X-pol Antenna for ISM Applications Optimized Through the Design of Experiment Theory

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Abstract – **In this study an optimization of X-pol antenna with reflector dimensions has been described. The goal is achieved using design of experiment theory for antenna suitable for use in 433MHz ISM band. This type of antenna is applicable on order to guarantee better communication in the available ICM bands, where the electromagnetic frequency resource is constantly take busier with more, even M2M, short or permanent in time data transfers.**

Keywords – **X-pol Antenna, Design of Experiment, Antenna Parameters Optimization, ISM band applications.**

I. Introduction

Nowadays, the communications, alongside with the mobility, are the two largest components of the progress of mankind. Transmission of huge amount of data for daily activity has entered deep into the life of every modern man. Sometimes the stream is continues data with high speed of around amount of Terabits per second. Other cases are when a very short digital messages are transmitted. In some specific cases mobility is needed when information is being transfered. In these cases, inevitably free electromagnetic waves as a carrier of information has been used [1], [2]. This leads to continuous increasing the load of the spectrum, which is not an unlimited resource. From this perspective, any moves for optimization the wireless transmission of information are of significant benefit.

The antenna plays a huge role for the realization of every wireless communication. In many cases they are complex technical solutions that are designed to implement specific characteristics. However, in some other applications sometimes is impossible to use complex antennas due to restrictions in size, weight, cost and the like. Some examples of similar aspects are the cases in the Industrial, Scientific and Medical (ISM) bands systems for access control, remote control and Radio Frequency Identification (RFID). The list expands with the attractive from today's perspective Smart Systems and other. A good example is the Machine To Machine (M2M) communications. M2M type remote communication uses a simple radiating elements. Optimization can be done for stationary antennas of these systems too. Such optimization can be done for better coverage. This will lead to a reliable communication link, to less need for retransmission of information, and so to that the ISM bands are going to be less overloaded.

In this article has been viewed the possibility of using X-pol antenna with reflector to achieve better radio coverage of a given area. The antenna optimization, used in the research, is based on the theory of design of experiment to achieve the best possible case and analysis of its other parameters and characteristics.

II. Description of the Problem

A. The X-pol Antenna Conception

In the idea to realize the X-pol antenna with reflector is the concept of forming a loop antenna [3], [4] in the form of the outer contour of the letter 'X'. On Fig. 1 is shown the structure of a planar developed frame of the antenna. Mainly two parameters define the shape - the length l of the arm and its angle of divergence α.

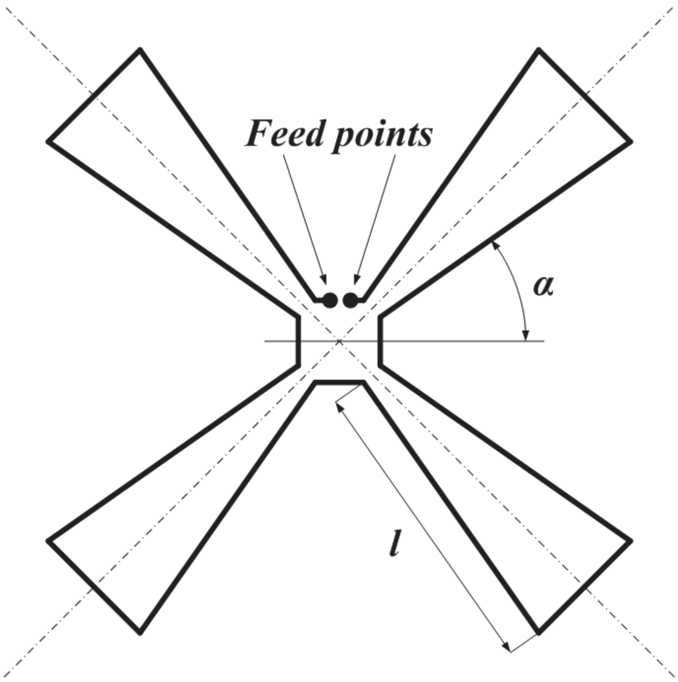

Fig. 1. Structure of a planar radiating loop element of X-pol antenna

The geometric variables largely defined the electromagnetic behaviour of the frame, respectively impedance match to standard 50Ω and the radiation pattern.

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In order to achieve directivity in a half-sphere, behind the active element a screen is added. Fig. 2 shows a three-dimensional appearance of such X-pol antenna with reflector.

