A Miniaturized GaAs MMIC Bandpass Filter for 5GHz Band

In Ho Kang*, Shi Wei Shan*, Xu Guang Wang*, Young Yun*, Ji Hoon Kim**, Chul Soon Park**
*Dept. of Radio Engineering, Korea Maritime University, Busan, Korea
**School of Eng, Information and Communications University, 119 Munjiro, Yuseong, Daejeon, Korea

***Abstract* — Novel miniaturized GaAs based bandpass filters for 5GHz band WLAN using diagonally end-shorted coupled lines and lumped capacitors are proposed. The new filter has a compact size, as small as a few degrees, and shows wider stopband characteristic over 35dB up to 60 GHz. A two-stage band pass filter with planar structure was designed and fabricated at a center frequency of 5.5 GHz, with chip surface area only 0.54×0.78 mm^2. The fabricated filter has been implemented using Knowledge*on GaAs process.**

***Index terms* — GaAs filters, miniaturization, parallel coupled lines**

I. INTRODUCTION

In modern wireless communication systems, the miniaturized MMIC microwave bandpass filters are required to reduce the cost and lower the efforts of RF system design, especially for single RF transceiver chip. Therefore, many studies on reducing the large size of conventional bandpass filter have been made. The lumped element approach, which uses spiral inductor and lumped capacitor, is one of the solutions to this problem. However, the design of lumped element circuits must be somewhat empirical and these circuit demonstrations have been confined to frequencies up to a few GHz due to the low quality factor (Q) [1] and low resonant frequencies. The folded hairpin resonator filters, stepped-impedance resonator (SIR) filters [2]-[4] and slow wave open-loop resonator filters [5] were developed. Using these methods, a relative compact bandpass filter can be designed. However, they still take up quite a large circuit area. Another disadvantage of these traditional microstrip filters is that they can't effectively suppress the spurious passband, which may seriously degrade the attenuation level in the stopband and passband response symmetry and could restrict the applicability of the filters.

Combline filters using low temperature co-fired ceramic (LTCC) or ceramic materials with the multi-layer technology can be used as a reduced size bandpass filter [6], [7]. However, conventionally the electrical length has been recommended by 45º or less for efficient coupling [8]. Nowadays SAW filters are widely used in the mobile communication market. But they are still not compatible with standard IC technology and presently available in the frequency range up to 3GHz [9]. An active bandpass filter can be integrated in single manufacturing process. In this case, the active circuit which behaves as a negative resistance is inserted [10] and has a drawback associated with nonlinearity and poor noise figures [11].

In this paper, a novel miniaturized GaAs process-based MMIC filter for RF single transceiver chip will be introduced, which allows for a complete module to be fabricated on a single chip, thus leading the way toward high-volume components at an affordable cost. It is composed of simple planar diagonally end-shorted coupled lines and lumped capacitors. The main advantages of this MMIC filter are as follows. Firstly, the electrical length of resonator can be reduced as small as a few degrees. So the most chip filter using this concept can be designed to be smaller than 2×1 mm^2. Good suppression of the spurious passband is another advantage. There is no any spurious up to about 10 times center frequency in this structure. This property will be most powerful as the image rejection filter in the transceiver system. Moreover this technology is available to any kinds of standard fabrication process because the topology of this circuit is only planar two dimensional structures. Finally, it is also broadly applicable up to millimeter band because the electrical length can be arbitrarily controlled.

A filter using the GaAs process technology is designed and fabricated at 5.5GHz to maximize the effect of size reduction method because SAW filter covers the frequencies below 3GHz and ceramic filter is still too large to insert in RF transceiver system. Simulation and measurement results are also provided to verify the miniaturized GaAs bandpass filter.

II. BANDPASS FILTER USING MINIATURIZED λ/4 SECTION

(a) (b)

Fig. 1 Hirota's reduced size λ/4 line including artificial resonance circuit (a) and the equivalent coupled lines circuit (b).

