Nonleaky Conductor-Backed Coplanar Waveguide-Fed Rectangular Microstrip Patch Antenna

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***Abstract*— A new arrangement for exciting microstrip patch antennas is presented here that allows easier integration with monolithic microwave integrated circuits (MMIC's). The nonleaky conductor-backed coplanar waveguide (NL-CBCPW) is described with emphasis on avoiding the leakage of power. This structure is utilized for feeding a rectangular patch through an aperture in the back plane. The full-wave analysis of this arrangement was carried out using the moment method in the spectral domain. The theoretical and measured results of such a patch are given.**

I. Introduction

A COAXIAL probe-fed patch or a microstripline-fed patch are the simplest direct contact feeding arrangements for a microstrip patch [1]. Among the noncontacting-type feeding arrangements, the microstripline-fed aperture-coupled patch is the most popular arrangement [2]. It is used to realize passive or active microstrip arrays. However, it has a major drawback when it comes to mounting components and active devices, particularly in shunt. A coplanar waveguide (CPW) has lower loss and allows series and shunt mounting of devices with equal ease on one side of a planar substrate, avoiding via hole connections. To exploit these advantages of CPW, a CPW-fed microstrip patch antenna has been proposed earlier [3]. However, in this arrangement, the feed circuitry is not isolated from the patch side. This causes interference, particularly in the case of series-mounted active devices near the patch. To facilitate the isolation between the patch side and feed circuitry, a conductor-backed coplanar waveguide (CBCPW) fed arrangement was subsequently proposed [4] in which the CPW is backed by an additional conducting plane (back plane) that acts as a ground plane for the patch. The patch is excited by a narrow slot in the back plane.

However, the conductor backing results in leakage of power into the dielectric region between the two planes [5]. Mathematically, it means the propagation constant of the CPW-mode becomes complex and improper, $\gamma = \alpha + j\beta$. Physically, this characteristic wave-leakage occurs in the form of a parallel-plate mode [5]. The fields grow in the transverse direction, theoretically violating the radiation condition, and attenuate heavily in the direction of wave travel. Practically, this has unpleasant consequences such as unwanted coupling into the neighboring lines. This leakage is unconditional and needs to be avoided. Several arrangements were proposed to suppress or eliminate leakage [7], [6]. One simple arrangement that was proposed in [7] employed an additional dielectric layer between the two planes, making the leakage conditional [7] and hence making it possible to avoid it over the frequency band of interest. In this paper, this nonleaky structure has been utilized to excite a rectangular patch and the experimental results are presented along with the analytical results using the moment method in the spectral domain.

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II. Nonleaky Conductor-Backed CPW

The cross section of a NL-CBCPW structure is shown in Fig. 1. The purpose of the introduction of an additional layer (dielectric-2) is to make the CPW mode slower than the parallel plate mode so that the characteristic wave leakage is avoided. This can be shown by determining the propagation constants of the two modes. For the NL-CBCPW structure shown in Fig. 1, spectral domain Green's functions can be derived starting from the Helmholtz equation and then applying the appropriate boundary conditions. The Green's functions yield the complex poles indicating the possibility of leaky modes. The poles can be determined using a complex root searching procedure.

The phase constants β of the CPW-mode and the parallel-plate mode are evaluated using proper expansion functions for magnetic currents on CPW and applying appropriate boundary conditions and solving the resultant homogeneous equation by an iterative procedure [8]. The propagation constant of CPW-mode is complex and its real part α is determined using the spectral domain perturbation method [9]. The characteristic impedance is similarly evaluated by evaluating the power flow through the cross section of the structure [8].

The phase constant and attenuation constant of the CPW mode and the phase constant of the parallel-plate mode are shown in Fig. 2. The desired range of operation would be the region A–B. Outside this region, α indicates heavy attenuation due to leakage while within the region, $\alpha \approx 0$, indicating a negligible small attenuation due to dielectric loss. A better estimate of α may be obtained by using more expansion functions for the magnetic currents [8] on the CPW, however, for the patch feeding arrangement, it is enough to ensure that

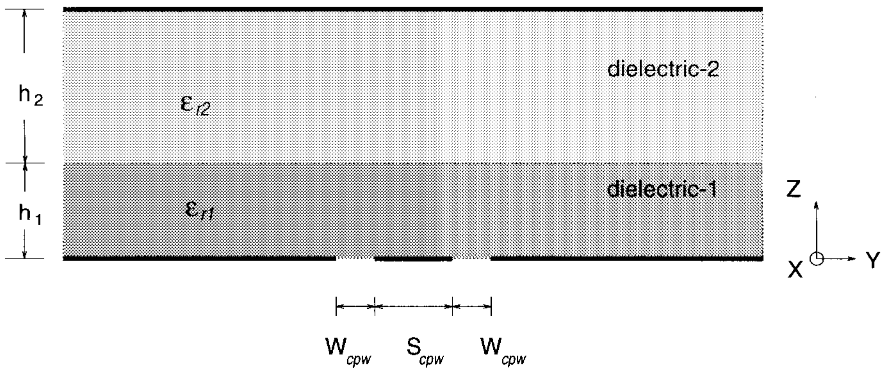

Fig. 1. Cross section of a NL-CBCPW.

