

REPORT 923-1

DESIGN OF FREQUENCY PLANS FOR SATELLITE TRANSMISSION OF SCPC CARRIERS USING NON-LINEAR TRANSPONDERS

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1. Introduction

In satellite communication systems, a number of SCPC carriers are transmitted via a single satellite transponder. For efficient use of satellite power, the transponder would be operated in the non-linear region, in which case intermodulation noise affects signal quality.

The intermodulation products falling into the frequency slots of occupied signal channels could be reduced by suitably positioning the channels within the available bandwidth. Babcock spacing [Babcock, 1953] is a typical example of this approach where the signal channels are completely free from third-order intermodulation noise. However, such an intermodulation-free frequency plan would not necessarily be desirable because of its inefficient use of available bandwidth, especially where a large number of channels have to be accommodated. For example, in order to accommodate 20 channels, it would be necessary to utilize a bandwidth more than 10 times the width of a plan using adjacent frequency slots [Hirata and Yasuda, 1976]. Hence, bandwidth-efficient frequency plans need to be developed, and one approach is to allow some intermodulation products to fall into the signal channels, but only to the extent that the degradation of signal quality can be acceptable.

A reasonable and effective approach to realize such an idea is to minimize the number of the third-order intermodulation products falling into the worst signal channel [Hirata, 1978]. The worst signal channel here means a specific signal channel into which the largest number of the third-order intermodulation products fall. This Report discusses the assignment of frequencies based on this approach, which is referred to hereafter as intermodulation-minimum frequency assignment.

2. Equal level SCPC carriers

2.1 Relationship between assigned bandwidth and intermodulation products

It is difficult to determine theoretically intermodulation minimum frequency plans. However, the attainable minimum number of intermodulation products falling into the worst affected signal channel can be estimated by the theoretically derived lower bound.

Figure 1 shows the theoretically derived lower bounds of the number of the $(f_1 + f_2 - f_3)$ type of the third-order intermodulation products falling into the worst signal channel as a function of the assigned bandwidth with a parameter of the number of signal channels to be accommodated. In this Figure, the number of intermodulation products, which is proportional to the intermodulation noise power, is normalized against the number produced in the worst signal channel in a plan using adjacent frequency slots. The result is then expressed in decibels. For convenience, the latter plan is referred to hereafter as minimum equal-spacing. The assigned bandwidth is also normalized by that required for the minimum equal-spacing plan. This Figure implies that the number of intermodulation products falling into the worst signal channel could be reduced to about one half compared to the case of minimum equal-spacing when the total frequency bandwidth occupied is 50% wider than that required for minimum equal-spacing.

2.2 Intermodulation-minimum frequency plan

Intermodulation-minimum frequency plans have been obtained for practical application by computer calculation. For a small number of signal channels, the optimum solution can be obtained by examining all possible combinations. Table I shows the results obtained where the number of signal channels K is 10.

For a large number of signal channels, the quasi-optimum solution, which may not be optimum but would be considered very close to optimum, can be obtained by an iterative approach [Okinaka *et al.*, 1982]. Table II shows the obtained results where K is 20 in 11a and 40 in 11b, respectively.

