

# Concurrent Tri-Band GaN HEMT Power Amplifier Using Resonators in Both Input and Output Matching Networks

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**Abstract**— This paper presents a novel method by using resonators in both input and output matching networks to design a tri-band GaN HEMT power amplifier. Two parallel resonators in series as one frequency selection element are used for each operation frequency. By applying this frequency selection element in both input and output matching networks constructed with microstrip line, tri-band matching network is realized. With our proposed frequency selection element, we can use the conventional L-type structure to design matching network for three frequencies so that the design analysis procedure is easier. We also propose a new simplified output matching network by using bias line to match the output impedance to reduce the number of resonators. To demonstrate our method, we fabricate a tri-band power amplifier that can work at 1 GHz, 1.5 GHz, and 2.5 GHz concurrently. Experimental results show that the output power is 39.8 dBm, 40.8 dBm, and 39.2 dBm with 56.4%, 58.3%, and 43.4% power added efficiency (PAE) at 1 GHz, 1.5 GHz and 2.5 GHz, respectively.

**Keywords**—multi-band; resonator; matching network; power amplifier; power added efficiency

## I. INTRODUCTION

With the trend of co-existence and interoperability between dissimilar standards, such as wireless local area networks (WLANS) and the global systems for mobile communication systems (GSM), multi-band mobile and satellite communication system will be widely required in future wireless networks. Power amplifier is certainly required for multi-band operation.

In previous works, to realize multi-band operation, technologies of diplexers [1]-[2], switched elements [3]-[5], and electronically tunable elements [6] are explored for multi-band power amplifier design. Toggle between different matching networks, adjustment of tunable components is required when frequency changes and these solutions are unable to offer simultaneous operation [7]. To reduce the size of circuit and to save component cost, especially for active component, we need to design a versatile matching network circuit to realize multi-band operation concurrently. One concurrent dual-band power amplifier has been presented before [8], in this work, we have improved the dual-band matching network for tri-band operation.

In the same bias condition, different frequency could have different impedance point in the smith chart for maximum PAE or maximum output power according to the loadpull simulation. Therefore, conventional single band L-type matching network cannot be applied for multi-band requirement. In this paper, we will propose a tri-band matching network by applying resonator group as frequency selection element as shown in Fig. 1 (d). The frequency selection element can reject two undesired specified operation frequencies while pass the signal generated at the remaining operation frequency. With this element, we can apply the simplest L-type matching network structure for tri-band application. To demonstrate our proposed multi-band design method, the operation frequencies in this paper we chose are  $f_1$  (1 GHz),  $f_2$  (1.5 GHz) and  $f_3$  (2.5 GHz).

In section II, we will present the topology and principle of our proposed multi-band structure including the simplified structure for load matching network based on the original proposed multi-band matching network. Fabrication and measurement analysis is discussed in section III.

## II. PROPOSED TRI-BAND TOPOLOGY

To realize tri-band operation, we employ parallel resonator circuit or parallel LC circuit as the frequency selection element in both input and output matching network. As Fig. 1 (a) shows, one parallel resonator circuit designed for frequency  $f_1$  contains one capacitor  $C_1$  and one inductor  $L_1$ . The resonant frequency can be calculated by (1), where  $C$  is capacitance of capacitor and  $L$  is inductance of inductor. In Fig. 1(d), signal generated at frequency  $f_x$  and frequency  $f_y$  is blocked by the resonator whose resonant frequency is  $f_x$  and  $f_y$ , respectively, while signal generated at  $f_z$  can pass through the frequency selection element. In Fig. 2, the simulation results of three designed parallel resonator circuits by using models (Fig. 1 (a), (b) and (c)) are shown. At three resonant frequencies  $f_1$ ,  $f_2$ , and  $f_3$  of each resonator circuit, insertion loss is more than 20 dB as shown in Fig. 2. Signal generated at these resonant frequencies can be blocked effectively. Insertion loss at the other two operation frequencies, except the resonant frequency, is better than 1 dB. Each designed resonator circuit practically not blocks the signals generated at the other two operation frequencies.

