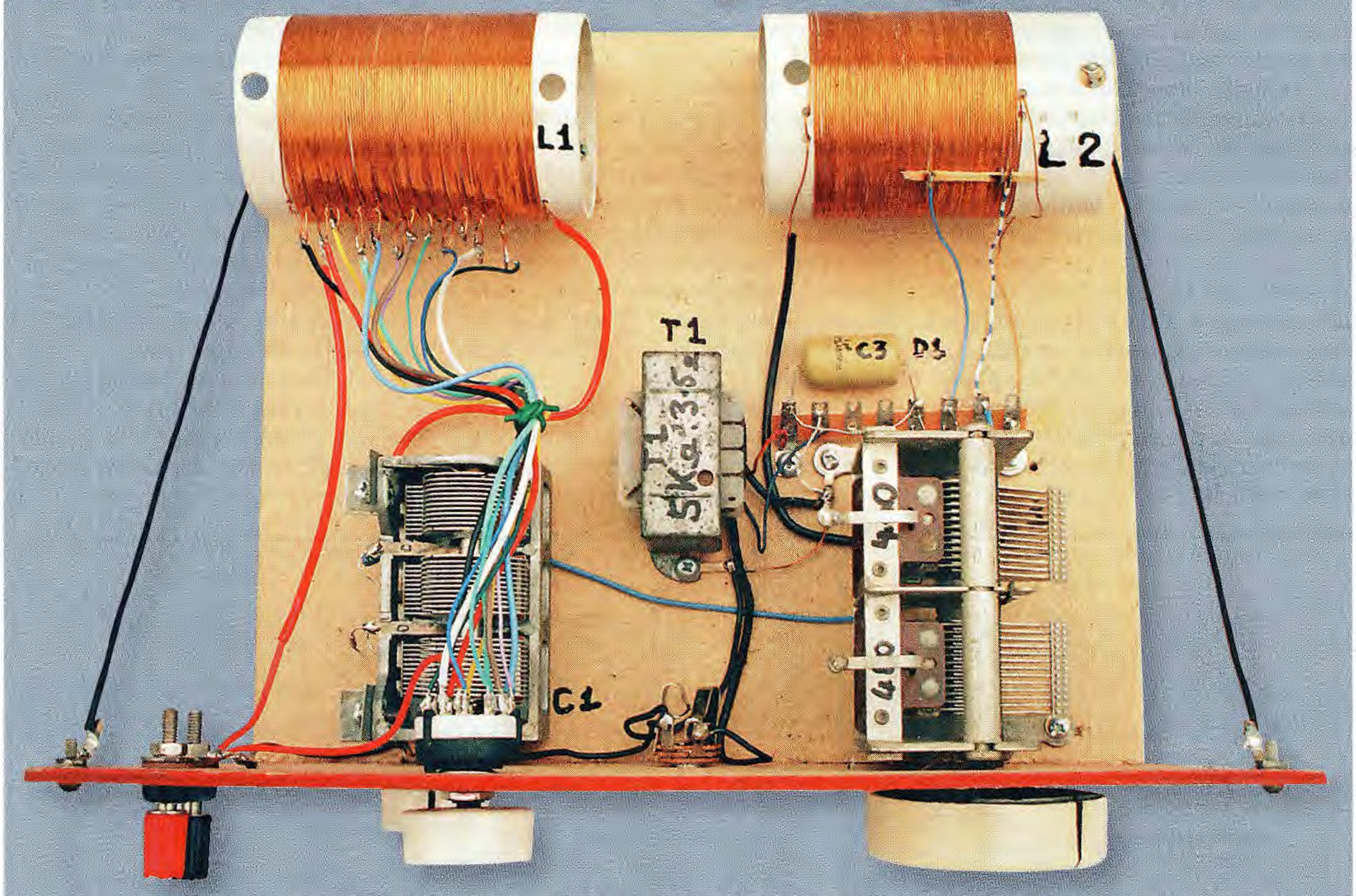
# Vintage Radio

By RODNEY CHAMPNESS, VK3UG

## How To Build A Super Crystal Set




This photo clearly shows the layout of the super crystal set. It's built on a baseboard measuring 280 x 240mm.

