Proceedings

of the

Radio Club of America

Incorporated

November, 1936

Volume 13, No. 4

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Volume 13 November, 1936 No. 4

SOME ASPECTS OF INTERFERENCE AND NOISE REDUCTION IN COMMUNICATION TYPE RECEIVERS

BY

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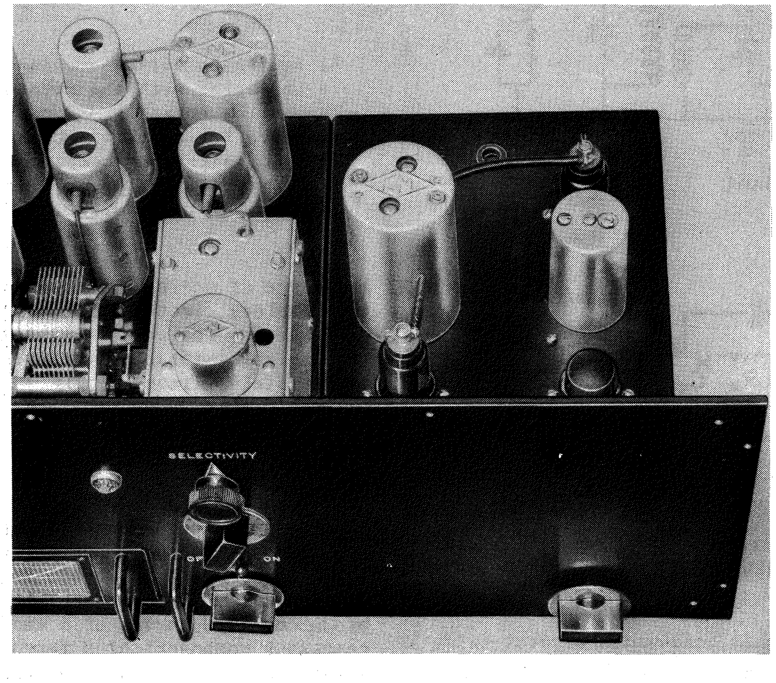
Delivered before the Radio Club of America
May 26, 1936

Only one of the fantastic features of radio communication in its present state is the continual compounding of complications that it inflicts upon itself both as the price of and as the result of progress. Each new technical advance that we make for the purpose of increasing the reliability and economy of operation of existing facilities through the reduction of interference discloses new possibilities which attract more users and give rise to further expansion and thus increase the load on the available frequency spectrum and, of course, threaten worse interference than before. This, then, requires further technical advances which result in more uses and more interferences - and so around the circle. And, while we are thus happily chasing ourselves in our own private vicious circle, the advances of civilization in other fields of endeavor are busily concocting new gadgets capable of bigger and better noise interference, such as the newest type of electric razor which has such excellant coverage -- all-wave and a block wide -- and likely to go off at hours of the day or night all out of keeping with normal shaving schedules. Worse yet, we are not content with complicating life for ourselves in our own field but we also must show outsiders how to use radio frequency equipment for purposes other than communication, with the result that we find ourselves being ungratefully bitten by diathermy "shadows" and the like.



Top view of the silencer section of the receiver using the circuit shown in Figure 9 on Page 35.

Viewed from this possibly pessimistic point of view, it might seem that technical progress in our chosen field is in the nature of a perpetual penance laid upon us, and that we must needs run as fast as we can in a modern sort of wonderland just to stay where we are. The way of the first pioneer may be hard; but sometimes we almost envy the young Marconi in that he had only to break through natural static, while man-made "static" was then still many years in the future.

But then if there were no complications such as these, perfection would have been too easily obtained and there would be no need to-day for the army of engineers, amateurs, experimenters and research workers still striving for further progress. And that would make the lot of many of us most unfortunate.

The problems of interference from man-made signal and noise interference concentrate in the amateur bands in a fashion which needs no detailed description. Hence some of the practical aids which have been applied in amateur communication receivers should be of general interest.

The general problem being interference, whether

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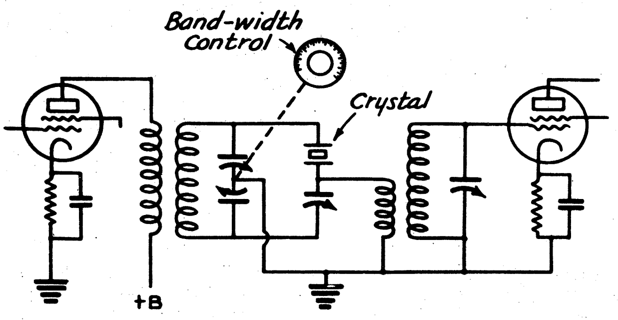
from undesired signals or noise, the attempts at solution take the form of improvement in selectivity; that is, selectivity in the broad sense of discrimination against everything but the desired signal. While selectivity is ordinarily considered as related only to the frequency characteristic of the receiver, in this instance it will be considered also in relation to the amplitude and phase characteristics of the receiving system. It may be permissible to distinguish three forms of selectivity: Frequency selectivity, amplitude selectivity and phase selectivity.

FREQUENCY SELECTIVITY

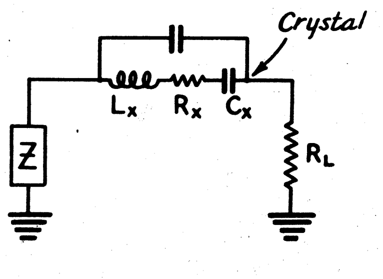
Perhaps the most widely used device for obtaining controllable high selectivity in communication receivers is the quartz crystal filter, used in the intermediate amplifier of superheterodyne receivers of the single-signal type. Two types of crystal-filter circuits are in general use, one of fixed sharpness of resonance with controllable symmetry, and the other of variable sharpness of resonance, also with controllable symmetry. This latter variable band-width type, which is adaptable to both c.w. telegraph and 'phone reception,, will be discussed here.

