Study of the Influence of Grounding for Microstrip Resonators

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Abstract— **The influence of ground terminal shape on the resonant frequency of a microstrip resonator is investigated through numerical simulations and experiments. Resonators are one of the basic components of very small high-dielectric stripline filters, named the *laminated planar filter*. The resonant frequencies are calculated by means of the finite-difference time-domain (FDTD) method and compared with experimental results. It is also shown that the resonant frequency is directly related to the square root of its line inductance when the resonator is regarded equivalently as a series LC circuit.**

Index Terms— **Finite-difference time-domain method, microstrip resonator.**

I. Introduction

HANDY portable telephones are becoming popular as personal communication systems. The downsizing of portable telephones requires the miniaturization of high-frequency components such as RF filters. Incessant technological innovation has been miniaturizing filters without degrading their performance at all. Coaxial filters have been mainly used so far, but are considered to have reached the limit of their miniaturization. Recently, LC chip filters have been developed on multilayer ceramic substrates [1]. This kind of filter, fabricated on relatively low-permittivity multilayer ceramics, consists of thin stripline inductors and laminated capacitors which form lumped elements. However, it suffers slightly larger insertion losses than a conventional coaxial filter due to its low inductor unloaded Q. To solve this problem, very small high-dielectric stripline filters, named the *laminated planar filter* have been devised [2]–[5]. They consist of planar resonators which are laminated in high-permittivity multilayer ceramics and show excellent performance.

In this paper, we investigate (through numerical simulations and experiments) the influence of ground-terminal shape on the resonant frequency of a microstrip resonator. The resonator, which is a basic component of a laminated planar filter, is composed of a microstrip of finite length which is open at one end, grounded at the other, and is enclosed with a rectangular cavity of metal. The ground terminal, which is necessary for fabricating this type of microstrip resonators, covers some area of the side of a substrate for easy grounding. However, the influence of such a kind of grounding has rarely been studied thus far. First, we calculate resonant frequencies of the microstrip resonators by means of the finite-difference time-domain (FDTD) method [6], [7]. Then, numerical data are compared with experimental results. Finally, we show that the resonant frequency has a close relationship to the square root of its line inductance when the resonator is regarded equivalently as a series LC circuit.

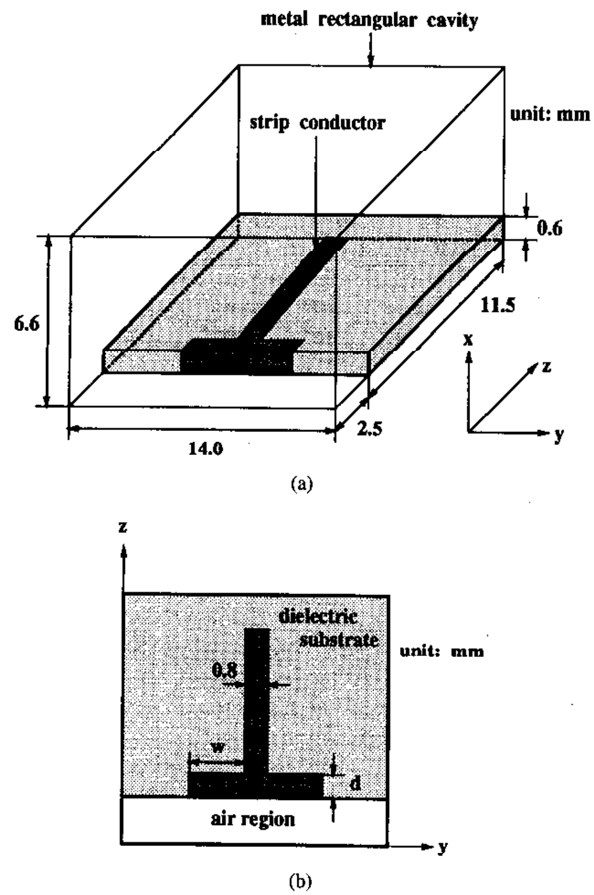

Fig. 1. Microstrip resonator. (a) The whole structure and the coordinate system used in this analysis. (b) The metallization pattern on the substrate.

