Hindawi Publishing Corporation
Active and Passive Electronic Components
Volume 2008, Article ID 742050, 6 pages
doi:10.1155/2008/742050

Research Article

High Efficiency and Broadband Microstrip Leaky-Wave Antenna

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Received 1 December 2007; Accepted 8 May 2008

Recommended by T. Kalkur

A novel layout of leaky-wave antennas based on tapered design has been proposed and investigated. The new tapered leaky-wave antenna (LWA) was designed running a simple procedure which uses an FDTD code, and using a suitable metal walls down the centerline along the length of the antenna connecting the conductor strip and the ground plane, which allows to use only half of the structure, the adoption of a simple feeding, and the reduction of sidelobes. The good performance of this new tapered microstrip LWA, with reference to conventional uniform microstrip LWAs, is mainly the wider band of 33% for VSWR < 2, higher gain (12 dBi), and higher efficiency (up to 85%). Furthermore, from the theoretical analysis we can see that, decreasing the relative dielectric constant of the substrate, the bandwidth of the leaky-wave antenna becomes much wider, improving its performance.

1. INTRODUCTION

Progress in the recent years has been obtained on the development of leaky-wave antennas based on the higher order mode of microstip [1, 2]. The LWAs possess the advantages of low-profile, easy matching, fabrication simplicity, and frequency/electrically scanning capability. But in some application especially for point-to-point communication, the main beam variation of LWA should be as low as possible. A tapered steps microstip LWA, in which each step can irradiate in subsequent ranges of frequency, is a possible solution to obtain a fixed mainbeam LWA [3]. Unfortunately, in this antenna the impedance mismatch between subsequent steps reduces the bandwidth, furthermore the excitation of higher order mode without dominant mode perturbation requires more elaborate feeding scheme. A curved design of tapered antennas with a physical grounding structure along the length of the antenna allows to reduce the impedance mismatch, suppressing the dominant mode (bound mode). This solution improves the band the gain, the efficiency, and simplifies its feeding. Moreover, due to the image theory it is possible to design only half antenna with the same property of entire, reducing the dimensions of the uniform miscrostrip LWA. The performance of the efficiency and band of this LWA can be improved further, if we use a substrate with relative dielectric constant that approached 1.

In this paper, we have proposed such new curve tapered LWA as discussed in the following section.

2. DESIGN OF MICROSTRIP CURVE LWA

We can explain the character of microstrip LWAs through the solution of the dispersion characteristic equation obtained with full-wave analysis methods. This solution allows to evaluate the radiation region of leaky-wave through the complex propagation constant $k = \beta - j\alpha$, where β is the phase constant of the first higher mode, and α is the leakage constant. The complexity of full wave analysis [4, 5] to solve the propagation characteristics suggests to use an easy FDTD algorithm which use a PML boundary condition, as proposed in [6], to obtain the normalized phase constant and attenuation constant. The leakage radiate phenomena, from the propagation characteristics, can only be noted above the cutoff frequency of higher order mode, and below the frequency such that, the phase constant is equal at the free space wave number.

From these characteristics of curves we know the frequency range of the leaky-mode radiation, that can be

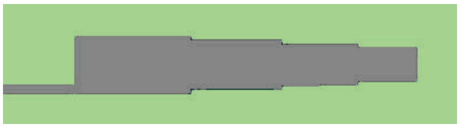
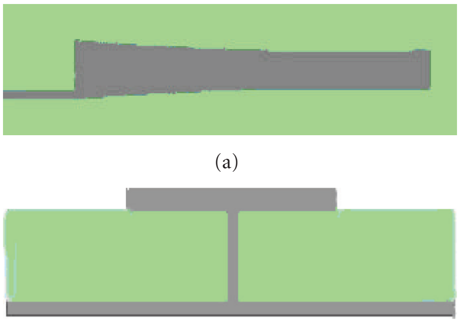


Figure 1: Layout of multisection LWA.



