A Ka-band 2-Stage Transformer Coupled Power Amplifier in 0.13μm SiGe BiCMOS Technology

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A Ka-band 2-Stage Transformer-Coupled Power Amplifier in 0.13-μm SiGe BiCMOS Technology

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***Abstract*—This paper presents a 30-to-40 GHz 2-stage power amplifier (PA) for 5G applications. Transformers are used to achieve a broad input, output and interstage matching while occupying a compact size. The neutralization technique is used to boost the power gain and improve stability of PA. According to the simulation results, the power amplifier achieves an output 1dB compression point (OP_{1dB}) of 14.9 dBm and a saturated output power of 17.4 dBm with a peak power added efficiency (PAE) of 39% at 35 GHz. The gain is larger than 30 dB from 30-40 GHz. Implemented in a 0.13-μm SiGe BiCMOS process, the overall chip size is 0.46 mm^2 including all RF and DC pads.**

Keywords—Ka-band, power amplifier (PA), transformer, SiGe BiCMOS, neutralization.

I. Introduction

With the rapid development of wireless communication, millimeter wave communication systems with high-speed data rates have received widespread attention in recent years. Power amplifier (PA) is a crucial component in modern phased-arrays which is widely used in modern communication systems. In order to achieve high-level system integration, silicon-based technology is a suitable choice to implement PA. Recently, several silicon-based power amplifiers have been reported. Stacked transistors are widely used to increase the output power of PA. Fabricated in 45nm SOI CMOS process, a stacked PA achieves a saturated output power of 24.8 dBm and a peak PAE of 26% at 29 GHz [1]. Power combining technique can be used to boost the output power. A Wilkinson-Lange combiner was proposed to achieve a robust output power as well as a good isolation for each port [2]. However, due to the long inter connection line the combiner is not suitable for broadband applications. Transformer coupled power amplifier is popular due to their high power transfer efficiency and compact size [3].

In this paper, we present a Ka-band transformer coupled power amplifier in a 0.13-μm SiGe BiCMOS process. The designed power amplifier achieves a saturated output power of 17.4 dBm with a peak PAE of 39% at 35 GHz. The gain of the PA is more than 30 dB across 30-to-40 GHz.

II. Circuit Analysis

The schematic of the proposed power amplifier is shown in Fig. 1. Differential structure is preferred especially in high frequency as it is less sensitive to the layout parasitic due to the virtual ground. Neutralization technique is used to boost the power gain and enhance stabilities of the PA [4]. Three transformers are used for input, interstage and output matching to ensure a high performance in broad frequency band. In addition, the power supply can be biased through the center tap of the transformers while have a little impact on performance. Large resistors are added between the base of transistors to further improve the amplifier stabilities. All transformers are optimized by careful EM simulation.

A. Neutralization technique

The parasitic feedback capacitor (C_{bc}) of a BJT deteriorates the power gain and reverse isolation, and causes instability. For a differential amplifier this effect can be easily canceled by adding a neutralized capacitor (C_N) as shown in Fig. 2 (a) and (b). In this design, C_N is implemented with mental-insulator-mental (MIM) capacitor. Fig. 2 (c) shows the maximum power gain (G_{max}) and stability factor (K_f) of the PA driver stage with 12×0.12 μm^2 transistors. Finally, a C_{N1} of 28.8 fF is adopted in driver stage to make a trade-off between gain and stability. The C_{N2} of 47.2 fF is chosen in power stage with its transistor size of 24×0.12 μm^2 to boost the performance of the PA. In addition, large resistors (R) are used to further enhance the stability.

