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Research paper

Effect of coupling on the performance a periodic leaky wave patch antenna

Charmolavy G. L. Nkouka Moukengue [1*], Barol Mafouna Kiminou [1]

[1] *Electronics and Electrical Engineering Laboratory, Marien Ngouabi University, Brazzaville, RC*
**Corresponding author E-mail: ln999kouka@gmail.com*

Abstract

This article demonstrates the effect of coupling between two metal strips and the substrate width of a periodic leaky wave patch antenna operating at 80 GHz. Increasing the width of the substrate and the distance between the metal patches results in directional radiation and a good reflection coefficient in the 72-86 GHz band.

***Keywords*: coupling; directional radiation; leaky wave antenna; width of the substrate; 72-86 GHz band.**

1. Introduction

The development of space telecommunications in recent years has required the realization of increasingly compact and efficient equipment, operating at higher and higher frequencies. The use of high accuracy radars in surveillance, detection and mobile communication systems is leading to a research focus on scanning antennas [1-5]. Antenna arrays are currently used in many radar, mobile radio and space applications, but little is known about the coupling phenomena that occur in them. Leaky wave antenna arrays are well suited in the millimeter band [4-9]. The coupling between two leaky antennas is of great importance in the design of antenna arrays. Several simulators are available to process these leaky structures and extract propagation, diffraction and radiation parameters [5-12].
In order to explore methods to reduce the angular aperture and the levels minors lobes, we propose to analyze the effect of the width of the two metal patches and the dielectric substrate on the performance of the leaky wave array antenna operating at 80 GHz.

2. Theory

Leaky waves are characterized by the loss of energy by radiation as they propagate. Consider the structure in Figure 1 and assume that the propagation is along (Oy), the propagation constant along this axis is written:

$$k_x^2 + k_y^2 + k_z^2 = k_o^2 \tag{1}$$

Where (kx , ky , kz) are the propagation constants along the three respective directions (Ox, Oy, Oz). $k_o = \frac{2\pi}{\lambda_o}$ is the wave number and λ_o is the free-space wavelength.
If the structure is infinite along (Ox) then kx = 0 and let us assume that the propagation is along (Oy) (Figure 1), we can then assume that:

$$k_y = \beta_y - j\alpha_y \tag{2}$$

$$k_z = \beta_z - j\alpha_z \tag{3}$$

$$(\beta_y - j\alpha_y)^2 + (\beta_y - j\alpha_y)^2 = k_o^2 \tag{4}$$

Equaling the imaginary parts, we obtain:

$$\alpha_y\beta_y + \alpha_z\beta_z = 0 \tag{5}$$

This equation allows us to draw the equi-amplitude lines and the equi-phase lines that are orthogonal and tilted with respect to the (Oz) axis by an angle θ given by:

$$\mathrm{tag}(\theta) = \frac{\beta_y}{\beta_z} = -\frac{\alpha_z}{\alpha_y} \tag{6}$$

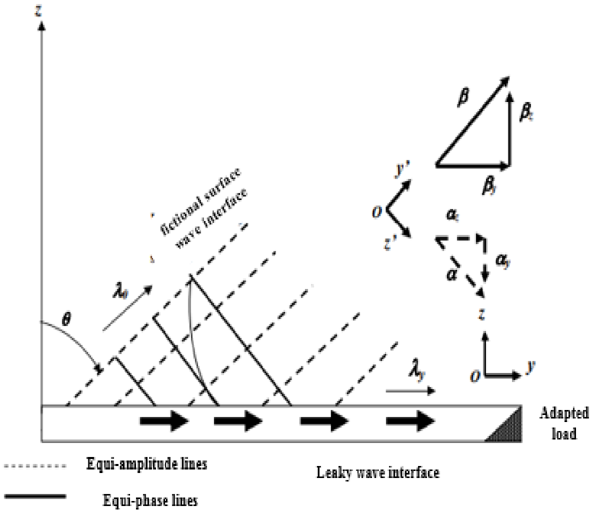

Fig. 1: Characteristics of Leaky Waves.

