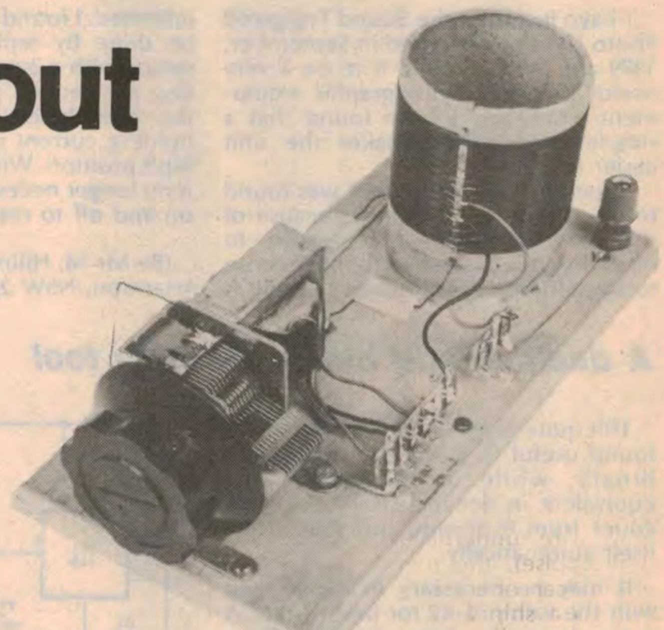
Basic Electronics

Let's talk about Crystal Sets



If you are just becoming involved with electronics as a hobby but have not yet decided what you would like to build as your first project, then we have just the thing for you. Generally the first thing that the budding electronics hobbyist constructs is a crystal set and despite the easy availability and the low cost of a transistorised radio receiver today, there is still that special satisfaction gained from building your own. We know you'll enjoy building it.

The crystal set was the first radio used by the public for broadcast reception. Its inherent simplicity was its main advantage, since it suffered from limited sensitivity, selectivity and signal output. When better sets became readily available it was soon discarded. Yet enthusiasts continually revive it from time to time, and marvel that such a simple device works as well as it does.

Rather ironically, the crystal set built as a novelty today is likely to perform a whole lot better than the serious version of 1923. Technological advances aimed at more elaborate circuits can also help the crystal set. Today we can produce more efficient coils, we have more efficient detectors and more efficient headphones. On top of that, broadcast stations use many times the power they did in the old days. It all adds up to a quite surprising order of performance for the "simplest radio set".

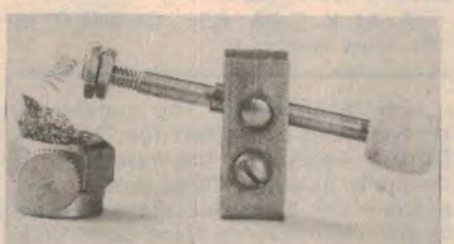
When I built my first crystal set nearly 15 years ago, one thing really puzzled me. That was the name "crystal set".

I knew what a crystal was — it was a device used as a frequency standard. But there certainly wasn't one of those in my set.

I wondered whether I had left something out, but no — "Radio & Hobbies" (predecessor to "Electronics Australia") assured me I hadn't. Besides which, the darn thing worked!

The trouble was, I was born about 50 years too late. Had I made a crystal set early this century — or even later — I would have used what was then one of the first types of detectors — a crystal.

The crystal detector of 50 years ago bears absolutely no resemblance to the frequency standard crystal we know today. Whereas the latter is a crystal of quartz, very accurately cut and mounted, the crystal detector resembled, to some extent, a small lump of shiny coke.



Crystal detectors used to look like this.

This material was actually galena, or lead sulphide. It was not just one crystal, but a crystalline structure. To make contact with the crystal, a fine wire was used to press against the surface. This could be moved around the surface of the crystal to find the best position. The wire assembly was known as a "cat's whisker".

Even though the cat's whisker and crystal were not forgotten, the invention of the thermionic valve led to their eventual demise. From the late 1920's radio receivers began to move away from the novelty stage, and crystal sets were left to the experimenters.

