Omnidirectional Antenna with Complex Conjugate Impedance for Radio Meteor Detection

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***Abstract*— In the field of meteor study using radio techniques, the transmitting antenna of the radio beacons is most of the time a classical turnstile antenna design. As an alternative, it is proposed a pyramidal shaped omnidirectional antenna with complex conjugate impedance, which exhibits similar performance. By design, this type of antenna does not require additional electrical components for obtaining the circular polarization and the impedance matching. Furthermore, the pyramidal shape allows the practical implementation of the antenna using a simple and light mechanical structure.**

Keywords—radio meteor detection; omnidirectional antenna; circular polarisation; complex conjugate impedance.

I. INTRODUCTION

Today, the radio beacons from the radio meteor detection networks, that operate in the Low-VHF frequency band (30-60MHz), use exclusively turnstile antennas with omnidirectional hemispherical radiation patterns (BRAMS [1][2], VVS [3], HRO-RMO [4], SkiYMet [5]). The turnstile antenna design was invented by George Brown in 1935 [6], and consists of two halfwave orthogonal dipoles with coplanar elements, which are fed 90 degrees out of phase/ fed in phase quadrature. The turnstile antenna can work in two modes: in the normal mode it radiates horizontally polarized waves perpendicular to the antenna's axis, and the axial mode in which it radiates circularly polarized waves along the axis. Otherwise, the circular polarization can be obtained by spacing the two dipoles by a quarter wavelength and feeding them in phase [7]. The turnstile antennas are fed with coaxial transmission lines, usually using a Gamma-match or, sometimes, a T-match.

As an alternative, a circularly polarized omnidirectional antenna with complex conjugate impedance [7][8][9] is proposed. This type of antenna is also known as self-phased turnstile antenna, and it is intended to be used as transmitting antenna for a radio meteor detection beacon that will operate in the 49-50MHz frequency band (allocated to space and geophysical research [10]).

II. PRINCIPLE OF OPPERATION

The proposed omnidirectional antenna consists of two orthogonal dipoles which have complex conjugate impedances and are fed in parallel by the same transmission line. The expressions of the two complex impedances are:

$$Z_{x,y}=R\pm jX \tag{1}$$

The total impedance, when connected in parallel, will be real and given by:

$$Z=Z_xZ_y/(Z_x+Z_y)=(R^2+X^2)/(2R) \tag{2}$$

For the particular case when 50Ω total impedance is required, for an easy match to regular coaxial transmission lines, the expression became:

$$Z_xZ_y/(Z_x+Z_y)=50 \tag{3}$$

The desired total impedance is obtained, having the two impedances Z_x and Z_y complex conjugated, for the solutions of the equation:

$$R^2-100R+X^2=0, \tag{4}$$

solutions for which the following conditions are simultaneously met:

$$\Delta\geq 0\rightarrow |X|\leq 50;\ R>0 \tag{5}$$

There are two practical situations for which the impedances of the two dipoles are complex conjugated and the total parallel impedance is 50Ω.

In a first case, the reactive components are zero and the total impedance is given by the resistive components (R=100Ω). This corresponds to an antenna made by two resonant halfwave dipoles fed asymmetrically (offset feedpoint). The currents in the dipoles are in phase, this having as a result a linear polarization of the radio waves.

The second case, of interest for the proposed application, assumes all the resistive and reactive components equal in absolute value, 50Ω each:

$$R=|X|=50\Omega\rightarrow Z_{x,y}=50\pm j50 \tag{7}$$

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This time the reactive components of opposite sign and equal in absolute value with the resistive components, introduce a ±π/4 phase shift of the currents compared to the input voltage (equivalent to a total π/2 phase shift between the currents in the dipoles of impedances Z_x and Z_y). The axial radiation field is circularly polarized.

Complex conjugate impedances of this form are obtained by the dipoles design (Fig. 1, Fig. 2).

One of the dipoles, L_x, is longer than a resonant dipole at the operating frequency. Its impedance having an inductive character introduces a negative phase shift of the current against the supply voltage.

