Low-Profile Wideband Conical Beam Double Ring Slot SIW Antenna

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ABSTRACT:
A low-profile wideband conical beam antenna which uses two concentric annular ring slots in substrate integrated waveguide (SIW) technology is presented. First, a single ring antenna is considered and then the effect of introducing the second slot on bandwidth is investigated and high bandwidth is achieved. A brief parametric study for different slot width is presented. A prototype of the proposed antenna is fabricated and measured. The measured reflection coefficient is in good agreement with simulation. The theoretical result is also provided for S11 to validate the simulation and measurement results. The proposed antenna shows 30% bandwidth in 17 GHz center frequency (|S11<-10 dB). Radiation pattern was measured in three different frequencies in the entire frequency bandwidth. Maximum measured radiation efficiency is 93%. The antenna is very simple and low profile with a planar structure. Electrical dimensions are ($1.76\lambda_0 \times 1.76\lambda_0 \times 0.08\lambda_0$) with very simple feeding network which could be a suitable choice in many practical applications from anti-collision radars to WLAN applications.

KEYWORDS: Antenna, Conical Beam, Ring, Slot, SIW, wideband, WLAN, planar, low-profile

1. INTRODUCTION

Conical beam pattern antennas are necessary for a good coverage in large service areas. Also with emerging the next generation of mobile communication (5G), the need for high bandwidths is unavoidable. Low profile with broadband characteristic and omnidirectional antenna could be a perfect choice to realize a reliable link in WLAN and other networks in future wireless communications. Conical beam antenna has various applications beside WLAN. Among those, remote sensing, automotive object tracking, automobile collision avoidance radars are the most important applications [1]-[3]. The antennas also should have simple structure for mass production and planar surface to integrate with other circuitries. In recent years SIW technology has attracted lots of attention in scientific communities due to its low radiation loss, ease of fabrication and high ability to integrate with planar structures [4]-[5].

A truncated circular cone slot antenna array with circular polarization is designed in [6] with 13% impedance bandwidth and peak gain of about 5.8 dBi. A CPW fed printed antenna with conical beam is presented in [7] with a capability to control beam pointing angle. -15 dB impedance bandwidth is about 11.4% at central frequency of 10.5 GHz with maximum gain of 10.3 dBi. A linearly polarized antenna with conical beam is presented in [2] which composed of a radiating circular loop, six arc strips, a 1-to-6 radial power divider and a conical reflector. In [8] an ultra-wideband linearly polarized antenna which uses sixteen Vivaldi arrays distributed along a circular array achieved 160% bandwidth and a gain variation less than 1.5 dBi. A wideband L-probe fed circular patch antenna which creates conical beam is also studied in [8]. Antenna has 30% bandwidth and maximum gain of 6.5 dBi.

Another class of antennas uses SIW technology to realize conical beam pattern [1]-[2], [10]-[11]. These structures use mainly annular ring slots on cylindrical cavities with TM_{0n} modes. In [10] a multi-mode multi-frequency antenna achieves two patch-like radiation patterns and one conical pattern. Antenna in its conical pattern mode has 4.5% bandwidth at 7.8 GHz and 4.7 dBi of gain. A SIW antenna array with single coaxial feed which uses 4 cylindrical cavities is investigated in [1] and achieves 3.1% bandwidth and 6.5 dBi of gain. A dual band conical beam antenna has been realized in [11] which uses TM_{01} and TM_{02} modes with 3 and 5.74 dBi of gain, respectively.

In this study we propose a very simple and low profile antenna with broadband characteristics and conical beam pattern. Two concentric annular ring slots are etched on a cylindrical cavity. The cavity is realized by putting an array of post vias in a radial waveguide. A simple 50 Ω coaxial probe is used to excite the

