

Data-Based Modeling of MMS/FPI Microchannel Plate Detector Resistance using Temperature Proxy

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Abstract—The Magnetospheric MultiScale (MMS) space physics mission studies magnetic reconnection in the Earth’s magnetosphere. This work presents the results of an analysis of the resistance of the microchannel plates (MCP) included in the particle spectrometers, which are components of the Fast Plasma Investigation (FPI) aboard each MMS spacecraft. We found that a proxy for the resistance of the MCPs can be estimated from the MCP bias voltage and MCP high voltage power supply (HVPS) temperature. This estimation of MCP resistance allows for an accurate determination of nominal MCP current.

I. INTRODUCTION

The Magnetospheric MultiScale (MMS) space physics mission studies magnetic reconnection in the Earth’s magnetosphere [1]. Aboard each MMS observatory is the Fast Plasma Investigation (FPI), in which MCPs are used in particle spectrometers for ion and electron detection [2]. Particle energy and angle are first filtered using a top-hat electrostatic analyzer (ESA). The particles then enter the channels of the MCP, where a cascade of particles is generated.

MCP-based detectors are usually operated at a bias voltage of up to a few thousand volts. When designing the high-voltage power supply (HVPS) for an MCP, the high voltage power supply must be designed to source enough current to replenish the channels of the MCP under high particle flux. In [3], a model was developed that shows the relationship between the MCP bias voltage, temperature, and resistance, as shown in Equation (1).

$$R_{mcp}(v, T) = R_0 - \alpha_v v - \alpha_T T \quad (1)$$

where α_v , α_T and R_0 are constants that will be unique for each MCP. v and T represent the MCP bias voltage and device temperature, respectively. According to this model, the resistance of the MCP must lie on a plane in voltage-temperature space. When the MCPs are instrumented in the lab, this model is adequate. In flight, modeling the resistance is more challenging because only proxies for MCP voltage and temperature are available.

II. MCP TEMPERATURE AND VOLTAGE PROXIES

The FPI instrument housekeeping data includes the temperature of a thermocouple that is close to the instrument, measurements of the applied bias voltage of the MCP, and the current that the HVPS supplies to the MCP. Upon analysis, the

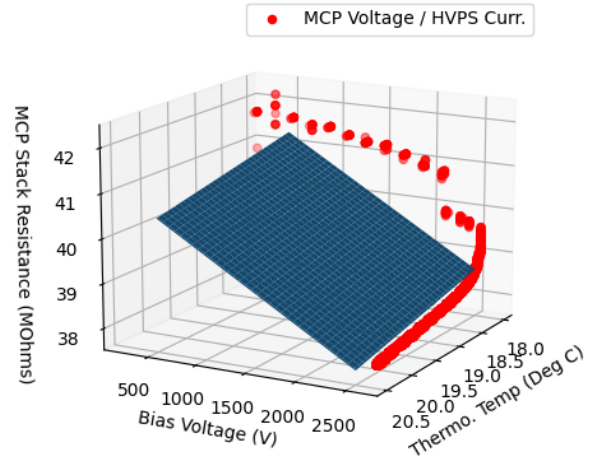


Fig. 1: Plane fit over calculated MCP resistance vs thermocouple temperature and MCP bias voltage.

measured bias voltage appears to be close enough to the actual voltage across the MCP stack temporally and in magnitude to assume that it is identical to the voltage across the MCP. The temperature of the MCP and the thermocouple follow a time-varying, but consistent, relationship over the course of an MCP voltage ramp. The results of the MCP/thermocouple temperature difference can be seen in Figure 1.

The red points in Figure 1 represent the MCP resistance as calculated using Ohm’s law. The blue plane represents a best effort at fitting a plane to the data. Clearly, the plane does not fit the data well as predicted by Equation (1). This is due to the fact that the thermocouple temperature does not always represent the true MCP temperature. To predict the MCP resistance, a time-based relationship between MCP temperature and thermocouple temperature is necessary to “correct” the thermocouple temperature.

