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A Frequency-Scanning Substrate-Integrated-Waveguide Meanderline Antenna for Radar Applications at 60 GHz

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Abstract - ***This paper describes the design and characterization of a frequency-scanning meanderline antenna for operation at 60 GHz. The design incorporates SIW techniques and slot radiating elements. The amplitude profile across the antenna aperture has been weighted to reduce sidelobe levels, which makes the design attractive for radar applications. Measured performance agrees with simulations, and the achieved beam profile and sidelobe levels are better than previously documented frequency-scanning designs at V and W bands.***

Keywords—Frequency-scanning; Meanderline; Antenna; Slot; Substrate Integrated Waveguide (SIW); 60 GHz; V-band; Radar.

I. INTRODUCTION

Antenna design is an important aspect of system design for radar applications. Key parameters include the antenna gain, beam profile and sidelobe level, amongst others. Radars typically use antennas having fixed beams that are mechanically rotated or fixed antennas incorporating electronic beam steering [1]. Electronic steering is often achieved using active elements in a phased array. Radars using phased arrays can achieve high performance but at the expense of cost and power requirements. At millimeter-wave frequencies, this approach might be prohibitively difficult.

Frequency scanning of the antenna beam is an alternative to phased arrays[2], which has previously been used to design a radar antenna at 60 GHz for the detection of fast-moving objects[3][4][5]. More recently, a variant has been designed for 77 GHz [6]. The described antennas were lightweight and cost effective owing to the use of substrate integrated waveguide (SIW) techniques. However, their documented performance was modest [3][6].

This paper describes the design and characterization of a frequency-scanning meanderline antenna for operation in the 60 GHz band (57-64 GHz) that improves on the antenna radiation characteristics. This design also uses SIW techniques but adopts an alternative approach to the slot-element design. Additionally, the amplitude profile across the antenna aperture has been weighted to reduce sidelobe levels, which makes the design much more attractive for radar applications.

II. DESIGN AND SIMULATION OF FREQUENCY-SCANNING ANTENNA

A. Substrate Integrated Waveguide Design

Deslandes provides practical design guidelines for SIW structures [7]. The spacing of the SIW via rows was selected to give an equivalent solid waveguide a-dimension of 2.5 mm. Rogers RT/duroid 5880 was chosen because of its low-loss characteristics at mm-wave frequencies. The laminate thickness was 0.031” (~0.79 mm).

B. Slot Element Design

The resonant length, L, for a radiating slot element in SIW is given by [8]:

$$L = \lambda_0 / [2(\varepsilon_r + 1)]^{1/2} \quad (1)$$

where λ_0 is the wavelength in free space and ε_r is the relative permittivity of the substrate used for the SIW. Longitudinal slots elements were chosen for this design to minimize cross-polar radiation [9]. By contrast, other researchers have used tilted slots [3] or bowtie slots [6], which result in substantial cross-polarization and degraded sidelobe levels.

C. Meanderline Considerations
In reference [3], the electrical length of the meanderline between adjacent slots was 900°, which resulted in a limited scan-angle range. For the proposed design, an electrical length of 1440° was chosen to give a larger beam-steering excursion without incurring too much loss in the SIW meanderline.To achieve a narrow azimuthal beamwidth, 32 slots were used. The slot element positions were adjusted relative to the meanderline centre to obtain weighting of the overall array amplitude profile, thereby reducing antenna sidelobe levels, which can be detrimental to radar system performance.

D. Simulation
SEMCAD X (FDTD method) was used to simulate the SIW meanderline antenna design [10].

III. MEASUREMENT OF FREQUENCY-SCANNING ANTENNA

Fig. 1 shows a close-up photograph of the fabricated 32-element SIW meanderline antenna in which the closely spaced vias and radiating slot elements are clearly visible.

