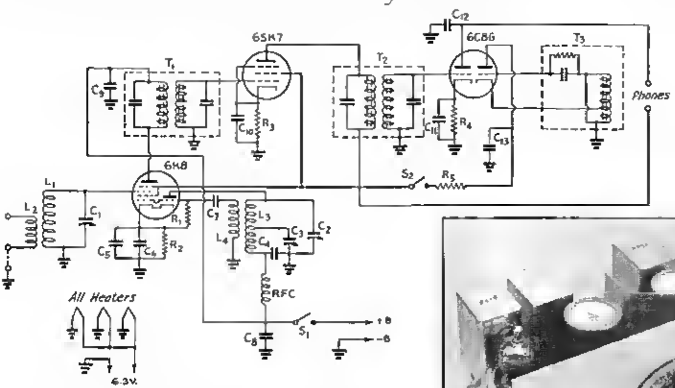
He demonstrated that a superhet could be built using no more parts and no more money (remember this was the Great Depression) than needed to build an inferior TRF.

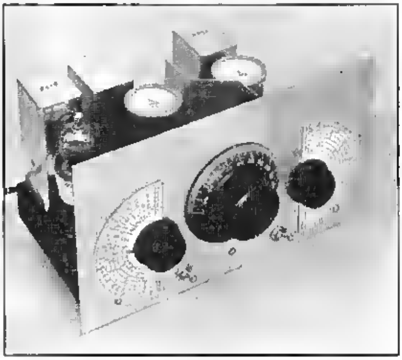
His goal was to create a receiver that delivered stability and reliability during emergencies. Because it was to be used in unusual locations, it must be battery operated. That restriction in turn, meant that the tubes could not draw excessive power. And the resulting receiver delivered on every one of those needs.

When I encounter crystal-set builders and others who are terrified of exploring new avenues of radio building, I'm always reminded of this simple little radio that could do so much. It really isn't all that scary. And it need not be expensive.

The Son of August 1938

When the beauty of the little three-tube superhet became apparent, improvements were immediately suggested. This little variation appears in my copy of the 1942 RADIO AMATEUR'S HANDBOOK *and other years as well.*





One of the major shortcomings of any superhet with a low IF frequency (455 or lower like ours) is the reception of images – that is, unwanted signals. We'll talk about that later.

Jacking the frequency up from 460 kc in the original signal to 1600 kc in this model immediately improved performance on higher frequencies. What was sacrificed was poorer selectivity (also to be discussed.)

Bringing the coils and other components closer together physically to reduce lead lengths together with a simple shield between coils also improved high frequency performance.

The other major improvement was the use of the 6SK7 pentode instead of the 6K7 version.

My initial experiments to replicate these sets on a breadboard were failures. I just could not get the 6K8 to oscillate reliably regardless of how I positioned components, how much tickler I put in the oscillator tank circuit, or anything else I tried. There may be something I overlooked but I suspect that the 6K8 will not tolerate the long lead lengths that are part of breadboarding.

If you plan to build your superhet on a metal chassis, the 6K8 is worth investigating. Even on a breadboard it performs as an excellent mixer, but I could not get it to oscillate well enough to meet my needs.

Finally, I said "Nuts!". Well, actually the word I used was much worse. I dug a 6SA7 pentagrid out of my tube box hooked it up to a coil left over from a previous project, and it oscillated without fail. In fact it oscillated too strongly. More on that later, too.

The 6K8 will work. We did that with the converter in Vol 2 to some degree. My advice is that if you like to breadboard, use the 6SA7 or its direct descendant, the miniature 6BE6. It has worked so well so many times for me, that anything else should be avoided until you have superhet experience under your belt.

IF Transformers

Intermediate frequency (IF) transformers are the heart of old-time tube superhet receivers. Understanding IF transformers is crucial to understanding over superhet performance.

It all comes down to Q – quality factor. When we connect a capacitor across the leads of an inductor to form a resonant circuit, what the old timers called a tank circuit, we become concerned with Q.

Tank circuits in radio building act as filters. They select a frequency for us. Their ability to select only the frequency of interest is related to Q. Let's suppose we have a tank circuit when a Q of 100 that resonates at 3000 khz. A very good estimate of its ability to select a frequency, can be calculated by dividing 3000 by 100 to give an answer of 30. This tank circuit would respond nicely to frequencies plus or minus 15 khz either side of 3000, or 2985 to 3015. If we have a tank circuit with a Q of 100 and a resonant frequency of 400 khz, the bandwidth is 400 divided by 100, or four khz. A 400 khz tank circuit with a Q of 80 would have a bandwidth of 400 ÷ 80, or 5 khz.

Since 5 khz is preferable to 15 khz for the reception the kinds of signals we're interested in, it should be obvious that if we can create a tank circuit with a Q of 80 to 100 that we should put it on the lower frequency of 400 khz to get the better selectivity than put it on 3000 khz where selectivity is much poorer.

In building a superhet, we choose a low frequency where IF transformers can be fabricated that will provide small bandwidths, that is, high selectivity. And since the stations we want to listen to don't exist at the low frequency chosen, we have to bring the stations to the low filtration frequency with the frequency converter stage.

Imperfections in coils and capacitors lower the Q. It is quite easy to make small capacitors we use for tank circuits from materials that deliver high Q. The two oldest and most common are ceramic and silver-mica capacitors. It's not uncommon for a capacitor to have a Q of 10,000. Technically, we don't talk about capacitor Q, but rather, dissipation which is one divided by Q. In other words, a capacitor with a Q of 10,000 would have a dissipation of 1 ÷ 10,000 or .0001 which is the same .01%. Parts catalogs will often rate capacitors on the basis of their dissipation. But regardless of what you call it, capacitors are so close to perfection that they have little impact on the overall Q of a tank circuit.

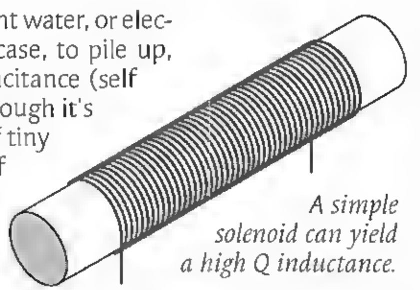
What we have to be concerned with in a tank circuit is the Q of the inductance – the coil. Coils are usually wound with copper wire which will have a small resistance to direct current. For example, a coil for a 400 khz tank circuit may have 2/10 ohm of resistance. That's not too bad, but another phenomenon pops up when we put high frequency into the coil: skin resistance. The laws of physics demand that high frequency alternating current flow on the outer most surface of the wire. As the frequency increases, less and less RF will flow through the center of the wire. More and more will flow on the skin of the wire. With less and less copper being used to conduct the RF, the resistance dramatically increases. A coil in a 400 khz tank circuit with a Q of 80 could easily present 38 ohms of resistance to RF, but only .2 ohm to DC. In fact at very high frequencies a silver plated broom handle will conduct RF every bit as well as a solid silver bar of equal diameter. RF refuses to flow on the inside of the conductor.

So we wind a coil by wrapping wire around a cylindrical form. RF current flows into the coil and travels around one turn. The RF current flowing through the resistance caused by skin effect creates a tiny voltage drop. So in a single turn of a coil you end up with two wires side-by-side that have a very tiny difference in voltage between them. Again, the laws of physics say that any time you have two conductors with a voltage difference between them, you have capacitance. In effect, the problem of skin effect resistance creates capacitance between adjacent wires in a coil, and that's big trouble for us.

If you think of a coil as a dam behind which you want water, or electrical energy in this case, to pile up, the turn-to-turn capacitance (self capacitance), even though it's tiny, is like a series of tiny holes in the wall of the dam. The dam leaks and can't do its job effectively. The winding-to-winding capacitance creates a kind of short circuit around windings and undermines the ability of the coil to generate a magnet field. In other words, the self-capacitance lowers the effective inductance of the coil, and decreases the coil Q which decreases tank circuit Q. And if you think about it, it makes sense. As the skin-effect becomes more and more prominent, in other words, the losses increase, the poorer the overall quality of the coil. And isn't that what Q means: overall quality?

Knowing these basic principles allows us to create better coils. But one other variable is important: the coil form. If you wind a coil on a cardboard tube, the cardboard will absorb some of the radio energy flowing in the coil. In a sense, it's like shoving one of your shoes in the microwave. Extremely high radio energy heats the shoe. That's fine if you're planning to eat the shoe for dinner. But in our coil we want the energy to stay in the coil and NOT heat the cardboard. So we need a coil form that is electrically inert – something that has high dielectric strength. Air is probably best. Mica is great. Cardboard isn't bad if it's dry, and you can keep it dry.

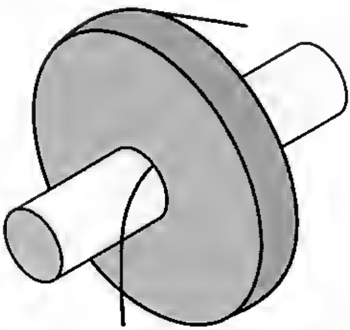
Winding a high Q coil requires a coil form of quality material, but a thin wall cardboard tube is good enough. High Q also requires larger diameter wire at high frequencies since it will have more surface area and thereby reduce skin effect resistance. Or at low frequencies we can reduce skin effect by using Litzendraht (Litz) wire which has enormous amounts of surface area. And probably most importantly, keeping the start and finish leads of the coil away from one another will yield high Q. The capacitance between windings allows them to "hear" one another, so anything you can do to "sound proof" the coil is better. Keep the two leads of the coil as far away from one another as possible.



A simple solenoid can yield a high Q inductance.

The simplest high Q coil is a solenoid. You merely wind the coil around the form with turns side by side. If the coil is four inches long, the start and finish leads are four inches apart. They don't hear one another very well. Capacitance is lower than if all the turns were just jumble wound on top of one another. It is possible to wind coils with Q's in the vicinity of 150.

Another trick in winding solenoids is to space out the turns of the coil. The further away from one another the plates of a capacitor are positioned, the lower the resulting capacitance. Since windings act as plates of a capacitor, spaced windings can significantly reduce winding capacitance.



A coil wound outwardly rather than down the length of the form with wires crossing at angles is called a universal coil. Small coils of high Q can be produced. A winding, as shown, is referred to as a "pie".

A third trick is to do away with the cylindrical form replacing it with just a few strips of styrene or similar quality dielectric. You end up with a coil that is mostly air. Q's of 200 to 300 are easily attainable for such coils.

For our IF transformers we'll wind solenoid coils on cardboard tubes that, for me, have delivered measured Q's of 130. The problem is that their overall length is almost six inches. That means the IF transformers are huge and that the radio will be as big as a table top. For us that's not such a problem.

If you were a manufacturer of tube radios years ago, you had to find a way to reduce the size of the IF transformers, so that you could reduce the overall size of the whole radio. That required a different coil geometry. In simple terms a wire was wound on a cylindrical form, but instead of letting windings progress down the tube, the windings were piled on top of one another resulting in a winding that looked like a platter, or "pie", as it's called. The diameter of the form might be 1/2" but the outside diameter of the coil might be 3". And the technique works well since the start winding and finish winding are much further apart than if jumble wound. Another trick is to use Litz wire to gain Q. But the best trick is to wind thin pies with adjacent layers of wires positioned at angles to one another which reduces capacitive coupling. This type of winding is called the universal winding. Such coils require very special equipment for winding, skill in its use, and experience in picking the right geometry for the right coil form for the frequency needed. This is something we cannot easily duplicate. But if we could, we could create IF transformers that are tiny compared to those we are about to build.

Creating IF Transformers

To create IF transformers we need to pick a frequency. We want a low frequency – below 1000 khz. If you're smart you'll pick a frequency below the broadcast band. You ask why. Let's suppose you create transformers tuned to 715 khz, and lets suppose there is an AM radio station whose transmitter is 20 miles away pumping out 50,000 watts on 720. That radio station signal is going to sneak inside those IF transformers, and no matter where you tune your receiver, you'll be hearing that 720 AM station loud and clear, and not much else.

The old-time rule-of-thumb for creating 455 khz IF transformers was that a high-Q inductance of about 1 mh (1000 µh) was needed. To get high selectivity I decided to use a frequency between 350 and 400 khz, and that means somewhat more inductance, about 1200 µh. Three 1-5/16" dia. by 12" long cardboard tubes from kitchen plastic wrap and saved for coil winding were pulled off the shelf. A spool of #30 wire was located, and a coil four inches long was wound. At 90 turns per inch that came to 360 turns. A 50 pfd capacitor was attached to the leads and a test oscillator (described later) was used to discover that the resonant frequency was about 600 khz. The pocket calculator and formulas on page 23 Vol 2 showed an inductance of about 1200 µh – pretty lucky for a first try. Adding more capacitance brought the frequency down to 350 khz.

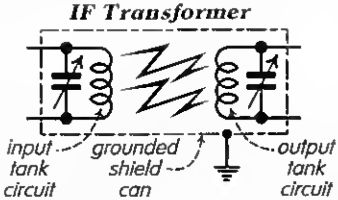
If you use cardboard tubes of slightly larger diameter, you'll end up with more inductance if you use 360 turns. You could cut back to 300 turns. A smaller diameter tube may require more turns resulting in a longer coil. Tubes in the range of 1-1/4" to 1-1/2" diameter are easy to find in paper towels, wax paper, aluminum foil and so on. You can use Wheeler's formula on page 24 Vol 2 to calculate other diameters and lengths. Just remember that Wheeler's formula is most accurate for coils that have a length about equal to the diameter. These coils have winding lengths far greater than the diameter.

Whatever diameter you choose, just be sure that you have six tubes of about 6" length with identical diameters so that the resulting coils are identical. It is of little importance whether you wind 300 turns or 400 turns so long as all six coils are identical so that you can get them on the same frequency without fancy test gear.

