An examination of the effect of mechanical deformation on the input impedance of HF LPDA's using MBPE

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Abstract

This article examines the application of Model Based Parameter Estimation (MBPE) to the evaluation of the input impedance of HF Log Periodic Dipole Arrays (LPDA) during mechanical deformation. A study of cases of lengthening, shortening and displacing one element as well as the effect of mechanical sagging of the array is made. It is found that MBPE is a useful tool for minimizing computations and/or measurements in the study of mechanical deformation.

1 Introduction:

The MBPE [1] technique is used to predict deviations in the input-impedance of a 4 to 30 MHz Log Periodic Dipole Array (LPDA). All the analyses were made using NEC-2 [2]. The work reported in this article is based in part on work done for the M.Eng. degree by one of the authors [3]. The MBPE technique works well if sufficient samples are used as input. Four (4) frequency samples per element [1] were found to be more than adequate for a good estimate of the impedance characteristics of the antenna. Over-sampling (that is for the MBPE model) occurred at very high sampling rates - in the order of 60 samples per element. The use of MBPE allows the forecasting of problem areas in the evaluation of the input impedance. By means of a more complete analysis, an evaluation of the accuracy of these predictions can be made. MBPE may be used to give an early warning of possible instabilities in the input impedance of an LPDA. Although the input impedance of the LPDA does not show instabilities within the operating frequency band, these may occur outside the band. During deformation of the LPDA, changes in the input impedance are to be expected, perhaps radical changes and singularities. MBPE can be used to provide early warning of such problems. (Early in the sense that it is not necessary to compute a very fine grid of frequency samples - which is computationally expensive). The development of MBPE described and used here is based on the work of Burke, Miller et al [1].

[1] An element is a single dipole, The LPDA consists of a number of dipoles spaced and scaled periodically

2 The Basics of MBPE

MBPE uses a control system type pole-null structure to represent the input impedance of an antenna (or other system) as a Laplacian transfer function. The LPDA actually consists of an array of dipoles, each easily represented by a pole-null combination. Because of this the characteristics of LPDA's, and many other antennas, could possibly be examined using this technique.

2.1 Mathematical model

In general, Equation 1 is used to represent a pole-null system. (In this case the input impedance of the LPDA.)

$$F(s) = F(j\omega) = G\frac{(s+z_1)(s+z_2)\ldots}{(s+p_1)(s+p_2)\ldots} \qquad (1)$$

In Equation 1 z_n represents nulls, p_n represents poles and G represents the gain, and s is the complex frequency usually represented only by $j\omega$. The poles and nulls, p_n and z_n, will be detected in the form $\sigma + j\omega$, where σ is the damping constant and $j\omega$ the complex angular frequency.

Unlike control system applications, estimation of the placement of the poles and nulls is not done by the structure or the properties of subsystems. The model will instead be applied in a curve fitting environment.

Equation 1 can conveniently be converted to:

$$F(s) = \frac{n_0 + n_1 s + n_2 s^2 + n_3 s^3 \ldots}{1 + p_1 s + p_2 s^2 + p_3 s^3 \ldots} \qquad (2)$$

Since the values of s ($s = j\omega$) and $F(s)$ (from input data) are known, Equation 2 can conveniently be solved. For multiple inputs for s and $F(s)$ a matrix equation is obtained. This is used for solving Equation 2, with mathematical routines such as Gauss-Jordan elimination (see for example [4]). The result returns the values of n_n and p_n. The actual placement of the poles and nulls is not important as a first objective, but they can easily be found from the values of n_n and p_n. The main objective is to reconstruct the frequency response of the system (of the input impedance in this case). Equation 2 is used to do just this. MBPE will be able to fill in the missing parts in the data, according to the pole null structure detected.

2.2 MBPE and the Data

Since MBPE tends to become unstable if too many data points are used, this study is limited to the use of four poles and four nulls per sliding window. The effect of using too many data points is well illustrated in Figure 1. In this case 40 poles and 39 nulls were used. These errors do not necessarily indicate a failure of the model but are rather due to limitations in numerical accuracy during the Gauss-Jordan elimination process (see for example [4]). An exact solution of Equation 2 would result in zero errors at the supplied data points. This is clearly not the case as seen in Figure 1.

