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A Novel TEM-Waveguide Using Uniplanar Compact Photonic Band-Gap (UC-PBG) Structure

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Abstract --- A novel TEM-waveguide using a photonic band-gap (PBG) structure is presented. The uniplanar compact PBG (UC-PBG) structure which realizes a magnetic surface in the stopband is used in the waveguide walls. TEM mode has been observed by measuring the field distribution and phase velocity of the waveguide.

I. Introduction

Rectangular waveguides with uniform field distributions are of great concern for the applications in the quasi-optical power combining [1]. Dielectric-loaded waveguides are often employed but there exists several constraints. A high dielectric constant material must be used in the standard waveguide or an oversized waveguide has to be designed [2]. Longitudinal corrugations can also be applied to provide a uniform field distribution. However, these approaches suffer from narrow bandwidth and complicated fabrication process [2]. Photonic band-gap (PBG) materials have been extensively investigated for microwave applications [3,4]. The uniplanar compact PBG (UC-PBG) structure has been demonstrated to behave like a perfect magnetic conductor (PMC) at stopband frequency [5], and therefore can be applied to build a TEM-waveguide by placing it in both side walls. The magnetic boundary condition generates a parallel-plate mode, which is desired for the spatial power combining applications. The UC-PBG structure can be easily fabricated on a thin substrate using standard etching techniques.

II. Numerical Simulation

Fig. 1(a) shows the proposed TEM-waveguide using the UC-PBG structure on the two side walls. The PBG structure is a 2-D periodic lattice etched on a conductor-backed dielectric substrate. A unit cell of the PBG lattice consists of square pads and narrow lines with insets, as displayed in Fig. 1(b). The gaps between neighboring cells provide capacitive coupling and narrow branches have inductive behavior, which is further enhanced by insets. The PBG structure forms a distributed LC network with specific resonant frequencies at which the periodic loading becomes an open circuit, indicating a magnetic surface is realized. An X-band waveguide loaded by the UC-PBG structure with a stopband centered at 10 GHz has been designed and simulated using finite-difference time-domain (FDTD) method.

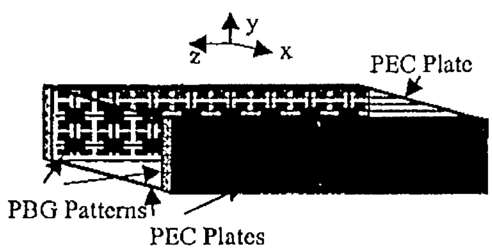

Fig. 1(a)

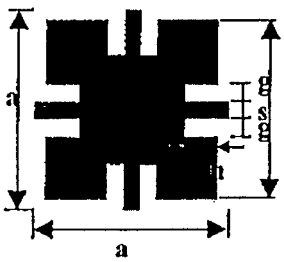

Fig. 1(b)

Fig. 1 Schematic of (a) a UC-PBG waveguide and (b) a unit cell of the PBG lattice

Fig. 2(a) shows the phase velocity of the PBG waveguide together with that of a standard metallic waveguide plotted as a reference. The PBG waveguide has a lower phase velocity over entire X-band and the velocity is close to the speed of light (*c*) at 10 GHz. Fig. 2(b) shows the E-field distributions in the waveguides loaded by different side walls simulated at 10 GHz. As can be seen, the PBG waveguide has a relatively uniform distribution compared to a standard waveguide. A waveguide loaded by bare dielectric slabs without PBG structure has also been simulated and its field profile is similar to that of a standard waveguide, indicating the more uniform field of the proposed waveguide is indeed created by the UC-PBG structure, not from the dielectric loading effect.

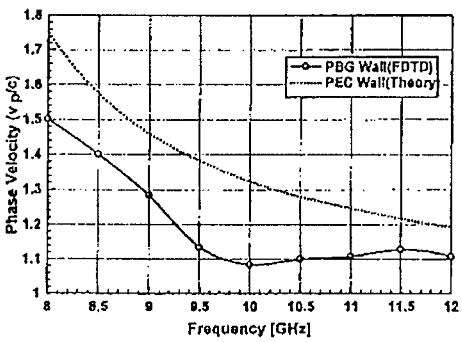

Fig. 2(a)

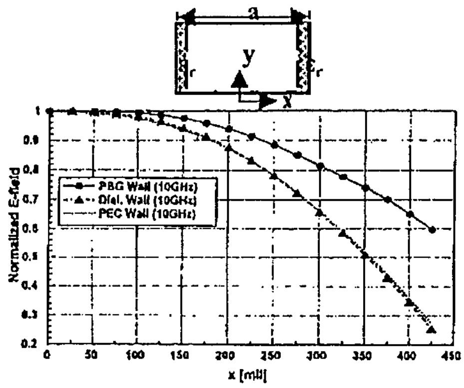

Fig. 2(b)

Fig. 2 Simulated results of (a) phase velocity and (b) E-field profile of the PBG waveguide.

