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SIMULATION OF SATELLITE TWTA NONLINEARITY USING TWO QPSK CARRIERS

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ABSTRACT

Effects of TWTA non-linearity are simulated using two QPSK carriers. A Simulink model is developed which uses Saleh model for TWTA nonlinearity. Simulation results are presented and discussed. QPSK carriers are widely used in satellite TV broadcasting and better represent real application scenarios. It is shown that NPR can be used to calculate total C/N for satellite link budget.

INTRODUCTION

Travelling wave tube amplifiers that are used in communication satellites has non-linear behaviours. A typical RF transfer characteristic of TWTA with and without linearizer is shown in Fig. 1 [Ulubey, Gulgonul and Kara, 2015]. This non-linearity is modelled by different approaches. There are several methods to model TWTA non-linearity such as Saleh model, Ghorbani model, Rapp model. Saleh model is widely accepted for memoryless TWTA and is used in this study. Transfer functions for Saleh model are given as

$$P(r) = \frac{\alpha.r}{1+\beta.r^2} \quad (1)$$

$$Q(r) = \frac{\alpha.r^2}{1+\beta.r^2} \quad (2)$$

where $P(r)$ and $Q(r)$ are corresponds for AM/AM and AM/PM characteristics, respectively and r is the input signal to TWTA [Saleh, 1981]. Alpha and Beta constants have to be chosen to fit to the real characteristics of the TWTA curves, which are derived by real measurements.

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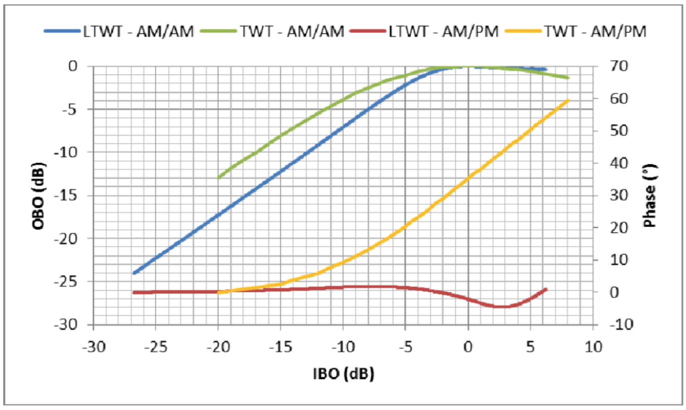

Figure 1. RF Characteristics of TWTA and LTWTA

There are two parameters to measure the level of nonlinearity. Carrier to 3rd Order Intermodulation (C/IM3) is a metric to measure non-linearity of TWTAs. C/IM3 is measured by using two un-modulated Continuous Wave (CW) carriers. Noise Power Ratio (NPR) is another measurement method to characterise the non-linearity of the satellite TWTAs (Travelling Wave Tube Amplifier). NPR measurements uses random white noise filtered by a notch filter at the centre of the amplifier [Maral and Bousquet, 2009]. NPR is the ratio of the white noise level at outside of the notch filter to the intermodulation noise level inside the notch filter. High value of the NPR corresponds higher linearity of the TWTA. Typical satellite LTWTA NPR performance is shown in Figure 2 [Ulubey, 2015]. NPR and C/IM3 curves are similar but NPR represents the worst-case scenario for the configuration of carriers on TWTA.

$$NPR(dB) = 10\log\left[\frac{N_o}{(N_o)_{IM}}\right] \quad (3)$$

Degradation caused by the nonlinearity of TWTA varies with the number and parameters of the carriers (center frequency bandwidth, C/N). There are two different approaches are observed in scientific studies: total degradation and inclusion of nonlinearity to total C/N calculation using C/IM3.

