

SIW Leaky Wave Antennas

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Abstract— The substrate integrated waveguide can easily be integrated with planar microwave circuits. Antennas designed on this transmission line have a planar structure, and can be fabricated by a standard PCB technology, so they are suitable for mass production. This paper presents the results of an investigation of leaky wave antennas designed on a substrate integrated waveguide. The interest is given to three antenna types: antenna radiating from a slot in the top waveguide wall, CRLH and dual band CRLH leaky wave antennas.

Keywords—leaky wave antenna, surface integrated waveguide, planar transmission line.

I. INTRODUCTION

In recent years, a new concept – substrate integrated waveguide (SIW) – for the design of microwave and millimeter-wave waveguide structures and components has been proposed [1, 2]. SIWs are based on the equivalence between well-known metallic waveguide structures and waveguiding structures on a dielectric substrate with field confined at sides by two rows of metal posts (vias). Cost-effective microwave SIW circuits are simple to design using this approach [1, 2].

The SIW leaky wave antenna concept was proposed in [3]. This antenna radiates energy through the SIW side wall with sparsely located shortening vias. The concept of an LWA based on radiation through the wide slot in the SIW top wall due to a leaky wave of the first order was proposed in [4]. The SIW designed as a composite right/left-handed (CRLH) transmission line was used as an LWA able to steer the radiation pattern main beam by changing the frequency from nearly backward direction to forward direction [5,6].

A line offering CRLH behavior in two frequency bands was proposed in [7], where the condition for this feature was derived. Based on these results, a new dual band SIW LWA working in two frequency bands was designed and fabricated [8,9]. The antenna radiates one main beam that can be steered from the backward direction to the forward direction by changing the frequency in both frequency bands. Radiation occurs through meander slots etched in the top metallization wall. Another novel form of a dual band SIW LWA was presented in [10]. The structure was designed on the basis of a circuit model that predicts its behavior.

This paper summarizes the results of SIW LWA research done by the author and published namely in [4, 8, 9]. The aim

is to design antennas with a planar structure that can be integrated simply with transmitter/receiver circuits and can easily be mounted on surfaces of large bodies without deteriorating their shapes. These antennas can be fabricated at low cost by a standard technology for printed circuits board technology.

II. ANTENNA RADIATING FROM A SLOT IN THE TOP WALL

An SIW LWA radiating from a longitudinal slot etched in the upper wide wall was designed and fabricated [4]. The antenna is fed through a microstrip line, Fig. 1, and the first space leaky mode with odd symmetry is excited along the line. The antenna radiates a beam that can be steered as in the case of standard LWAs in the forward direction by changing the frequency. The Rogers 4350B substrate with $h = 0.508$ mm in thickness with relative permittivity $\epsilon_r = 3.48$ and loss factor $\tan\delta = 0.0037$ was used. To get the maximum radiation in the frequency band around 19 GHz we chose according to the dispersion characteristics calculated in [4, 13] SIW width 9 mm and slot width 5 mm.



Fig. 1. Fabricated antenna radiating from a slot in the SIW top wall [4].

The chosen antenna length was 100 mm, measured along the slot with the full width, see Fig. 1, due to the requirement that the amplitude of the space leaky mode at the end of the antenna should be 10% of its magnitude on the feeding tip at mean operating frequency 19 GHz. The antenna gain might be increased by prolonging the antenna, since with the fabricated structure about 10% of the power coupled to the antenna is lost in the terminating impedance. The radiating slot was terminated by wedges to minimize reflections. A comparison of the measured and calculated radiation patterns at 20 GHz is shown in Fig. 2, with very good agreement. The measured radiation patterns normalized to 0 dB are plotted in Fig. 3. The antenna radiates a beam steered in the vertical plane from 48° at 18 GHz to 15° at 21 GHz, measured from the forward direction. The full width at half power of the main antenna beam in the vertical plane varies from around 13° at 18 GHz to 21° at 21 GHz. The side lobes are about 10 dB below the level of the maximum radiation.

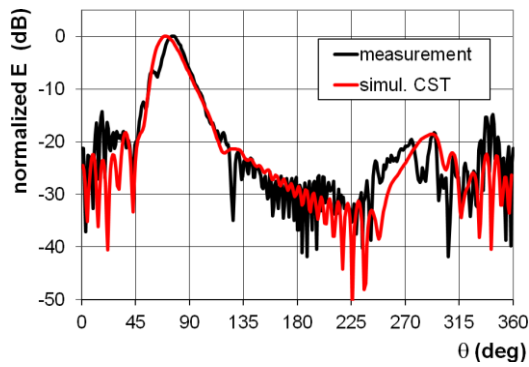


Fig. 2. Measured and simulated radiation patterns of the antenna from Fig. 1 at 20 GHz [4].

