Satellite transponder performance evaluation in the presence of the linearizer base circulator

Pedram. Hajipour,
1- Islamic Azad University from Young Research and Elite club, Shahrerey branch, Tehran, Iran
Email: Hajipour@itrc.ac.ir

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ABSTRACT:
In this paper, analysis of a linearized Travelling Wave Tube (TWT) under the digital modulation schemes is presented. The pre-distortion linearizer circuit based on the schottky diodes and circulator is used to compensate nonlinear behavior of the TWT amplifier in the noisy channel. The Quadrature Amplitude Modulation (QAM) is utilized and applied before linearized TWTA in order to capture results. The data passing through the linearized TWTA is analyzed by using Advanced Design System (ADS). Constellation and eye diagrams are obtained from a telecommunication link. In addition, Bit-Error-Rate (BER) performance of the system is evaluated using Monte Carlo estimation for three different values of Input-Back-Off (IBO). Finally, it is shown that the system performance is improved considerably by applying the proposed signal pre-distortion linearizer base circulator.

KEYWORDS: Travelling Wave Tube Amplifier; pre-distortion; circulator; Quadrature Amplitude Modulation

1. INTRODUCTION

The main part of a satellite communications payload is its transponder. Each transponder includes one or more antennas to transmit and receive signals, high-power transmitter and the receiver frequency converter. The transponder has the ability to communicate between the ground stations and satellite. Proper satellite transponder exploitation is a primary objective in satellite-communication systems in order to cope with the limited power and spectral resources. In satellites, assessing the end-to-end link performance is certainly a very complex and time-consuming task [1]. Accurate and efficient simulation techniques allow the evaluation of different operational conditions and the trade-offs between linearity versus efficiency in a reasonable amount of time [2-4]. One of the devices which are used in all satellite transponders is the Travelling Wave Tube Amplifier (TWTA). In TWTAs the amplitude and the phase distortion must be optimized according to the actual operational conditions and considering the severe impact that, in such circumstances, they can have on the communication link performance. The nonlinearity behavior causes adverse effects on the system performances such as deterioration of BER and constellation diagram. To compensate these nonlinear behaviors, analogue linearizer such as feedback, feed forward and signal pre-distortion techniques [5-7] and digital linearizer [8-9] have been introduced in literatures [10]. Signal pre-distortion technique has a simple circuit and ease of implementation, which makes it appropriate and applicable in satellite transponder. Also, the analogue pre-distortion has been used to eliminate the amplifier nonlinearity. This technique has used the baseband circuit components to modify the shape of the transmitted signal pulse [11].

In this paper, section II presents two transponder models which have been used in satellites' structure. Next, section III shows the performance of the specific linearizer for TWTA under QAM modulation. Section IV discusses the simulation results for QAM modulation which are applied to the system in Ku-Band. Finally, the paper has been concluded in section V.

2. TRANSPONDER MODELS

There are two different methods for transponders modeling based on the various services the satellite provide:

- Analogue modulation signals (including television signals with different formats)
- Digital modulation signals such as FDMA, TDMA, SCPC, etc.

As we see in Figure 1, analogue transponder configuration (bent-pipe) [12] includes the frequency band converter, IMUX, OMUX and high-power amplifier. First, the converter changes the received frequency band to a specific frequency. Then the IMUX/OMUX divides this frequency into different BW channels. Finally, before the transitions the signal is amplified through the amplifier.

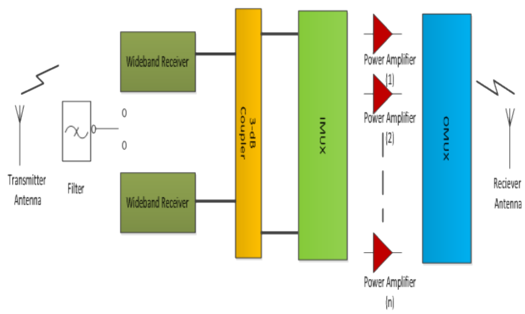

Fig. 1. Analogue transponder

Figure 2 shows a digital transponder (Digital On-Board Processing (DOBP) which includes the up/down frequency convertor, digital processing unit and high-power amplifier. First the convertor changes the received frequency band to a specific frequency. Then the digital processing unit converts information to analogue or digital code base satellite commands. Finally, before the emitting the signal through the antenna, it is amplified via the amplifier. In this model, the satellites can be considered as a part of the of the ground stations network. This transponder has high performance and efficiency in comparison with the first model but the structure is complicated.

