ISSN 1870-4069

Propagation in Linear Arrangements of Optical Antennas with Non-Uniform Separation

Alejandro Padrón-Godínez, Venancio Gerardo Calva Olmos

Universidad Nacional Autónoma de México,
Instituto de Ciencias Aplicadas y Tecnología,
México

alejandro.padron@icat.unam.mx

Abstract. In this work, the propagation in linear arrays of optical antennas with non-uniform separation by directional resonators for the coupling of light waves on one element to another is presented. The dependence of the element coupling factor on the spacing can control the amount of coupling between the elements of the optical antenna. The electromagnetic radiation that propagates through the dielectric elements of the optical antenna has greater intensity concentrated within the cores and the electric field decays exponentially outside of the elements with distance. The medium where these dielectric elements of the antenna are immersed acts as the coating as cladding in the case of wave guides. The following separation distributions were used: uniform, geometric, sinusoidal, binomial, and Tschebysheff polynomial. Each of them with five elements and a wavelength λ = 1550 nm was used, which correspond to one of the intervals for optical communications, with a dielectric constant of ε = 13.9876 ($\cong$ GaAs), each element has a diameter of d = 6.76 μm and a spread of 4.2 mm along the z axis, the dielectric constant of the coating or cladding is 0.5% smaller than antenna elements.

Keywords: Optical antennas, coupling, non-uniform separation.

1 Introduction

The electromagnetic radiation that propagates through the dielectric elements of the optical antenna has greater intensity concentrated within the cores and the electric field decays exponentially outside of the elements with distance. The medium where these dielectric elements of the antenna are immersed acts as the coating, that´s it as cladding in the case of waveguides. The perturbances in the resonance modes of the antenna elements are produced by the proximity of the other elements.

The variation of the dielectric constants of the elements of the optical antenna is another way to control the amount of coupling between the resonators. The appearance of super modes oscillations shows that they are a solution to the propagation equation and when an element is perturbed, it propagates towards the other elements, but if more than one element of the antenna is perturbed, the modes may have destructive superposition. In the work, we analyze the relationship of the propagation

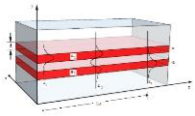

Fig. 1. Coupling between two flat waveguides.

optical antenna with the currents distribution in a radio frequency antenna through the Moment Method (MM).

2 Couplers Modes and Moment Methodology to Linear Arrays

2.1 Couplers Modes

Two optical devices that propagate radiation by approach can produce coupling phenomena; however, this can also occur if two similar waveguides are very close together, as in the case of coupled pendulums. With this, if you now have two waveguides very close to each other, in such a way that they exchange fields from one side to the other (electromagnetic radiation), the incident radiation will be able to propagate through the coupling of these guides. In other words, we can see that optical irradiance can be transfered between waveguides; we can take advantage of this phenomenon for the design and construction of optical couplers that can serve as switches or multiplexers.

To study this work case, there are five elements in the linear array and the coupling is governed by the sum of all the electric fields, that is:

$$E(r) = E_1 \exp(-\beta_1 z) + E_2 \exp(-\beta_2 z) + E_3 \exp(-\beta_3 z) + E_4 \exp(-\beta_4 z) + E_5 \exp(-\beta_5 z) \cdot \quad (1)$$

And the coupling of the arrangement can be expressed as:

$$\frac{dE(z)}{dz} = i \begin{pmatrix} n_1 & \alpha_{12} & 0 & 0 & 0 \\ \alpha_{21} & n_2 & \beta_{23} & 0 & 0 \\ 0 & \beta_{32} & n_3 & \gamma_{34} & 0 \\ 0 & 0 & \gamma_{43} & n_4 & \delta_{45} \\ 0 & 0 & 0 & \delta_{54} & n_5 \end{pmatrix} \begin{bmatrix} E_1(z) \\ E_2(z) \\ E_3(z) \\ E_4(z) \\ E_5(z) \end{bmatrix}, \quad (2)$$

where the refractive indexes of each element are $n_1=n_2=n_3=n_4=n_5=n$ and that α, β, γ, δ are the coupling coefficients, which would be the same if they were not dependent on the separation between each element array.

2.2 Moment Method

The moment method is a tool for the study of the operating properties of a linear arrangement of the resonator elements that make up an antenna [1]. The procedure for the currents approximation consists initially in dividing the conductor into a number N of segments, which may or may not have the same length. Each segment has its intrinsical impedance and a mutual impedance in each pair of them. The relationship of voltage, current and mutual impedance of the segments in matrix form is represented by:

$$\begin{array}{l} V_1(z) = I_1 Z_{11} + I_2 Z_{12} \\ V_2(z) = I_1 Z_{21} + I_2 Z_{22} + I_3 Z_{23} \\ V_3(z) = I_2 Z_{32} + I_3 Z_{33} + I_4 Z_{34} \\ V_4(z) = I_3 Z_1 + I_4 Z_{44} + I_5 Z_{45} \\ V_5(z) = I_4 Z_{54} + I_5 Z_{55} \end{array} \text{ , } o \text{ } bien \text{ } V(z) = \begin{pmatrix} Z_{11} & Z_{12} & 0 & 0 & 0 \\ Z_{21} & Z_{22} & Z_{23} & 0 & 0 \\ 0 & Z_{32} & Z_{33} & Z_{34} & 0 \\ 0 & 0 & Z_{43} & Z_{44} & Z_{45} \\ 0 & 0 & 0 & Z_{54} & Z_{55} \end{pmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \end{bmatrix}, \quad (3)$$

