Design of a 0.18-μm BiCMOS PA with Concurrent and Non-concurrent Operations in 10-19, 23-29 and 33-40 GHz Bands

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***Abstract* — A tri-band power amplifier (PA), that can operate concurrently or non-concurrently in Ku-, K-, and Ka-band, is designed using a 0.18-μm SiGe BiCMOS process. The tri-band PA is based on the distributed amplifier structure, which incorporates negative-resistance active notch filters for improved tri-band gain response. It exhibits measured small-signal gain around 15.4, 14.7, and 12.3 dB in the low-band (10-19 GHz), mid-band (23-29 GHz), and high-band (33-40 GHz), respectively. It can work in single-, dual-, and tri-band modes. In the tri-band mode, it exhibits measured 8.8/5.4/3.8 dBm maximum output power at 15/25/35 GHz. The tri-band PA has relatively flat responses in gain and output power across three different frequency bands, and good matching up to 40 GHz.**

Index Terms — Distributed amplifier, multi-band power amplifier, power amplifier, RFIC.

I. Introduction

Multiband RF systems provide numerous advantages as compared to their single-band counterparts for communications and sensing. Concurrent multiband power amplifiers (PAs) are the most important component in concurrent multiband transmitters. Concurrent multiband PAs are designed to support multimode (or concurrent mode) in which multiband signals occur simultaneously. Various approaches for multiband PAs have been reported [1]-[6]. The PAs in [1]-[4], however, do not support concurrent modes. The PAs in [5] and [6] provide concurrent operations. They are based on multiband input and output matching networks realized using inductors, capacitors, and resistors, which lead to increased insertion loss, especially for inductors on silicon substrates, and large size when many of them are used. Concurrent multiband PAs with less passive elements in matching networks are preferred for optimum performance and size.

In this paper, we report a new tri-band PA that can work concurrently or non-concurrently in three different bands of 10-19 GHz, 23-29 GHz and 33-40 GHz. The tri-band PA is based on the distributed amplifier structure and realized using a 0.18-μm SiGe BiCMOS process. Specifically, the tri-band PA implements active notch filters having negative-resistance property, instead of tri-band matching networks, to achieve the concurrent tri-band operation with improved tri-band gain response resulted from increased quality factor (Q).

II. Concurrent Tri-band PA Design

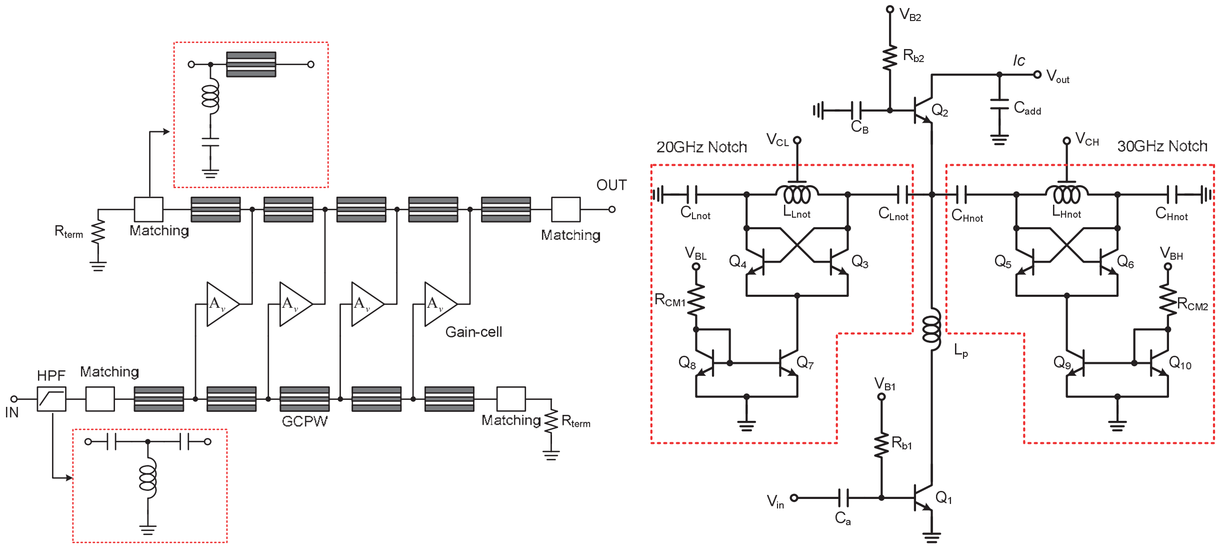
Fig. 1 shows the schematic of the tri-band PA designed based on the DA approach, which operates concurrently in three separate bands of 10-19, 23-29 and 33-40 GHz, and one of its gain cells. It consists of a high-pass filter (HPF) at the input, multiple gain cells, and grounded conductor-backed coplanar waveguide (GCPW) simulating inductive transmission lines. Each gain cell consists of a peaking cascode gain unit and two active notch filters at 20 and 30 GHz.

