Wideband H-plane Horn Antenna Based on Ridge Substrate Integrated waveguide (RSIW)

Ali Reza Mallahzadeh, *member, IEEE*, Samaneh Esfandiarpour, *student member, IEEE*

***Abstract*—A substrate-integrated waveguide (SIW) H-plane sectoral horn antenna, with significantly improved bandwidth, is presented. A tapered ridge, consists of a simple arrangement of vias on the side flared wall within the multilayer substrate, is introduced to enlarge the operational bandwidth. A simple feed configuration is suggested to provide the propagating wave for the antenna structure. The proposed antenna is simulated by two well-known full wave packages, the Ansoft HFSS and the CST microwave studio, based on segregate numerical methods. Close agreement between simulation results is reached. The designed antenna shows good radiation characteristics and low VSWR, lower than 2.5, for the whole frequency range of 18-40 GHz.**

***Index Terms*—RSIW, wideband, H-plane sectoral horn, substrate integrated waveguide, planar horn.**

I. INTRODUCTION

Manufacturing of the planar rectangular waveguide is now possible thanks to the developing of substrate integrated waveguide technique (SIW) which is a part of substrate-integrated circuits family. Waveguide-like structures can be fabricated in planar form by the use of periodic metallic via holes. SIW, a promising technology for planar microwave circuits, possesses the flexibility of planar structures and the well-known advantages of conventional waveguides, which recently, has attracted microwave engineers' attention[1]-[8].

In the microwave range, printed circuit technology is useful because of the compact size, light weight, and low cost of microstrip and coplanar components. In contrast, in millimeter-wave frequency range, the use of these components is not suitable because of high ohmic losses, radiation problems, and cross talk issue. Although, metallic waveguides are robust and have low losses, they have disadvantages like high fabrication cost, weight and size issue [1]-[8]. SIW technique solves all of these problems and is appropriate for low-loss millimeter-wave circuit design both microwave and millimeter-wave applications [2].

The rectangular waveguide horn antennas are probably the most widely used microwave antennas due to their particular characteristics such as symmetric patterns, relatively high gain, directivity performance, wide bandwidth, versatility, and simplicity [10].

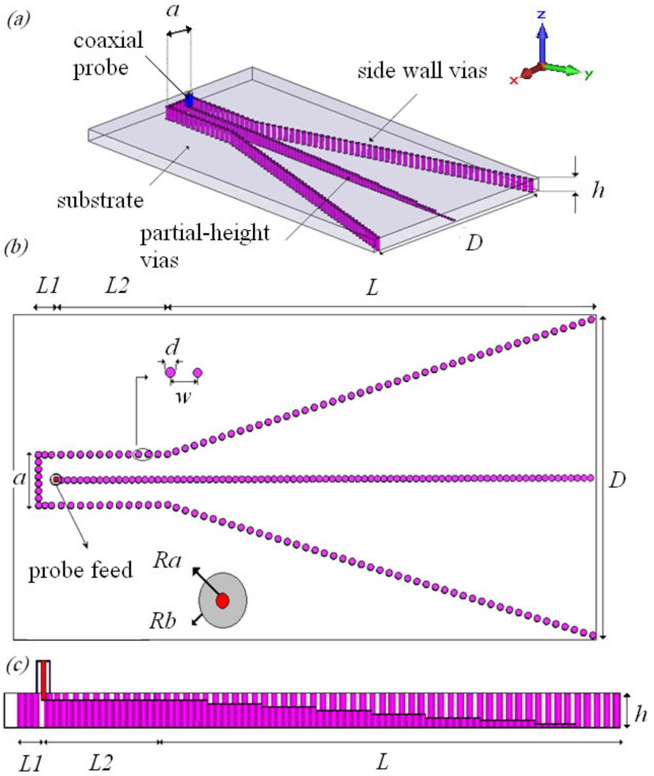

Fig.1. Geometry of the RSIW-horn antenna. (a) 3D view, (b) Top view, (c) Side view. w = 1.2mm, d = 0.8mm, a = 6.3 mm, h = 2.54 mm, D = 39.2 mm, L = 52.8 mm, L1 = 2.8mm, L2 = 13.6 mm, R_a = 0.3mm, R_b = 0.69 mm.