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

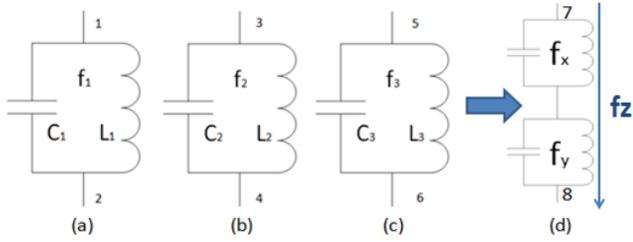


Figure 1. Parallel resonator circuits for frequencies  $f_1$  (a),  $f_2$  (b), and  $f_3$  (c). (d) Frequency selection element.

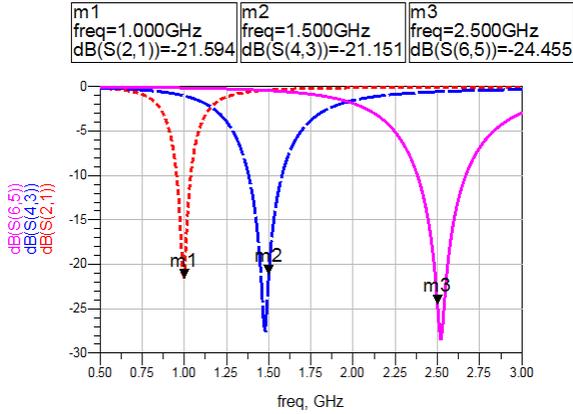


Figure 2. Simulation results of three designed parallel resonator circuits by using models for 1 GHz (dot line), 1.5 GHz (dash line) and 2.5 GHz (solid line).

In loadpull simulation, for different frequency, the impedance point of maximum PAE or maximum output power of input or output matching network is different. Fig. 3 shows the proposed topologies for both source and load tri-band matching networks by applying resonator groups. In these figures, each frequency selection element contains two parallel resonator circuits. By these resonator groups, each shunt microstrip line in Fig. 3 can affect only one specific frequency. With this characteristic, impedance at each frequency can be matched to 50 Ohm independently. For example, in Fig. 3 (a), the right side of the circuit in source matching network has two parallel resonators and one open stub. Signal generated at  $f_3$  can pass this frequency selection element to the stub directly, while signal generated at frequency  $f_1$  and  $f_2$  is blocked by this element. The same idea is adopted for the middle and left side of the circuit in this source matching network. With this characteristic, tri-band function in a single source matching network is realized.

For 1 GHz, the optimum load impedance is  $35.7 + j*17.25$  ohm as shown in Fig. 4. The bias circuit is applied to be part of the matching network for 1GHz. The structure of load matching network at 1 GHz is shown in Fig. 5 (a). For the other frequencies, resonator groups are employed to realize the multi-band matching network as explained in Fig. 3. The left resonator group, which resonates at 1 GHz ( $f_1$ ) and 1.5 GHz ( $f_2$ ) in Fig. 5 (b), couples the shunt line to the main transmission line when the frequency is 2.5 GHz ( $f_3$ ), so that matches the impedance at  $f_3$  to 50 Ohm. Same structure is

adopted for the 1.5 GHz ( $f_2$ ). Hence, the concurrent tri-band matching network is achieved. The layout of the whole proposed tri-band power amplifier is shown in Fig. 6.