A. Active Notch Filter with Negative Resistance

The tri-band response can be realized by incorporating notch filters at the desired stop-bands. Passive notch filters on silicon normally have low-Q inductors, which lead to high insertion loss, limited rejection, and large size. To overcome this problem, negative-resistance circuits, whose negative resistance compensates for the loss and hence improves the Q of the inductors, could be used. To generate a negative resistance needed to enhance the inductor's Q, a cross-coupled pair of two BJTs is used as shown in Fig. 1(b). Two active notch filters with negative-resistance cross-coupled BJT circuits as shown in Fig. 1(b) are designed to have resonance frequencies of 20 and 30 GHz.

B. Tri-band PA

Fig. 1(a) shows the schematic of the tri-band PA. A simple HPF is used in front of the input synthetic transmission line to suppress undesired gains at low frequencies below 10 GHz. Four identical gain-cells, A_v, are employed along with the GCPW to form the required input and output synthetic transmission lines. Fig. 1(b) shows the schematic of each designed gain cell. The gain cell is based on a cascode structure with gain-peaking series inductor incorporating two active notch filters at 20 and 30 GHz. The active notch filters provide the necessary tri-band function with good response for the tri-band PA. The input series capacitor (C_a) helps reduce the total input capacitance of the gain-cell unit and enables large device periphery to be used, hence resulting in improved power handling capability. Four transistors, each having



(a) (b)

Fig. 1. Schematic of the concurrent tri-band PA (a) and its gain cell (b).

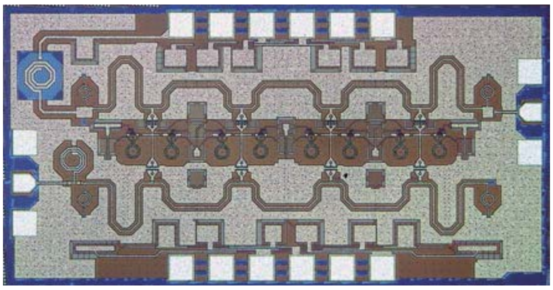


Fig. 2. Photo of the concurrent tri-band PA.

0.15µm emitter width and 4.52µm emitter width, are combined to generate each device (Q_1 or Q_2) in the cascode cell. The additional shunt capacitor (C_{add}) is used at the output node to achieve phase matching between the input and output synthetic transmission lines. Fig. 2 shows a photograph of the concurrent tri-band PA fabricated using Jazz 0.18-µm SiGe BiCMOS process [7], which occupies a die size of 2mm×1mm including the RF and DC pads.

III. Performance of Tri-Band PA

Small-signal S-parameters and large-signal responses were simulated and measured on-wafer. The large-signal characterizations include single-, dual-, and triple-band modes in which signals in one, two, and three bands were used as the input signals, respectively.

A. Small-Signal Performance

Fig. 3 shows the simulated and measured S-parameters of the tri-band PA, which show good agreements between them. Table I summarizes the results. Decent gains and input and output matching are obtained in the three frequency bands. The simulation and experimental results for tri-band mode, combined 15/25/35 GHz as the input signal, are shown in Fig.

