임피던스 공진기를 이용한 FR-4 임베디드 광대역필터

論 文
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FR-4 Embedded UWB Filter using Uniform Impedance Resonator

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Abstract - In this paper, a novel embedded ultra wideband (UWB) band-pass filter is presented on a FR-4 package substrate including high Dk resin coated copper (ε_r=30) film. The proposed UWB filter is comprised of a parallel resonator with meander-type uniform impedance resonator (UIR) and two series resonators with high Q circular stacked spiral inductor and metal-insulator-metal (MIM) capacitor. In order to obtain excellent attenuation characteristics by generating attenuation poles in lower and upper stop bands, a single MIM capacitor is added to each resonator. The fabricated FR-4 embedded UWB filter has insertion loss of -1.0dB and return loss of -11dB, respectively. It has also extremely wide bandwidth (over 50%) and small size (3.7 × 4 × 0.77 ㎣) which is compatible with LTCC devices.

Key Words : Ultra Wideband (UWB) Filter, Embedded, FR-4, Circular Spiral Inductor, MIM Capacitor, Uniform Impedance Resonator (UIR), High Dielectric Composite Film.

1. Introduction

Ultra-wideband (UWB) technology has recently attracted a wide attention since the Federal Communication Committee (FCC) in USA authorized the unlicensed use of UWB (3.1~10.6㎓) band for indoor and hand-held systems in 2002 [1]. In particular, the pass band ranged from 3.1㎓ to 4.85㎓ which is to avoid wireless LAN and ISM bands (5.15㎓~5.35㎓, 5.75㎓~5.85㎓) is the most attracted frequency regime for commercial UWB communication applications. For realizing low cost and miniaturized UWB communication systems, in addition to UWB chip set developments, band-pass filters have been widely researched [2~5]. For enlarging the bandwidth, two radial stubs was added into a double-ring resonator and stepped impedance resonator (SIR) was utilized on duriod substrate [3~4]. For miniaturizing the band-pass filter, LTCC technology was applied [5]. However, the LTCC technology has some limitations such as high temperature processes and small area manufacturing.

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In this paper, fully embedded UWB band-pass filter with 3 order resonators which are comprised of two LC resonators and an uniform impedance resonator is investigated by using FR-4 substrate and high dielectric composite film. To improve attenuation characteristics of the proposed filter, an attenuation capacitor is newly applied to each resonator.

In order to develop series LC resonator with high quality factor, vertically stacked circular spiral 3D inductor and MIM (metal-insulator-metal) capacitor are utilized. A meander type UIR is newly applied to the filter circuit in order to improve packaging efficiency, reduce a size, and minimize a number of tuning elements resulting in high yield. In order to minimize a size of attenuation capacitor with large capacitance, high dielectric composite film is developed and applied which is comprised of barium titanate ($BaTiO_3$, BT) powder and epoxy resin. These passive devices and filter circuit are simulated and optimized by using circuit simulator and 3D EM simulator.

2. Design and Fabrication

2.1 Design and Simulation

As shown Fig.1, the proposed UWB band-pass filter is first designed by interconnecting in parallel two series and one parallel LC resonators based on 3-order Chebyshev lumped element filter circuit topology [6]. In order to improve attenuation characteristics of the proposed UWB filter, an attenuation capacitor is newly added in series to the parallel LC resonator to generate an attenuation pole at the lower pass band slope and in parallel to the series LC resonators to generate an attenuation pole at the pass band slope. The proposed attenuation capacitors just affect the attenuation characteristics. The optimized equivalent circuit parameters through the circuit simulation are $C_{01}=C_{02}=0.35pF$, $L_{01}=L_{02}=4.8nH$, $Ca_{01}=Ca_{02}=0.23pF$, $Ca_{12}=4.8pF$, $C_{UIR}=2pF$, and $L_{UIR}=0.85nH$, respectively.

