MULTI-CARRIER 16QAM OVER A LINEARIZED TWTA

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ABSTRACT

A major concern relating to the transmission of Internet services by means of satellite has been the linearity of available high power amplifiers (HPAs). Traveling wave tube amplifiers (TWTAs) offer the greatest efficient and power capacity, but are somewhat limited in linearity. This paper investigates the use of linearized TWTAs for the transmission of high date rate bandwidth efficient traffic.

INTRODUCTION

The European Telecommunications Standards Institute (ETSI) has produced standards for the transmission of MPEG-2 transport streams over satellites using QPSK modulation (EN 300 421) and Bandwidth Efficient Modulation (BEM) techniques such as 8PSK and 16QAM (EN 301 210) [1,2]. ETSI also provides a mechanism for encapsulating Internet Protocol (IP) datagrams within a digital video broadcast (DVB) waveform (EN 301 192), thereby providing an open framework for delivering Internet services over satellite [3]. A typical DVB signal using QAM modulation requires about 2.0 MHz of RF bandwidth. This means that a standard 36 MHz satellite transponder can accommodate at least twelve such signals arranged in a frequency division multiplexed (FDM) format. Such a format greatly increases throughput and hence revenue. However, the non-linear characteristics of the high power TWTA result in significant impairments of these digital signals, especially for 16QAM. This degradation is to the point where without significant TWTA output power backoff (OPBO), the bit error rate (BER) will exceed the threshold for quality error free (QEF) transmission. This threshold is considered to be a BER less than 10^{-10} for coded data [1].

Power back-off of an HPA reduces efficiency as well as capacity. It results in increased size and weight of satellite ground systems and payloads. This can limit the number of transponders and ultimately reduce potential revenue [4]. There are several options for correcting these impairments and thereby minimizing the amount of OPBO required. These techniques include: correction at the ground transmitter, correction at the ground receiver, correction at the satellite, and correction at both the ground transmitter and the satellite [4,5,6,7].

When correction is done solely at the ground transmitter, the nonlinear characteristics of the satellite transponder need to be taken into account. However, these efforts are complicated by the filtering effects of the intervening medium and by the uncertainties of the transponder non-linearity. This technique, if considered, is better suited for narrow-band signals such as SCPC rather than for wide-band signals.

Correction at the ground receiver is usually done using adaptive techniques [10]. It does not require a priori knowledge of the non-linear mechanism. However, categorical knowledge of the signal is required. The adaptive algorithm uses this knowledge to amplify the desired traits of the signal while attenuating the non-desired traits and hopefully is able to reconstruct a better version of the signal. This technique is once again more suited for narrowband signals.

Correction at the satellite is a compelling solution because the correction is applied nearest to source of the problem. In a satellite link, the greatest non-linearity often occurs at the satellite since power on board the satellite is expensive and hence the satellite has to be operated in a mode that is most power efficient. In such a mode, the TWTAs and SSPAs on board the satellite are operated close to their saturation levels, which means they have highly non-linear transfer characteristics. The correction at the satellite, however, provides only part of the solution. Significant benefit can be obtained by correcting both on the ground and at the satellite [11].

Correction of the non-linearity is usually done by placing the linearization circuit (linearizer) prior to the high power amplifying devices. Modern linearizers work over a wide dynamic range and signal bandwidth. They offer the most practical solution to the problem of amplifier non-linearity [7,8,9].

Predistortion (PD) linearizers are favored for microwave and satellite applications because of their wide band performance, and ability to function as stand alone units. The PD generates transfer characteristics, which are the opposite of the power amplifier's in both magnitude and phase. The gain increase of the linearizer cancels the amplifier's gain decrease. Likewise, the phase change of the linearizer cancels the phase change of the amplifier. The desired result is the *ideal limiter* transfer characteristic of Figure 1. This is the best PD can do. PD can provide large benefits, especially as output power is reduced from saturation [7].

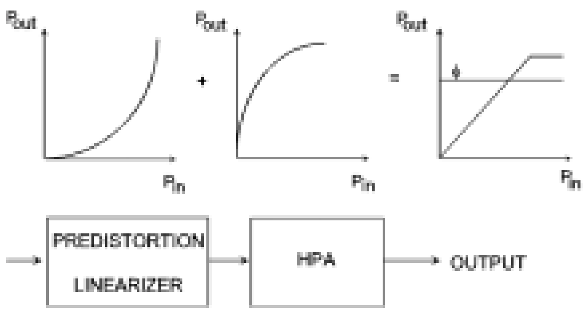

Figure 1. Predistortion linearization attempts to create an ideal limiter transfer characteristic

Current satellite systems are being increasingly used for multi-carrier traffic under a fairly non-linear mode of operation. The usual practice for studying such situations is to model the multiple signals in a nonlinear medium as noise, measured using the noise power ratio (NPR) as the metric. This reduces the problem to a signal to noise (S/N) problem. Such an approach is suitable for quick spreadsheet type calculation, but it is not clear whether it properly quantifies the effects of the distortion. In digital systems, the most important metric is the BER, which is governed by a number of factors, NPR being only one of them, albeit a very important one. Other factors include the distortions of the signal constellation, the modulation, the type of coding used, the number of signals in the group, the correlations between signals, the bandwidth of the transponder, the type of non-linearity and the linearization used, and perhaps other unknown phenomena. Computer simulations are extremely useful in studying how BER depends on these various factors, but due to the assumptions and idealizations that must be made, the accuracy of the results is unknown unless validated by hardware measurements.

