# New low loss inverted microstrip line using gap waveguide technology for slot antenna applications

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# New Low Loss Inverted Microstrip Line using Gap Waveguide Technology for Slot Antenna Applications

Elena Pucci*, Ashraf Uz Zaman*, Eva Rajo-Iglesias*† and Per-Simon Kildal*
*Department of Signals and Systems, Chalmers University of Technology
SE-412 96 Göteborg, Sweden
(elena.pucci@chalmers.se)
(zaman@chalmers.se)
(per-simon.kildal@chalmers.se)
†Department of Signal Theory and Communications, University Carlos III of Madrid
28911 Leganes, Spain
(eva@tsc.uc3m.es)

*Abstract*—**Recently, a new transmission line concept, called gap-waveguide, has been introduced. This technology generates a quasi-TEM mode in the gap between parallel metal plates and prohibits all other modes to propagate by making use of artificial magnetic conductors (AMCs) in the forms of e.g. lid of nails or mushrooms-type EBG surfaces. It has been shown how such geometry can replace standard microstrip lines and waveguides since it needs neither dielectric nor metal joints, being then an advantageous alternative that can be used for several applications at high frequency. This paper shows how the gap waveguide can also be realized in printed technology creating a new type of inverted microstrip line, called microstrip gap waveguide, which has low loss and large bandwidths can be achieved.**

## I. INTRODUCTION

The low loss gap waveguide technology has been developed in the last couple of years [1], [2]. Design and experimental validation for the ridge gap waveguide are shown in [3], where a quasi-TEM mode is allowed to propagate in the gap between two metal plates without need of dielectric. This is done by making use of an artificial magnetic conductor (AMC), such as bed of nails, which stops the field in any other directions except in the gap between the ridge and the upper lid. Analytical study for ridge gap waveguide realized by bed of nails is presented in [4]. Instead, TE mode propagation will result if the metal ridge is replaced by a groove [5], referred to as a groove gap waveguide. The bed of nails can also be replaced by other periodic AMC structures such as so-called mushroom surfaces consisting of microstrip patches with conducting vias [6]. Even more, it has been shown that gap waveguides have very low loss [7], being then an attractive solution in particular at high frequencies for integration of active components and as feed network for slot array antennas. This paper will present a new low loss inverted microstrip line made in gap waveguide technology. The proposed geometry is shown in Figure 1. It works like a suspended also called inverted microstrip line, but it is turned upside down in the drawing with the ground plane on top, followed by an air gap, a substrate with a printed microstrip line and lower printed plate working as an AMC. The AMC will create a high impedance condition below the microstrip line, forcing the field to propagate along the line as a TEM-mode in the air gap between the microstrip line and the upper metal ground plane.

It is very difficult to feed slot arrays from microstrip lines, because there will be generated undesired parallel-plate modes and resonances when packaging the microstrip feed network, and also the microstrip line will have losses. The new solution presented in this article can suppress such parallel-plate modes and associated resonances.

We will consider three possible geometries of inverted microstrip gap waveguide, shown in Figure 2. In the first one, the AMC is made of metallic pins, in the second the microstrip line is supported by a mushrooms-type EBG printed circuit board, and in the third the microstrip line is grounded by metallized vias and share the same substrate as the mushroom-type EBG. A similar approach of a suspended strip on bed of nails is already presented in [8]. In this paper the solutions made directly on printed board by using mushrooms-type EBG are proposed and a study in terms of bandwidth and losses is shown for all cases.

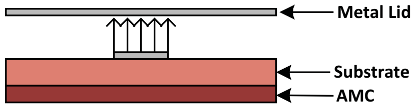

Fig. 1. Geometry of microstrip gap waveguide.

## II. BANDWIDTH STUDY

A study of the bandwidth is performed for the three cases presented in Fig. 2. The frequency range chosen is between

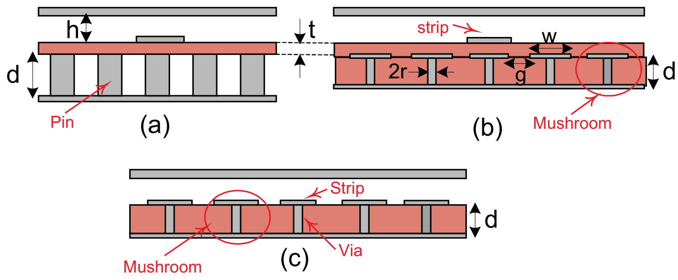

Fig. 2. Three geometries considered. In the first the AMC surface is made with metallic pins, in the second with mushrooms-type EBG, in the third microstrip line and mushrooms share the same substrate.

5 and 15 GHz. One of the main parameters determining the bandwidth is the air gap $h$. In [6] is shown how the parallel-plate stopband increases as the air gap decreases. In this paper $h$ is set to be 1 mm for all geometries. The substrate used is Duroid 5880 with $\varepsilon_r = 2.2$ and tan$\delta = 0.0009$. In Figure 3 the dispersion diagram for the solution with pins is shown together with a 2D color plot of the absolute value of the E-field. Simulations are carried out with CST eigenmode solver. Dimensions used are $d$ = 7 mm for the pins length and substrate thickness $t$ = 1 mm. As shown in Figure, the quasi TEM mode is propagating in the air gap between the line and the upper lid within the stopband of the parallel-plate modes, i.e. from 7 to 14 GHz.

