Postprint of the Upgrade and Retrofitting of the 2840MHz Solar Radio Flux Density Meter

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Abstract

The design features, performance, structure, and observational results of the upgraded 2,840 MHz solar radio radiation flux meter at the National Astronomical Observatories are described. The upgraded instrument will acquire solar flux at 2,840 MHz in real time with high temporal resolution, thereby accumulating extensive observational data for solar physics research and serving as one of the important parameters for solar activity monitoring and forecasting.

Full Text

Preamble

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Upgrading the Solar Radio Flux Telescope at 2840 MHz

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Abstract

This paper describes the design features, performance, structure, and observational results of the upgraded solar radio flux telescope at the National Astronomical Observatories. The upgraded instrument will obtain solar flux at 2840

MHz in real time with high temporal resolution, accumulating rich observational data for solar physics research and serving as an important parameter for solar activity monitoring and forecasting.

Keywords: radio astronomy; solar radio flux telescope; flux observation; radiometer

1. Introduction

Solar microwave radiation flux at 2840 MHz (10.7 cm) is one of the most important input parameters for space physics and is closely related to sunspot relative numbers. The 2840 MHz solar radio flux is also associated with high-energy electron and proton events, X-ray bursts, and high-energy particle events. Monitoring the 2840 MHz radio flux is therefore extremely important for studying solar activity patterns, solar long-term evolutionary behavior, establishing more sophisticated solar activity forecasting models, and advancing solar radio astronomy.

The 2840 MHz solar radio flux telescope at Huairou Solar Observing Station of the National Astronomical Observatories has participated in international network observations for over thirty years, providing continuous observational data to the International Solar and Geophysical Data Center and offering reliable data support for international solar activity forecasting. Long-term observations from this telescope have been used to study the similarity of solar cycle behaviors, including the start time and maximum activity intensity of solar cycle 24. Studies of the long-term activity behavior using 2840 MHz flux data have also revealed strong correlations between mid-to-short-term solar periodicities and planetary motions in the solar system.

As an important component of China' s Space Environment Monitoring Network, the 2840 MHz solar radio flux telescope has played a crucial role in providing space environment support for national aerospace missions. Located on the north bank of Huairou Reservoir at the Huairou Solar Observing Station, approximately 60 km from downtown Beijing (coordinates: 40.3°N, 116.6°E), the telescope exhibits distinct numerical characteristics that can be removed through mature data processing methods. However, due to aging components after years of operation, the instrument ceased observations. Given that this is the only single-frequency radio flux telescope in China and its significance for solar activity research, we conducted thorough investigations and completed a comprehensive upgrade of the 2840 MHz solar radio flux telescope.

2. System Upgrade Overview

The upgraded system includes improvements to the microwave front-end, analog receiving system, digital acquisition system, storage and display system, and the 2 m parabolic antenna. The new equipment employs an image-rejection superheterodyne receiver scheme, a K-factor radiometer, and new calibration techniques, making calibration more efficient and reliable. The upgraded telescope has already obtained excellent observational results. As a highly automated space detection instrument, the solar radio telescope system can operate continuously around the clock with high reliability, featuring automatic data acquisition, calibration, and transmission capabilities.

shows the system specifications of the upgraded solar radio flux telescope at 2840 MHz.

Table 1. System specifications of the upgraded Solar Radio Flux Telescope working at 2840 MHz

Parameter	Value
Output IF bandwidth	10 MHz
Time resolution	1 ms / 1 s
Step attenuator range	0 ~ 31 dBm

3. Receiver Design

Solar radio flux at 2840 MHz is primarily used for studying long-term solar activity behavior and solar forecasting, requiring high measurement precision and data stability. During this upgrade, we adopted an image-rejection superheterodyne receiver scheme to effectively suppress interference and ensure instrument sensitivity and stability.

In recent years, short-term solar activity behavior has received increasing attention from solar physicists. To meet these scientific requirements, we implemented methods to improve data dynamic range, including step attenuators and logarithmic amplifiers. The system structure is shown in [Figure 1: see original paper].

Figure 1. Block diagram of the upgraded Solar Radio Flux Telescope working at 2840 MHz

3.1 Image-Rejection Superheterodyne Receiver

The receiver employs an image-rejection superheterodyne design with a surface acoustic wave (SAW) bandpass filter at 2840 MHz. With an intermediate frequency bandwidth BW = 10 MHz and IF frequency f_{IF} = 225 MHz, the filter achieves a rectangular coefficient close to 5% and out-of-band attenuation of 20-30 dB, effectively suppressing image frequency interference and out-of-band interference, as well as low-frequency interference such as 50 Hz power line noise.

