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A Log Periodic Series-Fed Antennas Array Design Using A Simple Transmission Line Model

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Abstract

In this paper, a transmission line model is used to design a series-fed log periodic antennas arrays over a band of frequencies for satellite communications. The transmission line model is simple, precise and allowing taking into account the whole geometrical, electrical and technological characteristics of the antennas arrays. To validate this last, the obtained simulation results are compared with those obtained by the moment's method (MoM). Using this transmission line approach the resonant frequency, input impedance, return loss can be determined simultaneously. Agreements between transmission line model data and the moment's methods results were achieved.

Key words: Log periodic antennas, antennas array, transmission line model, moment's method (Momentum).

Introduction

Modern technologies are directed towards the miniaturization of antennas while trying to keep the best performances, the printed antenna is designed to satisfy these needs, it is a conductive metal of particular form placed on a substrate finished by a ground plane, its miniature character makes it possible to integrate it easily in emission and reception systems. A printed antenna presents a weak band-width and gain, association in array of several printed antennas makes it possible to compensate the single antenna limitations characteristic and to improve their gain and radiation performances, although their design is difficult because of their electromagnetic structure complexity, these antenna have the advantage of being able to be manufactured in great quantity with very weak cost. One of the antennas disadvantages remains a narrow band-width.

The broad band systems interest is confirmed day after day. The telecommunication standards multiplication of the future terminals, the exploitation of the ultra high frequency in various fields requires the use of broad band antennas.

Various techniques have been proposed to improve the bandwidth operation of microstrip elements, such as using thicker substrates combined with very low dielectric constant materials, using parasitic elements [1]-[3], using impedance matching networks [4] and using two or more electromagnetically coupled patches on top of one another or stacked [5]-[7]. Another successful attempt to enhance the bandwidth of microstrip antenna was made by applying the log-periodic technique to design a microstrip array.

The antennas analysis requires a significant number of electromagnetic simulations. The antennas characterization need the use of software based on rigorous numerical methods like the integral equations solved by the moment’s method. Such EM simulations are very expensive in CPU time and which increases dramatically with the unknown number resulting from discretization of the studied structure. Recently, fast algorithms models applied in electromagnetic have been reported in literature.

In the present work, an attempt was made to design a log-periodic printed antennas array (LPA) by the equivalent transmission line model which makes it possible to take in account the whole antennas geometrical, electrical characteristics of and their feed system.

Log periodic antennas formulation

The LPA have properties which reproduce periodically according to the logarithm of the frequency. They are made of radiating elements resulting from/to each other starting from a multiplication of their dimension by a factor τ .

The design of the wideband array was based on frequency-independent antenna principle which, when applied to a periodic structure, result in scaling of the dimensions from period to period so that the performance is periodic with the logarithm of frequency [8]- [9]. This principle was used to design each row of the microstrip linear array of Fig. 1. The patch length L, width W and spacing between two adjacent elements were related initially to the scale factor τ by:

$$\tau = \frac{L_{n+1}}{L_n} = \frac{W_{n+1}}{W_n} \tag{1}$$

The scale factor was chosen to overcome the disadvantage of the narrow band performance of microstrip patches. If one multiplies all dimensions of the array by with τ the element *n* become *n*+1 and the element *n*+1 become the element *n*+2. Consequently the array will have the same radiation properties at all the frequencies which are connected by the scaling factor τ .

$$f_1,\, f_2 = \tau . f_1,\, f_3 = \tau^2 f_1,\, f_4 = \tau^3 f_1 \tag{2}$$

Where:

$$\ln\frac{f_2}{f_1} = \ln\tau;\ln\frac{f_3}{f_1} = 2\ln\tau \tag{3}$$

Where:

l is the distance between two adjacent radiating element.

