

RECOMMENDATION ITU-R S.446-4*

**CARRIER ENERGY DISPERSAL FOR SYSTEMS EMPLOYING ANGLE
MODULATION BY ANALOGUE SIGNALS OR DIGITAL MODULATION
IN THE FIXED-SATELLITE SERVICE**

(1966-1974-1978-1992-1993)

The ITU Radiocommunication Assembly,

considering

- a) that use of carrier energy dispersal techniques in systems in the fixed-satellite service can result in a substantial reduction of interference to stations of a terrestrial service operating in the same frequency bands;
- b) that in many cases the use of such techniques can result in a moderate to substantial reduction in the level of interference between systems in the fixed-satellite service operating in the same frequency bands, although in other cases the use of such techniques may not reduce the level of interference between such systems;
- c) that such techniques are being regularly and successfully employed in systems in the fixed-satellite service without noticeable deterioration of the quality of operation;
- d) that Recommendation No. 103, relating to carrier energy dispersal in systems in the fixed-satellite service, was adopted by the World Administrative Radio Conference for Space Telecommunications (Geneva, 1979);
- e) that performance evaluation of various techniques of FM-TV signal dispersion is given in Annex 1 to Recommendation ITU-R S.671**;

recommends

- 1. that systems in the fixed-satellite service should use carrier energy dispersal techniques, as far as is practicable and in a manner consistent with satisfactory operation of the systems, with a view to spreading energy such that the interference to stations of a terrestrial service operating in the same frequency bands is maintained within specified tolerable limits at all times;
- 2. that the capability for carrier energy dispersal up to the maximum degree practicable should be included in the design of satellite systems to be available for implementation when necessary to maintain a reduced level of interference between systems in the fixed-satellite service operating in the same frequency bands;
- 3. that the following Note should be regarded as part of this Recommendation.

Note 1 – Annex 1 describes various dispersion techniques for use with FM analogue and PSK digital signals which can be recommended for practical utilization.

ANNEX 1

Energy dispersal in the fixed-satellite service

1. Introduction

It is clear from studies of frequency sharing between the fixed-satellite service and terrestrial radio-relay systems and between different fixed-satellite networks that, to ensure that mutual interference between the systems is kept to a tolerable level, it will be essential in most cases to use energy dispersal techniques to reduce the spectral

* New version of CCIR Recommendation 446. This Recommendation was developed from work carried out under ex-CCIR Study Programme 27A/4 which was suppressed according to Resolution 109 (Düsseldorf, 1990).

** Former CCIR Recommendation 671.

energy density of the transmissions of the fixed-satellite service during periods of light loading. The reduction of the maximum energy density will also facilitate:

- efficient use of the geostationary-satellite orbit by minimizing the orbital separation needed between satellites using the same frequency band; and
- multiple-carrier operation of broadband transponders.

The amount of energy dispersal required obviously depends on the characteristics of the systems in each particular case. It is clear, however, that it is desirable that the maximum energy density under light loading conditions should be kept as close as possible to the value corresponding to the conditions of busy hour loading.

In this Annex, the results of some theoretical and experimental studies of energy dispersal techniques, separately applicable to analogue frequency-modulation and to digital radiocommunication-satellite systems, are reported.

It is concluded that substantial energy dispersal can be obtained in most circumstances. However, there are some possible limitations on the efficiency of the dispersal and these are mentioned in the Annex.

