N67 12316

Demodulation Techniques for Use at Goonhilly Satellite-Communication Earth Station*

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As part of the programme of experimental and development work to determine the optimum demodulating techniques for communication satellite systems, three types of demodulators have been investigated at the Goonhilly earth station:

1. A conventional demodulator of the type used in 960-channel telephony or television microwave radio-relay links;
2. A frequency modulation feed-back demodulator in which the deviation of the signal is reduced before it reaches the final discriminator; and
3. A variable-bandwidth 'dynamic-tracking' demodulator in which the resonant frequency of a narrow bandwidth tuned circuit is moved rapidly to follow the nominal instantaneous frequency of the incoming signal.

The conventional demodulator will not be discussed in detail here; however, information is given on two specialised demodulators.

Up to a point, the baseband signal-to-noise ratio at the output of a broadband frequency-modulated microwave system can be improved by increasing the deviation. To accommodate the wider deviation signal, increased receiver bandwidth is required. If the noise temperature and gain of the receiver remain constant, the increased bandwidth will result in more noise reaching the limiter stage which precedes the discriminator. Thus, for the same received signal level the IF signal-to-noise ratio will be decreased.

So long as the instantaneous peaks of noise at the limiter input always remain a decibel or two below the carrier level, normal operation of the demodulator is maintained, i.e. changes of x db up or down in the carrier level will result in corresponding changes of ap-

* First published by the Institute of Electrical Engineers, November 1962.

proximately x db in the ratio of signal-to-basic noise measured at the baseband output. But when the peaks of noise are approximately equal to the carrier, a "threshold" condition is reached where any further decrease in carrier-to-noise ratio results in a much more than directly corresponding decrease in baseband signal-to-noise ratio.

For signals above the threshold level, good conventional demodulators of the types used in line-of-sight microwave links perform quite satisfactorily and nothing is to be gained by using more complex demodulating equipment. This will probably be the state of affairs under normal conditions in operational satellite systems. But when abnormally low-level signals have to be received, or when the noise level is unusually high (e.g. due to heavy rainfall) it is highly desirable that the demodulator should have the lowest possible threshold level. That is to say the demodulator should continue to operate down to the lowest practicable signal level before the output signal-to-noise ratio crashes catastrophically; under these conditions very complex demodulating equipment is justified, even if it lowers the operational threshold by only a few decibels.

A number of techniques are known or have been proposed for obtaining a lower threshold, but the basic principle of all involve either enhancement of the carrier or restriction of the effective bandwidth before demodulation. Baseband signal processing after demodulation (e.g. low-pass filtering) can affect the overall signal-to-noise ratio obtainable with any form of demodulator, but will normally have only a second-order effect on relative performance of various demodulators and a virtually negligible effect on attainable threshold levels.

FREQUENCY MODULATION FEED-BACK DEMODULATOR

Design Features

The frequency modulation feed-back demodulator[1, 2] follows the general principles laid down by Enloe[3], and is shown in block schematic form in Fig. 1. It accepts an input signal at a mean frequency of 70 Mc/s, up-converts to a mean frequency of 3590 Mc/s and then down-converts again to 75 Mc/s. The local oscillator for up-conversion is crystal controlled; but the oscillator used for down-conversion is a klystron which is frequency modulated in such a manner that the deviation of the final IF signal is reduced. The modulating signal for this klystron is obtained from the output of the final 75 Mc/s demodulator.