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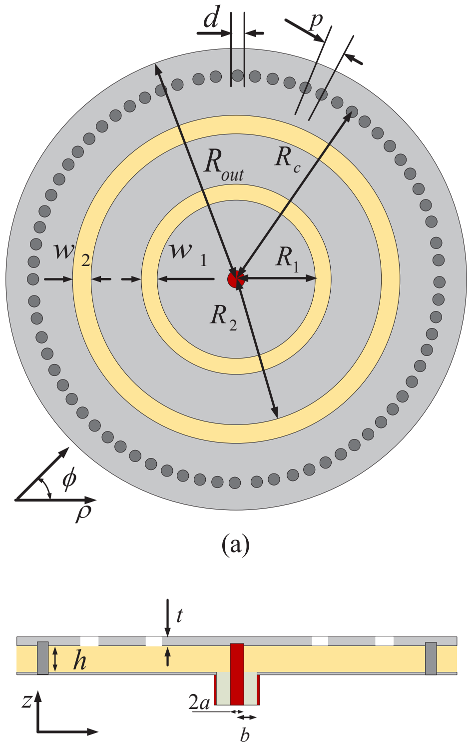
cavity modes. An analysis based on the works presented in [12], are used to obtain scattering parameters to validate simulation and measurement results. The rest of this paper is organized as follows. Designing annular slot antenna array is argued in section 2. Comparison of theory, simulation and measurement of the final antenna is presented in section 3. Finally, Conclusion is given in section 4.

2. ANTENNA CONFIGURATION

Consider a parallel plate, radial waveguide with an annular ring on its upper plate. If an array of post vias placed around the slot, a cylindrical cavity can be created. Such a structure with two annular slots is illustrated in Fig. 1 in which the number of vias should be large enough to form an ideal cavity. A number of methods can be used to analyse this kind of structures [12]-[16].

In this paper we are going to follow the work presented in [12] which utilize both Vector Henkel Transform (VHT) and Mode-Matching Technique (MMT) to analyze our antenna and validate our simulation and measurement results.



(a)

(b)

Fig. 1. Antenna structure (a) top view (b) side view

If one slot is loaded on cavity, Fig. 2 would show the reflection coefficient of antenna port for different values of slot width *W*. As the slot width increases the antenna matches in two distinct yet close frequencies until a certain value of *W* reaches. After that by increasing *W* matching will deteriorate. In addition, due to changing the resonant length of antenna, increasing the radius of ring would shift the resonant frequency to lower ones which has not been shown here. So one can add another slot to better match each of these frequencies to achieve a high bandwidth.

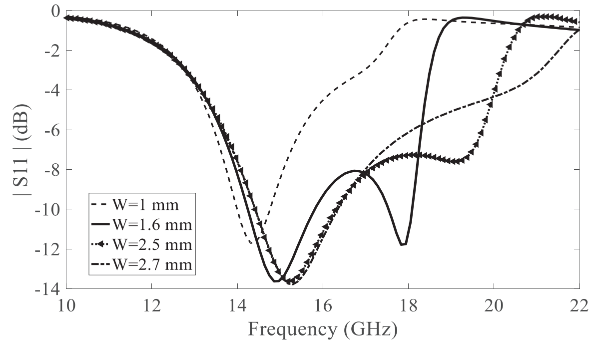
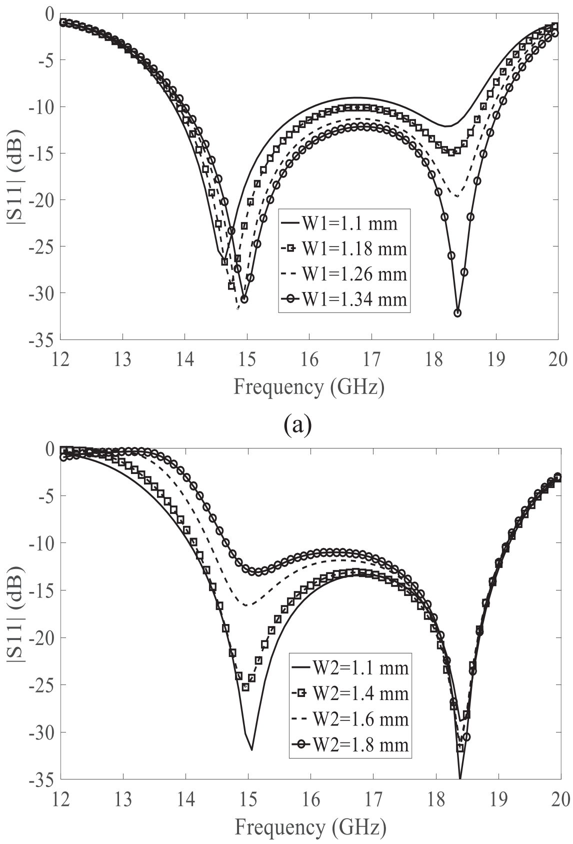


