This letter presents an analogue predistorter (APD) named Schottky diode (SD) and field effect transistor (FET)-paralleled APD (SDFP-APD) for the fifth-generation (5G) mobile system, which is composed of an FET paralleled with two SDs. The simulation results show that the APD (AD) module can generate predistorted signals by the SD modules. The FET module can generate predistorted signals by the best linearisation performance of the three APDs and reduce the error vector magnitude while applying a 100-MHz bandwidth 5G new radio signal. The proposed SDFP-APD can be a promising linearisation technique for 5G small-cell base stations.

Introduction: Linearity is the key indicator for the radio frequency power amplifier (RFPA), which determines the performance of the entire base station. Generally, the non-linear distortion would appear when the output power of the power amplifier (PA) is increased, which results in the quality degradation of the in-band signal and the out-of-band interference to the adjacent channels. To tackle the aforementioned problem, linearisation technique, in particular, the digital predistortion (DDP) [1] has been widely employed in the fourth-generation (4G) mobile system. However, with the recent arrival of fifth-generation (5G) mobile system, modulation bandwidth of the signal is wider than 100 MHz, which poses immense challenges to the indispensable analogue-to-digital converter (ADC) and digital-to-analogue converter (DAC) for the DPD. Moreover, the ADC, DAC and high-performance field-programmable gate arrays (FPGAs) adopted in the DDP bring additional power consumption, latency, and cost. In contrast, with advantages of broadband, low power consumption, low latency, and low cost [2], the analogue predistortion is very responsive to the demands of the 5G small-cell base stations. Recently, the analogue predistorters (APDs) based on Schottky diodes (SDs) or field effect transistors (FETs) have been reported [3, 4]. The SD-based APD (SD-APD) can work at very high frequency and ultra-broadband, but its action of the suppressing the inter-modulation distortions (IMDS) is not intense enough. The FET-based APD (FET-APD) can improve the third-order IMD, the fifth-order IMDs of the RFPA with the best linearisation performance among the three APDs and reduce the error vector magnitude while applying a 100-MHz bandwidth 5G new radio signal. The proposed SDFP-APD can be a promising linearisation technique for 5G small-cell base stations.

The SDFP-APD: The block diagram of the proposed SDFP-APD is shown in Figure 1, which consists of two modules, that is, the FET and the SD modules. The FET module can generate predistorted signals by adjusting the direct current (DC) bias of the FET to the non-linear region. According to the simplified equivalent circuit model, the FET can be expressed as a parallel combination of a capacitance (Cgd), a resistance (Rds), and a current source. The current source is a drain-source equivalent resistance (Rds) varying with Ib and Vd. The S21 of a FET-APD can be expressed as

\[ S_{21} = \frac{2}{2 + Z_0(G_d + jwC_{d})} \]  

where Z0 is the characteristic impedance of 50 Ω. It can be seen from Equation (1) that the FET-APD can achieve positive gain and positive phase expansion as Rs expands. In addition, we assume the electrical length of the microstrip line before the FET as \( \theta_1 \), which is marked in Figure 1. By adjusting \( \theta_1 \), the gain and the phase of the FET will compress or expand. When \( \theta_1 = 2\pi/9 \), the gain and the phase of the FET module will all expand, which can be applied to compensate for the compression of the RFPA.

The SD module consists of two parallel SDs, a bias network, and two DC blocks. The predistorted signal is generated by controlling the bias voltage of the SDs. Ignoring the parasitic parameters, an SD can be equivalent to a conductance \( G_d \) and a capacitance \( C_d \) paralleled. The S21 of an SD-APD can be expressed as

\[ S_{21} = \frac{2}{2 + Z_0(G_d + jwC_d)} \]  

where \( G_d = \partial I_d/\partial V_d = qI_d/nKT V_d^2 \) and \( Z_0 \) is the characteristic impedance of 50 Ω. K is the Boltzmann constant, q is the electron charge, \( I_d \) is reverse saturation current of SD, \( T \) is the absolute temperature (K), \( I_d \) is diode current. When the input power increases, the bias point of the diode will be changed and moved from the small-signal operating point to the large-signal operating point because of the voltage drop at the bias feed resistance R3 [7]. With the point movement, the node current \( I_2 \) of the diode increases and the node voltage \( V_2 \) decreases, and thus the conductance \( G_d \) decreases. Therefore, with the increase of the input power, the conductance \( G_d \) decreases. Accordingly, as shown in Equation (2), the S21 shows an expanding trend at the same time. Further, we assume \( \theta_2 \), which is marked in Figure 1, as the electrical length of the microstrip line before the SD. By adjusting \( \theta_2 \), the gain and the phase of the SD will compress or expand. When \( \theta_2 = \pi/3 \), the gain and the phase of the SD module will all expand. Therefore, the FET-APD and the SD-APD are all effective to expand the gain and the phase. Furthermore, combine FET-APDs and SD-APDs, as shown in Figure 1, can increase the gain and the phase expansion while making the circuit more adjustable. Moreover, due to the fact that different PAs have different non-linearity, the DC bias of the APD needs to be adjusted to meet the requirements of the different types of PAs.

Simulation validation: Figure 2 shows the simulation results of the amplitude modulation (AM)/AM and the AM/phase modulation of the RFPA with and without APD, that is, the RFPA output without APD, with FET-APD, with SD-APD and with SDFP-APD. The bias settings are exhibited in Figure 2. The RFPA model used in the simulation is the gallium nitride high electron mobility transistor CGH40010 (CREE) with an output power of 10 W. It can be seen that the phase is
Results: The experimental results are shown in Figures 4 and 5. The results illustrate that the adjacent channel leakage ratio (ACLR) of the RFP A is improved by 4.7, 7.2 and 11.8, respectively, by adding the FET-APD, SD-APD and SDFP-APD. Furthermore, after adding the SDFP-APD, the error vector magnitude (EVM) of the RFP A is improved from 5.93% to 3.42%. Table 1 exhibits the performance of some previously reported APDs, which indicates that the SDFP-APD is the most competitive among them in terms of the bandwidth and the modulation.

**Conclusions:**
An APD named SDFP-APD is reported in this letter. The simulation results indicate that the proposed SDFP-APD owns the best compression compensation among the SD-APD, the FET-APD and the SDFP-APD. Furthermore, the experimental results show that the SDFP-APD can not only improve the ACLR of the RFP A with the best linearity but also decrease the EVM with a simultaneous QPSK and 256-QAM 5G-NR signal, making the SDFP-APD a very promising linearisation technique for 5G small-cell base stations.

**References:**

Table 1. Performance comparisons of several analogue predistorters (APDs)

| Reference | Frequency (GHz) | Signal | Bandwidth (MHz) | ACLR improved |
|-----------|----------------|--------|----------------|---------------|
| [3]       | 2.14           | WCDMA  | 20             | 16.4 dB       |
| [4]       | 2.4            | WCDMA  | 5              | 13 dB         |
| [5]       | 23             | 64-QAM | 10             | 6 dB          |
| [6]       | 75.75          | 64-QAM | 250            | 5 dB          |
| FET-APD   | 3.5            | 5G-NR  | 100            | 4.7 dB        |
| SD-APD    |                |        |                | 7.2 dB        |
| SDFP-APD  |                |        |                | 11.8 dB       |

Abbreviations: FET is field-effect transistor, SD is Schottky diode, ACLR is adjacent channel leakage ratio, NR is new radio, QAM is quadrature amplitude modulation, WCDMA is wideband code division multiple access.
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