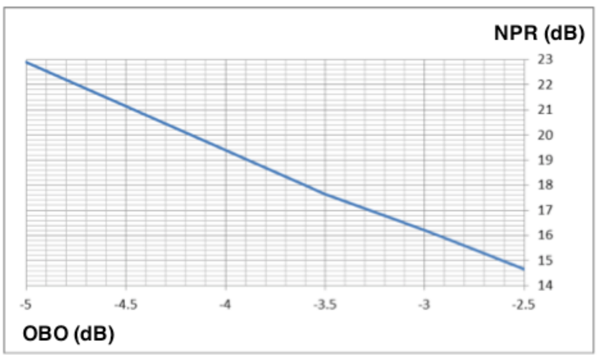

Figure 2. Typical LTWTA NPR Performances

Total degradation is an accepted approach to evaluate performance of TWTA [AI, Zhang, Pan et al., 2007]. Total degradation is sum of output back-off (OBO) and difference of signal to noise ratio (SNR) with HPA nonlinearity and without nonlinearity.

$$TD = OBO + SNR_{HPA} - SNR_{AWGN} \quad (4)$$

Total degradation caused by the non-linearity of the TWTA is studied for Turksat-3A measured TWTA characteristics [Ulubey, Gulgonul and Kara, 2015]. This study uses measured TWTA characteristics but unfortunately does not have comparison of calculated and measured TD values. Effect of TWTA nonlinearity can be included into satellite link budget C/N calculations as an additional noise source using C/IM3 values [Harold, 2016].

METHOD

There is a need to include degradation to the link budget calculations and to find OBO for maximum C/N. Non-linear characteristic of TWTA has two impacts on satellite link budget. Firstly, nonlinearity causes harmonics and raises the noise level, decreases carrier to noise ratio (C/N). To overcome this negative impact, TWTA is operated in linear region with backup-off by scarifying from the Effective Isotropic Radiated Power (EIRP). C/N raises but EIRP decreases by increasing OBO. There shall be an optimum OBO value to achieve the maximum C/N.

Uplink C/N depends on uplink ground system EIRP, free space loss (FSL), satellite receiver figure of merit (G/T) and bandwidth of the carrier (Bw). As it is seen that uplink C/N is independent from the TWTA nonlinearity.

$$C/N_{uplink} = EIRP_{uplink} - FSL + \frac{G}{T} - 10\log(Bw) + 228.6 \tag{5}$$

Similarly, downlink C/N is related to satellite EIRP, free space loss, ground receiver figure of merit and carrier bandwidth. Downlink EIRP and C/N decreases with applied OBO.

$$C/N_{downlink} = EIRP_{downlink} - FSL + \frac{G}{T} - 10\log(Bw) + 228.6 \tag{6}$$

C/N caused by TWTA linearity can be included into total C/N calculation.

$$(C/N_{total})^{-1} = (C/N_{uplink})^{-1} + (C/N_{downlink})^{-1} + (C/N_{nonlinearity})^{-1} \tag{7}$$

C/N caused by TWTA nonlinearity varies with parameters and number of carriers. Thus, Simulink has been used in this study to simulate the real configuration carriers as shown in Figure 3. Two QPSK carriers at different frequencies are fed into the TWTA. Saleh Model characterizes the TWTA nonlinearity. Alpha and Beta constants of the Saleh model shall be calculated to fit to measured TWTA performance curve. The shape of input and output amplitude curve is defined by calculated alpha and beta constants (Figure 4.)

