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Optimal Wideband LPDA Design for Efficient Multimedia Content Delivery over Emerging Mobile Computing Systems

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***Abstract*—An optimal synthesis of a wideband Log-Periodic Dipole Array (LPDA) is introduced in the present study. The LPDA optimization is performed under several requirements concerning the standing wave ratio, the forward gain, the gain flatness, the front-to-back ratio and the side lobe level, over a wide frequency range. The LPDA geometry that complies with the above requirements is suitable for efficient multimedia content delivery. The optimization process is accomplished by applying a recently introduced method called Invasive Weed Optimization (IWO). The method has already been compared to other evolutionary methods and has shown superiority in solving complex non-linear problems in telecommunications and electromagnetics. In the present study, the IWO method has been chosen to optimize an LPDA for operation in the frequency range 800-3300 MHz. Due to its excellent performance, the LPDA can effectively be used for multimedia content reception over future mobile computing systems.**

***Index Terms*—LPDA design, invasive weed optimization, optimization algorithms**

I. INTRODUCTION

MOBILE computing systems have been increasingly developed in recent years due to the need for high quality multimedia services. This development leads to the demand for network resources and efficient telecommunications equipment [1]-[5]. Antenna arrays play an important role in wireless communications, [6]-[10]. The radiation characteristics of an antenna array specify the operation efficiency of a communications base station in a real complex environment. Log-periodic dipole arrays (LPDAs) are special linear arrays composed of parallel dipoles of gradually increasing length as moving along the array axis from the feeding source to the end of the axis, and a pair of booms used to feed the dipoles in such a way that the feeding is inverted when passing from one dipole to the next one, [11]. These arrays usually demonstrate wideband behavior and low gain flatness (i.e., the difference between the maximum and the minimum forward gain values, respectively $FG_{\max}$ and $FG_{\min}$, over the operating bandwidth). This is due to the fact that, at every operating frequency, some of the array elements act as active dipoles while the rest of them behave as parasitic ones. Of course, these characteristics are achieved by properly selecting the geometrical parameters of the LPDA, such as the lengths and radii of the LPDA elements as well as the distances between adjacent elements.

The first and also most popular procedure for LPDA design has been introduced by Carrel, [12]. This method has later been corrected by Butson and Thompson, [13], and is still used until today. The main consideration of this method is that all the LPDA elements are located inside the same angular sector (see Fig. 1). Also, the two booms, that feed the elements, are modeled as a transmission line of two conductive wires, which are inverted when passing from one element to the next one. Therefore, the whole geometry, i.e., the element lengths, radii and distances, of an M-element LPDA can be easily defined by using two special geometrical parameters, known as *scale factor* τ and *relative spacing* σ. If the desired value of the average directivity is known, the above two parameters can be calculated from the constant directivity contour curves of the well-known Carrel's graph introduced in [12] and corrected in [13]. According to Carrel's method, the LPDA geometry is then estimated by using the expressions given below:

$$L_m = \tau^{M-m} L_M , \qquad m = 1,\ldots,M \tag{1}$$

$$r_m = \tau^{M-m} r_M , \qquad m = 1,\ldots,M \tag{2}$$

$$S_m = 2\sigma\tau^{M-m-1} L_M , \qquad m = 1,\ldots,M-1 \tag{3}$$

where L_m and r_m are respectively the length and the radius of the m-th element, while S_m is the distance between the m-th and the (m+1)-th element. In order to use the above three equations, the values of L_M and r_M (i.e., the length and the radius of the largest element) must be known. L_M is set equal to half-wavelength at the lower operating frequency and is then reduced approximately by 5% due to the dipole thickness. The radius r_M is set equal to a value that can easily

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be found in practice (e.g., 5mm).

The above design procedure is an easily applicable method. However, it is based on a rough consideration of the LPDA model and therefore it cannot estimate the exact behavior of the LPDA inside a wide bandwidth. Moreover, it generally has the ability to control the standing wave ratio (SWR), the forward gain (FG) and the front-to-back ratio (FBR). However, the method cannot control the side lobe level (SLL) as well as the gain flatness (GF) in cases of wide operating bandwidths. The need for low SLL is very critical since it helps to reduce the signal degradation due to multipath fading and also it avoids unnecessary spatial spread of radiated power. Also, a low GF value is desirable in order to keep the signal reception at similar levels over the entire operating bandwidth. It is therefore obvious, that a design method capable of controlling the values of SWR, FG, FBR, SLL and GF would result in an LPDA suitable for efficient content delivery. Such a method can be constructed by combing an optimization technique with a full-wave analysis of the LPDA.

