Predistortion Linearization of a Ku-Band TWTA for Communication Applications

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***Abstract*—This paper presents a Ku-band predistortion linearization for traveling wave tube amplifiers(TWTAs), it is composed of GaAs Schottky diode and resistor-terminated transmission line. By controlling the DC bias, the linearizer is capable of providing different combinations of the amplitude and phase characteristics. Otherwise, the predistortion circuit shows the perfect input matching characteristics which makes it small size and simple configuration. The tested results show that about 7dB gain expansion and 45 degree phase shift can be compensated for the TWTA.**

Keywords-Traveling Wav Tube Amplifier(TWTA); Nonlinear distortion; Predistortion; Expansion of gain and phase

I. INTRODUCTION

The constant demand for higher data rates in communication system has resulted in more complex digital modulation techniques that require efficient and linear power amplifiers. Traveling-wave tube amplifiers (TWTAs) are still a very effective means for microwave and millimeter-wave power amplification [1]. However, there is inherent contradiction between efficiency and nonlinearity in TWTAs. In order to achieve high efficiency power output, TWTAs want to work in the nonlinear condition and even in the area near saturation. It will bring many nonlinear problems such as harmonics , inter-modulation and so on, which has seriously affected the quality of communications system. Therefore, the nonlinearity phenomenon will be more prominent [2].

II. THEORY ANALYSIS

There are several power amplifier linearization methods [3][4] available which can be classified mainly free-forward, feedback and predistortion over the RF and microwave-band. These linearization techniques allow the high power TWTAs to work at lower back off values and consequently having high efficiency. Amongst all, the predistortion [5][6] is a compromise between complexity, bandwidth and linearity improvement.

In this paper we proposed a predistortion linearization of a Ku-band TWTA for communication applications. By adjusting the voltage bias of the diodes, different combinations of amplitude and phase characteristics of the predistortion linearizer can be obtained . Otherwise, the predistortion circuit shows the perfect input/output matching characteristics, and any additional isolator isn't required for matching.

A. Predistortion

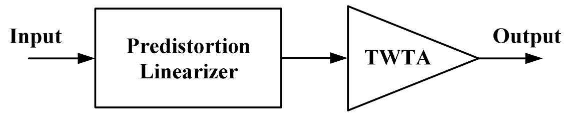


Figure1. The block diagram of predistortion linearizer with TWTA

The block diagram of the predistortion technique is shown in Fig.1.There is a predistortion linearizer before the TWTA[7]. In the predistortion linearizer, a nonlinear transfer function is created that complements the TWTA's amplitude and phase nonlinearities. This transfer function then is used to predistort the incoming signal such that it is restored to its original waveform after passing through both the nonlinear predistorter and the TWTA. The linearizer's gain increases as the TWTA's gain decreases while the phase shift introduced by the linearizer is equal and opposite to that of the TWTA. Hence, both the gain and phase shift of the linearized TWTA are corrected.

B. Reflective Schottky Diode Predistorter Using Dynamic Conductance

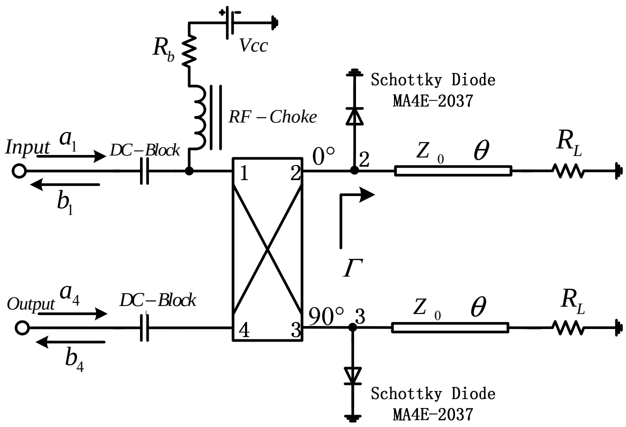


Figure2. Schematic diagram of the predistortion linearizer

The block diagram of proposed predistorter is shown in Fig. 2. When signal is fed into the Branch Line Hybrid Coupler, divided input signals go through termination resistor and Schottky diode, and then reflected signals are combined at output port. Owing to the inherent property of the Hybrid Coupler, input and output ports will be matched well. Each branch generates a nonlinear reflection coefficient, Γ, which relates the input signal, a_1, with the output signal, b_4, by the following matrix of the hybrid coupler[8]:

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & -j & 0 \\ 1 & 0 & 0 & -j \\ -j & 0 & 0 & 1 \\ 0 & -j & 1 & 0 \end{bmatrix} \begin{bmatrix} a_1 \\ \Gamma \cdot b_2 \\ \Gamma \cdot b_3 \\ 0 \end{bmatrix} \quad (1)$$

Where $a_2 = \Gamma \cdot b_2$ and $a_3 = \Gamma \cdot b_3$ .The above matrix manipulation results in:

$$b_4 = -j\Gamma \cdot a_1 \quad (2)$$

As input and output powers are represented by $|a_1|^2$ and $|b_4|^2$ respectively, so the following relationship of the output power versus the input power can be derived[9]:

$$P_{out} = |\Gamma|^2 \cdot P_{in} \quad (3)$$

Equation (3) shows the predistorter gain is equal to square value of reflection coefficient seen from both linearizer branches.

