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HORIZONTAL SHORT MONOPOLE ANTENNA FOR RADIOSOLARIZ SOLAR RADIO TELESCOPE

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Abstract

This paper elaborates on the possible implementation of a horizontally shortened monopole antenna in broadband radio reception of radio emissions originating from the Sun. The spectrum of interest is in the low portion of the very high frequency (VHF) radio band. The frequency range extends down to the top end of the high frequency (HF) spectrum near $20\ MHz$ *and up to* $65\ MHz$*. The ionosphere is mostly radio-transparent to these radio waves, permitting observations of solar activity in the mentioned radio band.*

The proposed monopole antenna is an un-tuned wideband antenna suitable for reception only. This aerial is inadequate for the transmission of radio waves due to its low efficiency. Another prerequisite for implementing this antenna is the presence of high background noise – the background noise level commonly encountered in the low part of the VHF band, even in rural regions, is of the expected magnitude.

The suggested antenna has superior qualities than most other antennas suitable for the task. It shows benefits such as small dimensions, being hard to break, simplicity of construction, and consisting of a single element both electrically and mechanically. Other advantages of the proposed antenna include a very low cost of building and maintenance, straightforward operation, small weight, portability, an omnidirectional gain pattern in the plane perpendicular to the antenna element, and a uniformly and monotonically increasing smooth gain curve as a function of frequency.

This aerial has been built for the aims of the radioSolariz project (www.radiosolariz.space), which is a Bulgarian radio telescope project initiated in 2019 at the Space Research and Technology Institute – Bulgarian Academy of Sciences. The project is backed by a number of designs and innovations protected by patents and utility models registered at the Patent Office of the Republic of Bulgaria.

Introduction

This paper investigates the benefits of implementing a horizontal shortened monopole antenna for radio reception purposes of wideband radio emissions from the Sun in the lowest portion of the very high frequency (VHF) radio band. The observed frequency spectrum is from 20 MHz to 65 MHz. Any higher frequencies are out of band because the radio telescope demands isolation of at least 60 dB from the frequency modulation (FM) broadcast radio band starting at 87.5 MHz. This isolation is to be achieved through lumped element LC-filters.

At the same time, for the radio band of choice, the ionosphere is radio-transparent; thus, solar events emitting radio waves in the specified frequency range can be observed and investigated [1–3].

The antenna design disclosed in the current paper exhibits wideband reception capabilities. Being un-tuned, the aerial has its resonant frequency beyond or near the reception band's top end. For all other frequencies, the antenna is un-tuned and has a complex impedance. For this reason, the antenna is strongly unmatched and exhibits low efficiency within the working band. Hence, the aerial is suitable for receiving only. To overcome the low efficiency of the antenna, the used radio band has to possess background noise levels in excess of 30 dB than the receiver's noise floor [4, 5]. The reason for this is described later in the article. The VHF band satisfies this condition.

Here we summarize the advantages of the device:

1. Small size, hard to break, and portable
2. Resistant to weather conditions such as strong winds
3. Cheap and easy to build and operate
4. Omnidirectional in the plane perpendicular to the antenna element

This antenna is an advancement of the existing radioSolariz project, whose website is freely accessible on the World Wide Web [6]. The radioSolariz project is a Bulgarian solar radio telescope initiated in 2019 at the Space Research and Technology Institute – Bulgarian Academy of Sciences. The project involves a number of designs and inventions protected by pending patents and registered utility models at the Patent Office of the Republic of Bulgaria, along with publications in scientific journals and conference reports [7–9].

Antennas employed with the radioSolariz project

The telescope was envisioned as a novel distributed radio telescope for solar observations. The frequencies of interest were specified to be in the range from 20 MHz to 300 MHz. The first telescope version used a circularly polarized spiral antenna working in the frequency band from 110 MHz to 180 MHz and was implemented in a test prototype in the city of Sofia, Bulgaria. For the lower portion of the band of interest from 20 MHz to 87 MHz it was desirable to have the same spiral circularly polarized antenna. The idea was abandoned due to the prohibitively large size and cost of such an antenna. At the time of the first tests, the high background noise in the city of Sofia and the quiet Sun rendered our observations non-prolific. We also realized that in the urban environment, we lacked an antenna for the lower frequencies where the solar transient events have larger radio wave power [1–3].

