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EMC design for actuators in the FAST reflector

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Abstract An active reflector is one of the three main innovations incorporated in the Five-hundred-meter Aperture Spherical radio Telescope (FAST). The deformation of such a huge spherically shaped reflector into different transient parabolic shapes is achieved by using 2225 hydraulic actuators which change the position of the 2225 nodes through the connected down tied cables. For each different tracking process of the telescope, more than 1/3 of these 2225 actuators must be in operation to tune the parabolic aperture accurately and meet the surface error restriction. This means that some of these actuators are inevitably located within the main beam of the receiver, and Electromagnetic Interference (EMI) from the actuators must be mitigated to ensure the scientific output of the telescope. Based on the threshold level of interference detrimental to radio astronomy described in ITU-R Recommendation RA.769 and EMI measurements, the shielding efficiency (SE) requirement for each actuator is set to be 80 dB in the frequency range from 70 MHz to 3 GHz. Therefore, Electromagnetic Compatibility (EMC) was taken into account in the actuator design by measures such as power line filters, optical fibers, shielding enclosures and other structural measures. In 2015, all the actuators had been installed at the FAST site. Till now, no apparent EMI from the actuators has been detected by the receiver, which demonstrates the effectiveness of these EMC measures.

Key words: radio telescope — active reflector: actuator — electromagnetic compatibility

1 INTRODUCTION

Over the past 23 years, the Five-hundred-meter Aperture Spherical radio Telescope (FAST) has been conceived, designed, optimized and constructed to provide a powerful radio tool at low frequencies for the astronomical community (Nan 2006). The active main reflector is one of the three main innovations of FAST. For each observation time tick of 1 second, a different portion of the spherical reflector is transiently changed to a corresponding parabolic reflector with an effective aperture of 300 m, focal ratio of 0.4611, a surface precision better than RMS 5 mm and optical axis pointing to the observational target with precision of $8''$. The deformation of such a huge spherically shaped reflector into different transient parabolic shapes is achieved by using 2225 hydraulic actuators which are used to change the position of the 2225 nodes through the connected down tied cables. For each different tracking process of the telescope, about $1/3$ of these 2225 actuators must be in operation to tune the parabolic aperture accurately and meet the surface error restriction.

Due to the extreme sensitivity of FAST, Electromagnetic Interference (EMI) issues were emphasized from the beginning of the telescope design. The most typical EMI sources for FAST are the thousands of actuators used for deformation of the reflector, and some of these actuators are inevitably located within the main beam of the receiver, as shown in Figures 1 and 2. Therefore, it is essential for FAST to evaluate the EMI effect of the actuators and make an Electromagnetic Compatibility (EMC) design for them. In the following sections, the EMC design study and testing will be described.

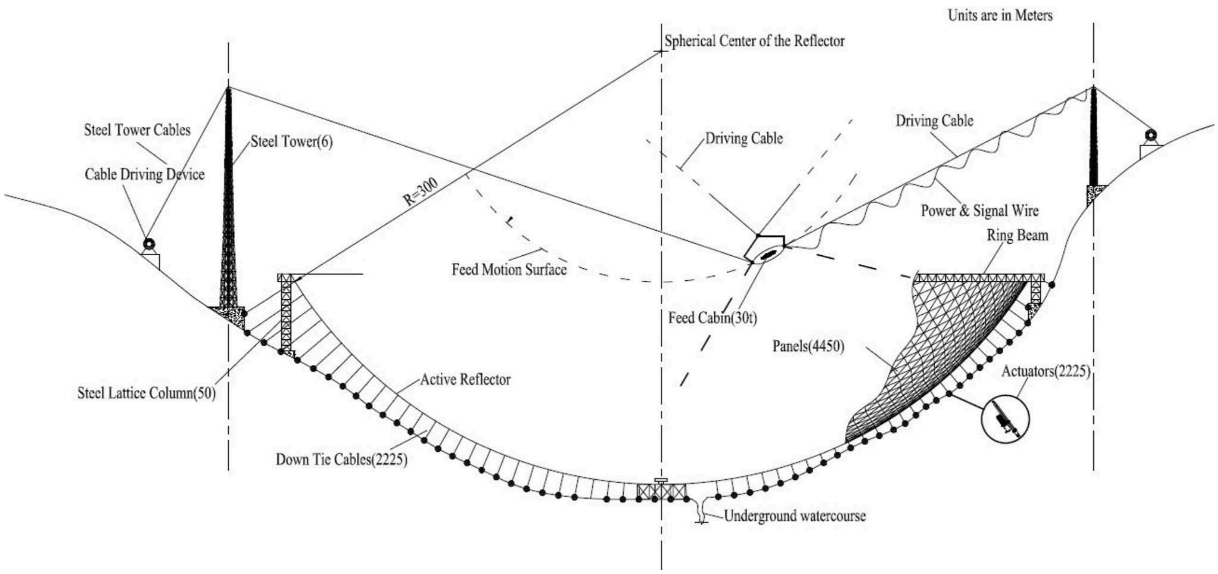

Fig. 1 Schematic Diagram of the FAST system.

