Optimalization of Radiation Pattern by Middle Waves Antenna Array

Marek Dvorský

Department of Telecommunications, FEECS
VŠB–Technical University Ostrava, 17. listopadu 15, 708 33 Ostrava – Poruba
CZECH REPUBLIC
Email: marek.dvorsky.fei@vsb.cz.

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 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 of this article 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 the radiators and their lay-out. The output value is then 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 loaded impedance. The shape of the radiation was then verified in simulation program ***EZNEC*** *demo v5.0.20*.

2. The strategic importance of the existing MW broadcasting canters

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. Most of frequencies is notificated in more locations, so they can create a network of transmitters. **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, which, given the smaller number of notified localities does not establish a network with nationwide coverage. 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 only in certain positions of existing transmitters can be virtually through to create the existing **AM** (Amplitude Modulated) broadcast only in 2 national programme 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). List currently used **MW** antennas indicating the frequency is given in Table.1 (updated 23.5.2008). 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.

Table 1. MW antennas of company Ceske Radiokomunikace a.s.

place	f (kHz)	type	height (m)	base
Liblice	639	2xARPO	355	grounded
Svinov	639	70 m	70	isolated
České Budějovice	954	107 m	107	isolated
Dobrochov	954	ARPO II	152	grounded
	backup	Unipól	55,5	grounded
Karlovy Vary	954	107 m	107	isolated
	backup	Jucho	40	isolated
Zbraslav	1062	Unipól	85	grounded
Litomyšl	1287	Unipól	125	isolated
Domamil	1332	107 m	107	isolated
	backup	Unipól	85	grounded

The current antenna systems meet the requirements of classical analogue broadcasting, but with the advent of digitisation 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.2.) describes the optimization of radiation pattern two vertical radiators powered according to the method proposed at Fig.1.

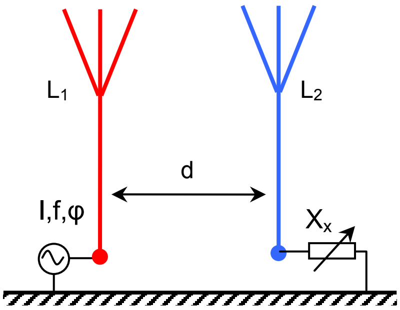

Figure 1. Antenna system with a passive element with load impedance X_x

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 $Fs(\theta,\varphi,X_x)$ in the required direction of the maximum φ_{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).

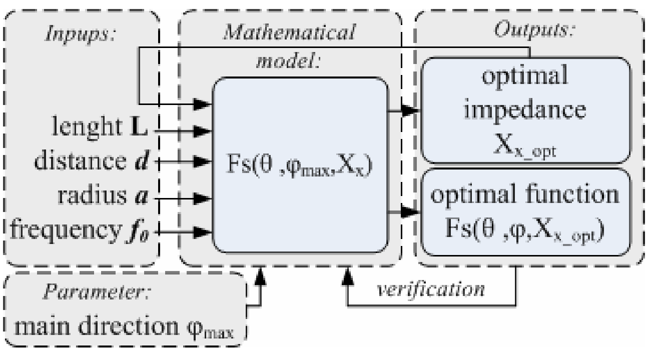

Figure 2. Mathematical model

The inputs into the proposed mathematical model (Fig.2.) are geometrical proportions of equal antenna towers:

- Length of tower ***L*** [m]
- Spacing ***d*** [m]
- Radius of towers ***a*** [m]
- 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 (3.3).

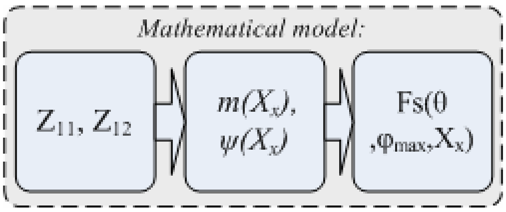

Figure 3. Detail of Proposed Mathematical Model

The proposed mathematical model is based on a calculation the optimal shape of radiation pattern $Fs(\theta,\varphi,X_x)$. It is based on known self and mutual impedance $Z_{11}(L)= R_{11}+X_{11}$ and $Z_{12}(d) = R_{12}+X_{12}$ [3]. The next step consists in calculation of the ratio of currents flowing in antenna towers *$m(X_x)$* (3.1) and phase *$\psi(X_x)$* (3.2) depending on X_x.

3.1. Radiation Pattern

The derivation of radiation functions $Fs\,(\theta,\varphi,X_x)$ for the array with passive element is necessary to know the circumstances of amplitude ratio and phase 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.