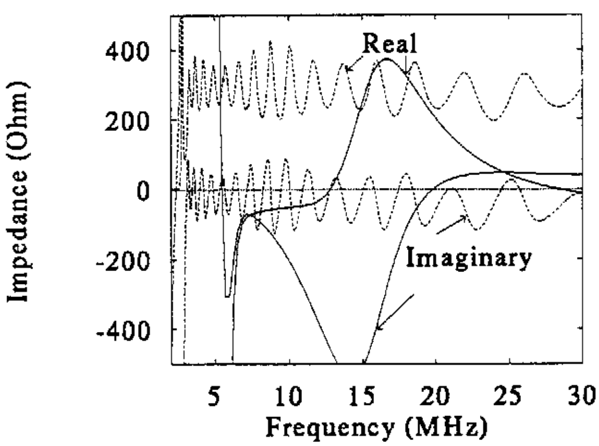

Figure 1: *Illustration of the effect of using too many samples simultaneously . MBPE was applied on 80 points of data with 40 poles and 39 nulls (solid lines). For reference 640 frequency points (from NEC2) were used, with straight line interpolation (SLI), of the same structure (dotted lines).*

Due to the wide frequency range of the LPDA, the application of MBPE will be on data-windows (with width $= 1 + poles + nulls$). This means MBPE is applied to frequency points 1 to 9, and then to frequency points 2 to 10 etc. All the outcomes are plotted on the same graph, since for a good solution these graphs are supposed to lie on the same curve. This can also be used to determine how stable the solution is. If the different graphs (over the same data area) differ too much from each other, further investigation should be made on that area. Instabilities are caused either by some singularity in that area or under-sampling or some kind of failure in the model. Using more data points to solve the problem will give a more stable solution, and better illumination of any singularities. It is also useful to investigate the placement of the poles and nulls as illustrated in Section 3.2.

The main objective is to have more than one pole-null pair per element. This amounts to more than 2 samples per element depending on the window size used. This corresponds with the Nyquist sampling criteria. At a total of 50 samples across the band $(2 - 30MHz)$, an error, in the real part of the impedance, of 4.9% was detected. This might be accurate for many applications, but for the investigation of deformations on the LPDA this accuracy is not high enough. Furthermore the poles and nulls detected, should move around under deformation. For these reasons a sample rate of about four (4) samples per element is used for the investigation of deformations. It is also important to use the correct method of frequency incrementing. Since the lengths of the elements in the LPDA are spaced periodically in frequency, we must also space our samples in a similar way. Throughout this article, logarithmic sampling is used.

3 The 'Ideal' LPDA and MBPE

The term 'ideal', as used here, means undeformed. In later sections, the applications of MBPE to deformed LPDA's, whether mechanical sagging, displacement or length changes of elements, are discussed. The ideal LPDA is described in Section 3.1. Application of MBPE to the input impedance of this LPDA is described in Section 3.2. Sections 4, 5 and 6, examine the effects of mechanical deformations on this LPDA.

3.1 Construction of the LPDA

A 20 element LPDA with a 30° apex (α), element reduction factor (τ) of 0.87 and a rear element total length of 42.13m was used for this study. The whole structure is located at a height of 20m above ground. The ground parameters used are: a relative dielectric constant (ϵ_r) of 15 and a conductivity (σ) of $0.005S/m$. The center fed transmission line has an impedance of 450Ω. The transmission line is terminated in a short 21.065m beyond the rear element. This construction is represented in Figure 2. In Section 6 the same structure is used, with nonconducting catenaries to support the structure as used in practice. This antenna is similar to that used in [3] and [5].