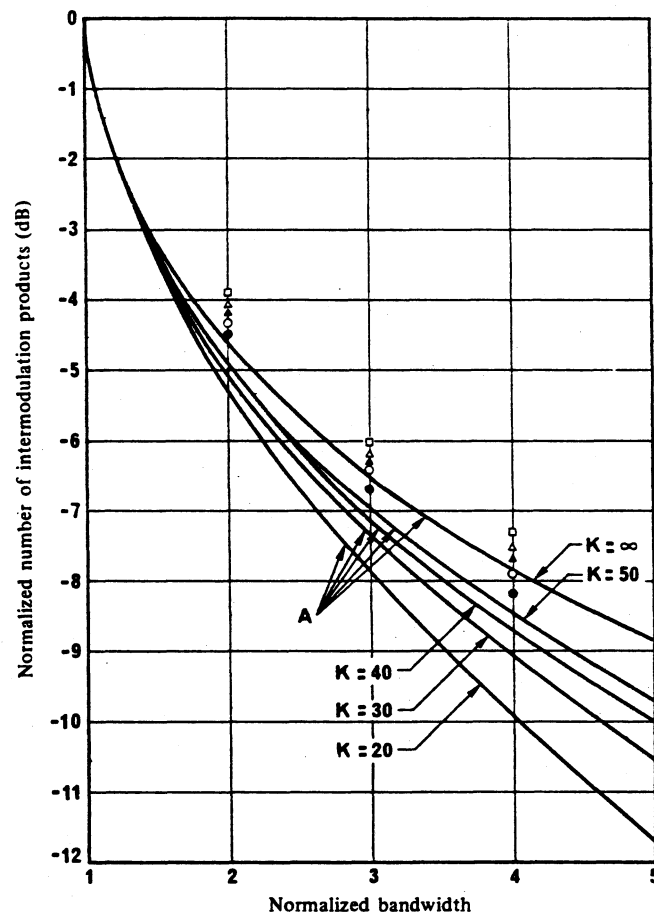


FIGURE 1 – Relationship between the number of intermodulation products falling into the worst signal channel and the assigned bandwidth

Obtained results :

- : $K = 20$
- : $K = 30$
- ▲ : $K = 40$
- △ : $K = 50$
- : $K = 100$
- A : lower bounds
- K : number of signal channels

TABLE I — Optimum intermodulation-minimum frequency plans (number of signal channels, $K = 10$)

Number of frequency slots	Normalized bandwidth	Normalized number of IM products (dB)	Assigned frequency slots
11	1.1	-1.0	1, 2, 3, 4, 5, 7, 8, 9, 10, 11
12	1.2	-1.7	1, 2, 3, 4, 6, 7, 9, 10, 11, 12
13	1.3	-2.4	1, 2, 3, 4, 6, 7, 10, 11, 12, 13
14	1.4	-3.0	1, 2, 3, 4, 6, 7, 10, 12, 13, 14
15	1.5	-3.5	1, 2, 3, 4, 7, 8, 11, 13, 14, 15
16	1.6	-3.9	1, 2, 3, 4, 7, 10, 12, 14, 15, 16
17	1.7	-4.3	1, 2, 3, 4, 7, 10, 12, 14, 16, 17
18	1.8	-4.7	1, 2, 3, 5, 7, 10, 13, 16, 17, 18
19	1.9	-5.2	1, 2, 3, 5, 9, 12, 14, 17, 18, 19
20	2.0	-5.4	1, 2, 3, 6, 8, 12, 15, 18, 19, 20
21	2.1	-5.7	1, 2, 3, 5, 10, 14, 15, 18, 20, 21

The normalized number of intermodulation products shown in Tables I and II are plotted in Fig. 1. Comparing them with their lower bounds, it is observed that the number of intermodulation products falling into the worst signal channel in the intermodulation-minimum frequency plans can be estimated effectively by using the lower bound curve for $K = \infty$ shown in Fig. 1.

3. Multi-level SCPC carriers

In future satellite systems it may be desirable to operate with several standards of mobile earth stations having different G/T values. One possibility would be to transmit signals destined to the various mobile earth station standards with different satellite e.i.r.p. levels. Even within systems that operate with a single mobile earth station standard, different satellite carrier power levels may be used for different services.

However, accommodation of large numbers of carriers of mixed power levels in a single non-linear satellite transponder by placing the carriers in arbitrarily-selected channel assignments could easily lead to situations where intermodulation noise from certain relatively higher-power channels would render several relatively lower-power channels unusable.

A carefully developed frequency plan, resulting in a distribution of intermodulation noise among channels in such a way as to be proportional to the carrier power of the channel could prevent such a situation.

This section briefly describes several frequency plans for multi-level carriers.

3.1 Mixed-level frequency plan alternatives

One type of frequency plan capable of easily accommodating mixed level carriers assigns carriers to channels selected from a set of equally spaced channels using a Babcock spacing [Babcock, 1953; Edwards *et al.*, 1969]. Resultant assigned channels are totally free of third-order intermodulation noise and could consequently be used for carriers of any power level. However, Babcock plans are generally impractical, unless the number of required carrier assignments is small, due to the inefficient use such plans make of the available bandwidth.