A 1-Watt Ku-Band Power Amplifier in SiGe with 37.5% PAE

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***Abstract* — This paper demonstrates a 1-Watt output power amplifier MMIC operating from 13.5GHz to 14.5GHz (Ku-band). The power amplifier employs an on-chip integrated 16-way in-phase output current combiner to achieve the required output power. Implemented in a 0.25-µm SiGe:C BiCMOS technology, the power amplifier achieves a power-added efficiency of 37.5% at 14.1GHz with greater than 35.5% across the band of interest.**

***Index Terms* — PA, SiGe, Ku-band, PAE, power combine**

I. Introduction

The Ku-band is currently widely used for a number of wireless applications such as the very-small-aperture terminal (VSAT), the point-to-point and point-to-multi-point radios. In addition, the frequency band from 14GHz to 14.5GHz is recently proposed by the Federal Communications Commission (FCC) to boost in-flight WiFi speed with air-to-ground wireless services. Traditionally these markets are dominated by costly III-V technologies such as GaAs because of their high output power capabilities. Recent researches demonstrate great interest to implement high power Ku-band power amplifiers (PAs) in SiGe technology, which allows a lower cost and a higher integration capability [1]-[4]. However, compared to existing GaAs PAs, either their output powers are not sufficient or their power-added efficiencies (PAEs) are too low.

In this work, a 1-Watt (or 30dBm) PA operating at Ku-band from 13.5GHz to 14.5GHz is demonstrated in a 0.25-µm SiGe:C BiCMOS technology with a PAE of 37.5% at 14.1GHz. The proposed PA achieves the highest output power with the highest PAE across X- and Ku-band in a Si-based technology. To the best of our knowledge, this is the first time that a Si-based Ku-band PA demonstrates a performance comparable to GaAs solutions.

II. PA Design

The Ku-band PA with a single stage is designed by combing outputs from 16 unit-cell PAs to achieve 1W output power (Fig. 1). Each unit-cell PA is designed using a low-voltage common-emitter (CE) device and a high-voltage common-base (CB) device in a cascode topology. Biased in class-AB mode with a 5V supply, an optimal load impedance of 36+j48 Ω is simulated for the unit-cell PA.

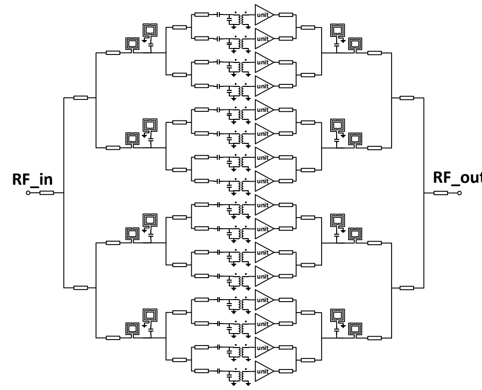

Fig. 1. Proposed Ku-band PA with 16-way output combiner.

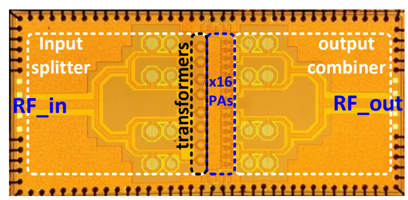

Fig. 2. Die photo of the PA.

The outputs from the unit-cell PAs are combined in-phase in the current domain by a 16-way output combiner. The output combiner also provides the load-line matching to transform the 50Ω to the optimal load seen by the 16 unit-cell PAs. Inductors are used in the output combiner to reduce the total length of the transmission lines. As compared to a pure λ/4 transmission line based solution, a lower combining loss with a compact size is achieved by optimizing the inductor values and losses. The simulated loss of the output combiner at 14GHz is 1.5dB. A 16-way input splitter is used to equally divide the input power to each unit-cell PA, and at the same time conjugate match the input impedance to 50Ω. A similar approach using inductors is applied to the input splitter design. However, due to a larger input transformation ratio, additional transformers are added just before the unit-cell PAs.

III. Measurement Results

The PA is fabricated in a 0.25-µm SiGe:C BiCMOS technology with a peak ft/fmax of 216/177GHz (Fig. 2). The collector-emitter break-down voltage BV_{CEO} is 1.45V for the low-voltage NPN device and 2.8V for the high-voltage NPN device. The chip area is 4.5mm×2.1mm. The

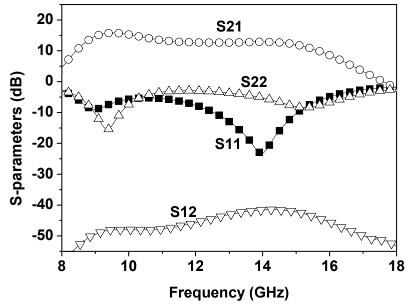

Fig. 3. Measured S-parameters of the PA.

