F.M. Receiver Design

Methods of Improving Capture Ratio to Combat Multi-path and Co-Channel Interference

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In America, where more than 500 f.m. broadcasting stations are in regular service, the problems of co-channel interference have lately directed attention to the inadequacy of "traditional" receiver designs.

This article presents the arguments which have led to the adoption of wide-band discriminator circuits in some of the more advanced American commercial f.m. tuners, and outlines alternative techniques for improving f.m. reception under adverse conditions either of receiver siting or anomalous propagation.

CONTRARY to expectations, frequency modulation has so far failed to bring about the revolution in broadcasting which has been predicted from time to time. F.M. was announced over twenty years ago; its advantages have been widely admitted, but nowhere has it replaced a.m. as the main broadcasting medium. The reasons are many, varied, and interesting; but in this article it is proposed to discuss one single contributory factor, namely the imperfect performance of f.m. receivers of what we may call "traditional" design.

Receivers at present used for f.m. reception are variants, almost without exception, of the basic design used by Major Armstrong in his tests in the middle thirties. On the one hand this might not seem too surprising, since a.m. receivers have undergone relatively little refinement in basic design in the same 20-year period. Yet it is perhaps just this tendency to think about new things in terms of similar subjects with which we are already familiar that leads to such "follow-the-leader" situations. Much that has been added to the literature of f.m. receiver design in the last 20 years has yet to find its way into receivers in commercial production. It cannot be denied that Armstrong's work[1] represented a thrilling example of creative engineering in the face of monumental scepticism on the part of organized radio, and it is no reflection on his work that the type of receiver he originated has since been shown to suffer from shortcomings, albeit subtle ones. But first let us review what has been accomplished in spite of them.

Before an f.m. broadcast service is established, field tests are generally made. Inspection of the available reports[2, 3, 4, 5] of these field tests reveals an interesting point. Although they were carefully conducted and meticulously recorded, it is apparent that some of the conclusions can be questioned. It must be clearly realized that such conclusions are valid concerning only the whole combination of transmitter, propagation medium, and receiver, rather than purely and simply about f.m. as a basic system of broadcasting. It appears that this distinction has been lost. Consider an analogy with a.m. broadcasting; one would not perform an a.m. field test with a crystal set, or even with a 1936 t.r.f. receiver, yet the diligent reader can find examples of recent f.m. field tests using receivers which from all accounts appear to be no more than refined versions of Armstrong's original design, to which we have assigned, we hope without offence, the descriptive adjective "traditional." It is of considerable importance to note that f.m. has been adopted in spite of the receivers used.

No stigma should be attached to the incorrectness of conclusions mentioned above, for the history of radio shows that many of the foremost authorities in the field, past and present, have jumped to incorrect conclusions about f.m.'s capabilities. It seems, in fact, to have been a sort of occupational hazard for radio engineers and scientists, afflicting the great and small alike. Perhaps it still is.

Many vague and excessively inclusive claims have been made at one time or another for f.m. Some have been incorrectly stated and others have been idealized versions of what f.m. can do when receivers of advanced design are used; but all these claims, of whatever validity, are based on the capture effect, by virtue of which a signal effectively "takes over" at the f.m. detector if its amplitude exceeds the sum of the amplitudes of any other signals present there. Proper consideration of the relevant vector diagrams will yield the correct answer. The literature[6,7,8] explores the subject in detail and we will do no more than outline some of the procedure by which the details of performance can be deduced.

Consider the rather special situation that exists when two signals of constant power are present on the same carrier frequency in nearly the same strength. Suppose that one signal has a field strength which yields one millivolt at the aerial terminals while the other yields nine tenths of a millivolt, and that both are now frequency-modulated. Let us examine their vector sum during a period short compared to the highest modulating frequency. Of particular interest is the angular velocity of the resultant, R, since it is that angular velocity which carries the intelligence we are planning eventually to recover. At the same time we must not lose sight of the amplitude behaviour of the resultant, since that too must influence our design decisions. Suppose for the time being that we have available a limiter circuit which will accept the sum signal and yield an output of constant amplitude, which will of necessity have the same angular velocity—or instantaneous frequency—characteristics as the original sum vector. For convenience we shall choose the one-millivolt vector as our reference in time, and we shall suppose that the other vector is slightly higher in frequency during the period of our examination, and so will be rotating anti-clockwise about our reference

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vector. Fig. 1(a) shows the situation when the two vectors are pointing very nearly in the same direction; then the resultant is nearly 1.9 millivolts, and is rotating with an angular velocity relative to the 1-mV vector only slightly different from half that with which the 0.9-mV vector is rotating.