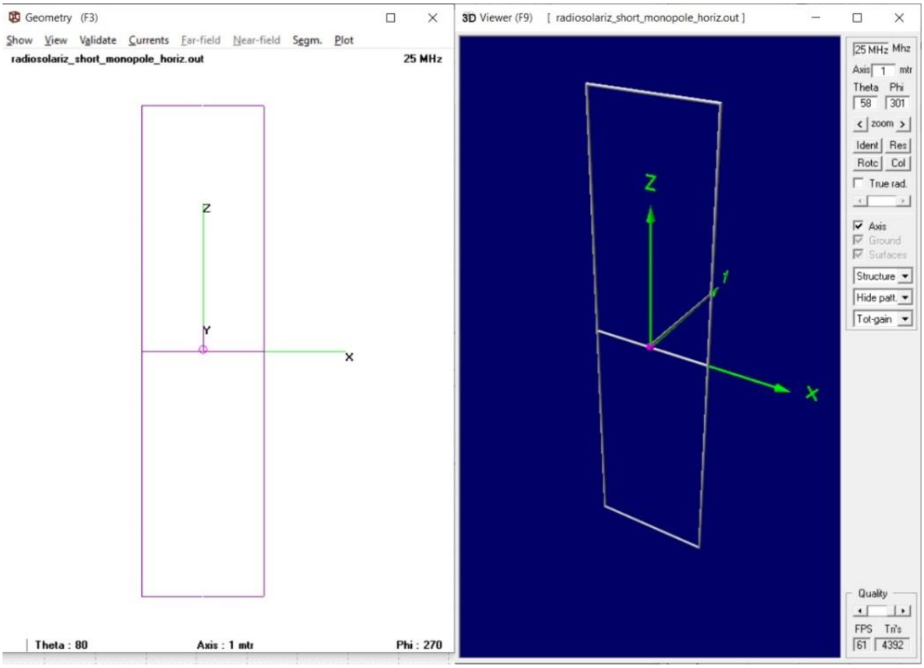

Fig. 1. Horizontal shortened monopole antenna design

The horizontal shortened monopole antenna design

The antenna required for the band from 20 MHz to 87 MHz has to be wideband and have small dimensions, preferably at a low cost, easy to build, and maintain. After conducting thorough research and experiments with magnetic loops, patch antennas, etc., we established a working design – a shortened monopole antenna. Initially we tested a vertical monopole [10]. In this article, we present a similar design, but with a horizontal element. This new design yields improved efficiency results.

The construction of the shortened horizontal monopole antenna mounted on a conductive structure, such as a balcony, is shown in Fig. 1. The aerial has been designed, calculated, and simulated using 4NEC2, a free antenna analysis software. The monopole element is positioned horizontally and is perpendicular to the plane encompassing the conductive grounded frame of opportunity. The latter may be a terrace, a window frame structure, etc. Such an approach, which utilizes existing structures, saves money and effort, and we only had to build the monopole element. The antenna is fed by a balance/unbalance (BALUN) impedance matching transformer (see Fig. 2).

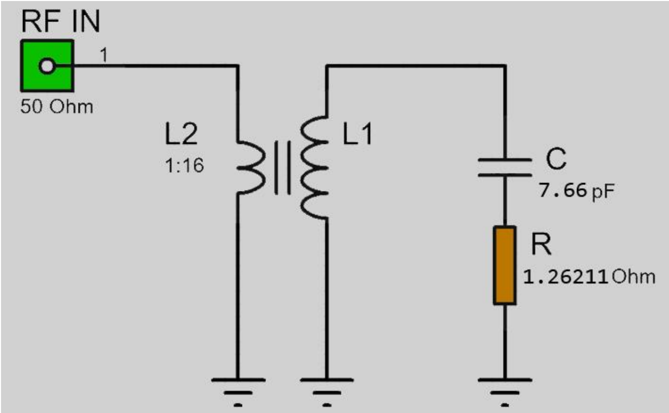

Fig. 2. Horizontal shortened monopole antenna equivalent schematic diagram at 20 MHz

The matching transformer is used to isolate the coaxial feedline from any present antenna imbalance and to match the antenna impedance to the receiver and feedline impedance.