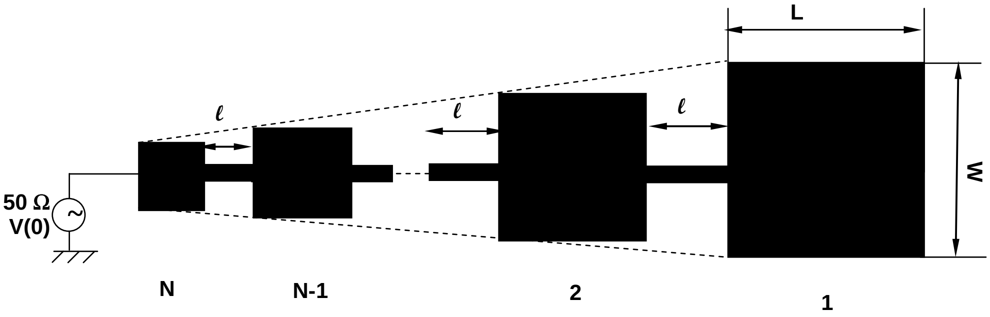


Figure 1: Log periodic antennas array architecture.

To calculate the input impedance of the printed antennas array, one supposes to exploit the electric model are equivalent of each radiating element to lead to a complete electric modelling of the entire array.

The LPA equivalent circuit is presented in the following Fig 2:

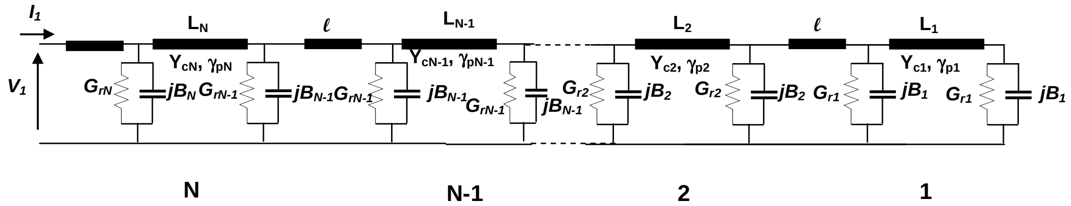


Figure 2: Equivalent circuit of the log periodic antennas array.

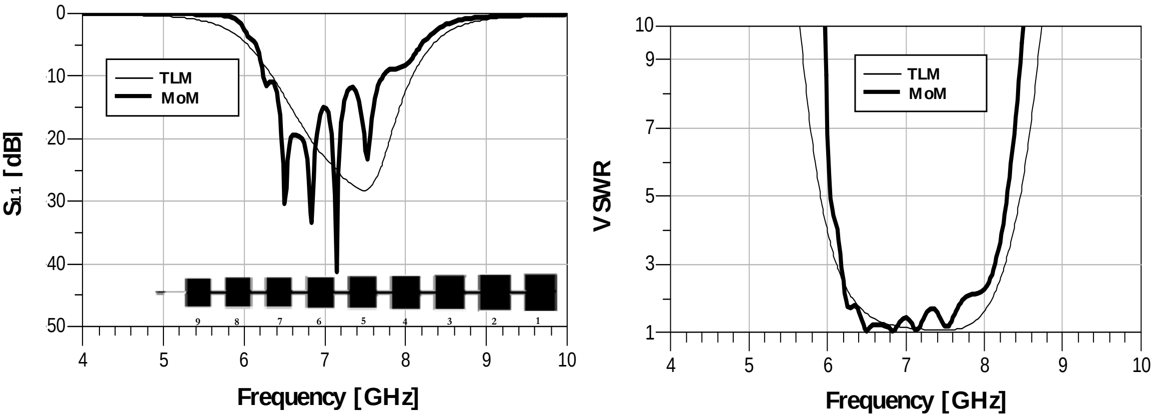
Antennas array operating in the band [6.2-8.2 GHz]

The antennas array is to be designed on RT/Duroid 5880 substrate which has a relative permittivity ε_r of 2.32, a dielectric thickness h of 1.588 mm, a loss tangent of about 0,002 and 0.05 mm conductor thickness. Log periodic array is designed to operate over the frequency range of 6.2 GHz to 8.2 GHz. Because the input impedance of a patch at its edges is usually too high for direct connection to the feeding line, whose standard impedance is 50 Ohm. A quarter wave transformer can be designed to achieve a satisfactory return loss at the resonant frequency. Using the procedure mentioned above, a linear log-periodic array with nine elements was initially designed. The resonant frequencies and dimensions of each radiating element are listed in table 1. The scaling factor is τ=1.031.

