Wide-stopband Millimeter-wave BPF on GaN MMIC Using Asymmetric Feeding Structure

Jin Xu Xu, Xiu Yin Zhang, and Xiao Feng Liu
School of Electronic and Information Engineering
South China University of Technology, Guangzhou 510640, China

Abstract— This paper presents a novel compact bandpass filter for 30 GHz millimeter-wave applications in Monolithic Microwave Integrated Circuit (MMIC). The proposed circuit consists of two symmetrical coupled quarter-wavelength transmission-line resonators and two coupled transmission-line feeding structures. Two feeding lines are designed as asymmetrical structures, which are utilized not only to cause mismatch at the third harmonic frequency between the resonator and feeding lines so that the third harmonic can be suppressed but also to provide source-loaded to generate two transmission zeros near the passband, resulting in high selectivity. To verify the proposed idea, an experiment filter has been implemented. High skirt selectivity and wide stopband are observed in the results.

1. INTRODUCTION

Filters are key elements in modern wireless and mobile communication systems. They are widely used in many aspects. Since most electronic devices become compact, it is important to decrease the size of bandpass filter. In response to this requirement, much research has been carried out and there are various methods proposed [1–6]. One of the method is using a compact quarter-wavelength resonators. For example, the dumb-bell-shaped slot resonator in [1], the microstrip net-type resonators in [2], the octagonal hairpin resonators in [3] as well as the parallel-coupled-line filters in [4]. In another method, dual-mode resonators is also used to reduce the circuit size [5]. Beside miniaturized size, high-selectivity and harmonic suppression are two important topics in filter design. In general, the selectivity can be improved by introducing transmission zeros near the passband. To suppress spurious responses, it is feasible to introduce transmission zeros in the spurious frequency [6] or move the spurious frequency to a higher frequency using stepped impedance resonators (SIRs) [7].

In recent years, with the development of IC industry and the operating frequency in wireless communication system shifting to higher frequency, more and more bandpass filters have been complemented at such high frequency. For instance, a 4-stage on-chip open loop resonators band pass filter which operate at 60 GHz is proposed in [8]. A 70-GHz Millimeter-Wave compact bandpass filter fabricated using standard 0.18-μm CMOS technology is designed in [9]. At such high frequency,the characteristic of miniaturized size, high-selectivity and harmonic suppression are also required in the bandpass filter of millimeter-wave applications.

In this paper, a wide stop-band BPF is designed on GaN MMIC with good performance. The circuit consists of two symmetrical coupled quarter-wavelength transmission-line resonators and two coupled transmission-line feeding structures. The asymmetric feeding structures are utilized to suppress the third harmonic, whereas the fundamental one can pass with less influence. Source-load coupling is introduced to generate two transmission zero near the passband. Thus, both wide-stop band and high-selectivity is achieved in this design. Base on the proposed idea, a bandpass filter with wide stop-band at the operating frequency of 30 GHz has been implemented. The design methodology and experimental results are also presented.

2. FILTER DESIGNED ON GAN MMIC

The configuration of the proposed bandpass filter is shown in Fig. 1. Two folded symmetrical coupled quarter-wavelength transmission-line resonators and two coupled transmission-line feeding structures are used to make up the circuit. By using this structures, miniaturized circuit size is achieved. The resonators and feeding line are connected by the via, thus both electrical and magnetic coupling are realized. The asymmetrical structures of the feeding line are used not only to cause mismatch at the third harmonic frequency between the resonators and the feeding line but also to provide source-loaded coupling to generate two transmission zeros near the passband, resulting in both wide stop-band and high selectivity.

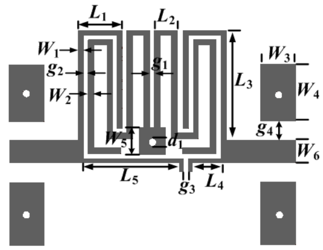

Figure 1: The configuration of the proposed circuit.

In this design, the harmonic suppression is obtained by the novel asymmetric feeding structure. One end of the feeding line is embedded in the gap of the resonators while the other end is put asymmetrical outside the resonator. The length of L_4 and L_5 is the length of each feeding lines which is put outside the resonators. Fig. 2 shows the simulated current distributions at 80 GHz with different L_4 and L_5. It is known that the asymmetric feeding structure caused by the unequal value of L_4 and L_5 will influence the asymmetric voltage distribution on the feeding line. Thus the external quality factor named Q_{e3} at the third harmonic frequency can be controlled by altering the value of L_4 and L_5. It is found that when L_4 and L_5 equal to 60 µm and 254 µm, the Q_{e3} approaches infinite. Therefore the mismatch between the resonator and feeding line can be caused, resulting in harmonic suppression. What's more, the end of the feeding line is extended in another direction to realize source-load coupling which can generate two transmission zero near the passband.

