Fully Embedded LC Diplexer Passive Circuit into an Organic Package Substrate

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유기 패키지 기판내에 내장된 LC 다이플렉서 회로

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Abstract

In this paper, fully embedded and miniaturized diplexer device has been developed and characterized for dual-band/mode CDMA handset applications. The size of the embedded diplexer is significantly reduced by embedding high Q circular spiral inductors and high DK MIM capacitors into a low cost organic package substrate. The fabricated diplexer has insertion losses and isolations of -0.5 and -23 dB at 824-894 MHz and -0.7 and -22 dB at 1850-1990 MHz, respectively. Its size is 3.9 mm x 3.9 mm x 0.77 mm. The fabricated diplexer is the smallest one which is fully embedded into a low cost organic package substrate.

Key Words : Organic SOP(유기 SOP), diplexer(다이플렉서), embedded(임베디드), packaging(패키징), high Q inductor(고품질 인덕터), high DK capacitor(고용량 커패시터)

1. Introduction

As mobile communication markets are demanding advanced electronic systems with small volume, low profile, light weight, low cost, excellent performance, and multi-functionality, system on package(SOP) is being considered as one of the most crucial research areas for realizing these advanced electronic systems. Embedded passive components(EPC) is the most actively researched area in SOP technologies, because the number of the passive components and IC chips is steadily increasing as the advanced electronic systems towards for higher and multi-functionality[(1)].

As dual-mode/band handsets usually require miniaturized

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components and modules, low temperature co-fired ceramic(LTCC) technology is widely used to fabricate due to its high integration density[2~4]. However the ceramic will shrink during the firing process at high temperature, which might lead to the limitation of the product reliability and the component yield. It is also limited to large area manufacturing. Therefore, several studies on diplexers on low cost organic substrate, which are easy to manufacture in large area and to integrate with other printed RF circuits, have been performed.

However, the sizes of these diplexers are much larger than LTCC diplexers[5~7]. Although the diplexer with a small size of 8.5 mm x 4 mm has been developed for low cost RF applications in system in package(SIP)[7], it is still much larger than LTCC based devices.

In this paper, fully embedded diplexer is investigated into an organic package substrate for small size and low cost front-end module(FEM) for dual-mode/band system (Cellular/PCS) applications. The size of the embedded diplexer is significantly reduced by using high Q circular spiral inductors and high DK MIM capacitors. The proposed diplexer is optimally designed for fabrication by using a circuit simulator and 3D-EM simulator.

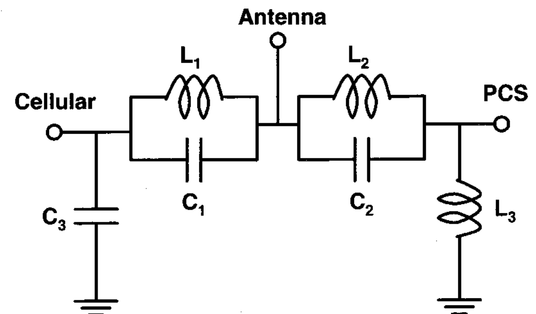

Fig. 1 Schematic drawing of proposed diplexer embedded into an organic package substrate.

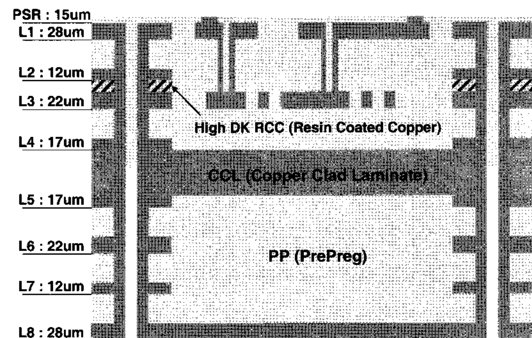

Fig. 2 A cross-sectional view of 8-layered organic package substrate to fabricate embedded diplexer with high Q circular spiral inductors and MIM capacitors.

2. Design and Fabrication

Fig. 1 shows equivalent circuit model of proposed diplexer to be embedded into organic package substrate for dual-mode/band CDMA(Cellular/PCS) handset applications. The reactance values of the proposed diplexer are obtained by using a lumped-element diplexer circuit topology[2]. The center frequency and bandwidth of the diplexer is designed and optimized by varying the inner diameters of the high Q circular spiral inductors. As shown in Fig. 1, the proposed diplexer is comprised of three high Q circular spiral inductors and three MIM capacitors. The inductors with circular spiral geometry are fully embedded into the first layer and third layer of 8-layered organic package substrate. The inner diameter(d_{in}) is varied for finding optimized geometry with high quality factor and self resonant frequency. The MIM capacitors are made with the high dielectric composite film which is comprised of $BaTiO_3$ powder and epoxy resin. The proposed embedded circular spiral inductors, MIM capacitor, and diplexer circuit are optimally designed by using a circuit simulator and 3D EM simulator.

Fig. 2 shows a cross-sectional view of 8-layered organic package substrate to fabricate embedded diplexers with high Q inductors and MIM capacitors. As shown in Fig. 2, the 8 layered organic package substrate is comprised of a PrePreg(first, third, sixth, seventh and eighth layer), high DK resin coated copper(second layer), and copper clad laminate(forth and fifth layer).

