Substrate Integrated Waveguide at Antenna Applications

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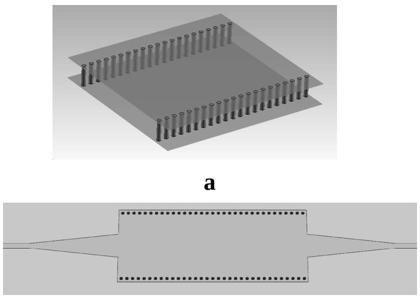
Abstract **The paper presents the substrate integrated waveguide applied as a basis of leaky wave antennas. The substrate integrated waveguide structures are extremely useful for integrating the antenna into any system or antenna array. The standard PCB process is applied to fabricate these antennas. The two antenna structures are presented. The first antenna radiates through the longitudinal slot in the surface integrated waveguide top wall. The second antenna is based on the compensated right-left handed line. It radiates through meander slots representing series line capacitances. This is a dual band antenna radiating simultaneously in two independent frequency bands. The characteristics and radiation aspects of the antennas are discussed. The measured characteristics of the two antennas are in good agreement with those predicted by the simulation.**

Keywords **waveguide, substrate integrated waveguide, leaky wave antenna, radiation, space leaky wave.**

I. INTRODUCTION

In its first stage, the microwave technology was based mostly on waveguides with metallic walls. The advantage of these waveguides is in their very low losses, inertness to EMC and in some applications ability to handle high power. In the contemporary stage of technology, these advantages, except some really special applications, are overridden by drawbacks. These are bulky structure unsuitable for integration, and high production costs.

Substrate integrated waveguide (SIW) has been proposed [1] as a new concept for the design of microwave and millimeter-wave structures. This periodic waveguide is composed of two rows of conducting cylinders embedded in a dielectric substrate that connect two parallel metal plates, see Fig. 1a [2]. This allows a complete integration with other planar transmission-line circuits such as microstrip and coplanar waveguide on the same substrate. Cost-effective microwave substrate integrated waveguide circuits could be designed using this approach [2].



a

b

Fig. 1: Substrate integrated waveguide (a), tapered line transitions from microstrip transmission lines (b).

Two kinds of leaky wave antennas (LWA) based on the SIW structure are presented in the paper. The SIW LWA radiating from a longitudinal slot etched in the upper wide wall was designed and fabricated. The antenna is fed through a microstrip line and the first space leaky mode with odd symmetry is excited along the line. The antenna radiates a beam that can be steered in the forward direction by changing the frequency. The SIW was used as an LWA able to steer the radiation pattern main beam by changing the frequency from nearly backward to forward directions and working in two independent frequency bands was designed and fabricated. This antenna is based on a compensated right/left-handed (CRLH) transmission line that offers two pass-bands composed of left-handed and directly adjoined right-handed bands without a band gap.

II. SUBSTRATE INTEGRATED WAVEGUIDE

The substrate integrated waveguide was studied in detail in [2]. As the side walls of the SIW are discontinuous and represent a periodic structure, see Fig. 1, their parameters must be properly designed not to cause some additional losses or even to create stop bands. This covers to design proper conducting pins diameter, distance, and the distance of the two pin rows. The system is designed as standard waveguide with metallic walls. The exception is its actual width that depends on the structure parameters [2] Eqs. (3, 4). Next pin distance in the row and pin diameter can be determined based on plots in [2] Figs. 5-9. Pin distance is from above limited by the Bragg condition.

III. SIW LEAKY WAVE ANTENNA RADIATING THROUGH THE WIDE SLOT

The designed and fabricated antenna is shown in Fig. 2. The antenna contains transitions from the microstrip line to the SIW at both ends, see Fig. 1b. It is connected at one end to a SMA connector and is terminated at the other end with a 50 Ω match. We measured and computed antenna input impedance and radiation patters. The antenna radiates a beam steered in the vertical plane from 48 deg at 18 GHz to 15 deg at 21 GHz. The full width at half power of the main antenna beam in the vertical plane varies from around 13 deg at 18 GHz to 21 deg at 21 GHz. The side lobes are about 10 dB below the level of the maximum radiation. The steering of the antenna beam is documented by measured radiation patterns shown in Fig. 3. The radiation pattern in the horizontal plane is remarkably wider than that in the vertical plane, and at lower frequencies it is split into two sub-beams. The finite dimensions of the antenna top conductor are responsible for radiation below the antenna plane. This portion of the radiation fades away with widening of this conductor. The measured antenna gain was 7.5 dB at 18 GHz, 7.2 dB at 19 GHz, 6.5 dB at 20 GHz and 2 dB at 21 GHz.

