Dual-band Bandpass Filter Based on GaN MMIC

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Abstract— Dual-band bandpass filter using stub-loaded resonators (SLR) based on GaN MMIC is presented in this paper. The proposed circuit consists of two symmetric stub-loaded resonators, which are folded and coupled to each other. The two passband frequencies can be easily controlled by tuning the length of the half-wavelength resonators and the open stubs shunted at the midpoint of the microstrip lines. Moreover, the ports are directly tapped at the resonators. And additional open stubs are added to the 50-ohm feed lines for better performance. Benefitting from the integrated circuit technology, the filter can be designed on GaN MMIC that only occupies a small size. For demonstration, a filter, centered at 40 GHz and 60 GHz, is designed and the simulated result shows good performance.

1. INTRODUCTION

In the recently years, the rapid developments of modem wireless communication systems attract great demand of multi-band (especially dual-band) bandpass filters. To meet this demand, much research has been carried out [1–11]. The most intuitive method to implement a dual-band bandpass filter is to simply combine two bandpass filters with two distinctive central frequencies [1] in parallel, at the cost of enlarged circuit size and complicated matching network. In [2–5], stepped-impedance resonators (SIRs) are very popular and have been widely adopted in dual-band bandpass filter designs. However, the SIRs are relatively large in size and can hardly provide sufficient flexibility for improving frequency ratios, coupling properties and harmonic responses. Moreover, the resonant frequencies of SIRs are dependent, complicating the filter design. In [6], by a cascade connection of a BPF and a bandstop filter, a dual-band bandpass filter (BPF) was achieved with the drawback of a large circuit size. Dual-band filters can also be realized by embedding a bandstop filter inside a wideband bandpass filter in [7] or combining two sets of resonators with common input and output in [8, 9].

What's more, a dual-band transformer is introduced to realize 90 phase shift at two frequencies and applied to dual-band branch-line coupler design in [10]. But the operating frequencies of the transformer are still dependent. So a resonator which has easily controlled resonant frequencies is proposed in [11]. Its resonant frequencies of even-mode can be conveniently tuned, while those of the odd-mode remain almost the same. Using the proposed SLR, a dual-band BPF is designed with three transmission zeros in [11]. But we can find that none of this filter is designed on MMIC and most of them are work at low frequencies.

Nowadays, the development of IC is fast. The electronic components on IC can be smaller, low power consumption, intelligent and high reliability. In addition, the dual-band filter based on MMIC can not only realize a small size, but also achieve a high operating frequency. Therefore, much research has been made for filters to work at high frequencies based on MMIC. For examples, A low-insertion-loss V-band CMOS bandpass filter whose center frequency is 63.5 GHz is demonstrated in [12]. A miniaturized and low-insertion-loss V-band bandpass filter implemented on the integrated passive device (IPD) is demonstrated in [13], which is centered at 55.85 GHz. In [14], a new 60 GHz fourth-order cross-coupled bandpass filter using a step-impedance-resonator (SIR) miniaturised open-loop resonator and the miniaturised-hairpin (MH) resonator was designed and fabricated on 0.13 mm bulk CMOS. In [15], a 77-GHz millimeter-wave on-chip bandpass filter with balanced output that was fabricated using a TSMC 0.18-μm standard CMOS process. However, none of this filters working at high frequencies is integrated on the substrate of GaN.

In this paper, a dual-band bandpass filter using stub-loaded resonators based on GaN MMIC is designed. The dual-band filter comprises two symmetric stub-loaded resonators, which are folded and coupled to each other. Every stub-loaded resonator is composed of a conventional microstrip half-wavelength resonator and an open stub. According to the even- and odd-mode analysis, the second passband can be controlled by the stubs while the first passband is fixed. The ports are directly tapped at the resonators. Moreover, additional open stubs are added to the 50-ohm feed lines, which are used to couple with the resonators that can improve the performance of the filter. A dual-band bandpass filter, with center frequencies of 40 and 60 GHz, is shown in this paper. Benefitting from the integrated circuit technology, the filter can be designed on GaN MMIC that only occupies a small size, but good performance. The design will be shown in the following sections.

2. DUAL-BAND FILTER DESIGNED ON MMIC

Figure 1 in [11] shows a stub-loaded resonator (SLR) consists of a conventional microstrip half-wavelength resonator and an open stub shunted at the midpoint of the microstrip line. Odd- and even-mode analysis can be adopted to characterize it since the SLR is symmetrical in structure.