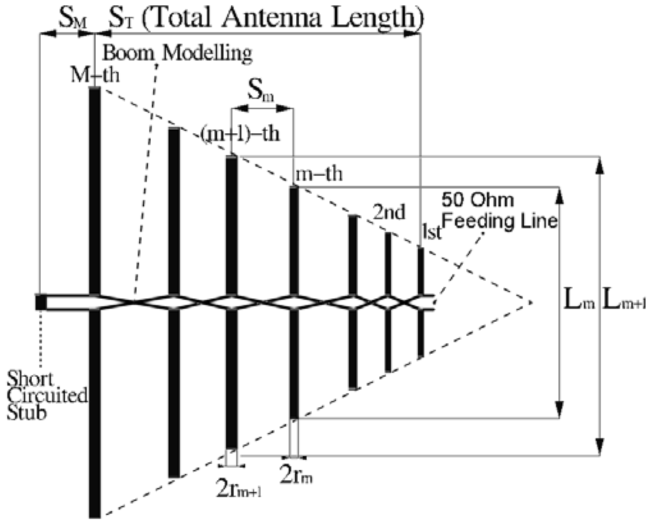

Fig. 1. Carrel's LPDA geometry.

The design method proposed here combines a recently introduced global optimization method called Invasive Weed Optimization (IWO), [14]-[17], and the Numerical Electromagnetics Code (NEC), [18], which implements a well-known full-wave analysis method called Method of Moments (MoM), [19]. Actually, the NEC calculates the radiation characteristics of the LPDA inside the operating bandwidth and returns them to the IWO method, every time this is required by the IWO in order to make fitness function calculations. To the best of the authors' knowledge, the IWO has not been applied so far to optimize LPDAs. Unlike Carrel's method, the proposed technique is an effective design tool that provides excellent approximation of the antenna behavior and has the ability to control all the electromagnetic characteristics mentioned above (i.e., SWR, FG, GF, FBR and SLL) inside a wide bandwidth. Also, this study is the first effort recorded in the literature to optimize simultaneously all these characteristics over a wide frequency range. The results shown below exhibit the superiority of the IWO-based technique over Carrel's design method.

II. DESIGN PROBLEM DESCRIPTION

The IWO method is applied in the present study to design an optimal 12-element LPDA (M=12) for operation in the frequency range 800-3300 MHz. Specific requirements have to be satisfied: (1) $SWR \leq 1.8$, (2) FG as high as possible, (3) $GF = FG_{\max} - FG_{\min} \leq 2$dB, and (4) $SLL \leq -20$dB on the E-plane of the radiation pattern of the LPDA. In the literature, the operating bandwidth is usually defined as the frequency range where $SWR \leq 2$ at the input of the RF system. To be sure that the LPDA will be in matching condition even in practice, the more strict value of 1.8 has been chosen in the 1st requirement. It must also be noted that, the SLL estimation takes into account all the secondary lobes on the E-plane of the radiation pattern including the back lobe. Therefore, an additional requirement that concerns the FBR is satisfied together with the 4th requirement, i.e., if the requirement for $SLL \leq -20$dB is satisfied then the requirement for $FBR \geq 20$dB is automatically satisfied as well.

In order to increase the degrees of freedom in comparison to Carrel's method and thus help the IWO method to find an optimal LPDA geometry, the LPDA elements are not considered inside the same angle and therefore their lengths L_m (m=1,...,M), radii r_m (m=1,...,M) and distances S_m (m=1,...,M–1) are independently optimized by the IWO algorithm (see Fig. 2). There are two additional optimization parameters: The first one is the distance S_M between the largest element (M-th) and a short-circuited stub located behind this element. The second is the characteristic impedance Z_0 of the line that models the booms of the LPDA. In total, there are $3M$+1 variables to be optimized.

