A Ka-band Diode-Based Analog Predistortion Linearizer for Solid-State Power Amplifiers

Kexin Song\textsuperscript{1,2,4}, Shengyang Lv\textsuperscript{3}, Zhifei Qin\textsuperscript{3} and Lei Xia\textsuperscript{3}

\textsuperscript{1}State Key Laboratory of Geo-information Engineering, Xi’an, China
\textsuperscript{2}Shanghai Aerospace Electronic Technology Institute, Shanghai, China
\textsuperscript{3}University of Electronic Science and Technology of China, Chengdu, China
\textsuperscript{4}Shanghai Academy of Spaceflight Technology Beijing R&D Center, Beijing, China
E-mail: sskkxx@263.net, xialei@uestc.edu.cn

Abstract: In this paper, a coplanar waveguide transmission type analog predistorter for the Ka-band (29-31GHz) solid-state power amplifier is developed and tested. Two Schottky diodes are adopted symmetrically connected between the main line of the coplanar waveguide transmission line and ground used as non-linear signal generating device. The measured results of the fabricated structure exhibited a gain comprehension greater than 3dB and more than 20 degree phase comprehension capability over 2GHz of bandwidth. As a result, measured 1dB compression point of the power amplifier can be significantly improved by 4.9dB at 30GHz.

1. Introduction
With the development of communication technology, especially the unprecedented demand of high datarates applications, the linearity requirements for power amplifiers are immensely desirable\cite{1-2}. However, with the increase of input power, the solid-state power amplifier will be in a large-signal operating state, which will produce significant amplitude and phase distortion (AM-AM and AM-PM). All kinds of linearization technique are often used under these circumstances to be developed to meet linearity requirements. Among them, analog predistortion technology is most widely used at higher frequencies\cite{3} with low cost, simple structure. This paper exhibits an Schottky diodes based analog predistorter. The predistorter uses a coplanar waveguide transmission structure to achieve gain expansion and phase compression in the Ka band (29-31GHz). Cascaded test with power amplifier, the output 1dB compression point has been significantly improved.

2. Circuit Structure
The schematic structure of the linearizer is shown in Figure 1:
The RF signal is fed from a microstrip line to coplanar waveguide. Two Schottky diodes connected in parallel to a coplanar waveguide transmission line. By adjusting the length of the coplanar waveguide transmission line and the Schottky diode bias voltage, we can get the required predistortion signal. The equivalent circuit model of the Schottky diode is shown as follows:

![Figure 2. Equivalent circuit model of Schottky diode](image)

The ABCD matrix of the Schottky diode equivalent model can be expressed as follows:

$$ T_D = \begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ G_d + j\omega C_j & 1 \end{pmatrix} $$

(1)

The ABCD matrix of a coplanar waveguide transmission line is:

$$ T_L = \begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} \cos \beta & j\omega Z_0 \sin \beta \\ j\omega Y_0 \sin \beta & \cos \beta \end{pmatrix} $$

(2)

Where $\beta$ is the phase constant of the passive transmission line, and $l$ is the length of the transmission line.

According to formulas (1) and (2), it can be obtained that the ABCD matrix of the two parallel diode integrated circuits connected through the coplanar waveguide is as follows:

$$ T = T_D1 \cdot T_L \cdot T_D2 = \begin{pmatrix} \cos \theta + jZ_0 Y_2 \sin \theta & jZ_0 \sin \theta \\ Y_1 \cos \theta + jY_0 \sin \theta + jY_1 Y_2 Z_0 \sin \theta + Y_2 \cos \theta & jY_1 Z_0 \sin \theta + \cos \theta \end{pmatrix} $$

(3)

Where $Y_1 = G_{d1} + j\omega C_{j1}$, $Y_2 = G_{d2} + j\omega C_{j2}$, $\theta = \beta \cdot l$, $C_j = wC_{j1}$, $\theta$ is the electrical length of the coplanar waveguide between two parallel Schottky diodes. The magnitude and phase of $S_{21}$ for the entire structure are:
\[ |S_{21}| = \frac{2}{\sqrt{X_0^2 + Y_0^2}} \]  
\[ \angle S_{21} = \tan^{-1}\left[ -\frac{Y_0}{X_0} \right] \]

where

\[ X_0 = 2\cos\theta + [(G_{d1}+G_{d2})\cos\theta - (C_1+C_2)\sin\theta - (G_{d1}C_2+G_{d2}C_1)Z_0\sin\theta]Z_0 \]
\[ Y_0 = 2\sin\theta + [(C_1+C_2)\cos\theta + (G_{d1}+G_{d2})\sin\theta + (G_{d1}G_{d2} - C_1C_2)Z_0\sin\theta]Z_0 \]

\[ C_1 = wC_{j1}, \quad C_2 = wC_{j2}. \]

