

https://dspace.org/

Characteristics of the log periodic dipole array

Onwuegbuna, Leonard Ikemefuna

2007-02-28T13:01:19Z
http://hdl.handle.net/10539/2164

Downloaded from a DSpace repository. https://dspace.org/

2 METHODOLOGIES

In this section the methodologies used in arriving at the results are introduced. Firstly the numerical model to be used for extensive investigation has to be validated by measurements. The first section of this chapter therefore explains the processes involved in this validation. The second part of this chapter introduces the concept of LPDA Antenna convergence and the criteria for establishing LPDA Antenna convergence, which is a unique aspect of this research.

2.1 EXPERIMENTAL VERIFICATION OF THE NUMERICAL MODEL

The main theme of this section is the comparison of measured results with theoretical predictions of the results as obtained from simulations. A favourable agreement between these sets of results is then taken as a sufficient validation of the numerical model used in obtaining the theoretical results.

Two sets of results are obtained by two different methodologies and then compared. Each of these two methodologies has to comply with either (i) the experimental criteria for establishing the validity of measurements, or (ii) the criteria for correct modelling of antennas, using the method of moments based computer simulation software ‘super Nec’.

Three antenna output parameters are going to be used as the basis for comparing measured and simulated results. These are impedance, voltage standing wave ratio and gain. Once validity is established, the numerical model is then used for comprehensive investigation of the characteristics of the LPDA antennas. The result of this investigation is presented in the proceeding chapter.

2.1.1 THE EXPERIMENTAL SITUATION

In all, four pairs of antennas were built and measured. Although, certain parameters of the antennas were varied (in this instance length to diameter ratio, operating bandwidth and boom-length), the aim at this stage is strictly validation of the numerical modelling tool. For this reason, a strict pattern of variation is not maintained neither was the range of variations wide enough to produce significant changes in antenna performance characteristics. A fixed boom impedance 'Z_o' of 75Ω was used for all the four models. This is because the transmission line (stripe line) is a lossy line resulting in average feed point resistance of about 50Ω, which can easily be matched to a coaxial cable of the same characteristic impedance value. For each pair of antennas, dipole elements of fixed diameters were used.
The antenna was fed directly using coaxial cables in all models. This involved passing 50Ω, RG 58 coaxial cable through aluminium tubes to the smallest dipole elements of each model. The measurement was performed in a shielded anechoic chamber using HP8753C network analyser. The analyser was calibrated and port extended to the feed point.

2.1.2 RESULTS: MEASURED VERSUS THEORETICAL

Table 2.1 below, gives the simulated and measured values of the antenna models built. The simulated values are denoted with an extension 'out', while the measured values are denoted as 'models'.

Thus, C_1.out, is the simulated output file, for the first model (diameter of dipoles = 2mm). Model 1a and Model 1b, represent measured values of the identical pair corresponding to C_1.out.

Similarly, C_2.out => diameter = 3.18mm, model 2a and model 2b => measured pair for diameter of dipoles = 3.18mm.

Lastly, C_3.out = diameter = 4mm, model 3a and model 3b = measured pair for diameter of dipoles = 4mm.

Table 2.1 Values of measured and simulated results for the six models of antenna built

FILE NAME	REAL INPUT IMPEDANCE		IMAGINARY IMPEDANCE		VSWR		(dBi) Mean Gain
	MEAN	STD	MEAN	STD	MEAN	STD	
C_1.out	52.78	8.87	-1.73	8.76	1.26	0.16	6.96
Model 1a	51.29	7.83	3.36	7.92	1.24	0.12	6.00
Model 1b	54.19	9.32	4.86	8.68	1.28	0.14	6.00
C_2.out	50.65	8.94	-2.34	8.37	1.25	0.17	6.96
Model 2a	57.13	12.87	6.13	12.26	1.40	0.26	5.82
Model 2b	55.83	11.68	5.73	11.49	1.42	0.28	5.82
C_3.out	49.50	8.81	-2.59	8.18	1.25	0.19	6.95
Model 3a	58.69	14.43	7.39	14.33	1.42	0.24	6.50
Model 3b	60.00	18.05	8.94	17.15	1.48	0.21	6.50

A fair agreement between the predicted values from simulations and measured values is evident as can be seen in table 2.1 above.