Some time later—approximately one half cycle of the frequency difference between the two component vectors—the situation is as shown in Fig. 1(b); here the two vectors are very nearly directly subtracting. Now the resultant is very nearly 0.1 mV, and of particular interest is the fact that its angular velocity relative to the 1-mV vector is now something like nine times that with which the 0.9-mV vector is rotating; but note that now the resultant vector is going clockwise, and so corresponds to an instantaneous frequency considerably below the frequency of the 1-mV signal, while in Fig. 1(a) its direction of rotation and relative angular velocity corresponded to an instantaneous velocity slightly above the frequency of the 1-mV signal. Thus the instantaneous frequency of the resultant varies over a considerable range during one cycle of the difference frequency, but since in the long run the resultant makes the same number of total revolutions as the longer vector, their average angular velocities must be equal. Also shown in Fig. 1(b) is the locus of the tip of the sum vector for one complete difference frequency cycle; this is to emphasize the extent of the amplitude variation during the difference frequency cycle.

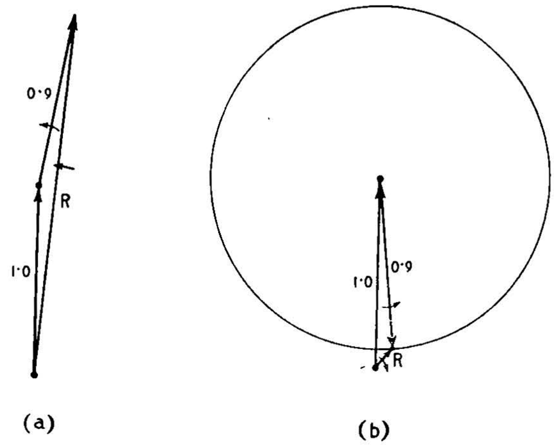

Fig. 1. The resultant of two signals of nearly equal strength and frequency varies in "instantaneous frequency" as well as amplitude, but the average frequency is exactly equal to that of the stronger signal.

Frequency Spectrum After Limiting

Thus we see that the resultant instantaneous frequency goes through periodic variations at the difference frequency, its average frequency being that of the larger vector; and the amplitude also undergoes variations at the difference frequency. A plot of the instantaneous frequency versus time would show a series of sharp spikes whose maximum frequency deviation from the nominal carrier frequency can exceed by far the nominal 75-kc/s peak deviation. Prior to limiting, that is to say for all stages which do not limit, purposely or accidentally, a 150-kc/s bandwidth will nevertheless suffice for undistorted transmission of the resultant; for since such a bandwidth would suffice for either signal separately it will by superposition, valid for linear systems, transmit them equally well simultaneously. But once limiting has taken place, having the useful effect of removing the amplitude variations, we encounter as an unavoidable consequence a broadening of the frequency spectrum which means that succeeding stages must have the new wider bandwidth if they are to transmit faithfully the limited signal. The frequency spectrum for the general case of the limited signal requires a bandwidth wide enough to accept at least the highest angular frequency deviation which the process described above may bring about; and this bandwidth must be present in all circuits after the first non-linear circuit, thus including, in terms of conventional design, the anode circuit of the first limiter, any subsequent limiters, and the detector.