**If you've never built a radio receiver, then a crystal set is a great place to start. Here's a design that's very easy to build and get going.**

RADIO SETS using all sorts of detectors have been around since the dawn of "wireless" just over a century ago. Very early in the 1900s, one particular detector gained popularity due to its simplicity and relatively high output. This was the "cats whisker" galena crystal detector – hence the name "crystal set".

Basically, this detector consisted of a galena (lead sulphide) crystal held in a metal cup which formed one end. At the other end was a piece of high-tensile wire wound into a short coil and attached to a positioning lever.

The positioning lever was manipulated so that the "pointy" end of the wire – known as the "cats whisker" – made contact with the galena crystal. As a result, it had one annoying deficiency when compared to other detectors – you had to probe around the galena crystal with the "cats whisker" until a sensitive point on the crystal was found. This was fine until something or someone dislodged the "cats whisker" from its sensitive spot, which meant that the procedure had to be repeated.

This was a nuisance which wasn't overcome successfully until detectors like the OA47, OA79, OA91, GEX66 and 1N34A fixed point contact germanium diodes became available. These devices eliminated the "fun" of trying to find the sensitive spot on the galena crystal, as it had all been done by the manufacturer. If the set didn't work, it was usual to look elsewhere for the fault, since these new detectors were very reliable.

However, I remember reading in "Radio and Hobbies" many years ago – in the "Serviceman Who Tells" – about a crystal set that was brought in because it had ceased to work. There isn't much that can to go wrong with a crystal set and is usual to expect the detector diode to be OK. However, in this particular case, the diode had failed, having been destroyed by a strong signal from an amateur radio transmitter next door. Of course, modern devices are much more rugged than those early types.

## High-performance sets

Designing a high-performance crystal set isn't quite as easy as it seems at first glance. A number of points need to be taken into consideration for a design to be successful.

The first two essential items are a good, high, long antenna and a good earth. I wrote about antennas and earthing in the March 2003 issue and readers should refer to this to achieve good results.

Unfortunately, the antenna/earth system I'd used for several years was inadequate for crystal set operation. The antenna was only about 6m high at the highest point and about 20 metres long. Its replacement has a maximum height of 9m and is around 27m long. It is also generally higher for most of its length than the previous antenna.

Ideally, the antenna should be up to 15m high and around 30m long but achieving this on a suburban block isn't always easy. However, in my case, the modest improvements in height and length noticeably improved the strength of the received signals.

As an amateur radio operator, I have always been well aware that the antenna in use needs to be tuned to the operating frequency. This is particularly important when the antenna is much shorter than a tuned length, which 99.9% of broadcast band receiving antennas are.

An antenna can be tuned by having a (loading) coil in series with the antenna wire where it connects to the crystal set, with either a tuning gang in series with the coil or a ferrite rod inserted into the coil. The coil may be tapped to suit as well (more of this later). In practice, the addition of an antenna tuning mechanism is extremely effective when it comes to increasing the signal level into the set.

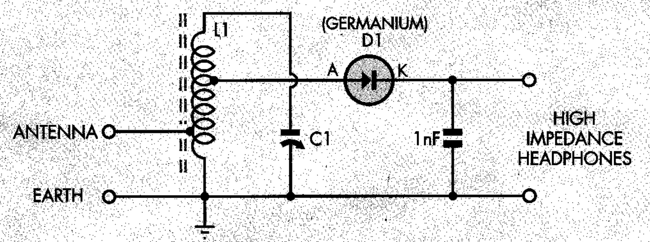



**Fig.1: the circuit for a basic crystal set. Coil L1 can be air-cored (see text for specifcations) or can be wound on a 100 x 20 x 5mm flat ferrite rod using 70 turns of 22 B & S enamelled wire tapped at 10, 20, 30 & 40 turns.**