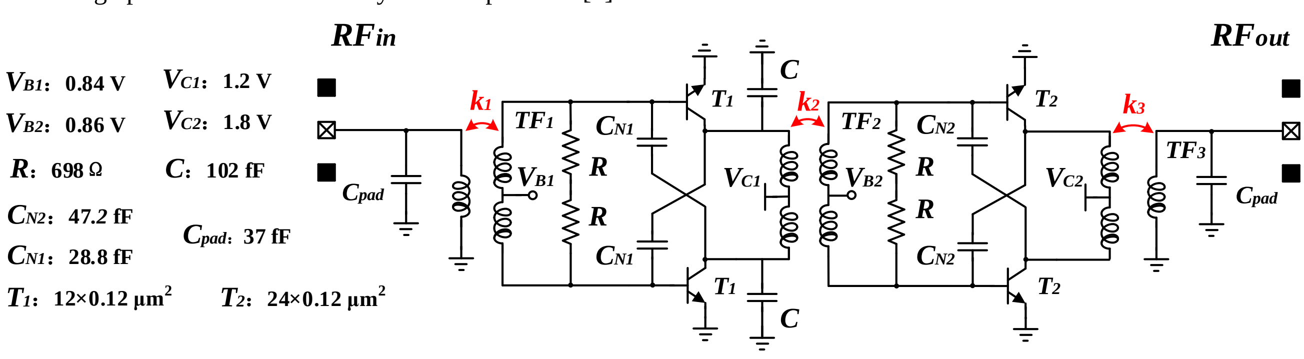
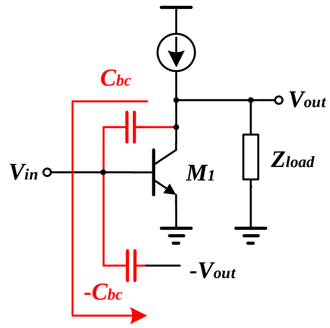
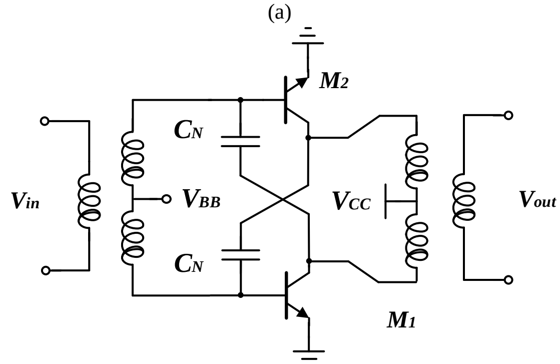


Figure 1. The schematic of the proposed Ka-band transformer coupled power amplifier.

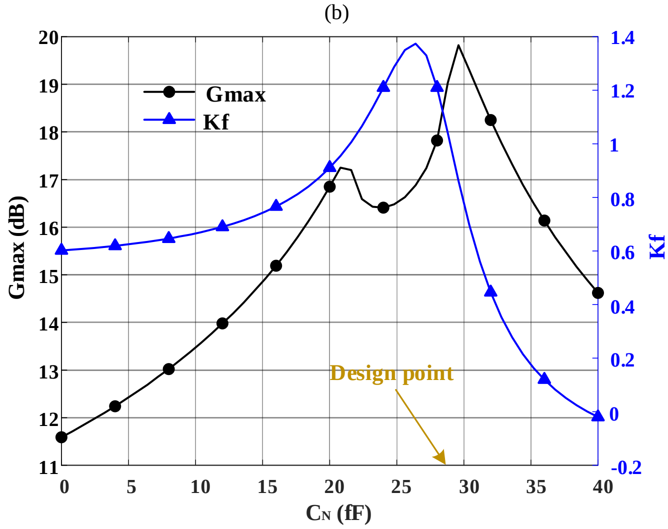
coefficient k and maximum power transfer efficiency η_{max} versus frequency of the output transformer. We can find that a high power transfer efficiency can be achieved and it also realizes the load impedance (50Ω) transformation to optimal load impedance (Z_{opt}) which is the power contour and PAE contour trade-off in Smith Chart.



(a)



(b)



(c)

Figure 2. (a) Neutralization technique. (b) Neutralization in a differential amplifier. (c) Simulated maximum power gain (G_{max}) and stability factor (K_f) versus neutralization capacitor (C_N) values.

