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Determination of Non Uniform Sinusoidal Microstrip Leaky-Wave Antenna Radiating Performances in Millimeter Band

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***Abstract*—**Here we have considered non uniform microstrip leaky-wave antenna implemented on a dielectric waveguide by a sinusoidal profile of periodic metallic grating. The non distribution of the attenuation constant α along propagation axis, optimize the radiating characteristics and performances of such antennas. The method developped here is based on an integral method where the formalism of the admittance operator is combined to a BKW approximation. First, the effect of the modeling in the modal analysis of complex waves is studied in detail. Then, the BKW model is used for the dispersion analysis of the antenna of interest. According to antenna theory, a forced continuity of the leaky-wave magnitude at discontinuities of the non uniform structure is established. To test the validity of our dispersion analysis, computed radiation patterns are presented and compared in the millimeter band.

***Keywords*—**antenna, leaky-wave, performances, sinusoidal.

I. Introduction

MICROSTRIP leaky-waves antennas have been, in last years, a field of research of much interests, especially with respect to millimeter wave frequency band for many applications, ranging from mobile communications to phased array radar systems, for their many known attractive features, like : electronic scanning is possible by a simple change in operating frequency [1-4]. Further, substrate integrated waveguides are built up of periodically arranged metallic via-holes or via-slots [5]. Here, an open periodic waveguide with a large via distance supports the propagation of leaky-wave modes and can thus be used for the design of a leaky-wave antenna where the leakage loss increases with the distance between the via-holes or via-slots. The proposed concept represents an excellent choice for applications in the millimeter wave band, particularly at 28–34 GHz. The authors in [6], developp a periodic finite-difference time-domain (FDTD) analysis applied for the first time in the study of a two-dimensional (2D) leaky-wave planar antenna based on dipole frequency selective surfaces (FSSs). To test the validity of the dispersion analysis, measured radiation patterns of a fabricated prototype are presented and compared with those predicted by a leaky-wave approach based on the periodic FDTD results. Otherwise, in [7] a re-radiating composite right left hand (CRLH) transmission line leaky-wave antenna using distributed amplifier structure is proposed. Furthermore, if the two CRLH leaky-wave antennas are designed to be identical, the radiated beam will be directed in the same angle but opposite direction that the incident wave arrived and can operate as a repeater or transponder. In addition, this leaky-wave antenna can also perform as a high gain frequency dependent beam scanning antenna if properly excited from one port. In order to perform radiating patterns with low side lobes levels, others distributions are preferred: A study in [8], based on a procedure of antenna width changes where non uniform profiles are considered. Further, other works have been elaborated from non uniform slotted structures [9,10]. Interesting results in concordance with experimental data are obtained, particularly when reducing the side lobes level.

Whereas, the authors in [11], suggest a compact wideband leaky-wave antenna (LWA) with etched slot elements and tapered structure. The proposed antenna is composed of an asymmetric-fed multi-section tapered short leaky-wave antenna with two embedded slots and a ground plane with etched slot elements. In order to achieve the impedance matching, this multi-section tapered short leaky-wave antenna is embedded with two rectangular slots. This technique not only improves the impedance matching but also suppresses the back lobe. According to the measured results, good performances are obtained. However in [12,13], a curved leaky-wave antenna is studied numerically which results are in concordance with [14].

This paper presents the analysis of non uniform (1-D) microstrip leaky-wave antennas where the distribution of the attenuation constant α along the propagation axis is determined in order to optimize their radiating characteristics and performances. The problem is formulated by an integral equation based on the formalism of the admittance operator combined with a technique of BKW approximation [15,16].