(a)

(b)

Figure 2: (a) Layout of curve tapered LWA Type II. (b) Cross-section of LWA Type II with a physical grounding structure along the length of the antenna which connects the conductor strip and the ground plane.

indicated in the more useful way for the design of our antenna [3]:

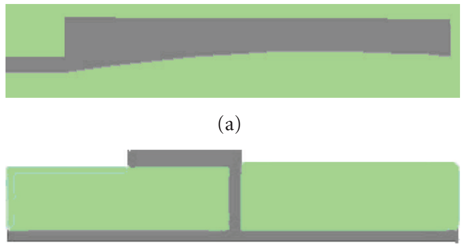
$$\frac{c}{2w_{\text{eff}}\sqrt{\varepsilon_r}} = f_c < f < \frac{f_c\sqrt{\varepsilon_r}}{\sqrt{\varepsilon_r - 1}}. \quad (1)$$

From (1) we can see that as the width of the antenna decreases, the cutoff frequency increases shift toward high frequency. This behavior allows to design a multisection microstrip LWA according [3] superimposing different sections in which each section can radiate in a different and subsequence to frequency range, obtaining a broadband antennas. In this way, each section should be into bound region, radiation region, or reactive region, permitting the power, to uniformly radiated at different frequencies. Moreover, we note from (1) that using a substrate material with relative dielectric constant which approached 1, the leaky-wave antenna bandwidth become much wider and increased drastically. Unfortunately, this multisection LWA (layout Type I in Figure 1(a)) shows ripples in return loss curve, spurious sidelobes, and impedance mismatch. Our idea to reduce ripples and sidelobes is to design a smooth contour antenna using the same contour of the cutoff phase constant or attenuation constant curve ($\alpha_c = \beta_c$), This curve was obtained varying the frequency for different width and length of each microstrip section, as mentioned in [7], employing the equation

$$\beta_c = c_1 f^2 + c_2 f + c_3. \quad (2)$$

This equation is given by linear polynomials interpolation of the cutoff point of the dispersion characteristic, where $c_1 = 0.13$, $c_2 = 5.4$, $c_3 = -10.41$. Further reduction of ripples and spurious sidelobes can be obtained using a suitable metal walls down the centreline connecting the conductor strip and the ground plane that allows the adoption of a simple feeding planar line (layout Type II in Figure 2).

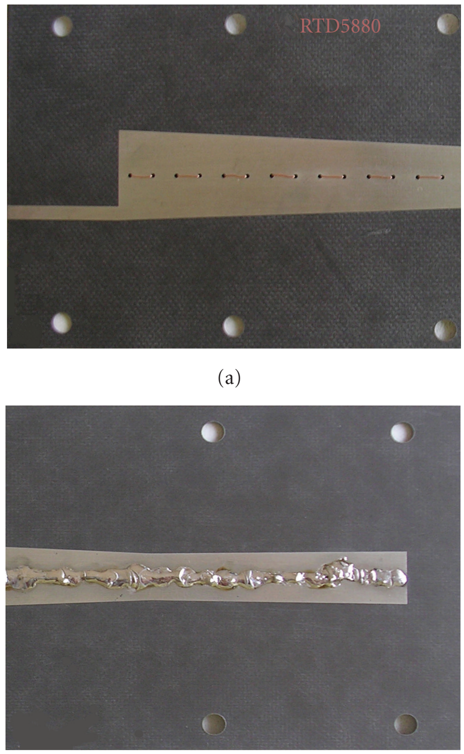
This physical grounding structure suppresses the fundamental mode, forcing the energy to propagate in the next higher mode. As mentioned previously, it is possible to design only half of the entire curve tapered LWA. The half curve tapered LWA is characterized by the same property of the entire, but with the dimensions reduced of the 20% from the entire tapered LWA and reduced of the 60% from the uniform microstrip LWA. The antenna layout Type III (half curve tapered LWA) shown in Figure 3 was optimized trough a 3D electromagnetic simulator (CST Microwave



(a)

(b)

Figure 3: (a) Layout of half tapered LWA. (b) Cross-section of half LWA.



(a)

(b)

Figure 4: (a) A prototype of tapered LWA with wires in the holes. (b) The soldering made in the centerline of the antenna to cover the wires in the holes.

Figure 5: A prototype of half curve tapered leaky-wave antenna..

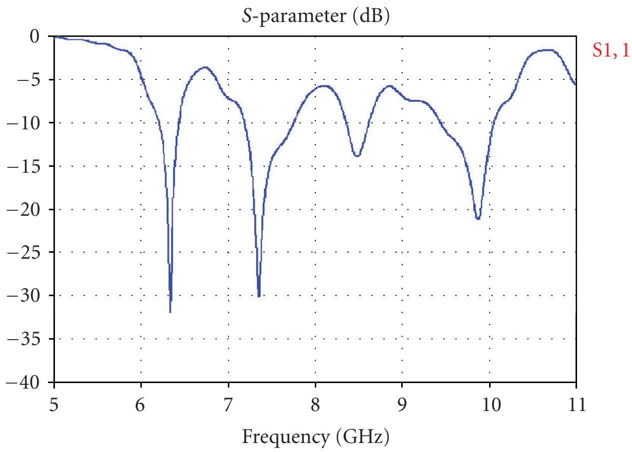


Figure 6: Simulated return loss of multisection LWA Type I.

