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CONTENTS

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Volume 23 April, 1946 No. 4

FREQUENCY DEVIATION RECEPTION

by

D. A. Griffin*

The problem of interference in radio communication has always concerned radio engineers. The demand for space in the spectrum has been such that only careful planning has prevented complete chaos. At no time has there been, or is there likely to be, sufficient room to take care of all possible services without a great deal of difficulty. The situation is particularly difficult in that portion of the short wave spectrum that is used for medium and long distance communication. The broad spark transmitter has given way to the precisely controlled tube transmitter, and receivers have progressed from the crystal detector to the modern superheterodyne. Despite these technical advantages, the demand for channels exceeds the supply.

The modern telegraph transmitter has been improved to the point where the amount of space required in the spectrum has been cut down to a practically irreducible minimum. At normal keying speeds it requires less than 100 cycles bandwidth. Yet we find commercial stations assigned to channels as much as 10 kilocycles apart, and, before the war, in the crowded amateur bands it was generally impractical to differentiate between stations spaced less than one kilocycle apart. Two factors enter into this picture; the first being the frequency stability of the transmitter and, second, the stability of the heterodyning oscillators in the receiver. Despite great improvements in this direction, it is still impossible to utilize the inherent selectivity of a superheterodyne equipped with a crystal filter using conventional receivers.

It is apparent that development in the field of receiver design offers the only means of improving this situation. A search for such improvements led to the development of "Frequency Deviation Reception". This name was selected to avoid confusion with the system of frequency modulation transmission. The latter can have no place in the low frequency amateur bands because the tremendous number of stations using these bands make it necessary to keep the bandwidth requirements of all transmitters at a minimum. The question was asked, could the process of frequency modulation within the receiver itself offer any advantages that could not be obtained with conventional methods? An affirmative answer was obtained that not only indicated improved selectivity could be secured, but also a considerable improvement in signal-to-noise ratio. In addition to these factors, the frequency deviation system requires much less attention on the part of the operator and the signals can be copied aurally for much longer periods without fatigue.

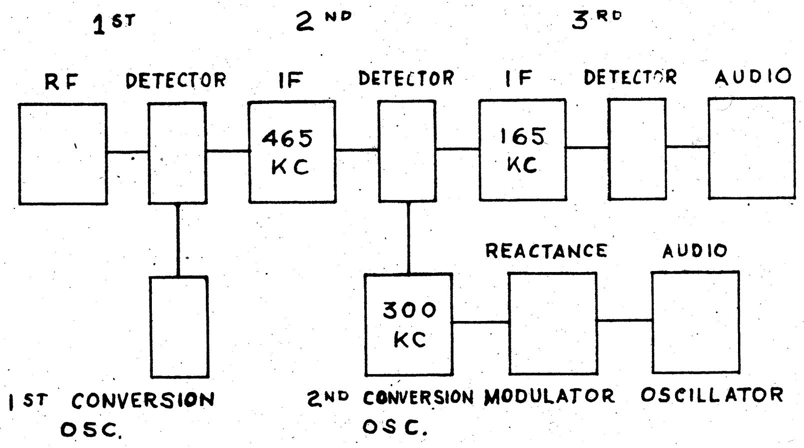

Figure 1

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*Communication Measurements Laboratory, New York City, Paper presented at the March 8, 1945 meeting of The Radio Club of America, New York City.