Fig. 2 Reflection Coefficient for single slot antenna

By inserting two slots in cavity we can improve the matching and bring the S11 of antenna below -10 dB in the whole frequency span covered by two resonant frequencies. Fig. 3*a* shows reflection coefficients of antenna for different values of w_1. As it is obvious Increasing w_1, improves matching for upper frequency band and deteriorates matching for lower frequency band by a little extent. Fig. 3*b* shows antenna reflection coefficient for different values of w_2. Unlike Fig. 3*a*, increasing w_2 deteriorates matching for lower frequencies.



(a)

(b)

Fig. 3. Reflection Coefficient for different values of (a) w_1 and (b) w_2

In order to understand the working mechanism of antenna, we should consider the field distribution in cylindrical cavity and the modes that are excited in that. The important parameters that determine the excited modes are cavity radius and height. Also the position of probe feed with respect to centre of cavity is an important factor. Centre feed position only excites TM$_{0m}$ modes that can create a conical beam with an annular slot aperture. Antenna cavity radius is considered 14 mm so in DC to 20 GHz only TM$_{0m}$ $(m = 1.2.3)$ modes are excited. It is worth mentioning that putting post vias in radial waveguide, not only generates TM$_{01}$ mode (moves TM$_{01}$ mode resonant frequency from DC to higher frequencies) but also enhances TM$_{02}$ mode [11].

Introducing slots into the cavity would have a loading effect and it would shift the resonant frequency of each mode. Input resistance for different values slot width is presented in Fig. in this case, we chose w_1 to be equal with w_2. As the width of slots increase the loading effect also increases so that the amplitude of TM$_{02}$ and TM$_{03}$ resonant frequencies decreases and the antenna will match at both modes.

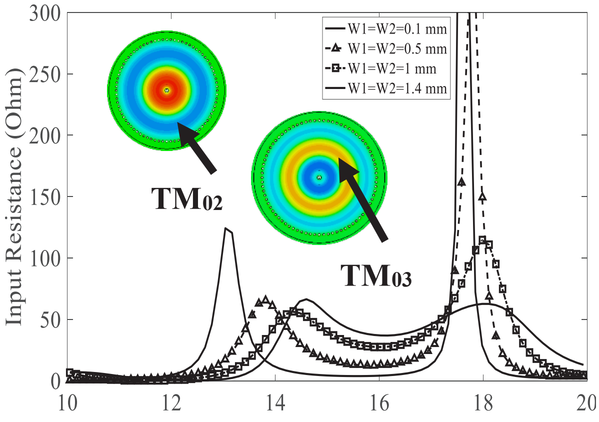


Fig. 4. Antenna input impedance for different values of W_1 and W_2 (different loading effect)

The electric field distribution along the two concentric slots construct an equivalent magnetic current loop based on $\vec{M} = \hat{n} \times \vec{E}$. Therefore, it is like having two current loop above a ground plane. The electric field vector distribution on the slot aperture is illustrated in Fig. 5.

3. EXPERIMENTAL RESULTS

An optimization on antenna parameters has been done. The antenna is fabricated based on final parameters presented in Table 1 on *RO4003*C substrate with thickness of $h = 1.524\,mm$ and $\varepsilon_r = 3.38$ and loss tangent of 0.0027. Photograph of fabricated antenna in shown in Fig. 5. The antenna reflection coefficient is measured on HP8722 VNA. Reflection coefficient of fabricated and simulated antenna along with theoretical result are shown in Fig. 6. Antenna shows 30% bandwidth. Measured and simulated results are in reasonable agreement with theoretical results.