For our purposes it will suffice here to record that the expansion of required bandwidth brought about by the ideal limiting of the resultant of two signals depends in a simple fashion upon the ratio of the magnitudes of the two signals. If we let a be the ratio of the weaker signal strength to the stronger, and B be the expanded bandwidth, if f_d is the maximum permitted frequency deviation at the transmitter, we have the relation:

$$B = 2 f_d \cdot \frac{1 + a}{1 - a}$$

If, for example, it is desired to receive the stronger of two signals when the weaker is 95% as strong as the former, in an f.m. system using 75 kc/s as the permissible peak deviation, the relation gives 5.95 Mc/s as the bandwidth required of the limiter and detector. This is quite a startling departure from the usual 150 kc/s, to say the least. That this extended bandwidth is necessary, but not sufficient, will be discussed below. Before this result has a chance to discourage the reader, let us turn to the general question of the applicability of the rather special problem we started out with, involving two signals of nearly equal strength.

It is plain that our problem applies directly to co-channel interference; that is the problem associated with the reception of one or the other (or, in unfortunate cases, both) of two signals using the same carrier frequency. That it should apply to most other interference problems as well takes a little more explaining. Adjacent-channel interference, so important in a.m., cannot be ignored in f.m. The example above covers adjacent-channel interference if we note that the difference frequency would simply be bounded differently. In the co-channel case the difference frequency can vary from zero to 150 kc/s, while in the adjacent-channel case it can vary from 50 kc/s, when carriers of adjacent channels are modulated the maximum amount toward one another, up to 350 kc/s, when they are modulated the maximum amount away from one another. Multi-path transmission, responsible for ghosts and aircraft interference on television, is perhaps for British listeners the most important of the types of interference; it arises when two paths of appreciably different length are possible, as in the case of reflection from a mountain, building, or airplane. When one observes that two versions of the same signal, one delayed, appear to the receiver much the same as two separate and distinct signals on the same channel, it is apparent that the same situation regarding expansion of bandwidth applies for multi-path transmission interference.

Impulse noise goes a little farther afield; what happens is that the transient shock-excites the receiver's front-end circuits at their natural resonant frequencies. Since these frequencies are within the pass-band of the receiver, they are amplified along with the desired signal, and appear to the limiter and discriminator stages as discontinuous bursts of un-frequency-modulated co-channel signal. Thus for a period of time of the order of the ringing time of the front-end circuits the situation is roughly the same as that which we chose, with almost startling foresight, as our special example. In this connection we note that the conditions of maximum selectivity and minimum ringing time are mutually incompatible, making some sort of a compromise necessary.

It should be clear, then, that the problem brought about by spectrum expansion is substantially the same for all the kinds of interference mentioned above, which with their variations constitute a fairly complete list of the things that keep radio transmission from working properly or perfectly. And we have established certain bandwidth requirements which when met allow the distortionless reproduction of the patterns of frequency spikes mentioned earlier. At this point one may sensibly ask whether or not this is worth doing, granting that the proper circuitry—rather fancy circuitry—can do it. This very question must have bothered some fairly high-powered authorities for some years; the principles behind the formation of the spikes had been well understood for some time before anyone decided that building a receiver with wide-band limiters and detector to do a good job of demodulating them might in fact be worth while. Until the work in the middle and late forties done by a group at M.I.T. under L.B. Arguimbau, it had apparently been concluded that the spikes represented unavoidable distortion that sufficed to prevent successful reception of the stronger of two signals of nearly equal strength. And it may be a holdover of this same feeling which accounts for the apparently wide-spread opinion that noise suppression suffers if the bandwidth is widened beyond, say, 200 kc/s.

Capture Ratio

The work of Arguimbau's group established that the actual audible distortion introduced by the spikes can be held to a very low degree, if the customary de-emphasis time constant is used at the receiver. Arguimbau's work, described in many publications,[6, 7, 9, 10, 11] was directed primarily at multi-path problems, and in particular at investigating the possibility of trans-Atlantic communication via f.m.[12, 13] It is interesting to note that his tests revealed that the principal drawback in that application lies in the fact that in trans-Atlantic work a multiplicity of signals is involved, no one of which is greater than the sum of the rest; since the best that can be done today in receiver design requires that one signal exceed the sum of all others, success has not yet been achieved.

