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Development and verification of an innovative photomultiplier calibration system with a 10-fold increase in photometer resolution

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Abstract

In this study, we construct a photomultiplier calibration system. This calibration system can help scientists measuring and establishing the characteristic curve of the photon count versus light intensity. The system uses an innovative 10-fold optical attenuator to enable an optical power meter to calibrate photomultiplier tubes which have the resolution being much greater than that of the optical power meter. A simulation is firstly conducted to validate the feasibility of the system, and then the system construction, including optical design, circuit design, and software algorithm, is realized. The simulation generally agrees with measurement data of the constructed system, which are further used to establish the characteristic curve of the photon count versus light intensity.

Keywords: Photomultiplier calibration, Airglow, Optical attenuator.

1. Introduction

The paper goal is to build a calibration system to calibrate airglow instruments with high sensitivity photomultipliers. In the visible spectral region, airglow of 630.0 nm emissions can be observed from the ground and satellites. Scientists (Barbier 1959; Porter et al., 1974; Mendillo et al., 1977; Kubota et al., 2001; Rajesh et al., 2010; Liu et al., 2011) often conducted 630.0 nm airglow ground-based experiments observing gravity waves, traveling ionospheric disturbances, and plasma depletions. On the other hand, satellite observations give a unique view of the global and/or the altitude-latitude distribution of airglow emission in nighttime with very high spatial resolution (*cf.* Rajesh et al., 2009, 2014). The 630.0 nm measurements have the advantage that the intensity is related to the plasma density and is also sensitive to the altitude variations of the ionosphere (Peterson et al., 1966; Nelson and Cogger, 1971; Bittencourt and Sahai, 1979; Herrero and Meriwether, 1980; Link and Cogger, 1988).

Bird et al. (1994) proposed a method for correcting high-sensitivity photomultiplier tubes. The proposed method uses a monochromatic UV light source as the test light source, and a photodiode as the standard optical sensor. In this method, the high-intensity photoelectric properties of the photodiode are first calibrated, and then a linear extrapolation of its low-intensity photoelectric properties is calculated. Finally, the optoelectronic properties of the low-intensity section of the diode can be used as a standard for calibrating photomultiplier tubes (Bird et al., 1994). Abbasi et al. (2010) built the IceCube Neutrino Observatory in Antarctica, used a photomultiplier group matrix as a sensor group, and proposed a calibration method for the observatory.

The key component of airglow instruments/payloads is a photomultiplier tube before CCD cameras became kind of a standard. This paper is to describe a calibration system for photomultipliers, which allows us to find the characteristic curve of the photon count versus light intensity, and correctly observe airglow emissions for tomography reconstruction (Hsu et al., 2009; Liu et al., 2010; Yeh et al., 2012). Here, we take the 630.0 nm emission as an example. Owing to the airglow intensity being rather low, a highly sensitive detector will be required. Photomultiplier tubes are the most sensitive detectors that are commercially available. However, a photomultiplier tube is very difficult to be calibrated, because any intense test light source could easily damage it. By contrast, optical power meters have been commonly used for optical calibration, and unfortunately, their sensitivity is too low to be employed observing airglow emissions. To resolve these difficulties, we construct a calibration system with a 10-fold optical attenuator. The system enables that after