where ***[V]*** is the voltage matrix, ***[I]*** is the current matrix, both are arrays of MxN elements and ***[Z]*** is the antenna impedance matrix. The matrix ***[V]*** is formed by the feeding points of the antenna, namely if the antenna is power in a single point. If ***[V]*** and ***[Z]*** are known, it is possible to find the currents distribution ***[I]***. From equation (3) we have:

$$[I] = [Z]^{-1} [V], \quad (4)$$

where $[Z]^{-1}$ is an admittance matrix.

2.3 Linear Arrays with Non-Uniform Separation

The spacing configurations of antennas linear arrays with separation considered here are uniform and non-uniform geometric, sinusoidal, binomial and Tschebysheff. It also is considered an array of five elements (antennas) and a wavelength λ=1,5.

The current distribution is obtained according to the MM, for each spacing configuration [2-6]. If it is considered the geometric series $a+ar+ar^2+ar^3+ \ldots + ar^{n-1}$ and taking at elements of sum as distances between each antenna, with a=1 and r=2, then the configuration of Fig. (2a and 2b) is obtained. Now it is taking five elements array, with separation of 1, 2, 4, 8 and a wavelength λ=1,5 the current distribution is obtained according to the MM.

For this array an evaluation of the sine trigonometrical function is made according to a sampling that it assists at division of 90º among the number of antennas array and with this the spacing between them is obtained as the Fig. (2c and 2d) it shows. Now if it is considered an array of five elements, with spacing of 1, 0.92, 0.7, 0.38 and a wavelength λ = 1.5 the current distribution is obtained according to the MM. In order to determine the configuration of a binomial array, it suggested that the function $(1+x)^{m-1}$ be written in a series, using the binomial expansion, as:

$$(1+x)^{m-1} = 1 + (m-1)x + \frac{(m-1)(m-2)}{2!}x^2 + \frac{(m-1)(m-2)(m-3)}{3!}x^3 + \ldots \quad (5)$$

For different values of m the results of series expansion give it the spacing configurations showed in Fig. (2e and 2f), this figure represents Pascal's triangle. If the values of *m* are used to represent the number of elements of the array, then the coefficients of the expansion represent the relative amplitudes of elements.

Taking *m=5*, it is had five elements array, with separation of 1, 3, 3, 1 and taking a wavelength λ=1.5 the current distribution is obtained according to the MM. In order to find the spacing of this configuration it is used de Euler's formula, in other words the distances between elements array. Since:

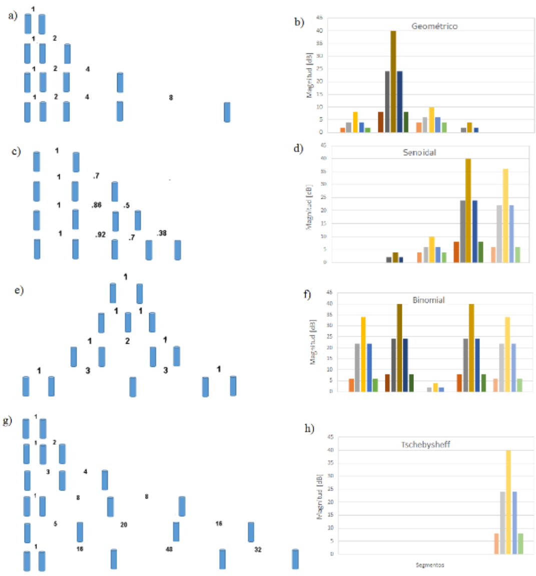

Fig. 2. Geometric spacing (left) and current distribution for 5-elements array (right).

$$[e^{ju}]^m = (\cos u + jsin u)^m = e^{jmu} = \cos(mu) + jsin(mu)\,. \qquad (6)$$

Using the trigonometric identity $sin^2\ u=1 - cos^2\ u$, and with $z = cos\ u$, the Tschebyscheff configuration is given as:

$T_0(z) = 1,$

$T_1(z) = z,$

$T_2(z) = 2z^2 - 1\ ,$

$T_3(z) = 4z^3 - 3z,$

$T_4(z) = 8z^4 - 8z^2 + 1,$

$T_5(z) = 16z^5 - 20z^3 + 5z,$

$T_6(z) = 32z^6 - 48z^4 + 18z^2 - 1,$

$T_7(z) = 64z^7 - 112z^5 + 56z^3 - 7z.$

And each is related to Tschebyscheff polynomial $T_m(z)$, according to this the spacing array is shown in the Fig. (2g and 2h). If it is considered an array of five elements, with spacing of 1, 16, 48, 32 and a wavelength $\lambda = 1,5$ the current distribution is obtained according to the MM.