The odd-mode resonant frequencies of the stub-loaded resonator is

$$f_{odd} = \frac{(2n-1)c}{2L'_1\sqrt{\varepsilon_{eff}}} \tag{1}$$

where $n = 1, 2, 3, \ldots, c$ is the speed of light in free space, ε_{eff} denotes the effective dielectric constant of the substrate. It can be observed that the odd-mode resonant frequencies are not affected by the open stub.

For even-mode excitation, the even-mode resonant frequencies can be attained as

$$f_{even} = \frac{nc}{(L'_1 + 2L'_2)\sqrt{\varepsilon_{eff}}} \tag{2}$$

From the Equations (1), (2) we can find that by changing the stub length L'_2, the fundamental even-mode resonant frequency can be shifted, whereas the fundamental odd-mode resonant frequency is preserved.

Based on the proposed SLR, A dual-band filter which consists of two folded SLRs is designed. Compared with the conventional open-loop resonator [12], this one has an extra open stub loaded inside the open loop. The passband frequencies are mainly determined by the entire length of the open loop and the length of the open stub.

As we know, the dual-band filter designed above works at low frequencies, which means that the open stubs of the filter can be put inside the open loops to get a small circuit size. However, when the dual-band filter works at high frequencies, the mutual coupling between the two open stubs is very serious, which can significantly inhibit performance of the filter. In addition, the space inside the filter may be not big enough for the open stubs if we want an appropriate rate of f_2/f_1 (f_1 presents the center frequency of the first passband while f_2 presents the second) since the lower of f_2, the longer of the open stubs. And the limited space in each resonator may cause unwanted coupling between the open loop and the open stub. In order to reduce the interference, the open stubs are arranged at outside of the open loops while are still located at the midpoint of the main microstrip lines. Moreover, the passband bandwidths of this filter depend on the external quality factors and the coupling coefficients between the two resonators. Accordingly, the gap between two folded SLRs and the position of the feed lines determine the bandwidths. Furthermore, additional open stubs are added to the 50-ohm feed lines, which are used to couple with the resonators that can improve the performance of the filter. The length and the position of the open stubs can be tuned by analyzing the simulated results. The layout of the proposed dual-band filter based on MMIC is shown in Fig. 1(a).

Therefore, the dual-band filter based on GaN MMIC can be designed as follows. Firstly, the desired two passband frequencies can be obtained by tuning the length of half-wavelength resonators and the open stubs according to Equations (1) and (2). Secondly, the gap of the two resonators and the position of the feed lines are tuned to obtain a bandpass response with given specifications. Finally, the couple strength between the open stubs added to the 50-ohm feed lines and the open-stub resonators can be tuned to get a better performance. The couple strength depends on the distance between the added open stub and the half-wavelength resonator as well as the distance between the added open stub and the open stub shunted at the midpoint of the microstrip line.

Figure 1(b) shows the side of the filter on MMIC. There are three layers of substrates in this design. They are SiN, GaN and Silicon with relative dielectric constants of 6.5, 9, 11.9 and dielectric loss tangents of 0.09, 0.09, 0.01 from top to bottom. Respectively, their thicknesses are 0.15 μm, 6.28 μm and 93.57 μm. The material of the microstrip lines we used is gold, with a relative dielectric constant of 1, and its thickness is 2.15 μm.

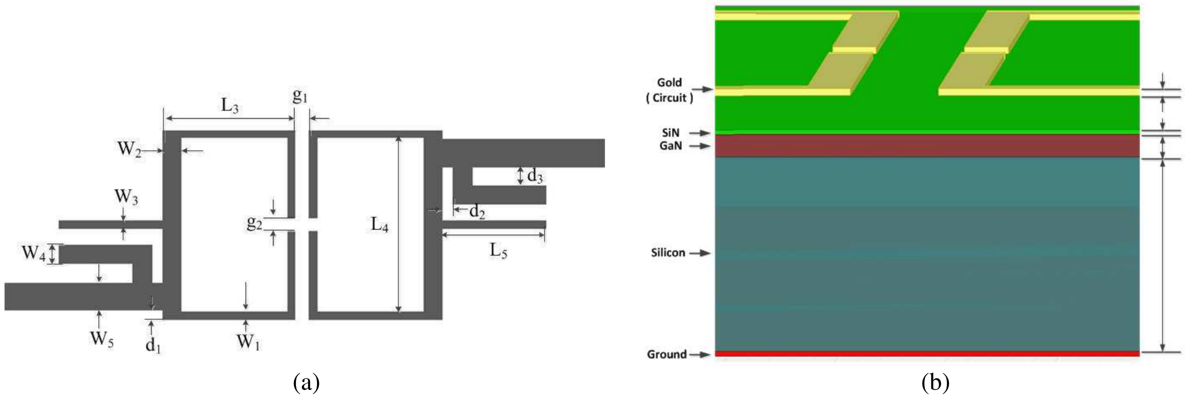

Figure 1: Proposed dual-band filter configuration. (a) Schematic diagram. (b) Partly 3-D view on IC.

