**Design of a Dual-Mode Horn Element for Microstrip Gap Waveguide Fed Array**

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*Abstract*— **The low loss microstrip gap waveguide provides an easy and suitable solution to be used as feed network for antennas at high frequency. This paper presents the design of a slot coupled dual-mode horn element fed by microstrip gap waveguide for array applications at 60 GHz. The directive dual mode horn is used to reduce the grating lobes which are generated when the slot array elements have a distance bigger than lambda. Simulation results of the proposed design are presented in terms of return loss and grating lobe level.**

***Keywords-gap waveguide; dual-mode horn; array.***

## I. Introduction

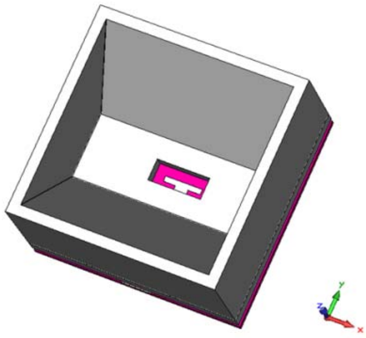
The new gap waveguide technology has already been proposed as an alternative to standard microstrip components and waveguides because of its low loss and advantageous manufacturing at high frequency [1-3]. Then gap waveguides exist in three basic geometries: ridge, groove and microstrip gap waveguides [4]. It has been demonstrated to be perfect for packaging of microstrip circuits [5] and in particular filters [6], and even to realize filters using groove gap waveguides [7]. Another quality of the gap waveguide technology is that it can be used to design feeding networks for high frequency antenna applications. At these frequencies, printed antenna arrays suffer from high dielectric as well as conductive losses in the feeding network, which have the effect of decreasing the antenna efficiency [8]. The conductive losses can be reduced by increasing substrate thickness, but then surface waves and radiation from the feed network start deteriorating performance. On the other hand, standard waveguide feeding networks have lower loss but are complex, non-planar, voluminous and expensive. The gap waveguide technology, however, has in comparison only advantages: It represents a planar geometry, the dimensions can be increased to reduce the conductive losses without exciting surface waves, and the substrate can be completely or partly removed to reduce the dielectric losses. The latter is in the present case achieved by an inverted microstrip gap waveguide.

A slot antenna fed by ridge gap waveguide was already shown in [9]. The present paper presents a planar design of a slot-coupled dual-mode horn array with inverted microstrip gap waveguide corporate feed network, working at about 60GHz. The microstrip gap waveguide works as an inverted microstrip line, supported by an artificial magnetic conductor (AMC), which allows propagation of the EM field in the air gap. Packaging capability and ohmic loss study, presented in previous works [10], [11], showed how this type of gap waveguide can provide a low loss printed design suitable for feeding slot antenna arrays. The inverted microstrip gap waveguide avoids surface waves and consequently prevents the mutual coupling coming from the feeding network.

## II. Characteristics of the Design

The corporate feed network takes - when using a suspended microstrip gap technology - more space than when using conventional microstrip technology as the field is travelling in the air. We can also make the lines wider and the air gap larger because there is no problem with radiation from the corporate feed network and from surface waves in the gap waveguide case. Therefore, the array elements need to be separated by a distance greater than a wavelength. For this reason, we use directive dual mode rectangular horn elements in order to attenuate grating lobes more than in conventional rectangular horns. The intention is to mold or machine the horns side-by-side in a thin metal plate, and we want this plate to be as thin as possible, preferably 5 mm. The proposed design is shown in Fig. 1. Fig. 1a shows the 3D design of the single element and Fig. 1b presents a 3D sketch of the array. The study is done for the single element, because directive horn elements are known to be nearly uncoupled when located side-by-side. The slot is fed by the microstrip gap waveguide, as shown in the two main planes in Fig. 1c. The square horn is $2\lambda$ wide and its total height is $h_1$ = 5 mm. The air gap between the microstrip gap waveguide and the slot must be smaller than quarter wavelength; chosen to be 0.25 mm at 60 GHz. The artificial magnetic conductor (AMC) used to create the stopband for parallel-plate modes can be either made of mushrooms-type EBG or bed of nails [10], [12]. The simulated initial results in the present section are presented by making use of an ideal PMC (Perfect Magnetic Conductor) below the microstrip line, which can be set as a boundary condition in CST Microwave Studio. This reduces computation time considerable [13]. In the next section this will be replaced by a regular array of pins and comparisons will be shown.

