Crystal Control for Amateur Transmitters

By John M. Clayton, Assistant Technical Editor

DR. TAYLOR of the U. S. Naval Research Laboratory has done more crystal-controlled work with high-power transmitters than any other man in the world, and it is his conviction that the crystal control transmitter is in a class by itself; that it is second to none; that its nearest competitor is a transmitter using a very rigidly supported antenna-counterpoise system and an oscillator keyed by some compensation method in which the load is on the tube at all times.

The various transmitters at NKF should for once and for all settle any doubt in the mind of anyone as to the merits of a crystal-control system and the tremendous advantage it would be to amateurs to have transmitters of this type.

Years ago the Curies found that if a crystal of Rochelle Salts is placed between two pieces of metal as in Figure 1 its shape can be changed by connecting the two pieces of metal to a battery or direct current generator. When the voltage is applied to the two pieces of metal the crystal will become shorter along the lines A-B and C-D, and longer along the lines A-C and B-D. The crystal will act just as if it were a sponge and were being squeezed by the two pieces of metal: it will become thinner and longer. Other crystals show the same effect but not as markedly as Rochelle Salts. However, the Rochelle Salts crystals are very weak mechanically and absorb moisture easily: hence in experimental

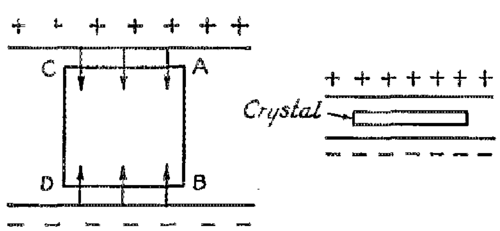
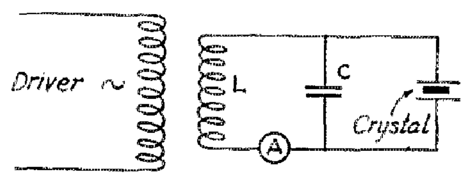


FIG. 1 CRYSTAL ACTION

work it is usual to use Quartz crystals, which are very hard and last almost indefinitely. In the case of the quartz crystal, if the polarity of the charge plate is reversed the mechanical strain on the crystal will be reversed also. In addition to this change, if the plate is compressed endwise by a potential applied to the edges of the plate it will become shorter and thicker. These changes are microscopically small, but they are there just the same.

This phenomena also works in the opposite manner. If the crystal is subjected to a mechanical strain or pressure its surfaces will become electrically charged.

When the shape of the crystal is distorted either by mechanical means or by means of a momentary voltage applied to the metal coatings on it, it immediately tries



CIRCUIT USED TO SHOW CRYSTAL ACTION
FIG 2

to return to its original shape, but in so doing it swings past its normal size and actually contracts. Then it tries to return to normal size by expanding but again swings past its normal size and becomes larger and so on. In other words, it oscillates. This oscillation is quite similar to the oscillation of an iron plate when struck by a hammer. In the case of the iron plate the oscillation is at an audio frequency—we hear the plate ring for some time after it has been struck. The crystal oscillates at a *radio* frequency. Each crystal will oscillate at two definite frequencies.

If a coil L, R.F. ammeter A and condenser C (Fig. 2) are connected in series and the two metallic coatings of a properly cut quartz crystal are connected across the condenser the frequency of the crystal can be found. A high frequency driver is coupled to the coil, and a curve showing the variation of current in the L-C circuit (as indicated by the ammeter A) with the variation in frequency of the generator is plotted. Referring to Figure 3, as the driver's frequency is increased the current in the L-C circuit increases up to a certain point where it sharply drops off. If the current variation around this point is carefully explored by minute changes in the driver frequency the depth of this dip can be found. The frequency corresponding to the bottom of the dip or crevasse is either the fundamental frequency or a harmonic frequency of the crystal. If the L-C circuit is now tuned to this frequency either by a variable capacity in place of the fixed C or a variable inductance in place of L, the crevasse will be much deeper, indicating that the crystal in the L-C are absorbing more power from the driver. If the driver is not very powerful it may cease to oscillate at the resonant frequency of the L-C circuit and the natural or harmonic frequency of the crystal. Some crystals that are cut from a piece of quartz which has irregularities in it may demonstrate all sorts of weird frequencies. It is also very easy to mix up the harmonics with the fundamental frequency, so if you are trying to find the fundamental of your crystal be sure that you are not playing with some harmonic.