The invention of the germanium diode was the last straw as far as the crystal and cat's whisker were concerned but, rather strangely, created a mild revival for the "crystal set" itself. In one small package came all the features of the crystal detector, but with improved sensitivity and none of the disadvantages. Perhaps some readers remember how the fiddling cat's whisker would move at the slightest heavy footstep — just as England won the test match!

So it was that germanium diodes became the "crystal" in a crystal set. And they are used in sets other than crystal sets. Many transistor radios use diode detection in exactly the same way as in the crystal sets to be described.

A crystal set is interesting because it performs, at an elementary level, all the functions needed to receive a radio signal, and most of those performed by larger sets. Granted, it does not do all of them particularly well, but an understanding of what it does and where it fails provides excellent grounding for understanding more elaborate circuits.

It is not difficult to understand how a

radio receiver processes a transmitted signal, at least at an elementary level. A first requirement is to understand the nature of the signal. This consists of a radio frequency "carrier" which is "modulated" by the speech or music we wish to transmit. The modulation is achieved by varying the amplitude of the carrier at the frequency of the signal. (Hence, amplitude modulation). Thus, if we wish to transmit a 1000Hz note we cause the carrier amplitude to vary 1000 times a second.

Reception of such a radio signal requires that we provide four basic facilities, (1) means to intercept a portion of the radiated signal, (2) a means to separate the wanted signals from unwanted ones, (3) a means to extract the audible ("audio") information from the radio frequency carrier and (4) a means to convert the audio signals into sound.

For (1) we use an aerial or antenna system. Considered at its most basic this is simply two plates of a capacitor. Traditionally, one plate is the aerial wire and the other plate the earth. However, the second plate can take a number of forms. It may be a second aerial wire underneath the first (a counterpoise), the metal frame of a vehicle (car or aircraft) or the metal body of a ship and the surrounding water. Generally, the larger the plates and the greater the distance between them, the more signal will be intercepted.

For (2) we use a tuned circuit or, in more elaborate sets, a number of tuned circuits.

A tuned circuit consists of two components; a capacitor and an inductor. The exact manner in which it works is quite complex, and somewhat beyond the scope of an article like this. Suffice it to say that any given combination of inductance and capacitance will resonate at a particular frequency. We make it resonate at the frequency of the station we wish to receive.

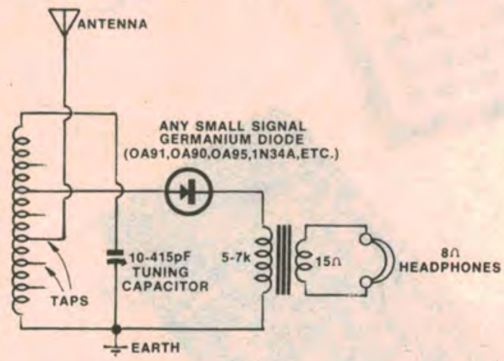
In our crystal set the tuned circuit is coupled to the two sides of the aerial system. At resonance, it allows the maximum signal voltage to be developed across it. Signals at any other frequency will develop a lesser voltage. By varying the inductance, or capacitance, or both, we can adjust the resonant frequency and select the signal we want.

For (3) we use our much discussed "crystal" or the diode which has replaced it. It can be considered simply as a half wave rectifier. The diode clips off one half of the cycle, leaving either a positive or negative going waveform.

Remember how we described an amplitude modulated signal? How the carrier strength (amplitude) varies up and down at the frequency of the modulating signal? Well, it is these variations in strength we wish to recover.

Since the carrier frequency is much too high for us to hear, neither can we hear any changes in its strength. As far as the ear is concerned each half cycle of the carrier occurs so rapidly after the previous one that it might just as well have occurred at the same time. As a result the two halves effectively cancel one another.

But if we remove one set of half cycles (with a rectifier) the remaining ones will all be effective in the one direction. While we still cannot hear the carrier frequency, we can create a new signal which is an exact copy of the changes in the carrier amplitude. This is our audio signal.



Our circuit employs a germanium diode and a transformer coupled set of low impedance headphones.

This brings us to requirement (4); a means to convert the audio signal into sound. For this we use a pair of headphones. In their most common form these are like miniature loudspeakers. When a varying current flows through the voice coil it causes the loudspeaker cone to vibrate in sympathy with it. This vibration we hear as sound. This is necessarily a much simplified explanation of headphones; also other types operate on quite different principles.