Several methods can be used to achieve frequency deviation reception. The one that provides the greatest flexibility and the best results to date is the use of a triple detection superheterodyne. Referring to Figure 1, we find a block diagram of such a system. The preselection stages for image suppression, the first detector, first conversion oscillator and the 465 Kc amplifier are conventional. Instead of feeding the output of the intermediate frequency amplifier into an audio detector in the conventional manner, the signal is fed into a second converter and then onto another IF amplifier at 165 Kc. The output of this amplifier is fed into a third detector operating as an audio detector and thence into an audio amplifier. If a signal is tuned in in the normal manner to convert to the peak of the first IF channel of 465 Kc, it will be necessary to tune the second conversion oscillator to exactly 300 Kc or 630 Kc to secure maximum signal strength at the third detector. If this is done, it will then be possible to receive telephone signals in the conventional manner. Now, let us assume that the shape of the selectivity curves of the two IF amplifier channels is the same as that shown in Figure 2. If the second conversion oscillator is deliberately mistuned far enough the two passbands will no longer overlap at any point, the result being that no signal will pass from the first IF channel into the second. If the curves have the shape indicated, it is possible to secure a substantially rectangular bandwidth that can be continuously varied merely by tuning the second conversion oscillator. This effect is of course a by-product of the system, but nevertheless provides a simple means of doing a rather difficult job. With proper IF design, the bandwidth can be varied from zero to 20 kilocycles, thus affording high fidelity broadcast reception or the degree of selectivity required to receive a telephone signal through heavy interference. Figure 3 shows how the steep edge of one IF channel cuts off the sloping portion of the other, thus providing a substantially rectangular overall passband. The solid lines indicate the overall passband, while the dotted lines show portions of the two passbands that are cut off.

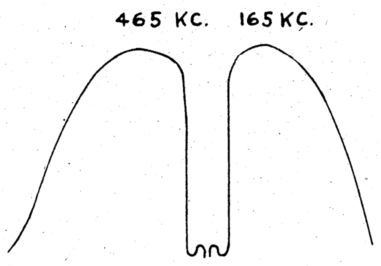


Figure 2

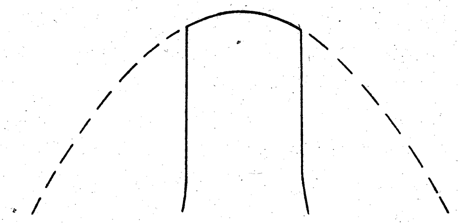


Figure 3

The first arrangement to be discussed illustrates the principle of variable bandwidth obtained in the manner just indicated, and at the same time can be used to demonstrate the results that can be obtained with frequency deviation reception of telegraph signals without using extremely selective circuits such as crystal filters.

Frequency deviation reception is, of course, only useful in telegraph reception. In this case the conversion oscillator is generally set so that signals from the first IF channel do not pass into the second IF channel. However, a reactance modulator is connected to the conversion oscillator so that it can be frequency modulated at an audio rate that is determined by the frequency of the audio oscillator. Referring to Figure 4, let us assume that there are three telegraph signals in the 465 Kc passband represented by lines A, B and C. For example, if the audio oscillator is set at 400 cycles, all of the signals can be passed into the 165 Kc passband 400 times a second. The result will be three signals of exactly the same tone and substantially the same strength, so that it will be impossible to copy any of them. However, if the amount of frequency deviation is properly controlled, signal C will be the only one passed into the second IF passband, the result being a single signal that provides perfect copy. If

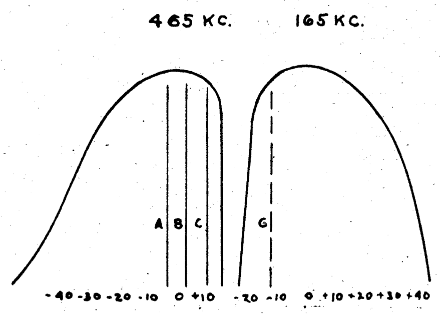


Figure 4

signal C is put on the edge of the 465 Kc passband by manipulation of the tuning control, the amount of deviation required is reduced. A decided improvement in signal-to-noise ratio is obtained as the overall passband is thus reduced to a minimum. If signal C were in the middle of the 465 Kc passband, it obviously would be necessary to pass at least half of the noise content of this passband into the 165 Kc passband if the signal were to be received. The process of tuning the signal to the edge of the 465 Kc passband, then using a minimum amount of frequency deviation, provides noise reduction ordinarily obtained with extremely high Q circuits. Further reduction in noise is obtained because the two passbands only coincide on one-half of the audio cycle.