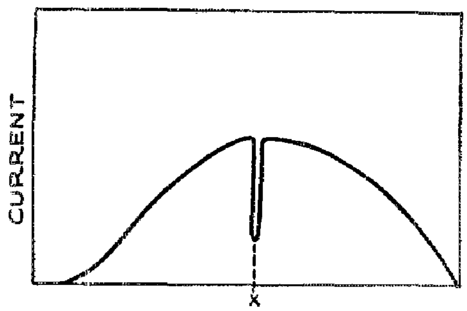


FIG. 3 RESONANCE CURVE OF CRYSTAL AND TUNED CIRCUIT

The Axes of a Crystal

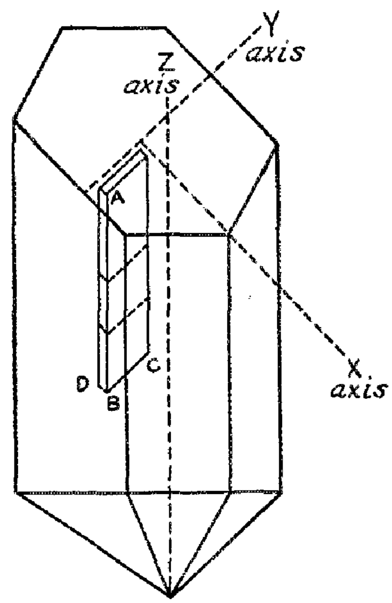
In order to get a good oscillating crystal it is necessary to cut out a piece along certain definitely set dimensions. These bounding lines are known as the axes of the crystal. The first is the optical axis. It is usually found in the geometric center of the crystal. It is known as the Z axis (Fig. 4). If this axis cannot be determined by inspection an optician can locate it in an optical machine in a very few seconds. The next axis is the Y axis, an imaginary one drawn at right angles to two parallel and opposite sides. The other is the X or electrical axis and is drawn from one corner of the crystal to the opposite corner, and at right angles to the Y axis. There is only one Z axis, but there are three 1 Y axes and 3 X axes (Fig. 5), one axis between each parallel side or opposite corner of the crystal.

Cutting the Crystal

When cutting the crystal it should be taken out so that its length AB is parallel to the Z axis (parallel to a side of the crystal), its width BC parallel to the Y axis and thickness DB parallel to the X axis (Fig. 4). If the raw crystal is clamped in a wooden vise and viciously attacked with the back edge of a hacksaw blade over which very fine carborundum dust and water are continually poured, you can grind out a piece. The slice taken out should be about 2½ millimeters thick and an inch wide. When cutting be sure that the cut is parallel to one of the Y axes. It will probably be best to cut in a direction lengthwise of the crystal first. (See Fig. 6.) Then cut it into pieces about an inch square. Be sure, though, that all of the edges are parallel to the axes of the crystal. This is important, for the crystal will not oscillate if its edges are cut at an angle very far from the correct one.

Grinding Them Down

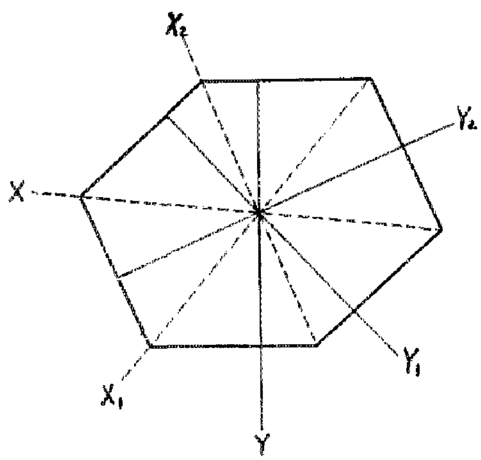
You now have a crystal cut along the right lines but entirely too rough to oscillate. It must be ground down until its faces are absolutely smooth and parallel. Mix up a quantity of No. 301 powdered emery and kerosene in a can and use this as the Rough grinding solution. It should have a consistency similar to tooth paste. Cover one face of the crystal with the mixture and lay it on a smooth steel plate or heavy glass plate, and push the crystal around in circles on the plate, at the same time turning the crystal around so that its whole surface will be ground equally. (See Fig. 7.) Keep a thin layer of the grinding mixture on the surface of the crystal, and



