

# A New Type of Printed Ku-Band SIW Horn Antenna with Enhanced Performances

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## Abstract

The performances of the Substrate Integrated Waveguide (SIW) horn antennas diminish when the substrate thickness is much smaller than the wavelength: they present a narrow bandwidth and high back radiation. A printed transition is proposed to overcome both problems while maintaining the most important features of SIW technology namely its compactness and ease of manufacturing.

The proposed transition is applied to a sectoral H-plane SIW horn antenna designed in a thin substrate (thickness  $< \lambda_0/10$ ) in order to reduce the back radiation (Front-To-Back Ratio  $> 15\text{dB}$ ) and achieve good return loss performances ( $< -10\text{dB}$ ).

## 1. Introduction

The Substrate Integrated Waveguide (SIW) technology allows to construct several types of commonly used antennas in a planar way. However, frequency limitations associated to commercial substrates appear in the implementation of certain types of antennas, e.g., SIW horns present a narrow bandwidth and high back radiation when the substrate thickness is much smaller than the wavelength.

To the author's best knowledge, the only currently available integrated solutions to improve the performances of SIW horns are based on dielectric lenses [1], [2]. Although this procedure provides good results in terms of Return Loss (RL) and radiation as reported in [2], its performances are limited by the thickness of the substrate. When using substrates of small thicknesses (generally speaking  $< \lambda_0/6$ ), the horn aperture practically behaves as a slot in a infinite ground plane with a Front-To-Back Ratio (FTBR) close to unity.

In [3], a printed transition to improve the matching of SIW horn antennas built in thin substrates (of thickness of even less than  $\lambda_0/10$ ) is proposed. This transition is composed of parallel plate blocks etched after the horn aperture to reduce the mismatch with the air (see Fig. 1). It presents good RL performances and keeps the properties of compactness and ease manufacturing of the SIW technology. However, this solution does not change significantly the radiation performances of a typical SIW horn antenna which still presents a poor FTBR.

In this paper, modifications in this printed transition to improve the FTBR of SIW horn antennas are proposed. A method to successfully control the back radiation levels using this transition is presented in Section 2. Guidelines and recommendations to choose the transition dimensions are also provided. In Section 3, a strategy to design the transition that respects the conditions for both a good RL and a high FTBR are given.

## 2. Control of the Back Radiation

In this Section, a way to use the printed transition of [3] in order to control the front ( $\theta = 0^\circ$ ) to back ( $\theta = 180^\circ$ ) ratio of H-plane SIW horn antennas is presented. The proposed transition is printed after the horn aperture and consist of blocks of parallel plate waveguides of length  $L$  separated a distance  $s$ . From now on, a 2 block transition as illustrated in Fig. 1 is considered.

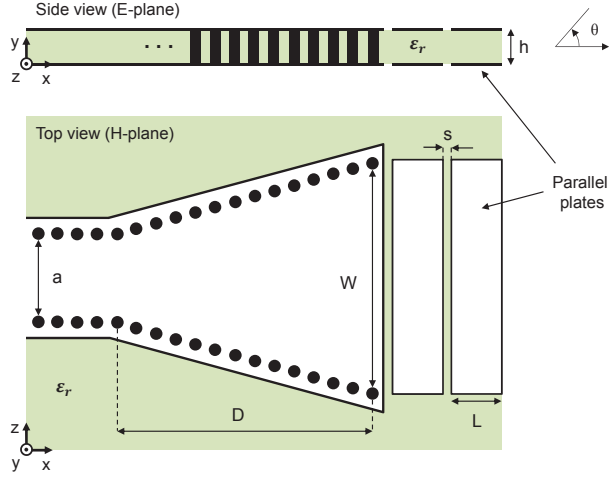


Figure 1: Side and top view of a SIW horn with a 2 block printed transition to the air.

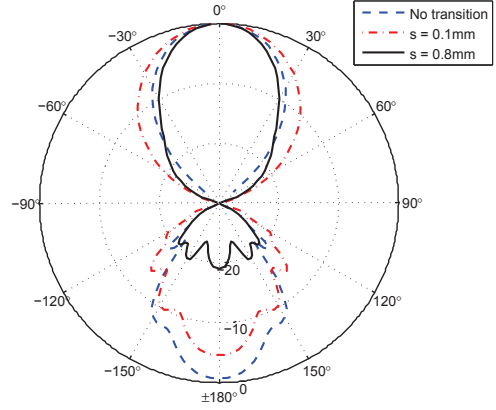


Figure 2: Normalized directivity (H-plane) comparison at 17GHz of a SIW Horn with and without transition for different  $s$  values.