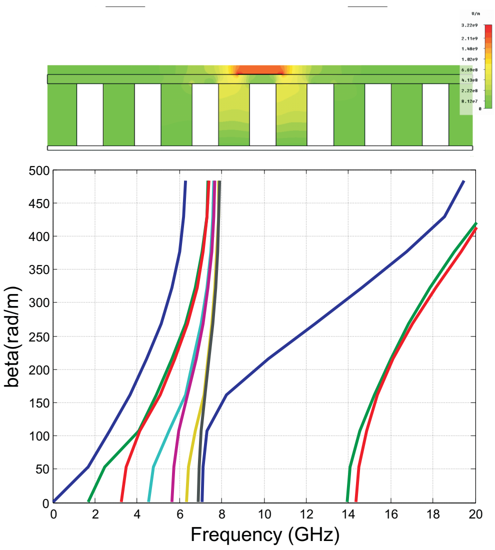

Fig. 3. Dispersion diagram of microstrip gap waveguide made with lid of pins below a 2D color plot of absolute value of E-field at 11 GHz (within the bandgap). Length of the pins is $d$ = 7mm, airgap is $h$ = 1 mm and substrate thickness is $t$ = 1 mm.

Dispersion diagram and 2D color plot of E-field for the second geometry (in Figure 2 (b)) are shown in Figure 4. In this case $t$ = 1 mm and $d$ = 3.2 mm. The bandwidth is determined not only by the air gap $h$, but also by the substrate thicknesses of microstrip line and mushrooms, $t$ and $d$, respectively. By keeping $h$ and $d$ constant, the upper frequency limit of the bandwidth is determined by $t$, as shown in Figure 5. The minimum frequency of the bandgap ($f_{start}$) is not affected by $t$, whereas the maximum frequency ($f_{stop}$) increases as the thickness decreases. Since the field is propagating on air, the substrate of the microstrip line adds an additional space between the upper lid and the point where the AMC condition is satisfied (h+t). For this reason, the smaller $t$, the smaller the total effective gap height, the larger the bandwidth (for both pins and mushrooms cases). Therefore, a better solution is achieved with the third geometry proposed in Figure 2 (c), where mushrooms and microstrip line share the same substrate with thickness $d$ = 3.2 mm. The microstrip line must in this case be shorted to the ground plane with vias in order to avoid propagation of a normal microstrip mode inside the dielectric. Figure 6 shows dispersion diagram and color plot of E-field. As it can be seen, the field is propagating on air within the bandgap created by the mushrooms, from 5.5 to 13 GHz. This solution is more compact, and provides larger bandwidth than the previous ones.

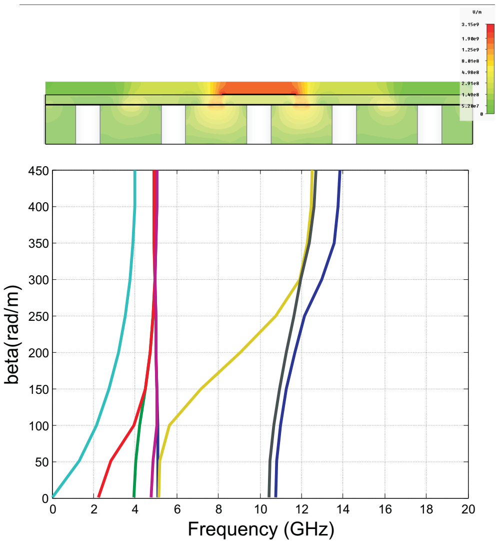

Fig. 4. Dispersion diagram of microstrip gap waveguide made with mushrooms-type EBG, below a 2D color plot of absolute value of E-field at 8.28 GHz (within the bandgap). Dimensions used are: $d$ = 3.2 mm, $t$ = 1 mm, $h$ = 1 mm, radius of grounded vias of mushrooms $r$ = 1 mm, width of the patches $w$ = 6 mm and gap $g$ = 1 mm.

## III. LOSSES STUDY

The purpose of this section is to show that the new topologies presented above are less lossy than typical microstrip lines, because in present cases the field is propagating in an air gap. As already shown in [7], the loss in a transmission line resonator can be characterized in terms of unloaded quality factors. Four cavities are considered: the three solutions proposed (solution A, B and C, as previously presented in Figure 2) and a standard microstrip line, with same substrate as before, thickness 0.787 mm and distance from the strip to the upper lid $h$ = 1 mm. Simulations are carried out with CST eigenmode solver at the same resonance frequency and same order mode. Color plots of absolute value of E-field for the four cavities are shown in Figure 7. In all four cases we choose