RELATION BETWEEN THE CUT CRYSTAL AND THE AXES
FIG. 4

see that the pressure on the crystal is equal at all points. When one side has been smoothed off turn the crystal over and grind the other side. Then the edges should be squared off. For high frequency work we use the thickness of the crystal as the oscillator. It does not matter what the crystal's length or width is. The wavelength at which the crystal will oscillate will be found to be very nearly equal to

105 meters per millimeter thickness of the crystal. In order to grind the crystals to a definite frequency the "grinder" must proceed most cautiously when he has begun to get down into the neighborhood of the required frequency. The final grind is done with No. 100 carborundum and oil. A micrometer caliper is a necessity. The crystal must be of uniform thickness and the wavelength must be tested often. A simple test circuit should be set up and frequent



CROSS SECTION OF CRYSTAL SHOWING X AND Y AXES
FIG. 5

use made of it or you will grind way past the wavelength you want.

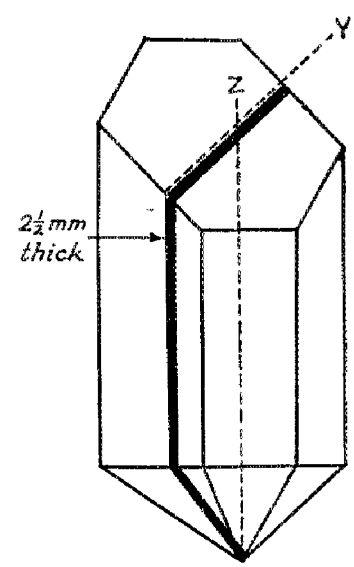
Unless one has a good crystal that oscillates at a useful frequency it is, of course, impossible to build a crystal control set. Quartz crystals ground to a known frequency can be obtained from the General Radio Company. If you have a lot of time and patience you can cut the crystals yourself. Grinding them to some useful frequency is a comparatively simple job. Uncut crystals can be obtained from a number of sources. The Master Optical Company of 19 West 36th Street, New York City, can furnish them, or they can be picked up from almost any wholesale optical company. Care must be taken, though, to see that the crystals are good for radio purposes. All crystals will not yield good oscillators. The uncut crystal must be free of flaws, bubbles or cracks, and should be tested by the optical company to see that it is not a "twin crystal". This cannot be determined by a casual glance by the uninitiated, but the optical people can tell you in a few seconds.

If you do not want to try the cutting job yourself, quartz crystals guaranteed not to be twin crystals and further guaranteed to be cut along the correct axes can be obtained from the Master Optical Company for a very reasonable sum. The crystals will be ground to any desired thickness. No guarantee is given as to their oscillating qualities. If you buy the cut crystals they can be ground down by yourself by hand. A crystal one millimeter thick and one inch square (or having a diameter of one inch if round) is a convenient size.

After the crystal has been ground it should be cleaned thoroughly in carbon tetrachloride (Pyrene Fire Extinguisher liquid or a Carbona) to remove all traces of emery and oil.

Mounting the Crystal

In order to operate the crystal it must be mounted. There are two forms of mountings that can be used. The type shown at the left of Fig. 8 allows the crystal to vibrate when it starts to oscillate. The insulating base has a metal plate (brass or copper) A attached to it. The upper surface of this plate is ground absolutely flat, as is the lower surface of the brass or copper cap. This cap fits over the plate A and the crystal vibrates between the plate A and the inside of the cap. This distance is very small, a few thousandths of an inch. Where extremely fine precision is desired this type of mounting is of advantage. For practical work and for operation in a radio transmitter it is sufficient to use a mounting similar to that shown at the right of Fig. 8. The base holds a lower plate whose upper surface is ground smooth. The crystal



TAKING OUT THE FIRST SECTION
FIG. 6

rests on this plate, and the upper plate (with a smooth bottom face) rests upon the crystal. The surfaces of the plates touching the crystal must be ground smooth.