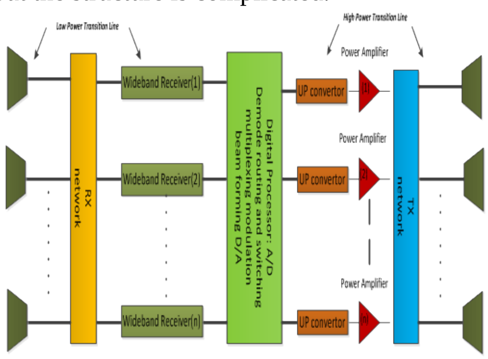

Fig. 2. Digital transponder

In this paper, the transponder is modeled in Advanced Design System software (ADS) and is composed of:

- A bit generator for producing digital information in a QAM system.
- Two input base band filters for Quadrature and in-phase components in modulators.
- A frequency translator (normally composed of an oscillator and a frequency mixer) used to convert the frequency of the received signal to the frequency required for the transmitted signal.
- An input Low Noise Amplifier (LNA).
- A Solid State Power Amplifier (SSPA).
- An attenuator for distance between transmitter antenna and receiver antenna in uplink.
- A ground station transmitter unit which includes an antenna, an amplifier and a band pass filter.
- A receiver in the satellite station which includes an antenna, an amplifier and a band pass filter.
- An Automatic Gain Controller (AGC) which controls the gain along the link.
- TWTA with linearizer (Mathematical or pre-distortion base circulator solution).
- An CAMP (Channel Amplifier) which is used for end of the link.
- A frequency translator (normally composed of an oscillator and a frequency mixer) used to convert the frequency of the send signal to the frequency required for the transmitted signal.
- Two input baseband filters for Quadrature and in phase components in demodulator [13].

2.1. Pre-Distortion Model

Consider a digital transmission system including a QAM modulator and a demodulator, along with the nonlinear TWT amplifier. As we show in Figure.3, we propose to configure a signal pre-distortion linearizer for the TWT amplifier to improve the nonlinearity of the digital transmission system. First, based on [14-16] the linearizer model is presented, and then, the QAM transmission system is discussed.

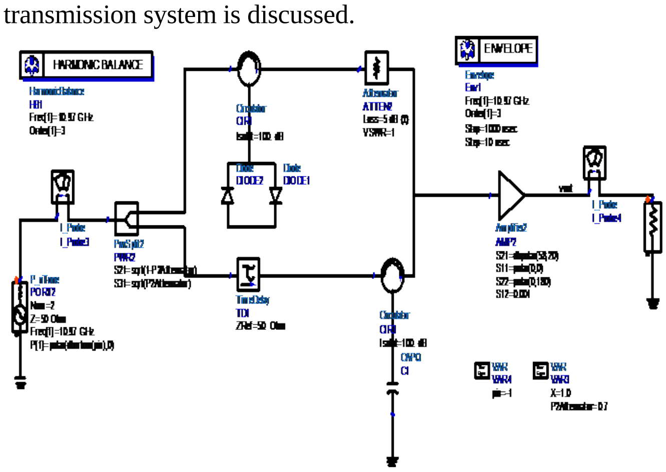

Fig. 3. Transponder with pre-distortion linearizer

In this simulation, pre-distortion linearizer uses a nonlinear algorithm to compensate the nonlinear behavior of the TWT amplifier. The reflection of the dynamic conductance and the anti-parallel schottky diodes [17-18], is used to design the pre-distortion linearizer at Ku band. The anti-parallel schottky diodes with dynamic conductance are used in the pre-distortion linearizer. The 3dB coupler divides input signal into the second and the third terminals. Output impedance at the second and third terminals is

depending on the input power. Therefore, the reflected power at forth terminal and the input power do not have linear relevance. So, the pre-distortion nonlinearity curve will be created. A resistance and a transmission line are employed after the Schottky diodes to tune the required impedance to the second and third terminals.
Based on equation (1) [14], the computed numeric linear gain is:

$$|S_{21}|[dB] = 20\log(|\frac{V_{out}}{V_{in}}|) = |\Gamma_{diode}|[dB] \qquad (1)$$

