

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

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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 to the base of passive antenna radiator. The proposed solution deals with finding the best values 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 the characteristics of radiation antenna 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 then loaded impedance in the base of passive element, which forms the radiation characteristics with regards 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 demo 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 **MIFR** (Master International Frequency Register), which

is conducted in **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 the creation of 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 notified only in certain positions of existing transmitters can be virtually through to create the existing **AM** (Amplitude Modulated) broadcast only in 2 national network transmitters. To apply this to the digital broadcasting system of **DRM** (Digital Radio Mondiale) [4] could be possible to create in The Czech Republic 4 programs of nationwide transmitters network (**SFN** – Single Frequency Network). There is also a spare antenna array at Litomyšl - Pohodlí notified the frequency **1 287 kHz**, which were verified by measuring the theoretical conclusions of proposed mathematical model.

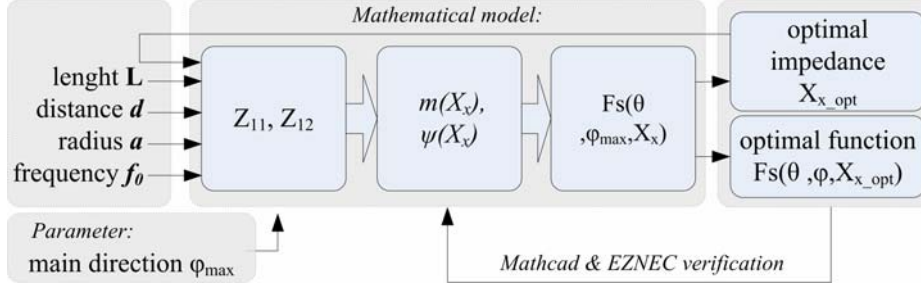
The current antenna systems meet the requirements of classical analogue broadcasting, but with the advent of digitization will need to assess whether to build new antenna systems or use existing ones, which is certainly not going to be without its adjustments.

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.

The reasons of the choice of 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  $F_s(\theta, \varphi, X_x)$  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 isolator through which is 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 system.



**Fig. 1.** Mathematical model

The inputs into the proposed mathematical model (Fig.1.) are geometrical proportions of 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 optimization 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 then 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  $F_s(\theta, \varphi, X_x)$ . 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  $\psi(X_x)$  (2) depending on  $X_x$ .

### 3.1. Radiation Pattern

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

Then can be expressed phase and amplitude ratio of the size of current in antenna elements that are functions of values embedded impedance  $X_x$  [2]:

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

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

Radiation pattern can be then drawn in the plane  $E(\varphi = 0)$ , and the plane  $H(\theta = \pi/2)$  as the absolute value of radiation group functions:

$$F_S(\theta, \varphi, X_x) = F(\theta, \varphi) |K(\theta, \varphi, X_x)| \quad (3)$$

where:

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

$K(\theta, \varphi, X_x)$  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  $F_S(\theta, \varphi, X_x)$ , must be the majority energy radiated under angle  $\varphi \rightarrow \pi / 2$ . The aim is therefore to find that the value embedded impedance  $X_x$ , which reaches the greatest possible value of maximum function (the size of the lobe)  $F_S(\theta, \varphi, X_x)$ . Optimizing the shape of radiation pattern two vertical radiators is therefore based on the search for maximum radiation function  $F_S(\theta, \varphi, X_x)$  (3).

Previously derived relations (1) - (4) were implemented into the development environment software of **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 maximum functions  $F_S(\pi/2, \varphi_{\max}, X_x)$  (Fig.3.).

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

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

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

$$\frac{d F_S\left(\frac{\pi}{2}, \pm(2n - 1)\pi, X_x\right)}{d X_x} = 0; \quad n = 1, 2, 3, \dots \quad (6)$$

Selecting the appropriate angle  $\theta = \pi / 2$  define 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 function  $F_S(\theta, \varphi_{\max}, X_x)$ , is necessary to determine the appropriate value  $X_x$  which corresponds to the found maximum (Fig.3.).

