



Estimation of Solar Observations with the Five-hundred-meter Aperture Spherical Radio Telescope (FAST)

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Abstract

We present the estimation of solar observation with the Five-hundred-meter Aperture Spherical radio Telescope (FAST). For both the quiet Sun and the Sun with radio bursts, when pointing directly to the Sun, the total power received by FAST would be out of the safe operational range of the signal chain, even resulting in damage to the receiver. As a conclusion, the Sun should be kept at least $\sim 2^\circ$ away from the main beam during observations at ~ 1.25 GHz. The separation for lower frequency should be larger. For simplicity, the angular separation between the FAST beam and the Sun is suggested to be $\sim 5^\circ$ for observations at 200 MHz or higher bands.

Key words: Sun: radio radiation – telescopes – techniques: miscellaneous

1. Introduction

Solar radio emission is related to hot plasma and magnetic activities in the solar atmosphere (Jursa 1985). With a brightness temperature of 10^6 – 10^{12} K (Maxwell 1965), the Sun is one of the strongest and closest radio sources in the sky.

There have been several radio telescopes or arrays with the capability of solar observations around the world (Mann 2010). Currently, arrays, such as LOFAR (van Haarlem et al. 2013), VLA (Lang & Willson 1979), ALMA (Bastian et al. 2018) and SKA (Nindos et al. 2019), have conducted observations of the Sun or have plans for solar-related sciences. Located at Mingantu, Zhengxiangbaiqi, Inner Mongolia, China, the Chinese Spectral Radioheliograph (CSRH, Yan et al. 2009) or Mingantu SpEctral Radioheliograph (MUSER, the name after its completion) has worked for years. It consists of 40 4.5 m-diameter dishes (covering a frequency range of 0.4–2.0 GHz, with spatial resolutions of $51''6$ – $10''3$) and 60 2 m-diameter antennas (covering 2–15 GHz, with spatial resolutions of $10''3$ – $1''3$) (Yan et al. 2021).

As the largest single dish radio telescope in the world, Five-hundred-meter Aperture Spherical radio Telescope (FAST) (Nan et al. 2011; Jiang et al. 2019, 2020; Qian et al. 2020) is now pushing China's radio astronomy forward to the frontiers in the fields including pulsars, fast radio bursts and interstellar medium. FAST covers some commonly used bands of solar observations, e.g., 100–240 MHz for non-thermal radio solar emission (Sharma et al. 2018) and 2.8 GHz which is related to solar extreme ultraviolet emissions on timescales of days or

longer (Covington 1947). Nowadays, the FAST 19 beam L -band receiver with a frequency range of 1.05–1.45 GHz is used. Its beam size is about $3'$, approximately one tenth the angular diameter of the Sun. The possible solar observation with this receiver can map the whole disk and atmosphere of the Sun. With its high sensitivity, FAST also has the potential to study short-timescale ($\sim 1 \mu\text{s}$ with a channel width of ~ 1 MHz) phenomena and track the evolution of ejected material from the corona to a lower brightness level.

The first and most important thing to consider is the safety of observation. In this study, we estimate the power from the Sun received by FAST, and check if the receiver will be damaged. The estimation of FAST solar observation is given in Section 2. The angular separation for proper observation of FAST is discussed in Section 3. The conclusions are provided in Section 4.

2. Will the Quiet Sun or Its Bursts Damage FAST?

Suppose that for a source with brightness temperature of T_b , the corresponding antenna temperature is T_a . The power that goes into the feed is then

$$P = kT_a \Delta\nu, \quad (1)$$

where $k = 1.3806 \times 10^{-23} \text{ J K}^{-1}$ is Boltzmann's constant, and $\Delta\nu$ is the bandwidth. Typically, for the L -band 19 beam receiver of FAST, $\Delta\nu$ is 400 MHz (1.05–1.45 GHz). In order to work in the linear range, the threshold of input power for this

receiver is roughly estimated as (Liu et al. 2021),

$$P_{\max} = -70 \text{ dBm} = 10^{-7} \text{ mW}. \quad (2)$$

This can be converted to an antenna temperature threshold as

$$T_{a,\max,l} = \frac{P_{\max}}{k\Delta\nu} \approx 1.8 \times 10^4 \text{ K}, \quad (3)$$

which depends on the bandwidth. As another threshold, the input power should be strictly lower than -52 dBm , otherwise the low noise amplifier would be damaged. This limitation corresponds to an antenna temperature of

$$T_{a,\max,s} \approx 1.1 \times 10^6 \text{ K}. \quad (4)$$

Since the angular size of the radio bright region of the Sun is usually larger than the FAST beam, there is no beam dilution. The antenna temperature equals the brightness temperature of the Sun.

If the bandwidth of the FAST receivers in the future is between 100 MHz and 1 GHz, the brightness temperature threshold for damage is between $\sim 4.5 \times 10^6 \text{ K}$ and $\sim 4.5 \times 10^5 \text{ K}$. The brightness temperature of solar radio emission in the quiescent state can be $\sim 10^6 \text{ K}$, while that of a burst may reach $\sim 10^9 \text{ K}$ or higher (Jursa 1985). Obviously, solar observation with either the current L -band 19 beam receiver or other possible FAST receivers would cause damage.