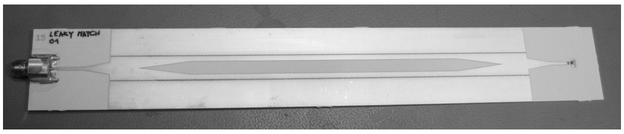


Fig. 2. Fabricated SIW leaky wave antenna with optimized transition from microstrip transmission line to SIW, and with 50 Ω match.

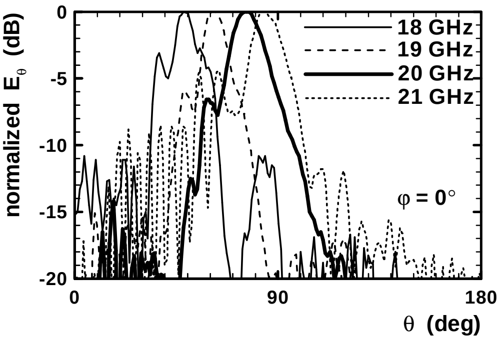


Fig. 3. Measured radiation patterns normalized to 0 dB showing the antenna steering ability. Angle θ = 90 deg corresponds to the forward direction.

IV DUAL BAND CRLH LEAKY WAVE ANTENNA

The SIW used to design the leaky wave antennas in [3] was designed as a standard CRLH transmission line cut periodically by series capacitors and shortened by parallel inductors. In order to get a line with the ability to close the LH and RH bands at two independently selected frequency bands, the unit cell of such a line has to contain in both series and parallel branches more than one element so as to have more degrees of freedom to design it [4]. This structure can be built using properly selected SIW inclusions. Presented LWA radiates through the meander slots of interdigital capacitors. The shunt components of the cell equivalent circuit are represented by four inductive metal pins short circuiting SIW. The SIW used here works below its cutoff in the lower frequency LH band. The lower and upper frequencies of the zero value propagation constant were chosen 8 GHz and 14 GHz. The final values of the frequencies resulting from the antenna design are 8.29 and 14.27 GHz. In fact, residual gaps about 15 and 100 MHz in width are left between the LH and RH bands. The antenna was designed as a cascade of 10 cells as shown in Fig. 4.

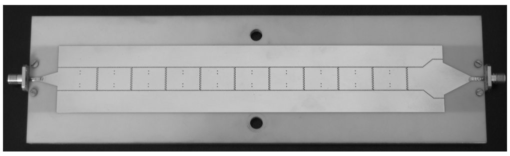


Fig. 4. Fabricated dual band SIW leaky wave antenna. The output SMA port is terminated by a 50 Ω match.

The measured antenna radiation patterns taken at the horizontal plane at the second CRLH band are plotted in Fig. 5. The first CRLH band is narrow from about 7.8 up to 8.65 GHz, but the steering of the radiation pattern is more sensitive to frequency variation. The main lobe of the radiation pattern can be steered from 50 to 130 deg here, i.e. about ±40 deg from broadside direction. The second CRLH band is wider than the first band. It spans from about 12.52 up to 16.34 GHz. The beam steering is here less sensitive and can be done in the span of ±25 deg from the broadside direction.

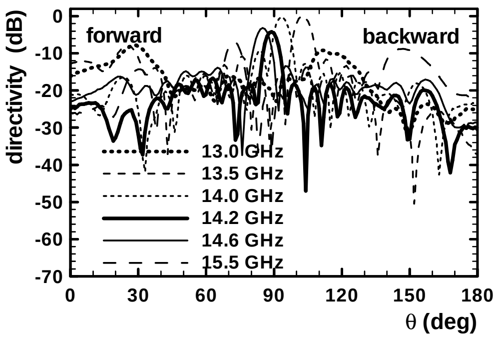


Fig. 5 Measured antenna radiation patterns at the second CRLH band calculated Angle θ is measured from the forward direction, so θ = 90 deg corresponds to the broadside direction.

V CONCLUSION

The substrate integrated waveguide is introduced in this paper. This transmission line represents a planar version of the metallic wall rectangular waveguide. It is well suited for mass production of microwave integrated circuits as it is compatible with standard planar microwave transmission lines. Two kinds of substrate integrated waveguide leaky wave antennas have been designed, fabricated and measured.

The first antenna radiates through a wide slot in the top waveguide wall and its beam can be steered in the vertical plane from 48 deg at 18 GHz to 15 deg at 21 GHz. The operating frequency band is from 18 GHz to 21 GHz and the gain is about 7 dB at 19 GHz.

The second antenna specimen is a substrate integrated waveguide leaky wave antenna based on the CTRL transmission line. The antenna radiates in two frequency bands, and in each of them the SIW transmission line fulfills the condition of the CRLH line with a closed gap between the LH and RH bands. The antenna has been designed so that these two bands span from 7.8 up to 8.65 GHz and from 12.52 up to 16.34 GHz. This antenna shows the scanning possibility of the radiation patterns typical for leaky wave antennas based on CRLH transmission lines in both working bands.

VI ACKNOWLEDGEMENTS

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