APPENDIX A

CONVERGENCE CRITERIA FOR LPDA ANTENNAS

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

(IV) It must yield a mean gain of at least 5dBi for a pair of design constant \( \tau \) and spacing constant \( \sigma \) (and by extension for a given value of number of dipole elements \( N \)) and for any given boom-length \( L \) and operating bandwidth \( B \).

(V) Doubling the number of dipole elements \( N \) results in average increase in mean gain of about 2.5dBi and the STD averages 1.15dBi.

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

(VII) It's electrical characteristics such as input impedance, radiation pattern and gain must vary periodically as the logarithm of the operating frequency.

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 any consideration.

A2: Trends in the pattern of variation of the average and standard deviation of the gain as the basis for LPDA antenna convergence.

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.
In other to study the trends in the pattern of variation of the standard deviation and average gain of LPDA antennas, the number of dipole elements 'N' is doubled each step for a given boom-length 'L' and operating band-width 'B'. For the purpose of this research, the boom-lengths considered are in the range \([0.5\lambda_{\text{max}}: 0.5: 2\lambda_{\text{max}}]\) where \(\lambda_{\text{max}}\) is equal to 1 meter (i.e. the wavelength at the frequency of 300MHz). The operating bandwidth is considered within the range 1:2, 1:5 and 1:10. It is to be noted that due to the computational capability of super numeric electromagnetic code (SuperNec) it has been possible to extend the range of investigation to values of spacing constant '\(\sigma\)' beyond 0.2. The length to diameter ratio is fixed at 100 and the boom-impedance at 75\(\Omega\). In the proceeding section, trends in the pattern of variation of the standard deviation and mean gain is used to determine the minimum number of elements for which the antenna becomes converged for a given boom-length and operating bandwidth. Once an antenna becomes converged not much is achieved in terms of VSWR, radiation pattern and gain performance by using more number of elements than that at convergence. It is imperative to point at this juncture that 'N' at convergence is not absolute. It is a guide to determining the minimum 'N' required to yield an average gain for a given Boom-length 'L' and operating bandwidth 'B'.

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 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. 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. It is to be observed that to obtain gain values outside this narrow range of values would require the values of spacing constant '\(\sigma\)' being outside the range of \(0.05 \geq \sigma \leq 0.2\). The result of this is an unreasonably large number of
dipole elements 'N' without necessarily yielding appreciable increase in gain. In some instances the gain is decreased. Since the aim here is the attainment of meaningful gain value with minimum number of dipole elements 'N' for a given boom-length and operating bandwidth, it is not advisable to use 'σ' values outside the range of 0.05 to 0.2 (although it is possible to do so). For the same reason, using design constant 'τ' value less than 0.7 is not also advisable as it does not yield meaningful gain value and does not aid convergence.

Figure A1.1 to A1.4 are plots of the variation of the gain with number of elements for fix values of boom-length 'L' and operating bandwidth ranging from 1:2 to 1:10. The plots are for both convergent and sparse Antennas. In these plots the mean gain values are denoted by solid lines while the standard deviation of the gain is denoted by broken lines. The main purpose of figures A1.1 to A1.4 is to serve as the basis for determining the point of convergence of the families of LPDA Antennas using trends in the variation of the mean and STD of gain as indicators of convergence. Once convergence is established no further reference will be made to the STD of the gain. The convergence value indicates the minimum number of elements required for the Antenna to meet convergence criteria (earlier stated) for a given boom-length and operating bandwidth.

With regards to figure A1.1, looking at the trends in the variation of the mean and STD of the gain with changing number of elements for L=0.5λ_{max} and operating bandwidth ranging from 1:2 to 1:5, it will be seen that the Antenna converges for N=8. For this value of N, a mean gain of 7dBi is obtained and the STD of gain, which is a measure of how dispersed the gain is relative to the mean gain, is seen to be 0.91.
**Figure A1.1** Plot of gain versus number of dipole elements for $L=0.5\lambda_{\text{max}}$ for converged and sparse LPDA Antennas. Solid lines represent mean gain while broken lines represent STD values.

**Figure A1.2** Plot of gain versus number of elements for $L=\lambda_{\text{max}}$ for both converged and sparse LPDA Antennas.
Figure A1.3  Plot of gain versus number of elements for $L=1.5\lambda_{\text{max}}$ for converged and sparse LPDA Antennas

Figure A1.4  Plot of gain versus number of elements for $L=2\lambda_{\text{max}}$ for converged and sparse LPDA Antennas

A low value of STD is an indication of LPDA Antenna convergence. As a guide, when an antenna is converged, the STD should range from 0.8dBi to 1.5dBi. For
this range of STD, the gain differs from the mean value by 0.2dBi (for STD=0.8) and by 0.5dBi for STD=1.5dBi.

In some instances the pattern of variation of the mean and STD of gain suggest a mean value of N rather than exact value for convergence. As an example in figure A1.1, for an operating bandwidth of 1:5, it will be seen that the Antenna is convergent for STD values of between 1.59 and 0.92 yielding an average STD of 1.26. This corresponds to a gain value of 5.62dBi (i.e. 5.53+5.75)/2 and to number of elements of about 12 (i.e. 8+16)/2.