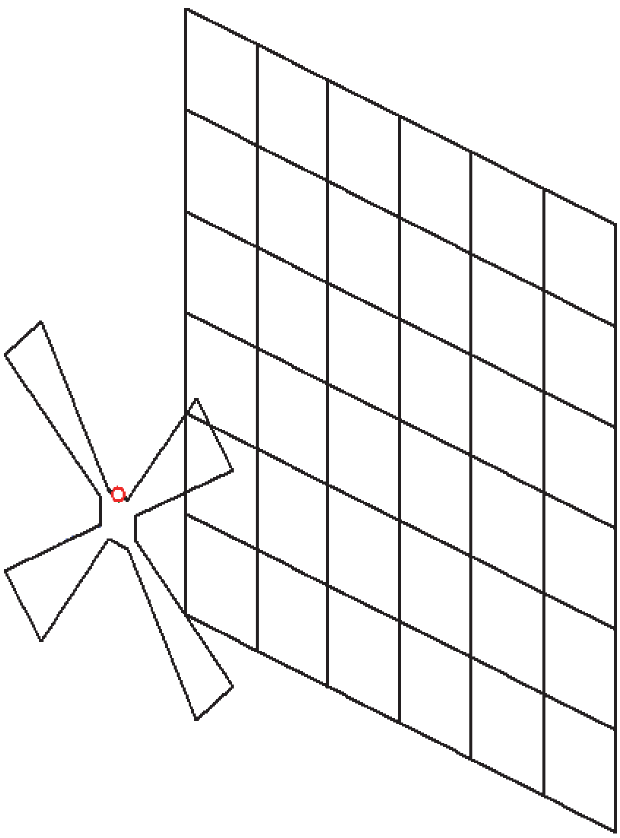

Fig. 2. 3D view of X-pol antenna with reflector

B. Optimization of the X-pol Antenna Geomery

Optimization of the geometry of the X-pol antenna at a particular input arm length $\boldsymbol{l}$ and an angle of divergence $\boldsymbol{\alpha}$ can be done by using the theory of the planned experiment. This theory gives the opportunity to make a model of considered parameter behaviour in relationship to changes of several factors. In this case is necessary to conduct full factorial experiment type 3^2, in which two factors are varied on three levels. In the specific task these factors are the arm length $\boldsymbol{l}$ and an angle of divergence $\boldsymbol{\alpha}$. It is appropriate the parameter to be the antenna matching represented by a standing wave ratio (SWR). Based on the data generated in nine attempts in a planned experiment type 3^2 the analytical dependence of the parameter in the factor field has the form [5]:

$$Y = b_0 + b_1.x_1 + b_2.x_2 + b_{12}.x_1.x_2 + \\ + b_{11}.x_1^2 + b_{22}.x_2^2 , \qquad (1)$$

In the upper equation $\boldsymbol{Y}$ is a parameter for impedance match or standing wave ratio - SWR and $\boldsymbol{x_1}$ and $\boldsymbol{x_2}$ are the two factors, in this case they are respectively the length $\boldsymbol{l}$ and the angle $\boldsymbol{\alpha}$. The coefficients $\boldsymbol{b}$ are defined according the laws:

$$b_0 = \frac{5}{9}\sum_{j=1}^{9} x_{0j}.\bar{y}_j - \frac{1}{3}\sum_{i=1}^{2}\sum_{j=1}^{9} x_{ij}^{2}.\bar{y}_j , \qquad (2)$$

$$b_i = \frac{1}{6}.\sum_{j=1}^{9} x_j.\bar{y}_j , \qquad (3)$$

$$b_{ik} = \frac{1}{4}.\sum_{i=1}^{2}.\sum_{j=1}^{9} x_{ij}.x_{kj}.\bar{y}_j , \qquad (4)$$

$$b_{ii} = \frac{1}{2}.\sum_{i=1}^{2}\sum_{j=1}^{9} x_{ij}^{2}.y_j - \frac{1}{3}\sum_{j=1}^{9}\bar{y}_j , \qquad (5)$$

III. Results

With the preliminary study were selected levels of variation of the two factors for the antenna that works in ISM band frequency 433,92 MHz. In this frequency band a number of systems for remote control are in use, like remote opening of garage doors or barriers, signals for alarm activation/deactivation etc. Specific values for these geometric indicators and the levels of their variations for this experiment are given in Table I.

