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Analysis of Radiation Patterns of Log-Periodic Dipole Array Using Transmission Line Matrix Model

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***Abstract*— The introduction of broadband systems to communication and radar technologies has demanded the design of broadband antennas. In this thesis, A broadband log-periodic dipole array antenna using Transmission Line Matrix Model is investigated. A log-periodic dipole antenna is analyzed using Transmission Line Matrix Model within the frequency band of 0.5 GHz-6 GHz. After the simulations made with MATLAB, a prototype single polarized LPDA antenna is produced. Developments on the prototype antenna are performed, both to improve the electrical characteristics of the antenna and to make the final design realizable. Results which are obtained in MATLAB are compared with results obtained by designing Log-Periodic antenna using PCAAD.**

***Keywords*— LPDA (Log-Periodic Dipole Array), PCAAD (Personal Computer Aided Antenna Design), TLM (Transmission Line Matrix Model)**

I.INTRODUCTION

An antenna is fundamentally a transmission line that transforms electrical energy into electromagnetic energy. The length of this line is inversely proportional to the transmission frequency. Therefore, as new wireless applications move up in frequency, their antennas correspondingly shrink in size. The gain of the antenna however is depending to a large extent on its physical size. New antennas therefore concentrate on volumetric efficiency.

Several planar broadband antennas covering one or two bands of mobile communications exist and are operational. This evolution has been gradual and resulting in higher bandwidth, gain and improved pattern. A few such advances are the Meander line antenna and Gaubau antennas, which are found to have small size with superior performance and Broadband.Most of this development have been on almost purely planar geometry of the antenna with changes in shape and drilled holes and so on. There has also been continued effort to improve the impedance by tapering the ground plane.

The next step in improving broadband antennas has been to deviate from the pure planar shape of the antenna. Presently several works on planar shape of LPDA antenna. It is found that many broadband antennas are designed are to cover one or two bands of the mobile communications or other applications. There are also broadband antennas designed to cover in the upper range such as 3GHz to 6GHz, 9GHz to 11GHz and so on. Hence, this project work has attempted to come out with broadband antenna with superior performance that works equally well in the entire range of 0.5GHz to 6GHz.

Frequency independent antennas, as a particular class of wideband antennas, were first studied by Rumsey. His simple but significant theory has become the foundation for studying many wideband antennas, such as log-periodic dipole antenna (LPDA). The LPDA, whose properties vary periodically with the logarithm of frequency, consists of linear dipoles as basic constituent elements. The elements are fed from a balanced transmission line, each element being placed in an alternating configuration that leads to 180° phase change from the adjacent elements.

A limitation of the LPDA is that the dipole element for the lowest operation frequency in the HF range may become too long to be conveniently handled in the environment of application. This fact has led to numerous modifications to the original structure in order to analyze the field distributions. The structure is implemented in TLM method and is analyzed for the radiation patterns in Azimuth and Elevation planes.

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II. OBJECTIVE

The main objective of thesis is to analyze E-fields and H-fields of LPDA using transmission line matrix method. This will help us to identify the factors that affect the impedance and radiation pattern of the antenna. The so obtained results are compared with the results obtained from PCAAD software.

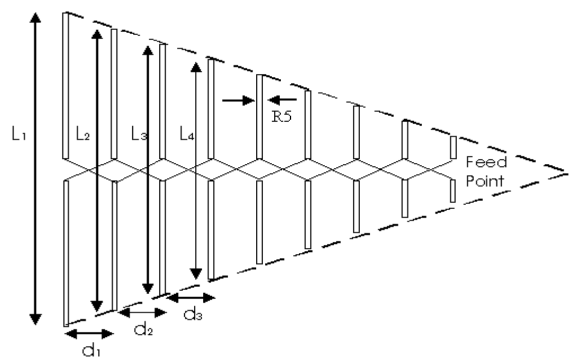

Figure 1: Schematic diagram of log-periodic dipole antenna

Transmission Line Matrix Method

The **transmission line matrix (TLM) method** is a space and time discretizing method for computation of electromagnetic fields. It is based on the analogy between the electromagnetic field and a mesh of transmission lines. The TLM method allows the computation of complex three-dimensional electromagnetic structures and has proven to be one of the most powerful time-domain methods.