How IF Transformers Work

Two tank circuits are mounted near one another and surrounded by a metallic box, or "can", to act as soundproofing of sorts to keep signals from the outside world from getting into the circuits. Signals are applied to one of the tank circuits. It rings, or vibrates electrically, just like a bell being hit by a hammer. The other tank circuit which is at exactly the same pitch hears the first tank, and it, too, begins to ring. Energy is transferred from the input tank to the output tank by electromagnetic waves – mostly magnetic. The input tank is a transmitter, and output tank is a receiver, so to speak. The output tank passes on what it "hears" to the next stage in the receiver.

IF Transformer



If the ability of the output tank to hear the input tank is adjusted by adding distance or shielding between the coils, you can adjust the "coupling" which dramatically affects the frequencies getting through. If the two tanks can barely hear one another, only the loudest signal is transferred (which at best is very weak) from one tank to another. That signal will be the resonant frequency and almost nothing else – 400 khz in our radio. This weak or "under" coupling gives the best selectivity possible, but much RF power is lost travelling through the IF transformer.

If we move the two tanks closer to one another, they'll hear each other very well. The power lost through the transformer will be minimal, but tanks start to interact and selectivity is dramatically reduced to the point where the whole purpose of the transformer is nullified. This "over" coupling offers low losses but very poor selectivity.

Between over and under coupling, is the best of both worlds: critical coupling. Here, we lose minimum amounts of power but achieve maximum selectivity. This is the ideal, but very difficult to achieve. In the real world, we attempt to achieve slight under-coupling so that we can maintain selectivity.

Our transformers consist of 4" long coils on 1-5/16" diameter x 6" long tubes that are then mounted on a wooden base 4" apart. Each coil is surrounded by a 4" square by 8" tall shield or can, with a 2" x 2" window cut to allow the two tanks to hear one another.

When used in a receiver, the natural Q of the tank circuits is significantly reduced by loading. Measurements under circuit conditions indicate a Q ranging from 75 to 90 at 400 khz with minimal signal losses.

It is quite possible to create with very simple equipment using very simple components, IF transformers that compete quite nicely with commercially manufactured units from years past. But I'm afraid you'll just have to overlook the fact that our transformers are 40 times larger than commercial units!

If you take radio building seriously, and you probably do if you're reading this booklet, then I believe that you MUST have one book in your reference library above all others: RADIO ENGINEERING *2nd edition by "Uncle Freddy" Terman. There are many good radio books on the used book market, but this 800 page volume is early enough to cover exactly the tube radio material we need, and yet it's late enough to cover almost all developments you and I are likely to use. Copies are common and available at this time for $8 to $30 each. You'll find very little math, but loads of charts, graphs and circuit diagrams that will explain to you important and sometimes complex concepts in far more detail than you'll get in, say, the* RADIO AMATEUR'S HANDBOOK *or* RADIO HANDBOOK.

Terman, "The Father of Silicon Valley", wrote many books and technical papers, all of them good, all of them worth owning. Terman was an incredibly knowledgeable and creative engineer who was two cuts above Tesla or DeForest, yet I wonder how many people have ever heard of him (or George Campbell, or Edwin Armstrong, or even Clerk-Maxwell).

RADIO ENGINEERING, *Fred Terman*, McGraw-Hill Book Co., 2nd ed, 1937
FUNDAMENTALS OF RADIO, *Terman & MacDonald*, McGraw-Hill Book Co, 1st ed, 1938 *"Engineering" is clearly the better of the two.*

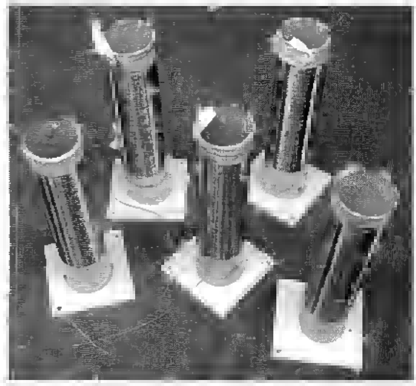
Making the Transformers

Winding the necessary coils is not at all difficult if you first make a simple coil winder (details later.) Digging through my box of cardboard tubes turned up three that were once wrapped with plastic kitchen film. Each is about 1-5/16" in diameter almost 12" long.

Using #30 enamel wire that I always have on hand, I wound 360 turns starting about 3/4" from one end. The coil length is 4" (90 turns per inch), leaving almost 1 1/4" of open cardboard at the far end which becomes the end glued to a 2-1/4" square of 3/16" plywood. When cutting the tubes in half, you'll end up with a ragged edge at one end, and the machine-made edge at the other. Start winding from the ragged edge so that you can use the machine edge to glue your coil to the plywood (or plastic or whatever) and be sure the coil will stand straight up in the air at a nice right angle to the base board.

Holes are easily punched in the cardboard with a nail, awl, or pin. The wires at beginning and end of the coil were secured with a little clear finger nail polish.

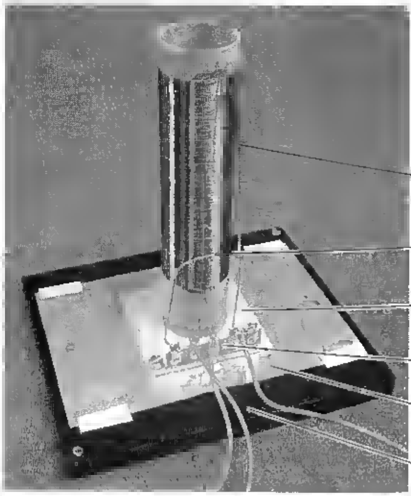
You need to wind six coils: four for the transformers, one for the BFO, and one for the alignment oscillator. Be sure to wind them as much alike as possible. Two coils must have a tap installed at about 25% from the bottom end (ground end) of the coil. In other words, you should start winding 3/4" from the ragged top end, and when you reach the 270th turn, twist a loop of wire so that it protrudes about 1/2". This tap will provide the feedback needed to create oscillation. Its position is not critical. Any turn from 270 to 300 can be tapped and will probably work.



Five identical coils must be wound for the radio, and a sixth for the alignment oscillator.

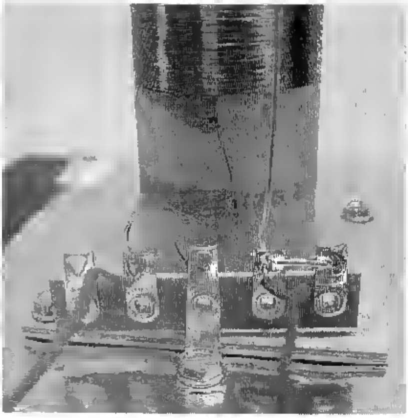
Sheet metal screws hold the coil and its base to the master base. A phenolic terminal strip is used to secure the leads. A length of #18 bus wire is soldered to a lug at the bottom, and put through a hole near the top and is anchored with a crimp in the wire.

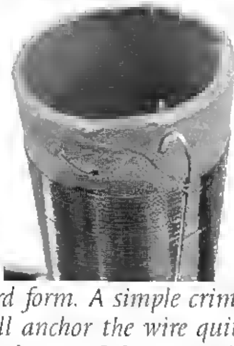
If you plan to build radios, get a box and every time you finish a roll of paper towels, aluminum foil, or plastic wrap throw the tube into the box. If you get in the habit of saving tubes, you'll always have the forms you need for coils.



(left) The BFO coil is mounted on a piece of scrap 1/2" plywood rectangle about 5-1/2 x 6-1/2 in dimension. A sheet of aluminum foil is put down for shielding before components are mounted.

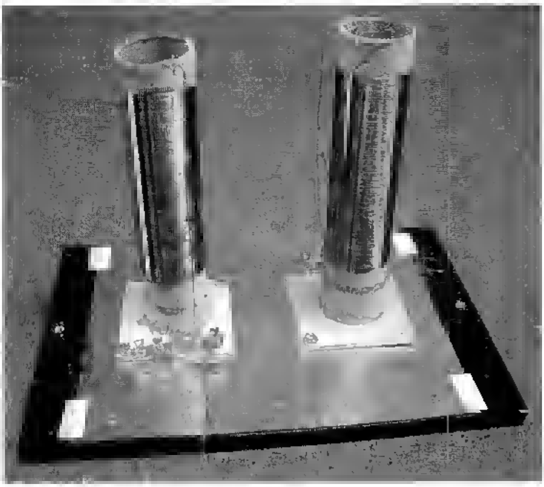
(right) The base of a transformer coil is connected up in much the same was as a BFO coil. Neither the start or finish leads of the coil is grounded. Use a consistent system to bring leads outside the transformer so that the bottom coil lead can always be bypassed or connected directly to ground. In wiring the BFO the bottom lead is connected to the center ground lug. It might be wise to connect a black wire the bottom coil lead, and red to the top coil lead. Common #6 x 3/8" sheet metal screws are used to anchor the coil and the terminal strip.





(right) A length of bus wire is soldered to the terminal strip at the base and slipped through a hole in the top of the cardboard form. A simple crimp in the wire will anchor the wire quite solidly without the use of glue. Keep the wire away from the windings so that it doesn't interfere with the fields built up around the windings.

This Boonton 160A Q meter is still very accurate after 50 years. Our coil shows a Q of 143 at 450 khz and 135 at 400.

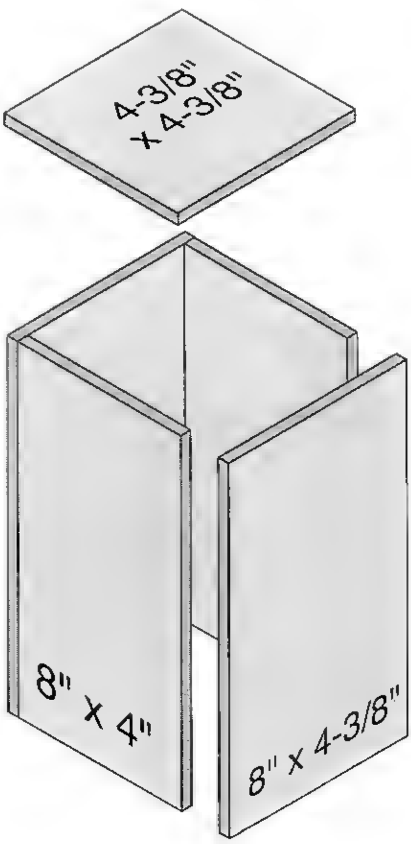


(left) The same mounting technique used on the BFO coil is used for the transformer coil pair. The base is about 6-1/2" x 10", and the coils are mounted on 4" centers. Make the master base large enough to accommodate the shield box you're installing but no larger than necessary, or you'll need two table tops to hold your radio instead of one.

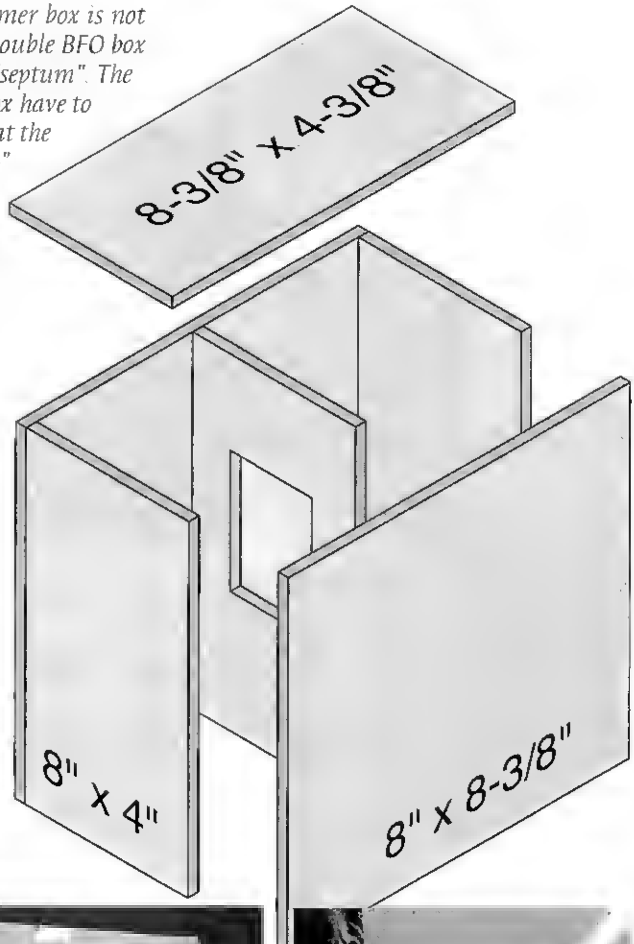
(right) All coils must be surrounded by a metallic, nonferrous shield. That means no steel! You can make the shield "cans" out of PC board if you have enough. Or you can fabricate them from 20 gauge sheet aluminum. But don't even think about slipping a length of 8" steel well casing over them. The iron will change the inductance radically.

The easiest approach for most people is probably the use of common corrugated cardboard glued into a box and wrapped with kitchen aluminum foil made sticky with spray adhesive. Most cardboard is about 1/8" to 3/16" thick and you must make allowances for this thickness if you're to build a strong box. The goal is to create a 4"x4" space in the center of which sits the coil. The top, or roof of the can, needs to be a significant distance from the top of the coil winding in order to avoid reducing tank circuit Q any more than necessary.

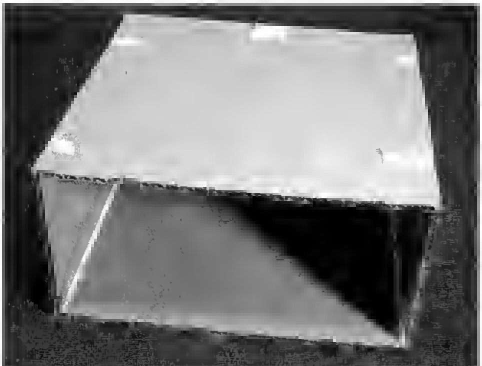
Be very careful to cut the cardboard accurately. Use a square and a utility knife. Accurate cuts will make assembly far easier. And it's important that both IF transformers are as identical as possible so that you can be assured they will tune to the same frequency.