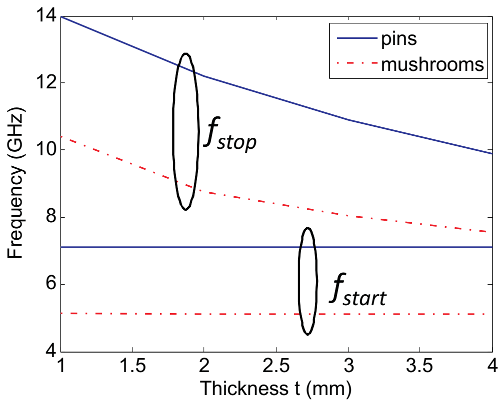

Fig. 5. Start and stop frequencies of bandgap for microstrip gap waveguide realized with pins and mushrooms as a function of the substrate thickness $t$. Dimensions used for the mushrooms are: $d$ = 3.2 mm, $r$ = 1 mm, $w$ = 6 mm, $g$ = 1 mm. Pins length is $d$ = 7 mm and air gap is $h$ = 1 mm for all cases.

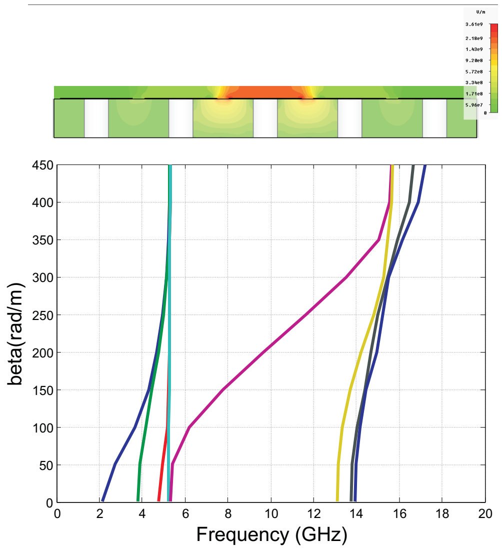

Fig. 6. Dispersion diagram below a 2D color plot of absolute value of E-field when microstrip line and mushrooms share the same substrate. The microstrip line is shorted to the ground with vias. Dimensions used are: $d$ = 3.2 mm, $h$ = 1 mm, radius of mushrooms $r$ = 1 mm, width of the patches $w$ = 6 mm and gap $g$ = 1 mm.

the fourth resonance of the line, which has two 90 degrees bends. The computed unloaded Q values are shown in Table I. The three microstrip gap waveguides have a much larger Q than the microstrip line, showing that the type of substrate used and its thickness should not affect the performance of the structure in terms of losses.

TABLE I
Q-FACTORS

| | **Unloaded Q** |
|---|---|
| **Solution A** | 2197 |
| **Solution B** | 1357 |
| **Solution C** | 1709 |
| **Standard Microstrip** | 602 |

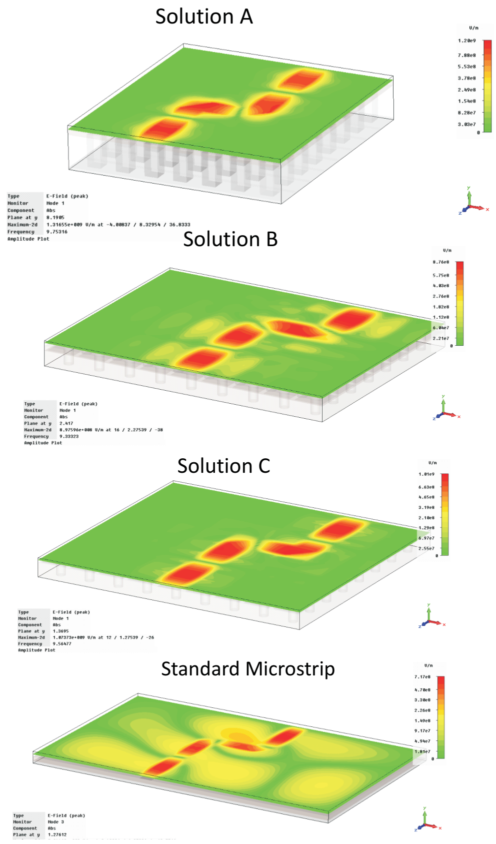

Fig. 7. Color plots of absolute value of E-field for the three resonators made in microstrip gap waveguide and a resonator made in standard microstrip line. Solution A is made with lid of pins, solution B with mushrooms-type EBG and solution C is made with microstrip line and mushrooms sharing the same substrate and line shorted to ground by via holes. The standard microstrip line is packaged by a metal lid at a distance $h$ = 1 mm (all upper lids are hidden in Figure).

## IV. CONCLUSIONS

In this paper a new inverted microstrip line, made in gap waveguide technology, has been presented. Three geometries with different AMCs have been considered, i.e., microstrip line supported by textured surface of metallic pins, mushrooms-type EBG and a third solution where the microstrip line is surrounded by mushrooms and shorted to the ground plane by via holes. Wide bandwidths can be achieved by proper choice of the gap height $h$ and substrate thickness. Even more, the new solutions have much lower loss than a standard microstrip line. The microstrip gap waveguide with pins can be suitable for applications at high frequency, while the one with mushrooms can be used at lower frequency, since it is easier to manufacture. This new transmission line can be convenient for feeding slot arrays in the overlaying metal plate and packaging of components with low loss constraint.

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