Generally, the equivalent circuit of Schottky diode consists of an equivalent conductance $1/G_d$ and an equivalent susceptance B_d (Fig.3). And the equivalent admittance of the resistance terminated microstrip transmission line seen at the diode consists of an equivalent conductance G_L and an equivalent susceptance B_L (Fig.3)

Schottky diode can be expressed as variable dynamic conductance, of which conductance value is changed according to input signal level. In this paper, B_d is assumed to be constant, because the conductance is clearly the dominant element.

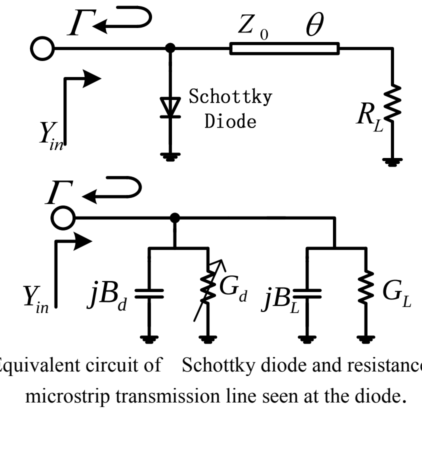


Figure 3. Equivalent circuit of Schottky diode and resistance terminated microstrip transmission line seen at the diode.

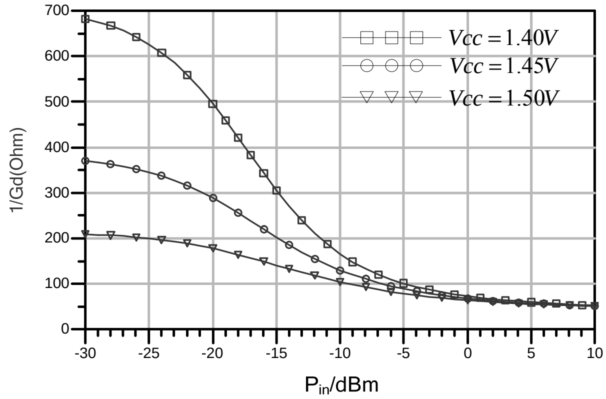


Figure 4. Dynamic conductance of Schottky diode versus the input power

From Fig.4, we can see that $1/G_d$ decrease with the input power increase, it indicates that G_d increase with the input power increase.Therefore the Schottky diode proposed in Fig. 2 has dynamic admittance versus the input power. And the Curves of dynamic admittance can be controlled by changing the DC bias.

The reflection coefficient at coupler connection point, Γ, is given below[10]:

$$\Gamma = \frac{(G_0 - G_d - G_L) - j(B_d + B_L)}{(G_0 + G_d + G_L) + j(B_d + B_L)} \quad (4)$$

The relative equation of magnitude and phase of Γ can be derived from the equation (4) as equation (5).

$$Mag[\Gamma] = \sqrt{\frac{(G_0 - G_d - G_L)^2 + (B_d + B_L)^2}{(G_0 + G_d + G_L)^2 + (B_d + B_L)^2}} \quad (5)$$

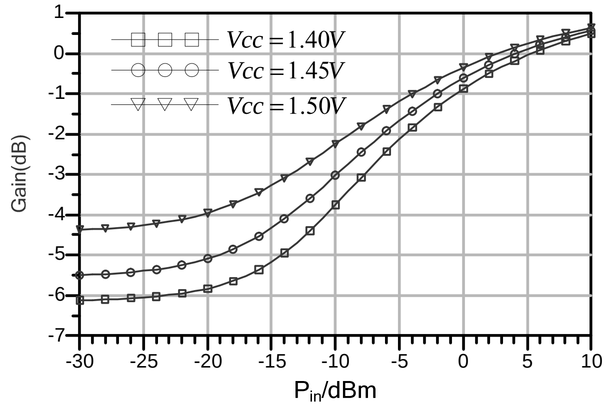
$$Ang[\Gamma] = \tan^{-1}\left[\frac{-(B_d + B_L)}{G_0 - G_d - G_L}\right] - \tan^{-1}\left[\frac{B_d + B_L}{G_0 + G_d + G_L}\right] \quad (6)$$

From the above equation, we can find that AM-to-AM and AM-to-PM of the proposed PDSG can be controlled by the parameters such as G_d, G_L, B_d and B_L .Therefore, the inverse AM-to-AM and AM-to-PM characteristics can be obtained with dynamic admittance of diode, transmission line impedance, its length and termination resistance.