Some work has been done showing the effectiveness of predistortion linearization in improving the BER of single carrier QPSK digital transmissions. These earlier studies show that a 2 to 3 dB increase in output power can be achieved with linearization of the ground and satellite amplifiers [9]. However, the effect of coding was not considered, nor was multi-carrier operation and the use of BEM as QAM investigated. It is with these considerations in mind that a hardware test platform was set up to investigate the performance of various classes of signals passing through different types of communication channels, linear and nonlinear. In this paper, the performance of a PD linearizer for a very important class of signals is reported. This class consists of a number of 16-QAM signals that are packed into the bandwidth of a standard satellite transponder using an FDM scheme. Measurements taken to date indicate that the addition of a predistortion linearizer to a TWTA results in a substantial improvement in BER.

SOFTWARE AND HARDWARE DESCRIPTION

The performance of multiple QAM signals through a nonlinear device has been studied using software and hardware simulations. In the computer simulation thirteen 16QAM signals were FDM combined and sent through a linearized TWTA whose operating point was set at a certain desired backoff from saturation. Typical TWTA transfer characteristics (AM/AM and AM/PM) were used. The output of the TWTA was received, demodulated and the errors were counted. In order to speed the computation of errors, the QAM signal was left uncoded. The QAM signal had a square-root raised cosine pulse shape and was demodulated using a matched filter. The individual QAM signals were separated from each other using a guard band that was 25% of the signal bandwidth. The results of the software simulation were recorded and later compared with the hardware measurements.

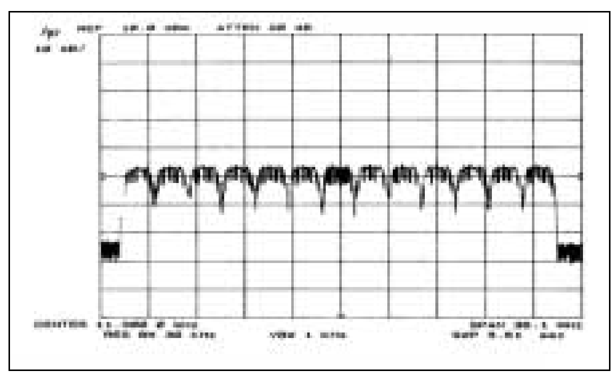

Figure 2. Thirteen 16QAM Test Signal

In the hardware simulation thirteen 16QAM signals were also generated. One of these is the main QAM signal under test and the remaining twelve signals are there to simulate the multi-carrier environment. The QAM test signal was placed in the center of the channel with six QAM signals below and the six

QAM signals above. Each QAM signal had a 2.0 Msps (16 Mbits/sec) data rate and was shaped with a square-root-raised-cosine filter with an alpha of 0.35. The signals were separated by a 0.5 MHz guard-band. The composite signal is shown in Figure 2.

A DVB2080 and a DVB2063 were used respectively to modulate and demodulator the test signal. The DVB2080 was used to generate DVB compliant MPEG frames with a rate 3/4 Convolutional code wrapped around a 188/204 shortened Reed-Solomon inner-code. The DVB2080 also modulated the encoded data into the 16QAM constellation, performed the square-root-raised-cosine pulse shaping and translated the resulting signal to L-band from which it was upconverted to Ku-band for linearization and amplification by the TWTA. The DVB2063 performed the inverse of the above functions, recovering the original data and counting the symbol errors on the coded and uncoded data.

Figure 3 shows the transfer characteristics of the TWTA and linearized TWTA. The linearizer moves the 1 dB compression point from about 10 dB input level from saturation to only 2 dB from saturation. Similarly the linearizer deduces the phase change of the TWTA from more than 30 to less than 5 degrees.