In Fig. 1 (a), two artificial resonances are inserted to Hirota's circuits [12]. The high impedance transmission line with shunt lumped inductors can be replaced by diagonally shorted coupled lines shown in Fig. 1 (b). Two dotted networks are equivalent when the following equations are satisfied:

$$\omega L_0 = Z_{oe} \tan\theta \qquad (1)$$

$$\omega L_0 = \frac{1}{\omega C_0} \qquad (2)$$

$$C = C_0 + C_1 \qquad (3)$$

When the miniaturized λ/4 transmission lines are connected in series, it becomes a typical bandpass filter, with the λ/4 section as an admittance inverter. The circuit and its principle circuit show in the Fig.2. The bandwidth can be controlled by the coupling coefficient [13].

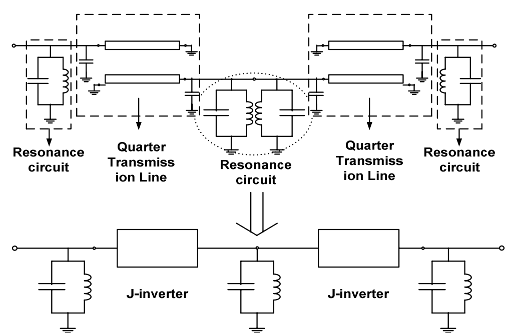


Fig. 2 The equivalent bandpass filter.

III. SIMULATION AND MEASUREMENT RESULTS

Firstly, a one stage GaAs process bandpass filter for 5GHz band WLAN applications, Z_0=50Ω and f_0=5. 5GHz is designed. The electrical length of coupled lines is set to 7 degrees. Arbitrary Zoe can be selected and then, Zoo finally is derived. The selection of Zoe is also related to the bandwidth. This specified response is achieved through circuit simulation by Agilent ADS with component values Zoe=80 Ω, Zoo=58 Ω, and C=3.52 pF. The physical dimensions of coupled lines are determined by Zoe and Zoo. Fig.3 shows the simulated result by ADS. From the figures, we can see that the skirt characteristic is not so good to accept even though the insertion loss is nice.

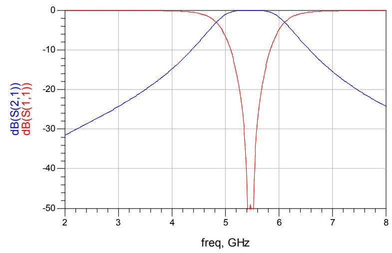
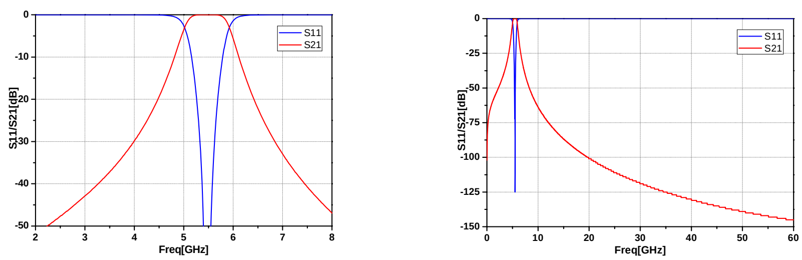


Fig. 3 Simulated results of one stage filter by ADS.

Then, two same one stage filters are cascaded for simple design. In the two-stage structure, bandpass filter behaves as 3 pole topologies like Fig. 2 because an admittance inverter per one stage includes two resonators. If conventional design technique, Butterworth or Chebyshev, is used, components (MIM capacitors and the conditions of coupled lines) of each section are different. In the extremely miniaturized circumstances, it is very difficult to fabricate each component exactly like designed one because of unexpected coupling between components. Fig.4 shows the simulated ADS results. The wide band characteristic expresses good suppression of the spurious passband.



(a) (b)

Fig. 4 Simulation results. (a) Narrow band characteristic, (b) broad band characteristic.

Subsequently, we simulated the circuit with HFSS to accomplish the effect of the overall response. For the actual circuits, an inter-stage connecting line has been employed to prevent the unexpected coupling between two neighboring stages. In order to investigate the inter-stage line length effecting on the characteristics of the filter, a group of two-stage bandpass filters with different 50 Ω inter-stage line length are simulated in HFSS. Fig. 5 shows the simulated results.