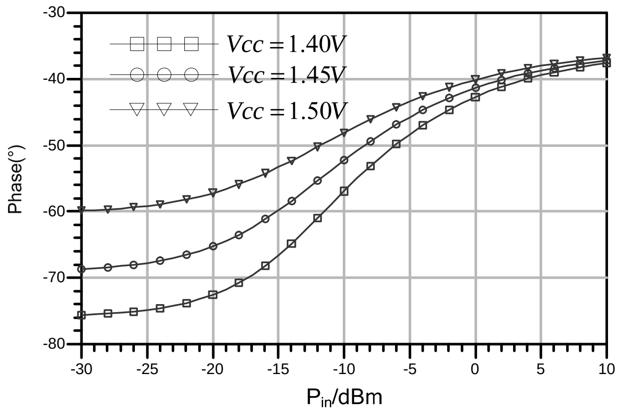
III. SIMULATION AND EXPERIMENTS

The characteristics of the proposed linearizer have been simulated using Agilent Technologies' ADS code. The linearizer is designed to satisfy linearization requirement of the high power TWTAs at the frequency band of 12.25~12.75GHz.

The AM-AM and AM-PM characteristics of the predistortion linearizer with different bias are shown in Fig. 5(a), (b). The DC bias resistance R_b is 50Ω. The termination resistor R_L is 75Ω, the electrical length θ and characteristic impedance Z_0 of the resistance terminated microstrip transmission line is 110° and 50Ω respectively. The Fig.5 shows that various combinations of amplitude and phase can be obtained by changing the DC bias of the Schottky.



(a) The gain response versus input power



(b) The phase response versus input power

Figure 5 (a),(b). Simulation AM/AM and AM/PM characteristics of The linearizer for different bias DC bias conditions.

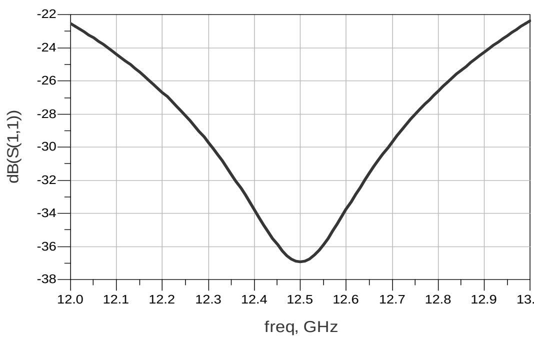


Figure 6.Input return loss with input power range from -30dBm to 10 dBm

The return loss of the predistortion linearizer at the input port has also been simulated with ADS. The Fig. 6 indicates that the good input matching characteristics can be achieved with the predistortion linearizer in the operating bandwidth range of 500MHz. And the return loss is nearly independent from the input power.

In this experiment , we used the MA-COM company's GaAs beam lead Schottky barrier diodes: MA4E-2037.The MIC photograph of the fabricated predistortion linearizer is shown in Fig. 7.

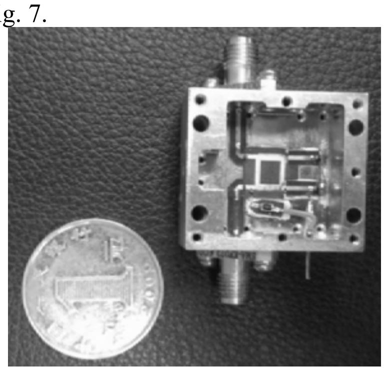


Figure 7. The photograph of predistortion linearizer

Agilent PNA-X Network Analyzer N5244A has been employed to test the linearizer. The linearizer has been measured with input power between -30dBm and +5dBm. Fig.8 shows the gain and phase curves for 12.50GHz, and when the bias voltage V_{CC} is 1.45V, the predistortion linearizer is capable of providing up to 7.2dB gain expansion and 45 phase degree.

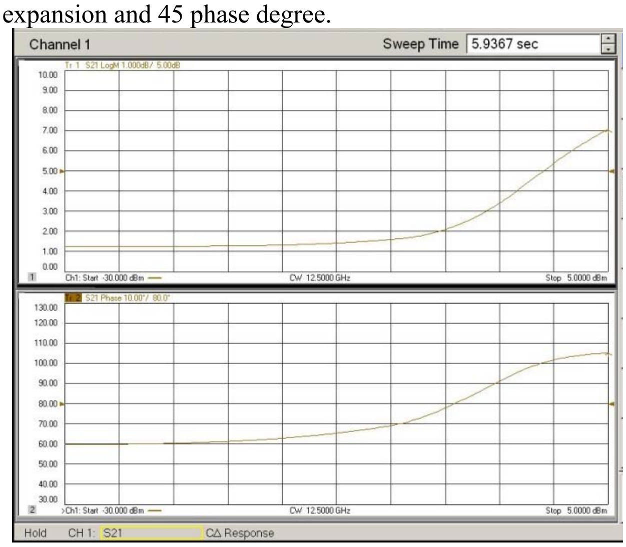


Figure 8. Measured gain expansion and phase advance curves

IV. Conclusion

In this paper a predistortion linearization of a Ku-band TWTA for communication applications has been designed. Various combinations of amplitude and phase can be obtained by changing the DC bias of the Schottky. The predistortion linearizer is capable of providing up to 7.2dB gain expansion and 45 phase degree. And good reflection characteristic can be obtained and any additional matching element is not required.

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