

RADIOSOLARIZ SOLAR RADIO TELESCOPE SHORT MONOPOLE ANTENNA

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Abstract

The current paper explores the possibility of implementing a shortened monopole antenna for the purposes of radio reception of broadband radio emission from the Sun in the low portion of the very high frequency (VHF) radio band. The frequency range of interest is the lowest band starting from the top high frequency (HF) spectrum near 20 MHz and extending to 65 MHz. In this range radio waves penetrate the ionosphere and observation of solar activities is feasible.

The proposed antenna is broadband, un-tuned, and receive-only and is suitable for reception in radio bands where the background noise is high, such as the low VHF band. The antenna exhibits numerous advantages over standard solutions. Among those are compactness, rigidity, low cost, ease of operation and maintenance, portability, uniform receiving characteristics and gain within the spectrum of interest.

RadioSolariz project (<http://www.radiosolariz.space>) 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.

Key words: solar radio telescope, wideband shortened antenna

Introduction. This article elaborates on the implementation of a shortened monopole antenna for radio reception of broadband radio emissions from the Sun

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in the lowest part of the very high frequency (VHF) radio band. The exact frequency range starts at 20 MHz and extends to 65 MHz. Any higher frequencies are not observed due to requirement for very good isolation from the frequency modulation (FM) broadcast radio band that begins at 87.5 MHz here in Bulgaria where the instruments are implemented.

The observed radio band is still high enough for the radio waves to be able to penetrate the ionosphere and certain solar events may be studied [1–3].

This antenna design ensures broadband operation. The antenna is not tuned to a certain frequency although the band of interest may or may not include a resonant frequency. The antenna is suitable for receiving only. Also, the radio band of reception needs to have around 30 dB larger noise level than the receiver's noise floor [4, 5]. This requirement is explained below. Low VHF band fulfils this requirement.

The antenna presents a number of benefits in comparison with standard solutions:

- Compactness
- Rigidity
- Wind resistance and low profile
- Low cost
- Ease of operation
- Ease and low cost of maintenance
- Portability
- Uniform receiving characteristics and gain within the band of operation

The current innovation is an update of the existing project radioSolariz. The website of the project is hosted online at a dedicated Internet site [6]. The radioSolariz system of hardware and software is a Bulgarian solar radio telescope started in 2019 at the Space Research and Technology Institute – Bulgarian Academy of Sciences. The project is backed by a number of novel designs and inventions presented in articles, conference papers and protected by pending patents and registered utility models filed at the Patent Office of the Republic of Bulgaria [7–9].

Current state of the radioSolariz solar radio telescope. The project was born in 2019 by a team of scientists at the Space Research and Technology Institute – Bulgarian Academy of Sciences. Current participants in the project come from two Bulgarian Academy of Sciences institutes – Space Research and Technology Institute and Institute of Astronomy and National Astronomical Observatory.

The instrument was designed as a novel distributed radio telescope system with the purpose of observing radio emissions from the Sun in the upper high frequency (HF) and the VHF bands encompassing frequencies from 20 MHz to 300 MHz. The first test version of the telescope as of September 2020 relied on a specialized antenna for circular polarization, both right-hand side circular polarization (RHCP) and left-hand side circular polarization (LHCP). The prototype

stage was tested in the city of Sofia at frequencies from 110 MHz to 180 MHz for which frequency portion a dedicated circularly polarized spiral antenna was calculated, simulated and built. A spiral circularly polarized antenna for lower frequencies was desirable but due to the prohibitively large dimensions of the device requiring extremely large facilities to host, and also very high cost to build and maintain, such an antenna was not developed.

The high background radio noise in the city of Sofia and the quiet Sun at the time of initial tests obstructed our observations. We needed to detect at lower frequencies where the solar transient events have larger radio wave power [1–3].

The shortened monopole antenna design. In the need for a more compact and simple low frequency antenna with uniform broadband characteristics we theoretically tested different shortened antenna designs such as magnetic loops, patch antennas, etc. The final decision to use a shortened monopole is due to its broadband characteristics and simplicity of design. The construction is shown in Fig. 1, while being designed, calculated and simulated in the free antenna analysis software 4NEC2. The monopole is positioned in one plane with a conductive rectangular frame connected to the ground. The latter is a window frame already available in buildings where we intend to install the antenna and a radioSolariz receiver. The benefit of this approach is that we rely on existing frames and build only the monopole element. Further benefit is that we attach the monopole to the inner surface of the glass of the window using the fact that the glass is radio wave transparent. Thus the antenna is protected from meteorological events. The maintenance efforts and cost are minimal. At the feeding point of the antenna there is a balance/unbalance (BALUN) impedance matching transformer (see Fig. 4). Its role is to isolate the coaxial feedline from the antenna imbalance and to adequately match the antenna impedance within the working bandwidth to the receiver and feedline impedance. This matching process is explained later in the current paper.