The emergence angle θ is therefore:

$$\sin(\theta) = \frac{\beta_y}{\beta} = \frac{2\pi}{\lambda_y}\left(\frac{1}{k_0^2+\alpha^2}\right)^2 \tag{7}$$

For values of α sufficiently weak:

$$\sin(\theta) = \frac{\lambda_o}{\lambda_y} \tag{8}$$

In the case of a periodically charged structure with spatial periodicity l, if (Oy) is the direction of propagation of the guided wave, the configuration of the fields at a point (x,y,z) will be the same as that at the point (x, y+l, z). Moreover, Floquet's theorem [13] states that the fields at two homologous points differ only by a complex constant.
So we can write:

$$\mathrm{E}(x, y + d, z) = \mathrm{E}(x, y, z)e^{-k_y l} \tag{9}$$

In this case, the pseudo-periodic field is decomposed into a Fourier series, giving rise to a fundamental term (n=0) and to space harmonics or Bloch-Floquet modes (n = ±1, ±2, ±3, ...) given by [13-14]:

$$\mathrm{E}(x, y, z) = \sum_{-\infty}^{+\infty} a_n(x, z)\, e^{-jk_{yn}y} \tag{10}$$

Where

$$a_n(x, z) = \frac{1}{d}\int_0^d \mathrm{E}(x, y, z)e^{-jk_{yn}y}dy \tag{11}$$

And

$$k_{yn} = k_y + \frac{2\pi n}{l} = \left(\beta_y - j\alpha\right) + \frac{2\pi}{l} = \beta_{yn} - j\alpha \tag{12}$$

With

$$\beta_{yn} = \beta_0 + \frac{2n\pi}{l} \tag{13}$$

β_{yn} is the phase constant the n^{th} harmonic of the leaky wave along (Oy);
β_0 is the phase constant of the fundamental mode of the dielectric guide without the periodic grating.
Equation (13) shows that β_{yn} can take an infinite number of values.
The harmonic can so constitute a forward, backward, slow or fast wave.
We can define for each space harmonic n, the angle corresponding to the direction of radiation. It is given by:

$$\sin\theta_n = \frac{k_{yn}}{k_o} \tag{14}$$

In some applications, to avoid minor lobes, it is recommended to consider only the space harmonic n=-1 [13]. Its angular direction is given by the relation (15)

$$\sin\theta_{-1} = \frac{\beta_{-y1}}{k_o} \tag{15}$$

Where $\beta_{-y1} = \beta_{yo} - \frac{2\pi}{p}$, with β_{-y1} : the phase constant of the space harmonic n=0 and p the periodicity.

3. Antenna design

Figure 2 shows the structure of a leaky wave microstrip antenna array, consisting of a dielectric substrate of relative permittivity ε_r, width B of thickness a with a perfectly conducting ground plane. On its upper side of the substrate are printed metallic patches of width w with periodicity l following (Oz).

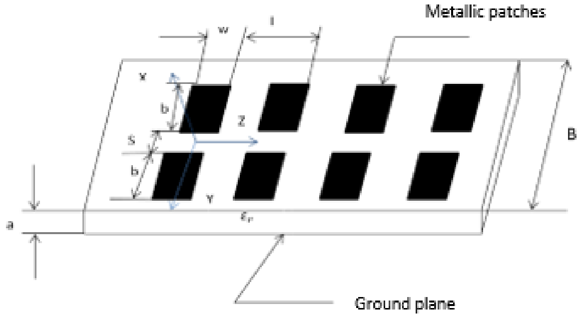

Fig. 2: Periodic Leaky Wave Antenna.

4. Results and discussion

This section presents the simulation results of the proposed leaky wave periodic patch antenna. The structure was designed and simulated using HFSSv13 Simulation software. The parameters evaluated are: reflection losses, propagation and radiation parameters.

4.1. Reflection coefficient

Figure 3 shows the curve of reflection coefficient variation as a function of frequency for a leaky wave patch antenna, varying the distance S between two metallic patches. This antenna resonates at frequency F=80 GHz for S=$3\lambda_o$ and F=81.5 GHz for S=$2\lambda_o$ with reflection coefficient values of -24.03 dB and -7.32dB respectively. We note that the antenna efficiency is significantly improved for S=$3\lambda_o$.