It is probably an over-simplification, perhaps a permissible one, to say that the principal conclusion of the M.I.T. work is that an f.m. receiver should have a good capture ratio. After explaining the term "capture ratio," we will discuss the capture ratio of the "traditional" receiver when compared with that of receivers built according to the M.I.T criteria, following which there will be a few words. about the steps one takes to embody these criteria.

We spoke earlier of the quantity a, which was defined as the ratio of the weaker signal strength to the stronger. The largest value of a—that is, the nearest to unity—for which a receiver will provide an interference-free signal is that receiver's capture ratio. (This definition glosses over the question of just exactly when is a signal interference-free; since there seems to be good precedent for this neglect, no more will be said.) One may also encounter capture ratio expressed in decibels; this is obtained by taking the negative of 20 times the common logarithm of the quantity a, or alternatively, 20 times the common logarithm of the reciprocal of a. Bearing in mind that capture ratio is a quantity of importance in reduction of all types of interference, let us consider the capture ratios of the general run of f.m. receivers. Several references point out that in general it has been observed that the desired signal must exceed the undesired by some 20 to 30 decibels for noise-free reception. Thus we may deduce directly that the receivers used in those tests had capture ratios of no better than 20 dB, or 0.1 in the fractional notation. Preliminary tests made as part of the work at M.I.T. support these observations, so that it is quite safe to say that until Arguimbau's group fabricated the first wide-band f.m. receiver in the early forties, capture ratios of twenty decibels and more were the order of the day.

Commercial Wide-band Receivers

Here we might pause and note that, while f.m. has been adopted by several nations in spite of the handicap under which it functions when receivers of poor capture ratio are employed, as far as can be determined no official field test has yet been conducted with receivers designed to take advantage of the M.I.T. research. It is fortunate that f.m. still surpassed a.m. even when forced, so to speak, to labour under an unfair handicap.

Earlier it was indicated that a receiver whose limiter and discriminator had bandwidths of 5.95 megacycles could possibly have a capture ratio of 0.95, or in decibels, 0.45 dB. The above phraseology is intended to suggest that other requirements must be met as well; if, for example, the intermediate frequency pass-band is x dB down $\pm$ 75 kc/s from channel centre, then the capture ratio cannot be better than x dB, even if the limiter and detector bandwidths are infinite. More about this later; suffice it to say that it is possible to build f.m. receivers with capture ratios as good as ½ decibel. It is not easy, nor is it inexpensive, but such receivers are described by Arguimbau, Granlund, Paananen, and Cross.[9, 10, 11, 14, 15]

A short description of what is now commercially available along these lines may be of interest. One manufacturer, Radio Engineering Labs., intimately associated with Major Armstrong during his f.m. work, makes an adaptation of the ½-decibel M.I.T. receiver; that this receiver should be the most expensive (over $300) on the American market is easily understood when the reports on its ancestor are inspected. Two other manufacturers, H. H. Scott and the National Company, make less expensive receivers ($100 to $200) embodying many of the characteristics recommended in the same and later

M.I.T. work. The capture ratios of these two are of the order of two decibels, while it appears that other manufacturers propose that the same amount of money should be paid for a receiver or tuner with a capture ratio of the order of 20 dB. Having no positive information about the characteristics of British or European f.m. equipment, the author would be pleased to think that the situation is more hopeful outside the U.S., but as yet no indication that this is so has been seen.

The bandwidth requirement for limiters and detectors has been dwelt on in some detail, and the requirement for flatness of i.f. amplifier pass-band touched upon. Further details along that line are contained in the literature; in passing it may be noted that if a receiver of infinitely wide limiter and detector bandwidths has an i.f. down 3 dB at $\pm$ 75 kc/s, then, when it receives a signal at band centre which is (at the aerial) 3 dB below a signal 75 kc/s away from band centre, the two signals will be of equal amplitude at the discriminator, and the effort devoted to widening the bandwidth of the limiter and detector will have been wasted. Thus we can see the type of reasoning behind the requirement that there be negligible ripple in the i.f. pass-band, where negligible means a variation in response small compared to the relative sizes of signals it is desired to separate.

