Non-resonant Long – Wire Feed for Parabolic Antennas

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***Abstract*—A traveling wave long-wire antenna is proposed to be used as a feed for classical, prime focus, parabolic reflectors. A non-resonant long-wire antenna was computer designed and simulated, optimizing the impedance match and forward gain. The analyzed experimental antenna feed was tuned in the 5.8 GHz frequency band. A qualitative assessment of the radiation pattern, of the antenna feed alone, was made in indoor environment.**

Keywords—End-Fed antenna, long-wire antenna, traveling wave antenna, parabolic reflectors

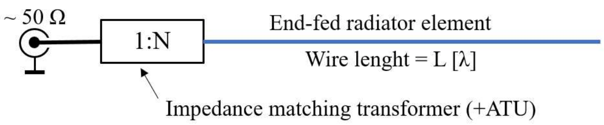
I. Introduction

Among the wire antenna designs, several end-fed topologies are encountered: random wire antennas, end-fed half-wave (EFHW) antennas, long-wire (LW) antennas. An end-fed antenna usually consists of a straight conductive wire with one end connected to the radio equipment and one free end (Fig. 1) [1],[2],[3].

All these end-fed antennas, have the feed-point impedance other than the commonly used 50 Ω impedance. The correct impedance match is realized using impedance matching transformers (impedance ratio 1:N) and antenna tunning units (ATU), with the expense of power loss on these components.

The random wire antennas, makes use of an opportunity wire radiator, of at least λ/4 in length, usually non-resonant, achieving marginal standing wave ratio (SWR) on one or multiple frequency bands of interest.

The end-fed half-wave (EFHW) antenna, is a resonant, mono-band, voltage-fed design. Due to resonance, the feed point impedance is very high (1000s of ohms). The radiation pattern is that of a center-fed half wave dipole. One can see that the EFHW antenna can be tuned on multiples of half wavelengths, but this introduces the next antenna design - the long-wire.



Antenna Type	L	1:N	I/V distribution
Random wire	≥ λ/4	1:4 v 1:9	I V
EFHW	λ/2	1:49 v 1:64	I V
Long-Wire	n*λ/2 (n ≥ 2)	1:49 v 1:64	I V

Fig. 1. End-fed wire antenna types. Current (I) and voltage (V) distribution.

"The long-wire antennas have the radiator length of at least one wavelength of the electromagnetic waves (multiples of half a wavelength, n*λ/2, where n ≥ 2)" [4]. The radiation pattern shows lobes that are aligned more with the axis of the antenna, as the wire length in wavelengths increases.

There are two categories of LW antennas: resonant and non-resonant.

The resonant LW antennas are open-ended, and are also named periodic, tuned or standing wave antennas. This antenna type is similar, in terms of current and voltage distribution, to the open-ended transmission lines. The reflections from the open end of the radiator wire, creates current and voltage standing wave patterns. For this reason, they have a bidirectional radiation pattern. The feed-point impedance is also high (1000s of ohms) (Fig. 2).

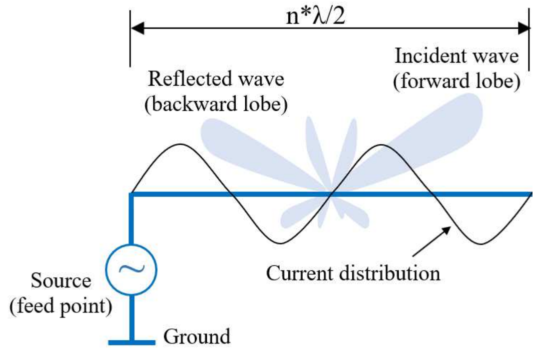


Fig. 2. Resonant long-wire antenna above ground.