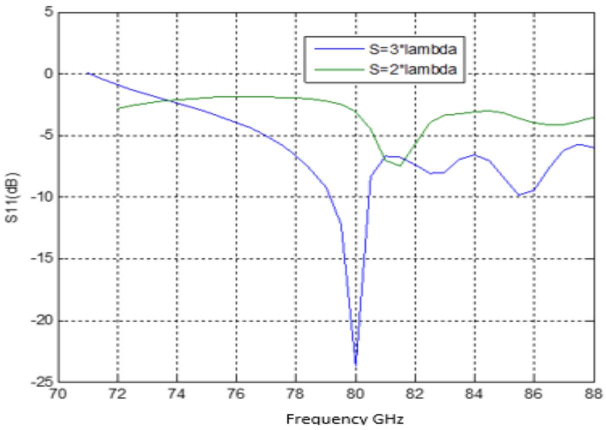

Fig. 3: Variation of the Reflection Coefficient as A Function of the Frequency: B= $0.8\Lambda_O$; W=$0.4\Lambda_O$; B=8λo.

4.2. Propagation parameters

In this section, we propose to study the influence of frequency on β_{-1}/k_o , θ_{-1}, and α/k_o at millimeter band. The variation of the depointing direction θ_(-1) and the attenuation constant as a function of frequency is shown in Figure 4. The curve for the variation of the angular direction θ_{-1} has a constant slope. Indeed, a step of 1 GHz subsequently results in an angular jump of 1.8° where the angular opening is 38.7° between [60; 85] GHz. As for the attenuation constant, it increases when the frequency decreases.

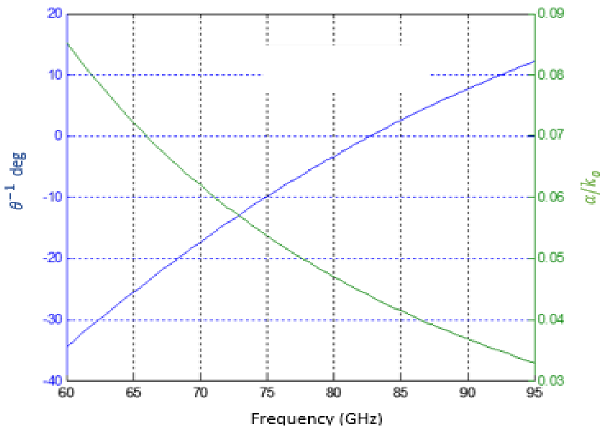

Fig. 4: Variation of Θ_{-1} and $^{A}/_{K_o}$ as A Function of Frequency.

In Figure 5, the normalized variations of the real and imaginary part of $^{\beta_{-1}}/_{k_o}$ as a function of frequency is shown. The attenuation constant $^{\alpha}/_{k_o}$ undergoes a monotonic decay with frequency, while $^{\beta_{-1}}/_{k_o}$ increases with frequency.

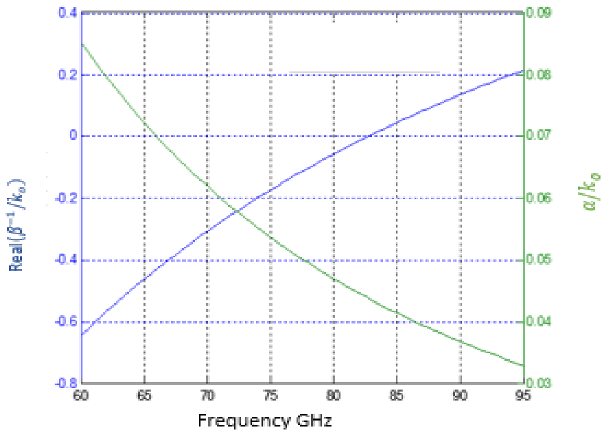

Fig. 5: Variation of $^{B_{-1}}/_{K_o}$ and $^{A}/_{K_o}$ With Frequency.

