3 RESULTS

In this section, results of investigations are presented in the order in which they were carried out. First generalised, extended parametric plots are presented for both convergent and sparse LPDA antennas (i.e. for both minimised and non-minimised LPDA Antennas).

Next, minimised (or convergent) LPDA antennas are presented and finally, the effect of boom-impedance and length to diameter ratio on the average gain of convergent LPDA antennas are presented.

3.1 PROBABLE GAIN PERFORMANCE CHARACTERISTICS OF LPDA ANTENNAS (CONVERGENT/SPARSE)

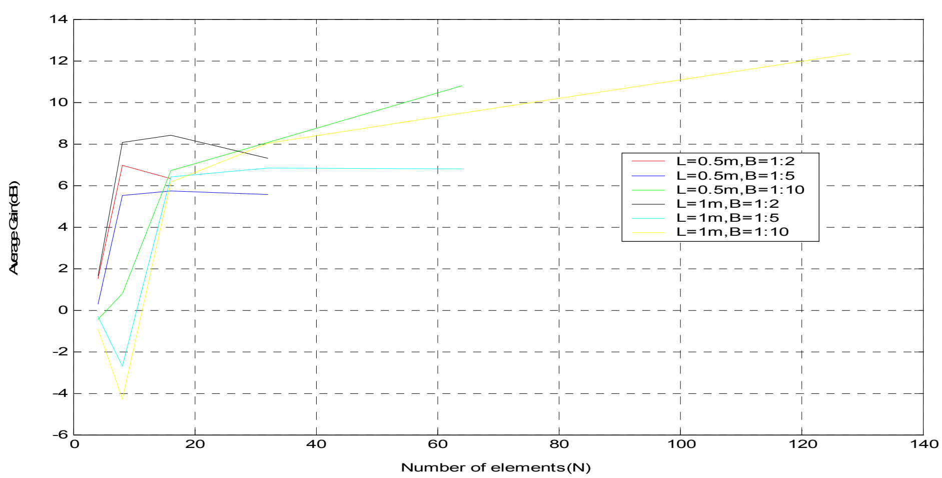

Figure 3.1 Plot of the variation of average gain with number of elements for fixed boom-lengths and changing operating bandwidths

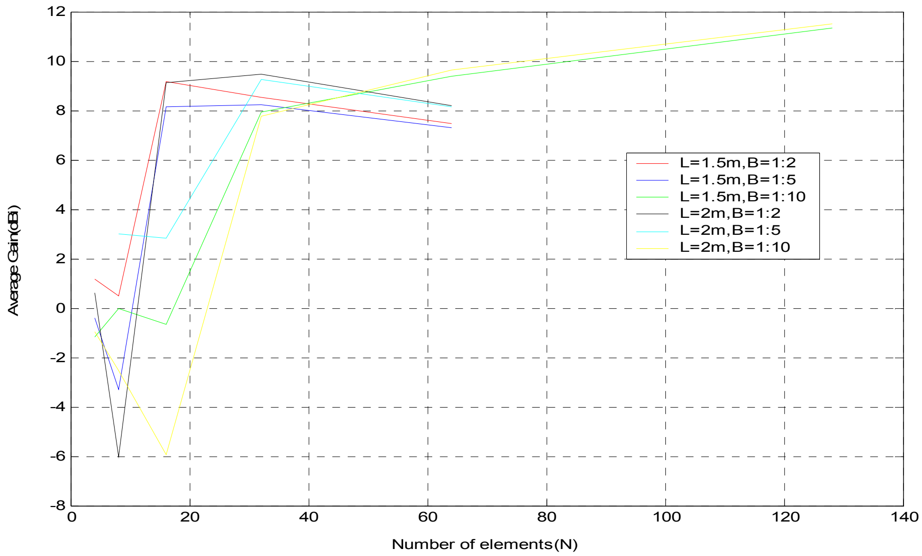

Figure 3.2 Average gain as a function of number of elements for fixed values of boom-lengths and changing operating bandwidths

Figures 3.1 and 3.2 show probable average gain in dBi as a function of number of dipole elements (N) for the range of boom-length (L) and operating bandwidth (B) covered in this dissertation. The plots cover both convergent and Sparse LPDA Antennas. The aim of these plots is to give at a glance, the probable average gain obtainable for any given number of element (N), within any given operating bandwidth and boom-lengths. It can be seen clearly, that for some values of N in any given bandwidth and boom-length, the average gain values are for all practical purposes not helpful. From the figures, for L = $0.5\lambda_{max}$, B = 1:2, N= 4 (corresponding to τ = 0.75 and σ = 0.215) results in average directive gain of 1.52dBi. Similarly, for L = λ_{max}, B = 1:5, N = 8 (corresponding to τ = 0.77 and σ = 0.276) results in average directive gain of -2.72dBi. These gain values are not useful, as they indicate a poor front to back gain ratio. The consequence of this is that the LPDA Antenna is not as directional as it should be. It is to be noted here that because the element number is doubled each incremental step, only four points are possible within smaller boom-lengths and shorter operating bandwidths.

These values of tau and sigma (by extension 'N') for which negative average directivity values result, implies that the LPDA Antenna radiates less in its maximum direction relative to an isotropic radiator or a dipole. Now since it is expected that a LPDA Antenna should be somewhat directional in radiation characteristic, such values of N should be avoided as the directive gain and the radiation pattern characteristics of the Antenna might to be very satisfactory.

Figures 3.3 to 3.6 are generalised plots of variation of number of elements (N) with scale factor (τ), for fixed boom-lengths (L) and changing operating bandwidths (B). The figures show that number of elements increases with increasing scale factor for any fixed boom-length. Also for a fixed boom-length, the number of elements increases with increasing bandwidth.