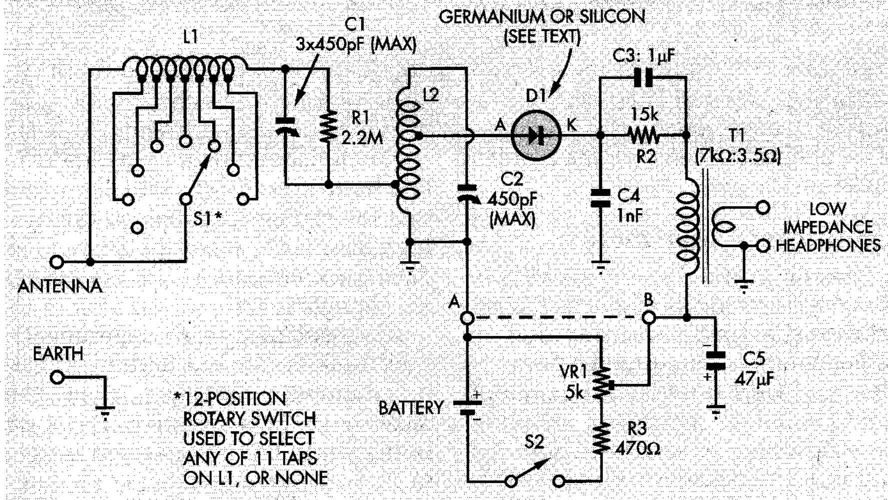



**Fig.2: the super crystal set circuit uses L1 & C1 to tune the antenna circuit, while L2 & C2 tune the received frequency. Transformer T1 is included for driving low-impedance headphones. Also included is an optional detector bias circuit consisting of VR1, switch S2, the 47μF capacitor, the 470Ω resistor & the battery – see text.**

When it comes to making coils, both the coils and coil formers need to be low loss. I've found that 60mm-diameter white PVC tubing (available from plumbing and hardware stores) is quite satisfactory for the job. By contrast, cardboard coil formers can attract moisture which increases coil losses.

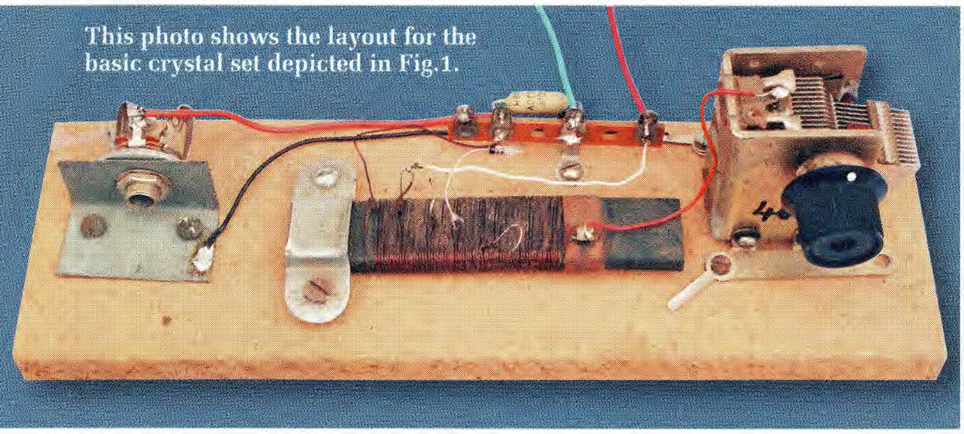
It is important that both the detector and antenna are matched to the tuned circuit(s) for best performance. This is achieved by simply connecting the detector and the antenna to the coil taps which provide optimum matching.

Detector efficiencies can vary considerably and you can experiment with various germanium and silicon signal diodes is to achieve the best results. Note however, that silicon diodes usually require a biasing voltage to operate efficiently as detectors.

## Headphones

Good quality headphones with good sensitivity are also needed to get the best performance from a crystal set. I have a pair of 4kΩ Kriegsmarine headphones which work well but are quite uncomfortable to wear. I also have a pair of Browns "F" type headphones but these have a relatively low impedance of about 150Ω. And I have a couple of other headphones of rather mediocre quality and a pair of 8-ohm padded stereo headphones.

In the end, I wired up the phones socket on the crystal set so I could plug my stereo headphones into the set with the ear pieces in series. I also used a speaker transformer (as used in valve radios) to transform the high-impedance output from the


This photo shows the layout for the basic crystal set depicted in Fig.1.

crystal set to a low impedance output for the headphones. This combination proved to be as sensitive as using the other phones on their own and is much easier on the ears.

## Crystal set experiments

Over the years, I have built a variety of crystal sets ranging a little matchbox monstrosity (mine was anyway) to rather complex twin-tuned coil varieties. And what did I learn from all of this? I found the match box set a very poor performer, as was the twin-tuned coil unit.

