A Structural Parameter Based Modification of Energy Conscious ESPAR Antenna System through Optimization for WLAN's Dual-Band Operability

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Abstract. Phased array antenna's radiation pattern can be electronically controlled, making them a relevant solution for multipath interference. Electronically Steerable Parasitic Array Radiator (ESPAR) antenna systems are part of the family of phased array antennas under the umbrella of aerial beam-forming antennas. Generally ESPAR antenna system design considers the quarter wavelength approach. In practice there are a significant number of multiband systems with many applications integrated in a single device. This paper looks at the design of a dual-band ESPAR antenna. The design is limited to the ESPAR antenna's structural parameter modification through the loading of its element with inductance load (circuitry). This results in an antenna system which operates in both 2.4GHz and 5.8 GHz bands of the IEEE 802.11 WLAN (Wireless Local Area Network) suitable for rural areas. The approach employed in this work consists of different stages of structural modification with careful optimization processes. The two adopted process are the quarter wavelength design and the optimization process, conducted through the genetic optimization algorithm.

Keywords: ESPAR Antenna system, WLAN, Genetic Algorithm.

1 Introduction

The recent trends on development of wireless technologies show that wireless networks are faced with many challenges. This is due to an increasing user demand, limited radio resource, search for cost effective, long range devices and limited supply power resource [1]. This implies that service providers must search for new and effective ways to counter the above outlined obstacles. The increasing user demand requires a high transmission rate communication system. There are two main challenges for high transmission rate realization: multiple interferences and the multiple access interference

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(MAI). One technique which addresses these impairments is the use of antenna array concurrently with effected detection scheme [2].

The question is: how can this antenna array be developed inexpensively and effectively for WLAN suitable for *open, rural areas* with minimum communication resources [3]? Earlier solutions which were adopted by operators include, with no limitation: tower-top amplifiers, high gain directional antennas and other available solutions. The challenge with these techniques is that they have a circuit complexity [4, 5]. One emerging technology is the Electronically Steerable Parasitic Array Radiator (ESPAR) antenna system. It is a hardware realization of the Aerial beam-forming antenna system. The configuration of the ESPAR antenna system consists of the following: one active monopole element and *N* reactive parasitic elements positioned near the active radiating element as depicted in FIG.1 [6, 7, and 8]. It is through this feature of using one active element that this antenna system is lower cost and energy efficient as compared to digital and microwave beam-forming which both have high fabrication cost and high energy consumption relative to the ESPAR [6]. The radiation pattern is steered in different directions using reactive loads and appropriate beamforming algorithms [9 and 10].

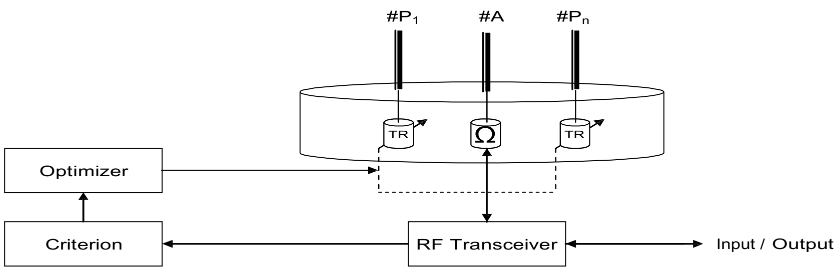

Fig. 1. A typical ESPAR antenna with N-number of ESPAR antenna

In this study the ESPAR antenna technique is adopted, its structural parameter is modified for IEEE 802.11a/b/g frequency bands. The main objective of the study is to develop a dual band ESPAR antenna which adopts cost effective techniques with low fabrication cost and is practical. The results expected are: (a) performance of allowed return loss value, (b) acceptable gain at the specified frequency bands (2.4GHz and 5.8GHz), and (c) by determining if the design of the antenna can be practically realized, while determining if it directs its beam with any variation in the combination of the reactance values.