"Non-resonant LW antennas are also referred to as aperiodic antennas or traveling wave antennas"[4].They are terminated with a non-inductive resistor and exhibit a unidirectional radiation pattern. The backward energy flow, of the otherwise reflected wave, is dissipated on the terminal load resistor. This eliminates (diminish) the standing waves and cancel (reduce) the backward lobe (Fig. 3).

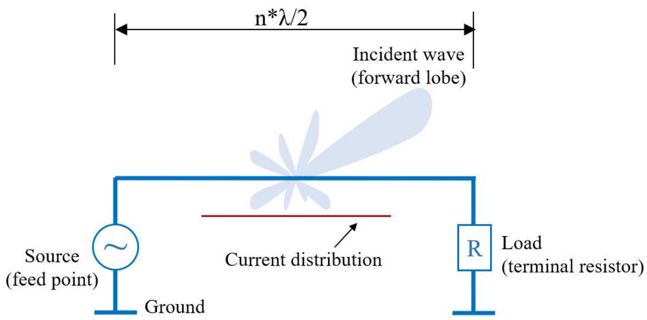


Fig. 3. Non-resonant long-wire antenna above ground.

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In Fig. 2 and Fig. 3, are presented simplified, the theoretical current distributions and radiation patterns for the LW antennas, resonant and non-resonant, in a setup above ground. These types of antennas are mainly used for ionospheric communications, at frequencies below 30 MHz.

There are few applications at higher frequencies, VHF and up [4],[5][6], where the height above the ground become much larger than the wavelength of the radio waves. In these situations, the LW antenna can be analyzed as being in free space.

For a resonant LW antenna in free space, the forward and backward lobes are conical in shape. The feed point is placed in the current maximum, a quarter wavelength from one end of the antenna wire (Fig. 4).

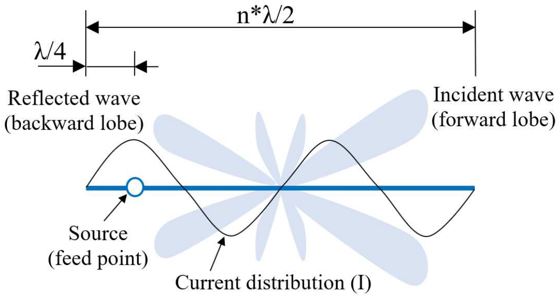

Fig. 4. Resonant long-wire antenna in free space.

In the case of a non-resonant LW antenna in free space, both the feed point and the terminal load resistor, are placed a quarter wavelength from the both ends of the antenna wire. The backward lobe is canceled (reduced) and the forward lobe remain theoretically unchanged, conical in shape and exhibit a deep null along the wire axis (Fig. 5).

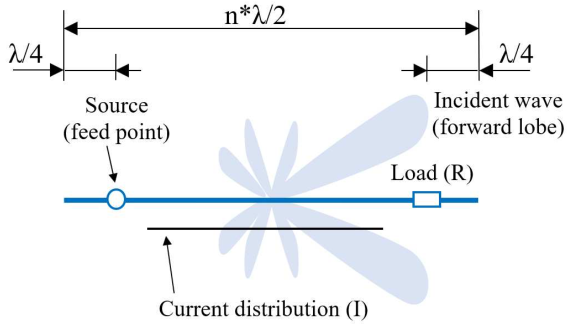

Fig. 5. Non-resonant long-wire antenna in free space.

A non-resonant LW antenna is proposed to be used as a feed for prime focus classical parabolic antennas, where the central feed shadow on the paraboloid reflector coincides with the null along the LW antenna axis.

II. The Geometry of Antenna

"The analyzed non-resonant LW antenna, designed for the 5.8 GHz band, consists of a straight wire radiator element" [4] that is four wavelengths long at the operating frequency (n = 8).

The impedance matching units of the source and the load, consists in "two radial elements each, a quarter-wavelength in size" [4]. Both impedances, of the source (feed line) and the terminal load resistor, are of 50 Ω. This impedance match is achieved by placing the radials symmetrically with respect to the radiator element and tilting them forward, similar to the Goubau single wire transmission line [7].