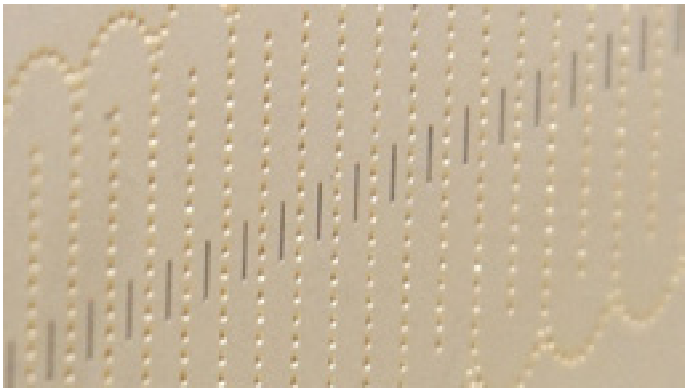

Fig. 1. Close-up photograph of 32-element SIW meanderline antenna showing closely spaced vias and radiating slot elements

The measured antenna return loss is, in general, better than 10 dB over the frequency range 57-64 GHz, except for a peak at ~61.7 GHz, which corresponds to the antenna boresight frequency where mismatches at each radiating slot element add in phase. The fabricated design operates ~2% higher in frequency than expected from simulation, which is most likely related to modelling simplifications and manufacturing tolerances.

The antenna radiation pattern was measured using a planar near-field scanner to give azimuth and elevation measurements over ±60°. The normalized azimuthal radiation pattern is shown in *Fig. 2.* The frequency scan characteristics are fairly linear between 59 64 GHz; from ~+43° down to ~−25° (~68° total angular excursion or ~13.6°/GHz). The azimuthal 3-dB beamwidth varies between ~4°-6°, while the elevation beam is inherently broad (~90°) because of the single row of radiating slots. Sidelobe levels are low – typically below −20 dB – which is better than previously published work using a SIW meanderline structure at 60 GHz and 77 GHz [3][6].

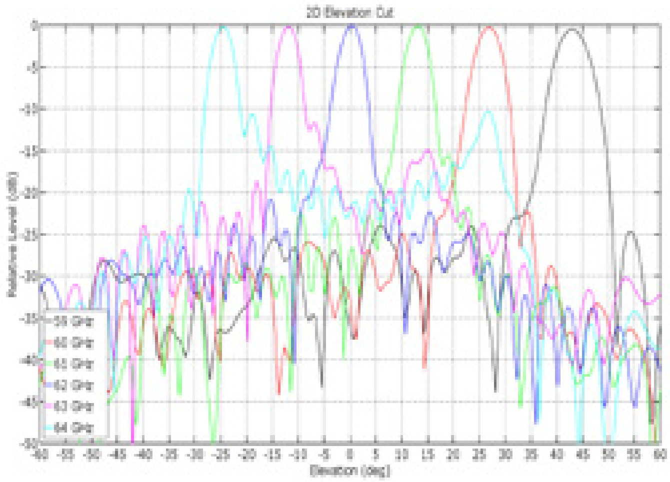

Fig. 2. Measured azimuthal radiation pattern (normalized)

The measured gain of this antenna varies between ~7 12 dBi over 59-64 GHz with the gain tending to reduce with increasing frequency as a result of the slot design being optimized for a lower boresight frequency than was realized. A slight gain reduction is observed at ~62 GHz owing to the antenna-boresight impedance mismatch.

IV. FURTHER WORK

The antenna-boresight impedance match might be improved. Adjustment of slot dimensions might help maximize the gain and reduce the gain variation over the band of interest. Optimization of slot placement might reduce sidelobe levels further. Finally, a sectoral horn array in front of the slots could provide additional gain and reduce the elevation beamwidth.

V. CONCLUSION

This paper has presented the design and characterization of a 32-element SIW meanderline antenna using slot-radiating elements. Measurements agree well with simulation results. The measured performance of this antenna is an improvement on previously described work using similar antenna designs for radar applications at 60 GHz and 77 GHz.

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