2 Dual ESPAR Antenna Configuration

ESPAR design is classified into two groups, which are significantly important for the design of this antenna system. The two groups are [11]: Structural Parameters and the Control Parameter. Structural Parameters refer to the mechanical properties of the antenna, these are: *N*- number of the passive elements; the length of the active antenna l_o; the length of the parasitic elements l_n (n=1, 2…N), where it is required that the length of all the passive elements be equal in order to achieve omni-directional pattern; the distance between the active and the passive elements *d*. The Control Parameter compose of the reactance X_n (n = 1, 2…N) , which are responsible for the control of the antenna's radiation pattern [12]. The scope of optimization is only limited to the structural parameters of the ESPAR antenna system, which is expected to satisfy the requirements of this study.

A basic configuration of ESPAR antenna system is composed of one active (fed) centre element surrounded by one or more elements not connected to RF directly (parasitic or passive elements). The main difference from the conventional phased array is that it uses one active fed element, and inter-element coupling with radiation mechanism is used for beam-forming and that the reactance devices are directly loaded to the ports of the parasitic elements. The centre element is the only element fed with RF signal, resulting in one transmitter / receiver front-end circuitry required. The bias voltage is always reverse to the varicap diode (variable reactance) used, meaning that very little DC current is used in the parasitic elements [13].

The literature shows that there are various types of design modification that can be conducted in order to enable it to operate in dual or multiple bands. These types includes: Fractals technology [13], RLC (Resistor, Inductor and capacitor circuit) loading [14], matching networks [15], etc.

In this work the RLC loading is considered. There are two approaches adopted for RLC loading, the conventional approach and an optimization-based approach [16]. The conversional approach is not efficient in terms of identifying the location and the magnitude of the loads.

The three challenges in loading the antenna are to identify the location(s) of the resonant circuits, define the component values and identify the resonant frequency for the prescribed frequency band. Optimization based RLC loading deals with a stochastic problem. Most popular tool used for these types of problems is the genetic algorithm (GA) [16]. GA operates on discrete and/or coded representation of the parameters which are to be optimized, but not directly on the parameters. Equation (1) shows the formula used to transform continuous parameters to chromosomes used for genetic algorithm.

$$X = X_{\min} + \frac{X_{\min} - X_{\max}}{2^{N_v} - 1} \sum_{n=0}^{N^X - 1} b_n^X 2^n \tag{1}$$

N^X–is the bit string and b_0^X,…, b (N^X - 1) X is the binary representation of X. Then $X_{\max}$ and $X_{\min}$ are the maximum and the minimum allowed values for X [16].

3 Optimization Procedure

This section was treated with a step by step hierarchical approach, resulting to identifying the range of the load's magnitude, and the following step being the optimization of the length of the monopole antenna plus the loading optimization and lastly it was the optimization of the ESPAR antenna.

3.1 Reactance Range Definition

The initial step is to identify the range by running the inductance range from zero to 400 Henry against the reflection coefficient and then identify the deeps in the coefficient. A much narrower initial range could have been used, by considering a realizable range only. In this work a wide range was considered as it will give the reader a different perspective if a wide range of inductance was realizable. The range that has minimum deeps will be defined as the inductance range of consideration. The resulting reflection coefficient is shown in FIG.2. The reflection coefficients plots were made with respect to the two resonant frequencies (2.4GHz and 5.8GHz) per single location of load (six lines graph expected). The only varying component was the inductance which was restricted to this range of zero to 400 henries [16]. The result shows that minimum deeps are observed below 50nH and that at zero it will start to behave as a capacitor as it goes towards the negative capacitor range. The range of 0-50 nH is the interesting part of this work as it gives the minimum reflection coefficient with respect to the inductance loads on the antenna elements. The minimum obtained reflection coefficient values were as follows:

- 2.4 GHz (S11a = 0.25, S11b =0.92, S11c =0.25) and
- 5.8 GHz (S11d = 0.56, S11e = 0.0.25, S11f =0.64).