Transmission line matrix (TLM) can be formulated in several means as a direct set of lumped elements solvable directly by a circuit solver (ala SPICE, HSPICE, et al.), as a custom network of elements or via a scattering matrix approach. TLM is a very flexible analysis strategy akin to FDTD in capabilities.

TLM method involves two basic steps:

- Replacing the field problem by the equivalent network and deriving the analogy between the field and network quantities.

- Solving the equivalent network by iterative methods.

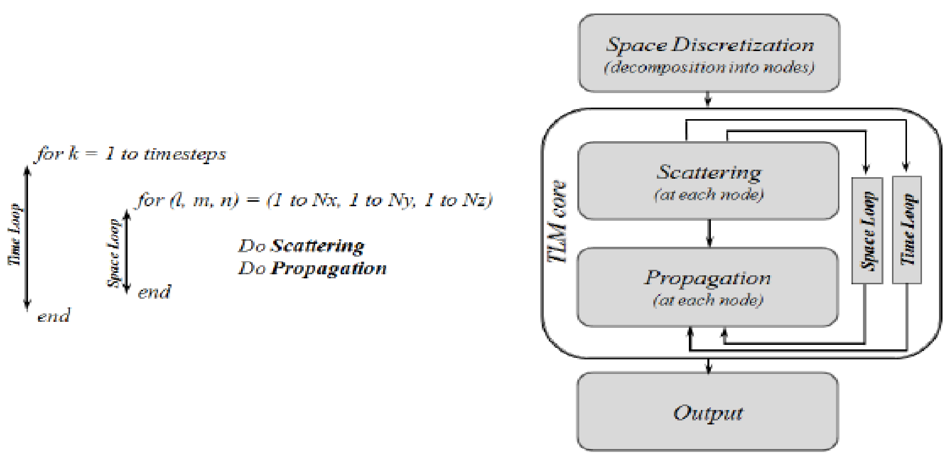

Figure 2: TLM Algorithm

N ANTENNAS CONNECTED BY N-1 TRANSMISSION LINES:

For a log-periodic dipole antenna consisting of N dipole elements, the procedure to find the currents at the bases of the dipole elements is as follows:

- Y_A matrix which is the inverse of the Z_A should be formed. If there are N dipole elements on the log-periodic dipole antenna, Z_A is an N-by-N matrix. The diagonal entries of Z_A are the self impedances of the dipole elements and the off-diagonal elements are the mutual impedances between the dipole elements. For example, $Z_A(2,4)=Z_A(4,2)$ is the mutual impedance between the second and the fourth dipole elements.
- For the transmission lines between the dipole elements, $[Y_N^{(i)}]$ 2-by-2 line matrices should be formed.
- Load admittance, Y_L, should be specified and should be placed into the last entry of the N-by-N matrix as seen in Equation 4.28.
- As one can see in Equation 4.28, $[Y_N^{(i)}]$ 2-by-2 line matrices should be placed into the diagonal and sub-diagonal parts of the N-by-N matrix. When all 2-by-2 matrices are placed in the N-by-N matrix, the last entry of the first Y_N matrix is summed up with the first entry of the second Y_N matrix and this procedure is repeated up to the last Y_N matrix as one can see in Equation 4.21. At the end, the last entry of the last Y_N matrix is summed with the load admittance, Y_L.
- Following Equation 4.28, the voltage values on the dipole elements should be found for a given excitation current, Is.
- By multiplying these voltage matrix and YA matrix, one can get the current values at the bases of the dipoles .
- A program to find the currents at the bases of the dipoles of a log-periodic dipole antenna is written in MATLAB. In the program "admittance matrix approach to LPDA" explained above is used. Tau, sigma, characteristic impedance of the feeder element, length of the dipoles and the spacing between the dipoles are the inputs for the program. Currents at the bases of the dipoles and using the currents E and H-plane patterns of the antenna are the outputs of the program.

III.FEEDING OF THE LOG-PERIODIC ANTENNA

The elements are energized from a balanced, constant impedance feeder, adjacent elements being connected to the feeder in an alternating fashion and they are energized starting from the smallest dipole.

