

Compact CMOS C-Band Bandpass Filter Using Interdigital Capacitor

† In-Ho Kang* · Xu-Guang Wang**

* Department of Radio Science & Engineering, National Korea Maritime University, Pusan 606-791, Korea

** Graduate school of National Korea Maritime University, Pusan 606-791, Korea

Abstract : A novel miniaturized CMOS C-Band bandpass filter based on diagonally end-shortened coupled lines and interdigital capacitors is proposed. The utilized coupled lines structure reduced the configuration in size, as small as a few degrees. Moreover, the characteristic of interdigital capacitor, relatively high Q and good capacitance tolerance, accounts for the satisfied performance of this new filter. A two-stage bandpass filter was designed and fabricated with chip surface area only $1.02 \times 1.4 \text{ mm}^2$.

Key words : Miniaturized bandpass filter, Coupled lines, Interdigital capacitor, CMOS fabrication process

1. Introduction

The progress of modern wireless communication technology is focused on the highest possible method integrating transceiver system into monolithic compact module when the size and performance are crucial. As a consequence, the miniaturization should satisfy the requirements to make the system smaller with higher reliability and to reduce design efforts and cost. Since microwave bandpass filter plays a key role in communication systems, many studies have been made for the purpose of reducing the large size of conventional bandpass filter. Lumped elements are used in the realization of small size. However, the design must be somewhat empirical and the upper side frequency is usually confined to a few GHz due to the low resonant frequency and low quality factor (Q) (Piernas, Nishikawa, Nakagawa & Araki, 2001). The folded hairpin resonator filters, stepped-impedance resonator (SIR) filters (Sagawa et al., 1989; Makimoto and Yamashita, 1980; Djaiz and Denidni, 2006) and slow wave open-loop resonator filters (Hong and Lancaster, 1997) are some other solutions. Nevertheless, only a relative compact size can be obtained by these methods.

Interdigital capacitors (IDC's) are widely employed as quasi-lumped elements in monolithic microwave integrated circuits for wireless technology applications, due to their simplicity of construction, relatively high Q, and repeatability (Alley, 1970). Their use also affords a considerable size reduction when compared with equivalent distributed matching structures. And, since interdigital capacitors do not use a dielectric film, their capacitance

tolerance is very good and is limited only by the accuracy of the metal pattern definition (Robertson and Lucyszyn, 2001).

In this paper, a novel miniaturized CMOS filter composed of diagonally end-shortened coupled lines and interdigital capacitors for C-Band will be introduced, which leads to fabricating a complete module on a single chip at an affordable cost because the electrical length of the coupled lines in resonator can be reduced as small as a few degrees. A further advantage is that the use of IDC results in good fabrication accuracy and thus, center frequency stability can be easily attained. In addition, it effectively suppresses the spurious passband, which restricts the applicability of traditional filters. Finally, it is also broadly applicable up to millimeter band because the electrical length can be arbitrarily controlled.

A filter using this technology is designed and fabricated centered at 7.2 GHz. Measurement results are also provided, from which attractive features are observed experimentally as to size reduction and suppression of harmonics.

2. Bandpass filter using miniaturized $\lambda/4$ section

In Fig. 1 (a), two artificial resonances are inserted to Hirota's circuit (Hirota, Minakawa and Muraguchi, 1990). 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:

† Corresponding Author : In-Ho Kang, ihkang@hhu.ac.kr (051)410-4422

** wangxg56@msn.com (051)410-4919

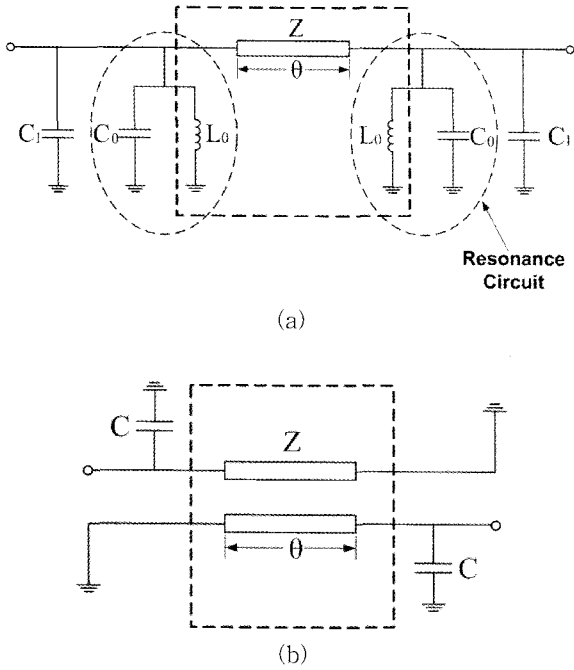


Fig. 1 Hirota's reduced size $\lambda/4$ line including artificial resonance circuits (a) and the equivalent coupled lines circuit (b)