The second dipole, L_y, is shorter than a resonant dipole at the same operating frequency. Having a capacitive character of the impedance, introduces a positive phase shift of the current with respect to the input voltage.

The circular polarization sense (LHCP or RHCP) in the direction of the vertical z axis is given by the sense going from the capacitive (short) dipole Ly hot element to the inductive (long) dipole Lx hot element (Fig. 2). The hot elements are considered to be the elements of the dipoles connected to the central conductor of the coaxial transmission line.

For practical reasons, the aim was to obtain these parameters using a pyramidal structure of the radiant system, with the two symmetrical orthogonal dipoles having the arms tilted down (Inverted-Vee), as shown in Fig. 2.

III. Simulation Results

Simulations of the proposed antenna with complex conjugate impedance were made using the antenna analyzer software MMANA-GAL [11]. The elements were made of copper wire 3 mm in diameter and medium ground properties were considered (dielectric permittivity ε=13F/m, conductivity σ=5mS/m).

First, independent simulations were carried out for the two dipoles (inductive L_x and capacitive L_y) tuned in the Low-VHF frequency band (49.5MHz). They were optimized such that the desired complex conjugate impedances have been obtained.

With both dipoles connected in parallel, another set of simulations were made for the radiating system obtained. The geometrical dimensions that have resulted from these simulations, after optimization, are summarized in TABLE I.

The tilt angles of the dipoles, for which are obtained, at the same height h above the ground (reflector), complex conjugate impedances of the form $Z_{x,y} \approx 50 \pm j50$, are: $\alpha_x = 45°$, $\alpha_y = 55°$.

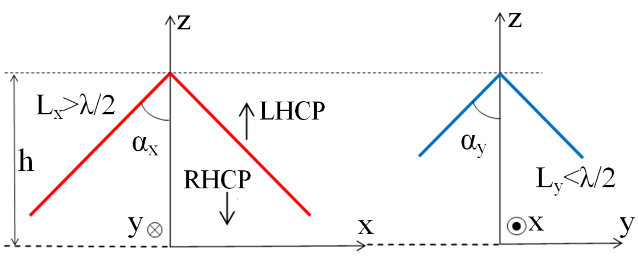

Fig. 1. Antenna geometry in xz and yz planes.

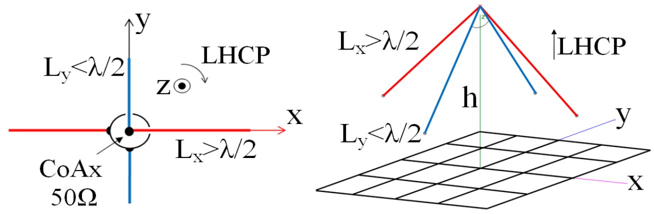

Fig. 2. Antenna geometry in xy plane and 3D.

TABLE I. Antenna Geometrical Dimensions

Antenna elements	***L_x***	***L_y***	***h***
Relative dimensions	*0.5λ*	*0.46λ*	*0.528λ*
Dimensions @ 49.5MHz [m]	*~3*	*~2.79*	*~1.6*

In Fig. 3 the total simulated radiation pattern is shown. The maximum theoretical gain at 90^0 elevation is Ga=4.78dB. There is a slight asymmetry of the radiation pattern due to the difference in length and tilt angle of the two dipoles. This asymmetry translates into a front to back radio F/B=-1.3dB (as measured at 120^0 azimuth and 60^0 elevation).

The total impedance is very close to the desired one: Z=50.3+j2.5. The variation of the resistive R and reactive X components of the impedance, obtained by simulation in a 1MHz frequency band (49-50MHz) is shown in Fig. 4.