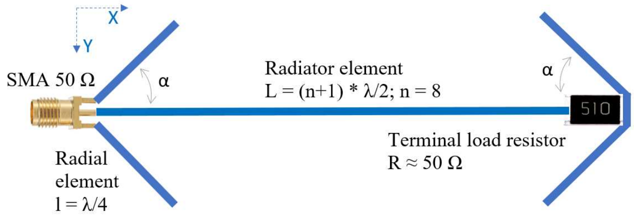

Fig. 6. Non-resonant long-wire antenna geometry.

The tilt angle α is the main factor that influence the impedance.

III. Simulation Results

The "simulations of the non-resonant LW antenna were conducted using the MMANA-GAL v.3.5" [8], an antenna-analyzing tool. Silver was chosen as the material for the elements (Ag "resistivity ρ=1.59*10^-8 Ω*m" [8]). All the simulations are made in free space, for a center frequency of 5750 MHz.

In a first step, a resonant LW antenna (having a zero load terminal impedance) was analyzed, as a reference for the following simulations and for a later comparison. The "geometry and current distribution" [4] for the resonant LW antenna are depicted in Fig. 7.

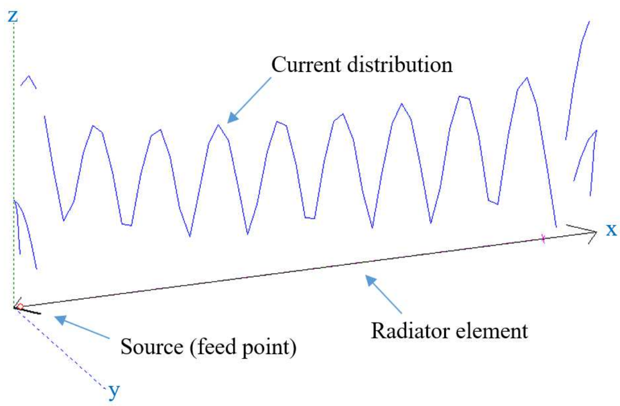

Fig. 7. Resonant LW antenna - geometry and current distribution.

The "total far-field radiation pattern" [4] simulated in the XOZ plane is illustrated in Fig. 8. "The maximum theoretical gain of Ga=8.7 dBi is achieved at a 22° offset angle from the wire radiator axis" [4].

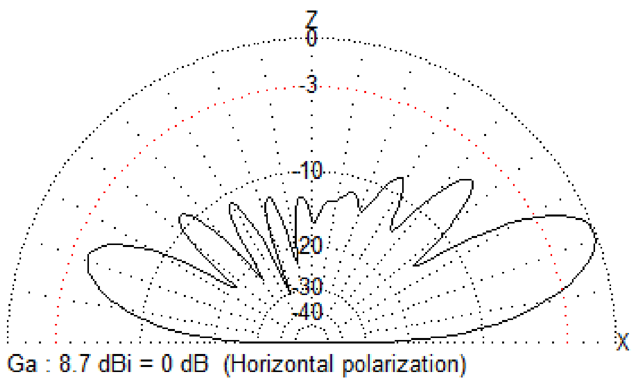

Fig. 8. Resonant LW antenna - total far-field radiation pattern in the XOZ plane.

Fig. 9 illustrates the total simulated radiation pattern in the XOY plane. Both forward (main lobe) and backward lobes are present, with a front-to-back ratio of F/B=4.1 dB.