These systems are commonly employed in diverse fields, e.g. reflector feeds, detection systems, radar, electronic warfare, EMC testing, and satellite tracking systems [10].

Despite the fact that bulky geometry of the horn antenna made it impossible to be fabricated in planar form, efforts for implementation of horn antenna based on SIW technology have been reported in recent papers. As introduced in [4], the proposed structures are good candidates for feeding the surface-wave or leaky-wave antennas. But, the reported antennas seem to suffer from poor bandwidth. While in [4] it is observed that the bandwidth (VSWR ≤ 2) is 1.5% at central frequency 27 GHz. Also, a bandwidth of 11% is obtained for the return loss S11 at the -10 dB limits in [5]. Moreover, a CPW-fed integrated horn antenna elevated on the top of the substrate using CMOS-compatible micro fabrication steps, presented in [6] for WPAN application in 60 GHz.

Manuscript received . The authors are with the Electrical Engineering Department, Shahed University, Tehran-Iran (e-mail: mallahzadeh@shahed.ac.ir, esfandiarpor@shahed.ac.ir).

According to our knowledge, there is not any publication available on the design of a broadband horn antenna based on ridge substrate integrated waveguide (RSIW) technique. On account of the fact that wideband antennas play an important role in the modern communication and radar systems, in this article we propose a novel structure of horn antenna using RSIW structure for broadband applications.

First, the main parts of the antenna and design procedure of them are described in detail. Then, simulation results are presented and discussed. The RSIW-horn antenna for the frequency range of 18-40 GHz is designed by using multilayered substrate with dielectric constant of 2.2. Overall size of the designed antenna is about 69.2 x 39.2 x 2.54 mm^3. Simulation results illustrate that the proposed antenna's VSWR is below 2.5. Also, it has good radiation efficiency and satisfactory patterns.

The proposed antenna is simulated by two established packages, Ansoft HFSS V11.1 and CST microwave studio based on two different numerical methods. The former is based on finite element method (FEM) and the latter on the integral equation (IE).

II. ANTENNA DESIGN

The configuration of the proposed antenna is shown in Fig.1. The designed antenna's size is about 69.2 x 39.2 x 2.54 mm^3 and contains three main parts: a single-ridged rectangular waveguide-like, i.e., RSIW, coaxial to RSIW transition with a cavity back structure, and finally the flare section with tapered ridge. All the parts are integrated using the same single substrate. To make constructing the tapered part possible, a substrate with dielectric constant ε_r of 2.2, $\tan\delta=0.0009$ and thickness h of 2.54 mm (10-layer dielectric substrate with the height of 0.254 mm in each layer) is used in all simulated results. The aforementioned parts will be described in details in continuation.

A. Design of the RSIW

Structure of the RSIW is given in Fig. 2. The side walls are formed by two rows of metallic vias, and the central ridge is formed by a row of partial-height of posts. As it would be discussed later, loading the extra posts in wider side of the SIW geometry causes the bandwidth enhancement, same as the presence of ridge function in waveguides. Here, a is the width of RSIW, h-g is the ridge posts height, and finally, R and w are the radius and spacing of vias, respectively.

The useful operational bandwidth of a waveguide is limited to the mono-modal band and determined by the cut-off frequency, f_1, of the fundamental mode for the lower limit and the cut-off frequency, f_2, of the second mode for the upper limit [1], [2].The mode spectrum of SIW structures presents a number of similarities with one of the conventional rectangular waveguides [1].

However, if TE_{20} mode sufficiently suppressed or not excited, the frequency bandwidth between TE_{10} and TE_{20} could become large enough. To do this, at first a two port RSIW, without coaxial cable, is simulated due to achieve the single mode operation in the bandwidth. As demonstrated in [2], the equivalent width a of the fundamental TE_{10} mode can be modified from the given formula in [3]:

$$a = \frac{2}{\beta_x} cot^{-1}\left(\frac{\beta_x w}{4} ln\frac{w}{4R}\right) \qquad (1)$$

Where $\beta_x=\pi/a'$, for the equivalent rectangular waveguide with the width of a'. Moreover, the cut off frequency of RSIW is given in [2]. Using these formulas and some tuning the above-mentioned parameters are obtained as: a= 6.3 mm, h= 2.54 mm, g= 0.508mm, R=0.4mm and w=1.2mm. The S_{12} parameter of the first and second order modes versus frequency is shown in Fig. 3(a). It is observable from Fig. 3(a) that the second order mode would not propagates in the RSIW structure, because the S_{12} parameter is much lower than 0 dB over 18- 40 GHz frequency band.