$$\omega L_0 = Z_{oe} \tan \theta \tag{1}$$

$$\omega L_0 = \frac{1}{\omega C_0} \tag{2}$$

$$C = C_0 + C_1 \tag{3}$$

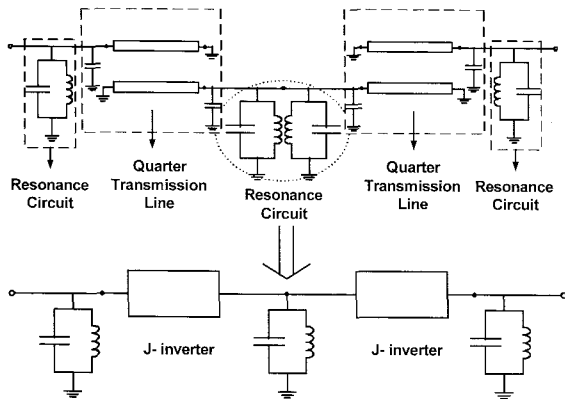


Fig. 2 The equivalent bandpass filter

When the miniaturized $\lambda/4$ transmission lines are cascaded, it becomes a typical bandpass filter, with the $\lambda/4$ section as an admittance inverter. The circuit and its principle circuit are shown in the Fig. 2(Kang and Xu, 2007). The bandwidth can be controlled by the coupling coefficient(Kang and Wang, 2005).

3. Interdigital capacitor design

Interdigital capacitors have proven to be useful components in monolithic integrated circuits and they are more accurate and repeatable than MIM capacitors. Fig. 3 describes the top view of a typical IDC with multiple fingers.

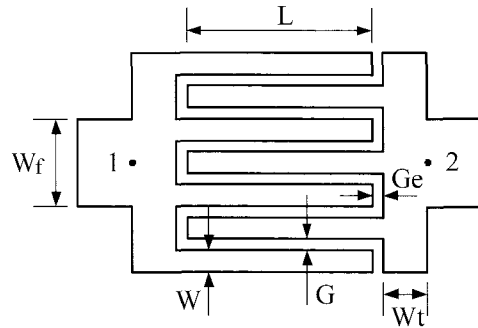


Fig. 3 The top view of typical IDC

The conventional IDC is a multi-conductor structure because many long and thin fingers are needed, along with thin gaps between them for high capacitance. Therefore, it brings about a major drawback that the resonances of the different modes appearing in this structure arise when more than three fingers are used. As a result, the IDC performance is degraded because its usable frequency band is shortened. The recently proposed wire bonded IDC (WBIDC) overcomes this problem by interconnecting the ends of the fingers on the same side of IDC (Casares-Miranda et al., 2005). In consequence, the operational frequency range is significantly increased. This enhancement is due to the elimination of the resonances appearing in the IDC(Dib, Zhang and Rohde, 2004). For the same reason, the IDC in this case fully used the 4 layers of CMOS, which connected by vias to form the WBIDC. By this means, high frequency response was improved.

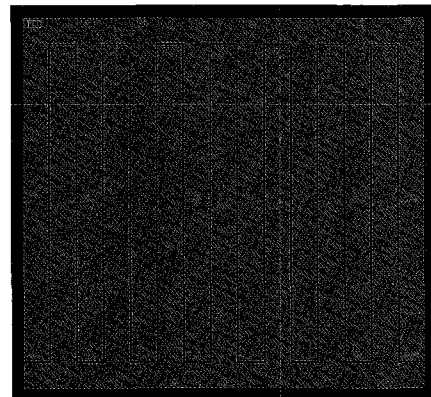
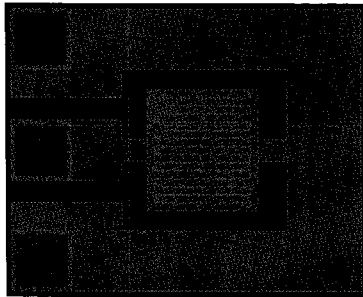
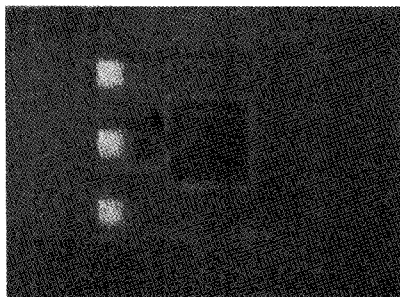


