Effect of TWTA non-linearity on satellite communication system: a simulation approach

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Abstract

Objective: In order to minimize the system degradation, the main aim is to measure the performance of the HPA by simulation. This has been done with the evaluation of Bit Error Rate because this quantifies the reliability of the entire communication system from 'bits in' to 'bits out' including the electronics, antennas and signal path in between.
Method: A comparative study and analysis of the performance of band limited M-ary PSK signal transmitted through band pass nonlinearity, typically an on-board TWT amplifier in a satellite repeater, exhibiting AM-AM and AM-PM conversions is carried out in terms of BER plots and constellation diagram using TOPSIM simulation tool.
Application: The measurement of performance by simulation will help in tracking down the offending elements and will be useful for implementation in the actual design
Conclusion: It is observed from the BER plots for M-ary PSK modulation system in the presence of TWTA non linearity having different uplink noise and input back off level that the performance of BER drastically goes down. Thus it gives the precaution that should be taken before passing the attenuated signal through high power amplifier.
Keywords: Bit error rate, TWTA, Phase shift keying, high power amplifier.

1. Introduction

In satellite communication, the length of channel is very long. The transmitted signal that is modulated by bandwidth efficient schemes like M-PSK, M-QAM etc. is attenuated up to great extent. So, at the satellite receiver, this attenuated signal is amplified by using power amplifier devices such as TWTA (traveling wave tube amplifier). For getting the maximum gain, this device works at nearly saturation region of its operating point. Hence, it behaves as non-linear device.

This device introduces two types of non-linearity: firstly, as AM to AM conversion and secondly, AM to PM conversion. Both of these non-linear effects can lead to significant signal distortion and system performance impairment. In modern satellite communication, because of the limited availability of bandwidth, the transmitted signal must be severely band limited. The purpose of this study is to evaluate the performance of TWTA non-linearity over M-ary PSK modulation system, as used for transmission over a non-linear channel.

1.1. Existing Models and Formulae for TWTA Simulation

The performance of M-ary PSK system over the non-linear satellite channels was investigated by many authors. In [1] proposed established a formula to evaluate the inter modulation due to non linear characteristic of TWT amplification and amplitude modulation Phase modulation (AM-PM) conversion when many arbitrarily modulated carriers and Gaussian noise are passed through TWT. In [2] proposed obtained exact error probabilities for the BPSK signal transmitted over a non distorting channel with additive Gaussian noise co-channel interference. In [3] proposed examined non linear satellite channels with uplink noise, downlink noise and a signal uplink CW tone interfere with random phase uniformly distributed over the interval. In [4] proposed observed the performance using computer modeling of satellite communication system.

In [5] proposed a model for the semi-analytical performance in digital satellite radio links in the presence of interference on both the uplink and the downlink. In [6] proposed investigated the performance of an M-ary PSK modulation system over the non-linearity satellite channels in the presence of an arbitrary number of interferers and Gaussian noise on the uplink and downlink path. In [7] has proposed a semi analytic procedure for evaluation of BER by simulation of channels, including a memory less band pass nonlinearity, typically an onboard TWT amplifier in satellite repeater, when the noise at the input of such nonlinear element is non negligible. The bit error probabilities were obtained using the Gauss quadrature formula and a two dimensional moment technique. He suggested his method to be used for design of the system to reduce the degradation in the performance of nonlinear satellite channels.

The travelling wave tube (TWT) amplifiers, and power amplifiers exhibit nonlinear distortions in both amplitude (AM-to-AM conversion) and phase (AM-to PM Conversion). Two equivalent frequency-independent band pass models of helix-type TWTA have been used [8] to study the adverse effects of these nonlinearities on various communication systems. These are:

1. The Amplitude-phase model and
2. The Quadrature model

To specify each model, one needs to know two functions – the amplitude and phase functions for the former and the in-phase and quadrature functions for the function involved in the Amplitude-phase and the Quadrature non-linear models of TWTA. In proposed the use of a soft-limiter characteristic to represent the instantaneous amplitude response of a TWT which results in an envelope amplitude functions A (r) that does not fall beyond saturation. He also proposed to represent $\phi(r)$ by a polynomial in r^2, which would require a large number of terms to fit realistic data, as are the case for polynomial representations in general. Suggested a three parameter formula to represent ϕ (r).

Here, A(r) and ϕ (r) are represented by two-parameter formulas

$$A(r) = \alpha_{ə} r / (1 + \beta_{ə} r^2)$$
$$\phi(r) = \alpha_{\varphi} r^2 / (1 + \beta_{\varphi} r^2)$$

For very large r, A(r) is proportional to 1/r, and $\phi(r)$ approaches a constant.

