LEAKY-MODES LEAKAGE FROM PLANAR CIRCUITS

Kuo-Cheng CHEN and Ching-Kuang C. TZUANG
Institute of Electrical Communication Engineering
National Chiao Tung University
Hsinchu, TAIWAN

Abstract

Inherent leakages in certain two-dimensional planar circuits are related to the propagation of leaky modes, contrasting to the conventional awareness of the association of leaky modes with the uniform waveguides. Both theoretical and experimental studies confirm the newly found phenomena exist in proximity-coupled or direct-fed two-dimensional planar circuits of irregular shapes. Hence the leaky modes are indispensable when designing a microwave planar circuit.

I. Introduction

Various forms and properties of leaky-modes propagation in the uniplanar and quasi-planar transmission lines had been investigated extensively in the past decade, to name a few [1-4]. Although much attention was also paid to apply the leaky-modes propagation to design a useful integrated antenna, e.g. Menzel's direct feed approach [3] or the uniplanar feed [5-6], virtually no mention of possibility of exciting leaky modes in arbitrarily shaped planar circuits was found in the literature. Since many two-dimensional planar circuits can be approximated by an assembly of truncated one-dimensional guided elements by the segmentation method [7-9], it is plausible to conjecture that *leaky modes would be excited in most planar circuits.* This motivates the search for such phenomena in planar circuits.

As in Fig. 1, we observe there are two useful coupling mechanisms frequently employed in the arbitrarily shaped planar circuit, namely, the proximity coupled type and the direct feed. Experimental and theoretical studies of leakages related to the excitation of leaky modes in the proximity coupled and direct-fed planar circuits will be presented in sections II and III, respectively. The implication of the results will appear in the concluding section.

II. Proximity-Coupled Planar Circuit

The most simplest proximity-coupled planar circuit that is likely to emit energy in the form of leaky modes is illustrated in Fig. 2, which consists of a straight microstrip line with a neighboring rectangular patch. Although the circuit is simple in configuration, it is not straightforward for us to conclude there exists leaky-modes radiation. The measured two-port scattering parameters referenced to 50 Ω load by the vector network analyzer are plotted in Fig. 3, where two resonant peaks are located at approximately 7.2 GHz and 9.6 GHz [10]. While we may easily conclude that the circuit arrangement of Fig. 2 belongs to one form of patch antennas, we should not neglect what the significant values of RPA (relative power absorbed) ($1-|S11|^2 - |S21|^2$) imply for frequencies between 7.8 GHz and 8.4 GHz, for example. The results of the full-wave analyses of Fig. 2 by the well-known frequency-domain integral equation approach are overlaid on Fig. 3, which shows good agreement between the theoretical and experimental results has been obtained. At the resonant frequencies, there occur sharp peaks of the RPA as expected. When we study the frequency range between 7.8 GHz and 8.4 GHz in detail, the RPA curve exhibits a small bump as shown in Fig. 3. Next we plot in Fig. 4 the theoretical radiation patterns along the H-plane (see Fig. 2) at 7.75 GHz, 8.25 GHz and 8.75 GHz, respectively. Fig. 4 reveals the same well-known frequency-scanning characteristics commonly found as leaky-mode emission from a uniform microstrip line. The theoretical modal analyses of a uniform microstrip line of the cross section the same width with the patch of Fig. 2 show that the beam angles of Fig. 4 can be estimated correctly by the obtained complex propagation constants. No matter how weak the

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coupling is between the microstrip feed and the patch, as soon as the coupling occurs and falls into the leaky frequencies of the transmission line, the leaky-modes radiation is clearly seen in the test circuit.

III. Direct-Fed Planar Circuit

The strongest coupling method of a (microstrip) bound mode to other forms of modes in the planar circuit is perhaps the direct feed as shown in Fig. 1. Contrasting to the rectangular patch of Fig. 2, a square patch is corner-connected to two microstrip lines as in Fig. 5, which essentially depicts a planar circuit without uniform cross section with respect to the longitudinal axis. In other words, the metalized pattern show certain degrees of irregularity, although it is symmetric about the bisection line connecting port 1 and port 2.