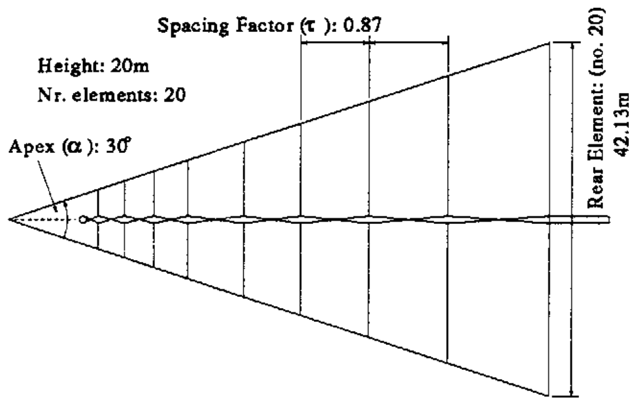

Figure 2: *The construction parameters of the LPDA used for this study. (Transmission line shown crossed to illustrate alternating connections of elements. The shorted stub length is 21.065m)*

3.2 Input Impedance of the Ideal LPDA

Due to the log periodic structure of the LPDA, logarithmic repetitions are expected for the input impedance. Since frequencies corresponding to the resonant lengths of the elements are spaced logarithmically in the frequency band, samples are spaced in the same way. NEC-2 was used to determine the input impedance of the LPDA.

The result of application of MBPE to 20 frequency data points is shown in Figure 3. Also shown for reference are the results of a 640 frequency point solution with straight line interpolation. A sliding sample 'window' [2] with only 4 poles and 4 nulls were used for this solution. Multiple overlapping solid curves in Figure 3 arise from this sliding window. Although the MBPE data is stable, it is very clear that not enough samples were used in this case. This sample rate violates the Nyquist sample criteria. A sample rate of 50 samples (above Nyquist) across the band gave stable results, but not accurate enough to use with the study of deformations. At 60 samples (across $2-30MHz$) the stability of MBPE solutions was much improved. However, with medium to heavy deformations, errors occured due to movement of poles and nulls. The authors therefore decided to use a sample rate of 80 samples across the band as a standard for the investigation of deformations.

Applying MBPE to the same LPDA with 80 frequency samples, a clear picture of the actual response of the LPDA is obtained. Figure 4 gives a more complete picture of the behavior of the LPDA. The data from the MBPE and a 640 frequency sample point Straight Line Interpolation (SLI) are plotted on the same graph in Figures 4 and 5. This gives an indication of the potential of the MBPE technique.

[2] see Section 2.2 Paragraph 2

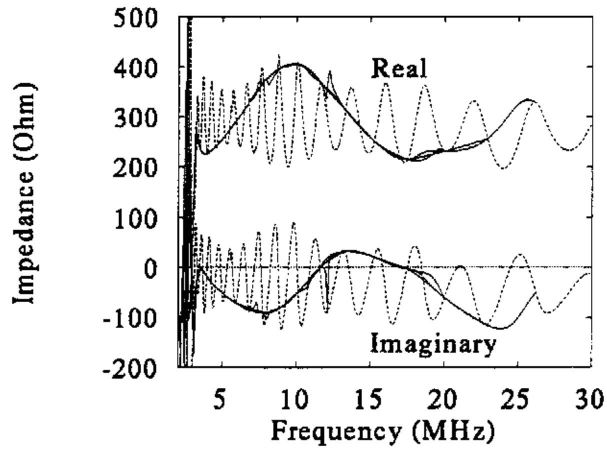

Figure 3: *The input impedance of the LPDA with MBPE (with 4 nulls and 4 poles) applied to 20 sample points in frequency (solid lines). Reference curve for 640 frequency sample points shown as dotted lines (SLI). See text.*

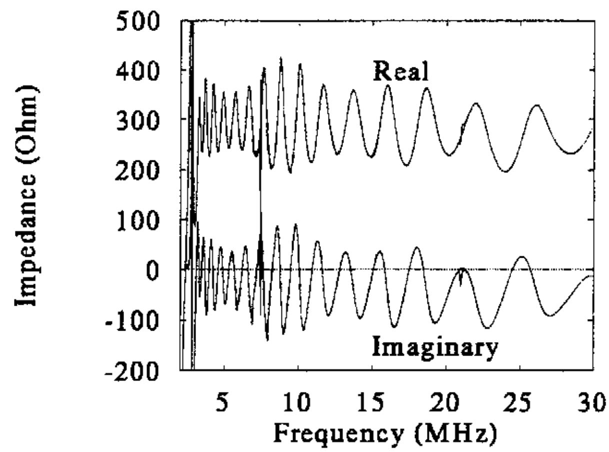

Figure 4: *The input impedance of the LPDA with MBPE (with 4 nulls and 4 poles) applied to 80 sample points in frequency (solid lines). Reference curve for 640 frequency sample points shown as dotted lines (SLI). See text.*