Table 1: Frequencies and radiating elements dimensions.

Element number	1	2	3	4	5	6	7	8	9
Frequency (GHz)	7.03	7.24	7.45	7.70	7.94	8.18	8.44	8.70	8.97
W=L (mm)	16.56	16.06	15.57	15.11	14.65	14.21	13.78	13.36	12.96

The antennas array architecture is shown in the figure below. The simulated input return loss of the antennas array is displayed for frequencies between 4.0 to 10.0 GHz in Fig. 3 (a).



(a) (b)

Figure 3: Log periodic antennas array.
(a) Computed return loss of the log periodic antennas array
(b) Computed VSWR

Let us note that the obtained band-width by the transmission line model is of about 1550 MHz and 1800 MHz by the moment's method. Notice according to the Fig. 3 (b), a good similarity between the two curves.

The impedance locus of the antennas array from 4.0 to 10.0 GHz is illustrated on Smith's chart in Fig. 4.

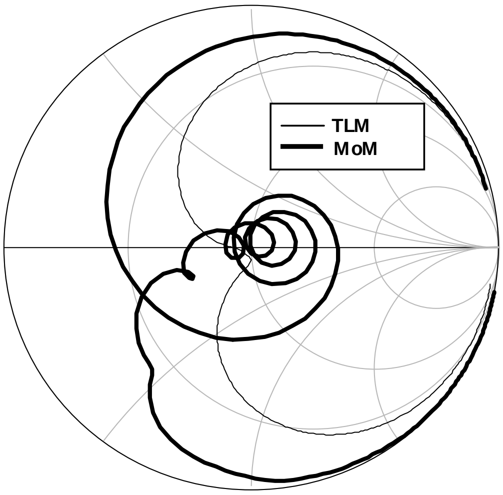


Figure 4: Smith's chart of the input impedance return losses. Frequency points given by start = 4.0 GHz, stop = 10.0 GHz.

The input impedance or the antenna has been calculated over a frequency range of 4.0- 10.0 GHz. It can be seen from Fig 4 that the comparison for the input impedance between transmission line model and the moment method results are in good agreement. Notice that the resonant frequency is very close to the axis of 50 Ohm.

Log periodic antennas array operating in the band [8.7-11.1 GHz]

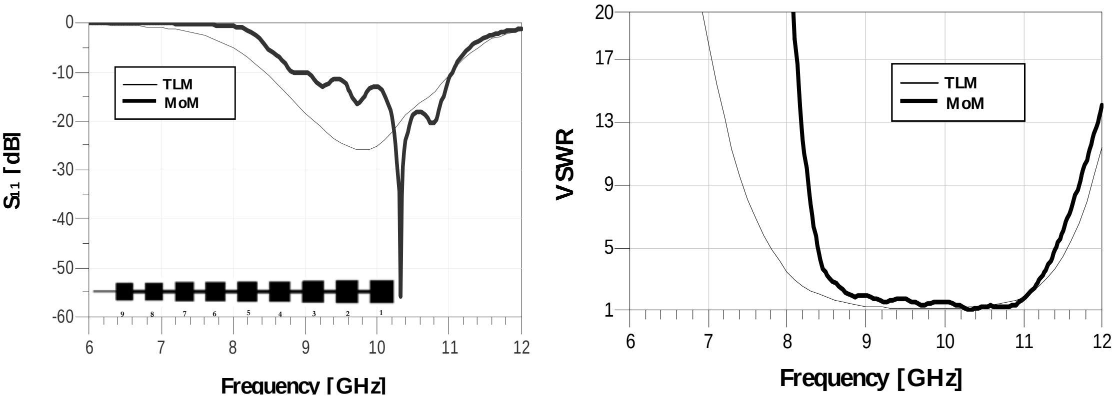
The antennas array is to be designed on substrate which has a relative permittivity ε_r of 2.2, a dielectric thickness h of 1.588 mm, a loss tangent of about 0,002 and 0.05 mm conductor thickness. Using the transmission line model, the return loss, VSWR, input impedance are presented and resonant frequency is found to be in the band [8.7-11.1 GHz]. Because the input impedance of a patch at its edges is usually too high for direct connection to the feeding line, whose standard impedance is 50 Ohm. A quarter wave transformer can be designed to achieve a satisfactory return loss at the resonant frequency.