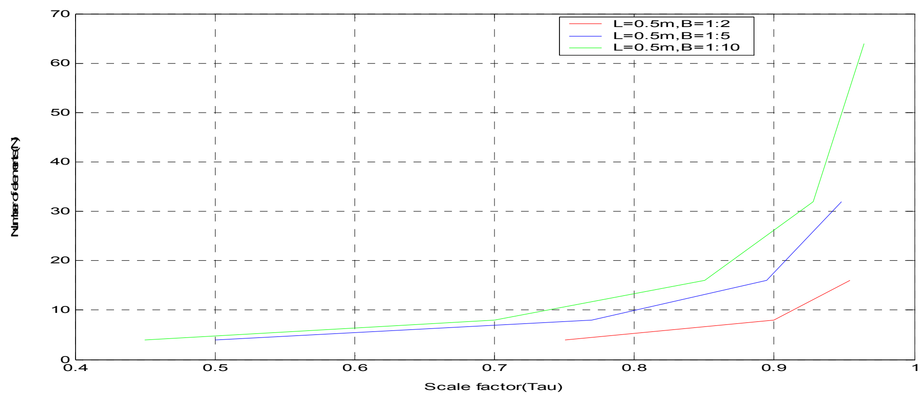

Figure 3.3 Variation of Number of element with scale factor (tau) for fixed boom-lengths and changing operating bandwidths

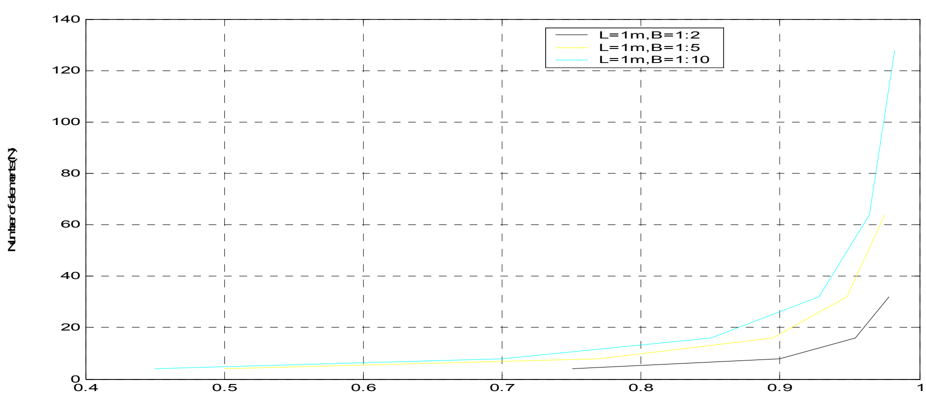

Figure 3.4 Variation of Number of elements with scale factor for fixed boom-lengths and changing operating bandwidths

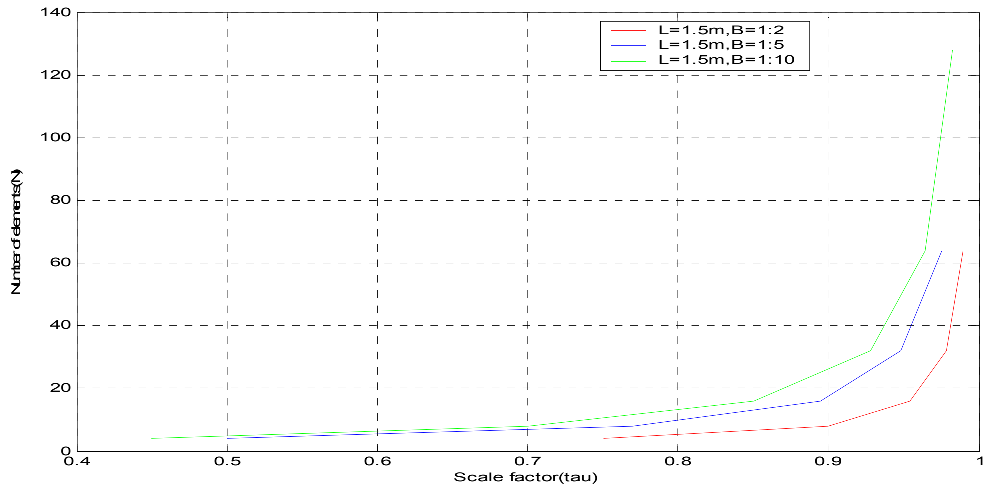

Figure 3.5 Number of element variation with scale factor for fixed boom-length and changing operating Bandwidths

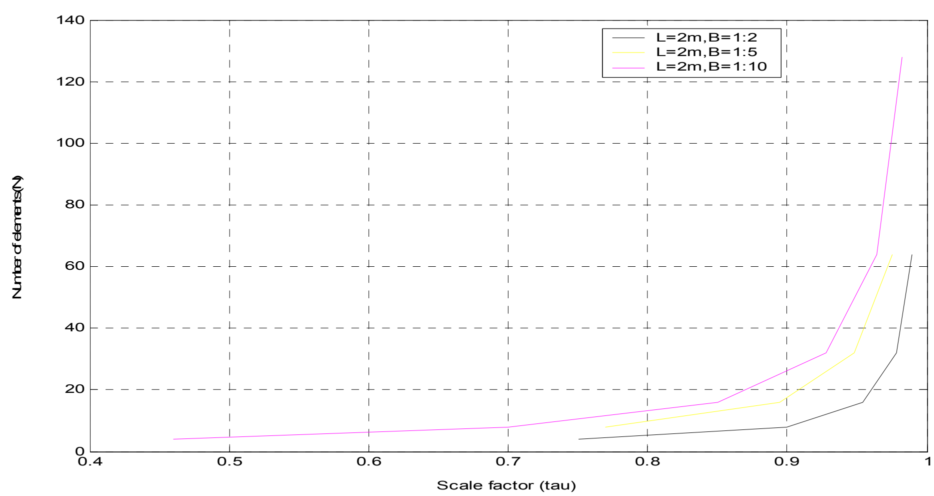

Figure 3.6 Number of element variation with scale factor for fixed boom-length and changing operating Bandwidths

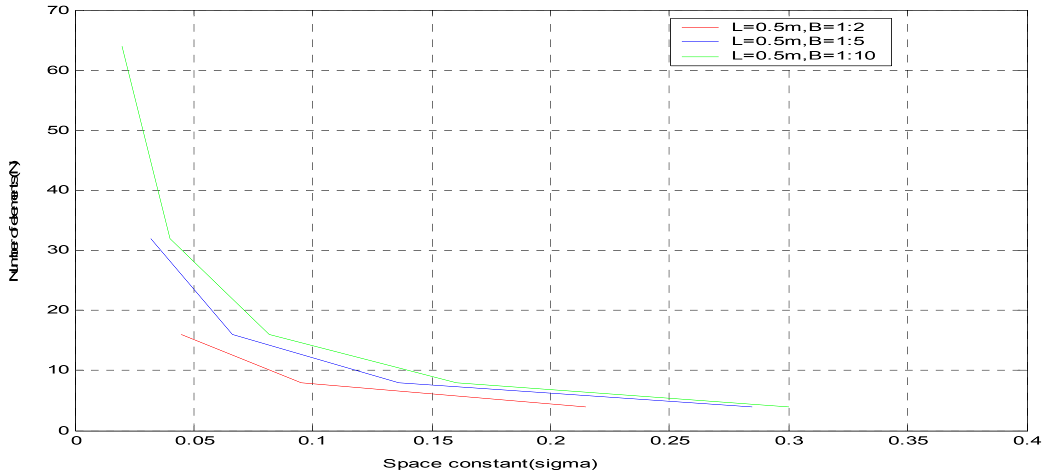

Figure 3.7 Number of element variation with space constant (σ) for fixed boom-length and changing operating bandwidths

