IMD Improvement of X-band TWT Amplifier with Predistorted Linearizer

[#]Won Choi, Kyung Heon Koo
[#]Victek Co., Ltd
Dept. of Electronics Engineering, University of Incheon
wchoi@incheon.ac.kr, khkoo@incheon.ac.kr

Abstract

This paper has analyzed the AM-AM and AM-PM characteristics of X-band TWT used for satellite communication and improved its linearity and IMD performance by using predistortion with linearizer. The TWT amplifier with the linearizer shows better AM-AM and AM-PM conversion, and has increased the 1dB compression point by 12.3dB and 2.0˚/dB phase distortion point by 10dB. The 3rd order intermodulation distortion, IMD3 is measured to be 37.0dBc that is 16.2dB improvement. This shows that TWT amplifier can have better linearity and output power by utilizing AM-PM conversion characteristics.

Keywords : TWTA, Linearizer, SSPA, AM-PM, IMD, Predistortion

1. Introduction

The traveling wave tube(TWT) has been used for a long time in the reliable high power amplifiers for satellite communication. However, as TWT is a kind of vacuum tube, it requires much higher operating voltage than the solid state power amplifier(SSPA), and lower mean time to failure (MTTF) [1]. In this paper, we designed a 600W TWTA(Traveling Wave Tube Amplifier) operating from 7.9GHz to 8.4GHz in X-band. TWT's 1dB compression point, P1dB, which is the linearity figure of power amplifier appears 10 to 12dB lower than the saturation power. It requires 4dB output power back off(OPBO) from maximum power level in order to improve the 3rd order intermodulation distortion(IMD3) to more than 15dBc [2]. Linearizer is used to improve the non-linearity characteristics of the TWT. TWT amplifier(TWTA) consists of RF module, power supply unit(PSU) and TWT, as shown in Figure 1. The PSU supplies high voltage for TWT. This paper has analyzed AM-AM and AM-PM conversion characteristics in order to improve the TWT nonlinearity. And then we have improved the IMD characteristics with a linearizer using predistortion. Section 2 presents the AM-AM and AM-PM characteristic of the TWT and the linearizer, and the measured IMD results to show the improvement, and section 3 concludes this paper.

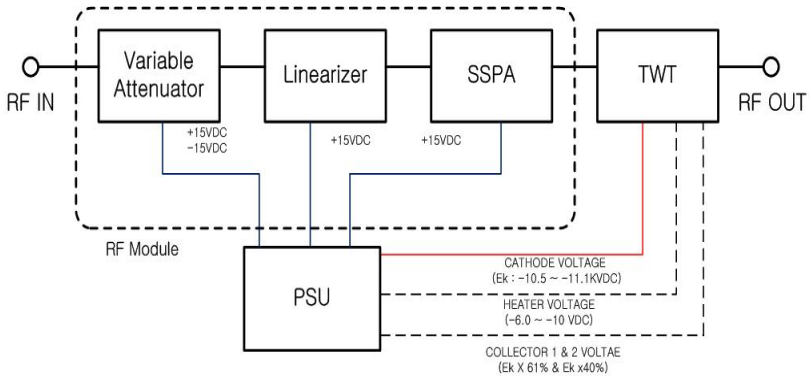

Figure 1: The structure of TWTA.

2. Analysis of AM-PM conversion

Generally, RF power amplifier shows strong nonlinear characteristics above the saturation or P1dB region. This is turned up by both AM-AM and AM-PM characteristics. AM-AM is the output amplitude characteristics and AM-PM is output phase characteristics with changing input power. Such nonlinear characteristics can be explained by two-tone test, and IMD3 which is an important nonlinearity coming by third harmonic component, can determine the performance of the digital communication system. The inputs of two-tone can be written by Eq. (1).