The circuit gain and phase of two parallel diodes connected through a coplanar waveguide are not only affected by \( G_d \) and \( C_j \) in the diode equivalent model, but also related to the electrical length of the transmission line. Therefore, by selecting a suitable coplanar waveguide transmission line length and adjusting the Schottky diode bias voltage (the junction conductance in the Schottky diode equivalent model changes with the voltage), the predistortion signal required by the target can be obtained.

3. Realizing and Testing

The passive transmission line of the non-linear generator designed in this paper uses a coplanar waveguide structure, it is very easy to install the Schottky diodes (we use MA4E2038). The overall passive structure simulation model is shown in Figure 3.

![Figure 3. The overall structure simulation model](image1)

The manufactured sample is shown in figure 4, the size is about 3.5mm×2.2mm×1.2mm.

![Figure 4. Internal structure of analog predistorter](image2)

With a bias voltage of 1.7V, the measured performance of predistorter at different frequencies are as follows:
The gain of the analog predistorter is expanding and the phase is compressing. At the center frequency of 30GHz, the gain expansion is more than 3dB and the phase compression is more than 20 degree. The test block diagram of linearized amplifier is shown in Figure 6.
When the bias voltage is set as 1.7V, the measured SSPA output power curve after adding the analog predistorter compensation at different frequencies is compared with the SSPA output power curve without the analog predistorter. The output power verses input performance is shown in Figure 8.

The test results show that the output 1dB compression point has been significantly improved. The 1dB compression point output power and improvement before and after adding the linearizer are shown in table 1.
Table 1. SSPA, L-SSPA 1dB compression point output power and improvement

|       | 29GHz |       | 30 GHz |       | 31 GHz |       |
|-------|-------|-------|--------|-------|--------|-------|
| SSPA  | 35.5  | L-SSPA| 39.2   | 4.3   | SSPA   | 36.6  |
|       | dBm   |       | dBm    | dB    |       | dBm   |
|       | 39.2  | L-SSPA| 41.5   | 4.9   | SSPA   | 40.8  |
|       | dBm   |       | dBm    | dB    |       | dBm   |
|       |       |       | 4.3 dB |       | SSPA   | 4.7   |
|       |       |       |        |       | L-SSPA |       |
|       |       |       |        |       |        | dB    |

4. Conclusions
This paper developed an analog predistorter with coplanar waveguide transmission structure and two Schottky diodes, suitable for Ka-band (29-31GHz) SSPA. The linearizer has a simple structure and is easy to implement. It significantly improves the output 1dB compression point and improves the linearity of the solid-state power amplifier, which has important engineering practical value.

5. Acknowledgement
This research was financially supported by the Foundation of State Key Laboratory of Geo-information Engineering and the code is No.SKLGIE2017-K-3-1.

6. References
[1] M. Nakayama, T. Umemoto, Y. Itoh, T. Takagi, "1.9GHz High-Efficiency Linear MMIC Amplifier", Proceedings of 1994 Asia-Pacific Microwave Conference, pp. 347-350.
[2] T. Yokoyama, T. Kunihisa, H. Fujimoto, H. Takehara, K. Ishida, H. Ikeda, O. Ishikawa, "High-efficiency Low Adjacent Channel Leakage Power GaAs Power MMIC for 1.9GHz Digital Cordless Phones", IEEE Trans. on Microwave Theory & Tech., vol. 42, no. 12, pp. 2623-2628, December 1994.
[3] A. Katz, "Linearization: reducing distortion in power amplifiers," in IEEE Microwave Magazine, vol. 2, no. 4, pp. 37-49, Dec. 2001.
[4] X. Zhang, "Millimeter-Wave Predistortion Technology Research [D]. " University of Electronic Science and Technology of China, 2014.