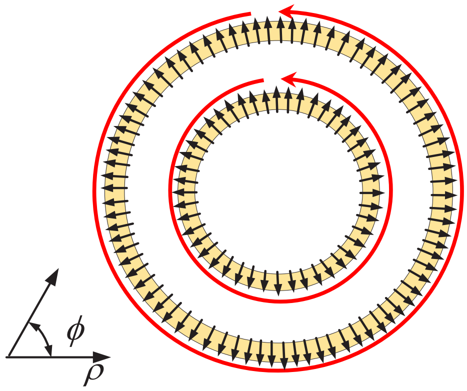


Fig. 5. Electric Field distribution and equivalent magnetic current

Para.	Value (mm)	Para.	Value (mm)
R_{out}	16	t	0.035
R_c	14	h	1.6
R_1	6.25	d	0.5
R_2	10	p	1 (4.5°)
w	1.4	a	0.5
N (number of vias)	80	b	1.67

Table 1. Antenna Parameters

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The discrepancies between measurement and simulation results are due to fabrication and measurement errors and the difference between simulation and theory is because in theory it is assumed that the ground has an infinite radius.

Antenna gain and efficiency are illustrated in Fig. 7. It shows that the gain variation is less than 3.5 dBi within the entire bandwidth and efficiency is between 91%-93%. Simulated efficiency is above 96%. This high efficiency is due to low spurious radiation which is the result of probe feed excitation and the inherent low loss characteristic of SIW technology. Antenna radiation patterns are measured in anechoic chamber by a far-field measurement setup in elevation and azimuth planes for three different frequencies in lower, upper and center frequencies of the bandwidth limit.

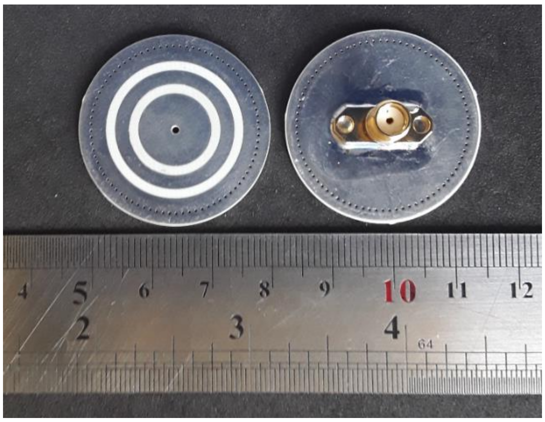

Fig. 5. Photograph of Double slot annular ring SIW antenna reflection

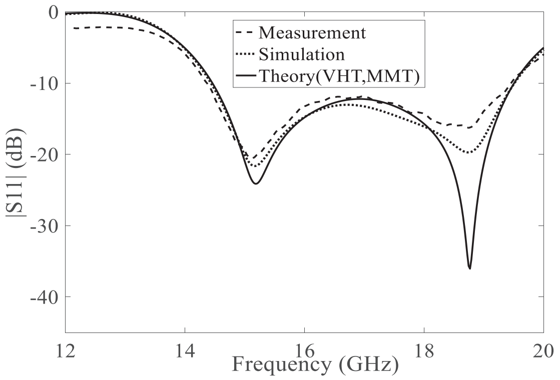

Fig. 6. Theoretical, simulated and measured reflection coefficient

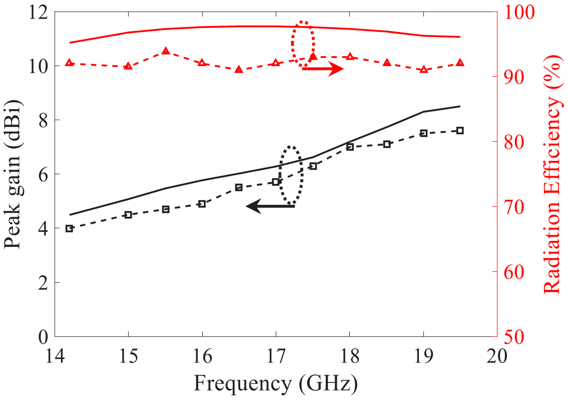

Fig. 7. Simulation and measured gain and efficiency

Antenna radiation patterns are depicted in Fig. 8 which shows a good agreement between simulation and measurement. HPBW changes between 50 degrees for 14 GHz and 30 degrees for 19 GHz. The simulated and measured cross polarization level in lower than -40 dB and therefore, it is not reported here. The reason behind this phenomenon stems from the fact that the antenna is symmetrical and field distribution on slot aperture is purely in radial direction (co polarization component) in any given phi. So the electric filed in phi direction (cross polarization component) is almost zero. This can be verified by observing Fig. 5.

