Wide-stopband Millimeter-wave Bandpass Filter Based on Discriminating Coupling on GaN MMIC

Jie Kai Lin[1], **Xiu Yin Zhang**[1], **Qing Yi Guo**[1], **and Hsuan-Ling Kao**[2]

[1]School of Electronic and Information Engineering
South China University of Technology, Guangzhou 510640, China
[2]Department of Electronic Engineering, Chang Gung University, Taoyuan, Taiwan

Abstract— This paper presents a third harmonics up pressed bandpass filter on GaN MMIC (Monolithic Microwave Integrated Circuit). By analysing the voltage distribution at fundamental frequency and third harmonic of the resonators, suitable coupling region between the feeding lines and resonators can be selected. In this way, we make the coupling coefficient at third harmonic to be zero while the coupling coefficient at fundamental frequency is not zero. Therefore, the third harmonic can be suppressed by the discriminating coupling scheme while the fundamental mode responses are unaffected. Meanwhile, to improve the selectivity, source-load coupling is employed to introduce transmission zeros near the passband. For demonstration, a millimeter-wave filter with wide sropband is implemented. The filter is designed based on the technology of GaN MMIC with center frequency of 33.5 GHz and insertion loss of 3.2 dB. The circuit area of the filter is only 410 μm × 210 μm, featuring very compact size.

1. INTRODUCTION

Bandpass filter is one of the most important elements in wireless communication system. Among bandpass filter, parallel-coupled bandpass filter is widely used in RF front-ends because of their simple configuration and easy design procedures. However, most parallel-coupled filters suffer from harmonic responses, which degrade system performance. To suppress these spurious responses, various methods have been proposed [1–3]. In [1], the author introduces two different open stubs tapped on the input and output port with length of quarter length of harmonic wave creating two transmission zeros to suppress harmonic. In this design, more extra circuit should be added, which increases the size of the filter. By separately allocating the two different transmission zeros, the suppression of spurious response at the third harmonic frequency can be achieved in [2]. In [3], fractal shape is employed to improve harmonic suppression by a factor of 2. In [4], a new method that suppresses the harmonic response by tuning the coupling coefficient between the two transmission lines is introduced to us. However, these filters are fabricated at lower frequency.

In recent years, with the development of IC industry and the operating frequency in wireless communication system shifting to higher frequency, more and more traditional RF circuit have been transplanted to IC platform. In [5], a 4-stage on-chip open loop resonators band pass filter which operates at 60 GHz is proposed. In [6], the author introduces a compact multilayer CPW MMIC spiral directional couplers and bandpass filter to us. More and more bandpass filters have been fabricated at such high frequency. However, fewer bandpass filters with wide bandstop are complemented on IC platform. Since the method mentioned in [4] is useful and the size of the designed filter is compact, it is necessary and essential to transplant it to IC platform.

In this letter, bandpass filter with third harmonic suppression has been introduced to MMIC. It is based on discriminating coupling. Therefore, no more extra circuits are employed to suppress the harmonic. Although the third harmonic signal is suppressed, the fundamental one can pass without any influence. Base on the proposed idea, a two-order bandpass filter with third harmonic suppressed has been implemented using quarter wave length short-ended microstrip line. The design methodology and experimental results are also presented.

2. ANALYSIS OF DISCRIMINATING COUPLING

The harmonic suppression is based on discriminating coupling, so it is necessary to present the theory of coupling coefficient. The electric coupling coefficient between the transmission lines can be defined, i.e.,

$$k_e = \frac{\iiint \varepsilon \vec{E}_1 \cdot \vec{E}_2 dv}{\sqrt{\iiint \varepsilon \left|\vec{E}_1\right|^2 dv \cdot \iiint \varepsilon \left|\vec{E}_2\right|^2 dv}} \tag{1}$$

where $\vec{E}$ represents the electric field vectors generated by the two lines and V is the volume. Since the dominant mode is quasi-TEM, the electric field can be replaced by corresponding voltage to evaluate the coupling coefficient, i.e.,

