Non-Linear Magnitude Response for Synchronous Sequence DS-CDMA Satellite Links

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Abstract: - DS-CDMA is one of the most practical techniques in satellite spread spectrum multiple access schemes. This paper shows an algorithm to calculate synchronous DS-CDMA satellite links with non-linear response amplifiers, where the probability error, active device parameters, and back-off compensation, are used to evaluate the performance.

Key-words: - Spread spectrum, CDMA, link budget, direct sequence, non-linear response.

1 Introduction

A digital satellite communication system has many earth stations and satellites sharing transmission media. That system must have a multiple access scheme.

In this paper, we analyze a digital satellite communication system where spread spectrum is used to increase the number of simultaneous users. Each user has a unique pseudorandom (PN) sequence to code the communication origin.

The architecture employed to obtain pseudo-random sequences is named PN sequence generator, and the features of the most important configurations are shown in [10]. The PN sequence generator gives us orthogonal sequences with mutual zero cross-correlation functions. The number of simultaneous users in the transmission media depends of the set size in a particular PN generator.

Unfortunately, the spread spectrum techniques improve their performance as a consequence of high power operation in satellite HPA. Due to this, harmonic and intermodulation products generation are analyzed in this article.

As a consequence of spreading original bandwidth with a secret PN sequence, CDMA encrypts the source signal and narrows down the effects of multi-path, see Figure 1. These two advantages enhance the CDMA features in comparison with other multiple access schemes.

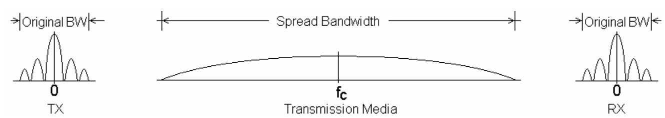

Fig. 1 Spread Spectrum

The multi-path effects reduction is increased if the spread bandwidth to original bandwidth ratio is also improved. In this article, we use the processing gain to handle the bandwidth ratio.

There is a drawback in CDMA implementation, it is necessary to employ near saturation amplifiers, because power efficiency is critical in these systems. Thus, non-linear behavior has a relevant importance in high power stages.

2 Synchronous Sequence CDMA

Although there are two main techniques to obtain spread spectrum as a multiple access scheme: frequency hopping and direct sequence; direct sequence is the only CDMA technique used in satellite communication systems. In this work we did not use frequency hopping CDMA.

The cross–correlation value determines the signal to interference ratio degradation, it can be calculated, with (1) [10].

$$R_{1m} = \sum_{j=1}^{N} p_j^{(1)} p_j^{(m)} \qquad (1)$$

Where R_{1m} is the cross-correlation value of sequences $\{p_j^{(1)}\}$ and $\{p_j^{(1)}\}$.
There are many filter options in pseudorandom sequence generation, the Gold, Bent and Kasami configurations and their variations. The advantages and disadvantages in linear synchronous sequence DS-CDMA satellite links are analyzed in [10].

In practical systems, set size is specially important, because implies the maximum number of simultaneous users.

The maximum number of simultaneous users in transmission media depends on size set of an specific shift-register configuration. The cross-correlation function of PN sequences implies the size of PN sequences set. The common shift-register configuration, allows a fast code synchronization [8].

3 Digital Link Budget

The Digital Link Budget gives the power requirements and terminal equipment features to get an adequate probability error as a function of the application. The Digital Link Budget is described in detail in [10]. Equation (2) allows to calculate the energy per bit to noise density ratio.

$$\left(\frac{E_b}{N_0}\right)=\frac{R_p}{R_b}\left(\frac{C}{N}\right) \qquad (2)$$

Where (E_b/N_o) is the energy per bit to noise density ratio, R_p is the chip rate, R_b is the bit rate, and (C/N) is the carrier to noise ratio. The main goal of this paper is HPA non-linear behavior, but channel coding modifies equation (2) to reduce error probability. Besides this is not necessary to see that digital modulation determines error probability in a digital channel, and channel coding can be used to reduce power system limitations.

