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New Microstrip Gap Waveguide on Mushroom-Type EBG for Packaging of Microwave Components

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***Abstract*—The gap waveguide has been recently presented as a new transmission line technology using *artificial magnetic conductors* (AMCs) to allow the wave propagation only along a desired path. The first validation has been provided using a lid of metal pins as AMC for high frequency applications. In this paper, simulations and measurement results are presented for another version called microstrip gap waveguide, working as inverted microstrip line and realized using a mushroom-type EBG surface. The transmission line is surrounded by mushrooms which create a parallel plate stop band, suppressing cavity modes and unwanted radiations compared to standard packaged microstrip transmission lines. The field propagates in the air gap between the upper lid and the mushrooms layer, providing a low loss compact circuit made in printed technology.**

***Index Terms*—Gap waveguides, microstrip lines, mushrooms-type EBG, packaging.**

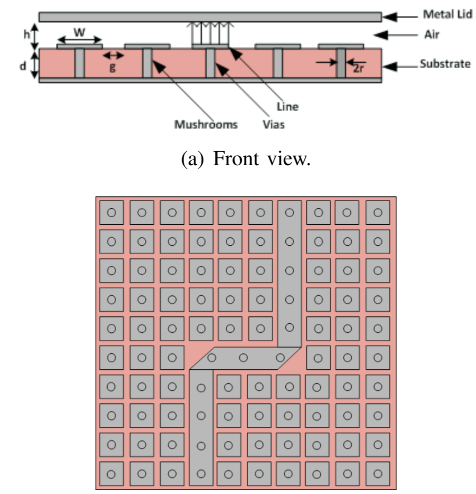
I. Introduction

RECENTLY, a new type of waveguide, so called gap waveguide, has been presented [1], [2]. This new technology is implemented with a periodic structure called bed of nails [3] which behaves as an *artificial magnetic conductor* (AMC) when the distance from the upper metallic plate to the pins is smaller than quarter wavelength. When this condition is verified, the AMC creates a parallel plate stop band which prevents the field from propagating in any direction except along a metal ridge or strip, surrounded by the AMC surface. Experimental validation of gap waveguide made with lid of nails has already been shown in previous works [4].

One of the advantages of this new technology is the packaging of components like microstrip lines and filters to avoid cavity modes and radiation from bends and other discontinuities. This has already been studied in [5], where the lid of nails is used to package microstrip circuits.

This paper presents the design and experimental validation of another type of gap waveguide, named microstrip gap waveguide, on a mushroom-type electromagnetic band-gap (EBG) surface [6]. The mushrooms were already analyzed as alternative AMC compared to the lid of nails in [7], [8]. Furthermore, they are suitable for packaging of microstrip circuits at lower frequency as they are manufactured in the same printed technology as the circuits, and they are more compact compared to the metal pins in terms of thickness. The study is performed at around 10 GHz.

The geometry is described in Fig. 1. The microstrip line is surrounded by mushrooms and they are printed on the same substrate. The EBG structure prohibits the wave propagation inside the dielectric forcing the field to propagate in the air, between the line and the upper lid. The mushrooms also prevent the radiation from bends in the line. The line is short-circuited to the ground plane with vias, in order to reduce the leakage of the field into the dielectric.



(a) Front view.

(b) Top view

Fig. 1. Front and top view of the proposed microstrip gap waveguide, surrounded by a mushroom-type EBG surface.

II. Simulation and Measurement Results

The dimensions of the EBG patches are chosen to be the following: W = 6 mm, g = 1 mm, vias radius r = 0.75 mm and substrate thickness d = 3.2 mm. The dielectric used is Duroid 5880 with ε_r = 2.2 and tanδ = 0.0009. The dispersion diagram of an infinite two-dimensional EBG array together with one-dimensional microstrip gap waveguide with these dimensions is shown in Fig. 2. The plot is generated using CST Eigenmode Solver and is calculated for the direction parallel to one of the sides of the mushroom unit cell. The stopband is generated between 5 and 11.5 GHz. The bandwidth is mainly determined by the thickness of the substrate and the air gap h between the EBG patches and the metal lid. In this case the gap height is chosen to be h = 1 mm. A numerical study in terms of stop bands for different geometries made with mushrooms and metal pins was already performed in [7], [8].