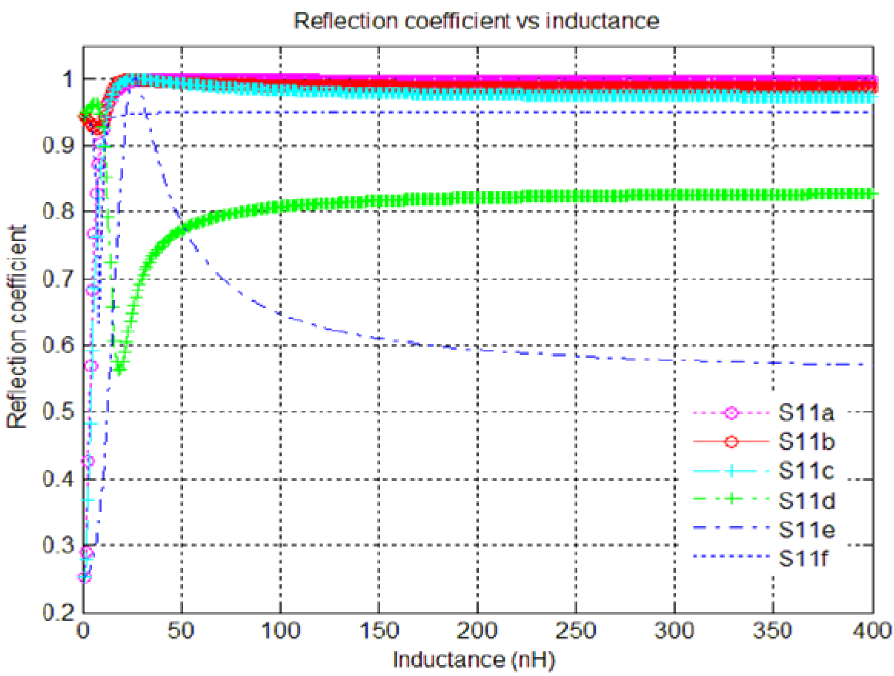

Fig. 2. Reflection coefficient resulting from inductance range conducted on three different locations on a monopole.

3.2 Monopole Antenna Optimization

This section focuses on both the length input parameter, which are the length of monopole and the effects of loading it through optimization. The following is the objective function used for the optimization of the loadings. The objective function (2) ignores the gain, which is a considered in the final stages of the work and the use of exponent five was done arbitrary for scaling purposes.

$$OF_a = |S_{11(2.4GHz)}|^5 + = |S_{11(2.4GHz)}|^5 \ . \tag{2}$$

The following stage is different compared to the inductance identifying stage. Different optimization process is conducted for the three different resonance frequencies (2.4GHz, 5.8GHz and the combination of the two frequencies). In this section, the theoretical monopole length was compared to the optimized length. In FIG.3 a depiction of a monopole antenna with three loadings as represented in (WIPLD) Wire Plate – Dielectric modeling tool. WIPLD is a software package tool, designed specifically for fast, accurate simulation and design of microwave circuits, devices and antennas [17]. The challenge in this section is to optimize the length of the parasitic elements and the loading to converge to the expected results both on gain and the return loss as the measure tool used for this work.

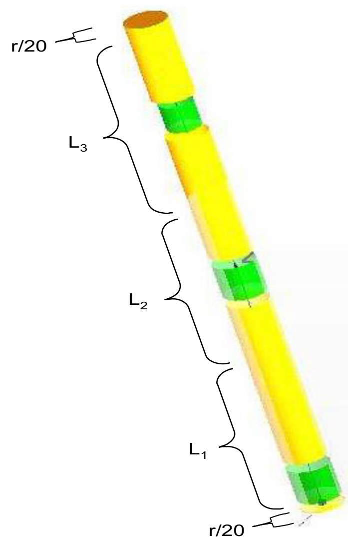

Fig. 3. Monopole antenna with three RLC loading

3.3 ESPAR Antenna Optimization

The number of elements used was varied from 3 to 7 elements, where the final number of elements used was 7 elements, because of the smooth switching that this number of element provides [18]. There are five input parameters included in TABLE I, which are the distance from the active element, the location of the loads, the number of loads, the loads value and the length of the parasitic element. This setup is such that the active element is fixed and the parasitic elements' distance from the active element and its length are optimized. The input parameters used are as follows: The distance range is from $0.2*\lambda_{5.8}$ to $1.3*\lambda_{5.8}$ and the height of the parasitic were ranged from $0.1*\lambda_{5.8}$ to $\lambda_{5.8}$ [19]. The loading was done in the following approach: Parasitic elements were kept as closed circuit while parasitic element one (P_1) was loaded with a reactance Z = 1e9 + 1e9j Ω. The second scenario is to load P_2 while P_1 is also kept loaded; this was done until P_6, the reactance load value which was used for reflection is Z = 1e9 + 1e9j Ω. The expected gain is 0 dB in the azimuthal direction and the Voltage Standing Wave Ratio (VSWR≤2).