From Figure 4 and 5 it is clear that a singularity occurred at about 2.8 MHz. This is due to the short used at the end of the LPDA's transmission line to increase bandwidth. Since the antenna is designed to work from 4 to 30 MHz it is clear that this 2.8 MHz point is not in the design area. Still, this irregularity shows the effectiveness of MBPE for detecting such anomalies.

Figure 4 can be used as reference for investigating how the input impedance of the LPDA changes with deviations. The 640 point solution for the ideal LPDA is used as a reference for further sections investigating the effect of deformation of the LPDA from the ideal.

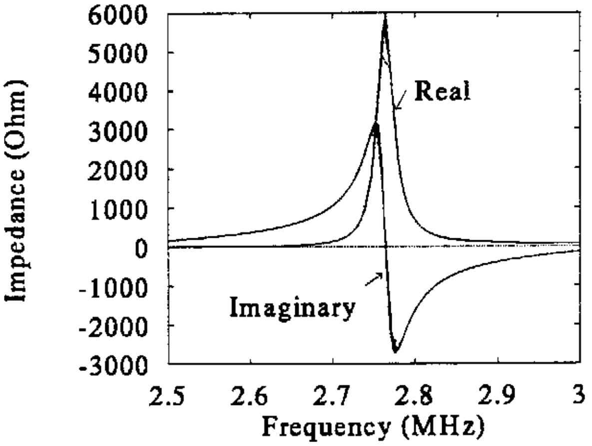

Figure 5: *The input impedance of the LPDA with MBPE (with 4 nulls and 4 poles) applied to 80 sample points in frequency (solid lines). The response of 640 sample points illustrate possible margins (dotted lines, SLI).*

Another instability was also detected at about $7MHz$. Further examination of the 640 point solution, shows a small inflection in the input impedance for this frequency, as is shown more clearly in the expanded frequency scale in Figures 8 and 9, later. For this case it is essential to look at the poles and nulls detected at that area. The poles and nulls detected in the frequency band 7.015 to $9.202MHz$ are shown in Figure 6. It is clear that a pole-null pair was detected at a point in the s-plane, corresponding to $7MHz$. This explains the occurrence of the instability at $7MHz$. Further investigation showed that this instability was caused by the short at the end of the transmission line.

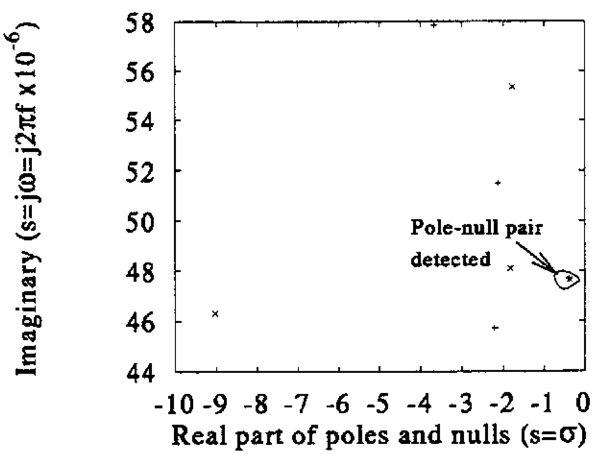

Figure 6: *The pole null pair detected, by MBPE, at about $8MHz$. This figure represents the frequency band 7.015 to $9.202MHz$. The poles are shown by crosses and the nulls with pluses.*