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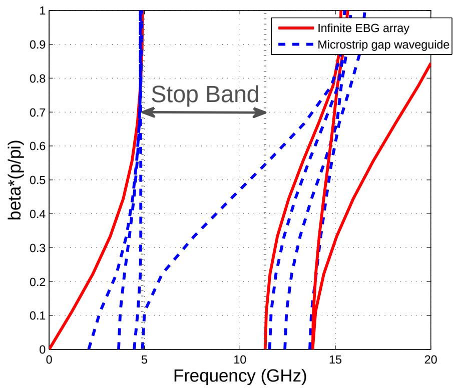


Fig. 2. Dispersion diagram of an infinite two-dimensional EBG array of a unit cell (red curves) together with one dimensional microstrip gap waveguide cell (red curves), with air gap of h = 1 mm between the patch and the upper PEC.

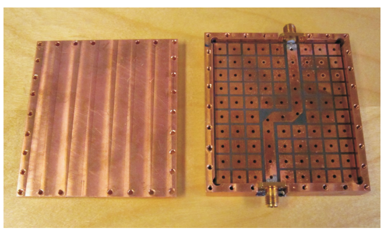


Fig. 3. Manufactured prototype with metal lid.

A 63 mm x 70 mm structure was designed and simulated with CST Microwave Studio. The line has two 90 degrees bends and a width of 5 mm, needed to match it to the 50 Ohm line impedance as in this case the field is propagating in air [9]. A printed circuit board was manufactured and packaged with a metal box, shown in Fig. 3. The metal used is copper and the feeding is provided from the side walls by SMA (SubMiniature type A) connectors. There is a hole at each side wall, where they are inserted and then fixed by screws to the package. Consequently, their inner conductors are soldered to each of the strip line ends. The SMAs were also included in the simulation.

Measured and simulated S-parameters are presented in Fig. 4 showing good agreement. The mushrooms works well within the frequency range 5.3-11.3 GHz providing a 2:1 bandwidth. The upper frequency limit has moved slightly downward for the measurement compared to simulation due probably to tolerances of the dielectric.

III. Comparison with Microstrip Line

Absorbers are typically used to remove cavity modes appearing when packaging standard microstrip transmission lines. However, they add losses to the circuit. The main advantage of the circuit presented in this paper is the removal of cavity modes and unwanted radiations. In addition, the field in this case is propagating in the air, providing lower losses. A standard microstrip line was also realized for comparison with the microstrip gap waveguide. The substrate is the same used for the mushrooms but with thickness 0.787 mm and

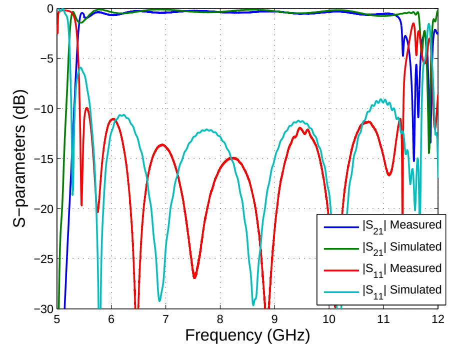


Fig. 4. Measured and simulated magnitudes of S-parameters for the microstrip gap waveguide with mushrooms.

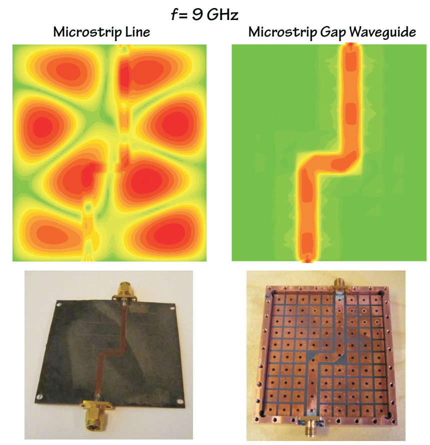
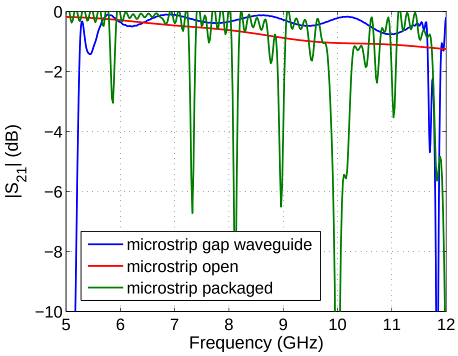