Figure shows an unsuccessful method of exciting the antenna. The elements are closely spaced with a distance of approximately 0.07λ. The phase progression along the array is such as to produce a beam to the right of the Figure.

As longer elements, to the right of the active region, are in the beam and have not alternating phase, they produce interference effects to the pattern result.

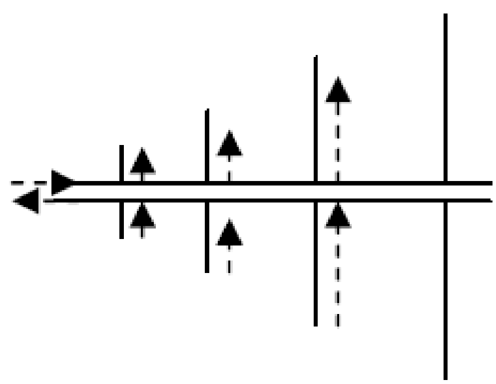

Figure 3: Unsuccessful method of feeding the antenna

Figure shows a successful method of exciting the antenna. Difference between the two method of exciting is, by criss-cross connection, a 180º phase is added to the terminal of each element.

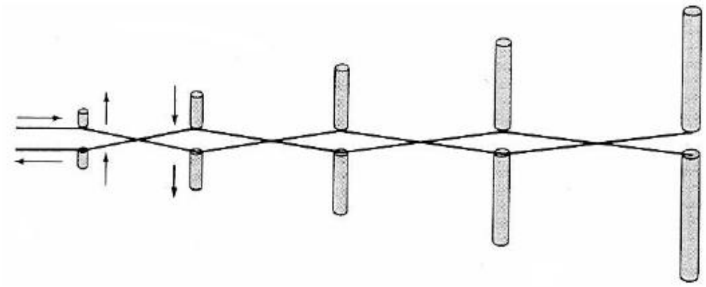

Figure 4: Successful method of feeding the antenna

Little energy is radiated by the adjacent closely spaced short elements because the phase between these elements is almost in opposite so their interference effects are very small. The longer and the larger elements radiate at the same time. The mechanical phase reversal between these elements produces a phase progression so that energy is beamed to the left of the Figure, in the direction shorter elements.

Alternative to the crisscross connection, the antenna can be energized from a coaxial line. By this way, the 180° phase reversal between adjacent elements is obtained. The shield of the coax is inserted through the hollow of the one feeder line, and at the front of the antenna the central conductor of the coax is extended and connected to the other feeder line as shown in Figure.

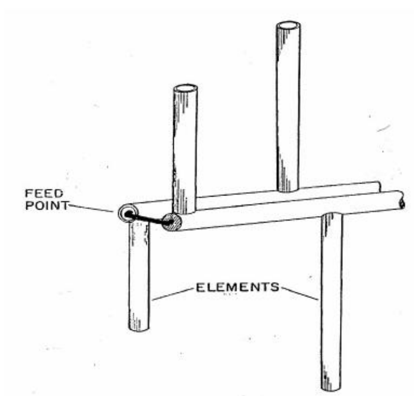

Figure 5: Energizing dipoles by using coaxial line

Using a coaxial cable as a feed line provides a built-in broadband balun resulting in a balanced overall. The antenna is fed from the smallest dipole element. A 180º phase difference between two equal dipole arms is formed by using a coaxial cable as a feed line which is a balanced structure

Each element is driven with a phase shift of 180^0 □ by switching or alternating element connections. The dipoles near the input, being nearly out of phase and close together nearly cancel each others' radiation. As the element spacing, d, expands there comes a point along the array where the phase delay in the transmission line combined with the 180^0 □ switch gives atotal of 360^0. This puts the radiated fields from the two dipoles in phase in a direction toward the apex. Hence a lobe coming off the apex results.

This phase relationship exists in a set of dipoles known as the "active region." If we assume that an LPDA is designed for a given frequency range, then that design must include an active region of dipoles for the highest and lowest design frequency. It has a bandwidth which we shall call β_{ar} (bandwidth of the active region).

Ideally the feeder should be conical or stepped to preserve the exact scaling between the elements, but in practice, it is found that two parallel cylinders can successfully replace the cones as long as the radius of the cylinders remains small compared to the shortest wavelength of operation. The element feeder configuration is shown in the Figure 4.