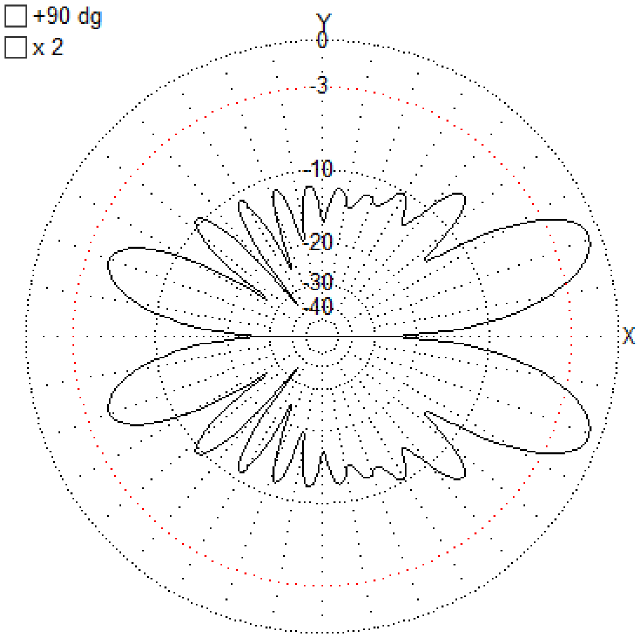

Fig. 9. Resonant LW antenna - total far-field radiation pattern in the XOY plane.

The 3D far-field plot displays “cone-shaped forward and backward lobes, featuring a deep null along the antenna radiating element” [4], as shown in Fig. 10.

“With the selected ratio of radiator length to wavelength, the maximum gain is achieved at an offset angle of approximately 22° from the radiator element” [4].

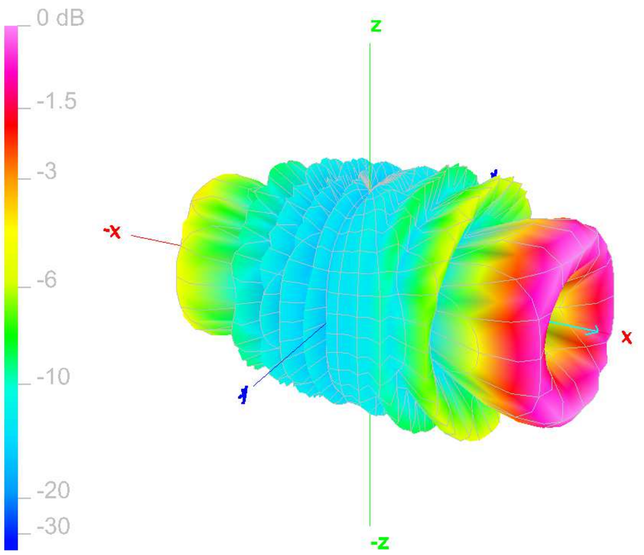

Fig. 10. Resonant LW antenna - 3D total far-field radiation pattern.

The resonance is achieved in this configuration for a tilt angle of the radial elements α = 55°.

“The theoretical standing wave ratio (SWR) characteristic across a 100 MHz frequency band” [4] is presented in Fig. 11. After optimization, at resonance, a SWR of 1.02:1 was achieved. The bandwidth for SWR of 1.5:1 is approximately 100 MHz.

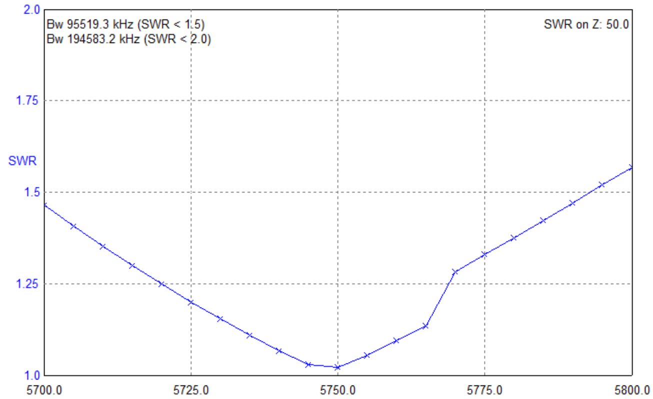

Fig. 11. Resonant LW antenna - simulated SWR.