III. ALGORITHM AND EXAMPLE RESULTS

To simplify the model of MCP and thermocouple temperature, some assumptions are made. First, after the HVPS has been on for a long time, the thermocouple and MCP temperatures will agree. Second, the thermocouple temperature at any given time can be converted to MCP temperature by applying

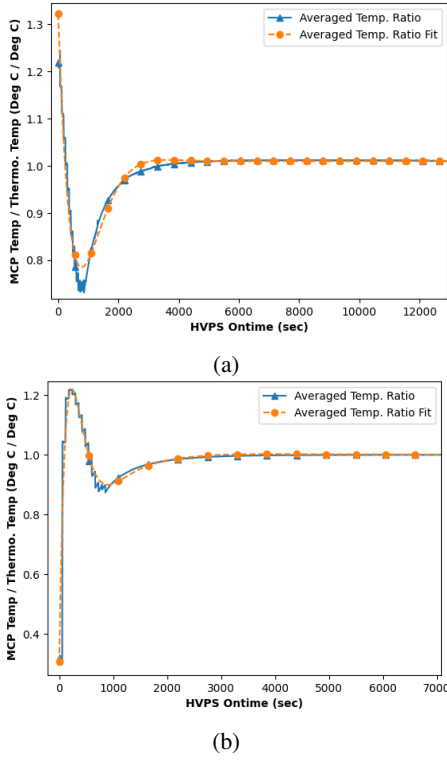


Fig. 2: (a) Electron spectrometer and (b) ion spectrometer thermocouple temperature ratios.

a scaling factor, $\beta(t)$, that is a function of only HVPS ontime, and not the current MCP temperature.

Assuming that the relationship between the actual MCP temperature can be modeled according to the above assumptions, the temperature relationship can be found by substituting

$$T_{mcp}(t) = \beta(t)T_{meas} \quad (2)$$

into Equation (1) and solving for $\beta(t)$. This yields

$$\beta(t) = \frac{R_{meas}(t) + \alpha_v v(t) - R_0}{-\alpha_T T_{meas}(t)} \quad (3)$$

where $R_{meas}(t)$ represents the actual MCP resistance measured at time t , which represents t seconds elapsed since the HVPS has been enabled, or "ontime". Similarly, $v(t)$ and $T_{meas}(t)$ represent measured voltage and thermocouple temperature at t seconds of HVPS ontime. Figures 2 show the results of calculating $\beta(t)$ for FPI ion spectrometers and electrons spectrometers.

Once $\beta(t)$ was found empirically for each type of spectrometer, an expression was fit to each curve. Equation (4) represents a fitted function on the average MCP temperature to thermocouple temperature over time for FPI electron spectrometers.

$$\beta_e(t) = \alpha \cos(\omega t + \phi) e^{-t/\tau} + 1 \quad (4)$$

where α , ω , ϕ , and τ are static values that are unique to each electron spectrometer. The ion spectrometers have

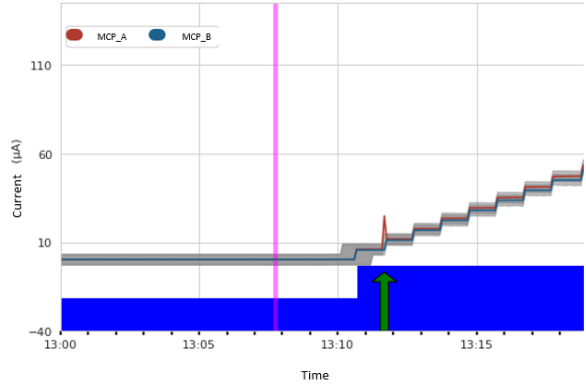


Fig. 3: Resistance model used to detect anomalous MCP current.

different thermal properties and thermocouple position, so the MCP/thermocouple temperature relationship is different. The equation for ion spectrometers is given in Equation (5).

$$\beta_i(t) = \alpha_1(1 - e^{-t/\tau_1} + \alpha_2(t/\tau_2)(1 - t/\tau_2)^4 e^{-t/\tau_3}) + k \quad (5)$$

where the values α_1 , α_2 , τ_1 , τ_2 , τ_3 , and k are static values that are unique for each ion spectrometer. Finally, we have the MCP resistance models for electron and ion spectrometer MCPs:

$$R_{mcp,e}(v, T_{meas}, t) = \alpha_v v + \alpha_T \beta_e(t) T_{meas} + R_0. \quad (6)$$

$$R_{mcp,i}(v, T_{meas}, t) = \alpha_v v + \alpha_T \beta_i(t) T_{meas} + R_0. \quad (7)$$

The MCP resistance models can predict nominal MCP current to within one or two microamps. The models presented in this work have been operationalized on the MMS mission. The resistance model is used in an automated current analysis process that monitors the MCP currents for anomalous values. Figure 3 below shows the model closely predicting the MCP current.

IV. CONCLUSION

The data-based model presented in this work estimates resistance of the MCPs in the ion and electron spectrometers onboard MMS/FPI as a function of MCP bias voltage, thermocouple temperature, and HVPS ontime. The methodology presented in this work could be used to design other physics-informed models that are a function of one or multiple proxies.

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