HOW CRYSTAL FILTERS WORK

Figure 1 illustrates the actual and equivalent circuits of a typical variable-selectivity quartz-crystal filter.(1) The crystal resonator is connected in a bridge circuit as shown in A, a two-section symmetric condenser forming two arms of the bridge, in parallel with a variable condenser which is used for adjustable tuning of the secondary of the input transformer. This arrangement gives an impedance stepdown of approximately 4 to 1 at the input. The primary of this transformer has approximately three times the inductance of the secondary, to which it is closely coupled, and is untuned. The primary of the output transformer is of such inductance and coupling as to match the output impedance to the series-resonance resistance of the crystal which is approximately 2500 ohms.



A-ACTUAL



B-EQUIVALENT

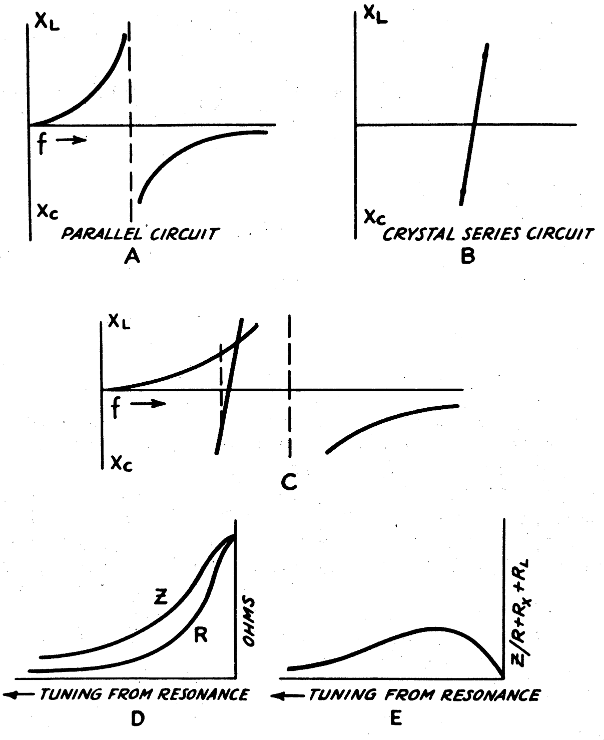
A, actual circuit of variable band-width crystal filter with adjustable rejection; **B**, equivalent circuit for illustrating variable band-width action.

Figure 1

The crystal and rejection condenser in series with it form the other two arms of the bridge, the crystal providing the coupling.

VARIABLE BAND-WIDTH ACTION

The equivalent series combination contains one half of the input circuit (across one section of the symmetric condenser) as well as the crystal and the primary of the output transformer. Series resonance occurs in this circuit when the capacitive and inductive reactances are equal. Reactance variation of R_L remains negligible over the range of operation, so that the resonant frequency of the complete circuit depends on the reactances of the crystal and Z. The parallel-tuned circuit, Z, is therefore the variable, tunable over a resonant frequency range near the crystal's frequency by adjustment of the band-width control. This means that the reactance curves for the parallel circuit, as shown in Figure 2, will be shifted along the frequency scale as the condenser is adjusted. Now, since the crystal has an extremely high inductance-capacitance ratio as a series circuit, its reactance curve is very steep, as shown in Figure 2-B. Hence the resonance frequency of the parallel circuit can be changed over a considerable range with but negligible effect on the resonance frequency of the complete circuit, as illustrated by the combined curves of A and B in Figure 2-C. With the reactance component of Z tuned out by the opposite reactance of the crystal, the variation in tuning of the parallel circuit by the band-width control will introduce, practically, only the varying resistance component



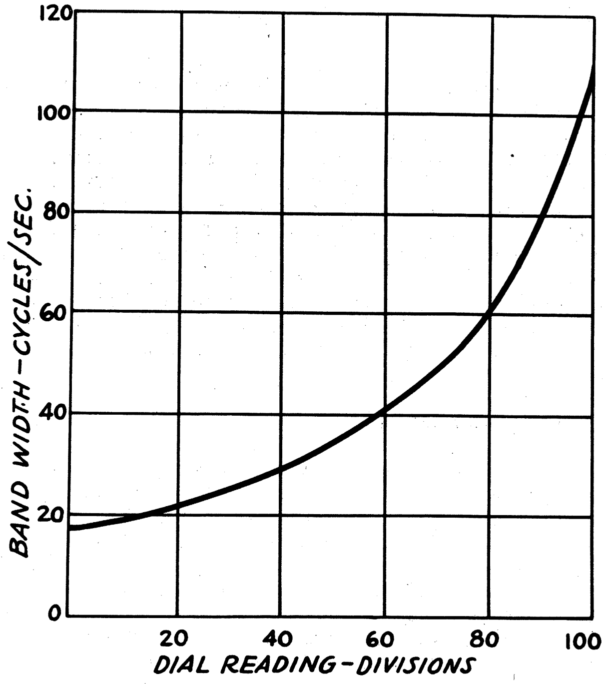
A, reactance curves of parallel-tuned circuit which is in series with the crystal; **B**, reactance curve of the series crystal; **C**, combined reactance curves of the parallel circuit and series crystal; **D**, impedance (Z) and resistance component (R) curves of the parallel circuit with tuning from resonance; **E**, variation in output voltage with tuning from resonance.