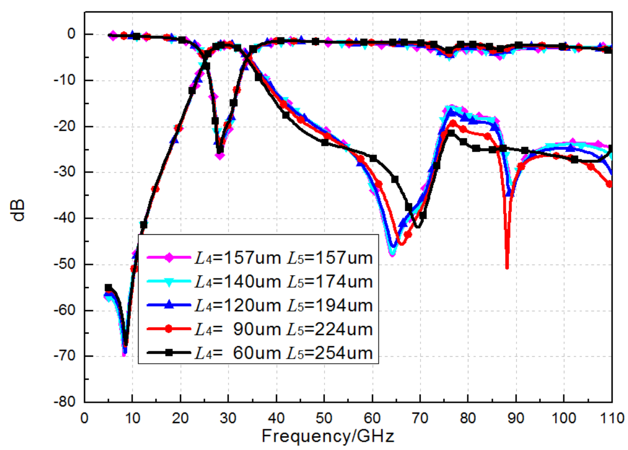

Figure 2: The simulated current distributions at 80 GHz with different L_4 and L_5.

3. EXPERIMENT

Based on the analysis above, the design procedures of the proposed filter are introduced as follows. The first step is to obtain the required operating frequency by determining the length of the resonators which have the electric length of quarter-wavelength. The second step is to obtain the required coupling coefficient k and external quality factor Q_e at the passband. In this design, a two-pole Chebyshev lowpass prototype with 0.5 dB passband ripple is chosen, the lumped circuit element values of the prototype filter are selected to be: $g_0 = 1$, $g_1 = 1.4029$, $g_2 = 0.7071$, $g_3 = 1.9841$. The proposed filter has a 3-dB bandwidth of 23%. Accordingly, the k and Q_e can be calculated by the equation below:

$$k_{12} = k_{13} = \frac{\mathrm{FBW}}{\sqrt{g_1 g_2}} = 0.23 \tag{1}$$

$$Q_e = \frac{g_0 g_1}{\mathrm{FBW}} = 6.1 \tag{2}$$

In this design, the gap g_1 can be adjusted to obtain the desirable k. As for Q_e at the passband, it is mainly determined by the position of the 50-ohm ports. In this design, we can alter the length

L_3, the width of the feeding line W_1 and the gap between the feeding line and the resonator g_2. The third step is to adjust L_4 and L_5 to get appropriate value to suppress the third harmonic.

For demonstration, a novel compact bandpass filter for 30 GHz millimeter-wave applications in Monolithic Microwave Integrated Circuit (MMIC) is designed. The dimensions are chosen as follows: (all in µm): $L_1 = 115$, $L_2 = 60$, $L_3 = 270$, $L_4 = 60$, $L_5 = 254$, $W_1 = 14$, $W_2 = 16$, $W_3 = 90$, $W_4 = 150$, $W_5 = 70$, $W_6 = 150$, $g_1 = 13$, $g_2 = 13$, $g_3 = 12$, $g_4 = 50$. The overall size of the fabricated filter is 7.9 mm × 5.4 mm or $0.1\lambda g \times 0.079\lambda g$. Fig. 3 shows the substrate structure of the MMIC filter. There are three layers of substrates in this design. They are SiN, GaN and Silicon from top to bottom with the relative dielectric constant of 6.5, 9, 11.9 and dielectric loss tangent of 0.09, 0.09, 0.01, respectively. And the thicknesses of each substrate are 0.15 µm, 6.28 µm and 93.57 µm. The material of the microstrip lines is gold, with a thickness of 2.15 µm.

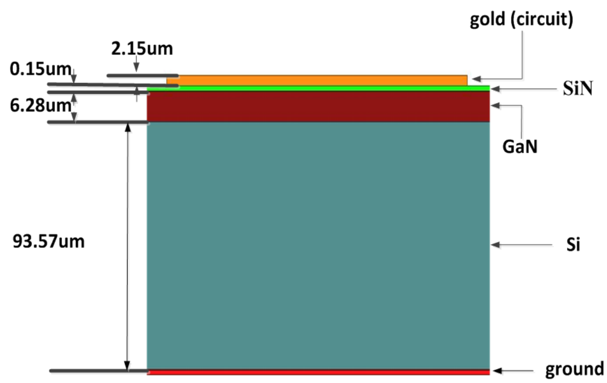

Figure 3: The substrate structure of the MMIC filter.