II. Theory and Background

On Fig. 1, a non uniform microstrip leaky-wave antenna is considered. It consists in etching N_{strip} metallic strips with a sinusoidal profile $b(y)$ on the top face of a grounded dielectric substrate of constant ε_r, height a and width C. The strips are d-periodically reproduced on the antenna of length $L_0=N_{strip}\, d$, which can be expressed in terms of λ_0 (in free space). In a leaky-wave antenna, the real part (phase constant) of the complex propagation constant control the main beam direction and the imaginary part (attenuation constant) determine the beamwidth. Further, the distribution profile $b(y)$ the radiating metallic strips can be adjusted in order to reduce the side lobes level SLL(dB), to produce predetermined conformal patterns or to fit specified gabarits in wireless applications. Once the non uniform exponential profile is elaborated, a computation

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procedure of the complex propagation along (O*y*) direction is performed. The phase constant is assumed invariable along this direction since all rays emanating from the radiating structure are pointed at the same direction. However, at the same time the attenuation constant is assumed variable.

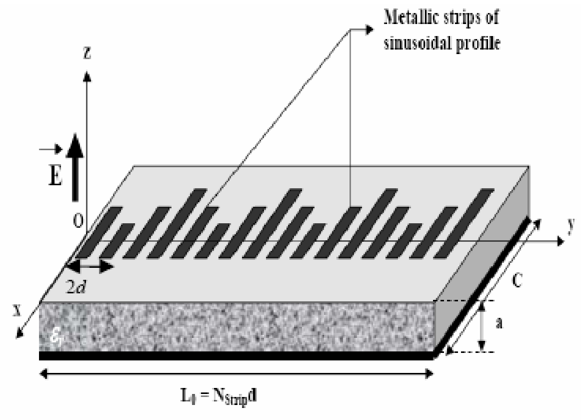


Fig. 1 Non uniform microstrip leaky-wave antenna.

This last is responsible of the radiating characteristics and performances control. The sinusoidal profile $b(y)$ is defined in Eq. (1), by given N and Δb parameters :

$$b(i) = b(1) + \Delta b \, Sin\left(\frac{N\pi}{N_{strip} d} y(i)\right) \qquad 1 \le i \le N_{strip} \qquad (1)$$

Since d is less than L_0, the exponential profiles are studied after performing the approximation which assumes that the non uniform profile is constant per section of length d as described on Fig. 2. Practically, the antenna's dimensions are finite, then the wave guide model with magnetic walls at x=0 and x=C and periodic walls is considered. In some applications, only the (-1) space harmonic is considered. Otherwise, the radiating characteristics of the non uniform leaky-wave antenna is reduced in computing the complex propagation constant at the i^{th} section of the non uniform antenna as described in [15,16]. Then, we can write:

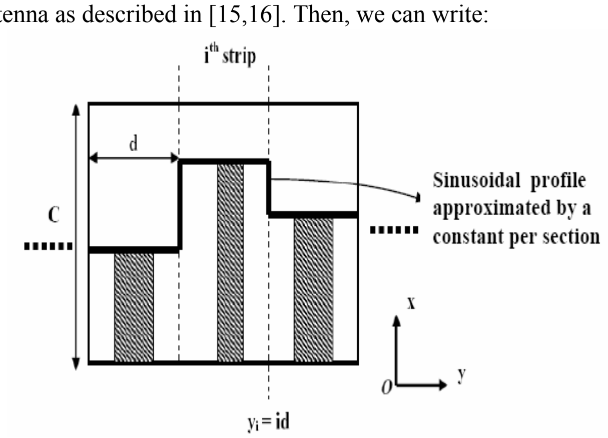


Fig. 2 Sinusoidal profile approximation

$$k_{y-1}(y) = \beta_{y-1}(y) - j\alpha(y) \qquad (2)$$

such that

$$\begin{cases} \beta_{y-1}(y) = \beta_{y-1}(y_i) = \beta_{y-1} & (3) \\ \alpha\ (y) = \alpha(y_i) = \alpha_i & (4) \end{cases}$$

where

$$y_i = i \ d \qquad (5)$$

and

$$\beta_{y-1} = \beta_y - \frac{2\pi}{d} \qquad (6)$$

β_y is the phase constant of the fundamental space harmonic. The determination of the far field (E_θ,E_ϕ) of the (-1) space harmonic a Fourier transform is performed in the aperture delimited by the real dimensions of the antenna as in [15,16].

