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## **Réseau d'antennes à fentes résonantes à guide d'ondes intégré sur substrat à gain élevé pour les radios en bande mm**

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Titre : Réseau d'antennes à fentes résonantes à guide d'ondes intégré sur substrat à gain élevé pour les radios en bande mm

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Résumé : Cet article présente un nouveau réseau d'antennes à fentes longitudinales à gain élevé basé sur la technologie du guide d'ondes intégré sur substrat (SIW) pour les applications en ondes millimétriques, capable d'atteindre une large bande passante d'impédance. Trois prototypes avec une bande passante d'impédance inférieure à -10 dB de 60 à 65 GHz, avec un gain maximal de 27 dBi et un gain minimal de 14 dBi, ont été conçus. Les résultats de l'analyse calculée des trois réseaux conçus montrent des bandes passantes d'impédance de -10 dB et des gains réalisés de 18%-21dBi (8×8), 10%-22dBi (16×16) et 8%-27dBi (32×16), respectivement. Chaque partie du réseau proposé, telle que la partie de rayonnement et le réseau d'alimentation, peut être optimisée indépendamment pour améliorer le processus de conception final. Un prototype du réseau est analysé en termes de paramètres S et de diagrammes de rayonnement. Les résultats simulés autour de la fréquence de 64 GHz démontrent la validité de la conception.

Mots-clés : Radio en bande mm, réseau d'antennes à fentes résonantes à guide d'ondes intégré sur substrat à gain élevé, technologie SIW, application en ondes millimétriques, paramètre S, diagramme de rayonnement de l'antenne, fréquence de 60 GHz à 65 GHz.

# High Gain Substrate Integrated Waveguide Resonant Slot Antenna Array for MM-Wave Band Radio

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**Abstract**— This paper presents a new high gain longitudinal slot array antenna based on substrate integrated waveguide (SIW) technology for millimeter wave application, which can achieve wide impedance bandwidth. Three prototype with impedance bandwidth lower than -10 dB from 60 to 65 GHz with a minimum 14dBi and maximum 27dBi peak gain are designed. Computed analysis results of the three designed arrays show -10dB impedance bandwidths and realized gain of 18%-21dBi (8×8), 10%-22dBi (16×16), 8%-27dBi (32×16), respectively. Each part of the proposed array such as radiation and feed network parts can be optimized independently to increase the final design process speed. A prototype of array is analyzed in terms of S-parameters and radiation patterns. The simulated results around the frequency of 64-GHz demonstrate the validity of the design.

**Keywords**-Substrate Integrated Waveguide (SIW), high gain antenna, millimeter-wave (mm-wave), 60GHz

## I. INTRODUCTION

In recent decades, millimeter wave communications has attract much attentions due to its ability to accede 1Gbit/s data transfer in short range communications range [1-58]. This capability opens the new doors for all RF engineer around the world to works on antenna elements as a key part of all wireless systems. Due to some advantages compare to other fabrication techniques for antenna engineering such as low loss, high Q, compact design, low cost, and easily integration with other planar structures, substrate integrated waveguide (SIW) has attracted much attentions for millimeter wave applications. In the recent years, the concept of substrate integrated waveguides (SIW) has enabled RF engineers and academic researchers around world to take advantage of low-loss transmission in rectangular waveguides (RW) within the printed circuit board. Using SIWs has led to light weight, low profile, High Q, low cost, and compact microwave devices that are suitable for monolithic integration with printed circuits and planar structures. Since its invention, a wide range of substrate integrated waveguide base components, such as power dividers, phase shifters, transitions, couplers, filters, diplexers, have been proposed and studied [1-27]. Substrate integrated waveguide is very promising candidate to feed the surface-wave antennas, due to easy integration of this technology with feed networks. Between different kind of antennas, waveguide slot array antennas such as longitudinal

rectangular slot, cross shaped slot, 45deg inclined slot and etc have received more attentions in a variety of microwave and millimeter-wave applications where high performance antennas are required. Due to their high aperture efficiency, low cross polarization, and low side lobe levels (SLL), resonant slot arrays have found various applications in mm-wave short range radars and wireless systems such as fixed, collision avoidance radars, broad Band home-link systems at 60 GHz, and mobile satellite terminals in Ku and Ka bands [1-10]. In [15], study of numerical simulation of waveguide slot arrays in detail is presented. According to the millimeter-wave frequency band allocation for different regions, low power output, and high atmospheric absorption rate for 60GHz, high gain antenna with good impedance matching are best candidate for 57-66 –GHz electromagnetic spectrum.

