International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 11, November - 2013

Design of substrate integrated Waveguide single longitudinal slot antenna

NOURI Keltouma [1, 2] and DAMOU Mehdi [1, 2]

[1] *Laboratoire de Technologies de Communications TC, Faculté des Sciences et de la technologie, -Université Dr Moulay Tahar, – BP 138– Ennasr, Saida, Algérie*

[2] *Laboratoire de recherche Systèmes et Technologies de l'Information et de la communication STIC, Faculté de Technologie - Université de Tlemcen – BP 119 – Tlemcen, Algérie*

Abstract

Planar slot antenna using Substrate Integrated Waveguide technology (SIW) is proposed in this paper. SIW has all the advantages required for a small size antenna package: Low-cost, high-performance and ease of integration.

The SIW antenna with tapered microstrip-SIW transitions are integrated and synthesized on a single substrate.

This structure is designed with Finite Element Method (FEM) using HFSS on substrate of Duroid 5880. Simulated results are presented and discussed.

Keywords: *Substrate integrated waveguide (SIW), Slot Antenna, transition, via-holes, microstrip technology*.

1. Introduction

Substrate integrated waveguide (SIW) technology of low loss transmission characteristic has recently become widespread in the design of many passive and active devices at microwave and millimeter-wave [1-4].

In the area of microwave antennas, the waveguide resonant slot array antenna, which has advantages of good direction of radiation, low cross-polarization levels and low side-lobe levels, act an important role [5-6].

However, the manufacturing of rectangular waveguide structures is rather expensive. Furthermore, High precision mechanical adjustment or a subtle tuning mechanism is needed to obtain the resonant slots at the standing wave peaks and the integration of such structures with planar circuits requires specific sophisticated transitions.

Microstrip lines are, in comparison, easy and not expensive to fabricate, but are not low loss radiation and not shielded.

But since the appearance of SIW all these disadvantages get changed [7].

The SIW is an excellent candidate for the integration of high density millimeter wave circuits which require a good quality factor. It benefits from the very low production cost of the PCB process and is relatively compact.

They are constructed by metal filled via-hole arrays in substrate and grounded planes which can be easily interconnected with other elements of the system on a single substrate plat form without tuning [8-9], this system can be miniaturised into small package called the system in package SIP which has small size and low cost [10].

It can therefore be fabricated on the printed circuit board (PCB) or the low-temperature co-fired ceramic (LTCC) for low-cost and mass-producible.

A schematic view of an integrated waveguide is shown in Fig. 1.

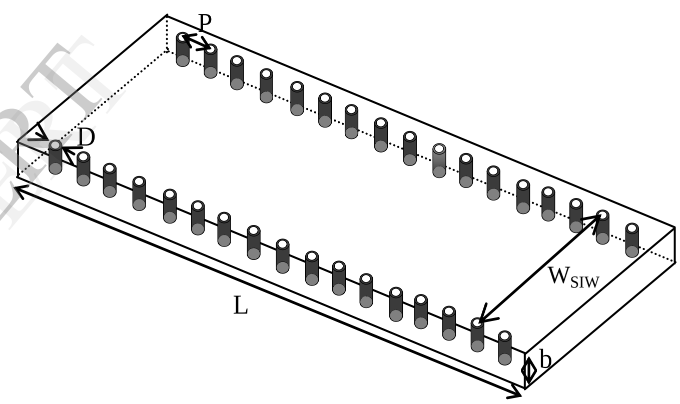


Fig.1: Geometry of the substrate Integrated Waveguide

In this paper, the commercial software package "HFSS" based on the Finite Element Method (FEM) has been applied to the analysis of a single longitudinal slot antenna with tapered transition. The slot antenna and the feeding microstrip line were synthesized on a single substrate

One slot is required in SIW Antenna to achieve the high performances in this kind of design.

2. SIW Slot Antenna Designs

2.1 SIW Slot array antenna

Planar resonant slotted-waveguide arrays are used in many applications, especially radar.

