A New Millimeter-Wave Stripline Resonator With Embedded Air Cavities In LTCC Multilayer Structure

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ABSTRACT — **We have designed and implemented an innovative low-loss and high-Q millimeter-wave stripline resonator by including air cavities in the LTCC substrate between the ground planes. Measurements of a stripline resonator with air cavities above and below the conducting strip reveal Q-factor of 290 and total loss of 0.03dB/mm at 34.8GHz, and they are improved by 138% and 58%, respectively compared to the conventional LTCC stripline resonator. The dielectric loss of this resonator is analyzed as small as 0.0003dB/mm at the resonant frequency, and that is equivalent to an improvement of a factor of 120 compared to the conventional one. The proposed stripline resonator with the embedded air cavities can meet demands for low-loss millimeter-wave MCM applications.**

I. INTRODUCTION

Multi-layer low temperature co-fired ceramic (LTCC) based multi-chip module (MCM) technology is attractive for millimeter-wave system integration such as the local multipoint distribution service (LMDS) module [1] and the 60GHz transmitter/receiver module [2] as well as L-band RF MCM module applications for personal communication system (PCS) [3] and Bluetooth.

For millimeter-wave LTCC MCM applications, stripline structures represent the most ideal transmission line because dispersion and radiation are negligible, and upper and lower ground planes provide effective shielding. In addition, because it is basically buried structures, the stripline is a valuable structure for 3-dimensional integration of the millimeter-wave module. Accordingly, stripline structures are commonly used as routing the signal within the module and passive devices such as low-pass filter [4], coupler [5], and resonator [6].

Resonators used for oscillator at the millimeter-wave frequencies are strongly required to have low-loss, high Q-factor, and compact size. Several technologies have been reported for low attenuation and high Q resonators. Micromachined silicon cavity resonators [7, 8] were developed for X-band and Ka-band applications. Their unloaded Q-factors of over 500 were reported, however, the lengths of the resonators were larger than 10 mm. Dielectric resonators (DRs) can achieve high quality factors, but they are not suited for compact MCM applications, because of their large size and mechanical tuning requirements. Using LTCC technology, stripline resonators have been reported [6, 9], however, their Q-factors were low under 120 even at the L-band frequencies.

In this paper, we devise and implement novel millimeter-wave low-loss stripline resonators with air cavities embedded in the LTCC substrate. To optimize the resonator structure for low-loss and high-Q performance, two different types of striplines are designed and fabricated. We evaluate the parameters such as Q-factor, losses, tanδ of the dielectric, and relative dielectric constant by comparing with those of a conventional stripline resonator.

II. DESIGN AND FABRICATION OF STRIPLINE RESONATORS

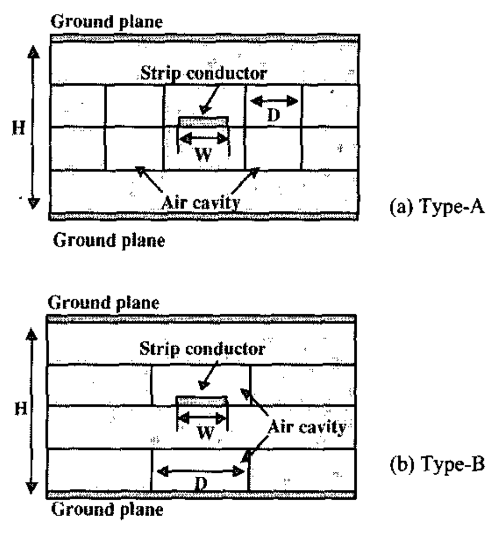

Fig.1 Geometry of the novel stripline structures with embedded air cavities (W: strip conductor width, H: substrate height, D: diameter of air cavity)

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Conventional structure of a stripline is that a conducting strip of width W is centered between two wide conducting ground planes, and the entire region between the ground planes is filled with a dielectric. In this work, the dielectric between ground planes was modified by embedding air cavities at the both side edges (Type-A) and above and below of the strip conductor (Type-B) for loss reduction as shown in Fig. 1. The type-A structure is designed for dielectric loss reduction through the dielectric medium, where the electromagnetic (EM) fields are concentrated between the strip edge and the ground plane. The type-B structure is devised for a decrease of conductor and dielectric loss. Because air cavities above the strip metal intercept the compression pressure during the lamination process, strip metal of the type-B structure is thicker than the conventional and the type-A structure, and therefore conductor loss can be decreased. The low-loss air cavities as the dielectric medium can diminish the dielectric loss. The type-B structure is similar to a suspended-stripline structure in air.