Fig. 2 One actuator connected to its node plate.

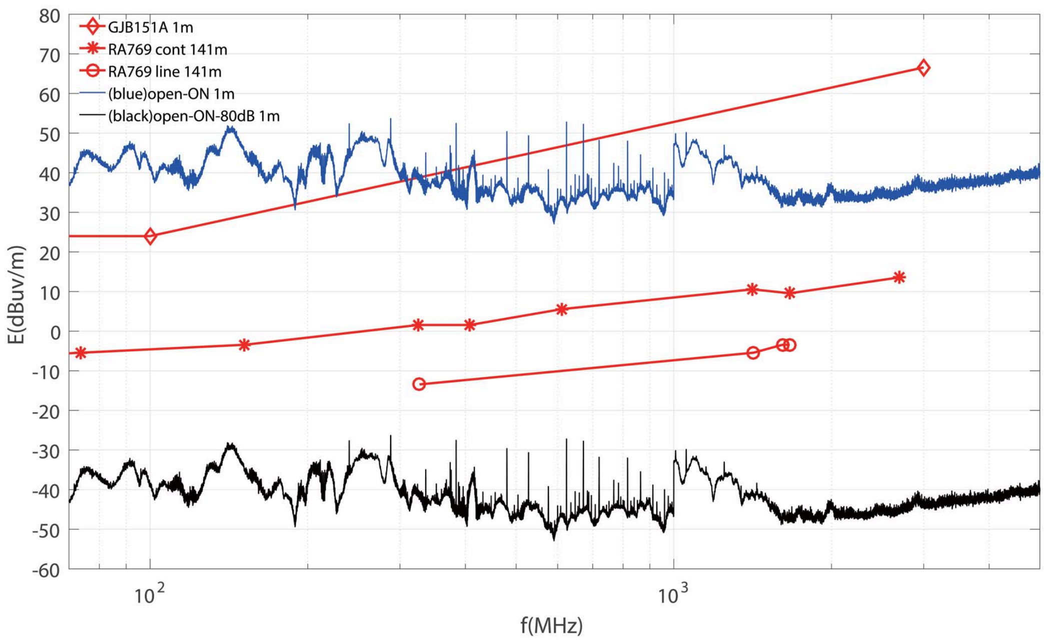

Fig. 3 Typical EMI from an actuator with an open enclosure measured in the anechoic chamber based on GJB151A RE102 with 80 dB reduction.

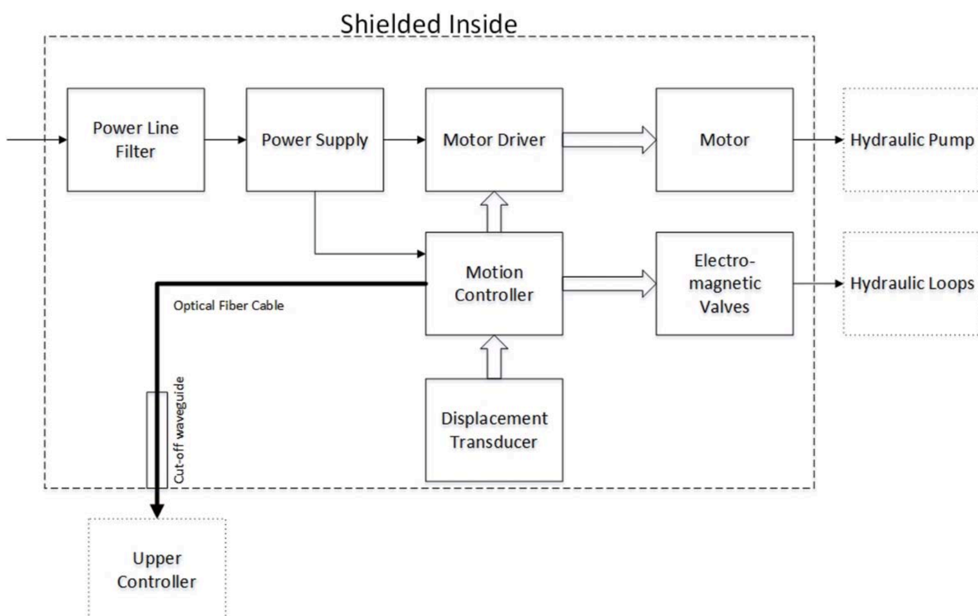

Fig. 4 A schematic diagram of the EMC design.