In all instances, real, imaginary impedance and VSWR are compared for simulated and measured results. The percentage difference between measured and simulated real input resistance ranges from 2.6% to the worst case of 21%. The VSWR and gain values of the measured and simulated values were in fair agreements. The VSWR was based on 50 ohms termination for the connecting transmission line, which in this case is an RG 58 coaxial cable. The numerical means and standard deviations of input resistance, VSWR and gain were presented as opposed to parametric curve presentation of the same parameters. The reason for this format of presentation is justified on the basis that trends in the variation of numerical values of these parameters form the criteria for determining the convergence or otherwise of a LPDA Antenna which is introduced in the next section of this chapter. The numerical modelling tool (in this case 'superNec) having been validated, can then be used for extensive investigation into the performance characteristics of LPDA Antennas.

In other to maintain a balanced presentation, one of the LPDA Antenna models designed to operate from 30MHz to 120 MHz with a boom-length of 1.5m and number of elements = 15 is presented in graphical format as can be seen in figures 2.1 and 2.2.

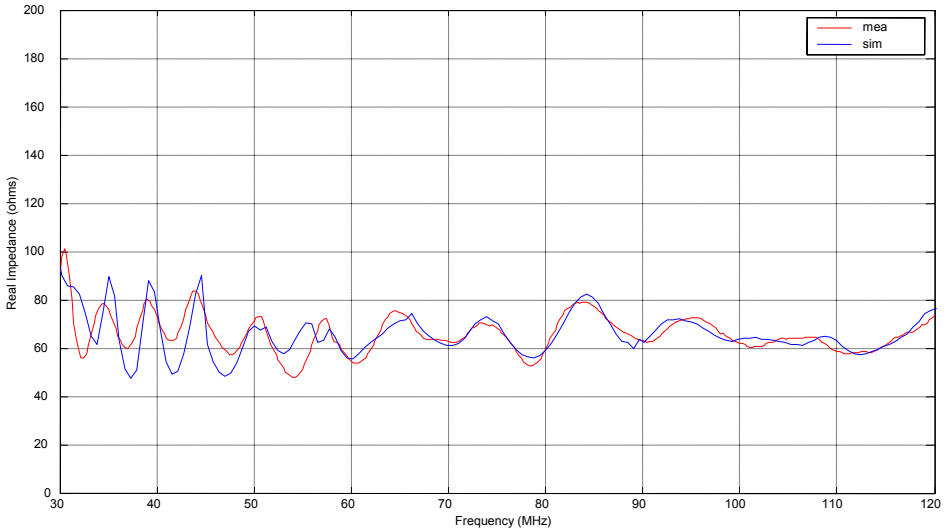


Figure 2.1 Plot of real input impedance variation with Frequency, L=1.5m, N=15, $\tau = 0.89$ and $\sigma = 0.073$

In figure 2.1, the measured and theoretical input resistance of the Antenna were compared and showed a fair agreement within the band-width of operation. In figure 2.2, the same comparison was made for the imaginary input resistance and agreement established as also was the case for the VSWR.