Figure 2

of parallel impedance in series with the crystal. The amount of this resistance determines the Q and, hence, the selectivity of the series circuit.

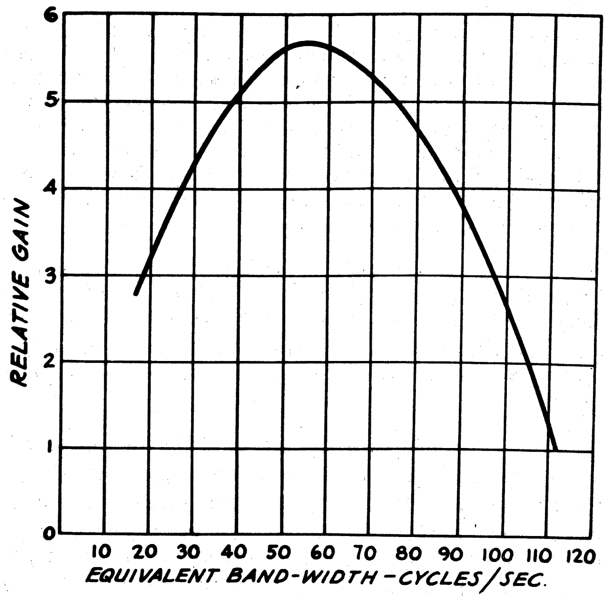
The voltage applied to the amplifier following the filter will depend on the current in the crystal series circuit. With this circuit resonant, the input voltage and series resistance will determine the current and, consequently, the output voltage. Now, both the input voltage and the series resistance are dependent on adjustment of the parallel-tuned circuit. Since the primary of the input transformer is not resonant, the voltage induced in series with the secondary will be comparatively constant over the small range required. Hence, the voltage applied to the series circuit, across the secondary (Z), depends on the secondary impedance. The impedance of the parallel circuit as it is detuned will change as shown by Curve Z of Figure 2-D, which curve also represents the voltage applied to the complete series circuit. Curve R of this figure illustrates the variation in the resistance component of the parallel impedance Z. The resonance current through the complete series circuit is dependent on the applied voltage and the total series resistance. This current, and hence the output voltage, will be represented by the ratio of Z to the total resistance of the series circuit and will vary with adjustment of the band-width control as illustrated in Figure 2-E.

It is evident that the maximum band-width (minimum selectivity) and minimum gain occur simultaneously with the input circuit tuned to resonance. An intermediate value of selectivity and maximum gain occur with the parallel circuit slightly detuned. This maximum gain condition (which occurs where the resistance and reactance components of the parallel circuit are approximately equal) is referred to as the adjustment for "optimum selectivity". Minimum band-width (maximum selectivity) and a lower value of gain occur with the parallel circuit detuned further from resonance. Experimental verification of the variation in selectivity by operation of the band-width control is shown is Figure 3. Variation in gain with selectivity is shown by the curve of Figure 4. Data for these curves were obtained by measurements on an early type single-signal receiver using this filter circuit.[2]



Experimental curve of the crystal-type S.S. receiver showing variation in band-width with tuning of the parallel circuit (Tuned to inductively reactive side of resonance).

Figure 3

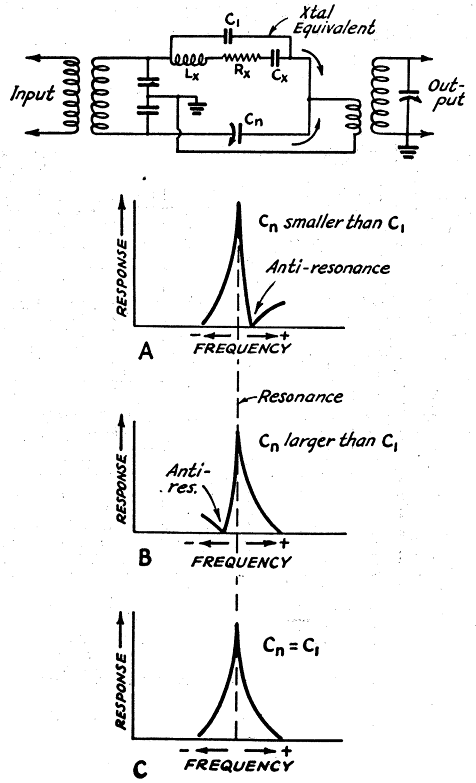


Variation in gain of the filter circuit with adjustment of the band-width control. (Cf E of Fig. 2)

Figure 4

REJECTION ACTION

As is well known from the equivalent circuit of the quartz crystal, the crystal is normally anti-resonant for a frequency approximately 1/2-percent higher than its resonant



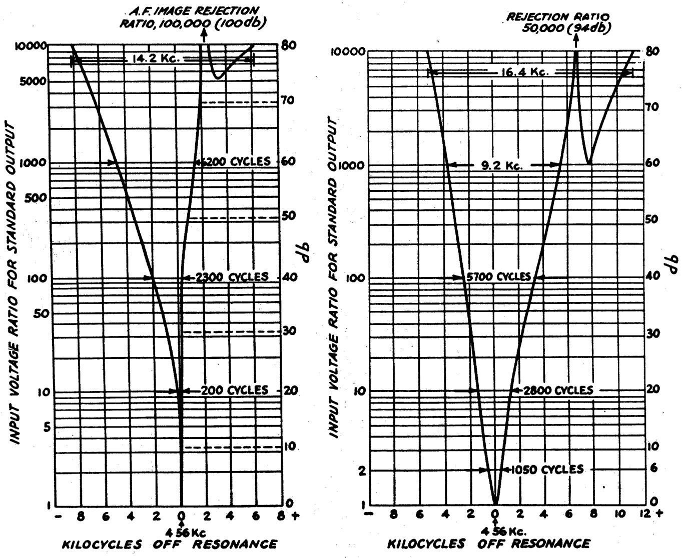
Illustrating the adjustable rejection action of the crystal filter, as used to eliminate heterodyne interference.

