Design and Experiment on Substrate Integrated Waveguide Resonant Slot Array Antenna at Ku-Band

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Abstract:

By transferring the conventional waveguide resonant slot array antenna to the substrate integrated waveguide (SIW) structure, The resonant slot array antenna can take the advantages of the SIW such as small size, low profile, low cost. The whole antenna is fabricated on a single substrate, the design process and experimental results of a five-slot SIW array antenna at Ku-band are presented.

1. Introduction

The development of the substrate integrated waveguide (SIW) has attracted great interest in the last years. Since it has the similar characteristic of the rectangular waveguide (RWG), many design concepts of conventional RWG can be transferred to this new platform, such as the waveguide divider, filter, antenna, etc.

The waveguide resonant slot array antenna, which has the advantages of good direction of radiation, low cross-polarization levels and low side-lobe levels, plays an important role in the area of microwave antennas. However, RWG components are voluminous and expensive to be made. High precision mechanical adjustment and subtle tuning mechanism are needed to obtain the resonant slots at the standing wave peaks, and RWG components are hard to be integrated within planar circuits. After the appearance of SIW, all these disadvantages get changed [1]. The SIW has lower leakage than microstrip line and also has much smaller size than RWG, which allows the integration of planar and nonplanar structures within the same substrate.

In this paper, the conventional RWG slot array antenna is transferred to the SIW slot array antenna which is fed by a microstrip line at ku-band [2]. The slot array antenna and the feeding microstrip line were synthesized on a single substrate. As a result, the size, weight and cost of the waveguide slot array antenna can be greatly reduced, and the manufacturing repeatability and reliability are enhanced. But when compared with RWG slot array antenna, the gain and efficiency becomes lower and the side lobe level becomes higher because of the leakage.

2. Analysis

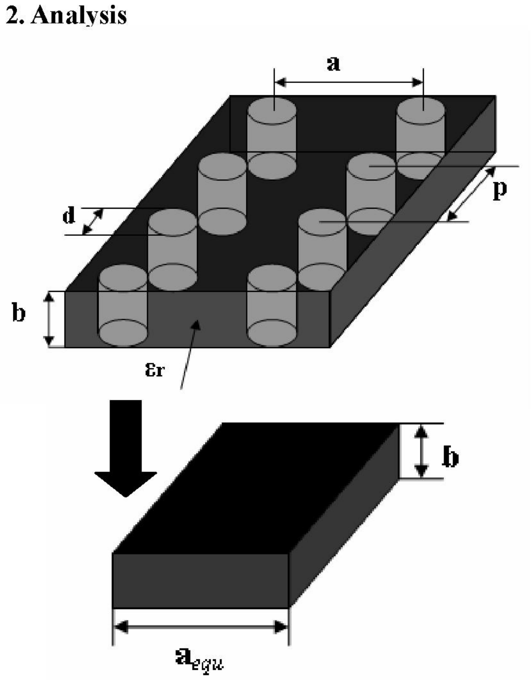

Figure 1. SIW and the equivalent RWG

The width of the equivalent broad wall of the RWG is the key of the design procedure. A schematic of SIW structure is shown in Fig 1. Such a waveguide is composed of two parallel arrays of metallic via-holes, which delimit the waveguide TE wave propagation area. The propagation constant and the radiation loss are determined by parameters "a", "p" and "d", which denote the width of the SIW, the period and the diameter of via holes, respectively. As shown in the right part of Fig. 1, the SIW is equivalent to a conventional RWG filled with dielectric and hence it can be analyzed just by using the width of the equivalent waveguide [3], the width of the broad wall of the equivalent RWG can be calculated by an experimental formula [4].

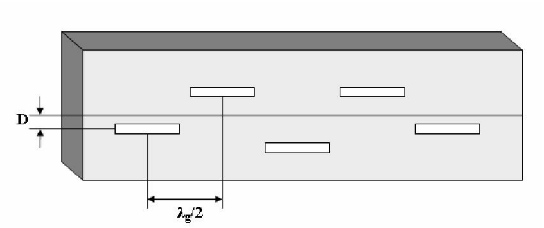

Figure 2. Conventional RWG slot array antenna

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 radiator 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.

Each slot is equivalent to a shunt conductance. In order to radiate all the effective power, the summation of the equivalent conductance of each slot should be 1. The offset relative to the waveguide centerline of each slot could be calculated by Steven- son method, the formula are as follows:

$$g_0 = (2.09a\lambda_g / b\lambda)\cos^2(\lambda\pi / 2\lambda_g) \quad (1)$$

$$D = \frac{a}{\pi} \times \arcsin(\sqrt{\frac{g_n}{g_0}}) \quad (2)$$

where a, b are the widths of the broad wall and the narrow wall, λ is the wavelength in the free space, λ_g is the guide wavelength, g_0 is the unitary conductance of a one-half guide wavelength longitudinal slot, g_n is the equivalent conductance of a certain slot, and g_n is in direct proportion to the square of the slot voltage level v_n. Here we set:

$$g_n = kv_n^2 \text{ (k is unknown)} \quad (3)$$

$$\sum_{n=1}^{N} g_n = k\sum_{n=1}^{N} a_n^2 = 1 \quad (4)$$

So we could locate the offset "D" by choosing the relative distribution of the slot voltages.