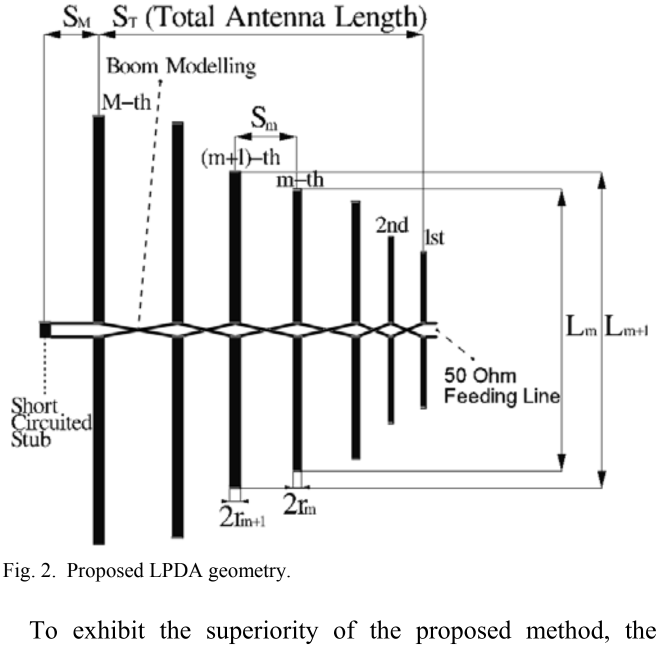

Fig. 2. Proposed LPDA geometry.

To exhibit the superiority of the proposed method, the

IWO-based LPDA is compared to a respective LPDA of the same total length S_T derived by Carrel's method. It must be noted that a short-circuited stub of proper length is used by both the LPDAs (see Figs. 1 and 2), since it helps the large LPDA elements to reduce the current that may arise due to high-order resonances induced on those elements.

III. RELATED WORK ON LPDA OPTIMIZATION

A deterministic design technique is not always capable of satisfying all the requirements defined by a non-linear design problem. Problems, where multiple requirements have to be met, can only be solved by applying evolutionary optimization methods. Several of these problems that concern LPDA design can be found in the literature, [20]-[29]. In some of these, a comparison between the proposed evolutionary method and other evolutionary or non-evolutionary methods is given regarding the satisfaction of the design requirements. In any case, Carrel's method is a reference LPDA design method for comparison.

A genetic algorithm (GA), the Nelder-Mead downhill simplex method and a hybrid method that combines the above two methods are used in [20] in order to optimize LPDAs under requirements that concern the average values of *FG* and *SWR* as well as their maximum deviation over the whole bandwidth. In [21] and [22], GAs are employed to maintain the values of *FG* and *SWR* over the entire operating bandwidth, and simultaneously minimize the LPDA length as well as the number of LPDA elements. The non-dominated sorting genetic algorithm II (NSGA-II) is applied in [23] to optimize LPDAs for operation in the range 3-30 MHz under requirements for minimum *SWR*, maximum *FG* and minimum LPDA length. A particle swarm optimization (PSO) algorithm is employed in [24] to design an optimal 10-element LPDA for operation in the range 450-1350 MHz under requirements that concern the average values of *SWR*, *FG* and *FBR*. In [25], an inverted-V LPDA is optimized in the range 6-30 MHz by using GAs under requirements that concern the values of *SWR*, *FG* and *SLL*, as well as the LPDA size. In [26], planar LPDAs are optimized for operation in the S-band by applying a PSO algorithm under requirements that concern the values of *FG* and *SWR*. In [27], a 13-element LPDA is optimized for operation in the GSM, WiMAX, Bluetooth, Wi-Fi and 3G bands by applying PSO under requirements for the values of *FG* and *SWR*. Also, a GA is applied in [28] to optimize a 10-element LPDA for operation in the GSM, WiMAX and Wi-Fi bands under requirements for higher *FG* and smaller size. Finally, the bacteria foraging algorithm is employed in [29] to optimize LPDAs for operation in the UHF TV band under requirements that concern the average values of *SWR*, *FG*, *FBR* and *SLL*.

In all the above studies, *FG* and *SWR* are considered under optimization, except for [28] where requirements are set for high *FG* and small LPDA size. Requirements for low *SLL* values are considered only in [25] and [29]. Nevertheless, the requirement for $SLL \leq -6$dB in [25] is soft enough (since values of *SLL* equal to –6dB are easy to be achieved) and is just defined to prevent main lobe splitting. It is also shown in [29] that the requirement for average *SLL* equal to –40dB is not satisfied by any of the LPDAs considered for optimization. In addition, the operating bandwidth considered in [29] is not as wide as that considered in the present optimization. In our study, practical requirements concerning the values of *SWR*, *FG*, *GF*, *FBR* and *SLL* have to be satisfied inside a wide frequency range (i.e., the range 800-3300 MHz). It has to be noted that, the minimization of the LPDA length is not of our concern, since our intention is to show that the proposed design method is capable of producing an optimized geometry with better radiation characteristics than those of an LPDA geometry with the same length S_T produced by Carrel's method.