Antenna properties

The antenna is calculated for the frequency band $20 - 65$ MHz. The active element is 1 m in length. Out-of-band frequencies are cut out through the use of an LC-lumped element bandpass filter. The filter has the task to suppress at least 60 dB the frequency modulation (FM) broadcast radio band extending from 87.5 MHz to 108 MHz. In this band, there are very large power electromagnetic emissions originating from the local broadcasting transmitters.

Fig. 3 (right) depicts a 3D-view of the aerial gain pattern near the lowest operating frequency – 25 MHz. The antenna has horizontal polarization. The axial ratio is excellent (see Fig. 3 – left). Fig. 4 shows the broadband characteristics of the device. The horizontal axes of all sub-charts start from 10 MHz and end at 80 MHz. At the lowest working frequency, the antenna characteristics are the worst. Here, at 20 MHz, the aerial has distinctively capacitive reactive impedance:

(1) $$Z = 1.26211 - j1039.4\ \Omega = R + jX;\ |Z| = \sqrt{R^2 + X^2} = 1039.4\ \Omega;$$
$$C = 7.66\ \text{pF}$$

The aerial equivalent circuit at 20 MHz may be represented with a resistor and capacitor in series (see Fig. 2). To match the antenna to feedline and receiver input impedance, a matching transformer is employed (see Fig. 4). The transformer is used to match the radio receiver and feedline impedance of $50\ \Omega$ to the higher aerial impedance for all working frequencies.

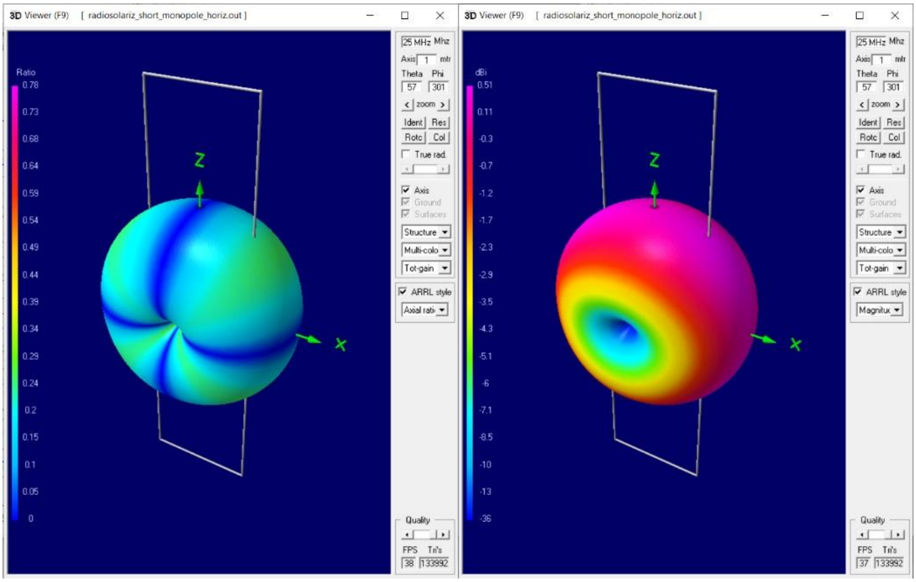

Fig. 3. Antenna axial ratio (left) and gain pattern (right) at 20 MHz

To find the best impedance transformation ratio k, we resolve the problem of maximizing power transfer from antenna to receiver. The closest equivalent resistance $R_e = k \times 50$ is chosen from the available transformers on the market. If the antenna voltage is V, then antenna current will be:

(2) $$I = \frac{V}{Z + R_e} = V\frac{R + R_e - jX}{(R + R_e)^2 + X^2};\ I^* = V\frac{R + R_e + jX}{(R + R_e)^2 + X^2}$$

Then we obtain the complex power S in volt-amperes $S = VI^* = II^*Z$ and real power P in watts $P = \mathrm{re}\,S = II^*R$.