Than can be expressed phase and amplitude ratio of the size of current in antenna elements that are functions of values embedded impedance Xx [1]:

$$m\left(X_x\right)=\sqrt{\frac{R_{12}^2+X_{12}^2}{R_{11}^2+\left(X_{11}\pm X_x\right)^2}} \quad (3.1)$$

$$\psi\left(X_x\right)=\pi+arctg\frac{X_{12}}{R_{12}}-arctg\frac{X_{11}\pm X_x}{R_{11}} \quad (3.2)$$

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

$$F_s\left(\theta,\varphi,X_x\right)=F\left(\theta,\varphi\right)\left|K\left(\theta,\varphi,X_x\right)\right| \quad (3.3)$$

Where:

$$\begin{aligned}K\left(\theta,\varphi,X_x\right)&=\left|1+m\left(X_x\right)e^{j\psi\left(X_x\right)}e^{j\left(kd\sin\theta\cos\varphi\right)}\right|=\\&\sqrt{\left(1+m\left(X_x\right)e^{j\left(kd\sin\theta\cos\varphi+\psi\left(X_x\right)\right)}\right)\left(1+m\left(X_x\right)e^{-j\left(kd\sin\theta\cos\varphi+\psi\left(X_x\right)\right)}\right)}=\\&\sqrt{1+m\left(X_x\right)^2+m\left(X_x\right)\left(e^{j\left(kd\sin\theta\cos\varphi+\psi\left(X_x\right)\right)}+e^{-j\left(kd\sin\theta\cos\varphi+\psi\left(X_x\right)\right)}\right)}=\\&\sqrt{1+m\left(X_x\right)^2+2m\left(X_x\right)\left(kd\sin\theta\cos\varphi+\psi\left(X_x\right)\right)}\end{aligned} \quad (3.4)$$

$K(\theta,\varphi,X_x)$ 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 *$Fs(\theta,0,X_x)$*, must be the majority energy radiated under angle $\varphi\rightarrow\frac{\pi}{2}$. The aim is therefore to find that the value loaded 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 *$Fs(\theta,\varphi,X_x)$* (3.3).

Previously derived relations (3.1) - (3.4) were implemented into the development environment software ***Mathcad*** from *Mathsoft Engineering & Education*, with added library for *Visual Electromagnetic Mathcad* [2]. In addition, they were through the above-mentioned software found a position of absolute maxim functions $Fs(\pi/2,\varphi_{max},X_x)$ (Fig.4.).

The 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 (3.5).

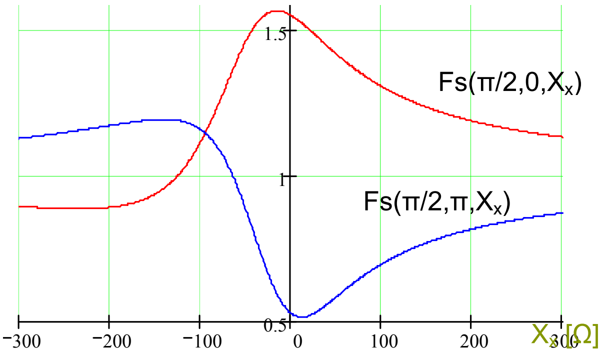

Figure.4. Fs ($\pi/2,\varphi_{max},X_x$) in the direction of φ_{max} depending on the value embedded impedance X_x

$$\frac{d\,Fs\left(\frac{\pi}{2},0,X_x\right)}{d\,X_x}=0 \qquad (3.5)$$

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

$$\frac{d\,Fs\left(\frac{\pi}{2},\pm(2n-1)\pi,X_x\right)}{d\,X_x}=0;\; n=1,2,3... \qquad (3.6)$$

To select 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 function $Fs(\theta,\varphi_{max},X_x)$, is necessary to determine the appropriate value X_x which corresponds to the maximum found (Fig.4.).

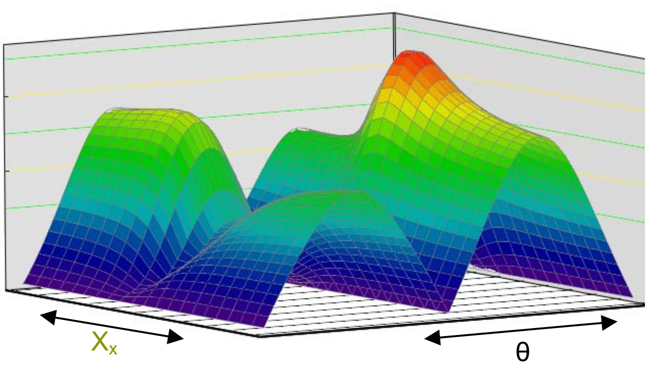

Figure 5. 3D Radiation Pattern of two Unipol Antennas with load impedance X_x

4. Evaluation

The final step of verifying the accuracy of the results achieved is drawing horizontal and vertical radiation characteristics 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 shape radiation pattern (Fig.6 and Fig.7).