A light spring brass strip is arranged to push the whole works together and hold the crystal in place. The output from a crystal mounted in this fashion is con-

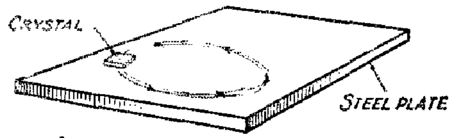
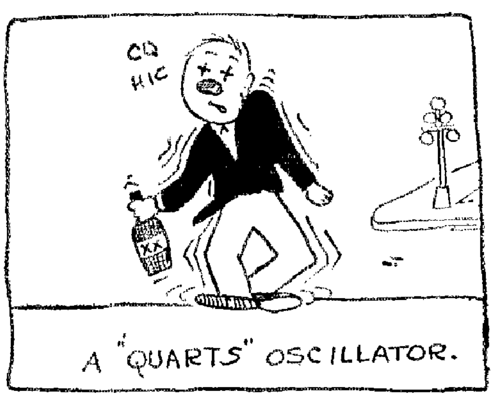


FIG 7 GRINDING THE CRYSTAL

siderably greater than from the other type of mounting, in which the crystal is loose between the two plates.

Testing the Crystal

A good testing circuit for the crystal is shown in Fig. 9. A UV-201A tube can be used. A plate voltage of from 90 to 200 volts should be used. The C battery voltage will vary between 1.5 and 10 volts. This, although almost any voltage can be used, is not critical. The coil L and a condenser C should be of such size that the combination can be tuned over the wavelength range in which the crystal is expected to oscillate. The grid choke (RFC) should be wound with fine wire and made as small (physically) as possible. In an operating circuit this choke should have a natural period equal to the period of the crystal itself. The ammeter A is used to show when the crystal is oscillating. If low plate voltages are used this meter can be a 0-100 milliampere hotwire meter. If high voltages are used it should be a 0.1 ampere R.F. meter. As the condenser C is rotated the current in the ammeter will vary as follows: At first there will be no indication on the meter—the crystal is not oscillating. As the condenser and coil begin to approach the resonant frequency of the crystal the current will



A "QUARTS" OSCILLATOR.

start to flow in the ammeter. The nearer the LC circuit is tuned to the frequency of the crystal the greater will be the current in the LC circuit. When this circuit is tuned to the same frequency as the crystal the tube will abruptly stop oscillating. The crevasse of Figure 3 will drop all the way to zero. When operating a crystal in a transmitter the plate coil is never tuned to the frequency of the crystal, for the crystal will cease to oscillate every time. It should be tuned always to a wavelength less than the crystal wavelength.

If the oscillating receiver is coupled very loosely to the coil L and a beat note with the crystal is picked up, a lot of things can be observed. In the first place, the beat note will virtually stay constant, no matter how much the condenser C is varied so long as the tube is oscillating. The condenser C, ammeter A and coil L comprise a tuned circuit. Here we are changing the capacity in the tuned circuit over quite a large range and the wavelength is not changing at all! Next, if we take a lead pencil and push down on the crystal mounting as hard as we can the beat note in the receiver will change only a few hundred cycles, proving that the crystal *can* be mounted between two metallic blocks that are pressed tightly against it. Then we vary the plate voltage. Nothing much happens so long as the tube does not stop oscillating. The beat note stays the same. Bring your hand close

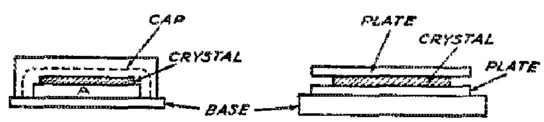


FIG. 8 CRYSTAL MOUNTINGS

to the coil L. The note remains constant. Try this in your present transmitter and —well, you note what happens to the note in your receiver and the other fellow's receiver also.

Practical Circuits

The circuit of Fig. 9 is one of the most elementary crystal circuits. It can be used as a very good transmitting circuit also. If the tube is changed to a UV-210 and the plate voltage raised to 350 or 400 and the C battery to about 40, we have the makings of a very good amateur transmitter The antenna is coupled to the oscillator by means of the coupling between coils L1 and L of Fig. 10, and is tuned to the oscillator's wavelength. Immediately the antenna ammeter shows signs of life and we are doing some crystal controlled sending. The antenna coil L1 must not be coupled too closely to the oscillator or the latter will cease to oscillate. The coupling, however, can be much closer than in the usual type of amateur transmitter. If your crystal does not have a natural wavelength in the amateur band you are interested in, but does have a harmonic in the band you want, you can tune the antenna to this harmonic and get some power into the antenna. The crystal generates a whole flock of harmonics, a lot of which can be used in this fashion. The amount of power that can be put into the antenna from such a simple circuit is relatively small. The crystal will crack if the plate voltage on the tube is much higher than 400. The UV-210 tube is an ideal crystal tube, and probably is the largest tube that can be directly crystal controlled. If we want more output in the antenna we must proceed to a power amplifier combination. A UV-210 crystal control will very satisfactorily control a 203-A tube or even a UV-204A. The circuit of the power amplifier is so well known that it is not repeated here.