It is seen that the elements don't lie on the same plane exactly, the departure there from is equal to the feeder spacing which is always small.

IV.LOG PERIODIC ANTENNA DESIGN PARAMETERS

One of the most important parameters that describe log periodic antennas in general is presented in Equation for τ. This parameter is known as the scaling factor. This scaling factor allows the antenna dimensions to remain constant in terms of wavelength. The condition is necessary to maintain the same impedance and radiation characteristics over a wide range of frequencies. This factor should be less than 1 and when the frequency is increased by $1/\tau$ input impedance, VSWR and radiation pattern should be very similar to the values from the previous period. Equation for σ is related to the spacing between adjacent elements. This space shrinks when frequency increases. One way to make each cycle as similar as the preceding one is to make design parameter α small, which implies that the elements are spaced more closely and more elements will be present in the active region. But one must be careful with parameter α because if it is set to a value which is too small or too large it will destroy the impedance bandwidth of the antenna. If the antenna elements are placed too close together or are extremely separated the reflection coefficient increases above the -10 dB level destroying the impedance bandwidth. A detailed design procedure for the log periodic folded slot antenna is presented in next chapter.

$$\tau = \frac{l_{i+1}}{l_i} = \frac{d_{i,i+1}}{d_{i-1,i}}$$

$$\sigma = \frac{d_{i,i+1}}{2l_i} = \frac{1-\tau}{4\sigma}$$

$$\alpha = \tan^{-1}\left(\frac{1-\tau}{4\sigma}\right)$$

V.PCAAD SOFTWARE:

PCAAD is an acronym of Personal Computer Aided Antenna Design, Software for the Analysis and Design of Antennas and Phased Arrays. This is proprietary software of Antenna Design Associates Inc. founded in 1990 by Dr. David M. Pozar, a well-known researcher and author in the areas of antennas and wireless communications.

PCAAD is a Windows–compatible antenna analysis, modeling, and design software package. It contains more than 50 routines treating wire antennas, aperture antennas, micro strip antennas, arrays, transmission lines and waveguides, and more. These routines are integrated into a menu–driven, user–friendly system allowing you to quickly evaluate the performance of a wide variety of antenna types.

Some of the main features of PCAAD include the following:

• A user-friendly Windows interface

• Full 32-bit compiled software

• Very simple and intuitive operation

• Fast results for first-cut designs

• Graphic illustrations of each antenna geometry

• Polar, rectangular, and 3-D pattern plots

• Smith chart, VSWR, and return loss plots for input impedance

• Data file output for patterns and impedance matrices

• On-line help

• Validation examples for each analysis routine

Log-Periodic Dipole Array Antenna Design Using PCAAD:

Figure shows the Log-Periodic Dipole Array antenna using PCAAD software. The antenna is designed to operate in the frequency range of 0.5 GHz to 6 GHz with 30 elements to meet the required specifications