The conventional RWG resonant longitudinal slots array antenna is exhibited in Fig.2; one port of the waveguide is short.

The spacing of each slot antenna is one-half guide wavelength at the design frequency in order to locate the slots at the standing wave peaks and all radiators have the same phase. The spacing between the last slot and the short port is one-quarter guide wavelength hence the short port is equivalent to open space [5].
The array is fed from the waveguide end.

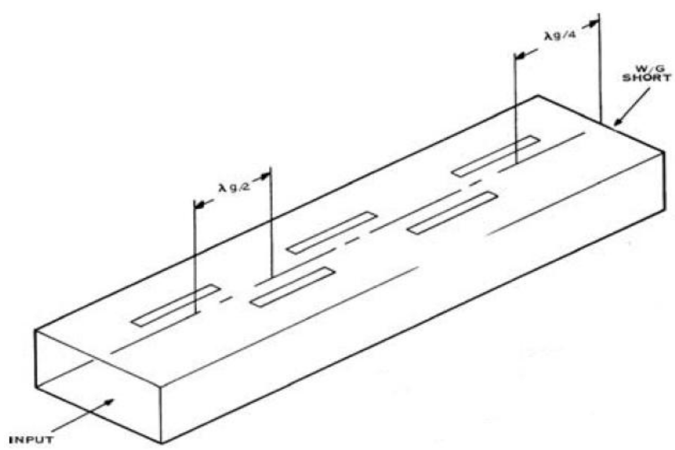


Fig.2: Linear resonant waveguide slot arrays with longitudinal slot elements.

A half-wavelength of transmission line has the useful property of repeating impedance, the input and output impedance are the same. As a result, the impedances, or admittances, of all the slots appear in parallel. Fig.3 shows this schematically.
Each parallel resistor represents one slot, so there must be N resistances in parallel.
The admittance Y is purely resistive and the calculation is extremely simple: adding N identical admittances together, where N is the number of slots:

$$Y_{input} = Y_1 + Y_2 + Y_3 + Y_4 + \cdots + Y_N \qquad (1)$$

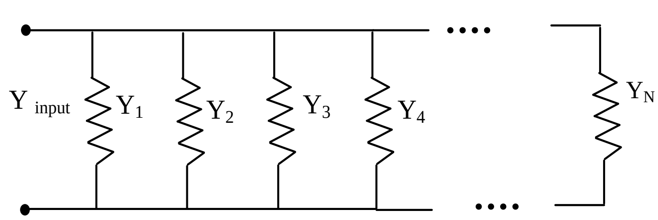


Fig.3: Schematic of Waveguide slot Antenna

Stevenson7 developed his formulas for representing slot characteristics by making the following assumptions: the slot was cut in a perfectly conducting, infinitely thin wall; the resonant slot length is assumed to be a half-wavelength in free space; and the slot was radiating over a perfectly conducting ground plane of infinite extent.
Using transmission-line theory and the waveguide modal Green's functions, Stevenson derived the values of normalized slot conductance, used to calculate the slot displacement [11]:

$$\frac{g_{Slot}}{g_{Waveguide}} = g_1 sin^2\left(\frac{\pi x}{W}\right) \qquad (2)$$

$$g_1 = \left(2.09\frac{W}{b}\frac{\lambda_g}{\lambda_0}cos^2\left(\frac{\pi\lambda_0}{2\lambda_g}\right)\right) \qquad (3)$$

Where W and b are the large and small dimensions of the waveguide, respectively, λ_0 is the free-space wavelength, and x is the slot displacement from the waveguide centerline.
Conductance g is the real (resistive) part of admittance Y; if the slot is resonant, then the admittance is has no reactive component and only the conductance is left.
The formula assumes a resonant slot in an infinitely thin wall of perfectly conducting material. The resonant slot length is assumed to be a half-wavelength in free space. If we use the normalized conductance, G_{slot} / $G_{waveguide}$, then we don't have to clutter the calculations with the waveguide conductance.

