Shifting Crystals *Colin Guy G4DDI*

In a letter published in newsletter 36, Gerald Stancey G3MCK asked if anyone had the knack of reducing the frequency of a crystal by “loading” it with pencil lead or other materials. This reminded me of when I spent many late nights “adjusting” various types of crystals so that they would multiply up to specific frequencies in the two-metre band, so I thought that, just for the heck of it, I’d see if I still had “the knack”…..

Fig.1. Test oscillator

Reverting to a ‘second childhood’ I dug out a box of assorted crystals and selected a few possible candidates. I first needed a means of testing them though so I built up the test oscillator shown in Fig1 & Fig 2. This consists of the transmitter oscillator removed complete from a Pye Vanguard, including the 6BH6 valve, although virtually any pentode or triode valve will do. A 1mA meter in the grid circuit serves to give a comparative indication of the activity or “goodness” of the crystal. A small chassis was made up for the oscillator and fitted with three different types of crystal socket located from my junkpile, including a McMurdo “two in one” job which will accept 10X and 10XJ types (Fig 4). The tuned circuit in the anode of the original oscillator was replaced with an RF choke (from the identical RX oscillator in the Vanguard) and the anode coupled via a low value capacitor to my Racal frequency counter to enable quick measurements. (In the ‘olden days’ I plugged in a crystal the searched for the carrier from it on a nearby receiver!) The test oscillator was powered from my Roband stabilised power unit which can be seen in the test set-up (Fig 3), but voltage is not critical and it would be perfectly OK to run it from an unstabilised unit, or even to borrow power from an existing receiver.

Fig.4. McMurdo ad from 1953

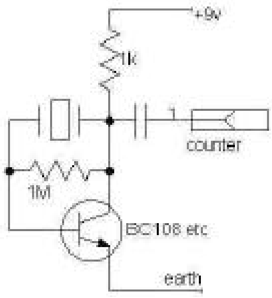

Fig.5 simple transistor oscillator

It is perfectly feasible to build a transistor oscillator (three components) and power it from a PP3 so why build a valve oscillator? Well, for one thing I was on a bit of a nostalgia trip, and in fact some of these older crystals (especially 10X types) need a lot of drive to get them to go after long periods of inactivity, in the past I’ve found that they often don’t start in a transistor circuit, but will work in one once they’ve been run in a valve oscillator for a while. The circuit of a transistor oscillator is given in fig 5 for those of you who really don’t want to go near 250 volts.

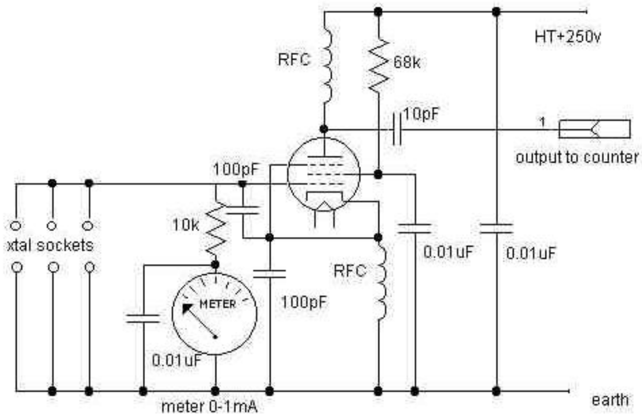

Fig.2 Test Oscillator circuit

Fig. 3. Test setup

Types of Crystals

There are numerous types of quartz crystal, each type for different applications, for the purpose of this article we need not be concerned with the theory, which is complex, but for those who are interested, references [1] and [2] will provide some insight. Of more concern is the type of holder. The most common types likely to be of relevance to the vintage radio enthusiast are the types 10X and

FT243, and possibly the modern HC6U type. The former two types consist of a (usually) bakelite case containing a quartz plate held between two metal plates (electrodes) which are accurately machined to be flat and then have their corners raised slightly so that the plate is supported only at its four corners. Electrical connections are made to the electrodes via thin copper plates and the whole assembly is held under pressure by a spring arrangement and is referred to collectively as the "holder". The case can be opened up easily by removing three or four screws and carefully separating the components. Take careful note of where everything goes! The quartz plate must be handled carefully as it is fragile, also it is essential that it is kept free of fingermarks, see later. The HC6U type is constructed in a different way so, although they can be shifted, they require a different approach. The component parts of an FT243 type are shown in Fig.6.

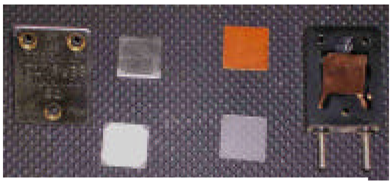

Fig.6. The component parts of an FT243 type crystal

How do crystals "work"?

This is a very simplified explanation of the working of a quartz crystal, those of you who know the theory can skip this bit!

Quartz is one of a small number of materials that has the property of being "piezoelectric". That is, if an electrical potential is applied to a sample of the material, it physically changes its shape (it should be noted that quartz is a good insulator, so no current flows through the sample in this situation), and conversely, if it's physical shape is altered by applying a mechanical force, an electrical potential is produced.