Reflection coefficient of the schottky diodes:

$$\Gamma_{Diode} = G_L \frac{Z_d - Zo}{Z_d - Z_o} = \frac{(G_0 - G_d - G_L) - j(B_d + B_L)}{(G_0 + G_d + G_L) - j(B_d + B_L)} \qquad (2)$$

The equivalent circuit of schottky diode consists of an equivalent conductance, G_d, and an equivalent susceptance, B_d. And the equivalent admittance of the resistance terminated transmission line seen at the diode consists of an equivalent conductance, G_L, and an equivalent susceptance, B_L[14-15].
From the above equation, we can find that the proposed pre-distortion can be controlled by the parameters such as Gd, GL, Bd and BL. Therefore, the inverse AM-to-AM (evaluating Amplitude distortion) and AM-to-PM (evaluating Phase distortion) characteristics can be obtained with the dynamic admittance of the diode, transmission line impedance, and its length and termination resistance.

$$Mag[\Gamma_{Diode}] = \sqrt{\frac{(G_0 - G_d - G_L)^2 + (B_d + B_L)^2}{(G_0 + G_d + G_L)^2 + (B_d + B_L)^2}} \qquad (3,4)$$

$$Ang[\Gamma_{Diode}] = \tan^{-1}(\frac{-(B_d + B_L)}{G_O + G_d + G_L}) - \tan^{-1}(\frac{-(B_d + B_L)}{G_O + G_d + G_L})$$

A modulated signal that is transmitted from ground station reaches the satellite. This signal is first filtered, right after up/down frequency converters, the signal passes further to the amplifiers before finally being transmitted through the TWTA. This signal which is now at a modulated frequency is radiated by a transmitting antenna towards the earth station.
The bit stream produced by the data generators get into the QAM modulator. Before the modulator, the raised-cosine filters are used to shape the bit stream. After the modulator, the modulated data passes through the RF module. The relative RF block contains a mixer for up-converting to the Ku-band, signal pre-distortion with combination of TWTA and a mixer for down-converting. As the ADS tool is partly a pictorial based interface where design details of each component can be compartmentalized into different levels of complexity, it allows the model to be easily accessible and understandable. The top level model of a signal that uses QAM transmission system is shown in Figure.4.

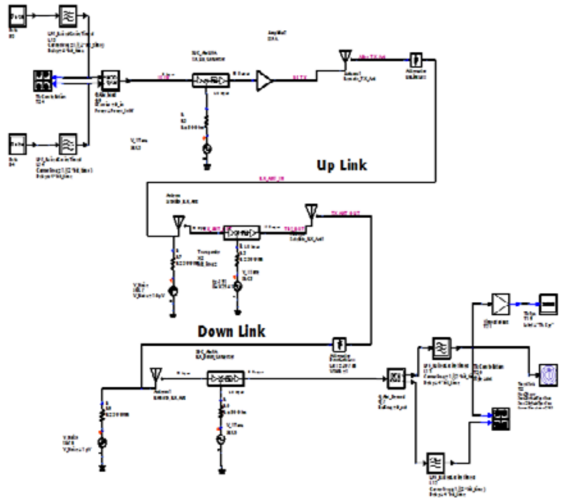

Fig. 4. Plan for Line-of-Sight link

3. SIMULATION RESULTS

In satellite channel simulation different blocks were cascaded allowing different types of stimuli to excite the payload model, this being harmonic balance simulation. This analysis allows the RF signal to be monitored as the signal passes through the TWTAs. A harmonic balance simulation applies one or more signal tones to be into the TWTAs under test and analyze the intermediated signals that emerge.
The effect of the signal pre-distortion for amplitude and phase distortion recovery is shown as AM-to-AM and AM-to-PM characteristics for linearized and non-linearized TWTA, presented in Fig. 5 can be seen, the amplitude distortion is improved in the presence of the Schottky diode linearizer.