II. Structure of Microstrip Resonator

The resonator is composed of a microstrip of finite length which is open at one end, grounded at the other, and is enclosed with a metal rectangular cavity, as shown in Fig. 1. An air region in front of the ground terminal isolates this

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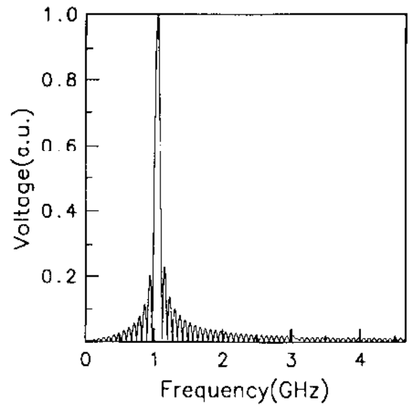


Fig. 2. Frequency spectrum of the voltage when the width $w = 0.0$ mm and the depth $d = 0.0$ mm.

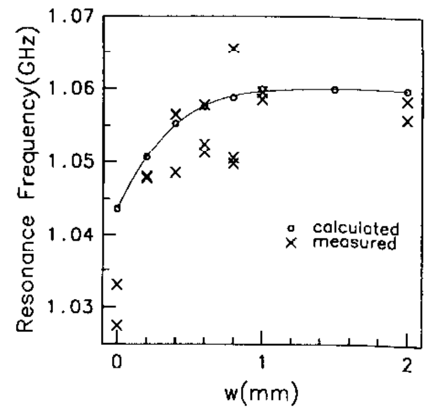


Fig. 3. Resonant frequency versus the width w when the depth $d = 0.0$ mm.

terminal from the front wall of the box. The ground terminal is symmetric with respect to the center axis of the microstrip resonator. The dielectric substrate is 0.6 mm thick and its relative permittivity is 92.6. We investigate—with the width w and depth d as parameters—how the ground terminal affects resonant frequencies.

The region for analysis, which, in this case, is the entire space inside the metal cavity, is divided into cells in the FDTD method. In the cross section, we employ nonuniform meshes whose sizes are $\Delta x = \Delta y = 0.2$ mm near the microstrip, six times as wide near the metal cavity, and twice as wide in the intermediary region. There exist 19×42 grids in total in this mesh which enables us to calculate the characteristics most efficiently and exactly within an available main memory size of the computer [8]. On the contrary, Δz is set uniformly along the z-axis as 0.25 mm. At the beginning of the computation, a quarter-wavelength sinusoidal field distribution is allocated to the E_x nodes located beneath the center axis of the microstrip to be maximum at the open end and zero at the short end [9]. After that, the Maxwell equations are solved repeatedly in the region enclosed with the metal cavity by using the FDTD algorithm. Voltage of the microstrip is calculated in the time domain with the line integral of the E_x-field component under the center of the microstrip. Voltage at the open end of the microstrip is transformed into that in the frequency domain by means of the fast Fourier transform (FFT) technique. As an example, the frequency spectrum when the width $w = 0.0$ mm and the depth $d = 0.0$ mm is shown in Fig. 2. The maximum sharp peak conspicuously sticking out indicates the resonant frequency which, in this case, is determined as $f_0 = 1.0436$ GHz.

For experimental measurements, some microstrip resonators, as shown in Fig. 1, have been fabricated on ceramic substrates having an identical permittivity and thickness. The metal cavity is made of copper, and silver paste is glued to the substrate to form microstrips and ground terminals. In this paper, 15 resonators (all of which have different microstrip patterns) have been fabricated. A small hole has been punched on one side of the metal box. A coaxial line has been put through the hole to excite electromagnetic fields near the microstrip open end through weak coupling between the microstrip and core of the coaxial line. The measurement has been done with a network analyzer.

