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Journal:	*IET Microwaves, Antennas & Propagation*
Manuscript ID:	draft
Manuscript Type:	Research Paper
Date Submitted by the Author:	n/a
Complete List of Authors:	Dvorsky, Marek; VSB-Technical University of Ostrava, Telecommunication
Keyword:	ANTENNA ARRAYS, ANTENNA RADIATION PATTERNS, ANTENNAS

Radiation Pattern Optimization by Loaded Impedance in the Base of Passive Element

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CZECH REPUBLIC

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Abstract. This article deals with optimizing radiation pattern by using two vertical middle wave's antenna array. Optimization is achieved by adding the appropriate impedance into the base of passive antenna radiator. The proposed solution deals with finding the best value of loaded impedance. The final result is to achieve the most effective shape of radiation pattern.

1 Introduction

The first part of article explains the reasons why this article deals with just this type of antenna array. The solution of this issue is connected to the starting digitalization process at radio bands below 30 MHz. The following part provides essential mathematical tools necessary to derive radiation pattern and the proposed mathematical model.

The inputs into the proposed mathematical model are the geometric dimensions of radiators and their lay-out. The output value is loaded impedance in the base of passive element, which forms the radiation characteristics regarding to the antenna array operator requirements.

Verification of mathematical model was carried out using the development environment of software Mathcad. In this program were implemented mathematical relationships and calculated the value of inserted impedance. The shape of the radiation was then verified in simulation program EZNEC v5.0.20.

2 The importance of the existing MW broadcasting centers

Frequency positions on Middle Waves (MW) are firmly committed to the internationally notificate to geographical area according to registered geographical coordinates, for a maximum radiated power (EIRP) and the particular time interval. Notifications are entered in Master International Frequency Register (MIFR), which is conducted in International Telecommunication Union Radiocommunication Bureau (ITU-BR), in the frequency plan,"GE75". National frequency allocation for The Czech Republic includes the MW band frequencies for the 24-hour operation, as well as frequencies to operate daily at an interval of 04 to 17 GMT. MW frequency allocation includes The Czech Republic only 4 high quality with low levels of frequencies night interference from foreign transmitters: 639, 954, 1 233 and 1 287 kHz. These frequencies allow creating networks with nationwide coverage. National frequency allocation includes additional frequency 1 071 kHz with more night disturbance. Further frequency positions, notified only for daily operations are: 846, 864, 900, 1 017 and 1 593 kHz.

Under above given circumstances, only 4 24-hour frequencies are notificated in certain positions of existing transmitters. These could be eventually used to create an Amplitude Modulated (AM) broadcast in 2 national transmitter’s networks. To take advantage of digital broadcasting system Digital Radio Mondiale (DRM) [4] could be possible to create in The Czech Republic 4 programs nationwide Single Frequency Networks (SFN). There is also a spare antenna array at Litomyšl - Pohodlí notified the frequency 1 287 kHz, where was made a verification measurement to confirm the theoretical conclusions of proposed mathematical model.

The current antenna systems meet the requirements of classical analogue broadcasting, but with the advent of digitization will need to assess whether to build new antenna systems or use existing ones, which is certainly not going to be without its adjustments.

In this context, there is also offered a question of optimization of radiation pattern. Antenna systems, which have all elements actively fed, can often be usefully adapted to the system with a passive tuned element. This will not only simplify a power supply antenna system, but also flexibility of any changes in radiation pattern. The following section contains the proposed mathematical model.

3 Proposed Mathematical Model

The proposed mathematical model (Fig.1.) describes the optimization of radiation pattern two vertical radiators. Only one of them is actively powered.

Reasons of the choice just this type of antenna array follow the best simplicity and efficiency this type antenna lay-out. Mathematical model describes how to find an effective value load impedance X_x to achieve the maximum value of a radiation function $Fs(\theta,\varphi,X_x)$ in the required direction of the maximum $\varphi_{max.}$ Basic precondition of this kind of antenna system are two geometrically identical linear vertical radiators with sinus current distribution. Antenna towers are placed on base insulator through which is one antenna fed. The second tower is grounded via loaded impedance X_x to the Earth's surface to assume ideally conductive, forming a mirror reflection of the antenna system.

