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Advanced Engineering Informatics

Elixir Adv. Engg. Info. 45 (2012) 7754-7757

ISSN: 2229-712X

Design and simulation of DRA for millimeter wave applications

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ARTICLE INFO

Article history:

Received: 5 January 2012;

Received in revised form:

17 March 2012;

Accepted: 4 April 2012;

Keywords

Dielectric resonator antenna (DRA),

Millimeter wave (mmW),

Planar waveguide,

Substrate integrated waveguide (SIW),

Radiation efficiency.

ABSTRACT

In this paper, a compact, low cost and high radiation efficiency antenna structure, planar waveguide, substrate integrated waveguide (SIW), dielectric resonator antennas (DRA) design using Advanced Design System (ADS) tool is presented. Since SIW is a high Q waveguide and DRA is a low loss radiator, then SIW-DRA forms an excellent antenna system with high radiation efficiency at millimeter-waveband, where the conductor loss dominates. The impact of different antenna parameters on the antenna performance is studied. Experimental data for SIW-DRA, based on two different slot orientations, at millimeter-wave band are introduced and compared to validate this antenna model. The measured gain for SIW-DRA single element showed a broadside gain of 5.51 dB. The Return Loss/Reflection coefficient is found to be -48.617 dB at the Cut off frequency 33.02 GHz.

Introduction

As the demand for wireless communications increases, cheaper and more reliable systems have to be developed. At the same time, constraints placed on the systems by spectrum allocation issues increase. A considerable amount of research is being devoted to the development of systems designed to work in the millimeter-wave (mmW) frequency range. This frequency band (30–300 GHz) [1], [2] is vastly unused compared to lower frequency bands which are heavily populated. Developing the communication systems at mmW frequency band allows compact system components, which are critical for mobile and portable systems. Furthermore, the mmW bands provide a greater bandwidth, meaning large amounts of data can be transmitted at higher speed with better reliability. In addition, Wireless Local Area Networks (WLANs) and other high-speed multimedia delivery services require large amounts of bandwidth to operate effectively. An important application for this frequency band is satellite communications. A portable system with fixed beam around 20/30 GHz for receive and transmit respectively has been investigated [3].Emerging low cost 60 GHz technologies and standard (IEEE 802.15 TG3c) have paved the way for mass production of mmW in a number of innovative mass market applications such as live HD video streaming and multi Gbps WAN.

Many different feeding mechanisms is used for DRA such as coaxial-probe feed [5], [6], aperture- coupling associated with micro strip line feed [7], [8], direct micro strip-line feed coplanar waveguide feed [9], [10], and other feeding Structures. However, feeding losses of these excitation methods are considerable at mmW. A new and low loss excitation scheme that employs rectangular waveguide is reported [11], [12]. However, it is bulky, expensive not compatible with Monolithic Microwave Integrated Circuits (MMIC) technology and low profile applications. On the other hand, Substrate Integrated Waveguide (SIW) [13], [14] which is a promising approach for future design and development of low cost millimeter wave RF circuits using conventional Printed Circuit Board (PCB) technology provides a compact, high-Q, and low profile feeding structure. SIW is a good compromise between air field rectangular waveguide and microstrip line. Accordingly, it minimizes radiation loss and parasitic radiation. Antennas based on SIWs with operation frequency range up to Ka- band have been realized using standard PCB processes [15], [16]. This paper is organized as methods and materials used in section 2, results and discussion in section 3 and finally conclusion in section 4.

Methods and Materials Used

In this paper, the SIW concept is utilized as a novel feeding mechanism for Dielectric Resonator Antenna (DRA) for low cost and high radiation efficiency antenna systems for mmW applications. Modeling, characterization, design and fabrications of SIW-based DRA are presented. A Rectangular Dielectric Resonator Antenna (RDRA) shown in Fig.1 is designed to resonate for radiation at mmW frequency. Then, a complete model of the proposed antenna consisting of RDRA excited by a narrow slot cut on the broad wall of SIW is used along with parametric analysis of the effect of each parameter on the antenna. Fig.2. Shows the Vector field distribution plots of isolated RDRA resides on infinite ground plane in order to strongly excite this mode a source (slot) should be located at a strong field (magnetic) to ensure a good coupling.

