Proceedings of the 5th WSEAS Int. Conf. on SIMULATION, MODELING AND OPTIMIZATION, Corfu, Greece, August 17-19, 2005 (pp645-649)

N-Carrier Frequency Domain Calculation of Intermodulation in Satellite HPA

MARIO REYES-AYALA, EDGAR ALEJANDRO ANDRADE-GONZALEZ
Electronics Department
Metropolitan Autonomous University
San Pablo 180, Col. Reynosa Tamaulipas, Azcapotzalco, ZIP Code 02200, Mexico City
MEXICO

Abstract: - In this paper, the satellite intermodulation is evaluated in frequency domain, for N-carrier input. Fourier transform is applied to avoid large equations where the number of carriers is quite low. The algorithm is probed with well-known series for particular cases with two input carriers. Additionally, it is also possible to evaluate AM-AM conversion in a large set of input carriers.

Key-Words: - Non-linear response, Intermodulation, Fourier transform, AM-AM Conversion.

1 Introduction

Non-linear effects in satellite HPA reduce links quality, because spurious generation narrows down amplifier gain and, enhance the level of interference. In satellite down-links the intermodulation products are extremely high, because satellites normally have some transmitters in simultaneous operation, where their power levels must compensate link losses. Additionally, many applications involve multi-carrier reception, because their users want to link directly with satellites, Direct Broadcasting Satellite Services (DBS) and Personal Communications Systems (PCS), for example [7].

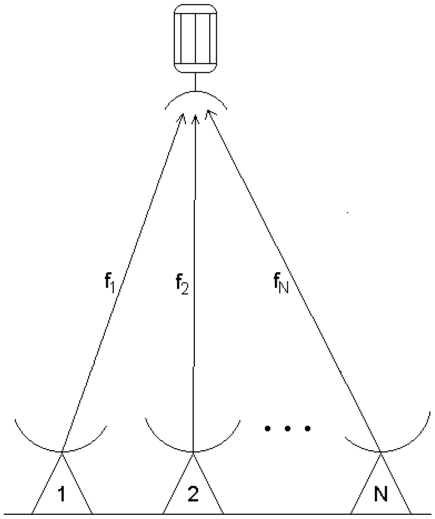

Fig. 1 Intermodulation in satellite system.

In Figure 1, a Frequency Multiple Division Multiple Access (FDMA) is shown for satellite system, where carrier frequency allows to distinguish the original earth station. Unfortunately, a large number of carriers causes non-linear behavior in HPA, because a lot of spurious signals are generated.

In section two, a two-carrier intermodulation analysis and simulation is presented, but in normal conditions, there are a lot of carriers in the HPA input [7][8], then it is important to have a procedure for N-carrier systems.

Many results are described for one carrier in transmission media [9], but a multi-carrier system implies large equations in limited conditions.

In this paper, a frequency domain procedure for real satellite systems is proposed in detail, where N-carrier intermodulation cause gain reduction. For power-saving and interference-reducing purposes, it is necessary to employ back-off.

In section three, the proposed algorithm is presented, where a set of N-carrier integrate a FDMA scheme. Finally, sections four and five show the algorithm results and conclusions, respectively.

2 Two-carrier Intermodulation

Although in a real satellite system the number of carriers is frequently quite large, a two-carrier intermodulation analysis is enough to illustrate non-linear effects like: harmonics generation, intermodulation products, odd-order intermodulation products and AM-AM conversion.

2.1 Harmonic Generation

If there is only one carrier, non-linear response causes harmonic generation in satellite systems. In TDMA satellite systems, harmonic generation is the most important non-linear effect, because a single transmitter uses transmission media.

Assume that *x(t)* is one-carrier signal, see equation (1). Where A is the carrier amplitude, *V*; ω_c is the angular frequency rad/m; and t is the time, s.

$$x(t) = A\cos(\omega_c t) \tag{1}$$

Similarly, *f(t)* represents an arbitrary non-linear third-order response for HPA, see equation (2). Where a_i are the polynomial coefficients

$$f(t) \cong a_0 + a_1 x(t) + a_2 x^2(t) + a_3 x^3(t) \tag{2}$$

Then, harmonic generation implies several equations, see Table 1.