The feeding is provided by using a line with a T-shaped section, as shown in Fig. 2. The T-shaped feed line is used to match the input impedance and extend the bandwidth of the slot [14]. The simulated $S_{11}$, presented in Fig. 3, is below -10 dB from 57.8 to 64.4 GHz.



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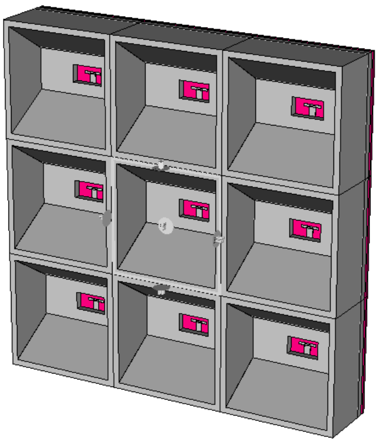

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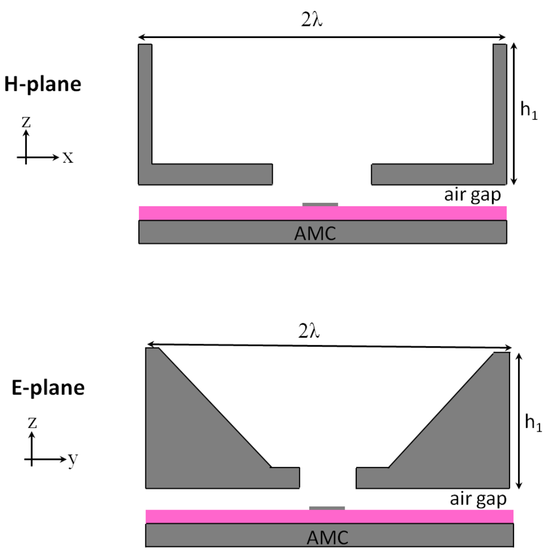



(c)

Figure 1. Slot-coupled dual-mode horn array with suspended microstrip gap waveguide corporate feed network. (a) The horn element. (b) 3*x*3 array. (c) Cross-sections in E- and H- planes.

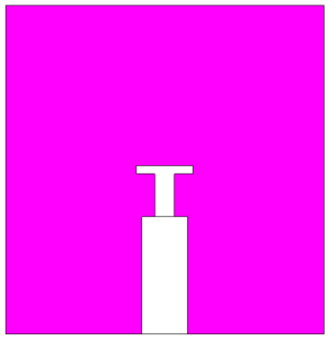


Figure 2. T-shaped feed line.

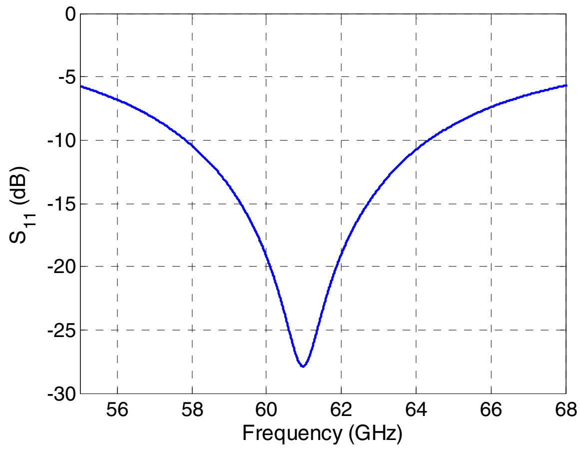



Figure 3. Simulated $S_{11}$ of the dual-mode horn with microstrip gap waveguide with ideal PMC condition.