Antenna properties in respect to the requirements of the solar radio telescope. The antenna is calculated for the frequency band starting from 20 MHz and ending at 65 MHz. The active vertical element has length of 1 m. The conductive rectangular frame has dimensions of 1.65×0.86 m. Any higher and lower frequencies are cut using a bandpass filter. Special attention is paid to the FM broadcast frequency band from 87.5 MHz to 108 MHz where large electromagnetic power is emitted in and near the city of Sofia from local broadcasting transmitters. In most locations in Sofia there is line of sight to one or more transmitters having powers at one station of 10 kW. The significant gap between 65 MHz and 87.5 MHz simplifies the design of the bandpass filter and improves its rejection characteristics guaranteeing tuning-free filter with excellent pass band linearity and complete attenuation of the unwanted signals below the receiver sensitivity threshold.

Figure 2 (top) shows a 3D view of the antenna gain at frequency of 60 MHz.

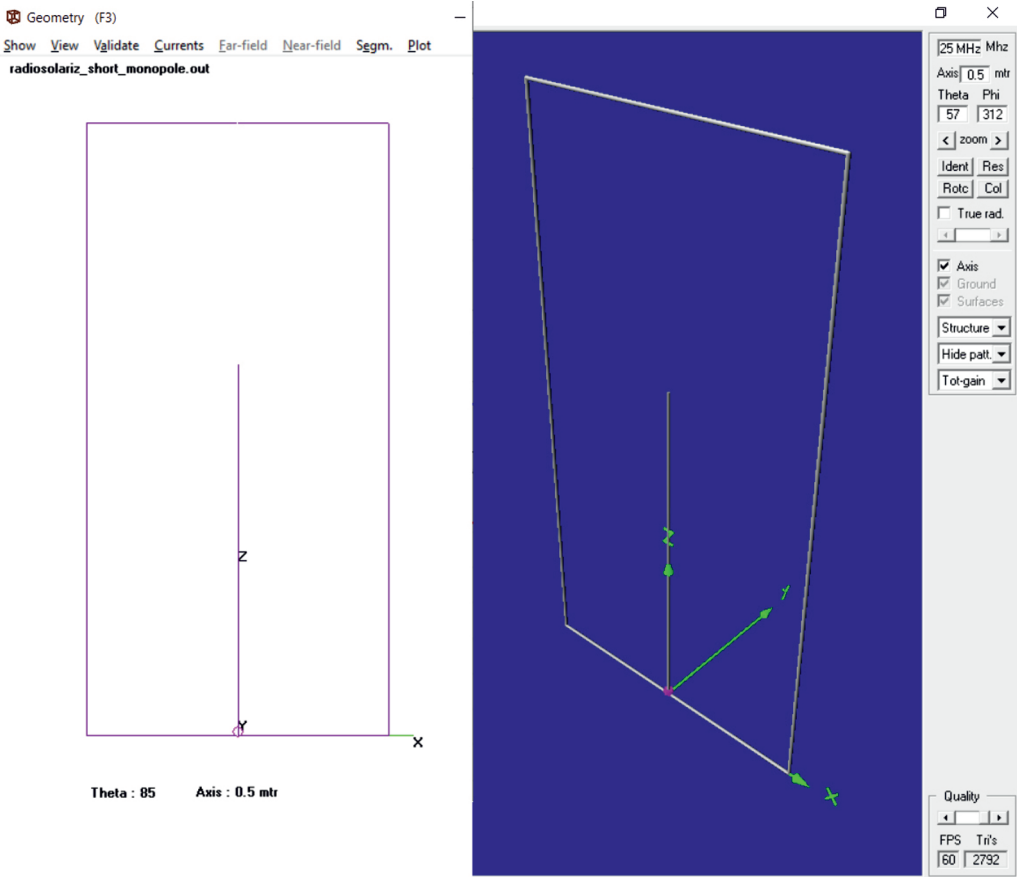


Fig. 1. Shortened monopole antenna design. The construction includes the monopole element with length 1 m and a conductive frame with dimensions 1.65×0.86 m

The antenna is almost omnidirectional with vertical polarization. Figure 2 (bottom) discloses the antenna axial ratio which is excellent. The worst axial ratio is established near the vertical axis and approaches the negligible value of 0.02.