2. Energy dispersal for analogue multi-channel telephony FM systems

In studying ways of achieving high degrees of carrier energy dispersal, it is useful to know what is the dispersing effect of the fully-loaded baseband signal, in order to have some reference value with which to compare what can be obtained artificially. It is legitimate, for the general class of wide-deviation frequency-modulation systems under consideration, i.e. those in which the multi-channel r.m.s. deviation (δF) exceeds the highest baseband frequency, and greatly exceeds the lowest baseband frequency, to assume that the mean power spectrum under the conventional busy-hour loading conditions is of Gaussian form. Hence, the dispersing effect obtained under these conditions is:

$$10 \log \left(\frac{\text{maximum energy per 4 kHz}}{\text{total energy}} \right) = 10 \log \frac{0.004}{\sqrt{2\pi} \delta F} = - (28 + 10 \log \delta F) \quad \text{dB}$$

(δF is expressed in MHz)

The dispersing effect when δF is less than the highest baseband frequency can be calculated using the information contained in Annex 1 of Recommendation ITU-R SF.675*.

There are a number of methods of maintaining a high degree of carrier energy dispersal in telephony systems, where the obtained dispersal is a function of the complexity of the means of dispersal and the increase in occupied radio-frequency bandwidth resulting from distortion. The methods fall into one or other of two general cases; one which adds a dispersal waveform not necessarily of constant magnitude to the input signal and the second which, in addition, effectively controls the deviation sensitivity of the frequency modulator. Various arrangements of these two methods are illustrated in Fig. 1.

2.1 Dispersal by added waveforms

2.1.1 Method 1a)

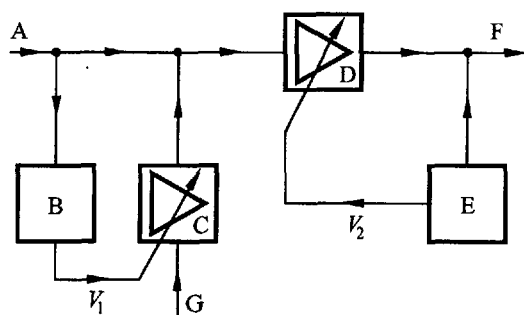
The simplest way of bringing about some degree of carrier energy dispersal is to add to the baseband signal, a suitable low-frequency dispersing waveform of fixed magnitude, as in Method 1a) of Fig. 1. Of a variety of dispersal waveforms that have been proposed, the following are examined in this Annex:

- a sinusoidal signal (Curve A of Fig. 2),
- a sinusoidal signal plus 30% third harmonic added in suitable phase (Curve B of Fig. 2),

* Former CCIR Recommendation 675.

- a band of low-frequency noise (Curve C of Fig. 2),
- a low-frequency triangular waveform (Curve D of Fig. 2).

FIGURE 1
Simplified block diagram

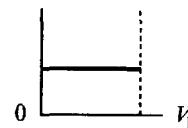


A: baseband signal input
B: r.m.s. detector
C: amplifier 1
D: amplifier 2
E: r.m.s. detector
F: output to frequency-modulator
G: dispersal waveform

Method

1a)
1b)

Gain



No control

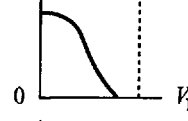
Gain



No control

2a)

Gain

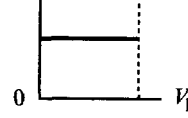


Gain

0 V2

2b)

Gain

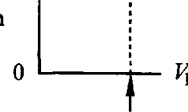


Gain

0 V2

2c)