The main radiating element of this new configuration is the open-ended termination of the last parallel plates waveguide keeping similar radiation performances as the horn alone. Nevertheless, by sufficiently increasing the distance  $s$ , electromagnetic waves are able to radiate at the junction between blocks as well as at the open-end: a 2 element array with an element spacing  $L$  is created. The distance  $s$  must be carefully chosen to make the contribution of both radiating elements comparable. There is indeed a trade-off between no radiation (small  $s$ ) and energy leakage (large  $s$ ). Thus, their Array Factor (AF) can be expressed as:

$$AF(\theta) = A_1 e^{-j\left(\frac{2\pi}{\lambda_0} \frac{L}{2} \cos \theta\right)} + A_2 e^{j\alpha} e^{j\left(\frac{2\pi}{\lambda_0} \frac{L}{2} \cos \theta\right)}. \quad (1)$$

where  $A_1$  and  $A_2$  are the amplitude of the elements and  $\alpha$  the phase shift between them.

Assuming that both radiating elements are fed with the same amplitude  $A$ , the analysis of AF shows that the back radiation can be canceled by properly choosing  $L$  and  $\alpha$ :

$$|AF(\theta = 180^\circ)| = 2A |\cos(L\pi/\lambda_0 + \alpha/2)| = 0 \implies L\pi/\lambda_0 + \alpha/2 = \pi/2 \pm P\pi. \quad (2)$$

In the presented structure,  $\alpha = \beta_{pp}L$ , where  $\beta_{pp}$  is the propagation constant inside the parallel plates waveguide calculated as  $2\pi \sqrt{\epsilon_{rpp}}/\lambda_0$ . In order to take into account the fringing fields effect in the value of the effective permittivity  $\epsilon_{rpp}$ , the quasi-static approximation and figures presented in [4] are used. Rewriting  $\alpha$  in (2), the required element spacing  $L$  to cancel the back radiation at the desired frequency  $f_{FTBR}$  is given by:

$$L = \frac{c}{2f_{FTBR}(1 + \sqrt{\epsilon_{rpp}})}. \quad (3)$$

In a real scenario,  $A_1$  and  $A_2$  are slightly different due to radiation losses. Therefore, the back radiation cannot be completely canceled, but greatly reduced. As an example, a transition of 2 blocks is used to maximize the FTBR of a H-plane SIW horn at  $f_{FTBR} = 17\text{GHz}$ . The substrate used is a Rogers TMM 4 ( $h = 1.524\text{mm}$ ,  $\epsilon_r = 4.5$ ) and the horn dimensions are [mm]:  $W = 30$ ,  $D = 70$ ,  $a = 7$ .

According to [4], a value for  $\epsilon_{rpp}$  of 3.83 is found and, applying (3), a distance  $L$  of 3mm is obtained. From the analogy with the radiation losses of a microstrip gap discontinuity [5], a reasonable amplitude difference of 15% between both elements is assumed. Thus a FTBR of 20.6dB is predicted using (1).

Figure 2 presents the comparison of the normalized H-plane directivity between a standard SIW horn and a 2 block transition SIW horn ( $L = 3\text{mm}$ ) using different  $s$  (0.1mm and 0.8mm). As expected, a poor FTBR is achieved when no transition is used (0.8dB) or when the block separation is too small (4.6dB). For an optimized  $s$  value of 0.8mm, a 19.2dB FTBR is obtained being in accordance with the predicted one.

### 3. Front-To-Back Ratio and Return Loss Compatibility

In Section 2, a procedure to determine the transition dimensions,  $s$  and  $L$ , to improve the FTBR of SIW horn antennas is described. In order to know if the horn also presents a good RL at the same frequency range (i.e.,  $< -10\text{dB}$ ), the Coupled Resonator model presented in [3] is applied in the case of a 2 block transition. Thus, the frequency  $f_{RL}$  at which the horn is well matched is estimated by:

$$f_{RL} = \frac{c}{2L(1 + 0.7h/L) \sqrt{\epsilon_r} \sqrt{1 - k_2}} \quad (4)$$

where  $k_2$  is the coupling factor of a 2 block transition which depends on  $s$  and  $L$  (its expression is derived in [3]). A maximum  $-10\text{dB}$  bandwidth of 10% around  $f_{RL}$  is typically achieved with this kind of transition.

The conditions to achieve simultaneously both a good RL (4) and a high FTBR (3) mainly depend on the distance  $L$  and, in general, are not compatible. For instance, let us assume that a 1.91mm Rogers TMM3 substrate ( $\epsilon_r = 3.27$ ) is used to implement a SIW horn at 15GHz. The dimensions of the horn are chosen as  $W = 32.5\text{mm}$ ,  $D = 35\text{mm}$ ,  $a = 8.5\text{mm}$  and, following the array strategy to improve the FTBR, the transition number of blocks is fixed to 2.

On the one hand, the condition to minimize the back radiation (3) gives an initial value for  $L$  of 3.8mm. After full-wave simulations, the optimum values of  $L = 4\text{mm}$  and  $s = 0.7\text{mm}$  are found. On the other hand, using (4), these transition dimensions provide a good RL at 16.8GHz. For a  $f_{RL}$  of 15GHz, a  $L$  of 4.6mm is required which decreases the FTBR below 10dB.

