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10-GHz ANTENNA ARRAY WITH SUBSTRATE INTEGRATED WAVEGUIDE PLANAR FEED NETWORK

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Abstract- A10-GHz tapered slot antenna (TSA) array of 1×8 elements is designed and fabricated using substrate integrated waveguide (SIW) technology. TheSIW binary splitters in the feed structure is utilized to minimize the feed structure insertion losses and achieve a broadband performance in X-band range.Unlike previous antennas with SIW technology, the proposed antenna array has wider impedance bandwidth (BW) and much better gain. The fabricated antenna array hasdimension of 190×130 mm^2.The simulated and measuredimpedance BWand radiation patternsare studied andcompared to demonstrate validity of this design.

I. Introduction

SIW is a synthetic rectangular waveguide (RW) formed in a dielectric substrate by arraying via-holes rather than solid fences. These posts can be either metallic posts or dielectric posts with a permittivity different from the background medium. Since SIW technology invention, a wide range of SIW components, such as phase shifters, transitions, filters, power dividers and couplers have been proposed and studied [1], [2]. Due to the easy integrating of SIW structure with feed network, it is good candidate to fed the leaky-wave antenna or the surface–wave antennas. The exponentially tapered slot antenna (ETSA) belongs to the class of end fire travelling wave antennas, which has theoretically infinite bandwidth is one of these choices. Compared to other wideband antennas, the ETSAs have moderately low profile, planar structure, easy to integrate, high directivity, low cross polarization, and symmetric beam in both H- and E-planes.

In the proposed SIW antenna array design, we used a microstrip-to-SIW transition to fed the planar SIW feed network. The SIW feed network with high performance is used to fed TSA cells to form high gain antenna arrays for X-band applications. The proposed feeding network and TSA are integrated on a substrate with thickness $h$of $0.508\ \mathrm{mm}$, dielectric constant ε_r of 3.55. Due to the high input impedance of TSA elements and low impedance of thinner SIW (thin substrate), integration of feeding system and TSA elements will be the main challenges of the proposed design.The good agreement between simulated and measured electrical performance of the proposed SIW antenna array confirms the advantages of this array. A high directivity and narrow beamwidth of the measured radiation patterns over the 8 to 12 GHz frequencies make it a viable choice for many applications.

Single cell TSA and array Configuration: The initial single TSA cell dimensions were obtained using [1] TSA equations to speed up the design process. The proposed single TSA cell is implemented on Roger RO4003 substrate with thickness of 0.508 mm and permittivity of 3.55(±5%).In this structure, instead of using balun, a SIW feed has been used, to integrate TSA cells and SIW feeding network,as shown in Fig.1.In the proposed antenna array structure, to prevent mismatching between high input impedance of the conventional TSA (≥ 100) and low impedance of thin SIW (thin substrate), we let the TSA metal curves to overlapped with each other. As shown in Fig.1, an optimized TSA was designed with following dimensions: $L_{ant} = 30mm$for antenna length, $W_{ant} = 25mm$for antenna width and $W_1 = 3.3mm$ for the envelope of metal flares. The proposed single TSA antenna impedance bandwidth ($\leq -10\ \mathrm{dB}$) cover 7.15 to 12.5 GHz frequencies or almost 54.4% at the central 10 GHz frequency. As shown in Fig. 1, a SIW waveguide is composed of parallel via-holes. The actual width of the SIW transmission line is $\mathrm{W_{SIW}} = \mathrm{a} = 12.1\mathrm{mm}$, the diameter of via hole is $2\mathrm{r} = 1\mathrm{mm}$ and the via spacing is d for minimum radiation, conduction and dielectric losses. The normalized SIW waveguide width is gotten from Deslandesformula [3]. As shown in Fig. 2,three stage SIW binary divider used to realize a 10-GHz SIW eight way divider. The input signal is entered from the Microstrip-to-SIW transition, and it is equally divided into two branched by an SIW T-junction with an inductive post. The discussed feed network array construction is based on the combination use of optimized 90° curvature, T (T-shape) and Y (Y-shape) type junctions. Here the SIW guides have $0.4\lambda(12.1\mathrm{mm})$width for single mode ($\mathrm{TE_{10}}$) operation over operating band. As shown in Fig.2, an H-plane T-junction is constructed from two H-plane bends. The T-junction is a three port structure whose port planes are not parallel. The proposed H-plane T-junction requires at least one inductive viapost to improve impedance matching entire the band. An optimal position of the proposed matching post were studied with simulations.In the proposed SIW antenna array, due to increasing the elements space, it is expected that the mutual coupling effect will be reduce. On the other hand, as mutual coupling decreases, the size of the array and grating lobes in higher frequencies will be increase. From the simulation results, we have found that the optimum spacing is 0.8λ. So for the 0.8λTSA elements space, it seems that the mutual coupling effect will not very significant. As shown in Fig. 2, the proposed sub array is formed by eight TSA elements. In the proposedarray design, the separation between the TSA elements were selected to be 0.8λ.Theproposed SIW arrayis optimized to achieve the maximum gain and impedance bandwidth characteristics. Two 1×4 sub-arrays is used to form proposed 1×8 array structure.The proposed array was printed on Rogers4003 material.

