Microstrip Leaky-Mode Antenna Array

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***Abstract*— The first-pass design of a linear eight-element microstrip leaky-mode antenna array is proposed, built, and tested, showing a gain of 18.5 dB, directivity of 23.5 dB, and pencil beam with 3-dB beamwidth (Az/El) of 10.2°/14.3°. Excellent agreement between the theoretical prediction and measured result for the array antenna performance is obtained.**

***Index Terms*—Microstrip arrays.**

I. INTRODUCTION

Advances in active integrated antennas mandate that a novel high-performance conformal planar printed array antenna that can easily and efficiently integrate transceiver front ends is essential for use in a low-cost and highly sophisticated subsystem module [1]. To date, most of the planar antenna arrays incorporated in the active integrated antenna modules are of resonator type, e.g., microstrip patch, slot dipole, wire grid, etc. Consequently the stringent photolithography control is usually necessary for carrying out the precise design of inherently narrow-bandwidth resonant-type antennas in the millimeter-wave regime in particular. Thus, an alternative approach for implementing the planar-array antenna is needed. Furthermore, to develop the pencil-beam radiation characteristics, the resonant-type antenna array must be two dimensional, making such a planar-array design very complex due to the feed network.

This paper applies a novel approach using the concept of the linear leaky-mode array [2], which essentially produces a pencil beam in a greatly simplified manner for array implementation. It is a linear leaky-mode-based array that is particularly suitable for integrating active devices such as PHEMT's (pseudomorphic high-electron-mobility transistors) and monolithic microwave integrated circuits (MMIC's). Fig. 1 illustrates a prototype with a corporate-fed structure. On the top side of the dielectric substrate, the microstrip lines are printed and on the opposite side the coplanar waveguide (CPW) corporate feeding lines, slotlines, and the CPW-slotline transitions are etched. The slotline excites the higher order leaky-mode radiating from the microstrip and the entire feeding structure is of uniplanar type [3], [4].

II. INTEGRATED ANTENNA ARRAY DESIGN

The linear microstrip leaky-mode antenna array (shown in Fig. 1) is fabricated on a 25-mil (0.0635 cm)-thick RT/*Duroid*™ 6010 substrate with a relative permittivity of 10.2. The width of the microstrip is properly chosen such that efficient leaky-mode emission can be attained at Ku-band (12.17 GHz). Assuming a periodic infinite array fed by an in-phase excitation based on the unit-cell approach, the equivalent electric walls can be introduced between the various radiating elements. Thus, one only needs to analyze a unit cell as indicated in the inset of Fig. 2 for obtaining the leaky-mode propagation characteristics of the microstrip. As shown in Fig. 2, by employing the full-wave spectral-domain approach [5], the complex propagation constant ($\gamma = \beta - j\alpha$) of the first higher order mode is plotted against the frequency of interest, taking into account all mutual coupling effects, provided the linear array is fed by an in-phase excitation. Extracting the data from Fig. 2, we expect a tilt beam at an angle of 46.2° ($\theta \cong \cos^{-1}(\beta/\kappa_0)$) measured from horizontal along the H-plane (Y-Z plane) at 12.17 GHz. The length of the array prototype is 135 mm (about 5.48 λ_0). The signal source is applied to the CPW input end on the back side of the array. Followed by a CPW T-junction power divider and two CPW 90° bends, the same power dividing sequence continues until, finally, each radiating element receives equal amounts of power. The last stage of the CPW-to-slotline transition, however, causes out-of-phase excitation. Therefore, to make in-phase excitation for each radiating element, one arm of the CPW power divider at the final stage is offset by a half-wavelength long CPW to compensate the 180° phase difference produced by the CPW-to-slotline transition.

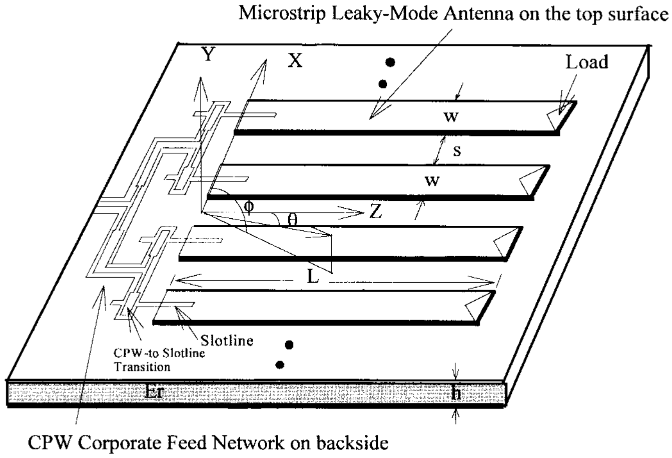

Fig. 1. The proposed CPW corporate-fed microstrip leaky-mode antenna array.

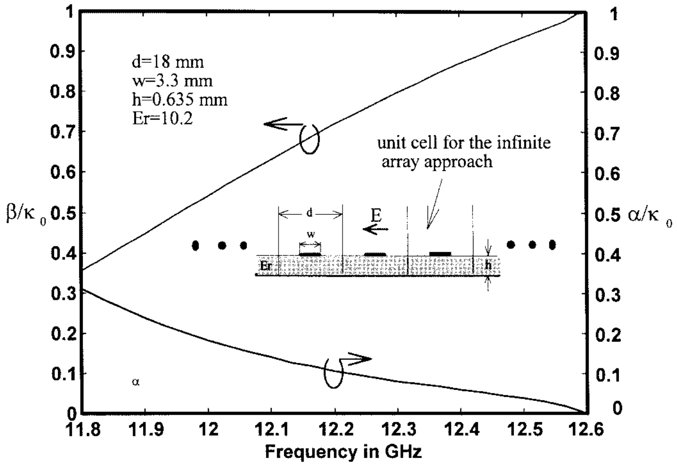

Fig. 2. The normalized complex propagation constant of the first higher order mode in the leaky region of interest.