IV. INVASIVE WEED OPTIMIZATION

Many studies are found in the literature, where evolutionary optimization techniques are applied to solve complex non-linear problems, [14]-[17], [30]-[45]. The IWO method was initially proposed in [14]. Thereafter, the method was used to solve several problems of antenna optimization and has exhibited superiority in terms of performance compared to other evolutionary methods. However, IWO has never been applied so far to perform LPDA optimization.

The IWO is an iterative method, completed within a predefined number I of iterations and inspired by the behavior of weeds in nature. The mathematical model of this behavior forms the IWO algorithm. According to this model, three phases are applied at every i-th (i=1,…,I) iteration: (1) *Reproduction*, (2) *Spatial Dispersion*, and (3) *Competitive Exclusion*.

In the beginning of the optimization process, a population of W weeds is distributed in an N-dimensional space, where N is the number of optimization variables x_n. Therefore, the position of each w-th weed is defined by the vector $X(w)=\left[x_1(w) \quad x_2(w) \quad \dots \quad x_N(w)\right]$. Also, in the beginning, the values of $x_n(w)$ (n=1,…,N, w=1,…,W) are produced by a uniform random number generator inside the interval [$xmin_n$, $xmax_n$], where $xmin_n$ (n=1,…,N) and $xmax_n$ (n=1,…,N) are user-defined parameters. The interval [$xmin_n$, $xmax_n$] is actually the search space of variable x_n. Besides, every weed is assigned a fitness value, which depends on the weed position as given below:

$$fit(w)=fit\left(x_1(w),x_2(w),...,x_N(w)\right) \tag{4}$$

In the reproduction phase, every weed produces a number of seeds $s_i(w)$, which is a linear function of the weed fitness as given below:

$$s_i(w)=\text{int}\left[\frac{fitmax_i-fit_i(w)}{fitmax_i-fitmin_i}\left(s_{\max}-s_{\min}\right)+s_{\min}\right], \quad i=1,...,I \;\;\&\;\; w=1,...,W \tag{5}$$

where *fitmin*$_i$ and *fitmax*$_i$ are the extreme fitness values at the i-th iteration, while s_{min} and s_{max} are user-defined parameters that represent the extreme values of s_i. It seems that weeds with low fitness values (good weeds) produce more seeds than weeds with high fitness values (bad weeds). Therefore, a good weed is more capable of finding better positions inside the search space than a bad one.

The spatial dispersion is the 2nd phase, where the seeds produced by a weed in the previous phase are dispersed around this weed according to a normal distribution with standard deviation given by the following expression:

$$\sigma_i = \left(\frac{I-i}{I-1}\right)^{\mu} \left(\sigma_{\max} - \sigma_{\min}\right) + \sigma_{\min} \ , \qquad i = 1,...,I \qquad (6)$$

where $\sigma_{\min}$ and $\sigma_{\max}$ are the extreme values of σ_i, while μ determines the decreasing rate of σ_i and is called *non-linear modulation index*. It is obvious that σ_i is the same for all the population at a given iteration. However, σ_i refers to seed dispersion in a unitary search space (i.e., the search space where $xmax_n$–$xmin_n$=1). If an optimization variable x_n corresponds to a non-unitary search space, then the actual standard deviation for this variable is set equal to $\left(xmax_n - xmin_n\right) \times \sigma_i$.

In the competitive exclusion phase, all the members of the colony (weeds and seeds) are sorted according to their fitness values, and only the best $W_{\max}$ ones (i.e., the $W_{\max}$ members with the lower fitness values) survive, while the rest ones are terminated. In this way, only the good weeds are able to keep searching for better positions in the next iterations.

In total, the user-defined parameters required by the IWO algorithm are: $xmin_n$ (n=1,…,N), $xmax_n$ (n=1,…,N), I, W, $W_{\max}$, $s_{\min}$, $s_{\max}$, $\sigma_{\min}$, $\sigma_{\max}$ and μ. The above optimization procedure of the IWO method is graphically given in Fig. 3.