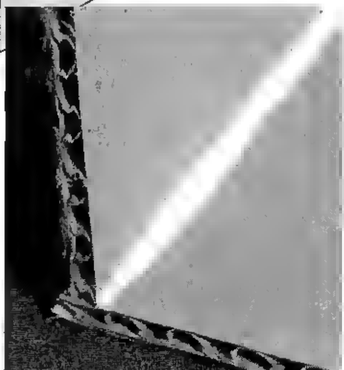


(right) The transformer box is not much more than a double BFO box with a partition, or "septum". The dimensions of the box have to be planned out so that the coils mounted on 4" centers on their master base fall in the center of each of the two 4" square cells created. Again, be sure to allow for cardboard thickness.



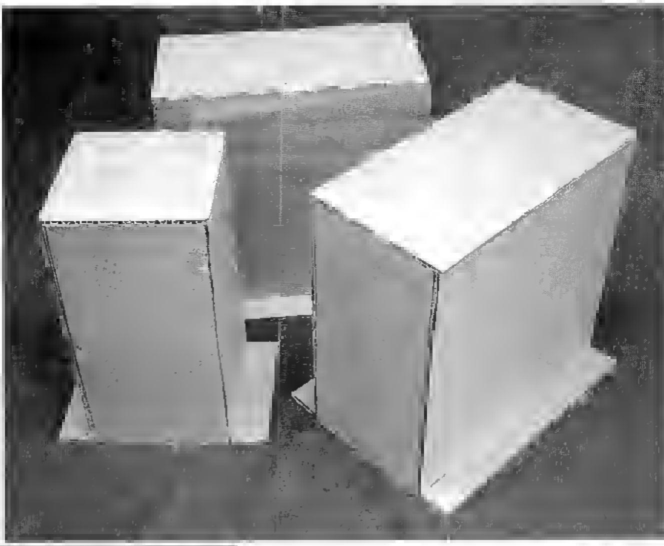
(below) After the cardboard panels are cut, they are assembled with masking tape. Tape the top securely in place to keep the box perfectly rigid and square while the glue sets up.

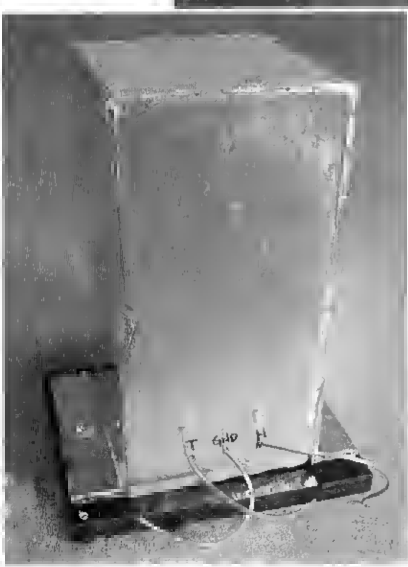




(above right) Making boxes is kindergarten stuff. Once taped together you simply lay a bead of white PVA glue like Elmer's into the corner joint much like laying a weld bead or a bead of caulk. In three or four hours the glue will be hard enough to turn the box over and glue the remaining seams.

(right) Here we see the glued up boxes ready for covering. Create 3/4" wide flaps at the base so that you can anchor the boxes to the master base with sheet metal screws. You do NOT want the cans to move around.



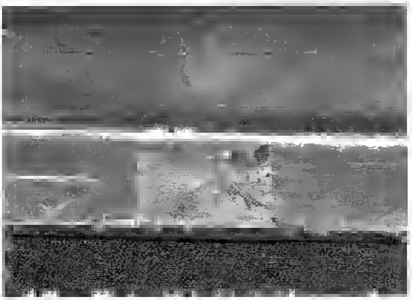


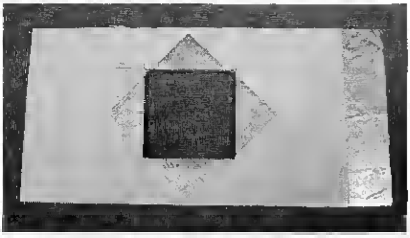
(left) The outside of the can is next covered with aluminum foil. Cut convenient sized panels of foil, and check their fit. Then lay them on a spread of newspapers and give them a solid coating of spray adhesive. Quickly, but carefully, work the panels into position and rub the aluminum foil down. Cut additional panels and overlap them until the whole can is covered. If you're ambitious, you can attempt to cover the interior of the box with foil, but that's tough to do unless you have small hands.

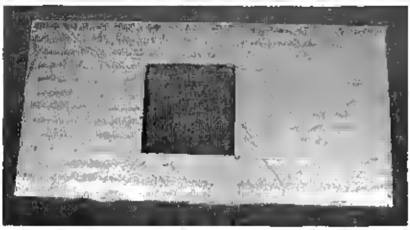
Use plenty of newspapers to protect the floor from adhesive overspray. The stuff can be nasty. You'll probably need lacquer thinner to clean up.

Use your ohmmeter to be sure all panels are electrically connected to one another. You would think that the adhesive would act as electrical insulation, but I have always found that panels glued together connect electrically.

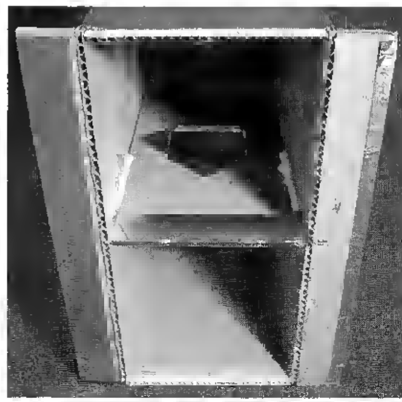
You'll want to cut a small piece of aluminum, bend it over the mounting lip so that the can shield can make contact with the foil shield on the master base. You can solder aluminum foil by carefully scraping with a soldering iron.







(left) A panel of cardboard is cut that just fits across the center of the cardboard can. It must not be so tight that the walls of the box bulge. It must not be so loose that it easily falls out. A 2"x2" window is cut above center to coincide with the center of the 4" coil windings. Then a panel of aluminum foil is cut and attached to form a shield. You can see how excess foil was wrapped around.



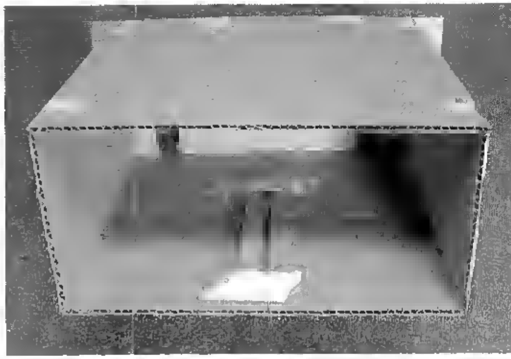
(right) After the septum is positioned and held in place by small pieces of masking tape, beads of glue are put down. It's not necessary to glue every edge, but put down enough glue to prevent the septum from moving. The next problem to solve is how to electrically connect the septum foil with the foil on the outside of the box.

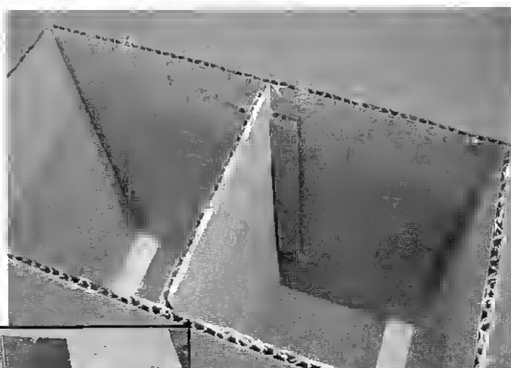
(left) A long narrow ribbon of foil is cut, and one end is soldered to the septum foil. Although aluminum does not solder well, it can be done. There are fluxes available that will make the job easier. But it can still be done by carefully scratching the aluminum with the tip of a soldering iron while applying rosin-core solder. The strip is then twisted and brought out around the mounting lip and soldered with another bead.

The septum is a very important component of the transformer. It is a kind of soundproofing that prevents one tank circuit from hearing the other. When you cut a hole in the septum you allow them to hear one another. The larger the hole, the better they hear, that is, the tighter the coupling.

The 4" square inch opening here provides under-coupling. The selectivity is very good, and signal loss (insertion loss) is only a bit more than commercially made transformers. You could probably open the the hole up to five square inches, but you run the risk of destroying the selectivity.

If you change the dimensions of the boxes to accommodate the coils you have wound for your radio, be prepared to adjust the size of the opening to get the right degree of coupling.

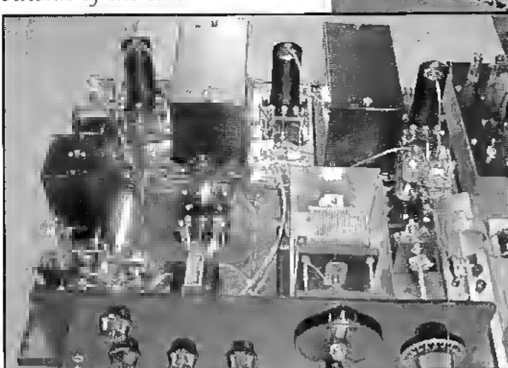


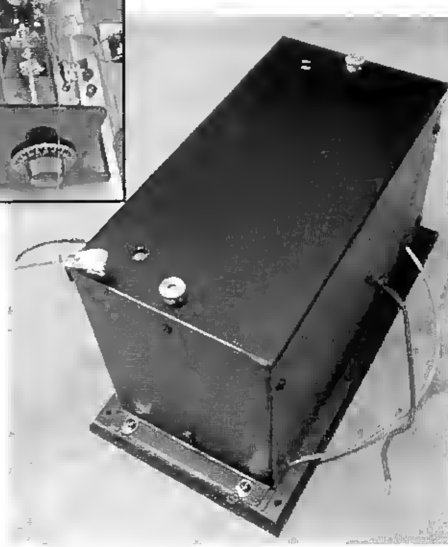


(right) Shown is the beginnings of a special can that was never completed. Instead of permanently gluing a septum to the inside of the can, a pair of cardboard rails was glued in. Into these guide rails a septum could be slid in and out as desired. The idea was to use a hinged shielded top so that septums with various sized openings could be quickly changed to allow experimentation with coupling.

If you're not going to closely duplicate the coils and boxes shown in this booklet, then perhaps this idea is worth pursuing.

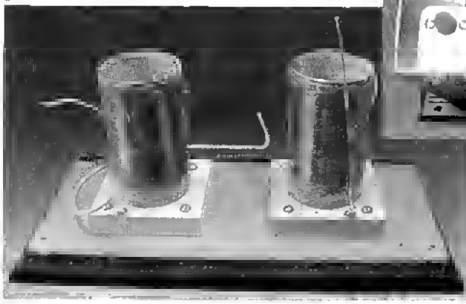
The greatest problem with this approach is connecting the septum foil to the foil on the outside of the can.





Some time ago a superhet was built using technology that existed in 1929. Towards the rear of the receiver can be seen large black boxes, shown in close up at the right. The cans are fabricated from 20 gauge aluminum and mounted on a solid oak base. Capacitors are incorporated into the transformer. Adjustment screws can be seen through the holes in the top. Thumb nuts allow removable of the can roof.

(below) The coil pairs used in the 1929 superhet. (right) looking down into the IF can with top removed. Wires exit through grommeted holes.



Although the construction techniques used here are much fancier than our cardboard box methods, the transformers shown here work no better than our cardboard versions.

Other Options

The coils wound here are anything but the best. Cardboard isn't the greatest material. If you're going to use it, it might be wise to bake it in the oven at very low temperature to drive out any moisture and then paint it with shellac to seal it. Bakelite would be even better.

But the single greatest improvement you can make is to change the geometry of the coil. Maximum Q is obtained when the diameter is approximately equal to the length of the coil.

Our coils measure about 1200 μh. Putting that number into the standard formulas for coils, the dimensions we need for maximum Q is a coil form 2-3/4" in diameter about 3" long. On it is wound 130 turns of #30 wire at 90 turns per inch. It should be obvious that our four-inch-long coils are not the best shape for optimum Q.

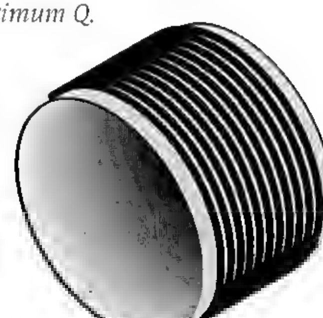
Winding transformer coils with these dimensions should make for some interesting experimentation. But coils this size will present mounting problems since the coil must be as far away from the shields as conveniently possible.

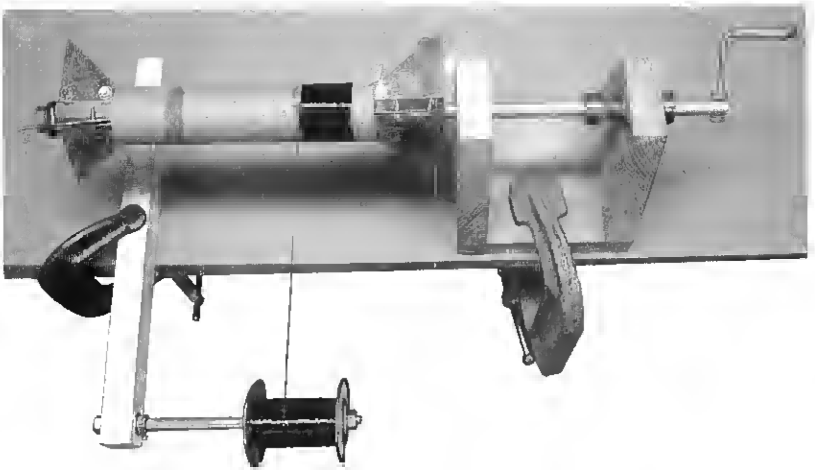
Although I used 1-5/16" diameter forms, you can use others. Different diameters will require a different number of turns to achieve 1200 μh.