Nine radiating elements are used in this case. The resonant frequencies and dimensions of each radiating element are listed in table 2. The scaling factor is of about τ=1.04.

Table 2: Frequencies and radiating elements dimensions.

Element number	1	2	3	4	5	6	7	8	9
Frequency (GHz)	8.52	8.86	9.21	9.58	9.96	10.35	10.77	11.20	11.65
W=L (mm)	13.66	13.13	12.62	12.14	11.67	11.22	10.78	10.37	9.97

The optimized antennas array layout is shown in the figure below. The simulated input return loss of the log periodic antennas array is displayed for frequencies between 6.0 to 12.0 GHz in Fig. 5 (a).



(a) (b)

Figure 5: Log periodic antennas array.
(a) computed return loss of the log periodic antennas array
(b) computed VSWR

It is well observed that the resonance of the antennas array is correctly predicted to 10 GHz with a light shift by the moment's method. By calculating the band-widths one finds a width of 2600 MHz obtained by the transmission line model and 2200 MHz by the moment's method. The band-width ($S_{11} \leq$ -9.54 dB) is obviously quite broad band. Notice according to Fig 5 (b) representing the computed VSWR that the two curves are almost identical. In the vicinity of the resonant frequency the VSWR is close to the unit which corresponds to an ideal matching.

The impedance locus of the antennas array from 6.0 to 12.0 GHz is illustrated on Smith's chart in Fig. 6.

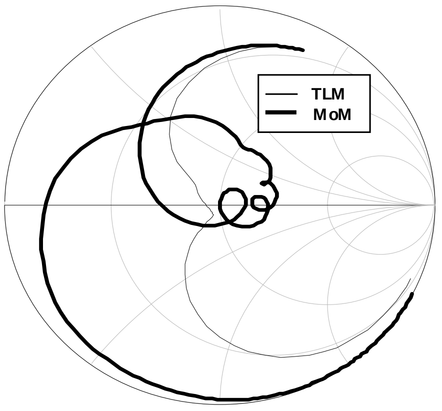


Figure 6: Smith's chart of the input impedance return losses. Frequency points given by start = 6.0 GHz, stop = 12.0 GHz.

Log periodic antennas array operating in the band [9.0–12.0 GHz]

In this section, other geometry is analyzed by using the method proposed in this paper. The permittivity and the substrate thickness are 2.32 and 1.588 mm respectively and the operation frequency band is [9.0-12.0 GHz]. A probe of 50 Ohm is employ to feed the log periodic antennas array.