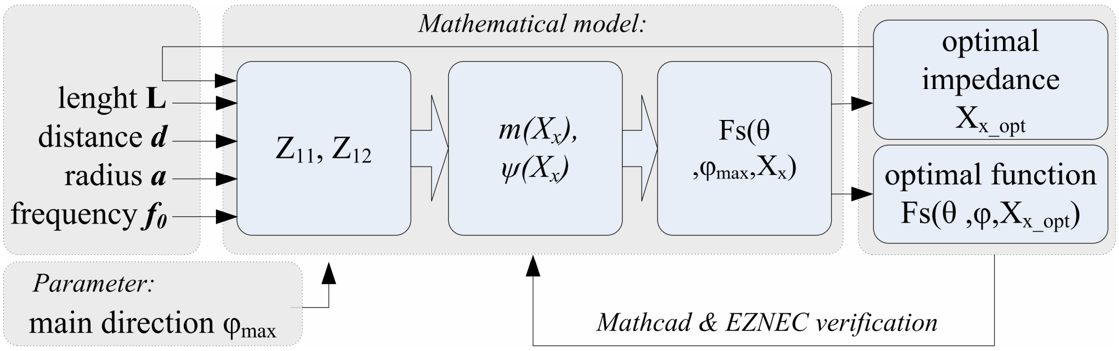

Fig. 1. Mathematical model proposed optimalization

The inputs into the proposed mathematical model (Fig.1.) are geometrical proportions of two equal antenna towers: Length of tower L [m]; Spacing d [m]; Radius of towers a [m] and working frequency f_0 [Hz]. The main parameter for optimalization is a direction of the main lobe $\varphi_{max.}$ The outputs are at the first step the optimal value of loaded impedance X_{x_opt}. This value is than inserted into radiation pattern calculation to achieve the main aim which is the optimal shape of radiation pattern (3).

The proposed mathematical model is based on a calculation the optimal shape of radiation pattern Fs(θ,φ,X_x). It is based on known self and mutual impedance $Z_{11}(L) = R_{11}+X_{11}$ and $Z_{12}(d) = R_{12}+X_{12}$ [4]. The next step consists in calculation of the ratio of currents flowing in antenna towers m(X_x) (1) and phase ψ(X_x) (2) depending on X_x.

3.1. Radiation Pattern

The derivation of radiation functions Fs (θ,φ,X_x) for the array with passive element is necessary to know circumstances of amplitude ratio (1) and phase (2) currents of individual emitters. The size and phase of current in a passive element depends on electrical properties and the reciprocal arrangement in relation to an actively fed element antenna.

Than can be expressed a phase and amplitude ratio of the size of current in antenna elements that are functions of values an embedded impedance Xx [2]:

$$m\left(X_x\right)=\sqrt{\frac{R_{12}^2+X_{12}^2}{R_{11}^2+\left(X_{11}\pm X_x\right)^2}} \qquad \mathbf{(1)}$$

$$\psi\left(X_x\right)=\pi+arctg\frac{X_{12}}{R_{12}}-arctg\frac{X_{11}\pm X_x}{R_{11}} \qquad \mathbf{(2)}$$

Radiation pattern can be drawn in the plane E(φ = 0), and the plane H(θ = π/2) as the absolute value of radiation group functions:

$$F_s\left(\theta,\varphi,X_x\right)=F\left(\theta,\varphi\right)\left|K\left(\theta,\varphi,X_x\right)\right| \qquad \mathbf{(3)}$$

where:

$$K\left(\theta,\varphi,X_x\right)=\left|1+m\left(X_x\right)e^{j\psi\left(X_x\right)}e^{j\left(kd\sin\theta\cos\varphi\right)}\right|= \qquad \mathbf{(4)}$$
$$\sqrt{1+m\left(X_x\right)^2+2m\left(X_x\right)\left(kd\sin\theta\cos\varphi+\psi\left(X_x\right)\right)}$$

$K(\theta,\varphi,X_x)$ is an interference function.

3.2. Optimal value inserted impedance

In-depth analysis can be assumed that if it is desirable to the closest form of the lobe in the plane E $Fs(\theta,0,X_x)$, must be the majority energy radiated under angle $\varphi\to\pi/2$. The aim is therefore to find that value embedded impedance X_x which reaches the greatest possible value of maximum function (the size of the lobe) $Fs(\theta,0,X_x)$. Optimizing the shape of radiation pattern two vertical radiators is therefore based on the search for maximum radiation function $Fs(\theta,\varphi,X_x)$ (3).