Fig. 4 Layout of interdigital capacitor by Cadence

An interdigital capacitor with 15 fingers were designed and fabricated, as shown in Fig. 4. To facilitate the S-parameters measurement, it was assembled on a test fixture. Fig. 5 (a) shows the layout by Cadence of this device and (b) shows the corresponding chip photograph.



(a)



(b)

Fig. 5 The Cadence layout of the fabricated IDC with test structure (a) and chip photograph (b)

The measured S-parameter of this IDC, given in Fig. 6, covers the frequency range of 2 GHz to 25 GHz. The quality factor (Q) extracted from these S-parameter data is presented in Fig. 7, from which it can be seen that the Q increases as frequency increases and it is more than 20 when frequency is higher than 7 GHz, relatively bigger than those of conventional MIM capacitors. Note that for frequency above 12GHz, the Q increases sharply.

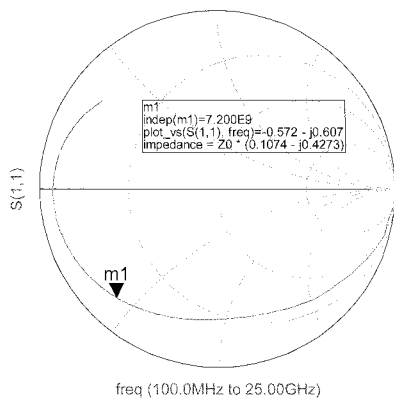


Fig. 6 Measured S-parameter of the fabricated IDC

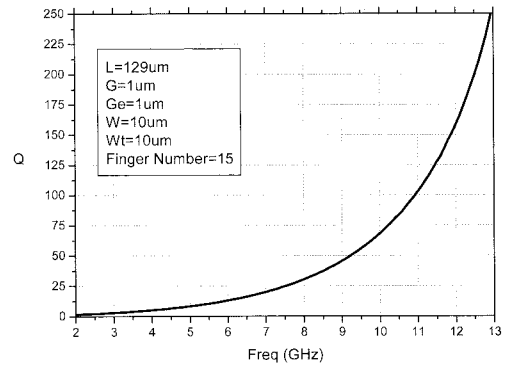


Fig. 7 Variation of Q as function of frequency

4. Bandpass filter design and measurement results

The size reducing method of $\lambda/4$ transmission line discussed in section 2 and the IDC described above are used to design a two-stage bandpass filter with $Z_0=50\Omega$ and $F_0=7$ GHz. Firstly, the electrical length of coupled lines is set to 9 degrees and Z_{oe} can be arbitrarily selected. After that, Z_{oo} is derived. The physical dimensions of coupled lines are determined by Z_{oe} and Z_{oo} , which are also related to the bandwidth. From the layout by Cadence available in Fig. 8, it is indicated that an inter-stage connecting line has been employed in order to prevent the unexpected coupling between two neighboring stages. Otherwise, passband response distortion will appear(Kang and Xu, 2007). Fig. 9 shows the photograph of fabricated chip, with limited size of 1.4×1.02 mm².



