28 GHz High Efficiency Planar Array Antenna with Hybrid Feed Network

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Introduction

Microstrip antennas and arrays have been widely used in military and commercial applications because of their ease of fabrication, low profile and low cost. In any microstrip array antenna, design of the feed network is always the most challenging task for which many different methods have been proposed. One method is to distribute the power to individual array elements by a coplanar microstrip network. A corporate (parallel) feed structure is the easiest to design, however, at higher microwave frequencies, antenna gain and aperture efficiency deteriorate significantly due to increase in losses of microstrip lines and unwanted radiation from the power distributing circuit [1]. A series-fed microstrip array can achieve a more compact size and better efficiency but still suffers from substantial losses in connecting transmission lines [1].

Hollow metallic waveguides can achieve extremely low loss up to very high frequencies and have been used in the feed network of slot arrays. Slotted waveguides have also been used to feed sub-arrays of microstrip patches [2,3]. In this approach, longitudinal slots on the broad wall of a rectangular waveguide are used to excite several rows of series-fed linear microstrip arrays. This hybrid design eliminates a substantial part of the feed loss and spurious radiation but compromises the low profile nature of the microstrip array. To alleviate this problem and still reduce the feed loss, in [4] substrate integrated waveguides were used as part of a corporate feed network for sub-arrays of circular patches.

In this paper, we propose a microstrip array antenna at 28GHz that utilizes a combination of coplanar feed network and slotted substrate integrated waveguide (SIW). The power is carried forward by a slotted SIW in longitudinal direction and each slot excites a row of series-fed rectangular microstrip patches in transverse direction. This combination significantly improves efficiency and is easy to fabricate using conventional PCB technology. The result is an array which is very well suited for fixed wireless access transceivers or LMDS applications.

The Coplanar Series Feed

Desired radiation pattern in a series-fed array can be obtained using identical patches with appropriate impedance transformers to control the amplitude and phase of each element. In a uniform array, the amplitudes and phases of all array elements are identical. To achieve equal phases without compromising directivity

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and at the same time to have enough space for etching adjacent patches without overlap, the distance between adjacent elements was chosen to be λ_g which is the wavelength in connecting microstrip line. Another approach would be to separate adjacent patches by $\lambda_g/2$ and put them on both sides of the connecting microstrip line alternately to compensate for the $180°$ phase change. In our design with a dielectric constant of $\varepsilon_r = 2.2$, the spacing between adjacent elements in terms of free-space wavelength is a little more than $\lambda_0/2$, thus, a higher directivity is obtained and no grating lobes appear. Now, in each branch of the array containing N series-fed elements, the input admittances of microstrip patches are simply added together and if these patches are identical they will all receive 1/N of the power delivered to that branch. In practice, the element spacing is not exactly λ_g in order to compensate for the T-junctions in microstrip lines.

Aperture Coupling Between Microstrip Line and SIW

Power is distributed in longitudinal direction by a SIW underneath the center of the planar array. The coupling between each branch of series-fed sub-array and the SIW is provided by a longitudinal slot on the broad wall of SIW. The presence of slots interrupts the current lines on the waveguide walls and displacement current replaces interrupted conduction current. This displacement current directs the energy from waveguide to microstrip line. Each coupling slot can be modeled by a shunt admittance whose real part represents the amount of energy coupled to the branch line and its imaginary part represents the energy stored around the slot. As slot is moved further from the waveguide axis more energy is coupled to the microstrip line and also more energy is stored. Imaginary part of the admittance is eliminated by tuning the length of slot. Real admittance occurs when the slot length approximately equals $\lambda_d/2$ or half wavelength in dielectric substrate. Note that the signals coupled to the microstrip lines on opposite sides of the coupling slot are $180°$ out of phase which must be accounted for in the design of array.

To extract the equivalent admittance of coupling slots, the structure depicted in Fig.1 is simulated. This junction has four ports but port 3 & 4 on the microstrip side will be connected to the matched input of series fed sub-arrays and, thus, we terminate these ports by a matched load and simulate the structure as a symmetrical two port. Then, the equivalent admittance of the slot is given by $Y_{eq} = -2S_{11}/(1+S_{11})$ where S_{11} is the input scattering parameter. The conductance and resonant length of a coupling slot vs. the slot offset is shown in Fig.2. Similar to conventional waveguide slot arrays, adjacent coupling slots here are separated by a distance $\lambda_W/2$ (λ_W is the guide wavelength in SIW) and placed alternately on the left and right of the waveguide axis. Thus, the antenna structure is now equivalent to M shunt elements each being a linear sub-array of patches and their admittances simply add up to give the total input admittance at the input port of the feed waveguide. Note that a short circuit must be placed a quarter wavelength away from the last slot.

64 Element Antenna Array

Based on the above procedure, an 8×8 uniform array at 28GHz was designed and simulated using CST Microwave Studio® 2006. The substrate material is low loss RT Duroid® 5880 from Rogers with 31mil thickness, $\varepsilon_r = 2.2$, and tanδ=0.0009. The complete array structure is shown in Fig.3 where the SIW is in the bottom layer. Overall size of the antenna is 71mm×57mm×1.64mm.

At first a linear sub-array composed of 4 microstrip patches with matched input without any impedance transformer is designed. Gain of each patch is 8.16 dBi. Then, multiple copies of this sub-array are placed on each side of coupling slots to construct the planar array. Since the array is uniform, the normalized equivalent admittance of each slot was set to 1/8 from which the corresponding resonant length and slot offset are determined using the data in Fig.2. To compensate the effect of coupling between adjacent patches, the actual slot offset must be slightly less than the design value. Return loss of the array antenna is shown in Fig.4 which shows 1 GHz bandwidth at -10dB. Radiation pattern of the entire array is shown in Fig.5. The antenna directivity is 24.4 dBi and its radiation efficiency is 87% with side lobe levels more than 12dB below the main beam.

