Bandpass Filter Embedded SwP (System with Probe) for High-Frequency Application

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Abstract

A new type of low-temperature co-fired ceramic (LTCC) probes for high-frequency measurements fabricated using SiP technology is proposed. The advantage of this probe is that the metal tips for the electrodes can be made easily by cutting LTCC sheets during the fabrication process. A system with probe (SwP) consisting of a probe and a bandpass filter (BPF) is designed and fabricated. The frequency dependence of the reflection parameter $S_{11}$ and transmission parameter $S_{21}$ showed the good agreement between simulation and measurement. Also, the S-parameters of a SwP with a commercial discrete BPF are measured and compared to three types of BPF embedded SwPs. Finally, the near-end crosstalk (NEXT) and far-end crosstalk (FEXT) for a fabricated SwP array are investigated.

Keywords: LTCC, SiP, Probe, High-Frequency, Band Pass Filter

1. Introduction

In recent years, high-performance requirements for wireless communication applications such as superior stability at high frequencies and the high-speed transmission of large volumes of data have been in demand. Therefore, the operating frequency has increased.

Generally, after the wafer process in IC fabrication, a wafer test using metal probes is performed. However, the higher operating frequencies of ICs nowadays makes the wafer test more difficult. A special configuration of probes must be used to reduce the transmission losses at high frequencies, resulting in an increase in the probe’s cost. Any solution for this problem must be considered from the viewpoint of cost as well as performance.

Recent system-in-a-package (SiP) technology, on the other hand, is believed to be promising for high-frequency applications. Stacked lines such as microstriplines (MSL), striplines (SL) and coplanar lines (CPW), and active devices are integrated in a SiP substrate at high density. One widely used SiP substrate material is low-temperature co-fired ceramics (LTCC), which has excellent high frequency properties such as a stable dielectric constant and a low loss tangent. Moreover, some discrete passive components such as inductors and capacitors can be embedded within the substrate.

In this paper, the high-frequency probes for an electrode are fabricated using SiP technology. It is called System-with-Probe (SwP) and consists of a probe and bandpass filter (BPF). The advantage of the SwP is that it is possible to make holes for metal tips easily by cutting trenches in the LTCC fabrication process. Therefore, multiprobes can be made more easily than is currently possible with existing probes. Moreover, the SwP can be applied to the high-frequency function modules with an amplifier. Three types of BPFs are designed, and the S-parameters of the fabricated SwP are compared with the simulation values.

2. Experimental Procedure

Figure 1 shows a schematic diagram (a) and an observed X-ray image (b) of the SwP fabricated with a LTCC substrate. The SwP consists of a ground-signal (G–S) type metal tip, MSL, CPW, SL, SMA connector, and BPF. The impedance of all lines and metal tips are designed as 50 ohms. Metal tips of the SwP are inserted into the substrate from the side plane. The diameter of the holes for the metal tips is 200 $\mu$m. The length of metal tip exposed in air is approximately 3 mm.

In order to find a superior structure for fabrication, three types of BPF-embedded SwPs were designed and fabricated. Figure 2 shows the structures of a LC type BPF (a), an edge-coupled type BPF (b), and a short-stub type BPF (c). All the BPFs were designed not as discreet compo-
nents but as line patterns. The resonance frequency of the three types of BPF was designed to be 2.4 GHz, as that is widely used in wireless applications.

The LC-type BPF consists of a spiral inductor and a parallel plate capacitor. The line/space length of the embedded spiral inductor is 100/100 μm. The inductance of the spiral inductor is 1.01 nH per turn. The capacitance required for a resonance frequency of 2.4 GHz is 4.36 pF. The electrode area of the parallel plate capacitor is approximately 4.8 mm².

Figure 2(b) shows the edge-coupled type BPF.[4, 5] The gap between the microstripline and the stripline acts as a capacitor.[6, 7] The width of the MSL and SL are 0.24 mm and 0.12 mm respectively, and the characteristic transmission-line impedance is 50 Ω. The length of stripline is 23.44 mm, equal to 1/2 of the wavelength.

The third type of BPF has a one-half wavelength stub of 2.4 GHz resonance frequency as shown in Fig. 2(c). The short-stub input impedance, \( Z_{in} \) of the transmission line without loss is given by

\[
Z_{in} = jZ_0 \tan \frac{2\pi \ell}{\lambda},
\]

where \( Z_0 \) is the characteristic impedance and \( \ell \) is the stub length. Therefore, the short-stub input impedance \( Z_{in} \) represents the pure inductance due to \( j \). When the stub length is \( \lambda/4, 3\lambda/4, 5\lambda/4, \ldots \), and \( (n+1)\lambda/4 \) (\( n = 0, 1, 2 \ldots \)), the input impedance becomes infinite. Therefore, the short-stub can play the role of BPF. For the characteristic impedance of 50 Ω, the width of the MSL and stub line is 0.24 mm. The length of stub line is 11.72 mm, equal to 1/4 of the wavelength.

