The Effect of Air Bridge Height on the Propagation Characteristics of Microstrip

Marc E. Goldfarb and Vijai K. Tripathi

Abstract—**The air bridge is often used for lowering the effective capacitance per unit length as well as fabricating crossovers in monolithic microwave integrated circuits (MMIC's). The static and dynamic propagation characteristics of this type of transmission line are computed by utilizing the spectral domain technique. The cases of air bridged lines on 100-μm GaAs substrate and spiral inductors are examined.**

I. Introduction

OTHER than its primary use as a non-connecting crossover between two transmission lines, air bridges are often used in the fabrication of GaAs MMIC's as a technique for the reduction of the shunt capacitance of the line. The cross section, shown in Fig. 1, is primarily employed in the fabrication of spiral inductors and transformers.

The propagation characteristics of such lines can be computed by using a host of techniques including the spectral domain technique that provides a solution to this multiple dielectric microstrip problem [1]. The result of this technique will be illustrated by the analysis of air bridges over 100-μm GaAs and the resulting quasi-TEM, as well as full-wave characteristic, transmission line parameters.

II. Analysis Technique

The analysis of the microstrip structure of Fig. 1 is performed using both the static and the full wave formulation of the spectral domain technique. Since this analysis is used to demonstrate the significant changes in the propagation characteristic as a function of the height of the air bridge, it is assumed that the microstrip consists of a infinitely thin, perfectly conducting strip. These assumptions will have some effect on the resulting propagation constants. However, it is seen that these effects are of considerably less significance when compared to the variation in propagation constants resulting from the repeatability of air bridge heights achievable using contemporary fabrication techniques. The quasi-TEM, as well as the full wave, propagation characteristics of the air bridge lines can be readily computed by using the spectral domain technique [1]. Since the objective of this letter is to demonstrate the significant change in the microstrip properties as a function of air bridge height, the simple formulation with zero line thickness is used.

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The authors are with Raytheon Company, Research Division, 131 Spring Street, Lexington, MA 02173.
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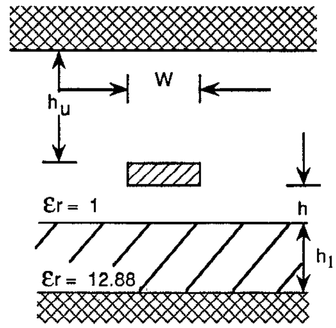

Fig. 1. Cross section of microstrip with air bridge.

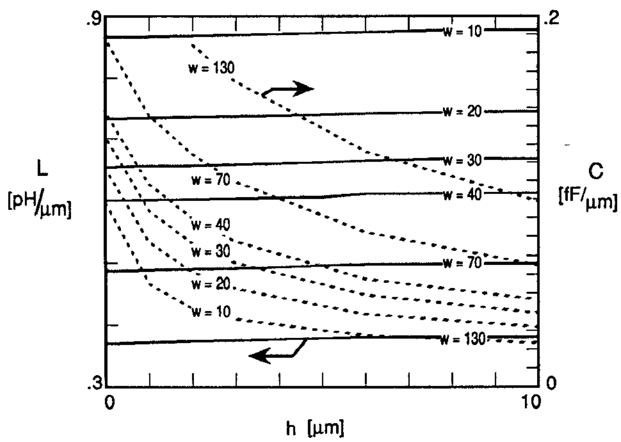

Fig. 2. Inductance and capacitance per unit length versus air bridge height.

Example 1—Air Bridge on 100 μm GaAs: The microstrip air bridge employed in GaAs MMIC spiral inductors often consists of a 1–5 μm air gap over a GaAs dielectric ($\epsilon_r = 12.9$, height = 100 μm). The spectral domain technique was used to calculate the equivalent quasi-TEM ϵ_{eff} and Z_0. These values were calculated for several line widths and the results plotted in Figs. 2 and 3. At first it appeared that Z_0 and ϵ_{eff} changed too rapidly to be physically possible. However, by plotting L and C, it was determined that the resulting shift in the inductance per unit length is very small ($< 5\%$) for air bridges up to 10 μm in height. The capacitance change is considerable. C drops to 35% of its nonbridged value for a 3-μm high air bridge.

Air bridge height variations of ± 1 μm are common in MMIC fabrication. Fig. 3 shows a $\pm 12\%$ variation in the capacitance per unit length for a ± 1 μm variation in air bridge height. This is an order of magnitude larger variation

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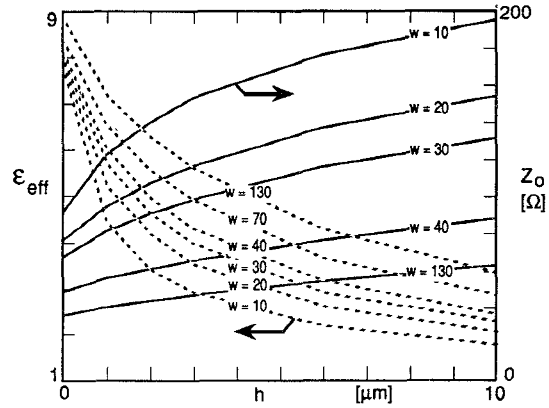

Fig. 3. Effective dielectric constant and characteristic impedance versus air bridge height.