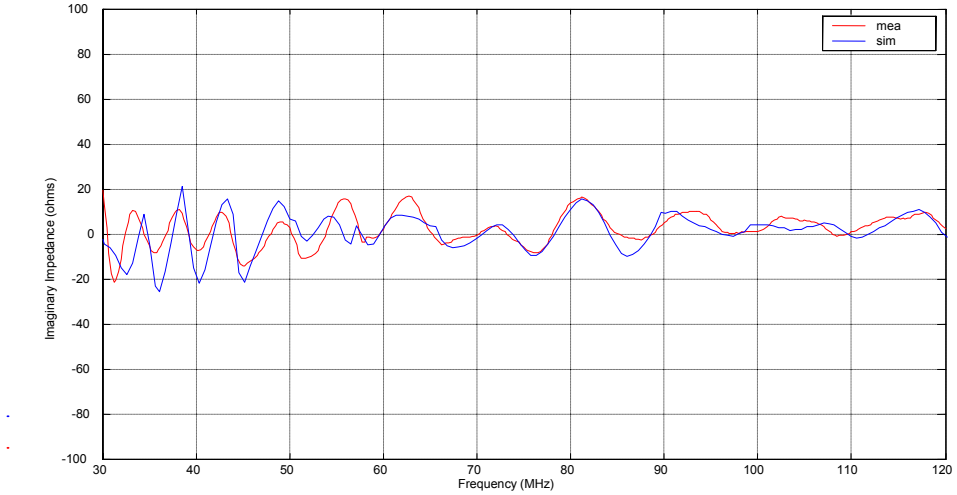


Figure 2.2 Plot of imaginary input resistance variation with frequency N = 15, L = 1.5m, $\tau = 0.89$ and $\sigma = 0.073$

Agreement between measured and simulated real and imaginary impedance is by implication agreement in VSWR since it is impedance derived parameter.

It is imperative at this juncture to point out that although every thing was done to ensure that there were no errors, this could not be achieved. Inevitably, measurement errors did occur, probably due to, imperfect terminations at the feed-points and the measurement environment being far from free space as was assumed. There is also the possibility of off resonance behaviours as a result of the dipole elements not being exactly half the wavelength at the resonant frequencies. Lastly, there is also the possibility of human errors.

These not withstanding, the faire agreement between measured values and the theoretical prediction of the values by the modelling tool, is enough validation of the modelling tool. Hence forth, it is to be assumed that the modelling tool has been validated and can then be used for extensive theoretical investigations.

2.2 CONVERGENT AND SPARSE LPDA ANTENNAS

The need to classify LPDA antennas arose due to the following reasons:

(1) It has been observed that some values of scale and design constants (and by extension number of elements) for a given boom-length (L) and operating bandwidth (B), do not yield meaningful gain, VSWR and radiation pattern characteristics (ref. Page 23). That is, for these values of τ and σ, (or N) the antenna gain, VSWR and radiation pattern characteristics are often not so good. There is therefore the need to avoid these values when designing LPDA antennas.

(2) One of the main objectives of this research is that the number of dipole element (N) should be the optimisation criteria. This is because, as pointed out by De Vito and Stracca [3], [4], the cost of the LPDA antenna is determined by the boom-length and the number of dipole elements. For this reason, it has become imperative to find a means of designating LPDA antennas, so that one can see at a glance, the minimum number of elements for any given Boom-length and operating bandwidth required for the antenna to yield acceptable performance characteristics. This delineation is therefore a means of minimising 'N' so as to produce a cost optimised LPDA antenna.

To achieve these objectives, LPDA antennas are designed such that every other parameter remains constant except the number of element, which are doubled in every step. Thus depending on the boom-length and operating bandwidth, the number of elements are given as N=[4 8 16 32 64 128]. The Boom-lengths are given as L = [$0.5\lambda_{max}$, λ_{max}, $1.5\lambda_{max}$ $2\lambda_{max}$] where λ_{max} is the wavelength at the lowest frequency of operation. The operating bandwidth is investigated in the range B= [1:2 1:5 1:10]. The boom-impedance Z_o =75Ω and L_n/D_n =100.
The antennas were simulated and the average and standard deviation of the gains are extracted from the simulated batch files.

Trends in the patterns of variation of the average and standard deviations of the gain are used as the basis for deciding the element density, at which the antenna yields acceptable performance. Once this optimisation is done, the standard deviation of the gain has no further use and will not be referred to again.

The justification for using the mean and standard deviation of the gain as the basis for determining the usefulness or otherwise of a LPDA antenna is that the mean (or average) value of a set of data (in this instance gain) is a measure of central tendency. It is a measure of the tendency of the gains of LPDA antenna to converge to a central value for variations of frequency within the operating bandwidth. The standard deviation of the gain on the other hand is a measure of dispersion of the gain values around the mean value. It gives an indication of how close a given gain value is to the mean. In looking at the trends in the variation in the standard deviation of the gain, a low standard deviation value is an indication of LPDA antenna convergence (or optimised performance). It is to be seen that once convergence is attained the STD values do not differ widely for doubling of 'N. It is also seen that for the mean gain, once convergence is attained, the mean values remain within a narrow band of values. As an example, consider a LPDA Antenna of length $L = 1.5\lambda_{max}$, with operating bandwidth of 1:5. The number of elements is doubled per step as 4, 8, 16, 32 and 64. Trends in the pattern of variations of the VSWR, gain and radiation patterns will be investigated with the aim of establishing the criteria for convergence or Sparse LPDA Antennas.