2 EMC REQUIREMENT FOR THE ACTUATOR

As a first step, the EMI of an actuator is identified and tested. EMI is produced by the electrical parts including the actuator controller, motor driver, power supply, integrated pressure and temperature sensor, position sensor and electromagnetic valves. In order to investigate the EMI properties of an actuator, measurements have

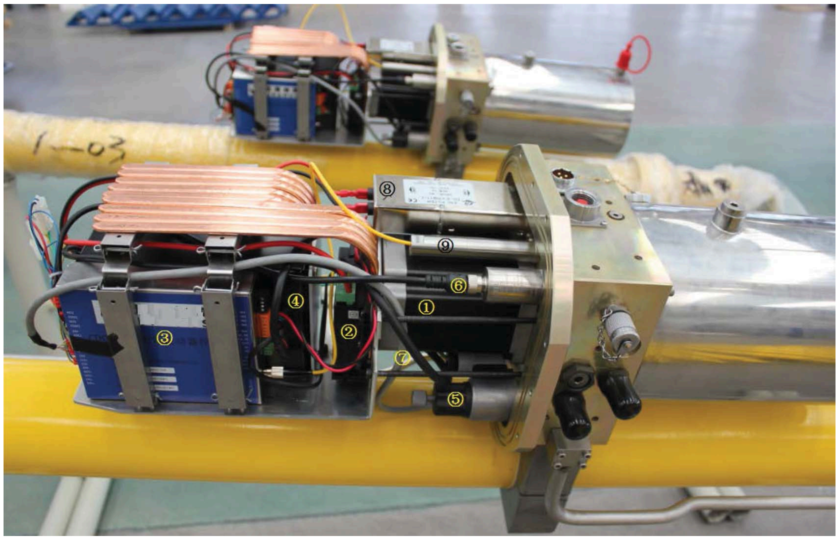

Fig. 5 Electrical components inside the actuator. (1) Stepper motor; (2) Motor driver; (3) Actuator controller; (4) Power supply; (5) Electromagnetic valve; (6) Pressure-temperature sensor; (7) Wire for the displacement sensor; (8) Power line filter; (9) Cut-off waveguide.

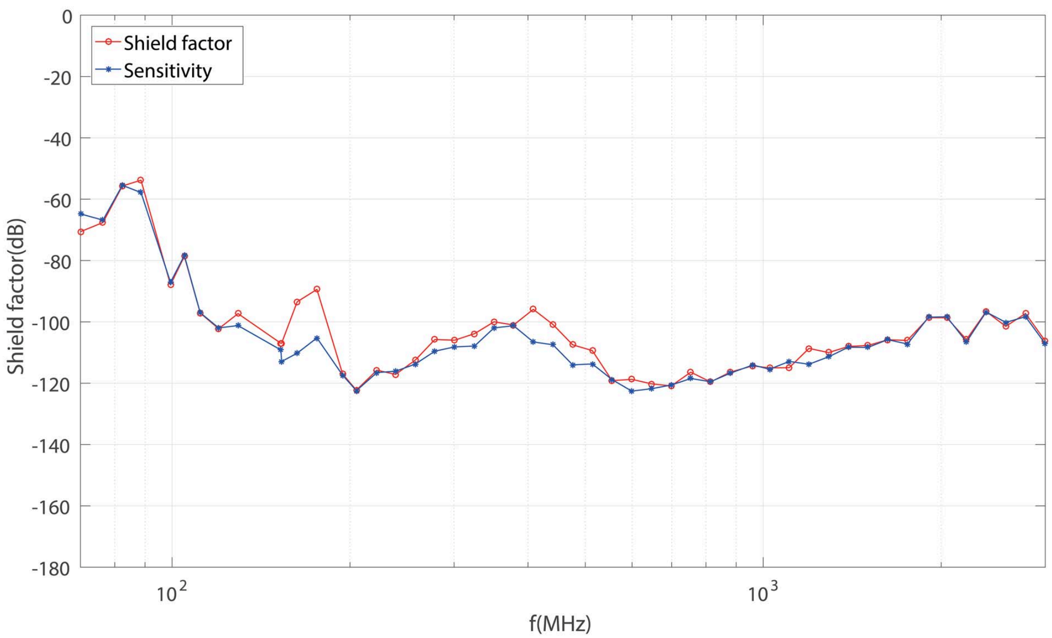

Fig. 6 SE measurement result of one actuator based on the measurement method (Yue et al. 2015).

been made to detect interference from the electrical parts of the actuator in an anechoic chamber according to the EMC national standard of GJB151A RE102 (GJB151A). The results of measuring EMI from one typical actuator are presented in Figure 3. In this figure, EMI in the wide band has been detected and most interference is located at frequencies below 1 GHz.