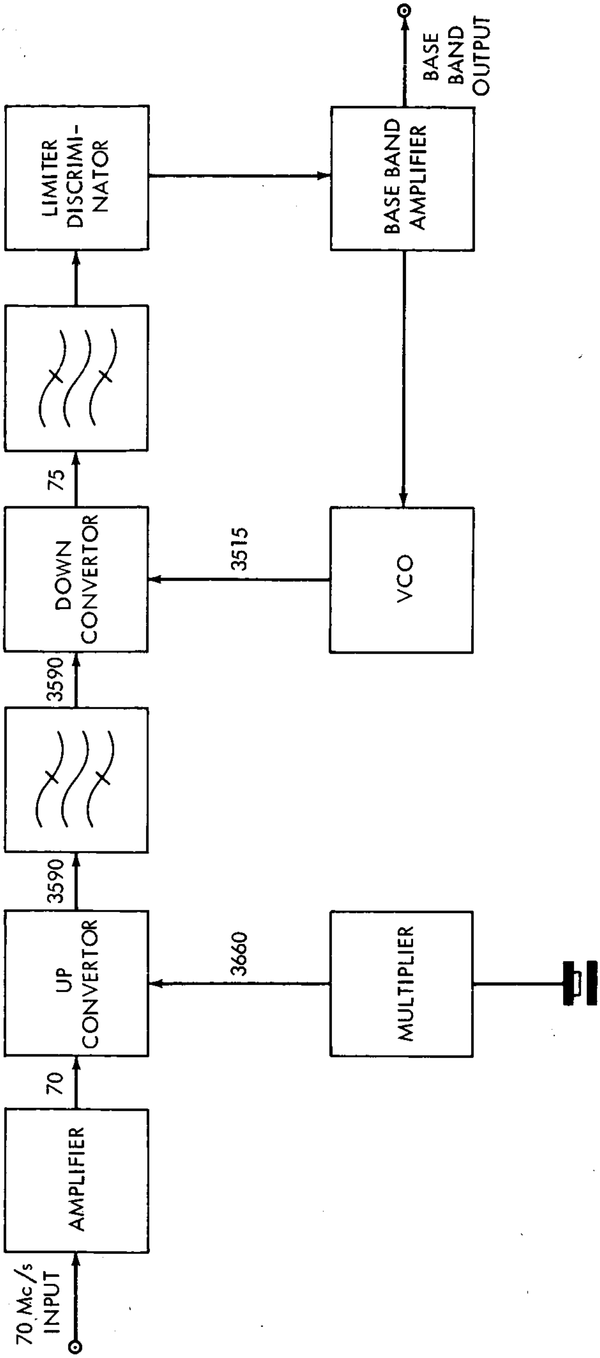
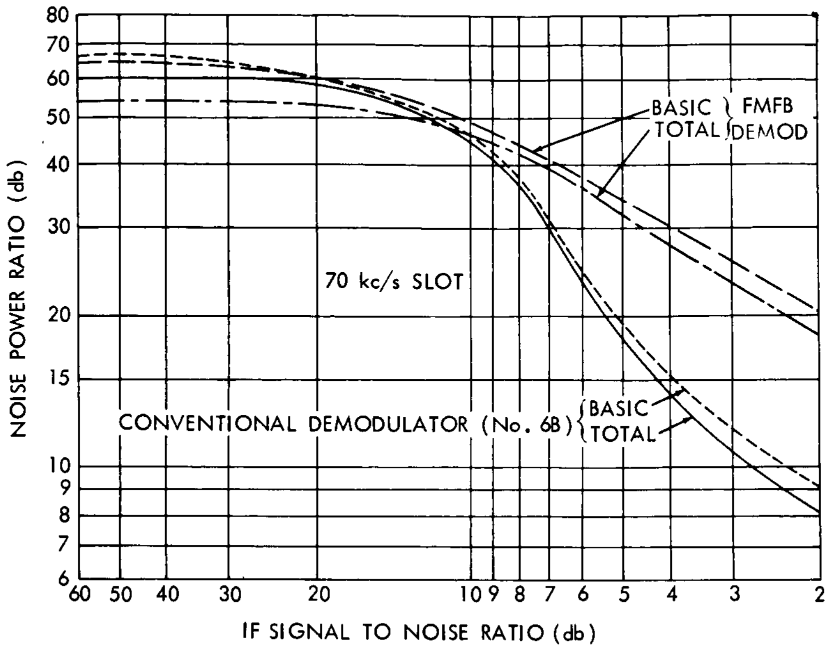


Fig. 1 — FMFB Demodulator: Simplified Block Diagram.