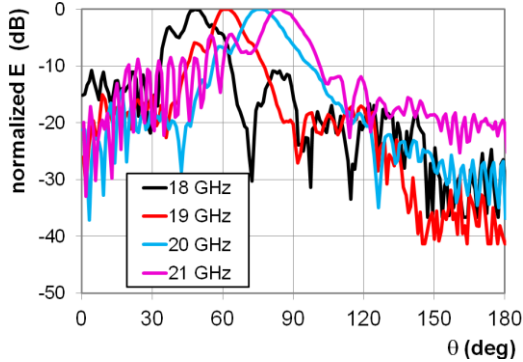


Fig. 3. Measured radiation patterns of the antenna from Fig. 1 [4].

III. CRLH SIW ANTENNA

An SIW-based antenna similar in form to the antenna already published in [5] was designed for application in an antimissile radar system [14]. The advantage was the ability to steer the angle of the main radiation beam simply by changing the frequency. The SIW is designed on the Rogers RO4003C substrate 1.524 mm in thickness and with permittivity 3.38. The antenna structure composed of 26 CRLH cells is shown in Fig. 3. The SIW cell is 9.5 mm in length and 9 mm in width. The antenna radiates through meander slots that represent series capacitors of the CRLH equivalent circuit. Shunt inductors are represented by two shunt inductive posts located in each SIW cell. The frequency band of this antenna operation is documented by the dispersion characteristic calculated by the CST Microwave Studio eigen mode solver in Fig. 5. The SIW CRLH line is balanced, with no band gap. The free space propagation constant k_0 limits the frequency band of the radiation from about 8.6 GHz to 11.7 GHz. This band was verified by the frequency characteristics of the scattering parameters. The measured radiation patterns and the radiation patterns simulated by the CST Microwave Studio are compared in Fig. 6. They are normalized to 15 dB. The antenna radiation pattern main lobe varies continuously with changing frequency from -50° to 70° , measured from the broadband direction. The steering of the radiation pattern by changing the frequency is documented in Fig. 7, where the calculated radiation patterns are plotted.

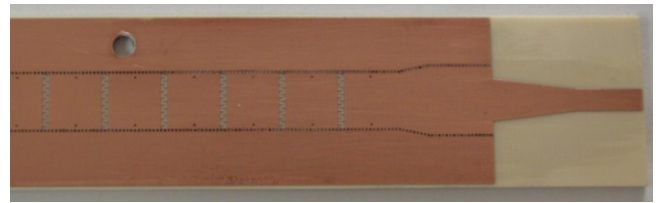


Fig. 4. Fabricated CRLH SIW LWA, a detail of the structure with the transition to the microstrip and widened SIW that works above its cut off.

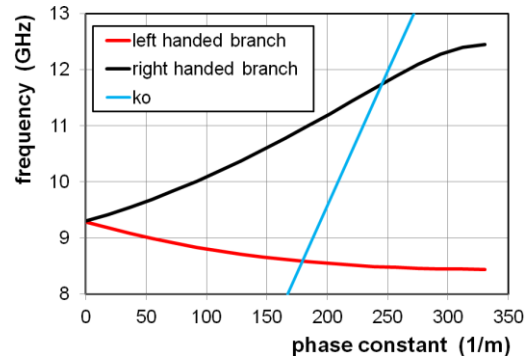


Fig. 5. Dispersion characteristic of the antenna from Fig. 4, calculated by the CST Microwave Studio.

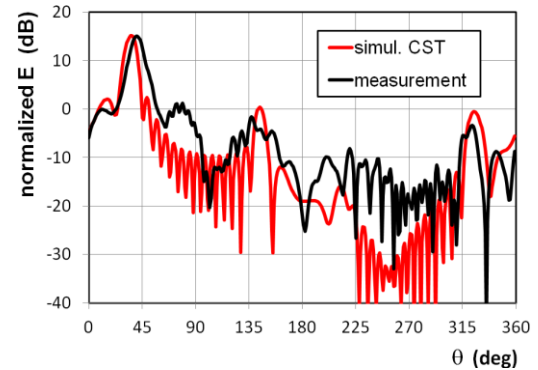


Fig. 6. Measured and simulated radiation patterns of the antenna from Fig. 4 at 11 GHz. 90° corresponds to the broad side, 180° corresponds to the forward direction.