For maximum power output with the highest efficiency the HPA should operate at its saturation points. However, many resources are sensitive and susceptible to AM/AM and AM/PM conversion. With such operating point, inter modulation distortion can take place which may degrade the system performance considerably. In order to minimize the system degradation, the main aim of this study is to measure the performance of the HPA by simulation which helps in tracking down the offending elements and will be useful for implementation in the actual design.

1.2. System description

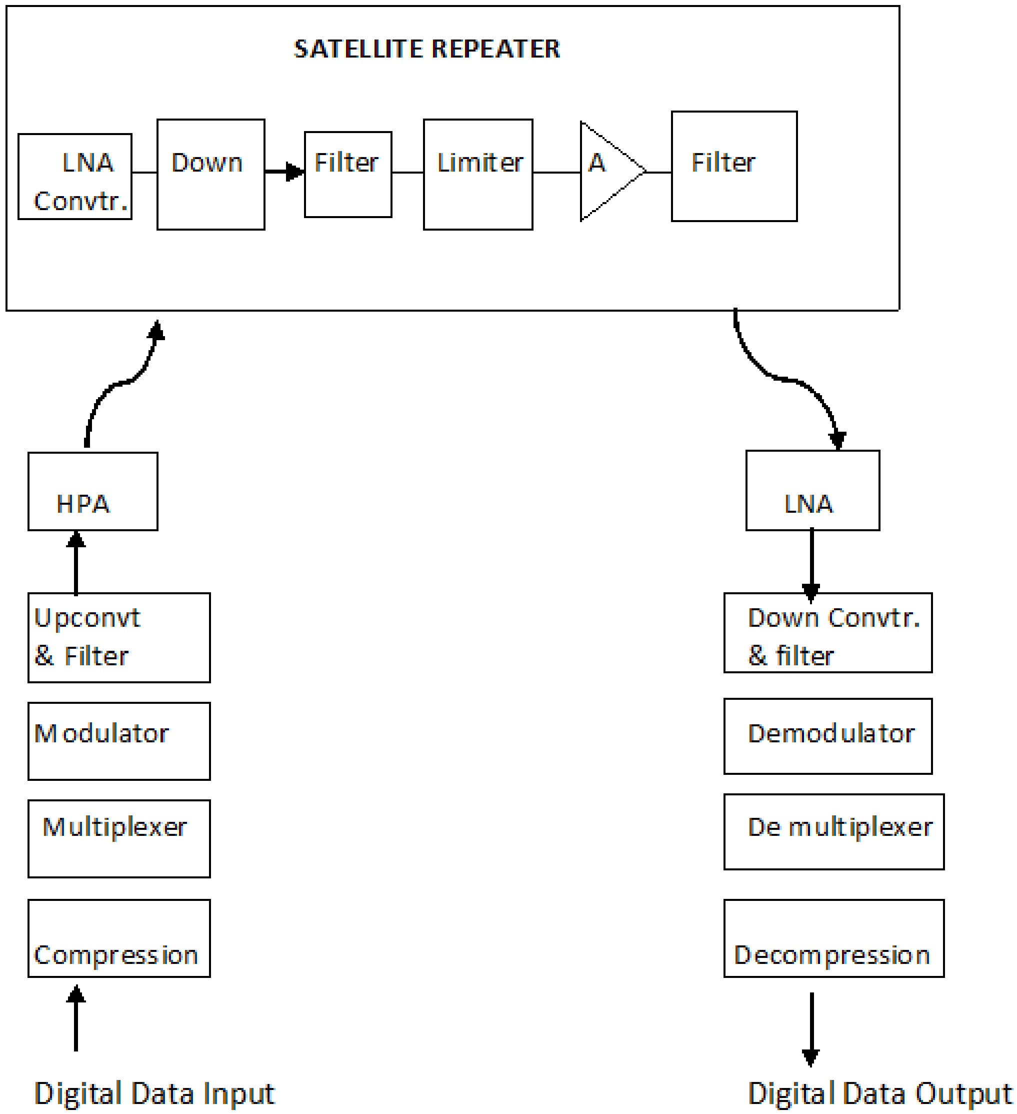
1. Satellite transponder communication link

The satellite communication is not directly point to point communication rather its two link communication system. The unique feature of communication satellites is their ability to simultaneously link all users on the earth's surface thereby, providing distance insensitive point to multi point communications. This capability applies to fixed terminals on earth and to mobile terminals on land, in the air and at sea. Also, with satellites, capacity can be dynamically allocated to users who need it. These features make satellite communication systems unique in design. The satellite can be thought of as a large repeater in space. The on board repeater may contain one or more transponder. The receiving earth station processes the modulated RF carrier down to the base band signal which is sent through the terrestrial network to user. Figure 1 shows the elements of basic satellite link showing earth stations and the satellite transponder.