III. Numerical Results

The original problem of non uniform leaky-wave antenna is decomposed in N_{strip} equivalent sub-problems. Their formulations by Galerkin method, yield to (N_{strip}-1)xN_{strip} subproblems of unknowns k_{yi}= β_y -jα_i. For the case of sinusoidal profile, several configurations for symmetric and non symmetric distributions $b(\lambda_0)$ and their radiation patterns are represented respectively. On Fig. 3, a comparison of the approximated method to the exact one is elaborated. The average error (%) versus the operating frequency f(GHz) and the strips number N_{strip} in millimeter band is represented. The approximation effects disappear for higher N_{strip}. Several examples are represented in order to show the versatile nature of the technique developed here for arbitrary profiles, including the non uniform sinusoidal profile $b(y)$.

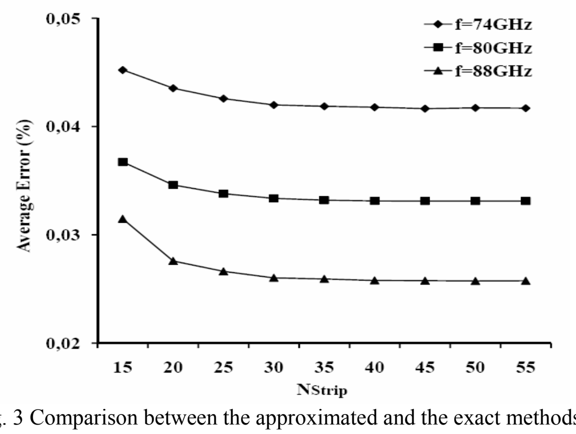
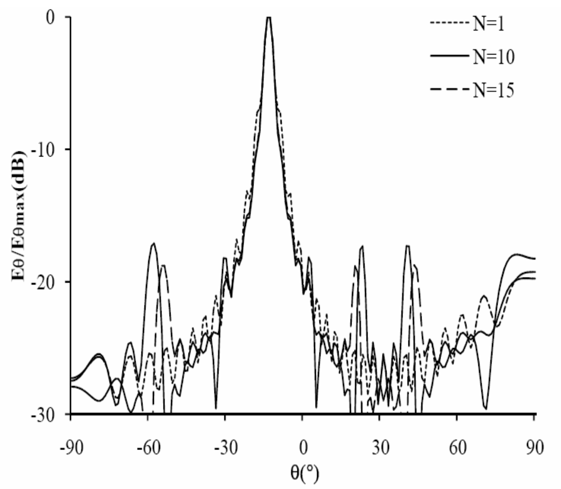
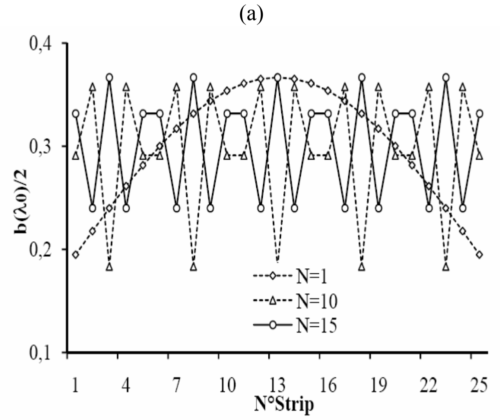


Fig. 3 Comparison between the approximated and the exact methods. The representation of the average error (%) versus the frequency f(GHz) and the number of strips N_{strip} in millimeter band.ε_r=2.5, b=C=0.734λ_0, a=0.32λ_0, d=0.667λ_0, W=0.3307λ_0. (λ_0=3.75mm à f=80GHz).