To appreciate the sensitivity of the antenna, we have plotted the variation of the attenuation constant $^{\alpha}/_{k_o}$ and the real part $^{\beta_{-1}}/_{k_o}$ as a function of frequency in Figures (6) and (7), varying the substrate width. It is easily to see that the latter has almost no effect on the attenuation constant and the phase constant.

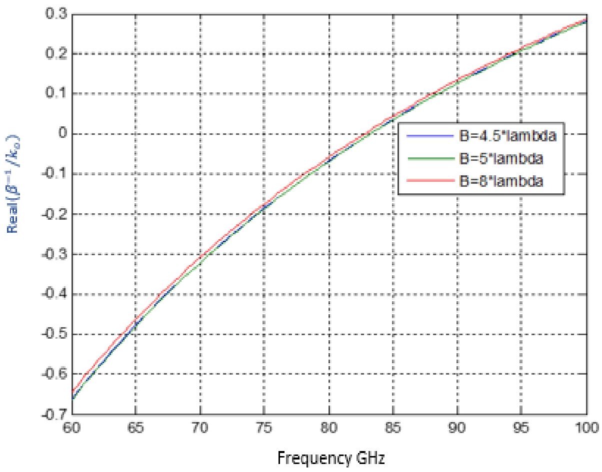

Fig. 6: Variation of $^{\beta_{-1}}/_{K_o}$ as A Function of Frequency.

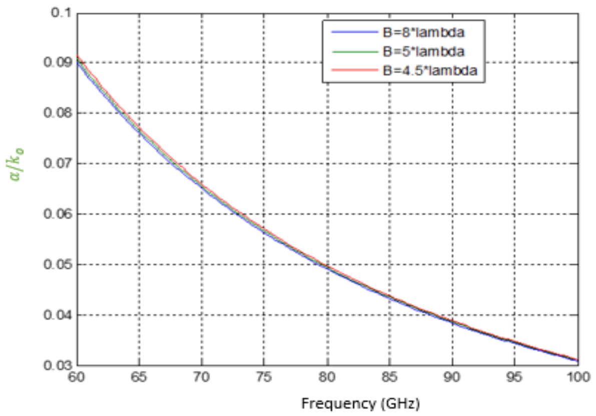

Fig. 7: Variation of $^{\alpha}/_{K_0}$ as A Function of Frequency.

4.3. Radiation patterns

To highlight the enhancement of the levels of minor's lobes and angular aperture, we have plotted in Figure 8 the radiation patterns versus θ diagram for different values of B.
In figure 8, we represented the radiation patterns of the LWA for different values of B. We note that, the efficiency of the antenna is clearly improved for B=8λ_0. The metal patterns should be far from each other, this decreases the electromagnetic coupling between them, due mainly to reflections from the edges of the metal. This coupling is practically very strong for very close patches.

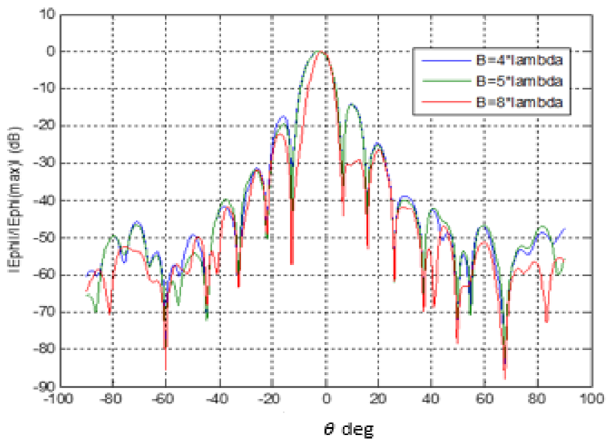

Fig. 8: Radiation Patterns Of The E-Plane at F=80 GHz; B= 0.8Λ_0 ; W=0.4Λ_0.

5. Conclusion

This study showed us that the use of a periodic leaky waves patch antenna coupled allows to reduce the minor's lobes levels and to improve the angular aperture when the metallic patches are far from each other.