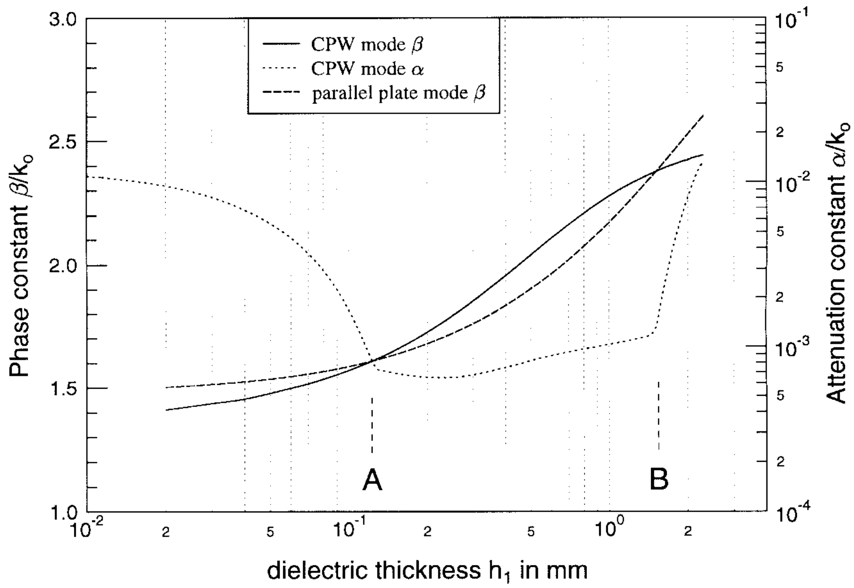

Fig. 2. Normalized attenuation and phase constants at 10 GHz: $S_{\rm cpw} = 1.2$ mm, $W_{\rm cpw} = 0.8$ mm, $\epsilon_{r1} = 10.2 \tan\delta = 0.001$, $\epsilon_{r2} = 2.2 \tan\delta = 0.001$, $h_2 = 0.508$ mm.

the structure remains nonleaky over the desired frequency range.

III. NL-CBCPW-Fed Rectangular Patch

An exploded diagram of a NL-CBCPW-fed rectangular patch is shown in Fig. 3. A coupling aperture is introduced in the back plane of NL-CBCPW to couple power to the patch. The structure can only be analyzed using full-wave analysis methods, such as the moment method in the spectral domain. The radiating and the wave-guiding structures can be replaced by equivalent electric and magnetic currents. These currents are then represented using appropriate expansion functions. The unknown patch currents are well represented using entire domain expansions functions, while the magnetic currents on the coupling aperture and CPW-slot are represented using piecewise sinusoidal (PWS) functions [10]. Traveling-wave expansion functions are used on the CPW to obtain the unknown reflection coefficient at the discontinuity. The testing functions used are the same as the expansion functions except for the traveling-wave function, for which an additional PWS mode is employed. The solution yields the reflection coefficient, which is translated into the input impedance.

Return loss measurements were made on samples of short-circuited NL-CBCPW's and conventional single-dielectric CPW's. The return loss followed the pattern of 1) a constant component arising from the coaxial connector to waveguide transition and 2) a component proportional to line length. A second set of measurements were made with leaky CBCPW's where there was significant return loss in addition to that accounted for 1) and 2); leakage was plainly evident.

Fig. 4 shows the calculated and measured values of the input impedance of a NL-CBCPW-fed patch; the reference plane for the impedance is at the CPW-slot discontinuity. There is a good agreement between these measurements, differences being attributed to fabrication and material tolerances, structural misalignments, and computational round-off errors.