With respect to trends in the pattern of variation of mean gain, it will be observed that once an Antenna becomes converged, doubling the number of elements does not result in a large change in mean gain. In some cases, doubling N after convergence produced no change in gain and in some cases produced reduction in mean gain. In all cases, to achieve increment of more than 1.5dBi in mean gain per doubling of N after convergence, would require values of σ below 0.05 and high τ values. This is not advisable as it does not make for cost optimization as N and L is prohibitively large.

Applying convergence criteria to figure A1.1 to A1.4 results in figure A1.5 to A1.7 below. They are a summary of figure A1.1 to A1.4. Figure A1.5 gives the minimum number of dipole elements required to produce a given gain for values of operating bandwidth for convergent LPDA Antennas. Figure A1.6 shows the average gain obtainable for a given boom-length for values of operating bandwidth for convergent LPDA Antennas, while figure A1.7 shows the variation of number of elements with boom-length for values of operating bandwidth for convergent LPDA Antennas.
Figure A1.5 Plot of the variation of gain with number of elements for values of operating bandwidth for converged LPDA Antennas.

Figure A1.6 Plot of the variation of Gain with Boom-length for values of operating bandwidth for converged LPDA Antennas
Figure A1.7  Plot of the variation of Number of dipole elements with Boom-length for values of operating bandwidth for converged LPDA Antennas

Figure A1.8  Plot of variation of space constant with scale factor for fixed Lengths and values of operating bandwidth for both convergent and sparse LPDA Antennas
Figure A1.9  Plot of the variation of space constant with scale factor for fixed values of boom-length and changing operating bandwidths for both convergent and sparse LPDA Antennas

Figure A1.10  Plot of scale factor (tau) versus number of elements (N) for values of operating band width and fixed length for convergent and sparse LPDA Antennas
**Figure A1.11** Plot of scale factor (tau) versus number of element(N) for a fixed Length and changing operating bandwidth for convergent and sparse LPDA Antennas.

**Figure A1.12** Plot of scale factor (tau) versus number of elements for a fix length and changing operating bandwidth for convergent and sparse LPDA Antennas.
Figure A1.13 Plot of scale factor versus number of elements for a fixed length for changing operating bandwidth for convergent and sparse LPDA Antennas

Figure A1.14 Plot of Space constant versus number of elements for a fixed length and for changing values of operating bandwidth for convergent and sparse LPDA Antennas
Figure A1.15 Plot of the Space constant($\sigma$) versus Number of elements for a fixed length for changing operating bandwidth for convergent and sparse LPDA Antennas

Figure A1.16 Plot of the space constant versus number of elements for a fixed length for changing operating bandwidth for convergent and sparse LPDA Antenna.
Figures A1.8 to A1.17 are generalized plots of various parameters of the LPDA Antenna, for both convergent and sparse. Figures A1.8 and A1.9 gives the range of values of spacing constant \( \sigma \) for values of scale factor \( \tau \) for a fix length and for changing operating bandwidth. Figures A1.10 to A1.13 are generalized plot of variation of design constant \( \tau \) with number of dipole elements for fix length and changing values of operating bandwidth, while figures A1.14 to A1.17 gives the variation of spacing constant with number of elements for fix length and changing operating bandwidth.

Next convergence criteria are applied to figures A1.8 to A1.17 to obtain figures A1.18 to A1.22.
Figure A1.18 Plot of scale factor versus spacing constant for values of boom-length for converged LPDA Antennas neglecting the effect of bandwidth 'B'.

Figure A1.19 Plot of scale factor versus space constant for values of operating bandwidth for convergent LPDA Antennas neglecting the effect of boom-length 'L'.

Figure A1.20  Plot of the variation of scale factor with number of elements for values of boom-lengths for convergent LPDA Antennas neglecting bandwidth 'B'.

Figure A1.21  Plot of the variation of scale factor with number of elements for values of operating bandwidth for convergent LPDA Antennas neglecting effect of boom-length 'L'.

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Figure A1.22  Plot of space constant versus number of elements for values of boom-lengths, for convergent LPDA Antennas neglecting the effect of bandwidth.

Figure A1.18 is a plot of the space constant versus the scale factor for values of boom-length for converged LPDA Antennas neglecting the effect of operating bandwidth. The figure indicates that short booms correspond to low scale factor values (i.e. low element density), while long booms correspond to high scale factors (i.e. high element density). Again, as the boom length is increased, tau and sigma also increases, slowly for the lowest boom and then rises steeply for high booms. It can be seen that for L =1.5m and 2m, the gradient of the curves are negative, which is suggestive of an anomaly. This anomaly may be due to the fact that due cognizance was not given to the effect of operating bandwidth. As was pointed out in the preceding sections, for a fixed boom-length, the number of element increases as operating bandwidth increases. The number of element is also dependent on the values of tau and sigma. Therefore, a plot of tau versus sigma in which effect of bandwidth is neglected is bound to show some anomaly. What the plot seeks to highlight is that for all values the boom-length, the variations of sigma are all within the optimum region for a converged LPDA Antenna.

