Performance Evaluation of Noisy Nonlinear QAM and QPSK Systems in the Presence of the Signal Predistortion Linearizer

Pedram Hajipour, Ali Forotanpour, Leila Mohammadi

Abstract— ***in this paper, the design and simulation process of a TWTA amplifier which is linearized with a signal predistortion method is presented. The aim of the linearizer circuit which is based on the schottky diodes is to compensation-linearity behavior of the amplifier in a noisy channel. The linearizer circuit is optimized to give the best AM-to-AM and AM-to-PM characteristics. In addition, the stability of the TWTA with combination of the proposed linearizer is investigated through computer simulations. The data is modulated by a 4-QAM and QPSK modulator, separately and is applied to the linearized TWTA.The received data after passing through the linearized TWTA is analyzed by using advanced design system (ADS) and the constellation and eye diagrams are obtained. Finally the BER performance of the system is evaluated using Monte Carlo estimation for three different values of input-back-off (IBO). It is also shown that decreasing the IBO degrades the performance. The results of the modulations are compared with together.***

Index Terms—TWTA, Predistortion, QAM, QPSK, BER

I. INTRODUCTION

With growth of satellite communication systems, evaluation of the elements in the satellite systems is becoming an important task for system designers. One of the devices which used in all satellite transponders is Traveling Wave Tube Amplifier (TWTA).The main problem with high power TWTAs is the nonlinearity behavior of these devices which results in, amplitude (AM-to-AM) and phase (AM-to-PM) distortion in the system. This nonlinearity behavior causes adverse effects on the system performances such as bit error rate (BER) and constellation diagram. To compensate these nonlinear behaviors, analogue linearizers such as feedback, feed forward and signal predistortion techniques [1-2] and digital linearizers [4], [5] have been introduced in literature. Feedback and feed forward techniques have several problems such as large size, high complexity of the system and high DC power consumption in satellite transponder. In contrast, signal predistortion technique has a simple circuit and ease of implementation, which makes it appropriate and applicable in satellite transponders [4].

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The analog predistorter has been used to eliminate the amplifier nonlinearity. These predistorters have used of the baseband circuit components to modify the shape of the transmitted signal pulse [6-7].Also, a K-band predistortion using reflective schottky diode has been used to improve the nonlinearity behavior of the TWTAs [8].

In this paper, we study the performance of system that uses the linearized TWTA.The TWTA is linearized by a signal predistortion technique in Ku band that use anti parallel schottky diodes. The proposed signal predistortion techniques have optimized and 7^{o} phase distortion and 2dB gain comparison saturation has obtained. First we simulate AM/AM and AM/PM benchmarks and compare linearized and no linearized TWTA.Then4-QAM and QPSK modula tions are applied to the system in Ku-Band to evaluate BER values versus Es/N0.

A. Model Description

Consider a Digital transmission system including 4-QAM/ QPSK modulator and demodulator, along with the nonlinear TWT amplifier. We proposed to configure a signal predistortion linearizer for the TWT amplifier to improve the nonlinearity characteristic of the proposed digital transmission system. First the Linearizer model is presented and then the stability of the TWTA is investigated in the presence of the linearizer. Finally the QAM/QPSK transmission system is presented.

B. Predistortion Linearizer Model

Predistortion linearizer uses a nonlinear behavior to componsanate nonlinear behavior of the TWT amplifier. The reflection of the dynamic conductance form anti parallel schottky diodes [8] is used to design the predistortion linearizer at Ku band. The schematic of such linearizer is shown inFig. 1. The anti-parallel schottky diodes with dynamic conductance are used in the predistortion linearizer. The 3dB coupler divides input signal into the second and third terminals. Output impedance at the second and third terminals is depended on the input power. Therefore, the reflected power at forth terminal and input power has not linear relevance. So the predistortion nonlinearity curve will be created. The proposed signal predistortion linearizer parameters are optimized for suitable specification of the linearizer [5], [8].

The stability of the linearized TWTA should also have studied. When we use a signal predistortion linearizer, the amplifier may be unconditionally stable or potentially unstable. This can be estimated using the *K*and delta stability factors. The amplifier will be unconditionally stable if the following conditions satisfy.
Parameters for simulation inserted to Table 1.

