Reduction of Interference in FM Receiver by Feedback Across the Limiter*

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Summary—Described in this paper is the theory of a feedback circuit around a limiter of an FM receiver, which has the effect of reducing the interference caused by an undesired signal of nearly equal intensity to the desired signal.

Theory of Operation

When two FM signals, covering the same frequency band, or at least having overlapping frequency bands but different amplitudes, are passed through a limiter, the radio-frequency output comprises principally the stronger signal with an amount of distortion dependent on a number of factors which include the ratio of the intensities of the two signals. If this signal output is fed back at some point of the system on the input side of the limiter, its effect will therefore be quite different from the well-known effects of applying feedback in an AM amplifier.

It was found that a suitable feedback across a limiter has the capability of reducing the amount of distortion in the output of the limiter, or alternatively, of permitting the ratio of the desired to the interfering signal to be decreased. Signals as close to each other as 1 or 2 db have been substantially separated. The explanation of this result is as follows:

A typical vector diagram is shown in Fig. 1. In this diagram OA is the stronger of the two FM signals. AB is the vector for the weaker. If OA is represented as stationary, then the vector AB rotates at a frequency equal to the difference in frequency between the two FM signals. If this corresponds to q radians per second, then

$$q = d\theta/dt. \tag{1}$$

The signal which is fed back from an ideal limiter is constant in amplitude. It is represented in Fig. 1 by the vector $C'O$, the point C' lying on the circumference of a circle of radius x and center O. This vector referred to as X' must terminate on the circumference of a circle because its amplitude is constant. The input to the limiter is the resultant R' of the vectors a, b, and X', and is therefore represented by $C'B$. The output of the limiter is in phase with R'.

The feedback vector X' is related to the input vector to the limiter R' solely by the characteristics of the feedback circuit. If this phase difference is zero, the vector diagram is $COABC$, with CB (representing R) in line with CO (representing X). If the phase of R' lags an angle α behind X', the vector diagram is $C'OABC'$, X becoming X' and R' making an angle α with X'.

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ϕ_R and ϕ_x are the angles that R' and X' make with the vector for the larger of the two signals represented by OA. The angle between the vector OB and OA is

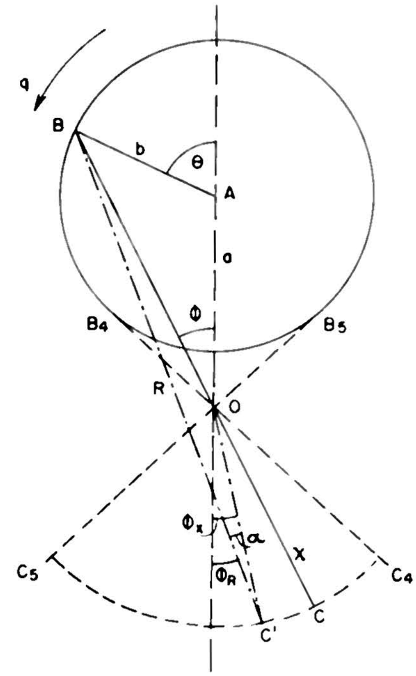

Fig. 1—Vector diagram of feedback operation.

ϕ. Either R' or X' may be applied to the discriminator as the designer may decide, although X' is preferred.

ϕ_R or ϕ_x, as the case may be, is the phase shift of the input of the discriminator relative to that of the desired signal. The differential of that phase shift with respect to time is therefore the distortion produced by the interfering signal when the amplitude variations are eliminated by the limiter.

Taking the more general case of R' and X' being out of phase by an angle α, it can readily be shown, if a is made unity that

$$\frac{1}{q}\,\frac{d\phi_R}{dt} = \frac{b\cos(\theta-\phi_R) - x\cos\alpha\,\dfrac{d\alpha}{d\theta}}{\cos\phi_R + b\cos(\theta-\phi_R)} \tag{2}$$

and

$$\frac{1}{q}\,\frac{d\phi_x}{dt} = \frac{b\cos(\theta-\phi_R) - \left[\cos\phi_R + b\cos(\theta-\phi_R) + x\cos\alpha\right]\dfrac{d\alpha}{d\theta}}{\cos\phi_R + b\cos(\theta-\phi_R)}. \tag{3}$$

If the vector diagram repeats itself every revolution of the vector b as it must do when a steady state has been reached, then

$$\int_0^{2\pi} \frac{d\phi_R}{dt}\, d\theta = 0 \quad \text{and} \quad \int_0^{2\pi} \frac{d\phi_x}{dt}\, d\theta = 0. \tag{4}$$

This means that if the whole of $d\phi_R/dt$ or $d\phi_x/dt$ is accepted by the discriminator circuit the average distortion due to the presence of the weaker FM signal b is zero over each complete rotation of the vector AB. In practice, when the weaker signal b is nearly equal to the strong signal a, $d\phi_R/dt$ will reach higher peaks than $d\phi_x/dt$. It is therefore preferable to apply the vector X' rather than the vector R' to the discriminator.