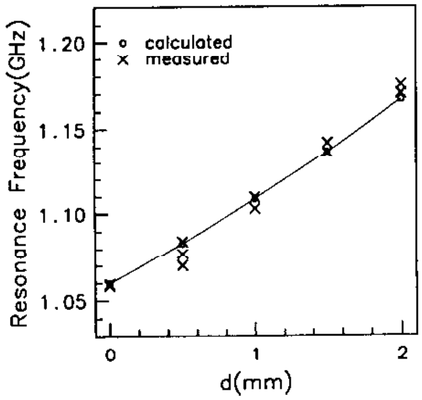
III. Numerical and Experimental Results

Fig. 3 shows the resonant frequency versus the width w of the ground terminal when the depth $d = 0.0$ mm. The numerical results indicated by small circles lie among the experimental data indicated by crosses except when $w = 0.0$ mm. We can see that the resonant frequency monotonously increases as w becomes larger in the region of w being narrower than 1.0 mm. On the other hand, when w is wider than 1.0 mm, the resonant frequency converges at a constant value. This result indicates that the width of the ground terminal has no significant influence on the resonant frequency when it is wider than a specific value. This is because the electromagnetic field of the microstrip mode is tightly concentrated within a small region near the microstrip.

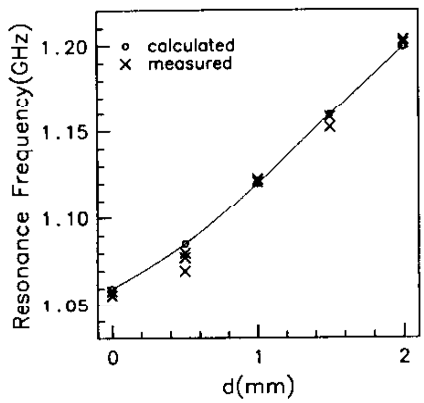
The variation in the experimental results observed in this figure is due to errors in fabrication and measurements. It is considerably difficult to fabricate (exactly as designed) narrow ground terminals. Therefore, it is reasonable to consider that the narrower the width w becomes, the more errors the experimental data contain.

The resonant frequency versus the depth d of the ground terminal when the width is as $w = 1.0$ and 2.0 mm is shown in Fig. 4(a) and (b), respectively. As illustrated in this figure, the resonant frequency increases parabolically as d becomes larger. It is also understood that the agreement between the numerical and experimental results is very close.

Finally, to give a reasonable explanation of these resonant-frequency characteristics, we consider the inductance of the ground terminal when the resonator is regarded as a series LC circuit. A short-ended microstrip shown in Fig. 5 is analyzed by means of the FDTD method. The region for analysis is enclosed with absorbing boundaries instead of a metal cavity in order to remove the reflection from it. An excitation plane is placed on the front surface and E_x-fields are excited under the microstrip. The excitation pulse has a Gaussian shape in time domain. First, an infinitely long microstrip which has the same cross section as the short-ended microstrip is calculated and the incident voltage $V_{\mathrm{inc}}(t)$ is obtained with the line integral

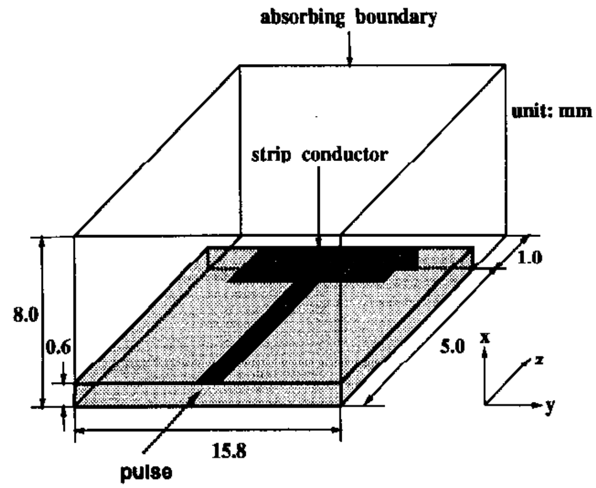


(a)