On Fig. 4, the radiation patterns normalized $E_\theta/E_{\theta\max}$(dB) versus N=1, 10 and 15 for $b(1)/C$=0.5, $\Delta b/C$=0.5 and N_{strip}=25 ($L_0\approx 17\lambda_0$) at f=80GHz. Their respective half-sinusoidal distribution $b(\lambda_0)/2$ is also represented. Another example is given on Fig. 5 where the normalized radiation patterns $E_\theta/E_{\theta\max}$(dB) for N=19 and 29, $b(1)/C$=0.5, $\Delta b/C$=0.5, respectively for N_{strip}=20 and 30 at f=80GHz are shown. One can note that the control of the radiating patterns, the side lobes levels and the main beam width is achieved by the judicious choice of the sinusoidal profile parameters. Thus, diagrams with high directivities can be obtained when N_{strip} increases.

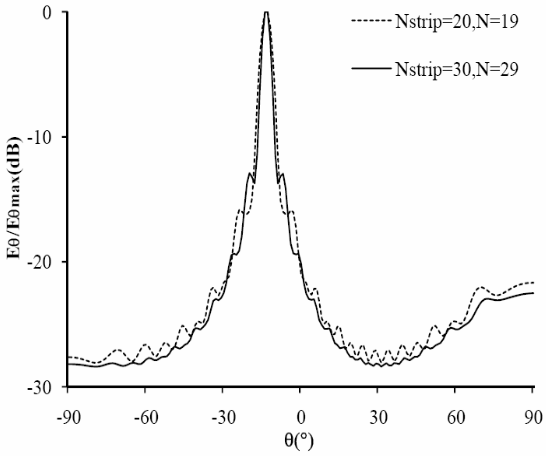


(a)

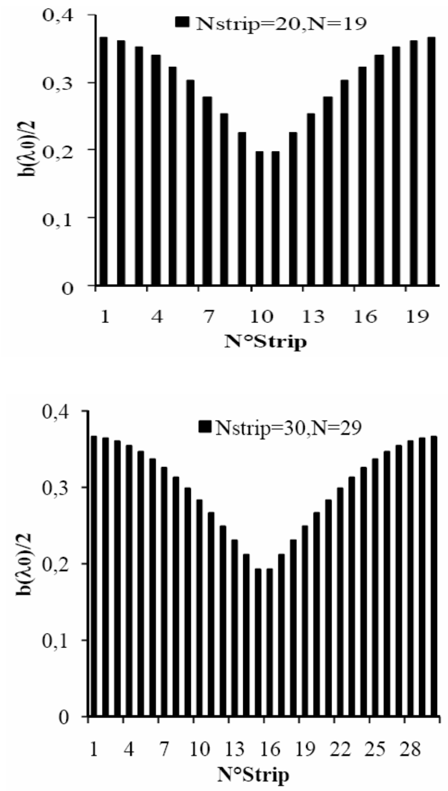


(b)

Fig. 4 (a) Normalized radiating patterns $E_\theta/E_{\theta\max}$(dB) versus N=1,10 and 15, $b(1)/C$=0.5, $\Delta b/C$=0.5 and N_{strip}=25 ($L_0\approx 17\lambda_0$) at f=80GHz. (b) Sinusoidal distributions $b(\lambda_0)/2$ of metallic strips. ε_r=2.5, C=0.734λ_0, a=0.32λ_0, W=0.3307λ_0, d=0.667λ_0. (λ_0 =3.75mm at f_0=80GHz).



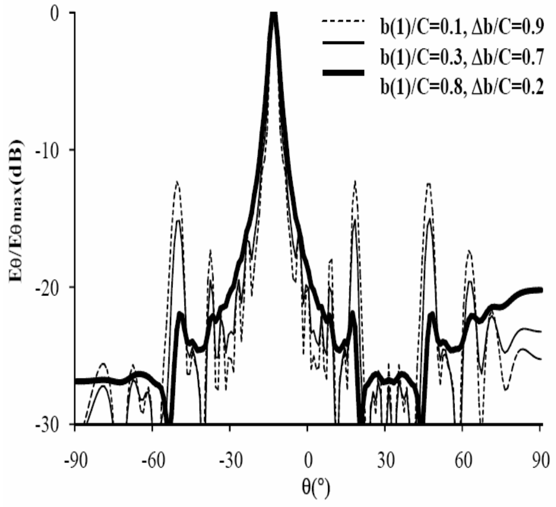
(a)