Also, the characteristic impedance of the RSIW construction versus frequency is depicted in Fig. 3(b). As inferred from the diagram, the characteristic impedance varies between 51.3 Ω (at 18 GHz) and 47.1 Ω (at 40 GHz), which shows there is a good impedance matching between the coaxial transmission line and RSIW part in the context of single mode operation over entire frequency band of 18-40 GHz. As described in [1], if there is a gap between partial-height ridge posts, the flowing current density in axial direction experiences the periodic loading of the ridge posts and causes the band gap.

B. Design of the Coaxial to RSIW Transition

One of the usual feeding methods in SIW-based constructions is using a tapered microstrip line integrated into the same substrate as the other parts of structure. However, it is not effective in this work due to some constraints. For instance, relatively high thickness of substrate and also low dielectric constant causes the tapered part of the feed line to operate as a radiator which distorts the radiation patterns of the antenna. To solve this problem, the coaxial line is the preferred feeding for the proposed antenna.

A 50Ω cable, sufficient for use up to the K_a frequency bands with dimensions of core radius, R_a= 0.3 mm, and shield radius, R_b= 0.69 mm, is applied to excite the structure.

The transition between coaxial probe and the RSIW is important to the return loss performance of the antenna. Commonly, a cavity back is used to improve the VSWR of the coax to conventional waveguide transition. Using this idea, in order to have a low VSWR, i.e., an adequate impedance matching, the cavity back dimensions as well as probe distance from the edge of the ridge should be optimized. As is shown in Fig. 4, the shield of the coaxial probe is connected to the upper plate and the inner conductor is connected to the end of the ridge posts. Also, it should be noticed that the authors assumed that the RSIW absorbs the full wave which is propagated from the coaxial prob. The optimized dimensions are shown in Fig.4.

C. Design of the Tapered Component

After the single mode operation (TE_{10} mode) is established, increasing the effective radiation aperture, the waveguide begins to flare out. In fact, flare part provides a transition from wave propagating in the RSIW part to free space propagating wave. It is not affordable by SIW technology to flare the waveguide out in both H-plane and E-plane, i.e., this technique allows widening the aperture just in the H-plane. A linear flare, only in the H-plane, is used in this paper.

The dimensions of the horn are found following the guidelines provided in [9] to maximize the gain of the suggested antenna, at centre frequency, in absence of the ridge part. The axial length of the flare part and the aperture size is found to be 69.2 mm and 39.2 mm respectively.

In the next stage, the ridge part should be designed. A noteworthy part of the structure, which the voltage standing wave ratio of the antenna is deeply affected by, is the tapered section.

In conventional ridged-horn antenna design, the dimensions of the flare part regarding to the exponential tapering is derived as described in [10].

However, in the SIW technique the number of substrate layers and the thickness of each laminate are acting as confiners, therefore this procedure seems to be impractical. Overcoming the limitations, the following algorithm is implemented. At first, the axial length of the flare section (L) is divided into 9 parts and the same procedure is done. The obtained values are in very close to the integer multiples of the thickness of one layer substrate, 0.254mm. Therefore, the height of the ridge decreases from 8 x 0.254 mm at the input aperture of the section, step by step, to 0 mm at the output aperture (Fig. 1(b)). Accordingly, using such a smooth tapering, an appropriate impedance matching is achieved as the characteristic impedance moves gently from 50Ω in RSIW section to 377Ω in the free space. The summary of these activities is listed below: The length of each section is 4.8 mm and the height of them are 2.032mm, 1.778mm, 1.524mm, 0.762mm, 0.508mm, 0.254mm and finally 0mm, respectively.

