2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

A Reconfigurable Goubau-Line-Based Leaky Wave Antenna

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Abstract

A periodically-modulated leaky-wave antenna based on Goubau transmission line with an electronically steerable main beam is presented. Binary switches are connected between the conductive patches along the Goubau line antenna, allowing to vary the phase constant of the propagating wave and to make the antenna reconfigurable. In this way, the main beam of the antenna can be steered to a desired direction by combining the ON and OFF states of the switches. Several leaky-wave antennas of different switch configurations are designed and simulated to demonstrate the fixed-frequency beam steering performance.

1. Introduction

Goubau line has attracted considerable attention in the past few years [1-2]. Due to its groundless structure and strong electrical field confinement, low-loss transmission property of Goubau lines has been demonstrated in terahertz frequency bands [3-5]. Recently, the Goubau line leaky-wave antennas with periodical modulations that are featuring frequency scanning ability have been demonstrated in microwave [6] and millimeter wave frequency band [7]. The electromagnetic fields are highly confined to the metallic surface of Goubau line, resulting in the propagation of the surface wave. The dispersion curve of the fundamental mode of Goubau line is plotted in Figure 1 (line width w_G is varied and the length is 5 mm). It shows that the fundamental mode of Goubau line is bounded and the radiations of antennas are produced by adding the periodical modulation along the antenna to compensate the phase mismatch with the wave in the air.

While the frequency-scanning property of leaky-wave antennas is useful in some applications, the control over the direction of the main beam at any given frequency within the leaky-wave band is more interesting, especially in most communication systems operating in a relatively narrow and predefined frequency band. Many efforts have been made and several methods have been developed for beam scanning at a fixed frequency [8-9]. The technique of loading lumped capacitors was employed in a half-width leaky-wave antenna [8], however the scanning angles were limited due to the capacitor values. Another method is to use the PIN diodes to electronically control the beam steering performance [9], but resulting antennas allowed two discrete beam angles due to the two states of diodes. There is no related research work published on fixed-frequency beam steering of Goubau-line-based periodic leaky-wave antennas. In this paper, we propose the concept of Goubau line leaky-wave antenna with an electronically controllable main beam.

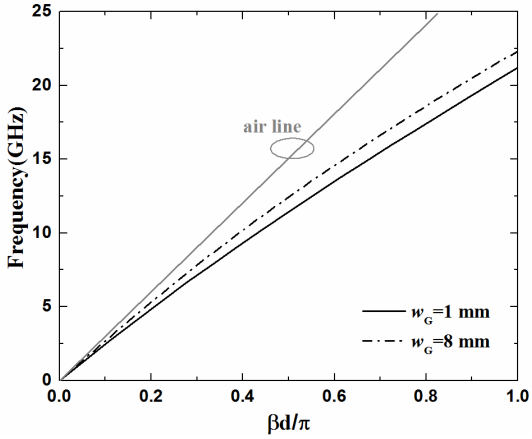


Figure 1. Dispersion curve of the planar Goubau line of different line width w_G (length is 5 mm) on a 1.52-mm-thick Rogers 4003C substrate (ε_r=3.38, tanδ=0.0027).

2. Antenna Design

For a leaky-wave antenna within the leaky regime, the direction of the main beam angle is approximately given by [6]:

$$\theta_{f,p} = \arcsin\left(\frac{\beta_0}{k_0} - \frac{c_0}{fp}\right) \qquad (1).$$

Where β_0 is the phase constant of the unmodulated Goubau line, k_0 is the wavenumber in the free space, c_0 is the light speed in the air, f is the operational frequency and p is the modulation period. The direction of the main beam depends on both the periodicity of the added modulations p and the frequency f. If the frequency is

determined, further varying the modulation period can redirect the main direction of antennas.

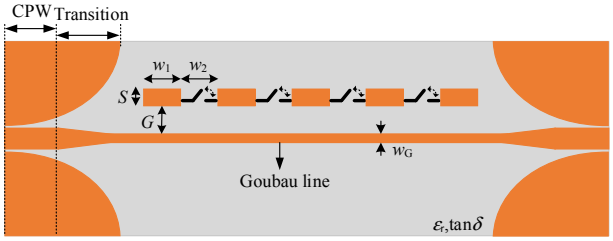
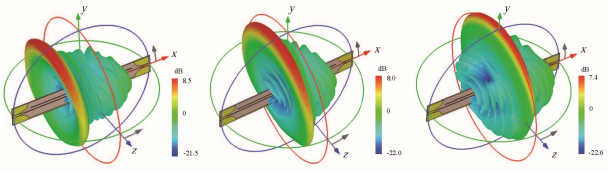


Figure 2. Schematic description of the proposed reconfigurable leaky-wave antenna based on Goubau transmission lines.



(a) (b) (c)

Figure 3. 3D radiation pattern of Goubau line leaky-wave antenna of different modulation periods at 8.5 GHz. (a) p=20 mm, (b) p=24 mm, (c) p=28 mm.

Figure 2 illustrates the concept of the proposed reconfigurable leaky-wave antenna based on Goubau transmission lines. The antenna consists of a groundless Goubau transmission line printed on a thin dielectric substrate with series of patches and switches along the Goubau line. These periodic elements are placed in a distance G away from the Goubau line and are employed to produce the radiations. The reconfigurable performance of the main beam angles of the antenna depends on the ON or OFF state of switches. Indeed, combination of patches and switches biased to different states provides a large number of modulation periods. Therefore, at a fixed-frequency, different switch configurations create different beam angles as shown in Eq. (1).