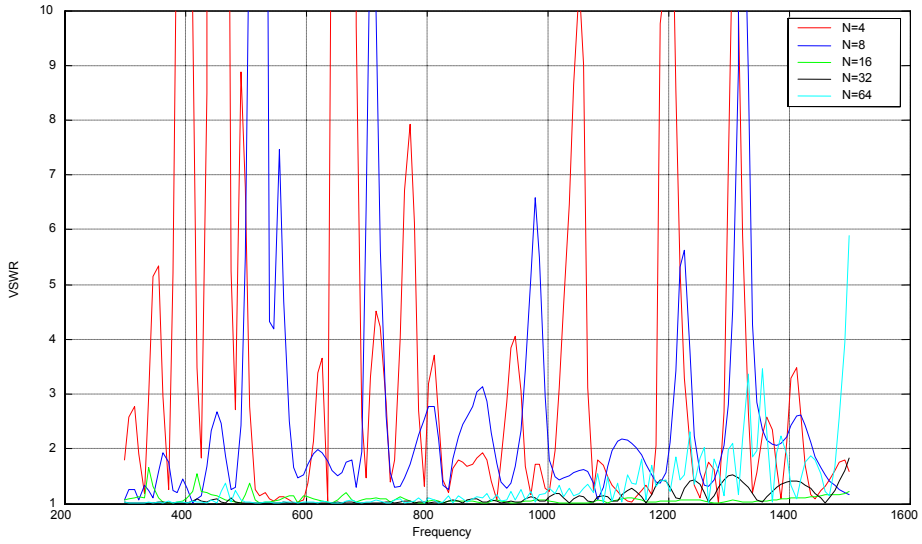


Figure 2.3 Variation of VSWR with frequency for fixed values of N

As can be seen from figure 2.3 above, this antenna does not yield acceptable VSWR performance for all frequencies within the operating bandwidth until the number of dipole elements became at least greater than 16. Figures 2.4 and 2.5 represents variations of gain and radiation pattern with frequency for fixed values of number of elements. The azimuth radiation pattern was taken at a mid-frequency of 900MHz. As can be seen from figure 2.4, the variation of gain with frequency was not acceptable until the number of dipole element 'N' became greater than 16. It can be seen also that increasing the number of dipole element beyond the convergence values can be sometimes not achieve much by way of performance.