A two-port scattering measurement was conducted and the results plotted in Fig. 6, which also showed good agreement between the theoretical and measured data. The first (0,1) (or (1,0)) mode resonant frequency of the patch was estimated at 5.87 GHz, which could not be clearly seen in Fig. 6 since port 2 was terminated by the same 50 Ω reference impedance. Furthermore, our detailed leaky-mode analyses show that there is an additional leaky mode of order N near every (N,0) (or (0,N)) patch resonant mode frequency. Daniel et al. applied the corner-fed patch antenna in various applications. They, however, incorporated the first resonant mode, without discussing the tangled physical phenomena complicated by the existence of leaky-mode radiation [11-12]. The first leaky mode of order one, for example, corresponds to the first odd-mode leakage for frequencies between 5 GHz and 6.5 GHz. The frequency range of the higher-order leaky mode is approximately the integral multiple of the first leaky odd mode. When increasing the order of the higher modes, the leakage range is wider and wider. As a result, the leakage phenomena become significant if the operating frequency falls in the ranges of much higher order modes. Under the condition of the strong coupling, the leaky-modes emission in fact overwhelms the resonant phenomena. In Fig. 6, we can easily observe that in the frequency range of the second higher order mode, between 9 GHz and 12.5 GHz, the RPA values are significantly larger than those of the first higher order mode. Since the validity of the full-wave analyses had been established by examining the results shown in Fig. 6 and Fig. 3, respectively, the current distribution on the square patch should provide another reliable information to decide whether the leakage phenomena or the resonant phenomena dominate the radiation process. Fig. 7 plots the vectored current distribution of Fig. 5 at 11.5 GHz, which is in the second leaky mode region. As expected, the surface currents concentrate along the perimeter of the square patch at the left-top corner (port 1) and change sign once along the feed edges for the second higher-order leaky mode. In addition, as the surface current travels to port 2, its magnitude continuously decreases and finally reaches port 2. Hence we are convinced that the leaky-mode emission prevails in the particular case study. The above-mentioned observations become more obvious when discussing leaky-mode radiation of much higher order.

The E-plane radiation pattern of Fig. 5 is plotted in Fig. 8, showing a different form of fan beam with a tilt angle. The detailed discussion of the radiation characteristics is beyond the scope of this paper. Nevertheless, the emission from the square patch of Fig. 5 manifests the leaky-mode radiation, which may cause undesired coupling or resonance in microwave circuits.

IV. Conclusion

The leaky-modes radiation from planar circuits, which was previously unknown to microwave community, has been experimentally and theoretically confirmed to be related to the excitation of leaky modes by both proximity coupling and direct feed methods. Both theoretical and experimental results show that it is very important to assess the effect of exciting leaky modes that are almost inevitable on the performance of a planar circuit of arbitrary shapes.

Acknowledgment

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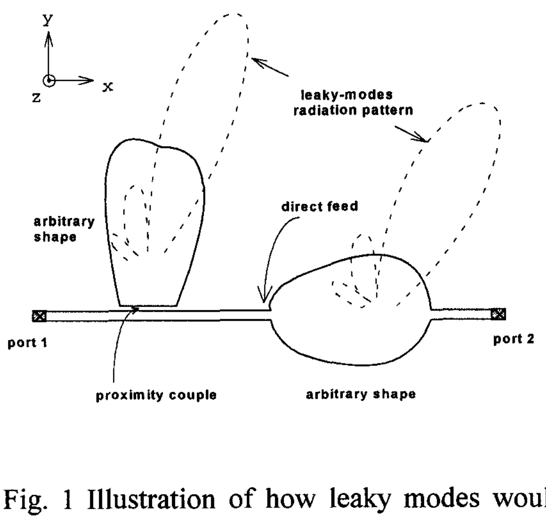

Fig. 1 Illustration of how leaky modes would leak from arbitrary planar circuits by means of proximity coupling and direct feed.

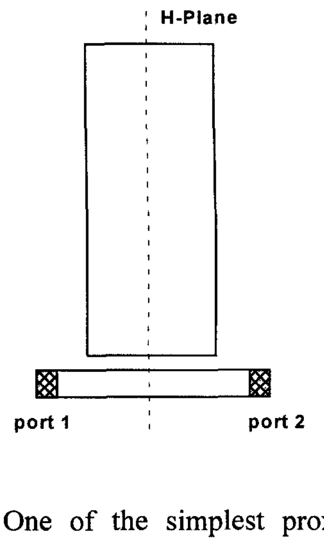

Fig. 2 One of the simplest proximity-coupled planar circuit that emits leaky modes.