If the discriminator can accept the whole of $d\phi_x/dt$ without appreciable distortion or cutting off, then the audio output will be substantially free from distortion from the weaker signal b. With perfect operation the remaining distortion would then be due only to the distortion occurring within a single revolution of the vector AB, and will therefore comprise only harmonics of the beat frequency. There may also be a distortion due to the initial stage before a steady state is reached. Since the amplitudes are relatively small with the feedback circuit and the frequencies are frequently beyond the acceptance of our senses, this remaining distortion will in general be small, and certainly much reduced as compared with the distortion obtained without the feedback circuit.

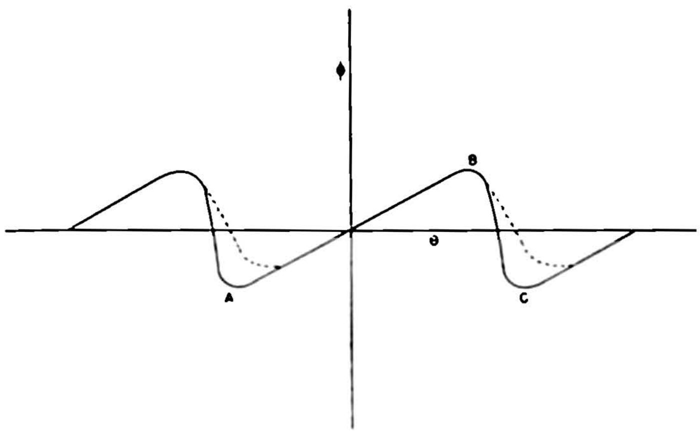

Fig. 2—Relation of phase of weaker signal to resultant of input to system, with and without feedback.

A typical curve of the relationship between ϕ and θ is shown in Fig. 2. During the period A to B, ϕ varies relatively slowly. This corresponds to the point B in Fig. 1 moving from position B_5 around the greater part of the circle to position B_4. But as B moves from B_4 to B_5 through the smaller arc, the change of ϕ is much more rapid, as shown by the steep part BC of the curve. The steepness of this part increases rapidly as the ratio of the intensity approaches unity. In fact, the maximum gradient increases in proportion to $a/(a-b)$.

If a feedback circuit is inserted around the limiter and that circuit contains a band-pass filter wide enough to carry the intelligence contained in Signal A, but not much more, the circuit will follow the changes in the phase ϕ quite closely over the portion AB while ϕ is changing only slowly; but when ϕ changes rapidly during the portion BC, it may not be able to do so. Instead it will follow a value, shown by a dotted curve, which corresponds to ϕ_x instead of ϕ.

This means that the angle α between R' and X' changes in value while the value of ϕ changes rapidly. The change in that value is represented by the difference between the dotted line and the solid line in Fig. 2.

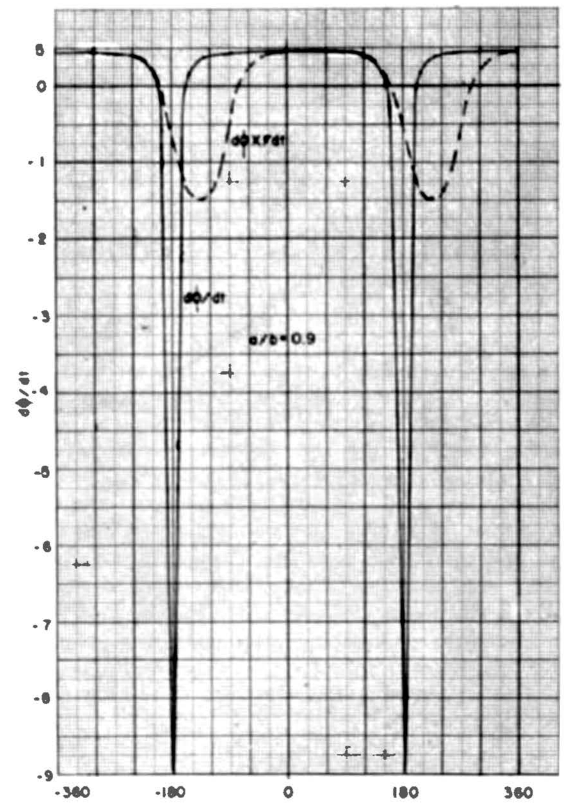

Fig. 3—Rate of change of phase, with and without feedback.