## III. Comparisons between Ideal PMC and Bed of Nails

A uniform grid of pins can be replaced to the ideal PMC condition in the simulated design. The pins have a width $a$ = 0.4 mm, length $d$ = 1 mm and distance $p$ = 0.5 mm between each other, as shown in Fig. 4. For these dimensions the dispersion diagram, simulated in CST and presented in Fig. 5, shows a stop band between 51.7 and 67.8 GHz. The stop band can be increased by choosing a thinner dielectric and/or changing the shape of the pins, e.g., with a pyramidal shape [15]. The dispersion diagram is calculated for a row of microstrip gap waveguide periodic along both $z$ directions, as shown in the figure. The air gap and the substrate thickness are both set to 0.25 mm. The substrate used is Rogers RO3003, with permittivity equal to 3 and tan$\delta$ = 0.0013. The simulated $S_{11}$ for the case with bed of nails below the dielectric is compared with the previous PMC case and shown in Fig. 6. The main difference is due to a frequency shift for the design with bed of nails compared to the ideal case. A slightly smaller bandwidth is also noticed for the pins case, but overall the two cases show similar performances. Therefore it is possible to optimize the gap waveguide designs by using the ideal case with PMC, reducing then the computation time as discussed in [13].

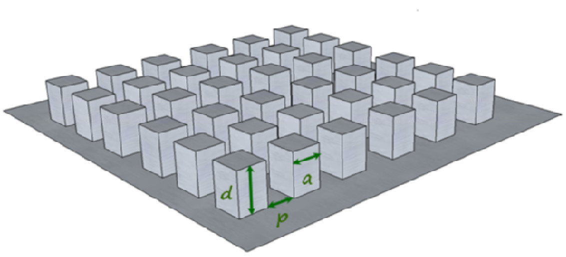



Figure 4. Sketch of a uniform grid of pins.

## IV. GRATING LOBES AND RADIATION PATTERN

Dual mode horns are typically used as feeds for reflector antennas. They can be designed either to provide a tapered horn-aperture distribution in both E and H-planes and a resulting reduced cross-polarization in the 45 deg plane (normal in circular horns), or to obtain a more uniform horn-aperture distribution [16] in H-planes (square horns). The uniform aperture distribution is obtained by superposition of $TE_{10}$ and $TE_{30}$ modes, the latter being excited by introducing a step in the horn in H-plane. This gives a more directive horn that is the goal in the present paper, in order to reduce the grating lobe level, which will have effect on both the sidelobes and directivity of the array, the latter being more important at 60 GHz. The grating lobe level versus frequency for the proposed design is plotted in both E- and H-planes and presented in Fig. 7, indicated respectively as 'E plane opt' and 'H plane opt'. The dashed curves are the values before optimizing the design. The calculation is done by determining the direction of the first grating lobe from the broadside direction, using the formula [17] $\sin\theta = \lambda/d$, where $d$ is the horn-aperture width (same as the element spacing), which is 9.8 mm. Then, the grating lobe level is extracted from the element far field functions in E- and H-planes as a function of the frequency. The element far field functions for the proposed design are shown in Fig.8.

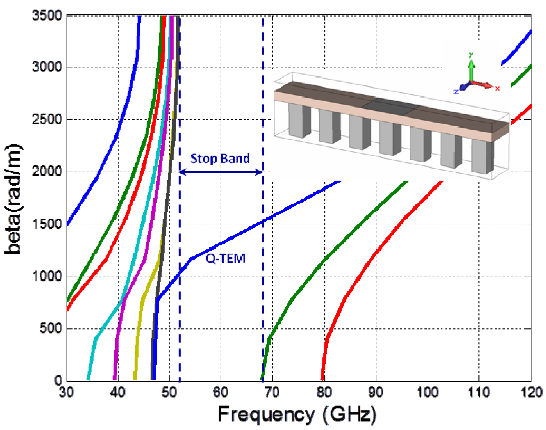



Figure 5. Dispersion diagram of a periodic row of microstrip gap waveguide along ± $z$ axis.

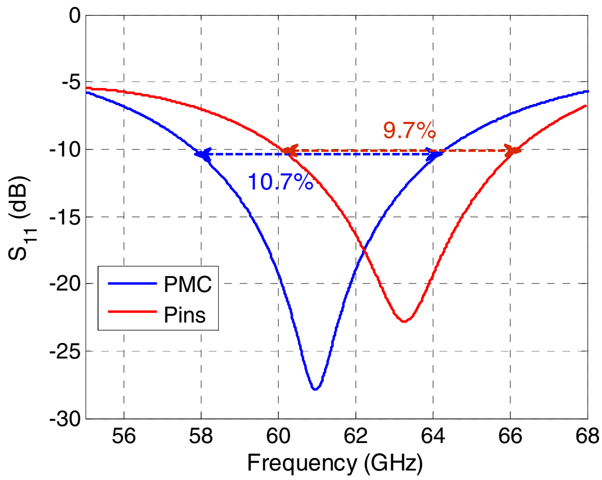



Figure 6. Simulated reflection coefficients for ideal PMC and bed of nails.