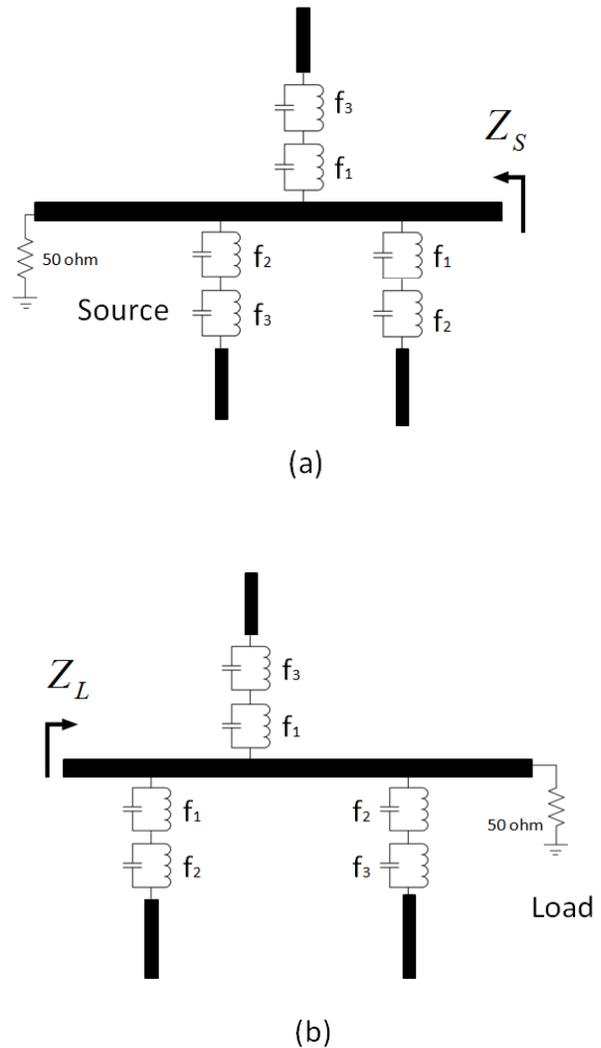


Figure 3. Proposed tri-band input (a) and output (b) matching networks using resonators.

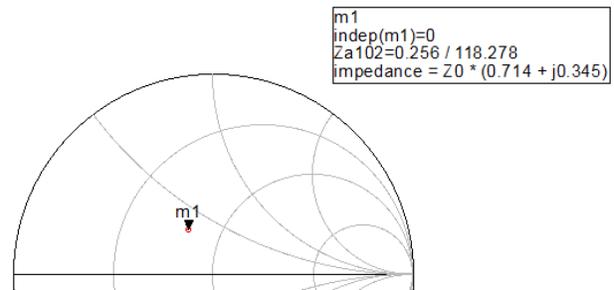


Figure 4. Load matching network impedance point chosen for 1 GHz.

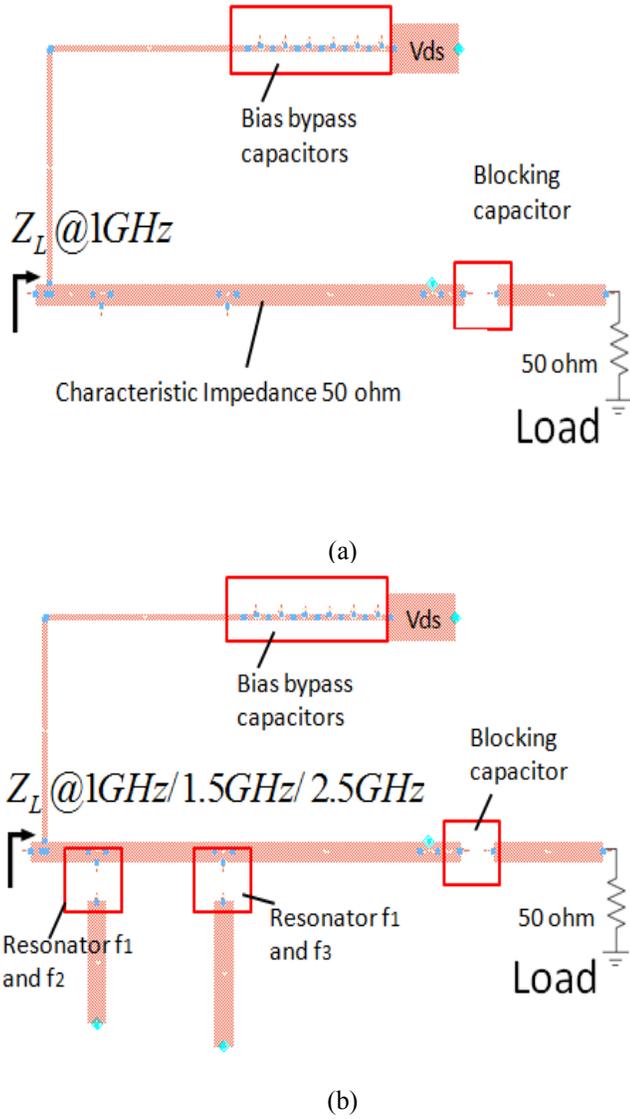


Figure 5. Advanced design of load matching network. (a) Designed topology for 1 GHz; (b) Proposed tri-band load matching network.