In Fig. 3 we can observe the broadband characteristics of the antenna. The horizontal axes of the sub figures extend from 10 MHz to 80 MHz. Due to being shortened, the antenna characteristics at the lowest working frequency exhibit the worst values, namely around 20 MHz the antenna has pronounced capacitive reactive impedance:

$$\begin{aligned}
 (1) \quad Z &= 0.65474 - j990.88 \, \Omega = R + jX; \quad |Z| = \sqrt{R^2 + X^2} = 990.88 \, \Omega; \\
 X &= -j990.88 \, \Omega = -j \frac{1}{\omega C} = -j \frac{1}{2\pi f C}; \quad f = 20 \, \text{MHz} \\
 C &= \frac{1}{125\,663\,706 \times 990.88} = 8.03 \, \text{pF}.
 \end{aligned}$$

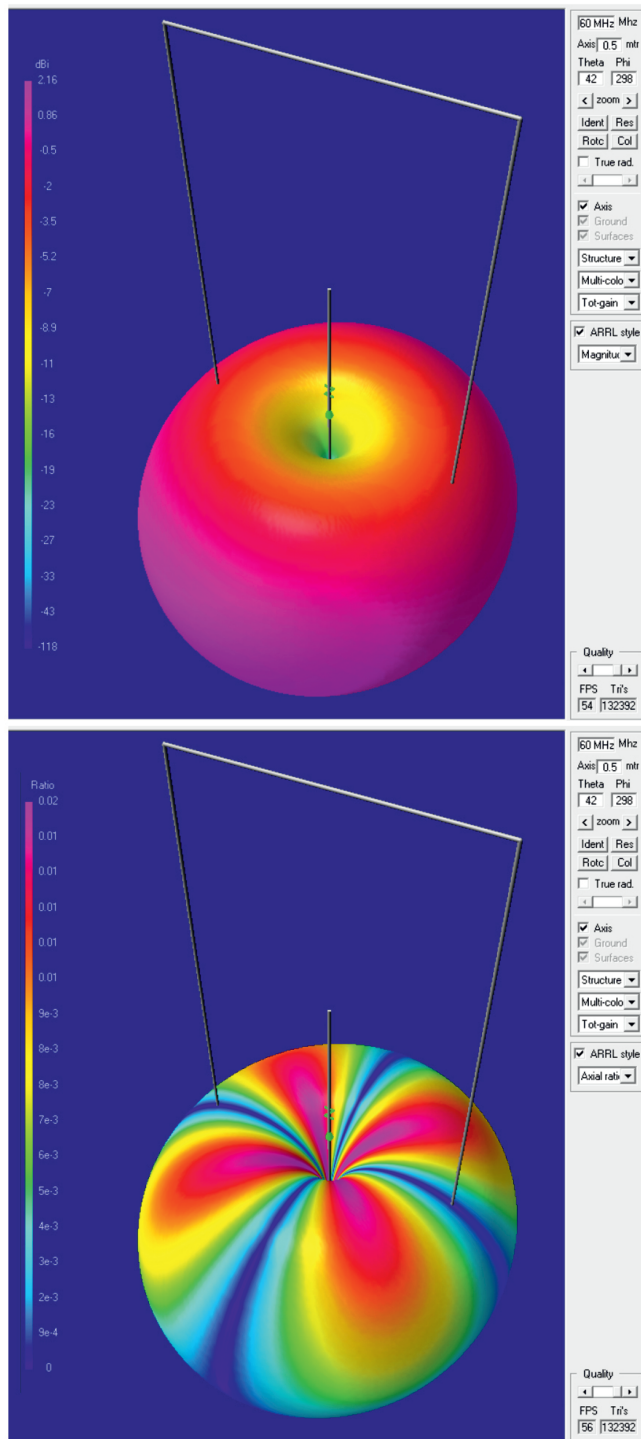


Fig. 2. Antenna total gain magnitude (top); antenna total gain axial ratio (bottom)