## V. CONCLUSIONS

This paper presents the design of a slot-coupled dual-mode horn array with suspended microstrip gap waveguide corporate feed network. Simulation results for the reflection coefficient are promising. 15 % bandwidth can be obtained by further optimization of the design. The grating lobe level has been reduced compared to conventional rectangular horns and is now quite low in both E-and H-planes. We are also working with ways to reduce it further in particular because the related power loss of approximately 1 dB can be improved. Manufacturing can be made easier by using a circular shape for the horn aperture, compared to the rectangular one. Such results will be included in the final paper. The final paper will also include measured results on a prototype.

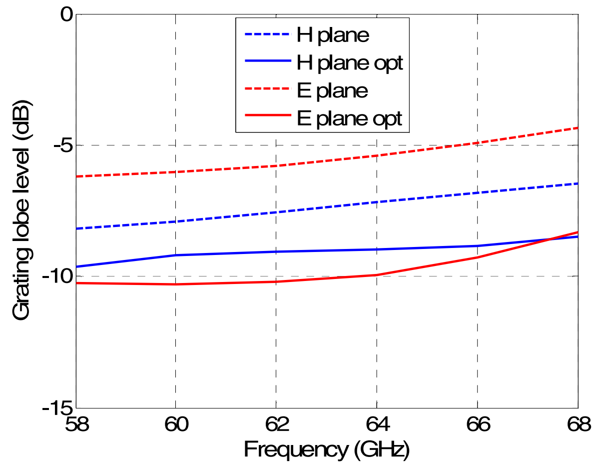
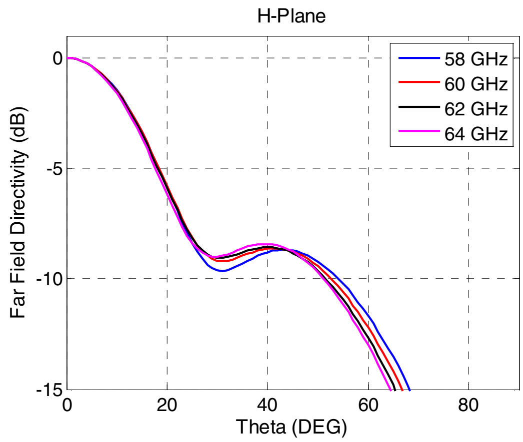



Figure 7. Simulated grating lobe level versus frequency in E- and H-planes. Dashed curves correspond to the values before optimizing the design.

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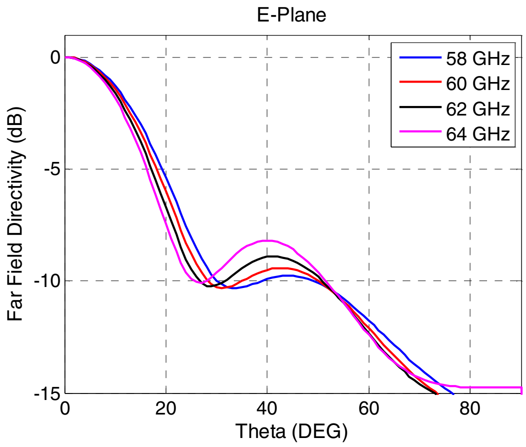


(b)

Figure 7. Element far field functions in (a) E-plane and (b) H-plane.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] P. S. Kildal, A. U. Zaman, E. Rajo-Iglesias, E. Alfonso, and A. Valero-Nogueira, "Design and experimental verification of ridge gap waveguide in bed of nails for parallel-plate mode suppression", *IET Microwaves, Antennas & Propagation*, vol. 5, no. 3, pp. 262–270, 2011.