IV. Conclusion

A new but relatively complex arrangement for exciting the microstrip patch antennas is presented here that pro-

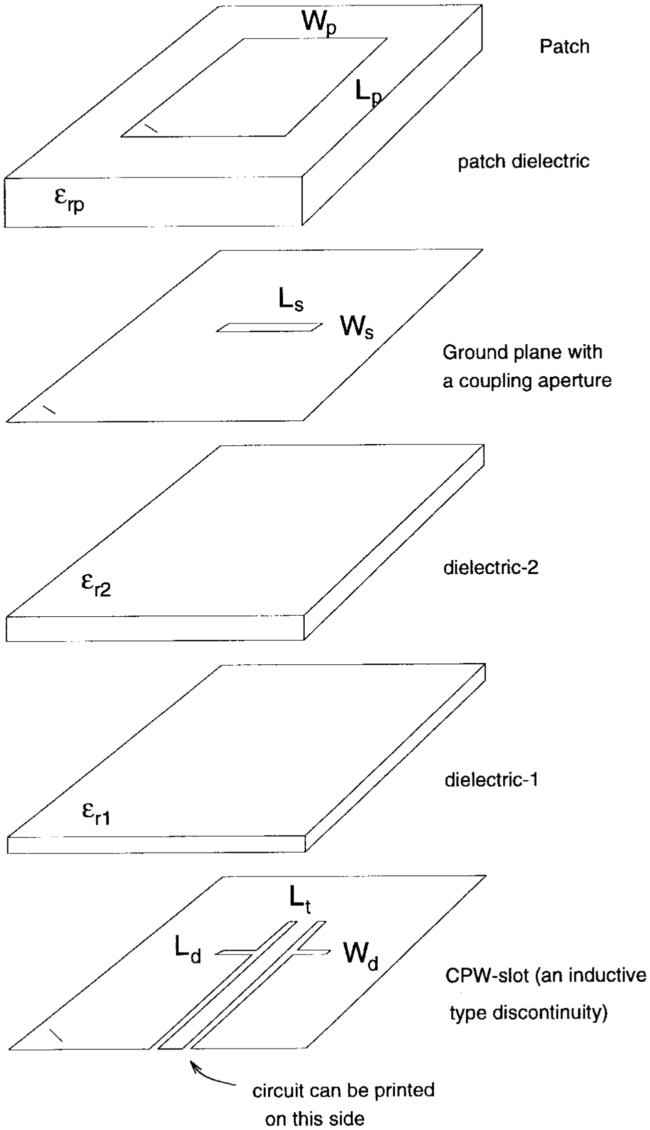

Fig. 3. An exploded view of a NL-CBCPW-fed patch.

vides easier integration with monolithic microwave integrated circuits (MMIC's). This arrangement has cumulative advantages over the earlier microstripline-, CPW-, and CBCPW-fed patch arrangements. Moreover it provides improved mechanical strength, easier heat removal, and more convenient dc biasing for circuits. The disadvantage is an additional dielectric layer and relatively difficult analytical treatment.

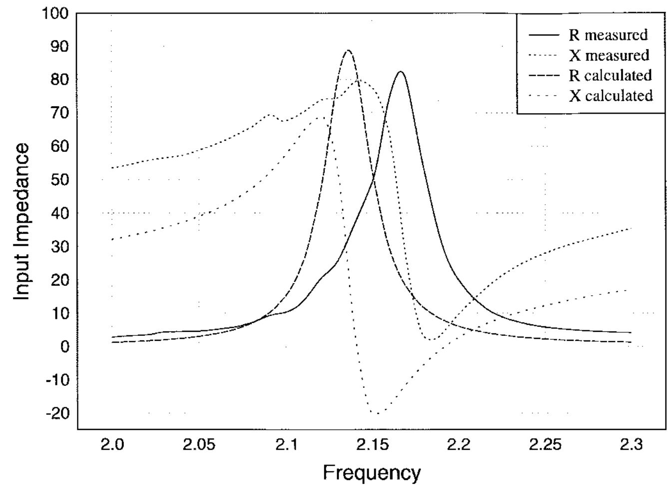

Fig. 4. Input impedance of a NL-CBCPW-fed patch: $\epsilon_{rp} = 2.2$, $h_p = 1.59$ mm, $L_p = 42$ mm, $W_p = 32$ mm, $L_s = 17.3$ mm, $W_s = 1.016$ mm, $L_d = 16.26$ mm, $W_d = 1.27$ mm, $\epsilon_{r1} = 10.2 \tan\delta = 0.001$, $\epsilon_{r2} = 2.2 \tan\delta = 0.001$, $h_1 = 0.635$ mm, $h_2 = 0.508$ mm, $S_{\rm cpw} = 1.2$ mm, $W_{\rm cpw} = 0.8$ mm.

This arrangement would be particularly useful for millimeter-wave integrated arrays using the current MMIC technology.

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