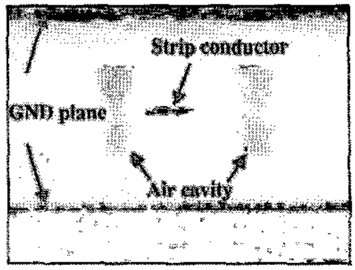
The striplines were fabricated on a 5-layer LTCC substrate and the thickness of each layer was 108μm. The nominal relative dielectric constant of the LTCC material was 7.6. The ground planes and strip conductors were made with Ag metal. The conventional structure for 50Ω strip line has the strip width (W) of 95μm and the substrate height (H) of 432μm.

The unique air cavities were of round column shape and placed along the direction of the strip conductor. The diameters (D) of them were 116μm and 162μm, respectively for the type-A and B. The whole fabrication process for the novel strip resonators follows a standard LTCC procedure, and the air cavities were formed using a conventional via formation process.

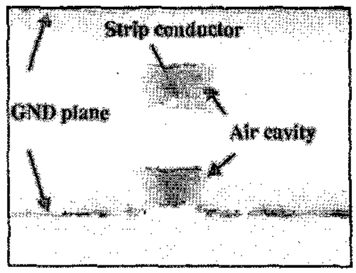
The first resonant frequency of the conventional resonator was designed to be 35GHz. The stripline length was 780μm in order to use as a λ/4 stripline T-resonator, and the width and the height were same as those for 50Ω stripline.

The measured strip conductor width (W), length, and substrate height (H) of the fabricated stripline resonators were 100μm, 786μm, and 402μm, respectively. The strip metals of the conventional and the type-A resonator were 10μm thick, but the thickness of the type-B was 20μm, because the strip metal was not compressed during lamination process due to air cavities above that.

Fig.2 shows the cross sections of the fabricated LTCC stripline resonators with embedded air cavities. The air cavities were defined clearly, and no crack and depression was observed around the air cavities, even though small misalignment of 30μm was observed at the type-A.



(a) Type-A



(b) Type-B

Fig.2 Cross sections of the fabricated stripline resonators with air cavities (W=100μm, stub length=786μm, H=402μm)

III. PERFORMANCE OF RESONATORS

Scattering parameters of the resonators were measured using a vector network analyzer and on-wafer probing. Through-Reflect-Transmission line (TRL) calibration technique was used for the resonator characterization. The resonant frequency, f_o, of the resonators was determined directly from the frequency response of the transmission coefficients (Figs. 3 and 4), and unloaded Q-factor, Q_u, total attenuation, and relative dielectric constant, ε_r, were also extracted from the measurements [10]. The conductor loss, dielectric loss, and loss tangent (tanδ) of the dielectric were calculated from experimental data [11].

Fig.3 reveals the frequency characteristics of the resonator with the type-A stripline structure in comparison with those of the conventional stripline. The novel type-A resonator shows an increase of the resonant frequency by 400 MHz compared to the 34.3 GHz of the conventional one, and that is attributed to the decreased relative dielectric constant of 7.56 in contrast to 7.74 of the conventional. Despite the higher resonant frequency of the novel LTCC stripline resonator, the sharper valley was observed. The type-A resonator reveals Q_u of 248 in comparison with 122 of the conventional structure, which is 103% improvement.

Fig.4 shows the measured frequency responses of the type-B resonator in contrast to those of the conventional one. Its resonant frequency is 34.8GHz, which is 500MHz higher than that of the conventional stripline resonator, and its unloaded Q-factor is 290, that is 137% and 17% higher value than that of the conventional and the type-A resonator, respectively.