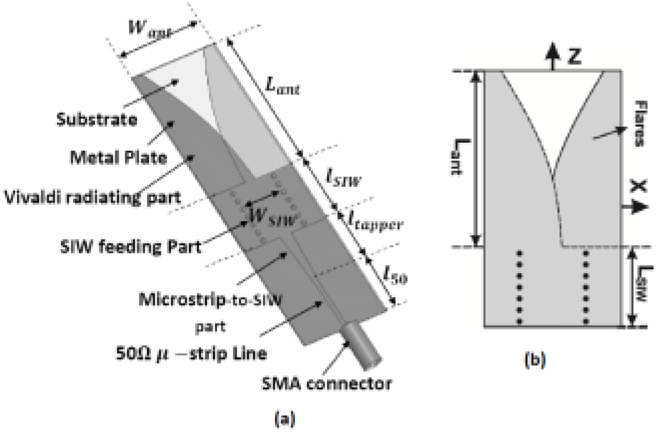

Fig.1(a) Configuration of the proposed experimental single cell Vivaldi antenna (b) Exponentially tapered slot antenna.

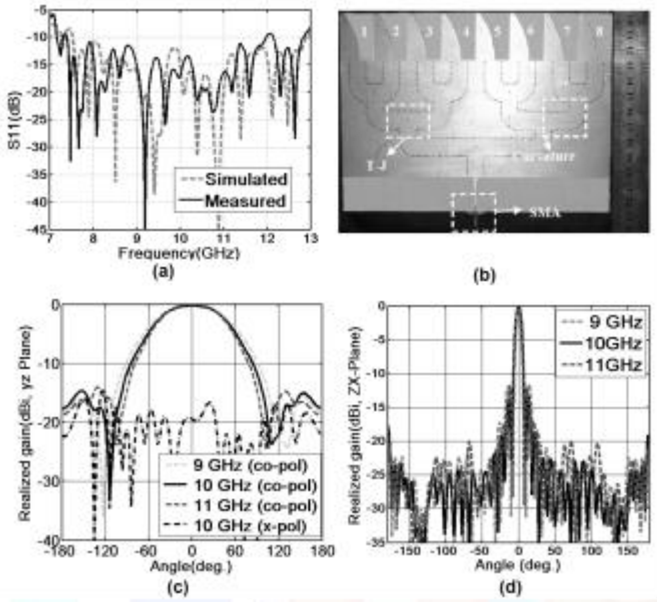

Fig. 2(a) Measured and simulated S-parameters of 1×8 SIW antenna array. (gray dash line denotes simulated results and black solid line denotes measured results); (b) Photograph of the fabricated 1×8 SIW antenna array. Inset shows a photograph of fabricated parts such as curvature, T type junction and SMA connector;(c) Measured Co- and X-Polar H-Plane response of 2nd array at 9-, 10- and 11-GHz. (gray dash line denotes 9-GHz results, black solid line denotes 10-GHz results, black dash line denotes 11-GHz results and black dash dot line denotes 10-GHz x-polar results); (d) Measured Co-Polar E-Plane response of 1×8 SIW antenna array at 9-, 10- and 11-GHz. (gray dash line denotes 9-GHz results, black solid line denotes 10-GHz results and black dash line denotes 11-GHz results);

II. Results and Discussions

The simulated and measured S-parameters of the eight elements TSA array is illustrated in Fig.2(a). The proposed antenna bandwidth spans from $7.67\ GHz$ to $12.72\ GHz$ at $10\ GHz$. Fig.2(b) shows the realized eight element SIW antenna array. Due to fabrication tolerance errors and additional losses during test process differences between the simulated and measured results is achieved. The measured radiation patternsare obtained by using rotating standard horn antenna and an Agilent 8722ES network analyzer. The measured radiation pattern results for the proposed array antenna for *E*- and *H*- planes in different frequencies are shown in Figs.2(c) and (d). From the obtained results in Figs.2(c) and (d), it is observed that the radiation patterns are directive and symmetrical in both planes. Fig.2 (d)show the co-polar zx-plane radiation patterns of the proposed array at 9-, 10- and 11-GHz. At 10-GHz, the 3-dB beamwidthis 8°. First sidelobes of 10-GHz radiation pattern in E-plane appear at $\pm 13^{\circ}$. As shown in Figs.2(c) and (d), all responses are 13 dB below the main beam averagely. Fig. 2(c) shows the co- and cross(X)-polar H-plane responses at 9-, 10- and 11-GHz without any significant sidelobes. The measured 3 dBbeamwidth radiation pattern at 10 GHz is 100° degree. The measured maximum gain for the proposed eight element array is$17.5\ dBi$ at 12.5 GHz. Moreover, the measured radiation efficiency is about 87%. The overall size of the proposed 1×8 SIW sub-array structure was $190mm \times 130mm$.A high directivity of the proposed array over the operating band ($i.e., 8 \sim 12GHz$) frequencies with narrow half power beam width angle, allow a very close scanning angle unlike standard horn antenna. Therefore, our design properties such as good bandwidth and a $17\ dBi$gain, highlight its potential for multi beam antenna and beam forming systems.

III. Conclusion

A SIW antenna array operating at X-band carried out in this work. The proposed array design is based on Substrate Integrated Technology. This configuration was constructed by microstrip-to-SIW transition, SIW feeding and TSA elements. The experimental results verified the proposed design and offers the conception of high gain antennas ($17.5\ dBi$ was reached). The simulated and measured electrical performance of the SIW array antenna such as S-parameters and gain are in good agreement with each other.

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