Zero gain



Gain

0 V2

Full load

Full load

d07

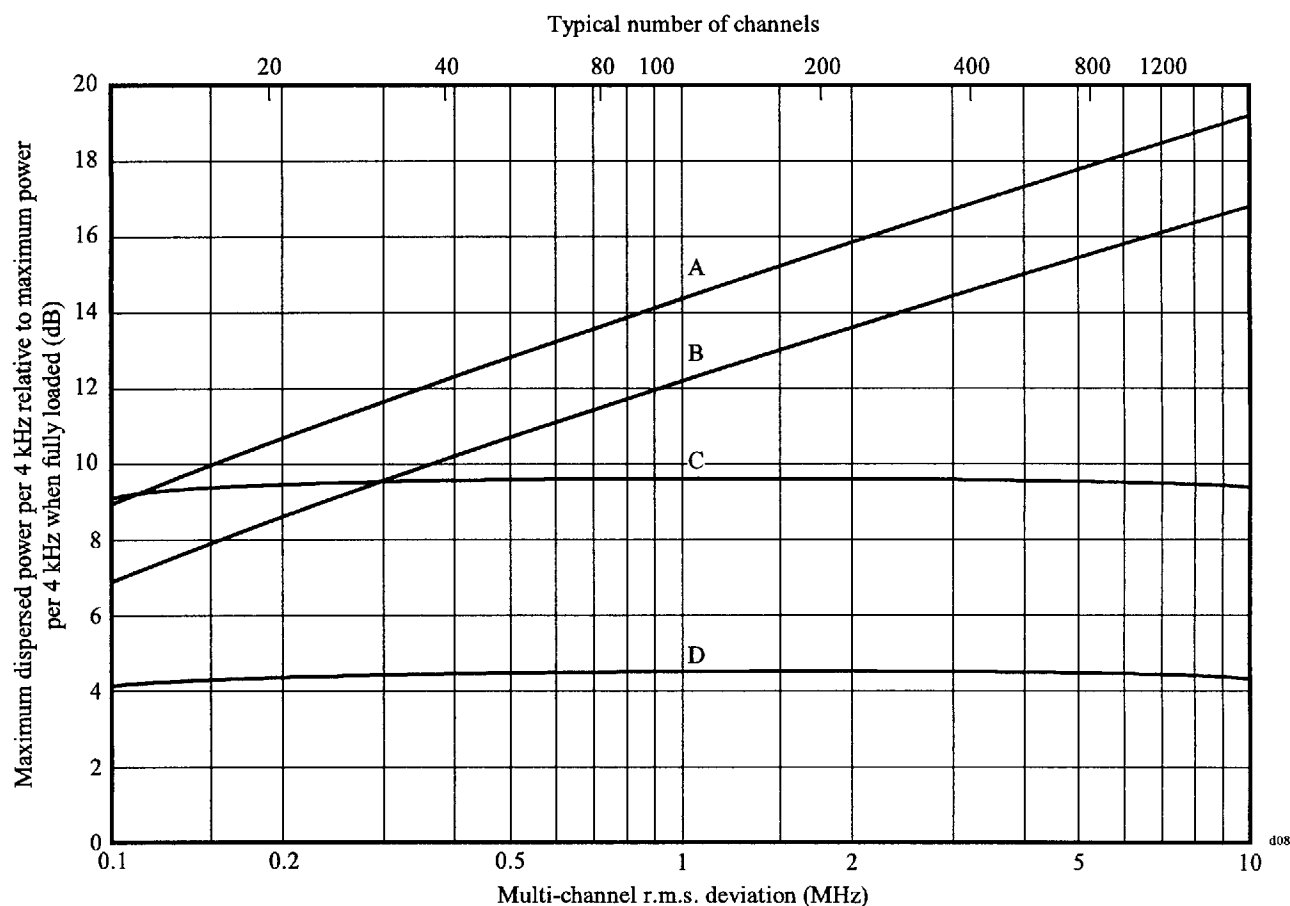
(Possible filters, buffer-amplifiers and gain-regulating pilots omitted)

To provide some basis for comparing the efficiencies of these waveforms, the maximum energy spectral density, which they produce when applied to an unmodulated carrier, has been calculated for an assumed 10% increase in occupied radio-frequency bandwidth. The results are plotted in Fig. 2, relative to that which would occur under the conditions of busy-hour loading; the curves of Fig. 2 have been designated A-D as described above. However some approximations have been made, as the problem of the relation between signal distortion and radio-frequency bandwidth limitation has been avoided by assuming:

- Carson bandwidth occupancy (with peak-to-r.m.s. ratio of 12 dB) throughout;
- that this bandwidth formula may also be applied to the sum of the signal and dispersed r.m.s. deviation when the dispersal is by noise band;
- in other cases, that the occupied radio-frequency bandwidth is increased by the peak-to-peak dispersal deviation.