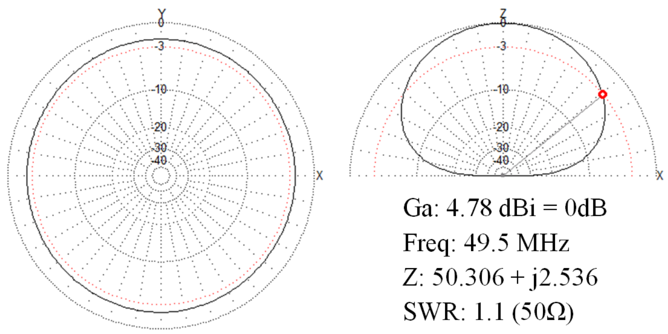

Fig. 3. Total radiation pattern of the complex conjugate impedance antenna in the horizontal and vertical planes.

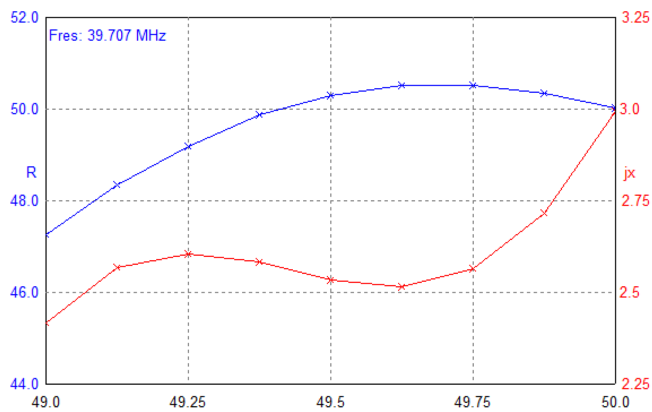

Fig. 4. The impedance Z=R+jX components for the complex conjugate impedance antenna (R–blue, jX–red).

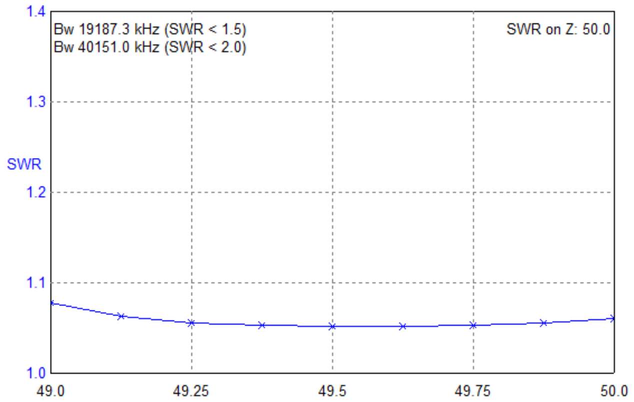

Fig. 5. The standing wave ratio SWR for the complex conjugate impedance antenna.

At resonance (49.5MHz) the change in the behavior of the antenna reactance can be noticed.

The theoretical standing wave ratio SWR (Fig. 5) across the same frequency band of 1MHz is better than 1:1.1. When implementing such an antenna for a radio beacon, the frequency of operation is known and fixed, that means that the tuning can be done for optimum parameters without the concern of a wide bandwidth required.

The far field radiation pattern of the complex conjugate impedance antenna was compared to that of a turnstile antenna with coplanar resonant dipoles fed in phase quadrature (Fig. 6). For both antenna designs, the vertical (V) and horizontal (H) field components are equal at 90 degrees elevation angle (at the zenith), hence the axial circular polarization. In the case of the complex conjugate impedance antenna, can be noticed a higher value of the vertical field component at elevation angles below ~55 degrees. This behavior is due to the V-shape structure of the antenna dipoles and, for the same reason, the overall theoretical efficiency is lower (the antenna elements are progressively closer to the ground plane, fact that translates into higher losses).

