A Design of K-band Predistortion Linearizer using Reflective Schottky Diode for Satellite TWTAs

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Abstract — **In this paper, a new predistortion method to reduce nonlinearity of a traveling wave tube amplifiers (TWTAs) is proposed. Nonlinear transfer characteristics of TWTA are analyzed using a Carrier Complex Power Series (CCPS). An inverse complex power series of a predistortion linearizer to linearize TWTA are also proposed. The inverse nonlinear distortion characteristics of predistorter can be realized with reflective structure that is composed of schottky diode and resistor-terminated transmission line. The AM-to-AM and the AM-to-PM characteristics of TWTA on K-band were improved from -5.8dB and -37.3° to 0.8dB and 6.7° by proposed predistortion linearizer, respectively.**

I. INTRODUCTION

With the rapid growth of high volume multimedia data in satellite communication systems, a linearization of high power TWTAs has become critical, since the poor linearity induced by the high power TWTAs cause amplitude (AM-to-AM) and phase (AM-to-PM) distortion. To compensate these nonlinear distortions, many linearization techniques have been proposed, such as feedback, feedforward and predistortion [1]. They have an advantage of providing large compensation for distortion of TWTA. However these linearizers have several weakpoints such as large size, complexity of a system and high DC power consumption in satellite transponder without predistortion method.

Several predistortion methods using distortion generator, reflective diode, passive MESFET and so forth have been already presented [2]-[4]. Distortion signal generation method that consists of distortion generator, variable attenuator, phase shifter, divider/combiner and control circuits has a large circuit size and the adaptive control is required [2]. The reflective diode linearizer method uses a diode as predistortion signal generator and requires additional isolators to input/output matching [3]. And the passive MESFET structure is simple, but this scheme would require additional isolators to input/output matching [4].

In this paper, nonlinear AM-to-AM and AM-to-PM characteristics of general high power amplifier (HPA) are analyzed using CCPS analysis method, and the Inverse Carrier Complex Power Series (ICCPS) of predistortion linearizer had proposed [5]. Since AM-to-AM and AM-to-PM nonlinearities of TWTA are stronger than those of amplifiers using solid transistor, we have extend CCPS analysis to over saturated region to characterize TWTA. To realize the ICCPS of predistorter, we proposed a new K-band reflection-type predistortive linearizer using anti-parallel schottky diode with a bias circuitry, which makes the size smaller and configurations simpler than before. Also any additional isolator isn't required for matching.

II. CARRIER COMPLEX POWER SERIES ANALYSIS

If two ports network is memoryless and the signal is narrow band-limited, the output voltage can be expressed with power series of input signal. But this conventional power series can only express AM-to-AM phenomena of the nonlinear network. If the magnitude and the phase of output signal were expressed with those of input signal and complex coefficients as eq.(1), however, AM-to-PM effect could be explained in addition to AM-to-AM, which we call this series as CCPS of HPAs.

$$v_{os}=f_1 v_{is}+f_3 v_{is}^3+f_5 v_{is}^5+\cdots \qquad (1)$$
$$f_i=M_i e^{j\theta i},\ v_{is}=A_i e^{j\theta i}$$

Where f_1 is a linear complex gain, and v_{is} is a phasor form of the applied input voltage of HPA. In case of a weak nonlinearity, the output voltage can be represented by first two terms. And if the phase θ_i of input signal is calibrated as zero,

$$v_{os}\approx f_1 v_{is}+f_3 v_{is}^3 \qquad (2)$$

If the HPA is operated in linear region, then a linear complex gain coefficient is obtained as equation (4).

$$v_{os}\approx f_1 v_{is}=f_1 A_i \qquad (3)$$

$$f_1=\frac{v_{os}}{v_{is}}=\frac{v_{os}}{A_i} \qquad (4)$$

Fig. 1 shows the complex nonlinear transfer characteristics of HPA. When output power level is near 1dB compression point (P_{1dB}), assume that the input signal is $v_{is\text{-}1dB}=A_{1dB}$. Then ideal linear complex output signal can be defined as $v_{os}=f_1 v_{is\text{-}1dB}$. Therefore, a relationship between ideal output signal v_{os} and real output signal $v_{os\text{-}1dB}$ is defined as equation (5).

