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PROCEEDINGS
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Volume 14 December, 1937 No. 3

# THE APPLICATION OF THE BROAD BAND CRYSTAL FILTER TO BROADCAST RECEIVERS

BY

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Delivered before the Radio Club of America
December 9, 1937

The piezo-electric crystals are known to have a very sharp resonance and are used either to control one single frequency with a sharp definition as, for instance, in radio transmitters or to resonate for a very narrow band as used for telegraphic, so called single frequency receptions, where they function as filters. There are however exceptions, for instance, in ultra-sonic sea signaling where the crystal is dampted by the radiated energy. In such applications the selectivity of the crystal is of no importance and the energy producing the damping is precisely the energy which is used. But, if we try to damp the crystal artificially in most applications its resonance curve will be less sharp, but it will still provide a characteristic not unlike that of a simple tuned electrical tuned circuit. For some other applications, as for instance, for optical relays, such artificially dampted crystals require too much energy for their operation and thus lose most of their valuable qualities.

It has long been obvious that crystals which would resonate over a broad band of frequencies would be extremely useful and, indeed, attempts have been made to obtain such crystals. The first thought was to artificially damp the crystal, but as explained above this method is in many cases unsuitable because it destroys the very characteristics of the crystal which make it especially useful.

The second thought was to use several crystals connected in parallel, the frequency of the several crystals differing from one another so as to cover the desired band. The difficulty in this expedient is that between the two frequencies corresponding to two successive crystals there is always one at which the two crystals vibrate in opposite phase, one crystal being operated below resonance and the other one above. This results in the fact that the electrical resonance curve has a sharp minimum-approaching zero - which makes the arrangement generally unsatisfactory.

Let us now discuss a solution of the problem making it possible to obtain a single crystal with a practically uniform response for any desired band of frequencies, while, at the same time providing a response abruptly decreasing at the limits of the band. This solution is, primarily, the use of a crystal of non-uniform thickness.

### CRYSTAL OF NON UNIFORM THICKNESS.
### EARLY YEARS OF TELEVISION.

When about 1926 the first steps had been taken in practical television, one of the greatest difficulties had been that of synchronization, this difficulty increasing with the number of the picture elements per image, i.e., definition. The idea of operating the scanning at the receiving station by the scanning system at the transmitting station seems to have been first suggested by Prof. Rosing in the early years of the century. This method makes the synchronization independent from the speed of scanning. To make this method practical it is possible to perform the television by using two parameters of a radio wave, its amplitude and its frequency; the amplitude corresponding to the luminosity of the transmitted picture element and the frequency to its sequential position.

Let us, in order to make it simpler, consider the transmission of only one line of the image supposing that the second scanning, at relatively low speed, can be made by other already known methods.

At the transmitting station a rotating optical scanning device is mechanically coupled to a rotatable, variable condenser which determines the frequency of the transmitted wave.

To every position of the scanning device there corresponds a frequency determined by the variable condenser and while the amplitude as determined conventionally by a photo-electric cell, corresponds to the luminosity of the transmitted picture element. At the receiving station we have then only to make the position of light spot correspond to the frequency of the received signal and its luminosity to the signal amplitude. The first idea was to use for this purpose a series of crystals of different frequencies corresponding to the received band width, each of these crystals constituting an electro-optical relay passing light when it is operated to the corresponding position. Its amplitude which is a function of the amplitude of the received signal determines the luminosity of the projected light. For this purpose the crystals have been disposed in a system of polarized light, their vibrations modifying the polarization and thus modulating the intensity of the light. Later this series of crystals were replaced by single crystal of a thickness varying from place to place to cover continuously the entire band of frequencies, every frequency determining a localized resonance in the portion of the corresponding thickness. As an example, a crystal of 10 cm. long and resonating over a band around 80 meters gave a localization of resonance of about 1 mm. The width of the band was about 300 kc.

SOUND RECORDING SYSTEM.

The next use of the crystals has been as a light valve for photographic sound recordings.