A sample of quartz can be cut in such a way that it will resonate at a particular precise frequency, this frequency is determined by the physical characteristics of the sample, such as shape, thickness, mass amongst other things in much the same way that a clock pendulum "resonates" at a particular frequency, determined by it's length and the mass of the weight.

If this sample of quartz is now suspended in such a way that it can "bend", (this is why, in the types of crystals we are discussing here, the plate is held only at its corners by the raised corner areas of the electrodes) the application of an electrical potential to it will cause it to distort in some way. If the potential is now removed, it will revert to its original shape, but in doing so it will 'ping' or vibrate briefly at its natural resonant frequency: compare this with the action of holding a ruler over the edge of the desk, bending it downwards a little then letting it go. This vibration is physical movement therefore due to piezoelectric action an electrical potential, alternating at the resonant frequency of the sample will be produced. It should be noted at this point that the degree of movement produced is minuscule, any attempt to bend the quartz by hand will result in its immediate fracture.

We can take the electrical potential produced and feed it into an amplifier, if some of the output is fed back to the crystal in such a way as to reinforce the movement producing it, a sustained oscillation is set up at the resonant frequency of the quartz plate. The oscillation can build up to a level limited by the characteristic of the amplifier, and it is important not to "overdrive" a crystal or it can fracture as noted above. Factors such as the characteristics of the external circuit connected to the electrodes supporting the crystal, temperature etc. have very little influence on the resonant frequency of the crystal, so an oscillator of accurate frequency can be produced.

"Activity"

The activity, or goodness, of a crystal could be described in the simplest of terms as a measure of how much the shape of the sample changes for a given applied potential, or of the electrical potential produced for a given change of shape. This depends on many factors and varies from one sample to another. Therefore the gain of the amplifier required to sustain oscillation without overdriving the crystal as previously described will vary, depending on the crystal. In some professional applications the oscillator circuits incorporate automatic gain control circuits to compensate for different crystal activities and other factors, but in most amateur applications this is unnecessary, so long as there is enough gain to start the crystal when required, and there is no possibility of overdriving the crystal, that is all that is required. It is useful and interesting, though, to have a means of comparing the activity of different crystals, because the method to be described of changing the frequency of a crystal also has an effect on its "activity". In the test oscillator described, this is achieved by measuring the grid current of the oscillator, because this is related to the amount of "drive power" returned to the valve from the crystal.

Changing the frequency of a crystal

There are various ways of changing the frequency of a crystal, the most obvious one is to make a change to its physical size. Grinding is possible but quartz is a very hard material, and also it is necessary to ensure that the sides of the sample remain essentially parallel. Methods have been described whereby the crystal is carefully slid around on a piece of plate glass with a cutting compound made from "Vim" in water. I haven't tried this, I'm not even sure if you can still obtain this product but I understand that it did work.

The sample can be etched in hydrofluoric acid or ammonium biflouride, this is described in [1]. These substances are highly dangerous and this method is not to be recommended unless you are very certain of what you are doing (and if you can obtain the chemicals). I do remember trying this many years ago, and finding that it could take a week to change the frequency of an FT243 crystal by 1kc/s. I still have all my fingers!

Both these methods work by removing quartz and so reducing the mass of the sample, and it should be obvious that reducing the mass will increase the resonant frequency. But what about adding to the mass of the sample and thus reducing its frequency? Obviously there is no practical way to add quartz, but Gerald referred in his letter to using pencil lead and other materials and in fact this is the method used here. Pencil lead is the easiest to use, and it can be removed easily if the frequency is shifted too far, but it only has a minimal effect on the crystal. A much greater shift can be achieved by rubbing the quartz with lead solder, but it is difficult to remove, so the technique is to get the crystal close to the required frequency using solder then trim it in with pencil lead.

It should be noted that the added material does not contribute to the "piezo-electric" effect in either direction and so is electrically "dead weight" which therefore reduces the efficiency of the crystal, which effect manifests itself in reduced activity.

Practical methods.

Having first measured the frequency of the crystal, and making a note of its "activity" reading on the grid current meter, the crystal holder needs to be carefully dismantled and the quartz plate placed on a hard flat surface. A piece of plate glass is ideal. If the activity of the crystal appeared low on the initial test (compared with other crystals of the same type), it is worth trying cleaning the quartz plate before proceeding (see below) and reassembling it to see if the activity has increased.

Carefully mark a line close to the centre of the plate with the solder, keeping the mark away from the edges or the points where the electrodes make contact, then carefully reassemble the holder, and test the crystal again. You should find that the frequency has reduced by a few hundred cycles, and also that the activity has reduced. It will then be possible to estimate approximately how many more similar marks will be needed to reduce the crystal to the target frequency. Apply a few more marks at a time and keep reassembling and testing the crystal until it is close to the target frequency.