Following, a non-resonant LW antenna having a 50 Ω load impedance was analyzed (Z = 50 ± j·0 [Ω]). The geometry and current distribution for the non-resonant LW antenna are illustrated in Fig. 12.

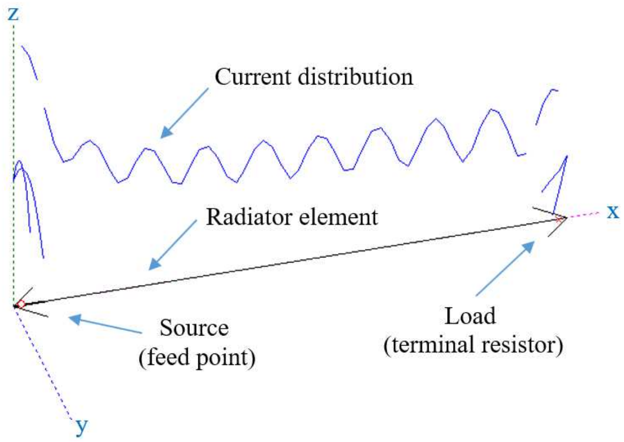

Fig. 12. Non-resonant LW antenna - geometry and current distribution.

The current distribution is flattened due to the absence (attenuation) of the reflected wave.

The resonance was achieved this time for a tilt angle of the radial elements α = 45°, a total radiator length L = 248 mm and radial elements length l = 17 mm.

In Fig. 13 is presented “the simulated total far-field radiation pattern in the XOZ plane. The maximum theoretical gain of Ga=8.14 dBi is achieved at the same 22° offset angle from the wire radiator axis” [4].

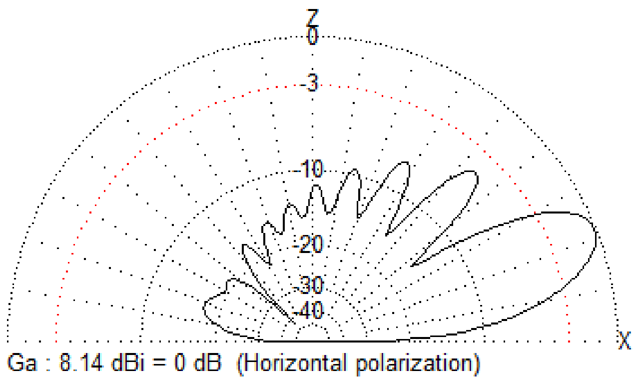

Fig. 13. Non-resonant LW antenna - total far-field radiation pattern the XOZ plane.

The illustration in Fig. 14 presents the total simulated radiation pattern in the XOY plane. The backward lobe is highly attenuated. This time, the front to back ratio is F/B=16.9 dB.

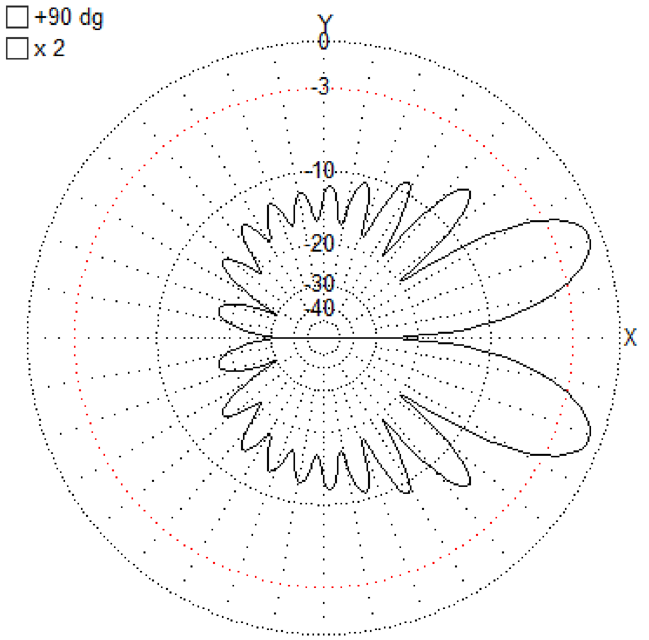

Fig. 14. Non-resonant LW antenna - total far-field radiation pattern in the XOY plane.