References

[1] Z. Mekkioui et H. Baudrand, ''Analyse rigoureuse d'antennes diélectrique microruban à ondes de fuite. Application au balayage électronique'' Numerical methods in Electromagnetism Proceedings. Numelec 2000, pp.158-159, Poitiers, France.
[2] Ghayath El Hal, Ronan Souleau '' Antenne à ondes de fuite à balayage angulaire à fréquence fixe à 77 GHz," 17é Journée Nationale micro-ondes 18, 19, 20 Mai 2011 Brest.
[3] Z. Mekkioui et H. Baudrand, ''Contribution to dielectric microstrip leaky-wave antenne analysis'' AMSE Press, Journal on Modelling, Mesurement and Control, vol A 76, N°2, pp 21-31, 2003, France
[4] Ghomi M " Contribution à l'étude des antennes micro-ruban à ondes de fuite" Thèse de doctorat à INP-Toulouse 1992
[5] Charmolavy Goslavy Lionel Nkouka Moukengue , Rostand Martialy Davy Loembe Souamy , Nzonzolo , Aristide Mankiti Fati , Désiré Lilonga-Boyenga and Junwu Tao '' Analysis Of A New Leaky-Wave Antenna For W-Band Applications'' Int. J. Adv. Res. 8(12), 358-363, ISSN: 2320-5407, December 2020. https://doi.org/10.21474/IJAR01/12158.
[6] Rahul Agrawal, Pravesh Belwal, Suresh Gupta "Asymmetric Substrate Integrated Waveguide Leaky Wave Antenna with Open Stop Band Suppression and Radiation Efficiency Equalization through Broadside" Radioengineering, VOL. 27, NO. 2, pp: 409-416, JUNE 2018 https://doi.org/10.13164/re.2018.0409.
[7] Sajad Mohammad-Ali-Nezhad and Alireza Mallahzadeh "Periodic Ridged Leaky-Wave Antenna Design Based on SIW Technology" IEEE antennas and wireless propagation letters, VOL. 14, pp: 354-357, 2015 https://doi.org/10.1109/LAWP.2014.2361175.
[8] Bin Xi, Yuanxin Li , and Yunliang Long " A Miniaturized Periodic Microstrip Leaky Wave Antenna with Shorting Pins" Hindawi International Journal of Antennas and Propagation, pp:1-7, 2019 https://doi.org/10.1155/2019/4068572.
[9] Zahéra Mekkioui, "Contribution à l'analyse d'antennes diélectriques micro-rubans à ondes de fuite unidimensionnelle et bidimensionnelle à motif métalliques quelconques" Thèsede doctorat, université AbonBekrBelkaid de Tlemcen Algérie, 2004
[10] Charmolavy G. L. Nkouka Moukengue, Franck Moukanda Mbangou, Nzonzolo and D. Lilonga-Boyenga '' A 80 GHz Microstrip Leaky-Wave Antenna with Degraded Ground Plane Design ,'' Journal of Scientific and Engineering Research, 6(8):97-101 ,2019

[11] Sajad Mohammad-Ali, Ali Nezhad and Alireza Mallazadh ‘’Periodic ridged leaky-wave antenna design based on SIW Technology,’’ IEEE Antennas and wireless propagation letters, vol.14, pp. 323-333, 2015 https://doi.org/10.1109/LAWP.2014.2361175.
[12] Simon Otto, Zhichao chen, Amar Al-Bassam, Andreas Rennings, Kmlauss S and C Caloz ”Circular polarization of periodic leaky-wave antennas with axial asymmetry : Theoretical Proof and Experimental Demonstration” IEEE Transaction on antennas and propagation, vol 62, n°4, april 2014 https://doi.org/10.1109/TAP.2013.2297169.
[13] Robert E. Collin, "Theory of Guides Waves", 2nd Ed., OEEE Press, 1991 15.
[14] Lilonga-Boyenga D ”Contribution à l’étude du couplage par onde de charge d’espace dans les structures interdigitale et bigrille” Thèse de dotorat 3e cycle INP-Toulouse 1984