Figure 5

frequency. This results from the reactance of the shunt capacitance of the electrodes resonating with the inductive reactance of the crystal network at a frequency slightly above the latter's natural frequency. In the bridge arrangement of the crystal filter, this normal behavior is modified to shift the anti-resonant or rejection frequency to different values, both above and below resonance, within a limited range. The operation is illustrated by Figure 5.

The diagram of this figure shows the filter circuit with the crystal in its electrical equivalent form. Voltage is applied through the condenser C_n in anti-phase to the voltage operating on the crystal circuit. This will be recognized as similar to the neutralizing action for bridge circuits.

Now it might appear that C_n serves only to balance out C_1. However, in this instance C_n does not serve simply to neutralize the effect of the capacitance C_1, and thus to prevent unselective transmission past the crystal, but rather, as C_n is varied from minimum to larger capacitance the anti-phase voltage serves to make the effective shunting reactance of C_1 vary from its normal capacitive value, through zero, to a slightly minus capacitive value, when the effect is as if inductance were substituted for C_1. In the latter condition, the shunt reactance having changed sign, the complete crystal network is effectively in parallel resonance (or is anti-resonant) for a frequency below the crystal's natural frequency. Thus, while having maximum response to the desired-signal frequency, the circuit can be adjusted to reject an interfering signal having a carrier frequency in the range from several kilocycles above to nearly the same amount below crystal resonance. The rejection is most pronounced with the band-width control at optimum selectivity, but remains highly effective at minimum selectivity, as shown by the curves of Figure 6. These curves are made from measurements on a standard HRO receiver using this type of variable band-width filter.

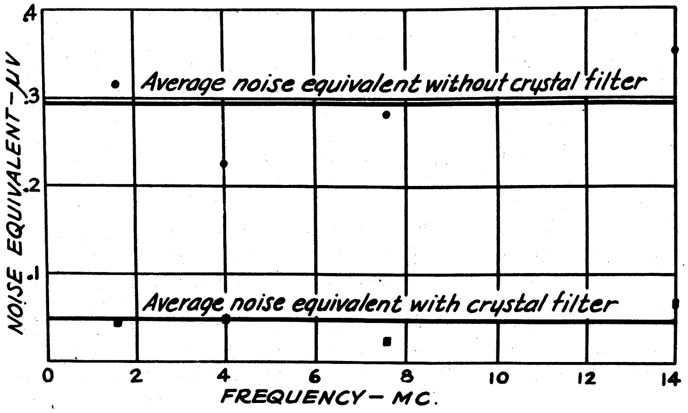


Maximum and minimum selectivity curves of a S. S. type receiver using the variable band-width crystal filter. Rejection adjustments are for two different interfering frequencies. Rejection is also effective on other side of resonance in both cases.

Figure 6

FREQUENCY SELECTIVITY AND NOISE

In addition to discriminating against undesired radio signals, the high-selectivity crystal filter also discriminates against noise, especially noise of the "hiss" type which consists of overlapping wave trains of noise pulses which are of amplitude comparable to that of the signal, or of smaller amplitude. As has been shown, particularly by V. D. Landon in a paper presented at the annual convention of I. R. E. in May, 1936, the peak and r.m.s. value of this type of noise varies as the square root of the band-width in a particular receiver. That is, the noise power is reduced in direct proportion to the reduction in band-width, and the effective voltage sensitivity of a receiver for c.w. signals is, therefore, increased as the square root of the ratio of reduction in band-width. Experimental verification of this improvement is shown in Figure 7, which is plotted from measured data taken on an early "single signal" type receiver, the noise being that of the receiver itself. The upper mean curve is for conventional superheterodyne selectivity with equivalent c.w. band-width of approximately 6600 cycles. The lower curve is for optimum crystal filter selectivity, the equivalent band-width being approximately 50 cycles. The ratio of improvement in effective voltage sensitivity is of the order of 20 db. At maximum selectivity of the filter (band-width approximately 20 cycles) the improvement would be approximately 50 db, while at the minimim filter selectivity (band-width of approximately 120 cycles) the improvement would be around 15 db.



Improvement in receiver noise equivalent with increased selectivity. Straight superhet values are for an equivalent band-width of approximately 6600 cycles, crystal filter values for e.b.w. of approximately 50 cycles. (N. E. varies inversely as square root of e.b.w. ratio)

Figure 7

AMPLITUDE SELECTIVITY

While the high-selectivity circuit discriminates against "hiss" type noise in the manner just described, the behavior of the receiver is markedly different under the influence of high-amplitude noise pulse excitation.

As has been pointed out by V. D. Landon in the paper referred to above, the ratio of peak to effective values for "hiss" noise voltage remains constant at a crest factor of approximately 3.4, regardless of the receiver band-width, both peak and effective values being reduced equally as the band-width becomes smaller. When, however, the noise excitation is of a staccato nature and the discrete noise pulses are of short duration as compared with the time separation of successive pulses so that the wave trains do not overlap, this peak-to-effective ratio or crest factor varies with band-width, being greater for large band-widths and becoming smaller as the band-width decreases. The explanation of this is, of course, that the individual wave trains generated within the receiver circuits by the noise pulses increase in duration and thus, the effective value increases relative to the peak value as the band-width is reduced through the improvement of circuit selectivity.