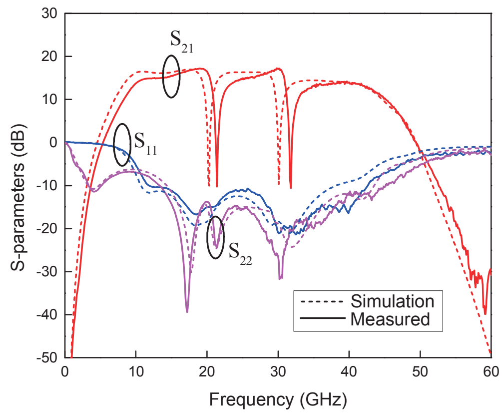
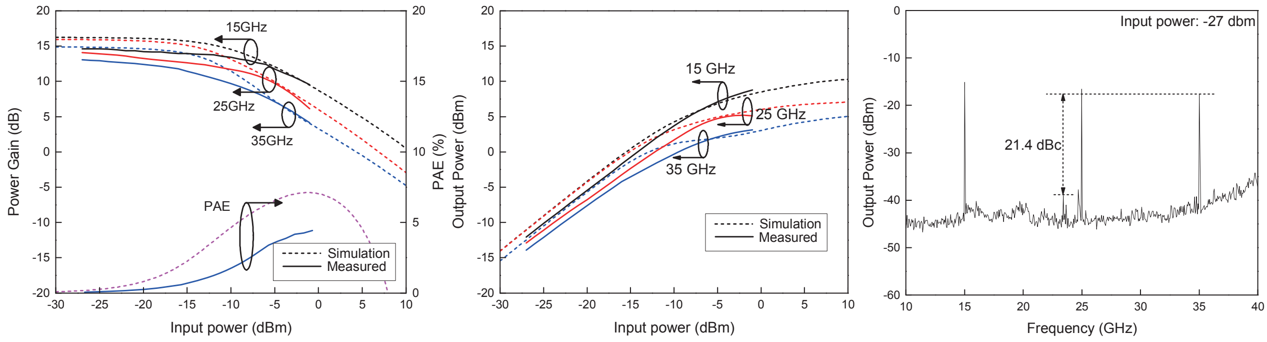


Fig. 3. Measured and simulated S-parameters.

4. The measured results show $P_{out,max}$ of 8.8, 5.4, and 3.8 dBm, P_{1dB} of 2.9, -5, and -4.9 dBm at 15, 25, and 35 GHz, and maximum PAE of 4.4% at -1-dBm input power, respectively. Fig. 4(c) shows the measured frequency spectrum of the output signal, showing more than 21 dB suppression of unwanted signals. It is noted that the maximum available input power is limited at -1 dBm due to the limited output power from available sources and use of the 13-dB coupler for signals combination, hence resulting in less output power and PAE. Table II summarizes the performance under the tri-band operation.

IV. Conclusion

The design of a 0.18-µm SiGe BiCMOS tri-band PA working concurrently or non-concurrently at 10-19, 23-29, and 33-40 GHz has been presented. The tri-band PA utilizes the distributed amplifier topology with capacitive coupling to increase the power handling capability. It also implements gain cells with series peaking inductor for enhanced gain peaking. Particularly, the tri-band PA incorporates two active



(a) (b) (c)

Fig. 4. Performance for the 15/25/35GHz concurrent tri-band mode: measured and simulated power gain and PAE (a) and output power (b), and measured frequency spectrum at -27-dBm input power (c).

TABLE I

SUMMARY OF MEASURED AND SIMULATED S-PARAMETERS

	Gain (S_{21})		
	Low-Band (10-19 GHz)	Mid-Band (23-29 GHz)	High-Band (33-40 GHz)
Simulation (dB)	15.5-16.1	15.3-16.1	13.9-14.2
Measured (dB)	13.7-17.1	13-16.4	10.6-13.9
Gain Variation	< 1.8 dB 0.9dB at 15GHz	< 2.3 dB 1.4dB at 25GHz	< 3.3 dB 1.2dB at 35GHz

	Measured Input and Output Matching
S_{11}	< −10 dB between 11.8 GHz and 42.6 GHz
S_{22}	< −10 dB between 13 GHz and 46 GHz

TABLE II

SUMMARY OF TRI-BAND PERFORMANCE

		15GHz	25GHz	35GHz
$P_{out,max}$ (dBm)	Simulation	10.3	7.1	5
	Measured	8.8	5.4	3.8
P_{1dB} (dBm)	Simulation	2.5	0.9	-1
	Measured	2.9	-5	-4.9
Max. PAE (%)	Simulation	7.1 at -1 dBm input		
	Measured	4.4 at -1 dBm input		

notch filters having negative resistance in each gain cell to enhance the *Q* of the notch filters to produce good tri-band gain response. The tri-band PA exhibits fairly flat responses in gain and output power across the designed three bands and good input and output matching up to 40 GHz. It can operate in tri-band as well as dual-band and single-band modes. The tri-band PA should be attractive for tri-band communication and sensing systems operating in Ku, K and Ka bands. The concurrent tri-band design technique can be extended for other multiband distributed PAs and circuits involving more than three bands at different frequencies.

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