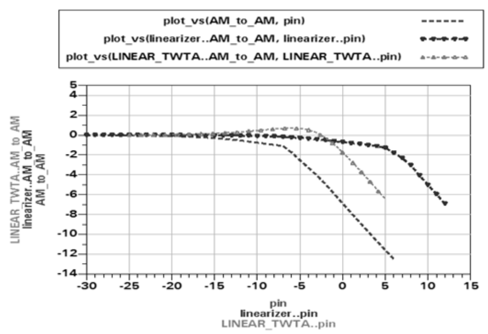

Fig. 5. AM to AM characteristic for TWTA

Figure 6 represents AM-to-PM characteristic of the linearized and non-linearized TWTA. In the case of the non-linearized TWTA, the phase distortion is 35 Deg/dB while it is improved to 7 Deg/dB by employing the signal pre-distortion linearizer.

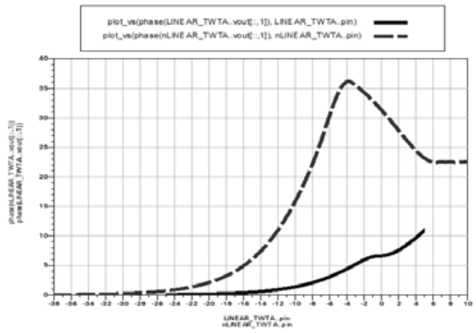

Fig. 6. AM -to- PM characteristic for TWTA

Also, 3rd inter-modulation for simulation link with/without the presence linearizer presented in Figures 7 and 8.

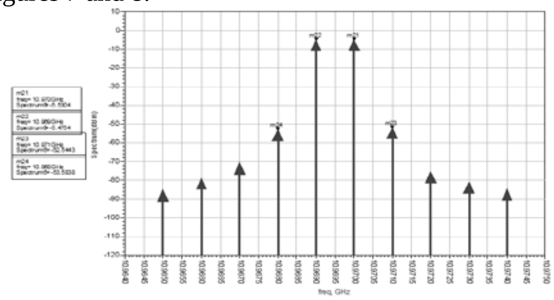

Fig. 7. Spectrum for line of sight link with predistortion

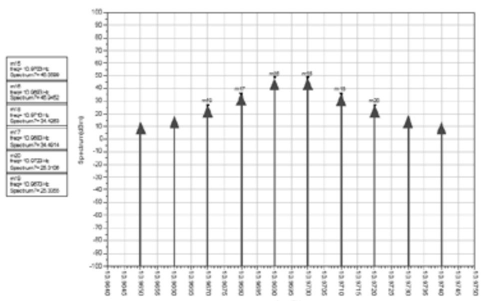

Fig. 8. Spectrum for line of sight link without pre-distortion

Figure 9 represents output Gain after TWTA which it uses a pre-distortion circuit. In this figure shows a 48 dB output power when TWTA works in 0 dBm (Input power)which TWTA has high efficiency. and non-linearized TWTA.

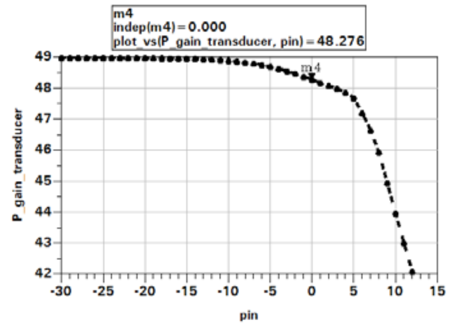

Fig. 9. Stability Gain for TWTA

The performance analysis of the QAM digital transmission system has been performed. The parameters used in the simulation are listed in Table I.

Table 1. RF and QAM modulated signal properties

System Parameters	Modulation/Demodulation
$F_{Carrier}$	100/100 MHZ
Amplifier Output Power	-6 dBw
Input/Output Resistance	50/50 Ohm
Physical Temprature	-273/-273 K
System Parameters	Value
Bit Rate	20 Mbps
reference phase	0 deg
RF Frequency	10.97 GHz
Transmitter Antenna	46 dB
Reciever Antenna	35 dB

The eye diagram pattern for the QAM modulated signal with and without pre-distortion is shown in Figures. 10 and 11. As we see, the eye diagram is much closer and distorter in the case of without pre-distortion Than the situation where the pre-distortion is used.