The important feature of this feedback system is that the vector X' cannot contain frequencies or large values of $d\phi/dt$ that fall outside of the band-pass of the filter of the feedback circuit. Therefore, the phase angle ϕ_x cannot change very rapidly, even during those short periods that ϕ changes rapidly as it does around the condition $\theta=\pi$ and particularly when the ratio of the signal vectors (b/a) is nearly equal to unity. Fig. 3 shows the curve for the variation of $d\phi/dt$ with θ when the ratio of b/a is 0.9. The tremendous spike that is produced near $\theta=\pi$ cannot be carried without distortion by a normal discriminator, for the spike corresponds to frequencies far beyond the linear portion of the discriminator characteristics. Distortion will therefore occur in an ordinary circuit since it is only if the full spike is carried that condition (4) will hold. Arguimbau[1] has

[1] L. B. Arguimbau and J. Granlund, *Electronics*, vol. 22, pp. 101–103; December, 1949.

proven this practically by using very wide-band discriminator characteristics.

If, however, an inverse feedback circuit is used with a limited frequency response and if the voltage corresponding to the vector X' is applied to the discriminator, condition (4) still holds when a steady state has been reached. The frequency limitation of the filter has the effect of blunting the spike and at the same time spreading it out. The filter circuit is designed to reduce the amplitude of the transient inherent in the spike and to attenuate its effect as rapidly as possible.

A block diagram of the circuit is shown in Fig. 4, on which the corresponding vector of Fig. 1 is indicated at each point of the circuit.

It is believed that this circuit may prove particularly useful when dealing with wide-band transmission.

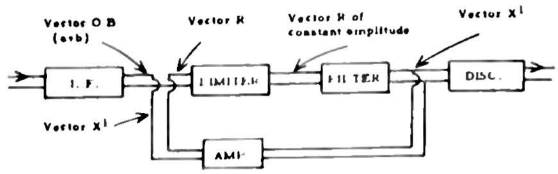

Fig. 4—Block diagram of circuit.

ACKNOWLEDGMENTS

Mr. Gregory Harmon assembled some circuits which produced results indicated by the above theory. He was able to separate adequately FM signals which had a ratio of amplitude of less than 2 db. Closer ratios could probably have been used if flatter IF amplifiers had been available.

Quartz-Crystal Measurement at 10 to 180 Megacycles*

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Summary—A method is described for measuring the equivalent parameters of both the main and spurious modes of very high-frequency crystal units. The crystal is placed between the plate and cathode of an amplifier tube, and the voltage developed across it is recorded as a function of frequency. The series resistance R_s can be obtained by comparing the resulting voltage peaks with the voltage developed across a pure capacitive load. The series capacitance C_s is measured by recording the resonance curve with the crystal unit in circuit, and then recording a second resonance curve when the capacitance across the crystal unit has been increased by a known amount. The frequency difference between the two curves gives a measure for C_s. Correction functions are derived for evaluating the recorded data for crystal units having high R_s and low reactance of the static capacitance C_0.

I. Introduction

As Van Dyke[1] has shown, the electrical behavior of a piezoelectric crystal can be described by its equivalent circuit, consisting of the series connection of an inductance L_s, capacitance C_s, and resistance R_s in parallel with the static capacitance C_0. This circuit corresponds to the main resonance frequency of the crystal. At very high frequencies, the frequency spectrum of a crystal is rather complicated. It shows, besides the main resonance frequency, a multitude of other resonance frequencies which would be represented by similar networks more or less coupled together, as well as to the network representing the main response.

The most important task in producing crystals for very high frequencies is to eliminate, or at least to reduce, the spurious responses. To be able to perform this task, measuring equipment is necessary which not only surveys the crystal spectrum but allows simultaneous measurements of the equivalent parameters of the main and spurious responses.

This paper discusses such equipment, and gives a brief description of a unit developed and built at the Signal Corps Engineering Laboratories for the 10-mc to 180-mc frequency range.

II. Principles of Operation

A. Measurement of the Series Resistance R_s

Because voltages, if not too small, may be measured without great difficulties even at high frequencies, an antiresonance arrangement is used, as shown in Fig. 1. The crystal is placed between the plate and cathode of an amplifier tube, and the voltage e_p is measured. As the frequency of the signal generator is changed, the recording of the plate voltage e_p will appear as in Fig. 6.

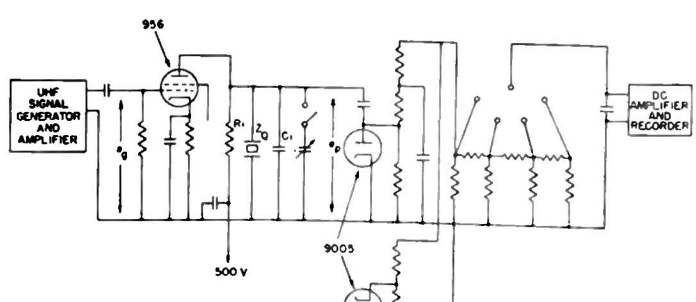

Fig. 1—Principal circuit diagram of the unit.

If the resistance R_1 and the reactance of C_1 are both larger than the series resistance R_s at the operating fre-

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[1] K. S. Van Dyke, "The electric network equivalent of a piezoelectric resonator," *Phys. Rev.*, vol. 25, p. 895; 1925.