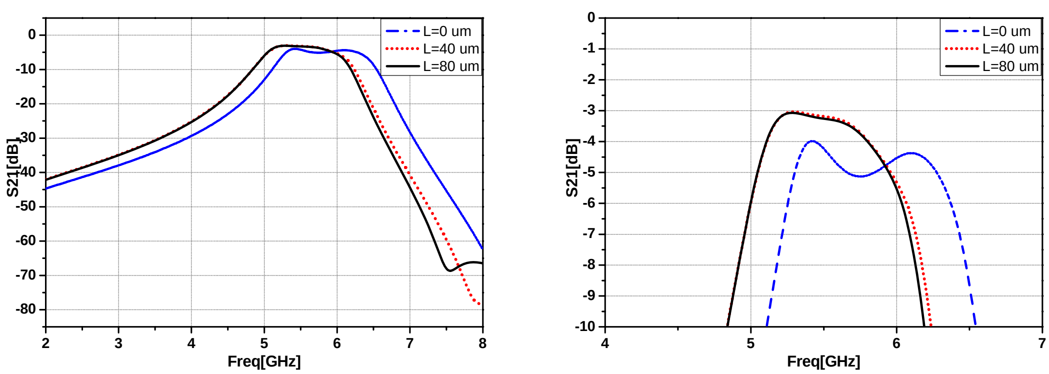


Fig. 5 Simulated results according to different inter-stage connecting transmission line.

From the Fig. 5 we can see that if the inter-stage transmission line is not included between two stages (L=0um), distortion appears. So it is indispensable and the filtering characteristics get better as the line length is longer. This concept is well explained by [14]. However we pursue a compact size, so we have to make a tradeoff between the size and good performance.

Another comparison is also made according to the electrical length of coupled lines. Fig. 6 showed the different performances of 10°, 15°, 25° and 45°coupled lines filters. Obviously the skirt characteristic of long electrical length filter is worse than that of small electrical length filter.

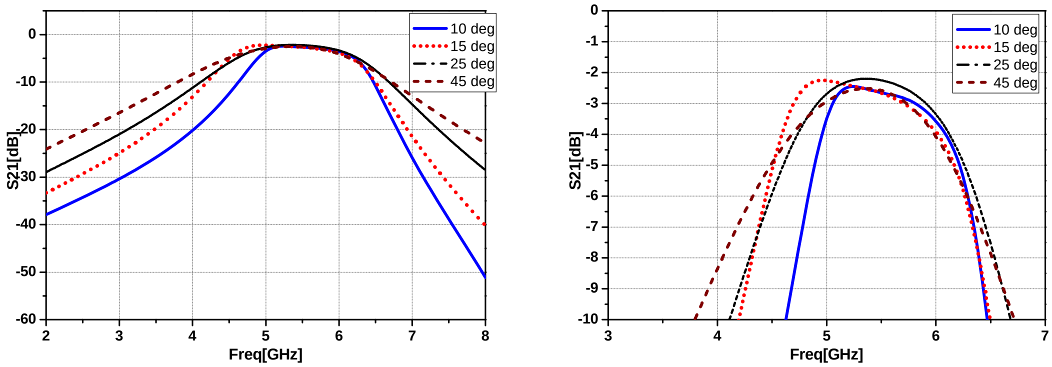
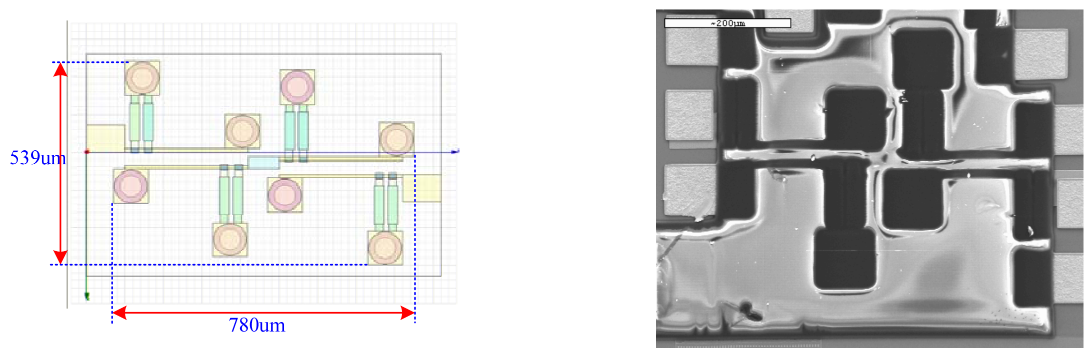