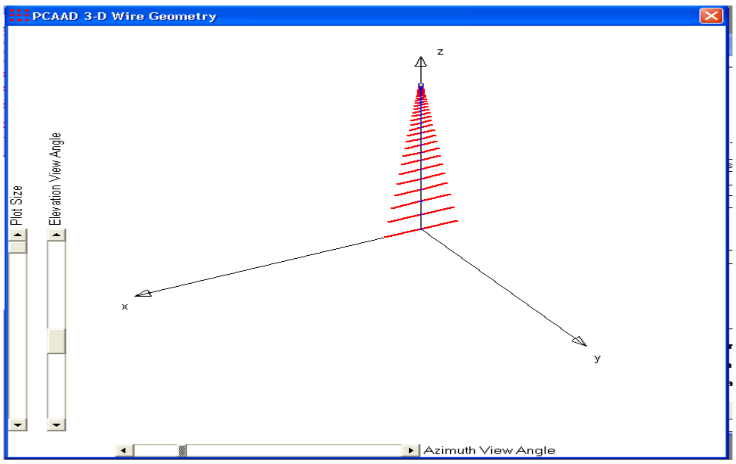

Fig 6: The LPDA design using PCAAD Software

VI. SIMULATION RESULTS:

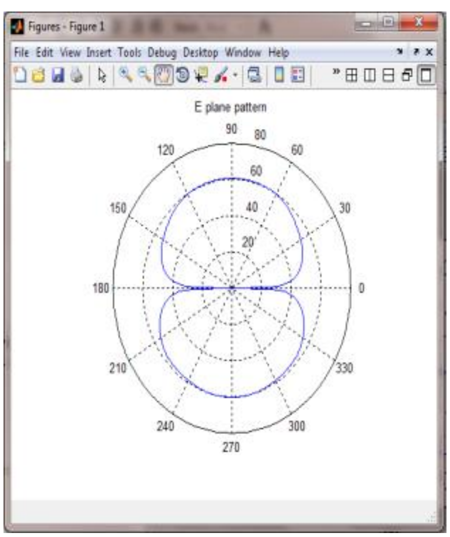

Figure 7: E-Plane pattern at 0.5GHz

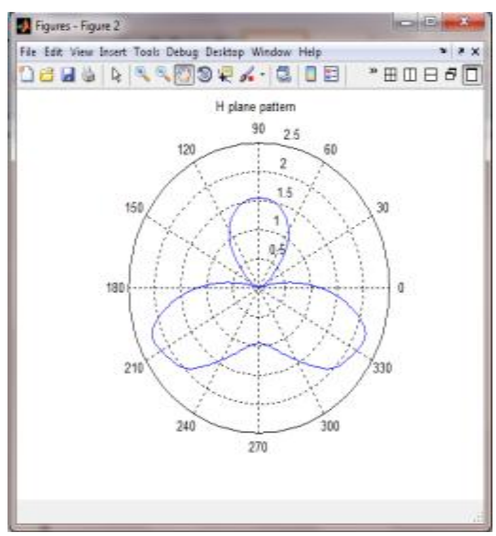

Figure 8: H-Plane pattern at 0.5GHz

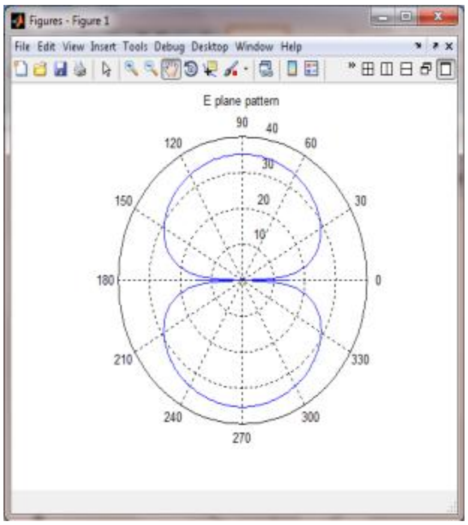

Figure 9: E-Plane pattern at 6 GHz

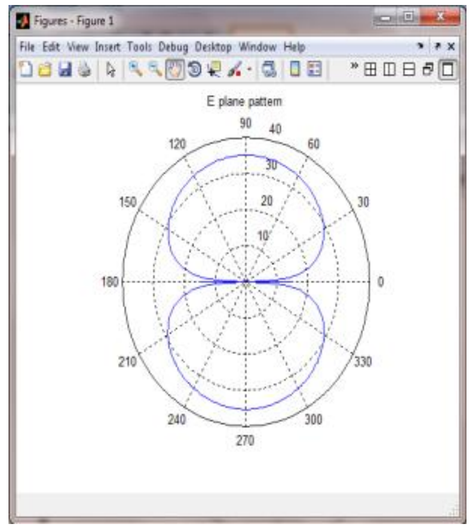

Figure 10: H-Plane pattern at 6 GHz

Using PCAAD:

