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Meter to Decameter Wave Spectral Radio Heliograph

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Abstract

To detect the solar intense activities including the solar flare, Coronal Mass Emission(CME), interplanetary shock wave, non-thermal particles, solar winds, etc. in the interplanetary space, a meter-decameter wave spectral radio heliograph has been proposed as one of the main instruments for Meridian II project in China. It can achieve the solar imaging at the frequency range from meter to decameter with the capability of high-temporal, high-spectral and high-spatial resolutions. To serve the space weather study, this radio heliograph can monitor fully the disturbance sources produced by the solar radio bursts in the interplanetary space.

1 Introduction

Solar flare, coronal mass ejections (CME), interplanetary shock waves and high-energy particle events, induced by the solar radio bursts, are called as solar electromagnetic storms, the super solar radio burst will produce a series of disastrous effects on the space weather. Therefore, it is important to investigate and grasp the laws of the occurrence, development and activity of these events, not only for space sciences, but also for the mankind society development. Solar radio observations provide important diagnosing tool on the related parameters, like the magnetic field, plasma temperature, electron density, etc.

The density model of solar heliosphere [1] directly relates the frequency of the burst emission to coronal height: higher frequencies originate closer to the surface, while lower frequencies originate further out. Solar radio imaging spectroscopy can therefore provide detailed information of the movement of plasma through solar surface and out into interplanetary space. Solar radio emission over metric and decametric wavelength range is important for addressing the problems of CME acceleration, interplanetary shock and solar wind departure zone. Until now there are several solar radio instruments operating at this frequency range such as the Nancay radioheliograph (NRH) in France [2], the low frequency array (LOFAR) in the Netherlands [3], and the Murchison widefield array (MWA) in Austrilia [4], etc. However, among these radio instruments, some of them can only image the sun at several frequencies though they are dedicated solar arrays (NRH), some of them cannot do the daily solar observation as they only have few time for the sun (LOFAR & MWA). Therefore, a dedicated spectral radio heliograph working at meter to decameter is high required not only for the solar physics studies, but also for the space weather studies.

2 System Description

In inner Mongolia, we are operating a solar radio heliograph (MUSER), which is a solar dedicated radio interferometric array. MUSER contains 40 antennas of 4.5 m diameter and 60 antennas of 2 m diameter for different frequency bands respectively. All the 100 antennas of MUSER locate on 3 log-spiral arms, and the maximum baseline length for MUSER is 3 km [5]. Based on the MUSER, we proposed a meter to decameter wave spectral radio heliograph, it consists of 100 Log Periodic Dipole Array (LPDA) antennas. Due to the dense configuration of the antenna at MUSER center, the LPDA antennas of this new array cannot be installed there (no more space). Some of them will be installed along the same spiral arms with MUSER, and the other antennas locate centrally at the north-west of the MUSER center as shown in Figure 1.

To achieve good phase and flux calibrations for this array system, there are 80 more LPDA antennas employed to calibrate this array. Unlike the 100 antenna of this array, the 80 antennas will be divided into some groups, and the signals of them will be combined by beamforming.

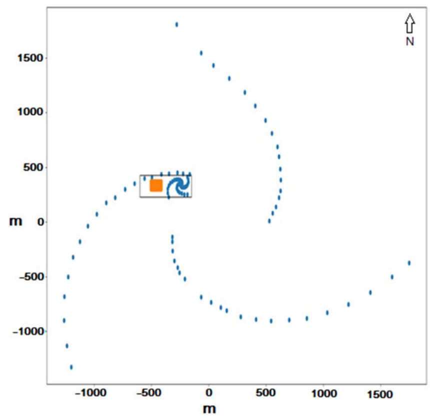

Figure 1. Array configuration of meter-decameter wave spectral radio heliograph. The yellow block represents the 80 LPDA calibration antennas. In the right of it are the central antennas of this array.

The radio signals detected by the array antennas will be transmitted via optical fibers to indoor receivers including analog receiver and digital receiver. In order to reduce the phase differences and variations between the different signal chains, all the optical fibers are buried underground with the same lengths. The analog receiver will amplify and filter the signal induced on the antenna to a proper level with desired bandwidth for sampling. The output signal will be sampled and processed by a digital receiver. The whole system is controlled and synchronized by a monitoring and control unit.