The bandwidth and flatness requirements bear equally on all types of interference, as can be seen from the preceding discussion. A special problem associated with adjacent-channel interference is that of selectivity; it should be clear that its minimization dictates a maximum of selectivity as early in the receiver as possible. This same conclusion presents itself as a means for admitting a minimum amount of wide-band noise.

Ease of Tuning

An extra dividend is gained through the use of a wide-band detector in conjunction with a flat-top steep-skirted i.f. This dividend, having nothing to do directly with interference suppression, is that the receiver is many times easier to tune than the " traditional" design with round-topped i.f., and detector bandwidth of the same order as the i.f. bandwidth. In the " traditional " design one encounters " three-point tuning ", which is an unavoidable consequence of the S-curve detector characteristic; thus the subsidiary linear sections of the S-curve on each side of the main linear section give rise to additional responses to the same station as one tunes on either side of the main response. These responses are generally weaker than the main response, are usually noticeably distorted, and can serve to confuse the operator. In addition there is the fact that the limited width of the main linear portion of the characteristic makes tuning for minimum distortion very critical with receivers of " traditional" design. The wide-band flat-top steep-skirt design, on the other hand, gives a tuning ease comparable to if not exceeding that encountered in a good a.m. receiver. This is by virtue of the fact that the discriminator characteristic, as modified by the i.f. response, is more like a letter N than an S on its side; thus the subsidiary responses are so very narrow, being associated with slope detection on the i.f. skirts, that they are heard only as noisy spots on each side of a broad area of undistorted reception. This fortunate situation seems generally to make unnecessary automatic frequency control.

This must not be interpreted as justification for avoiding the building of a stable local oscillator. It is simply that a.f.c.'s chief reason for being—ease of tuning—is no longer existent. Just as one should not design a sloppy audio amplifier, expecting to clean up its deficiencies later on with inverse feedback, neither should one depend on slipping by with an unstable receiver with the idea of covering up those deficiencies with a.f.c.

The considerable difference between frequency allocation policy in the United States and Great Britain places differing degrees of emphasis on the various types of interference. In many U.S. locations, particularly along the Atlantic seaboard, adjacent-channel and co-channel problems are serious, while there are probably a negligible number of such problems in Great Britain. On the other hand, multi-path transmission and impulse noise are not mitigated by careful and intelligent allocation planning, so that these problems are encountered in varying degrees in all parts of both areas, and thus provide good reason for the desirability of good capture ratio in f.m. receivers everywhere.

An interesting example of the importance of good capture ratio, suggested by B. G. Cramer[16], is particularly applicable to the co-channel situation common in the U.S., but is of sufficient interest and importance to be included here. It involves the rather theoretical situation of two transmitters on the same channel situated, say, some 100 miles apart on a flat earth free from mountains or other reflecting bodies. This distance of separation of co-channel stations is a realistic one for the U.S., and so is the assumption that they have the same effective radiated power, made only for convenience. Finally, if we assume, also for convenience, that the receivers to be considered use non-directional aerials we can plot contours which enclose areas for which a receiver of a given capture ratio will receive the stronger signal without interference from the weaker. Fig. 2 shows this situation plotted for stations 100 miles apart when receivers of 0.1 capture ratio (small circles) and 0.9 capture ratio (large circles). One would have predicted that the contours were circles, and naturally enough they are not centred on the transmitting sites. The usable areas inside the contours are actually reduced in accordance with whatever figure we may choose as the maximum service range for an f.m. transmitter of a given power. If we choose 100 miles as that maximum range, the shaded areas shown join the excluded cross-hatched areas. There is still quite a difference between the service areas brought about by the capture ratio difference between the receivers used.

We will now proceed with a few notes on the means now available for achieving the ends described above. Regarding broad-band detectors, it may be noted that several varieties are successfully used. The simplest are nothing more than versions of the familiar ratio detector modified for bandwidths of the order of megacycles, while considerably more complicated designs are used to achieve the 6-Mc/s bandwidth mentioned earlier. Regarding the ratio detector, it should be remarked that its inherent limiting properties are a valuable adjunct to limiters which precede it, but that these limiting properties are not sufficient to do a good job when used alone in a receiver intended to have a good capture ratio.