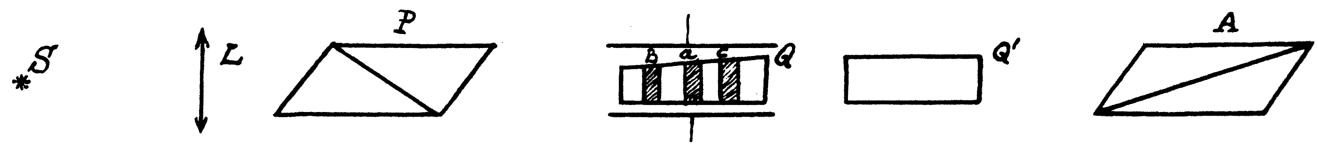


Figure 1

Figure 1 illustrates this application. The crystal, Q, is traversed by a beam of polarized light produced by source, S, a lens, L, and the polarizer, P. On its way the light traverses the portions of crystal of the different thicknesses. In the absence of any vibration of the crystal, the system is compensated by the compensator, Q', and the analyzer, A, at extinction. The crystal is excited by an oscillator of a frequency, f, corresponding to its middle portion, a. The generator is modulated by the microphonic current.

If the microphonic current is of a frequency F, there will be three portions of the crystal a, b, c, simultaneously set into vibrations corresponding to the frequencies f, f+F, f-F. The action on the polarization by the deformations of these three portions will be recomposed with conservation of phase and the luminosity of light correctly modulated for the whole band determined by the thicknesses of the crystal.

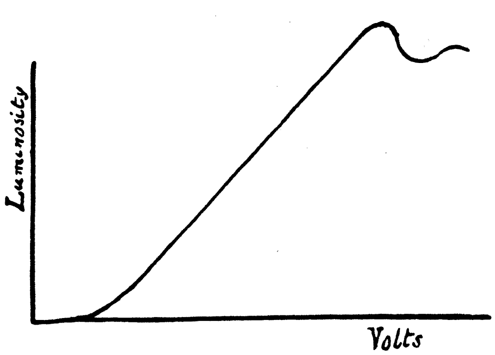


Figure 2

The curve giving the luminosity as function of the voltage across the crystal is shown in fig. 2. This curve has an important linear portion and the light can be modulated practically without distortion up to 90%. The luminosity is very good. In one set of equipment, when the Eastman sound negative is used, with a gamma of 0.5, the density is 0.5 for an A.C. voltage across the crystal of about 100 volts.

SOME OTHER APPLICATIONS OF THE NEW CRYSTALS

In all its applications these crystals are intended to vibrate either simultaneously or successively for a band of frequencies, as in sound recording and television.

Amongst other applications and before discussing the band-pass filters, which is the main object of the present paper, we will only mention two. First, the control of a transmitter, the frequency of which it may be desired to vary to avoid possible interferencies; and second the use as microphone.

To control a transmitter a wedge shaped crystal can be used, one of the electrodes being a narrow plate sliding along its surface, the portion of the crystal positioned between the electrodes determining the frequency.

In its use as a microphone, the crystal vibrates at a high frequency and its impedence which depends largely on the damping determines the useful microphonic current.

As a matter of fact the damping varies according to the density of the air around the crystal which density is modulated by the sound.

The same idea was used by Prof. Riabouchinsky and myself to make a dynamo-meter for aerodynamic measurements and recordings, the wedge shaped crystals making it possible to record rapid variations of air density or pressure.

The two last methods are schematically shown in fig. 3.

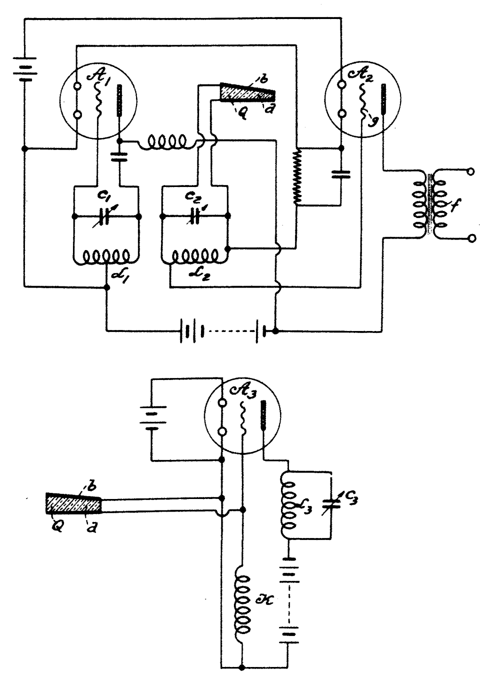

Figure 3

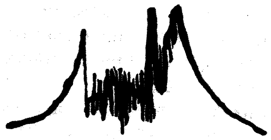

Figure 4

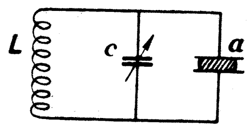


Figure 5

VIBRATION OF THE CRYSTAL.