$$Q=\frac{v_{os-1dB}}{v_{os}}=\frac{A_{1dB}^0 e^{j\theta_{1dB}^0}}{f_1 A_{1dB}}=\frac{A_{1dB}^0}{M_1 A_{1dB}}e^{j(\theta_{1dB}^0-\theta_{f1})} \qquad (5)$$
$$=0.891e^{j(\theta_{1dB}^0-\theta_{f1})}$$

where $v_{os-1dB}=A_{1dB}^0 e^{j\theta_{1dB}^0}$

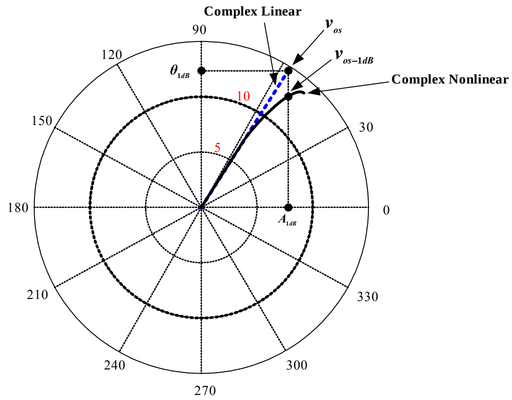


Fig. 1 Complex nonlinear transfer characteristics of HPA.

Complex constant Q can represent the amplitude and phase of distortion simultaneously at P_{1dB}. The 3rd complex coefficient can be extracted as below;

$$f_3 = \frac{f_1(Q-1)}{A_{1dB}^2} \tag{6}$$

Fig. 2 shows the block diagram and signal diagrams of the predistortion linearizer mechanism. If input voltage signal of TWTA is predistorted and these nonlinear characteristics could be expressed with ICCPS as $v_{is}=g_1A_{in}+g_3A_{in}^3$, then the overall transfer function can be explained as blow;

$$v_{os} = f_1 g_1 A_{in} + (f_1 g_3 + f_3 g_1^3) A_{in}^3 + 3 f_3 g_1^2 g_3 A_{in}^5 + 3 f_3 g_1 g_3^2 A_{in}^7 + f_3 g_3^3 A_{in}^9 \tag{7}$$

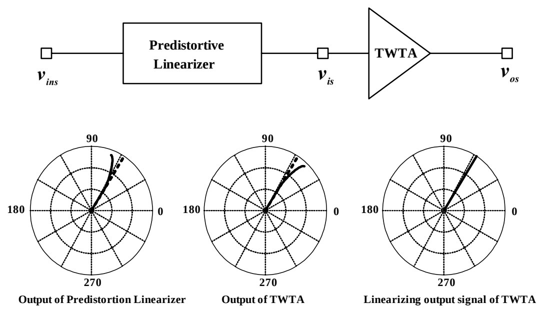


Fig. 2 Proposed predistortive linearizer and TWTA.

If predistorted TWTA has linear complex gain, the 2nd term of equation (7) is zero. Equation (8) shows the 2nd term of ICCPS of predistorter.

$$g_3 = -\frac{f_3}{f_1} g_1^3 = -\frac{f_3}{f_1} e^{j3\theta_{g1}} \tag{8}$$

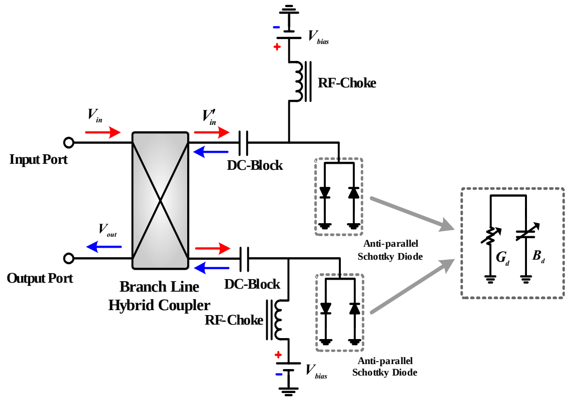
$$v_{is} = v_{in} - \left(\frac{f_3}{f_1}\right) v_{in}^3 e^{j3\theta_{g1}} \tag{9}$$

From the above equation, we can find that ICCPS of a predistortion linearizer depends on carrier complex power series of HPA. Since g_3 is inverse characteristic of (f_3/f_1), predistorter can be regarded as pre-distortion signal generator (PDSG).