Fig. 8 The filter layout by Cadence

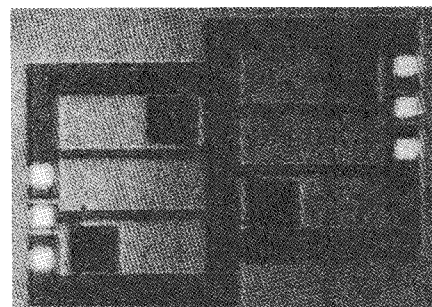


Fig. 9 Photograph of the fabricated filter chip

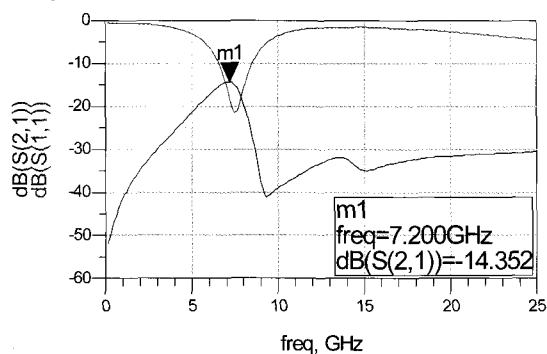


Fig. 10 The measurement results

In the measurement results of Fig. 10, the passband has a maximum insertion loss 14 dB with 0.6 GHz bandwidth, from 6.8 GHz to 7.4 GHz and 20 dB return loss. The lower band suppression is more than 22 dB from 0 - 5 GHz and the upper spurious stopband is no less than 30 dB up to 25 GHz. This wide stopband characteristic is a special advantage, comparing the ceramic or SAW filters. However, the insertion loss is not as perfect as we expected. It is presumed to be resulted from two possible reasons: one is mismatching and the other is the error in capacitance calculation, since the analysis model of IDC is so complex and difficult that the obtained capacitance is not exact. Therefore, the more accurate model suitable to analyze the characteristics of IDC should be investigated again and filter CAD simulation should be corrected. All of these will be dealt with in the future study.

4. Conclusion

A novel miniaturized CMOS bandpass filter using combination of diagonally end-shortened coupled lines and interdigital capacitors was proposed in this paper. This approach not only makes a compact size and stable center frequency, but also results in a wider upper stopband characteristic of the fabricated filter over 30 dB up to 25 GHz. This technology is expected to be extended the various fabrication processes owing to simple structure.

References

- [1] Alley, G. D. (1970), "Interdigital capacitors and their application to lumped-element microwave integrated circuits", *IEEE Trans. Microwave Theory Tech.* vol. MTT-18, pp. 1028 - 1033.
- [2] Casares-Miranda, F. P., Márquez-Segura, E., Otero, P. and Camacho-Peñalosa, C. (2005), "Wire bonded interdigital capacitor", *IEEE Microw. Wireless Compon. Lett.* vol. 15, no. 10, pp. 700-702.
- [3] Dib, N., Zhang, Q. and Rohde, U. (2004), "New CAD model of microstrip interdigital capacitor", *Active Passive Electron. Comp.* vol. 27, pp. 237-245.
- [4] Djaiz, A. and Denidni, T. A. (2006), "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.
- [5] Hirota, T., Minakawa, A. and Muraguchi, M. (1990), "Reduced-size Branch-line and Rat-Race Hybrids for Uniplanar MMIC's", *IEEE Trans. Microwave Theory Tech.* vol. 38, no. 3, pp. 270-275.
- [6] Hong, J. S. and Lancaster, M. J. (1997), "Theory and experiment of novel microstrip slow-wave open-loop resonator filters", *IEEE Trans. Microwave Theory Tech.* vol. 45, pp. 2358-2365.
- [7] Kang, I. H. and Wang, K. (2005), "A broadband rat-race ring coupler with tight coupled lines", *IEICE Communications*, vol. e88-B, no. 10, pp. 4087-4089.
- [8] Kang, I. H. and Xu, H. Y. (2007), "An Extremely Miniaturized Microstrip Bandpass Filter", *Microwave Journal*. vol. 50, no. 5, pp. 228-233.
- [9] Makimoto, M. and Yamashita, S. (1980), "Bandpass filters using parallel coupled strip-line stepped impedance resonators", *IEEE Trans. Microwave Theory Tech.* vol. MTT-28, no. 12, pp. 1413 - 1417.
- [10] Piernas, B., Nishikawa, K., Nakagawa, T. and Araki, K. (2001), "Improved Three-Dimensional GaAs Inductors", *IEEE MTT-S Int. Microwave Symp. Dig.* pp. 189-192.
- [11] Robertson, I. D. and Lucyszyn, S. (2001), "RFIC and MMIC design and technology", *The Institution of Electrical Engineers*, pp. 91.
- [12] Sagawa, M., Takahashi, K. and Kakimoto, M. (1989), "Miniaturized hairpin resonator filters and their application to receiver front-end MICs", *IEEE Trans. Microwave Theory Tech.* vol. 37, pp. 1991-1997.

Received 22 August 2007

Accepted 20 December 2007