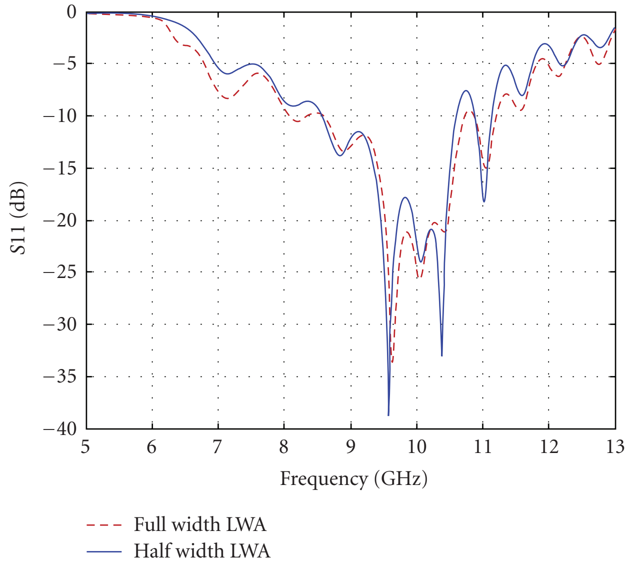


Figure 7: Simulated return loss (S11) of tapered LWA (Type II) and half tapered LWA (Type III) obtained by 3D electromagnetic simulator.

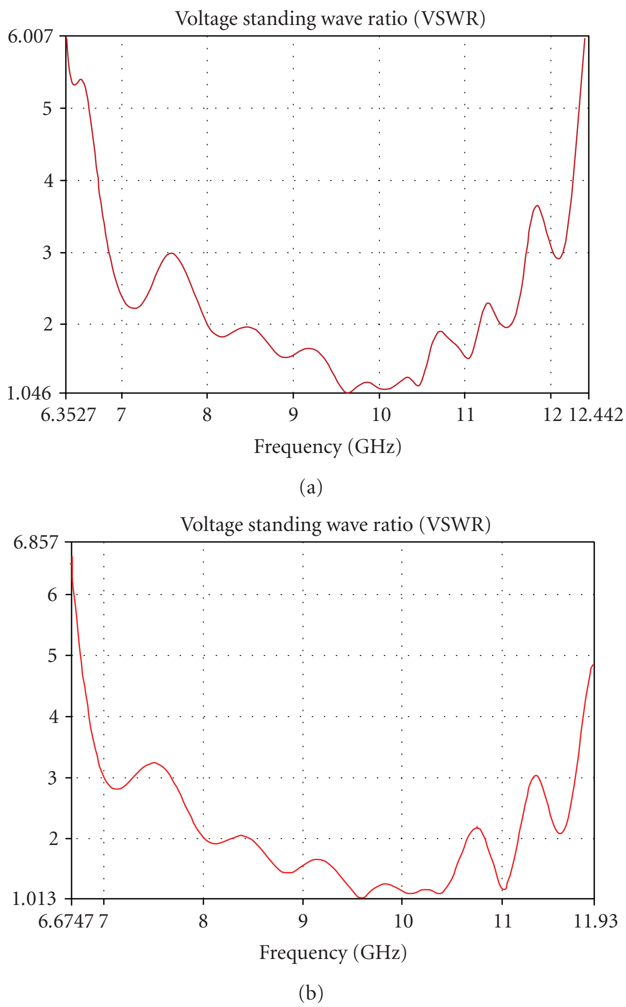


Figure 8: (a) Simulated VSWR of LWA Type II. (b) Simulated VSWR of LWA Type III.