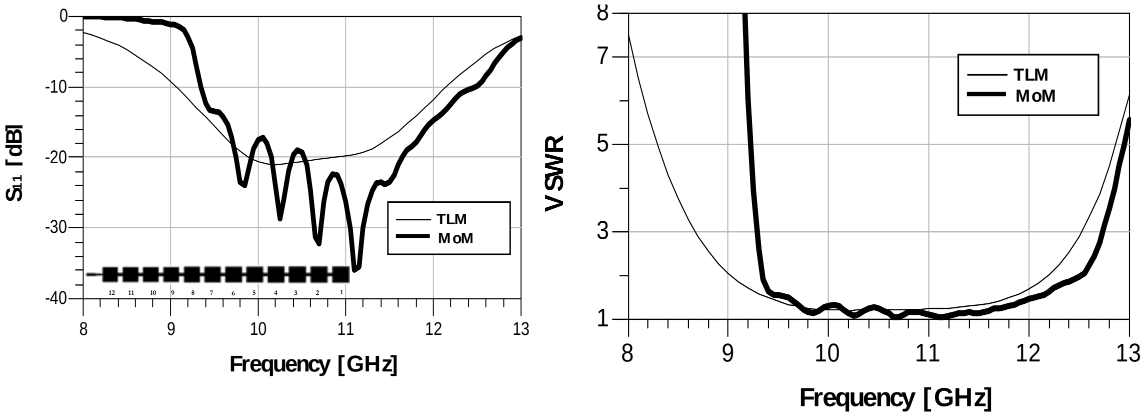
A linear log-periodic array with 12 elements was initially designed. The resonant frequencies and dimensions of each radiating element are listed in table 3. The scaling factor is chosen to be τ=1.01.

Table 3: Frequencies and radiating elements dimensions.

Element number	1	2	3	4	5	6	7	8	9	10	11	12
Frequency (GHz)	11.22	11.33	11.44	11.55	11.67	11.79	11.91	12.02	12.14	12.27	12.39	12.51
W=L (mm)	10.37	10.26	10.16	10.06	9.96	9.86	9.76	9.67	9.57	9.48	9.38	9.29

Figure bellow presents the mask layout for the log periodic antennas array operating in the band [9.0-12.0 GHz].

The simulated input return loss of the log periodic antennas array is displayed for frequencies between 8.0 to 13.0 GHz in Fig. 7 (a).



(a) (b)

Figure 7: Log periodic antennas array
(a) return loss of the log periodic antennas array
(b) computed VSWR

Notice according to Fig. 7 (a) that both models are almost the same curves and that curve obtained by the moment’s method presents several peaks in the frequency band predicted in the table above. One obtained a band-width of 3200 MHz by the transmission line model and 3050 MHz by the moment's method. It is a quite broad band what still proves the effectiveness of the log-periodicals structure in widening the band-width.

The simulated VSWR represented on the Fig. 7 (b) justified the obtained results by the computed return loss.

The impedance locus of the antennas array from 8.0 to 13.0 GHz is illustrated on Smith's chart in Fig. 8.

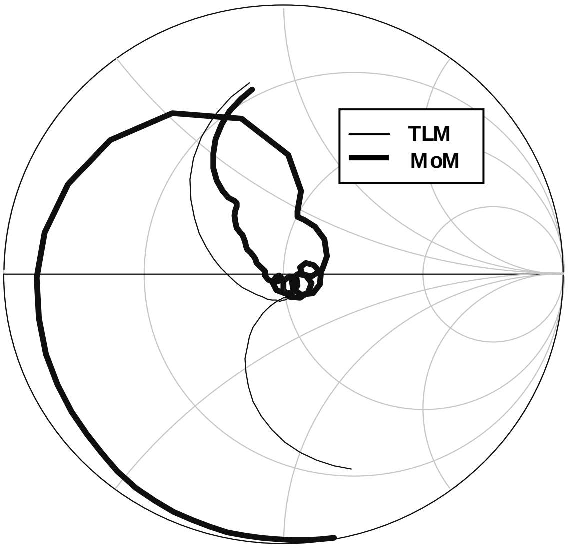


Figure 8: Smith's chart of the input impedance return losses. Frequency points given by start = 8.0 GHz, stop = 13.0 GHz.

It is observed that the two models curves passes by the axis of 50 Ω and present both a null imaginary part witch mean a perfect matching at the resonant frequency.

Conclusion

In this paper several log periodic antennas arrays geometries to be employed in wide-band applications have been designed using a flexible and computation-efficient transmission line model. The results so far show that the transmission line model can be successfully used to predict the input characteristic of the antennas array over wide band frequencies. Even though the model is conceptually simple, it still produces accurate results in a relatively short period of computing time.

The results obtained highlighted a good agreement between the transmission line model and the moment's method.

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