Coupling Phenomena in Conductor-Backed Slotline Structures

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Abstract

Leakage phenomena possible in conductor-backed slotlines were investigated through an analysis of coupled slotlines for possible application for a non-proximity directional coupler. Obtained propagation constants and experimental results confirm that coupling is caused by leakage through the conductor backing. It was found that the leakage can be controlled by a modification of the structures.

I. Introduction

Recently the power leakage phenomena in conductor-backed CPWs or slotlines have drawn significant interest[1]-[4]. Most of these reports address the analysis of the leakage phenomena which are often considered detrimental. The purpose of the present contribution is to find a potential to construct useful devices based on the leakage mechanism.

In this paper, two coupled slotlines with finite width of conductor backing are analyzed using the spectral domain method. The results show that the slotlines couple with each other even if they are physically separated by a large distance. The coupling phenomena were confirmed through an experiment on forward-coupling directional couplers. It was found possible to prevent the leakage by a modification of the structure.

II. Analysis of Conductor-Backed Coupled Slotlines

The cross section of the coupled structure analyzed here is shown in Fig. 1. Two parallel slotlines are located on one side of the substrate and they are backed by a strip conductor on the other side. An additional substrate is placed on the top. The side walls do not affect the phenomenon investigation, because no leakage takes place towards the side walls.

Difference of the effective dielectric constants of CPW and coupled-slot modes is used as an indication of the coupling. Difference is smaller if the lines are uncoupled and is larger if coupled.

The substrate used in the calculation is 0.635 mm in thickness and its relative dielectric constant ε_{r2} is 10.5. Slotline gap G is 0.25 mm. Line separation S is fixed at 12 mm. If W=0 and $\varepsilon_{r1} = 1.0$, we obtain the normal coplanar waveguide which supports CPW and coupled-slot modes. As shown in Fig.2, the difference of effective dielectric constants of CPW and coupled-slot modes vanishes as the frequency is increased, indicating that no coupling between two slotlines. The coupling at low frequencies is due to the proximity effect.

The conductor-backed slotlines in Fig.1 ($W > 0$, $\varepsilon_{r1} = 1$) supports several other modes in addition to the CPW and coupled-slot modes as shown in the Figs. 3 and 4. Mode 1 is a dominant microstrip mode while Mode 3 is the CPW mode. Modes 2 and 4 require clarification. They are formed by the coupling of the 2nd microstrip mode for the limiting case of vanishing slots (G=0) with the coupled-slot mode in the limiting case of W=0. The CPW mode does not take part in the coupling because of different symmetry. In Fig. 3, Mode 2 has characteristics of the coupled-slot mode at frequencies below 11 GHz. On the other hand, above 11 GHz, Mode 2 exhibits characteristics of 2nd microstrip mode and Mode 4 those of the coupled-slot mode. Around 11GHz, both Modes 2 and 4 have no clear mode characteristics. It is seen that difference of dielectric constants for CPW and coupled- slot modes is always small for the frequency above 5 GHz. Two slotlines are not coupled each other because of small width of conductor backing.

In contrast, a wide conductor backing (W > S) causes coupling of two slotlines. When one of the slotlines is excited, the energy leaks to another through the parallel plate mode. As shown in Fig. 4, the difference between the effective dielectric constants of CPW and coupled-slot modes is always large in all frequency range. Two slotlines are coupled to each other due to the presence of wide conductor strip in spite of large separation. The parallel plate mode travelling back and forth between two slotlines is the main ingredient of microstrip type modes. The effect of an increasing W on the coupling was studied in the case of $\varepsilon_{r1} = 1$[5].

If an additional substrate with a higher dielectric constant (i.e. $\varepsilon_{r1} > \varepsilon_{r2}$) is placed on top of slotline, the effective dielectric constant of the slot mode increases and may become higher than that of parallel plate mode. This means the leakage phenomenon in the conductor-backed slotline can be prevented. In the structure in Fig.1, the presence of such an additional substrate may prevent leakage coupling between two slotlines. Fig. 5 shows the effective dielectric constants for different modes for the conductor-backed slotlines. Here, the relative dielectric constant ε_{r1} is 10.5 while ε_{r2} is 2.33. It can be seen that the difference between the effective dielectric constants for CPW and coupled-slot modes diminishes and coupling between two slotlines is negligible as the frequency is increased.