III. Experimental Results

A broadband quasi-Yagi antenna [6] is inserted in the E-plane of the PBG waveguide to launch the TE wave since a standard coaxial-to-waveguide adapter is designed for TE_{10} mode excitation only. The PBG waveguide with a narrow slot on the top plate has been used for the phase velocity measurement. An HP 8350B sweep oscillator is connected to the quasi-Yagi antenna to generate the modulated signal and the E-filed probe is connected to an HP 415E SWR meter for measuring the guided wavelength, λ_g, from which the phase velocity can be calculated. The experimental result is shown in Fig. 3(a), where the simulated data of the PBG waveguide is repeated here for comparison. The measured phase velocity is 20% slower than that of a standard waveguide and reaches a minimum of $3.14 \cdot 10^8$ m/s at 9.8 GHz. The velocity curve is relatively flat and close to the speed of light from 9GHz to 10.2 GHz, indicating that a TEM mode has been created.

In the measrement for the field profile, the top plate of the PBG waveguide is replaced by a solid cover and a conductor-backed dielectric slab with a small iris is attached at the end as a shorting plate. The E-field probe is placed above the surface of the slab so that it will not disturbe the field inside the waveguide, and the image problem can be avoided. Shorting plates with the iris at different locations along the x-axis have been used to probe the field distribution. Fig. 3(b) shows the measured E-field strength of a PBG waveguide at 10 GHz with the result of a standard waveguide plotted for comparison. For the standard waveguide, E-field strength decreases substaintially as the probe moving from the center to the wall and it is only 10% of the peak value at the location close to the side wall. On the other hand, the field distribution in the PBG waveguide is more uniform and the field strength maintains 60% of its maximum value when probing near the side wall. Field profiles at different frequencies have also been measured and the results show that a fairly uniform field distribution has been achieved from 9.4 GHz to 10.4 GHz.

IV. Conclusions

A novel TEM-waveguide using the PBG structure has been presented. The UC-PBG structure has been used as the side walls in a rectangular waveguide to provide magnetic boundary conditions. The PBG waveguide generates a relatively uniform E-field distribution from 9.4 GHz to 10.4 GHz. Phase velocities close to the speed of light have also been measured at that frequency range, indicating a TEM mode has been established. Numerical simulations using FDTD reveal good agreement with experiments. This new PBG waveguide is a promising candidate as the feeding structure for the quasi-optical power combining amplifier arrays.

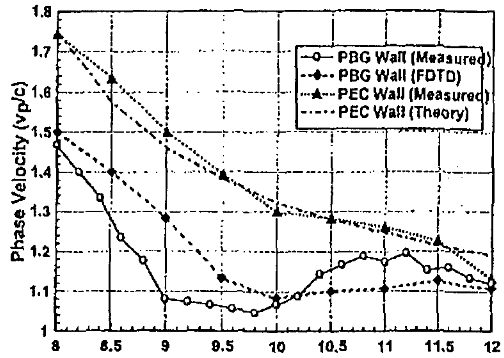

Fig. 3(a)

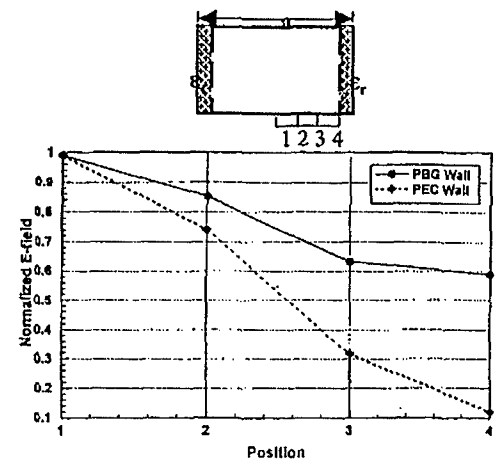

Fig. 3(b)

Fig. 3 Measured results of (a) phase velocity and (b) E-field strength of the PBG waveguide

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