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RFI measurements and mitigation for FAST

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Abstract Radio Frequency Interference (RFI) mitigation is essential for supporting the science output of Five-hundred-meter Aperture Spherical radio Telescope (FAST) due to its high sensitivity. In order to protect FAST from RFI, an Electromagnetic Compatibility (EMC) study has been carried out and the operation of a Radio Quiet Zone (RQZ) is ongoing. RFI measurements of the telescope instruments and monitoring of the active radio services outside the site have revealed the radiation properties of the RFI sources. Based on the measurement results and theoretical analysis, various EMC methods have been implemented for the telescope to decrease the RFIs. Meanwhile, the main RFI sources in the FAST RQZ, such as mobile stations, broadcast stations and navigation instruments, have been identified, and the technical measures have been adopted to protect the quiet radio environment around the site. The early science outputs of FAST have demonstrated the efficiency of RFI mitigation methods.

Key words: radio telescope: FAST — radio frequency interference — measurement — mitigation

1 INTRODUCTION

Five-hundred-meter Aperture Spherical radio Telescope (FAST) is now in the commissioning stage since its construction was completed in 2016 (Nan et al. 2016). Till now, more than 50 new pulsars have been discovered. However, due to its high sensitivity, FAST is very susceptible to Radio Frequency Interference (RFI) from the electronic instruments integrated with the telescope and active radio services around the FAST site. Based on ITU-R Recommendation RA.769 (RA7 2003), the RFI protection threshold of FAST has been achieved, and has been implemented to assess the influence from Electromagnetic Interference (EMI) and RFI outside the site. The comparison indicates that the protection threshold for spectral observation of FAST is much lower, about 100 dB weaker than the National Electromagnetic Compatibility (EMC) standard of GJB151A (GJB 1997).

In order to protect FAST from RFI, systematic and integrated RFI mitigation methods have been implemented during the design and construction stages. The main task consists of two parts. The first part of the task focuses on the EMC design and realization (Zhang et al. 2016), and the second part of the task is to maintain Radio Quiet Zones (RQZs) and protect the quiet radio environment around the site (Zhang et al. 2014). In the following sections, the RFI identification and measurements, methods that strongly mitigate EMIs from the instruments, and the compatibility study between FAST and active radio services will be described.

2 RFI MEASUREMENTS

2.1 EMI Measurements of the Telescope Instruments

As the first step, the main RFI sources of the telescope have been identified system by system. For instance, about 2300 actuators attached to the reflector, the drives and controllers of the cable suspension system, various electronic instruments inside the feed cabin, the total stations of the measurement system, the instruments in the laboratory, and the supporting facilities of the observatory have been assessed. Such typical RFI sources have been measured in a microwave chamber to assess the properties of EMIs. An example of EMI measurement results of one total station is displayed below (Fig. 1), which reveals wide and strong EMIs covering the wide frequency bands. Therefore, EMC methods are essential for FAST to mitigate the EMIs from the telescope itself and assure science output.

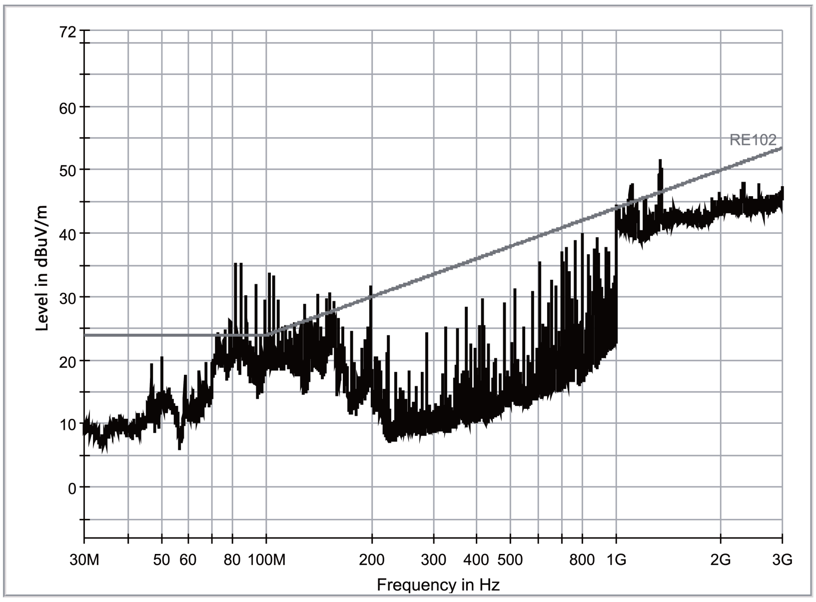

Fig. 1 EMI measurement of one total station in the microwave chamber. The *straight line* on the map indicates the National EMC standard of GJB151A (RE102).