The signal is of course 100% modulated at the audio rate determined by the audio oscillator. As long as the signal is deviated in and out of the second passband, it will be audible and will maintain the same pitch. This makes it possible to secure a further improvement in signal-to-noise ratio as it then becomes perfectly practical to use a selective audio filter in the audio system. It is impossible to do this if the conventional beat frequency oscillator is used to heterodyne with the signal at the audio detector. Frequency shifts of the high frequency conversion oscillator of the BFO in the order of an extremely small fraction of a percent will cause a shift in the audio beat frequency of many cycles, making a selective audio filter useless.

The BFO beats against all of the noise components that are generated in the RF and IF stages that reach the second detector in the conventional superheterodyne. If the amplitude of the BFO is fixed so that it will provide at least 100 per cent modulation of a fairly strong signal, its amplitude will be far greater than that required to 100 per cent modulate an extremely weak signal of the order of 1 microvolt or less. Tests indicate the desirability of reducing the amplitude of the BFO substantially for best signal-to-noise ratio on very weak signals. An amplitude control of the BFO is not provided in receivers simply because it would be next to impossible to keep it properly adjusted. Naturally no such problem is encountered with FDR as all signals regardless of amplitude are 100 per cent modulated.

The third and most important disadvantage caused by the use of the BFO is found in receivers using crystal filters. Operators attempting to use the best receivers on the market find it next to impossible to use the crystal filter and attempt to copy signal speeds above 35 words a minute. A ringing noise is set up so that the dots and dashes run together into an almost continuous blur. The generally accepted theory is that this is due to the high Q of the crystal filter. However, the best crystal selectivity curves indicate that there is sufficient bandwidth to pass keying speeds of approximately 100 words per minute, with still greater speeds possible if the selectivity is reduced slightly. Oscilloscopic studies show visually the tails that are put on the characters by the BFO. They are completely absent with the FDR system. The real cause of the ringing effect seems to be slight amount of leakage of the BFO into the crystal filter. This keeps it continuously agitated with the incoming signal superimposed on it as a pedestal. For this reason the crystal does not get a chance to come to rest at the conclusion of each character and the tailing effect is the result.

A novel form of aural selectivity can be obtained with the FDR system when a selective circuit such as a crystal filter is employed. This is illustrated in Figure 5. Let us assume that there is a great deal of interference and the desired signal this time is signal B. If the deviation is done from left to right, signal C will be received as well as signal B. Conversely, if the deviation takes place from right to left, signal A will be received as well as signal B. With the FDR system all signals are modulated at the same rate so that there is no possibility of utilizing the advantage of aural selectivity that can be obtained with the BFO. However, the second conversion oscillator can be set so that the signals are within the passband of the crystal filter as shown. Then, if the frequency deviation is properly adjusted, signal A and signal B can be shifted out of the passband on the left. Signal B and signal C can be shifted out of the passband on the right.