In figure A1.19, the same plot of sigma versus tau for values of operating bandwidth, while the effect of boom-length is neglected. Again the plot is mainly aimed at showing that for all variations of operating bandwidth, sigma remains
within optimum range. Since the values of tau and sigma used were for different bandwidths and boom-lengths, neglecting boom-length effect, inevitably introduced anomalies in the curves. In figure A1.20, variations of number of elements with scale factor for values of boom-lengths are shown with operating bandwidth effect ignored. The plot basically aims to re-affirm that number of element increases with increasing boom-length. Figure A1.21 shows the same variation with operating bandwidth, while neglecting the effect of boom-length. Again, it is seen that number of element increases with increasing bandwidth. In figure A1.22, variation of N with sigma is shown for values of boom-lengths for neglected values of operating bandwidth. The number of element decreases with increasing space constant (sigma). In conclusion, the non-linearity inherent in the plots is a consequence of neglected parameters. Secondly, convergence represents a point, which was condensed from a number of points. When these few points of convergence are plotted, curves appear as straight lines. The parameters were of necessity ignored, so as to allow for the sturdy of the effect of each parameter separately on the performance characteristics of the LPDA Antenna.
APPENDIX B

THE EFFECT OF BOOM-IMPEDANCE ON GAIN

Using the converged LPDA Antennas as reference, the effect of Antenna boom-impedance $Z_o$ on the gain performance of LPDA Antennas is investigated. The aim is to see if a generalized conclusion can be made using these Antennas as references.

In all instances the range of boom-impedance investigated is from $50\Omega$ to $600\Omega$. The reason for this is to cover the range of impedance for two wire lines and for coaxial cables. A fix length to diameter ratio of 177 is used throughout this investigation. The incremental step for the boom-impedance is $50\Omega$.

![Figure B1](image_url)

**Figure B1** Plot of the variation of gain with boom-impedance for fixed lengths and varying operating bandwidths for convergent LPDA Antennas.
Figure B2  Plot of the variation of gain with boom-impedance for fix lengths and changing operating bandwidth for convergent LPDA Antennas

Figure B3  Plot of the variation of gain with boom-impedance for fixed operating bandwidth and changing boom-lengths for convergent LPDA Antennas.
Figures B4 Plot of the gain variation with boom-impedance for fixed operating bandwidth and changing boom-lengths for convergent LPDA Antennas

Figures B1 and B2 are plots of the effect of the boom-impedance on the gain for fixed boom-lengths and changing operating bandwidths, while figures B3 and B4 shows the same plots for varying boom-lengths and fixed operating bandwidths for convergent LPDA Antennas. The plots suggest that apart from a very small region of low boom-impedance values, that irrespective of the boom-length or operating bandwidth, and number of dipole elements, there is a very slight decrease in the average gain as boom-impedance is increased. However, these decreases are very small per 50Ω increase in the boom-impedance. On average, a 50Ω increment in boom-impedance produces less than 0.2dBi decrease in gain for all the range of boom-length, number of elements and operating bandwidth investigated. Within these ranges, even an increase in boom-impedance from 50 to 600Ω, produces less than 1dBi decrease in gain.
APPENDIX C

EFFECT OF LENGTH TO DIAMETER RATIO ON GAIN

In this section, the effect of length to diameter ($L_n/D_n$) ratio on the gain of convergent LPDA Antennas is investigated. In all instances the boom-impedance is fixed at $75\Omega$.

**Figure C1** Plot of the variation of gain with length to diameter ($L_n/D_n$) ratio for fixed lengths and changing operating bandwidths

**Figure C2** Plot of the variation of gain with length to diameter ratio for fixed lengths and changing operating bandwidths
Figure C3  Plot of the variation of the gain with length to diameter ratio for fixed lengths and changing operating bandwidths

Figure C4  Plot of the variation of gain with length to diameter ratio for fixed lengths and changing operating bandwidths
**Figure C5** Plot of the variation of gain with length to diameter ratio for fixed operating bandwidths and changing boom-lengths.

**Figure C6** Plot of the variation of gain with length to diameter ratio for fixed operating bandwidths and changing boom-lengths.
Figures C7 Plot of the variation of gain with length to diameter ratio for fixed operating bandwidths and changing boom-lengths

Figures C1 to C4 are plots of the variations of the mean gain with length to diameter ratio for fixed lengths and changing operating bandwidths, while figures C5 to C7 shows the same plots for fixed operating bandwidths and varying boom-lengths. In all of these plots, it is easy to see that the gain is affected more for low values of length to diameter ratio (i.e. for thick dipoles) than for high values of length to diameter ratio (or thin dipoles). The plots indicate that the gain slightly appreciates for thick dipoles and slightly degrades for thin dipoles. These effects are generally not drastic. It should however be noted that these effects seem to occur in region of practical LPDA Antennas (i.e. regions for which L/n/Da ratio ≤1000). Therefore, cognizance must be taken of these effects where great accuracy is of the essence.