III. MEASURED DATA AND THEORETICAL RESULTS

An eight-element experimental microstrip leaky-mode antenna array was fabricated and tested. The dimensions of the prototype

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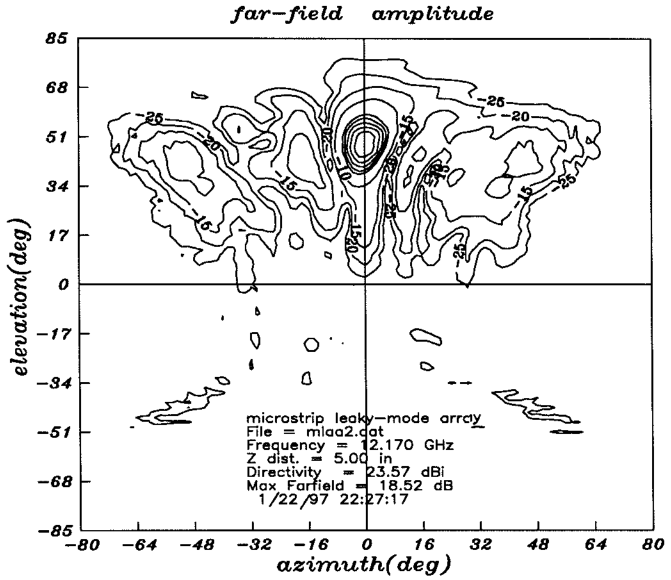

Fig. 3. The measured radiation contour of the microstrip leaky-mode antenna array at 12.17 GHz without loads.

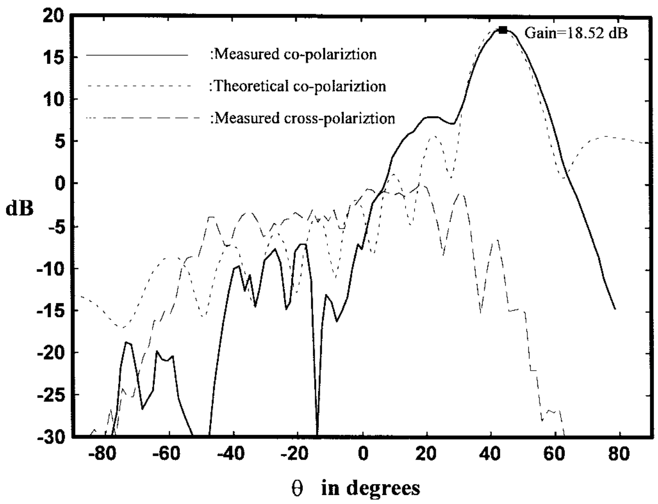

Fig. 4. The theoretical and measured radiation patterns along H-plane without loads.

are listed in the inset of Fig. 2. We obtained VSWR's less than 2.0 ($|S_{11}| < -10$ dB) for frequencies between 12.0 and 12.6 GHz. Then, we performed a far-field pattern measurement using the apparatus from Nearfield System, Inc. Fig. 3 plots the radiation contour of the microstrip leaky-mode antenna array, showing a tilt pencil beam pointing at the elevation angle of 47.2° and azimuth angle of 0°. The theoretical far-field radiation pattern can be derived from the Fourier transform of the equivalent magnetic current distribution over the apertures [5]. Fig. 4 plots the measured copolarization far-field pattern along the H-plane ($\phi = 0°$), showing that the tilt of the beam angle is 1° higher than the theoretical prediction and the beamwidth is slightly broader than the theoretical pattern. This slight discrepancy between theoretical and experimental data can be attributed to the absence of loads at the microstrip ends in the experimental prototype with a consequent small amount of power reflection from the end of each radiating element. The cross-polarization pattern is also measured and plotted in Fig. 4, showing -18 dB below the peak radiation power throughout the measurement and demonstrating negligible cross polarization, which confirms one of benefits of this leaky-wave antenna [2]. The measured overall transmission loss is approximately 3.5 dB. Table I lists a performance comparison between the measured results and theoretical predictions. As summarized in Table I, the performance of this first-pass design, without any tuning, demonstrates that by employing a leaky-mode-based antenna, a planar printed array can be designed in a greatly simplified manner while achieving very good performance as well.

TABLE I
SUMMARY OF ANTENNA PERFORMANCE

Specifications	**Measured**	**Predicted**
Aperture size (cm^2)	13.5 x 13.5	13.5 x 13.5
Polarization	Horizontal	Horizontal
Directivity	23.5 dB	23.9dB
Gain (F=12.17GHz)	18.5 dB	19.1 dB
Losses	5.0 dB	4.8 dB
Beam scan loss	1.4 dB	1.4 dB
Ohmic loss	3.5 dB	3.3 dB
Non-ohmic loss	0.1 dB	0.1 dB
3dB Beamwidth(Az/El)	10.2°/14.3°	10.1°/14.2°
VSWR(12.0 -12.4 GHz)	< 2	< 2
Sidelobe (Az/El)	-10/-11 dB	-13/-13 dB
Cross-polarization	<-18 dB	< -15 dB

IV. CONCLUSION

A first-pass design of a proposed microstrip leaky-mode antenna array is presented. Except for the losses at the feeding network, the proposed leaky-mode linear array shows very good agreement between the measured data and theoretical predictions.

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