PAPER Memo: Temperature Dependent Gains

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1. Gainometer Tests

1.1. Background

As reported in Parsons et. al. (2010), laboratory tests have measured temperature dependent gain variations in the PAPER psuedo-differential amplifier (PDA), with a coefficient of -0.024 dB K^{-1}. A similar coefficient of -0.018 dB K^{-1} has also been found for the RG-6 cables used to connect the PDAs to the receiver cards. Further investigations have refined these models into 3^{rd} and 4^{th} order polynomials, the exact form of which is given below in Equations 1 and 2. In order to correct for these gain fluctuations, the temperature of a representative PDA and cable are actively monitored by a thermister.

Past analyses have shown the gain corrections using these temperature measurements lower the variance in the total power levels seen by the PAPER system between integrations. This has been confirmed in both sky data and data from a gain-o-meter. However, there has been no study of the effects of these corrections on the perceived fluxes from single, specific celestial sources. To produce a reliable catalog of source fluxes, it will be necessary to correct for these temperature dependent gains.

1.2. Analysis

12 days of data from PGB-16 taken in summer 2009 were used for this analysis. The data were reduced using AIPY with relatively minimal prodcedures. First, the gain linearization and RFI excision algorithms described in Parsons et. al. (2010) were applied to the raw data. Then the MCMC application of delay/delay rate (DDR) filters were used to extract the brightest sources: the Sun, Cygnus A, Casseopeia A, the Crab Nebula and Virgo A.

These filters reconstuct source data with antenna-based solutions, allowing each antenna's gain to vary independently. Two hours data from each day near the transit of Cyg A were selected for analysis, over 480 frequency channels ranging from 123.4 to 170.2 MHz, a relatively clean window in Green Bank. The magnitude of each reconstructed visibility was corrected for the modelled response of the PAPER primary beam to Cyg A at that time and freqeuncy. The median value across the band was then taken in order to compress each 480-channel integration into a single data point. All visibilities from each antenna were then divided by their median in order to reduce the effects of antenna-to-antenna gain differences. The resulting data are plotted in Figure 1 vs. the measured cable/PDA temperature. The y-axis is a ratio of the perceived flux with the predicted flux from the beam model. The slope of the best fit line is -0.047 dB K^{-1} and -0.036 dB K^{-1} when plotted against the balun and cable temperatures, respectively. Issues concering the uncertainties in these measured values are addressed in Section 1.3 below.

Although these fits are illustrative of the general trend, there is, of course, strong covariance between the PDA and cable temperatures. The perceived power cannot be fit for each gain coefficient individually. Fitting for both parameters simulataneously yields values of -0.030 dB K^{-1} and -0.013 dB K^{-1} for the PDA and cable coefficients, respectively. These values are still highly covariant, however. Without an estimate for off-diagonal terms in the covariance amatrix, standard error calculations would underestimate the uncertainty in these figures. Instead, attempts to assess the significance of these figures compared with the models are presented in Section 1.3.

Running the same analysis with data near the transit of Cas A yields coefficients of -0.078 dB K^{-1} for the PDA and +0.036 dB K^{-1} for the cable. This result further illustrates the degeneracy between these two measurements. The positive slope for the cable gain is in direct contradiction with all laboratory measurements. However, the sum of the two coefficients yields a *total* temperature