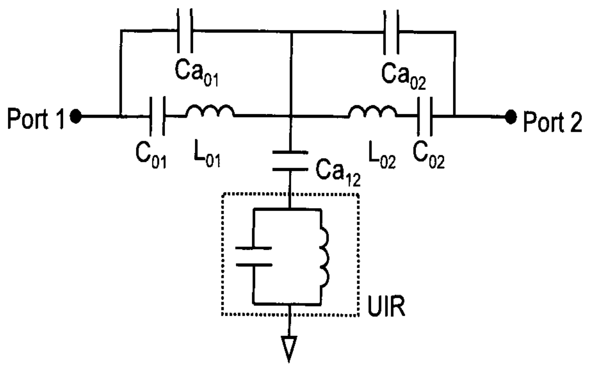
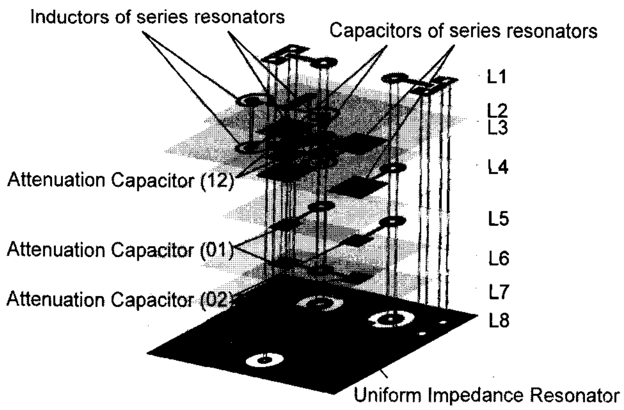


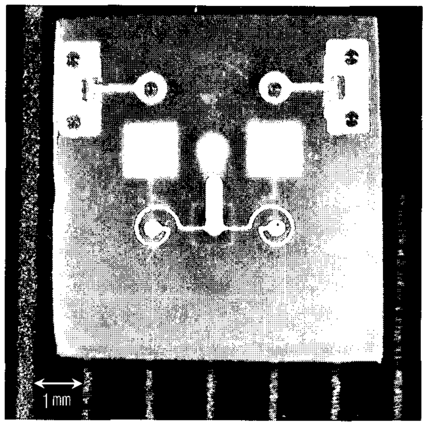
Fig. 1 Equivalent circuit diagram of proposed FR-4 embedded UWB band-pass filter

These passive circuit elements are designed to be fully embedded into low cost FR-4 substrate. For implementing high Q series LC resonator, two-turn circular shaped spiral inductor which is vertically stacked from the 1st layer to the 3rd layer and square shaped metal-insulator-metal (MIM) capacitor which is designed on the 3rd layer through the 4th layer of the proposed FR-4 package substrate [7]. The newly applied attenuation capacitors (Ca_{01}, Ca_{02}) are designed on the 5th layer through the 6th layer. Since these capacitors have small capacitance values, they are easily designed by using conventional low dielectric film with $\varepsilon_r=4.1$. However, the attenuation capacitor (Ca_{12}) with relatively high capacitance value is designed on the 2nd through 3rd layer by using a high dielectric composite film with $\varepsilon_r=30$ and loss tangent=0.03. It helps to reduce the size of the attenuation capacitor resulting in higher packaging density. In order to improve quality factor of the parallel resonator, packaging efficiency, and reduce a number of tuning elements, the parallel LC resonator is modified with uniform impedance resonator (UIR) [8]. A meander type UIR is designed and embedded into the 7th layer to reduce a size of the filter.

Fig. 2 (a) shows circuit layout diagram of the proposed FR-4 embedded UWB filter. the proposed passive components, resonators, and UWB filter are optimally designed by using circuit and 3D EM simulators.