ω **(rad/s)**	A_ω **(V)**	
0	$\left(a_0 + \frac{a_2 A^2}{2}\right)$	(3)
ω_c	$\left(a_1 A + \frac{3a_3}{4} A^3\right)$	(4)
$2\omega_c$	$\left(\frac{a_2 A^2}{2}\right)$	(5)
$3\omega_c$	$\left(\frac{a_3 A^3}{4}\right)$	(6)

Table 1. Two-Carrier Harmonic Generation in HPA

2.2 Two-Carrier Intermodulation

Now, if *x(t)* has two carriers instead of one, then *x(t)* is defined by (7). Where A_1 and A_2 are carrier amplitudes, V; and, ω_1 and ω_2 are carrier frequencies, rad/s.

$$x(t) = A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t) \tag{7}$$

Therefore, in addition to harmonic generation, output will include intermodulation products as a result of two-carriers input, where their frequencies jare arithmetic combinations of ω_1 and ω_2. In Table 2, the amplitude of intermodulation products are given.

ω **(rad/s)**	A_ω **(V)**	
0	$a_0 + \frac{1}{2} a_2 \left(A_1^2 + A_2^2\right)$	(8)
ω_1	$a_1 A_1 + \frac{3}{4} a_3 A_1 \left(A_1^2 + 2A_2^2\right)$	(9)
ω_2	$a_1 A_2 + \frac{3}{4} a_3 A_2 \left(A_2^2 + 2A_1^2\right)$	(10)
$2\omega_1$	$\frac{1}{2} a_2 A_1^2$	(11)
$2\omega_2$	$\frac{1}{2} a_2 A_2^2$	(12)
$\omega_1 \pm \omega_2$	$a_2 A_1 A_2$	(13)
$3\omega_1$	$\frac{1}{4} a_3 A_1^3$	(14)
$3\omega_2$	$\frac{1}{4} a_3 A_2^3$	(15)
$2\omega_1 \pm \omega_2$	$\frac{3}{4} a_3 A_2 A_1^2$	(16)
$2\omega_2 \pm \omega_1$	$\frac{3}{4} a_3 A_1^2 A_2$	(17)

Table 2. Two-Carrier Intermodulation

Intermodulation products are illustrated in Table 3 where: $A_1 = 3.12$ V, $A_2 = 5.143$ V, $f_1 = 105.7$ MHz, $f_2 = 106.5$ MHz, $a_0 = 0.04$, $a_1 = 10.6$, $a_2 = 0.01$, and $a_3 = -0.015$.

	Amplitude V	**Magnitude dBm**	**Frequency MHz**
DC	0.220924245	16.88486759	0
f2-f1	0.1604616	14.10742237	0.8
2f1-f2	-0.563220216	25.0135647	104.9
f1	30.87350104	59.79171762	105.7
f2	51.85896965	64.29647768	106.5

2f2-f1	-0.92841076	29.3548033	107.3
2f1	0.048672	3.745583847	211.4
f1+f2	0.1604616	14.10742237	212.2
2f2	0.132252245	12.42806106	213
3f1	-0.11389248	11.129901	317.1
2f1+f2	-0.563220216	25.0135647	317.9
2f2+f1	-0.92841076	29.3548033	318.7
3f2	-0.510129972	24.15361681	319.5

Table 3. Two-Carrier intermodulation example.

Figure 2 shows the frequency distribution of intermodulation products generated in the example.

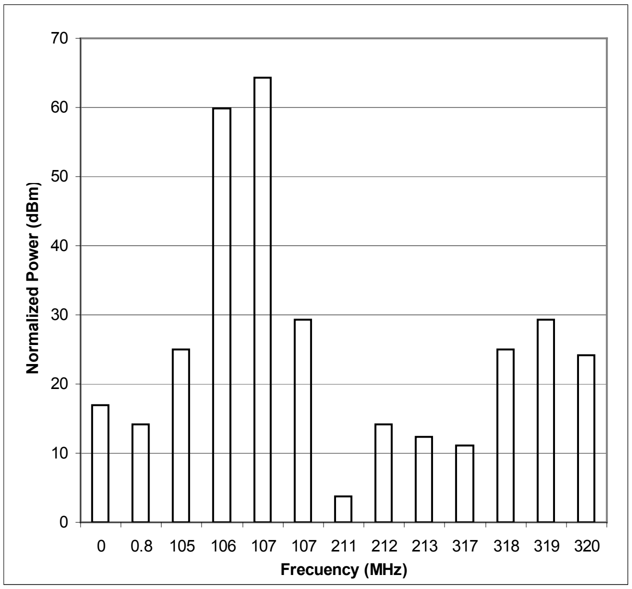

Fig. 2 Spectral distribution of Two-Carrier intermodulation example.