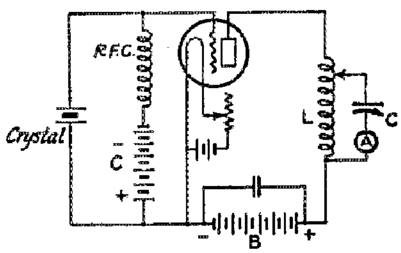


FIG. 9 ELEMENTARY CRYSTAL CIRCUIT

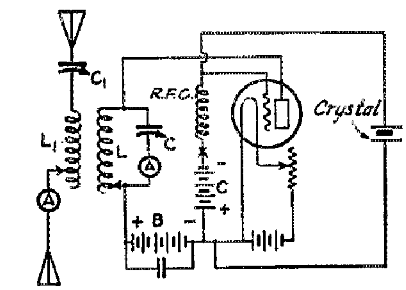


FIG. 10 THE SIMPLEST TRANSMITTER CRYSTAL-CONTROLLED

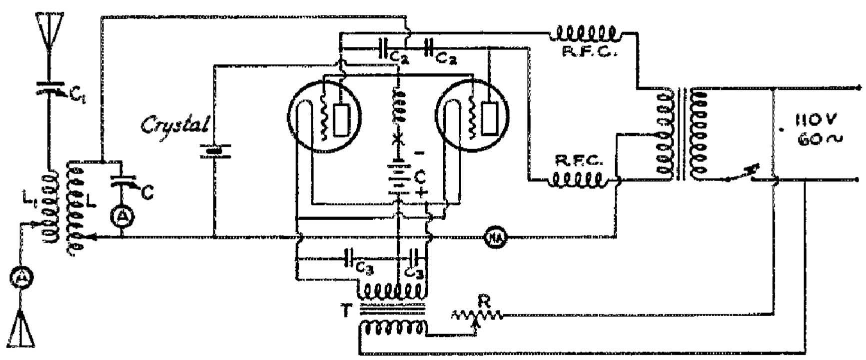


FIG. 11 CIRCUIT OF AN A.C. CRYSTAL SET

The A.C. Crystal Set

If two UV-210 tubes are connected in the familiar self-rectification circuit to give full wave rectification of the 60-cycle supply, they can be very successfully crystal controlled. The note, contrary to all expectations, is very pretty indeed. As the crystal, once set into oscillation, tends to continue to oscillate for a short time it will successfully "ride over" that portion of the cycle in which the plate voltage to the tubes is at a minimum, and the note from the set will correspondingly hold on. At a distance it is very nearly equal to a pure D.C. note. There is nothing unusual in the circuit of Figure 11. It is our plain old everyday full wave rectification circuit in which we have left out the grid coil and added a crystal. The ammeter A in the LC circuit, while not necessary, greatly aids in tuning the transmitter, since it shows when the crystal is oscillating. If each tube is supplied with 400 volts of A.C. this ammeter should have a zero to 3 ampere scale. It is an R.F meter of course. The set can be keyed either in the primary of the plate transformer or in the C battery circuit at "X" of Fig. 10 and 11. Both L and L1 should be of "low loss" construction. They should be wound with copper or brass strip laid flat on the supporting pieces and spaced a distance equal to the width of the strip.

An A.C. Power-Amplifier Circuit

If you want more power than can be obtained from the two tube set working in the circuit of Figure 11, an A.C. power-amplifier can be added. The oscillator tubes and the amplifier tubes are fed from the same high voltage transformer. The R.F. choke in the leads from the transformer keep the tubes from getting mixed-up. The input to the amplifier tube is governed by the position of the grid tap on the coil L. The setting of this tap is not very critical. If the C battery in the amplifier circuit is made unusually high the harmonic of the amplifier will be more pronounced, and it will be possible to get a lot of energy into the antenna on this harmonic. The two crystal controlled oscillator tubes can be operated at 80 meters, say, and the amplifier tuned to 40 meters by means of L1-C3, and there will be plenty of pep in the antenna on 40 meters when the antenna circuit is tuned to 40.