In all the above discussion it has been assumed that the localized vibrations in the crystal travel continuously from one end to the other when the frequency varies. It is not however always so. If we record the resonance curve, this curve presents many irregularities. One of such curves can be seen on the fig. 4 which is an oscillogram of the voltage as function of frequency, of a circuit such as is shown in fig. 5, the "crevasse" of fig. 4 showing the resonance curve of the crystal.

To explain this curve and show how to correct the irregularities let us examine what occurs in the crystal when it is submitted to the action of an electric field of frequency varying between corresponding limits.

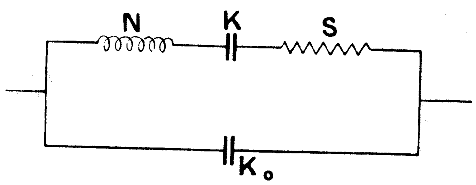


Figure 6

Let us consider first a usual crystal of uniform thickness. This crystal can be represented by the equivalent cell shown on the fig. 6, the inductance N, resistance S and capacities K and $K_o$ depending on the dimensions of the crystal. The corresponding resonance curve is shown in fig. 7. The sharp rise a corresponds to the resonance of the circuit NKS and the point b to the parallel resonance of the complete cell.

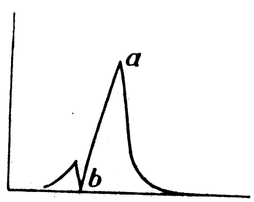


Figure 7

If now the crystal is of non-uniform thickness, it is represented by an infinity of small crystals of different thicknesses coupled together and the equivalent cell will be an infinity of elemental cells connected in parallel and coupled in such a way as to prevent any important shift of phase between any two adjacent cells. This condition corresponds to the mechanical realities of the crystal structure.

The resonance curve will be broad and will include all the frequencies of the band of the crystal, but to determine its shape we must not neglect all the phenomena which may occur.

First of all when the crystal is subjected to a frequency f a portion a, Fig. 8, is set in resonance vibration.

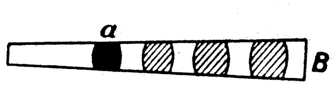


Figure 8

The corresponding elongation will also produce elongations in perpendicular direction the importance of which depends on the value of Poisson's modulus for the particular orientation of the crystal with respect to its axis. These latter elongations produce a wave propagated along the crystal in all directions. The edges of the crystal, such as the edge B, reflects a wave returning in a with a phase depending from the distance to B. When f varies the phase varies and the electrical effect will have as many maxima and minima as the varying phase. To avoid the reflections on the edges it is practically sufficient to dispose on these edges some absorbent material such as Canada balsam or any similarly viscous material. This will produce only useful damping, without markedly affecting the localized vibrations of the portion a.

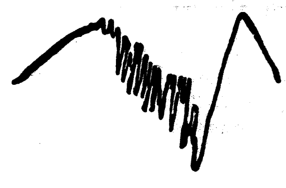

Figure 9

Figure 10

The oscillogram of voltage as a function of frequency fig. 9 shows the characteristic of the crystal after the edge reflections have been attenuated as suggested above. There are still many maxima and minima due now to the coupling of the main mode of vibration with other resonators such as the harmonic resonances along the length, of flexion, torsion etc. These resonances are well understood and can be eliminated by localized damping. The curve resulting from such treatment as this is shown in fig. 10.

The curve of fig. 4 is of an X cut crystal as has been shown to illustrate better the different phenomenae. In the modern cut crystals, such as AT, AC, etc., the couplings and consequently the irregularities in the characteristic are greatly reduced and the corrections to be made are much easier and, when less uniformity is required, may be completely unnecessary.