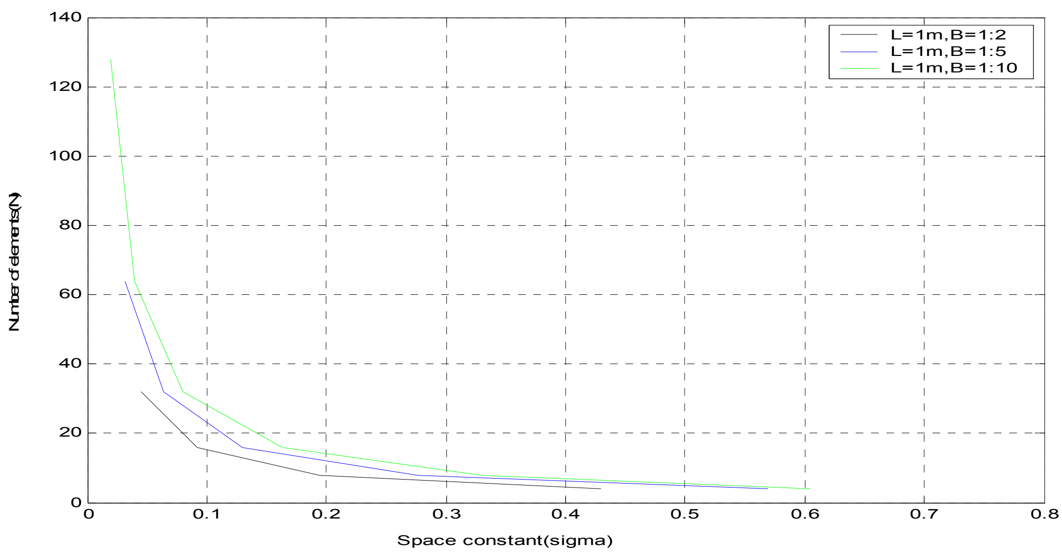

Figure 3.8 Number of element variation with space constant for fixed boom-length and changing operating bandwidths

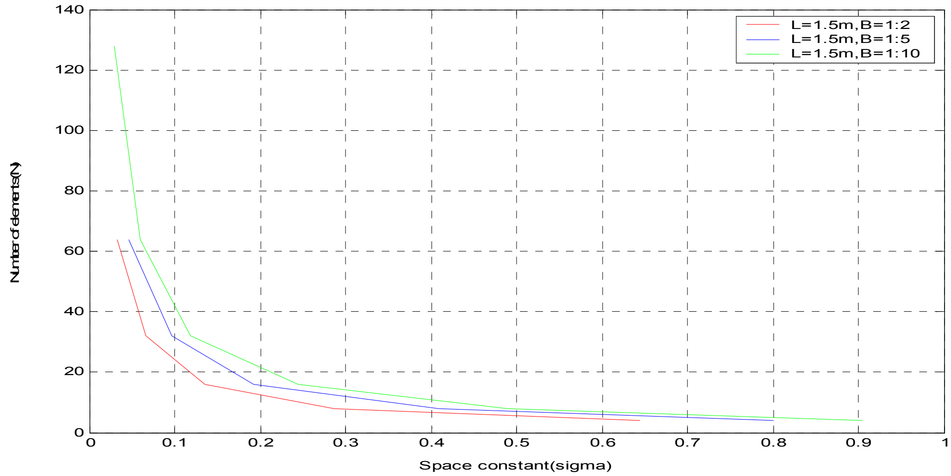

Figure 3.9 Number of element variation with space constant for fixed boom-lengths and changing operating bandwidths

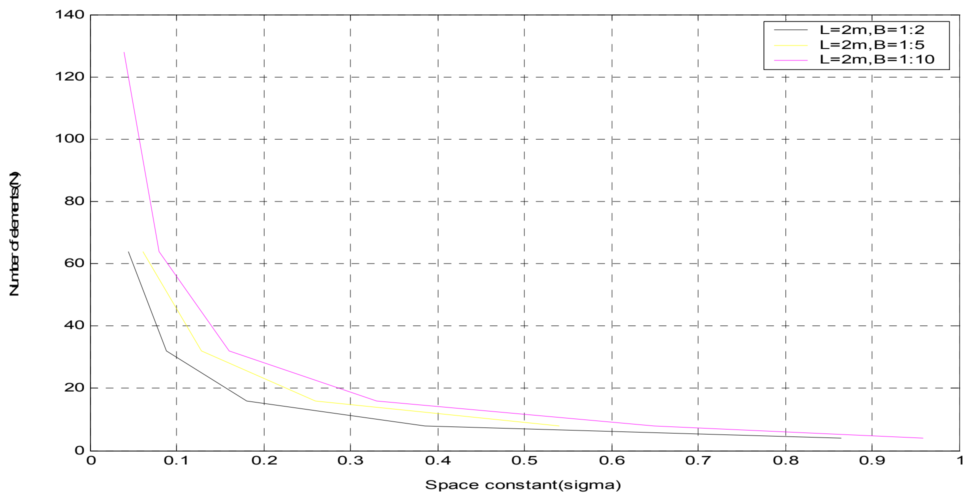

Figure 3.10 Number of element variation with space constant for fixed boom-lengths and changing operating bandwidths

Figures 3.7 to 3.10 are generalised plots of number of elements variation with space constant for fixed boom-lengths and changing operating bandwidths. From the plots, it can be seen that number of elements decreases with increasing space constant within the operating bandwidth. It can be seen also that for any given boom-length, space constant increases with increasing operating bandwidth and also that the range of space constant increases with increasing boom-lengths. From figures 3.1 all the way to figure 3.10, used in conjunction it will be seen that plots give probable gain performance characteristics of both convergent and sparse LPDA Antennas for values of scale factor ranging from 0.45 to 0.99 and for space constant ranging from 0.02 to 0.96. This is way beyond the range covered by Peixeiro [5], thus achieving one of the aims of this research, which is the extension of the parametric curves beyond the range given by Peixeiro [5]. It can be surmised that the scale factor (tau) is related to number of elements, while the space constant (sigma) is related to the boom-length.