IV. Experimental Results

For the experimental verification of the results obtained by simulation, an omnidirectional antenna with complex conjugate

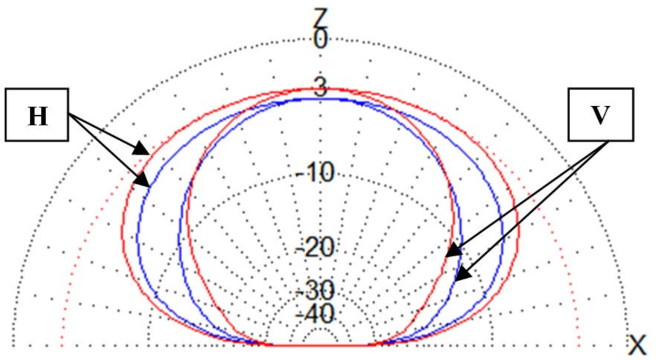

Fig. 6. Compared far field radiation patterns of the vertical (V) and horizontal (H) field components in the vertical plane: complex conjugate impedance antenna (blue), turnstile antenna (red).

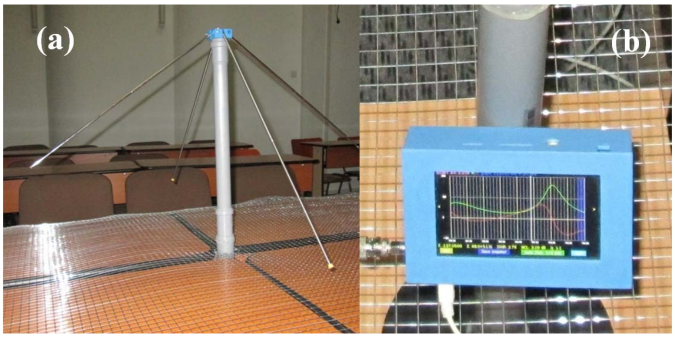

Fig. 7. The experimental setup: complex conjugate impedance 137MHz test antenna (a), EU1KY vector antenna analyzer (b).

impedance reduced in scale was built. The test antenna was dimensioned for the 137MHz band allocated to NOAA weather satellite communications, with the purpose of determining with their help the radiation pattern under real operating conditions [12].

The antenna was designed in such a way as to allow the modification of the geometric parameters: the two dipoles constructed from telescopic antenna elements, the central insulator (3D printed) with the possibility of changing the angles of the dipoles elements, the central support made of height-adjustable PVC pipes (Fig. 7a).

The radiant system was installed above a surface made of metal mesh (dimensions 1x1m, mesh sizes 10x10mm) with reflector role.

The antenna was fed with coaxial cable RG58 (50Ω) with a length of ~6·λ/2 at the test frequency, on which two ferrite cores (TDK ZCAT 2132-1130) were mounted below the antenna feed point. The dimensioning of the coaxial cable length and the installation of the ferrite cores were done in order to minimize the influence of the coaxial cable (of the braid) on the measurement results.

Measurements were performed using a EU1KY vector antenna analyzer (Fig. 7b) in a frequency range of 120-160MHz.

Initially independent measurements of the electrical parameters of the two dipoles were made. Starting from the dimensional values obtained by simulation, the antenna elements were adjusted such the complex conjugate impedances were obtained on the tuning frequency of 137.5MHz.

Fig. 8 shows the variation of the resistive and reactive components of the impedance obtained experimentally for the inductive dipole. The impedance value at the frequency of interest, obtained in these preliminary measurements Z=49.5+j53, is close to the theoretical value.

Keeping the same height of the feed point, the lengths and angle of the dipole arms were modified according to the values obtained by simulation, with the aim of obtaining the impedance with capacitive character (Fig. 9). The value of the impedance for the capacitive dipole obtained experimentally Z=50.4-j50.2, is also close to the desired theoretical value.