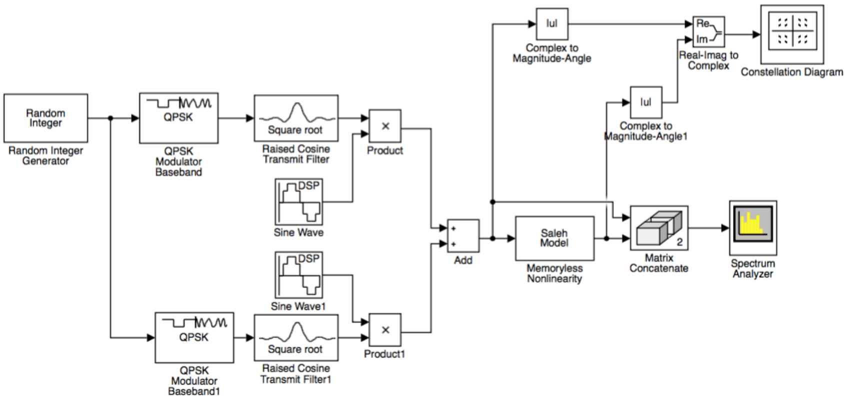

Figure 3. Simulink Model

QPSK modulator uses Gray Coding and modulates 4 Msps randomly generated input symbols. Square Rooted Raised Cosine (SRRC) filter has 0.2 rolloff factor. Bandwidth of the signal is 4.8 MHz.

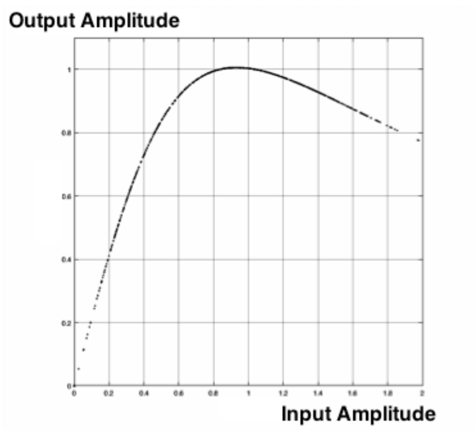

Figure 4. Input and Output Amplitudes

Spacing between two carriers has to be adjusted according to the real configuration and it is 1.2 MHz for this example. Input and output spectrum are shown at Figure 2 for two carriers having centre frequencies at 3 MHz and 9 MHz. OBO level is adjusted by setting the gain of Square Rooted Raised Cosine Filter.

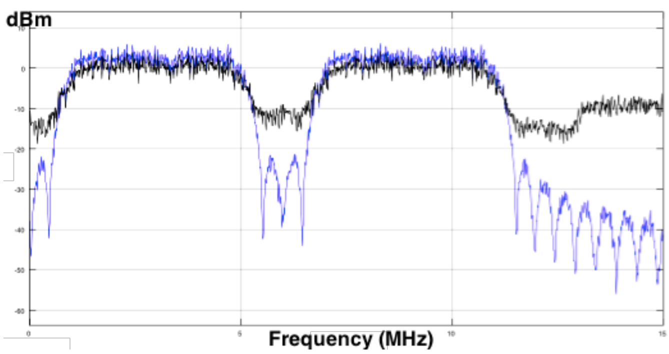

Figure 5. Input and Output Spectrum of TWTA

DISCUSSION OF RESULTS

C/N caused by TWTA nonlinearity is measured for the input amplitude levels between 0.125 and 1.0 with 0.125 steps. Output amplitude is calculated using Figure 4 and used to simulate OBO in logarithmic scale. As expected, $C/N_{nonlinearity}$ increases with OBO (Figure 6.). It is important to notice that $\mathrm{C/N_{nonlinearity}}$ curve is very similar to NPR characteristics.

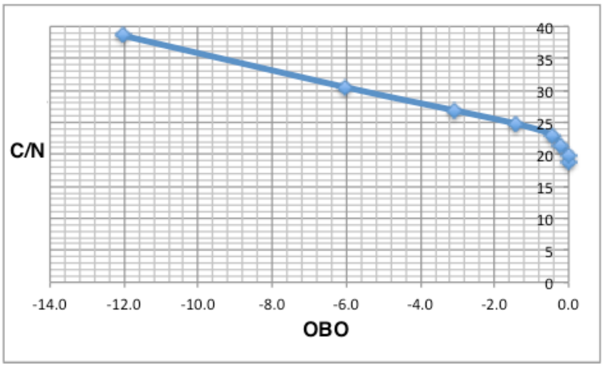

Figure 6. $\mathrm{C/N_{nonlinearity}}$ and OBO Curve

It is observed that $\mathbf{C/N_{nonlinearity}}$ versus OBO characteristic is similar to NPR curve for the example of two QPSK carriers. We can conclude that NPR values can be used to calculate overall C/N for multicarrier scenarios that are better represented by NPR. Thus we can adopt (7) to calculate effect of TWTA nonlinearity to total C/N calculation. It has to be remembered that $\boldsymbol{C/N_{uplink}}$ and NPR values depend on OBO.