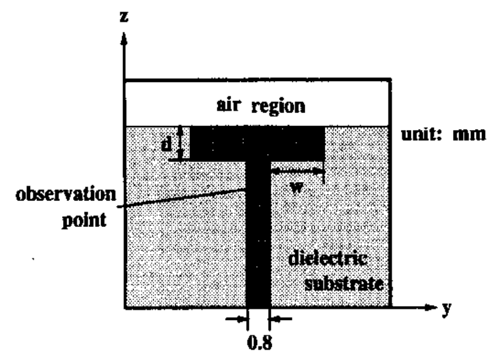


(b)

Fig. 4. Resonant frequency versus the depth d, where the width is (a) w = 1.0 and (b) 2.0 mm.



(a)



(b)

Fig. 5. Short-ended microstrip. (a) The whole structure and the coordinate system used in the analysis. (b) The stripline pattern on the substrate.

of the E_x-field at some observation point. Second, the short-ended microstrip is calculated and the reflection voltage $V_{\mathrm{ref}}(t)$ is obtained at the same observation point by the difference between the total voltage of the short-ended microstrip and the incident voltage $V_{\mathrm{inc}}(t)$. The reflection coefficient $S_{11}(f)$ is defined as follows:

$$S_{11}(f) = \frac{V_{\mathrm{ref}}(f)}{V_{\mathrm{inc}}(f)} \cdot \exp\{2\beta(f)l\} \tag{1}$$

where, $V_{\mathrm{ref}}(f)$ and $V_{\mathrm{inc}}(f)$ represent the FFT's of $V_{\mathrm{ref}}(t)$ and $V_{\mathrm{inc}}(t)$, respectively. The $\beta(f)$ is the propagation constant of the infinitely long microstrip, which is obtained from the FDTD simulation and l is the distance between the observation point and short end. The inductance $L(f)$ seen at the observation point is determined in terms of $S_{11}(f)$ as follows:

$$L(f) = \frac{1}{2\pi f} \cdot \mathrm{Im}\left[Z_0(f) \cdot \frac{1 + S_{11}(f)}{1 - S_{11}(f)}\right]. \tag{2}$$

In (2), Im[ ] means to take the imaginary part of the factor in the brackets, and $Z_0(f)$ is a characteristic impedance of the infinitely long microstrip.

Fig. 6 shows the inductance $L(f)$ versus the frequency with the width w as a parameter when the depth is $d = 0.0$ mm. As shown in Fig. 6, the inductance increases linearly as the frequency gets higher. It is also shown that at any frequency the

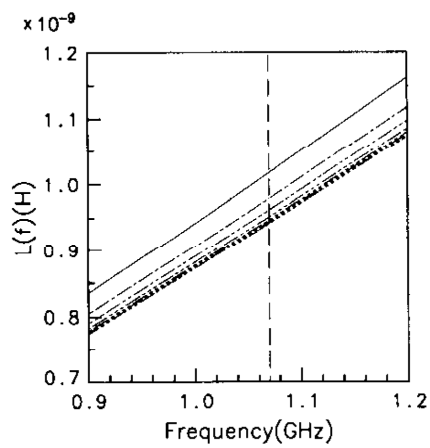


Fig. 6. Inductance $L(f)$ versus the frequency f when the depth $d = 0.0$ mm, where the width is w = 0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, and 2.0 mm in order from top to bottom.

inductance monotonously decreases, but eventually becomes stationary as w becomes wider.

