A Dual Band SIW Leaky Wave Antenna

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Abstract — This paper presents the results of an investigation of a new version of a leaky wave antenna that is based on a CRLH substrate integrated waveguide (SIW). The antenna is designed so that it can radiate in two frequency bands. The direction of the main lobe of the antenna radiation pattern can be steered by changing the frequency in both bands from backward direction to forward direction. The measured characteristics are in good agreement with those predicted by the simulation. The SIW structure based on standard PCB technology makes the antenna suitable for integration directly into T/R circuits or antenna arrays.

Index Terms — Composite right/left-handed transmission line, leaky wave antenna, substrate integrated waveguide.

I. INTRODUCTION

Planar antennas can be integrated with other circuits and can be easily fabricated. They are therefore suitable for cheap mass production. A substrate integrated waveguide (SIW) is a possible version of a low profile planar transmission line that can be simply designed and fabricated [1].

The concept of a leaky wave antenna (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 [2]. The SIW was used as an LWA able to steer the radiation pattern main beam by changing the frequency from nearly backward direction to forward direction [3]. This antenna is based on a composite right/left-handed (CRLH) transmission line working without a frequency gap between the LH and RH bands [4]. Exactly the same concept was used in [5]. A line offering CRLH behavior in two frequency bands was proposed in [6]. This line is composed of elementary cells consisting of combinations of series and parallel resonant circuits in both through and shunt branches.

A new dual band SIW LWA based on the CRLH line working in two frequency bands was originally proposed in [7], and an improved version of it is proposed in this paper. The antennas radiate one main beam that can be steered from the backward direction to the forward direction by changing the frequency in both bands. The radiation goes through meander slots etched in the top metallization wall.

II. DESIGN OF A DUAL BAND CRLH SIW UNIT CELL

The leaky wave antenna designed in [3, 5] uses a standard SIW CRLH transmission line. In order to design a line with the possibility to close the gaps between the LH and RH bands at two frequency bands, the unit cell of such a line has to contain more elements than a standard CRLH [6]. This offers more degrees of freedom for designing the antenna. This structure can be built using properly selected SIW inclusions. An interdigital capacitor [3] is applied. Its equivalent circuit can be composed of a series L-C circuit modeling the interdigital structure itself [8] in combination with a parallel L-C circuit representing the radiating slot in the waveguide wall [9]. The shunt components of the cell equivalent circuit are represented by four or eight inductive metal pins short circuiting SIW. The cell layouts are shown in Fig. 1.

Assuming mutual coupling between particular elements, we have an equivalent circuit similar to that described in [6], which is able to obey the condition [6, Eq. 4] of closing the gaps, and to ensure CRLH operation in two frequency bands. Due to the frequency dependence of all elements of the equivalent circuit, the cell design is not straightforward. We therefore used a manual optimization process performed in the CST Microwave Studio (CST MWS). The SIW was opposed to Fig. 1 in all CST MWS models terminated from the sides by solid PEC walls to simplify the simulation.

A Rogers RO4003C substrate 0.813 mm in thickness with relative permittivity 3.38 ± 0.05 and loss factor 0.002 was used. The unit cells shown in Fig. 1a,b were used to determine the antenna dispersion characteristics. Choosing frequencies where the SIW propagation constant is zero equal to 8 and 12 GHz, respectively, the dispersion plot shown in Fig. 2 was obtained for the antenna with the cell shown in Fig. 1b. The final values of the frequencies defined above were shifted from the originally chosen values to 7.85 and 12.2 GHz.

Fig. 1 Layouts of the SIW unit cell, non-symmetric [7] (a), symmetric (b), detail of the meander slot (c). The dimensions in mm were obtained in the design process in CST MWS.
residual gaps about 25 and 105 MHz in width were left between the LH and RH bands. The first CRLH band is narrow, from about 7.71 up to 8.08 GHz, whereas the second band spans from about 11.3 up to 13.43 GHz. Fig. 2 shows even the third band, but there are not enough elements of the cell structure to close its gap. Thus it is a challenge to design the antenna to work even in more frequency bands. The dispersion curves of a non-symmetrical cell are similar [7]. The centers of the bands are at 8.29 and 14.27 GHz. Generally, the first band center frequency is determined by the SIW width and the second band center frequency by the cell length.