$$k_e = P \times \frac{\int_{-d/2}^{d/2} v_1(x) v_2(x) dx}{\sqrt{\int_{-d/2}^{d/2} |v_1(x)|^2 \, dx \times \int_{-d/2}^{d/2} |v_2(x)|^2 \, dx}} \tag{2}$$

where $V_1(x)$ and $V_2(x)$ represent the voltage-wave functions on the two coupling lines, p represents a constant and d is the length of the coupling region. In order to suppress harmonic, it is necessary to create a zero value of k_e upon the frequency. Letting the integrand in the numerator to be an odd function is one of the easy and efficient way to create a zero value. When one of the voltage-wave functions is odd and the other one is even, the integrand in the numerator will be an odd function, which implies that the electric coupling coefficient is zero.

According to the mechanism above, an instance of discriminating coupling and its application to filter design is shown in Fig. 1. There are two transmission lines in Fig. 1(a). In Fig. 1(b), the voltage-wave function on line1 is odd, while even on line2 at a specific frequency, which leads to an odd function of the integrand in the numerator. As a result, the value of k_e is zero at a specific frequency. Similarly, the value of the magnetic coupling coefficient is

$$k_m = 0 \tag{3}$$

Thus, the total coupling coefficient is

$$k = k_m + k_e = 0 \tag{4}$$

According to the instance, it is easy to observe that the coupling coefficient between the two transmission lines could be zero at specific frequencies. It means that the signal cannot pass across the coupling region and thus it will be suppressed.

3. FILTER DESIGN

Figure 2 shows the configuration of the wide-stopband millimeter-waveband pass filter based on discriminating coupling on GaN. The filter consists of two symmetric quarter-wavelength resonators and they are folded to reduce the size. The two feeding lines are coupled with the resonators and the ports are tapped at the middle of the feeding line. Meanwhile, source-load coupling is employed to introduce transmission zeros near the passband [7].

For quarter-wave length shorted-ended microstrip line, the voltage wave function at fundamental frequency can be described as

$$V_{f_0}(x) = \cos(\beta x) \quad x \in [0, L] \tag{5}$$

while third harmonic frequency

$$V_{3f_0}(x) = \cos(3\beta x) \quad x \in [0, L] \tag{6}$$

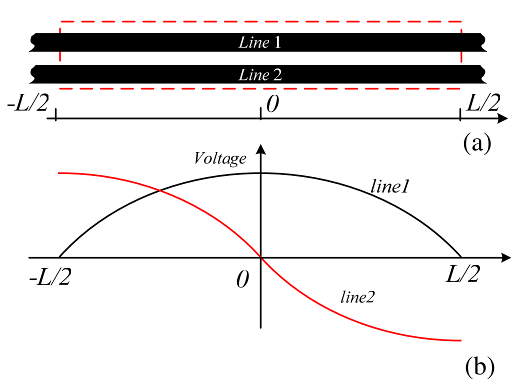

Figure 1: Coupling region with zero coupling coefficient. (a) Coupled microstrip lines. (b) Normalized voltage on the two lines.

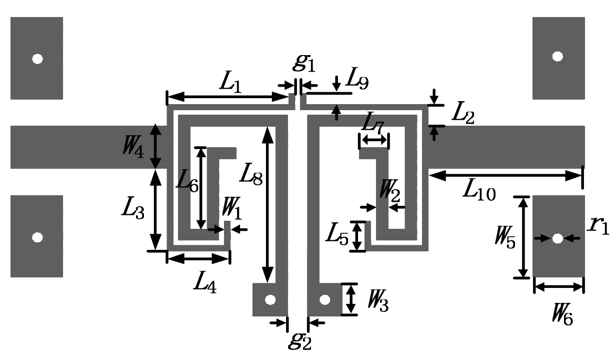

Figure 2: The configuration of the third harmonic suppression filter based on discriminating coupling on MMIC.