Table 1. Input parameters for optimization process

Input Parameters	**Minimum**	**maximum**	**Steps**
N_l = Number of Loads (units)	≥ 1	≤ 3	1
L = Monopole length (m)	$\geq \lambda_{5.8GHz}/10$	$\leq \lambda_{5.8GHz}$	$0.05\ \lambda_{5.8GHz}$
L_1=load 1 location range (m)	> r/20	≤ L/3	$\frac{\left(\frac{L}{3}-\frac{r}{20}\right)}{32}$
L_2=load 2 location range (m)	> L/3	≤ L/1.5	$\frac{\left(\frac{L}{1.5}-\frac{L}{3}\right)}{32}$
L_3=load 3 location range (m)	> L/1.5	≤ L – (r/20)	$\frac{\left((L-\left(\frac{r}{20}\right))-\frac{L}{1.5}\right)}{32}$
L_{v1} = The range value of load 1(nH)	≥ 0	≤ 100	0.1 nH
L_{v2} = The range value of load 1(nH)	≥ 0	≤ 100	0.1 nH
L_{v3} = The range value of load 1(nH)	≥ 0	≤ 100	0.1 nH
d_p = distance from active element	$\geq 0.2*\lambda_{5.8}$	$\leq 1.3*\lambda_{5.8}$	$0.05*\lambda_{5.8}$
h_p = parasitic element's height	$\geq 0.1*\lambda_{5.8}$	$\leq \lambda_{5.8}$	$0.05*\lambda_{5.8}$

4 Simulation Results

The simulation process was conducted with the consideration of the input parameters shown in TABLE 1 and the procedures described in the previous section. Fig.4 Shows one of the final configuration which was optimized.

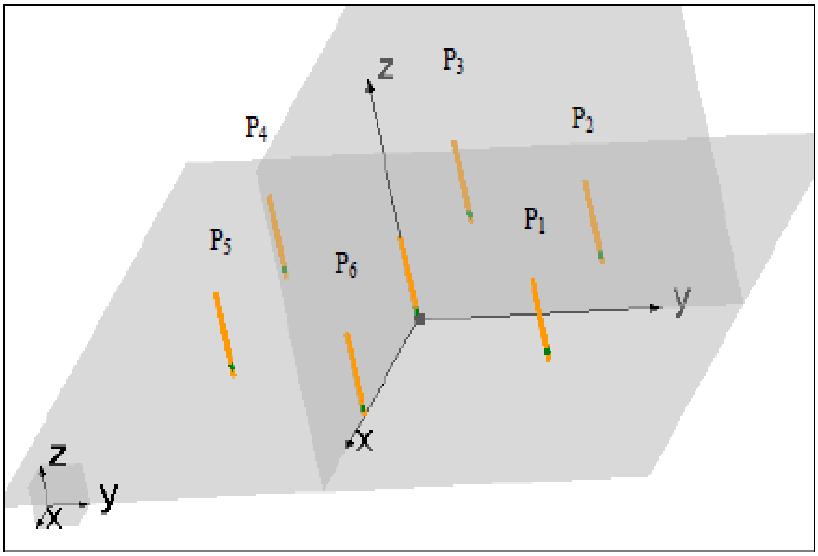

Fig. 4. The configuration of the ESPAR antenna system

The following diagram in FIG.5 shows the gain which is about 4 dB for the 2.4 GHz and 8dB for the 5.8 GHz in omni-directional pattern.