System Characteristic	Values
Frequency	30MHz－240MHz
Antenna	100 LPDA antenna
Frequency Resolution	1MHz~5MHz
Temporal Resolution	100ms
Spatial Resolution	1.7’@240MHz
	14.0’@30MHz
Polarization	I、Q、U、V

Table 1. System specifications

The main frequency band of the antenna system is from 30 to 240 MHz. Besides, it can also cover the frequency from 240 to 400 MHz, which will make it possible to observe the sun at the ultra-wide frequency range from 30 MHz to 15 GHz with MUSER together. To achieve the scientific studies, the frequency resolution of 3-5% central frequency, temporal resolution of subsecond, and high spatial resolution are required to obtain the location and the detailed source structure at this frequency range [6].

3 Antenna

The new radio heliograph require that the antenna can cover the frequency band from 30 to 240 MHz, and have a gain of 5 dB to do the dual-polarization observations.

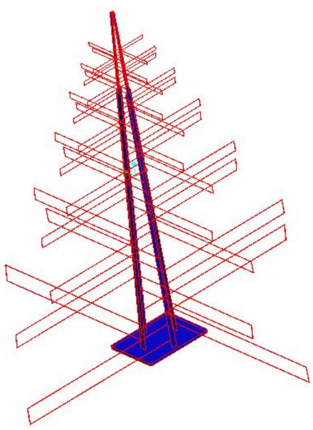

Figure 2. Basic design of the LPDA prototype antenna

With the considerations above, a LPDA prototype antenna has been designed and optimized to meet the requirements as shown in Figure 2. This antenna consists of a 6 dipole designed to be fed by a differential low noise amplifier (LNA), for minimum noise in order to achieve maximum sensitivity in the desired Field of View (FoV). The whole dimension of the antenna is about 3.0m (L)×3.0m (W)× 3.0m (H), which is much smaller than the normal half-wavelength dipole. The gain of the antenna is more than 5 dB above 47MHz, which meets the antenna gain requirement of 5dB for the new radio heliograph. Although the gain is lower than 5dB below 47 MHz, it is acceptable due to the quite small size of the antenna.

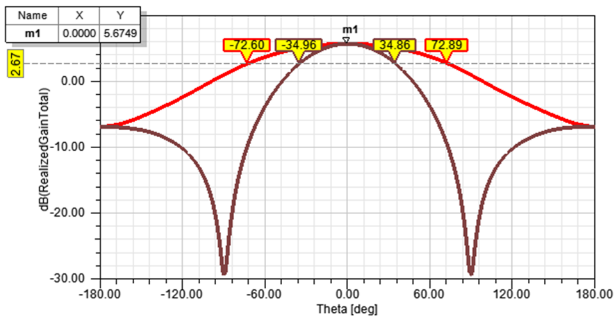

Figure 3. Gain patterns at 50 MHz for the prototype antenna. Red and brown lines denote H-pland and E-plan respectively.

4 Receiver

The general receiver for the radio heliograph contains all the instruments except the antenna. In order to describe it easily, we divide it into analog and digital receivers.

4.1 Analog receiver

The analog receiver includes all the related instruments between the antenna and digital receiver (Figure 4).

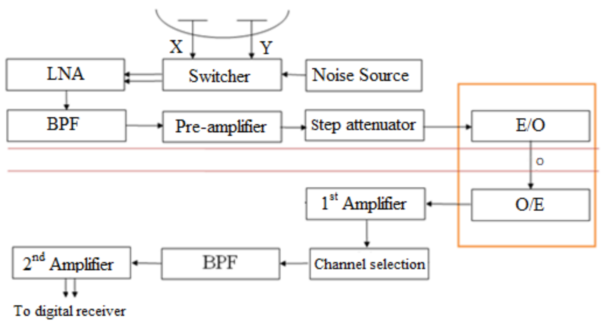

Figure 4. Analog receiver schematic

As mentioned before, the antenna is fed by a differential LNA with a low noise figure of less than 1.5 dB. A noise source is used to calibrate the signal chain. Both of the two polarization signals induced on the antenna will be received at the same time. Band-pass filters are used to obtain the signal with a desired frequency band. In order to keep the signal at suitable power levels, a pre-amplifier and step attenuator are employed to adjust the system gain. An optical transmitter converts the radio signal to optical signal, which will be transmitted to the receiver indoor via optical fiber. Accordingly, an optical receiver converts the optical signal to radio signal indoors. The amplifiers, band-pass filters, and switchers will be then designed to amplify the signal at the desired frequency band, which will produce the intermediate frequency (IF) signal for the digital receiver.

