A Low Profile 77 GHz Three Beam Antenna for Automotive Radar

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***Abstract* — The design and fabrication of a 76.5 GHz, planar, three beam antenna is presented. This antenna has greater than 31 dB of gain and sidelobes that are less than –29 dB below the main beam. This antenna demonstrates the ability to achieve very low sidelobes in a simple, compact, and planar structure. This is accomplished uniquely by feeding waveguide slots that are coupled to microstrip radiating elements. This illumination technique allows for a very low loss and highly efficient structure. Also, a novel beam-scanning concept is introduced. To orient a beam from bore sight it requires phase differences between the excitations of the successive elements. This is achieved by varying the width of the W-band waveguide. This simple, beam steering two-dimensional structure offers the advantage of easy manufacturing compared to present lens and alternative technologies.**

I. INTRODUCTION

Automotive applications, such as intelligent cruise control (ICC) and collision avoidance radar, require highly directional antennas that are capable of distinguishing targets in a predetermined field of view. These antennas can be switched beam arrays, but must have very low sidelobes. This is crucial as side lobes lead to false alarms in a collision avoidance radar system and in ICC applications they can lead to false tracking of vehicles. These antennas must be low in cost to manufacture and as small as possible. The automotive manufacturers typically dictate the size constraint, so that minimal changes need to be made to the automobiles' structure. At least three beams are needed for most Automotive Radars. There are various ways to achieve this beam scanning: mechanical scanning, switching between antenna feeds, frequency scanning, etc.

Two of the more prominent technologies employed for automotive antennas at 76.5 GHz are microstrip patch antennas and folded optical lens antennas. Both of these types of antennas have their own advantages and disadvantages.

Folded optical lens antennas have been used in the industry for over 10 years. The main advantage of these antennas is that they have very little feed loss, thus yielding a high amount of gain for a given surface area. One of the disadvantages of this type of antenna is the blockage on the antenna due to the 3 feed ports. This blockage limits the achievable sidelobe level. Another disadvantage to this antenna is the necessary volume to achieve the beam forming via the focal point. Even an innovative folded optical antenna requires almost one and a half inches of depth at 77 GHz. This is troublesome, when it comes to integrating the radar into the grill or front bumper of an automobile. As there are typically obstacles (radiator, etc.) interfering and space is at a premium.

The main advantages of microstrip patch antennas are their low profile and suitability for a low-cost mass production. However, they can suffer from their enormous feed loss for high-gain large aperture arrays. D. Pilz and W. Menzel have used planar folded reflect array antenna to overcome this problem [1].

The novel design approach presented in this paper circumvents these limitations by performing the feed network in waveguide and the radiating structure in microstrip. The microstrip lines are coupled to the slots on the broad wall of the waveguide. These lines feed the microstrip patch radiators. This feed structure will result in reduced feed loss and hence enhanced gain for a given radiating aperture area. Also, it is easier to control the amplitude/phase distributions of the elements in the waveguide-slot feed structure than the microstrip distribution network. Moreover, the waveguide milling is an integral part of the supporting base plate, and hence it does not require any extra space or component.

This paper also presents a novel beam scanning concept: Three distinct waveguide feeds (of different widths) are used, each for a beam of particular angle. These waveguides are designed to have predetermined phase accumulations, thus yielding three distinct, directed antenna beams. A unique feature of this design is that all three waveguides share the same antenna. This allows for a smaller overall aperture. The waveguide feed serves as a very low loss mechanism for distributing the RF energy at 76.5 GHz.

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Proper implementation of the illumination function is key to the success of this project. To design these illumination functions, three-dimensional analysis is required. Modeling tools such as Momentum, IE3D and HFSS have been used in modeling these feed networks and antenna arrays.

II. ANTENNA TOPOLOGY AND DESIGN METHODOLOGY

The antenna is constructed in two parts. The first part is a plate that serves as a supporting structure and feed network. The feed network consists of three waveguides. The second part is the microstrip antenna board that is fabricated on Taconics TLY-5 material. It is etched on both sides. The slots are etched on the bottom side which serves as the top wall of each of the waveguides. It is conductively adhered to the plate. The slots then transition the energy to the microstrip feed structure on the top side where the power is radiated by patch elements. The design of the feed networks and microstrip arrays is described below.