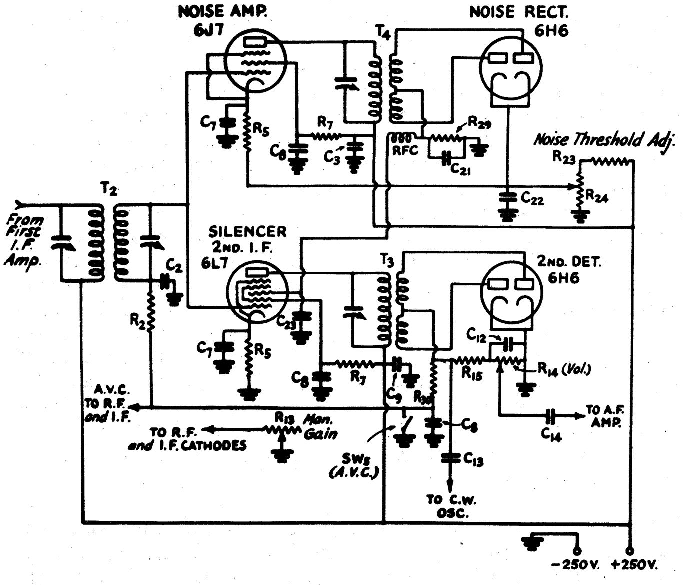
While high selectivity may perhaps be effective against this intermittent type of noise so long as it is of relatively small amplitude as compared to the signal, it becomes impotent when the action of the narrow-band filter circuit increases the duration of the individual wave trains and thus raises the effective value of the noise to a point where it becomes comparable with that of the desired signal. Incidentally, it is a happy fact that "hiss" noise voltage at the receiver's input circuit is generally of low amplitude, while high-amplitude noise is characteristically of the intermittent type.

Because of this, some means other than frequency selectivity must be employed in the case of noise pulses to bring down the effective value of the noise relation to the signal. And, in fact, the very characteristics of this type of noise suggest the method of its amelioration. Thus, since this type of noise is characterized by the fact that it occurs at relatively infrequent pulses - as compared with the frequency of other types of noise and as compared with the audio signal - the reduction of its effectiveness in interfering with the signal should result from its elimination through making inoperative the entire receiving system at the instant of its impingement. Indeed, it would be most effective to make the receiving system momentarily ineffective <u>just before</u> and during the impact of the noise pulse; and, indeed, this may be done by subjecting the signal to some delay in the receiving system while employing the noise pulse itself without delay in making the output portions of the receiving system inoperative for just sufficient duration as to wipe out the influence of the noise pulse. In practice, however, it has been found sufficient to provide for the effective reduction of the amplification of some one element of the radio receiver to substantially zero during all or part of the time during which the noise pulse would otherwise make itself troublesome.

For accomplishing this, two different circuit arrangements (3, 4) have been devised and are shown in Figures 8 and 9. In both of these the desired silencer action is obtained by providing several additional elements to an otherwise conventional superheterodyne circuit. Thus, a special noise amplifier stage is employed including its own noise rectifier which, in Figure 8, feeds a biasing voltage to the silencer tube which itself is in the chain of amplifier tubes between the second detector and the intermediate frequency amplifier. Normally it acts as a portion of the I. F. amplifier but, on the impressing of a noise pulse on the noise amplifier and rectifier, becomes momentarily inoperative and thus protects the second detector from the influence of the noise pulse. It is, of course, essential that the silencer operation occur for only such values of noise pulse amplitude as exceed the signal amplitude, lest the signal itself interfere with its own free transmission through the system of the receiver. To provide for this requirement the "Noise Threshold Adjustment" is provided in the form of a manually controllable bias on the noise amplifier and on the noise rectifier.

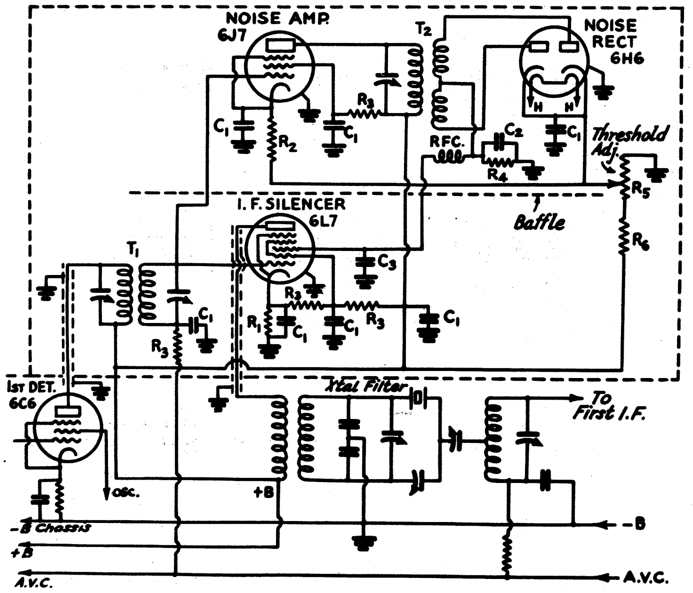
Such an arrangement as this provides very effectively for the reduction of the noise due to noise pulses of all kinds, such as result from the operation of other electrical equipment in the region of the radio receiving equipment. It is highly effective in connection with all radio telegraphic reception and for certain kinds of radio telephone reception but it must be admitted that for truly high fidelity radio transmission, its usefulness is markedly limited. Where, however, intelligibility - as in amateur and commercial non-public radio service - is the primary requirement it serves most effectively to convert transmissions which would be otherwise quite unuseable to perfectly useable transmissions; and thus it provides much of value to many types of radio communication.