(b)

Fig. 5 (a) Normalized radiating patterns $E_\theta/E_{\theta\max}$(dB) versus N=19 and 29 for $b(1)/C$=0.5, and $\Delta b/C$=0.5, respectively for N_{strip}=20 and 30 at f=80GHz. (b) Sinusoidal distributions $b(\lambda_0)/2$ of metallic strips. ε_r=2.5, C=0.734λ_0, a=0.32λ_0, W=0.3307λ_0, d=0.667λ_0. (λ_0 =3.75mm at f_0=80GHz)

On the other hand, we show on Fig. 6 by varying the ratios $b(1)/C$ and the gaps $\Delta b/C$, that other representations of radiating patterns are possible for N =19, N_{strip}=30 ($L_0\approx 20\lambda_0$) at f = 80GHz.



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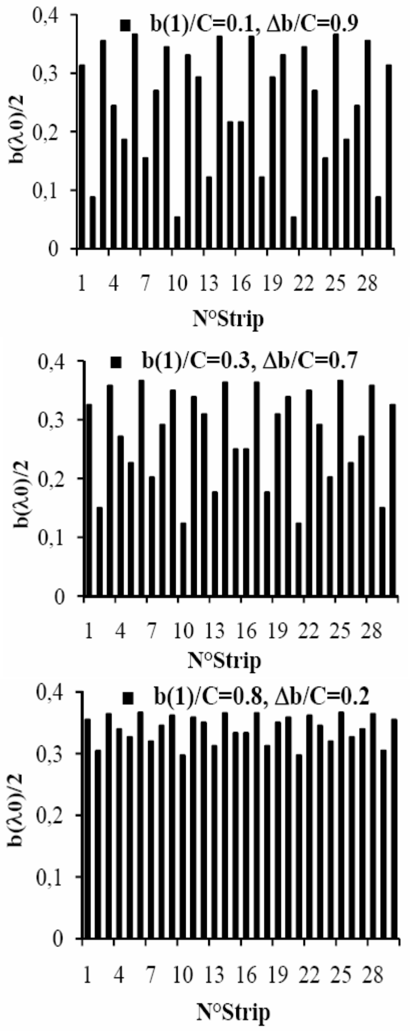

(b)

Fig. 6 (a) Normalized radiating patterns $E_\theta/E_{\theta max}$(dB) for N=19 and N_{strip}=30 ($L_0 \approx 20\lambda_0$) at f=80GHz. (b) Sinusoidal distributions $b(\lambda_0)/2$ of metallic strips. ε_r=2.5, C=0.734λ_0, a=0.32λ_0, W=0.3307λ_0, d=0.667λ_0. (λ_0 =3.75mm at f_0=80GHz).

On Fig. 7, SLL(dB) and η(%) variations are represented at f=80GHz according to N for N_{strip}=25 ($L_0 \approx 17\lambda_0$) and $b(1)/C=\Delta b/C$=0.5 in the case of sinusoidal profile. A periodicity of their respective values is noted for N greater than N_{strip}.

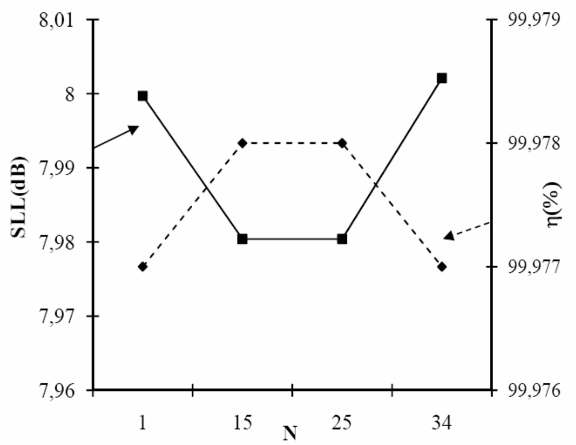

Fig. 7 SLL(dB) and η(%) variations at f=80GHz versus N for N_{strip}=25 ($L_0 \approx 17\lambda_0$), $b(1)/C=\Delta b/C$=0.5, ε_r=2.5, C=0.734λ_0, a=0.32λ_0, W=0.3307λ_0, d=0.667λ_0. (λ_0 =3.75mm at f_0=80GHz)

A comparison of the normalized radiating patterns $E_\theta/E_{\theta max}$(dB) at f=80GHz between non uniform linear, triangular and sinusoidal are given on Fig. 8.