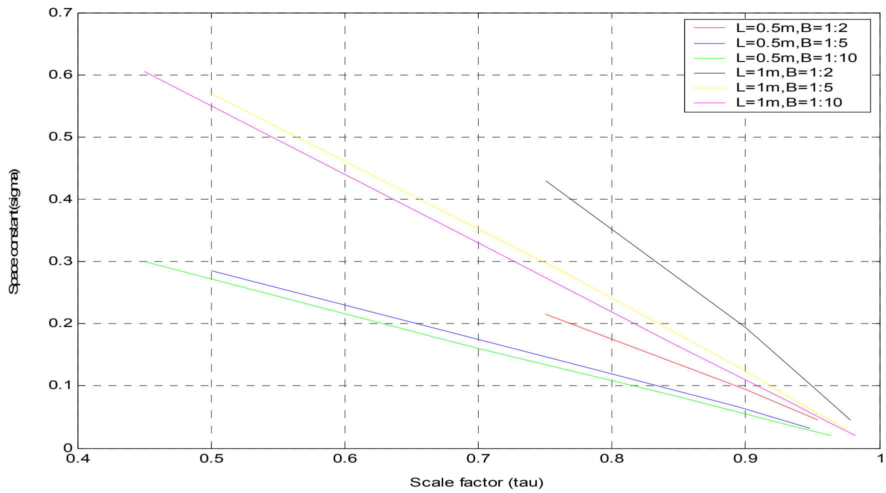

Figure 3.11 Variation of the space constant with scale factor for fixed boom-length and changing operating bandwidths

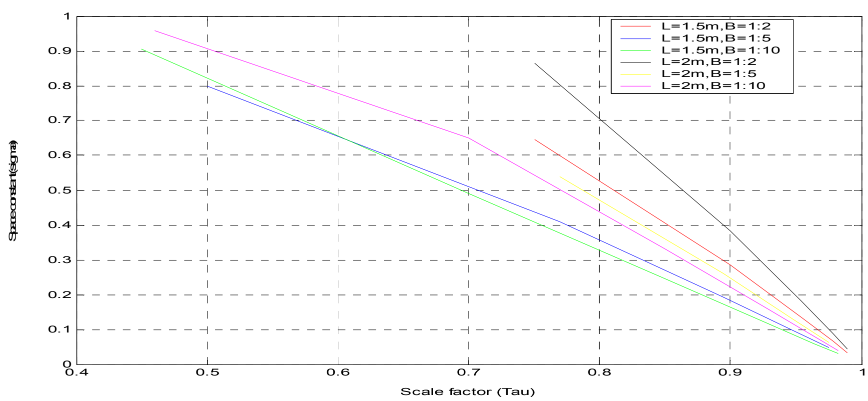

Figure 3.12 Variation of space constant with scale factor for fixed boom-length and changing operating boom-lengths

Figures 3.11 and 3.12 gives the relationship between space constant (sigma) and scale factor (tau) for fixed values of boom-length and changing operating bandwidths. These plots give the range of values of tau and sigma for any given boom-length and operating bandwidth.

The aim of section 3.1 and all plots contained therein, is to present the probable performance characteristics of both converged and sparse LPDA Antennas for the range of number of elements, boom-lengths and operating bandwidth covered in this dissertation. It can also be seen that some values of 'N' (and by extension tau and sigma) result in unacceptable directive gain performance (and by implication unacceptable radiation pattern performance) for any boom-length and operating bandwidth. This section is therefore meant to present to the designer, all the available options. The designer sees at a glance, the probable average gain that is obtainable for any given number of dipole elements, the value of tau and sigma corresponding to that number of elements for any boom-length and operating bandwidth. For fixed 'L' and 'B', there exists a range of 'N' for which the LPDA Antenna displays variations in performance characteristics. The convergence criterion allows one to find the 'N' for optimum characteristics. In the next section, the result of applying the convergent criteria to all figures of section 3.1 is then presented

3.2 CONVERGENT LPDA ANTENNAS

The convergent criteria gives the minimum number of elements required for a given LPDA antenna of fixed length and operating bandwidth, to yield acceptable gain, VSWR and radiation pattern performance. It has been shown in appendix A, that once convergence is attained by LPDA antennas not much will be achieved in terms of performance by using more number of elements than those at convergence. In some instances, more average gain can be achieved by using number of elements greater than those at convergence. The cost implication does not encourage the use of N greater than N at convergence, and in any case, one of the aims of this research is the use of minimal number of element to achieve cost optimisation.

The convergence table 3.1 below was synthesised from figure 3.1 to 3.12 above by applying the convergent criteria. A look at the table clearly indicates that the values of tau and sigma are all within the optimum region. Therefore convergent antennas are somewhat also optimised LPDA antennas. In this region tau ranges from 0.85 to 0.98, while sigma ranges from 0.08 to 0.13.

The convergent table gives the minimum number of element (and by extension tau and sigma) for any given boom-length (L) and operating bandwidth (B) that will be required for a LPDA antenna to yield a mean gain value and acceptable VSWR and radiation pattern performance. It is to be noted that the convergent table given here is not absolute. The values are extendable to about ±2 or 3 elements depending on boom-length and operating bandwidth. Figures 3.13 to 3.15 give the convergent curves. Figure 3.13 is a convergent curve given the minimum number of elements required to attain a given gain value for values of operating bandwidth and neglecting the effect of boom-length (L).