$$v_i(t) = v\cos(\omega_1 t) + v\cos(\omega_2 t) \tag{1}$$

$$\begin{aligned} v_o(t) = {} & a_1 \cdot v \cdot \left(\cos(\omega_1 t) + \cos(\omega_2 t)\right) \\ & + a_2 \cdot v^2 \cdot \left(\cos(\omega_1 t) + \cos(\omega_2 t)\right)^2 \\ & + a_3 \cdot v^3 \cdot \left(\cos(\omega_1 t) + \cos(\omega_2 t)\right)^3 \\ & + a_4 \cdot v^4 \cdot \left(\cos(\omega_1 t) + \cos(\omega_2 t)\right)^4 \\ & + a_5 \cdot v^5 \cdot \left(\cos(\omega_1 t) + \cos(\omega_2 t)\right)^5 \\ & + \ldots \text{etc.} \end{aligned} \tag{2}$$

The output signal of the amplifier generates many sum and difference frequency components. Especially, the 3rd order intermodulation product, $2\omega_2$-ω_1 or $2\omega_1$-ω_2 is difficult to remove by using a filter because they are very close to the fundamental. Improving the IMD3 needs to change the nonlinear characteristics of the AM-AM and AM-PM. But, the TWT used for the research has the 1dB gain compression point, P1dB, appearing at 15dB back-off from the maximum power, very different from the SSPA situation, and showed 2.0°/dB AM-PM characteristics at 13 dB back-off from the maximum power.

2.1 AM-PM Analysis of the TWT and linearizer

The measured IMD for the TWT shows 20.8dBc without a linearizer at 8.15GHz, which is to small to be used in the practical wireless communication system[3]. This paper has obtained the IMD improvement and linearity with using a proper linearizer by analyzing the AM-AM and AM-PM of the TWT. Figure 2 shows the AM-AM conversion with input level from -15dBm to 10dBm and measured output power. The graph shows the maximum output power and the AM-AM with input power change. The AM-AM shows P1dB characteristics from -15dBm to -6dBm input and then more than 10dB distortion characteristics at the maximum power. Usually, SSPA shows the nonlinear region over 1dB compression point which is very different from the TWT that shows the P1dB at 15dB lower than the maximum output.

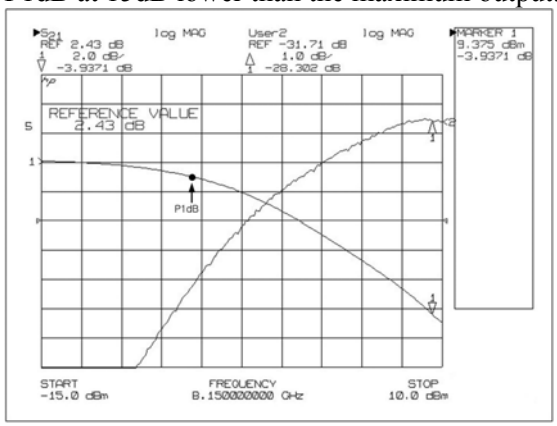

Figure 2: AM-AM for TWT without linearizer at 8.15GHz

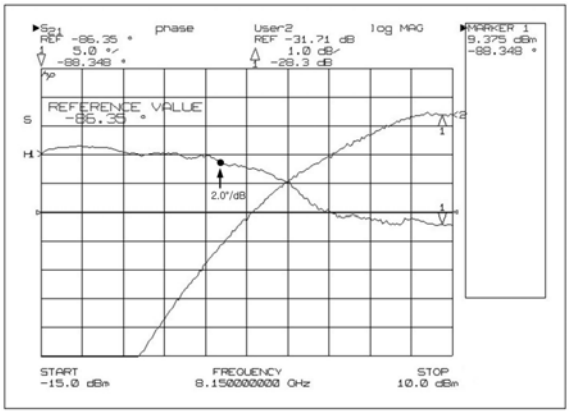

Figure 3: AM-PM for TWT without linearizer at 8.15GHz

Figure 3 shows measured AM-PM characteristics for the TWT at 8.15GHz. Phase changes as input power increases, and shows 2°/dB characteristics at 10dB lower than the maximum power. The phase distortion is 14 ° at the maximum output power. To improve these AM-AM and AM-PM, we analyze the TWT nonlinearity and have designed the linearizer. Table 1 shows the linearizer characteristics. To maintain the linear TWT amplifier operation up to maximum output, input power condition from -21dBm to -15dBm is important.