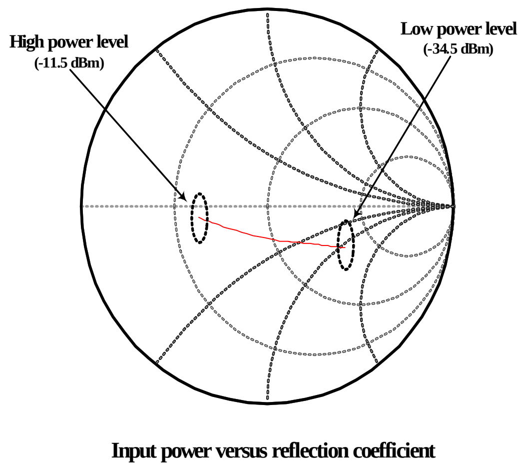
III. Reflective Schottky Diode Predistorter using Dynamic Conductance

Schottky diode can be expressed as variable dynamic conductance, of which conductance value is changed according to input signal level. Generally, schokky diode is treated as open in case of low level input signal condition and short in case of high level signal condition. Fig. 3 shows a schematic diagram to extract dynamic admittance of schottky diode and a simulated result. By measuring transfer coefficient, the equivalent admittances of schottky diode according to input signal level are obtained.

Fig. 4 shows the schematic diagram of the proposed PDSG and equivalent circuits. When low-level signal is fed, divided input signals go through termination resistor due to almost open condition of diode. And then reflected signals are combined at output port, where a termination resistor is less than Z_0. When high-level signal is fed, divided input signals experience almost short condition due to diode, therefore signal reflection ratio is higher than low-level signal condition. Because divided signals don't go through termination resistor, the phase lead of reflected signals occurs. And good reflection characteristic can be obtained because of reflective type and any additional matching element is not required.



(a)



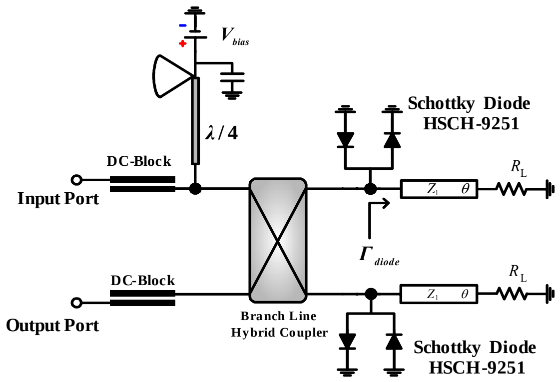
(b)

Fig. 3 (a) Schematic diagram to extract schottky diode dynamic admittance, (b) the simulated result.

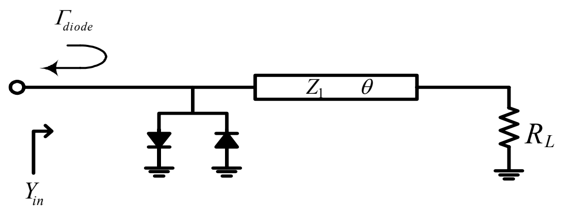
The equivalent circuit of schottky diode consists of an equivalent conductance G_d and an equivalent susceptance B_d. And the equivalent admittance of the resistance terminated transmission line seen at the diode consists of an equivalent conductance G_L and an equivalent susceptance B_L. The reflection coefficient at coupler connection point, Γ_{diode}, is given below.