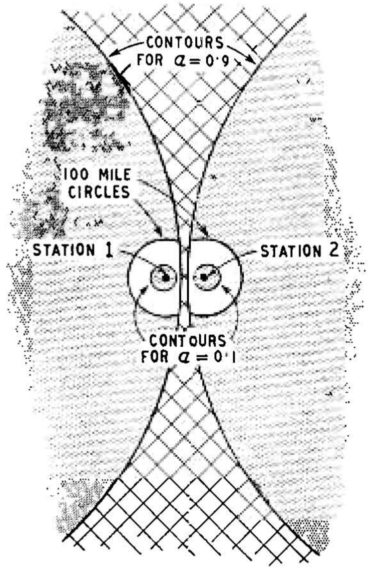

Fig. 2. Service areas (stippled) for capture ratios of 0.1 and 0.9 with co-channel transmitters spaced 100 miles apart.

Other things being equal, as one widens the detector bandwidth, the audio output amplitude for a given deviation decreases; as a consequence one must supply more audio amplification than is customary in conventional designs, but in these days of high-quality disc and tape recorder pre-amplifiers this presents no problem.

Another point in detector design is the choice of the intermediate frequency. On the chance that some may be daring enough to break away from the well-established 10.7 Mc/s, we may note that it is only with considerable effort that a 6-Mc/s bandwidth can be achieved at the standard i.f.; this is understandable in view of the large fraction, some 60%, of the centre frequency which the bandwidth represents. On the other hand, if an i.f. in the neighbourhood of 30 Mc/s were chosen, the problems associated with achieving a 6-Mc/s bandwidth are reduced considerably. It is a slight over-simplification to say that achieving 6 Mc/s at 30 Mc/s is just like achieving 2 Mc/s at 10.7 Mc/s, yet it may be that in these days of considerable experience with television's rather high i.f.'s, a higher f.m. i.f. might be a very sensible choice. Other pros and cons enter; spurious responses are probably reduced, local oscillator interference problems may be increased, etc.

The actual design decision regarding capture ratio deserves careful consideration. Here an analogy may be drawn with the sometimes-hazy subject of the source impedance of audio amplifiers used to drive loudspeakers. That certain benefits are derived from driving the loudspeaker from a source impedance low compared to the loudspeaker impedance is well known; the trend which some years ago led from un-fed-back pentodes, with their source impedances considerably higher than the load, has now brought us to source impedances of the order of one tenth the load impedance. The point here is that very little is gained in lowering further the source impedance, say, to one hundredth the load impedance, since the gain in performance is likely to be imperceptible while the effort involved in accomplishing the reduction is considerable. We are faced with a very similar situation regarding capture ratio; proceeding from the rather poor ratio of 0.1 up to a respectable 0.7 or 0.8 represents a great improvement in performance, while the additional effort required to extend the capture ratio to 0.9, 0.95, or even 0.99 would not be proportionately reflected in performance improvement, even though it would be interesting from a technical standpoint.

Improved Limiters

Limiters play an exceedingly important role in the overall system; they must remove the violent variations in amplitude which occur from many causes, including the mixing of two nearly-equal signals, as set forth earlier. Because of the speed with which amplitude variation may take place, the limiter must be fast-acting. Such is not the case with conventional designs depending on grid-current and cut-off limiting with pentodes operated at low screen and plate voltages; recent designs have unanimously adopted other means for limiting. The simplest quick-acting limiter employs biased diodes, with care taken to assure that time constants in the bias source do not lead to the same recovery time troubles which hamper pentode limiters.

A means which does not present the signal-attenuation disadvantage of the diode limiter is available through use of the gated-beam tube (6BN6) as a limiter. This tube was originally designed as a combination limiter-discriminator[17,18], and is so employed in many television receivers. Its use as a detector in high quality receivers has not yet been reported, but when properly used it is unsurpassed as a limiter[19]. It has the fortunate property of depending on electron-optical beam-switching for its limiting action, rather than on grid-current biasing. Literature on its application is extensive but apparently not widely familiar. Interested experimenters might do well to investigate its use as a combined wideband limiter and discriminator. Of course, in all limiting means mentioned, care must be taken that the bandwidth appropriate for the desired capture ratio is maintained; in general such wide-band limiters have single-tuned low-Q circuits and are only broadly tuned.