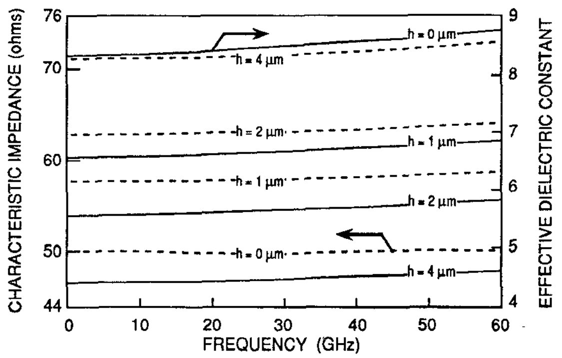

Fig. 4. Effective dielectric constant versus frequency and characteristic impedance versus frequency.

in propagation constants than that engendered by dispersion, loss, or the thin strip approximations.

The frequency dependent solution for 70-μm wide microstrip line above the 100-μm GaAs substrate is shown in Fig. 4 as a function of the air bridge height. The results achieved using the spectral domain technique were also checked at points using a method of moments based simulation technique with excellent agreement [2].

Example 2—Effect of Capacitance Change on the Self-Resonance of a Spiral Inductor: Two spiral inductors were fabricated on 100 μm GaAs. One inductor was in contact with the substrate, while the second inductor had 50% of its line length approximately 3 μm above the substrate surface. The physical dimensions of the inductors are given in Fig. 5. Resonant frequencies of the resonators employing bridged versus nonbridged inductors are 19.700 GHz vs. 18.550 GHz. This 6.2% increase in resonant frequency corresponds to a total resonator capacitance shift of 12.8%. Since the interconnecting lines and coupling capacitances must also be included in the total resonator capacitance, the total shift in the capacitance of the spiral is significantly greater.

From the graph in Fig. 2, a 0.3% change in inductance of approximately 7 pH would be expected due to the air bridges. This value is two orders of magnitude less than the expected change in capacitance and can be neglected. The values of capacitance extracted for each leg of the equivalent circuits for these two structures are 0.020 pF and 0.028 pF for the bridged and nonbridged spirals, respectively. This is approximately a 27% decrease in effective capacitance of the spiral. From Fig. 2, it would be expected that the capacitance of a completely air bridged spiral, which is somewhat problematic to construct, would be reduced by 62% compared to that of its nonbridged counterpart. Since only half of the spiral is bridged, it would be expected that the actual capacitance is reduced by 31%. This compares favorably with the 27% reduction observed experimentally.

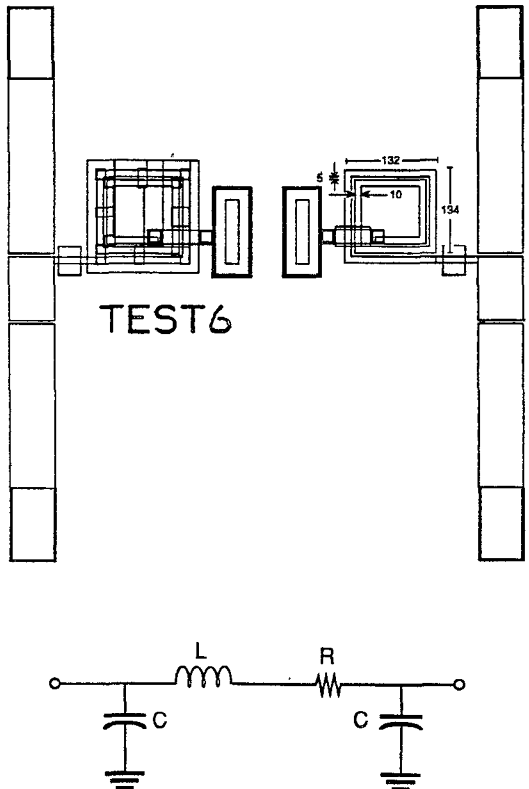

Fig. 5. Layout of spiral resonators and equivalent circuit of spiral inductors.

While this was not meant to be an exhaustive experiment, it does provide a qualitative understanding of the reduction in capacitance expected by raising the conductor above the substrate.

III. Conclusion

In conclusion, it is shown that the reduction in the capacitance of the air bridge lines is quite significant leading to a considerable improvement in the self-resonant frequency of a spiral inductor used in a MMIC design. The propagation characteristics of such lines have been computed using the spectral domain technique and typical results for 100-μm GaAs MMIC's have been presented. These curves should provide a useful reference for the design of components for MMIC's that utilize the air bridge lines.

References

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