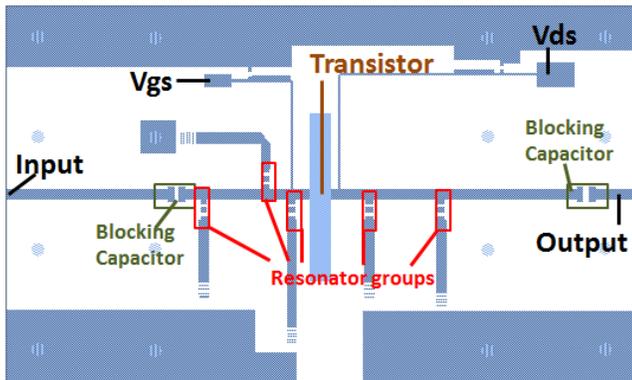


Figure 6. Layout of proposed tri-band power amplifier.

With the topology designed for 1 GHz by using bias circuit as a part of matching network, we reduce the number of frequency selection elements, and compactness is kept. Fig. 7 (a) shows the momentum simulation result of the impedances of input matching network at different operation frequencies. Load resistance and characteristic impedance is 50 ohm. By tuning the length of series and shunt microstrip lines at frequencies  $f_1$ ,  $f_2$ , and  $f_3$ , we got the expected impedance values for source, marked with mark m1, m2, and m3, respectively. With the same procedure, at Fig. 7(b), we tuned the load matching network impedances to the desired impedances at three operation frequencies separately.

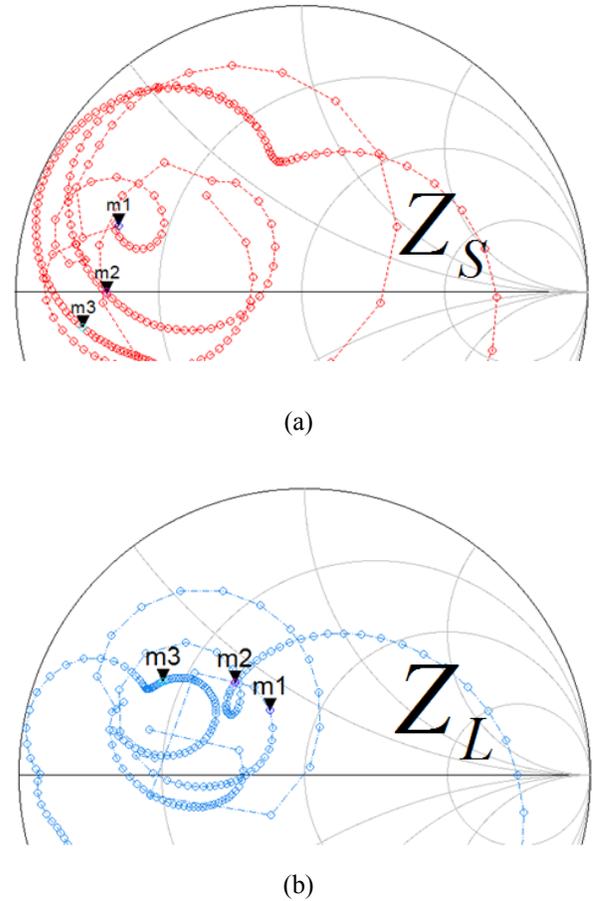


Figure 7. Momentum simulation result of input (a) and output (b) matching network impedances at  $f_1$  (m1),  $f_2$  (m2) and  $f_3$  (m3) with 50 ohm load resistor and characteristic impedance.

### III. FABRICATION AND MEASURED RESULTS

In our tri-band power amplifier fabrication, we use 10 W GaN HEMT packaged transistor CGH40010 from CREE Inc. The substrate we use is TLX-8 from Taconic with dielectric constant of 2.55 and dielectric thickness of 31mils. We set bias point as class-AB operation, the  $V_{gs} = -3\text{V}$ , and  $V_{ds} = 28\text{V}$ . The fabricated proposed concurrent tri-band power amplifier by using resonator groups in both input and output matching networks is shown in Fig. 8.