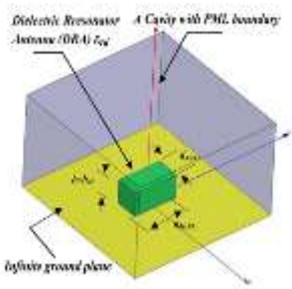

Fig.1. Rectangular Dielectric Resonator antenna (RDRA) resides on infinite ground plane

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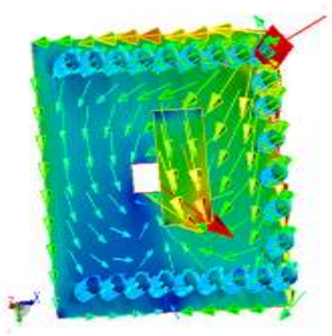

Fig. 2.Vector field distribution plots of isolated RDRA reside on infinite ground plane.

Rdra Theoretical Model Analysis

The mode resonant frequency f_o of the RDRA is determined using dielectric waveguide model (DWGM). For convenience, these equations are written as,

$$f = \frac{C}{2\Pi\sqrt{\varepsilon_{rd}}}\sqrt{Kx^2 + Ky^2 + Kz^2} \qquad (1)$$

$$Ky = \frac{\pi}{\alpha RDRA} \qquad (2)$$

$$Kz = \frac{\pi}{2b} \qquad (3)$$

$$\tan\left(\frac{dRDRA\,Kx}{2}\right) = \left(\frac{Kxo}{Kx}\right) \qquad (4)$$

$$Kxo = \sqrt{Ky^2 + Kz^2} \qquad (5)$$

Where ε_r is the dielectric constant of the resonator, C is the speed of light, and the lengths a_{DRA}, b, d_{DRA} are shown in Fig. 1. Alternatively, these equations are used to determine the parameters of the resonator for a desired frequency of operation. Modal analysis is carried out for different RDRA dimensions. The model consists of RDRA, which resides on infinite ground plane. In order to strongly excite this mode, a source (slot) is located at a strong field (magnetic) to ensure a good coupling.

Siw Fed Rdra Model

A narrow transverse slot cut on the SIW broad wall forming two different polarizations (horizontal and vertical) is used to excite the RDRA for radiation as shown in Fig. 3(a) and (b). The presented SIW structure consists of two integrated rows of metallized vias of diameter d_{via} and separated by a_{SIW} (SIW width) and each two neighboring vias are S_{vias} apart. The SIW substrate has a dielectric constant ε_r of and a thickness h_{sb}. The SIW parameters are chosen to minimize the guided wave transmission losses. the SIW a_{SIW} width is chosen for single fundamental TE_{10} mode operation. The SIW a_{SIW} width is calculated by using the equivalent rectangular waveguide concept. The SIW substrate thickness and the dielectric constant are selected to provide a compact design. Furthermore, the slot's dimensions, L_{slot}, W_{slot} and the position, X_{sc} , are optimized in order to efficiently couple the energy from the SIW to the RDRA. Fig. 3 represents the SIW- based RDRA driven model. (a) Using horizontal polarized (transverse) slot. (b) Using vertical polarize (longitudinal) slot using Advanced Design System (ADS).

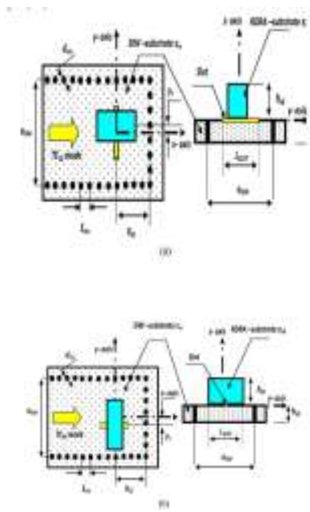

Fig.3. SIW- based RDRA driven model. (a) Using horizontal polarized (transverse) slot. (b) Using vertical polarized (longitudinal) slot.

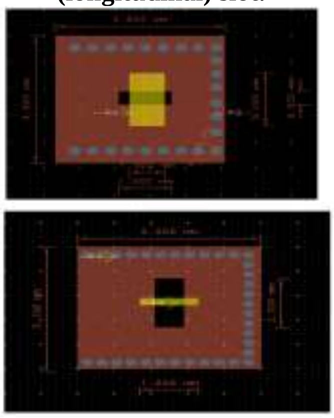

Fig.4. SIW- based RDRA driven model. (a) Using horizontal polarized (transverse) slot. (b) Using vertical polarize (longitudinal) slot using ADS.

Fig.4. (a) & (b) show the SIW- based RDRA driven model using horizontal polarized (transverse) slot and vertical polarized (longitudinal) slot using Advanced Design System respectively. The size of the DRA is 4.8 mm width, 4.8 mm length, and 5.08 mm thickness with a dielectric constant of 10.2, and it is supported by a 30x30 mm^2 RT6002 substrate with a dielectric constant of 2.94 and a substrate thickness of 0.762 mm. The ground plane is partially printed on the substrate under the DRA. The size of ground plane is 11x 30 mm^2 on one side and a printed probe extends from the micro strip line of the same width that ends with the 50 Ω line after certain length that is used as a matching transformer.