Figure 4 shows S-parameters of the proposed filter. The filter has a 3-dB bandwidth of about 6.8 GHz at the center frequency of 30 GHz. The insertion loss of the passband is about 3 dB and return loss is better than 15 dB at the center frequency. Also, four transmission zeros appear at the frequency of 10 GHz, 46 GHz, 75 GHz and 85 GHz, which help achieve the wide stopband and high skirt selectivity. The rejection level is more than 25 dB within the frequency range from 41 GHz to 110 GHz. The area of the filter is only 400 µm × 310 µm ($0.092\lambda g \times 0.069\lambda g$), where λg is the guided wavelength at the operating frequency of 30 GHz.

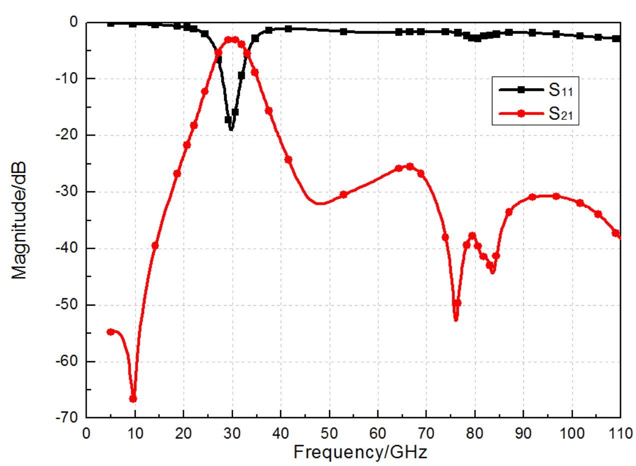

Figure 4: The S-parameters of the proposed filter.

4. CONCLUSION

A wide-stopband millimeter-wave BPF on GaN MMIC using asymmetric feeding structure has been proposed in this paper. The design methodology and experimental results have been presented. Due to the MMIC technology and its compact structure, the filter is only 400 µm × 310 µm ($0.092\lambda g \times 0.069\lambda g$) and a wide stopband response is realized by the novel feeding structure. Two transmission zeros are realized near the passband edges by introducing the source-load coupling to this design which can help to achieve high selectivity. The BPF works at the frequncy of 30 GHz. The compact size as well as wide stopband makes it attractive for many millimeter-wave applications.

REFERENCES

1. Jung, D., J. Hansen, and K. Chang, "Miniaturised bandpass filter using dumb-bell-shaped slot resonator," *Electronics Letters*, Vol. 48, No. 22, 100–102, 2012.
2. Chen, C.-F., T.-Y. Huang, and R.-B. Wu, "Novel compact net-type resonators and their applications to microstrip bandpass filter," *IEEE Trans. Microw. Theory Tech.*, Vol. 54, No. 2, 755–762, 2006.
3. Liu, H. W. and W. M. Li, "Miniaturised microstrip bandpass filter using octagonal hairpin resonators with side-coupled technique," *Electronics Letters*, Vol. 44, No. 24, 1410–1411, 2008.
4. Park, J.-H., S. K. Lee, and Y. S. Lee, "Extremely miniaturized bandpass filter based on asymmetric coupled lines with equal reactance," *IEEE Trans. Microw. Theory Tech.*, Vol. 60, No. 2, 261–269, 2012.
5. Wang, J. P., J.-L. Li, J. Ni, S. S. Zhang, W. Wu, and D. G. Fang, "Design of miniaturized microstrip dual-mode filter with source-load coupling," *IEEE Microw. Wireless Compon. Lett.*, Vol. 20, No. 6, 319–321, 2010.
6. Gao, J. and L. Zhu, "Asymmetric parallel-coupled CPW stages for harmonic suppressed $\lambda/4$ bandpass filters," *Electronics Letters*, Vol. 40, No. 18, 1122–1123, Sep. 2004.
7. Chan, H. K. and K. Chang, "Wide-stopband bandpass filters using asymmetric stepped-impedance resonator," *IEEE Microw. Wireless Compon. Lett.*, Vol. 23, No. 2, 69–71, Feb. 2013.
8. Pokharel, R. K., X. Liu, R. Dong, A. B. A. Dayang, H. Kanaya, and K. Yoshida, "A high selectivity, low insertion loss 60 GHz-band on-chip 4-pole band pass filter for millimeter wave CMOS SoC," *Proceedings of the 6th European Microwave Integrated Circuits Conference*, 660–663, Oct. 2011.
9. Hsu, C. Y., Y. S. Lin, C. Y. Chen, et al., A 70-GHz millimeter-wave compact bandpass filter fabricated using standard 0.18-μm CMOS technology," *38th European IEEE Microwave Conference, EuMC*, 215–217, 2008.