3 N-Carrier Intermodulation

It is clear that generation of intermodulation products for N-carrier systems is quite difficult, see (18). Many analytical procedures where this problem can be explored are shown in [1] and [6].

$$x(t)=\sum_{i=1}^{N}\{A_i\cos(\omega_i t)\} \tag{18}$$

The final expressions for N-carrier systems may be obtained substituting equation (18) in equation (2). But that procedure are not solved in general case, some results are presented in [5]. In this work, it is presented the architecture shown in Figure 3, where $s_i(t)$ signals represent each carrier at the amplifier input.

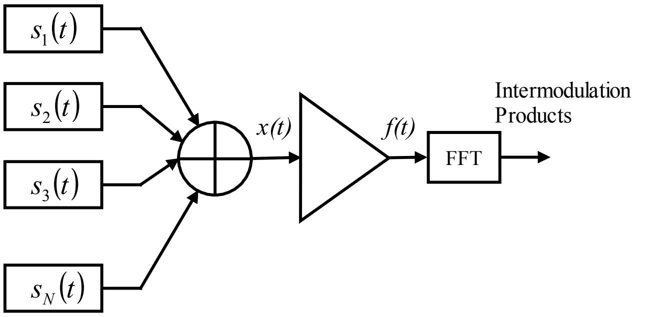

Fig. 3 Frequency domain structure to intermodulation analysis.

In that architecture, discrete Fourier transform is employed to keep away from analytical solutions. In this way, generation of intermodulation products are determined by *f(t)* spectra.

In Figure 4, Linear amplitude of intermodulation products is given, where frequency separation of two carriers was increased.

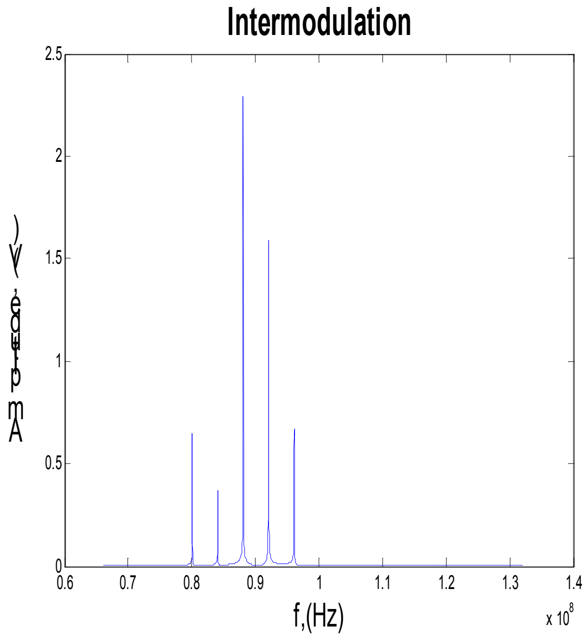

Fig. 4 Frequency domain structure to intermodulation analysis.

Discrete Fourier Transform shows an special problem for this algorithm, one frequency tone can not be calculated, if its frequency is not an integer. But in practical systems, frequency separation of multiple carriers in a FDMA scheme is regular [3] [4]. This feature can be used, because it is possible to employ this algorithm with a normalized carrier frequency, where this normalization produces always integers carrier frequencies.

4 Results

Intermodulation products for Two-Carrier systems is illustrated in Figure 5, where proposed algorithm was used. It is necessary to emphasize that this picture shows a difference in relation with Figure 2, where there are a limited number of tones. Fourier transform causes this differences.