The threshold level of interference which is detrimental to radio astronomy, as presented in ITU-R Recommendation RA.769 (ITU-R RA.769), has been chosen for FAST. Moreover, the nearest distance of 141 m between the feed and actuator has been used to estimate the propagation loss based on the free space propagation model. In order to meet the requirements of ITU-

R RA.769 in the desired frequency range, a Shielding Efficiency (SE) of about 70 dB is necessary for the actuators. Since the actuators are located beneath the aluminum reflector panels, the shielding effect of the reflector was evaluated during the design stage. Based on the theoretical analysis and practical tests by using the FAST 30 m demonstrator at Miyun Station, which is administered by National Astronomical Observatories, Chinese Academy of Sciences, the SE of the reflector has been estimated to be more or less than 10 dB. Due to the uncertainty of this result, the shielding effect of the reflector is considered as a redundancy to ensure protection of receiver. Moreover, considering possible long term degradation, any inconsistency in shielding measures among different actuators and the effect of aggregation, an SE requirement of 80 dB is favored with a margin of about 10 to 20 dB. Combining the theoretical analysis and practical measurements, the SE requirement of the actuators is set to be 80 dB in the frequency range from 70 MHz to 3 GHz. The typical EMI from an actuator with 80 dB reduction is also presented in Figure 3.

3 EMC DESIGN OF THE ACTUATOR

The overall EMC design of the actuator uses a shielding enclosure to accommodate all EMI sources. A power line filter is used to handle the AC power input. Optical fiber cables are used to transmit control and status signals. The schematic diagram of the EMC design is shown in Figure 4 and the components of the electrical parts in the actuator are presented in Figure 5. The detailed design and tests for several devices are described below (Wu et al. 2015a,b).

3.1 Power Line Filter

The actuator uses AC220 V 50 Hz as power input. A power line filter is designed to prevent EMI transmission along the power line. The filter is designed to work at a rated voltage of 250 VAC and a rated current of 6 A, at the frequency of DC $\sim$ 60 Hz. The insertion loss of the filter is listed in Table 1.

Table 1 The Insertion Loss of the Filter

Frequency (MHz)	Insertion Loss ($\geq$dB)
1	95
5	100
10	100
100	100
300∼10000	100

3.2 Cut-Off Waveguide

The cut-off waveguide is a stainless steel tube with inner diameter $D = 12$ mm and length $L = 115$ mm. The tube is installed inside the shielded enclosure, which allows the optical fiber cable to transmit control and status signals with EMI kept inside. The cutoff frequency and SE are estimated empirically to be

$$f_{\rm cutoff} = 17.6/D = 15\,({\rm GHz})$$

and

$$\mathrm{SE} = 32L/D = 32 \times 115/12 = 307(\mathrm{dB}),$$

where D and L are in centimeters.

3.3 Shielding Measures

A nickel plated graphite electroplated rubber ring has been used in the interface of the enclosure and the valve block. The material satisfies the SE of better than 80 dB.

3.4 Other EMI Routes and Measures

All the cables, except the AC220 V power line and the optical fiber cable, are enclosed in the corresponding enclosure. The cable of the displacement transducer is located in another enclosure at the bottom part of the cylinder. All the related EMI leak interfaces are shielded by EMC measures.

4 CONCLUSIONS

The actuators of the FAST reflector were manufactured after the completion of the EMC design. Before installation at the FAST site, EMC measurements of the actuators based on the national standard of GJB151A RE102 were made, and results showed that EMI from the actuators is lower than the background of the anechoic chamber. Moreover, the SE measurements have also been carried out based on the measurement method of Yue et al. (2015). The measurement result for one actuator is shown in Figure 6. In this figure, the actuator meets EMC requirements of 80 dB in most of the band used by the receivers. In addition, each of the power line filters was tested to verify its compliance with the insertion loss requirements.

For the 2225 actuators, Factory Acceptance Testing was performed. The sample rate was over 10%, including more than 200 actuators. In 2015, all the actuators had been installed at the FAST site. So far, no apparent EMI from the actuators has been detected by the telescope receiver, which demonstrates the effectiveness and success of these EMC protection measures.

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