Analysis of a CRLH SIW dual band antenna

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Abstract

This paper presents the results of an investigation of a new version of a CRLH substrate integrated waveguide leaky wave antenna. The antenna operates in two frequency bands and its main beam can be scanned by changing frequency from backward to forward. The antenna structure is planar and can be fabricated by a standard PCB technology, so it is suitable for mass production.

1. Introduction

A substrate integrated waveguide (SIW) is a suitable candidate for applications as low profile planar antennas [1]. The CRLH SIW was used as an LWA in [2,3]. A line offering CRLH behavior in two frequency bands was proposed in [4]. This line is composed of cells consisting of combinations of series and parallel resonant circuits in both series and shunt branches. This paper presents details of the investigation of the SIW LWA antenna working in two frequency bands, originally reported in [5]. The dispersion characteristics, the Bloch impedances and the cell equivalent circuit [6] were evaluated for LWAs differing by cell length. This data helped to match the antenna to the SIW. An antenna prototype has been fabricated and measured.

2. Dispersion Characteristics, Antenna Design

The SIW used in the design of the leaky wave antenna [2,3] is a standard CRLH transmission line. In order to get a line with the ability to close the LH and RH bands at two frequency bands [4], the unit cell of the line has to contain more elements in order to have more degrees of freedom for the design. Properly selected SIW inclusions therefore have to be applied. The LWA radiates through the meander slots of series capacitors. The shunt components of the cell equivalent circuit are represented by inductive metal pins short circuiting the SIW. A Rogers RO4003C substrate 0.813 mm and 1.524 mm in thickness with relative permittivity 3.38 ± 0.05 and loss factor 0.002 was used. The unit cell is sketched in Fig. 1a, where the pins are not shown. The analysis was performed using solid PEC walls terminating the cell from the sides in order to simplify the computation process. The dispersion characteristics of three antenna prototypes differing mainly by cell length are plotted in Fig. 2. The characteristic were determined by the CST Microwave Studio eigenmode solver. The cell structures of these antenna specimens were designed by a manual optimization process performed with the aim to close the gaps between the LH and RH bands. Generally, the first band central frequency is determined by the SIW width, which is 10.8, 11.2, 11.4 mm, and the second band central frequency is determined by the cell length, which is 12, 16.8, 22 mm. The second band is shifted to higher frequencies and the two bands are spanned over wider frequency intervals if the cell length is shortened. The phase constant β determined by the argument of S_{21} of one cell as $\beta = -\arg(S_{21})/d$, where d is the cell length, fits well the data shown in Fig. 2 around the frequency points where $\beta = 0$, Fig. 3. This substitution is not valid near the Bragg reflection condition $\beta d = \pi$. The real part of the complex propagation constant $\gamma = \alpha + j\beta$ representing the attenuation due to radiation and losses was calculated from the cell radiation losses calculated as $\alpha = -\ln\sqrt{|S_{11}|^2 + |S_{21}|^2}\,/d$ using the scattering parameters calculated by the CST Microwave Studio. On the other hand, the complex propagation constant is a solution of $\cosh(\gamma d) = A$, where A is the element of the cell *ABCD* matrix. The cell lumped equivalent model was derived using the model of the CRLH line presented in [6]. The data calculated for the LWA with the cell 12 mm in length is shown in Fig. 3. The antenna was designed as a cascade of cells. Fig. 1b shows 10 cells in the case of an LWA with cell length 16.8 mm. Proper tapers match the antenna to the feeding microstrip lines, and the antenna output is terminated by a matched load. A comparison between the antenna matched and without matching is presented in Fig. 4. The SIW leaky-wave antenna has a finite number of cells, so it is not possible to apply Bloch impedance, which is often used to describe infinite periodic structures. The input impedance is a function of the number of cells in the antenna. The reactive part of the input impedance was compensated by the reactance of opposite sign provided by a shunt connected stub to provide Im(Z_{in}) almost equal to zero. And then a quarter-wavelength transformer was used to transform the real part of Z_{in} to nearly the same value as the impedance of the empty SIW. The improvement by antenna matching namely in the first band is visible in Fig. 4.

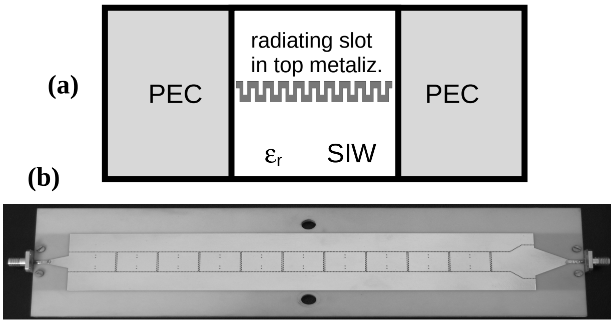


Fig. 1: Top view of the SIW LWA unit cell (a) and the fabricated prototype (b).