2. Role of TWTA in satellite communication

The transponder is consisting of low noise amplifier (LNA) and high power amplifier (HPA). TWTA is used as a high power amplifier in satellite communication systems. TWTA's continue to offer the microwave high power amplifier performance in terms of power efficiency, size and cost, but lag behind solid state power amplifier (SSPA's) in linearity. TWTAs have wider operating bandwidth than another type of high power amplifier such as klystron amplifiers and can cover the full 500-MHz bandwidth allocated for satellite communication. The input-output characteristic of a TWTA as high power amplifier in satellite communication system. The TWTA produces maximum output at what is called the saturation point but atsaturation the TWTA is operating in the nonlinear region of its characteristic; the output power is not linearly related to input power. Thus frequencies components appear at the TWTA outputs that were not at the input. Non-linear operation leads to the creation of inter modulation (IM) products and inter modulation distortion. Power characteristics curve of TWTA defines the input and output back off levels in terms of saturation level. For maximum power output with the highest efficiency (eg, to minimize solar panel d.c. supply), this amplifier should be operated at its saturation point. A further increase in the TWTA input power will result in adecrease in the output power).

Figure 1. Elements of basic satellite link showing earth stations and satellite transponder



3. System impairments

The transmitting earth station on the uplink side willcause its share of distortion as will the receiving earthstation of the downlink side. Some of this distortion is uncorrelated, which means that its contribution cans beadded more or less algebraically. However, for this to becorrect, one must know the individual contributions. Other types of distortion, notably group delay, AM/AMand AM/PM interact with one another and independencies no longer assured [9]. Simple link budgeting techniques are available for evaluating links with additive noise; however a communications simulation tool is necessaryfor analyzing related impairments and their interaction

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The most significant impairments are:-
1. Filter gain and phase distortion
2. Thermal noise
3. TWTA AM/AM and AM/PM conversion
4. Pre amplifier and mixer non linear ties
5. Signal fading
6. (f). Radio frequency interference (RFI) from internaland external sources.

2. Description and Methodology

In order to simulate an M-ary PSK modulation having AWGN channel, firstly combine n = log M bits at a time to get symbols. Now these bits are mapped with Gray code. As the Gray code mapped data signal has low bit error probability during the symbol transition at the time of detection. As in this mapped data there is only one bit transition to its all neighboring symbols. Thus if in decision making algorithm leads to wrong decision then it will produce of only single bit error. This gray code mapped data was converted to decimal and according to this value phase was assigned to each symbol. And subsequently these two quadrate values were multiplied with carrier frequency signal. Two cycles of carrier frequency and three samples of each cycle have been taken. Resulted signal is added with noise having variance corresponding to given SNR. Resulted signals of both I& Q channels are added. This signal is received at receiver and is multiplied with carrier frequency sample. Due to its quadrate nature both I & Q channels becomes separate and then used integrate and dump method as amatched filter. Then decision was taken firstly by deciding the quardature and then calculating the minimum distance from its neighborhood. This gives the index of that corresponding symbol and finally it is converted to its bits and compared by the bits that were transmitted. This gives the number of error in bits that were transmitted. For simulating TWTA, complex domain analysis has been used.
The real part is given by $A \cos(\omega t + \Theta_i)$
Along with this imaginary part is given by $a \sin(\omega t + \Theta_i)$
For each sample instant, the amplitude was calculated by taking the envelope of above two quadrate signals. And using *SALEH* model new amplitude was derived.
Now for phase -------> $A \cos(\omega t + \Theta_i)$ and $A \sin(\omega t + \Theta_i)$ is chosen. These are (x,y), by using these
$\rho = \sqrt{x^2 + y^2}$ is calculated.
Now from *SALEH* model A (ρ) was calculated along with this $\tan\Theta = y/x$ was also calculated.

2.2. Approach to simulation

1. Algorithm for M-ary PSK Modulation System
1. Generation of random number sequence.
2. Gray code mapping.
3. Assigning of phase to each symbol
4. Carrier mixing
5. Addition of I and Q channel
6. Addition of noise depending on given SNR
7. To get I and Q channel multiplication with carrier quadrature signal.
8. Use integrate and Dump (I&D) method and take the decision.