Fig. 7 shows the inductance $L^{-1/2}(f)$ versus the width w when the depth is $d = 0.0$ mm and the frequency is $f = 1.0687$ GHz, as shown by the vertical dotted line in Fig. 6. This frequency is very close to the resonant frequency. By

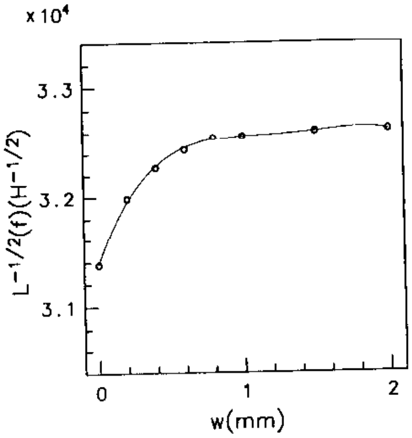


Fig. 7. Square root of the inductance $L^{-1/2}(f)$ versus the width w when the depth $d = 0.0$ mm and the frequency $f = 1.0687$ GHz.

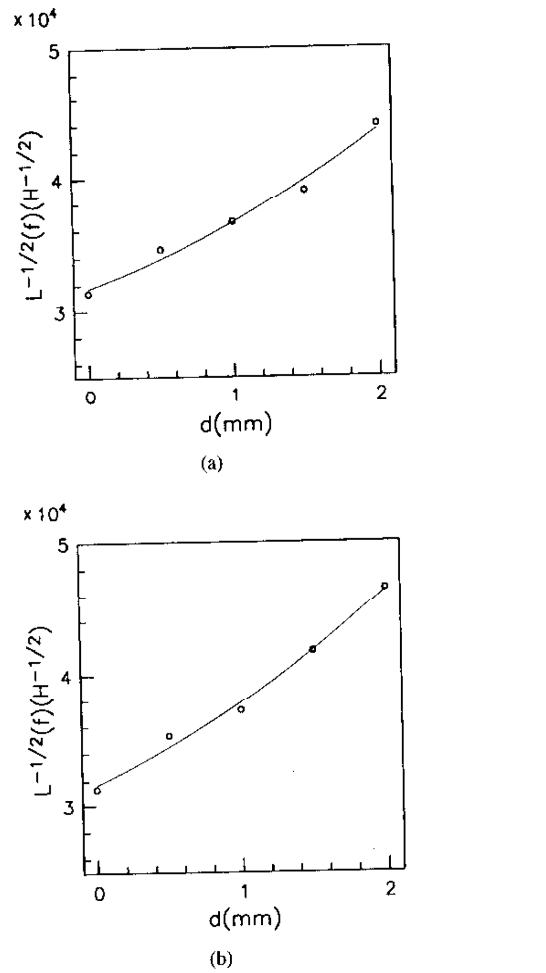


Fig. 8. Square root of the inductance $L^{-1/2}(f)$ versus the depth d when the frequency $f = 1.0687$ GHz, where the width is (a) $w = 1.0$ and (b) 2.0 mm.

comparing Figs. 3 and 7, we can see that both of the resonant frequency and $L^{-1/2}(f)$ show quite a similar dependence on the width w.

$L^{-1/2}(f)$ versus the depth d when the frequency is $f = 1.0687$ GHz, where the width is $w = 1.0$ and 2.0 mm is shown in Fig. 8(a) and (b), respectively. In both cases, the resonant frequency and $L^{-1/2}(f)$ show similar characteristics as a function of the depth d.

The resonator is about a quarter-wavelength long. The structure of the open end, whose reactance at the observation point is thus capacitive, remains unchanged while varying the shape of the short end; hence, the capacitance of the open end remains constant. On the other hand, the short end seen at the observation point has a changing inductive reactance while varying the ground terminal shape. When regarding the resonator as an equivalent series LC circuit with the inductance L of the short end and the capacitance C of the open end, the capacitance of the circuit may be considered constant. This is why the resonant frequency changes depending solely upon $L^{-1/2}(f)$.

IV. Conclusion

We have investigated the influence of the ground terminal shape on the resonant frequency of a microstrip resonator through numerical simulations by means of the FDTD method and experiments. It has been found that the numerical results compare very well with the experimental results. It has also been shown that the resonant frequency is closely related to the square root of its line inductance when the resonator is equivalently regarded as a series LC circuit.

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