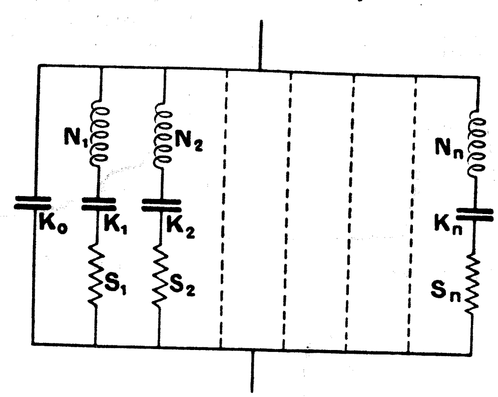


Figure 11

Now, assuming that all the spurious oscillations have been eliminated the crystal is fully represented by the equivalent cell of the fig. 11, (where the above discussed couplings between adjacent cells have been however omitted). The construction of the resonance curve is similar to the construction of the curve on the fig. 4. When the frequency reaches the value corresponding to the resonance of the first elemental cell, the current increases to the point A on the fig. 12 and then remains constant because of the identity of different elemental cells, until the antiresonance of the first cell is reached. At this point the current decreases to the point B and remains constant until at C the resonance of the last cell ceases. Then the anti-resonance of the

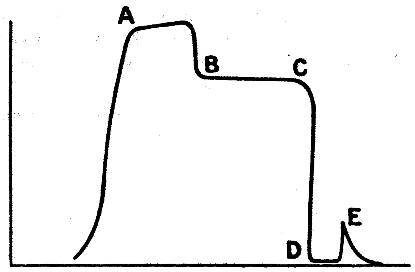


Figure 12

last cells produces a decrease of the current to the point D which corresponds to the point b on the fig. 4. The last anti-resonance ceases at the point E.

If we compensate the parallel capacity of the crystal by a bridge circuit, the current in the absence of resonance will be zero and any variation of the impedance will produce an increase of the current. The curve on fig. 12 will obviously become the curve on the fig. 13.

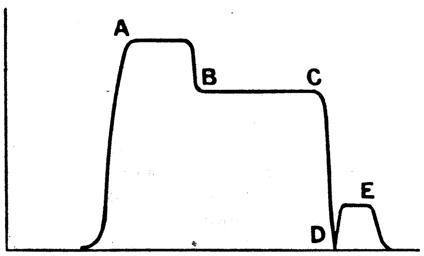


Figure 13

We see that this curve has three steps, but the importance of the height and width of the steps depends on the ratio of the portion of the crystal simultaneously vibrating to the whole of the crystal, or the number of elemental cells simultaneously resonating to the ensemble of cells. It means that by differently choosing the dimensions of the crystal, its length, thickness, slope, very different curves can be obtained which can be easily compared to the curve on the fig. 13. Some of such examples are shown by the oscillograms on the fig. 14, 15, 16.

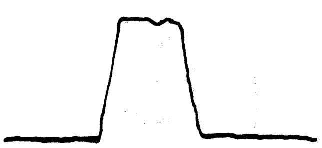

Figure 14

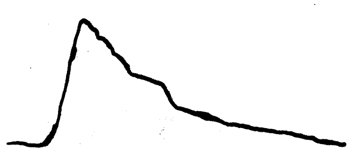

Figure 15

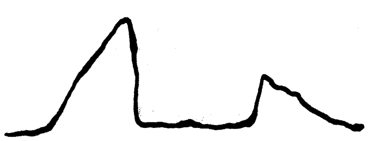

Figure 16

Furthermore, if the slope is too small the vibrating portion will be an important part of the crystal, as seen on the fig. 17 and for a small variation of frequency this portion will decrease and the corresponding curve will have no flat top and will resemble the usual curve of an electric tuned circuit. While if the slope of the crystal is too large the resulting damping may become seriously important.

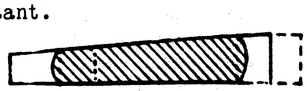

Figure 17

When a crystal must be made for a predetermined frequency with a predetermined band it must be determined what is the value of the localization of the resonance, either theoretically, by considering the elastic constants of the crystal, usually quarz, or experimentally by analyzing the vibrating crystal in polarized light and by gradually changing the angle between faces.

## I. F. TRANSFORMERS

The above described features of wedge shaped crystals make it possible to use the crystals to improve the response of pass-band filters and especially IF transformers. As a matter of fact, these crystals can be made for frequency bands as desired, the sharpness of the skirts of the resonance curve, being practically independent from the band width. Furthermore, the transformers using those crystals will have the selectivity practically independent from their frequency which can be, for example, as effective for 470 KC as for 1,500 KC or higher.