Previously derived relations (1) - (4) were implemented into the development environment software Mathcad from Mathsoft Engineering & Education, with added library for Visual Elektromagnetics Mathcad [3]. In addition, they were through the above-mentioned software found a position of absolute maxim functions $Fs(\pi/2,\varphi_{max},X_x)$ (Fig.3.).

The main aim is to find such a point where the value of partial derivatives function $Fs(\theta,\varphi_{max},X_x)$ under X_x is zero (5).

$$\frac{d\,Fs\left(\frac{\pi}{2},0,X_x\right)}{d\,X_x}=0 \tag{5}$$

If is the main requirement a minimum backward factor for the reflector type of antenna system, the value of $\varphi = (2.n - 1)\pi$, n = 1, 2, 3…

$$\frac{d\,Fs\left(\frac{\pi}{2},\pm(2n-1)\pi,X_x\right)}{d\,X_x}=0;\ n=1,2,3... \tag{6}$$

Selecting the appropriate angle $\theta = \pi / 2$ defines the vertical plane E, $\varphi_{max} = 0$ and determines the direction of the lobe in the direction of the axis of antenna system. After finding the absolute maximum of function *$Fs(\theta,\varphi_{max},X_x)$,* is necessary to determine the appropriate value X_x which corresponds to the found maximum (Fig.2.).

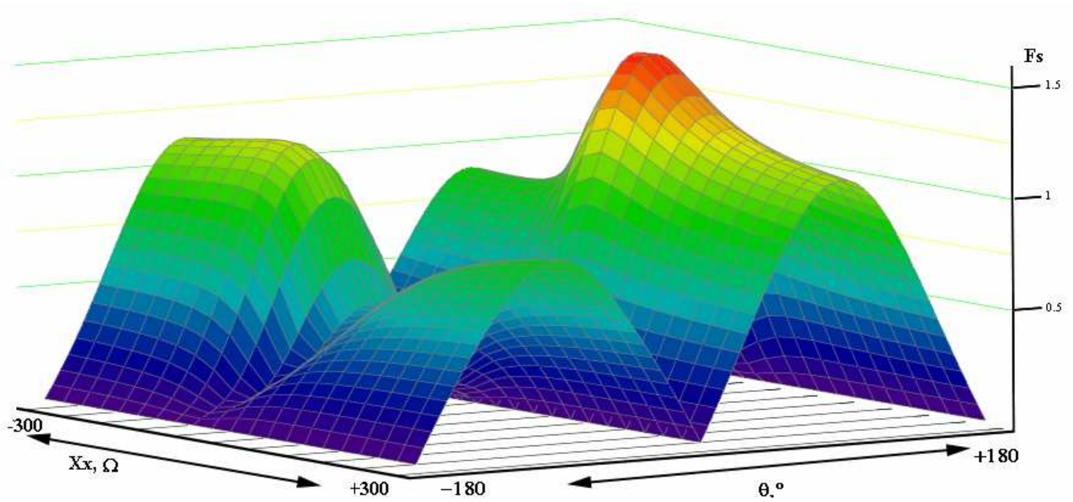

Fig. 2. 3D Radiation Pattern of two Unipol Antennas with load impedance X_x

4. Evaluation

The final step of verifying the accuracy of the results achieved is drawing horizontal and vertical radiation characteristics in the spherical coordinate system with optimized value loaded impedance X_{x_opt}. By comparing characteristics of different value loaded impedance is obvious that the value of X_{x_opt} corresponds to the optimal/maximal shape of radiation pattern (Fig.3.a and b).