Owing to the similarity between SIW structures and classical rectangular waveguides, most of the planar (H-plane) waveguide components have been implemented in SIW technology. This solution usually permits a substantial reduction in size and in weight of components if compared to classical waveguide; moreover, losses of SIW components are lower than in the corresponding microstrip devices.
The conventional RWG slot array antenna is transferred to the SIW slot array antenna (Fig.4).

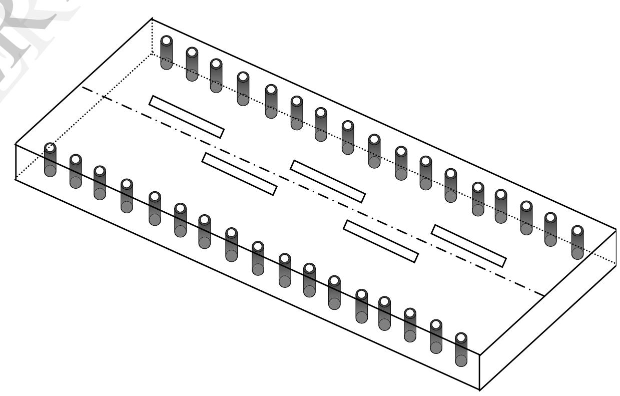


Fig.4: Linear resonant SIW slots array antenna

Since the E field distribution in the SIW looks like that of a classic rectangular waveguide, the width w_{SIW} can be approximated as follows [12]:

$$w_{SIW} = w - \frac{D}{0.95P} \qquad (4)$$

These relations allow for a preliminary dimensioning and design of SIW components, without any need of full-wave analysis tools.
In this equation, w is the width of the dielectric waveguide. The parameters D and P are the wall post diameter and the

period of vias respectively as shown in Fig.1; and the rule of design are:

$$b \leq 2D \quad (5)$$

$$D < {\lambda_g}/{5} \quad (6)$$

The electrical wavelength in waveguide is longer than in free space, so we must calculate the guide wavelength:

$$\lambda_g = 1 \Big/ \sqrt{\left(\frac{1}{\lambda_0}\right)^2 - \left(\frac{1}{\lambda_C}\right)^2} \quad (7)$$

where λ_C is the cutoff wavelength.

2.2 SIW single slot antenna

A SIW resonant single-slot antenna is shown in Fig. 5. This is a simple type of slot antenna. The coupling slots are cut on the top surface of the SIW.

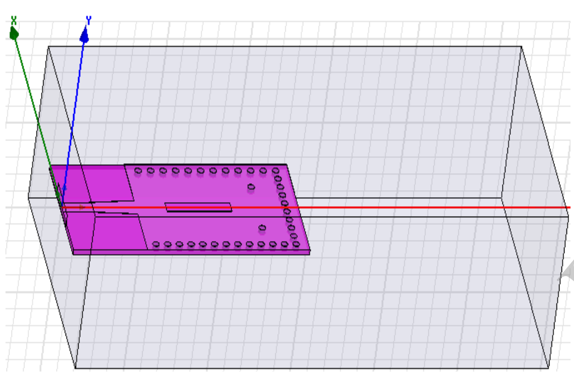


Fig.5: SIW Single slot antenna

In order to combine SIW and microstrip technologies, microstrip-SIW transitions are very required [4]-[13-14].
In particular, microstrip-to-SIW transitions are typically based on a simple taper (Fig. 6), provided that the microstrip and the SIW structure are integrated on the same substrate. This transition consists of the tapered microstrip line and the step between the microstrip and the rectangular waveguide.