A. Waveguide-Slot-Microstrip Feed Design

The microstrip patch radiators are fed via transmission lines each connected through the slots along the rectangular waveguide. A WR10 waveguide is used for the boresight beam. In this case, the slots are placed a half-wavelength (in the waveguide) apart. Alternate displacement of the slots along the center axis of the waveguide gives another 180 degrees phase shift between the slots, resulting in a zero degree phase shift required between the excitation amplitudes for the beam normal to the waveguide axis. This “resonant” slot design has a short circuit placed a quarter wavelength away from the center of the last slot. To accomplish +/- 3.5 degrees beam scanning, two waveguides that have slightly different widths than the WR10 are used. These widths are chosen to achieve the extra phase accumulation along the slots for the beam scanning. For example, to steer the beam +3.5 degrees, each element that is fed in series lags the other by 16 degrees. For scanned beams, the “traveling” wave design is used to design the slots.

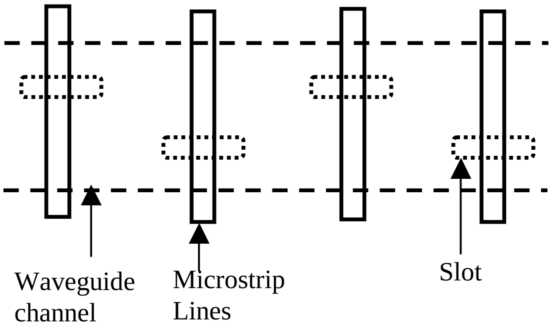

Fig.1: Slots in a rectangular waveguide coupled to microstrip lines

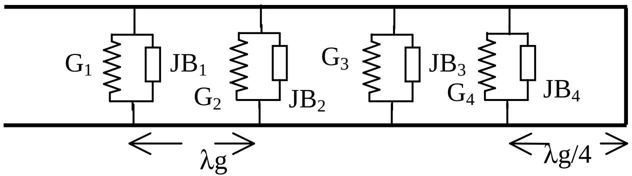

Fig.2: Equivalent circuit of the above geometry

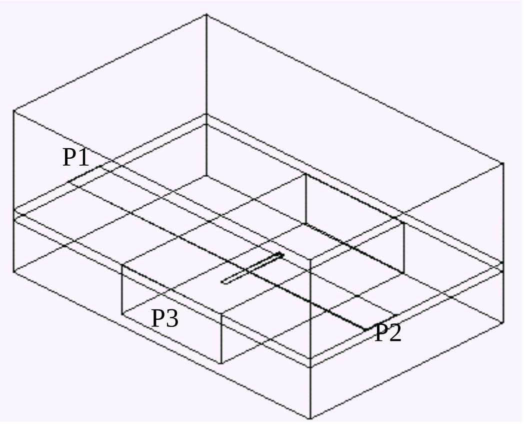

Fig.3: Single Waveguide-Slot-Microstrip Transition

Microstrip Ports: P1, P2; Waveguide Port: P3

A Dolph-Chebyshev excitation amplitude distribution is chosen along the slots to achieve low side lobe levels. 28 elements or slots are chosen. The waveguide-slot-microstrip feed geometry is shown in the Figure (1). The input power to the waveguide is distributed among the slot-coupled microstrip lines in accordance with the excitation amplitudes of the Dolph-Chebyshev distribution function. This is done by designing slots such that they provide the proportionate conductances in the waveguide.

Figure 2 shows an equivalent circuit model of a microstrip coupled, slotted, waveguide feed. The broadside-coupled waveguide slots are represented by shunt elements: the radiation conductance G and the susceptance jB. Several papers deal with modeling of waveguide slots radiating into free space. But the fact that the slots are coupled to the microstrip lines (rather radiating into free space) complicates modeling. In the case of a resonant array for a broadside beam, since all the slots are 360 degrees apart, the equivalent input impedance of the waveguide is the