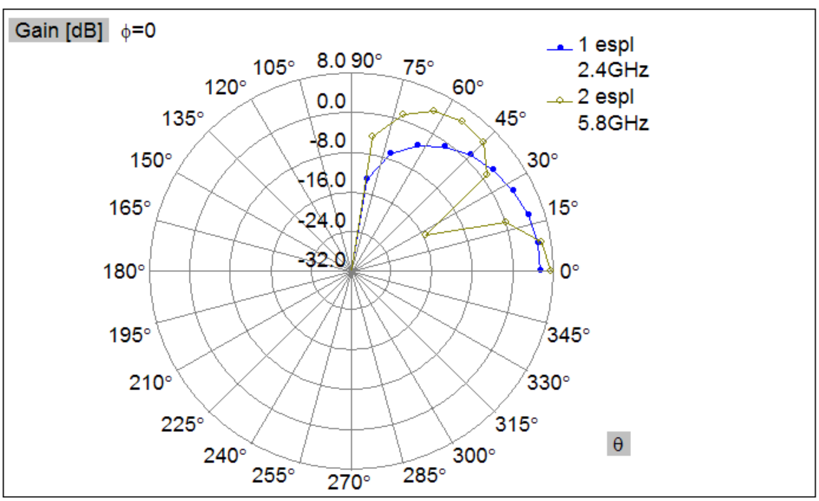

Fig. 5. The elevation gain of the ESPAR antenna using the spherical view

The last result shown is the standing voltage wave ratio (SVWR) or the return loss. The return loss is depicted in FIG.6, with the magnitude of -8 dB and -9.6 dB for both 2.4 GHz and the 5.8 GHz respectively.

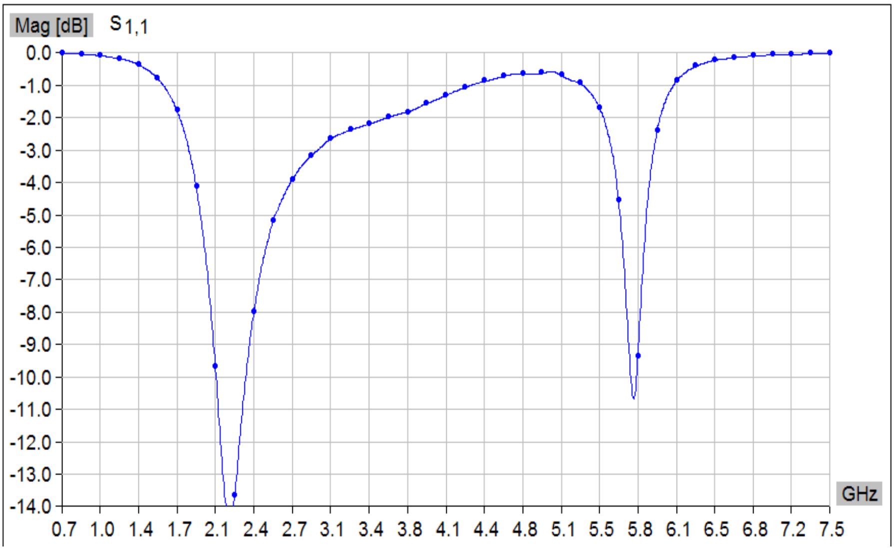

Fig. 6. The return loss for the ESPAR antenna which has shown improvement with respect to the optimization

5 Conclusion

This work has achieved the integration of ESPAR antenna system with loading technique. This is traditionally observed on wire antenna without being adopted for smart antennas systems, but if it is adopted it is extended to reactance parameter. In this study the optimization is only limited to structural parameters. The dual band ESPAR antenna was design with simulation results showing -8 dB and -9.4 dB in both 2.4 GHz and 5.8 GHz frequency bands. The only challenge which was encountered was on the steering capabilities which were limited for three different separated optimization processes with three separate different conditions. Investigations are conducted ensure acceptable pattern steering maintains the same return loss for the omni-directional ESPAR antenna. The investigation is in different stages. The genetic algorithm was used in three stages through the scope of the structural based optimization. The three stages involve monopole length antenna its loading and the ESPAR antenna optimization.

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