The waveform at (a) represents a modulated RF carrier. (b) shows the waveform after rectification by a diode while (c) is the audio modulation.

But it is not hard to see how a series of RF pulses, all operating in the same direction, will behave when applied to such a device. Each pulse will try to move the diaphragm, and will succeed to some extent. Each following pulse will have the same effect and, because they occur so rapidly one after the other, each will reinforce the previous one. The inertia of the diaphragm is too great to allow it to respond to the gaps between pulses but not so great that it cannot respond to the relatively slow variations in the strength of succeeding pulses.

As already explained, tuning the set involves adjusting the resonant frequency of the tuned circuit. There are three ways of doing this — adjusting the capacitor and leaving the inductor fixed, adjusting the inductor and leaving the capacitor fixed, or, in some cases, adjusting both the inductor and capacitor.

Most readers will be familiar with tuning capacitors — a device with two sets of plates, which can be adjusted so that the area they have in common changes. When the plates are fully closed ("in mesh") they provide the maximum capacitance obtainable (usually about 400 picofarads). Conversely, when they are wide open they are at minimum capacitance (usually about 10 picofarads).

But now let us look at our most popular crystal set. This one has become our "standard" model, because it is about the simplest and easiest to make. The parts involved are readily obtainable from either the junk box or your normal parts supplier. You should be able to "scrounge" some of the parts, at least.

For example, you should be able to find a suitable tuning capacitor in almost any discarded receiver. Do not worry if it has more than one section as it is still quite useable, as only one section is needed.

Crystal sets generally were connected to a set of high impedance headphones but these are now generally unavailable, so we have opted to use ordinary HiFi headphones and these are matched to the set using an impedance matching transformer. If you don't happen to have a set of these headphones, you will find that the small earpiece usually supplied with portable radios will do almost as well, again with the matching transformer.

The transformer we used in the prototype has a primary impedance of 5000 ohms and secondary impedances of 4, 8 and 16 ohms. The transformer was supplied to us by Dick Smith Electronics who assure us that they have adequate stocks. Another possible source for a transformer would be from an old valve radio or television set.

The headphones are arranged with the voice coils in series. Take note of the headphone plug (usually a 6.5mm jack plug). You should see three distinct sections — the tip, then a ring of insulation, another band of metal, another ring of insulation, and finally the main metal body of the plug. Disregard the main metal body, and make the receiver connections to the tip and first band. It is easier to do this using a suitable socket. These connect to the "hot" side of both voice coils, effectively connecting them in series.

With a good antenna, this set will give quite reasonable volume in the headphones. With an exceptionally good antenna, results are outstanding.

If you have a good antenna setup and you are close to a radio transmitter you may find that the output of the set is high enough to drive a loudspeaker at modest volume levels. If you wish to try this, use the largest speaker you can find. Contrary to popular belief, a large speaker is not harder to drive than a small one. Rather, the larger one may be more efficient.

Now that we have explained how it works, we can get down to building the actual device. The best place to start is the coil.

You will need approximately 15-20 metres of 22-24 B&S enamelled copper wire and a stiff cardboard former. The one we used was a cardboard mailing tube, approx 5.5cm diameter. If thin wall cardboard tube has to be used, it would be wise to give it one or two coats of clear enamel to stiffen it.

The tube should be long enough to allow easy working — say 15cm or so. It can be trimmed after the coil is completed. Incidentally other non-metallic materials can be used for the former, such as a plastic bottle.

Start by drilling two 2mm holes, close together, near one end of the tube. Pass about 15cm of wire through one hole then the other, several times, to provide a secure anchorage. Then wind on five turns (either direction, it doesn't matter) and make a tap. This is to be repeated every five turns.

The easiest way to do this is to wind the tap turn over a match. The match can be pushed up the coil as the turns progress. While we used ten taps on the prototype, we recommend seven. We found that only seven of the taps are useful — and it is easier to wind without taps.

After the seventh tap (35 turns) wind on another 35 turns, making 70 in all. This number will be adequate for coil formers close to or the same as ours, but may have to changed slightly for readers who (a) use different size formers or (b) have a station close to either end of the band.

