Compressed-Width Leaky EH_1 Mode PBG Antenna

Ching-Kuo Wu, Yu-Chiao Chen, and Ching-Kuang C. Tzuang

***Abstract*—The recently developed electric-magnetic-electric (EME) microstrip is successfully used to design a compact leaky-mode antenna with fan beam radiation patterns. The EME microstrip consists of composite metals paralleling the electric and magnetic surfaces, where the magnetic surface is made of an array of coupled inductors. The frequency scanning behavior, experimentally and theoretically confirmed by matrix-pencil analyses, indicates that the line width can be reduced by 20%, compared to that of the conventional microstrip with the identical radiation angle of the first higher order (EH_1) mode at the same frequency.**

***Index Terms*—Leaky-mode antenna, matrix-pencil method, photonic bandgap (PBG).**

I. Introduction

Recently, various forms and properties of the photonic bandgap (PBG) structures have been investigated extensively for their versatility in controlling the propagation of electromagnetic waves [1]–[3]. Practical applications in microwave frequency such as bandpass filters, power amplifiers and antennas have been presented. An electric-magnetic-electric (EME) microstrip has also been proposed and demonstrated to be useful in enhancing performances of microwave circuits [4], [5]. This novel PBG structure has several advantages, including broad stopband, compact size, and low loss under the dominant mode operation.

Leaky mode propagation has found to be a common behavior to most printed waveguides in open or partially open space [6]–[8]. This paper investigates the leaky effects due to the radiation from the first leaky higher-order (odd) mode of the EME microstrip, which incorporates a PBG structure and experiences periodic perturbations on the strip line itself. The EME microstrip antenna not only reduces the width but possesses all the inherent unique characteristics of uniform microstrip leaky-mode antennas, such as narrow fan beam and frequency scanning. Therefore, a compact and high performance integrated antenna array can be designed using the proposed EME composite structure.

II. Operation and Design Guidelines

The EME microstrip is like a conventional microstrip on a continuous, uniform ground plane except in that the signal line consists of composite metals made of electric-magnetic-electric conducting surfaces, as depicted in Fig. 1. The electrical surface is an ordinary metal strip of a certain thickness. Coupled, connected metallic coils form a periodic array and realize the magnetic surface. The proposed guiding structure is symmetrical about its central plane, which is an electric wall for the microstrip odd-mode operation. The presence of the frequency-dependent magnetic surface at the central plane alters the modal current distributions along the transverse and longitudinal directions of the guide, thereby changing the dispersion characteristics. Proper widths ($\mathrm{W_{EL}}$, $\mathrm{W_{ER}}$ and $\mathrm{W_M}$) of the electric and magnetic surfaces, respectively, can be chosen to obtain the required propagation constant, operating frequency and useful bandwidth of the leaky-mode antenna.

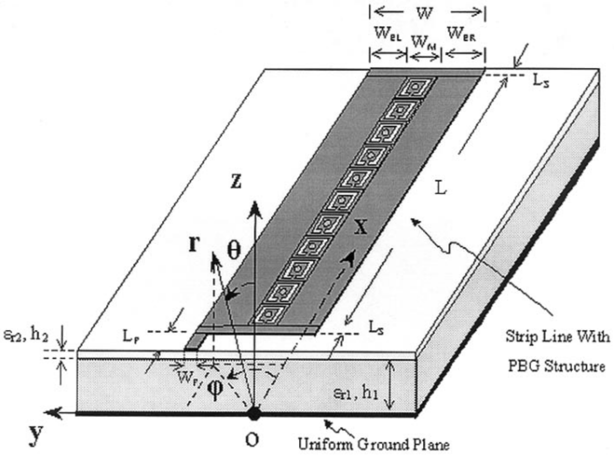

Fig. 1. Geometry structure of the EME microstrip leaky-mode antenna. $\varepsilon_{r1} = 3.38$, $h_1 = 0.508$ mm, $\varepsilon_{r2} = 3.38$, $h_2 = 0.203$ mm, $\mathrm{W_{EL}} = \mathrm{W_{ER}} = 3.201$ mm, $\mathrm{W_M} = 2.134$ mm, $\mathrm{W_P} = 1.6$ mm, $\mathrm{L_P} = \mathrm{L_S} = 0.5$ mm, and $\mathrm{L} = 256.08$ mm.

In the design presented here, the electric and magnetic surfaces are made on a two-sided, printed RO4003™ circuit board of thickness (h_2) 0.203 mm and relative permittivity (ε_{r2}) 3.38; the EME composite strip is then glued to a conductor-backing RO4003 substrate of thickness (h_1) 0.508 mm under proper heat and pressure. The unit cell of the PBG structure is 2.134 mm wide in both the x- and y-directions. The dispersion diagram, obtained by the finite-element model of one anisotropic PBG cell with enforced Floquet's boundary conditions at the cell sidewalls, predicts a stopband, between 8.8 GHz and 12.4 GHz with the center frequency at 10.6 GHz [9].

III. Experimental Results

To demonstrate the potential application of the EME microstrip as a leaky-mode antenna, an 8.536-mm-wide (W) EME microstrip prototype is built and tested (see Fig. 1). The cell designs of the PBG structure are sketched in [4], [5]. The EME microstrip has $\mathrm{W_{EL}} = \mathrm{W_{ER}} = 3.201$ mm and $\mathrm{W_M} = 2.134$ mm, with one cell in the transverse direction.