B. *Tansformer design*

Transformer is extensively used in the mmwave amplifier designs because they simplify routing, ensure a compact layout and thus reduce the losses of extra interconnects [4]. Transformers can be used for the broad band input and output matching of differential amplifiers, and it can also complete single-ended signal and differential signal mutual conversion. Compared to traditional *LC* impedance matching networks, transformer has been proved to have better power transfer efficiency [4] which is especially crucial in PA output stage designs. Fig. 3 shows the maximum power gain G_{max}, coupling

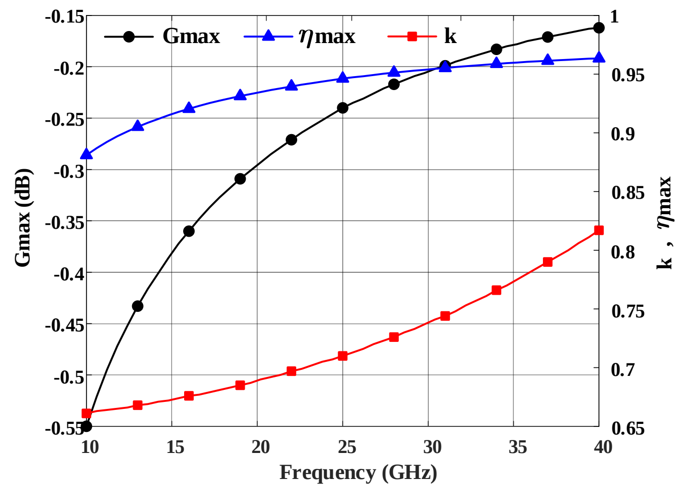


Figure 3. Simulated maximum gain G_{max}, coupling coefficient k and maximum power transfer efficiency η_{max} of the output transformer

III. Simulation Results

The proposed Ka-band PA is implemented in 0.13 µm SiGe BiCMOS technology. The simulated S-parameters are shown in Fig. 4. The power gain S_{21} of PA achieves more than 30 dB with a flatness of less than 2 dB from 30-40 GHz. The input return loss is greater than 8 dB and the output return loss is greater than 6 dB. The large signal behavior of the PA is shown in Fig. 5. The PA achieves an output 1dB compression point OP_{1dB} of 14.9 dBm and a saturated output power P_{sat} of 17.4 dBm. The peak power added efficiency (PAE_{peak}) and 1dB compression power added efficiency (PAE_{1dB}) are 39% and 35% at 35 GHz respectively. Table I shows the comparison of the proposed PA with previous reported PAs.