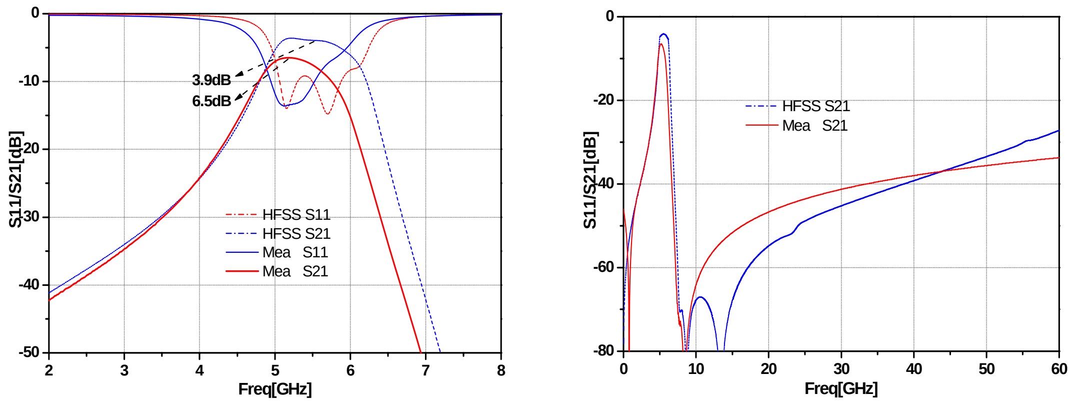
Fig. 6 Simulated results according to different electrical length of coupled lines.



(a) (b)

Fig. 7 Layout circuit by HFSS (a) and Microphotograph of MMIC (b).

Considered all above discussed factors, a two stage bandpass filter with 7 degrees electrical length of coupled lines and 80 um inter-stage line is designed for fabrication. The layout in HFSS is shown by Fig. 7 (a) and Fig. 7 (b) shows the microphotograph of MMIC. Its size is only 0.54×0.78 mm^2**.** As far as authors know, this size is the most miniaturized filter for 5GHz band WLAN reported till now.



(a) (b)

Fig. 8 The comparison of measurement with simulation. (a) Narrow band characteristic, (b) broad band characteristic.

According to the HFSS simulation results shown in Fig. 8, the effects of eight via holes in the filter circuit can be ignored. Fig. 8 also compares the measured data with simulated results and it is clear that there is good agreement with the two. In the measurement results, the passband has a maximum insertion loss 6.5dB with 0.9 GHz bandwidth, from 4.8GHz to 5.71GHz and 13dB return loss.

The measured center frequency is shifted to lower frequency by 0.15 GHz. It is presumed to be resulted from MIM capacitance fabrication accuracy and simulation error. The bandwidth of measured data is shrunk from 1.15 GHz into 0.9 GHz. Simultaneously, the insertion loss also, gets worse from 3.9 dB to 6.5 dB. The loss error is resulted from the HFSS simulation accuracy using bulk conductivity 5.8×10^{7} siemens/m and ignoring dielectric tangential loss of GaAs substrate. And it will be improved if bandwidth is designed to be wider because the wider bandwidth is, the better insertion loss is.

The lower band suppression was > 24dB form 0 – 4 GHz and the upper spurious stopband is >35dB up to 60 GHz. This ultra-wide stop band characteristic is a special advantage, comparing the ceramic or SAW filters.

Finally, a comparison of the sizes of different types of compact filters is made here to show the advantage of the proposed compact bandpass filter, as illustrated in Table 1.

Table 1: Comparison of sizes of different MMIC bandpass filters

Refer -ence	Band width	S_{11} (dB)	S_{21} (dB)	Physical size of a resonator (mm × mm)	Electrical Length (deg)	Technology	Year
[15]	11.4~12.5	-	-1. 5	0.58×1.32	90.0	Inter-digital capacitor and lumped inductor	1983
[16]	25~35	<-12	-3.17	3.8×0.225	90.0	Finite Ground Coplanar	2001
This work	5~6	<-13	-6.5	0.54×0.78	7.0	Modified combline	2006

IV. CONCLUSION

A novel miniaturized GaAs MMIC bandpass filter using combination of diagonally end-shorted coupled lines and lumped capacitors was proposed in this paper. Using this method, the size of MMIC bandpass filter for RF single transceiver chip was reduced to 0.42 mm^2. This filter also has a wider upper stop band characteristic over 35 dB up to 60 GHz. Measured results are well agreed with simulated performances. This technology is expected to be extended the various fabrication processes owing to planer structure.