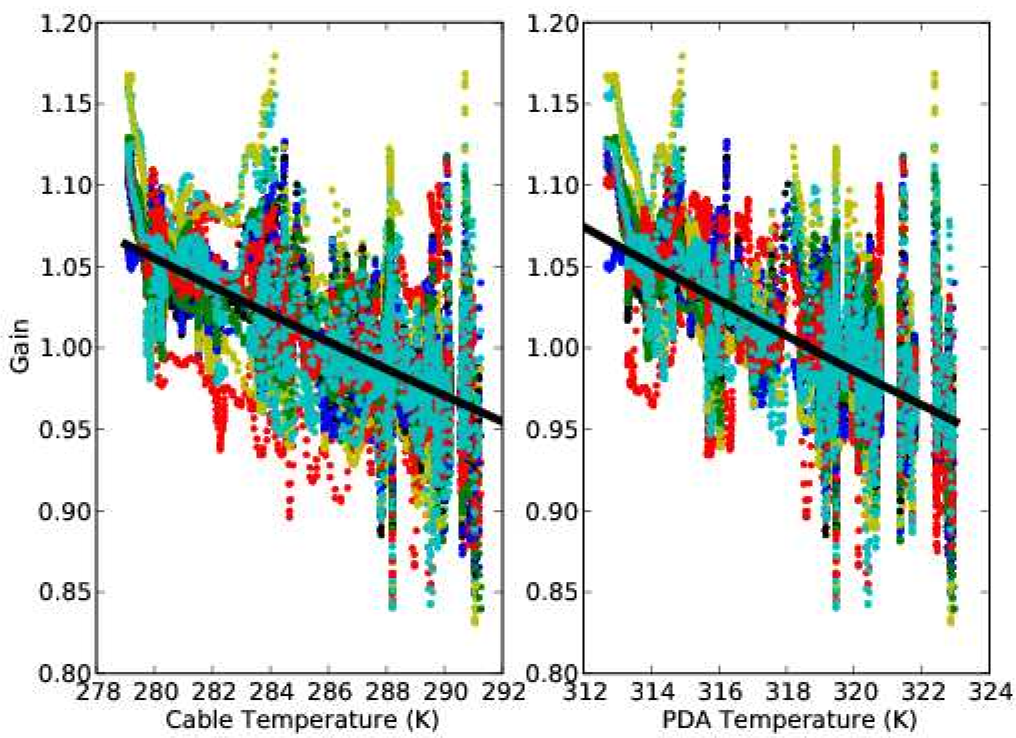

Fig. 1.— Temperature dependendent gain effects vs. a single measured temperature (PDA or cable). Each color represents data from one antenna.

dependent gain that is consistent with all previous analyses. It should also be noted that the scatter around the fit is significantly larger for Cas A than Cyg A, and so the result from the Cyg A fit will be taken as the best estimate from this technique.

1.3. Significance

In this section, we will compare the fit presented above to the two laboratory derived models. One model assumes a linear relationship between temperature and gain, and has been the model used to correct these effects in data analysis up to now. As mentioned above, this model uses coefficients of $H_{balun} = -0.024$dB K^{-1} and $H_{cable} = -0.018$dB K^{-1}. The other model uses 3rd and 4th order polynomial fits to represent the gain flucatuations of the PDA and cable, respectively. These formulae are given in Equations 1 and 2; note that temperatures used in these fits are in Celsius.

$$g_{balun} = 30.3573 - 0.02485T_b + 0.00010256T_b^2 - 0.000001979T_b^3 \tag{1}$$

$$g_{cable} = 15\times(-0.72167-0.0032929T_c+0.000078251T_c^2-0.0000013723T_c^3+0.0000000098601T_c^4) \tag{2}$$

The fit derived from the approach outlined above is compared with both models in Table 1. The "residuals" are the sum of the squares of the residuals, given by:

$$\chi^2 = \frac{\sum_i (V_i - m_i)^2}{\nu}, \tag{3}$$

where V_i is a reconstructed visibility with an associated T$_{cable}$ and T$_{balun}$, m_i is the model or fit prediction for that same T$_{cable}$ and T$_{balun}$, and ν is the number of degrees of freedom in the fit. It should be noted that χ^2 as defined is not a true χ^2, as no estimate of the variance in the measurements has been used; instead we have only divided by the number of degrees of freedom.

Since these residuals are not true χ^2, additional analysis is necessary to assess the significance of the differences in residuals. In order to get a characteristic scale for the reported residuals, we fit the null hypothesis, i.e., that there are no temperature dependent gains. This yields a χ^2 of 0.002077. The fit and linear model are therefore both 42% improvements over the null model, whereas the polynomial fit is a 36% improvement. The idea that the linear models are favored

	Balun	Cable	Residuals
Fit	-0.030	-0.013	0.001207
Linear Model	-0.024	-0.018	0.001208
Polynomial Model	—	—	0.001333

Table 1: Residuals from fit and both models. Residuals are calculated using Equation 3.

over the polynomial fit with statistical signifance is supported by the data shown in Figure 2. This figure shows the *total* gain change for a given (T_{cable}, T_{balun}) pair; on the x-axis is the gain change predicted by the fit, whereas the y-axis is the gain change predicted by the two models. The fit appears indistinguishable from the linear model. The polynomial model, however, appears to overpredict the amount of gain change at a given temperature.