Table 3.1 Convergent LPDA Antennas

τ	σ	N	G(dBi)	L(METER)	B
0.90	0.095	8	7	0.5λmax	1:2
0.86	0.086	12	5.6	0.5λmax	1:5
0.85	0.082	16	6.7	0.5λmax	1:10
0.936	0.125	12	8.23	λmax	1:2
0.93	0.086	24	6.61	λmax	1:5
0.928	0.08	32	8.03	λmax	1:10
0.97	0.09	24	8.87	1.5λmax	1:2
0.93	0.128	24	8.30	1.5λmax	1:5
0.928	0.119	32	8.00	1.5λmax	1:10
0.9778	0.089	32	9.45	2λmax	1:2
0.948	0.129	32	9.25	2λmax	1:5
0.952	0.107	48	8.72	2λmax	1:10

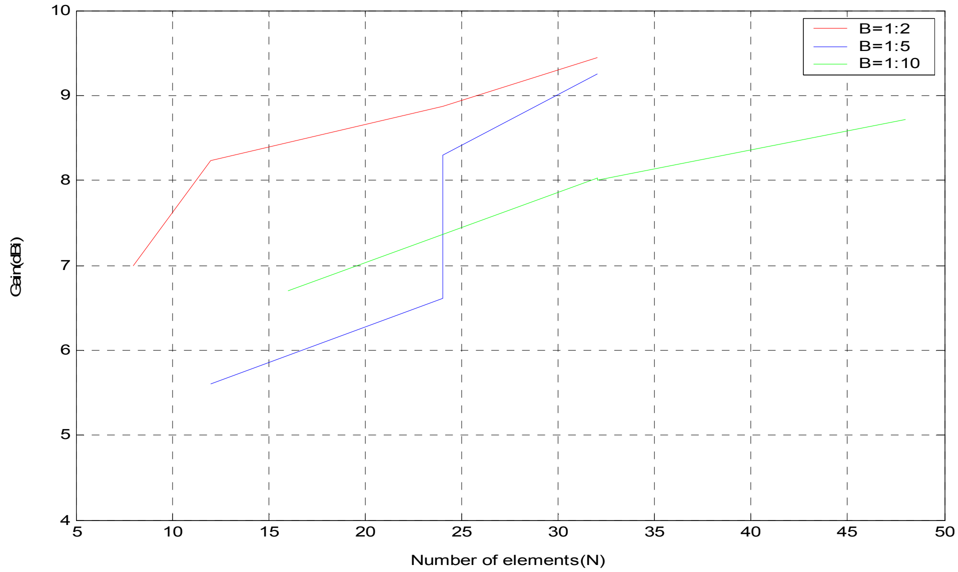

Figure 3.13 Convergent pair of [N, G] for values of operating bandwidth neglecting the effects of 'L'

Figure 3.13 gives the minimum number of elements required to attain a mean gain value within any operating bandwidth. This plot assumes the effect of the boom-length (L) to negligible. To obtain a higher average gain, you need to increase the number of element (N). Within the operating bandwidth of 1:2, increasing the number of element from 8 to 12, resulted in gain increment of 1.23dBi and doubling the number of element from 12 to 24, resulted in gain increment of 0.64dBi and increasing the number of element from 24 to 32, resulted in gain increment of 0.58dBi. Within the operating bandwidth of 1:5, doubling the number of element from 12 to 24, caused the gain to be increased by 1.1dBi and increasing N from 24 to 32, caused the gain to be increased by 0.95dBi. In the operating bandwidth of 1:10, doubling N from 16 to 32 resulted in increase in gain of 1.33dBi. On average therefore, once an Antenna is converged, doubling the number of element can at best result in maximum gain increment of 1dBi. Since the aim here is to minimise the number of element so as keep the cost of producing the LPDA antenna at a minimum, the derivable gain is not worth the cost in element terms.

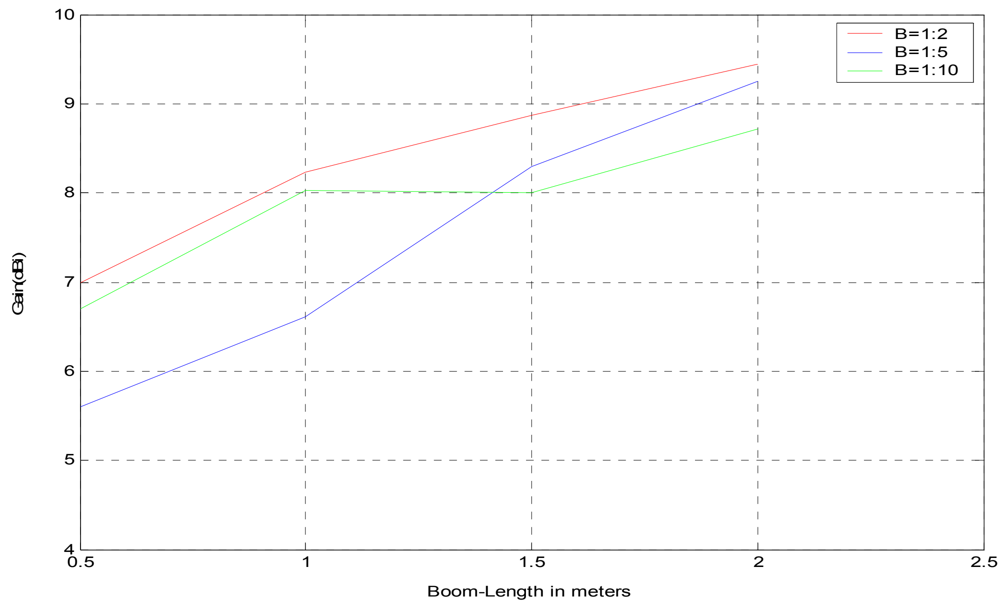

Figure 3.14 Convergent pair of [G, L] for changing values of operating bandwidth neglecting the effects of 'N'

Figure 3.14 is a plot of the average gain obtainable for any given boom-length within a specified operating bandwidth. This plot neglects the effect of number of elements on the gain. The figure shows that the average gain increases with increasing boom-length within a given operating bandwidth, but this increase in mean gain tend to decrease as operating bandwidth increases. Doubling the boom-length from $0.5\lambda_{max}$ to λ_{max} results in gain increment of 1.23dBi for B =1:2, 1dBi for B = 1:5, and 1.3dBi for B = 1:10. Similarly doubling the boom-length (L) from λ_{max} to $2\lambda_{max}$, results in gain increases of 1.22dBi for B = 1:2, 2.64dBi for B = 1:5 and 0.69dBi for B = 1:10. Since the boom-length and the number of elements are the cost determinants of a LPDA Antenna as pointed out by De Vito and Stracca [3][4], the cost implication of using long Boom-lengths so as to obtain higher gain values, acts as a disincentive to such practice. In this regard, discretion is the key word, as factors other than increased gain may encourage the use of larger boom-lengths.