In this paper, a novel high gain slot array antennas using substrate-integrated waveguide (SIW) technology with more slot elements has been proposed for mm-wave applications. In many application such as microwave and mm-wave design of antennas with high directivity to meet demand of long distance communication is necessary [6]. This can be only be accomplished by increasing the electrical size of the antenna [6], [16]. One of useful method to increase the array antenna dimension without increasing its elements size, is to form an assembly of radiating elements. The proposed mm-wave array, composed with multi longitudinal rectangular slot elements, is referred to as an array. In most of designed antenna structures, the elements of an array are identical. The relative physical positioning of the elements and their relative electrical excitations are two parameters that can be used to exercise control over the shape of the radiation pattern of an array. Depending on the elements space and type of termination (either matched or shorted) slot arrays fall into two categories resonant arrays and non-resonant arrays [1-4]. The fields' setup in the waveguide differ due to the different terminations and consequently require different design procedures. In resonant slot array, elements are half-guide waveguide apart and are places alternately on the either side of the guide axis for broadside operation. But in non-resonant slots array consist of a number of elements spaced a little more or little less than  $\lambda_g/2$ .

## II. MODELING OF LONGITUDINAL SINGLE SLOT

The equivalent electrical circuit model of a single cell longitudinal rectangular radiating slot is shown in Fig.1 [1], [2]. It consists of a shunt admittance ( $Y$ ) for which a model must be developed in terms of operating frequency, slot length, and slot offset from the waveguide axis (Z-Plane). For this purpose, a single slot cell is simulated by CST as a two port network for a range of slot lengths, offsets, and frequencies [1-5]. As shown in Fig.1, the YZ-plane is defined at the center of slot and the normalized admittance parameters is extracted from S-parameters. According to the equivalent circuit in Fig.1, we can write Eq. 1,[1-4]:

$$\frac{Y(x,l,f)}{G_0} = \frac{-2S_{11}}{1+S_{11}} = \frac{2(1-S_{21})}{S_{21}} \quad (1)$$

As show in Fig. 1,  $G_0$  is the characteristic admittance of the proposed waveguide. According to Elliot studies in [3-4], the field on the longitudinal slot is somewhat unsymmetrical. Therefore, due to this unsymmetrically field characteristics of Equation.1, to produce better results average value was used for slot admittance [2-4]. Of course the best equivalent circuit model for extracting the proposed single radiating slot is a T network which consists of two small series impedances on both sides of the shunt admittance [2]. The reason is that the amplitudes of forward and backward scattered waves from the slot are slightly different, in other words  $S_{21}$  is not exactly equal to  $1 + S_{11}$ . However, in the proposed slot antenna array this asymmetry is negligible. The numerical simulations results show that the directivity of a single resonant slot radiating is 6.05 dB. In these simulations the width and height of the waveguide are 1.7 mm and 0.508 mm, respectively. The proposed slot array is implemented on an RO5880 (Roger) substrate with electric permittivity of 2.2, a loss tangent of 0.024, thickness of 0.508 mm and the width of slot is  $w = 0.2$  mm. Different Substrate Integrated Waveguide components such as bends, couplers, combiner and splitters designed, simulated and can be constructed and their scattering parameters can be tuned by combining several different sections, adding or removing posts or making other modifications for the proposed feed network [1-27].

## III. SLOT ANTENNA ARRAY CONFIGURATIONS AND RESULTS

The proposed array antenna structure have three parts: A microstrip-to-SIW transition, feed network and radiating elements. The proposed feeding network consists of three steps SIW binary splitters to achieve a broadband performance and minimize the feed structure insertion losses. At first, a slot single element slot antenna cell with compact size and constant gain in operating band is designed. A  $\mu$ -strip line transition is used to transfer the power to or from the SIW antenna array. This transmission line is connected to the Taper line to feed SIW. The transition between  $\mu$ -strip line and SIW is critical for achieving good impedance matching. A tapered transition was proposed by Deslandes and K. Wu which is useful in most applications and operating bands [6].

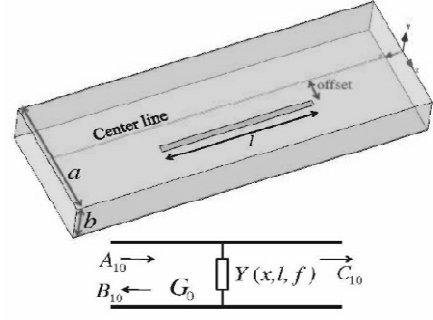


Fig.1. Single cell longitudinal slot equivalent circuit and radiating element.