3. The Proper Angular Separation of FAST Beam from the Sun

Radio emission comes from the upper atmosphere of the Sun. The typical size of the radio bright region of the Sun during an outburst is $\sim 1^\circ$ (Chhabra et al. 2021).

According to the design and laboratory tests (Dunning et al. 2017), the power pattern of FAST can be approximated with

$$P_n(u) = \left[\frac{2^{p+1} p! J_{p+1}(\pi u D / \lambda)}{(\pi u D / \lambda)^{p+1}} \right]^2, \quad (5)$$

where J_{p+1} is the Bessel function of the $(p+1)^{\text{th}}$ order and $p=2$ is for the illumination of FAST feeds. Based on this theoretical beam pattern (see Figure 1), to ensure that the total power received lies in a safe range (Equation (4)), a bright region of the Sun with $T_b \sim 10^9 \text{ K}$ should be kept ~ 2 beams away from the main beam. To keep FAST working in the linear range (Equation (3)), the bright region should be kept ~ 5 beams away. In addition, the Sun should be kept further away to avoid damage from more extreme solar radio bursts, although they may be rare. A 10 beam ($\sim 0.5^\circ$, with beam size $\sim 1.22 \frac{\lambda}{D}$) separation would keep FAST working in the linear range during a 10^{11} K burst.

The diameter of the field of view of the FAST 19 beam receiver is approximately $30'$. To summarize, we suggest that the center of the Sun should be kept at least 2° away from the

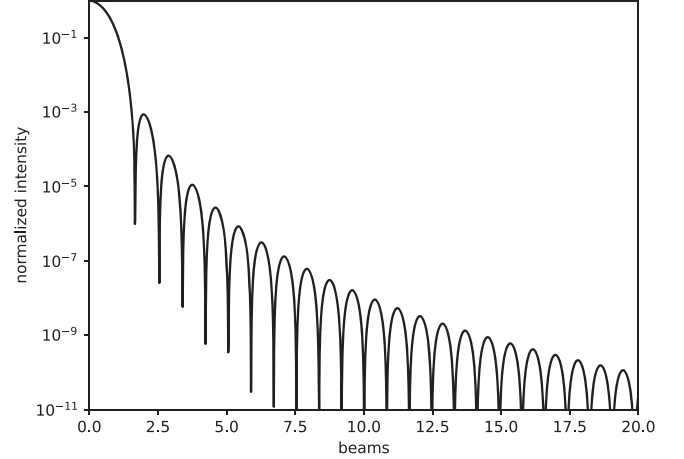


Figure 1. The approximate beam pattern of FAST.

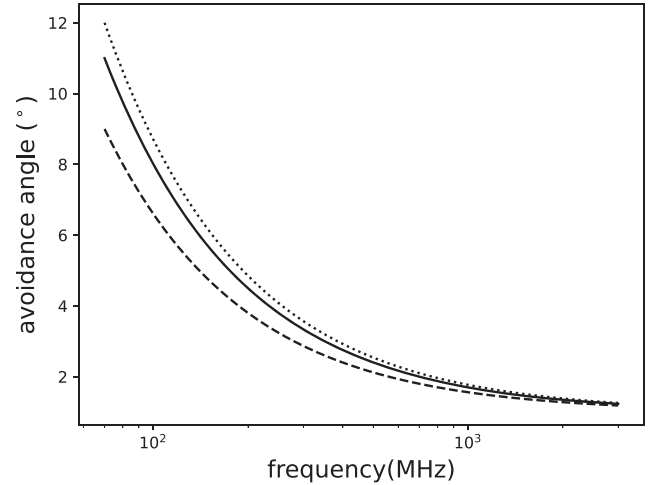


Figure 2. The proper separation between the Sun and the main beam of FAST, as a function of frequency, for a bandwidth of 100 MHz (dashed line), 400 MHz (solid line) and 1 GHz (dotted line).

main beam of the central element of the 19 beam receiver to avoid damage to the receiver.

The separation depends on the observing frequency (corresponding to the beam size) and the bandwidth (corresponding to the antenna temperature threshold). In the designed FAST frequency range (70–3000 MHz), it varies from more than 8° to around 1° (see Figure 2). It is clear that 5° is enough for observation above 200 MHz (Figure 2).

4. Conclusion

We have estimated the possibility of using FAST for solar observation. The conclusions are as follows:

1. Either the current *L*-band 19 beam receiver or other possible FAST receivers in the future will be damaged if the telescope directly points to the Sun.
2. Based on the beam pattern and safety considerations, we suggest that the main beam of FAST should be kept at least $\sim 2^\circ$ away from the Sun during observation when using the *L*-band 19 beam receiver.
3. The proper angular separation between the FAST beam and the Sun varies with observing frequency and bandwidth. For simplicity, a separation of $\sim 5^\circ$ for observation above 200 MHz is suggested for most FAST observations.
4. If one considers solar observation as a science goal of FAST, receivers should be specifically designed to deal with the large power received.

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