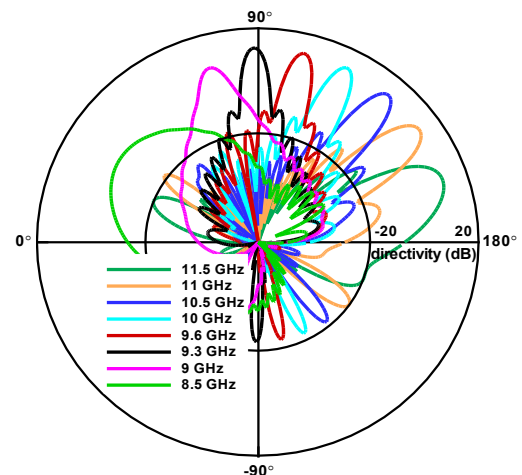


Fig. 7. Steering of the radiation pattern (normalized) of the antenna shown in Fig. 4. 90° corresponds to the broad side, 180° corresponds to the forward direction.

The parameters of the fabricated antenna specimen were partly deteriorated by improperly mounted SMA connectors to relatively wide $50\ \Omega$ microstrip transmission lines on relatively thick substrate – 1.524 mm, see Fig. 4. However, a pair of these antennas works well in the designed radar system [14].

IV. DUAL BAND CRPH SIW ANTENNA

The design of the antenna is based on the conclusions of [8] concerning the dual/quad band operation of the CRLH transmission line. The equivalent circuit (EQC) of such a line is composed of combinations of series and parallel resonant L-C circuits both in the through branch and in the shunt branch. This is taken into account by the proposed antenna unit cell structure shown in Fig. 8. The series elements are represented mainly by the meander slots through which the antenna radiates. The parallel elements are represented by four conducting vias. All these elements are however mutually coupled, and the EQC of the cell derived from its dispersion characteristic [8] fully corresponds to the EQC presented in [7]. The designed antenna was fabricated in two specimens having 15 and 25 cells.

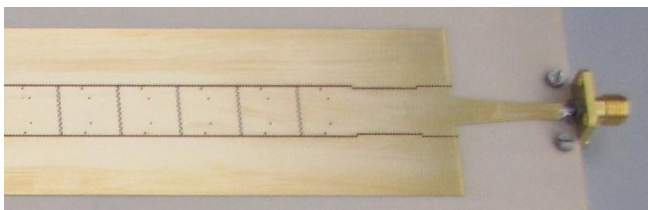


Fig. 8. Fabricated dual band CRLH SIW LWA [8].

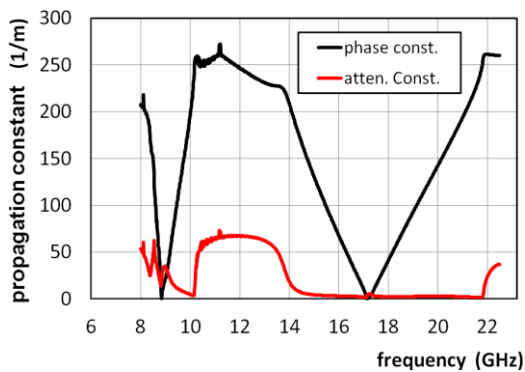


Fig. 9. Complex dispersion characteristics phase and attenuation constants of the antenna from Fig. 8 [9].

An analysis of the SIW antenna structure was made by the CST Microwave Studio using solid PEC walls terminating the SIW from the sides in order to simplify the computation process [8,9]. A Rogers RO4003C substrate 1.524 mm in thickness with relative permittivity 3.38 ± 0.05 and loss factor 0.0027 was used. The design of the antenna was performed by a coarse optimization performed in the CST Microwave Studio, aimed at closing the band gaps between the LH and RH bands. However, there are finally some gaps left. For the structure presented here, with the cell 12 mm in length and 10.8 mm in width, the gaps are at 25 and 85 MHz in width.