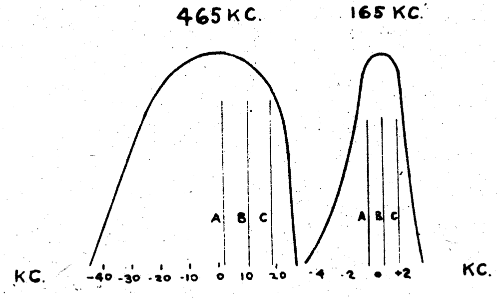


Figure 5

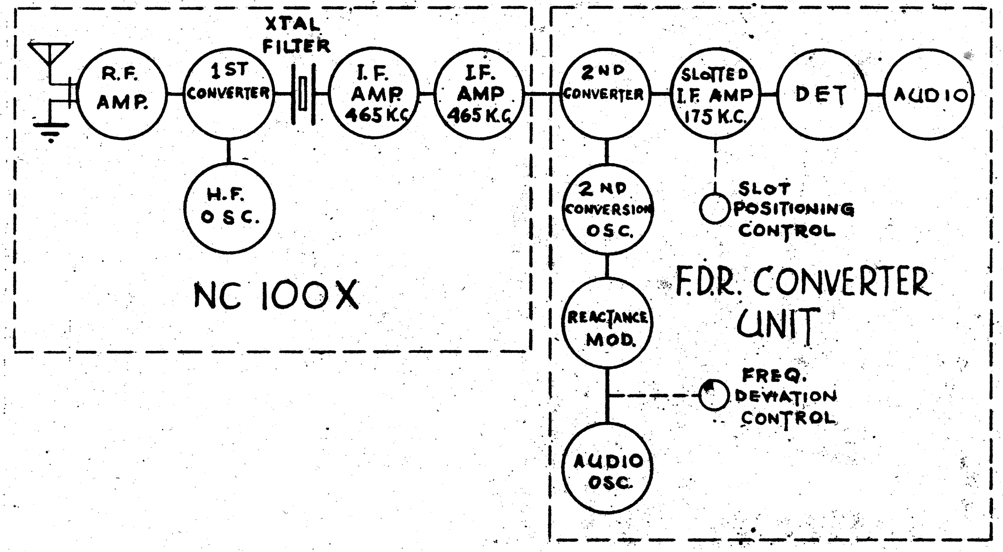
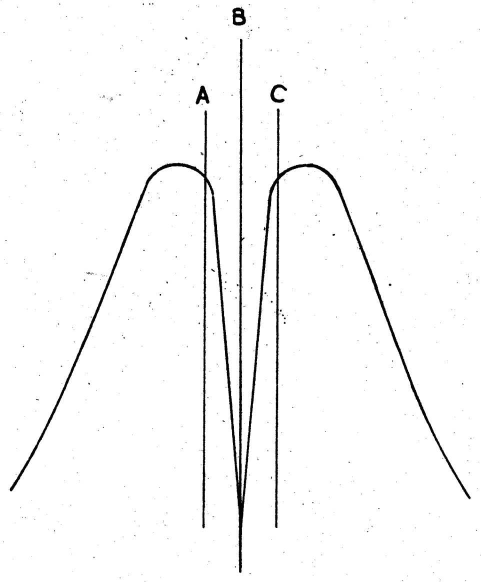


Figure 6

The result is that signals A and C deviate in and out of the passband in the normal manner. Signal B, however, is deviated in and out twice as many times. Signal B then is modulated at double the rate of the other two, and assumes a characteristic tone twice that of the audio oscillator. This provides aural discrimination, making it easy to copy signal B. Further attentuation of the undesired signals can be secured by the use of a selective audio filter tuned to accept the double frequency term and discriminate against the fundamental audio modulating frequency.

The second arrangement to be discussed employs a standard communications receiver and a special converter unit. The arrangement is shown in block diagram form in Figure 6. With this setup it is possible to compare the performance of the BFO method of CW reception with the FDR method. The NC-100X receiver can be used in the normal manner as a double-detection superheterodyne, or the second detector can be removed and the 465 Kc IF signal can be fed into the converter unit by means of an adapter plug. No change is made in the efficiency, signal-to-noise ratio, or bandwidth in any of the stages before the second detector when the converter is connected to the receiver, so that the comparison is a fair one except for a slight decrease in bandwidth when the converter is used.

For best results we use the crystal filter in order to secure maximum selectivity in both cases. The converter unit employs a frequency converter that shifts the 465 Kc IF signal from the receiver to 175 Kc. This is followed by an IF amplifier connected to provide infinite rejection of a single frequency within the passband. The characteristic curve of this stage is shown in Figure 7. With this arrangement it is possible to get exactly the same effect as that obtained when a crystal filter is employed at this point. The position of the rejection point can be moved about to any point in the passband, but the best effect is secured when the rejection point is at the center. A conventional diode detector and audio amplifier follow this IF stage. The audio oscillator and reactance modulator make it possible to frequency modulate



INFINITE REJECTION SLOT

Figure 7

the conversion oscillator of the converter. This enables the operator to pass the signal from the 465 Kc amplifier back and forth across the "slot" in the 175 Kc response curve at an audio rate. Control of the audio oscillator amplitude also controls the amount of frequency shift of the conversion oscillator.