The errors so incurred are not thought to be large, and in any case should be in the same sense for all waveforms. As a further approximation, each type of dispersing waveform is represented in Fig. 2 by a single curve.

FIGURE 2
Energy dispersal for multi-channel telephony systems



2.1.1.1 Sinusoidal dispersal

It is evident from Curve A of Fig. 2 that carrier energy dispersal by a sinusoidal signal is rather inefficient, while Curve B shows that a sinusoidal signal with 30% of third harmonic is only about 2 dB better. For a typical 20-channel transmission, the maximum power density in either case, exceeds that which occurs under full-loading conditions by about 10 dB. It is a feature of both these types of dispersal that the amount by which the dispersed power-density exceeds that at full loading, increases with the r.m.s. multi-channel deviation and hence with channel capacity. For example, the excess for 1 200 channels is about 18 dB.

2.1.1.2 Triangular dispersal

The most effective way, for a given increase in occupied bandwidth, of dispersing the energy present in a single spectral line is, at least theoretically, by the application of a triangular waveform. The dispersed power-density is inversely proportional to the permitted percentage increase in radio-frequency bandwidth and Curve D of Fig. 2 shows that, if a 10% increase in occupied bandwidth is permitted, the dispersed power per 4 kHz exceeds that under full-loading conditions by only about 4.5 dB for most numbers of channels.

When a low-frequency (≤ 1 kHz) triangular dispersal waveform is used on multi-channel systems, a wanted single-channel-per-carrier system can be exposed to nearly the full power of an interfering carrier for significant periods of time.

The triangular waveform evidently offers a simple and efficient means of dispersing the energy present in isolated spectral lines of telephony transmissions. It must be remembered, however, that its effectiveness depends upon faithful preservation of the shape of the wave until it appears as frequency-modulation, particularly when a high degree of dispersal is required. If 32 dB of dispersal were required for a 1 200-channel transmission, for example, flattening of the extremities of the wave by only 0.25% might lead to a local doubling of spectral energy density.

The triangular signal may have to be filtered before being applied, to prevent the harmonics of the fundamental from disturbing the lower channels of the telephone multiplex. For triangular waveform frequencies of up to 150 Hz and for a low frequency multi-channel baseband of 4 kHz, filtering causes deformation at the angles of the signal waveform and thus at the energy density peaks at the extremities of the modulation spectrum under light-loading conditions.

Table 1 shows measured values for the increase in energy density at the extremities of the spectrum in relation to the density at the centre frequency of the spectrum, for a 132-channel multiplex, as a function of the frequency of the triangular waveform. Discontinuous single step regulation was used for this system.

TABLE 1

Frequency of triangular waveform (Hz)	Increase in energy density (dB)
20	3
80	5
150	7

The low-pass filter used was a 7-pole Chebyshev-type filter with a cut-off frequency of 2.7 kHz and an attenuation at 4 kHz equal to 34 dB.

It is, however, possible to take account of the presence of the continuity pilot at the modulator input provided it is generated independently of the telephone multiplex. Under the same measurement conditions as indicated earlier, the application of a pilot at a level of -20 dBm0 makes it possible to reduce the energy density peaks at the extremities of the band from 7 to 3 dB.

2.1.1.3 Dispersal by a band of low-frequency noise

A form of carrier energy dispersal that is not critical in its application and shares with triangular dispersal the property of yielding a maximum energy spectral-density, inversely proportional to the amplitude of the waveform, may be accomplished by adding a band of low-frequency noise to the multi-channel baseband. Curve C of Fig. 2 shows that, for a 10% increase in occupied bandwidth, the maximum dispersed power per 4 kHz exceeds that under full-loading conditions by about 9.5 dB for all numbers of channels.