The simultaneous use of these two methods of noise suppression, one useful in the reduction of the troublesome effectiveness of the hiss type of noises and the other useful in the reduction of the effectiveness of the pulse type of noise at the same time, suggests itself immediately and, indeed, has been found of great usefulness. It is, however, to be noted that in order that both expedients may be effective, it is essential that the silencer



Noise-silencing circuit applied to second i.f. stage of communication-type superhet receiver.

Figure 8



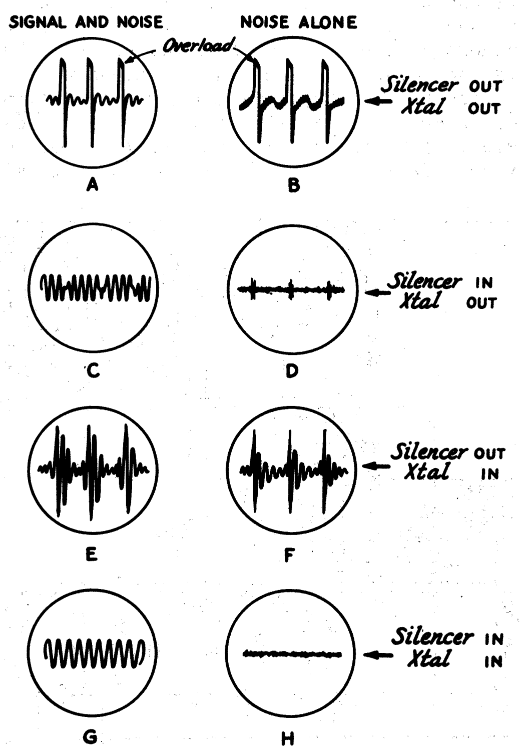
Silencing circuit applied between first detector and crystal filter of a S. S. type receiver.

Figure 9

arrangements precede the crystal filter in the chain of amplification comprising the radio receiver since, if the order is reversed, the noise pulse when impressed on the crystal filter will, thus, be converted from its original form of that of a pulse of high amplitude and short duration to one of long duration and only little decrement and thus give it something of the characteristics of the signal itself and make it highly effective in interfering with the signal. When used in the proper order, however, in which the silencer circuit wipes out the noise pulse before it can be offered to the crystal filter, a most effective combination results.

The circuits of such an arrangement are shown in Figure 9 in which the silencer circuits follow immediately on the output of the first detector of a conventional superheterodyne type of receiver and in which the output of the multifunction silencer-amplifier tube feeds the crystal filter directly.

The effectiveness of this combination of noise suppression arrangements can, of course, be best appreciated by listening to its operation in the reception of signals. It has, however, been found possible to show by oscillographic analysis the wave forms resulting from its operation and thus provide some visual evidence of its effectiveness. This is indicated by the wave form reproduced in Figure 10 of which the four traces shown on the left-hand column are those of the combined signal and noise under different conditions of noise suppression, while those shown in the four traces in the right hand column are those of the noise alone. Thus, in Figure 10, A and B, are shown the untreated noise and noise-signals which are characterized by the fact that the noise amplitude is not only so great as to vastly exceed the signal amplitude but so great as to cause actual overloading of the receiver circuits as indicated. In Figure 10D is shown the effect of the operation of the silencer circuits from which it will be evident how thoroughly effective these circuits are in reduction of the impulse type of noise. Figure 10C shows, similarly, how relatively free of the impulse type of noise is the signal as the result of the operation of the silencer circuits.



Oscillograms of c.w. beat note output obtained with the S. S. receiver using the silencer circuit ahead of the filter. (Beat-note c.w. reception with spark) interference.)

Figure 10

On the other hand, it will be noted from Figure 10, E and F, and their comparison with A and B, how markedly the crystal filter builds up the impulse noises so as to mask the signal completely. And in Figure 10G and H is shown the result of the operation of both the crystal filter and the silencer circuits. From these it will be noted that not only does the silencer circuit almost completely eliminate the influence of the impulse noise but the crystal filter does, to a surprising degree, fill in the "hole" in the wave form made by the operation of the silencer circuit.

EDITOR'S NOTE

At this point in Mr. Lamb's dissertation, an extended demonstration of the operation of his arrangements in the reception of long distance short wave signals was made. Locally generated interference was provided in the interest of having a constant and controllable source of noise; and reception under the several conditions of noise suppression, as indicated in Figure 10, was accomplished. It is to be reported that precisely as suggested by Mr. Lamb's oscillographs, the overpowering intense impulse type of noise was so far suppressed by the action of the silencer circuits as to make otherwise unintelligible telegraph signals easily and comfortably readable. Similarly, it was noted how the action of the crystal filter alone converted the staccato noise pulse into clear, rounded, bell-like tones that persisted for easily appreciable periods and thus even more completely masked the signal than did the original noise itself. And, finally, it was shown how the combination of the silencer circuits followed by the crystal filter resulted in signals which, as far as the ear of the auditor could tell, were completely free of all of the originally overpowering noises.