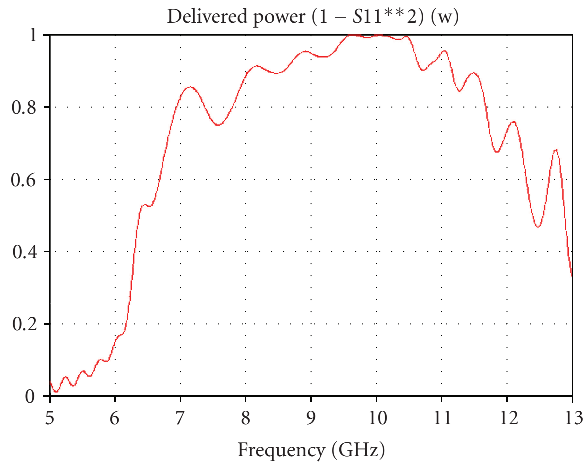
Studio), and the return loss, the radiation pattern, and antenna efficiency were compared with the multisection LWA (Type I) and with curve tapered LWA (Type II). A prototype of tapered LWA was designed and fabricated on RT/Duroid 5880 substrate, with $\varepsilon_r = 2.32$ and a thickness of 0.787 mm. The length of the LWA was chosen to be 120 mm. to allow 90% radiation at an upper frequency of 9.5 GHz, with a 15 mm start width, and 8.9 mm of final width. A sequence of covered wires was inserted in the holes made in the centerline of the antenna to obtain a simple physical grounding structure along all the length of antenna (see Figure 4).

Moreover, a prototype of half tapered LWA was designed and fabricated with the same substrate mentioned previously, applying an adhesive conductor at the edge centerline, to connect the conductor strip and the ground plane, along all the length of antenna (see Figure 5).

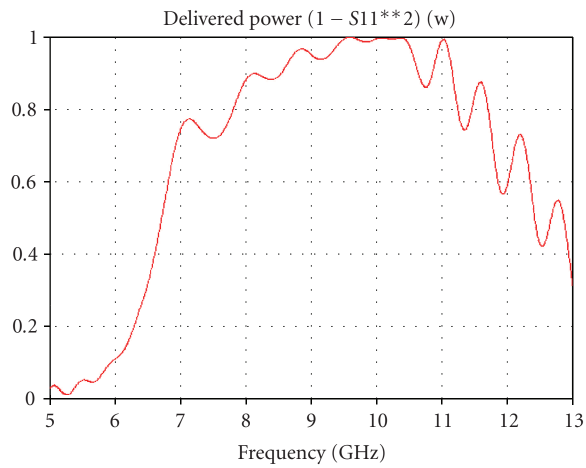
This layout, therefore, improves the band, (33% for VSWR < 2), the gain (12 dBi), and the efficiency (up to 85%) with reference to the conventional uniform microstrip LWAs [8] (which have band of 22% for VSWR < 2, peak gain up to 10 dBi, and efficiency up to 75%).

3. THEORETICAL AND EXPERIMENTAL RESULTS

To excite the higher-order mode TE10 in our LWA is necessary simply by an asymmetrical planar feedline of 50Ω. In fact, the physical grounding structure along the centreline of the LWA allows to suppress the dominant mode excited in the antenna. The multisection tapered antenna Type I was made as an open circuit, with a 15 mm start width and 8.9 mm of final width designed using for-section calculation according to [3], while the smooth contour of the LWA Type II was designed through (2). As said previously, the



(a)



(b)

Figure 9: (a) Simulated efficiency LWA Type II. (b) Simulated efficiency LWA Type III.

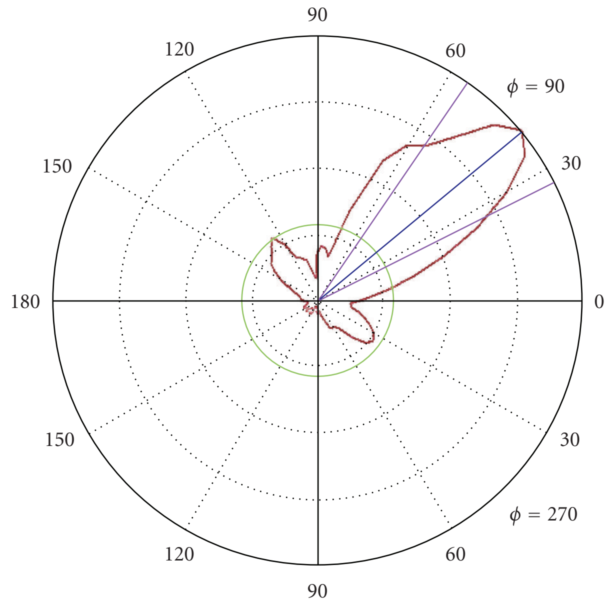


Figure 10: Radiation patterns of electric field (H plane) LWA Type III, at 9.5 GHz.