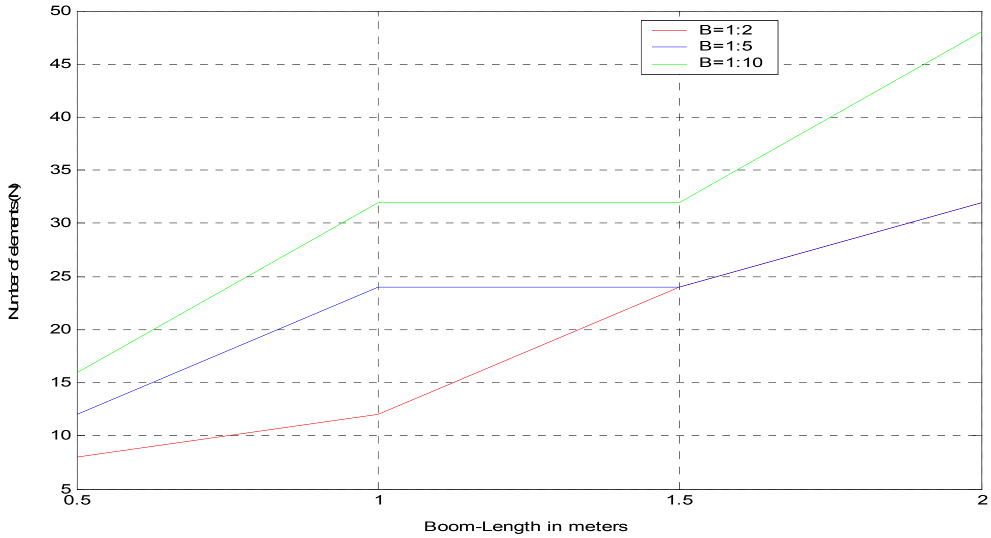

Figure 3.15 Convergent pair of [N, L] for changing values of operating bandwidth

Figure 3.15 gives the minimum number of element required for a LPDA Antenna of given boom-length and operating bandwidth to yield acceptable performance characteristics as specified in the convergence criteria. Clearly, within any given bandwidth, the number of element required for convergence increases with increasing boom-length and operating bandwidth. For instance, doubling the boom-length from $0.5\lambda_{max}$ requires the number of elements to be increased by 4 for B = 1:2, 12 for B = 1:5, and 16 for B = 1:10. Since we seek minimisation of N, using very wide bandwidths may no be useful except when unavoidable.

3.3 THE EFFECT OF BOOM-IMPEDANCE (Z_o) ON THE GAIN PERFORMANCE OF OPTIMISED (OR CONVERGENT) LPDA ANTENNAS

One of the arguments by Peixeiro [5], was that the neglect by Carrel [2] of the effect of the Antenna boom-impedance (Zo) and the elements length to diameter ratio (L_n/D_n) on the gain performance characteristic of the LPDA Antennas, contributed immensely to errors in Peixeiro's curves. In the proceeding sections, the results of these effects on the gain performance characteristics of convergent LPDA Antennas as investigated in appendix B and C are presented here. In this section, the effect of boom-impedance on the gain performance characteristics of convergent LPDA Antennas are presented. There after, the effects of the variation of length to diameter ratio on the gain performance characteristics of LPDA Antennas are presented in section 3.4.

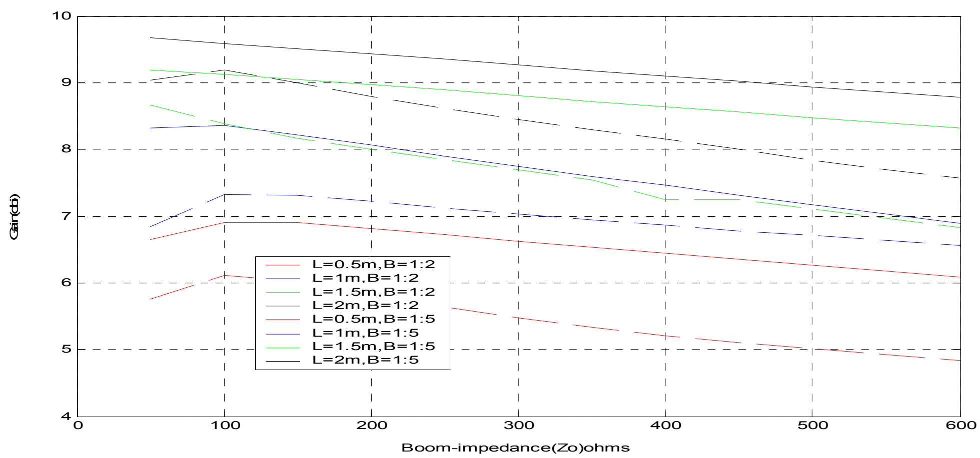

Figure 3.16 Effect of boom-impedance (Z_o) on the gain of convergent LPDA antennas

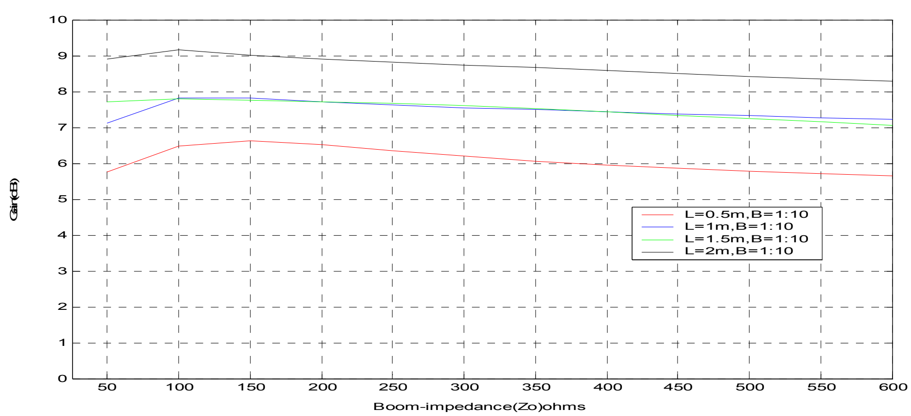

Figure 3.17 Effect of boom-impedance (Zo) on the gains of convergent LPDA Antenna

Figures 3.16 and 3.17 show the effect of boom-impedance (Zo) on the gain performance of LPDA Antennas for values of boom-length (L) and for fixed operating bandwidths. The figures indicate that for Zo between 50Ω and 100Ω, there is a slight improvement in the gain values and for Zo ranging between 100Ω and 600Ω, slight degradation in gain is observed. On average, this degradation/improvement in gain appears to be less than 0.12dBi per 50Ω change in boom-impedance (Zo).