The radiation patterns of the longer antenna with 25 cells taken in the longitudinal plane normal to the antenna surface were calculated by CST MWS, and were also measured; see Fig. 10. Angle θ was taken from the backward direction, and equals 90° at the broad side. The narrow main beam is radiated from about 8.6 up to 9.5 GHz in the lower CRLH band. The main lobe of the radiation pattern can be steered from 65° to 125° in this frequency band. The radiation patterns exhibit side lobes around 150° that are only about 6 to 10 dB lower than the main lobes. These lobes are caused by spurious radiation of the SMA connector to microstrip transition, as characteristics calculated for the antenna model without these transitions are free of this spurious radiation. The second CRLH band is wider than the first band, and spans from about 15 up to 19 GHz. The beam is narrower than in the lower band. The beam steering is less sensitive here, and can be done in the span of 65° to 105° . The radiation patterns suffer from the existence of a side lobe, directed in elevation angles between 130° and 170° , which is about 6 to 12 dB smaller in the measured plots than the main beam. The decrease in antenna efficiency with increasing frequency may be due to residual radiation of the feeding cables used in the measurement setup but not included in the EM model.

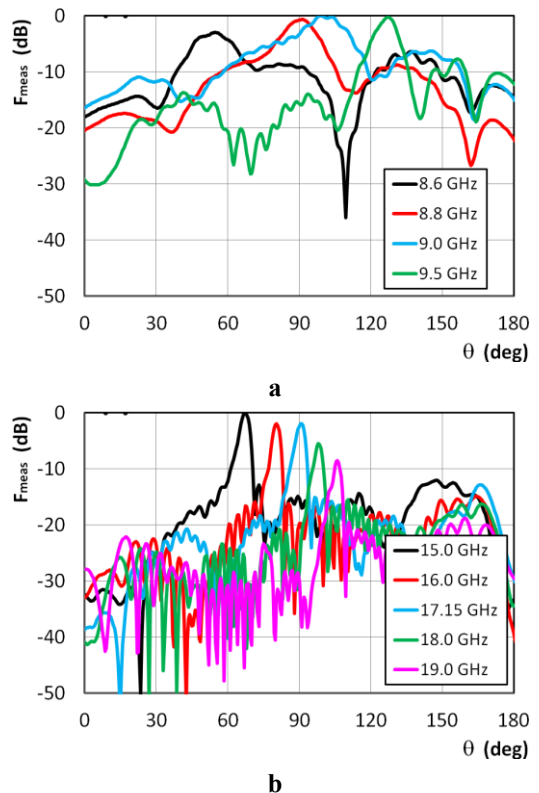


Fig. 10. Measured radiation patterns for varying frequency in the first band (a), and in the second band (b) of the antenna from Fig. 8 [10].

The antenna gain was evaluated by the comparison method, which uses measurements performed by DRH20 double ridge horns, see [15]. This gain is 6.5 dBi at 8.8 GHz, and 16 dBi at 17.15 GHz.

V. CONCLUSIONS

This paper has summarized the results of the author's investigation of leaky wave antennas designed on a substrate integrated waveguide. The antennas are: an antenna radiating from a slot in the broad wall, a CRLH substrate integrated waveguide antenna, and a CRLH substrate integrated waveguide antenna radiating two frequency bands.

A substrate integrated waveguide leaky wave antenna radiating from a slot in the broad wall parallel to its axis was designed and fabricated. The initial dimensions of the SIW and of the slot were obtained from analytical expressions for equivalent rectangular waveguides and from the dispersion characteristics. The SIW, the antenna layout and the feeding circuit were then optimized, using the CST Microwave Studio. The measured S-parameters and antenna characteristics fit well with the calculated results. The operating frequency band is from 18 GHz to 21 GHz, and the gain is about 7 dB at 19 GHz. The antenna radiates a beam steered in the vertical plane from 48° at 18 GHz to 15° at 21 GHz measured from the forward direction.

A CRLH substrate integrated waveguide leaky wave antenna was designed and fabricated. This antenna operated in the frequency band from 8.6 GHz to 11.7 GHz, and the main beam of the radiation pattern can be steered by changing the frequency from -50° to 70°, measured from the broad side direction. This antenna works in an antimissile radar system.

A dual band substrate integrated waveguide leaky wave antenna was designed, fabricated and measured. The balanced CRLH substrate integrated waveguide was used to provide the possibility to scan the radiated beam from backward direction to forward direction by changing the frequency. The antenna radiates in two frequency bands spanned from approx. 8.6 up to 9.5 GHz and from 15 up to 19 GHz. The exact scanning ability is 60° across the broad side direction in the lower band, and about 40° across the broad side direction in the upper band. The analysis performed by CST Microwave Studio verifies the measured antenna characteristics well.

The designed flat - planar antennas are intended to be integrated into antenna arrays, and directly into T/R systems where beam scanning is required. The antennas are fabricated by a simple PCB process, and are therefore cheap and suitable for mass production.

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