Results And Discussions

The numerical investigation is important because it provides some understanding of the antenna characteristics to the antenna engineer since the designed antenna has several contributions. (i) Improvement in the radiation patterns, (ii) improvement in bandwidth and (iii) comparison of performance.

Characterization and Parametric Study

Some design parameters may affect the coupling between the slot and the RDRA. These parameters are slot position X_{sc}, slot length L_{slot}, slot width W_{slot} and the RDRA relative position to slot. These parameters have to be optimized to obtain maximum energy coupling between both the slot and RDRA.

Slot Position Characterization

The position of the transverse slot on an SIW board wall controls the amount of coupled power to the RDRA. The center position (along y-axis) on the SIW broad wall, and at $X_{sc}=\lambda_g/2$ (along x-axis) guarantee a maximum excitation to RDRA's fundamental mode (maximum-coupled power). Since the effective dielectric constant ε_{eff} seen by the slot is not known accurately, the guided wave length is calculated based on the average dielectric constant. The DWGM that is used on this analysis assumed that the RDRA resided on an infinite ground plane and it did not take the slot effect into consideration. In other words, the isolated RDRA's height is replaced with its half. However, due to the slot effect, the assumption of using half of RDRA's height will not be accurate and it may shift to as frequency (the RDRA resonance frequency is height dependent). Fig.5 shows the impact of the slot position X_{sc} (mm) variation on S_{11} (dB) and the cut off frequency is found to be 33.02 GHz and the reflection coefficient is -48.617 dB.

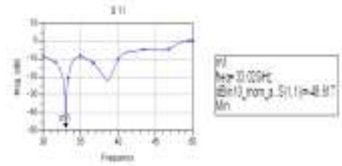

Fig.5. Impact of slot length L_{slot} (mm) variation on S_{11} (dB)

B Slot Length Characterization

As the slot length is shortened, the f_0 of the DRA is increased. The effect of placing RDRA on the top of the slot is used to change the slot impedance so that it is matched at frequency other than its natural resonance frequency. A significant portion of energy coupled into RDRA at different frequencies which give a good indication of its broadband behavior and the slot length tuning property. Fig.6. shows the impact of slot length L_{slot} (mm) variation on S_{11} (dB) and the cut off frequency is found to be 34.06 GHz and the reflection coefficient is –28.50 dB.

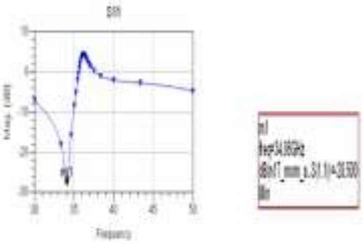

Fig.6. Impact of slot length L_{slot} (mm) variation on S_{11} (dB)

Slot Width Characterization

Increasing the slot width has the effect of increasing both the resonance f_0 of RDRA and the bandwidth Δ%. Namely, the RDRA resonance frequency f_0 changes from low frequency 36.64 GHz when the slot width is 0.20 mm to a high frequency 37.43 GHz when the slot width is 0.40 mm. Fig.7. gives the impact of slot width W_{slot} (mm) variation on S_{11} (dB) and the cut off frequency is found to be 41.08 GHz and the reflection coefficient is –31.712 dB.

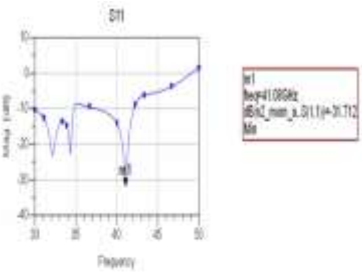

Fig.7. Impact of slot width W_{slot} (mm) variation on S_{11} (dB)

Conclusion

This work presents modeling, characterizations, and design procedure of a low manufacturing cost and high radiation efficiency planar waveguide based dielectric resonator antenna for mmW application. The SIW feed is used for the RDRA excitation. This idea is demonstrated by using two different coupling slot orientations to excite the RDRA in its fundamental mode for radiation. A parametric study (characterization) for all antenna parameters has been conducted between the SIW and RDRA. The designed DRA has very high antenna efficiency of 95% with stable gain over the frequency band of 33.02GHz. The parametric study shows that the designed DRA has excellent characteristic that make it a good candidate for millimeter wave applications. This design has further extended the use of DRA as thin antennas suitable to be easily integrated with portable wireless devices. The Return Loss/Reflection coefficient is found to be -48.617dB at the Cut off frequency 33.02 GHz.

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