Table 1.Parametrs for measuring stability properties

Parameters	Explain
S_{11}, S_{22}, S_{12}, S_{21}	Scattering parameters
K	Stability Factor
Δ	Scattering parameter determinant
M_u	Measurement unit for Scattering parameters

1. Stability Factor should be bigger than one that obtains as follow.

$$K(StabilityFact)=\frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{12}S_{21}|} \quad (1)$$

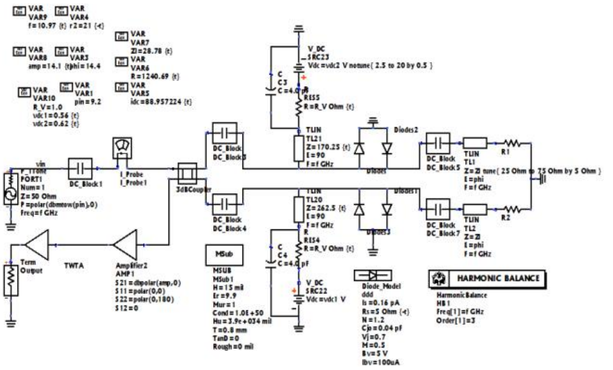

Figure 1.TWTA with Predistortion

2. S-parameter determinant (must be lower than 1unit as:

$$\Delta = S_{11}.S_{22}-S_{12}.S_{21} \quad (2)$$

3. And M_u (Measurement unit) parameter must be bigger than one as [13]

$$M_u=\frac{1-|S_{11}|^2}{|S_{22}-S_{11}^{*}.\Delta|+|S_{12}.S_{21}|} \quad (3)$$

II. QAM TRANSMISSION SYSTEM

The block diagram of a 4-QAM/QPSK transmission system is shown in Figure 2.The bit stream produced by data generator get into the 4-QAM/QPSK modulator. Before modulator the rise cosine filters are used to shape bit stream. After modulator, the modulated data cross through the RF module. The RF block contains a mixer for up-converting to the Ku-band, signal predistortion with combination of TWTA and a mixer for down-converting. The amplified signal after demodulation detect by a TK-constellation. The constellation and eye diagram represent the performance of the detected signal. The MonteCalro estimator is employed to predict BER performance for different value of Es/N0 and IBO as the results are presented in the next section [10].

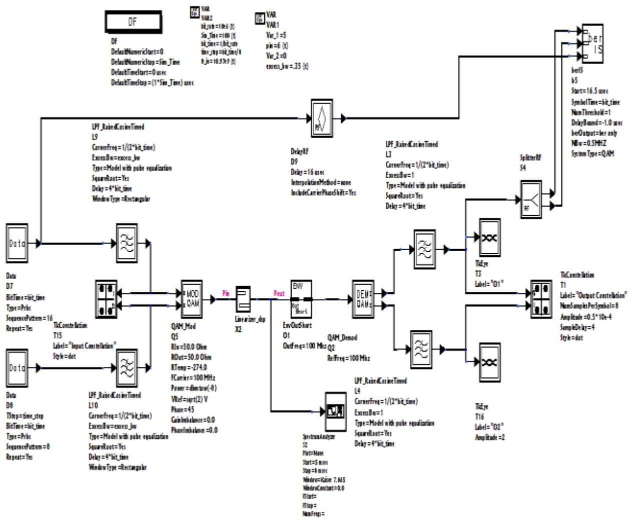

Figure 2.TWTA with Predistortion in QAM system

III. SIMULATION RESULTS

The effect of the signal predistorter for amplitude and phase distortion recovery is shown as AM-to-AM and AM-PM characteristics for linearized and no linearized TWTA, presented in Figures 3 and 4. As can be seen the amplitude distortion is improved in the presence of the schottky diode linearizer. The results show 2 dB gain comparison saturation while its value for no linearized TWTA is 7.1 dB in Ku-band. The linearity characteristics are improved by tuning of the linearizer parameter such as biasing circuit and micro strip transmission lines.
Figure 4 represents AM-to-PM characteristic of the linearized and no linearized TWTA. In the case of the no linearized TWTA the phase distortion is 3.5 Deg/dB while it is improved to 1.5 Deg/dB by using the signal predistortion linearizer.