The real power entering the receiver is a function of the receiver's equivalent impedance R_e:

(3) $$P(R_e) = II^*R_e = \frac{V^2 R_e}{(R + R_e)^2 + X^2}$$

This function has maximum value when:

(4) $$R_e = |Z| = 1039.4\ \Omega$$

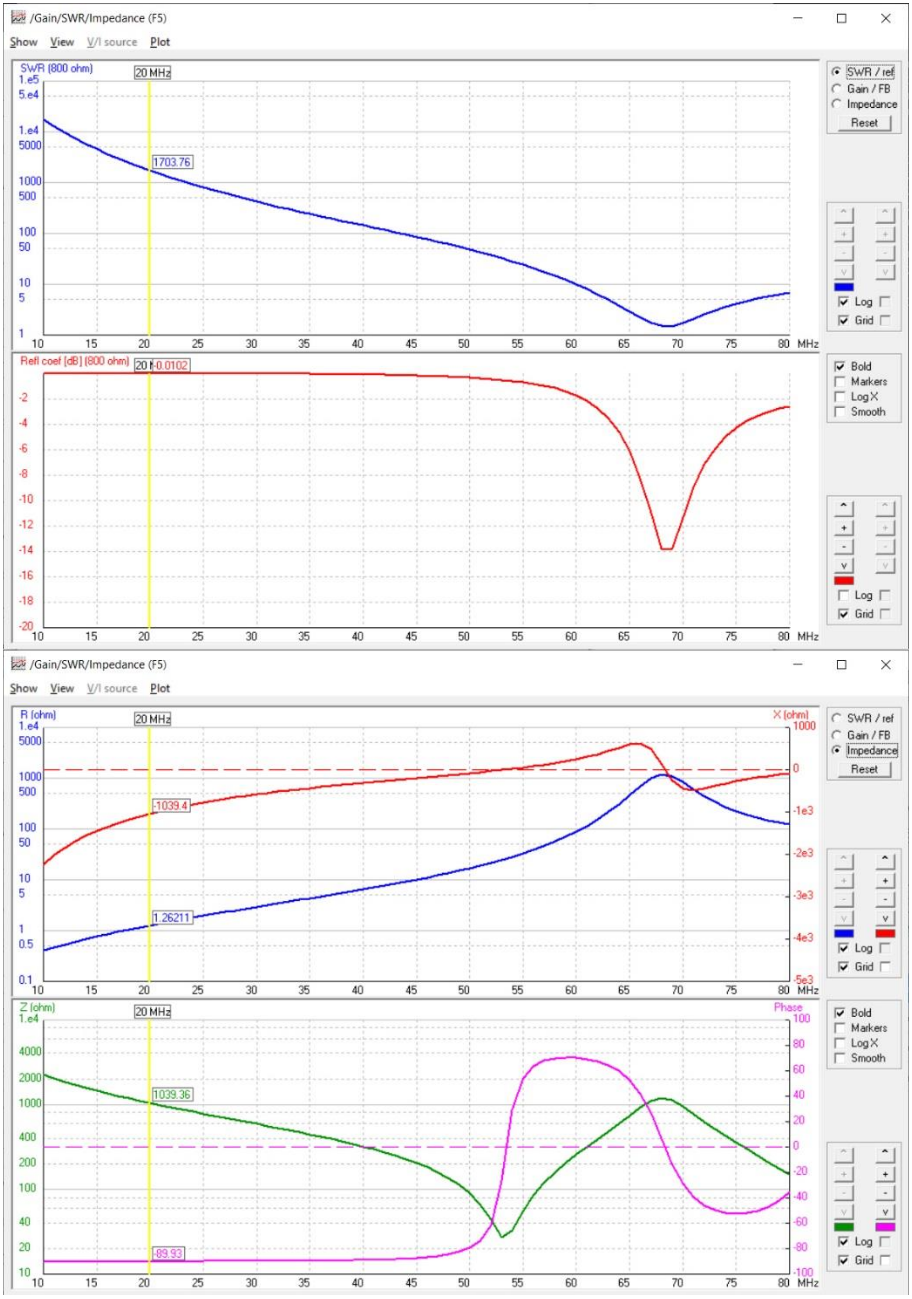

Fig. 4. Antenna parameters as a function of frequency

The nearest impedance obtainable through standard transformers is $800\,\Omega$ by employing an impedance transformation ratio of $1:16$. If we calculate the VSWR at 20 MHz from antenna impedance at the same frequency after impedance match, we obtain:

(5) $$VSWR_{20\,MHz} = \frac{1+|\Gamma|}{1-|\Gamma|};\ \Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}; |\Gamma| = 0.9988$$

$$VSWR_{20\,MHz} = 1703.85$$

Here Γ is the reflection coefficient, $Z_L = 800\,\Omega$ is the load impedance, and $Z_0 = 1.26211 - j1039.4\,\Omega$ is the source impedance. We should recall that Γ of -1 means short circuit load; Γ of $+1$ means open or disconnected load; Γ of 0 means a perfect impedance match. The power efficiency of the aerial at 20 MHz is:

(6) $$Eff_{20\,MHz} = 1 - |\Gamma|^2 = 0.002344$$

At 20 MHz the efficiency of the antenna is the lowest within its working range. At first glance, it seems extremely low being -26.3 dB. At the same time, we should consider the minimum expected background noise at 20 MHz being 22 dB above ambient thermal noise (thermal noise at 290 K). Further, we may take into account the urban environment background noise reaching 42 dB. At the same time, a general-purpose uncooled low-noise preamplifier yields 0.5 dB noise figure. This noise figure is equivalent to the amplifier noise temperature of 36 K or 9 dB below the ambient thermal noise floor of 290 K. Having these figures, we calculate our noise margin: $22 + 9 = 31$ dB between the input rural background noise and the radio receiver noise floor. We add the antenna gain of -26.3 dB to this number and obtain the total system noise margin: 4.7 dB. This is the noise margin between the input background noise and the radio receiver's noise floor. Being a positive value, this margin corresponds to a gain rather than a loss. Hence, the implementation of such an antenna is practical.

Conclusion

The design of compact, wideband antennas with excellent properties enables the radioSolariz project to continue to be an adequate solar radio telescope platform suitable for scientific experiments with solar radio wave emissions in the lower VHF radio band. Further innovations in solar radio telescopes are envisioned, including improvements to the receiver hardware and software.

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ХОРИЗОНТАЛНА СКЪСЕНА МОНОПОЛНА АНТЕНА ЗА СОЛАРНИЯ РАДИОТЕЛЕСКОП RADIOSOLARIZ

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Резюме

Настоящата статия разкрива възможното приложение на хоризонтална скъсена монополна антена в широколентовото радиоприемане на радио-излъчване от Слънцето. Спектърът на наблюдения се намира в ниската част на ултракъсите вълни (УКВ) и в самия горен край на късите вълни (КВ). Честотният диапазон на наблюдения започва от 20 MHz и свършва до 65 MHz. Йоносферата е почти радиопрозрачна в този честотен диапазон и позволява наблюдение на слънчевата активност.

Монополната антена представлява ненастроена широколентова антена подходяща за приемане, но неадекватна за предаване на радиовълни. Друго изискване за използване на антената е високо ниво на фоновия шум –

съизмеримо с фоновия шум, наблюдаван в ниската част на УКВ обхвата дори в тихи по отношение на радиовълните не-градски региони.

Предложената антена има по-добри характеристики от повечето други антени, подходящи за задачата. Тя демонстрира предимства като малки размери, трудна за счупване, простота на конструкцията, състои се от един единствен елемент, както в електрически план, така и в механичен план. Други предимства на предложената антена са много ниската цена за построяване и поддръжка, простота на използване, ниско тегло, портативност, всепосочност на усилването в равнината перпендикулярна на антенния елемент, еднообразна и гладка крива на усилването като функция от честотата и др.

Антената е построена за целите на проекта radioSolariz (www.radiosolariz.space), който представлява български радиотелескоп, иницииран през 2019 г. в Института за космически изследвания и технологии при Българската академия на науките. Проектът е подкрепен от редица дизайни и иновации, защитени в Патентно ведомство на Република България.