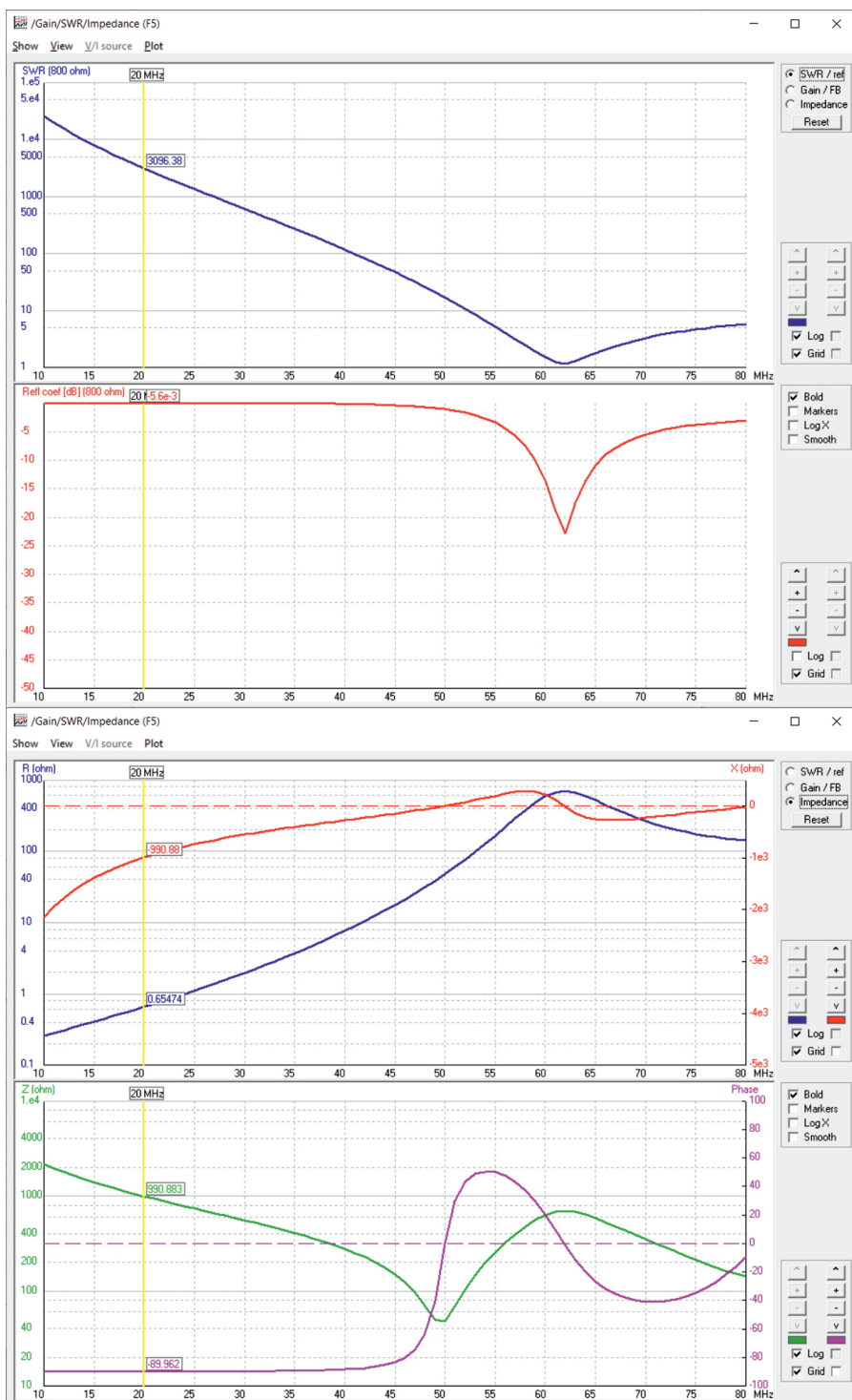


Fig. 3. Antenna parameters as functions of frequency

At 20 MHz the antenna may be represented by an equivalent circuit of a resistor and a capacitor in series as shown in Fig. 4 (top). To match the antenna to the feedline and the receiver input impedance, a matching transformer is employed (see Fig. 4). The function of the transformer is to transform the radio receiver input impedance and feedline impedance of $50\ \Omega$ to a higher impedance better matching the antenna for all working frequencies.

The ideal impedance transformation ratio k is found through solution of the problem of maximizing power transfer from antenna to receiver and the closest equivalent impedance $R_e = 50 \times k$ is selected from available real world transformers offered by manufacturers. Let the antenna voltage be V . Then the antenna current is:

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

Complex power S in volt-amperes is $S = VI^* = II^*Z$ and real power P in watts is $P = \text{re } S = II^*R$. Real power entering the receiver as a function of the receiver equivalent impedance R_e is as follows:

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

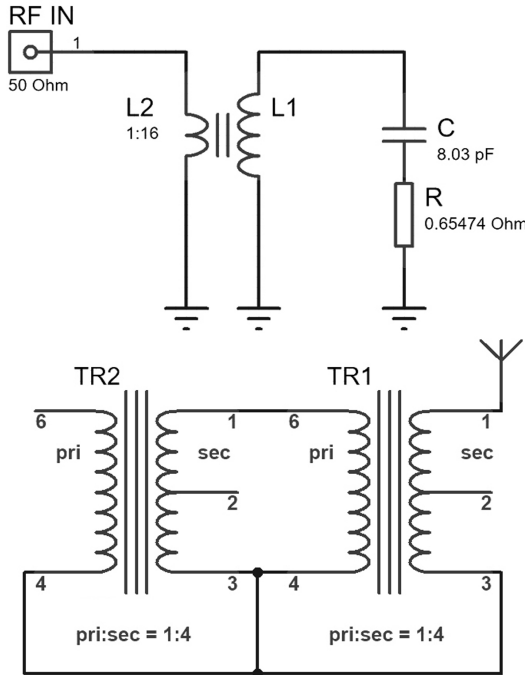


Fig. 4. Short antenna equivalent schematic diagram at 20 MHz (top); real transformer solution using two 1:4 impedance ratio transformers in series to form 1:16 impedance transformation ratio (bottom)

In order to obtain its maximum value we find its derivative:

$$\begin{aligned}
 (4) \quad P'(R_e) &= \left(\frac{V^2 R_e}{(R + R_e)^2 + X^2} \right)' \\
 &= \frac{(V^2 R_e)'((R + R_e)^2 + X^2) - V^2 R_e((R + R_e)^2 + X^2)'}{((R + R_e)^2 + X^2)^2} \\
 &= V^2 \frac{R^2 + 2RR_e + R_e^2 + X^2 - 2RR_e - 2R_e^2}{((R + R_e)^2 + X^2)^2} \\
 &= V^2 \frac{Z^2 - R_e^2}{(Z^2 + R_e^2 + 2RR_e)^2}.
 \end{aligned}$$

We find the root of the equation $P'(R_e) = 0 \Rightarrow R_e = |Z| = 990.88 \, \Omega$. The closest impedance we may obtain is $800 \, \Omega$ by employing a standard transformation ratio of 1:16. If we lack such a transformer, although it being standard, we may utilize two 1:4 transformers in series as shown in Fig. 4 (bottom).

The VSWR value at 20 MHz can be derived from antenna impedance at this frequency after the impedance match has been employed:

$$\begin{aligned}
 (5) \quad \text{VSWR}_{20 \text{ MHz}} &= \frac{1 + |\Gamma|}{1 - |\Gamma|}; \quad \Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}; \quad |\Gamma| = \left| \frac{799.34526 - j990.88}{800.65474 + j990.88} \right| = 0.99935, \\
 \text{VSWR}_{20 \text{ MHz}} &= 3096.35,
 \end{aligned}$$

where Γ is the reflection coefficient, Z_L is the load impedance, and Z_0 the source impedance. Γ ranges from -1 meaning short circuited load, to $+1$ indicating an open or disconnected load. Γ equals 0 in the case of perfect impedance match.

The obtained VSWR result is in accord with the calculated by the simulation software 4NEC2 value (see Fig. 3). In Fig. 3, the antenna match to $800 \, \Omega$ was already implemented in the simulation software 4NEC2. All wideband characteristics of the antenna were simulated at antenna load impedance of $800 \, \Omega$.

Finally, we may establish the power efficiency at 20 MHz:

$$(6) \quad \text{Eff}_{20 \text{ MHz}} = 1 - |\Gamma|^2 = 0.00129.$$

The efficiency of the antenna at 20 MHz is the lowest within the working frequency band and may seem too low being -28.89 dB . But the minimum expected background noise at this frequency is 22 dB over ambient thermal noise (thermal noise at 290 K). In urban environment the background noise may raise with another 20 dB or more. On the other hand, an uncooled general purpose low noise preamplifier exhibits noise figure lower than 0.5 dB , which is equivalent to amplifier noise temperature of 36 K or 9 dB below ambient thermal noise floor of 290 K . This gives a margin of $22 + 9 = 31 \text{ dB}$ between input background noise and radio receiver noise floor. Adding the antenna gain of -28.89 dB we obtain a

total system noise margin of 2.11 dB between input background noise and radio receiver noise floor. This noise margin is still a positive value which corresponds to gain instead of loss. The latter calculation proves that the implementation of such an antenna is feasible.

Conclusion. By designing, tuning and building a small sized broadband antenna having compact size and yet possessing excellent receiving characteristics, radioSolariz project shall be employed in observing the solar radio wave emissions in the near future. Further development and improvements are planned in the receiver hardware and software of the solar radio telescope.

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