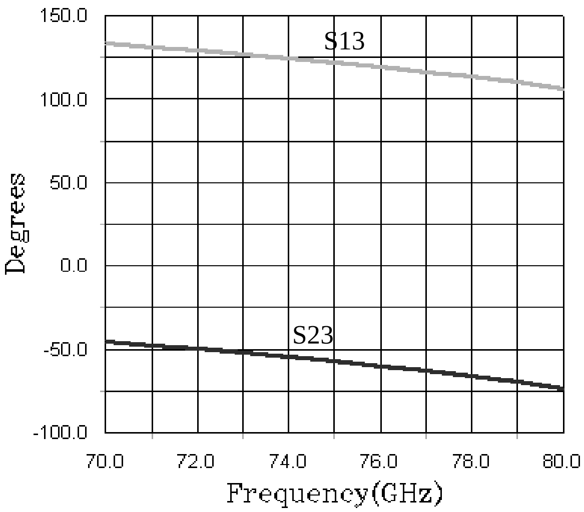

Fig.4: Phases of Signals coupled to the microstrip ports from the WR10 waveguide. Slot width = 5 mils.

sum of all the individual slot admittances. The power coupled to the i^{th} slot is ½ $V_i^2 g_i$, where g_i is the normalized slot conductance and V_i is the equivalent voltage that appears across the i^{th} slot.

The conductance g of a slot is a function of the slot width, the slot offset and width of the coupled microstrip lines [2]. The HFSS geometry used to calculate the slot conductance is shown in the Figure 3. Note that the signal powers coupled to the two microstrip ports through the slot are equal but 180 degrees out of phase (see Figure 4). The variation of coupling (S13 or S23) as a function of the displacement of the slot is plotted in Fig. 5.

Figure 6 shows the typical phase variations (as a function of frequency) of some of the signals coupled to the microstrip ports (through slots). We can see that the phases are almost equal over a frequency bandwidth of almost 1 GHz, and diverge thereafter. This indicates that at least 1 GHz of bandwidth can be obtained from the resonant slot design.

B. Microstrip Antenna Design

A microstrip array pattern fed from waveguide slots is shown in Figure 7. We can see that the microstrip length between the slot and the first microstrip patch is larger on one side of the slot than the other side. This is to account for the 180 degrees phase difference of the slot-coupled ports. As the energy propagates along the microstrip patch axis, some power is coupled off to the patch elements. Similar to the azimuth design (waveguide slot axis), this coupling sets the weighting function for the amplitude function, which determines the antenna parameters such as the side lobe levels and 3-dB beam width. The patches are spaced one microstrip-wavelength apart. The design/analysis of the microstrip patch itself is a relatively simple task.

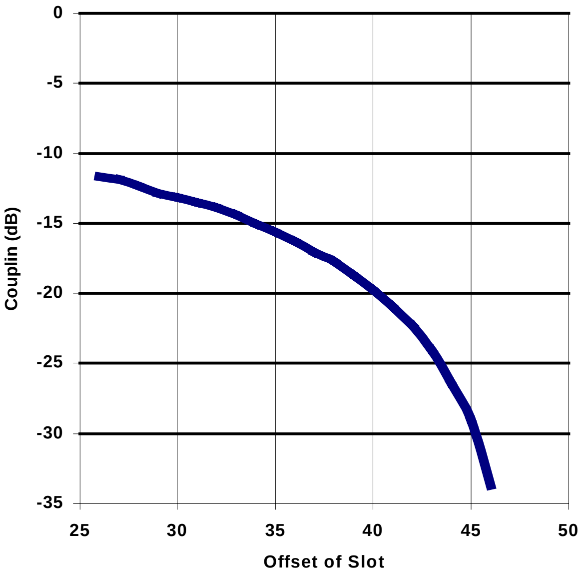

Fig. 5: Variation of coupling versus slot displacement

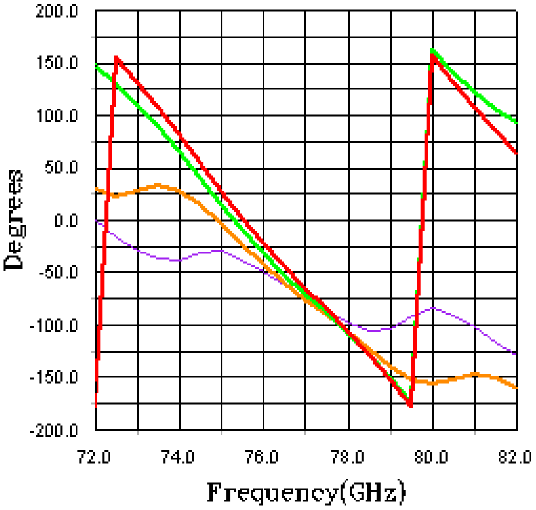

Fig. 6: Phase deviation of the coupled signals at the microstrip ports coupled to the slots

III. EXPERIMENTAL RESULTS

A 28x36 element microstrip antenna array was built and tested. The overall antenna size was approximately 4.4 by 3.6 inches. The measured antenna gain in the main (zero) degree beam is greater that 31 dB at 76.5 GHz.