"The 3D far-field plot demonstrates a similar cone-shaped forward lobe, with a pronounced null along the antenna's radiating element" [4] and a significantly attenuated backward lobe, as illustrated in Fig. 15.

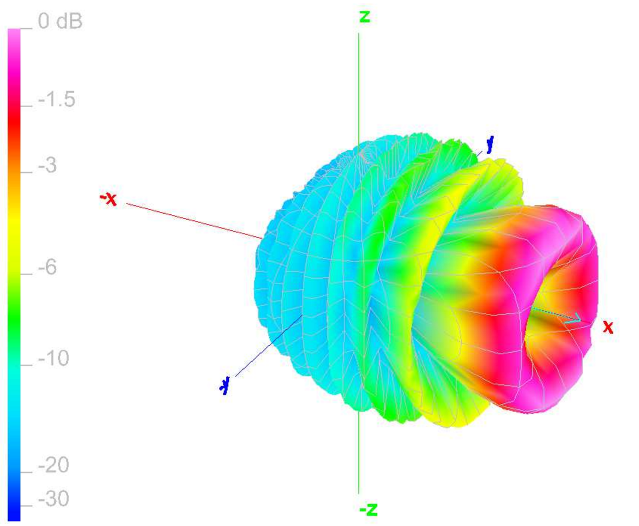

Fig. 15. Non-resonant LW antenna - 3D total far-field radiation pattern.

The Fig. 16 displays "the theoretical standing wave ratio (SWR) characteristic across a 100 MHz frequency band" [4]. Following optimization, at resonance, a SWR of 1.08:1 was achieved.

The presence of the terminal load resistor has as an effect the bandwidth widening, the SWR is below 1.2:1 across at least 100 MHz frequency band. This render the non-resonant LW antenna much easier to tune. On the other hand, with the non-resonant LW antenna in transmission mode, half of the injected power is dissipated on the terminal load resistor.

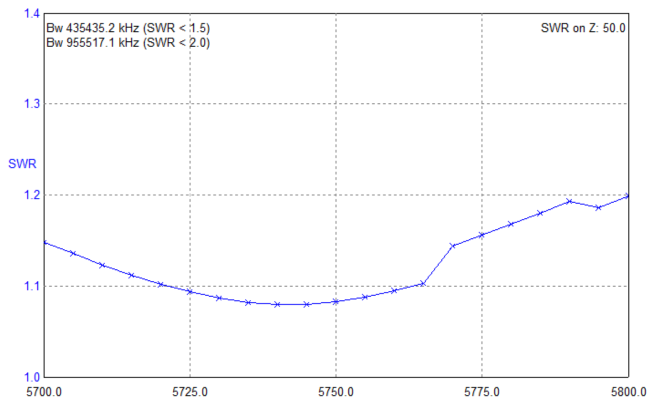

Fig. 16. Non-resonant LW antenna - simulated SWR.

"The variation of the resistive (R) and reactive (X) components of the impedance, obtained through simulation in the same 100 MHz frequency band" [4], as shown in Fig. 17.

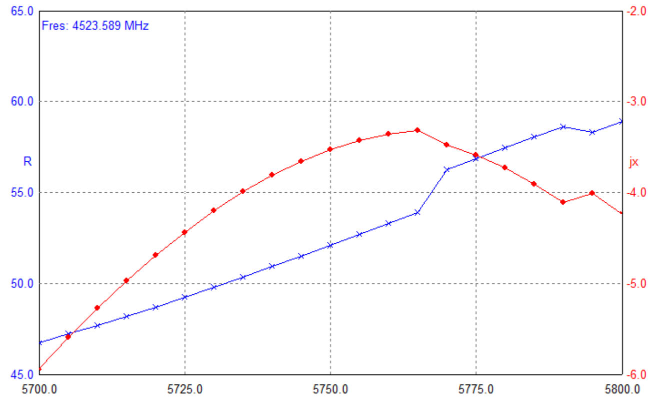

Fig. 17. Non-resonant LW antenna - impedance Z=R±jX components.