3. EXPERIMENTAL RESULTS

To verify our proposal, a dual-band bandpass filter based on GaN MMIC is designed and implemented. According to the three design steps above, the design parameters of the proposed dual-band filter in Fig. 1(a) are $W_1 = 20\,\mu\text{m}$, $W_2 = 50\,\mu\text{m}$, $W_3 = 20\,\mu\text{m}$, $W_4 = 50\,\mu\text{m}$, $W_5 = 78\,\mu\text{m}$, $L_3 = 360\,\mu\text{m}$, $L_4 = 500\,\mu\text{m}$, $L_5 = 280\,\mu\text{m}$, $d_1 = 10\,\mu\text{m}$, $d_2 = 30\,\mu\text{m}$, $d_3 = 72\,\mu\text{m}$, $g_1 = 40\,\mu\text{m}$, $g_2 = 40\,\mu\text{m}$.

Figure 2 shows the simulation result of the dual-band filter on MMIC which without open stubs added to the 50-ohm feed lines. The center frequencies of the passbands are located at 40 and 60 GHz, and their insertion losses are 4.1 and 5.1 dB at the lower and upper passbands. For improving the performance of the filter, additional open stubs are added to the 50-ohm feed lines. Fig. 3 shows the simulation result of the proposed dual-band filter on MMIC. The center frequencies of the passbands are located at 40 and 60 GHz, with 3 dB bandwidths of 15% (37 to 43 GHz) and 13.3% (56 to 64 GHz). The insertion losses are 3.4 and 4.0 dB at the lower and upper passbands and the return losses within the two passbands are better than 17 dB, which means better performance than the simulation result shown in Fig. 2. If the relative dielectric constant of GaN is 10, the center frequencies of the filter will be a litter lower by Equations (1) and (2). So we have to decrease the length of the SLRs, making sure that the center frequencies of the dual-band are 40 GHz and 60 GHz. Let $L_3 = 350\,\mu\text{m}$, we get the frequency responses that the insertion losses are 3.3 and 3.8 dB at the lower and upper passbands with almost the same bandwidths, which shows that the performance is better.

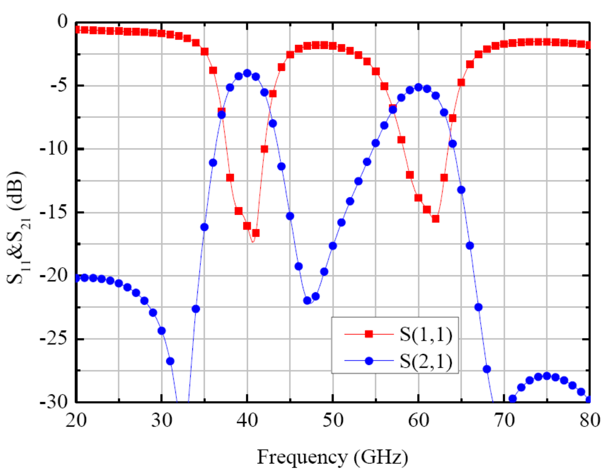

Figure 2: Frequency responses of the filter on IC without open stubs added to the 50-ohm feed lines.

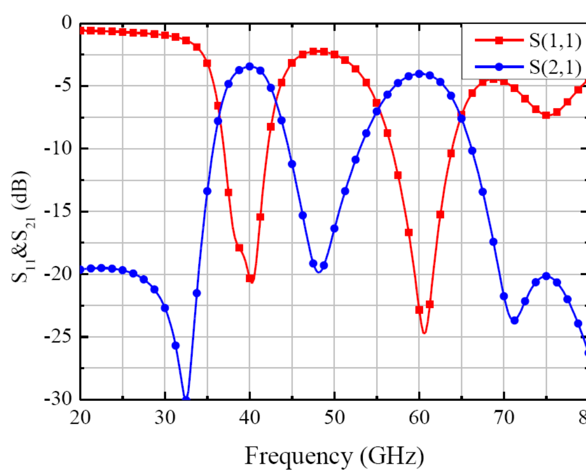

Figure 3: Frequency responses of the proposed filter on IC.