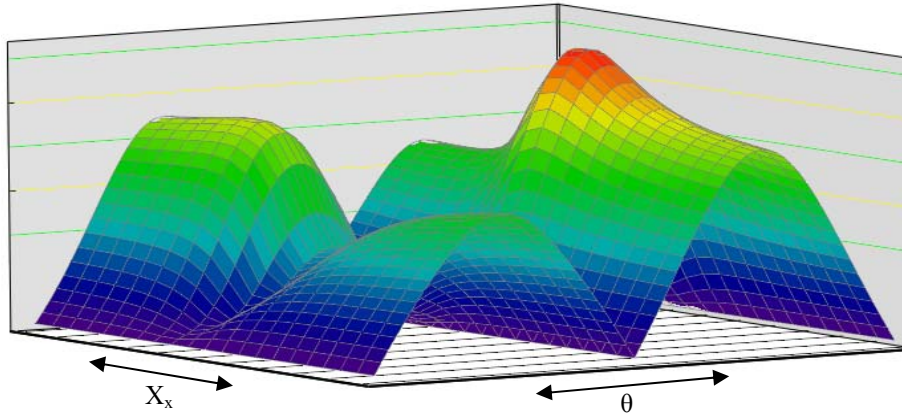


Fig. 2. 3D Radiation Pattern of two Unipole Antennas with load impedance  $X_x$

#### 4. Evaluation

The final step of verifying the accuracy of the results achieved is drawing horizontal and vertical radiation characteristics of the spherical coordinate system with optimized value loaded impedance  $X_{x\_opt}$ . By comparing the characteristics of different value loaded impedance than  $X_{x\_opt}$  can clearly see that the value of  $X_{x\_opt}$  corresponding optimal/maximal shape radiation pattern (Fig.3a and b).

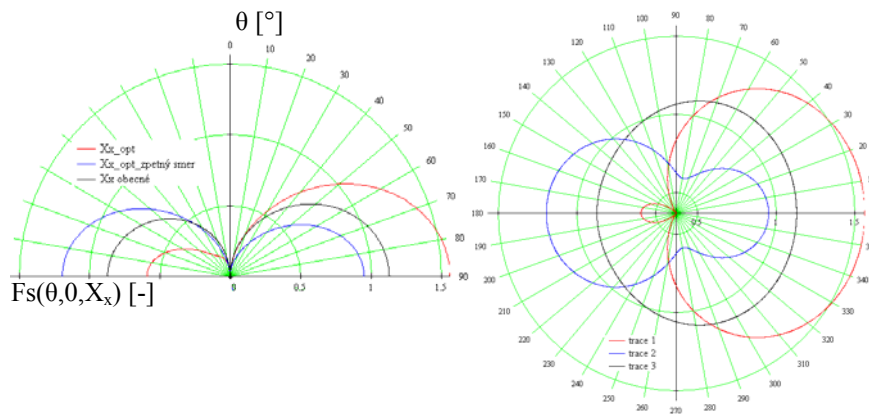


Fig. 3. a) Vertical pattern  $F_s(\theta, 0, X_x)$  (left); b) Horizontal pattern  $F_s(\pi/2, \varphi, X_x)$  (right)

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 red diagram reaches

the best values of  $F_S(\theta, \varphi_{max}, X_v)$  in direction  $\varphi_{max}=0^\circ$ . This approves the theory of proposed mathematical model.

## 5. Conclusion

The presented article has drowned out *The Optimization 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 (**DRM**). This study is focused on middle waves vertical antenna system that appears to be the most perspective for digital broadcasting below **30 MHz** (the reasons are listed in Chapter 2).

Nowadays, optimization of radiation pattern existing antenna systems is also the 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 the 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 of existing middle waves antenna systems. Benefits for the practice is creating a new procedure for calculating technical optimized radiation antenna pattern of two linear transmitters with a passive element inserted in the base of a passive element. The proposed mathematical model is based on the 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.

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