If a signal is tuned in so that it appears in the 175 Kc IF amplifier at frequency A of Figure 7, there will be little or no signal at the detector because of the enormous attentuation of the infinite rejection circuit. The application of frequency deviation to the second conversion oscillator, so as to vary the position of the signal between the frequencies B and C, provides a fairly high degree of modulation with a very narrow frequency shift. By limiting the amount of frequency modulation to a very narrow band, it is possible to apply modulation to one signal while leaving a nearby interfering signal unmodulated. Even if the two signals are so close together that both will be modulated, the one which is tuned to the exact frequency of the infinite rejection slot will be deviated into and out of the slot twice each cycle, causing the fundamental modulation frequency to be twice the deviation frequency. The other signal will not be deviated through the slot, but only into it, and then out of it on the same side so that its modulation frequency will be equal to the deviation frequency.

Some of the preliminary measurements we have taken indicate that this system has a signal-to-noise ratio at least 10 db better than the BFO system. This is a considerable improvement as it is obtained as an additional benefit after all possible avenues of improvement have been exhausted in the design of the high frequency stages.

The most startling advantage of the FDR system is the improvement in the definition of high speed dots and dashes when a sharply tuned crystal filter is used. Figure 8 is a reproduction of an oscillogram of a series of dots, about 7 per second, received with a standard receiver using a BFO. You will notice how the dots seem to run together producing the continuous "ringing" sound usually associated with sharply tuned crystal filters. Figure 9 shows the same signal received on the same set with the identical crystal filter selectivity setting, but using FDR instead of the BFO.

In addition to this advantage, there are two others that are important to the operator rather than to the design engineer. First, frequency instability of the transmitter or the receiver will not cause any change in the pitch of the signal. This eliminates the necessity of constantly retouching the tuning of the receiver when extreme selectivity is employed. The second advantage is physiological. If the waveform of the audio oscillator is distorted, the received signal assumes a pleasing characteristic in comparison with the pure tone encountered with the BFO. There is no question that operator fatigue is materially reduced when the received signal is rich in harmonics, as anyone can testify that has been forced to listen to a pure tone for any substantial period of time.

We have not had time to investigate a number of other avenues that seem to hold much promise using the basic FDR system. Workers in the field of communications may be interested in some of the possible improvements and applications of the FDR system that have not been explored. Inasmuch as the problem of BFO leakage is no longer present, it is possible to locate the crystal filter in a much more favorable position in the IF amplifier than was possible heretofore. In conventional receivers the crystal filter is put ahead of the IF amplifier to avoid BFO leakage. While it cuts out much of the internal set noise that is developed in the preselector and first detector stages due to the reduction in bandwidth, noise in the IF amplifier is not cut down because the bandwidth of the IF amplifier is not decreased by the introduction of the crystal filter. With the crystal filter located ahead of the third detector in the second IF chain, the effective bandwidth at the third detector will be that of the crystal filter itself. This should result in a still further substantial reduction in the noise level.

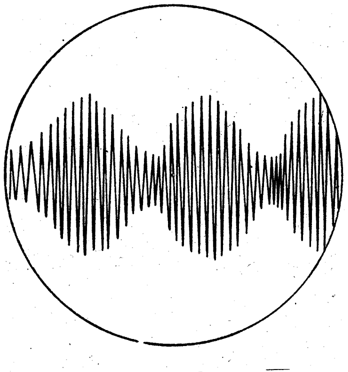


Figure 8

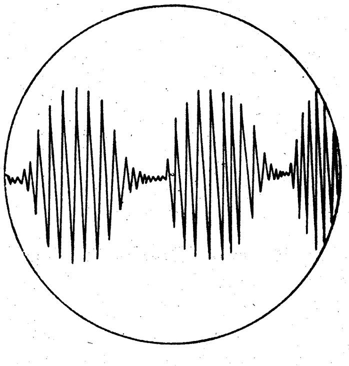


Figure 9