TABLE I
BASE FACTOR LEVELS

Level of variation	**Factor**	
	$\boldsymbol{x_1}$	$\boldsymbol{x_2}$
+1	88 mm	38°
0	85 mm	35°
–1	82 mm	32°

In Table II are listed data readings of the parameter $\boldsymbol{Y}$ for the nine attempts with different levels of varying factors.

TABLE II
EXPERIMENTAL VALUES

j \ *i*	x_1	*L, mm*	x_2	*α, °*	Y_{SWR}
1	+1	88	+1	38	1,25
2	+1	88	0	35	2,31
3	+1	88	-1	32	4,63
4	0	85	+1	38	2,87
5	0	85	0	35	1,22
6	0	85	-1	32	1,97
7	-1	82	+1	38	6,29
8	-1	82	0	35	3,05
9	-1	82	-1	32	1,46

In Table III the calculated values, according to (2) ÷ (5), for the coefficients ***b*** are recorded. A self-developed code has been made in order to visualize the parameter behaviour in the factors field and to search the optimal point that corresponds to best antenna match. On Fig. 3 is plotted using a programming environment MATLAB [6] the behaviour of obtained according (1) parameter Y in the factor space.

TABLE III
VALUES FOR COEFICIENTS

b_0	1,4300
b_1	0,3917
b_2	-0,4350
b_{12}	-2,0525
b_{11}	0,8850
b_{22}	1,1450

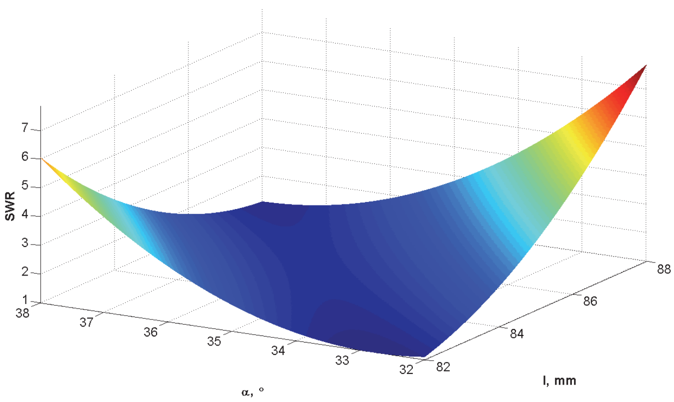

Fig. 3. Variation of parameter Y in factor field

As an optimized result, developed with the design of experiment theory, are the reading for *l* = 82,31 *mm* and *α* = 35˚.

Fig. 4 shows the resulting 3D simulation radiation pattern of the antenna with optimal size. This result is achieved with the help of antenna planning software MMANA-GAL Basic. MMANA-GAL [7] is an antenna-analysing tool based on the moment method. The estimated gain is 7,12 dBi, and the standing wave ratio - SWR = 1,01 for the central frequency of 433,92 MHz. The simulation shows enough bandwidth for application of this type of antenna as described above. The bandwidth at SWR<2 is 18582,4 kHz and the bandwidth at SWR<1,5 is 10860,6 kHz. Fig. 5 shows the simulated SWR behaviour in this frequency range, and fig. 6 – the gain and the front-to-back ratio.

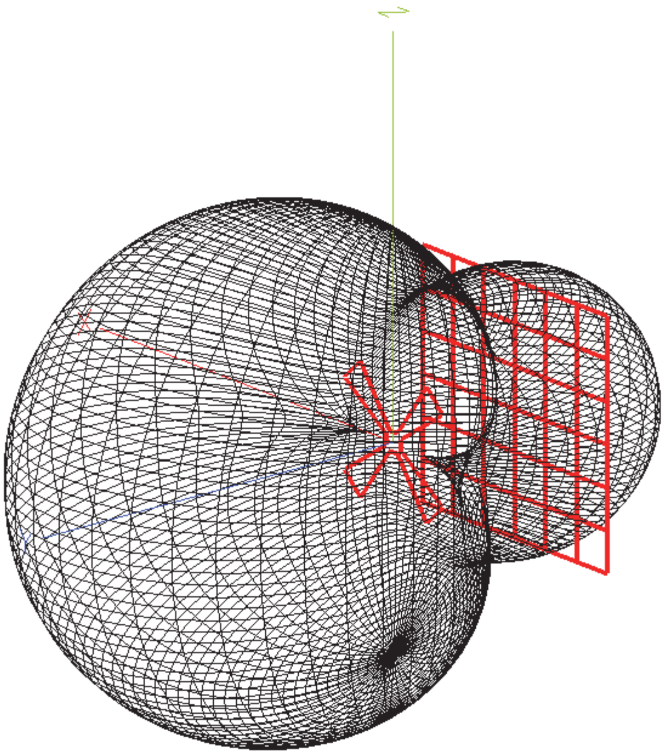
Fig. 4. 3D radiation pattern of optimized X-pol antenna