For the evaluation of the effect of physical deformation of the LPDA, one would prefer to have some kind of curve fit to another dimension. An ideal case would be to fit a curve to the poles and nulls with a polynomial fit. This would result in the position of the poles and nulls being represented by a polynomial as shown in Equation 3, where z is the pole or null, z_0 and k_n are constants and d is a value connected to the deformation:

$$z = z_0(k_0 + dk_1 + d^2k_2 \ldots d^n k_n) \tag{3}$$

Each element (dipole) in the LPDA can essentially be represented by a pole and a null. These poles and nulls are spaced to have poles approximately where the real part of the impedance is a maximum, and nulls where it is a minimum. These are the fundamental poles and nulls for the impedance. To complete the curve-fit - since MBPE is an exact solution - some extra poles and nulls are detected. The presence of these extra poles and nulls moves the fundamental poles and nulls. These extra poles and nulls sometimes occur in pairs on the resonant part of the s-plane. For different extremes of a deformation the extra poles and nulls are detected at completely different places. If a curve fit on the extra poles and nulls is made, the intermediate extra poles and nulls may cause very unstable solutions. Since the fundamental poles and nulls are moved by the detection of extra poles and nulls, this further complicates the application of a polynomial curve-fit. In Figure 7 the poles and nulls from the 12 to $20MHz$ band are shown. The difference between the poles and nulls detected on the same data-set by merely using different windows of data is illustrated.

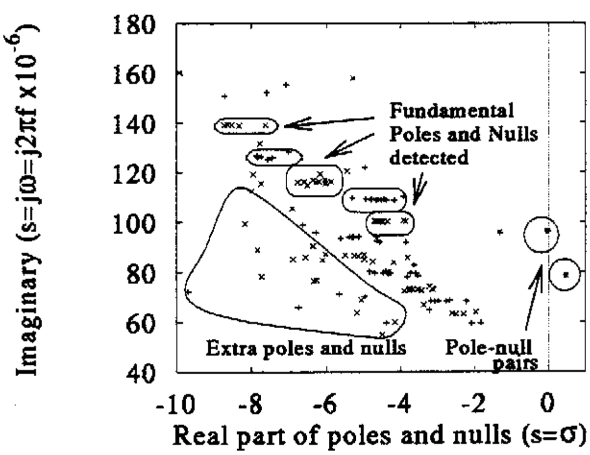

Figure 7: *The poles and nulls detected across the 12 to $20MHz$ band of the LPDA. Groupings of poles and nulls can be found, but they are not uniquely defined. Poles and nulls (usually in pairs) were also detected in the resonant ($\sigma > 0$) region.*

Due to the quality of the results obtained from MBPE an attempt was made to implement a curve fit on the poles and nulls detected during application of MBPE to a two dimensional impedance plot, with both frequency and deformation dependence. These results were however difficult to interpret, and essentially meaningless.

Due to the difficulty of implementing a two dimensional fit, the rest of this paper is limited to the use of MBPE at discrete deviations for single parameters.

4 The effects of changing the element length

For this and the following sections, physical deviations from the structure of an ideal LPDA, as used in [5], are considered. Data can not be compared directly to that in [5], since only 20 linearly spaced sample points were used in [5]. With the help of MBPE the validity of assumptions made in [5] is evaluated, since MBPE gives a better indication of the actual response than the few data points used in [5]. The first case study will be on the deviation in the length of one of the elements of the LPDA. The effects on the radiation pattern of the LPDA were found to be minimal [5, 3].

4.1 Increasing the 10MHz element length

In this case the length of element no. 13, with an isolated free space resonance of around 10MHz is increased by 6.5% of its original length. (This is much more than allowed in Smith [6]). At first there does not seem to be much difference between the impedance of this deformation and that of the ideal LPDA.

With the application of MBPE, more definite deviations in the input impedance of the LPDA can be detected, as can be seen in Figure 8. This is still not as radical as assumed by Smith [6], but not as insensitive as expected in [5]. The effect of this deviation is clearly illustrated in Figure 8.

To verify the results from MBPE, the MBPE model used in Figure 8 was compared with a 640 data point solution. From this comparison it was clear that the MBPE is a very good approximation and therefore can be used as a basis for further comparisons to the ideal LPDA.

