

## VII. FREQUENCY MODULATION

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### A. REGENERATIVE FEEDBACK AROUND THE LIMITER

An experimental study is being conducted in order to test qualitatively and quantitatively the principles recently stated (1) on the advantages to be achieved by employing positive, band-limited feedback around the amplitude limiter in an FM receiver. The theory shows that one such stage with feedback can be used instead of several narrow-band cascaded limiters for greatly improving the capture performance of an FM receiver, and also that the feedback which produces an oscillation in the FM limiter circuit causes an automatic squelch that reduces the annoying interstation noise that is common with FM receiver systems.

We decided to test the effect of regenerative feedback in a standard low-cost FM receiver. An i-f discriminator strip was built, as shown in Fig. VII-1. It had a standard 150-kc bandwidth at 10.7 mc, both in the i-f and discriminator stages. A single stage of feedback was used around the limiters. It was necessary to employ a tube in the feedback loop, since a control of feedback gain that would be independent of feedback bandwidth would otherwise have been almost impossible.

The unit worked very well in cutting down interference and thus improved the capture performance of the receiver. Figure VII-2 shows oscillograms of the effect of feedback on the dynamic intermediate-frequency characteristics of the unit. It is seen that positive, band-limited feedback is actually occurring, since the i-f gain at midband has increased, and the bandpass of the system has decreased.

Listening tests were used extensively for showing qualitatively the effectiveness of the system in improving capture performance. This scheme not only reduces co-channel interference, but also nearly eliminates adjacent-channel interference because of the resultant step-sided intermediate-frequency characteristic shown in Fig. VII-2.

Figures VII-3 and VII-4 show oscillograms of interference conditions before and after feedback is applied. Figure VII-5 shows how effectively the oscillation caused by the feedback squelches the interstation noise. We found that it would be very difficult

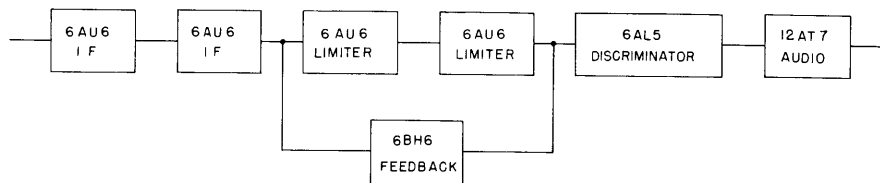


Fig. VII-1. Block diagram of experimental i-f discriminator unit.

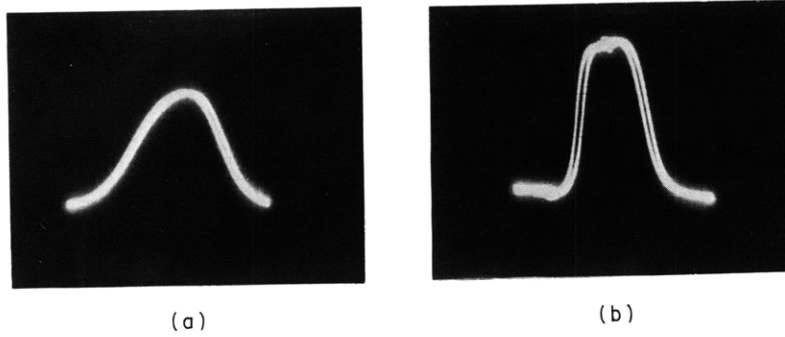


Fig. VII-2. (a) Dynamic intermediate-frequency response without feedback. The total sweep is 480 kc. (b) Dynamic intermediate-frequency response with feedback. With the same total sweep, the response narrows down to approximately 150 kc, and the midband gain is increased by positive feedback.