III. Experiment

Forward-coupling directional couplers shown in Fig.6 were designed and fabricated to confirm the coupling phenomena experimentally. Two slotlines are located on bottom side of the substrate. These slotlines are electromagnetically coupled to microstrip feeds #1 - 4 through quarter-wavelength transition circuits. Conductor backing is attached to the top side of the substrate. The conductor backing is lifted by absorbers at its edges, which forms vertical taper sections for input/output matching. The length of uniform coupling section is 40 mm. The taper section is 17mm long.

Measured results for the slotlines with conductor backing of 18 mm wide are shown in Fig. 7. Obtained coupling is about -7 dB with respect to the insertion loss. The coupling is somewhat smaller than that predicted.

Coupling strength (S_{31}) is plotted in Fig. 8 for different structures. Without a conductor backing($W = 0$), coupling is less than -25 dB. The coupling is strong for the conductor-backed slotlines. The coupling becomes small (less than -20dB) for conductor-backed slotlines with a high dielectric constant upper layer.

IV. Conclusion

Coupling phenomena in conductor-backed slotlines have been investigated both by modal analysis of propagation constants and by experiment. It has been shown that slotlines separated by a large distance couple each other when a conductor backing covers the area between two slots, thus providing a directional coupler based on leakage. On the other hand, such leakage coupling can be prevented by adding an additional top layer.

Acknowledgments

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References

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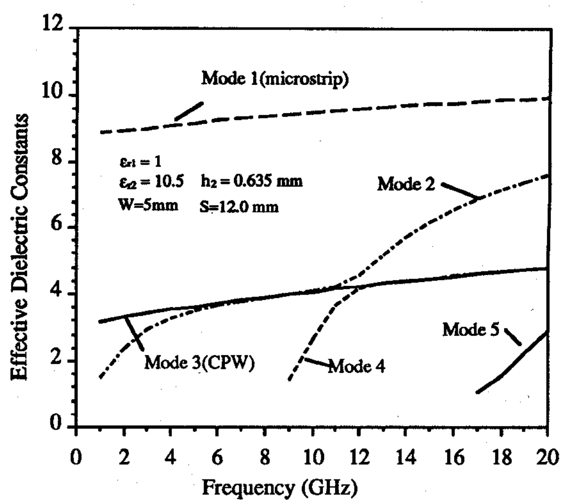

Fig. 3 Effective dielectric constants for the condutor-backed slotlines with narrow condutor strip

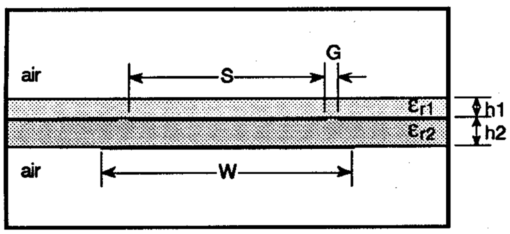

Fig. 1 Structure of coupled slotlines with a conductor backing

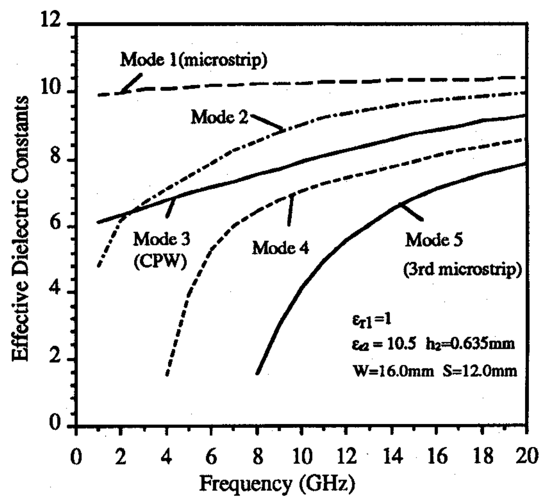

Fig. 4 Effective dielectric constant for conductor-backed slotlines with wide conductor strip