To solve the incompatibility between both conditions, the parallel plates structure composing each block can be modified. Instead of using full metallic strips of width  $W$ , a grating is introduced along the width in order to decrease the  $\epsilon_{rpp}$  of the transmission line (see Fig. 3). Thus, the strip length  $L$  has to be increased to guarantee a good FTBR, being the same condition needed to improve the RL.

The presented grating concept is applied to the previous 15GHz SIW horn. The 3 versions of the 2 block transition are compared to show the advantages of the grating:

- *SIW horn A*: Transition optimized for FTBR ( $L = 4\text{mm}$ ,  $s = 0.7\text{mm}$ )
- *SIW horn B*: Transition optimized for RL ( $L = 4.6\text{mm}$ ,  $s = 0.7\text{mm}$ )
- *SIW horn C*: Transition with gratings optimized for both FTBR and RL ( $L = 4.5\text{mm}$ ,  $s = 0.9\text{mm}$ ,  $p = 2.6\text{mm}$ ,  $g = 1.2\text{mm}$ )

The results for the RL and the normalized directivity are plotted in Fig. 4(a) and Fig. 4(b), respectively. As expected from (3), the best FTBR is obtained with horn A (18.8dB), while horn B has a poor FTBR (7.4dB) and horn C is relatively close to the horn A performance (FTBR = 15.7dB). Concerning the RL, the predictions of the Coupled Resonator model are quite accurate and, therefore, only horns B and C present a  $RL < -10\text{dB}$  around 15GHz. Thus, the only SIW horn which performs well in both aspects is the one with a grating transition, horn C.

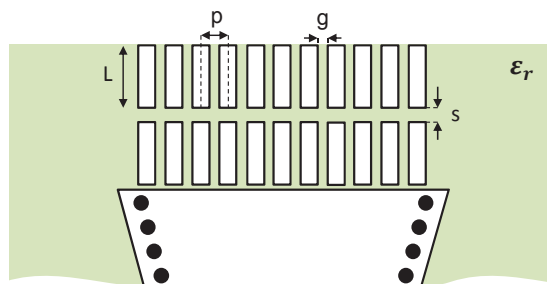


Figure 3: Top view of a H-plane SIW Horn with a 2 blocks grating transition with the associated notations.

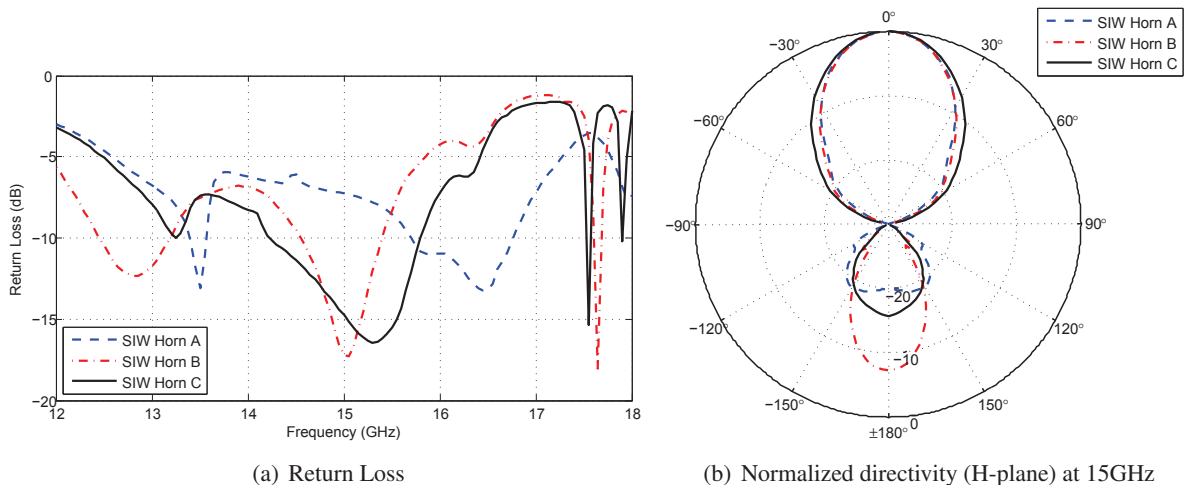


Figure 4: Comparisons of return loss and radiation pattern of SIW horns A, B and C.

## 4. Conclusions

A printed transition to improve both the FTBR and RL of H-plane SIW horn antennas has been proposed. Its aim is to reduce the antenna mismatch without the use of bulky elements to maintain the compactness and ease of manufacturing of the SIW technology.

Guidelines and recommendations to choose the transition dimensions are provided. They have been applied to greatly reduce the back radiation (FTBR > 15dB) of a H-plane SIW horn antenna implemented in a substrate of small thickness ( $< \lambda_0/10$ ).

The proposed transition allows the use of commercial substrates to built compact SIW horns working well below 20GHz extending their range of interest for many other applications.

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