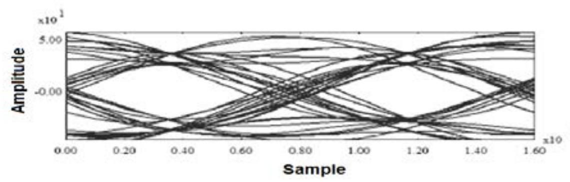

Fig. 10. TK-Eye output in QAM system with pre-distortion

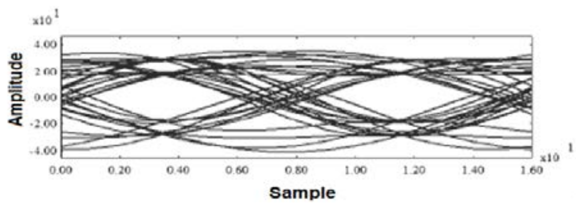

Fig. 11. TK-Eye output in QAM system without pre-distortion

The performance analysis of the QAM digital transmission system has been performed. The performance analysis of the QAM digital transmission systems has been performed. The value of BER for this modulation is calculated by using Monte Carlo estimation. It is obtained for different values of IBO and is plotted as a function of E_s/N_0 as shown in Figure. 12 under QAM modulation system, respectively. These results indicate that increasing IBO decreases BER for a specified value of E_s/N_0. The BER depends on the bit to symbol mapping, If we assume $E_s/N_0 >> 1$, we can compute each symbol error causes only one bit error[19].

The bit-error rate equation is approximately:

$$P_b \approx \frac{(2.P_S)}{k} \qquad (9)$$

• P_S : Probabilityof symbol error

• P_b : Probabilityof bit error

The probability of symbol error rate can be calculated from following relations as:

$$P_{b(M-QAM)} = 1-(1-P_{b\sqrt{M-PAM}})^2 =$$

$$1-\left(1-2(1-\frac{1}{\sqrt{M}})Q(\sqrt{\frac{3.\gamma_s}{M-1}})\right)^2 \le 4Q(\sqrt{\frac{3.\gamma_S}{M-1}}) \qquad (10)$$

• M : Numberof symbols in modulation constellation

• γ_S : Energy per symbol

The effects of high data rate are shown in Figure 13,The telecommunication link have been collapsed by high dada rate.

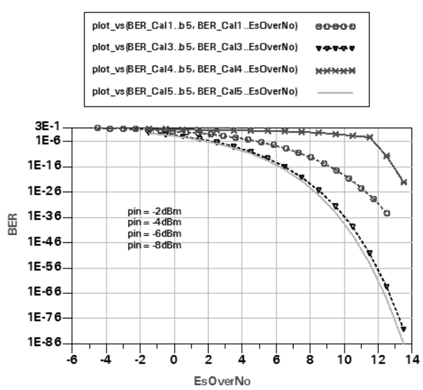

Fig. 12. Eye BER versus Es/N0 for three diffrent value of IBO

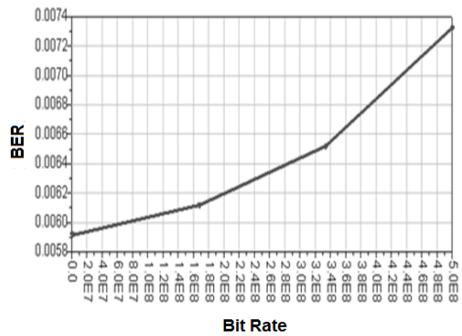

Fig. 13. BER versus Data Bit Rate

V. CONCLUSION

In this paper, analysis of a linearized Travelling Tube Amplifier (TWT) under the digital modulation schemes has been presented. The pre-distortion linearizer circuit based on the Schottky diodes has been employed to compensate nonlinear behavior of the TWT amplifier in the noisy channel. The QAM modulator has been utilized before the linearized TWTA. The data which passed through the linearized TWTA has been analyzed by using advanced design system (ADS). In addition, constellation and eye diagrams are obtained from QAM modulation. Finally, the Bit-Error-Rate (BER) performance of the system is evaluated using Monte Carlo method for three different values of Input-Back-Off. It has been shown that the performance is improved by applying the proposed signal pre-distortion linearizer.

Based on the achieved results, it has been demonstrated that the proposed linearizer shows proper linearizing operation. At the same time, it has satisfied the critical requirements of communication satellite, such as compact size and light weight.

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