4.2 Decreasing the length of the 10MHz element

Decreasing the length of an element produces results similar to those in Section 4.1. The deviations shown in Figure 8, are expected to be reversed. In Figure 9 the

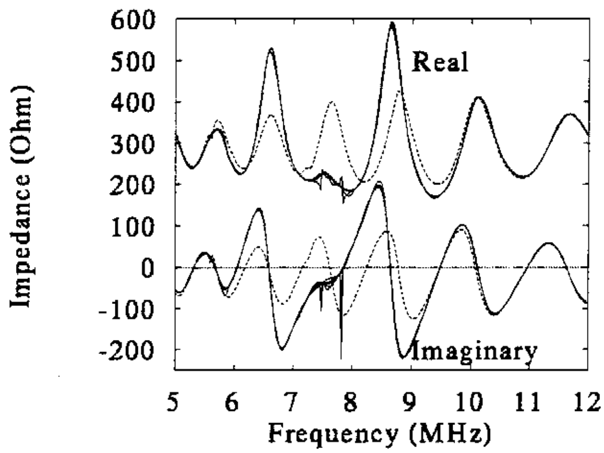

Figure 8: *The comparison of the input impedance of the ideal LPDA (dotted lines, SLI) and the input impedance of a LPDA with the length of the element around 10MHz increased by 6.5% of its original length (solid line, MBPE).*

results from applying MBPE for this case, are compared to the ideal LPDA. The effects in Figure 8 can be explained with three fundamental poles at about $8MHz$. (The centre pole would be associated with the deformed element.) The center pole moved away, ($\sigma << 0$) and the two neighboring poles moved closer to the $j\omega = 0$ axis.[3] (Please also refer to Figures 6 and 7 for the use of $j\omega$ and σ.) In Figure 9 this effect has inverted: the center pole moved closer to the $j\omega = 0$ axis, and its neighboring poles moved away. The instabilities at about $7.6MHz$ are caused by the short at the end of the transmission line.

From the above it is clear that the effects of these deviations show up at lower frequency values than expected due to the actual operation of the LPDA. An LPDA typically has an active region of a few localized elements at any in-band frequency. This active region is displaced towards elements shorter than those which would normally correspond to resonance in isolation at a given in-band frequency. This may explain why the deviations occur at lower frequencies than expected, since at that stage the deformed element will be in use.

5 Displacing the 10MHz element

In this section the 13'th element, corresponding to resonance at 10MHz, is moved along the transmission line by 10% of its spacing from the previous element. The results (with MBPE applied) of moving the element towards the region of the LPDA with longer elements, are shown in Figure 10, and those from moving the element

[3] $j\omega$: Angular frequency. σ: Damping coefficient.

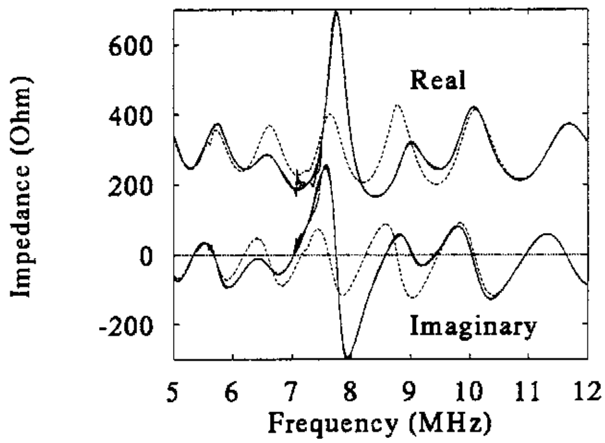

Figure 9: *The comparison of the input impedance of the ideal LPDA (dotted line, SLI) and the input impedance of a LPDA with the length of the element around 10MHz decreased by 6.5% of its ideal length (solid line, MBPE).*

towards the shorter elements in Figure 11. From these two figures it is clear that this change does not have much effect on the input impedance of the LPDA.