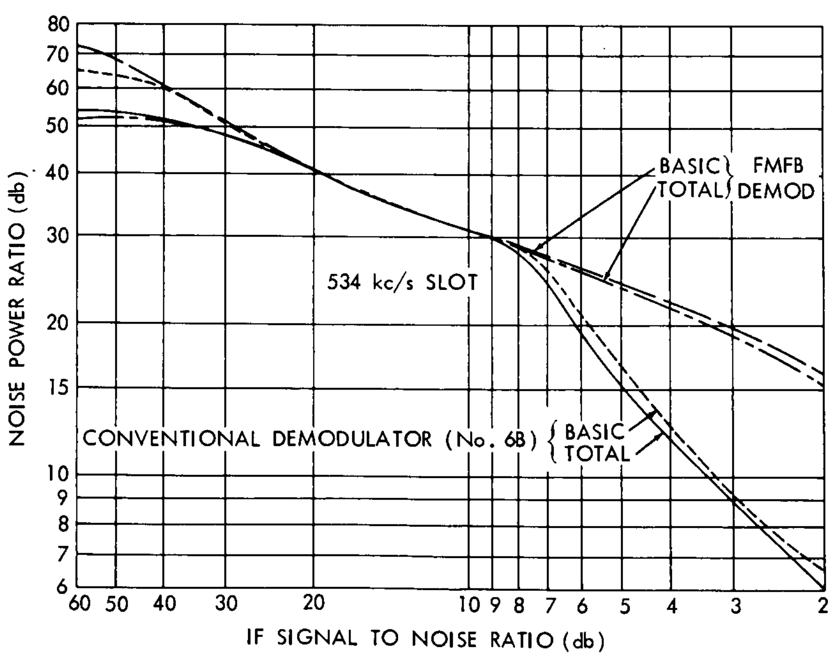


Fig. 2 — FMFB Demodulator: Comparison with Conventional Demodulator (No. 6B) with 240-channel Noise Loading.

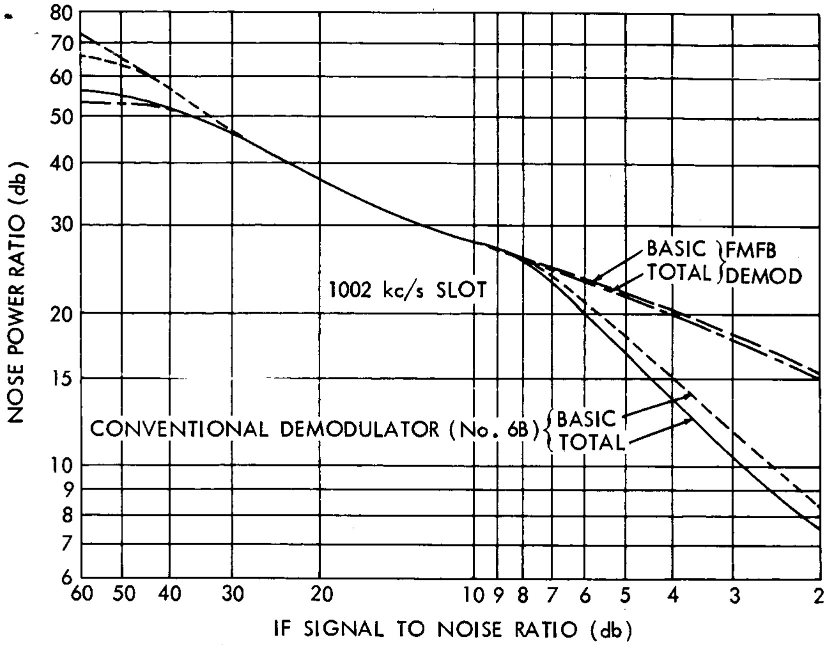


Fig. 2 (continued)

The version of this demodulator which is installed at Goonhilly normally operates at one or the other of two fixed bandwidths; however, experiments have been carried out using continuously variable bandwidth facilities, so that the operating conditions can be more accurately adjusted to optimum for the signal level or modulation being received.

Performance

For television signals the threshold of the FM feed-back demodulator is some 4 to 5 db below that for a conventional demodulator when operated at adequate bandwidth to allow satisfactory reception of both the video signal and the sound sub-carrier.

The performance for 240-channel telephony signals is indicated by the curves in Fig. 2. It will be noticed that the FM feedback demodulator provides appreciable improvement over a conventional demodulator (No. 6B) at values of IF signal-to-noise ratio below 10 db; however, a further improvement in this region would be required to meet accepted international standards of performance.

Fig. 3 shows the baseband frequency response under open and closed-loop conditions.