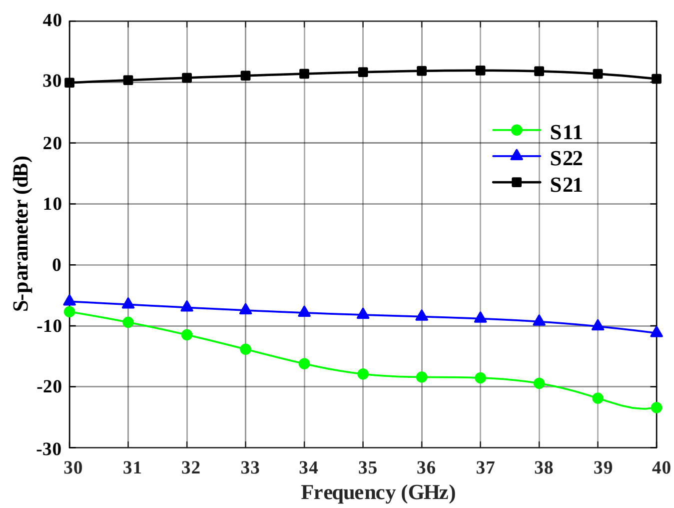


Figure 4. Simulated S-parameter of the proposed PA

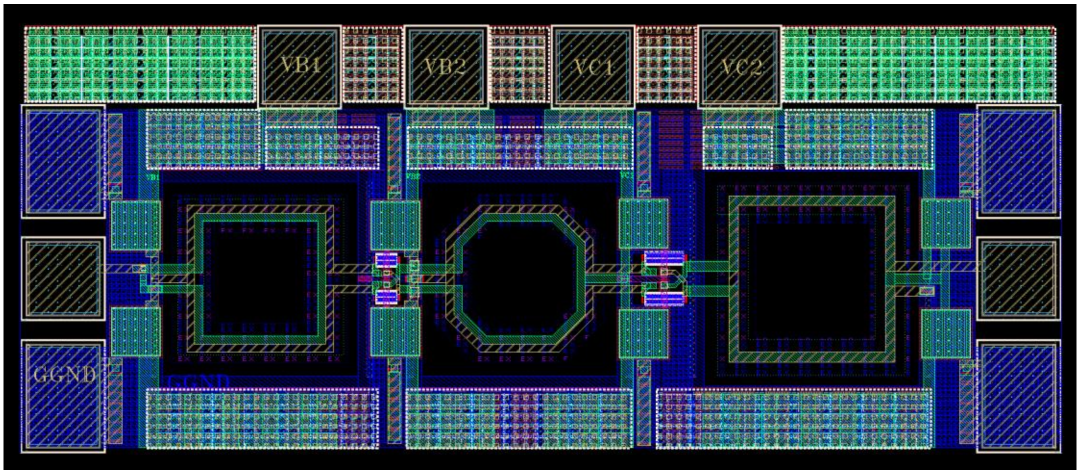


Figure 6. The layout of the proposed Ka-band power amplifier

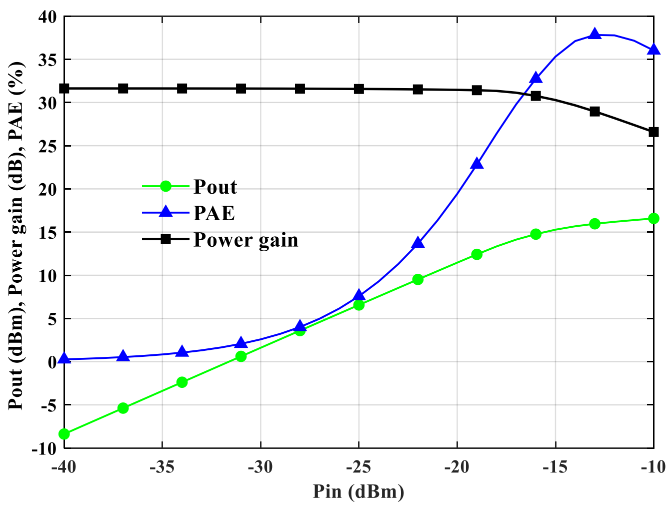


Figure 5. Simulated power gain, PAE and output power versus input power of the power amplifier at 35 GHz

TABLE I

PERFORMANCE SUMMARY AND COMPARISON

Reference	[5]	[6]	[7]	**This Work***
Technology	65 nm CMOS	0.13 µm SiGe	0.13 µm SiGe	**0.13 µm SiGe**
Frequency (GHz)	38	38	37	**35**
Gain S_{21} (dB)	17.6	16.5	17.1	**31**
OP_{1dB} (dBm)	21.7	15	15.5	**14.9**
P_{sat} (dBm)	24.8	16.5	17.1	**17.4**
PAE_{peak} (%)	24.3	38.5	22.6	**39**
Area (mm^2)	0.15	0.5	1.755	**0.46**

*Simulation result

IV. CONCLUSION

A Ka-band 2 stage transformer coupled power amplifier is implemented in 0.13 µm SiGe BiCMOS technology for the 5G applications. This power amplifier is based on a differential structure which is less sensitive to the layout parasitic. The neutralization technique is used to boost the power gain and improve stabilities. Transformers are used for broad band input, output and interstage matching. The output transformer is optimized to achieve maximum power transfer efficiency. The simulation results show that it can be used in many 5G communication systems.

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