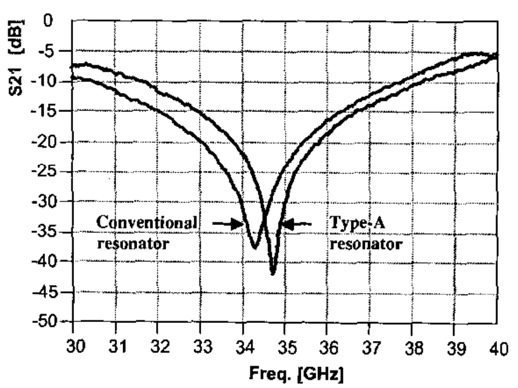


Fig. 3 Frequency responses of the fabricated conventional and type-A resonators

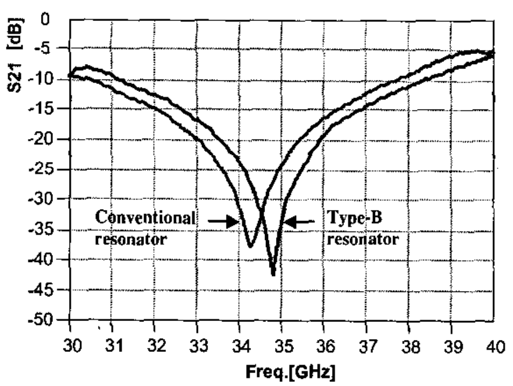


Fig. 4 Frequency responses of the fabricated conventional and type-B resonators

Table 1 summarizes the extracted values for the transmission line parameters from the novel LTCC stripline resonators in comparison with the conventional one. The novel stripline resonators with air cavities result in slightly decreased relative dielectric constant from 7.74 to 7.56 and 7.52, respectively for the type-A and the type-B, and the characteristic impedances, Z_0, reveal a few higher values than that for the conventional one.

The total attenuations of the novel stripline resonators (type-A and type-B) show 0.035dB/mm and 0.03 dB/mm, respectively that is 51% and 58% lower values than the conventional stripline resonator, as would be expected from the remarkable improvement of the Q_u. Contribution of dielectric loss is observed to be slightly larger than that of conductor loss to the total attenuation at the millimeter-wave frequencies. The conductor losses of the conventional and the type-A resonator remain unchanged because of the same physical dimensions of the strip conductors, but the type-B resonator with thicker strip metal has 14% lower conduction loss than the previous two cases.

Table 1 Summary of the extracted transmission line parameters

Items	Conventional	Type : A	Type : B
f_o[GHz]	34.3	34.7	34.8
Q_u	122	248	290
ε_r	7.74	7.56	7.52
Z_o[Ω]	47.6	48.1	48.3
total Loss [dB/mm]	0.071	0.035	0.030
Con. Loss [dB/mm]	0.035	0.035	0.0297
Dielec. Loss [dB/mm]	0.036	0.0004	0.0003
tanδ	41.8×10^{-4}	0.4×10^{-4}	0.3×10^{-4}

The dielectric losses are significantly reduced due to the embedded air-cavities in the dielectric between the ground planes. The dielectric losses of novel resonators (type-A and B) are analyzed as small as 0.0004dB/mm and 0.0003dB/mm at the resonant frequency, and these are equivalent to an improvement of a factor of 90 and 120 compared to the conventional LTCC stripline structure. This considerable improvement of the attenuation property results from the reduction of the dielectric loss due to the embedded low-loss air cavities. The tanδs of 0.4×10^{-4} and 0.3×10^{-4} are obtained for the new stripline structures (type-A and B) with the embedded air cavities, and they are equivalent to an improvement of a factor of 104 and 139, respectively compared to the conventional one.

The type-B stripline resonator with air cavities above and below the conducting strip shows higher Q-factor and lower total attenuation than those of the type-A resonator. This demonstrates that a suspended-stripline resonator in air is more effective structure for low-loss transmission line.

IV. Conclusion

We have successively implemented novel low-loss and high-Q LTCC stripline $\lambda/4$ T-resonators by embedding air cavities in the LTCC substrate between the ground planes for millimeter-wave applications. The stripline resonator with air cavities above and below the conducting strip reveals Q-factor of 290 and total loss of 0.03dB/mm at 34.8GHz, and they are improved by 138% and 58%, respectively compared to the conventional LTCC stripline resonator. The dielectric loss of the novel resonator is analyzed as small as 0.0003dB/mm at the resonant frequency, and that is equivalent to an improvement of a factor of 120 compared to the conventional one. The proposed new stripline resonator with the embedded air cavities can meet demands for low-loss millimeter-wave MCM applications.

Acknowledgement

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