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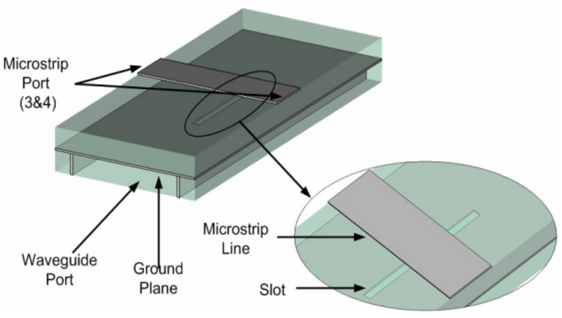

Figure 1. Coupling slot from SIW to microstrip

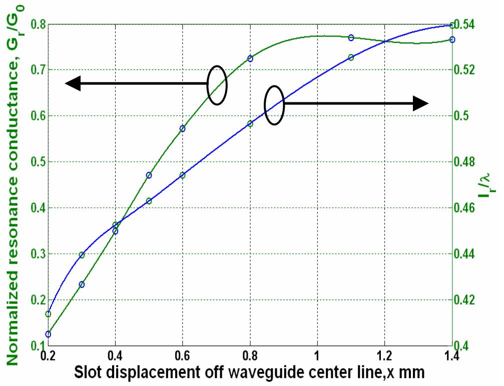

Figure 2. Slot conductance and resonant length vs. offset

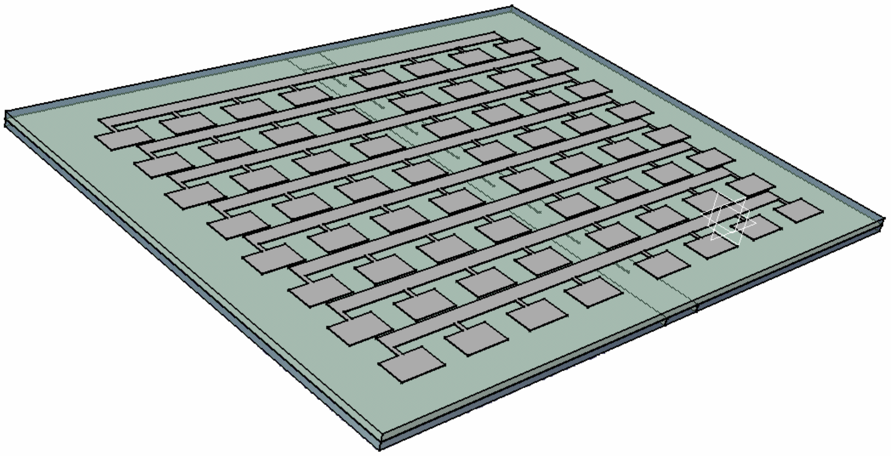

Figure 3: Two layer series-fed microstrip array with slot-coupled SIW feed line

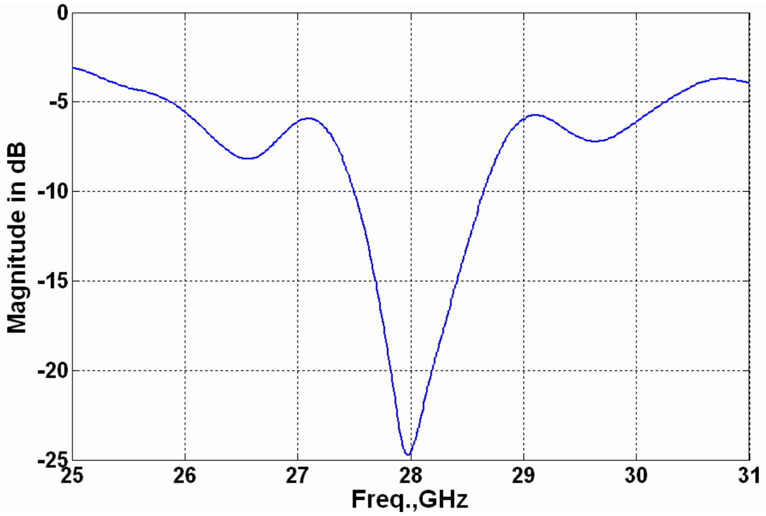

Figure 4. Simulated return loss (S_{11})

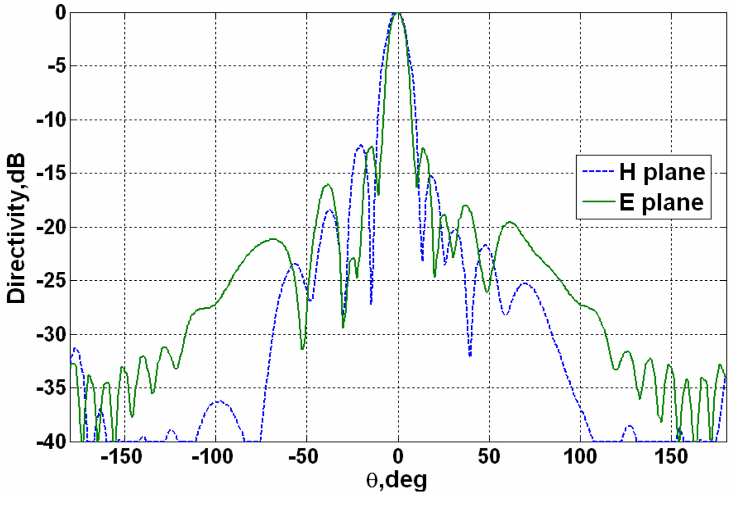

Figure 5: Simulation results for E- and H-plane directivity patterns of the array