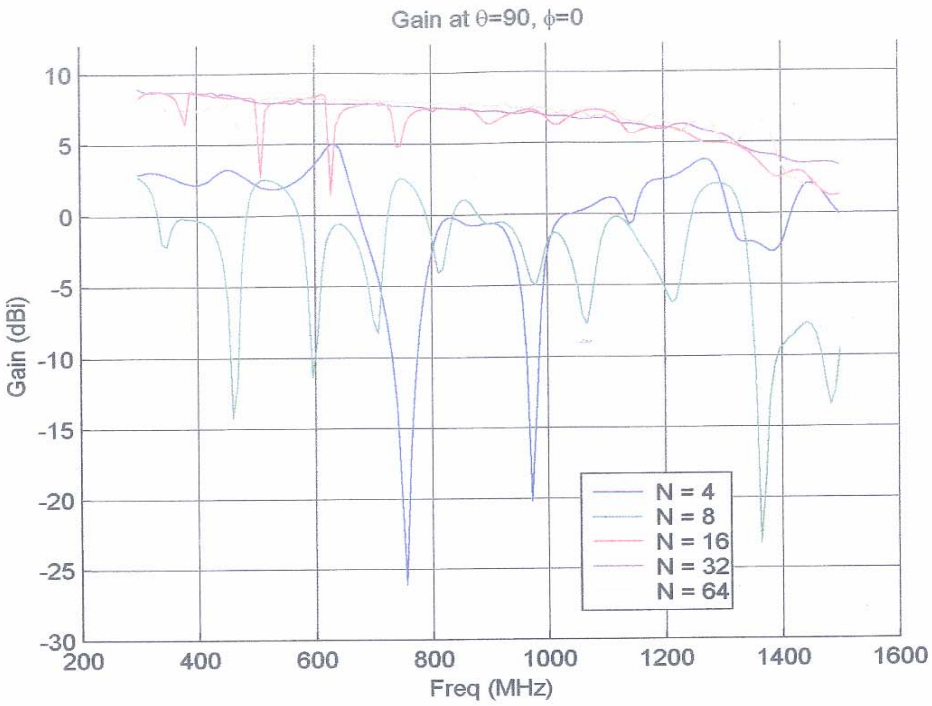


Fig 2.4: Variation of gain with frequency for values of number of element 'N'.

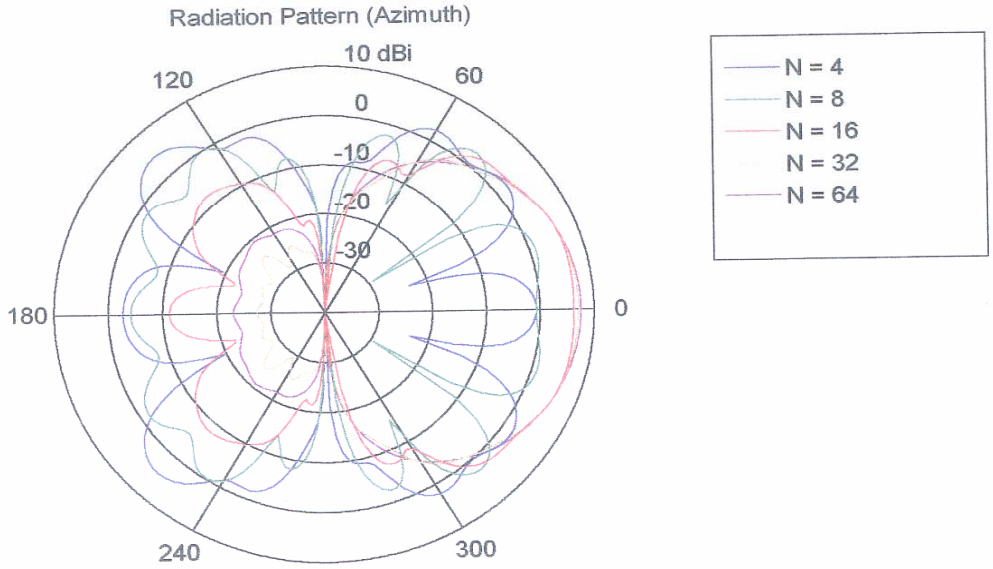


Fig 2.5: Variation of radiation pattern with values of number of element 'N'.

As can be seen in figure 2.4, the gain variation with frequency became a bit irregular for N greater than 32.

Figure 2.5, shows the azimuth radiation pattern, at a frequency of 900MHz, for values of number of dipole elements. The radiation pattern is not acceptably directive until the number of dipole element became greater than 16 and for N greater than 32, the radiation pattern does not show marked improvement (as would have been expected) to justify using more than 16 elements. The implication of this is that even though increasing the number of elements beyond the convergence point does sometimes increase the average gain, the pattern of variation of gain with frequency may render this increased gain useless. Since the aim here is minimisation of 'N', using values of N greater than N at convergence does not necessarily result in improved performance of the LPDA as to justify the cost implications.

Figures 2.3 to 2.5 are qualitative treatment of the issue. In other to define LPDA Antenna convergence, there is the need for quantitative presentation of the trends in the variation patterns of VSWR and gain for fixed N as can be seen from table 2.2 below.