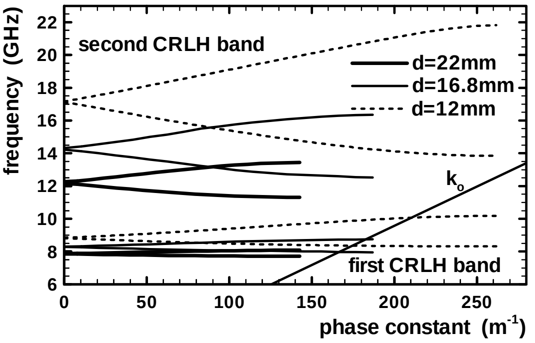


Fig. 2: Dispersion characteristics of three SIW LWAs of different unit cell length.

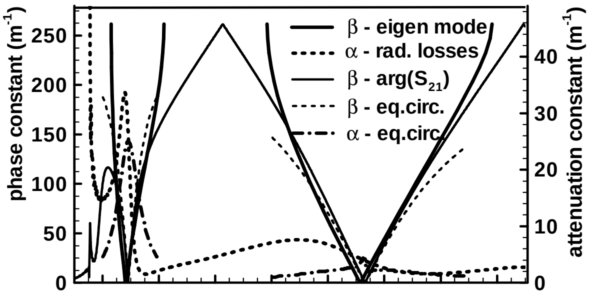


Fig. 3: Phase and attenuation constants of the LWA with the cell 12 mm in length.

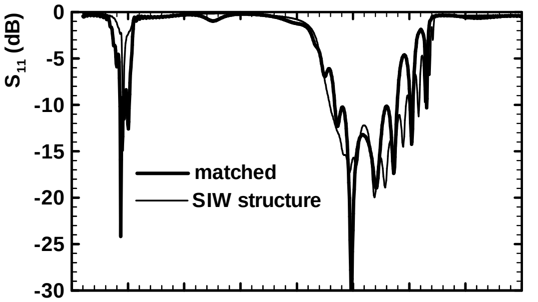
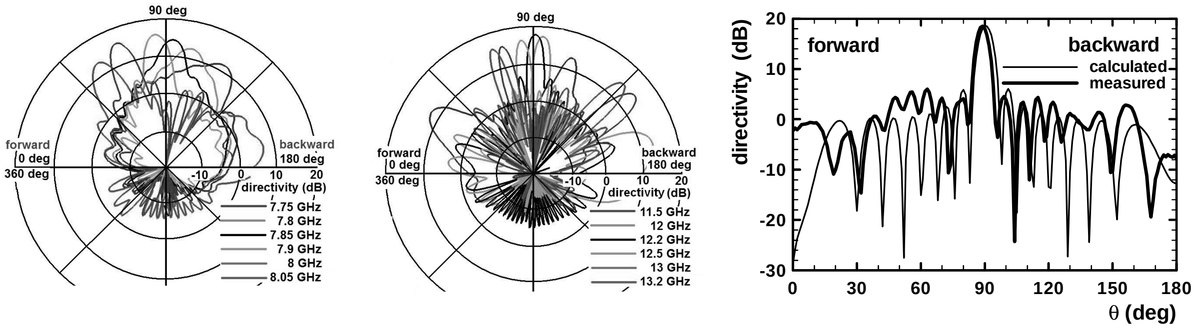


Fig. 4: S_{11} of the matched antenna and the simulation of the cascade of 10 cells 22 mm in length from Fig. 1a.

3. Antenna Radiation and Measurement

The antenna radiates one main beam in both frequency bands. This beam can be steered by changing the frequency, as in the case of a standard LWA based on a CRLH line. The antenna radiates to the broadside direction at frequency $\beta = 0$. Leakage takes place in the fast wave frequency bands, where

$|\beta| < k_o$. At $\beta < 0$ the radiation goes to the backward direction, and at $\beta > 0$ it goes to the forward direction at an angle estimated as $\theta \approx \arccos(\beta / k_o)$. The steering sensitivity is higher in the first frequency band, which is narrower than the second band. Fig. 5 plots the measured and simulated radiation patterns of the two LWA prototypes.



(a) **(b)** **(c)**

Fig. 5: Calculated radiation patterns of the antenna with the cell 22 mm in length for varying frequency in the first band (a), in the second band (b), comparison of the measured and calculated radiation pattern of the LWA with the cell 16.8 mm in length at 14.2 GHz, the central frequency of the second band (c).

4. Conclusion

A composite right-handed/left-handed surface integrated waveguide has been applied as the basis of a leaky wave antenna radiating in two frequency bands. Three antenna prototypes differing, apart from the fine cell structure, mainly by the length of the unit cell have been designed and investigated in detail. The designed antenna is aimed for integration into antenna arrays and into transmitting or receiving systems where beam scanning and double band operation are required at the same time. The standard PCB process is applied for fabrication, so this solution offers a cheap planar antenna suitable for mass production.

Acknowledgement

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