The circuit used for IF transformers is very much like the crystal transformers used in amateur so called single signal receivers, but I have tried to make them as simple as possible, because the price is in a radio receiver of a great importance. The circuit is represented on the

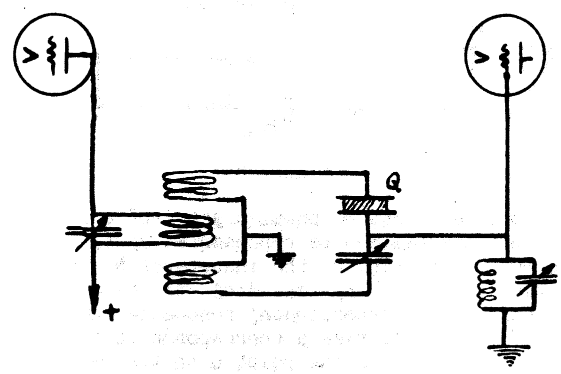


Figure 18

fig. 18. The anode circuit is tuned but the secondary circuit is not tuned. It comprises two coils connected in series and wound on the same bakelite tube as the primary coil, and arranged symetrically with respect to the primary. These two coils constitute two branches of the bridge, the connection between them being grounded. The two other branches of the bridge are the crystal with its electrodes and the neutralizing condenser, which may be the conventional trimmer. The junction of the two condensers is connected to the grid of the following tube. To fix the potential of the grid I use instead of the usual resistor, a tuned circuit. A simple resistor in this circuit arrangement would considerably reduce the gain of the stage because the effective input impedance of the tube must be large as compared with the coupling impedance which in this arrangement is practically the impedance of the vibrating crystal. The Q of this tuned grid circuit may be low and the coil may be made of solid wire because its resonant impedance must be of importance only as compared with the resonant impedance of the crystal which cannot be in any case more than a few thousand ohms. The important point, here, is to obtain high attenuation outside the crystal band. It means that the bridge must be perfectly balanced for a very broad frequency band, at least 40 to 50 KC. Theoretically, the balance of the bridge can be kept independent of the frequency only if the two coils are identical as well as the two condensers. In this case the ratio of the coil impedances as well as the ratio of the capacities is equal to 1 and independent of the frequency. Practically the two coils are never precisely equal,

especially because it is not only their self inductance which must consider, but also their mutual inductances with the primary coil.

If we call L the equivalent inductance of the first coil, R its resistance, $L + \Delta L$ and $R + \Delta R$ the corresponding values for the second coil, and $\Delta\omega$ its range of variation, V the potential across the two coils; then the voltage on the grid due to the variation of the frequency which as the result of lack of balance of the bridge will be given by

$$e_g = \frac{\Delta\omega}{\omega}\left(\frac{\Delta R}{R} + \frac{\Delta L}{L}\right)\frac{V}{Q^2}$$

This value is obviously always negligible even if the coils are only approximately identical.

This is true, of course, only if we may assume that $\frac{1}{\omega C}$ is very large as compared to $\omega L$, that is, if the coil system is operated at frequencies remote from the natural frequencies of the individual coils. If not, the expression for the coil impedance instead of being $\sqrt{\omega^2 L^2 + R^2}$ will become

$$\frac{\frac{1}{\omega C}\sqrt{R^2 + \omega^2 L^2}}{\sqrt{R^2 + (\omega L - \frac{1}{\omega C})^2}}$$

and R is then of importance as compared to $(\omega L - \frac{1}{\omega C})$

In this C is the capacity across the coil which is the distributed capacity plus the capacity due to the connections and the like.

Consequently it is suitable to be as far as possible from the resonance for every individual coil and have a Q reasonably high.

The balance of the bridge in the receiver which I am demonstrating is obtained by a variable balancing condenser and the two coils of the bridge are fixed. However it is possible to use a fixed balancing condenser, constituted by a plate of glass or mica, the balancing of the bridge being obtained either by varying the inductance of one of the coils or merely by changing its position relatively to the primary coil. The only element which must be adjusted with precision is the element determining the balance, because other circuits must not be sharp, the selectivity resulting largely from the crystal. Indeed their sharpness may spoil the curve. Consequently it is very important to choose all the elements on which the balance of the bridge depends so that they do not change with temperature or any other condition.

The crystal in the demonstration receiver is silver plated and the holder is a metal plate on which the crystal rests and which provides one of the contacts, the second contact being provided by a spring pressing upon the opposite face of the crystal.

The curve 1 on the fig. 19 represents the response of the demonstration receiver comprising a RF stage, a crystal transformer operating at 475 KC and a second and almost a periodic transformer. The curve 2 is the response of the same receiver with the same RF, but with two good iron core transformers. The gain in both cases is approximately the same. In this case the flat top is of about 7KC wide to obtain a very great selectivity, but it is of course possible to make it as broad as desirable. The same crystal without the RF gives a flat top of 8KC.