V. FITNESS FUNCTION DESCRIPTION

It is obvious that the optimization problem is inherently multi-objective since several requirements must be satisfied at the same time. On the other hand, the IWO, like every other evolutionary optimization method, aims at minimizing a single mathematical function, which is the fitness function mentioned above. In order to simultaneously satisfy multiple requirements by applying such a method, the fitness function must be described as a linear combination of terms, where each term is an expression of a respective requirement. When the fitness function finds the global minimum point, all the terms have achieved their respective minimum values, which means that all the requirements have been satisfied. According to the requirements described in Section II, the fitness function is defined as follows:

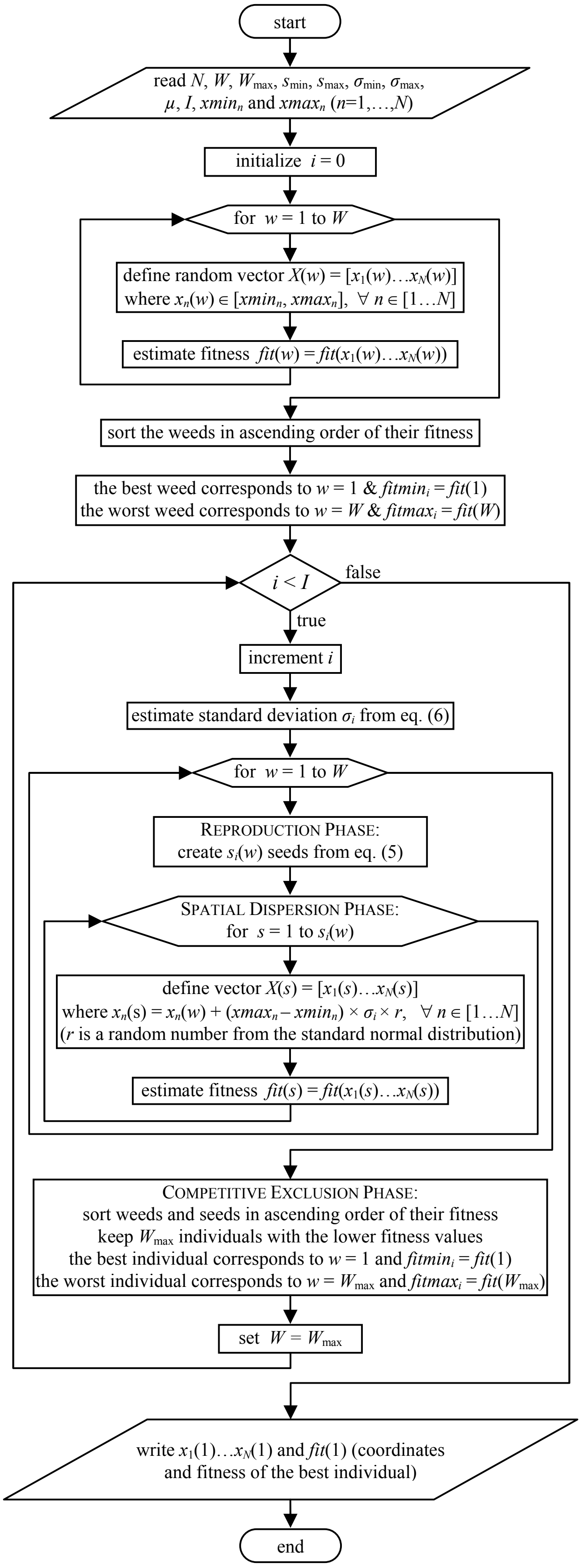

Fig. 3. Flow chart of the IWO method.

$$\begin{aligned} fit = & -k_1\, FG_{\min} + k_2\left[\max\left(GF,\, 2\right) - 2\right] \\ & + k_3\left[\max\left(SLL_{\max},\, -20\right) + 20\right] \\ & + k_4\left[\max\left(SWR_{\max},\, 1.8\right) - 1.8\right] \end{aligned} \quad (7)$$

where, $FG_{\min}$, GF, $SLL_{\max}$ and $SWR_{\max}$ are respectively the minimum forward gain (in dBi), the gain flatness (in dB), the maximum *SLL* (in dB) and the maximum *SWR*, found over the entire operating bandwidth, which, in our case, is 800-3300 MHz. To estimate the above four values, the values of *FG*, *SLL* and *SWR* are calculated over the range 800-3300 MHz at steps of 10MHz by employing the NEC software. Finally, k_1, k_2, k_3 and k_4 are user-defined positive coefficients, which aim to balance the minimization of the four terms shown in (7) or reinforce the minimization of any of these terms in cases when this term is not minimized as the rest ones.