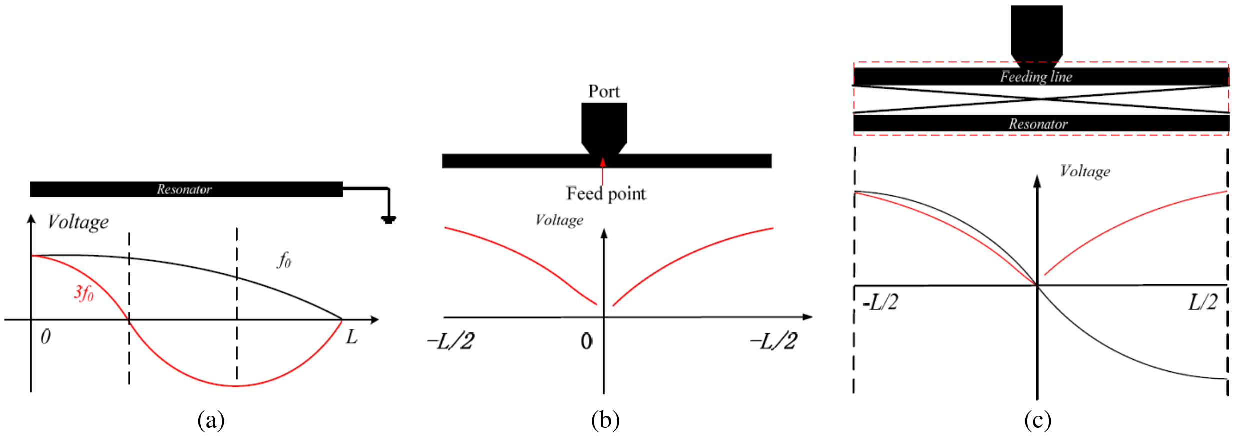

Figure 3: (a) The wave function of fundamental and third harmonic on quarter wave length shorted-ended mircostrip line. (b) The wave function on feed line. (c) The wave function between the coupling regions.

where β represents the propagation constant at fundamental resonant frequency and L is the whole length of the transmission line. Fig. 3(a) shows this two voltage wave function.

For the feeding line, the voltage wave function on it is always even. In addition, it is kind of subsection function and can be described as

$$V(x) = \begin{cases} \sin(px) & x \in (0, L/2] \\ -\sin(px) & x \in [-L/2, 0) \end{cases} \tag{7}$$

where p represents a constant and L is the whole length ignoring the port. Fig. 3(b) shows its voltage wave function and the combination of voltage wave function between the coupling regions is shown in Fig. 3(c).

According to (1), we can easily draw a conclusion that the coupling coefficient of third-harmonic between this two transmission lines is zero, which implies that the third-harmonic can be suppressed. Based on this discriminating coupling mechanism, the BPF with the third-harmonic suppression and wide stopband can be implemented.

The filter is fabricated on GaNas shown in Fig. 4, which consists of three layers of substrates. The dimensions of the proposed filter are determined as follows: $L_1 = 212.5\,\mu\text{m}$, $L_2 = 40\,\mu\text{m}$, $L_3 = 152\,\mu\text{m}$, $L_4 = 110\,\mu\text{m}$, $L_5 = 55\,\mu\text{m}$, $L_6 = 150\,\mu\text{m}$, $L_7 = 20\,\mu\text{m}$, $L_8 = 320\,\mu\text{m}$, $L_9 = 20\,\mu\text{m}$, $L_{10} = 272.5\,\mu\text{m}$, $W_1 = 10\,\mu\text{m}$, $W_2 = 20\,\mu\text{m}$, $W_3 = 60\,\mu\text{m}$, $W_4 = 78\,\mu\text{m}$, $W_5 = 150\,\mu\text{m}$, $W_6 = 90\,\mu\text{m}$, $g_1 = 10\,\mu\text{m}$, $g_2 = 35\,\mu\text{m}$, $r_1 = 20\,\mu\text{m}$.

