

Compact Two-Layer Slot Array Antenna with SIW for 60GHz Wireless Applications

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Introduction

In a variety of microwave and millimeter-wave applications where high performance antennas are required, waveguide slot arrays have received considerable attention due to their high aperture efficiency, low side lobe levels, and low cross polarization. Resonant slot arrays usually suffer from narrow bandwidth and high cost due to high precision required in manufacturing. Furthermore, because of using standard rectangular waveguides, the antenna array is thick and heavy and is not suitable for monolithic integration with high frequency printed circuits.

Recently, the concept of substrate integrated waveguides (SIW) has enabled RF engineers to take advantage of the low-loss transmission in rectangular waveguides within the printed circuit board [1]. SIW benefits from light weight, low cost, and compact size compared to conventional metallic waveguides and is perfect for monolithic integration with printed circuits. A few SIW-based slot array antennas that have been reported so far consist of one layer of substrate and are fed from one end through a coplanar feed network that significantly increases the size of the antenna [2]. Furthermore, radiation from microstrip feed lines can severely compromise the low side-lobe level of the slot array.

In this paper the design and manufacturing of a novel waveguide slot array antenna with two layers of substrate integrated waveguides is presented. This antenna which operates at 60GHz is very compact and is suitable for a variety of 60GHz applications which have become a hot topic recently [3]. The feed waveguide runs underneath the main substrate layer containing the slot array and is coupled to the branches of the array via slanted slots. The proposed feeding structure results in a considerable reduction in size and eliminates unwanted radiations from the feed network.

Design Procedure

Design procedure of waveguide slot arrays was presented by Elliott in [4,5]. In first step, we must develop a model for the shunt admittance of a longitudinal slot in terms of frequency, slot length, and slot offset from the waveguide axis. To do this, a single slot was simulated in Ansoft HFSS for a range of lengths, offsets,

and frequencies. The normalized admittance is extracted from the input scattering parameter of the above symmetrical two port network.

In second step, the feed structure is designed. A common mechanism for feeding waveguide slot arrays is a center-inclined slot [6]. Each coupling junction consists of a slanted coupling slot and a pair of straddling longitudinal radiating slots located a quarter wavelength away in the branch line. The slanted slot acts as an impedance transformer between the feed waveguide in the bottom layer and the coupled branch on the top layer where the radiating slots are located. This type of feed for conventional waveguide slot arrays has been extensively studied in the past [6]. In [6] it was shown that the effect of higher-order modes for soft coupling configurations, in the tilt range of 0 to 15 degree, are not significant. For hard coupling configuration, in the same range of tilt angles, amplitude is not affected significantly but phase error must be corrected. This is accomplished by tuning the length of two adjacent radiating slots in the coupling junction.

The last step is to design the substrate integrated waveguide. The propagation constant in SIW is determined by its width, the period and the diameter of metallic vias. In this work, the empirical equation given in [7] was used to calculate the propagation constant of SIW and its equivalent width. The main line of the array must be connected to a microstrip line which will accommodate for the input connector. Designing the transition from microstrip to a narrow SIW at 60GHz proves to be a challenging task. A novel transition consisting of two back to back tapered lines was designed and optimized using EM simulations to achieve the best return loss.

Finally, a computer program based on Elliott's design procedure was developed to find the lengths and offsets of slot radiators. Due to small thickness of SIW compared to its width, the internal higher order mode coupling between the adjacent radiating slots cannot be neglected and the modified design procedure presented in [5] was implemented.

Simulation and Measurement Results

Structure of the two-layer array antenna which consists of 16 elements in 4×4 configuration is shown in Fig.1 without the input microstrip feed line. It was designed with two substrate layers of RT Duroid 5880 from Rogers with $\epsilon_r = 2.2$ and thickness of 31mil each. The spacing and the diameter of metallic vias are 20mil and 12.5mil, respectively, and the tilt angle for all coupling slots is 8°. To fabricate the top layer, radiating and coupling slots were etched on both sides of a dielectric substrate. The bottom layer was fabricated from a dielectric layer with copper cladding on one side and it was attached to the top layer using low loss silver epoxy. The measured return loss of the array is shown in Fig. 2. The major factor in degradation of the return loss compared to the simulation results (not shown here) is the junction of connector to the input microstrip line which is not matched properly. The simulated return loss at 60GHz is -22.1dB. Simulation and

measured results for E-plane and H-plane patterns of the array are shown in Fig. 3 and Fig. 4, respectively. The measured gain of the array at 60GHz is 14.8dB and the simulated gain is 17.5dB. If we factor out the effect of lower return loss in measurements, the gain of antenna would be 15.3dB (referred to accepted power). The 2.2dB difference is mainly because of two reasons: (a) the actual dielectric loss at 60GHz is higher than what is considered in simulations, and (b) the addition of silver epoxy may substantially increase the loss in feed waveguide. The physical size of the aperture in this array is 14mm×16mm.