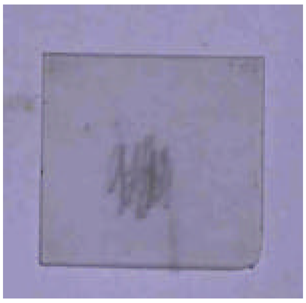

Fig.7. Quartz plate with loading applied.

Marks made nearer the edge of the plate will have less effect on the frequency than those at the centre, and you can mark both sides of the plate. The final few hundred cycles should be trimmed in using pencil lead rather than solder, and if you overshoot the mark some of it can be removed using a cotton bud dipped in a switch cleaning product such as "*Servisol 10*". A lot of patience is needed at this stage! Fig 7 shows a plate with lead loading added as described.

It will be noted that the "activity" as indicated on the grid current meter will reduce at each test, and if a point is reached where the crystal refuses to oscillate, it may be recovered by removing the last applied amount of loading material and if it then works, you are at the lowest frequency you can get it to, though it may go lower in a circuit with more "gain", results are likely to be unreliable. But try cleaning it first before giving up.

Cleaning

The activity of any crystal, even one that hasn't been loaded, will be reduced if the surface is contaminated with grease or fingermarks, for this reason cleaning of the plate and electrodes is advocated. The classic method is to wash the plate in carbon tetrachloride (*Jenclean*), but this is another of those chemicals which was freely available in my younger days but is now considered to be "politically incorrect". Whilst pondering this, I realised that I clean my spectacles every day with nothing more than a breath of air and an impregnated cloth supplied for the purpose by any optician, and this method works admirably on quartz crystals, several "dead" 10X types have been brought back to life in this way, and even loaded ones that have stopped have responded to a quick clean. More stubborn marks, and excess pencil lead can be removed by first *very gently* rubbing the mark with a cotton bud dipped in a suitable solvent such as "Servisol 10".

Results

To try out the technique I took one FT243 and one 10X type from my collection, the results of these are tabulated below.

Type FT243 Initial Freq 7173.21 kc/s Target Freq 7165 kc/s		Type 10X Initial Freq 3063.76 kc/s Target Freq 3060 kc/s	
No. of lead "marks"	Frequency kc/s	No. of lead "marks"	Frequency kc/s
1	7172.90	1	3063.76
2	7171.74	2	3062.87
3	7168.47	3	3062.44
4	7167.04	4	3062.22
5	7166.27	5	3061.18
6	7165.21	6	3061.47
Trimmed in with pencil	7165.00	7	3060.95
		8	stopped

To draw a meaningful conclusion from these results it would be necessary to try more samples of both types, to start with the 10X types are physically larger and so I would expect a given amount of loading material to have a lesser effect, this would also be true because, everything else being equal, the lower frequency crystal used in the test here would be larger anyway. 10X crystals seem to be inherently less active, and were used with larger valves, even power types such as the 6L6, and were thus driven at levels which would destroy modern small crystals. However, the above results may be taken as an indication of the results that may be expected. Quantities of these crystals on apparently useless frequencies turn up regularly at the rallies and junk sales, so it would be a good idea to practice on one or two before committing to adjusting a crystal that is close to a wanted frequency.

HC6U types

These, and the 10XAJ versions, are constructed entirely differently, but usually do respond well to "adjustment". The metal case is soldered to the base, and can be removed by holding the pins of the crystal in a vice and applying enough heat with a large soldering iron to melt the solder whilst at the same time pulling the casing straight upwards. It will be seen from Fig 8 that the quartz plate is held not by a pressure contact, but instead by fine wires soldered to electrodes deposited directly onto the crystal. Adjustment can be carried out by adding lead or pencil to the electrodes, a little at a time as before and testing at each stage. When the target frequency is attained, the casing can be carefully soldered back together.

Fig.8. HC6U crystal innards

Overtone crystals

Over about 20Mc/s, the plate becomes so thin that it is impractical to manufacture, so crystals that are intended for use above this frequency are cut in such a way that, in a suitable circuit they will oscillate at *approximately* three or five times their actual resonant frequency. Such crystals will usually oscillate on their fundamental frequency in the test oscillator design given here so, for example, an HC6U crystal marked a 45 Mc/s will oscillate at about 15 Mc/s. The mechanism of this is complex, and in the "overtone" mode the crystal does not oscillate on exactly the harmonic of the fundamental frequency. "Adjusting" these types of crystal is not to be recommended as the result can be unpredictable.

Stability

In my experience "adjusted" crystals do drift upwards a little in the short term, but not usually very far: less than 200 c/s which could be critical in ssb applications, but for most other applications is unimportant. It is a way of making use of an otherwise useless crystal, and could save you £7.50 in the process.

References

[1] Radio Communication Handbook 4^{th} Edition, pp 1.31 – 1.32, Tebbit & Wiles (Eds) Radio Society of Great Britain, 1968.

[2] The Radio Amateur's Handbook 1947 Edition, p58
American Radio relay League, 1947. (Also subsequent editions)