[2] E. Pucci, A. Uz Zaman, E. Rajo-Iglesias, P.-S. Kildal, A. Kishk, "Losses in ridge gap waveguide compared with rectangular waveguide and microstrip lines", EuCAP 2010, Fourth European Conference on Antennas and Propagation, Barcelona, 12-16 April 2010.

[3] S. Rahiminejad, A. U. Zaman, E. Pucci, H. Raza, V. Vassilev, S. Haasl, P. Lundgren, P.-S Kildal, P. Enoksson, "Micromachined Ridge Gap Waveguide and Resonator forMillimeter-Wave Applications", accepted for publication in *Sensors and Actuators A: Physical*, an international open access journal by Elsevier, March 2012.

[4] P.-S. Kildal, "Three metamaterial-based gap waveguides between parallel metal plates for mm/submm waves", *European Conference on Antennas and Propagation (EuCAP 2009)*, Berlin, Germany, 2009.

[5] E. Rajo-Iglesias, A. U. Zaman, and P. S. Kildal, "Parallel plate cavity mode suppression in microstrip circuit packages using a lid of nails", *IEEE Microwave and Wireless Components Letters*, vol. 20, no. 1, pp. 31–33, 2010.

[6] A. A. Brazález, A. U. Zaman, and P.-S. Kildal, "Improved microstrip filters using PMC packaging by lid of nails," *IEEE Trans. Compon., Packag. Manuf. Technol.*, vol. 2, no. 7, pp. 1075–1084, Jul. 2012.

[7] A. U. Zaman, P.-S. Kildal, and A. Kishk, "Narrow-band microwave filter using high Q groove gap waveguide resonators with manufacturing flexibility and no sidewalls," *IEEE Trans. Compon., Packag. Manuf. Technol.*, vol. 2, no. 11, pp. 1882–1889, Nov. 2012.

[8] E. Levine, G. Malamud, S.Shtrikman and D. Treves, "A study of microstrip array antennas with the feed network", *IEEE Transaction on Antennas and Propagation*, vol.37, no.4, pp.426–464, April 1989.

[9] A. U. Zaman, and P.-S. Kildal, "Slot antenna in ridge gap waveguide technology", EuCAP 2012, European Conference on Antennas and Propagation 2012, Prague, Czech Republic, 26-30 March 2012.

[10] E. Pucci, E. Rajo-Iglesias, P.-S. Kildal, "New Microstrip Gap Waveguide on Mushroom-Type EBG for Packaging of Microwave Components", *IEEE Microwave and Wireless Components Letters*, Vol. 22, No. 3, pp. 129-131, March 2012.

[11] A. Valero-Nogueira, M. Baquero, J. I. Herranz, J. Domenech, E. Alfonso, and A. Vila, "Gap Waveguides Using a Suspended Strip on a Bed of Nails", IEEE Antennas and Wireless Propagation Letters, Vol. 10, 2011.

[12] M. G. Silveirinha, C. A. Fernandes, and J. R. Costa, "Electromagnetic characterization of textured surfaces formed by metallic pins," *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 2, pp. 405–415, 2008.

[13] A. Kishk, A. Uz Zaman, P.-S. Kildal, "Numerical Prepackaging with PMC lid - Efficient and Simple Design Procedure for Microstrip Circuits including the Packaging", ACES Applied Computational Society journal, Vol. 27, No. 5, May 2012.

[14] Y.-W. Jang , "Wide–band T-shaped microstrip-fed twin-slot array antenna", ETRI Journal, Vol. 23, No. 1, March 2001.

[15] A. U. Zaman, V. Vassilev, P.-S. Kildal, and A. Kishk, "Increasing parallel plate stop-band in gap waveguides using inverted pyramid-shaped nails for slot array application above 60GHz", EuCAP 2011, European Conference on Antennas and Propagation 2011, Rome, Italy, 11-15 April 2011.

[16] A. D. Olver, P. J. B. Clarricoats, A. A. Kishk, and L. Shafai, "Microwave Horns and Feeds", 1st ed. IEEE Press, 1994, ch. 1.

[17] P.-S. Kildal, "Foundations of Antennas: A Unified Approach", Studentlitteratur AB, January 1 2000.