As the value of $FG_{\min}$ increases, the 1st term of (7) decreases. Thus, this term aims at maximizing *FG* over the entire bandwidth. The next three terms are formed so that values of *GF* less than 2dB, values of $SLL_{\max}$ less than –20dB and values of $SWR_{\max}$ less than 1.8 do not cause further minimization of the fitness function, since the desired values of *FG*, *SLL* and *SWR* have already been achieved. Finally, it has to be noted that the 3rd term of (7) aims at satisfying not only the *SLL* requirement but also the requirement for the desired value of *FBR* ($FBR \geq 20$dB).

VI. OPTIMIZATION RESULTS

The IWO method is used here to design an optimal 12-element LPDA (M=12) for operation in the frequency range 800-3300 MHz under the requirements given in Section II. As mentioned in the last paragraph of Section IV, some parameters need to be defined in order to execute the IWO algorithm. Therefore, the initial and the maximum weed population are both considered to be composed of 20 weeds (W=$W_{\max}$=20). The number of seeds produced by a weed ranges from $s_{\min}$=0 (for the worst weed) to $s_{\max}$=5 (for the best weed) and is calculated from (5) according to the weed fitness value. The boundary values for the standard deviation of the seed dispersion are $\sigma_{\min}$=0 and $\sigma_{\max}$=0.15, while the non-linear modulation index μ is set equal to 2.5. The optimization procedure is completed within 2000 iterations (I=2000).

The optimization variables are L_m (m=1,...,12), r_m (m=1,...,12), S_m (m=1,...,12) and Z_0, i.e., 37 variables in total ($3M$+1=37), as explained in Section II. Therefore, the weed position is defined by the vector

$$X = \left[x_1\, x_2 \ldots x_{37}\right] = \left[L_1\, L_2 \ldots L_{12}\, r_1\, r_2 \ldots r_{12}\, S_1\, S_2 \ldots S_{12}\, Z_0\right] \quad (8)$$

which means that the variables x_n (n=1,...,12) are the dipole lengths L_m, the variables x_n (n=13,...,24) are the radii r_m, the variables x_n (n=25,...,36) are the distances S_m, and finally x_{37} is equal to Z_0. The radius limits are $r_{\min}$=0.001m and $r_{\max}$=0.005m. In order to avoid elements touching each other, the lower limit of the distances between adjacent elements is considered to be $S_{\min}$=$2r_{\max}$+0.002=0.012m. The upper limit of the distances is considered to be $S_{\max}$=$\lambda_{\max}$/4=0.094m, where $\lambda_{\max}$ is the wavelength at 800MHz, considering that the maximum variation of voltage, current or impedance is obtained along a quarter of the maximum wavelength (i.e., at 800MHz). The values of Z_0 range from 50 Ohm to 200 Ohm. Finally, the limits of the element lengths are derived separately for each element and are based on length values derived from Carrel's method. In particular, from the corrected Carrel's graph, [46], and by considering antenna directivity equal to 7.5dBi, it results τ=0.86 and σ=0.16 (optimum σ value). The length L_{12} of the largest element is set equal to half-wavelength at the lower operating frequency (i.e., at 800MHz) and is then reduced approximately by 5% due to the element thickness. The rest of the lengths (L_1,…,L_{11}) are calculated from (1). These initial values are shown in the 2nd column of Table I. The average length value $\left(L_m + L_{m+1}\right)/2$ of two adjacent elements is considered to be the upper limit U_m for L_m and the lower limit D_{m+1} for L_{m+1}. In this way, all the length limits are estimated except for D_1 and U_{12}. These can be considered to be at the same distance from the respective lengths as the opposite limits (U_1 and D_{12}) from the same lengths, i.e., $U_1 - L_1 = L_1 - D_1$ and $U_{12} - L_{12} = L_{12} - D_{12}$. All the length limits are given in columns 3 and 4 of Table I. The idea for different length limits restricts the search space of the element lengths and helps in this way the optimization procedure to reach faster the optimum result.