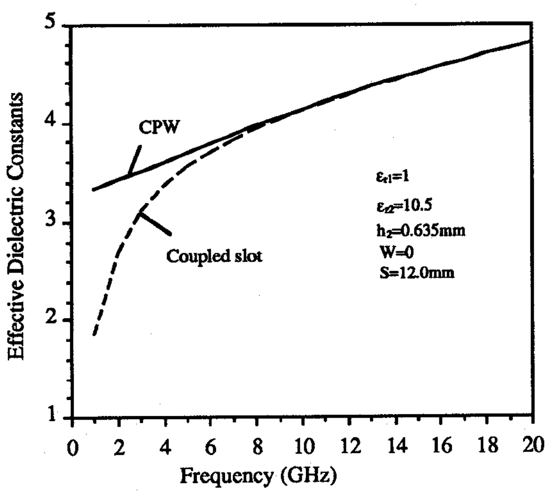

Fig 2 Effective dielectric constants for normal coplanar waveguide

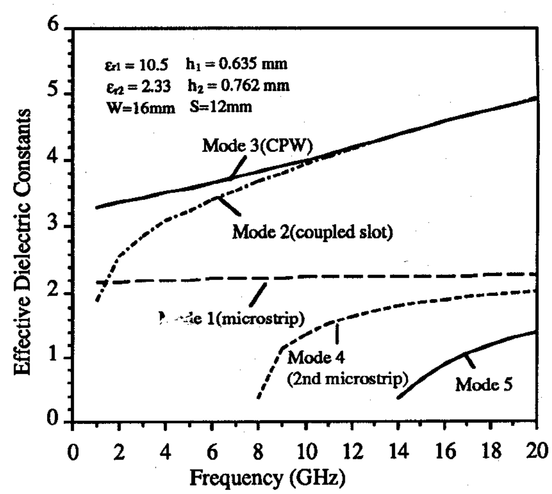

Fig 5 Effective dielectric constants for the conductor-backed slotlines with a high dielectric constant upper layer.

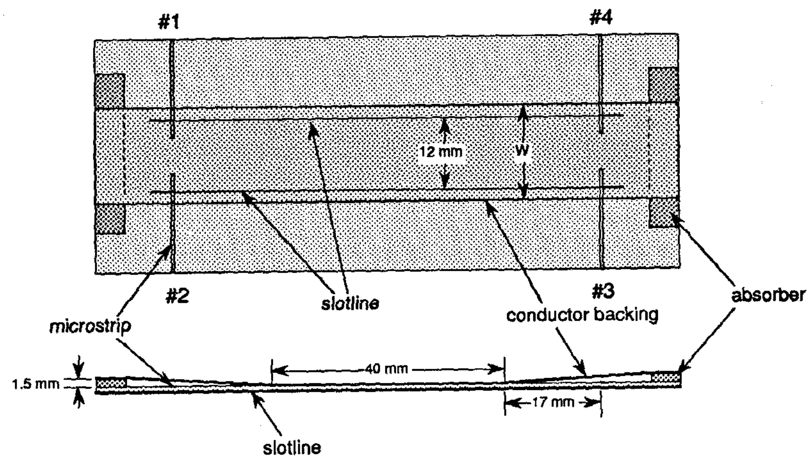

Fig. 6 Structure of the fabricated forward-coupling directional coupler

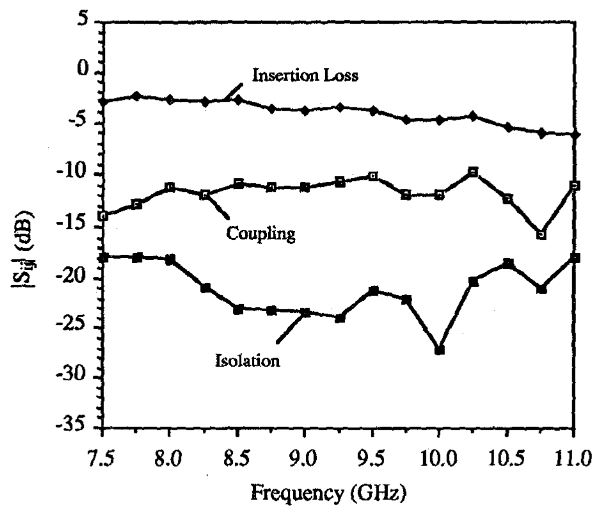

Fig.7 Measured characteristics of a forward-coupling directional coupler

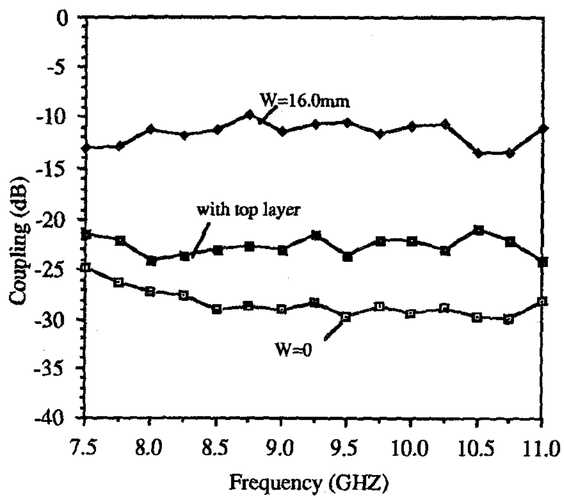

Fig. 8 Measured coupling strength of directional couplers