3. Experiment and Results

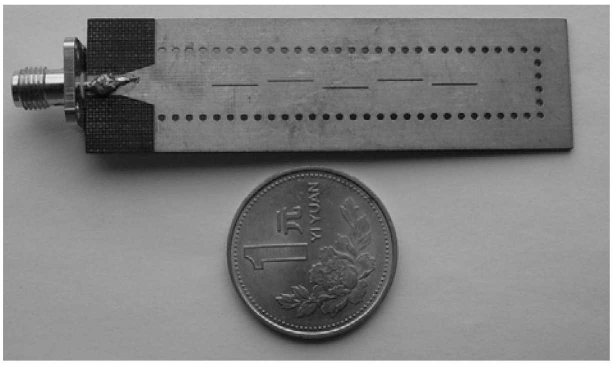

Figure3. Photograph of the substrate integrated slotted-waveguide array antenna. a=10mm, a_{equ}=9.36mm, b=1mm, p=2mm, ε_r=2.65. Design frequency is 14.5GHz.

A SIW resonant five-slot array antenna is shown in Fig. 3, the slot voltages are set in the proportion of 1:2:3:2:1, and the offsets are 0.2, 0.43, 0.65, 0.43, 0.2 mm, approximately. The width, length of the slot is 0.2 and 6.8 mm respectively which were optimized by Ansoft HFSS. The spacing between the last slot and the short face is set of $3\lambda g / 4$ and the width of the top metallic surface is set of 20 mm in order to get better radiation.

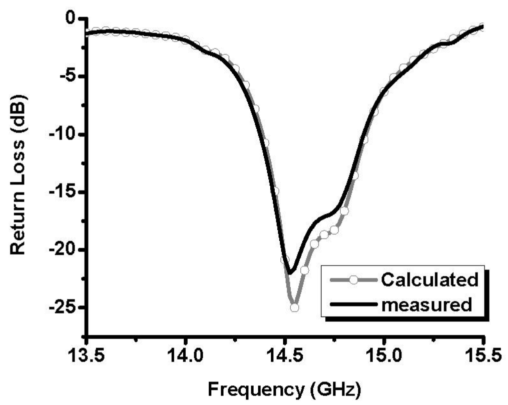

Figure 4. Return loss of the substrate slot array antenna

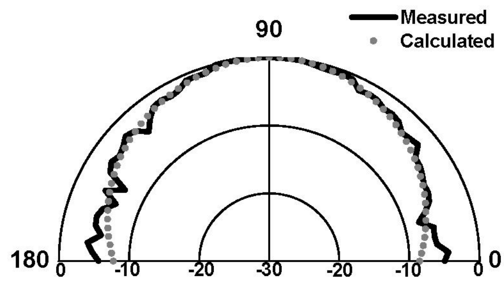

Figure 5. Measured and calculated E-plane radiation at a frequency of 14.5 GHz

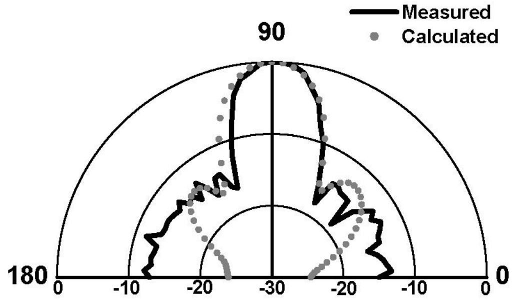

Figure 6. Measured and calculated H-plane radiation at a frequency of 14.5 GHz

The measured and calculated return loss of the SIW slot array antenna was measured from 13.5 to 15.5 GHz, and the result is shown in Fig.4. The return loss is less than 10 dB within a wide bandwidth of 500 MHz. The patterns of the SIW slot array antenna have been measured in far field chamber at a distance of about 5m (in order to be in a far field configuration). The transmitting antenna is a ridged horn BJ140, a pyramidal horn is used as a standard antenna for measuring the gain of this antenna, and the network analyzer is used for the measurements. The measured and calculated E-plane and H-plane patterns at 14.5 GHz are shown in Fig. 5, Fig. 6, respectively.

4 Conclusion

A SIW resonant five-slot array antenna has been presented, which is integrated on a single substrate. Featuring the direct integration, small size and low loss, the new structure is suited for the design of low-cost planar array antennas at microwave and millimeter-wave frequencies. The results show that this structure has much better directivity, gain but lower side lobe level than normal planar antenna. It has distinctive resonant performance, especially at the resonant frequency, the return loss is less than -20dB and the measured results show the availability of the SIW structure.

References

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