3.4 EFFECT OF LENGTH TO DIAMETER (L_n/D_n) RATIO ON THE GAIN PERFORMANCE OF OPTIMISED (OR CONVERGENT) LPDA ANTENNAS

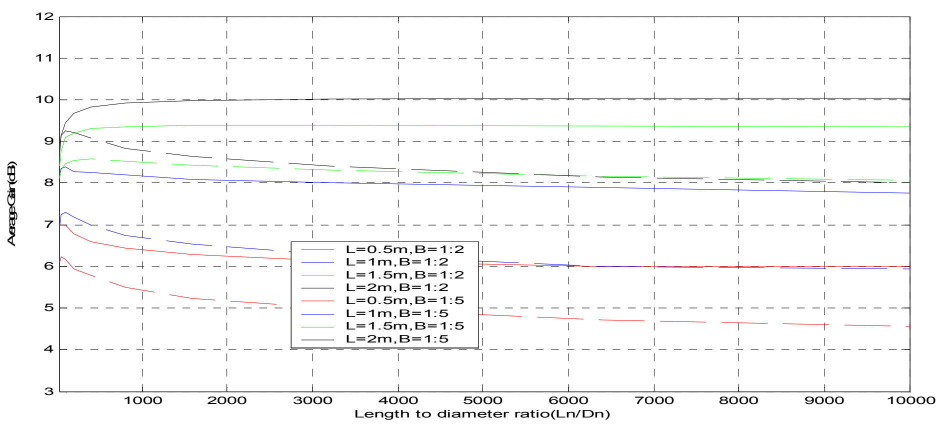

Figure 3.18 Variation of average gain with length to diameter (Ln/Dn) ratio for optimised LPDA Antennas

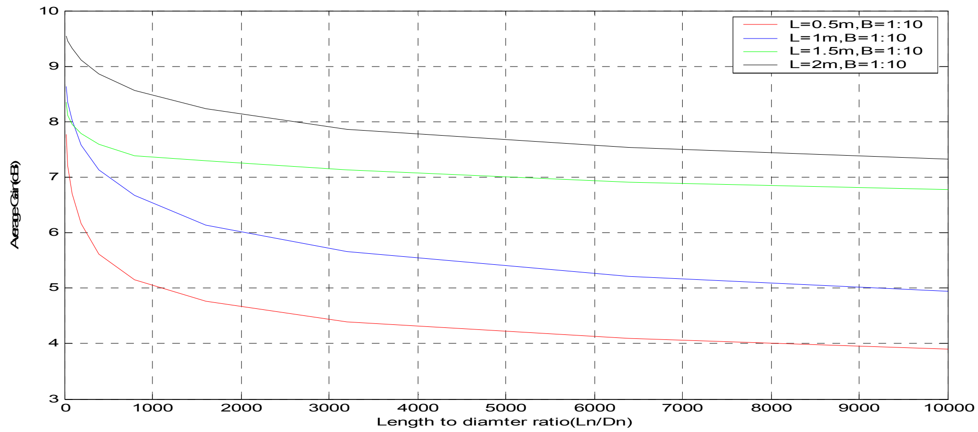

Figure 3.19 Variation of average gain with length to diameter ratio for convergent LPDA Antennas

Figures 3.18 and 3.19 show the effect of length to diameter ratio on the gain performance of optimised LPDA Antennas. The effect of Ln/Dn ratio on the gain is rather ambiguous. The graphs suggests in some instances that the gain appreciates slightly for a narrow range of values of length to diameter ratio while in other instances the gain depreciates all the way as length to diameter ratio is increased. In all of this, one thing is certain though, and that is that the sensitivity of the gain to changing length to diameter ratio is more for thicker dipole elements than for thinner elements. The effect on the gain appears to increase with increasing bandwidths, which suggests that the effect could be more due to off resonance phenomenon than due to increasing length to diameter ratios. However, since the plots suggests appreciation in gain for thicker dipole elements than for thinner ones, and since it is known that improvement in VSWR performance is obtained by using thicker materials, the bias should be in favour of thicker dipoles than thin dipole elements subject to practical limitations.

3.5 APPLICATIONS OF THE RESEARCH

In other to apply the procedures given here to the design of a functional LPDA Antenna, it is necessary to relate this work to that of Peixeiro [5]. It will be shown in this section that the procedures given here are meant for use with that of Peixeiro [5]. The argument has been made in the preceding sections that the characteristic curves as given by Peixeiro, may sometimes result in more or less elements than necessary. Further more, it has been stated as an argument for this dissertation, that the number of elements 'N' and the boom-Lengths "L', are the main determinants of the cost of a LPDA Antenna as buttressed by De Vito and Stracca [3], [4] [ref. 2.4]. It is therefore imperative that a means of minimising 'N' be found as a way of reducing the cost of LPDA Antenna, having taken for granted that the boom-Length and operating bandwidth are pre-specified. The design procedure using Peixeiro includes the following steps:

- Pairs of (τ,σ) are chosen to take into account both directivity and input resistance requirements.
- The truncation constants K_1 and K_2 are then obtained from the same curves based on the specified directivity and the selected σ.
- Suitable dipole diameters are chosen to meet L_n/D_n requirement.
- The boom-length 'L', number of elements 'N' and L_1, L_n appears as output.
- The procedure is iterative to allow for finding the best compromise.

The difference between peixeiro [5] and the procedure given in this dissertation is that the convergence process is then applied once L (pre-specified) and N are obtained. This results in minimisation of N leading to cost optimised LPDA. Thus, this dissertation could aptly be titled 'an extension to Peixeiro'. The convergence procedure reduces the iterative process inherent in Peixeiro[5].

This application is illustrated below, in which the procedures are modified for use with Super Nec version2.

1. Consider the problem of designing a LPDA Antenna with the following specifications:

Length (L) = λ_{max}.

Gain (dBi) $\geq$ 7.