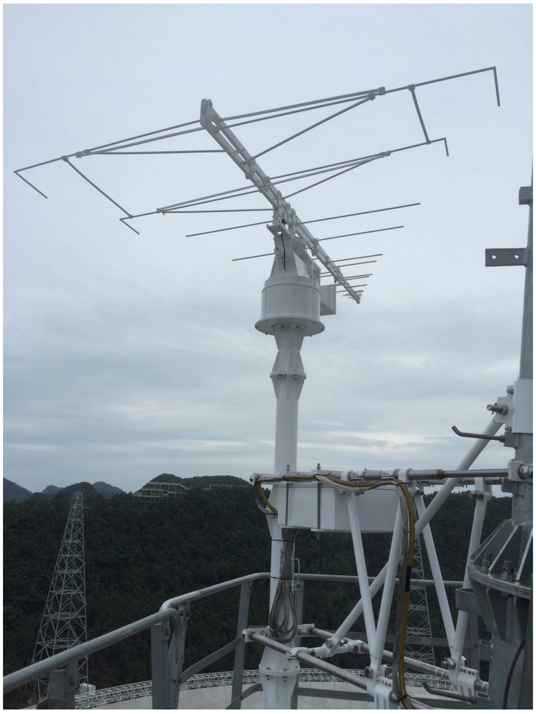

Fig. 2 RFI monitoring system at one of the cable suspension towers.

2.2 RFI Monitoring System

A series of RFI monitoring efforts has been carried out at the FAST site (Peng et al. 2004). Long-term RFI monitoring results imply that the radio environment of the site is quiet and suitable for constructing a large radio telescope. In 2018, a fixed RFI monitoring system was established at the top of a cable suspension tower. Two antennas, including one log periodic antenna and one double-ridged horn antenna, have been installed to cover the frequency bands from 70 MHz to 5 GHz. The system temperature is below 300 K in the frequency bands above 400 MHz. A photo of the actual system is presented in Figure 2. Meanwhile, a portable RFI monitoring system has also been deployed

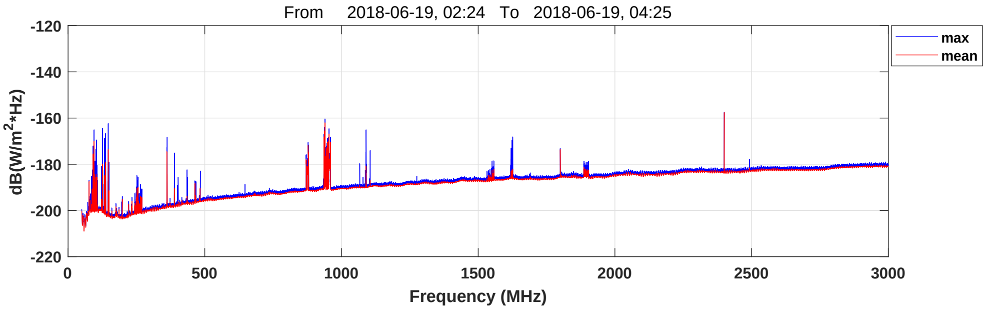

Fig. 3 RFI monitoring results detected in June 2018.

Fig. 4 Combined shielding measures for the feed cabin.

to measure RFIs from external transmitters. The results of RFI measurement conducted in June 2018 are plotted in Figure 3. No apparent degradation in the radio environment around FAST has been detected compared to the results measured in 2005.