References

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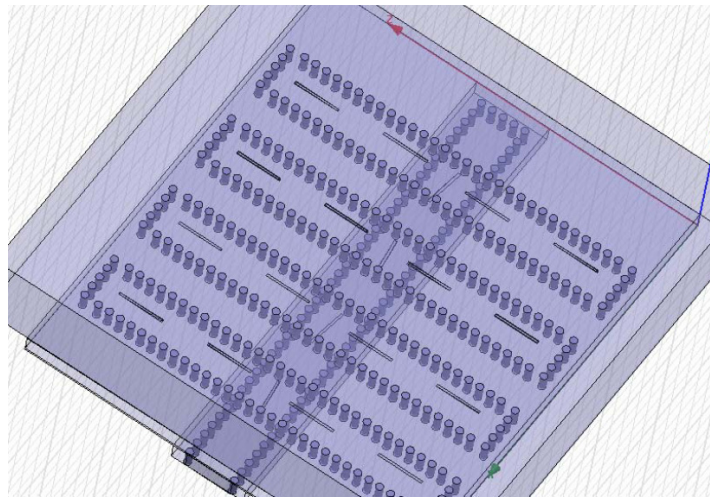


Fig. 1: 16 element integrated waveguide slot array antenna

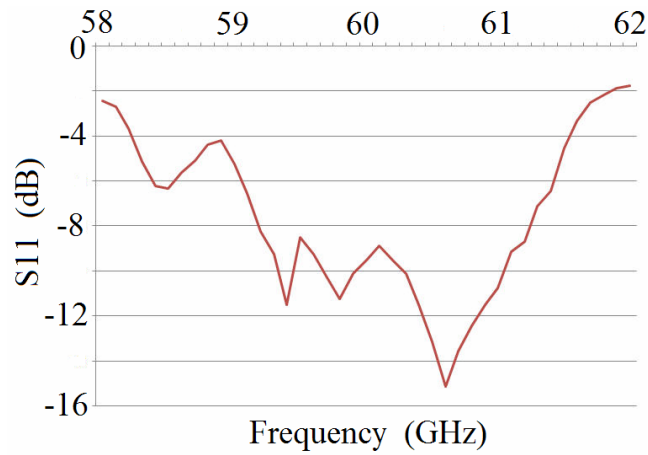


Fig. 2: Measured return loss

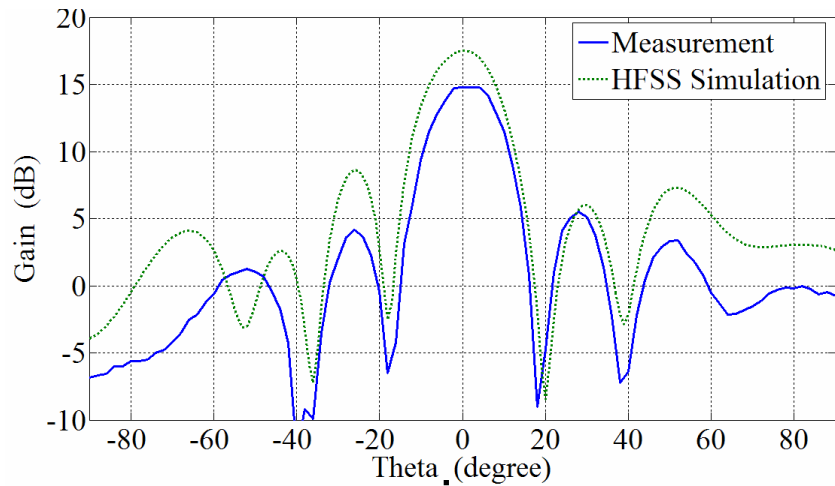


Fig. 3: Simulated and measured E-plane radiation pattern of the array at 60GHz.

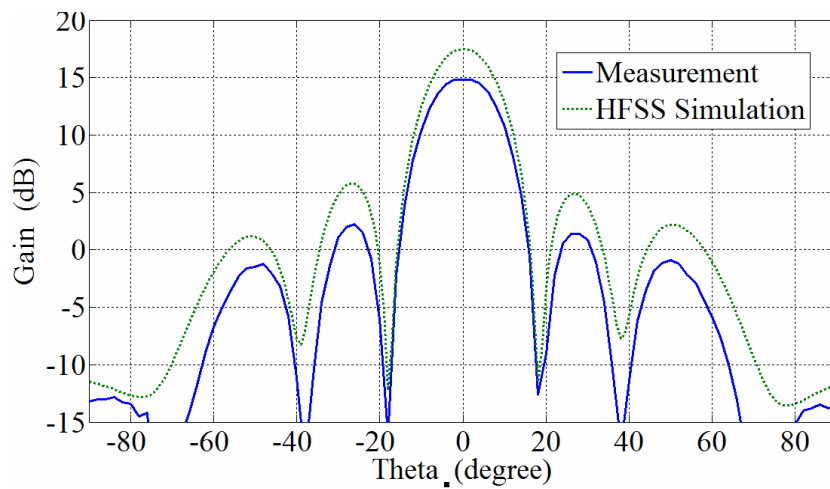


Fig. 4: Simulated and measured H-plane radiation pattern of the array at 60GHz.