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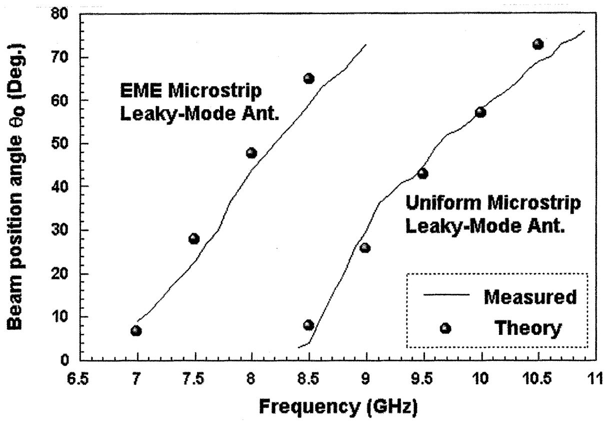

Fig. 2. Comparison of the main beam angles for the EME and uniform micro strip leaky-mode antennas with the same antenna length (L) and width (W).

The EME microstrip is 256.08 mm long (L), corresponding to 6.8 λ_0 (free-space wavelength at 8 GHz). A short, 0.5 mm long (L_S) metal strip is added at each end of the EME microstrip to facilitate the connection to the feeding structure. The experimental antenna is fed asymmetrically with a 50 Ω uniform microstrip of 1.6 mm wide (W_P) and 0.5 mm long (L_P).

We conduct the far-field radiation pattern measurement in an anechoic chamber. The particular design leaks in a fan beam fashion from about 7 to 9 GHz, polarized in the ϕ-direction with its maximum located in the $\varphi = 0°$ plane, which is the H-plane (x-z plane) of the antenna. Outside the space-wave leaky region, the peak power gain of the tilted mainbeam is lower than 8 dBi and the radiation pattern contains many lobes and nulls. The gain and the efficiency of the EME microstrip antenna at 8.5 GHz are 10.4 dBi and 49.72%, which are comparable with the uniform microstrip antenna with the same width. The gain and the efficiency of the uniform microstrip antenna at 10.1 GHz are 12.1 dBi and 52.09%. Fig. 2 plots the main beam angle θ_0 as a function of the frequency, measured from the broadside direction (z-axis). The angle θ_0 of the leakage is also related to the phase constant β of the first higher order mode by $\sin\theta_0 \approx \beta/k_0$ [8], where β is extracted by matrix-pencil analyses [5] and k_0 is the free-space wavenumber. The theoretical values, in circle symbols, are superimposed to the measurement curves of Fig. 2, showing excellent agreement has been achieved and the difference is less than 5°. Fig. 2 also plots the main beam angle of the uniform microstrip leaky-mode antenna with the same strip width (W) of 8.536 mm. It is obvious that the operating frequency of the EME microstrip is lower than that of the uniform microstrip for the same radiation angle, i.e., the physical width is 20% less than that of a conventional microstrip, needing 10.668 mm for the same radiation angle of 44° at 8.0 GHz.

Along the H-plane, the normalized radiation amplitude patterns of the EME microstrip leaky-mode antenna are plotted in Fig. 3 for different operating frequencies. Frequency scan characteristics of the antenna are shown at 7.5, 8.0, and 8.5 GHz where the beam position varies from 23° through 44°, to 59° as the 3-dB beamwidth is narrowed from 26° through 13.8°, and to 12°.

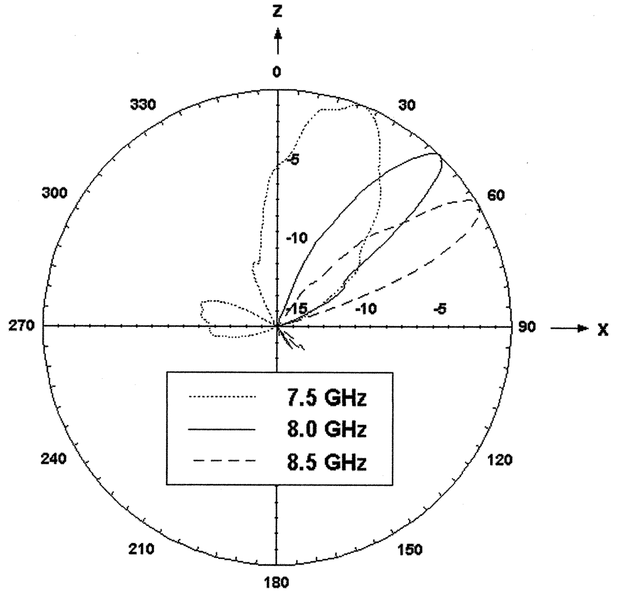

Fig. 3. Measured far-field H-plane radiation patterns of the asymmetrically fed EME microstrip leaky-mode antenna for three different frequencies.

IV. CONCLUSION

This paper presents the radiation characteristics of the EME microstrip that incorporates a uniform grounded substrate and uses PBG structures alongside the signal line in the axial direction. The leakage, produced by the excitation of the first higher order microstrip mode, are validated by measured radiation patterns. The physical dimension of the EME leaky line is reduced by 20%, compared to the conventional uniform microstrip on the same substrate. The implementation of the EME composite strip reduces the circuit dimension without compromising the performance of the leaky mode antenna.

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