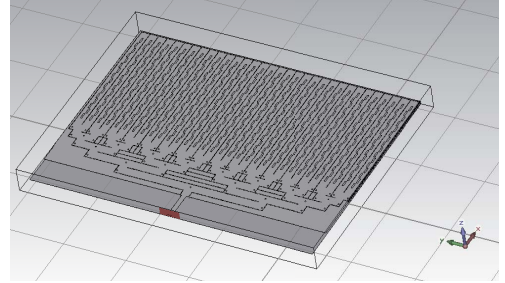


Fig. 2. The proposed 32 × 16 Substrate Integrated Waveguide (SIW) slot antenna array CST model

The proposed structures insertion loss at 63 GHz is 1.12 dB. Different square slot arrays 8 × 8, 16 × 16, and 32 × 16 were designed in this work but only 32 × 16 elements was presented. All arrays have uniform slot voltage distribution and operate at 63 GHz. Roger 5880 with dielectric constant of 2.2 was used for all substrate layers. The thickness of substrate was 0.508mm with 17 $\mu$ m metal cladding. The spacing and the diameter of metallic vias were  $p = 0.2$ mm and  $d = 0.35$  mm, respectively. To maximize the antenna gain, the spacing between adjacent slots is selected to be 2mm at 63 GHz. The 60 GHz frequency band rectangular waveguide (WR-15) width is 3.759 mm. By using Ref. [14] formula both SIW width and SIW effective width is calculated [6], [7]. The calculated effective SIW width is 2.8 mm. The total size of the optimized slot array is 90mm × 50mm. An important parameter in EM simulation of antennas and circuits at very high frequencies is the loss tangent  $\tan(\delta)$  of dielectric substrate used in the structure. In the proposed design to obtain a best estimation of dissipative losses over the desired operating band, it is critical to use accurate values of  $\tan(\delta)$  at frequencies of interest. Consequently, during all EM simulation the loss tangent at 63 GHz must be very close to 0.001. The proposed SIW array antenna feeding network at the input of the antenna divides the signal to 32 in-phase, equal amplitude signals and a 50 Ohm microstrip-to-SIW transition is used likewise. The 32 × 16 SIW slot antenna array CST model is presented in Fig. 2. Slot Spacing is equal to the half of guided wavelength  $\lambda_g$  and Slot to Top (ST) is equal to the three-quarter of  $\lambda_g$  short circuit termination [1-7].

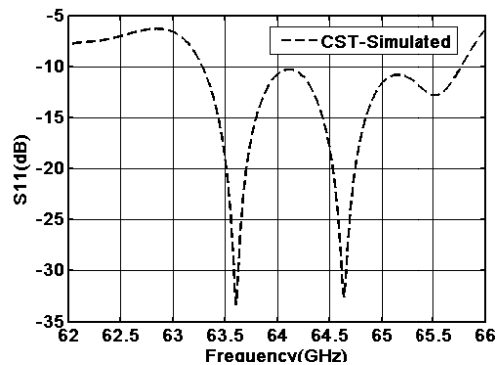


Fig.3. Simulated CST S<sub>11</sub> results for the proposed 32 × 16 Substrate Integrated Waveguide (SIW) slot antenna array CST model.

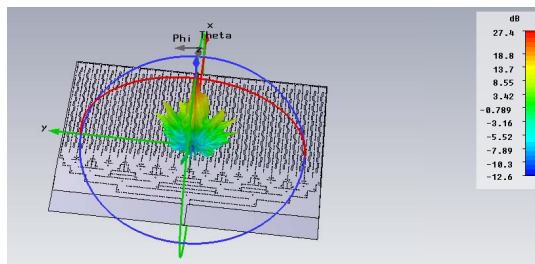


Fig. 4. The 3d radiation field of the proposed SIW slot antenna array at 64 GHz.

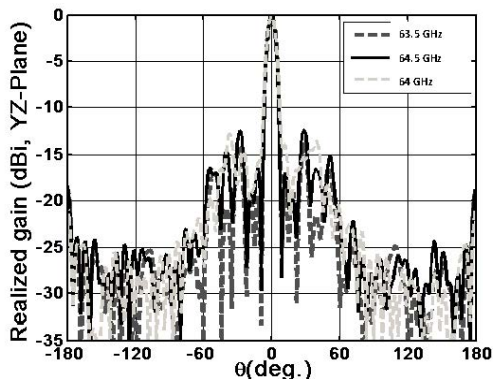


Fig. 5. Computed 2-D gain patterns spectrum corresponding to the proposed SIW slot antenna array at 63.5-, 64-, and 64.5- GHz.

Simulated  $S_{11}$  results of the proposed 32 × 16 slot array is shown in Fig. 3. As shown in Fig. 3,  $S_{11}$  varies below -10 dB in the range from 63.3 GHz to 65.8 GHz. Figs. 4 and 5 shows computed radiation pattern and 3D-CST radiation results of the proposed slot array antenna at 63.5, 64 and 64.5 GHz. The maximum computed gain is 27.4 dBi.

#### IV. CONCLUSION

In this paper, a new substrate integrated waveguide based resonant slotted waveguide array working at 64-GHz band has been demonstrated. In this design, to improve the impedance bandwidth and gain, the excitation voltages is minimized. Computed analysis results of the three designed arrays show – 10 dB impedance bandwidths and realized gain of 18%-21dBi (8×8), 10%-22dBi (16×16), 8%-27dBi (32×16), respectively.

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#### Related Works:

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