V. ACKNOWLEDGMENT

The authors wish to acknowledge the Knowledge*on for their assistance and the realization of the chip. The authors also wish to express their gratitude to Joon Hwan Shim and Young Kun Seo for their supports.

REFERENCES

[1] B. Piernas, K. Nishikawa, T. Nakagawa and K. Araki, "Improved Three-Dimensional GaAs Inductors," *IEEE MTT-S Int. Microwave Symp. Dig*., pp. 189-192, May 2001.

[2] M. Sagawa, K. Takahashi, and M. Kakimoto, "Miniaturized hairpin resonator filters and their application to receiver front-end MICs," *IEEE Trans. Microwave Theory Tech.*, vol. 37, pp. 1991-1997, 1989.

[3] M. Makimoto and S. Yamashita, "Bandpass filters using parallel coupled strip-line stepped impedance resonators," *IEEE Trans. Microwave Theory Tech*., vol. MTT-28, no. 12, pp. 1413–1417, Dec 1980.

[4] A. Djaiz and T. A. Denidni, "A new compact microstrip two-layer bandpass filter using apertured-coupled SIR-hairpin resonators with transmission zeros," *IEEE Trans. Microwave Theory Tech.*, vol. 54, no. 5, pp. 1929-1936, May 2006.

[5] J. S. Hong and M. J. Lancaster, "Theory and experiment of novel microstrip slow-wave open- loop resonator filters," *IEEE Trans. Microwave Theory Tech.*, vol. 45, pp. 2358-2365, 1997.

[6] C. W. Tang, Y. C. Lin and C. Y. Chang, "Realization of transmission zeros in combline filters using an auxiliary inductively coupled ground plane," *IEEE Trans. Microwave Theory Tech*., vol. 51, no. 10, pp. 2112-2118, Oct 2003.

[7] A. Kundu and N. Mellen, "Miniaturized Multilayer Bandpass Filter with multiple Transmission Line Zeros", *IEEE MTT-S Int. Microwave Symp. Dig*., pp. 760-763, June 2006.

[8] G. Matthaei, L. Young, E. M. T. Jones, *Microwave Filters, Impedance-Matching networks, and Coupling Structures*. Artech House, pp. 500, 1980.

[9] A. Hussain, *Advanced RF Engineering for Wireless systems and Network*, Wiley, pp. 262, 2005.

[10] C. Tzuang, H. Wu, H. Wu and J. Chen, "A CMOS Miniaturized C-Band Active Band pass Filter," *IEEE MTT-S Int. Microwave Symp. Dig*., pp. 772-775, June 2006.

[11] Jia-Sheng Hong and M.J. Lancaster, "Microstrip Filters for RF/Microwave Applications," *Advanced Materials and Technologies*, pp. 217-219, 2001.

[12] T. Hirota, A. Minakawa and M. Muraguchi, "Reduced-size Branch-line and Rat-Race Hybrids for Uniplanar MMIC's," *IEEE Trans. Microwave Theory Tech*., vol. 38, no. 3, pp. 270-275, 1990.

[13] I. H. Kang and K. Wang, "A broadband rat-race ring coupler with tight coupled lines," *IEICE Communications*, vol.e88-B, no. 10, pp. 4087-4089, 2005.

[14] I. H. Kang and H. Y. Xu, "An Extremely Miniaturized Microstrip Bandpass Filter," *Microwave Journal,* May 2007.

[15] R. Esfandiari, D. W. Maki, and M. Siracusa, "Design of integrated capacitors and their application to gallium arsenide monolithic filters," *IEEE Trans. Microwave Theory Tech*., vol. 31, pp. 57-64, Jan 1983.

[16] J. Papapolymerou and G. E. Ponchak, "Microwave Filters on a low Resistivity Si Substrate with a Polyimide Interface Layer for Wireless Circuits," *2001 IEEE Radio Frequency Integrated Circuits (RFIC) Symposium*, pp. 129-132.