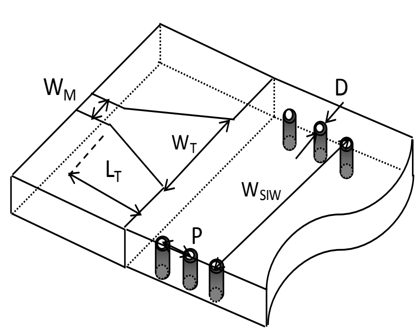


Fig. 6: Configuration of the microstrip to SIW transition

The taper length L_T must be chosen as a multiple of a quarter of a wavelength in order to minimise the return loss.
After Optimization, we can find $W_T = 2.286\ mm$. The taper length is equal to L_T= 5.58 mm.
The SIW antenna is constructed into one substrate with height h=0.508 mm, dielectric constant$\varepsilon_r = 2.2$ and $tg\delta = 0.0009$, $w_{SIW} = 12.6\ mm$ is the width of SIW. The post diameter is D =0.8 mm and the P=1.5 mm is the cylinder spacing. The resonant length for the slot is approximately L=7.8 mm and the slot width is 1.4 mm.
The SIW Slot Antenna is done with HFSS using the Finite Element Method (FEM). Simulated return losses of the proposed antenna are shown in Fig. 7.

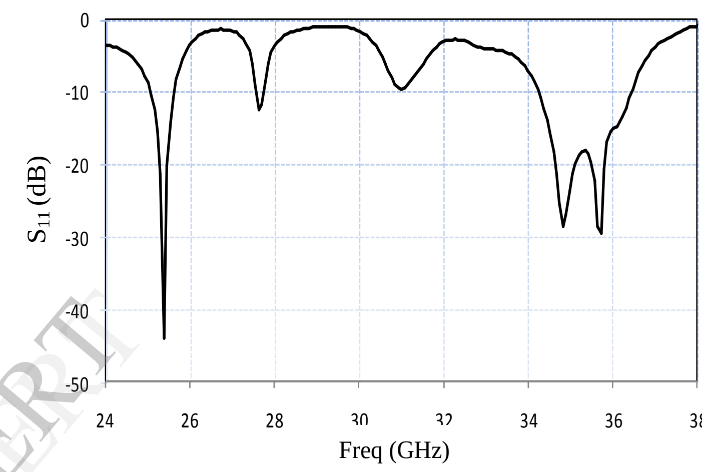
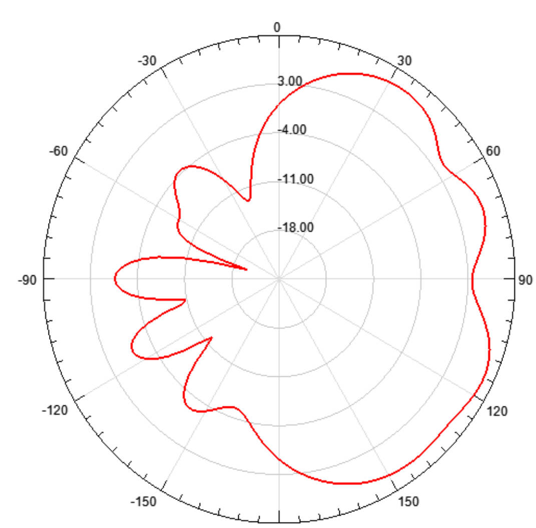


Fig. 7: Reflection coefficient of the SIW Slot Antenna

The return losses are lower than 40 dB for 25.36 GHz and lower than 18 dB for frequency band [34.6 -35.9] GHz.

The simulated radiation Patterns for the slot antenna at frequency f = 25.36 GHz are shown in Fig.8 and Fig.9 respectively.