The total carrier to noise ratio is determined by (3).

$$\left(\frac{C}{N}\right)_T^{-1}=\left(\frac{C}{N}\right)_u^{-1}+\left(\frac{C}{N}\right)_d^{-1}+\left(\frac{C}{N}\right)_i^{-1} \qquad (3)$$

Where $(C/N)_T$ is total carrier to noise ratio, $(C/N)_u$ is the uplink carrier to noise ratio, $(C/N)_d$ is the downlink carrier to noise ratio, and $(C/N)_i$ is the carrier to intermodulation noise ratio. Note that the total carrier to noise ratio is limited by the lowest carrier to noise ratio, [3] [4]

We can find the individual link carrier to noise ratio, as a result of the combination of power requirements and noise sources. In the uplink, we can use (4), where brackets indicate lineal to dB conversion.

$$\left[\frac{C}{N}\right]_u=\left[EIRP_u\right]-\left[L_{FSU}\right]+\left[\frac{G_u}{T_u}\right]-\left[kB_u\right]-\left[BO_i\right]-\left[L_u\right] \qquad (4)$$

The downlink is determined similarly, see (5):

$$\left[\frac{C}{N}\right]_d=\left[EIRP_d\right]-\left[L_{FSD}\right]+\left[\frac{G_d}{T_d}\right]-\left[kB_d\right]-\left[BO_O\right]-\left[L_d\right] \qquad (5)$$

Where $EIRP$ is Equivalent Isotropic Radiated Power, W; L_{FS} are the free space losses; G/T is the gain to noise temperature ratio of the receiver, K^{-1}; kB is the Boltzmann constant and noise bandwidth product, HzJ/K; L are the additional losses, due to atmosphere, feed, polarization and tracking losses, dB; BO_o is output back off; and BO_i is input back off.

When output back-off and input back-off are zero, the link is denominated linear, but almost always the link behavior is non-linear and it is necessary to calculated the output-input response.

EIRP is the radiated power by transmitting antenna in the receiver path, where a real antenna has an arbitrary gain. Then, input and output back-offs are varying, because it is important to preserve linear operation. If we do not compensate received power deviations, the spurious radiation is quite high, including harmonics and intermodulation products. Additionally, AM-AM and AM-PM conversions are the most important impairments in satellite communications systems.

One of the most widely used active devices for High-Power Amplifiers (HPA) is the Traveling Wave Tube (TWT). The RF input signal to be amplified travels down a helix structure, where electrons emitted from the cathode are focused. As a result, the RF output signal is amplified. But it is necessary to emphasize that the TWT amplifier response is non-linear.

4 Amplifier Non-Linear Response

The amplifiers have a non-linear response if the input power level is high and it is possible to employ a polynomial model, in the output level prediction.

In Figure 2 is illustrated the Satellite Amplifier Response, where:

[$EIRP_R$]	Real uplink EIRP, dBW.
[$EIRP_S$]	EIRP for HPA saturation , dBW.
[$EIRP_{R,S}$]	Real Output EIRP, dBW.
[$EIRP_{S,S}$]	Output EIRP in saturation, dBW.
EIRP	Equivalent Isotropic Radiated Power

The [$EIRP_S$] is designed to saturate the satellite HPA in normal conditions, but the real uplink EIRP is normally lower, see Figure 2.

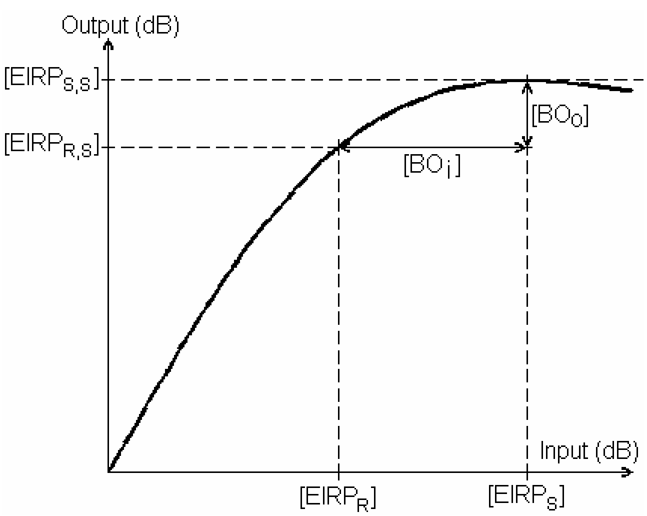

Fig. 2 TWTA Non-Linear Magnitude Response

In practice the HPA operating point, does not only depend on input level, in addition to this link losses may cause a new input-output conditions.

$$[BO_i] = [EIRP_R] - [EIRP_S] \tag{6}$$

Where:
[BOi] Input Back-off, dBW.

The input back-off is the uplink compensation needed to saturate satellite HPA. If we want to use a normalized curve of TWT non-linear response, it is necessary to define R_{TWTA}.

$$R_{TWTA} = [EIRP_R]/[EIRP_S] \tag{7}$$

Where:
R_{TWTA} Real to Saturation EIRP Ratio.