The latter unit used a 2-gang tuning capacitor and was a failure because, at that time, I didn't understand that the two (identical) tuned circuits needed to "track" each other. In operation, each tuned circuit was being detuned according to where the antenna and detector connections were made to the respective coils.

"Tracking" for those new to vintage radio is the requirement for both circuits to tune to the same frequency no matter where the tuning control is set on the broadcast band. Anyone who has built crystal sets will be aware that the station locations on the tuning dial alter if either the antenna or detector connections on the coil(s) are changed.

As a result of my early experiments, I fell back on the old faithful single-tuned circuit – see Fig.1. It isn't the most sensitive or selective crystal set in the world but it works and is easy to get going.

In my case, I built one with a normal air-cored coil and another using a ferrite rod as the former for the coil winding. They both worked but would only receive two stations clearly in the Shepparton area – the old 3SR 2kW station on 1260kHz around 20km away and the local 500W community station on 1629kHz about 10km away.

If you want to experiment with a ferrite-rod coil crystal set, the coil information is as follows: 70 turns of 22 B & S enamelled wire tapped at 10, 20, 30 and 40 turns on a 100 x 20 x 5mm flat ferrite core. The experimental layout can be seen in one of the photographs.


**The photo shows the author's Browns "F" type headphones plus two other miscellaneous units. High-impedance headphones (eg, 4kΩ) are necessary for the circuit shown in Fig.1.**

## Super crystal set

I've always wanted to design and build a "super crystal" radio receiver, so I did some experiments back in 2002 with methods of tuning the antenna. My early experimental antenna tuning system was described in the March 2003 issue of SILICON CHIP. Using this device, I could detect four radio stations instead of the single station I could normally receive on my "standard" crystal set.

By this time, I had a reasonable idea of what might work well but without being too complex. However, I didn't want to make a set which used exotic parts, or parts that were hard to make, or one that was so complex that a university degree was necessary to "drive" it.

In particular, a twin-tuned circuit would not be suitable, as getting the two tuned circuits to "track" across the broadcast band using a single control would be impractical. By contrast, it would work if I used two independently tuned circuits but that would add additional complexity and the tuning would be a nightmare. And for best performance, the coupling between the two tuned circuits would need to be carefully done otherwise its performance would be inferior to a crystal set with a single tuned circuit.

As stated, I had previously had quite good success using a loading coil in series with the antenna. This then connected to an antenna tap on the tuning coil. However, it was purely experimental and although it worked well (and improved the number of stations received), it was touchy to adjust.

In particular, the position of the ferrite rod in the coil was quite critical and it had to be adjusted for each station received.

What it did show was that the "Q" of the loading coil was quite high. For those unfamiliar with "Q", it is basically a term relating to the quality (or "sharpness") of a tuned circuit. The higher the "Q", the better a circuit is at discriminating between stations across the broadcast band. After all, we only want to listen to one station at a time!

## Detector bias

Some crystal set designs use a battery and a potentiometer to bias the detector to the point where it just conducts. The reason for this is quite simple.

Diodes all need a certain amount of voltage applied to them before they conduct. As a result, if we apply a DC voltage to a signal diode so that it just conducts, the diode will be in its most sensitive state and will thus give good performance in a crystal set.

This "bias" voltage varies according to the diode used. For example, silicon diodes such as the 1N4148 and the 1N914 require around 0.6V of positive bias to operate, while a germanium diode only requires about 0.2V of bias. On the other hand, the OA47 diode I've used works quite well with no forward bias, which has kept my crystal set just that bit simpler. Your own experience may be different, however so be prepared to experiment.

By the way, transistor radio detectors often use forward bias to improve sensitivity. (Editor's note: forward bias on a diode detector also reduces harmonic distortion).