2.3. Algorithm for simulation of TWTA
1. Get the sample value of experimental resulted curve (z_i, r_i)
2. Used LMSE method to find r, b_i, $a\phi$ and $b\phi$
3. Now p-----→ A (ρ) and Ψ (ρ)
4. Use the trigonometric function to get $\cos(wt + \Theta + \Psi)$
5. Rest similarly as simple PSK modulation.

3. Results and Discussions

In this study mixed semi-analytic procedure is adopted for the simulation of the noise components whereas the evaluation of the error probability is performed using analytic expression. In this output process is decomposed into signal component plus an additional term representing an equivalent noise component. On that basis, an equivalent nonlinear transformation relating the input signal useful signal to the output signal component is derived.

The noise simulation is used to estimate some of the parameters used by the analytic expression. In this case there is an advantage with respect to the error counting procedures because the entire available statistics, the signal and noise components before the decision are used. Using MATLAB, results of BER plots for M-ary PSK modulation system (M=2,4,8,16) have been plotted and it was observed BER performance decreases as the value of M increases. On the other hand getting more in terms of bandwidth. For simple PSK modulation system BER performance o fhigher M is also acceptable, but as observed from results that in presence of high power amplifier as like TWTA's nonlinearity, performance goes down drastically; low value of M has to be adopted. Here, the work has been carried out for M=4. Further using TOPSIM SIMULATION, BER plots for M =4 PSK modulation system in the presence of TWTA non linearity having different uplink noise (SNR=11dB, 100dB) and input back off level (Ibo = 0dB, -5dB) have been obtained and it has been observed from the results that as on operating atIbo 0 dB = level the performance is worse even the uplink SNR is assumed to be 100 dB. Therefore from the characteristics it's obvious that if the operating point Ibo is 0dB then only the phase shift wills be maximum, hence the probability of error will be maximum, that the performance of BER drastically goes down in presence of TWTA.

4. Conclusion

The bit error rate for the bandwidth efficient schemes is very important from the point of view of digital satellite communication. As observed from the results, the BER performance goes down with the increasing M. On the other hand getting more in terms of bandwidth. So trade off approach has been made. For simple PSK modulation system BER performance of higher M is also acceptable, but as observed from results that in presence of HPA as like TWTA's nonlinearity, performance goes down drastically so the work has been carried out for low value of M. The simulation indicates that the input to nonlinear device should be appropriate according to its Input Back off level (IBo). As observed from the results that as on operating at 0 dB Ibo level the performance is worse even the uplink SNR is assumed to be 100 dB. Thus from the characteristics it's obvious that if the operating point is 0dB IBo then the phase shift will be maximum, hence the probability of error will be maximum. Thus it gives the precaution that should be taken before passing the attenuated signal through high power amplifier (HPA).For BER calculation, conventional error counting method and semi-analytic method has been used as it reduce the simulation time up to a great extent.

5. References

1. O. Shimbo. Effects of intermodulation, AM-PM conversion and additive noise in multicarrier TWT systems. *Proceedings of the lEEE*. 1971; 59(2), 230-238.
2. A. Rosenbaum. Binary PSK error probabilities with multiple co-channel interferences. *IEEE Transactions on Communication Technology*.1970; 18(3), 241-253.
3. TC. Huang, JK. Omura, WC. Lindsey. Analysis of co-channel interference and noise. *IEEE Transactions on Communication*. 1981; 29, 593-604.
4. LC. Palmer. Computer modeling and simulation of communication satellite channels. *IEEE Journal on Selected Areas in Communications*. 1984; 2(1), 89-102.
5. A. Bernardini, R. Bausani, R. Pattuelli. Semi-Analytical performance evaluation in satellite digital links in the presence of interference. *IEEE Transactions on Communications*. 1993; 41(7), 1031-1035.
6. IK. Hwang, L. Kurz. Digital data transmission over nonlinear satellite channels. *IEEE Transactions on Communications*. 1993; 41(11), 1694-1702.
7. M. Pent. Semi analyatic BER evaluation by simulation for noisy nonlinear band passes Channels. *IEEE Journal on Selected Areas in Communications*. 1988; 6, 34-41.
8. AAM. Saleh. Frequency-independent and frequency dependent nonlinear models of TWT amplifiers. *IEEE Transactions on Communications*. 1981; 29(11), 1715-1720.
9. TT. Ha. Digital satellite communications. *MC Graw-Hill*. 1990; 100, 1-641.