$$(\boldsymbol{C/N_{total}})^{-1} = (\boldsymbol{C/N_{uplink}})^{-1} + (\boldsymbol{C/N_{downlink}})^{-1} + (\boldsymbol{NPR})^{-1} \qquad (8)$$

For an example; we can calculate the optimum OBO value for $\boldsymbol{C/N_{uplink}} = \mathbf{30}\boldsymbol{dB}$ and $\boldsymbol{C/N_{downlink}} = \mathbf{30}\boldsymbol{dB}$ at saturation. $\boldsymbol{C/N_{uplink}}$, $\boldsymbol{C/N_{downlink}}$, $\boldsymbol{C/N_{nonlinearity}}$ and $\boldsymbol{C/N_{total}}$ are drawn onto the same curve at Figure 7. It can be observed that $\boldsymbol{C/N_{total}}$ maximum value 22.94dB has been reached at OBO=-3.1dB.

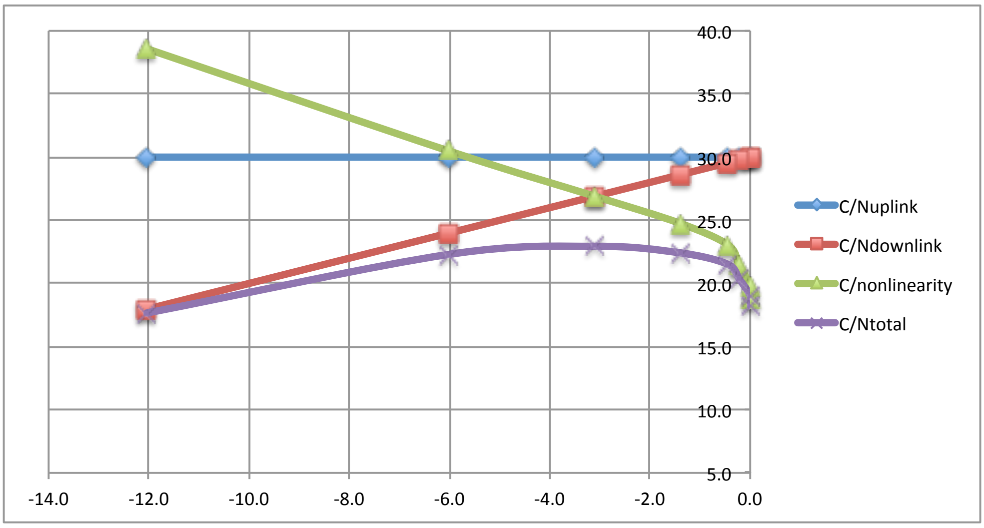

Figure 7. *C/N values* and OBO Curve

CONCLUSION

Satellite TWTA's work at saturation for single carrier to achieve the maximum power, EIRP and C/N. In case of multi carrier operation, nonlinearity of TWTA raises noise level and decreases C/N. OBO is adjusted to decrease nonlinearity but decreases EIRP, too. There is an optimum OBO value to have maximum C/N. Unfortunately; there is not an analytical solution for this problem. In this study, A Simulink model is developed to simulate effects of satellite TWTA nonlinearity for two QPSK carriers. QPSK carriers are widely used for TV broadcasting through satellite. It is shown that measured NPR performance of a TWTA better represents multicarrier QPSK configuration and can be used to find optimum OBO graphically or numerically. Optimum OBO to provide maximum C/N can be searched using a graphical curve of NPR and C/N values.

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