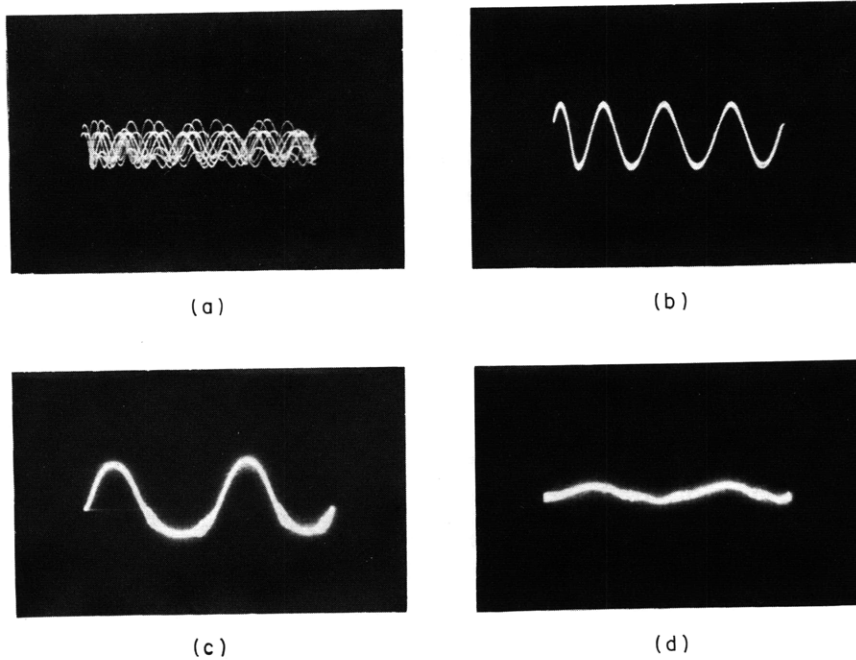


Fig. VII-3. (a) and (b) Improvement obtained when two 1000-cycle FM signals are being received on the same frequency, both below receiver threshold, with one signal of twice the magnitude of the other. It is seen that with the introduction of feedback, the stronger signal is brought up above threshold by increasing the limiter gain, and it captures the receiver. (c) and (d) Effect of feedback and of no feedback when the stronger signal is unmodulated, and the interference is modulated at a 50-cycle rate.

(VII. FREQUENCY MODULATION)

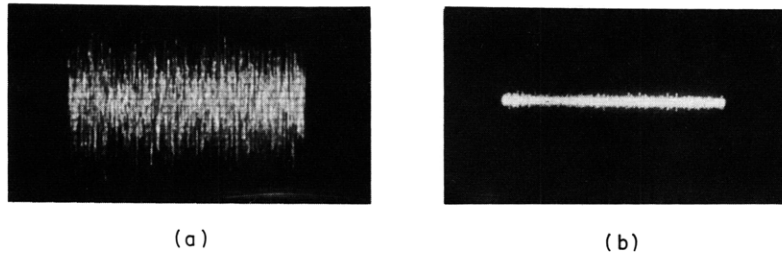


Fig. VII-4. Audio-output waveform with the receiver tuned between stations. The squelch effect of the oscillation is quite evident.

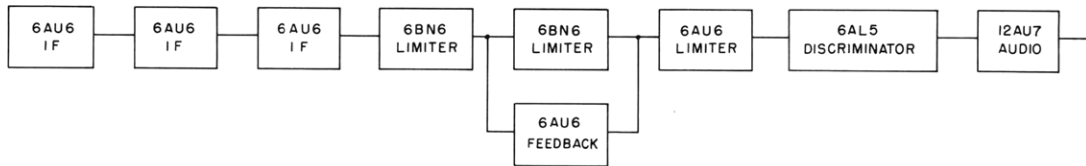


Fig. VII-5. Block diagram of a new version of a unit for facilitating measurement of circuit characteristics.

to make quantitative measurements on this particular circuit. Since the discriminator transformer and the last i-f transformer formed part of the feedback loop, it was impossible to vary the discriminator and i-f bandwidths without upsetting the feedback gain, the frequency of free oscillation, and the feedback bandwidth. We determined that, for ease in measurement, the feedback loop should be isolated, as far as possible, from the rest of the receiver.

Difficulties were encountered in obtaining the squelch feature of this circuit, since it appeared that the oscillation in the system would capture the system itself, unless the incoming signal were of sufficient strength. Automatic control of the oscillation appears to be needed in order for the receiver to be sensitive to weak signals.

To obviate these difficulties, a new version of the receiver was designed, as shown in Fig. VII-5. The feedback loop is effectively isolated from the i-f and discriminator circuits, and the single stage of limiting before the loop brings all signals that would have been above threshold up to a common level. Consequently, the amount of feedback can be the same for all signals, and the squelch feature becomes quite effective in its simplest form.

Measurements are being made on this receiver in order to obtain quantitative data on the effectiveness of the feedback technique.

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References

1. E. J. Baghdady, Interference rejection in FM receivers, D.Sc. Thesis, Department of Electrical Engineering, M.I.T., May 16, 1956.