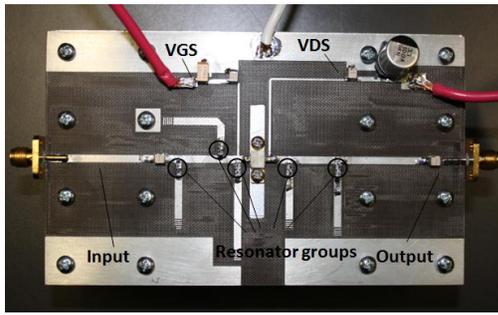


Figure 8. Fabricated concurrent tri-band GaN HEMT power amplifier.

For verifying the resonator performance, the capacitor and inductor are directly measured by the Network Analyzer. Fig. 9 shows the measured results for our designed three resonators with the chosen capacitor and inductor. As measured results show, at 1GHz, 1.5 GHz, and 2.5GHz, insertion loss is better than 20 dB, signal can be suppressed well at each targeted suppressing frequency by the corresponding resonator.

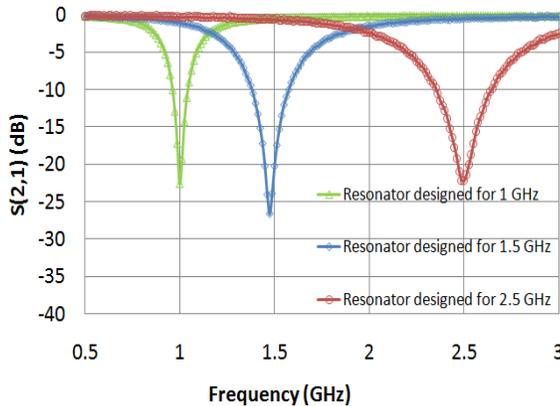


Figure 9. Resonators designed to block signal generated at 1 GHz (triangle), 1.5 GHz (rhombus), and 2.5 GHz (round) separately.

For testing this amplifier, Anritsu signal generator MG3700A, Agilent signal analyzer N9020A, 20 dB attenuator, 45 dB ZHL-4240W pre-amplifier from Mini-Circuits, and 30 dB attenuator added after the tested tri-band power amplifier are used.

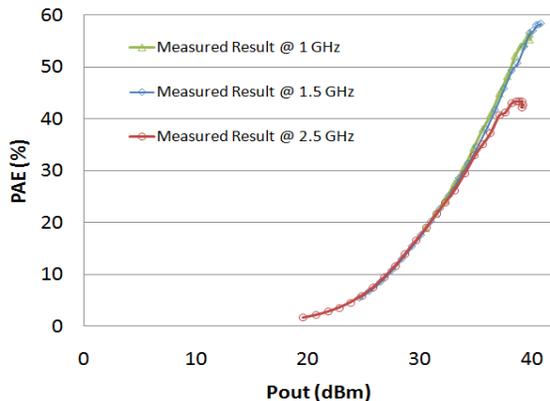


Figure 10. Measured PAE versus power output curves for three operation frequencies 1 GHz (triangle), 1.5 GHz (rhombus), and 2.5 GHz (round).

At 1 GHz, 1.5 GHz and 2.5 GHz, the maximum PAE is obtained 56.4%, 58.3% and 43.4% with output power 39.8 dBm, 40.8 dBm and 38.9 dBm, respectively. The maximum power output at these three operation frequencies is 39.8 dBm, 40.8 dBm and 39.2 dBm. The curves of PAE versus output power at our three operation frequencies are shown in Fig. 10.

#### IV. CONCLUSION

Concurrent tri-band GaN HEMT power amplifier by employing resonator groups in both input and output matching networks as frequency selection elements is designed, fabricated and tested in this paper. Resonators are designed to block signal generated at each specified resonant frequency. With our novel proposed structure, source and load impedance are matched by the simplest L-type matching network structure at each operation frequency independently. The complexity of design procedure is reduced. In addition, we simplified the load matching network by using bias line to match load impedance at 1 GHz to reduced complexity of the power amplifier circuit. At three distinct operation frequencies 1 GHz, 1.5 GHz and 2.5 GHz, the PAE is 56.4%, 58.3%, and 43.4% and maximum output power is 39.8 dBm, 40.8 dBm and 39.9 dBm, respectively. This design method can be easily applied in multi-band applications.

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