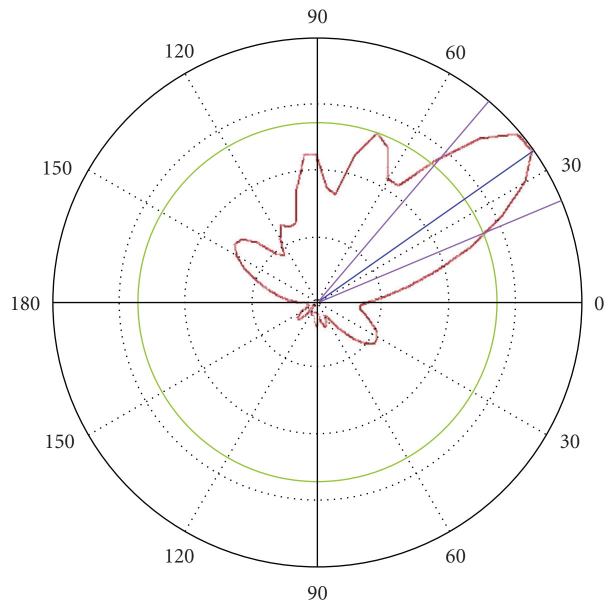


Figure 11: Radiation patterns of electric field (H plane) LWA Type I, at 9.5 GHz.

antenna Type III was obtained using only half of transversal dimension of antenna Type II, and both (Type II and Type III) were made as an open-circuit LWA like Type I. We have implemented the simulations using a substrate of thickness of 0.787 mm and relative dielectric constant of 2.32. From the return loss (S11) of Type I, we note that it is below −10 dB only in three short-range frequencies (see Figure 6), while S11 of Type II and Type III is practically the same, below −10 dB from 8 to 11.2 GHz as shown in Figure 7. Moreover, the VSWR of LWAs Type II and Type III (VSWR < 2 between 8.01 and 11.17 GHz) are in agreement like the antenna efficiency (about 85% in the same range frequency) as shown in Figures 8(a)-8(b) and Figures 9(a)-9(b). The main lobe pattern of LWAs Type I and Type III at 9.5 GHz is shown in Figures 10 and 11. From these figures, we can see a reduction of sidelobe, the peak of gain of LWA Type III up to 12 dBi, and only few degree of mainlobe variation between Type I to Type III. The results of the measured return loss of half LWA (Type III) and the measured E-field pattern (at 8 GHz) of the half LWA (Type III), compared to the simulated return loss and the simulated E-field pattern (at 8 GHz) plotted in Figures 12 and 13, show a good agreement.

These results indicate a high performance of antenna Type III (33% for VSWR < 2, high antenna efficiency, and high power gain) compared with uniforms LWAs (20% for VSWR, peck power gain up to 10 dBi) as mentioned in [8]. Nevertheless, this performance were obtained reducing up to 60% the uniform antenna's dimensions.

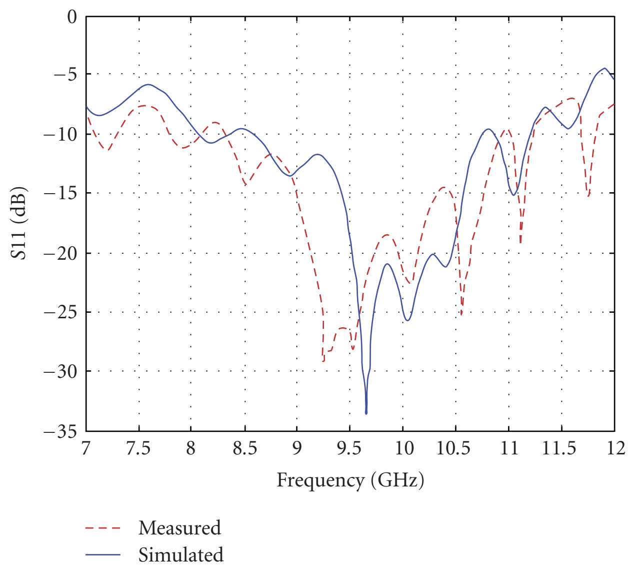


Figure 12: The measured and simulated return loss of half tapered LWA.

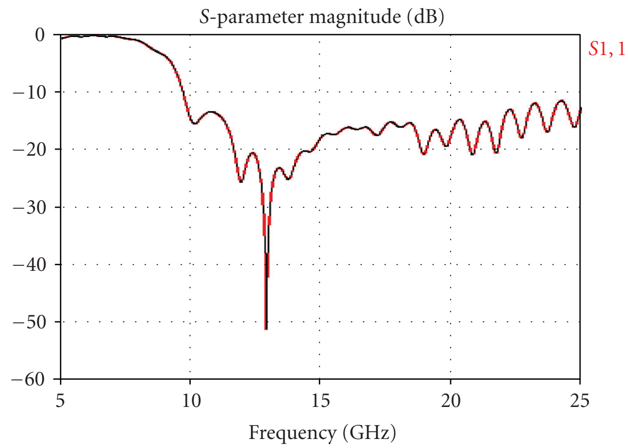


Figure 14: Simulated return loss LWA type III with relative dielectric constant 1.1.

