Single-Layer End-Fire Substrate Integrated Waveguide Antenna Systems

Sara Salem Hesari, Chad Bartlett, Jens Bornemann
Department of Electrical and Computer Engineering
University of Victoria
Victoria, BC, Canada

Yu Luo
School of Microelectronics
Tianjin University
Tianjin, China

***Abstract*—This paper presents an overview of a group of substrate integrated waveguide (SIW) antenna design activities at the University of Victoria. Emphasis is placed on single-layer SIW prototypes with end-fire characteristics which can be fabricated by conventional printed-circuit board techniques. Examples highlight antenna combinations for circular polarization, a system for tracking applications, a Butler matrix, and right-angled power dividers as feed components. Individual antenna elements include SIW horns, an antipodal printed dipole and antipodal Vivaldi elements.**

***Keywords*—substrate integrated waveguide; printed-circuit antennas; feed systems.**

I. Introduction

Substrate integrated waveguide (SIW) antenna and beam-forming technology is widely used in various millimeter-wave applications [1]. Many antenna elements and arrays are created by introducing slots in the top SIW metallization [1, 2] which quite often results in a dual- or multilayer application, e.g. [2]. Moreover, such systems are broadside arrays with radiation perpendicular to the substrate plane. For some applications, radiation in the substrate's plane, i.e., end-fire, on a single substrate layer is required, because such systems are easy to fabricate and allow stacking of individual antenna boards.

Therefore, this paper focuses on single-layer end-fire SIW antenna systems. We use antenna elements which lend themselves to easy integration which SIW technology, such as SIW horns, antipodal dipoles and antipodal Vivaldi antennas. They are demonstrated in SIW systems involving circular polarization, a tracking system based on sum and difference ports, a 4x4 Butler matrix and right-angled power divider feeds for Vivaldi arrays.

II. SIW Antenna Systems

The first two examples demonstrate that circular polarization (CP) can be created when using end-fire SIW systems. Fig. 1 shows an SIW horn-dipole combination [3] that provides five percent bandwidth for 3 dB axial ratio and a return loss better than 10 dB. Moreover, due to the Potter horn and dipole designs, a very directive CP beam in the plane of the substrate is achieved and, therefore, the gain is significantly higher (7.5 dB) than those of previously reported similar antennas, e.g. 2.5 dB in [4].

Another way of creating end-fire circular polarization with a single-layer SIW circuit is to combine an SIW horn for vertical polarization with a Vivaldi antenna for horizontal polarization [5]. Fig. 2 shows such a system. The 90-degree phase difference between the two elements is achieved by using a 3 dB hybrid. This CP end-fire system operates between 23 GHz and 27 GHz with a return loss better than 10 dB. The results show that the proposed antenna system obtains a wideband 3-dB axial ratio from 24.25 to 26.5 GHz and a high and uniform gain of almost 8 dB.

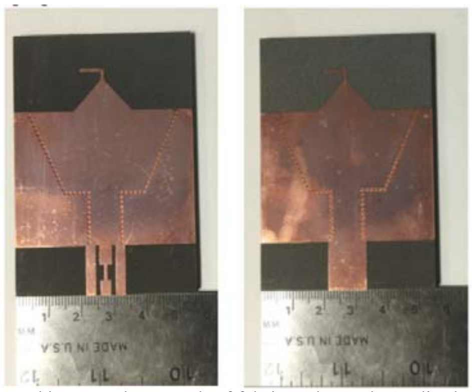

Fig. 1 Top and bottom photograph of fabricated SIW horn-dipole antenna.

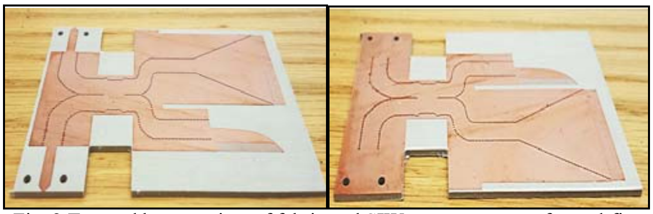

Fig. 2 Top and bottom view of fabricated SIW antenna system for end-fire circular polarization.

Fig. 3 shows a single-layer end-fire SIW system for tracking applications [6]. It comprises two Vivaldi antennas, two SIW cross-overs and an SIW sum/difference power combiner. Both crossovers and the power combiner provide 3rd/2nd order filtering functions which eliminates the need for subsequent filtering. The system operates at a center frequency of 23.9 GHz with 540 MHz bandwidth. The maximum achievable gain is 6.2 dB at mid-band frequency, and a 30-degree field of view is obtained. Moreover, the proposed system has an on-axis isolation performance of better than 25, 22, and 27 dB in the difference port at 23.7, 23.9, and 24.1 GHz, respectively.

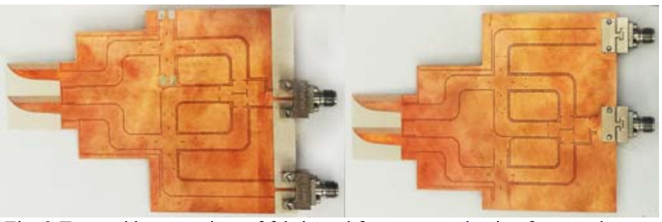

Fig. 3 Top and bottom view of fabricated frequency-selective front-end system for tracking applications.

A 25 GHz SIW 4x4 Butler matrix feeding four Vivaldi antennas is shown in Fig. 5 [7]. In contrast to [8], which shows the Butler matrix circuit only, our design also includes practical feeding ports and antennas. The system demonstrates a ±25º sweep of the main beams as well as a gain that ranges between 8.7 dB and 11.7 dB over a 3 GHz bandwidth centered at 25 GHz. Both measured return loss and isolation values are better than 10 dB over the entire bandwidth of operation.