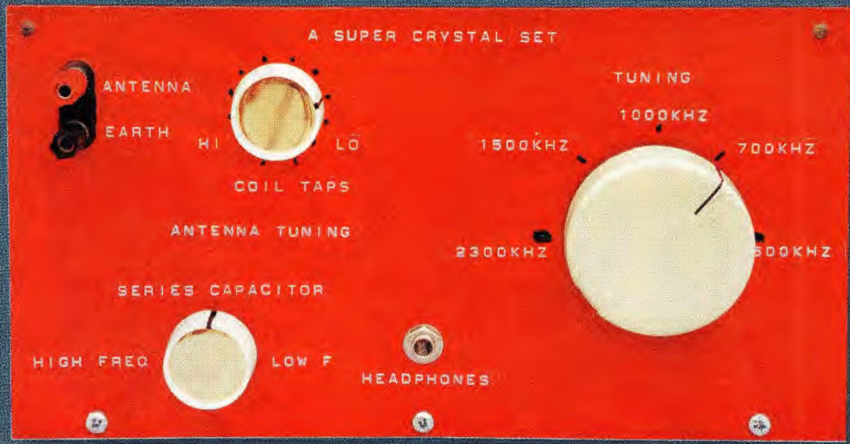
## Detector load

The load that the detector works into is usually a pair of headphones which may have between 2kΩ and 4kΩ total resistance. However, the diode will be more efficient if it works into a higher load resistance and some designs use a resistor of about 15kΩ in series with the headphones to achieve this. In addition, a capacitor of around 1μF is placed in parallel across the resistor so that the audio is not noticeably attenuated.

Although my 4kΩ headphones are good performers they are uncomfortable, so I compared the performance of other headphones against the 4kΩ pair. As stated above, I ended up using low-impedance stereo headphones fed through a speaker transformer. (Editor's note: we also recommend the 32Ω earphones supplied with iPods and MP3 players).

## Putting it all together

The set described here is not only easy to build and operate but outperforms many other so-called high-performance sets.




This view shows the front-panel layout for the super crystal set. A good aerial and earth are necessary to achieve good performance – see text.

Fig.2 shows the circuit. L1 & C1 tune the antenna circuit, while L2 & C2 tune the received frequency. Transformer T1 is included for driving low-impedance headphones, while the optional detector bias circuit consists of VR1, switch S2, a 47μF capacitor, a 470Ω resistor and the battery.

The set was built on a 12mm-thick particle board measuring 280 x 240mm. This is fitted on the underside with four self-adhesive felt pads (available from hardware stores) to keep it clear of the bench.

The front panel is made of thin plywood measuring 300 wide x 160mm high. This was given several coats of red paint from a spray can and the labelling on the front panel completed using red Dymo® embossing tape (to match the paint job).

## Tuning capacitors

Tuning capacitors can be scrounged from old valve radios that are not worth restoring. For C2, I used one section of a 2-gang full-size 460pF tuning capacitor. This has a 3/8-inch shaft which suits few knobs (and certainly none of my collection). It did, however, have a dial drum which was left on. I fitted a cut-down top from a tin of cream spray paint over the top of the dial drum (it fitted perfectly), which makes it look better and acts as a "handspan" dial.

I was more fortunate with C1 which is a 3-gang 450pF per section tuning capacitor, as this had a ¼-inch shaft. All three sections of the capacitor are used in parallel. The only disadvantage with this tuning gang is that it has a reduction drive, which means that more than a full turn of the knob is required to go from minimum to maximum capacitance.

C3 is a 1μF polyester or greencap type, while C4 is a 1nF unit. The voltage ratings of these capacitors can be quite low.

## Resistors & switches

Resistor R1 is used as a "static leak". Its purpose is to prevent a high-voltage static charge from building up across C1 (eg, during storms) which could lead to flash-over. Note also that if a particularly big antenna is in use, it would be advisable to disconnect and earth it when the crystal set is not being used.

Resistor R2 (15kΩ) is the DC load for the detector. Both R1 and R2 can be 0.5W or smaller. If detector biasing is used, R3 can be a 0.5W unit, while VR1 can be a standard 1kΩ linear trimpot or a normal potentiometer. VR1 will not normally require readjustment once set.

S1 is a 12-position switch which selects one of 11 tappings on L1. Only 11 positions are used; the 12th is left with no connection so that the whole of L1 is in circuit. S2 (if fitted) turns the detector biasing on or off as required.

T1 is a standard speaker transformer with a 5kΩ or 7kΩ primary impedance and a 3.5Ω secondary winding. This drives two 8-ohm headphone earpieces in series, so that the reflected impedance to the primary from a 16-ohm secondary load is at least 20kΩ. Within reason, increasing the reflected

**This view shows the author's stereo 8Ω headphones at right and a pair of 4kΩ Kriegsmarine headphones at right. The latter can be used with the basic crystal set circuit shown in Fig.1.**

impedance will assist in maximising the audio output of the receiver.