Table 1: Specifications of the linearizer

Frequency Range	7.9~8.4GHz
Output power Level	-26 to -16dBm
Input Power Level	-18±3dBm
Gain Flatness	< ± 0.5dB
Gain Slope	< 0.02dB/MHz
Gain Stability	± 1.0dB
AM/PM Conversion with TWTA	< 2deg/dB @ > 4dB OPBO
Input/Output VSWR	< 1.35:1

The structure of the proposed linearizer is shown in Figure 4. Figure 5 shows AM-PM conversion of the linearizer. Input power is from -25dBm to -5dBm. The phase showed 28° difference in the input condition and has pre-distorting characteristics of 1.67°/dB in the main operating region. These characteristics shows the opposite phase characteristics of the TWT. The amplitude shows the slope of 1.38. Considering that gain slope of linear power amplifier is unit, the slop of 1.38 has predistortion effects at distortion parts of the TWT.

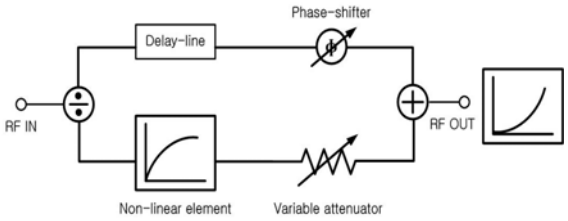

Figure 4: Structure of typical linearizer using pre-distorter

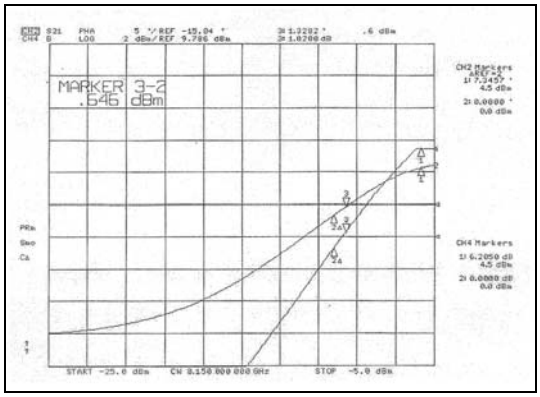

Figure 5: AM-PM characteristics for the linearizer at 8.15GHz

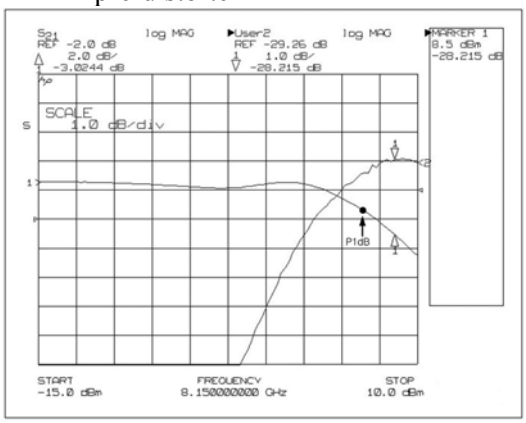

Figure 6: AM-AM for the TWT with linearizer at 8.15GHz

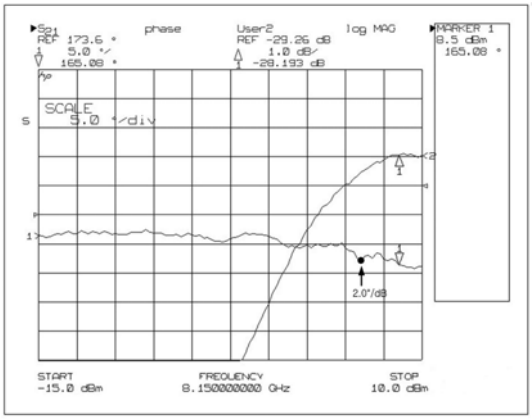

Figure 7: AM-PM for the TWT with linearizer at 8.15GHz

2.2 Improved IMD for the TWT amplifier

The TWT amplifier linearity has been improved by AM-AM and AM-PM conversion with the linearizer using predistortion, which was shown in section 2.1. The measured results show the improvement as in Figure 6 and Figure 7. The P1dB occurs at 2.5dB OPBO, which is 12.3dB improvement for the TWT. The TWT phase shows 2.0°/dB characteristics has improvement of 10dB at 2.5dB OPBO. This enhanced AM-AM and AM-PM shows the better IMD of the power amplifier, and