Figure 3 shows the simulated 3D radiation pattern of the proposed Goubau line antenna for different modulation periods at 8.5 GHz. It shows clearly that steerable radiation angles of the antenna can be achieved with the variation of modulation periods.

3. Results

An example of the reconfigurable Goubau-line-based leaky-wave antenna is designed and simulated, where the line profile is modulated by series of connected patches and switches. The antenna is implemented on a 1.52 mm-thick Rogers 4003C substrate with ε_r=3.38 and tanδ=0.0027. The Goubau line of w_G=1 mm is excited by coplanar waveguides (CPW) of 50 Ω (signal width: 4.5 mm, signal-ground distance: 0.3 mm, ground width: 15 mm, respectively). On both sides of the antenna, tapered ground planes and lines are employed for a smooth transition and mode conversion between CPW line and Goubau line. This transition structure efficiently converts the transversal electromagnetic (TEM) mode in CPW to a transversal magnetic (TM) surface-wave mode in Goubau line. Note that 48 patches and switches placed at a distance G of 4.75 mm away from Goubau line are employed for radiations in the antenna. The geometrical dimensions are S=1 mm, w_1=3.4 mm and w_2=0.6 mm. Note that the equivalent length of one unit cell of patch and switch equals to 4 mm.

In simulations, a simple model of an ON switch state is achieved by connecting the adjacent patches using a rectangular patch of the same size of switch. In contrast, the OFF state is achieved by leaving a gap between the patches for simplification. All the electromagnetic simulations are carried out by employing the simulation tool CST Microwave Studio.

Figure 4 shows the simulated S-Parameters performance for leaky-wave antenna of different modulation periods. It is easy to calculate that the simulated modulation periods of 16 mm, 20 mm, 24 mm and 28 mm correspond to 4, 5, 6 and 7 units cell of patch and switch, respectively. The transmission coefficients $|S_{21}|$ for all structures are around -5 dB within 8-12 GHz and the reflection coefficients $|S_{11}|$ is lower than -12 dB, showing that a good impedance and momentum matching is achieved. The steerable performance of the proposed Goubau line antenna of different modulation periods at given frequencies is illustrated in Figure 5. The simulated E-plane radiation patterns shows that the antenna is steerable from 87° to 159° with a scanning range of 72° and from 83° to 140° at a frequency of 8.5 GHz and 9.0 GHz, respectively.

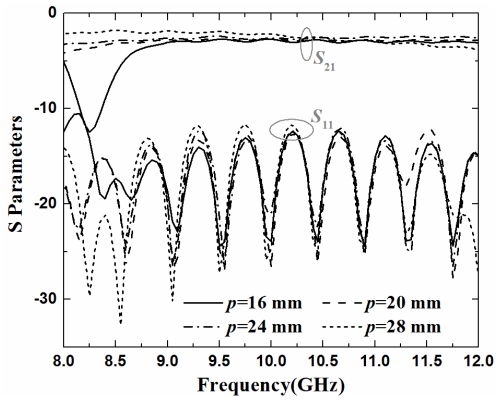
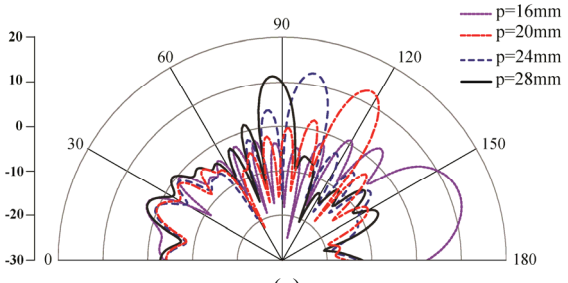
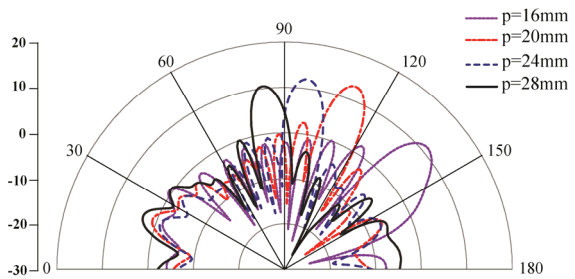


Figure 4. S-Parameters of the proposed Goubau line leaky-wave antenna of different modulation periods.



(a)



(b)

Figure 5. Radiation patterns of the proposed Goubau line leaky-wave antenna of different modulation periods. (a) at 8.5 GHz, (b) at 9.0 GHz

4. Conclusions

We demonstrated the concept of a reconfigurable Goubau line leaky-wave antenna using switched patch modulations. These antennas provide the possibility of continuous beam scanning at a given frequency. It has been shown that the modulation periods can be dynamically varied by using the ON or OFF state of the switches, which enable a flexible control of the main beam direction of the proposed antenna. The antenna is suitable for fixed-frequency beam scanning application in radar and communication systems of narrow bands where large phased-array beam scanning is required.

5. Acknowledgements

This work is supported by National Natural Science Foundation of China (61401191), Guangdong Natural Science Funds for Distinguished Young Scholar (2015A030306032, S2013050014223), Shenzhen Science and Technology Innovation Committee funds (KQJSCX20160226193445650, JCYJ20150331101823678, KQCX2015033110182368, JCYJ20160301113918121, JSGG20160427105120572), and Shenzhen Development and Reform Commission Funds (Grant [2015]944).

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