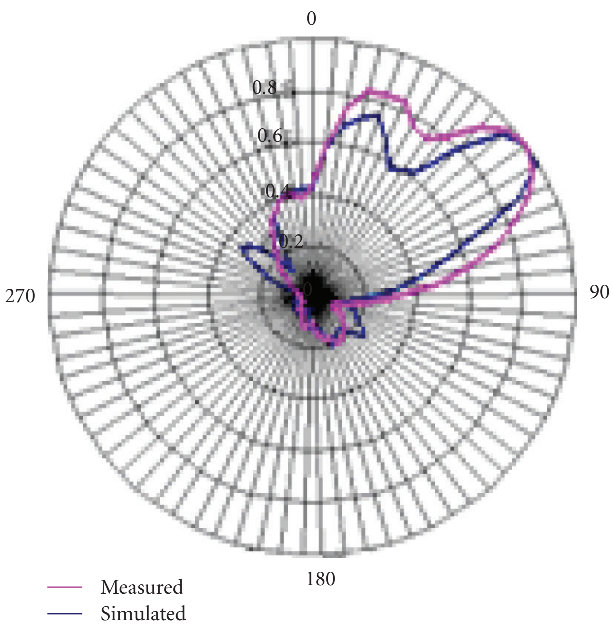


Figure 13: The measured and simulated radiation patterns of E field of half tapered LWA (at 8 GHz).

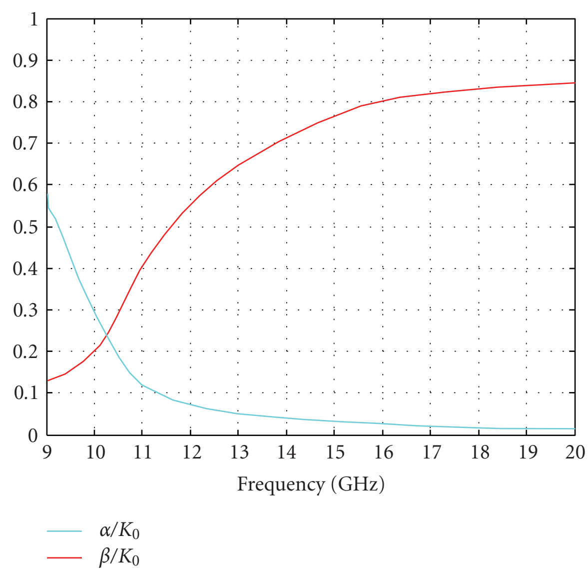


Figure 15: FDTD dispersion characteristics of LWA Type III first high mode with relative dielectric constant 1.1 and width 12 mm.

Finally, from (1) we note also that if the relative dielectric constant approaches 1, the cutoff frequency shifts toward high frequency and the upper limit of radiation region frequency becomes infinite, increasing drastically the bandwidth of LWA, as we can see from the simulation return loss of antenna Type III obtained with a ε_r 1.1 shown in Figure 14. Moreover, from the dispersion equation solved with FDTD for ε_r 1.1 and for an average width of antenna Type III (12mm) we note (see Figure 15) flat values of β near 0.8 and flat values of α near 0. This produces a low variation of mainlobe angle ($\vartheta = \cos^{-1}(\beta/K_0)$) for a wide range of high frequency and a narrow shape of the same mainlobe.

4. CONCLUSIONS

In this study, a new design of broadband microstrip leaky-wave antenna from 8 to 11 GHz was proposed with high added value. An FDTD code was used to determinate the propagation constant of LWA, which was necessary for designing a smooth contour of LWA, obtained from the interpolation of the cutoff phase constant or attenuation constant curve calculated by varying the frequency of a multisection broadband microstrip LWA. The simulations and the measured results, of this curve tapered microstrip leaky-wave antenna with a physical grounding structure along its length, demonstrate the good performance compared to conventional uniform microstrip LWAs (wider band and higher gain). This performance improves when ε_r approaches 1 and indicates that this structure is attractive for the design of high-performance microstrip leaky-wave antennas for microwave and millimeter wave applications.

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