the IMD characteristics are summarized as in Figure 8. The measured IMD is -37.0dBc at 4dB OPBO from the maximum power at 8.15GHz. The TWTA by using the predistortion of the linearizer has enhanced IMD of 16.2 by extended the 1dB compression point. Figure 8 shows the measured IMD comparison with and without the predistorted linearizer at 7.9GHz, 8.15GHz, and 8.4GHz, respectively. The IMD is measured at 1dB, 3dB, and 4dB back-off from the maximum output power at 8.15GHz. Improvement of 3.4dB, 13.1dB, and 16.2dB are measured for the 1dB, 3dB, and 4dB back-off, respectively.

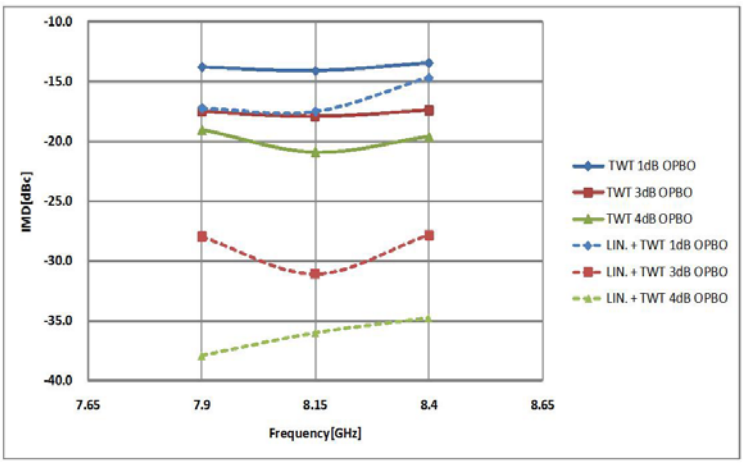

Figure 8: Improved IMD of the TWTA using linearizer

3. Conclusions

The AM-AM and AM-PM characteristics have been analysed both for the TWT and the linearizer. TWT amplifier's P1dB point and AM-PM characteristics with 2.0°/dB have been improved by 12.3dB and 10dB with using predistortion of the linearizer. Enhanced IMD3 characteristic shows 37.0dBc at 4dB OPBO, by 16.2dB improvement. This paper has shown that enhanced TWT linearity can be obtained with linearizer through the analysis of AM-PM conversion characteristics.

References

[1] Jan M. Weekley and Bill J. Mangus, "TWTA versus SSPA: A comparison of on-orbit reliability data," IEEE Trans. on Electron Devices, vol.52, no.5, pp.650-652, May 2005.
[2] Allen Katz, "TWTA linearization," Microwave Journal, vol. 39, no.4, pp.78-90, Apr. 1996
[3] Steve C. Cripps, *RF Power Amplifier for Wireless Communication*, Artech House, 2006
[4] Xin Hu, Gang Wang, Zi-Chen Wang, and Ji-Run Luo, "Predistortion linearization of an X-band TWTA for communications applications," IEEE Trans. on Electron Devices, vol.58, no.6, pp.1768-1774, June 2011