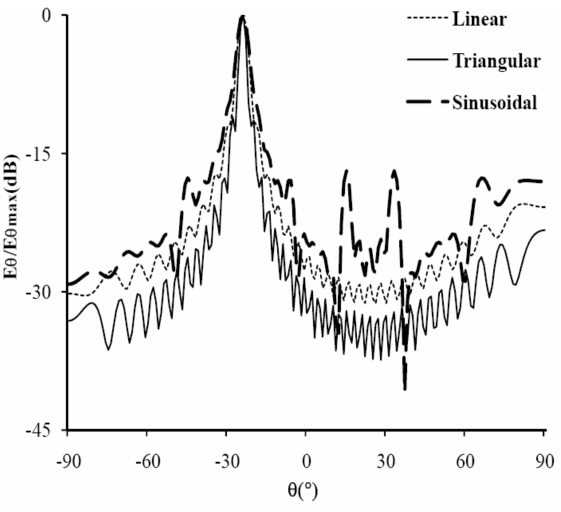

Fig. 8 Comparison between normalized radiating patterns $E_\theta/E_{\theta max}$(dB) at f=80GHz. ε_r=2.5, C=0.734λ_0, a=0.32λ_0, W=0.3307λ_0, d=0.667λ_0. (λ_0 =3.75mm at f_0=80GHz)

Similarly, the SLL(dB) and η(%) variations versus the operating frequency are given in Fig. 9, for N_{strip}=35 ($L_0 \approx 23\lambda_0$). The SLL(dB) are best, respectively for linear, sinusoidal and triangular profiles. However, the efficiencies are better at lower frequencies.

IV. Conclusion

In this paper, we propose an approximated analysis method for microstrip non uniform leaky-wave antenna of sinusoidal profile. This scheme is susscefully applied to compute the antenna's radiating characteristics and performances of symmetric and non symmetric sinusoidal profiles. Here, the non uniform attenuation distribution is obtained since approximation of constant profile per period and the BKW method are applied to compute electric field. Thus, the continuous leaky-wave antenna is replaced by a linear progressive phased array of discrete elements. Several examples are obtained and compared where at most amelioration in the performances of such antennas are achieved, including, side lobe level reduction, acceptable efficiencies, conformal patterns, etc. Furthermore, comparison with others profiles is performed.

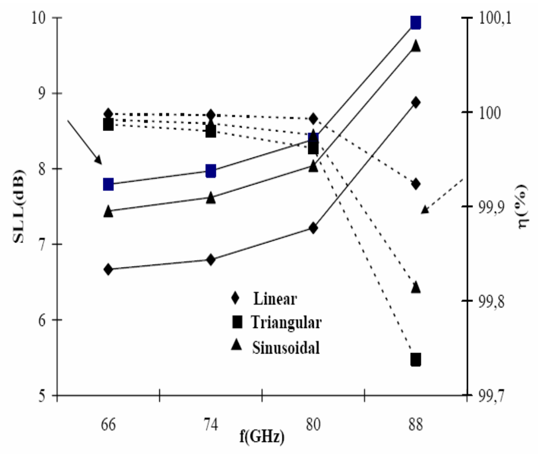

Fig. 9 *SLL*(dB) and *η*(%) variations versus operating frequency for N_{strip}=35 ($L_0 \approx 23\lambda_0$). ε_r=2.5, $b=C=0.734\lambda_0$, $a=0.32\lambda_0$, $W=0.3307\lambda_0$, $d=0.667\lambda_0$. (λ_0=3.75mm at f_0=80GHz).

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