(a)

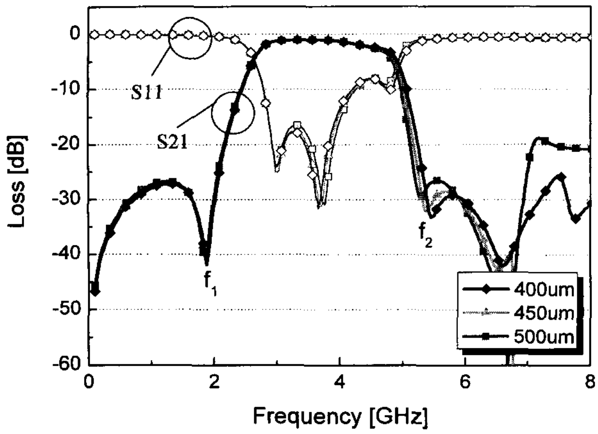


(b)

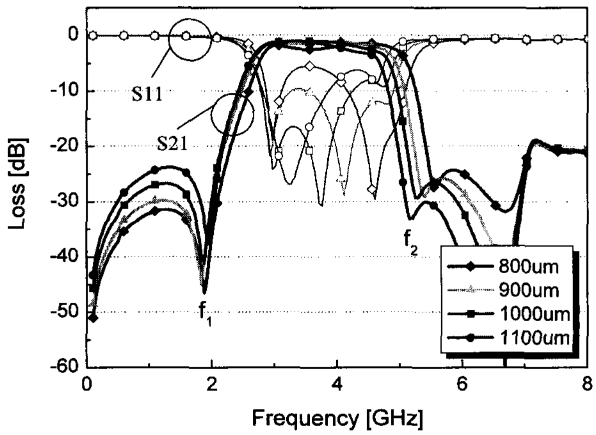
Fig. 2 Schematic drawing (a) and photomicrograph (b) of FR-4 embedded UWB band-pass filter

2.2 Fabrication

As shown in Fig. 2 (a), the proposed UWB filter with UIR is fabricated and embedded into FR-4 substrate which is comprised of prepreg (1st, 3rd, 6th, 7th and 8th layer), high dielectric resin coated copper (2nd layer), and copper clad laminate (4th and 5th layer) films. The utilized PP, CCL, and high Dk RCC materials have dielectric constants of 4.1, 4.4, and 30, and tangent losses of 0.022, 0.02 and 0.03, and a thickness of 90μm, 150μm and 16μm, respectively (exceptionally, a thickness of 8th prepreg is approximately 60μm). After fabrication of these embedded UWB filters, the PSR (photo-imageable solder resist) was coated and patterned on top of the filter components. Fig.2 (b) shows a photomicrograph of the fully embedded UWB filter into FR-4 substrate. It has 3.7 × 4 × 0.77 ㎣ which is the smallest filter embedded into an organic package substrate.



(a)



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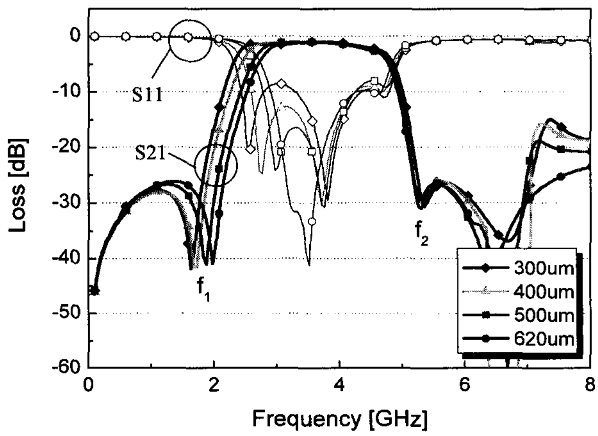

(c)

Fig. 3 Frequency responses of FR-4 embedded UWB filters as some geometry are varied: (a) attenuation capacitors (Ca01, Ca02), (b) series capacitors (C01, C02) and (c) line width of uniform impedance resonator

3. Experimental results and Discussions

The fabricated UWB band-pass filters have been measured and characterized by using HP 8510B network analyzer and two PICOPROBE coplanar ground-signal-ground (GSG) probes with 250㎛ in pitch size.