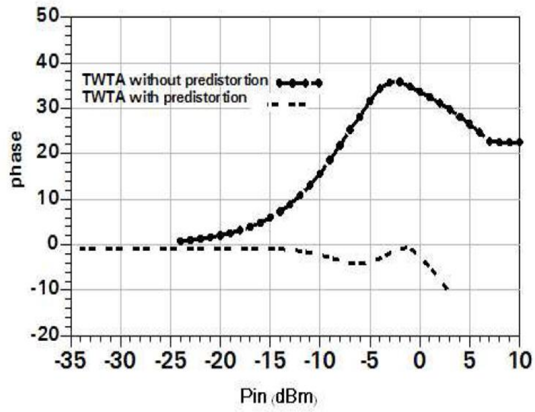

Figure 3.AM to AM characteristic for TWTA with Predistortion

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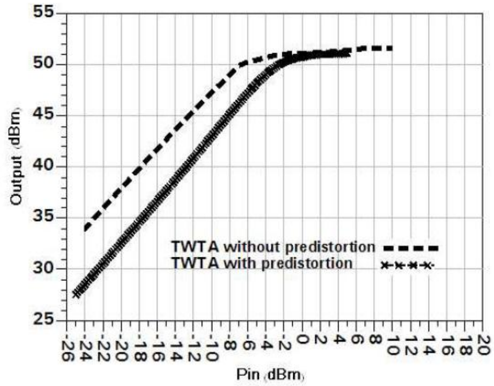

Figure 4.AM to PM characteristic for TWTA with Predistortion

We have used two-tone signals with equal power as input source and have applied the harmonic balance simulation to see how the intermodulation noise appears in the output. Each input tone has power of 6 dB less than TWTA saturation point that means 3 dB IBO .As can be seen in Figure 5; the 3rd order intermodulation noise power generated by linearized TWTA is about 13 dB less than each output tone power. So the spread spectrum provided by linearization of a TWTA will be reduced. As mentioned in the last section, the stability of the amplifier may be degraded in the presence of the predistortion linearizer. The stability conditions have been introduced in the last section. The first and second conditions are mandatory for the stability while the third condition is sufficient [7]. First we plot the in stability region in Smith chart. As seen in Figure 6 the input and output stability circles of TWTA with combination of signal predistortion linearizer is located out of the Smith chart which indicates the unconditional stability. Three defined parameter above is obtained as function of frequency and plotted in Figure 7. It is seen that the value of the K and M_u parameters are more than one and the value of the delta parameter is less than one that show satisfying all conditions by applying the predistiortion linearlizer.

