A Novel High-Q LTCC Stripline Resonator for Millimeter-Wave Applications

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***Abstract*—We have implemented a novel high-Q low temperature co-fired ceramic (LTCC) stripline resonator by including air cavities in the LTCC substrate for millimeter-wave applications. This new resonator presents Q-factor of 290 and total loss of 0.03 dB/mm at 34.8 GHz, and they are improved by 138% and 58%, respectively, compared to the conventional one. Its dielectric loss is analyzed as small as 0.0003 dB/mm at the resonant frequency, and that improved by a factor of 120 compared to the conventional one.**

***Index Terms*—Air cavity, low temperature co-fired ceramic (LTCC), resonator, stripline.**

I. Introduction

LOW temperature co-fired ceramic (LTCC) based multichip module (MCM) is one of key technologies for integration of millimeter-wave systems as well as L-band RF module applications due to its good metal conductivity, excellent high frequency characteristics, and three-dimensional (3-D) integration capability. For high-performance 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. Over there, the stripline is a valuable structure for 3-D integration of the millimeter-wave module because it is basically buried structures. Accordingly, stripline structures are commonly used as routing the signal within the module and passive devices such as band-pass filters, couplers, and resonators.

Resonators used for oscillators at the millimeter-wave frequencies are strongly required to have low-loss, high Q-factor, and compact size. Various technologies and research attempts have been made for low-attenuation and high-Q resonators. First of all, micromachined silicon resonators [1] using low-loss air cavity was developed for Ka-band applications. Its unloaded Q-factor of over 500 was reported, but the length of the resonator was larger than 10 mm. Dielectric resonators (DR's) can achieve high quality factors, but they are not suited for compact MCM applications, because of their large size and mechanical tuning elements. Using LTCC technology, stripline resonators have been reported [2], [3], In order to improve the Q-factor by reducing conductor loss, the strip conductor width and the substrate height of the strip line were enlarged [3], however, this approach needs more vertical space as well as lateral dimension

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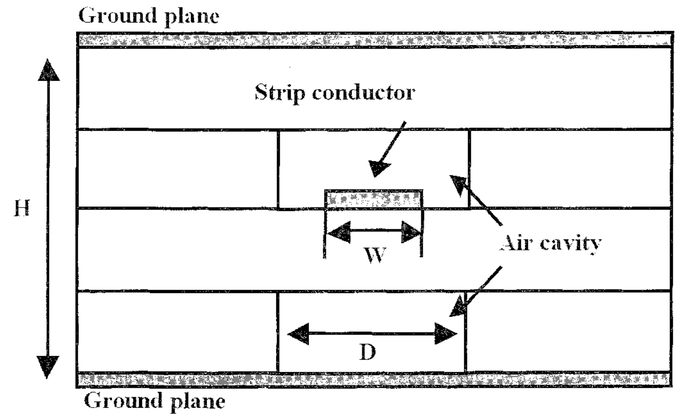

Fig. 1. Geometry of the novel stripline structure with embedded air cavities (W: the strip conductor width, H: the substrate height, D: diameter of air cavity).

in order to maintain characteristic impedance (Z_o) of the transmission line. Despite several efforts, their Q-factors were under 120 even at the L-band frequencies. In this paper, we implement a novel high-Q millimeter-wave stripline resonator with air cavities in LTCC substrate. We evaluate the transmission line parameters by comparing with those of a conventional one.

II. Design and Fabrication

Conventional structure of a stripline is that a conducting strip is centered between two ground planes, and the entire region between them is filled with a dielectric. In this work, this dielectric was modified by embedding air cavities on and below the strip conductor for loss reduction as shown in Fig. 1. The reduction of both the conductor and dielectric loss can be expected from the novel structure. Because air cavities on the strip conductor keep the strip from compression during the lamination process, the strip conductor of the new structure is thicker than the conventional one, and therefore the conductor loss can be decreased. More importantly, air cavities as the dielectric medium can diminish the dielectric loss. Air cavities were of the same shape and size as the signal vias but they were not filled with metal. Air cavities in LTCC substrate were placed along the direction of the strip conductor as shown in Fig. 2. Diameter (D) of air cavities was 162 μm, and the spacing (S) between them was 225 μm. With these small dimensions we can avoid any unwanted resonance at the operation frequencies.