Note 1 – When the level of the dispersal signal is not fixed, the required amount of dispersion can be attained by other methods.

2.1.2 Method 1b)

An obvious variant of Method 1a) would incorporate an automatic means for adjusting the degree of artificial energy dispersal which would be applied according to the state of loading of the system, as shown in Method 1b) of Fig. 1. It might, in fact, be possible by using noise band dispersal in this way, to maintain the maximum energy spectral-density of a transmission quite close to its full-loading value without any increase in occupied radio-frequency bandwidth. The performance that could be achieved in practice, would depend on the distortion produced by the interaction (via radio-frequency bandwidth limitation and other transmission characteristics) of the dispersal waveform

and isolated tones and active telephone channels under light-loading conditions. It is probable that the matter can only be settled experimentally, since there is as yet no generally accepted way of calculating the distortion that frequency-modulation signals undergo during transmission, even for the simplest case of white-noise loading.

A particular method which has been proposed for applying the variable degree of dispersal to which the present sub-section relates, relies on filling a suitable proportion of unoccupied telephone channels with simulated speech (i.e. band-limited noise). Although full dispersal could in this way be maintained without increase of bandwidth, the complexity of the apparatus likely to be required for the method is a serious disadvantage, as is the probable necessity for applying it at the audio switchboards from which the baseband originates.

2.2 *Dispersal by automatic deviation control*

2.2.1 *General*

It would clearly be possible to adjust the signal level entering the system frequency modulator so as to maintain the r.m.s. (or peak) frequency deviation at some constant value. The desired level could be obtained merely by subjecting whatever the baseband content happens to be, to sufficient amplification, or by so amplifying after the addition of some fixed or variable amount of artificial dispersal. The overall baseband transmission loss of the system would be kept sensibly constant by a compensating adjustment of the post-demodulation gain through the medium of a system pilot tone. The possibilities are discussed in the following paragraphs.

2.2.2 *Method 2a)*

The most general method of carrier energy dispersal of which the others are in a sense degenerate forms, is Method 2a) in Fig. 1. This consists in adding to the baseband, before the application of automatic deviation control, a source of artificial energy dispersal whose amplitude is made to depend upon the loading conditions. The use of this method might add little or nothing to the occupied radio-frequency bandwidth. Furthermore, if the application of artificial dispersal were delayed until the approach of light-loading conditions, a valuable decrease in the sensitivity of the system to thermal noise, distortion and interference might result. The magnitude of this decrease would depend upon what fraction of the fully-loaded baseband power was attributable to speech signals. As for Method 1b), some determination of the baseband distortion associated with this method is desirable, although, other things being equal, such distortion would be less than in the earlier method, because the increased deviation-per-channel under light-loading conditions would render the system less sensitive to the radio-frequency distortion components produced.

With regard to the choice of a means of artificial dispersal to be added to the baseband, this might consist of any of the low-frequency dispersal waveforms considered in § 2. The noise-band waveform resembling one or more perpetually active telephone channels is perhaps to be preferred, because it is moderately efficient and because it has the same dispersing effect for a given r.m.s. deviation as the baseband signal. It also allows accurate deviation control to be obtained by a simple r.m.s. detector and presents no difficulties of application at large amplitudes.

2.2.3 *Method 2b)*

As a trivial simplification of the foregoing method, the amplitude of the added dispersing waveform might be set at some fixed value. There would be some increase in occupied radio-frequency bandwidth, although not so much as in Method 1a) for the same degree of dispersal.

2.2.4 *Method 2c)*

The complete omission of artificial dispersing waveforms from the modulating signal would reduce dispersal by automatic deviation control to its simplest form. The effectiveness of the method would seem to depend on the baseband spectrum retaining some moderate degree of complexity even under light-loading conditions. Unfortunately, it may not be possible to count upon this; in the complete absence of telephone channel activity, the system loading would degenerate to a number of pilot tones, carrier leaks and the like. There might be enough of these in a large