3 RFI MITIGATION

3.1 EMC Measures of the Telescope Instruments

The main challenge for FAST EMC measures comes from three factors including the high sensitivity of the telescope, the observing frequency bands and the complexity of the operating conditions. EMC requirements have been fixed based on the protection threshold of FAST, EMI property of the instruments and propagation loss. Therefore, various EMC measures have been applied to FAST. For example, in order to mitigate RFIs from the feed cabin, the Shielding Efficiency (SE) of three parts have been developed including the feed cover, two shielded rooms inside the cabin and the Stewart platform. The shielding methods that incorporate a combination of dynamic and static methods have been developed with a steel shell, soft fabric, power and signal filters, waveguide window and tube, etc. (Fig. 4). An SE of more than 120 dB has been achieved for the feed cabin, and an SE of even more than 140 dB in part of the spectrum has been obtained (Zhang et al. 2018b). Meanwhile, for the hydraulic actuators, multi-interface and hydromechatronics shielding measures have been applied successfully (Zhang et al. 2018a). Moreover, a special shielding cabinet with a waveguide window produced by a 3D printing method has been designed to mitigate the RFIs from the total station. Due to the unusual requirement of a 10 KV power filter at the FAST site, a power filter with a ceramic capacitor has been produced and installed at the site. Additionally, a highly-dynamic wideband SE measurement system has also been developed and utilized during the FAST construction and commissioning stage (Yue et al. 2015).

3.2 Adaptive Filter for RFI Mitigation

By employing the RFI monitoring antenna at the top of one cable suspension tower as the reference antenna, a digital adaptive filter based on a Field-Programmable Gate Array (FPGA) has been designed and tested in a laboratory and at the FAST site. An artificial signal at 700 MHz has been generated at the FAST site during the experiment, and the

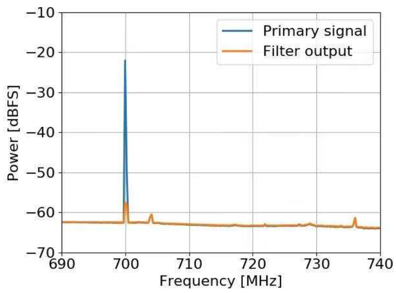

Fig. 5 Adaptive filter output of the experiments.

output of the filter is displayed in Figure 5. The signal has been decreased about 30 dB which demonstrates the feasibility of this adaptive RFI mitigation filter.

3.3 RQZ Operation

In 2013, the RQZ was established around FAST with a radius of 30 km. Moreover, the RQZ in the airspace that surrounds FAST with a radius of 30 km has been in operation since 2017. The legislation of FAST RQZ has also been released. In the central zone with a radius of 5 km around FAST, any new transmitters and facilities are prohibited from being constructed. In the coordination zone with radius from 5 to 30 km, compatibility studies between FAST and active services are required. Meanwhile, the main RFI sources in the FAST RQZ such as mobile stations and broadcast stations, have been assessed. Several technological measures including decreasing the emission power of the transmitters, adjusting the pointing direction of the transmitter antennas, lowering the height of the transmitters, etc, have been applied to protect the quiet radio environment around the FAST site (Zhang et al. 2017). Moreover, the software to estimate the propagation loss between FAST and the proposed RFI sources has been implemented, and the RFI database of terrestrial and space-based transmitters has been developed. All these methods have helped FAST to slow down the speed of deterioration of the radio environment effectively.

4 CONCLUSIONS AND PROSPECTIVE

4.1 Conclusions

According to the science outputs during the commissioning stage of FAST, most new pulsars have been discovered in low frequency bands. These outputs manifest at least two aspects. One aspect demonstrates the extremely high sensitivity of FAST, and the other aspect indicates the success of the RFI mitigation measures. The RFIs from the telescope instruments and transmitters outside the site have been decreased efficiently, which ensures the discovery of new pulsars soon.

4.2 Prospective

Further works associated with RFI mitigation have been planned. The EMC methods will be implemented on any new instruments proposed to be installed in the telescope. Moreover, annual RFI investigation will be carried out based on cooperation with the local government. Meanwhile, according to the rapid development of the local economy around FAST, study of RFI mitigation methods in the data processing pipeline with machine learning is underway, such as RFI identification, warning, flagging, filtering, etc. Therefore, based on these measures, a quiet radio environment is expected during the whole lifetime of FAST.

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