## B. FM TRANSIENTS

An experimental study of the FM transient response and of the conditions for the quasi-stationary response of a single-tuned circuit was carried out. The instantaneous-frequency transients in the response of a tuned circuit to an excitation which is modulated in frequency by a square wave were studied to determine the effect of frequency jumps between any two frequency values whose difference, as well as positions relative to the resonant frequency, are varied.

The results are completely accounted for by a simple theoretical model (1) which explains the mechanism of the generation of FM and AM transients in terms of the normal modes of the filter. The theoretical model shows, for example, why the details of the FM and AM transients that are caused by fast jumps in the frequency of the excitation are completely determined, for a given filter, by the positions of the

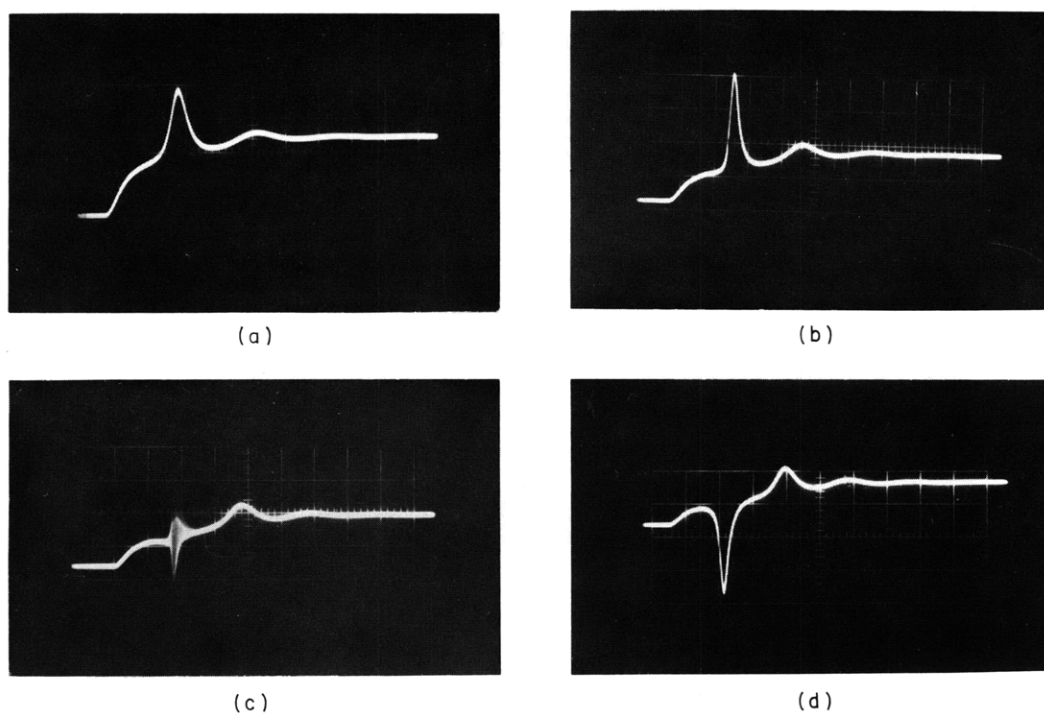


Fig. VII-6. Instantaneous-frequency transients in the response of a single-tuned circuit to an excitation which is modulated in frequency by a square wave;  $f_0 = 10$  mc,  $BW = 60$  kc.

- (a) Jump from  $f = f_0 - 36$  kc to  $f = f_0 + 81$  kc.
- (b) Jump from  $f = f_0 - 24$  kc to  $f = f_0 + 94$  kc.
- (c) Jump from  $f = f_0 - 20$  kc to  $f = f_0 + 98$  kc.
- (d) Jump from  $f = f_0 - 12$  kc to  $f = f_0 + 104$  kc.