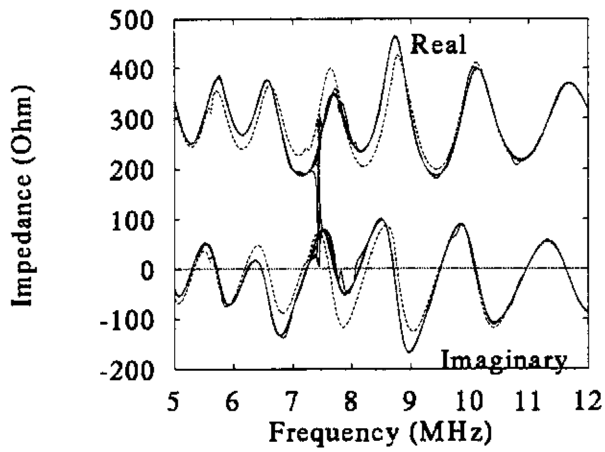

Figure 10: *The comparison of the input impedance of an ideal LPDA (dotted lines, SLI) and a LPDA where the element corresponding to 10MHz is moved 10% of its spacing towards the wide-end of the LPDA (solid lines, MBPE).*

In Figure 10 an instability or 'glitch' occurred at about $21MHz$. These glitches also occurred in the impedances examined in Figures 8 and 9, and in some other implementations, these glitches occurred at the edge of the data window used. The MBPE technique has no *a priori* knowledge of the impedance values outside the data-window and therefore sometimes place poles and nulls close to the window in irregular places. This causes the ends of the reconstructed window to be more unstable. MBPE can be used to reconstruct the impedance of an antenna outside the sample window, but it was found that such expectations outside the data-window were not very accurate for the LPDA. It was also found that the reconstruction in the center of the window is more reliable than on the edges. This effect can be eliminated by only using the inner eg. 60% of the reconstructed window.

From Figures 10 and 11 the effects of misplacement could also be explained using movement of poles and nulls.

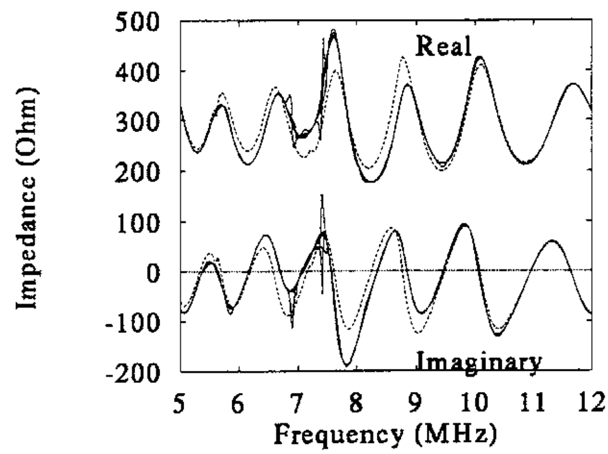

Figure 11: *The comparison of the input impedance of an ideal LPDA (dotted lines, SLI) and a LPDA where the element corresponding to 10MHz is moved 10% of its spacing towards the small-end of the LPDA (solid lines, MBPE).*

6 Mechanical sagging of the LPDA

In this section the use of MBPE to investigate the effects of mechanical sagging, is examined. The same deformations as used in [5] are used here. Once again the results of these sagged cases are compared to those of the ideal LPDA.

The program TOWEROPT, used for structural analysis and optimizations, (See [5]) was used to evaluate the sagging of a practical LPDA at discrete points. These points were used to construct a NEC input file. The effects of sagging was evaluated with the aid of NEC-2. Practical load parameters were used for the structure, namely: 117gm/m for the conductors and 275gm/m for the parafil ropes. A tensile strength of 20kN was used for the 'parafil'[4] rope. All possible information available was

[4]'Parafil' is a trade name for a class of pre-strained terylene rope encased in a UV absorbing sheath (see [7])

used for the construction of the TOWEROPT input file. (This include for example the weight of the fiberglass joints used to join the parafil rope with the conductors etc.) This was done to get the best practical evaluation possible. Only one adjustable parameter, prestrain, was available. By adjusting the prestrain, on certain cables, different cases of sagging could be evaluated.

The moderately sagged and extremely sagged cases as described in [5] were compared to the ideal LPDA. Comparisons as in Figure 12 for the extremely sagged case and Figure 13 for the moderately sagged case were obtained.