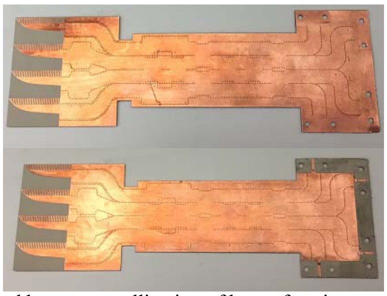

Fig. 4 Top and bottom metallization of beam-forming antenna system.

A novel SIW feeding technique for planar antipodal Vivaldi arrays is shown in Fig. 5 [9]. Contrary to inline divider feeds, e.g. [10], our designs consist of right-angled power dividers that allow the phases of the output ports to be changed so that different array performances can be obtained. Several circuits are designed on a single layer of Rogers 6002 substrate with relative permittivity of $\varepsilon_r = 2.94$ and thickness $h = 508$ µm which make them low profile, compact, low cost, and easy to fabricate. The antenna array system including a two-way power divider (left circuit in Fig. 5) with 8.5 dB gain provides a dual radiation pattern which is suitable for nulling/tracking applications. The proposed antenna arrays with three- (right circuit in Fig. 5) and four-way dividers (Fig. 6) have high directivity with a maximum gain of 14 dB which make them suitable for many mm-wave and microwave applications. The four-element array exhibits frequency-agile single- and dual-beam performance. Good cross-polarization levels are obtained due to corrugations in the Vivaldi elements. All proposed antenna systems provide a radiation efficiency better than 80 percent and polarization efficiency of 98 percent in end-fire directions.

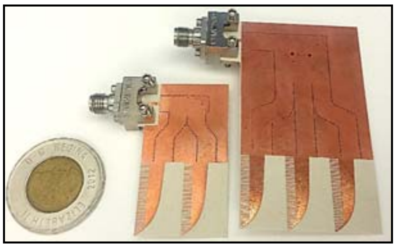

Fig. 5 Prototypes of SIW antenna arrays with two-way and three-way right-angled power dividers (size comparison with a Canadian Two-Dollar coin).

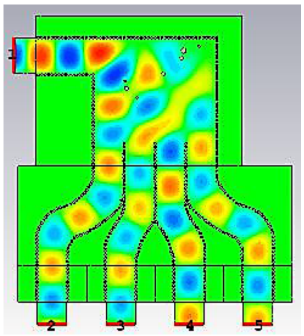

Fig. 6 Electric field of four-way SIW power divider at 23 GHz.

III. Conclusion

Some single-layer end-fire substrate integrated waveguide (SIW) antenna systems are presented that can be easily fabricated using standard printed-circuit board techniques. Examples include antenna combinations for circular polarization, a system for tracking applications, a Butler matrix, and right-angled power dividers as feed components. SIW horns, an antipodal printed dipole and antipodal Vivaldi elements are used as individual antenna elements.

References

[1] K. Wu, Y.J. Cheng, T. Djerafi, and W. Hong, "Substrate-integrated millimeter-wave and Terahertz antenna technology," Proc. IEEE, vol. 100, pp. 2219-2232, July 2012.

[2] L.-H. Zhong, Y.-L. Ban , J.-W. Lian, Q.-L. Yang, J. Guo, and Z.-F. Yu, "Miniaturized SIW multibeam antenna array fed by dual-dayer 8×8 Butler matrix," IEEE Antennas Wirel. Propag. Lett., vol. 16, pp. 3018-3021. 2017.

[3] Y. Luo and J. Bornemann, "Substrate integrated waveguide circularly polarized horn-dipole antenna with improved gain," Microw. Opt. Technol. Lett., vol. 58, pp. 2973-2977, Dec. 2016.

[4] W.-H. Zhang, W.-J. Lu, and K.-W. Tam, "A planar end-fire circularly polarized complementary antenna with beam in parallel with its plane," IEEE Trans. Antennas Propagat., vol. 64, pp. 1146-1152, Mar. 2016.

[5] S. Salem Hesari and J. Bornemann, "Wideband circularly polarized substrate integrated waveguide endfire antenna system with high gain," IEEE Antennas Wireless Propag. Lett., vol. 16, pp. 2262-2265, 2017.

[6] S. Salem Hesari and J. Bornemann, "Frequency-selective substrate integrated waveguide front-end system for tracking applications," IET Microw. Antennas Propag., vol. 12, pp. 1620-1624, Aug. 2018.

[7] C. Bartlett, S. Salem Hesari, and J. Bornemann, "End-fire substrate integrated waveguide beam-forming system for 5G applications," Proc. ANTEM, pp. 1-4, Waterloo, Canada, Aug. 2018.

[8] Q.-L. Yang , Y.-L.Ban, Q.-Q. Zhou, and M.-Y. Li, "Butler matrix beamforming network based on substrate integrated technology for 5G mobile devices," Proc. APCAP, pp. 413-414, Kaohsiung, Taiwan, July 2016.

[9] S. Salem Hesari and J. Bornemann, "Antipodal Vivaldi antenna arrays fed by substrate integrated waveguide right-angled power dividers," Applied Sciences, vol. 8, no. 12, pp. 1-17, Dec. 2018.

[10] S. Yang, A. Elsherbini, S. Lin, A. E. Fathy, A. Kamel, and H. Elhennawy, "A highly efficient Vivaldi antenna array design on thick substrate and fed by SIW structure with integrated GCPW feed," IEEE AP-S Int. Symp. Dig., pp. 1985-1988, Honolulu, USA, June 2000.