The geometry of the optimized LPDA extracted from the IWO algorithm is given in Table II. The total LPDA length is calculated from the expression

$$S_T = \sum_{m=1}^{11} S_m \quad (9)$$

and is found equal to 0.393m. In order to examine the performance of the proposed method, a new LPDA is designed by applying Carrel's method and is compared to the IWO-based LPDA. To have a fair comparison between the two LPDAs, the new LPDA is composed of the same number of elements (i.e., 12 elements), has the same length (0.393m), operates in the same frequency range (800-3300 MHz) and uses a short-circuited stub of proper length as does the IWO-based LPDA. As mentioned in Section II, the short-circuited stub helps the large LPDA elements to reduce the current that may arise due to high-order resonances induced on these elements. The geometry of this LPDA is given in Table III. From both the LPDA geometries given in Tables II and III, the values of *SWR*, *FG* and *SLL* versus frequency are extracted by applying the NEC software and are displayed respectively in the comparative graphs of Figs. 4, 5 and 6. These graphs are used to find the minimum, the maximum and the mean value as well as the standard deviation of *SWR*, *FG* and *SLL*, and finally the value of *GF* over the entire frequency range. These values are given in Table IV.

From Fig. 4, it is easy to realize that the LPDA derived from Carrel's method has better behavior in terms of *SWR* within the entire bandwidth. Nevertheless, the IWO-based LPDA produces *SWR* values less than 2, which means that it satisfies the impedance-matching condition over the entire bandwidth according to the literature.

In addition, as shown in Fig. 5, the values of *FG* produced by the Carrel-based LPDA have rapid variations with significant drops, which cause an increase in the value of *GF*. It seems that this behavior is due to high-order resonances induced on large LPDA elements despite the use of the stub. On the contrary, the IWO-based LPDA exhibits a smoother variation of *FG* and a value of *GF* less than the required value of 2dB (also see Table IV).

Finally, the *SLL* values produced by the IWO-based LPDA are kept below the desired value of –20dB inside the whole operating bandwidth, as shown in Fig. 6. On the other hand, Fig. 6 confirms the inability of Carrel's method to perform *SLL* control. It seems that the IWO method has the ability to suppress high-order resonances, while Carrel's method does not, even with the use of a short-circuited stub of proper length.

TABLE I
INITIAL ELEMENT LENGTH VALUES DERIVED FROM CARREL'S METHOD AND ELEMENT LENGTH LIMITS

Element m	Initial Length L_m (meters)	Lower Length Limit D_m (meters)	Upper Length Limit U_m (meters)
1	0.034	0.031	0.037
2	0.039	0.037	0.043
3	0.046	0.043	0.050
4	0.053	0.050	0.058
5	0.062	0.058	0.067
6	0.072	0.067	0.078
7	0.084	0.078	0.091
8	0.097	0.091	0.105
9	0.113	0.105	0.123
10	0.132	0.123	0.141
11	0.153	0.142	0.164
12	0.178	0.166	0.191

TABLE II
IWO-BASED LPDA GEOMETRY

Element m	Element Length L_m (meters)	Element Distance S_m (meters)	Element Radius r_m (meters)
1	0.034	0.012	0.0017
2	0.039	0.016	0.0017
3	0.047	0.021	0.0024
4	0.054	0.022	0.0031
5	0.062	0.031	0.0042
6	0.076	0.040	0.0047
7	0.090	0.040	0.0049
8	0.105	0.038	0.0041
9	0.120	0.070	0.0047
10	0.129	0.068	0.0021
11	0.157	0.035	0.0041
12	0.184	0.061	0.0023
$Z_0 = 108.6\Omega$			

In overall, the IWO-based LPDA geometry satisfies all the design requirements and has better behavior in terms of *GF* and *SLL* than the Carrel-based geometry. In other words, the IWO-based LPDA has all the desired radiation characteristics that make it suitable for efficient multimedia content reception. Also, the IWO method seems to be a very useful design tool for future mobile computing systems.