The stripline resonators in a 5-layer LTCC substrate were designed and fabricated using low-loss dielectric and low-resistive Ag metal. The nominal relative permittivity (ε_r) of the dielectric was 7.6, and each layer was 108 μm thick. The conventional structure for 50 Ω stripline has the strip width (W) of 95 μm

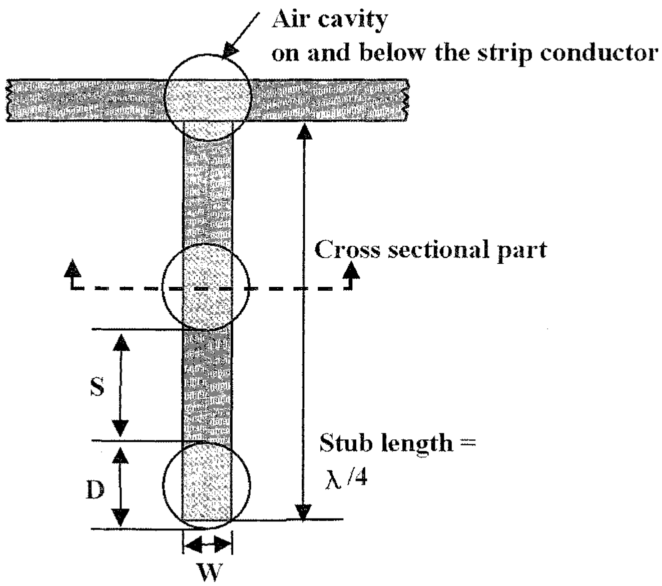

Fig. 2. Layout of the novel resonator.

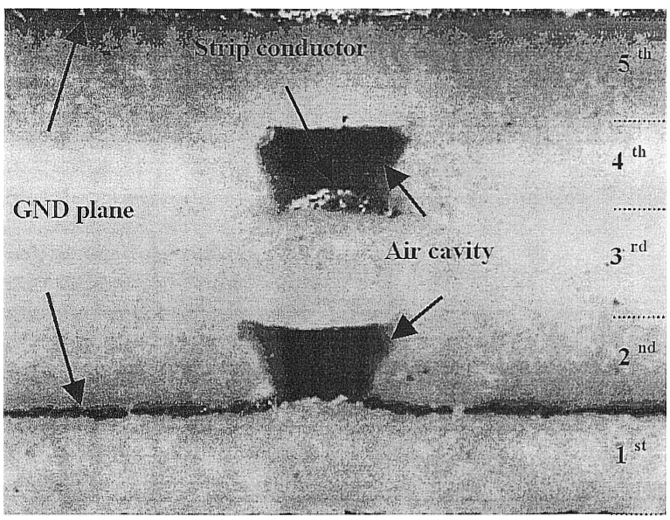

Fig. 3. Cross section of the fabricated stripline resonator with air cavities.

and the substrate height (H) of 432 μm. The whole fabrication process for the novel strip resonator follows a standard LTCC procedure. The first resonant frequency (f_o) of the conventional resonator was designed to be 35 GHz. Its stub length (L_{stub}) was 780 μm in order to use as a $\lambda/4$ stripline T-resonator, and W and H were the same as those for 50 Ω stripline. A 3-D electromagnetic simulation on the effect of the air cavities revealed that the resonator with a typical misalignment of air cavities of ± 40 μm resulted in 10% degradation in Q value compared to that with exact position.

After LTCC co-firing process, the measured W, Lstub, and H of the fabricated resonators were 100 μm, 786 μm, and 402 μm, respectively. The strip conductor of the conventional resonator was 10 μm thick, but that of the proposed one was 20 μm thick due to air cavities on it. Fig. 3 shows the cross section of the fabricated new resonator with embedded air cavities, which were defined clearly, and no crack and depression were observed around it.