Figure 5 depicts the simulated result of this filter. The passband is centered at 33.5 GHz with 3 dB fractional bandwidth of 27.5% and the insertion loss is 3.2 dB. Three transmission zeros can be observed. The lower transmission zero is caused by quarter-wave resonance that short out

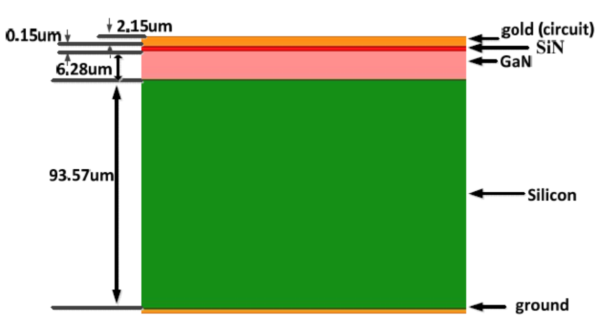

Figure 4: Configuration of the substrate.

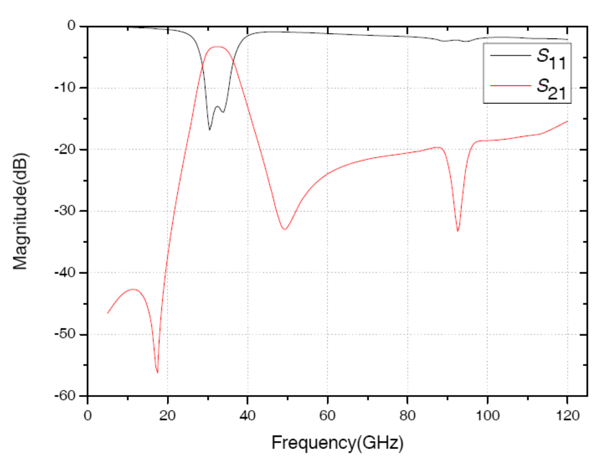

Figure 5: Simulated responses of the proposed filter.

the port at the frequency above the resonant frequency. The other one near the passband result from the source-load coupling. Another transmission zero is generated at about 95 GHz, which is introduced by discriminating coupling. The coupling coefficient at this frequency is zero, namely third harmonic. The rejection level reaches 35 dB, helping enhance the rejection level within the upper stopband. Due to these transmission zeros, high selectivity and wide-stopband is realized, which verifies the analysis.

4. CONCLUSION

In this letter, we have introduced a third harmonic suppressed bandpass filter on GaN MMIC. Discriminating coupling mechanism is introduced two suppress third harmonic on GaN MMIC with no extra circuit. The feeding lines and resonators can be folded to make the circuit miniaturization with no effect to discriminating coupling. It means the miniaturization and wide stopband of the filter can be both realized on MMIC circuit. Moreover electronic source-load coupling is employed to introduce transmission zeros near the passband, which contribute to the good selectivity of the filter. The experimental results show the demonstrated filter is applicable to wireless communication system.

REFERENCES

1. Gao, L., X. Y. Zhang, and B. J. Hu, "Tunable dual-band bandpass filter using varactor-loaded short-ended resonators," *2013 IEEE International Wireless Symposium (IWS)*, 1–3, Apr. 2013.
2. 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
3. Esa, M., N. Hassan, M. A. M. Abas, N. N. N. A. Malik, and N. Fisal, "Reduced size microstrip fractal filter with suppressed second harmonic," *Asia Pacific Microwave Conference, 2009, APMC 2009*, 1462–1464, Dec. 2009.
4. Zhang, X. Y. and Q. Xue, "Harmonic-suppressed bandpass filter based on discriminating coupling," *IEEE Microwave and Wireless Components Letters*, Vol. 19, No. 11, 695–697, Nov. 2009.
5. 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.
6. Sun, Q., J. Yuan, J. Lu, A. Rezazadeh, L. Krishnamuthy, and V. T. Vo, "A compact multilayer CPW MMIC spiral directional couplers and bandpass filter," *Proceedings of the 40th European Microwave Conference*, 561–564, Nov. 2010.
7. Liao, C. K. and C. Y. Chang, "Design of microstrip quadruplet filters with source-load coupling," *IEEE Trans. Microw. Theory Tech.*, Vol. 53, No. 7, 2302–2308, 2005.