Diameter	Turns #30
1-3/4"	235
1-1/2"	295
1-5/16"	360
1-1/4"	395

There is nothing magical about #30 wire. You can use #28 or #32 or even #12 if you want. But different wire diameter changes the coil geometry and that changes the inductance. If you intend to use a thinner wire, you'll get more turns per inch and therefore a shorter coil. Be sure to use the formulas in Vol 2, to see how many turns will be needed.

This coil shape gives maximum Q.



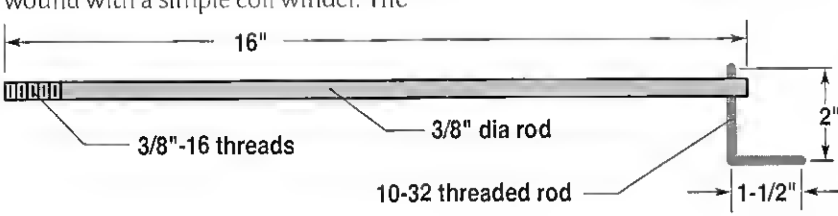


Building a Coil Winder

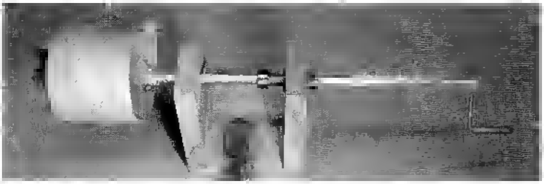
Coils with few turns are easy enough to wind by clamping one end of the wire in a vise on the far side of the room and by rotating the coil form in your hands while walking toward the vise. But if you have to wind coils with many turns of fine wire, the technique becomes difficult. Fatigue sets in and mistakes happen. Turns get jumbled. The form slips out of your hands. The wire breaks.

Coils with many turns are best wound with a simple coil winder. The coil form is mounted on an axle that is turned with a crank with one hand, while the other hand feeds wire onto the form from the supply spool. It's a relatively easy device to build and is valuable tool for building old time radios.

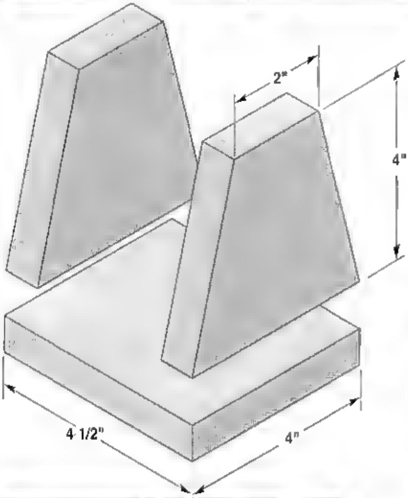
A shaft is held by a pair of simple pillow blocks fabricated from scrap lumber or heavy sheet metal. It is such a simple device that construction details are easier shown than described.



The shaft for the coil winder is fabricated from 3/8" to 1/2" shaft from the hardware store. I used a piece of 3/8" aluminum I happened to have left over from another project. The crank is a 3-1/2" length of 10-32 threaded rod bent into an L shape. It slips into a cross-drilled hole in the main axle and is held in place with nuts. A short section of steel brake line becomes a spinner. At the far end of the main axle threads are cut with a common 3/8-16" die. A nut and washer on these threads puts pressure on one of the stars holding the coil form. You may not need these threads for smaller coil forms.

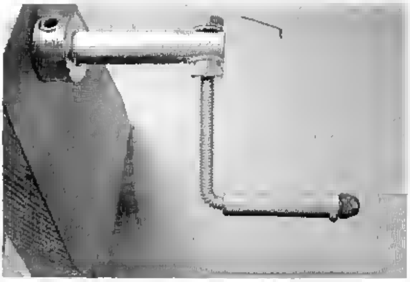


There is nothing magical about the length of the shaft. If you plan to turn mostly short, large diameter coils, you may want to shorten the shaft dramatically.

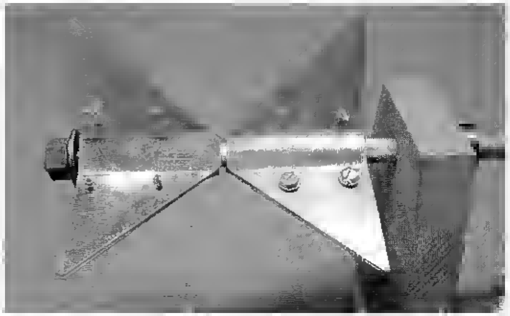


(left) The pillow blocks were cut from scrap dimension lumber: 3/4" thick fir. The dimensions show are what was used here, but are anything but critical. Wood screws hold the blocks to base board. A large C-clamp holds the winder to the table.

(below) Details of the crank. The brake line spinner saves the fingers when winding long coils.



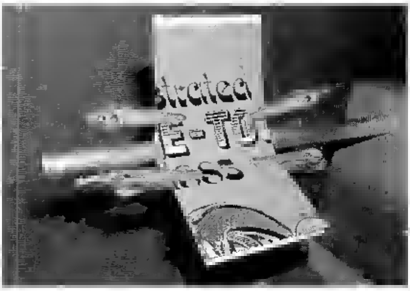
(left) A common shaft collar together with a hardware store spring and a washer create drag on the shaft – a simple brake. You'll want some drag so that coil form does not rotate should you take your hand off the crank midway through winding a coil. If the coil unwinds, it will be ruined.

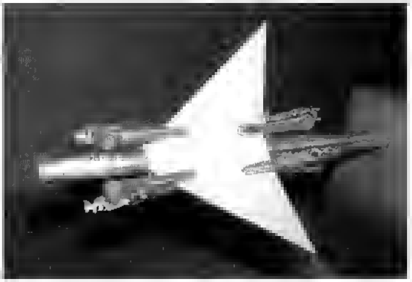


(right) The most difficult components to make are what I call star adapters that slip into the ends of the hollow coil form. If you have a lathe, turn cones from wood. But if you don't have a lathe, you'll have to make a pair of these adapters from sheet metal. I used scrap .040 aluminum. You could probably get by using an old aluminum cookie sheet, or a piece of steel stove flue. Tin can metal would probably be too flimsy, but might be worth a try.

Three triangular pieces are held together and to the shaft with #6-3/8" sheet metal screws.

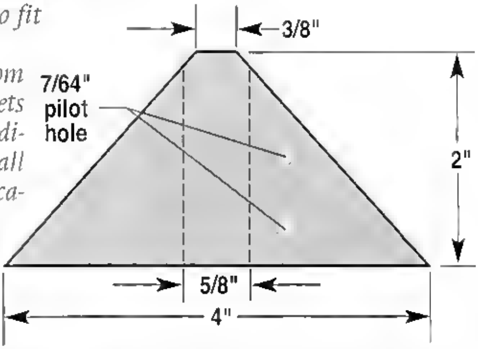
(right) In the process of designing the stars, the first step was to cut three pieces of 2"x4" heavy paper and mount them on the shaft using alligator clips. Once I was sure the wings of each star would be large enough to hold a large coil in place, I drew some rough markings on the paper with a marker.





(left) Next, cuts were made to create the triangle shape needed. The paper was then clamped back in place to check for fit. These tests revealed that two bends a bit more than 5/8" apart would create a tight fit around a 3/8" shaft.

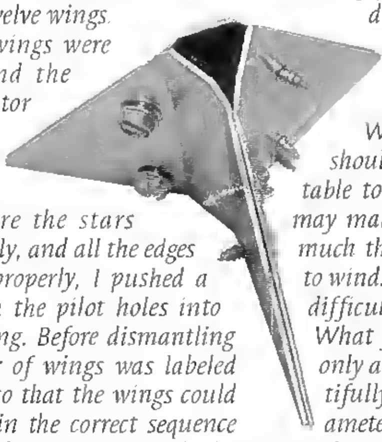
(right) The final pattern for stars to fit a 3/8" dia shaft.



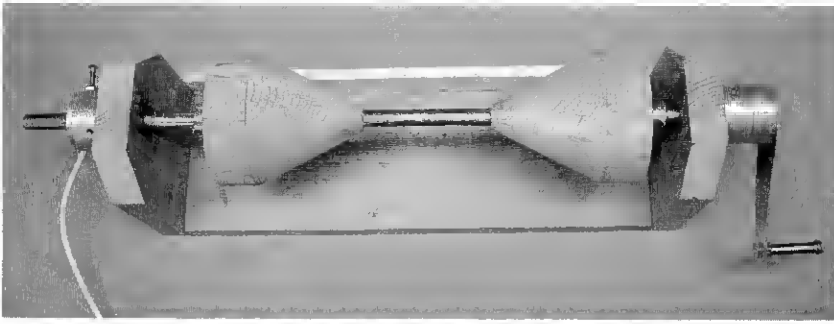
Six stars were carefully cut from scrap .040 aluminum. All six sheets were clamped together and 7/64" diameter holes were drilled through all six plates at approximately the locations shown. These become the pilot holes for sheet metal screws.

The bend lines were lightly scribed on the sheet metal, and the wing was clamped between the jaws of a large vise. A 30° bend was made in each of the twelve wings.

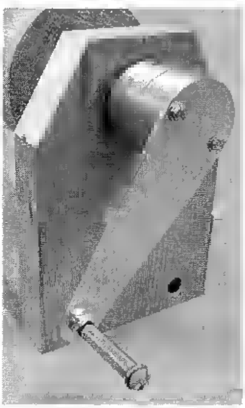
Next, the wings were clamped around the shaft with alligator clips, adjustments made to the bend angles. Once I was sure the stars would fit correctly, and all the edges were lined up properly, I pushed a marker through the pilot holes into each mating wing. Before dismantling them, each pair of wings was labeled with a marker so that the wings could be reassembled in the correct sequence should there be discrepancies in the locations of pilot holes. Next, the marker dots were carefully center-punched and drilled 9/64" to pass the #6 x 3/8" sheet metal screws.



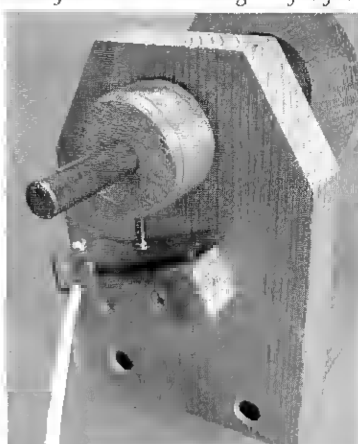
When assembled, the stars should stand straight up from the table top (left). If they don't, they may make your coil form wobble so much that it becomes very difficult to wind. Although the stars may look difficult to build, they really aren't. What you see here is my first and only attempt. And they work beautifully. If you use a shaft of a diameter other than 3/8" you'll have to perfect your own patterns.



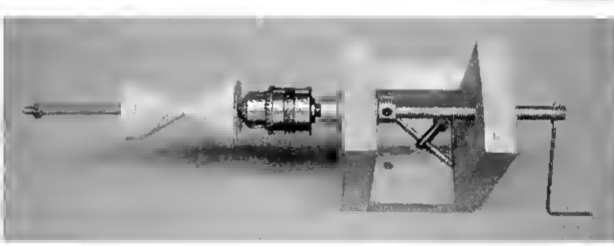
(above) This large coil winder was built a few years ago. The shaft is 1/2" diameter steel and the cones were turned from oak on a lathe. This winder is far larger than necessary for the vast majority of coils we'll ever wind. If you machine cones and find that the coil form slips due to inadequate friction between the cones and form, glue sand paper to the cones.



(left) A fancy crank was fabricated from a long machine screw, a piece of brake line, a piece of scrap aluminum sheet and a homemade shaft collar. This design is far fancier than it needs to be.



(right) One great advantage of this winder is its counter switch. A machine screw inserted into the side of a home made shaft collar comes around on each revolution to push a small section of brass sheet against the head of a wood screw. A pair of wires between the brass sheet and wood screw closes a circuit which triggers an outboard electronic counter.



(right) Yet another coil winder uses a 3/8" steel shaft onto which an old drill chuck was mounted. Threads were cut with a die, and although there is some wobble because the threads are not perfectly concentric with the shaft, the wobble is not all that objectionable. The crank is a section of bronze gas welding rod soldered into a hole drilled in the shaft. Cones were machined from oak and are mounted on a threaded rod this is held by the chuck.

Alignment Oscillator

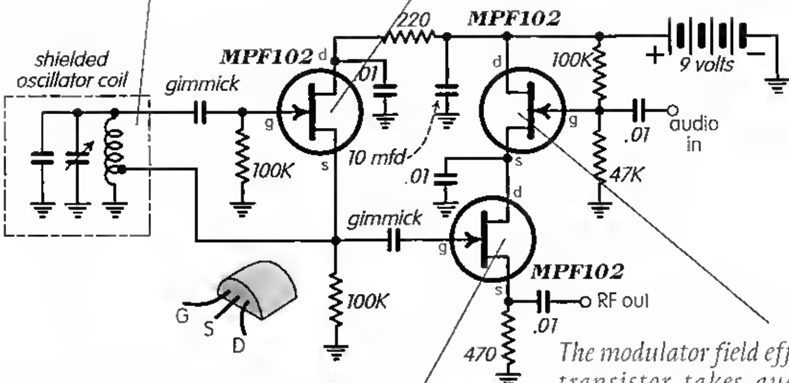
An alignment oscillator is needed to put all the IF transformers on the same frequency. Old tube oscillators can be found at flea markets and, I suppose, on the internet. But it's easy to build one. All you need is about a dollar's worth of components.