It is obvious that response of a particular TWTA may be modified, if its TWT is changed, because each tube has a particular response. The following equations offer a way to obtain a normalized prediction for TWTA non-linear input-output ratio.

$$P = \frac{R_{TWTA}\alpha_p}{\left(1+\beta_p R_{TWTA}{}^2\right)} \tag{8}$$

$$Q = \frac{R_{TWTA}{}^3\alpha_q}{\left(1+\beta_q R_{TWTA}{}^2\right)^2} \tag{9}$$

$$Z = \sqrt{P^2 + Q^2} \tag{10}$$

Where:

α_P	TWT coefficient.
β_P	TWT coefficient.
α_q	TWT coefficient.
β_q	TWT coefficient.
P	In-phase normalized non-linear response.
Q	In-quadrature normalized non-linear response.

$$[EIRP_{R,S}] = [EIRP_{S,S}]Z \tag{11}$$

Where:
Z Magnitude of normalized non-linear response.

It is possible to back with the real non-normalized parameters. Finally, we can obtain the output back-off in the real amplifier, as a consequence of compensating the input power level.

$$[BO_O] = [EIRP_{S,S}] - [EIRP_{R,S}] \tag{12}$$

Where:
[BOo] Output Back-off, dBW.

In this paper, we use three TWT devices to compare the non-linear response in satellite HPA, see Table 2.

TABLE 2.
TWT DEVICES USED IN SIMULATION

	TWT_1	**TWT_2**	**TWT_3**

α_p	1.90947	2.11075	2
β_p	1.07469	2.22764	1
α_q	4.35023	7.33959	0
β_q	2.33525	2.11475	0

The TWT_1 and TWT_2 are commercial tubes, and TWT_3 is an ideal tube, where there is not phase distortion.

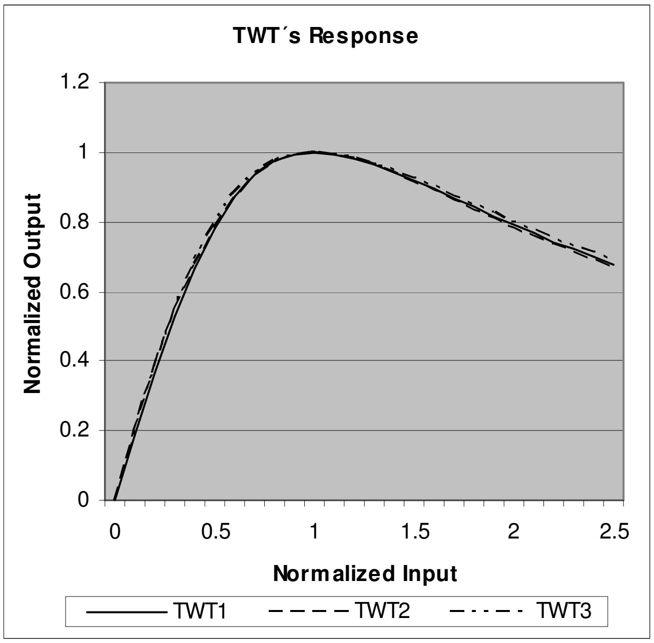

Fig. 3 Normalized TWTA Non-Linear Magnitude Response.

Normally, the TWT works near saturation, because in this operating point we have power optimization. In Figure 3, it is shown three TWT non-linear magnitude responses.

AM-PM conversion is one of the most important problem to solve in digital satellite communications, because phase and frequency modulations are almost always chosen as a consequence of noise level and very high media attenuations.

The autocorrelation coefficient is obtained with ViaSat for following shift-register configurations: Kasami (small and large set), Bent and Gold (normal and odd versions).

5 Results

We used ViaSat to compute the probability of error in a synchronous DS-CDMA, where TWT_2 (see Table 2), was used in carrier amplification.