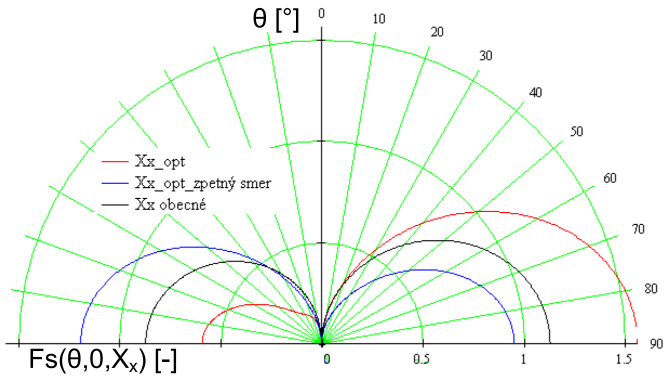

Figure 6. Vertical pattern Fs(θ,0,X_x)

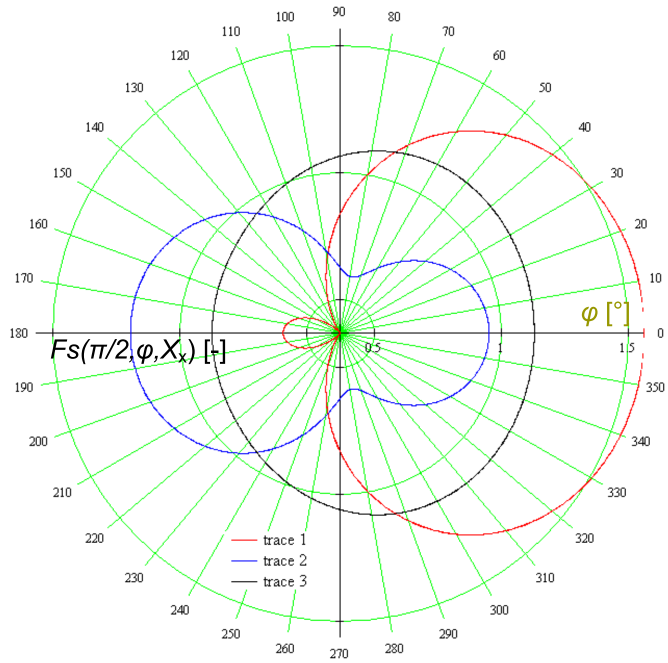

Figure 7. Horizontal pattern ***Fs($\pi/2,\varphi,X_x$)***

Red curve (Fig.6 and 7) 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 embedded impedance. It can be clearly seen that the red diagram reaches the best values of $Fs(\theta,\varphi_{max},X_x)$ in direction $\varphi_{max}=0^o$. This approves the theory of proposed mathematical model.

5. Conclusion

The presented article deals with O*ptimalization 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, otimalization 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 often be 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 optimised radiation antenna pattern of two linear radiators with a passive element loaded in the base of a passive element. The proposed mathematical model is based on the basic mathematical calculations integrated & differential equations, which is supplemented by new findings.

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

References

[1] CAHA, Vladimír, PROCHÁZKA , Miroslav. *Anteny*. 1. vyd. Praha : Státní nakladatelství technické literatury, 1956. 462 s. ISBN 621.396.67.

[2] *Mathcad* [online]. 2008 [cit. 2008-06-13]. Dostupný z WWW: <http://www.ptc.com>.

[3] VAVRA, Štefan, TURÁN, Ján. *Antény a širenie elektromagnetických vĺn*. 1. vyd. Bratislava : ALFA, 1989. 421 s. ISBN 621.396.67(075.8).

[4] DVORSKÝ, Marek. *DIGITAL RADIO IN THE BROADCASTING BANDS BELLOWS 30MHz.* In 7. Seminar of Telecommunications Department. [s.l.] : [s.n.], 2007. s. 95. ISBN 978-80-248-13.

[5] BANALIS, Constantine A. *Antenna Theory : Analysis and design.* 3rd edition. United States : [s.n.], 2005. 1117 s. ISBN 0-471-66782-X.

[6] King, R. W.: The theory of Linear Antennas, Cambridge 1956

[7] DVORSKÝ, Marek. *Optimalizace vyzařovacího diagramu pomocí soustavy dvou vertikálních zářičů.* Ostrava, 2008. 110 s. Disertační práce. VŠB-TUO 2008.