4. CONCLUSION

In this paper, a proposed dual-band bandpass filter based on GaN MMIC is demonstrated. The two passband frequencies can be easily controlled by tuning the length of the half-wavelength resonators and the open stubs shunted at the midpoint of the microstrip lines. In each SLR, the open stub is arranged at outside of the open loop to reduce interference. Furthermore, another open stub is added to the 50-ohm feed line respectively, which can be used to improve the performance of the filter. Benefitting from the integrated circuit technology, the design only occupies a small size. For verification, a dual-band filter whose center frequencies are 40 GHz and 60 GHz is given.

REFERENCES

1. Miyake, H., S. Kitazawa, T. Ishizaki, T. Yamada, and Y. Nagatomi, "A miniaturized monolithic dual band filter using ceramic lamination technique for dual mode portable telephones," *IEEE MTT-S Int. Microw. Symp. Dig.*, Vol. 2, 789–792, 1997.
2. Kuo, J.-T., T.-H. Yeh, and C.-C. Yeh, "Design of microstrip bandpass filters with a dual-passband response," *IEEE Trans. Microw. Theory Tech.*, Vol. 53, 1331–1337S, 2005.
3. Sun and L. Zhu, "Compact dual-band microstrip bandpass filter without external feeds," *IEEE Microw. Wireless Compon. Lett.*, Vol. 15, No. 10, 644–646, Oct. 2005.
4. Chang, S.-F., Y.-H. Jeng, and J.-L. Chen, "Dual-band step-impedance bandpass filter for multimode wireless LANs," *Electron. Lett.*, Vol. 40, No. 1, 38–39, Jan. 2004.
5. Wang, J., Y.-X. Guo, B.-Z. Wang, L. C. Ong, and S. Xiao, "High-selectivity dual-band stepped-impedance bandpass filter," *Electron. Lett.*, Vol. 42, No. 7, 538–539, Apr. 2006.
6. Tsai, L.-C. and C.-W. Huse, "Dual-band bandpass filters using equal-length coupled-serial-shunted lines and Z-transform techniques," *IEEE Trans. Microw. Theory Tech.*, Vol. 52, No. 4, 1111–1117, Apr. 2004.
7. Tsai, L. C. and C. W. Hsue, "Dual-band bandpass filters using equallength coupled-serial-shunted lines and -transform technique," *IEEE Trans. Microw. Theory Techn.*, Vol. 52, No. 4, 1111–1117, Apr. 2004.
8. Chen, C.-Y. and C.-Y. Hsu, "A simple and effective method for microstrip dual-band filters design," *IEEE Microw. Wireless Compon. Lett.*, Vol. 16, No. 3, 246–248, May 2006.
9. Chen, J.-X., T. Y. Yum, J.-L. Li, and Q. Xue, "Dual-mode dual-band bandpass filter using stacked-loop structure," *IEEE Microw. Wireless Compon. Lett.*, Vol. 16, No. 9, 502–504, Sep. 2006.
10. Zhang, H. and K. J. Chen, "A stub tapped branch-line coupler for dual-band operations," *IEEE Microw. Wireless Compon. Lett.*, Vol. 17, No. 2, 106–108, Feb. 2007.
11. Zhang, X. Y. and Q. Xue, "Dual-band bandpass filters using stub-loaded resonators," *IEEE Microw. Wireless Compon. Lett.*, Vol. 17, No. 8, 583–585, Aug. 2007.
12. Chang, J.-F., Y.-S. Lin, P.-L. Huang, and S.-S. Lu, "A micromachined V-band CMOS bandpass filter with 2-dB insertion-loss," *Electronic Components and Technology Conference*, 2009.
13. Lin, W.-C., T.-M. Shen, C.-F. Chen, T.-Y. Huang, and R.-B. Wu, "A miniaturized V-band bandpass filter using integrated passive devices technology," *Proceedings of Asia-Pacific Microwave Conference*, 2010.
14. Yang, B., E. Skafidas, and R. J. Evans, "60 GHz compact integrated cross-coupled SIR-MH bandpass filter on bulk CMOS," *Electronics Letters*, Vol. 44, No. 12, Jun. 5th, 2008.
15. Hsu, C.-Y., C.-Y. Chen, and H.-R. Chuang, "A 77-GHz CMOS on-chip bandpass filter with balanced and unbalanced outputs," *IEEE Electron Device Letters*, Vol. 31, No. 11, Nov. 2010.