Five of the coils we wound are destined for the receiver. The sixth, one of the coils with a tap, becomes a Hartley alignment oscillator. We intentionally made it the same as all the other coils so that we could be sure it would tune to the same frequency range as the others.

I wired my oscillator up using the "dead bug" technique on a little printed circuit board in just minutes. By changing the tank circuit capacitor you can put it on other frequencies and use it to align almost any superhet.

The actual oscillator transistor. The gimmick capacitor that links the gate to the tank circuit is nothing more than two 2" of hookup wire twisted together.

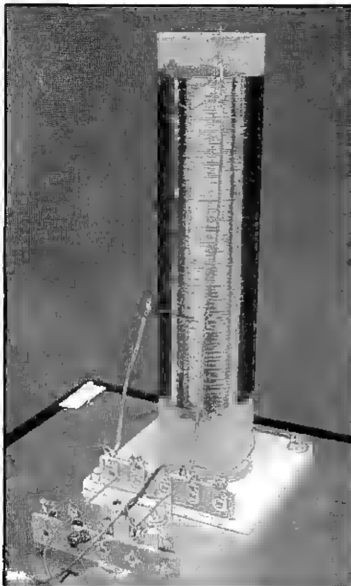
Our coil with a 50 pfd fixed capacitor and 6-70 trimmer wired in parallel to form a tank circuit.



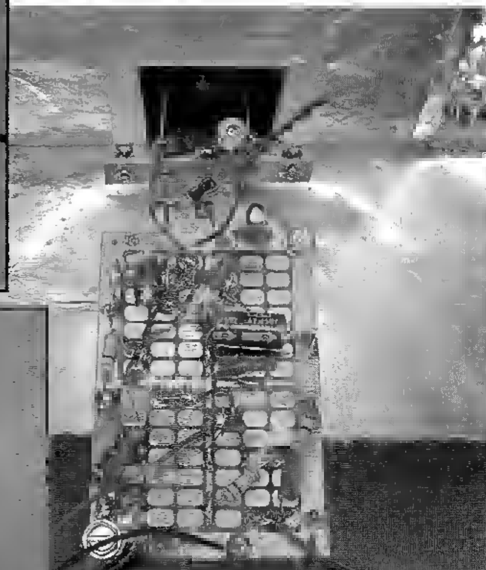
This buffer transistor isolates the outside world from the oscillator transistor. And makes modulation easier. The gimmick capacitor on the gate is two 4" pieces of twisted hookup wire.

The modulator field effect transistor takes audio from the bridge oscillator we built in Vol 3 for our bridge and uses it to throttle the supply voltage to buffer. It acts as a "plate" modulator.

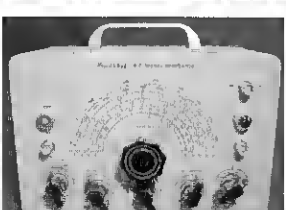
What we have here is essentially a weak AM radio station broadcasting a constant tone on 400 khz or whatever frequency we want to align our IF transformers to. The oscillator feeds the 400 khz to the buffer. Audio from the tone generator we built to drive our impedance bridge in Vol 3 supplies audio to the modulator transistor which varies the supply voltage to buffer transistor. To align our receiver we'll simply listen to the tone broadcast by this transmitter and adjust all the transformers so we get the loudest signal in our headphones. It's just that easy to do!



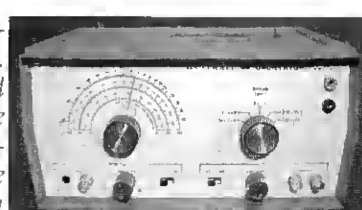
(left) The alignment oscillator coil is fabricated just like that of the BFO. A second terminal strip outside the shield box supports the fixed 50 pfd and variable 6-70 pfd capacitors that form the tank. (below) A mere 2" x 3" pc board etched with pads offers more than enough room for all the components, most of which can be stripped from old pc boards. A simple 9V transistor radio battery will generate a signal far more powerful than we'll need.



(left) The entire alignment oscillator is ready for use. A length of miniature coaxial cable with alligator clips carries the signal from the buffer transistor to receiver being aligned. You can hook the oscillator up to a length of hook up wire, and listen for harmonics in a common AM radio. For instance, you'll know you're on 400 khz when you hear a dead spot at 800 and 1200 on the AM band.



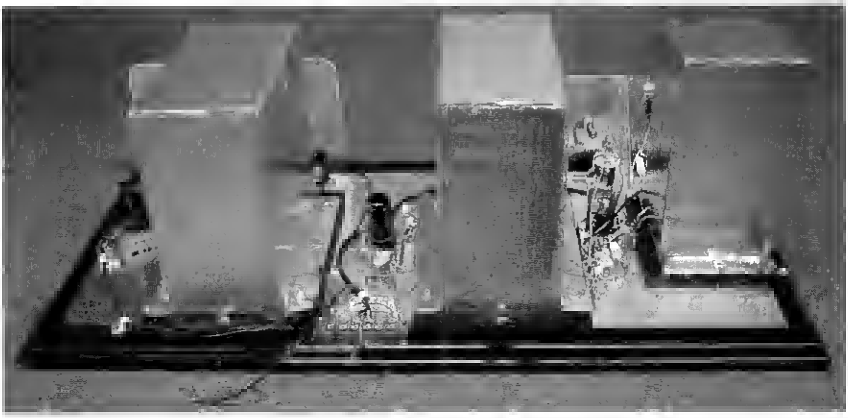
If you have an oscillator use it. (left) an old Heathkit tube alignment oscillator (right) the solid state version



Building the Superhet

Actual construction of this superhet uses the same techniques seen in other volumes of the Experimenter. A sheet of aluminum foil is attached to a pine breadboard and the components are mounted on it. Inexpensive relay sockets with screw terminals hold the tubes, and inexpensive phenolic tie strips and ground lugs anchor all the small components. ering IF transformers. If the plate and grid can hear one another through long leads to any great degree, you run the risk of the IF amplifier turning into a 400 khz oscillator.

As shown here, the receiver is much fancier than need be. The whole radio was built on a 14"x30" breadboard with a decorative detail cut into three edges with a router. It

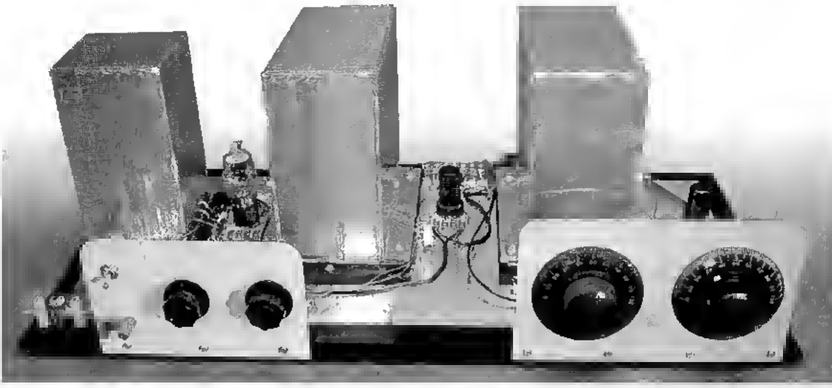


Looking from the rear from left to right, we see the frequency converter stage, the if amplifier, and detector/BFO tube. Notice how closely the large IF cans are positioned to the tube sockets in order to keep lead lengths to a minimum. You probably don't want to use a fancy breadboard like this until you've built the radio, tinkered with it, and understand exactly what improvements you want to install.

was painted satin black, and an aluminum foil ground plate attached with spray adhesive. Hard-to-find National Type A slow-motion dial drives are used to tune both the antenna and converter oscillator. But none of these things are necessary. In fact, it might be wise to build your receiver on an old board and not use any dial drives at all until you're sure that the radio works, and you have an idea of how your particular components are going to be positioned. After it's working, it's relatively easy to transfer components to a fancier breadboard and install better controls.

The only really critical rule that must be observed is to keep lead lengths going into and coming out of the shielded boxes as short as possible. If you noticed, the transformers have their input and output leads exiting the shielded box on opposite sides. This helps in building the radio. The leads from the plate of a tube going into a transformer must be kept as far away as practically possible from those on the grid which come out of the previous transformer. Examine the IF amplifier tube (page 32), and you'll see what I mean. The tube is sandwiched between the two tow-

From the front from right to left we see the frequency converter stage, the IF tube sandwiched between the skyscraper IF transformer cans, and to the left the detector BFO stage. Obviously, the two boxes to the right are transformers, and the box at the far left is the BFO oscillator coil.

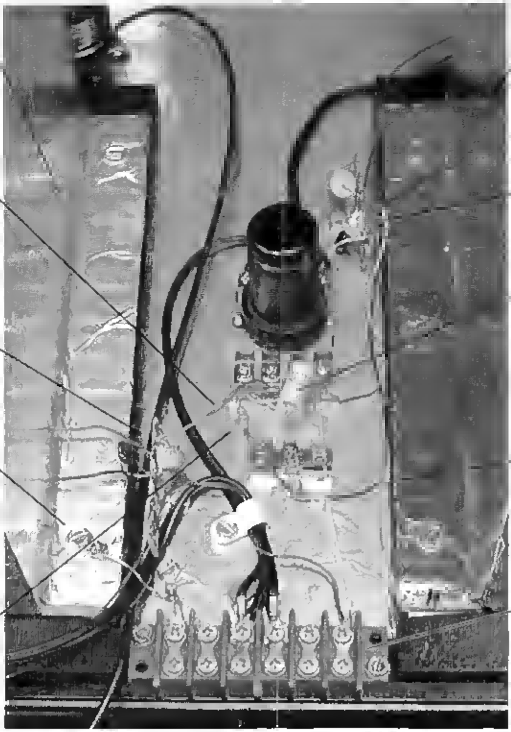


Two fancy slow-motion dial drives were used here, simply because I had them. The dial to the right is connected to the variable capacitor across the oscillator coil on the pentagrid converter. The dial drive to the left controls the variable capacitor across the antenna tuning tank circuit, but because the tuning of the antenna tank circuit is very broad, no reduction dial drive is needed at all. You DO need a dial drive on the oscillator tank circuit, but these uptown dial drives are more for looks than anything else.

(right) Commercial IF transformers have capacitors installed inside the can. Ours do not. The leads must be brought out of the can and attached to an adjacent pair of lugs on a phenolic terminal strip. Across those lugs you solder the fixed 50 pfd capacitor and the 6-70 pfd variable capacitor.

At first I merely punched a hole in the sides of the can and threaded the wires through. But that was quite difficult, so the small slit-like window was cut which made bringing wires out while anchoring the can to its base much easier.

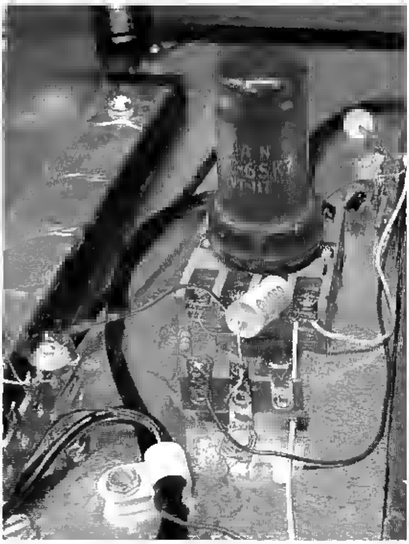
Putting the capacitors on the outside allows us to quickly change the frequency of the IF's. We can lower the frequency by adding capacity, or raise frequency by using less.



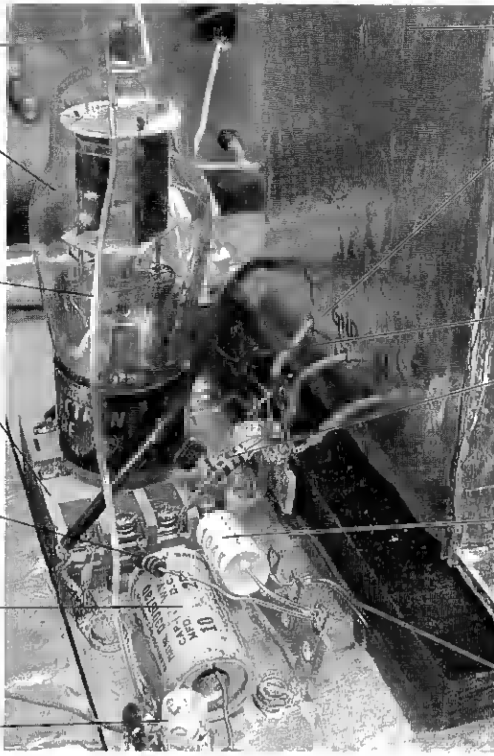
(above) The IF amplifier shows how components should be laid out to minimize the chances of unwanted oscillation.

After the IF cans have been attached to their master bases with sheet metal screws and flat washers, the master bases are, in turn, attached to the main bread board with longer sheet metal screws at opposite ends of the master bases. All aluminum foil whether on the inside or outside of the cans, or on the breadboard and bases must be in electrical contact one another if the shielding is to work properly. Checking continuity with an ohmmeter is always a good precaution.

A barrier strip or terminal block is used to help make attaching leads from the power supply to the radio easier. Since this radio only needs 90 volts at 22 mA maximum, you can power it with the small power supply we built in Experimenter Vol 1.



The black zip cord carries filament current to the tube base. To minimize AC hum problems, twisted wire should really be used. But this works okay.