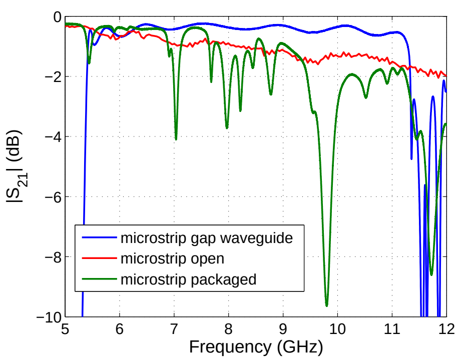
Fig. 5. 2D color plot of the absolute value of the E-field in the middle of the air gap for a packaged microstrip line (left) and microstrip gap waveguide on mushrooms EBG (right) at a frequency of 9 GHz. Prototypes in the figures are shown without lid.

the line is made in copper. 2D color plots of the absolute value of E-field are shown in Fig. 5 for a packaged microstrip line with metal lid and for the microstrip gap waveguide with mushrooms. The plots are taken in the middle of the air gap at 9 GHz. It can be clearly seen that cavity modes appear in the microstrip line case, whereas they are totally suppressed by the microstrip gap waveguide.
Measurements were also performed for the microstrip line first in ‘open case’, i.e. unpackaged, and then measured with a metal lid on top (mounted at a distance corresponding to 2-3 times the substrate thickness) and covered with copper tape on the sides.

Measurements and simulations results are compared in Figs. 6 and 7. There is a good agreement for both reflection and transmission coefficients. As expected, cavity modes appear for the packaged microstrip line, even more at higher frequency. The simulated $|S_{21}|$ shows deeper dips than the measured one. This happens because the packaged microstrip is covered with copper tape on the sides between the substrate and the lid which may allow some radiations during the measurement, while it is packaged by solid metal walls in simulations. It is interesting to notice that the open case exhibits higher losses than the microstrip on mushrooms from above 7 GHz. The difference in insertion loss between open

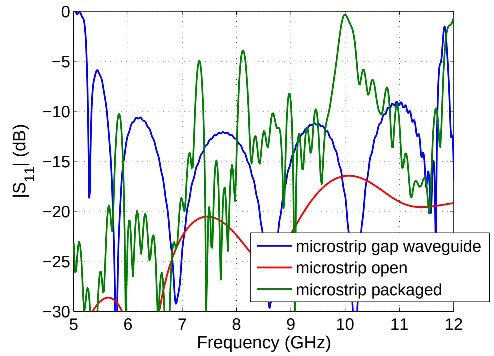


(a) Simulated $|S_{21}|$

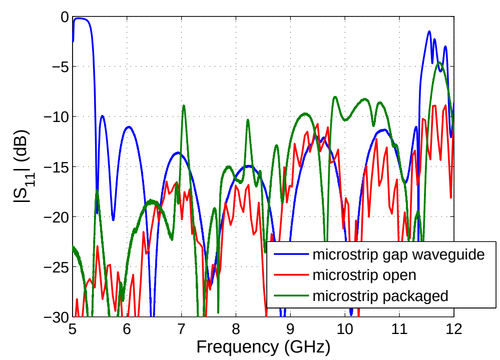


(b) Measured $|S_{21}|$

Fig. 6. Simulated and measured $|S_{21}|$ for the microstrip gap waveguide with mushrooms, microstrip line in open case and microstrip line packaged.



(a) Simulated $|S_{11}|$



(b) Measured $|S_{11}|$

Fig. 7. Simulated and measured $|S_{11}|$ for the microstrip gap waveguide with mushrooms, microstrip line in open case and microstrip line packaged.

case and mushrooms is about 1 dB at 10 GHz and it increases with the frequency. It should be also mentioned that for the mushrooms case there is an additional contribution to the mismatch, as the feeding is provided from the sides and some field leaks into the dielectric before going in the air. This could be avoided by, for example, feeding from the top directly into the air gap. More importantly, in this case we used a very low loss dielectric with $\tan\delta = 0.0009$. The microstrip line will present more losses if a more lossy substrate is used whereas this should not affect the microstrip gap waveguide so much because of its propagation in the air. The choice of the substrate depends only on its permittivity and thickness which contribute to the determination of the bandwidth for the microstrip gap waveguide.

IV. Conclusion

A new transmission line, made on a mushroom-type EBG surface, has been presented in this paper. The structure is a different version of gap waveguide technology, called microstrip gap waveguide. Experimental validation has been provided, showing good performance over a 2:1 bandwidth. This new structure can remove cavity modes and radiation from bends which typically cause loss and signal distortion when packaging microwave components. Furthermore, the circuit provides less losses than microstrip lines above 6-7 GHz. This version of gap waveguide is compact and suitable for lower frequency applications.

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