3 Results

The results that are presented is when in each arrangement of five linear resonators the electric field propagation is made along the z axis, by means finite element simulation with separation according to how the distribution of currents in the linear arrangements

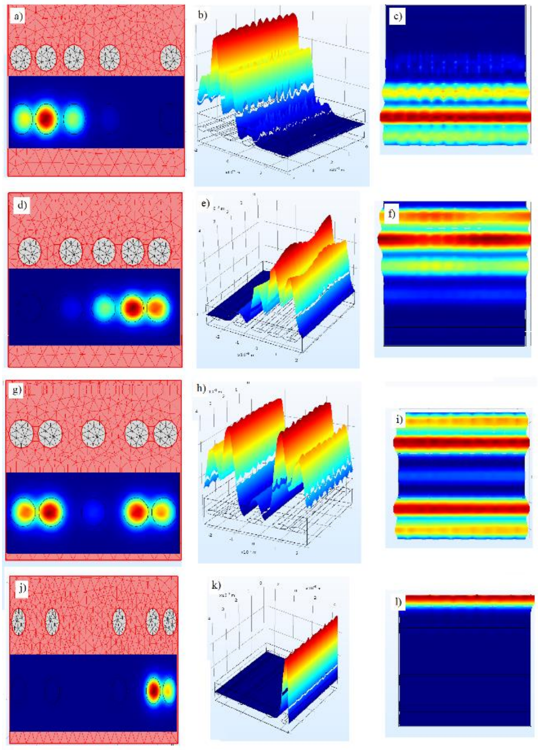

Fig. 3. Linear array of five elements with a) geometric, d) sinusoidal, g) binomial and j) Tschebysheff separation, b), e), h), k) propagation on optical antenna and c), f), i) l) modes of propagation.

was obtained. Recall that we use antenna elements with 6,76 μm of diameter, a wavelength of λ = 1550 nm, along 4.2 mm propagation distance, refractive indexes n_{cladd} = 3,74 in the coating and n_{ker} = 3,745 in the elements of GaAs.The displacements are multiples of a distance d = 3,88 μm according to uniform, geometric, sinusoidal, binomial and polynomial arrangement of Tschebysheff separation.

The radiation propagation over a five elements array with non-uniform spacing Fig. (3a), shows the non-uniform geometric separation, we observe here that the separation (1, 2, 4, 8) for five elements decouples the distant elements and there is only propagation in the nearby (1, 2, 3) elements. Fig. (3d), illustrates the sinusoidal separation, with a separation of (1; 0.92; 0.7; 0.38) for five elements, in this case there is decouples on first elements and there is a bit coupling in 4 and 5 elements on high amplitudes.

Fig. (3g), shows the binomial separation, with a separation of (1; 3; 3; 1) for five elements. Here there is little coupling in (1, 2) and (4, 5) elements, while in 3 element it propagates with lower amplitude than others as channel separation. Fig. (3j), shows the Tschebysheff polynomial separation, with a separation of (1; 16; 48; 32) for five elements. In this case, the (1, 2, 3, 4) elements are completely without propagation, zero amplitude and propagation is only observed in 5 elements of the linear array.

4 Conclusions

We have shown the obtaining of distribution currents for five elements with different arrangements with uniform and non-uniform separation by the method of moments.

We have also shown the radiation propagation in the elements of optical antenna for the same non-uniform separations of the linear arrays, using the finite element method. Both methods show some analogy between the coupling coefficients and the measurement of the own and mutual impedances, where the solutions to the analytical models are similar.

This can be observed in the forms of the propagations and the current distributions in the different analyzed arrangements. On the other hand, the graphs of the radiation propagation obtained by the EFM can show the resonance amplitudes along the *z*-axis, the separation between the elements and if there are coupled modes.

Further, the analogy between the methods occurs at the beginning of propagation by FEM. The wavelength for optical communications in 1,5 μm, leaves us, in perspective, the motivation to work with optical antennas resonators in biometric recognition sensors, opto-electrical switches and light multiplexers to mention a few topics.

References

1. Neri-Vela, R.: Análisis de antenas lineales por el método de momentos. Ingeniería Investigación y Tecnología. vol. 1, no. 2, pp. 73–83 (1999) doi: 10.22201/fi.25940732e.1999.01n2.009
2. Padrón, A., Garduño, J. I., Herrera, A., Prieto, R.: Antennas array adjust with adaptive neuronal system. Journal of Applied Research and Technology, vol. 2 no. 3. pp. 189–198 (2004)
3. Padrón, A., Garduño, J. I.: Current distribution interpolation for antennas linear arrays with nonuniform spacing. Instrumentation & Development. vol. 5, no. 2, pp. 74–82 (2001)
4. Balanis, C. A.: Antenna theory analysis and design. New York: John Wiley & Sons, Inc., (1997)
5. Garduño, J. I. Padrón. A.: Análisis de antenas lineales empleando redes neuronales artificiales. X Congreso Internacional de Electrónica, Comunicaciones y Computadoras, CONIELECOMP´00, pp. 393–397 (2000)