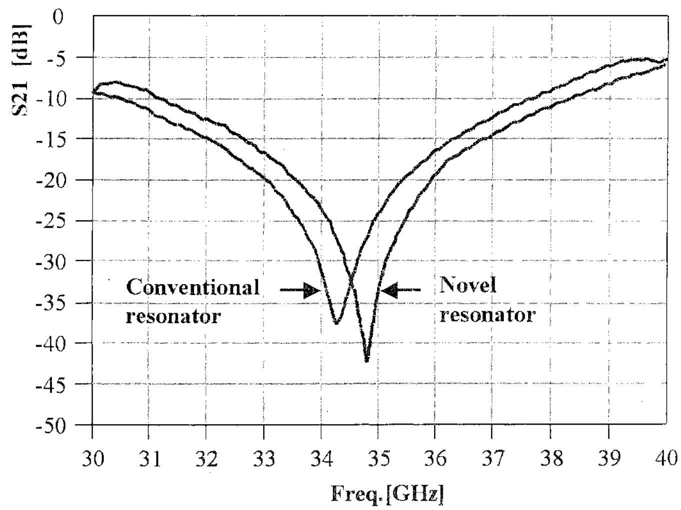

Fig. 4. Frequency responses of the fabricated conventional and novel resonator.

III. Measured Performance

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. f_o was determined directly from the frequency response of the transmission coefficients as shown in Fig. 4, and unloaded Q-factor, Qu, can be extracted using following equations [3], [4]:

$$Q_L = \frac{f_o}{BW} \tag{1}$$

$$Q_u = \frac{Q_L}{1 - 10^{\frac{(dB1-dB2)}{20}}} \tag{2}$$

where QL is loaded Q-factor, BW is the 3 dB bandwidth, dB1 is insertion loss through the resonator at the resonant frequency and dB2 is insertion loss of the input/output lines without the resonator, respectively in dB scale. Equation (2) shows that the measurement system has little effect on the Qu of the open stub resonator, because the denominator of (2) is equal to 0.99 for low-loss line [3], [4]. In our input/output lines, dB2 was 0.16 dB at 35 GHz. Total attenuation, and relative dielectric constant, εr, were also extracted from the measurements [3], [5] Total attenuation includes the conductor, dielectric, and radiation losses. The radiation loss may be neglected since this component is very small for the stripline. The conductor loss was calculated from the measured physical geometry, the strip conductor width and thickness, and the substrate height, as well as the impedance, conductivity, and extracted dielectric constant [5]. Loss tangent, $\tan\delta$, is then derived from calculated dielectric loss and extracted material parameters [5].

Fig. 4 shows the measured frequency response of the novel resonator compared to that of the conventional one. Its f_o is 34.8 GHz, which is 500 MHz higher than that of the conventional one. Its Q_u is 290, which is 137% higher value than that of the conventional one. Table I summarizes the extracted values for the transmission parameters from the novel and conventional resonator. The novel one presents slightly decreased ε_r from

TABLE I
SUMMARY OF THE EXTRACTED TRANSMISSION LINE PARAMETERS

Items	Conventional	Novel
f_o [GHz]	34.3	34.8
Q_u	122	290
ε_r	7.74	7.52
Z_o [Ω]	47.6	48.3
Total Loss [dB/mm]	0.071	0.030
Con. Loss [dB/mm]	0.035	0.0297
Dielec. Loss [dB/mm]	0.036	0.0003
Loss Tangnet (tanδ)	$4.2\text{x}10^{-3}$	$0.3\text{x}10^{-4}$

7.74 to 7.52, and its characteristic impedance (Z_0) reveals a little higher value than that for the conventional one. The total loss of the novel resonator shows 0.03 dB/mm, which is 58% lower value than the conventional one. Contribution of the dielectric loss is observed to be slightly larger than that of conductor loss to the total loss of the conventional one. The novel resonator has 14% lower conduction loss than the conventional one because of its thicker strip conductor. The dielectric loss of the new resonator is analyzed as small as 0.0003 dB/mm at the resonant frequency, and that is equivalent to an improvement of a factor of 120 compared to the conventional one. This considerable improvement of the attenuation property results from the reduction of the dielectric loss due to the embedded low-loss air cavities. $\tan\delta$ of 0.3×10^{-4} is obtained for the new resonator, and that is equivalent to an improvement of a factor of 139 compared to the conventional one.

IV. CONCLUSION

We have successively implemented a novel high-Q LTCC stripline $\lambda/4$ T-resonator with air cavities on and below the strip conductor for millimeter-wave applications. This novel stripline resonator reveals Q-factor of 290 and total loss of 0.03 dB/mm at 34.8 GHz, and they are improved by 138% and 58%, respectively compared to the conventional one. Its dielectric loss is analyzed as small as 0.0003 dB/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 can meet demands for low-loss millimeter-wave MCM applications.

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