If the coil cannot pick up stations at the high frequency end of the band, take a few turns off. If it cannot pick up stations at the low end, add a few turns.

As can be seen from the photo, the start, taps and finish are all in one straight line.

To finish the coil, drill another pair of 2mm holes, and pass at least 15cm of wire through them, as before. This wire goes vertically through the coil centre, and emerges through another hole near the bottom. This makes a neat coil and keeps the windings tight.

We used a small tagstrip to mount the diode and provide tags for the headphones connection. A flying lead makes connection from the detector to the tap required. The same system is used for the aerial connection.

On the same tagstrip, connections to the impedance transformer are made.

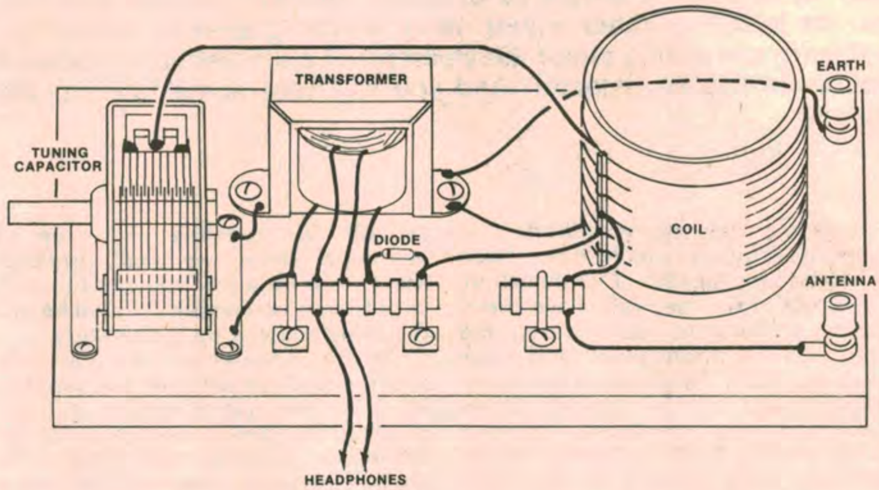
There are a number of ways of fastening the coil to baseboard, but avoid using metallic parts. Metal near the coil may not only change its inductance, but could effect what is called the "Q". The Q is a measure of the quality of the coil — and it should be as high as possible for optimum results.

We glued our coil former directly onto the baseboard. Aquadhere or a similar wood glue does the job nicely. The antenna and earth terminals are screwed directly into the baseboard, with a solder lug under each. A single length of stiff tinned copper wire runs from each terminal to its respective connection.

The tuning capacitor and impedance transformer, can be mounted so that they share a common mounting hole — a convenient arrangement, as we will explain. All parts are screwed into the baseboard using number 4 self-tapping screws.

Because the capacitor and transformer are connected together, the connections from the earth terminal need be connected only to the transformer case, simplifying the wiring. The components on the tagboard are connected by a short length of wire to the capacitor frame.

We fitted an extra three lug tagstrip on the baseboard.One lug connects to the antenna terminal, and another to a tap on the coil. This was for an experiment which we will discuss later. For the present, the two lugs are simply joined together.



Together with a typical set of low impedance stereo headphones, this easy-to-build crystal set can give surprisingly good results.

Use of the crystal set is simple. It does, however, depend on a good antenna and an equally good earth. Remember that there are no power connections, so the set is not earthed through the power cord. You must provide an external earth, preferably a water pipe or a metal stake driven well into moist ground.

Connect the antenna and earth to the terminals the antenna terminal to a tap about midway up the coil, and the diode to the one below — toward the earthy end. Connect your headphones, and you should hear signals when you tune the capacitor. If not; try changing the taps.

The best antenna and detector taps will be found by experiment. The higher taps will give the loudest signal, but poor selectivity, and vice versa. A compromise is necessary depending on your location, size of antenna, etc. Use the highest taps which will allow you to separate the stations.

This, then, is our basic crystal set. Our next article on this topic will describe a number of variations on the crystal set theme, each one designed to exploit one or other of the novel characteristics of the "simplest radio set".