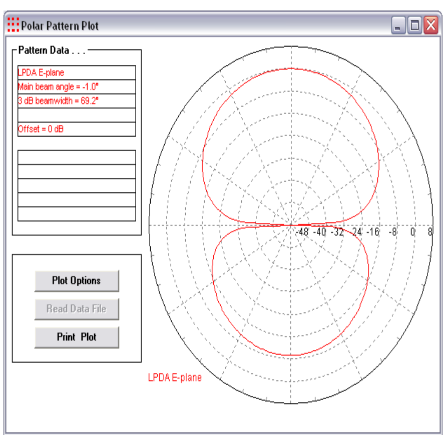

Figure 11: E-Plane pattern at 0.5 GHz

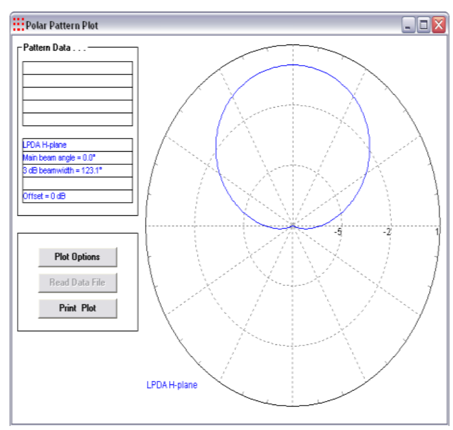

Figure 12: H-Plane pattern at 0.5 GHz

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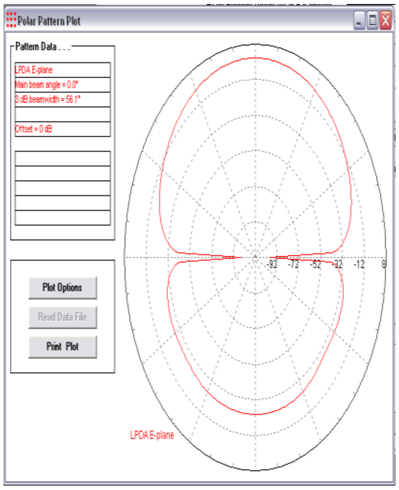

Figure 13: E-Plane pattern at 6 GHz

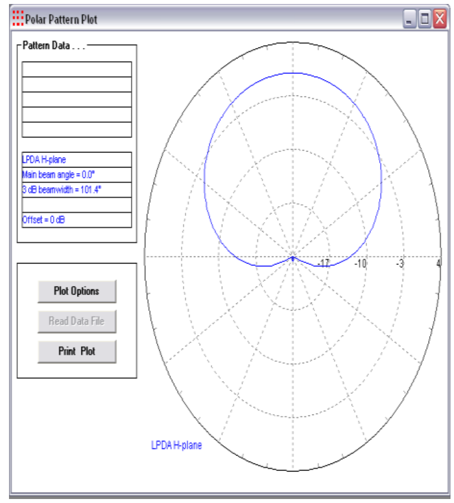

Figure 14: H-Plane pattern at 6 GHz

VI.CONCLUSION

This Research highlights are as follows:

Initially the concept of Frequency-Independent Antennas are Studied. The concept of Log-Periodic Dipole Array antenna has been studied. Based on given specifications and for assumed values of Scale Factor (τ) and Spacing Factor (σ) Log Periodic Dipole Array antenna has been designed.

The designed values are fed to PCAAD (Personal Computer Aided Antenna Design) software and is analyzed Radiation Patterns both in Azimuth and Elevation Planes.

Application of Transmission Line Matrix (TLM) Method to Microwave Circuits is studied. A MATLAB code is written to analyze the Radiation Patterns of Log Periodic Dipole Array (LPDA) antenna in both Elevation and Azimuth Planes using Transmission Line Matrix Method.

The results so obtained from MATLAB are compared with those obtained using PCAAD software and it is observed that both the results replicate each other.

Future Scope

The Designed antenna is ready for commercial production with minor modifications in it outlook. An attempt can be made to further increase the size and number of elements of LPDA, and we can extend the band beyond 0.5-6 GHz, the problem is that lengths of elements and spacing between elements are very less, so fabrication process is quite difficult.

The advantage of increasing elements and extend the band is, Beam width reduced and Gain become increased. We know the relation, if frequency increases the Directivity and Gain increases but Beam width decreases. So we have to compromise at any one parameter.

LPDA with good performance from the point of view of gain, bandwidth, beam width, etc., can be designed by optimizing its geometry. If the optimization is made by controlling τ (scale factor), σ (spacing factor), α (subtended angle), zero offset, etc., higher gain, wider polarization or input impedance bandwidth are likely to be achieved.

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Biography

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