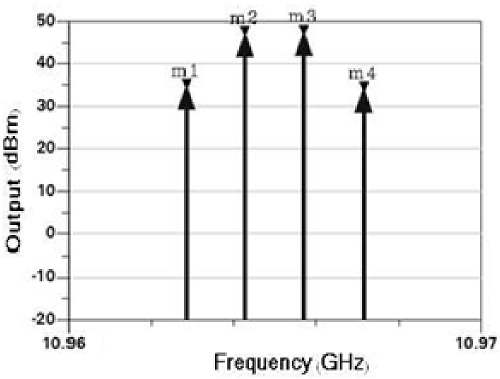

Figure 5.3rd harmonic amplitude in simulation versus main harmonic

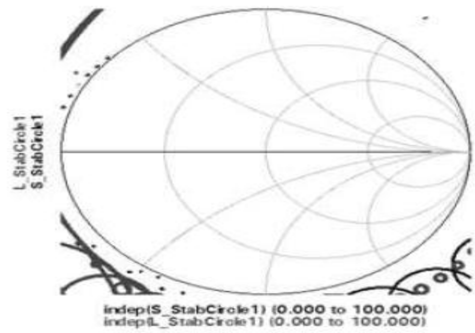

Figure 6.stability of performance in smith-chart

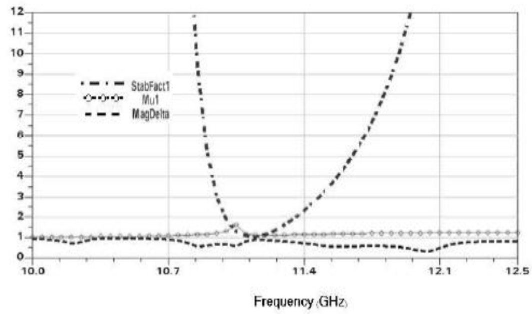

Figure 7.TWTA stability

The performance analysis of the QAM/QPSK digital transmission systems has been performed. The parameters used in the simulation are listed in Table 2. The effect of the nonlinearity behavior of the linearized TWTA on the 4-QAM and QPSK modulated signals are shown in Figure 9 and Figure 10, respectively. The power of input signal is 3 dB less than saturation point (3 dB IBO).The nonlinearity effect causes phase and amplitude distortion results in circulating the constellation diagram and expansion of symbol amplitude, respectively. The output of the TWTA is demodulated through a 4-QAM and QPSK demodulator, and in phase and quadrature components is separated to detect the received signal. The eye diagram pattern for the 4-QAM and QPSK modulated signals are shown in Figure 10 and 11. As seen, the signal predistortion can decrease the eye closing. As is clear in the figures, the constellations diagram circulation when using 4-QAM modulator is less than the QPSK one. Also the eye diagram is closer when QPSK modulator uses.

The value of BER for these modulations calculated by using Monte Carlo estimation. It is obtained for three different values of IBO and is plotted as function of Es/N0 as shown in Figure 12 and 13. These results indicate that increasing IBO decreases BER for a specified value of Es/N0.By comparing the BER results of the 4-QAM and QPSK modulator one that can be find out is that the BER value of the 4-QAM modulator is better than QPSK modulator. This can be finding from following relations as:

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Table 2.RF and 4-QAM/QPSK modulated signal properties and parameters [11-12]

System Parameters	Modulation &Demodulation
p_{QAM}	Probability of Quadrature Amplitude Modulation
p_{QPSK}	Probability of Quadrature Phase Shift Keying
γ_S	Energy per symbol
M	Order of Modulation
$F_{Carrier}$(MHZ)	100
TWTA saturation point (dBm)	0
reference phase(deg)	0
Bit Rate (Mbps)	10
RF Frequency (GHz)	10.97
Modulation	4-QAM/QPSK

$$P_{QAM} = 4Q\left(\sqrt{\frac{3.\gamma_S}{M-1}}\right) \quad (4)$$

$$P_{QPSK} = 2Q\left(\sqrt{2.\gamma_S}.Sin(\pi / M)\right) \quad (5)$$

As we know is modulation order. For comparison between two equations, we divided two 4-QAM/QPSK different arguments and this ratio called R_Q which it has amount less 1. This can be finding from following relation as:

$$R_Q = \frac{\frac{3.\gamma_s}{M-1}}{2.\gamma_s.Sin^2(\pi / M)} \approx \frac{\frac{3}{M-1}}{2.\{1-(1-\frac{4\pi^2}{M^2})\}} \le 1 \quad (6)$$