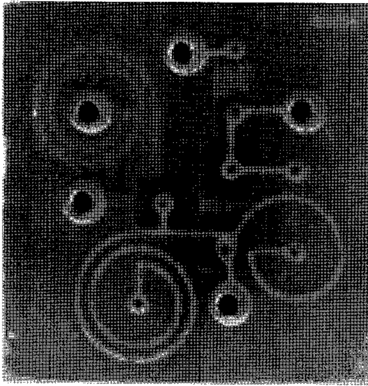

Fig. 3 **Photomicrograph of fabricated diplexer embedded into an organic package substrate for dual-mode CDMA(Cellular/PCS) handset.**

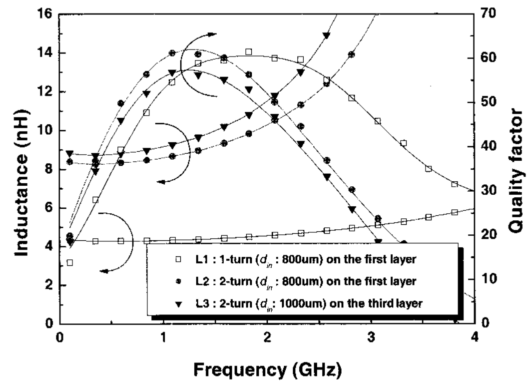

Fig. 4 **Comparison of inductance and quality factor of circular spiral inductors embedded into the first layer and third layer of 8-layered organic package substrate with different windings and inner diameter(din).**

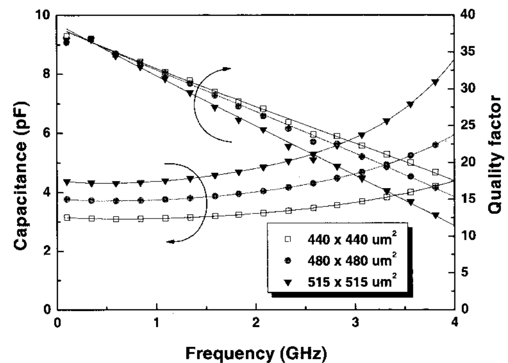

Fig. 5 **Comparison of capacitance and quality factor of circular spiral inductors embedded into the second layer and third layer of 8-layered organic package substrate with different windings and inner diameter(d_{in}).**

3. Experimental Results and Discussions

3.1 Fully embedded inductors and capacitors

The fabricated embedded spiral inductors and MIM capacitors have been measured and characterized by using HP 8510B network analyzer and PICOPROBE coplanar ground-signal-ground(GSG) probes with 250μm pitch size. The inductance, capacitance, and quality factor of the fabricated circular spiral inductors and capacitors were obtained based upon the Y-parameters and Z-parameters taken from the measured two-port S-parameters. Fig. 4 shows comparison of inductance and quality factor of the circular spiral inductors embedded into the first layer and third layer with different windings and inner diameter (d_{in}). The embedded spiral inductors have the quality factors ranged from 60 to 50 at the frequency ranged from 1 to 2 GHz. Fig. 5 shows the comparison of capacitance and quality factor of the MIM capacitors embedded into the second and third layers with different top electrode area. The embedded MIM capacitors have the quality factors ranged from 35 to 25 at the frequency ranged from 1 to 2 GHz.

3.2 Fully embedded diplexer

The fabricated dual-mode embedded diplexer is measured with an HP8510B network analyzer after mounting on a PCB test jig. Since this is only a two port measurement system, the unused port is always terminated with a 50-Ω load.

The embedded diplexer is centered at 859 MHz and 1.92 GHz for dual-mode/band system(Cellular/PCS) applications. The center frequency and bandwidth can be optimized by varying the inner diameters of the circular

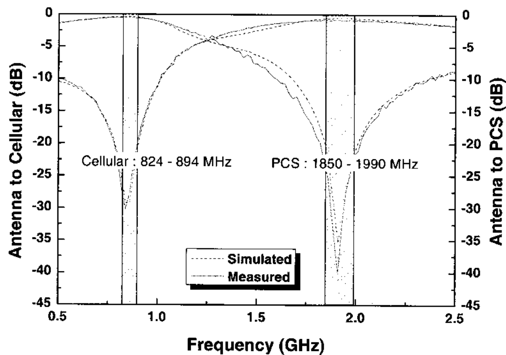

Fig. 6 Comparison of simulated and measured performance characteristics of fully embedded diplexer with high Q embedded circular spiral inductors and MIM capacitors.

spiral inductors.

Fig. 6 shows the EM simulated and measured insertion loss and isolation characteristics of the fabricated diplexer. The fabricated diplexer has insertion losses and isolations of -0.5 and -23 dB at 824-894 MHz and -0.7 and -22 dB at 1850-1990 MHz, respectively. The size is 3.9 mm x 3.9 mm x 0.77 mm. The measured result shows good agreement with the simulated one.

4. Conclusions

Fully embedded diplexer with several high Q circular spiral inductors and MIM capacitors has been designed, fabricated, and characterized for small size and low cost FEM for advanced handset applications. The size of the diplexer has been dramatically reduced by using embedded circular spiral inductors and high DK MIM capacitors.

It has excellent performance characteristics, which are well agreed with the simulated ones. The developed embedded passive circuit technology is widely applicable to advanced mixed signal electronic systems with low cost/profile, small size/volume, and multi-functionality.

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