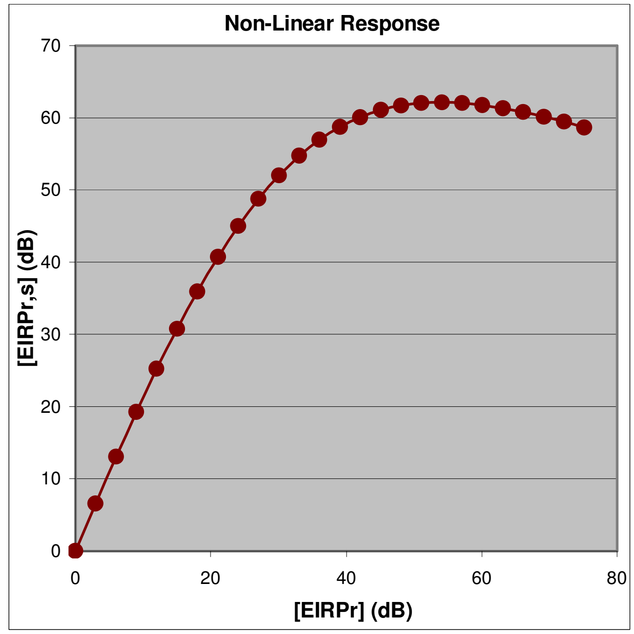

Fig. 4 TWT_2 Non-Linear Magnitude Response.

Phase and quadrature components, magnitude, real satellite output EIRP and output back-off; are illustrated in Table 3, where HPA uses TWT_2.

TABLE 3
LINK BACK-OFF

	EIRPr	BOi	P	Q	Z	EIRPr,s	BOo
1	**0.00**	-54.000	0.0000	0.0000	0.0000	0.000	**62.133**
2	**3.01**	-50.994	0.1060	0.0007	0.1060	6.584	**55.549**
3	**6.01**	-47.987	0.2098	0.0057	0.2099	13.042	**49.091**
4	**9.02**	-44.981	0.3097	0.0179	0.3102	19.271	**42.861**
5	**12.03**	-41.974	0.4037	0.0386	0.4056	25.199	**36.934**
6	**15.03**	-38.968	0.4907	0.0673	0.4953	30.773	**31.359**
7	**18.04**	-35.961	0.5696	0.1021	0.5786	35.952	**26.181**
8	**21.05**	-32.955	0.6398	0.1403	0.6550	40.694	**21.438**
9	**24.05**	-29.948	0.7010	0.1795	0.7237	44.962	**17.170**
10	**27.06**	-26.942	0.7535	0.2175	0.7842	48.727	**13.405**
11	**30.07**	-23.935	0.7975	0.2526	0.8365	51.975	**10.158**
12	**33.07**	-20.929	0.8335	0.2840	0.8805	54.708	**7.424**
13	**36.08**	-17.922	0.8622	0.3110	0.9165	56.947	**5.186**
14	**39.08**	-14.916	0.8842	0.3337	0.9451	58.721	**3.411**

15	**42.09**	-11.909	0.9004	0.3521	0.9668	60.072	**2.061**
16	**45.10**	-8.903	0.9115	0.3667	0.9825	61.043	**1.089**
17	**48.10**	-5.896	0.9181	0.3778	0.9927	61.681	**0.451**
18	**51.11**	-2.890	0.9208	0.3858	0.9984	62.030	**0.102**
19	**54.12**	0.117	0.9203	0.3912	1.0000	62.133	**0.000**
20	**57.12**	3.123	0.9171	0.3944	0.9983	62.026	**0.106**
21	**60.13**	6.130	0.9116	0.3958	0.9938	61.746	**0.387**
22	**63.14**	9.137	0.9042	0.3956	0.9869	61.321	**0.811**
23	**66.14**	12.143	0.8953	0.3942	0.9782	60.779	**1.353**
24	**69.15**	15.150	0.8852	0.3917	0.9680	60.143	**1.989**
25	**72.16**	18.156	0.8741	0.3884	0.9565	59.431	**2.701**
26	**75.16**	21.163	0.8623	0.3844	0.9441	58.661	**3.471**

It is very important to evaluate the output back-off as a real EIRP function, because spurious generation can reduce output signal power. In addition to this, generation of intermodulation products is one of the most important interference sources. In figure 4, output back-off is shown.

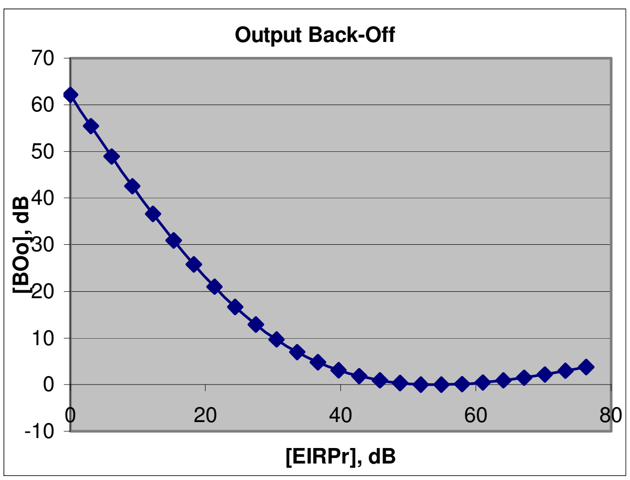

Fig. 4 Output Back-Off using TWT_2

If we analyze an specific satellite link (see Tables 3, 4 and 5), ViaSat software gives several results. Tables 4 and 5, determine this DS-CDMA link budget.