Things to Watch Out For

There are a number of things to watch for when playing with crystals. In the first place, do not try to grind the crystal to too short a wavelength. Dr. Taylor at NKF has made a good crystal oscillate at 26 meters. If you look very hard at a crystal that thin it may collapse. It will probably be best not to try to grind them to a wavelengh lower than 75 meters. If you want to operate on wavelengths shorter than 75, grind the crystal so that its fundamental is at twice the wavelength you want and either operate directly on a harmonic of the crystal or on a harmonic of the crystal through the power amplifier, as explained above.

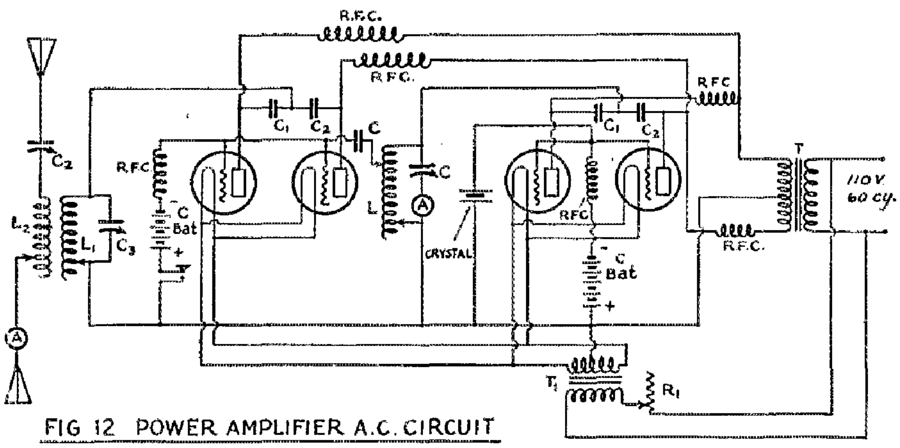


FIG 12 POWER AMPLIFIER A.C. CIRCUIT

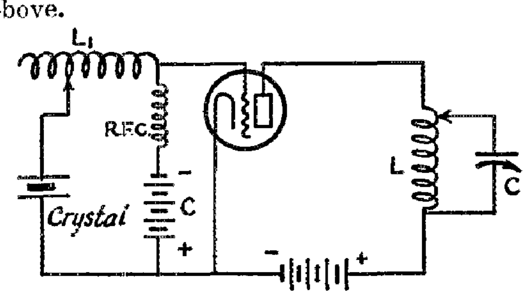


FIG. 13 ADDING REGENERATION WHEN THE CRYSTAL WON'T OSCILLATE.

If too much plate voltage is used the crystal will crack. Do not use a crystal controlled tube larger than a UV-210, and use only one tube of this size unless you want an AC set, when two tubes can be worked successfully.

The crystal must be clean at all times. It will not oscillate if it is scratched. Grind the scratch out. In so doing, though, you will shorten the wavelength.

It does not matter whether the crystals are square or round. For some reason the Optical people who cut and grind them find it easier to turn out a round crystal than a square one. It does not hurt to have the surface of the crystal unpolished. The unpolished surfaces look "frosted", but crystals with this finish oscillate just as well as the polished ones.

If you think you have a good crystal and the darn thing just won't oscillate, it is possible to make it go by means of a little regeneration in the crystal controlled tube. In Fig. 13 we have added a coil L^1 in series with the crystal and the grid. If we disregard the crystal for a moment—just short circuit it—and increase the number of turns in L, we will have a simple tuned plate oscillator. With the crystal in the circuit the action is just the same. If we increase L_1 the tube will regenerate and the crystal, if it has any oscillating tendencies at all, will pick up and maintain oscillation. A warning, though: if the crystal does oscillate satisfactorily without a grid coil, don't try to introduce any regeneration or the crystal will be cracked.

In the power amplifier combination it is perfectly possible for regeneration to occur in the amplifier. If this happens it is likely to react upon the crystal tube and the crystal will be cracked. It is highly desirable to actually neutralize the power amplifier just as a neutrodyne is neutralized to prevent any oscillation in it.

When grinding the crystals it is possible to proceed with this process to such an extent that the crystal will cease to oscillate. Be very careful when you are grinding to wavelengths below 75 meters. The crystal should be tested quite often.

The day of the amateur crystal control transmitter is here. Soon we will have steady waves like NKF; wavelength accuracies second to none, notes sufficiently close to allow the advantageous use of high-peak audio transformers and the resulting increase amplification secured thereby.