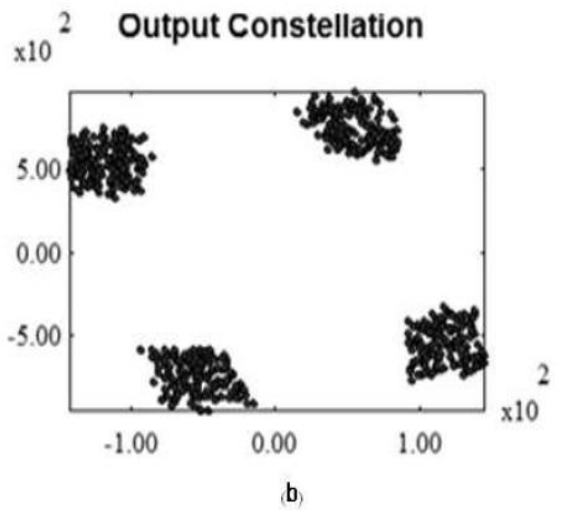

Figure 8. Output Consellation fo 4-QAM modulated data

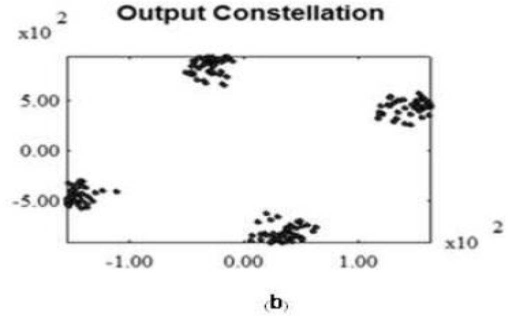

Figure 9. Output Consellation for QPSK modulated data

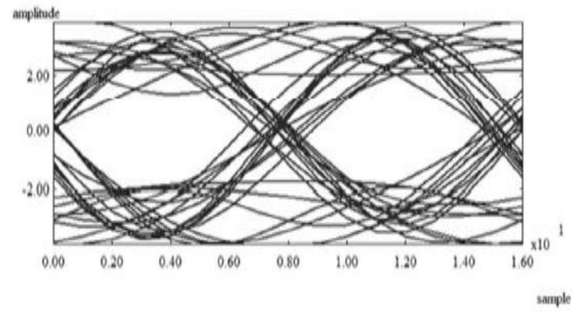

Figure 10.TK-Eye output in QAM system

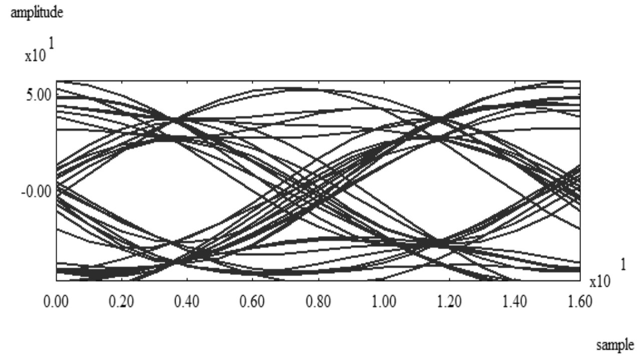

Figure 11.TK-Eye output in QPSK system

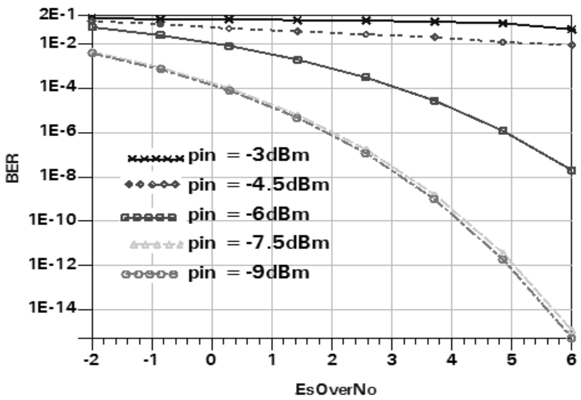

Figure 12.BER versus Es/N0 for three different value of IBO

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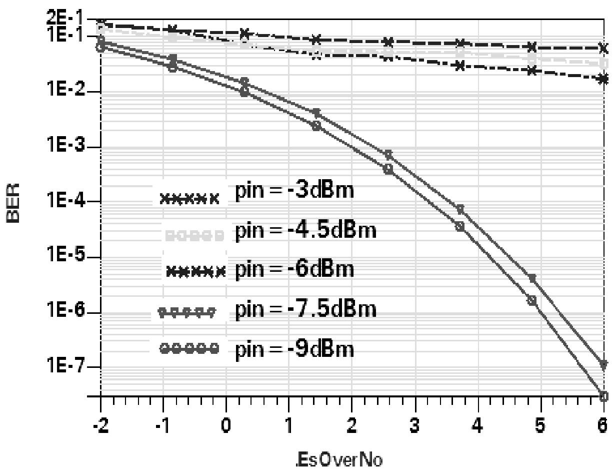

Figure 13. BER versus Es/N0 for three different value of IBO

IV. CONCLUSION

A signal predistortion linearizer has been presented to correct the nonlinearity behavior of a TWT Amplifier. The parameter of the predistortion circuit has been optimized to give the best phase and amplitude distortion characteristics. 4-QAM and QPSK data modulators have been used to evaluate the linearized characteristics in the presence of the proposed modulated signal. The constellation and eye diagrams for each modulation have been plotted to show how the amplitude and phase of the modulated signal affect by linearized TWTA. We have calculated BER values as function of Es/N0 for IBO of 2 dB, 3dB and 4 dB for both modulations. It has been shown IBO increasing cause BER decreasing. Also it has been obtained that the performance of the 4-QAM modulator is better than QPSK modulator performance.

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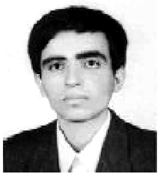

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