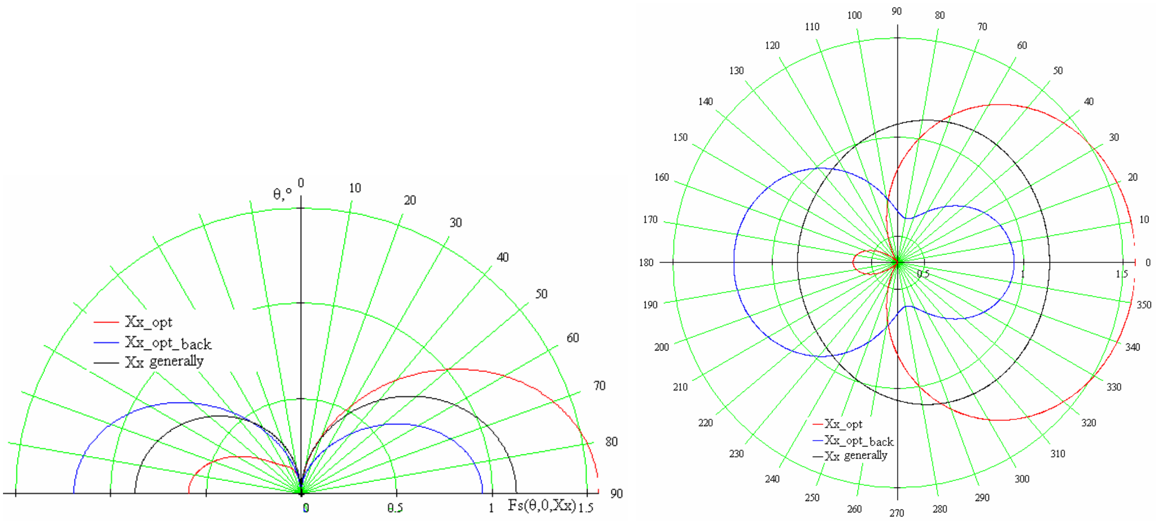

Fig. 3. a) Vertical pattern Fs(θ,0,X_x) (left); b)Horizontal pattern *Fs(π/2,φ,X_x)* (right)

Red curve (Fig.3) describes the antenna system with loaded impedance with optimum value X_{x_opt}, blue curve optimization for the re-direction and the black curve of general value of loaded impedance. It can be clearly seen that the red diagram reaches the best values of Fs(θ,φ_{max},X_x) in direction φ_{max}=0°. This approves the theory of proposed mathematical model.

5. Conclusion

The presented article has drowned out Optimalization of Radiation Pattern by Middle Waves Antenna Array in the context of the potential use of existing antenna systems for the distribution of digital radio signal such as DRM. This study is focused on middle waves vertical antenna systems that appears to be the most perspective for digital broadcasting below 30 MHz (reasons are listed in Chapter 2).

Nowadays, optimalization of radiation pattern existing antenna systems is also an issue in the context of digital radio broadcasting expansion. Antenna systems, which have all elements actively fed, can be often usefully adapted to the system with a passive tuned element. This will not only simplify power supply antenna systems, but also flexible any changes of antenna radiation pattern.

The presented model is currently the unique which deals with issues of re-use existing middle wave's antenna systems. Benefits for the practice is creating a new procedure for calculating technical optimized radiation antenna pattern of two linear elements antenna arrray with the passive element inserted in the base of the passive element. The proposed mathematical model is based on basic mathematical calculations integrated & differential equations, which are supplemented by new findings.

Under given circumstances, it could be created "Radiation diagrams dictionary" in practice most used middle waves antenna configuration.

References

1. Dvorsky, M.: 'Optimization of Radiation Pattern by Loaded Impedance in the Base of Passive Element'. PhD thesis, VSB Technical University of Ostrava, 2008.
2. Caha, V., and Prochayka , M.: 'Anteny'. (SNTL perss, Praha, 1956. ISBN 621.396.67).
3. Mathcad [online]. Avaliable from WWW: <http://www.ptc.com>. accessed 2008-06-13.
4. Vavra, S, and Turan, J.: 'Antény a širenie elektromagnetických vĺn'. 1st. Bratislava: ALFA, 1989. ISBN 621.396.67(075.8).
5. Dvorsky, M.: 'Digital Radio In The Broadcasting Bands Bellows 30MHz'. In 7. Seminar of Telecommunications Department. Ostrava, 2007. ISBN 978-80-248-13.
6. Balanis, C. A.: 'Antenna Theory: Analysis and design'. 3rd edition. United States, 2005. ISBN 0-471-66782-X.
7. King, R. W.: The theory of Linear Antennas, Cambridge 1956