The Fig. 18 presents a comparison of the LW antennas: the total far-field radiation pattern in the XOZ plane of the resonant LW antenna is represented in red, while that of the non-resonant LW antenna is depicted in blue.

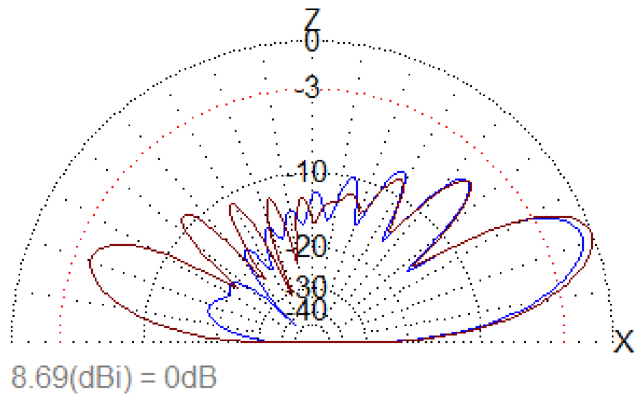

Fig. 18. The total far-field radiation pattern in the XOZ plane of the resonant LW antenna (red) and non-resonant LW antenna (blue).

The comparison of the simulated total radiation pattern in the XOY plane is illustrated in Fig. 19. The theoretical backward lobe attenuation, between the two antenna designs, is 12,8 dB.

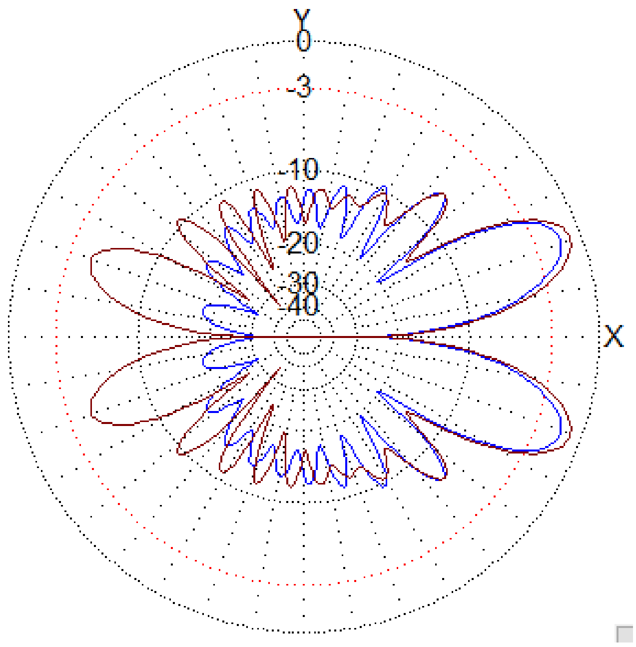

Fig. 19. The total far-field radiation pattern in the XOY plane of the resonant LW antenna (red) and non-resonant LW antenna (blue).

IV. Experimental Results

Following the simulation parameters and results, a prototype 5.5 GHz non-resonant long-wire test antenna was constructed (Fig. 20). The material chosen for the elements was silver-plated copper wire (CuAg), with a diameter of 2 mm for the radiator element and 1 mm for the radial elements. Radiator length L = 235 mm, top radials l = 17 mm.