ISSN: 2278-0181
Vol. 2 Issue 11, November - 2013

Fig.8. Simulated radiation at frequency of 25.36 GHz for φ =90°

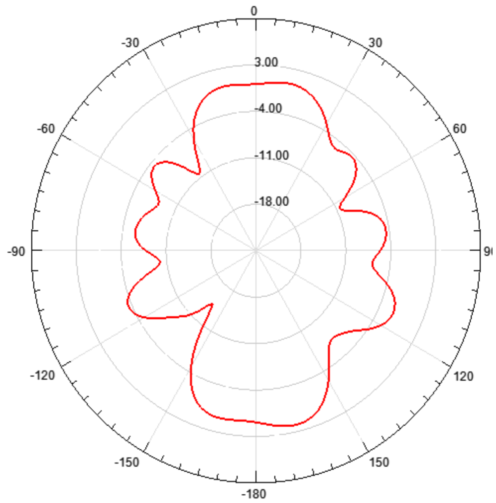


Fig.9. Simulated radiation at frequency of 25.36 GHz for φ =0°

3. Conclusion

SIW resonant single-slot antenna with SIW-microstrip transitions have been presented in this paper, which is integrated on a single substrate.
The SIW antenna shows good performances in terms of return losses. The main characteristics of these kinds of SIW structures are small size, low loss and easy to manufacture.
Future work should be done for the substrate integrated slotted-waveguide array antenna.

References

[1] Tarek Djerafi and K. We," Super-compact Substrate Integrated Waveguide Cruciform Directional coupler", IEEE Microwave and Wireless Components Letters, Vol.17, N°11, pp: 757 - 759, 2007.

[2] Chao Wang, Wenquan Che, Chao Li, and Dongtian Liu, "Multiway microwave planar power divider / combiner based on Substrate Integrated Rectangular Waveguide Directional couplers", Microwave and Optical Technology, .50, N°6, June 2008

[3] Y. J. Cheng, K. Wu, and W. Hong, "Substrate integrated waveguide (SIW) broadband compensating phase shifter,", IEEE MTT-S Int. Microw. Symp. Dig., pp. 845–848, 2009

[4] Asanee Suntives, and Ramesh Abhari, "Transition Structures for 3-D Integration of Substrate Integrated Waveguide Interconnects,", IEEE Microwave And Wireless Components Letters, Vol. 17, pp. 697-699, October 2007

[5] Li Yan, Wei Hong, Guang Hua, Jixin Chen, Ke Wu, and Tie Jun Cui, "Simulation and Experiment on SIW Slot Array Antennas, ", IEEE Microwave andWireless Components Letters, vol. 14, N° 9, pp.446-448, September 2004.

[6] Farrall, A. J., Young, P. R. "Integrated waveguide slot antennas, ", Electronics Letters, Vol. 40, N°16, pp. 974-975, Aug 2004.

[7] Hiroshi, U., Takeshi, T., and Fujii, M.: 'Development of a ''laminated waveguide''', IEEE Trans. Microw. Theory Tech., , 46, (12), pp. 2438–2443, 1998

[8] Wenquan Che, Liang Geng, Kuan Deng, and Y. Leonard Chow, "Analysis and Experiments of Compact Folded Substrate-Integrated Waveguide,", IEEE Transactions on Microwave Theory and Techniques, Vol. 56, No. 1, January 2008

[9] D. Deslandes and K. Wu, "Integrated Microstrip and rectangular waveguide in planar form," IEEE MicrowaveWireless Compon. Lett., Vol. 11, pp. 68-70, February 2001.

[10] L. Yan, W. Hong, K. Wu and T.J. Cui, "Investigations on the propagation characteristics of the substrate integrated waveguide based on the method of lines," IEE Proc.-Microw. Antennas Propag., Vol. 152, No. 1 , February 2005.

[11] R. J. Stevenson, "Theory of Slots in Rectangular Waveguides," J. App. Phys., Vol. 19, pp.24–38, 1948.

[12] Y. Cassivi, L. Perregrini, P. Arcioni, M. Bressan, K. Wu, and G. onciauro, "Dispersion characteristics of substrate integrated rectangular waveguide," IEEE Microw. Wireless Compon. Lett., Vol. 12, pp.333–335, February 2002.

[13] C. L. Edwards, S. Cheng, and R. K. Stilwell, "A simplified analytics CAD model for linearly tapered microstrip lines including losses,", IEEE Trans. Microw. Tech., Vol. 52, No. 3, pp. 823–830, March 2004.

[14] K. Nouri, M. Feham and A.Saghir, "Design and characterization of tapered transition and inductive window filter based on Substrate Integrated Waveguide technology (SIW)", IJCSI International Journal of Computer Science Issues, Vol. 8, Issue 6, No 3, ISSN: 1694-0814, November 2011