DIVERSITY RECEPTION

In addition to its well-known ability to mitigate fading effects, diversity reception also offers possibilities for improving effective selectivity in reception, particularly for reducing heterodyne interference in the reception of amplitude modulated signals. This may be considered as a species of phase selectivity, as has been pointed out by the mathematical analysis of J. Robinson ("The Elimination of Inter-Station Interference", Wireless Engineer, April, 1935). If two spaced antennas connected to separate receivers are used for the reception of amplitude modulated waves and the audio-frequency outputs of the two receivers are combined, the signal outputs from the two detectors will, in general, add up arithmetically, but beat-frequency heterodyne products from an interfering carrier will add up vectorally. Hence, heterodyne interference in even a simple diversity system will, at worst, be the same as in a single receiver and may be reduced to zero when the beat note outputs of the two final detectors are equal in amplitude and 180° different in phase. This phase relationship may be controlled by the spacing and the directivity of the antennas or perhaps by adjustable phase-shifting networks in the receiver proper.

While the writer has been occupied during the last year in the development of a diversity receiving system of this kind(5) and will doubtless have reports of its performance to make some time in the not too distant future, no specific report can be given at this time. It is felt, however, that this mode of interference reduction should be here given mention.

This brief discussion of methods for the reduction of noise and interference would not, however, be complete without some reference to at least one other method that seems to have tremendous possibilities. More specifically, it should be pointed out that in such methods as are here discussed, the problem which is faced is that of differentiating between the interfering noise and a signal which are largely identical in characteristics and thus give little latitude for differentiation: so small a latitude that minor operational improvements are viewed as major technical accomplishments. Indeed, as long as the nature of the signal and the noise continue to be so nearly identical, just so long will the solution of the noise suppression problem be exceedingly difficult of attainment. There are then, two general directions in which further work in this direction may take: either the magnitude, nature of the noise, or both, may be so modified as to improve the operation of radio systems; or the magnitude, nature of the signal, or both, must be so modified as to bring about improved operation. Much work is being done by many in all of these directions.

Those who are associated with the sources of interference, i.e., the electrical and automotive industries, have become keenly conscious of their responsibility in this matter and are achieving some success in the elimination of many sources of noise interference with radio.

The broadcast radio receiver manufacturers are recognizing the fact that carelessly installed antennas can be expected to do little more than to invite noise interference and are, therefore, educating the radio-listening public to the advantages to be found in elevated antennas connected to the receiving set through transmission lines isolated from the sources of noise interference.

The operators of broadcasting stations are, to such a degree as economic and regulational considerations make it possible, slowly but surely building the power level of broadcasting stations upward against the noise level which their signals encounter.

And, of course, such expedients as have been here described are contributing their share to the reduction of the effect of noise interference.

There is thus left one major direction of this work as yet little investigated and only recently brought to the general attention of the technicians in the radio field. That is, the possibilities of other types of radio transmission in the interest of providing for the easier and more effective differentiation between the noise and the signal. Outstanding in this direction is the recently announced work of Major E. H. Armstrong in the development of a practical system of frequency modulation.(6) The writer is as yet too unfamiliar with the work in this direction to justify an opinion on its ultimate possibilities, but he can't resist the desire to point out that perhaps, with the passing years, we will all come to view the work here discussed and reported as having been of far less importance than the mere facing of the fact that since we can do so relatively little in changing the nature of the noise to which our radio signals are subjected, we might best do all we can to change the nature of the signal.

Above all, engineers in our field must view new developments, no matter how radically they may transgress our preconceived notions, with open minds. If our present methods are actually obsolete, and amplitude-modulated transmissions are due ultimately to be thrown "out the window", we should be the first to realize the situation and get into action. Not to be the first to try, nor yet the last to adopt, may be an adage satisfactory to the philosophical way of thinking. But an obstinate engineer can never tell how long he can remain reactionary without missing the bus entirely.

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RADIO INTERFERENCE

BY

ALLEN W. HAWKINS*

Delivered before the Radio Club of America

April 9, 1936

"Radio Interference" is the term applied to all electrical radiations which interfere with radio reception. Radio interference can be classified in three groups: interference resulting from atmospheric and other natural causes; interference by radio transmitters; and interference arising from the operation of electrical equipment commonly termed "man-made static". It is the purpose of this paper to discuss the latter class, and to discuss it mainly from a stand-point of locating the sources of interference.

The sources of "man-made static" can be classified in two groups. The first group includes high voltage or high frequency apparatus such as x-ray equipment, diathermy machines and vacuum tube bombarders. The second group includes all other equipment giving rise to interference radiations through sparking and arcing.

The first class of interference sources such as x-ray apparatus need not be discussed at any length because that type of equipment is confined to relatively few areas and because of high levels of such interference produced by it the sources are easily located.

The second class of interference sources, those arising from the arcing and sparking can develope in any piece of electrical apparatus or circuit wiring. Thus unless we retire to the wide open spaces, we are surrounded at all times with potential sources of radio interference. It is no wonder, then, that most radio interference comes from some sparking wire, motor commutator, oscillating thermostat, or something else that makes an electrical arc. Since new types of appliances are constantly appearing on the market, there are always new sources of interference being called to the attention of the radio trouble-shooter.

Quite a large proportion of these appliances are not inherently producers of interference. It is only because of loosened contacts, improper adjustment, or faulty installation that they become troublesome to the radio listener.

It may be interesting to consider the actual figures of radio interference found in a large portion of the State of New Jersey. This summary contains only cases where complaints were made by individuals to the local power company. These figures are probably typical for any other geographical area of similar distribution of industrial, residential, and rural areas.