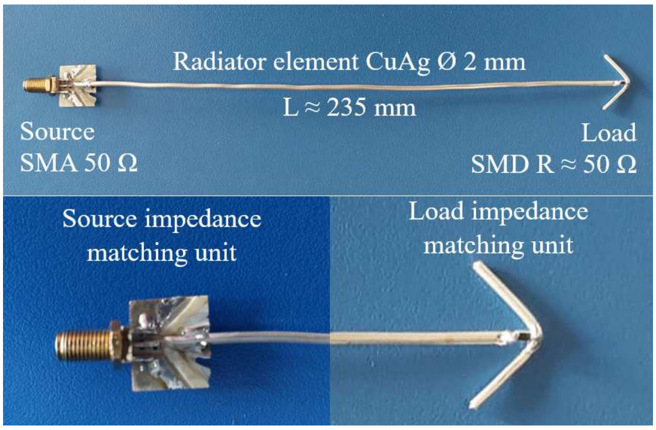

Fig. 20. The prototype of the non-resonant 5.5 GHz LW antenna (general view – upper image, the impedance matching networks - lower images).

The Agilent N9912A FieldFox RF Analyzer was used for SWR measurements. The bandwidth for a standing wave ratio (SWR) of 1.5:1 is approximately 500 MHz (Fig. 21).

The radiation pattern shape was qualitatively assessed in indoor environment. These measurements and tests validate that the proposed "non-resonant LW antenna behaves in accordance with expectations" [4].

V. Conclusions

"The long-wire antennas are among the most straightforward antenna structures that can provide directivity" [4]. One of the applications in view, is to use a non-resonant LW antenna as a feed for parabolic antennas.

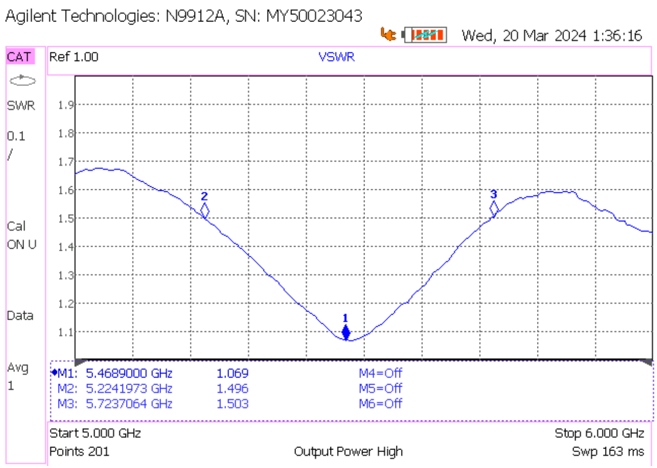

Fig. 21. Non-resonant long-wire antenna SWR measurement.

Classical parabolic antennas, also known as prime focus or on-set, have the central region of the reflector shaded by the feed placed in the focal point. The feed can be an antenna solely, or can comprise also associated electronics, in the form of a LNB (Low Noise Block). The LNB may consist in a simple LNA (Low Noise Amplifier) or a LNC (Low Noise Converter). In transmission mode, also a PA (Power Amplifier) can be placed in the focal point.

For a non-resonant LW, the conical shape of the main lobe of the radiation pattern, with a deep null along the symmetry axis, can be an advantage in terms of efficiency, when it is used as an antenna feed for prime focus paraboloid reflectors. The axial null of a non-resonant LW antenna, coincides with the central feed shadow on the paraboloid reflector. The wave polarization is radial in respect to the propagation direction (Poynting vector S), aspect which might be of importance in some applications.

An investigation was conducted on a non-resonant long-wire antenna operating in the 5.8 GHz band. Indoor testing confirms that the proposed antenna meets expectations.

The upcoming work entails designing and simulating a 10 GHz non-resonant LW antenna using HFSS, a 3D electromagnetic simulation software. The use of Rogers RT Duroid 5880 PCB is intended for the implementation of impedance matching networks, also anechoic chamber RF measurements are in view.

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