Bandwidth (B) = 1:2

Boom-impedance (Z_o) = 75Ω.

Length to diameter (L_n/D_n) ratio = 100.

The antenna must maintain a VSWR of 1:2 and below within the operating bandwidth to prevent destroying the system's electronics due to power surges.

Solution1 (non-minimised 'N'):

From fig3.1, we see for Antenna length of λ_{max} (where λ_{max} = 1meter in this case) and operating bandwidth of 1:2, the highest gain obtainable for this antenna is 8.4dBi which corresponds to number of dipole elements (N) of 16. Still from fig3.1, we find that even for N=32, the gain equals about 7.4dBi. Therefore for non-minimised design, an N = 16 meets our requirement.

In figure 3.11, we see that for antenna length of 1m and operating bandwidth of 1:2, the range of sigma is from 0.43 to 0.045 and tau ranges between 0.75 and 0.98. From figure 3.7, we obtain σ = 0.092 for N=16 and from figure 3.4, we get τ = 0.954 for N=16.

Solution2 (minimised 'N'):

Table 3.1 shows that for a boom-length (L) =1m and operating bandwidth of 1:2, the antenna is converged for N = 12 and yields an average gain of 8.23dBi within this operating bandwidth. This corresponds to τ = 0.936 and σ = 0.125. This means that with N = 12, we can obtain the same gain, VSWR and radiation pattern characteristics as with N=16 without any degradation in LPDA Antenna performance.

2. Another case is the one for which L = $0.5\lambda_{max}$, VSWR must be at least 1:2 and gain of at least 6dBi and operating bandwidth of 1:2.

Using figure 3.1, N =16 meets the requirements. This corresponds to tau = 0.954 and sigma = 0.05 from fig3.3 and 3.7. However, application of minimisation using table 3.1 results in N= 8 meeting all the requirements.

In this way, the parametric curves of chapter 3 can be used for the design of any LPDA Antenna, given a set of specifications. Its principal aim is element minimisation leading to cost optimisation.

3. In this final example, my procedure is compared with that given by Stutzman and Thiele [11]. In this example, an optimum design of a LPDA Antenna is done using [11] and the parameters and performance is compared to those obtained using my procedure. Consider the problem of designing optimally, a LPDA Antenna with the following specifications.

Gain ≥ 6.5dBi.

Operating bandwidth = 1:5 (300MHz to 1500MHz).

VSWR ≤ 1:2.

Using fig 6.39 (from Stuzman and Thiele [11], pp 266), for G = 6.5dBi, $\tau = 0.882$ and $\sigma = 0.149$. Letting L_1 and L_N be the longest and shortest dipole elements respectively, and d_1 and d_n be the spacing between the longest and shortest elements. Where, $L_1 = 0.5\lambda_L$ and $L_N = 0.5\lambda_U$ (and λ_L and λ_U are wavelengths at the lowest and highest frequencies respectively). Using free space velocity,

λ_L = 1m (at 300MHz) and λ_U = 0.2m (at 1500MHz).

$L_1 = 0.5 \times 0.1 = 0.5$m.

$L_N = 0.5 \times 0.2 = 0.1$m.

$L_2 = \tau L_1 = 0.882 \times 0.5 = 0.441$m.

$L_3 = \tau L_2 = 0.882 \times 0.441 = 0.389$m.

$L_4 = \tau L_3 = 0.883 \times 0.389 = 0.343$m.

Continuing this process results in, L_5 = 0.303m, L_6 = 0.267m, L_7 = 0.235m,

L_8 = 0.208m, L_9 = 0.183m, L_{10} = 0.162m, L_{11} = 0.142m, L_{12} = 0.126m,

L_{13} = 0.111m, L_{14} = 0.098m. L_{14} should be the smallest element, as L_N can not be less than 0.1m.

The use of equation 3 of page 2 confirms that N = 14 will result. However, in other to ensure smother performance over the operating bandwidth, two elements each are added to both ends of the boom, resulting in 18 elements.

Next, the spacing of the dipole elements is calculated using equation 6-91 on page 267 of [11]. Using this equation, $d_n = 2\sigma L_N$. Thus,

$d_1 = 2\sigma L_1 = 2\times 0.149 \times 0.5 = 0.149$m.

$d_2 = 2\sigma L2 = 2 \times 0.149 \times 0.441 = 131$m.

$d_3 = 2\sigma L3 = 2 \times 0.149 \times 0.389 = 0.116$m.

Continuing the process results in d_4 = 0.102m, d_5 = 0.090m, d_6 = 0.080m,

d_7 = 0.070m, d_8 = 0.062m, d_9 = 0.055m, d_{10} = 0.045m, d_{11} = 0.042m,

d_{12} = 0.038m, d_{13} = 0.033m, d_{14} = 0.029m.

The total boom- length $L = d_1+d_2+d_3+d_4+\ldots d_n = 1.542$m. Note however that due to the four added elements, L will be slightly longer than above.

Having obtained the geometry of the LPDA Antenna, Simulation was then performed using any available soft-ware, and the performance of the Antenna is then evaluated to see if it meets the requirements specified. If not, adjustments are made and the entire calculation done again, until satisfactory characteristic is obtained. The process is therefore iterative.

Applying the procedure given in this dissertation to the same problem.

$L \approx 1.5m$ (assumed pre-specified), B = 1:5.

Using figure 3.2, a gain of 6.81dBi is obtained for N = 32 (not minimised).

Using figure A1.3 in appendix A (page 49), it will be seen that the Antenna converges for N between 16 and 32 (ref. Pages 16,18 and 19). Averaging was then used to result in N = 24.

From the convergence table 3.1, N =24 corresponds to Gain of 8.3dBi. My procedure suggests that the same Antenna can be designed using N ranging between 16 and 24.

Using the methodology in [11] and that given in this dissertation resulted in the same optimised design using fairly equal N. The difference though is that my procedure will not require any iterative step as it is guaranteed that the LPDA Antenna will meet the required performance characteristic. As a matter of fact, Stutzman and Thiele [11], does indeed confirm my statement [ref. pp 29], that for a boom-length and operating band width, there exist a range of number of element 'N' for which the LPDA Antenna displays slight variations in performance characteristics. Stuzman and Thiele [11] takes that 'N' to be the optimum value. Indeed, the essence of my dissertation has been on how to obtain that 'N' which yields optimum performance in terms of all the electrical characteristics of the LPDA Antenna.