Fig. 3 (a) shows performance characteristics of the UWB filters, as the attenuation capacitors (Ca_{01}, Ca_{02}) are varied in their sizes. As predicted in their design and simulation, it has much better attenuation characteristics than the filter without any attenuation capacitors connected in parallel with series LC resonators. And the upper attenuation poles (f_2) are slightly decreased as the attenuation capacitors have higher capacitances, while other performance characteristics are not varied. Fig. 3 (b) shows performance characteristics of the UWB filters, as the series capacitors (C_{01}, C_{02}) have different sizes. The upper attenuation poles (f_2) get lower as the capacitors have higher capacitances. The rejection losses of the lower stop band are increased and the bandwidths are decreased as the series capacitances are increased. Fig. 3 (c) shows performance characteristics of the UWB filters, as the line width of the UIR is varied. As the line width is increased, the lower attenuation pole (f1) is slightly increased. The proposed meander type UIR is much less sensitive to the performance characteristics of the UWB filter than conventional LC parallel resonator. And it has better performance characteristics, small size, and higher yield than the filter with LC parallel resonator.

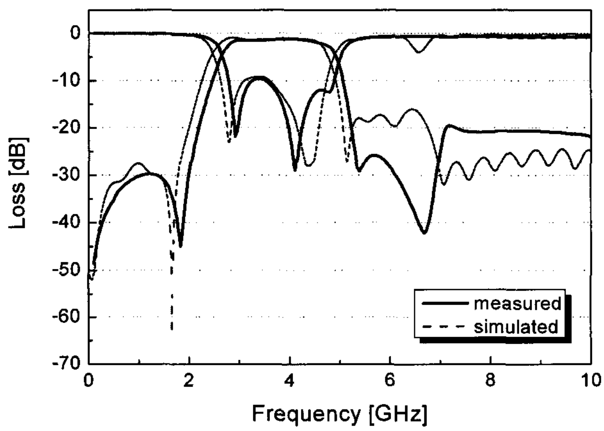

Fig. 4 *Comparison of measured and simulated results of* FR-4 embedded UWB filter (Ca01=C02=500x500㎛2, C01=C02=900x900㎛2, line width of UIR=500㎛)

Fig. 4 shows comparison of measured and simulated performance characteristics of the fabricated UWB filter. As shown in Fig.4, there is small discrepancy between the simulated and measured results. It might be occurred since there is inaccurate geometry after fabrication and change of dielectric constant as frequency is varied. Table 1 shows comparison of the fabricated UWB filter with the other works. It has similar performance characteristics and size of the LTCC based filter. However, it has much lower profile, larger bandwidth, lower cost, and higher yield.

Table 1 Comparison with Other Related Works

Ref.	Package Substrate	BW (GHz)	IL (dB)	RL (dB)	Size
[3]	Duriod	3.15~5.28 (50.5%)	-0.637	-34.8	5x5㎠
[4]	-	3.1~5 (50%)	<-1	<-18	9x9㎟
[5]	LTCC	2.96~4.91 (48.75%)	<-2.2	<-10	3x2㎟
This Work	FR-4	2.75~4.8 (54%)	-1~-3	<-9.5	3.7x4㎟

4. Conclusion

FR-4 embedded UWB band-pass filters have been realized by using conventional low cost PCB fabrication processes. The fabricated filter is comprised of high Q circular stacked spiral inductors, MIM capacitor, attenuation capacitor, and meander-type uniform impedance resonator. It was extremely miniaturized and highly packaged into low cost substrate by using high Dk resin coated copper film and FR-4 substrate. It has excellent performance characteristics and wide bandwidth which are directly applicable to UWB communication systems with low cost and small size. The attenuation characteristic of fabricated filter was dramatically improved by using the attenuation capacitors which was connected to each resonator. The embedded passive circuit design and fabrication technology can be widely applied for advanced mixed signal and electronic systems.

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