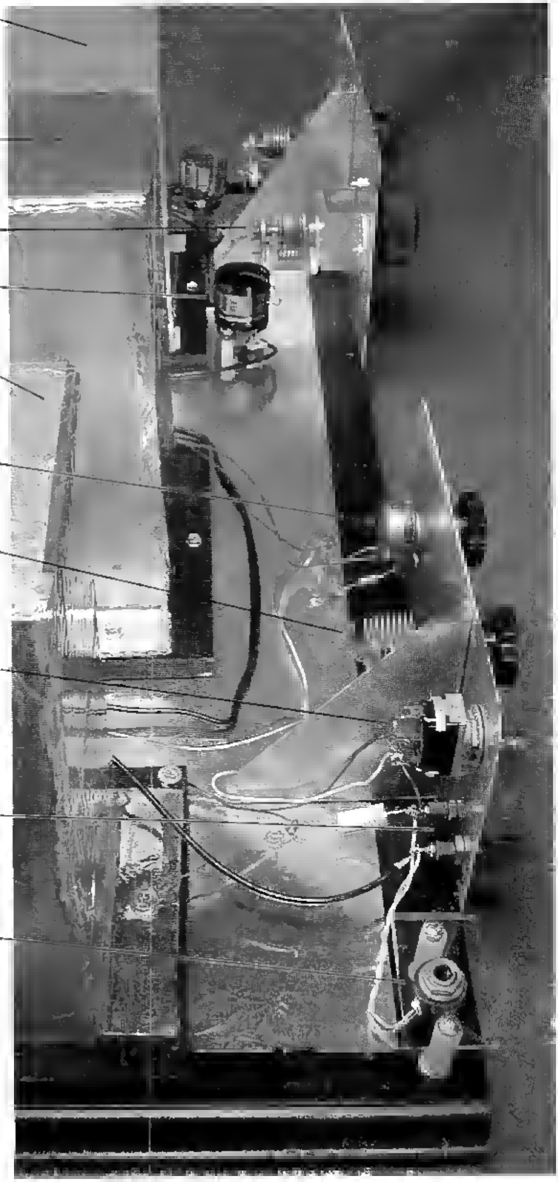


From the rear we see the 6C8 dual triode. And just like the schematic, to the left is the second IF transformer and to the right is the BFO section.

RF from the IF transformer is fed to the grid through a rigid length of bus wire soldered to the terminal strip with the IF tank capacitors at one end, with the other end being soldered to a friction fit strap around the grid cap. You may have a grid cap connector that will fit. If not, you can easily make one by cutting a 1/4" by 3/4" strip of brass sheet and by wrapping it around a twist drill smaller in diameter than the cap. The strap should easily slip over the cap but be tight enough to give good electrical contact. The bus wire is easily soldered to the brass.

All coils were wound alike. And all coils have the same 50 pfd and 6-70 pfd capacitors soldered across them. If all tank circuits are mounted in identical cans, you should have no trouble getting all of them to tune to the same frequency.

The .1 mfd bypass capacitors used throughout this receiver are new simply because they were inexpensive and had 600 volt ratings. You can use old capacitors. Just be sure to check them on your bridge to be sure they are at least .1 mfd. And you can use larger sizes, too. If you have .22 or .47 capacitors use them. Mix and match. Since we're only using 90 volts to power our receiver, the capacitors don't need a voltage rating of more than 150 volts. The electrolytic bypass capacitor on the detector cathode is quite old, but still works very nicely.



Looking at the front panel layout from the BFO end of the receiver.

EXTREMELY IMPORTANT: Note that the front panels are connected to ground through the foil. If you mount a standard 1/4" phone jack (as seen here) on one of the front panels, one of its terminals will be grounded as well. Because the 90 volt B+ flows through the headphones to the plate of the detector, that means that you'll either short the B+ to ground and blow a fuse, or you'll burn out your earphones. The phone jack seen here is mounted on 1/8" acrylic plastic so that both terminals of the phone jack are insulated from ground.

The frequency converter stage is laid out to minimize lead lengths. The antenna coil and oscillator coil are positioned away from each other on opposite sides of the front panel support bracket to minimize interaction. Signal is brought in from the rear of the receiver through miniature coax, resonated in the antenna tank circuit, and fed to the converter grid through more coax. (right) the antenna tuning tank circuit. Place leads from the alignment oscillator near this coil to feed signal into the receiver for adjustments.

Winding the Coils

"Well, exactly how many turns should I use on my coils?"

I've been asked that so many times, I cringe when I hear it anymore. The answer is that I don't know. It depends on the diameter of the coil form you're using, and the diameter of the wire if you're going to use to close wind the coil or, if not the diameter of the wire, then at least how many turns per inch you'll put down on the form.

What's more, my advice, even if I could give it, is unnecessary. Everything you need is contained in EXPERIMENTER VOL 2. You start by using the bandspread formulas on pg 39 Vol 2. Once you decide on the inductance needed, you use the Wheeler formula on page 24 to find a combination of form diameter, turns per inch (TPI), and number of turns to give you the inductance you need.

What I will to do here is walk you step-by-step through the process I used to wind the coils for this receiver. Although my target was the 80 meter amateur band, you may want to go somewhat higher for broadcasts, or lower and use a crystal-controlled down converter like that shown in EXPERIMENTER 4. But remember that the 6SA7 converter tube usually does not oscillate very well at higher frequencies.

First, you decide the band of frequencies you want to receive: 3.5 mhz to 4.0 mhz in my case. To be safe add a little to the width so you can be sure that the entire band falls inside the range of the tuning variable capacitor. I decided to add 50 khz (.05 mhz) to each end of the band: 3.45 to 4.05 mhz. This is what the antenna coil must tune.

Next, I decided on 400 khz as the IF frequency. The oscillator frequency range must be 400 khz (.4 mhz) above that of the antenna coil. So, add .4 mhz to the frequencies just decided upon: 3.85 to 4.45 mhz. This what the oscillator must tune.

Digging through the junk box I located two 100 pfd double-bearing Hammarlund variables that are still quite common. For them I always assume they'll tune 8 pfd with plates unmeshed to 100 pfd with plates fully meshed. That's a pretty good estimate. If you're not sure, use the bridge we built in Vol 3 to measure.

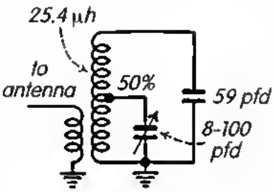
Antenna Coil

Using the bandspread formula on page 24 Vol 2 with 3.45-4.05 mHz and the 100 pfd variable across the whole coil, I calculated 6.3 µh of inductance with a fixed capacitor of 235 pfd. That seemed like a lot of capacitance and too little inductance – a high-C tank circuit.

If the 100 pfd variable is connected to a tap halfway down the coil, 50% or .5, then the capacitor will have far less effect on the tank circuit. It's effect won't be half. It will be a half squared or 25%. So 25% of 8 to 100 pfd is 2 to 25 pfd. This 25% number is not exactly right, but it's close, and works very well for these kind of calculations.

Plugging 2 to 25 pfd into the bandspread formula gives 25.4 µh of inductance with 59 pfd across the whole coil when the variable is connected at a 50% tap. We now have more inductance and much less capacitance. In fact, I can use exactly the same 6-70 pfd trimmer across the antenna coil that I used on each of the IF transformer coils to provide the 59 pfd (actually a bit less when you take into account the stray capacitance added by the wiring.) Being variable, the pad will put the coil right on the target frequencies. This tank circuit feeds the converter tube grid.

Next, I dug through the junk box and found an ancient five pin tube base that had been used to as a plug-in coil years ago. After cleaning it up, I measured a diameter of 1.35" with a length of about .85". Since we'll want to add a smaller winding of about five turns to connect to the antenna, we'll have to be sure that our converter grid winding is less than .85" long.



calculated antenna coil values

We can plug these numbers into Wheeler's formula to calculate how many turns we need to get the inductance required. Using #24 wire at 42 TPI, the formula told me that 27 turns would give 26.7 µh and a coil length of .64" while 26 turns would give 25.2 µh at .62". Both coils are less than .85" long, so there will be plenty of room for the 5 or so turns.

A slot was sawn in the side of the five pin socket and the winding started from the top end. At 13-1/2 turns, a small loop was twisted for the capacitor tap, and then another 13-1/2 turns were wound to give 27 total. A piece of wire soldered to one of the pins was taken out the top of the coil, over the edge, and soldered to the tap loop.

In the remaining space at the bottom of the coil, another five to seven turns of a smaller wire, #30 here, was wound and soldered to pins.

Oscillator Coil

Again, using the bandspread formula with the 3.85 to 4.45 oscillator frequencies and a 100 pfd variable on a 50% tap, I calculated 18.7 µh of inductance with a fixed capacitor of 66 pfd.

Another 1.35" tube base, this one with only four prongs was found in the junk box.

I found that if I closewound #22 enamel wire, I could get about 36 TPI. Remember, the coil length is simply the number of turns divided by TPI. For instance: a coil of 27 turns is 27/36 or .75" long.

Plugging #22 wire specs into Wheeler's formula showed that 23 turns would give 19.4 µh and a length of .64. And 22 turns would give 18.2 µh and .61" length.

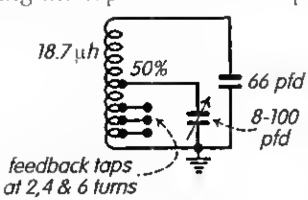
Running another set of calculations with #24 enamel wire which gives about 42 turns per inch closewound showed that 22 turns would give 19.5 µh with a length of .52. With 21 turns the coil would exhibit 18.1 µh of inductance with a length of a half inch.

Although either wire size could be used, I chose #22 and 23 turns figuring that a little longer coil might give a bit higher Q, and that the extra turn could always be easily taken off if not needed. It's almost impossible to add a turn later.

Like the antenna coil we must install a tap loop at 11-1/2 turns for the 100 pfd capacitor. But in addition we need a tap near the ground end for feedback if we are to get oscillation. And we need to be able to vary the amount of feedback. Too much feedback will create far too strong an oscillation which will kill the converter tube's ability to amplify. It would be wise to create several feedback taps so that we have a choice.

I wound two turns starting at the bottom and put in a loop for the tap. Then after another two turns another tap was created. Another 7-1/2 turns was wound giving a total of 11-1/2 turns. A loop was twisted in, and the remaining 11-1/2 turns were wound and end of the wire soldered to a pin. Two wires were soldered into the remaining two pins, one being connected to the tap four turns above the bottom, and the other was connected to the tap at 11-1/2.

In testing the receiver, I found that the converter tube had good gain and oscillated strongly using the tap at four turns. Moving the feedback point down to two turns did not improve gain, so I put it back on four turns. Two turns out of 23 is about 8.7% while four turns is about 17.4%. If you plan to wind a coil for higher frequencies you may want to put in additional taps every two turns until you've got one at about 30%. For instance, a 30% tap for this coil would 30% x 23 or 7 turns. If the coil you wind has 18 turns, 30% of 18 is 5.4. So you may want to put taps in at 2, 4, and 6 turns for feedback. In wiring up your receiver, BE SURE that the feedback tap is closest to the end of the coil tied to ground, otherwise you'll never get it to oscillate.



calculated oscillator coil values

In winding your own coils, you have to use whatever you can find. You may want to use whatever wire you have on hand, say #26. Wind a small coil with a few turns separated by string. Use a ruler to determine the turns per inch, and use that number in your calculations. If you discover, for example, that you're getting 8 turns per inch with string spacing, you can use that number in your formulas. And if you use the string to accurately space the wire, many other gauges will work, too. You're not stuck using the coil specifications published in books and magazine articles.

So did the coils work? The first time. Right on frequency. Well, the truth is, they actually tuned a bit more bandwidth than I wanted. The antenna coil tuned almost exactly 3.5 to 4.0 and no more. But the oscillator coil could convert signals that ranged from about 3.3 to 4.1 – more than I wanted. But that's because of the extra turn and possibly the socket.

If you find that your coil has too wide a range, you can remove a turn. To compensate for the lost inductance you have to add a little more fixed capacitance with your trimmer to bring the tank circuit back to the desired frequencies. That means the 8 to 100 variable capacitance provides less of the total capacitance, and as a result, it tunes a narrower band of frequencies. If you find the bandwidth is not large enough, you'll have to rewind the coil with more turns.

The coils are installed in sockets held above the breadboard with standoffs. The antenna coil was placed in a cheap ol' phenolic wafer socket. Because the windings are so near to the bottom edge, a metal socket could change the inductance. I suspect this is exactly what happened with the metal four pin socket I used to hold oscillator coil. The steel rim supporting the phenolic socket, no doubt, increased the inductance of winding slightly which increased its tuning range. Had I used another wafer socket with much less metal, the 27 turns might very well have been dead on frequency like the antenna coil.

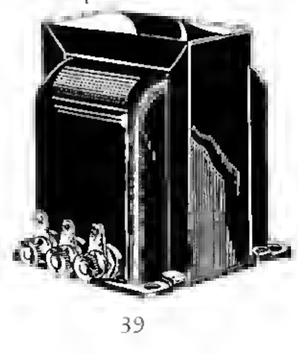
Winding coils for any receiver is a monstrous pain if you use cut-and-try methods. You can use the winding specs provided in magazine articles and books, but ultimately you need to calculate your own specs to fit the components you have on hand. I don't know about you, but despite the boxes and boxes of parts I have on hand, I never seem to have exactly the part specified in the construction article. So being able to adapt is essential. The formulas work. Use them.

Setting Alignment Oscillator Frequency

Before you can use the alignment oscillator, you have to put it on frequency. If we had a precisely calibrated dial on our oscillator, we could just dial in 400 khz. But we can't. So just use your digital frequency counter. The trouble is that the truly impoverished radio builder doesn't have a counter (but should always be looking to acquire one.) If you have one, hook it up to the oscillator, and set the trimmer until you have 400 khz.