TABLE III
CARREL'S LPDA GEOMETRY

Element m	Element Length L_m (meters)	Element Distance S_m (meters)	Element Radius r_m (meters)
1	0.034	0.015	0.0010
2	0.039	0.018	0.0011
3	0.046	0.020	0.0013
4	0.053	0.024	0.0015
5	0.062	0.028	0.0017
6	0.072	0.032	0.0020
7	0.084	0.037	0.0024
8	0.097	0.043	0.0027
9	0.113	0.050	0.0032
10	0.132	0.058	0.0037
11	0.153	0.068	0.0043
12	0.178	0.087	0.0050
$Z_0 = 80\Omega$			

TABLE IV
LPDA PERFORMANCE PARAMETERS

Performance Parameter	IWO Method	Carrel's Method
SWR_{min}	1.21	1.17
SWR_{max}	1.99	1.66
SWR_{mean}	1.77	1.44
SWR_{std}	0.21	0.12
FG_{min} (dBi)	7.56	7.45
FG_{max} (dBi)	9.41	9.64
FG_{mean} (dBi)	8.30	8.68
FG_{std} (dBi)	0.52	0.55
GF (dB)	1.85	2.19
SLL_{min} (dB)	–32.60	–30.72
SLL_{max} (dB)	–20.00	–8.39
SLL_{mean} (dB)	–25.71	–21.50
SLL_{std} (dB)	3.56	4.32

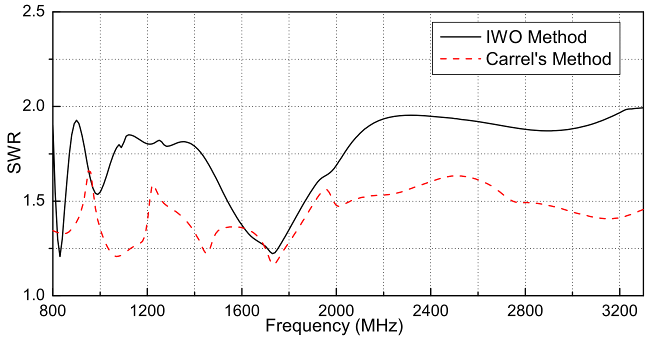

Fig. 4. SWR vs. frequency.

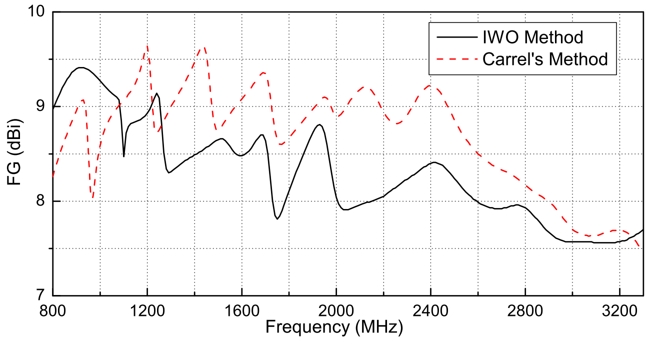

Fig. 5. Gain vs. frequency.

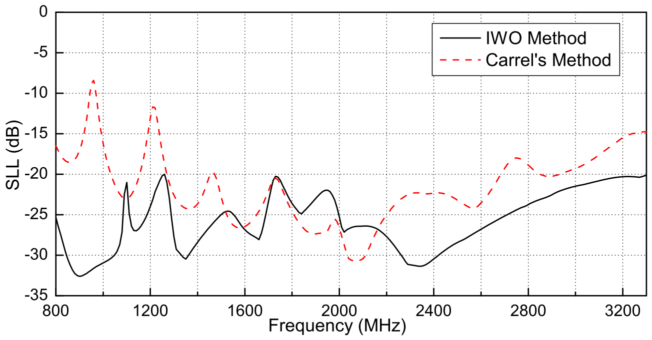

Fig. 6. SLL vs. frequency.

VII. CONCLUSION

The IWO method has been applied in combination with the NEC software to design an optimal 12-element LPDA for operation in the frequency range 800-3300 MHz. The optimization has been performed under multiple requirements concerning the desired values of *FG*, *GF*, *SLL*, *FBR* and *SWR*. The optimized LPDA geometry has better radiation characteristics inside the entire operating bandwidth compared to a respective LPDA with the same length produced by Carrel's method, which is the basic technique for LPDA design. This work is the first effort recorded in the literature to optimize simultaneously the values of *FG*, *GF*, *SLL*, *FBR* and *SWR* over a wide frequency range. The LPDA derived from the optimization procedure is suitable for efficient multimedia content reception. Due to its effectiveness, the IWO method can be a very useful design tool for emerging mobile computing systems.

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