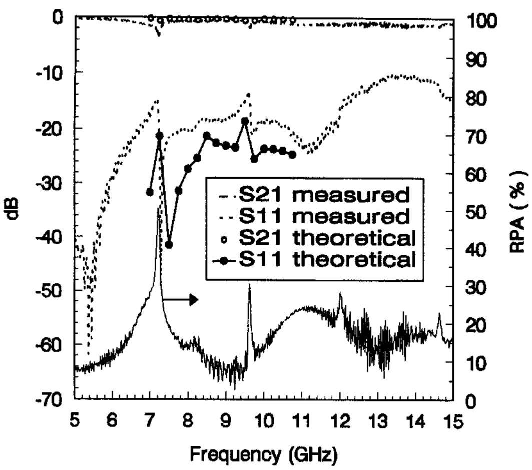

Fig. 3 The scattering parameters and relative power absorbed (RPA) of the proximity-coupled planar circuit of Fig. 2

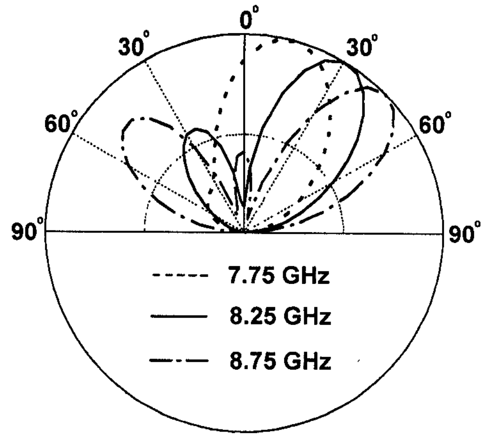

Fig. 4 The E_{Φ} radiation pattern in the H-plane of Fig. 2.

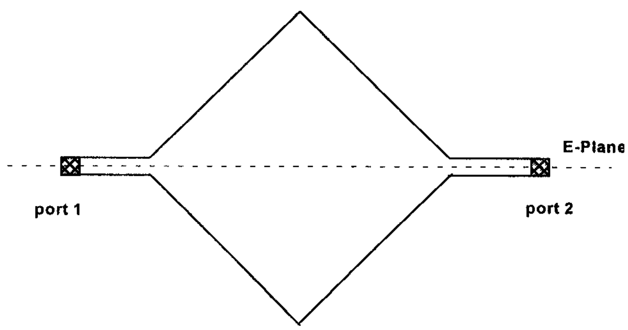

Fig. 5 The two-port corner-fed square patch planar circuit that emits leaky modes.

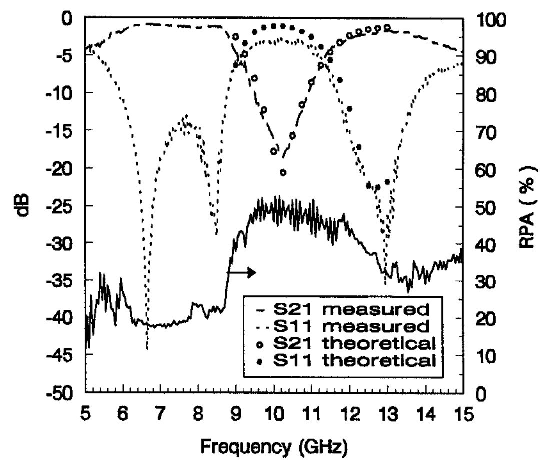

Fig. 6 The scattering parameters and relative power absorbed (RPA) of Fig. 5

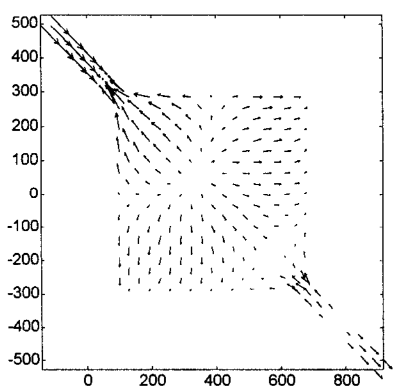

Fig. 7 The current distribution of Fig. 5. (unit : mil)

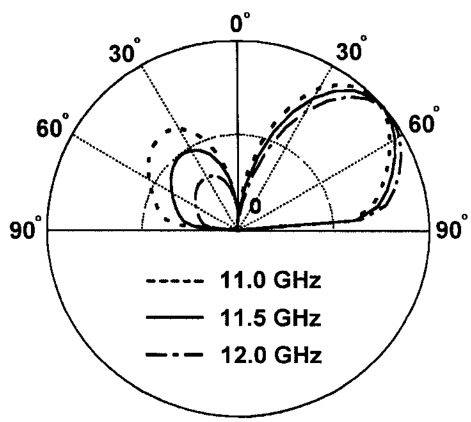

Fig. 8 The E_{Θ} radiation pattern in the E-plane of Fig. 5.