But you don't need a frequency counter. What you DO have to have is an AM radio receiver, one that tunes from 550 to 1600 khz. You can use it to detect harmonics of the fundamental frequency. It works like this. Our oscillator will put out a very strong 400 khz fundamental signal, but in addition it will put out much weaker signals at 800 khz, 1200 khz, 1600 khz (multiples of the fundamental) and on up the band. Each signal is separated by 400 khz. If we have our oscillator set at 450 khz, we'll find a signal on the AM radio at 450 x 2, or 900, and 450 x 3 or 1350. The 900 and 1350 signal are, of course, separated by 450 khz. You'll know what frequency your oscillator is running on by noting the distance between adjacent harmonics. Two harmonics at 1000 and 1500 are separated by 500. So the oscillator must be set to 500 khz.

We can set our oscillator by tuning the AM radio to about 800 khz, and by connecting a length of hookup wire to the output of the oscillator to simulate an antenna. As you adjust the oscillator trimmer, the AM radio should go quiet, indicating the oscillator has taken control. Now roll up the AM radio dial and see if radio goes quiet in the vicinity of 1200. If it does, you're on 400 khz. If it doesn't go quiet, move up the dial to about 1600 and see if you can find a quiet zone. If you find one there, the distance between signals, 1600 minus 800 = 800, will be your fundamental frequency. You're much too high. If you find a signal at 750, 1125, and 1500, you'll know that you're a bit low at 375 khz because all of these signals are 375 khz apart.



This is certainly not an ultra-precise of determining frequency, but for our needs it's more than accurate enough. Use it to put your oscillator on 400 khz (or whatever you think it should be.)

Getting it to Work

The first step in getting the superhet working is to double check all the wiring. Be sure that you don't have some wire with B+ on it touching foil or another wire. It's easy to do.

Next, put only the 6C8 in its socket, remove the grid cap, hook up the earphones, shut off the BFO with the panel switch, and turn on the filament voltage. You should see a the filaments glow a dull red. After 30 seconds or so, turn on the B+. You should hear a little noise. Put your finger on the grid cap. It's safe. There is no voltage on the cap. You should hear a fairly loud hum indicating the amplifier is working. If you don't hear anything, put your multimeter on pins 2 and 7 to be sure you have about 6 volts AC feeding the filament. Switch your meter over to DC and touch pin 3, the plate. Be sure you have about 90 volts. Be sure that you have about 5 volts on pin 4, the cathode, on the socket. If you don't have these voltages, you most likely have a wiring error. About the only other possibility is a faulty component. A little detective work is called for.

Then I think you should install the 6SK7 in its socket. Turn the gain pot all the way to the ground end which is maximum gain. Measure pin 5, the cathode, and be sure you have 2.5 to 3 volts. The plate should have full B+ on it. You might want to make sure you have filament voltage on pins 2 and 7. Again, if you don't find these voltages, you've probably got a wiring problem. The circuit is so simple, there is very little that can go wrong.

Now we start alignment. Lay the leads from the alignment oscillator very near the grid lead feeding the 6SK7, pin 4. You don't have to actually connect to anything. Stick them inside a plastic bag if necessary so they can't short something out. Just getting it near the grid should be enough. Hook the oscillator up to the nine volt battery, and turn on the audio oscillator. If you're lucky, you'll hear a faint tone in the earphones. Adjusting the pitch on the audio oscillator feeding the alignment oscillator should change the tone you hear in the headphones. That means you're hearing the alignment oscillator and not some signal from aliens parked on your front yard.

Most likely you won't hear anything. That's what happened to me. Take a screwdriver, or better yet, an alignment tool with a plastic shaft and adjust the trimmer on the output of the second IF transformer feeding the detector grid. Then try the capacitor on the input side of the transformer. And then the variable on the grid of the 6SK7. One of these adjustments should give you a very faint tone in the headphones. Once you have the tone, adjust all three trimmers for maximum volume.

If you still don't have a tone, feed the output of your alignment oscillator into one end of a .01 capacitor, and hook the other end of the capacitor to pin 8, the plate, of 6SK7. Adjust capacitors on the input side and output side of the 2nd IF transformer for maximum volume.

In doing this alignment you should find that the detector is quickly overwhelmed with signal. The alignment oscillator pumps out far more power than we need. When that happens, reduce the volume control on your audio oscillator and/or just lay the oscillator leads near a grid lead (without shorting anything out). Doing that should provide a weak but yet strong enough signal for you to go through and tweak everything to get all the coils very close.

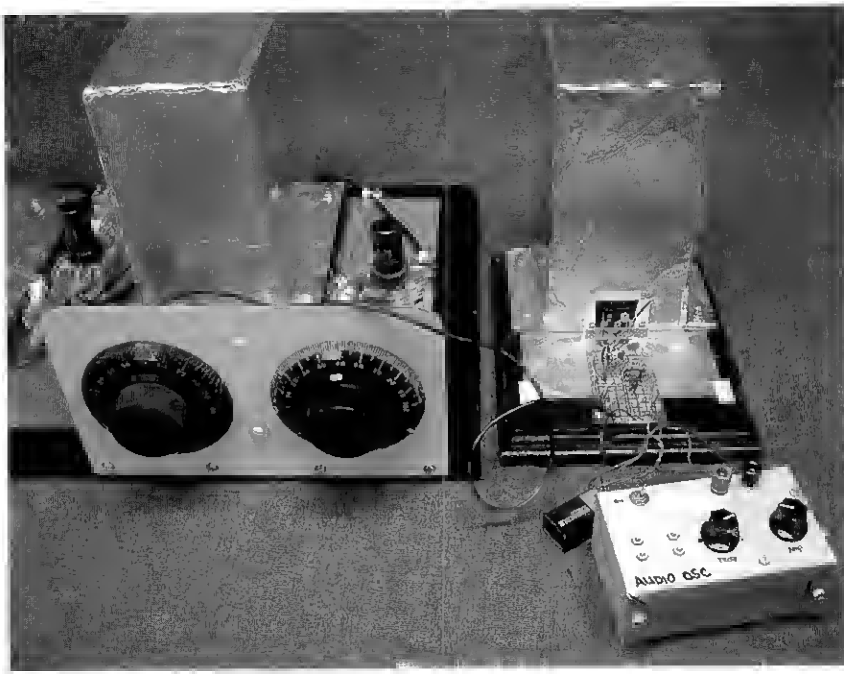
If, despite having tried all these things, you still can't get it to work, then there must be something wrong with your tubes, sockets, the voltages, or something else. Of course, this assumes that you made all your coils very much alike, and that you put identical capacitors across each of the windings.

Once you have a nice tone in the headphones, shut the audio oscillator off, but let the alignment oscillator run. Turn on the power to the BFO with the panel switch. Set the BFO tuning capacitor on the front panel to half mesh. Take your alignment tool and adjust the trimmer on the BFO coil. You should hear a number of squeals, one of which is louder than the rest. Continue to adjust until the pitch gets lower and lower, disappears, and then gets higher again. In other words, adjust for "zero beat". On my receiver this adjustment is touchy – too touchy, really. Once done, adjusting the BFO capacitor on the front panel should vary the tone through zero beat. I used a 100 pfd variable capacitor in series with a fixed 10 pfd. For my coils and layout, adjusting the variable from minimum to maximum varied the pitch from very high to none to very high. If you may have to change the 10 pfd to something more if you use a smaller variable capacitor, or something smaller if the variable tunes too quickly. A little experimentation will be needed.

At this point you have the IF amp, detector, and BFO fairly well aligned and working nicely together. Now it's time to insert the pentagrid converter tube and let it warm up. You should have filament voltage on pins 2 and 7, again, B+ on pins 3 and 4 (plate and screen), and about -5 volts on pin 5, the oscillator grid. The minus five volts is the bias created by the grid leak pair, and is present only if the tube is oscillating. If it is not oscillating check your wiring. Be sure the tap on the coil you chose is close the ground end of the coil and not the high end. It's important. Troubleshooting the oscillator is no different than troubleshooting a regenerative detector, and in fact it's easier. Even the worst, most poorly wound coil with the poorest choice of feedback tap has easily oscillated in the 6SA7 breadboard circuits I've lashed together. So if your oscillator doesn't work, the problem must be very simple. Start investigating. You'll figure it out.

Next, turn the audio back on feeding the alignment oscillator and attach the alligator clip to the edge of the coil form on which the antenna coil is wound as seen in the photo at the bottom of page 35. With signal now getting into the 6SA7 grid, you can adjust the trimmer on the input side of the 1st IF transformer (6SA7 plate) for maximum signal. In fact, reduce the signal strength to a minimum and adjust all the trimmers, including the BFO, one last time for maximum signal and for zero beat. Shut off the alignment oscillator. Having done this, you are now an expert at superhet alignment. It's not tough. It takes longer to explain it here than it does to do it.

All that's left to do is check the front end coils, that is, the antenna and oscillator coils. Get out your grid dip oscillator (GDO) and put it near the 6SA7. Turn on the BFO. Tune the



Alignment oscillator and audio oscillator feeding signals into the antenna tank circuit for the final check on alignment.

GDO back and forth through the 3 and 4 mhz frequencies. You should hear two loud whistles, one is the desired signal, the other is the image. Set the GDO (or signal generator if you have one) to about the middle of the 80 meter band, 3.75 mhz and put the oscillator variable capacitor on the front panel slow-motion dial drive at about half mesh. Now adjust the trimmer across the oscillator coil until you hear the loud squeal of the GDO. If your coil calculations are correct, and you've wound the coil in accordance with your calculations, you should find that fully unmeshing the oscillator plates will let you hear a signal around 4 mhz on the GDO dial (assuming, of course, the GDO dial is reasonably accurate). Fully meshed plates should let you hear a signal with the GDO is set to about 3.5 mhz. If you're not getting the right range or you're getting the wrong frequencies altogether, the most likely reason is that something is wrong with the oscillator tank circuit – wrong capacitor values, wiring problems, wrong number of windings, etc.

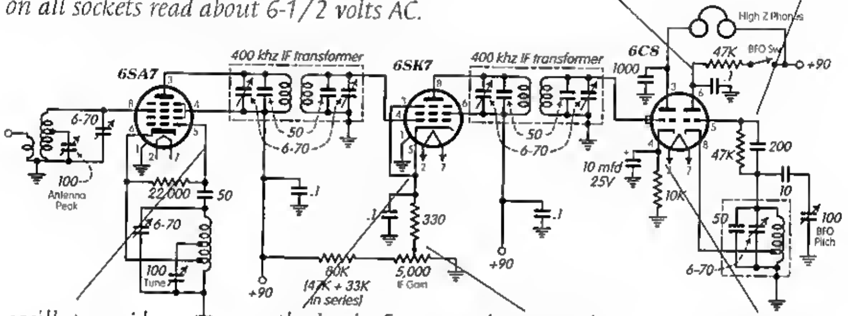
Setting up the antenna coil is done the same way. Set the GDO to about 3.75, tune it in with the main tuning capacitor, set the antenna capacitor plates to half mesh, and adjust the trimmer for maximum volume. You'll find that the antenna tank circuit tuning is quite broad and not at all critical, and that's why you really don't need a slow-motion dial drive on the antenna tuning capacitor. You can check the range of the antenna tank by tuning in a signal at about 3.5 and 4 and make sure that you can maximize the signal you hear

Approximate Voltages

In addition you should find 90 volts B+ on plates and screen grids. Be sure pins 2 and 7 on all sockets read about 6-1/2 volts AC.

BFO plate, pin 6: 33 volts

BFO grid: -5 volts



oscillator grid pin 3: -5 volts

cathode pin 5: 2.5 to 3 volts

gain pot varies voltage from 0 to 12 volts

cathode, pin 4: 5 volts

in your headphones by adjusting the antenna capacitor. If you can't peak all signals from 3.5 to 4, then the problem can only be the tank circuit.

At this point, you can hook your receiver up to an antenna. The 80 meter band doesn't offer much more than noise during the day, and doesn't come alive until sundown. If that's the case, you can place your GDO at about the middle of the band several feet away on the work bench. With a signal to listen to, you can try moving the tap on the oscillator coil closer to the ground end. If doing this increases the strength of the signal in your earphones, try moving down another tap if there is one. If you hear no change in signal strength, put the wire back on the tap where it was. If you use too high a tap on the coil, the pentagrid converter oscillates so strongly that its ability to amplify is destroyed – poor conversion transconductance. If the tap is too close to the ground end, the tube may not oscillate, or it may only oscillate at one end of the band or the other.

Having made all of these adjustments, you're now a full-fledged superhet builder. Ham radio operators over the years have built transmitters of all shapes and sizes. Yet very few radio amateurs have ever built a receiver, not even the simple superhet you've just completed. And that's a shame, because we both now know how easy, inexpensive, and satisfying building a radio can be. As crude as this receiver is, it CAN be used on the air. Those hams really missed out on something. But you've done it. You deserve a pat on the back.

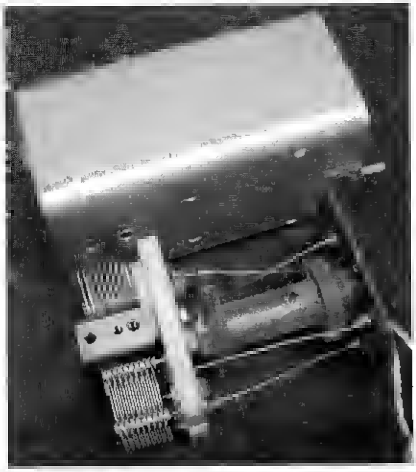
To simplify construction I purchased these tiny ceramic 6-70 pfd trimmers from Mouser for a bit more than a dollar a piece and used them on all coils. They're intended for solid-state circuits and have a low voltage rating, but work very well since in our radio, we put practically no voltage at all across them. There are many other trimmers available from many other dealers. Search!