TABLE 4
DS-CDMA UP-LINK EXAMPLE

UP-LINK	
[G/Ts] dB/K	12.9905143
[LFSu] dB	207.27991
[k] dB J/K	-228.601209
[Bu] dBHz	70.7918125
[Lu] dB	4.99587201

TABLE 5
DS-CDMA DOWN-LINK EXAMPLE

DOWN-LINK	
[G/Ts] dB/K	3.85350881
[LFSd] dB	205.824791
[k] dB J/K	-228.601209
[Bd] dBHz	70.7918125
[Ld] dB	5.77512007

Figure 5 shows the total carrier to noise ratio. The best quality is obtained when non-linear effects are minimized, or saturation point is selected in satellite HPA.

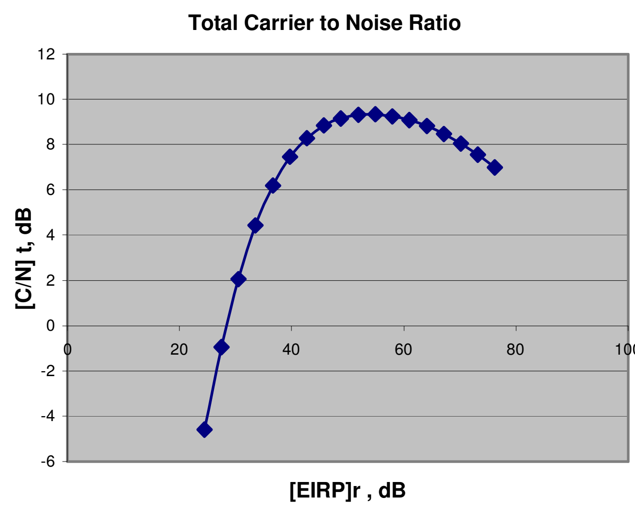

Fig. 5 Analog Link Performance

Figure 6 illustrates the error probability in a DS-CDMA link, where: 50 simultaneous users, 1023 even gold 10-stage PN-sequence length and, a normalized autocorrelation coefficient equal to 6.3538×10^{-2}.

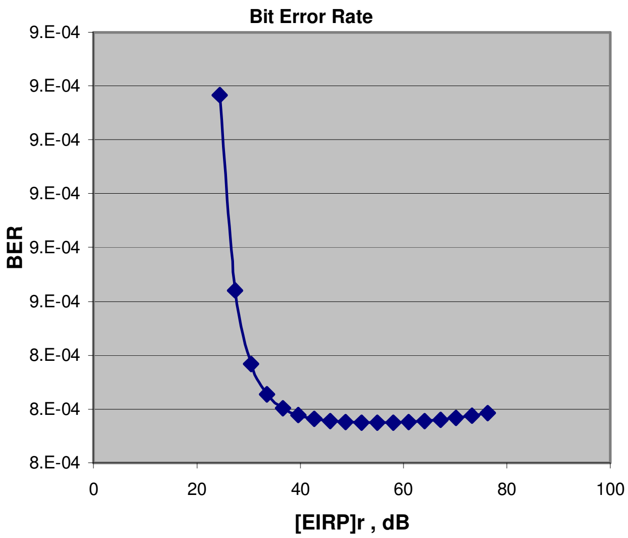

Fig. 6 Digital Link Performance

6 Conclusions

The active devices non-linear behavior may cause several practical impairments, for example: spurious generation, a power efficiency reduction, AM-AM and AM-PM conversions. If we know the active device parameters, it is possible to predict the magnitude satellite HPA non-linear response. Normally, satellite CDMA systems have to use high power transmission signals, because this is the only way to improve its performance. In addition to this, the PN sequence generator determines the number of simultaneous users, and the maximum level of interference in the channel, then the link performance may be reduced consequently.

Link budget was calculated by ViaSat software. ViaSat is a preliminary software to teach digital satellite systems in the Metropolitan Autonomous University, where we enhance its features constantly.

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