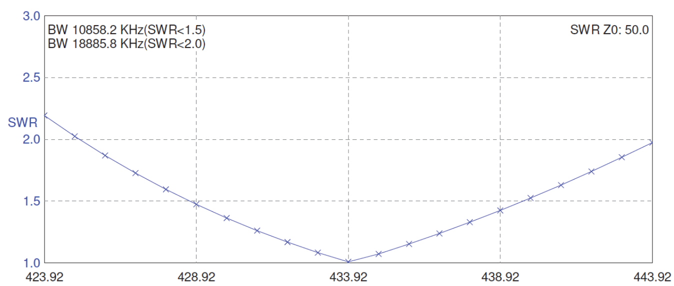

Fig. 5. SWR bahaviour in the working frequency range

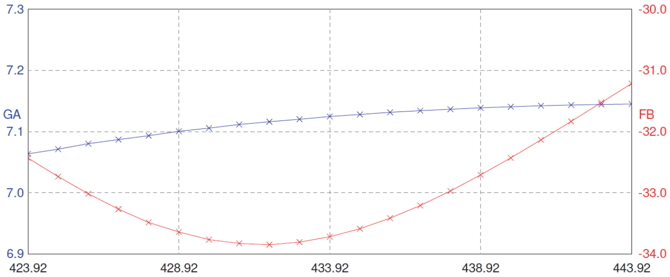

Fig. 6. Gain and Front-to-back ratio behaviour in the working frequency range

Fig. 5 shows an example for practical use of proposed antenna in case of remote control of garage door. In this case the antenna is oriented in direction of the eventual arriving vehicles and makes the data transfer in this area more reliable. That tends to better transmitting, less data resending and decreasing the noise level for other communication units in this area, that are using the same frequency.

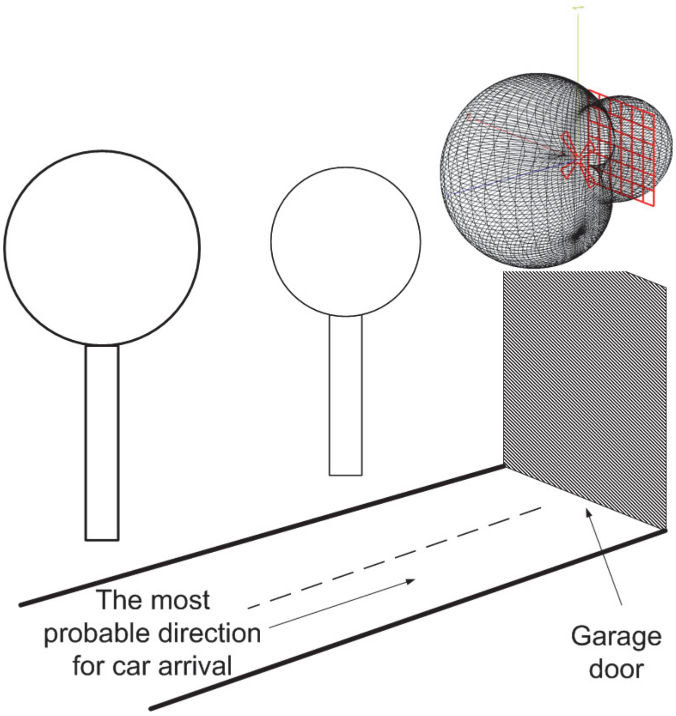

Fig. 5. Practical application of X-pol antenna with reflector

IV. Conclusion

Based on the experimental results the following conclusions can be made:

- X-pol antenna with reflector consequence of the impedance match optimization achieved extremely good value;
- The resultant directivity can help in improving wireless communication in ISM frequency bands;
- It is appropriate to seek ways to reduce the size of the antenna, which can be accomplished using fractal design of the elements;

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