3.2 High Dynamic Range Design

To achieve large dynamic range, we employed two methods: step attenuators and logarithmic amplifiers. The system uses a digitally controlled step attenuator with maximum attenuation of 31 dB to adjust IF output signal levels, controlled automatically by computer. The attenuator method provides higher precision for quiet Sun and small burst observations, but large bursts may cause data jumps due to the 31 dB attenuation steps. While computational processing can restore continuous variation characteristics, precision is somewhat reduced. The logarithmic amplifier method provides continuously varying records, particularly suitable for recording large bursts with 0.2 dB precision.

4. K-Factor Radiometer

The K-factor radiometer is a new type of radiometer developed based on principles by German astronomers. It operates in total power mode to measure calibration constants. The 2840 MHz solar radio flux telescope employs a K-factor radiometer with integrated modulated noise source for antenna temperature calibration. After upgrading, this enables simultaneous automatic observation and temperature calibration, improving calibration precision.

4.1 Principle

[Figure 2: see original paper] shows the block diagram of the K-factor radiometer, with component codes and symbols listed in .

Figure 2. Block diagram of the radiometer for the K-factor measurement

Table 2. Component codes and symbols in the block diagram

Component Code or Symbol	Description
RF/IF alternating quantity peak-to-peak value	
RF/IF direct current component	
RF/IF noise temperature	

4.2 Basic Relationships

The noise components and time-varying states at the antenna aperture of the K-factor radiometer are illustrated in [Figure 3: see original paper].

Figure 3. Diagram of the noise components and time-varying state for the antenna of the radiometer with the K-factor measurement

Assuming an ideal square-law detector and linear amplifier operation, the two output channels relate to temperature T as follows:

When observing a radio source:

$$V = k_0 GKT$$

When pointing to background:

$$V = k_0 GT$$

The K-factor is:

$$K = \frac{V_{\text{source}}}{V_{\text{background}}} = \frac{CK - T_{\text{background}}}{C - T_{\text{background}}}$$

4.3 Calibration Process

In practice, we first obtain the flux S of the Sun and other radio sources using other radio telescopes for comparison. After determining the calibration constant C, we observe both the Sun and background. Using the equations above, we can derive the solar flux value, converting relative measurements to absolute measurements. The calibration constant C is input into the calibration software as a configuration parameter.

The working parameters of the K-factor radiometer are shown in .

Table 3. Working parameters of the radiometer with the K-factor measurement

Parameter	Value
Antenna temperature (quiet Sun)	774 K
Receiver noise temperature	290 K (NF = 3 dB)
Total insertion loss	0.89 (-0.5 dB)
IF bandwidth	10 MHz
System noise temperature	804 K
Theoretical sensitivity	0.031 sfu

5. Computer System and Software Functions

The computer system controls the step attenuator based on A/D values, acquires monitoring voltages (DC output V_{DC}, AC output V_{AC}, and logarithmic amplifier output V_{log}), and preprocesses data. Both standard and logarithmic data can be displayed and recorded simultaneously. The observation software interface for the upgraded 2840 MHz solar radio flux telescope is shown in [Figure 4: see original paper].

Figure 4. The interface of the observation software

The software displays real-time solar flux, shows daily solar flux variations, and converts logarithmic values to ratio displays. It stores data with standard integration times of 1 ms (.nwm files) and 1 s (.nws files). Millisecond-level files use integer data storage with 2-byte headers and observation data, with each sampling point represented by 2 bytes. Daily data volume is approximately 56 MB for millisecond files and 60 KB for second-level files when observing 12 hours per day.

Observations began in 2010, and the equipment was upgraded in 2014. The data have been continuously accumulated for over three decades and are regularly released at the National Astronomical Observatories Solar Data Center (http://csr.bao.ac.cn/data/), where users can freely download them.

6. Observational Results

Using the upgraded radio flux telescope for solar observations, we successfully observed an X2.2 class flare event on February 15, 2011. This was a typical long-duration radio burst event with complex multi-peak structures corresponding to the same event. Rich fine structures such as zebra patterns and slow drift features were observed in spectral observations at this frequency.

Figure 5. The X2.2 solar flare on Feb. 15 observed with the new system

7. Conclusion

This paper introduced the upgrade of the 2840 MHz solar radio flux telescope at Huairou Observing Station of the National Astronomical Observatories. The new equipment employs a K-factor radiometer and new calibration techniques, improving antenna observation performance and upgrading the microwave front-end, analog receiving system, digital acquisition system, and storage/display system. These data are significant for studying flare physical dynamics, solar activity patterns, and long-term solar evolutionary behavior, providing rich observational evidence for related research.

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Note: Figure translations are in progress. See original paper for figures.