For high-frequency measurements, the SwP tips were contacted on a microstrip line with characteristic impedance of 50 Ω fabricated on an organic substrate. To evaluate the high-frequency characteristics of the SwP, electromagnetic simulation by HFSS was performed in the same configuration at a frequency range up to 6 GHz. Measurements of the S-parameters of the fabricated SwP were performed using a Vector Network Analyzer (VNA: Agilent Technologies E8364B).

3. Results and Discussion

Figure 3 shows the simulated and measured results of the S-parameters for the LC-type BPF of the SwP. The simulations showed a reflection parameter, \( S_{11} \), of less than –32 dB and a transmission parameter, \( S_{21} \), of –1.1 dB at the resonance frequency. On the other hand, the measured \( S_{11} \) was less than –13 dB, and \( S_{21} \) was –1.4 dB at the resonance frequency.

The S-parameters for the edge-coupled-BPF SwP are shown in Fig. 4. In the simulation, \( S_{11} \) was less than –38 dB, and \( S_{21} \) was –0.8 dB at the resonance point. On the other hand, the measured \( S_{11} \) was less than –13 dB, and \( S_{21} \) was –1.3 dB.

The S-parameters for the short-stub-BPF SwP are shown in Fig. 5. In the simulation, \( S_{11} \) was less than –20 dB, and \( S_{21} \) was –0.5 dB at the resonance frequency. On the other hand, the measured value of \( S_{11} \) was less than –9.8 dB, and \( S_{21} \) was –1.8 dB.

The S-parameters for the short-stub-BPF SwP are shown in Fig. 5. In the simulation, \( S_{11} \) was less than –20 dB, and \( S_{21} \) was –0.5 dB at the resonance frequency. On the other hand, the measured value of \( S_{11} \) was less than –9.8 dB, and \( S_{21} \) was –1.3 dB at the resonance frequency. It is seen that the frequency dependence of the reflection parameter, \( S_{11} \),
and transmission parameter, $S_{21}$, showed the good agreement between the simulation and measurement. The slight differences in the resonance frequencies for the three types BPF is due to the tolerance of approximately $\pm 10 \mu m$ in the fabrication process. Also there are different conditions between simulation and measurement such as the contact area between the metal tips and microstripline on the measuring substrate, and the solder for mounting the SMA connector. Moreover, accurate control for the clearance of G–S type metal tips has to be considered.

Figure 6 shows the measured S-parameters of the SwP with a commercial discrete BPF. At the resonance frequency, $S_{11}$ was less than $-11$ dB and $S_{21}$ was $-2.3$ dB. This shows that the designed SwP with three types of BPF can provide better transmission performance than the commercial one.

To make the SwP array, the crosstalk between the transmission lines has to be considered. Two parallel lines in the SwP were designed for a crosstalk investigation as shown in Fig. 7. The active line was driven with a signal source at port1 and terminated at the opposite end port2. The victim line ends were port3 and port4, respectively. Near-end crosstalk (NEXT) was taken at port3, and far-end
crosstalk (FEXT) was taken at port 4. The NEXT and FEXT of the adjacent SwP were simulated for various spacings. Figure 8 shows the simulated results of these crosstalk investigations. The magnitudes of NEXT and FEXT decreased with increased spacing. At 0.15 mm, the shortest separation distance, $S_{31}$ was approximately $-11$ dB and $S_{41}$ was $-20$ dB at 2.4 GHz. Many other factors such as coupling line lengths, signal edge rates, line terminations, substrate dielectric constants, and frequencies, affect the crosstalk between parallel SwPs.

4. Conclusion

BPF-embedded SwPs for high-frequency applications were fabricated with a LTCC substrate and the high-frequency characteristics were investigated. The frequency dependence of the reflection and transmission parameters showed good agreement between the simulation and the measurement. The slight differences in the resonance frequency for the three types of BPF was due to the approximately ± 10 μm tolerances in the fabrication process. Also there were different conditions between the simulation and the measurement such as the contact area between the metal tips and microstrip line on the measuring substrate, and the solder for mounting the SMA connector. Moreover, accurate control for clearance of G–S type metal tips has to be considered. The designed SwP with three types of BPFs showed better transmission performance than a commercial discrete BPF embedded SwP. Moreover, it was expected to achieve the higher performance because the active devices such as amplifiers could be integrated on the SwP.

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References