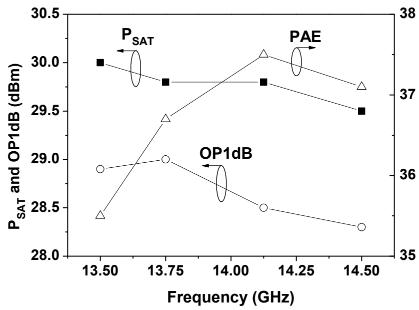

Fig. 4. Measured P_{SAT}, OP1dB and PAE.

RF measurements were carried out by probing on the RF input and output pins with the rest of the pins wire-bonded to a test board. Fig. 3 shows the measured small-signal S-parameters. The small-signal gain (S21) is 12.8dB (+/-0.1dB) between 13.5GHz and 14.5GHz. The input return loss (S11) is better than -16dB within the band of interest. Due to the load-line matching instead of conjugate matching, the output return loss (S22) within the band is between -4.5dB and -6.7dB. Fig. 4 shows the measured saturated output power (P_{SAT}), OP1dB and PAE as a function of frequency. The P_{SAT} varies between 29.5dBm and 30dBm, while OP1dB varies between 28.3dBm and 29dBm. The PAEs are greater than 35.5% over the whole band of interest with a maximum PAE of 37.5% at 14.1GHz. Fig. 5 shows the measured output power, gain and PAE versus the input power at 14.1GHz, where a saturated gain of more than 10dB is achieved.

Table I compares the performance with other state-of-the-art X- and Ku-band PAs in different technologies. The proposed PA outperforms other Si-based PAs with the highest P_{SAT} and the highest PAE. To the best of our knowledge, this is the first time that a Si-based Ku-band PA demonstrates a performance comparable to GaAs solutions.

V. Conclusion

A 1-Watt Ku-band power amplifier MMIC has been demonstrated with a PAE of 37.5%. The high output power is achieved with an integrated 16-way output combiner.

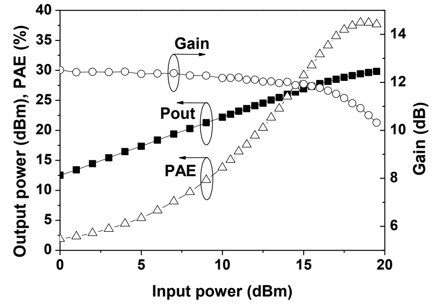

Fig. 5. Measured output power, gain, and PAE versus input power at 14.1GHz.

TABLE I

Performance Comparison With X- and Ku-Band PAs

Ref.	Freq (GHz)	OP1dB (dBm)	P_{SAT} (dBm)	PAE (%)	Tech.
[1]	14	21	24.5	29.1	SiGe
[2]*	8.5-10.5	28.3	29.3	18	SiGe
[3]	8-12	27.8	29.5	17.8	SiGe
[4]*	11-13	20.4	23.4	37.3	SiGe
[5]	8	22.6	25.2	21.6	CMOS
[6]	9-15	21.9	22.8	21.8	CMOS SOI
[7] (product)*	12.5-17	-	33.5	30	GaAs
[8] (product)*	12.5-15.5	30	31.5	31	GaAs
This work	13.5-14.5	29	30	37.5	SiGe

*Packaged die

Acknowledgement

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References

[1] Y. S. Noh, M. S. Uhm, I. B. Yom, "A Compact Ku-Band SiGe Power Amplifier MMIC With On-Chip Active Biasing," *IEEE MWCL*, vol. 20, no. 6, pp. 349-351, Jun. 2010.

[2] J. Andrews, et al., "A 840 mW X-Band SiGe Power Amplifier," in *IEEE BCTM*, Oct. 2008, pp. 109-112.

[3] C. Liu, et al., "An 890 mW Stacked Power Amplifier using SiGe HBTs for X-band Multifunctional Chips," in *IEEE ESSCIRC*, Sep. 2015, pp. 68-71.

[4] S. Gerlich, P. Weger, "Highly Efficient Packaged 11-13 GHz Power Amplifier in SiGe-Technology With 37.3% of PAE," *IEEE MWCL*, vol. 23, no. 10, pp. 539-541, Oct. 2013.

[5] H. Wang, C. Sideris, A. Hajimiri, "A 5.2-to-13GHz Class-AB CMOS Power Amplifier with a 25.2dBm Peak Output Power at 21.6% PAE," in *IEEE ISSCC*, Feb. 2010, pp. 44-45.

[6] J.-H. Chen, et al., "A Wideband Power Amplifier in 45 nm CMOS SOI Technology for X Band Applications," *IEEE MWCL*, vol. 23, no. 11, pp. 587-589, Nov. 2013.

[7] Triquint, "http://www.triquint.com/products/p/TGA2510-SG," TGA2510-SG datasheet.

[8] Triquint, "http://www.triquint.com/products/p/TGA2527-SM," TGA2527-SM datasheet.