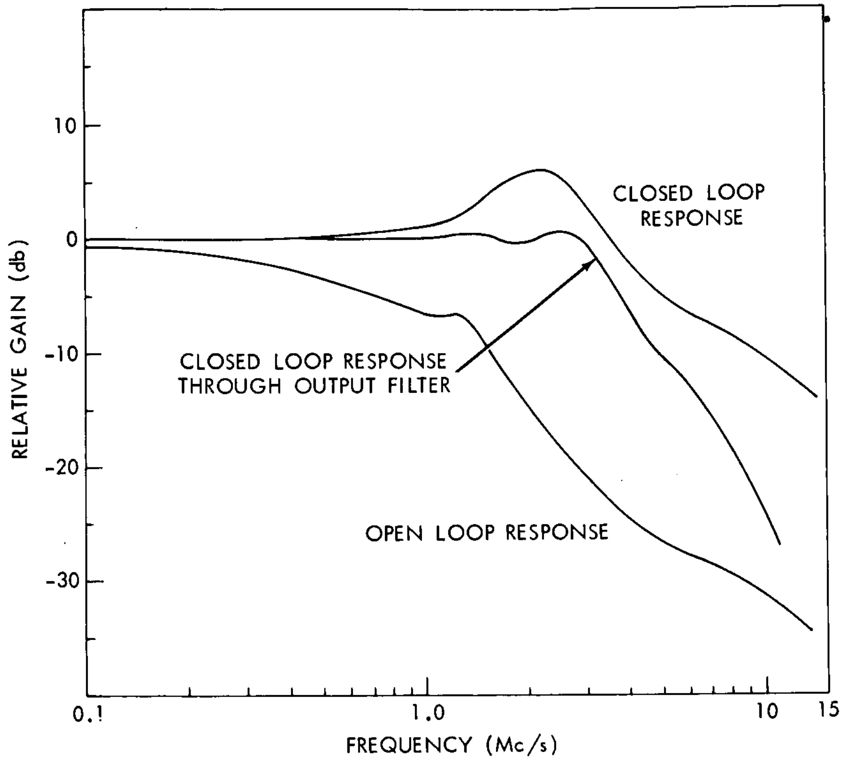


Fig. 3 — FMFB Demodulator; Baseband Frequency Response.

DYNAMIC-TRACKING VARIABLE-BANDWIDTH DEMODULATOR

Principles Involved

Automatic control of the IF bandwidth prior to limiting is already quite well known as a method of improving threshold performance of a receiver demodulator in fairly low deviation FM systems. In essence such an arrangement maintains normal receiver bandwidth until the input signal drops to a level close to threshold, but for still lower levels of signal the effective bandwidth of the receiver is progressively reduced. This reduced bandwidth lowers the total noise and hence the threshold, at the cost of rapidly rising distortion. The occasional rises in inter-modulation noise which result from restricted bandwidth are generally to be preferred to the relatively severe bursts of noise which occur when a fading signal drops below threshold—especially in lightly-loaded telephony systems.

An automatic bandwidth control arrangement of this type is particularly useful for rapidly fading signals and was used very successfully in Post Office tests on a tropospheric—scatter link during 1959-60; but it is not suitable for use in wide-deviation television systems.

It has been pointed out by Baghdady[4], that in many wide-deviation FM systems only limited parts of the total signal bandwidth are carrying essential information at any specific moment, and that it should be possible to improve the threshold by a narrow-band IF filter—provided that the filter could be tuned rapidly enough to follow the changing location of the main energy in the signal spectrum. Baghdady describes such a system in outline and calls the device a "dynamic selector".

Design Features

A simplified block diagram of the demodulator is shown in Fig. 4. A single tuned circuit is used as the variable filter, and a varactor

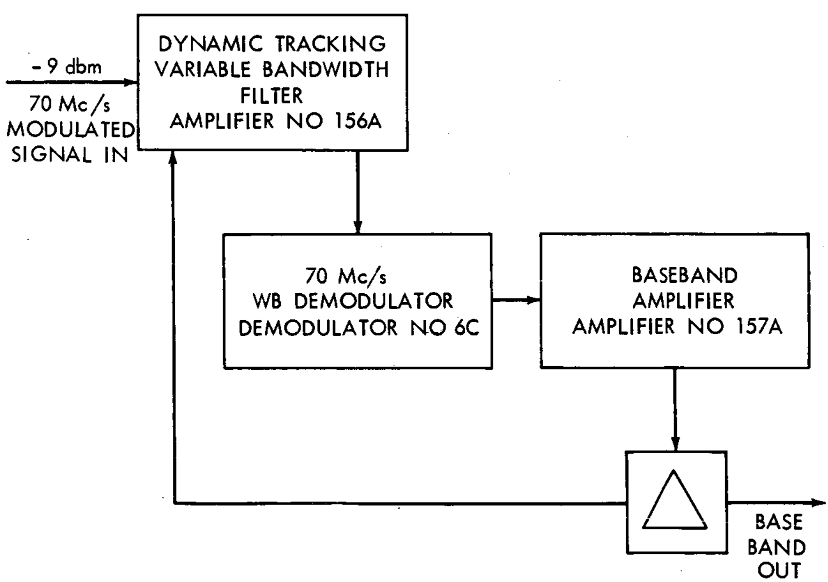


Fig. 4 — Goonhilly Radio Station; Dynamic Tracking Demodulator.

diode forms the tuning element. Variation of the bandwidth is accomplished by altering dc current through a thermistor bead.