Commercial IF Transformers

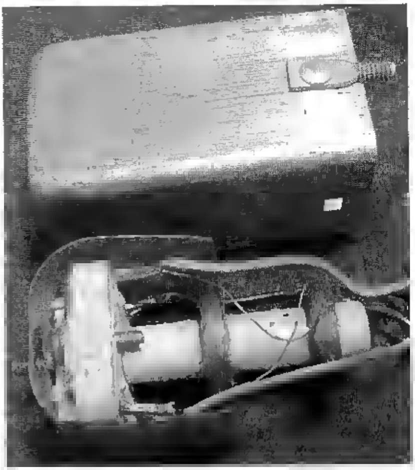
If you have or can find commercial IF transformers, use them. Some are new, in-the-box transformers, but most have been stripped out of old radios. Half the transformers I've acquired for little or no money are bizarre animals that don't fill my needs. The other half look something like these.

You'll find them at flea-markets, in boat-anchors, or you can get them from dealers in antique/used parts.

Miller 132 khz — *National 460 khz (NC-200)* — *Stanwyck 355 khz* — *Meissner 455 khz* — *Millen 1600 khz*

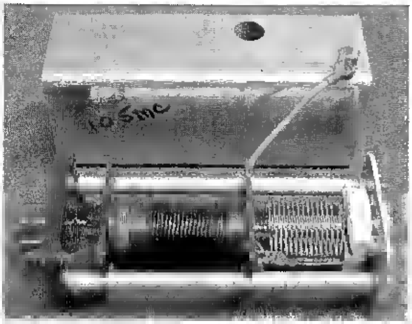


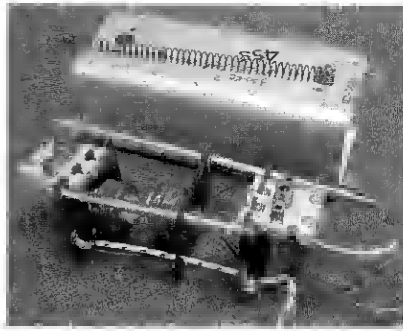
This coil was stripped from a 1941 vintage National NC-200 receiver. Two universal wound coils on a plastic form can be seen to the right. Two air-variable trimmers to the left tune the transformer. Air variables are preferred for their stability over time. Be sure there are no cobwebs or bugs between the plates. These turned up at a flea market for 50¢ along with other NC-200 components.

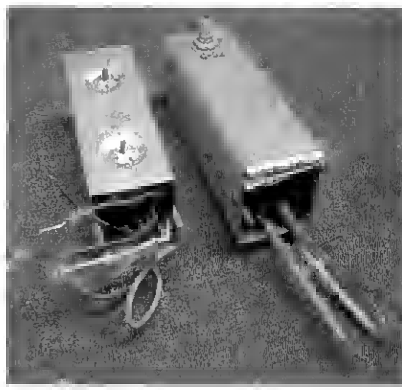


This 455 khz IF transformer consists of two universal wound coils positioned much closer together on the coil form than those seen in the NC-200 transformer. Cheaper compression mica trimmers can be seen at the left end. This is, no doubt, a transformer built for an inexpensive AM broadcast radio. The NC-200 was considered a high-quality communications receiver in its day.

Avoid Transformers Like These

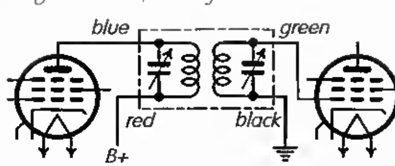






(above) This is a high-quality 10.5 mc IF transformer. Any transformer with a grid-cap lead is usually 50 years old or more. (above right) This is an unusual variable coupling transformer. Pushing a spring-loaded shaft brought the windings closer together to create more coupling. (right) The transformer on the left has too many wires coming out of it. And the cheap construction makes getting it apart to investigate its internal wiring and getting it back together difficult at best. At the right is, according to the slip of paper inside the can, a Hallicrafters BFO transformer. You can tell it's unusual by the heavy shielded leads exiting the can. YOUR BEST BET is to look for cans that have four wires: green, red, black, blue protruding from the bottom on the can.

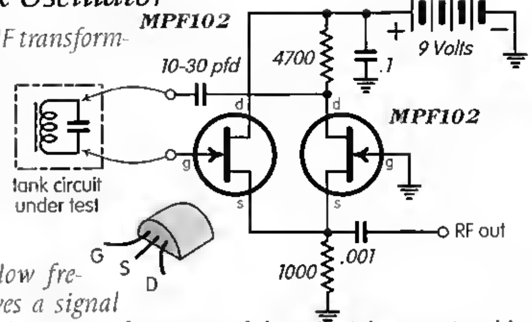
Most run-of-the-mill IF transformers use the standard color code shown. If your transformer does not use the code, you may have something unusual, or you may not have a transformer at all despite the fact that it resides inside an extruded aluminum can.



Three varieties of IF transformers have been manufactured. The input transformer is installed on the plate of the mixer, and is built with undercoupling so that selectivity is maximized. The interstage variety is built to have coupling that produces good selectivity but with minimal loss so that the IF tube can amplify adequately. The output type of IF transformer is built to drive the diodes that appear alongside the cathode of specialized tubes like the 6SQ7 and 6AV6. It has poor selectivity, but heavy coupling to drive the low impedance diodes. An impoverished radio builder always uses what he has. Any one of these commercial IF transformer varieties will probably give you quite acceptable results.

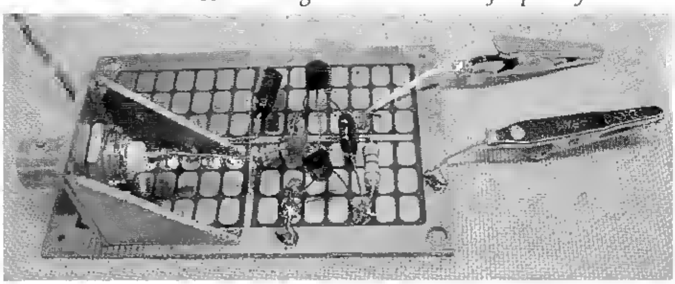
IF Transformer Check Oscillator

It's almost impossible to check IF transformers with a grid dip oscillator. And other methods load down transformers too much. Just attaching probes can add so much capacitance to a transformer that a 455 khz unit may read 275 khz!



This oscillator clips to low frequency transformers, and gives a signal that is very close to the natural resonant frequency of the coil. A known 455 khz transformer, for instance, registers 465 khz on the frequency counter (below).

I use my check oscillator with a Heathkit frequency counter I bought years ago. I have another, an old but high-quality 100 mhz Hewlett-Packard, that I bought from dealer for only $60. Good counters are available. But here again, you don't need a counter. When measuring the frequency of the transformer you can use an AM radio and the harmonic technique used to set the alignment oscillator frequency.



The oscillator is built on a tiny printed circuit board. The alligator clip connects to the coil, the BNC connector drives the frequency counter, and another clip is used to get power from the 9 volt battery.

Other Topics to Study

We've built a simple, but surprisingly good superhet. Unlike crystal sets and regenerative receivers, there are many ways to expand and improve superhets.

We have not examined basic issues of unwanted interactions of the local oscillator, incoming signals, and IF frequencies. These problems were once called birdies, but are now referred to as spurious responses, or spurs. Frequency conversion of unwanted signals creates image problems which are most severe with simple receivers with a low IF frequency. Solutions include higher IF frequencies or multiple conversion.

Selectivity can be improved with the use of crystal filters, both the simple types of the 1930's and 40's, and the more modern multiple-crystal types. Introducing regeneration into the IF amplifier tube will improve the Q (and the noise). It can be done by adding a winding, raising the IF amplifier cathode above RF ground, or by using an outboard tube and tank circuit usually called a Q-multiplier. An audio version of the Q-multiplier, called the Select-o-ject, is worth experimenting with.

And you can add fancy audio stages, rf amplifiers, down converters, crystal calibrators, product detectors, and on and on. If the terms used here are new to you, it's time to dig through old radio books and find out what you've been missing.

The first two references below are written for builders. The others are for engineers.

WIRELESS COILS, CHOKES AND TRANSFORMERS AND HOW TO MAKE THEM, edited by *F J Camm*, George Newnes Ltd, London, 1938

"The Double-Tuned Circuit: An Experimenter's Tutorial", Wes Hayward, QST, December 1991 and QRP POWER, ARRL, 1996

"Double-Tuned Transformer Design", D Espy, ELECTRONICS, Oct 1944, p 142

"Graphical Analysis of Tuned Coupled Circuits", Harrison & Mather, PROC IRE, Sep 1949, p 1016

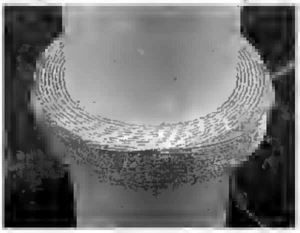
"Aids in the Design of Intermediate-Frequency Systems", Gardiner & Maynard, PROC IRE, Nov 1944 p 674

"Measurements on Intermediate-Frequency Transformers," E Stern, JOUR BRITISH INST RADIO ENGINEERS, Apr 1949, p 157

"Notes on Intermediate-Frequency Transformer Design", FH Scheer, PROC IRE, Dec 1935, p 1483

Winding Universal Coils

Professional IF transformers use universal windings to get high inductance and high Q in a small space. Universal windings are self-supporting and must be wound by machine. You may be able to get results of a sort with the Morris and/or Gingery coil winder with tinkering and luck, but to do top-of-the-line predictable winding, you need a precise machine with heart-shaped cams and an almost infinite number of precise gear ratios.



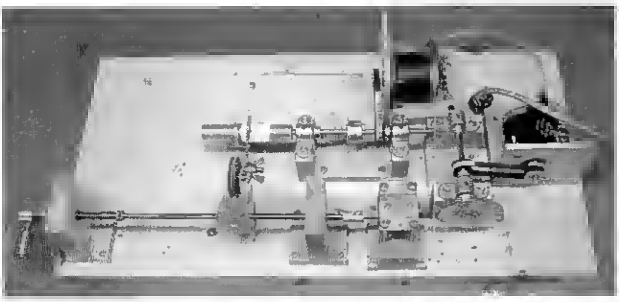
This coil wound with heavy Litz wire exhibits a Q of 135 at 300 khz

Assuming such a machine is available, precise gear ratios must be calculated based on coil form diameter, winding thickness, and the diameter of the wire. A guide finger must be chosen or fabricated to a precision of a few thousandths of inch, and it must be very precisely adjusted. Unless these conditions are met, the chances of winding a tight, self-supporting coil are close to zero.

Universal coils, like all coils, have maximum Q over a small range of frequency. That range will be determined by the number of turns per pie, the number of pies, their separation, the type of wires used, etc. Most of these details are trade secrets.

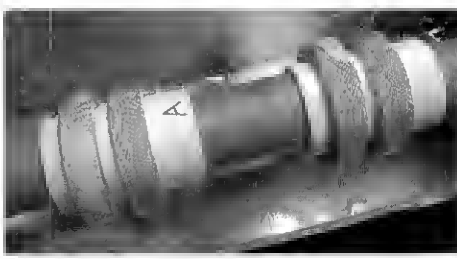
Winding universal coils is quite difficult. You need a machine similar to a lathe. Then you must learn how to use it expertly. Then and only then can you begin to wind professional quality IF transformers.

(right) Litzendraht (Litz) wire consists of many fine strands of wire, individual insulated, wrapped into a larger cable and covered with a cloth-like insulation. For instance, a 7 x 41 Litz, consists of seven strands of No. 41 enamel wire twisted together. Since Litz wire reduces skin-effect losses, winding universal coils with anything but Litz is self-defeating. A spool of Litz can cost $100 to $150.



(above) This homemade universal coil winder uses stepper motors driven by digital electronics to achieve the almost infinite number of gear ratios necessary to wind universal coils of different geometries. If this area of experimentation interests you, you must read AND understand Querfurth's book on coil winding. It is an incredible source of practical information, and is available on the used book market. After reading his book, you may decide that the process is too involved to pursue.

(below) An experimental homemade IF transformer sits inside its test shield. Measurements indicate a loaded, in-circuit Q of 85 at 220 khz. These double-pie windings use smaller diameter Litz wire to achieve high Q and tight windings.



The first three references below are the best of the lot. Read them first.

COIL WINDING, Wm Querfurth, Geo Stevens Mfgs Co Inc, 2nd ed 1958

"Universal Coil Winding", E Watkinson, JOUR BRITISH INST RADIO ENGINEERS, Feb 1941, p 61

"The Design of the Universal Winding", LM Hershey, PROC IRE, Aug 1941, p 41

"Universal Coil Design," AW Simon, Radio, Feb-Mar 1947, p 16

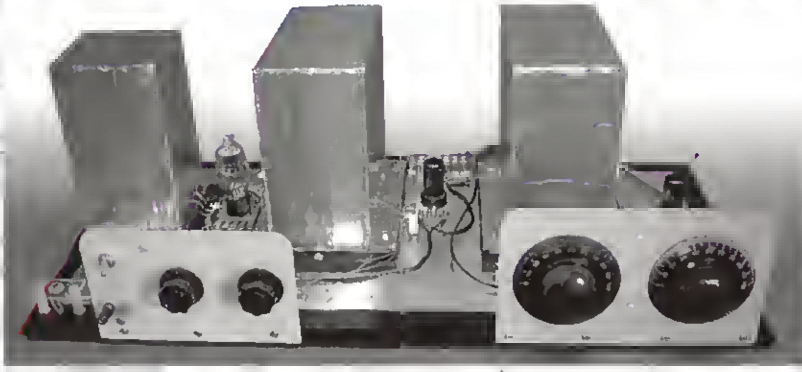
"Theory and Design of Progressive and Ordinary Universal Windings", M Kantor, PROC IRE, Dec 1947, p 1563

"On the Theory of the Progressive Universal Windings", AW Simon, PROC IRE, Dec 1945, p 808

"Winding the Universal Coil," AW Simon, ELECTRONICS, Oct 1936, p 22

"Determining Form Factors of I-F Transformers", WC Vergara, ELECTRONICS, July 1949

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...

www.lindsaybks.com

ISBN 1-55918-293-8
90000
9 781559 182935

5