第62卷 第4期 天 文 学 报 Vol.62 No.4
2021年7月 ACTA ASTRONOMICA SINICA Jul, 2021

doi: 10.15940/j.cnki.0001-5245.2021.04.013 博士学位论文摘要选登

大口径射电望远镜电磁兼容评估技术研究

刘 奇†

(中国科学院新疆天文台 乌鲁木齐 830011)

电磁兼容性是设备或系统的重要性能指标, 也是保障系统的工作效能和提高系统可靠性的重要因素. 大口径射电望远镜运行阶段, 台址周围无线电业务及内部潜在的电磁干扰会降低观测系统灵敏度、影响天文观测的质量. 本论文针对拟建的新疆110 m全向可动射电望远镜(Qi Tai raido Telescope, QTT)开展了系统电磁兼容评估技术及控制方法研究, 具有重要的工程应用价值.

首先, 依据现有电波环境测量方法的不足, 深入分析了仪器设备的关键参数配置方法及测量时间计算方法, 采用Y因子法校准测量数据, 提出一种准实时电波环境测量方法. 面向高重复性宽带频谱, 分析了宽带频谱信号和噪声特征, 结合标准差理论, 提出一种基于邻值比较的信噪分离方法, 并采用邻值统计方法优化关键参数, 提高信噪分离精度. 针对QTT台址, 开发了自动化电波环境监测系统, 该系统6 GHz以下频段系统增益大于40 dB, 系统噪声系数小于2 dB, 测量不确定度小于1.49 dB, 具有极高的系统灵敏度和测量精度; 分析了频谱监测数据流, 设计了基于HDF5 (Hierarchical Data Format version 5)的数据存储格式, 开发了自动化电波环境测量和监控软件及数据处理软件. 依据QTT台址长期监测数据, 评估分析了台址电磁环境、主要干扰源特征及其影响.

其次, 提出大口径射电望远镜馈源口面干扰电平限值量化方法, 建立了基于台址地形的电波传播模型, 分析了现有电波传播模型的优缺点及适应性, 结合QTT台址实际地形及地质特征, 采用Longley-Rice和Two-Ray电波传播模型, 预测分析了QTT台址潜在干扰区域电磁干扰达到射电望远镜的电波路径衰减, 结合大口径射电望远镜天线增益量化方法, 提出设备所在位置干扰电平限值量化方法, 运用该方法对QTT台址潜在干扰区域的干扰电平限值进行量化. 依据设备所在位置干扰电平限值, 调研分析了国内外军用、民用电磁兼容测量标准, 结合电磁干扰对射电天文观测的影响, 提出一种大口径射电望远镜电磁兼容控制方法, 解决了现有电波暗室测量系统无法直接测量评估电子设备电磁兼容的问题, 该电磁兼容控制方法计划应用于QTT建设及运行阶段, 确保系统拥有良好的电磁兼容性.

最后, 依据QTT台址潜在干扰区域干扰电平限值, 结合典型电子设备电磁辐射频谱, 分析了QTT电磁兼容设计需求, 提出电磁兼容设计初步方案. 另外, 针对台址建筑设施内的中低电磁辐射干扰源, 提出一种低成本建筑屏蔽方法, 应用于QTT台址现有建筑.

Research on EMC Evaluation for Large Diameter Radio Telescope

LIU Qi

(*Xinjiang Astronomical Observatory, Chinese Academy of Sciences, Urumqi 830011*)

ElectroMagnetic Compatibility (EMC) is an important performance indicator of equipment or system, which is also an important factor to ensure the working efficiency of the

†2019-06-30获得博士学位, 导师: 新疆天文台王娜研究员; liuqi@xao.ac.cn

system and improve the reliability of the system. For large diameter radio telescope constructing and operating stage, potential electromagnetic interference from the radio service around the site and the internal various types of electrics will affect the quality of certain observations or specific observation types, limiting the overall efficiency of radio astronomical observations. This theis investigated the electromagnetic compatibility evaluation technology for the proposed 110 m diameter fully steerable radio telescope (QTT, Qi Tai radio Telescope) in Xinjiang province, which has an important engineering application value.

Firstly, according to the shortcomings of the existing radio environment measurement methods in radio astronomical field, the key parameters configuration and measurement time calculation methods for signal analyzer were analyzed deeply. We use Y-factor method for system gain measuring to calibrate Radio Frequency Interference (RFI) data, and a quasi-real-time radio environment measurement method is proposed. For broadband spectra, this thesis analyzed the characteristics of broadband spectra signal and noise, combined with standard deviation theory, a high precision signal-to-noise separation method based on neighborhood value comparison was proposed to realize signal extracted and counted effectively. Additionally, an automated, high-sensitive radio environment monitoring system was developed for QTT site. System performance testing data indicate that, below 6 GHz, the system gain is greater than 40 dB, system noise figure is less than 2 dB, and the measurement uncertainty is less than 1.49 dB, which is sensitive enough for weak signal detection. According to the data flow of spectrum monitoring, we designed a HDF5 (Hierarchical Data Format version 5) data format for data storage, and a measurement and monitor software including a data processing software were developed for spectrum monitoring and data processing effectively. Based on the long-term monitoring RFI data, we evaluated RFI environment of QTT, and analyzed the main interference sources characteristics and their effects on observations as well.

Secondly, we proposed an interference level limit quantified method for feed aperture of large diameter telescope. Then a radio wave propagation model based on QTT site terrain was established by analyzing the advantages and disadvantages of the existing radio wave propagation methods. We used Longley-Rice and Two-Ray models to predict the path loss between the potential interference area and QTT. Combined with the proposed large diameter radio telescope antenna gain quantified method, the interference level limit of the potential interference area at QTT were calculated. Furthermore, we investigated and analyzed the EMC measurement standards, and an EMC evaluation method was established for large diameter radio telescope with interference impacting on observations analyzed, which will be applied to the QTT construction and operation stage ensuring that the system has good electromagnetic compatibility.

Finally, we calculated the EMC design requirements according to the interference level limit of potential interference areas, and the preliminary EMC design scheme for QTT was provided. Additionally, in order to mitigate the RFIs in facilities, we proposed a low cost building shielding approach, which was applied to the existing buildings at QTT site.