The relationship between frequency and voltage which the varactor diode provides is distinctly non-linear, but this is compensated by shaping networks in the video amplifier.

A number of different ways of varying bandwidth were tried; but the majority of these resulted in tuning changes, and a thermistor was found to be the most satisfactory device.

The 3 db bandwidth of the tuned circuit is adjustable from about 2 to 20 Mc/s, but the narrowest bandwidth is rarely useable in practice. A useful feature of the arrangement is that, under wide-band (i.e. high signal level) conditions, the overall performance becomes virtually that of the associated high-grade conventional demodulator. The automatic bandwidth control is adjusted to maintain full bandwidth until the signal falls to within a decibel or two of threshold, and then decreases bandwidth at a rate of approximately 2 to 1 for a 3 db drop in signal.

Performance

For television reception under the usual conditions used for tests on Telstar and Relay, this modulator gives an average threshold improvement of about 4 or 5 db. The improvement is greatest on fairly uniform areas of grey, or on areas of slowly changing brightness; but is limited by noise in regions where there is a sudden change in brightness, due to inability of the narrow-band circuit to follow fast enough. This feature can result in some roughness of vertical edges under conditions of very low signal-to-noise ratio, which can be considerably reduced by fly-wheel synchronization, or synchronizing-pulse restoration.

The dynamic-tracking demodulator gives optimum results only if the incoming television signal includes a dc component, i.e. when specific frequencies correspond to the synchronizing pulse, black and white levels in the video waveform. It is less effective if the earth-station transmitter originating the signals uses no pre-emphasis and mean-frequency automatic frequency control. Furthermore, if the bandwidth restriction is excessive, cross modulation from the video channel into the sound-sub-carrier channel may occur.

The variable-bandwidth dynamic tracking demodulator is considered unsuitable for multi-channel telephony, and it is probable that a simple variable-bandwidth system (i.e. without the tracking feature) may be preferred.

POSSIBILITIES FOR FURTHER IMPROVEMENT OF DEMODULATOR PERFORMANCE

Noise Limiting Techniques

At the output of a wide-band demodulator operating at or just below threshold, the noise peaks are very narrow. It is suggested that a peak-clipping device might be used at that point to restrict the video signal to limits appropriate to the white and synchronising pulse levels, and if the bandwidth is subsequently restricted, (e.g. to 3 Mc/s) the amplitude of the noise peaks will be still further reduced. The clipping must take place before the video bandwidth is restricted.

It is possible that still further suppression of these short duration noise peaks could be obtained by arranging for automatic variation of the clipping levels, especially if the main signal can be very slightly delayed and advance information on its levels obtained from an earlier part of the circuit.

Alternative Sound Channel Arrangement

The use of a sound sub-carrier at 4.5 Mc/s necessitates, for television a minium IF bandwidth of slightly over 9 Mc/s. If this sub-carrier is eliminated an IF bandwidth of just over 6 Mc/s would give a full-bandwidth video response. In difficult reception conditions some restriction of video bandwidth is permissible and the effective IF bandwidth could then be further reduced. For example, a 2.5 Mc/s IF bandwidth would represent an improvement of about 10 db in threshold relative to a conventional demodulator of 25 Mc/s bandwidth.

CONCLUSIONS

When the carrier/noise ratio is appreciably greater than that corresponding to threshold conditions, a conventional demodulator is to be preferred. At carrier/noise ratios (measured in 25 Mc/s bandwidth) less than 10 db there is some benefit from the specialised demodulators, and at carrier/noise ratios less than 6 db there is a marked benefit.

It is possible that further development work on noise limiting techniques in demodulators might result in yet better performance, and there is no doubt that elimination of the sound sub-carrier, e.g. by transmission of the sound on pulses within the synchronizing interval of the television signal, would greatly increase the threshold margin for television under difficult conditions.

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