III. SIMULATION RESULTS

The VSWR of the RSIW-based horn antenna with rectangular cavity back is presented in Fig.5. It is observed that, the simulated VSWR is lower than 2.5 (<2.5) for the frequency range of 18-40 GHz.

Fig. 6 illustrates the far-field radiation patterns of the total electric field in the E-plane (y-z plane) and the H-plane (x-y plane) of three typical frequencies. To some extent good agreement between the simulation results of two methods is observed and they follow the same profile except in side lobe region.

Moreover, it is seen that the proposed antenna shows satisfactory and stable far-field radiation patterns over the whole frequency bandwidth. However, the E-plane patterns have relatively high side lobes; this is expected due to the thickness of the substrate at h = 2.54 mm.

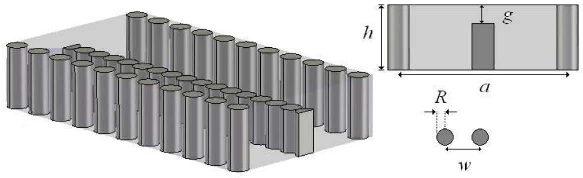

Fig. 2.Geometry of RSIW

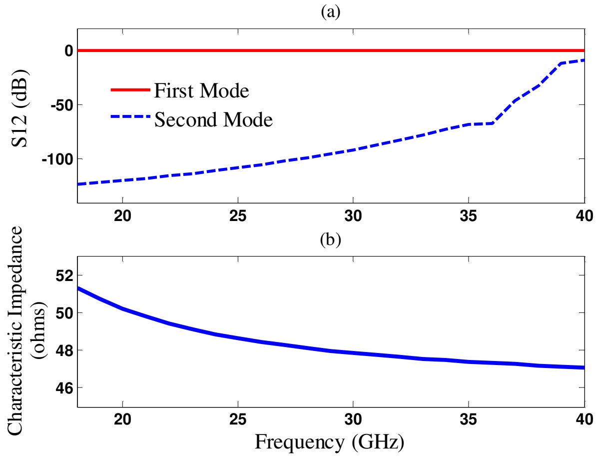

Fig. 3.(a) S_{12} of the first mode (TE_{10}) and second mode (TE_{20}) versus frequency, (b) The characteristic impedance of the fundamental mode in RSIW (TE_{10}) versus frequency.(simulated by Ansoft HFSS)

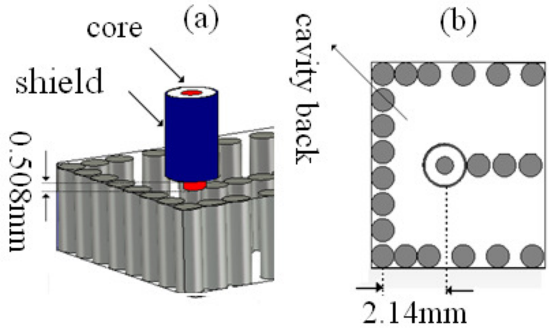

Fig. 4.Coaxial probe to RSIW transition and corresponding dimensions, (a) 3D View (b) Top View.

The peak gain of the proposed antenna versus frequency, in the main beam direction is shown in Fig. 7(a).

Additionally, radiation efficiency of the antenna versus frequency is depicted in Fig. 7(b). As it can be seen an appropriate efficiency is obtained. So, as a result it can be said that the presence of the central ridge in the structure does not lead to substantial ohmic losses, while bandwidth increases in RSIW remarkably.

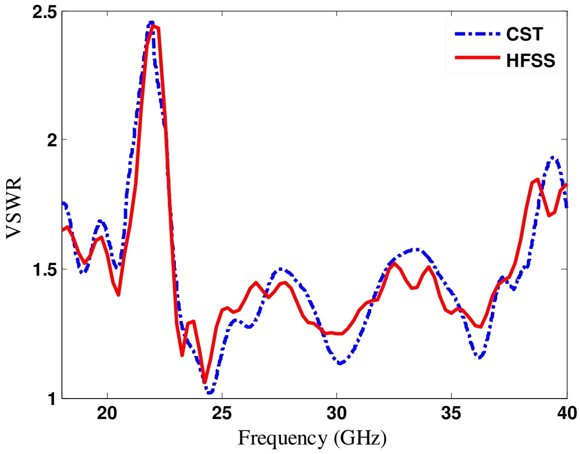

Fig. 5.Simulated voltage standing wave ratio (VSWR) of the RSIW-horn antenna versus frequency