$$\Gamma_{diode} = \frac{(G_0 - G_d - G_L) - j(B_d + B_L)}{(G_0 + G_d + G_L) + j(B_d + B_L)} \quad (10)$$

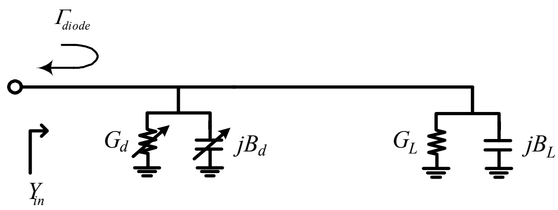
The relative equation of magnitude and phase of Γ_{diode} can be derived from the equation (10) as equation (11).



(a)



(b)



(c)

Fig. 4 Proposed PDSG schematic diagram and equivalent circuit.

$$\text{Mag}[\Gamma_{diode}] = \sqrt{\frac{(G_0 - G_d - G_L)^2 + (B_d + B_L)^2}{(G_0 + G_d + G_L)^2 + (B_d + B_L)^2}} \quad (11)$$

$$\text{Ang}[\Gamma_{diode}] = \tan^{-1}\left[\frac{-(B_d + B_L)}{G_0 - G_d - G_L}\right] - \tan^{-1}\left[\frac{B_d + B_L}{G_0 + G_d + G_L}\right] \quad (12)$$

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.

IV. Simulation and Experiments

To show the validity of the proposed PDSG circuit, a system simulation is done with the components such as PDSG, driver amplifier and TWTA. The used TWTA is TH3990C of Thomson. It has a gain of 67.7dB at the frequency band of 19.8~20.2GHz. The used schottky diode is HSCH-9251 of Agilent. The substrate is alumina with the dielectric constant of 9.9 and thickness of 15mil. Fig. 5 and Fig. 6 show the simulation results of the proposed predistortion linearizer.

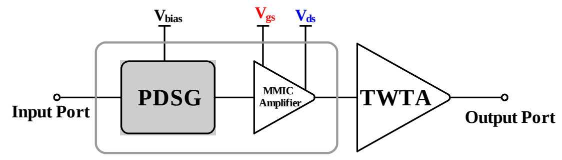
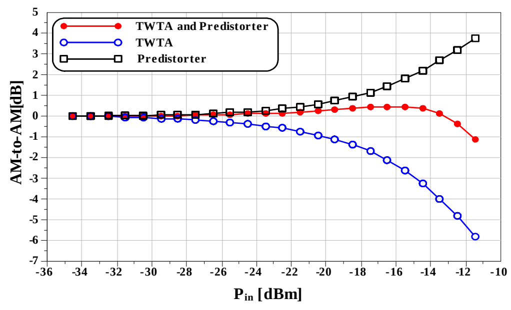
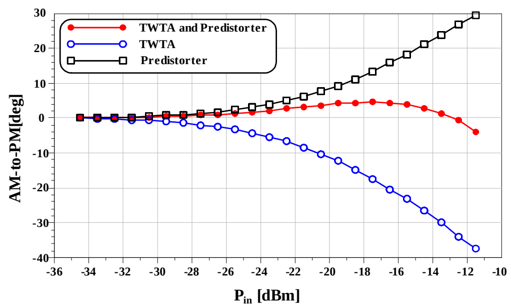


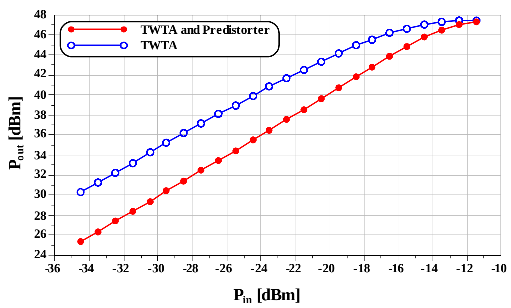
Fig. 5 Simulation line-up.