## Winding the coils

Now we come to the all-important coils (ie, L1 and L2).

First, L1 is wound on a 100mm length of 60mm-diameter white PVC pipe. In my case, I wound on 102 turns of 0.63mm (22 B&S) enamelled wire over a length of 70mm. In hindsight, though, around 110 turns would have allowed somewhat more adjustment range to tune the antenna system.

When winding L1, it should be tapped every seven turns and there should be 12 tapping points in all, starting right from the antenna end of the coil. If your antenna is significantly different from mine, then the number of turns on this coil to achieve optimum tuning will vary accordingly.

L2 is also wound on a 100mm x 60mm-diameter white PVC water pipe and consists of 80 turns of 0.63mm (22 B&S) enamelled wire. This winding is spread over 60mm of the former's length and the coil is tapped at 3, 6 & 35 turns from the "earthy" end.

In my case, I found that using turn three as the tap gave good results. You will need to experiment here – you may need even fewer turns to the first tap if your antenna is larger than mine. Note that the correct position may vary from the high-frequency end of the band to the low-frequency end.

Because the detector load is relatively high, it's possible to connect the detector to a tap quite high up the coil. I found that 35 turns was optimum for best performance in my receiver.

As can be seen from the photos, different tapping methods are used for the two coils. For example, L1 has the wire raised away from the former and twisted to make each tapping. By contrast, on L2, a match is slid under the wire at the first tapping point and is then slid along the winding to go under each successive tapping point as the coil is wound. This is the neater of the two methods but is difficult to do effectively if the winding is long and has lots of tappings.

With either method, it is necessary to thoroughly clean the enamel off the wire at the tapping points so that a good soldered joint can be made. This can be done by scraping away the enamel using a sharp utility knife.

## Receiver layout

The parts layout on the baseboard is not critical, although the coils should be mounted at the back of the receiver for ease of access. The accompanying photos show the author's unit.

In my case, tuning coil L2 was mounted at the right rear of the baseboard, with L1 in the opposite rear corner. It's important that L1 is kept several centimetres away from L2, to minimise unwanted coupling between them.

## Diode biasing

As mentioned earlier, some diodes (particularly silicon signal diodes) require about 0.6V of positive bias to maximise sensitivity. Normally, without diode biasing, points A and B are connected together on the circuit. Conversely, if forward biasing is used, points A and B are separated and the small circuit consisting of B1 (a 1.5V dry cell), toggle switch S2, a 470Ω resistor, a 1kΩ trimpot (VR1) and a 47μF electrolytic capacitor added between these two points.

This circuit is easily adjusted. Switch S2 is closed and trimpot VR1 is adjusted for best volume – simple.

## Summary

Those who have never built a crystal set radio before will find this little set worth the effort. It works well, isn't difficult to tune and provides good headphone volume on all local stations.

For best reception, use a high, long antenna that's clear of buildings and trees. A good earth is also necessary and a pipe driven about one metre into the ground and kept damp should suffice.

Finally, if you wish to read about other people's designs, the following list makes a good starting point:

(1) Look on the Internet. Typing "crystal set society" into Google will give you many interesting sites (and lots of designs) that you can explore.

(2) Look in SILICON CHIP for October 1988 (crystal set), March 1990 (wave traps), October 1994 (Hellier Award crystal sets), March 2003 (antennas).

(3) Look in "Electronic Australia" for June 1988 (crystal set), July 1994 (crystal sets), November 1998 (coils) and July 2000 (crystal set).

(4) An excellent Australian book on crystal sets is "Crystal Sets 'N' Such" by Bob Young (7 Hayes Rd, Swanpool, Vic. 3673). He has a few available for $19:95 posted in Australia. **SC**

## Photo Gallery: Targan Airmaster

**MANUFACTURED BY TARGAN ELECTRIC PTY LTD** in 1933, the Airmaster was a 3-valve TRF receiver in an upright wooden cabinet. It used the following valve types: 57 detector; 59 audio output; and 80 rectifier. Photo: Historical Radio Society of Australia, Inc.