I.F. and front-end design should follow general good design practice for low noise, with special attention to selectivity and flat-top characteristics. As mentioned earlier, it is important to obtain as much selectivity as early in the receiver as possible. Special attention should also be directed to the overload characteristics of the front end, with an eye to minimizing spurious responses. Note also that the later stages of the i.f. amplifier should not limit, for if they do, the spectrum is broadened with consequent possible distortion and degradation of capture ratio due to loss of sidebands. Both of these last two points indicate the desirability of an effective, fast-acting automatic-gain-control system. If the a.g.c. is fast-acting enough, it will in fact be of considerable assistance to the limiters in maintaining a constant signal amplitude at the detector.

And now, in closing, a few remarks about some alternative schemes and some new developments. A device used successfully some years ago, which does not seem to have been exploited in the design of receivers of good capture ratio is the locked-oscillator detector[20, 21]. In short, this scheme locks the frequency of an oscillator in the receiver which is normally operating at the i.f. to that of the received signal; it is the resulting variations in the frequency of this oscillator which are detected. An advantage of this system is its inherently perfect limiting, since the oscillator's output amplitude depends in no way on the incoming signal amplitude. For satisfactory locking it is obvious that the incoming signal would have to exceed some threshold, as is always the case with any detector. With suitable design the frequency excursions encountered under interference conditions can be handled by making the oscillator such that it cannot quite follow the extreme variations; it will thus perform, in effect, to limit bandwidth.

Pulse-counting Discriminators

Counter-type detectors are frequently proposed for f.m. receivers[22, 23, 24]. Their advantages are considerable, the principal ones being excellent linearity over the design range, and in most cases, admirable simplicity. Since they customarily use a low i.f., of the order of 150 kc/s, it is easily predictable that strange things must happen under interference conditions. If the instantaneous frequency were to head towards 150 kc/s below channel centre, the frequency into the counter would approach zero, which it cannot be expected to detect satisfactorily. And if the instantaneous frequency heads for a frequency more than 150 kc/s below channel centre, it is plain that the i.f. output into the counter will reverse phase at zero frequency and start back up again, giving rise to considerable distortion, since if the instantaneous frequency went 300 kc/s low, the counter would think that it was seeing the same 150 kc/s that corresponds to an unmodulated carrier. These results are somewhat analogous to overmodulation in an a.m. transmitter, or to partial carrier suppression in an a.m. receiver; the consequence is that the obtainable capture ratio is severely restricted by the use of the low i.f. that is dictated by practical considerations in counter-detector design. Use of higher i.f.'s in counter-detector circuits brings with it considerable complication; if money and size were no object, one might employ a digital frequency divider to proceed from the customary i.f. range down to the neighbourhood where a counter discriminator can operate conveniently. The deviation would then have been reduced by the dividing ratio, making good capture ratio possible with a second i.f. of the order of 150 kc/s; other things held constant, the output voltage would be reduced by the same division factor.

A recent paper[25] describes the theory behind a plan to accomplish interference rejection without recourse to the wide-band limiter-detector system discussed above. This suggested system, results of the experimental confirmation of which have not yet been reported, is an outgrowth of the M.I.T. work mentioned earlier. Its conclusion is that the wide-band scheme is, in the mathematical sense, sufficient but not necessary, the newer plan involves alternate stages of amplitude limiting and bandwidth limiting. Thus every time a limiter broadens out the spectrum by removing amplitude modulation, a steep-skirted bandpass filter reduces the bandwidth at least part way back to its original value. Cascading a succession of such ideal limiters and bandpass filters is shown to be capable of yielding a good capture ratio without the necessity of including broad-band circuits. Pending further experimentation with this idea, one can be reasonably certain that the broad-band technique will do the job. Perhaps in a few years the broad-band techniques will have become the traditional techniques, with which the newer narrow-band system will be competing for recognition.

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