The centers of the bands are at 8.29 and 14.27 GHz. Generally, the first band center frequency is determined by the SIW width and the second band center frequency by the cell length. The 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 $\beta > 0$ to the forward direction at the angle estimated by $\theta = \arccos(\beta/k_o)$. 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 pattern of the antenna with a non-symmetrical cell, Fig. 1a, at the center of the second band, where the radiation goes to the broadside [7]. The measured pattern fits the simulated pattern well.

The antenna with a symmetrical unit cell, Fig. 1b, which is better matched than the antenna from Fig. 1a, radiates as described above. The radiation patterns calculated by the CST MWS for the two frequency bands are plotted in Fig. 6. The main lobe of the radiation pattern in the first band can be steered from 55 to 120 deg, i.e. about ±30 deg from the broadside direction. The beam can be steered in the second band in the span of ±20 deg from the broadside direction.

The radiation patterns in the second CRLH band at frequencies close to the edges of this band suffer from the existence of an intensive side lobe mirrored into the direction opposite to the main lobe direction. These are, e.g., the mirror lobe at 11.5 GHz radiating into the direction defined by angle 30 deg, and the mirror lobe at 13.2 GHz radiating into the

![Fig. 2](image.png)  
Calculated dispersion characteristics of the designed CRLH SIW symmetrical unit cell operating in two frequency bands around 8 and 12 GHz. The third band does not have the closed gap.

![Fig. 3](image.png)  
The layouts, fabricated antenna from Fig. 1a [7] (a), CST MWS model of the antenna from Fig. 1b (b).

![Fig. 4](image.png)  
Antenna scattering parameters and radiating losses (1).

### III. Antenna Analysis, Design, and Measurement

The principle of antenna operation was proved by designing and fabricating two specimens as a cascade of 10 cells from Fig. 1a,b. The layouts are shown in Fig. 3. The ground plane of the prototype is extended about 15 mm in width on each side due to a mounting fixture, Fig. 3a. The input microstrip line 1.8 mm in width feeds the antenna periodic structure through a microstrip taper, optimized by CST MWS. The output microstrip line is terminated by a 50 Ω resistor to minimize reflections, or can be used to measure transmission. The diameter and the distance of the pins in the side walls were chosen according to [1] to be 0.4 and 0.6 mm. The SIW width defined by the distance of the centers of the two rows of pins was chosen to be 11.5/11.7 mm for the antenna from Fig. 1a/1b instead of the originally designed waveguide width 11.2/11.4 mm [1].

The input reflection coefficient of the two antenna specimens is plotted in Fig. 4. The plot clearly shows two antenna working bands that correspond to the two bands of the dispersion characteristics in Fig. 2 and in [7, Fig. 2]. However, the first band is narrower than indicated by the dispersion characteristic. The antenna from Fig. 1b is matched significantly better than the antenna with the non-symmetrical cell. The radiating losses are calculated as

$$A_r = 10 \log(|S_{11}|^2+|S_{21}|^2),$$  
and this quantity indicates the ability of the antenna to radiate power. The dip in the $S_{11}$ characteristics of both antennas is at the frequency band of the fully non-closed gap of the dispersion characteristic around 12.2 and 14.27 GHz.

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 broad side direction at frequency $\beta = 0$. The 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 $\beta > 0$ to the forward direction at the angle estimated by $\theta = \arccos(\beta/k_o)$. 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 pattern of the antenna with a non-symmetrical cell, Fig. 1a, at the center of the second band, where the radiation goes to the broadside [7]. The measured pattern fits the simulated pattern well.
direction at 135 deg. The main lobe directions at 11.5 and 13.2 GHz are 110 and 70 deg, respectively. The origin of this distortion is in the Bragg reflection at the band edges where wavelength $\lambda = 2d$, $d$ being the cell length.

**Fig. 5** Calculated and measured radiation patterns of the non-symmetric antenna at 14.2 GHz [7].

The measured S-parameters fit very well with the calculated results. Similarly, the measured radiation patterns correspond with the calculated patterns.

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 fabricating this antenna.

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**REFERENCES**