The analog receiver for the 80 calibration antennas is different from the 100-antenna array. After the LNAs and pre-amplifiers, the signals of calibration antennas will be grouped and combined to make the analog beamforming. Several beams can be achieved by changing the fixed delay lines between different antennas. The beamforming signals for each group will be then sampled to do the digital beamforming further.

4.2 Digital receiver

All the analog IF signals from 100 LPDA antennas will be sampled by the A/D convertor operating at 250 Million Samples per Second (MSPS). The digital signals are then channelized by a polyphase filter to 512 channel outputs simultaneously, which can be summed to obtain subband signals with a frequency bandwidth of 1-5 MHz. These subband signals will be finally auto-correlated and cross-correlated between all the array antennas to get the array visibilities for imaging. All the auto and cross correlation results for each subband will be output together with some additional information including time, frequency band ID, polarization, etc. The output data produced by the digital receiver will be stored in a hard disk array for further offline processing. The schematic of the digital receiver is shown in Figure 5.

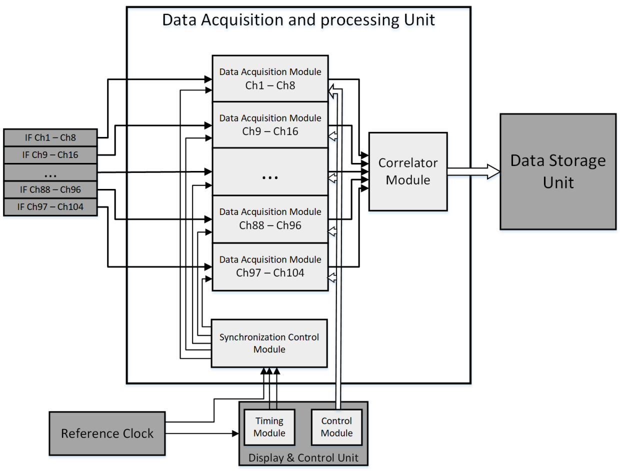

Figure 5. Digital receiver schematic

Unlike the digital receiver above, the digital receiver for the 80 calibration antennas will not sample the signal from each antenna, but the beamforming signal from each antenna group. The sampled signals from all the groups will be summed for the digital beamforming. In order to calibrate the array, the summed signal will be sent to the correlator receiver of the 100 antenna array. Besides, the summed signal can also be processed further to obtain a desired spectrometer.

5 Monitoring and control unit

The monitoring and control unit is the control core of the whole system, and it is also the key the man-machine interaction and communication interface among the system, the operator and the remote control terminal. It is composed of the timing sequence generator, instruction distribution module and switch, etc., and responsible for generating and distributing the control signals. Meanwhile, it regularly queries the system state and returns the system running state.

As shown in Figure 6, the monitoring and control unit use a high performance industrial computer as the master control platform, mainly including the following modules: antenna servo control and status display module, front-end and microwave switch control and status display module, analog receiver control and status display module, digital receiver control and status display module, reference clock control and status display module, timing control signal control and distribution module, etc.

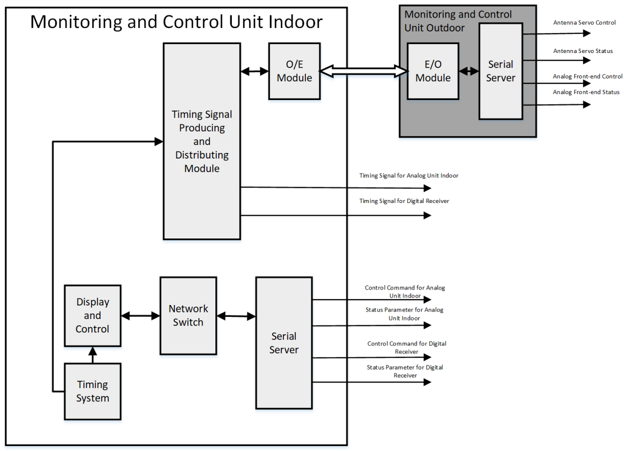

Figure 6. Interface schematic for the monitoring and control unit.

6 Summary

In this paper we proposed a meter to decameter wave spectral radio heliograph for Meridian II project in China. It consists of hundreds of LPDA antennas locating at three spiral arms. The signals detected by the antennas are amplified and transmitted to the indoor receivers via the optical fibers. With the design described above, this solar radio array is capable to monitor and image the sun with high-temporal, high-spectral and high-spatial resolutions. Furtherly, it can extend the dedicated solar radio imaging from centimeter to decameter wavelength with MUSER together.

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8 References

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