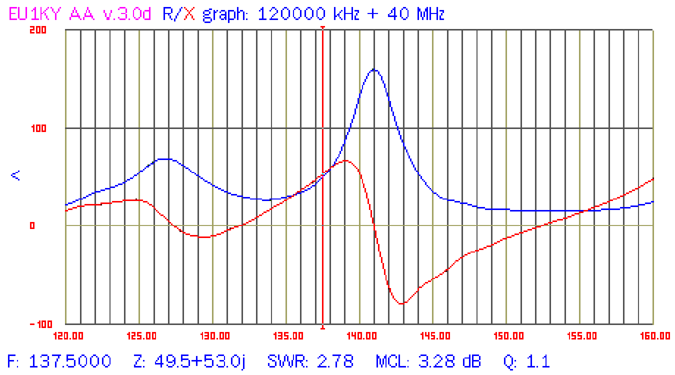

Fig. 8. The impedance components R,X measured for the inductive (long) dipole.

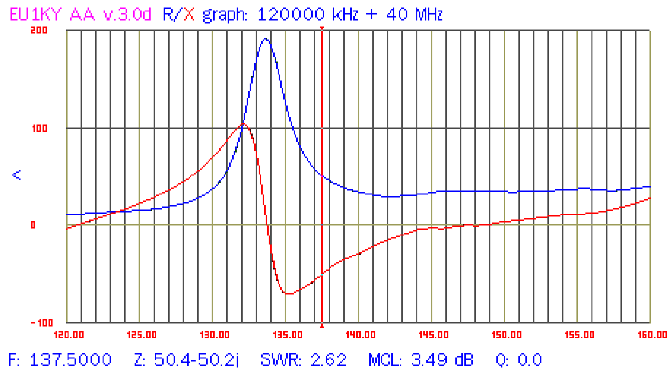

Fig. 9. The impedance components R,X measured for the capacitive (short) dipole.

After fitting the two dipoles in parallel, the total impedance of the obtained radiant system was measured (Fig. 10), on the 137.5MHz central frequency of interest, its value being Z=53.5-j0.6. The standing wave ratio measured on the central frequency is SWR=1.07. The bandwidth obtained for a standing wave ratio of 1:1.5 is ~26MHz (128.4-154.6MHz).

These impedance measurements were performed indoors, in an enclosure not treated in terms of the radio frequency field, with dimensions in all directions of about 3λ, the presence of adjacent structures presumably influencing the obtained results.

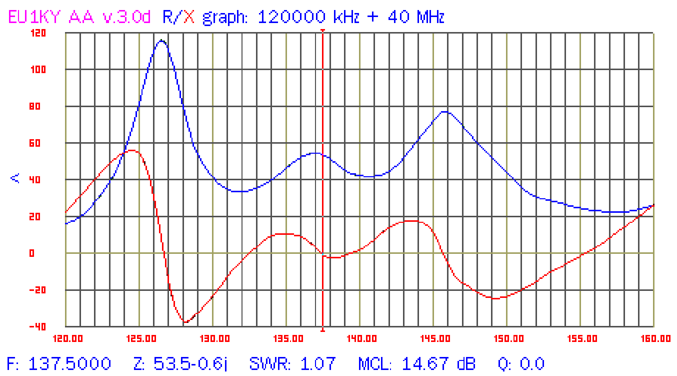

Fig. 10. The complex conjugate impedance antenna measured impedance components R,X.

V. CONCLUSIONS

The experimental results confirm the validity of the concept and the dimensional values obtained by simulation.

Among the advantages, worth to mention that this antenna has the input characteristic impedance of 50Ω, being easy to feed with usual coaxial cables through a common mode choke balun (**bal**anced-**un**balanced). The radiation pattern is omnidirectional and has axial circular polarization, obtained by design without an additional phase shifting circuit. It has a simple mechanical structure with only few electrical contacts and makes use of a single central antenna mast (e.g. UV resistant PVC pipe) that houses the coaxial cable, the choke balun and protects the connectors from the elements.

This antenna can be used as well for the radio meteor detection receiving stations, provided that the gain is high enough to cover the required link budget.

Outdoor impedance and SWR measurements, as well as radiation pattern measurements of the test antenna, using LEO (Low Earth Orbit) artificial satellites as reference radiofrequency sources, are in view. A full scale antenna prototype is intended to be used, in a first step, for meteor scatter and Es (Sporadic E) communications in the 50MHz frequency band.

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