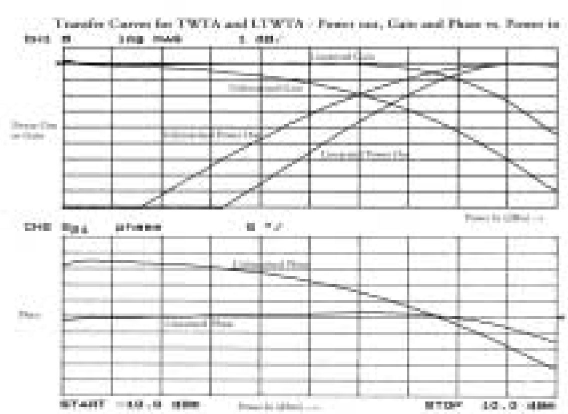

Figure 3. Linearized TWTA Transfer Response

RESULTS

Initially, a verification of the test setup and the signal levels must be made in order to ensure the validity of the results. This was done by replacing the twelve 16QAM signals by a gaussian noise signal and evaluating its BER versus Eb/No performance. If a linear channel is used in place of the TWTA, the resulting curve should be close to the theoretical curve thereby assuring that all parts of the test setup are performing correctly. After this verification was completed, the twelve 16QAM signals were reinstated and the RF signal was observed on a spectrum analyzer. By varying the input drive into the TWTA, a functional relationship between the OPBO of the TWTA versus symbol error rate (of the coded and uncoded) data was obtained. This is shown in Figures 4, 5, and 6.

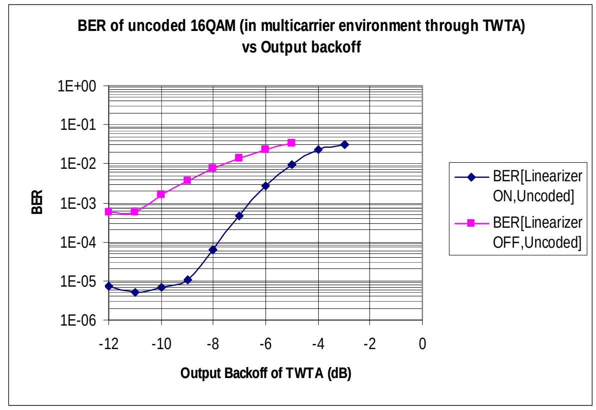

Figure 4. BER of Uncoded Data

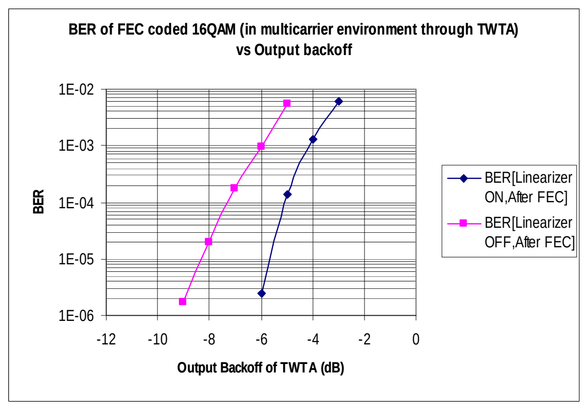

Figure 5. BER of Rate 3/4 convolutional FEC Data

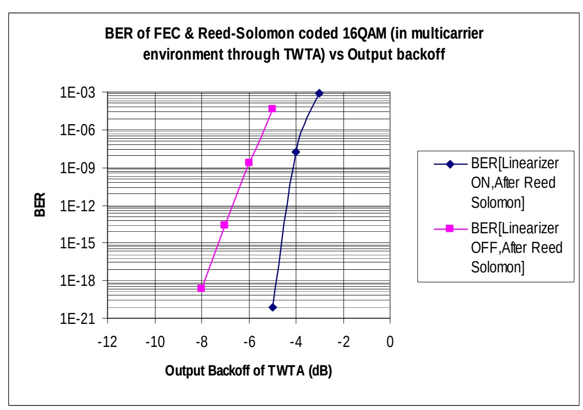

Figure 6. BER of FEC + RS Coded data

The performance of linearized and unlinearized TWTAs are superimposed on both curves. The uncoded data's curve exhibits two properties. As the signal passing through the TWTA approaches saturation, the BER increases due to the increasing presence of intermodulation distortion from the other QAM signals. As the signal is backed off, it reaches a point of optimal performance where the BER is minimized. Then, as the signal is backed off further, the noise figure of the system begins to dominate, and the BER once again starts to pick up. The BER of the coded data shows that dramatic coding gains are obtained by the concatenated coding scheme. QEF performance can be obtained at output backoffs of 4.5 dB for the linearized TWTA, whereas for the unlinearized TWTA a similar performance requires atleast 6.5 dB of backoff. More improvement (~3 dB) can be obtained at lower BER (10^{-20}) by using the linearizer. These values agree closely with those obtained from the computer simulation.

CONCLUSION

The improvement in performance of the linearized TWTA over its non-linearized counterpart has been quantified using hardware and software simulations. This comparison is done using BER as the metric. It is seen that an improvement of more than 2 dB can be obtained for coded data from the linearized TWTA for QEF bit error rates.

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