A. Azimuth Results

The measured azimuth radiation pattern for the boresight or the zero degree antenna beam is plotted in Figure 8. The 3-dB beam width is 3.0 degrees and the primary sidelobe is at –30 dB.

By switching between similar waveguide ports, three scanned beams having similar characteristics as the center beam can be obtained.

B. Elevation Results

The measured elevation pattern for the center (zero) degree beam is plotted in Figure 9. The 3-dB beamwidth is 3.2 degrees and the first primary sidelobe is at -24 dB. It should be noted that the sidelobes reduce very rapidly as a function of angle. This is important because sidelobes in the elevation plane illuminate road over-passes and the ground. Illumination on the ground can significantly increase the noise/ground clutter in a radar system. This reduces the overall signal/noise of the radar.

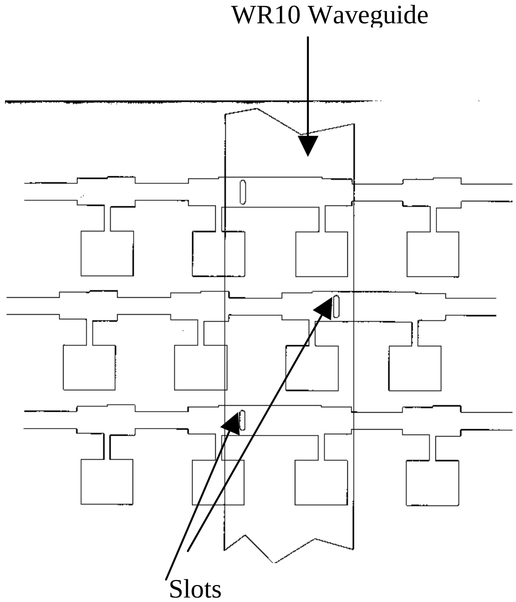

Fig.7: Microstrip Array Pattern fed by slots in a waveguide

IV. CONCLUSIONS

The principle, design and measured results of a planar, low profile three-beam antenna for automotive applications were presented. Employing waveguide fed slots has considerably reduced the array feed loss. An initial design has been analyzed, fabricated and evaluated. Some deterioration of the sidelobes has been observed due to the stray coupling from the main guide (which feeds the main beam) to the secondary waveguides (which feed the +/-3.5 degree beams) and vice versa. Improvements to further improve this performance are underway.

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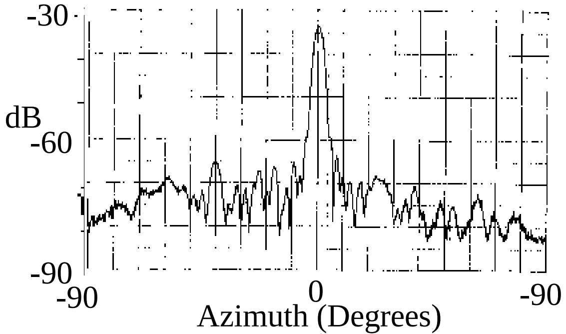

Fig.8: Radiation pattern of the boresight beam in the azimuth direction

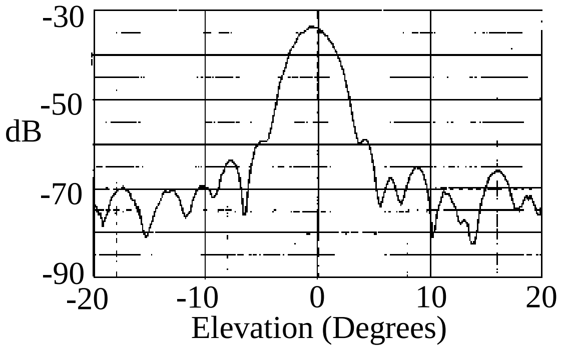

Fig.9: Radiation pattern of the boresight beam in the elevation direction