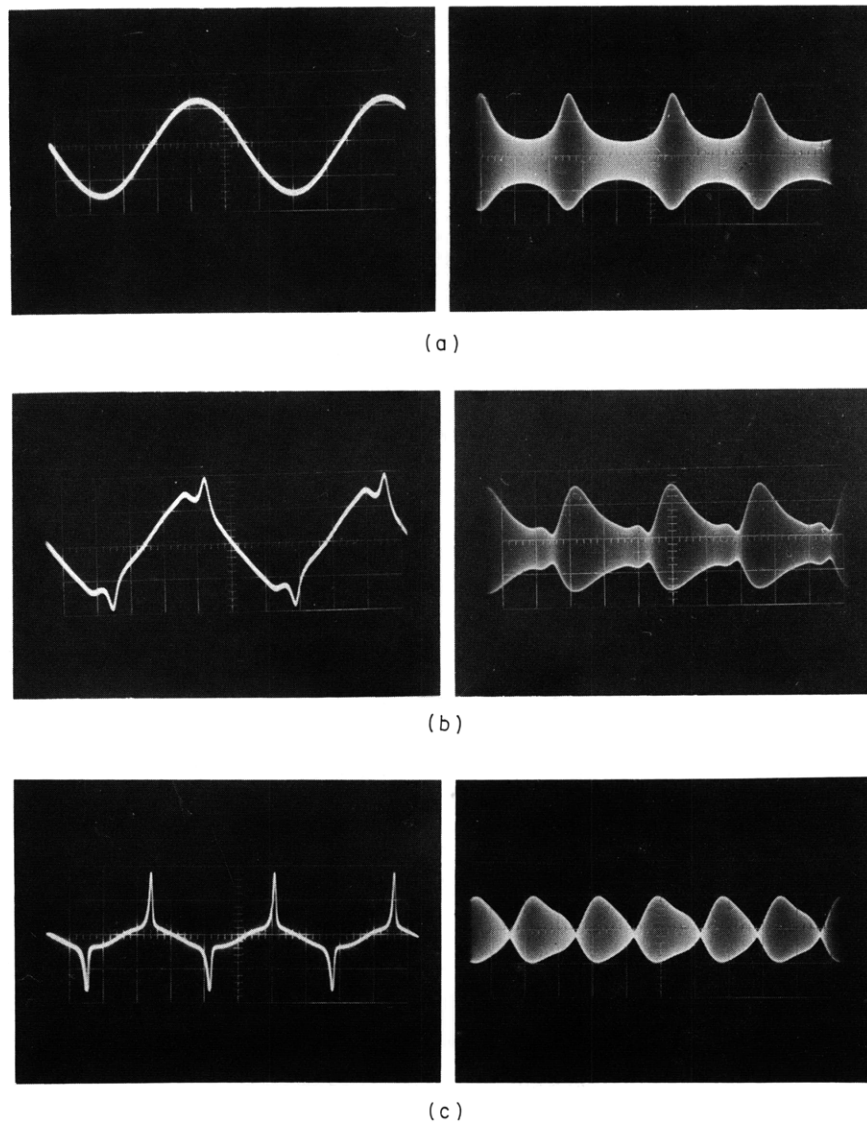


Fig. VII-7. Instantaneous frequency and amplitude of the response of a single-tuned circuit to a sinusoidally modulated FM wave; unmodulated-carrier frequency = resonant frequency = 10 mc; BW = 60 kc; frequency deviation is  $\pm 75$  kc. (a)  $\epsilon = 0.076$ ; (b)  $\epsilon = 0.760$ ; and (c)  $\epsilon = 2.20$ .

## (VII. FREQUENCY MODULATION)

initial and final values of the frequency of the excitation on the ac steady-state response characteristics of the filter, and not by the actual size of the step. This point is illustrated by the oscillograms shown in Fig. VII-6a, b, and c.

The results of a theoretical treatment of the conditions for quasi-stationary response to frequency-modulated excitations (2), as they apply to a single-tuned circuit excited by a sinusoidally modulated FM wave, were also tested. The theory has shown that a single-tuned circuit, whose bandwidth between half-power points is given by  $(BW)$  rad/sec, will respond in a quasi-stationary manner to a carrier, whose frequency is deviated sinusoidally by  $\pm\Delta\Omega$  rad/sec, with a modulation frequency of  $\omega_m$  rad/sec, provided that

$$\frac{\omega_m}{(BW)/2} \cdot \frac{\Delta\Omega}{(BW)/2} = \epsilon \ll 1$$

The quantity  $\epsilon$  represents the fractional error incurred in assuming that the complex amplitude of the filter response is given by the system function of the filter as a function of the instantaneous frequency of the excitation. The practical significance of this condition is illustrated by the oscillograms shown in Fig. VII-7.

Further work on more complicated filters is contemplated.

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### References

1. E. J. Baghdady, FM transient analysis (unpublished work).
2. E. J. Baghdady, Theory of quasi-stationary analysis with application to FM interference and video problems, to be published.