Highly Compact Embedded Duplexer Implementation for WiMAX Dual-band Front-end Module with Organic Package Substrate

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Abstract—In this paper, low cost and high performance duplexer are investigated for WiMAX front-end module with multi-layered organic package substrate. This dual band FEM includes a 2.5 GHz power amplifier die with switch and has tiny PKG form factor. In addition to module size limitation, FEM requires higher gain and stringent attenuation characteristics specification. The embedded BPFs and duplexer were designed on 8 layer organic substrates by using ADS and HFSS for finding out efficient structure and verifying FEM specifications.

The dual-band FEM with embedded passive components incorporates duplexer including 2 GHz and 5 GHz BPFs. BPFs and duplexer have size of 1.65 × 1.8 × 0.12 mm, 1.32 × 1.2 × 0.12 mm and 2 × 2 × 0.6 mm respectively. Integrated dual-band BPFs show an insertion loss of < −1.8 dB in path band and 22∼40 dB attenuation performance in rejection band. The measured results of BPFs and duplexer show good electrical performance with low insertion loss, high attenuation.

Embedded passive Packaging technology has many advantages such as improving packaging efficiency and better electrical performances for low cost and highly compact RF SOP (System on Package) applications.

1. INTRODUCTION
Nowadays wireless communication systems are getting faster and requiring smaller size which are able to operate in multi-band frequency. In addition, cost issue is very strict for time to market. Many papers have introduced two representative technologies for achieving higher integration module. One is SoC (System on Chip) technology. The other is SoP (System on Package) technology. SoC technology integrates signal collection, signal conversion, data storage, I/O functionalities into single chip. It has many advantages, such as fast, high integrity, low power, small size. However design of SoC is highly complex and cost of SoC is high. In contrast, SoP is a functional system or subsystem assembled into a single package. It contains two or more dissimilar die, typically embedded other components such as passives, filters, antennas into substrate. Therefore, SoP has mainly focused on cost reduction, high reliability and small size form factor. In particular, the embedded passive device technology in SoP provides outstanding solution for these issues. In the present, LTCC has been widely used for wireless application such as FEM, BT, and WLAN module, since LTCC is possible to integrate high Q passive components. However, LTCC materials are more expensive than organic materials. And LTCC has a limitation of size, and mismatch of CTE (coefficient of thermal expansion) between LTCC module and organic main board. In the contrast, embedded passive technology has many advantages with organic material since passive components implement low cost material with high Dk, low Df. Therefore EPD with organic dielectrics becomes replacing ceramic or silicon substrates.

This paper presents the application of embedded passive technology in a dual-mode FEM. Originally, LTCC technology is adopted in this module but it is replaced with organic substrate in this research. This dual band FEM has 1 duplexer consist of 2 GHz and 5 GHz BPFs embedded in organic substrate. Designs, organic substrate structure for embedded each BPF device and electrical characteristics of BPFs and duplexer are shown as results.

2. DUAL-BAND FEM STRUCTURE
Figure 1 illustrates WiMAX FEM system architecture. The WiMAX dual band FEM consists of power amplifier (PA), SP4T, baluns, transmit band pass filter and receiver band pass filter. This front-end module support 2.4 GHz band and 5.2 GHz band. To reduce size and cost of module, FEM was designed using embedded passive technology on organic substrate.

LTCC material is good electrical characteristics such as high dielectric of 6~10 and low loss tangent of 0.002, but also has cost conflict. The choice of material set depends on the application,
cost, performance and size. This paper introduces organic material with low cost and high electrical performance. The main material of FEM substrate is epoxy material of composite type with high Dk, low Df at microwave frequencies. The Dk value is 18 @10 GHz and Df value is 0.008 @10 GHz. The whole process using this material is compatible with standard printed circuit board process. For the FEM device, two composite layers were laminated with BT prepregs symmetrically. Microvia drilling and Cu plating used for interconnection with each layer. Microvias were accomplished using CO\textsubscript{2} laser to get via size on 60\,\sim\,80\,\mu m.

Figure 2 shows 8 layer structure using this material. The composite materials used into 3-4 and 5-6 layer, so embedded passive components were designed using these layers. Capacitors can locate in 3-4 or 5-6 layers. And inductors were designed using core layers (L4, L5) that are possible to implement fine line and space with minimum 30/30\,\mu m.

3. BAND-PASS FILTER DESIGN

Figure 3 shows conventional second-order filter prototype that uses the capacitive coupling to link two LC tank resonators. The reason why it prefers capacitive coupling to inductive is because inductor Q factor is somewhat lower than LTCC. For getting additional transmission zeros, it can use either C feedback or L feedback. The prototype BPFs considered matching with other components using capacitors. Capacitors can locate in 3-4 or 5-6 layers from Fig. 2. And inductors were designed using core layers (L4, L5) that are possible to implement fine line and space.

The 2.5 GHz Band-pass filters shown in Fig. 4 can be realized by stack-up structure of Fig. 2. BPFs have size of 1.65 \times 1.625 \times 0.12 mm, 1.32 \times 1.2 \times 0.12 mm respectively. In order to achieve performance, these BPFs were simulated by ADS and HFSS 3D simulator. Simulation results are shown in Fig. 5. 2 GHz BPF has a low insertion loss $-1.4 \sim -1.5$ dB in pass band from 2.3 to 2.7 GHz and high rejection, $-20.3$ dB, required at 2 GHz band. 5 GHz BPF shows that in band insertion loss is $-1.5$ dB (5.15 $\sim$ 5.875 GHz). The out of band rejection is 30 dB at 4 GHz.
4. WIMAX FEM DUPLexER EPMBEBEBED SUBSTRATE IMPLEMENTATION
This paper presents an embedded duplexer design for WiMAX dual FEM using BPFs design. To optimize the electrical performance of duplexer, additional matching network used between 2 and 5 GHz BPF. The key to implement matching network is to make meander line inductor with fine line. Duplexer design combining 2.5 GHz BPFs is shown in Fig. 6(a). Fig. 6(b) shows the result of duplexer 3D simulation. The insertion loss in pass band $-1.7$ dB and attenuation is less 20 dB below 2 GHz.
Figure 6: (a) Duplexer design in substrate, (b) Duplexer simulation result.

Figure 7 shows the sample image of WiMAX FEM embedded duplexer into organic substrate. Also this sample met the reliability condition of PKG level. The Strip has size of 105*82 mm and 144 unit. Through hole vias used for effective thermal transfer from top and to bottom.

5. CONCLUSIONS
In this paper, we presented the organic embedded passive technology using multilayer PCB process. The most important is to design complex passive components as well as to consider a limitation of size and cost. Embedded BPF and duplexer have been implemented in composite material layer. The overall size of module which includes PA and bypass capacitor is 5.4*4*1.5 mm. The duplexer and each BPFs shows the good electrical performance.

REFERENCES