The total number of radio interference cases investigated in 1935 was 1990 distributed as to the source of interference, as follows:

Electric power lines and equipment	11%
Other Utilities (trolleys, telegraph, telephone, traffic lights, railroad signals, etc.)	3%
Radio set defects	21%
Complainants' wiring & appliances	17%
Other appliances in neighborhood	20%
Unknown responsibility (noise disappeared)	28%

From these figures we see that in 72% of the cases the source of the interference was found and in the other 28% the interference disappeared before a location of the source could be made. So let us consider only the cases where the trouble was found.

Thus a new tabulation follows:

Electric power lines and equipment	16%
Other utilities .	4%
Radio set defects	29%
Complainants' equipment	23%
Other appliances in neighborhood	28%

By adding the percentages of complaints due to radio set defects, 29%, to those due to complainants' household equipment, 23%, it is evident that the trouble-shooter will find the trouble in the complainant's establishment in about 52% of the cases he is called on to investigate. In any case, adding 28% for other appliances in the neighborhood, the source of the trouble will be in or near the complainant's house 70% of the time.

Thus, the radio trouble-shooter should visit the complainant's house first. If the interference is not in evidence at the time, he will be able to gain helpful information from the complainant regarding the disturbance. The trouble-shooter should try to ascertain the approximate time of day the annoyance occurs, wave bands covered, volume level and characteristics of the noise itself. From this information he will know when to come back, what sort of apparatus to bring with him and something about the character of the interference.

Now that the trouble-shooter is well started on his job, let us consider what sort of a problem he faces.

A spark discharge can, of itself, produce any and all frequencies of the radio spectrum. The circuits of conductors connected to it become the tank and antenna system. The resonant characteristics of these conductors determines the frequency or frequencies of interference. The area of disturbance as well as the frequency depends upon the size of this resonant network. Resonance of this network can be either broad or sharp although it is usually very broad. This network can be of almost any size since it may include building wiring and the vast extent of power lines. In spite of this threat to all radio reception in any large area the interference is usually limited to an area of a city block or less.

Interference usually leaves a building where it originates through the electric service wires, in spite of the fact that the iron service tube or pipe should be an excellent radio frequency shield. From the service wires the interference may pass along the street on the power lines and be radiated therefrom. It may pass through power transformers from secondary to primary or vice versa. The interference may be picked up on adjacent power circuits and carried to other areas. A noise originating on a power line is usually of high intensity and covers large areas.

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In most cases the interference in power lines will be of highest volume level near the source and for some distance will be without apparent standing waves. At sufficient distance from the source, however, standing waves usually occur, tapering off gradually at considerable distances from the area of intense interference.

Now let us consider the method of locating the trouble.

The two most practical attacks on the problem are the "hot and cold method" and the "cut and try method".

In using the "hot and cold method", it is assumed that the interference is loudest near its source. The trouble-shooter simply makes a survey of the interference zone from the standpoint of intensity, the point of highest intensity indicating the location of the source.

The "cut and try method" is based on the theory that the interference will vanish when the electrical potential is taken off the source. In using this method, all electrical circuits in the area of interference are de-energized one at a time. When the circuit that feeds the source is de-energized, the noise will disappear. Parts of this circuit can then be de-energized one at a time to further localize the trouble. This method is carried on until the source itself is discovered.

The "cut and try method" is usually limited in use to one building because it is not expedient to interrupt the electric service to many consumers at once.

In the average case of radio interference both methods are used. The "hot and cold method" is used first to locate the source of interference within a comparatively small area, then the "cut and try method" is used to more definitely locate it.

When the trouble is apparently on an overhead power line, the vicinity of the interference is found by the "hot and cold method". Then a lineman is sent up to inspect the suspected poles. The greatest amount of noise interference will occur when he climbs the pole from which the noise originates.

When the trouble is found by the "hot and cold method" to be in a building, then the noise is located by de-energizing the building circuits one at a time.

These two methods usually suffice to locate sources of radio interference. In some cases, however, they fail. In these cases the noise may not be loudest at its source. De-energizing a circuit may make the noise disappear in certain locations, but only because the circuit network is detuned by the switching operation.

The radio trouble-shooter must be wary of these possibilities. He should recheck himself continually to avoid being led on a wild goose chase. Above all, the trouble-shooter should not allow himself to form any premature theories concerning the interference. These theories are apt to bias his observations to such an extent that his location of the trouble will be difficult.

Permit me my frankness when I say, that most radio engineers I have met have made incorrect judgments in cases of radio interference because they have formed premature theories.

The use of a loop antenna as a direction finder of the source of interference is rarely effective. The loop will simply indicate the direction of the nearest conductor of the interference. The loop antenna is usually used, however, because of its easy portability and to indicate what wires are carrying the troublesome interference.

The character of the noise cannot be depended on to identify the source, because a variety of sources can produce the same sort of interference. However, a thermostatic noise from a heating pad or a fish bowl heater can easily be recognized by its regular intermittant character. Motor commutation usually produces a cyclic noise which is recognizable.

By way of illustration let me take an actual case of radio trouble-shooting.

Leaving the complainant's house, we walk north along the street. The noise falls off in intensity so we walk back south, past the complainant's house. As we continue south the noise increases and then falls off. Then we return to the point of maximum intensity and use the loop antenna to pick out the electric service wire giving rise to the greatest intensity of noise. We enter the house to which the service is attached. The main switch is opened and the noise disappears. As the woman of the house is assuring us that no appliances are being used, the maid suddenly departs to the attic and the noise stops. When the maid returns, she acknowledges that she had left a heating pad operating in her bed. And thus another source of interference is discovered.