(a) AM-to-AM characteristic



(b) AM-to-PM characteristic

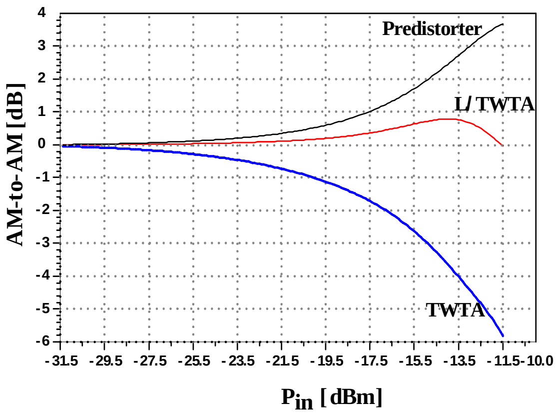


(c) Power sweep characteristics

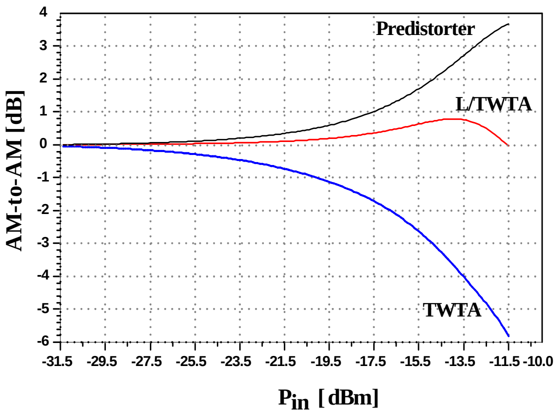
Fig. 6 Simulation results.

AM-to-AM and AM-to-PM characteristics of TWTA over a 24dB dynamic range are -5.8dB and -37.3°, respectively. Total gain of the predistortive linearizer is -4.76dB at linear region. AM-to-AM and AM-to-PM characteristics of the proposed predistortion linearizer over the same dynamic range are 3.8dB and 29.3°, respectively.

The AM-to-AM and AM-to-PM characteristics for TWTA by proposed predistortive linearizer were improved from -5.8dB and -37.3° to 0.8dB and 6.7°, respectively. Fig.7 shows measurement results. These results are similar to simulation results. We can easily control both AM-to-AM and AM-to-PM characteristic by adjusting the V_{bias} of PDSG.



(a) AM-to-AM characteristics



(b) AM-to-PM characteristics

Fig. 7 Measurement results.

The MIC photograph of the fabricated predistortion linearizer is shown in Fig. 8. MMIC driver amplifier implemented by ETRI (Electronics and Telecommunications Research Institute in Korea) has a gain of 18dB and P_{1dB} of 12dBm at the frequency of 20GHz, and we can compensate the insertion loss of the proposed linearizer through controlling V_{gs} of the driver amplifier.

VI. Conclusion

We designed the PDSG using new reflective anti-parallel schottky diode and resistor-terminated transmission line, of which transfer function is analyzed. Through the reverse AM-to-AM and AM-to-PM characteristics of a proposed linearizer, we compensated the nonlinear transfer characteristics of TWTA effectively.

In view of the results so far achieved, the proposed linearizer shows proper linearizing operation. At the same time, it satisfies the critical requirements of communication satellite, such as compact size and light weight.

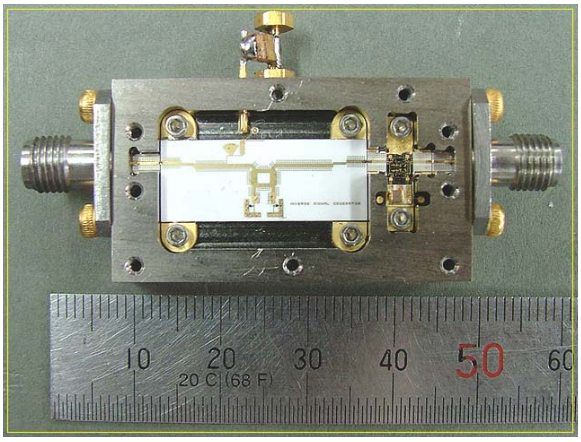


Fig. 8 Photograph of the fabricated predistortion linearizer.

Acknowledgement

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