If broader band is desired the selectivity will of course decrease, but the attenuation at the ends of the band remains practically the same.

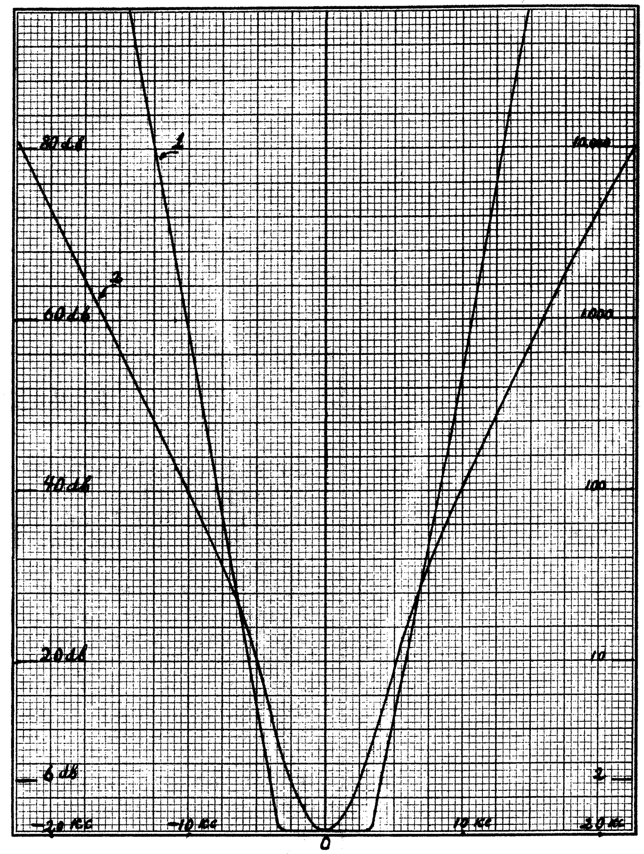


**Figure 19**

To obtain a variable selectivity it would be sufficient to provide a switch disconnecting the crystal. In this case the balance of the bridge will be destroyed and the resulting curve will be the curve of the electric circuit.

When the circuits in the receiver, other than the crystal transformer, are too sharp, it may be desirable to compensate the sharpness by giving to the resonance curve of the crystal the appropriate shape instead of the shape with a flat top. In fact the response for some frequencies can be increased and for some other frequencies attenuated by giving to the crystal a shape which would make the portions of the thicknesses corresponding to the frequencies to favor larger than the other portions.

## FILTERS BY ABSORPTIONS

When a crystal is connected in parallel with a condenser of a tuned circuit the impedance of the latter decreases at the frequencies at which the crystal resonates. If we connect two crystals resonating for the whole band of the circuit except a band to transmit, all the frequencies outside the latter band will be greatly attenuated. The maximum thickness of the thinner crystal will be smaller than the minimum thickness of thicker crystal, the difference corresponding to the transmission band. This method can be applied in cases when the price is of no importance, because the crystal must be much larger covering much broader band. Furthermore, they must be much more active, the attenuation depending upon the variation of the impedance.

* * * * *

I wish now to express my profound gratitude to Mr. H. W. Houck for all his valuable advice and all the assistance he has given in the work here reported.

## DEMONSTRATION

On the completion of the delivery of Mr. Guerbilsky's paper he showed a typical application of his broad band crystal filter to broadcast receivers by demonstrating a typical radio receiver in which the commonly used multistage I.F. amplifier had been replaced by a crystal filter of the type he described in his paper. In brief, this comprised a bridge circuit including the crystal working out of the converter tube and into an I. F. amplifier tube which, in turn, was coupled to the diode detector through a single tuned circuit.

While no quantitative demonstration of the selectivity nor the fidelity of the receiver was possible, it could be observed by the manipulation of the frequency control dial of the receiver that it had a high degree of selectivity and still acceptable fidelity. Especially was this evident as the receiver was tuned first to WOR operating on 710 K.C. and then to WLW operating on 700 K. C. with no marked interference between the two signals. To more definitely indicate the characteristics of the crystal filter, the crystal was then quickly, successively, and repeatedly removed and replaced and, when removed, left the receiver with little selectivity.

After the close of the formal portion of the meeting, those in attendence were given opportunity to operate the receiver themselves and to note its operating characteristics.