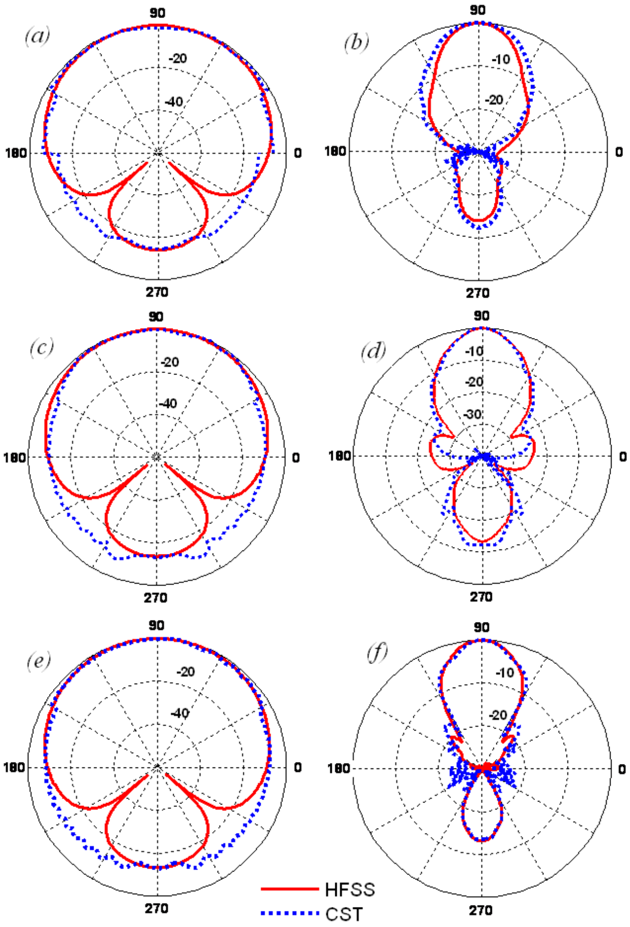

Fig. 6. Radiation Patterns of the Antenna: (a)E-plane at 18 GHz, (b) H-plane at 18 GHz, (c) E-plane at 33 GHz, (d) H-plane at 33 GHz, (e) E-plane at 40 GHz, (f) H-plane at 40 GHz.

IV. CONCLUSION

In this article, a novel H-plane sectoral horn antenna using SIW technique for the K and K$_a$ frequency bands is presented. The main parts of the proposed antenna are described in details. To increase the maximum practical bandwidth of the Antenna, considering the ridge effects in the conventional waveguides, a row of partial height metal cylinders, located in the broad side of the antenna, has been employed. VSWR of the designed antenna is lower than 2.5 over the 18- 40 GHz. Acceptable gain, good radiation efficiency and satisfactory patterns are the other characteristics of the suggested antenna. Reasonable agreement between the simulation methods results verifies the correctness of the designs.

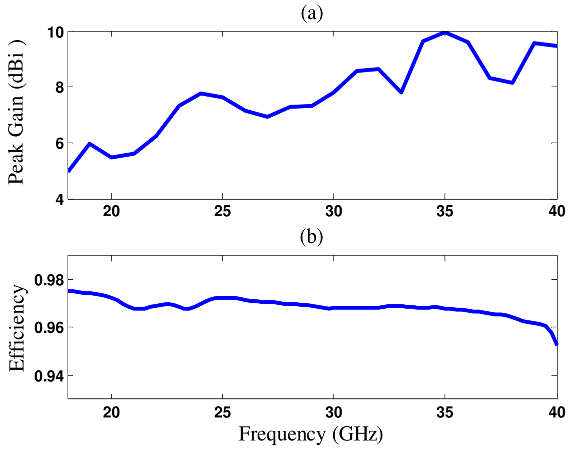

Fig.7. (a) Peak Gain,(b) Efficiency (simulated by Ansoft HFSS) versus frequency for the proposed RSIW-horn antenna.

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