1.4. Discussion

The conclusion suggested by this analysis is that the linear model of $H_{balun} = -0.024$dB K^{-1} and $H_{cable} = -0.018$dB K^{-1} should continue being used to correct the data. Although this model appears indistinguishable from the fit produced by this analysis, it is also derived from laboratory measurements, and therefore has more credibility. One should also be cautious of the results of the fit due to the strong degeneracy between the two coefficients, as can be seen from analysis of Cas A.

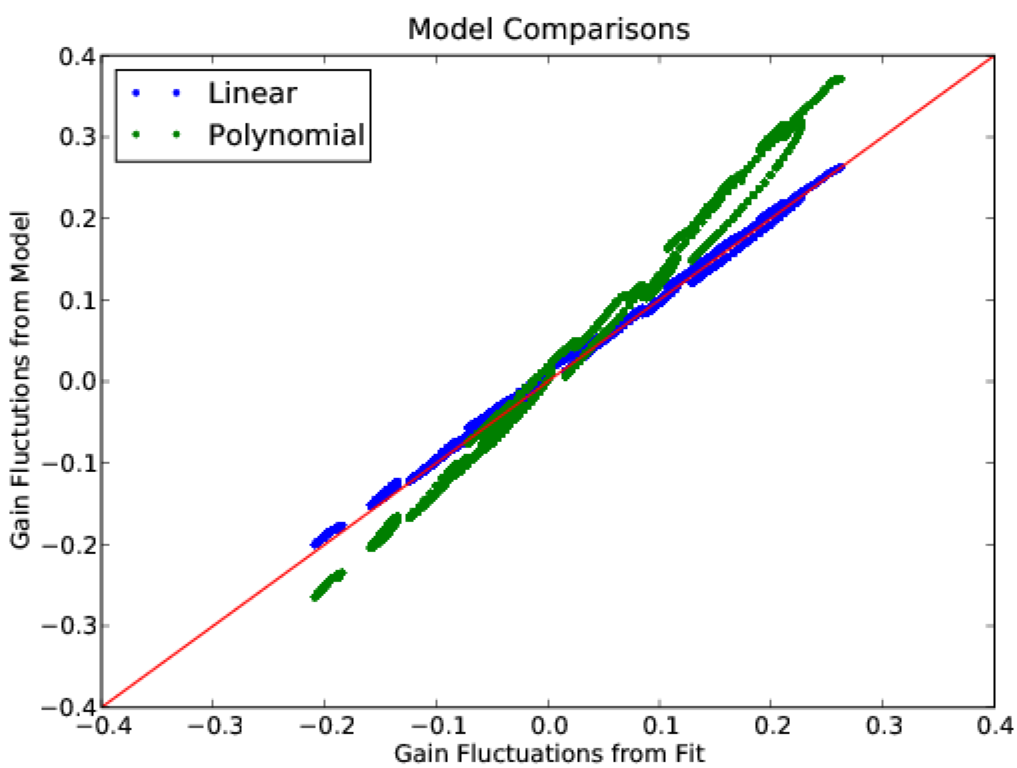

Fig. 2.— Comparison of total gain predictions: linear and polynomial models vs fit. The red line is y=x, i.e., it represents indistinguishable models.

It is worth offering some speculation about the polynomial model, as it is certainly the product of careful and concerted efforts. Perhaps it actually is the more accurate model when the true balun and cable temperatures are known, as they were in these laboratory experiments. However, data taken in the field uses values reported by thermisters near the balun and cable as proxies for the balun and cable temperatures themselves. If the balun or cable were hotter than the value reported by the thermister (a realistic possibility for the balun, which produces its own heat), then this model would *underpredict* the gain decrement. This hypothesis therefore predicts the opposite result as is seen in the data. I am open to any other suggestions.

REFERENCES

Parsons, et al. 2010, AJ, 139, 1468