N	$(VSWR)_{avg}$	$(VSWR)_{STD}$	$(Gain)_{avg}$ dBi	$(Gain)_{STD}$ dBi
4	5.29	9.37	-0.39	3.75
8	3.06	4.12	-3.31	4.55
16	1.08	0.08	6.40	1.99
32	1.12	0.15	6.81	1.52
64	1.32	0.60	6.80	1.64

Table 2.2 Trends in pattern of variation of VSWR and Gain for fixed values of N, for LPDA Antenna of $L = 1.5\lambda_{max}$, B =1:5

The mean VSWR does not meet acceptable value until N greater than 16. This suggests a convergent value of N of about (16+32)/2 =24. The reason for this approach is based on the fact that the mean VSWR approaches 1:1 between N=16

and 32 and the mean gain appears to stabilize between these values. Also for N=16, the STD of gain =1.99 and for N=32, STD of gain =1.52. Now, if N exceeds 32, the STD of gain increases, suggesting that the point of convergence lies between N = 16 and 32, hence the justification for averaging. After convergence, doubling the number of elements does not result in any appreciable change in the VSWR. With respect to standard deviation of the VSWR, once the number of elements became greater than 16, the value of STD dropped drastically suggesting little dispersal from the central value. After convergence, the STD values due not vary greatly. Looking at the trends in the pattern of variation of the mean gain, it was also observed that for N greater than 16, the Antenna for the first time yields acceptable mean gain and doubling the number of elements does not result in appreciable change in gain values. The same is true for the STD of the gain. This was the procedure adopted for all four hundred and ten LPDA Antennas (410) and information gathered from this is used for setting the convergence criterion, which follows next.

These trends in the pattern of variation of the VSWR and gain as typified by table 2.2, form the basis for classifying LPDA Antennas as convergent or sparse. By observing these trends in variations in the values of mean and standard deviations of the VSWR and gain, bearing in mind that the mean values are measures of central tendency while the standard deviation measures dispersion around mean values, it was then possible to determine the element density at which a given LPDA Antenna of fixed length and operating bandwidth will yield acceptable VSWR, radiation pattern and gain characteristics. Details of these investigations are presented in appendix A. It was necessary that convergence be delineated in quantitative terms as opposed to qualitative. This informed the use of mean and STD values of these parameters instead of qualitative description of their graphs. A converged LPDA Antenna is therefore an Antenna that produces acceptable VSWR, gain and radiation pattern characteristics using the minimal number of elements for that boom-length and operating bandwidth.

2.2.1 CONVERGENCE OR OPTIMISATION) CRITERIA FOR LPDA ANTENNAS

A log periodic dipole array antenna shall be considered converged if it meets the following requirement: -

(I) It must yield a mean gain of at least 5dBi for a pair of scale factor 'τ' and spacing constant 'σ' (and by extension for a given value of number of dipole elements 'N') and for any given boom-length 'L' and operating band-width 'B'. A gain of 5dBi indicates that the LPDA Antenna radiates at least, three times more in the direction of maximum field compared to that of an isotropic radiator.

(II) Doubling the number of dipole elements 'N' results in at most average increase in mean gain of about 1dBi and the STD averages 1.15dBi (deduced from observation).

(III) It must maintain a VSWR value of 2:1 and below within the designed operating bandwidth.

(IV) It's electrical characteristics such as input impedance, radiation pattern and gain must vary periodically as the logarithm of the operating frequency. This Antenna must therefore yield acceptable radiation patter within its operating bandwidth.

A log periodic dipole array antenna that does not meet the requirements I to IV above is considered UN-converged (or sparse) antenna. These families of antennas are not of much use and will forthwith not be given much consideration. Although the criteria for convergence have been stated in terms of the VSWR, radiation pattern and gain characteristics of the LPDA antenna, the latter will be used as the basis for establishing convergence. Any of the electrical characteristics can be used but I have chosen the gain for the sake of uniformity as the effect of boom-impedance 'Z_o' and length to diameter ratio on the gain of LPDA antenna are considered elsewhere in this study. It is to be noted however,

that a converged antenna must meet all of the requirements. Appendices A, B and C give the details of these investigations.

It is necessary at this stage to point out that the convergent value is not absolute. It is however more sensitive at the lower values than at higher values. What I mean is this, if for a given boom-length and operating bandwidth, a given LPDA Antenna converges for N = 8. If the elements were reduced by 2 elements, the convergence of that Antenna may no longer be guaranteed. On the other hand, if convergence was attained at N=12, reducing the number of elements by two or three may not affect the convergence. Convergence provides a means of using the number of elements as the optimisation criteria.