A comparison of the proposed antenna with previously published studies is presented in Table 2. By evaluating the level of fabrication complexity, bandwidth and size, it could be concluded that the presented antenna can compensate for some of the drawbacks of these reference.

5. CONCLUSION

A wideband double slot SIW antenna with conical beam is presented. A comparison with 1 annular slot and a parametric study is provided. Antenna is fabricated and measured. Its reflection coefficient in measurement, simulation and theory is compared. Antenna shows 30% bandwidth. Far-field radiation pattern is measured in three different frequencies. A good agreement is observed between measurement and simulation for both patterns and reflection coefficients. Peak measured and simulated efficiencies are 91% and 97% and the discrepancies are due to measurement errors and fabrication process. A comparison among previous works has been presented. The proposed antenna is very compact and planar with the simplest feeding network. It can be a perfect choice for mounting on room ceiling, moving vehicles or for integrating with planar structures in various indoor and outdoor communication systems

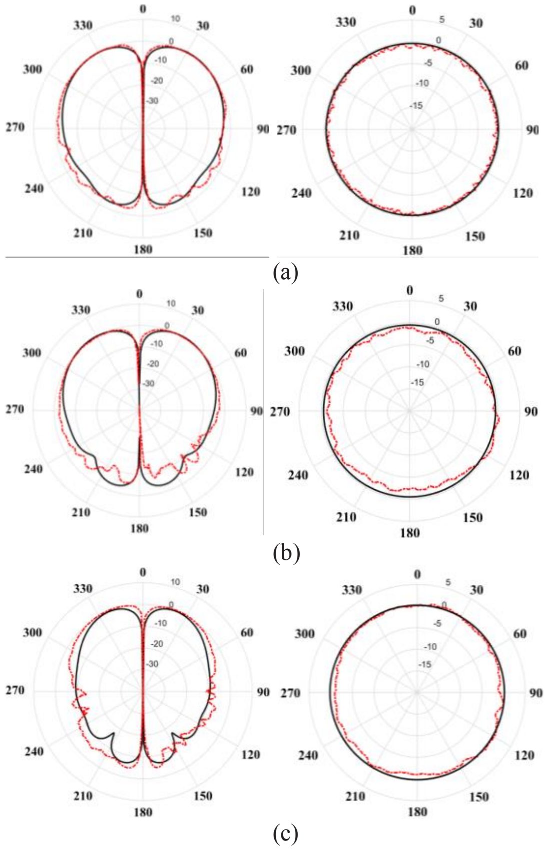

Fig. 8. Simulated and measured normalized radiation pattern in azimuth (right) and elevation (left) at (a) 14.5 GHz (b)17 GHz (c) 19.5 GHz.

Ref.	Type of pattern	Operating bandwidth (|$S11$|<10dB)	Electrical dimension (λ_0 at center frequency)	Feeding network and fabrication complexity
[2]	Omnidirectional	22.9%	$2.26\lambda_0\times 2.26\lambda_0\times 0.074\lambda_0$	Complex
[9]	Conical	30%	$0.13\lambda_0\times1.25\lambda_0\times1.25\lambda_0$	Complex (planar)
[10]	Conical	5%	$1.04\lambda_0\times1.04\lambda_0\times0.04\lambda_0$	Simple (planar)
[14]	Conical	30%	$0.16\lambda_0\times0.64\lambda_0\times0.56\lambda_0$	Complex (planar)
[16]	Conical	94%	$46\lambda_0\times46\lambda_0\times0.91\lambda_0$	Complex (Not-planar)
[17]	Omnidirectional	3%	$0.14\lambda_0\times0.14\lambda_0\times0.04\lambda_0$	Simple(planar)
[8]	Omnidirectional	160%	$3.75\lambda_0\times3.75\lambda_0\times0.02\lambda_0$	Medium(feeding network required)
This work	Conical	30%	$1.76\lambda_0\times1.76\lambda_0\times0.08\lambda_0$	Simple (planar)

Table 2. Comparison with previous studies

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