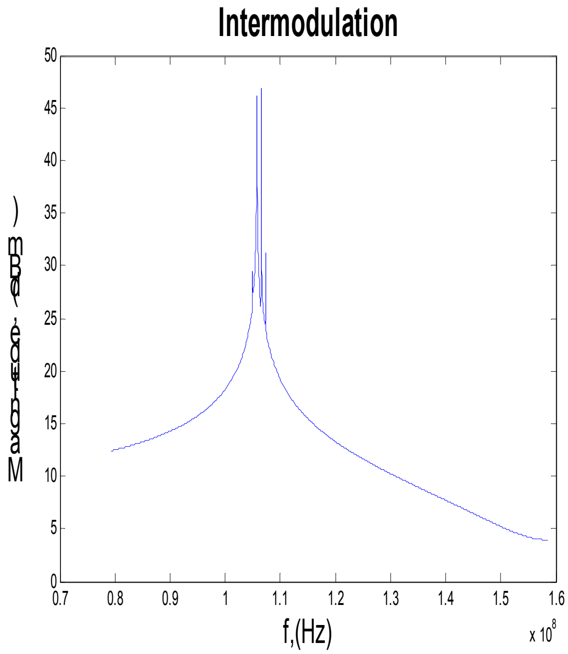

Fig. 5. Two-carrier spectra employed in section three.

Simplifying a FDMA scheme with equal carriers amplitude, the resulting power spectral density is illustrated in Figure 6.

This algorithm can run with non-identical amplitude of FDMA scheme carriers, then it is possible to evaluate directly AM-AM conversion.

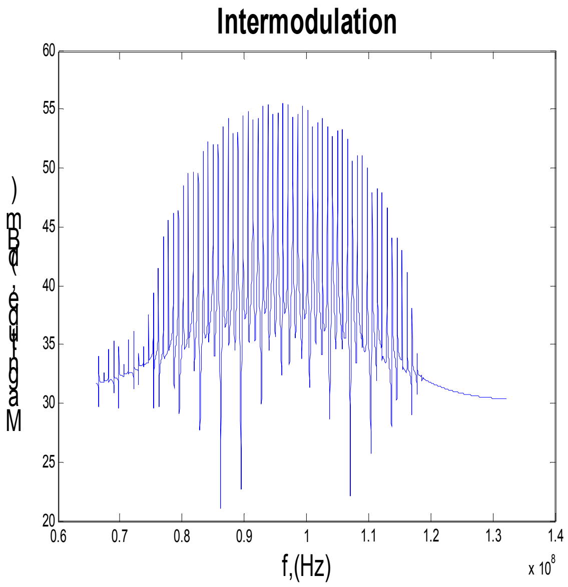

Fig. 6. Intermodulation in a FDMA scheme

In Figure 6 the amplitude of carrier is the same, but the algorithm presented here can be work with arbitrary amplitudes.

5 Conclusions

The frequency domain technique presented in this paper allows to reduce significantly the calculation complexity of intermodulation products in a N-carrier satellite systems.

There some advantages in this technique, the number of carriers can be very large, the amplitude of each carrier may be different, frequency separation could be arbitrary.

It is easy to use this algorithm for practical systems, because employing the well-known least-square method, an input-output table it is possible to obtain a_i polynomial coefficients.

One additional application of the algorithm presented is the calculation of up-link and down-link back-off, for near saturation HPA operating point, where CDMA system are important [5].

Harmonic generation is less aggressive than intermodulation, because the harmonics frequency are higher than the original carrier.

References:

[1] Shimbo O., “Effects of intermodulation AM/PM conversion and additive noise in multicarrier

TWT systems". *Proceedings of the IEEE*, February 1971.

[2] Ha T., "*Digital Satellite Communication Systems*", Mc-Graw-Hill 1990.

[3] "*Satellite Handbook*", ITU, Grenoble 2003.

[4] Pratt T., Bostian C., Allnut J., "Satellite Communications", Wiley 2003.

[5] Reyes-Ayala M., Andrade-González E. A., Roa-Franco J., "QPSK and BPSK Synchronous Sequence DS-CDMA Satellite Links", *8th WSEAS Int. Conf. On Communications*, Athens, Greece, July 2004.

[6] Wescott, R. J., "Investigation of Multiple FM/FDM Carriers through a Satellite TWT Operating near to Saturation," *Proceedings of the IEE*, Vol. 114, No. 6, June 1967, pp. 726-740.

[7] International Telecommunication Union, "Handbook on Satellite Communications", John Wiley & Sons, Third Edition, Suiza 2002.

[8] Saleh A. A. H., "Intermodulation Analysis of FDMA Systems Employing Compensated and Uncompensated TWT's," *IEEE Transactions on Communications*, Vol. COM-30, No. 5, May 1982, pp. 1233-1242.

[9] G. R. Stette. "Calculation of Intermodulation from a Single Carrier Amplitude Characteristics," *IEEE Transactions Communications*, Vol. COM-22, No. 3, Mar. 1974, pp. 319-323.