Figure 12 displays the effect of extreme sagging on the LPDA. This case represents an antenna laid out on the ground, with no prestrains in the cables/ropes, which is then hoisted to a height of 20m. In this case the final strain in the cables was only 8% of its rated strength. The maximum physical sag of 4.33m occurred at element sixteen - corresponding to 18% of the total element length. The maximum percentage sag was at element four with 28% sagging. This case is represented by a zero prestrain value in the stay-wires and supports.

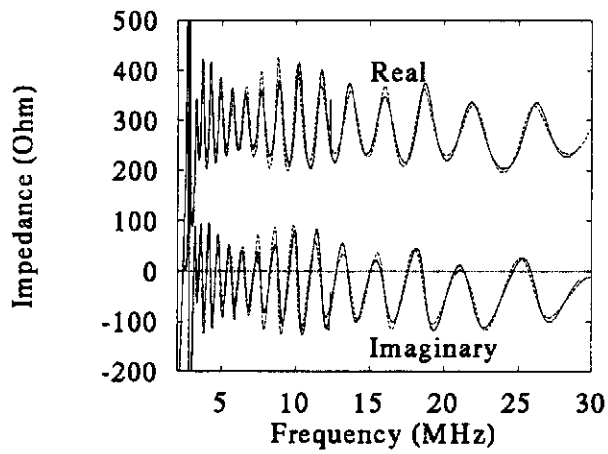

Figure 12: *Comparison between predicted impedances for the Extremely sagged LPDA (solid lines, MBPE) and the ideal LPDA (dotted lines, SLI).*

Figure 13 displays the input impedance of the moderately sagged case. The same type of approach as above, except, some of the cables were prestrained [5], corresponding to ropes 2% shorter than the actual distance between their connecting points, and then stretched to reach these points. The structure was then 'hoisted' to a height of 20m as described above. This gave a maximum tension of 40% of the breaking strength of the catenary material used. This case is represented by a 2% prestrain in the parafil stay-wires and supports.

[5]The prestrained cables were: the transmission line tension rope, the rear element pull-up ropes and the stay-wires on the sides of the antenna

It is clear that the effects of mechanical sagging on the input impedance are very limited. The limitations set in Smith [6] are clearly very conservative. The effects on the radiation pattern may be of more concern as suggested in [5], although these effects were also limited.

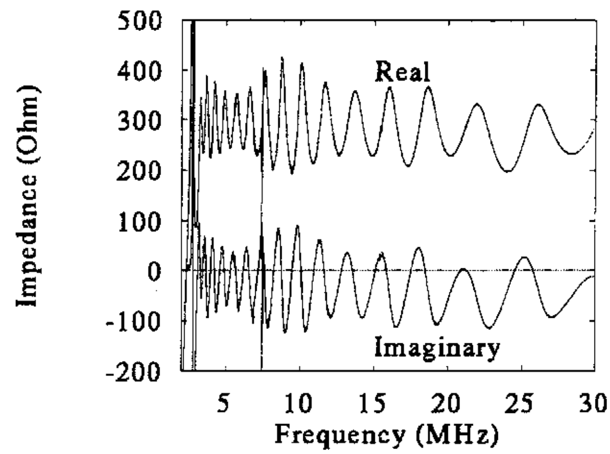

Figure 13: *Comparison between predicted impedances for the Moderately sagged LPDA (solid lines, MBPE) and the ideal LPDA (dotted lines, SLI).*

7 Conclusion

MBPE is a useful tool for investigating singularities in LPDA's (and antennas in general). It has proved to be very helpful in the study of deformation of an LPDA. Since the study of mechanical deformation needs a whole new set of data for each 'mechanical movement'[6], it is computationally intensive. By reducing the amount of computations for a given mechanical movement one can - for the same amount of computation time - get a much better view of how the antenna reacts. MBPE also gives a clear indication of problem areas in the frequency band used. Sometimes a deviation of an element shows its effect in a different place in the frequency band from that expected as discussed in Section 4.

Acknowledgement

The authors gratefully acknowledge the suggestion by E.K. Miller to use the MBPE method [1] for the investigation, as well as useful discussions held with him concerning the method.

[6]Mechanical Movement: This includes any type of mechanical deformation of concern - whether sagging, wind loading or even improper construction

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