Temperature Coefficients for DC Resistance of Match and Reference Attenuators

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Description

This report presents the measurements of DC resistance of the *match* standard (from Agilent 85033E calibration kit) and the reference 6-dB and 10-dB Mini-Circuit attenuators chosen to establish the accuracy of the VNA calibration.

The measurement proceeded as follows:

- The 6.5-digit multimeter was placed in the control room, subject to $\sim 5^\circ$C temperature variations.
- The load (*match* or attenuator) was connected to the multimeter using 50-cm leads. A female SMA connector was soldered to the end of the leads, in order to properly attach the load.
- The load, and part of the cables, were placed outside in order to monitor the resistance of the load subject to air temperature variations of $\sim$15°C.
- The resistance of the cables and its stability with time and temperature was established by shorting the ends and monitoring it for two days. It was found to be very stable (figures 1 and 2).
- The resistance of the *match* and attenuators was measured for at least two days each.
- The correlation of resistance with temperature was modeled with polynomials (figures 3 through 8).
- Relevant results are presented in table 1.

Description

Figure 1 shows the stability of the leads + connector resistance. Figure 2 presents the correlation with temperature. The residuals obtained when fitting a constant, a slope, and a second-order polynomial, to the correlation are within ± 1 mΩ. Therefore, the simplest model is assumed for the resistance: a constant of 50 mΩ. The residuals of ± 1 mΩ are considered for the computation of the uncertainty.

Figures 3 and 4 show the dependence of the Mini-Circuits 6-dB attenuator on temperature. The resistance of the leads and connector (50 mΩ) has been removed from the data. The residuals of a first- and second-order fit are $\pm$ 8 mΩ. No improvement is appreciated by going to second-order.

Figures 5 and 6 show the dependence of the Mini-Circuits 10-dB attenuator on temperature. The resistance of the leads and connector (50 mΩ) has been removed from the data. The residuals of a first- and second-order fit are $\pm$ 2 mΩ. Even though the margin is the same, using a second-order fit improves the profile of the residuals with temperature (red is flatter than blue on the lower panel of figure 6). Because of this, a second-order model is preferred.

Figures 7 and 8 show the dependence of the *match* standard on temperature. The resistance of the leads and connector (50 mΩ) has been removed from the data. The residuals of a first- and second-order fit are $\pm$ 4 mΩ. No improvement is appreciated by going to second-order.

Summary

The model for the resistance measurement is:

$$m = LR + (a + bT + cT^2) + Residuals. \tag{1}$$

The LR term represents the resistance of the leads and connectors. The terms in parenthesis represent the polynomial model. Only the 10-dB attenuator is actually modeled with a second-order polynomial. The other two cases are modeled as a slope, with $c = 0$.

The uncertainty assigned to a resistance value derived from the models is the sum of the uncertainty in the cable resistance (ΔLR) and the residuals of the fit.

The following table summarizes the results, using the notation of the previous equation.

Table: (1) Fit coefficients for the attenuators and *match*.

Load	LR [Ω]	a [Ω]	b [mΩ/°C]	c [mΩ/(°C)^2]	ΔLR [Ω]	Residuals [Ω]	Total [Ω]
6-dB Attn	0.05	83.666	-5.96		±0.001	±0.008	±0.009
10-dB Attn	0.05	60.884	0.925	0.0199	±0.001	±0.002	±0.003
Match	0.05	50.206	-3.72		±0.001	±0.004	±0.005

Resistance of Leads + Connector

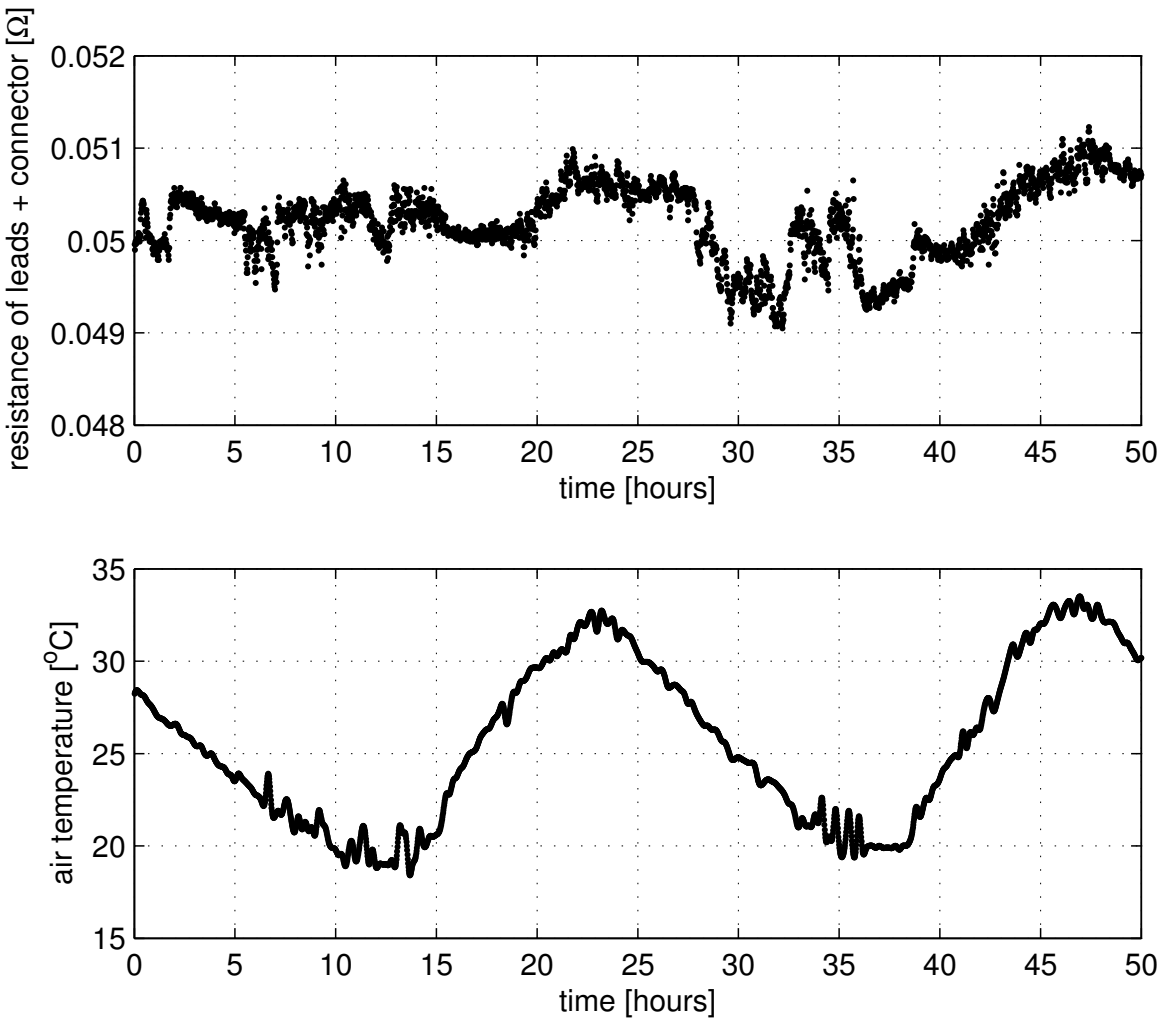

Figure: (1) Stability of resistance of cables and female SMA connector. It was obtained connecting a *short* standard at the connector.

Resistance of Leads + Connector

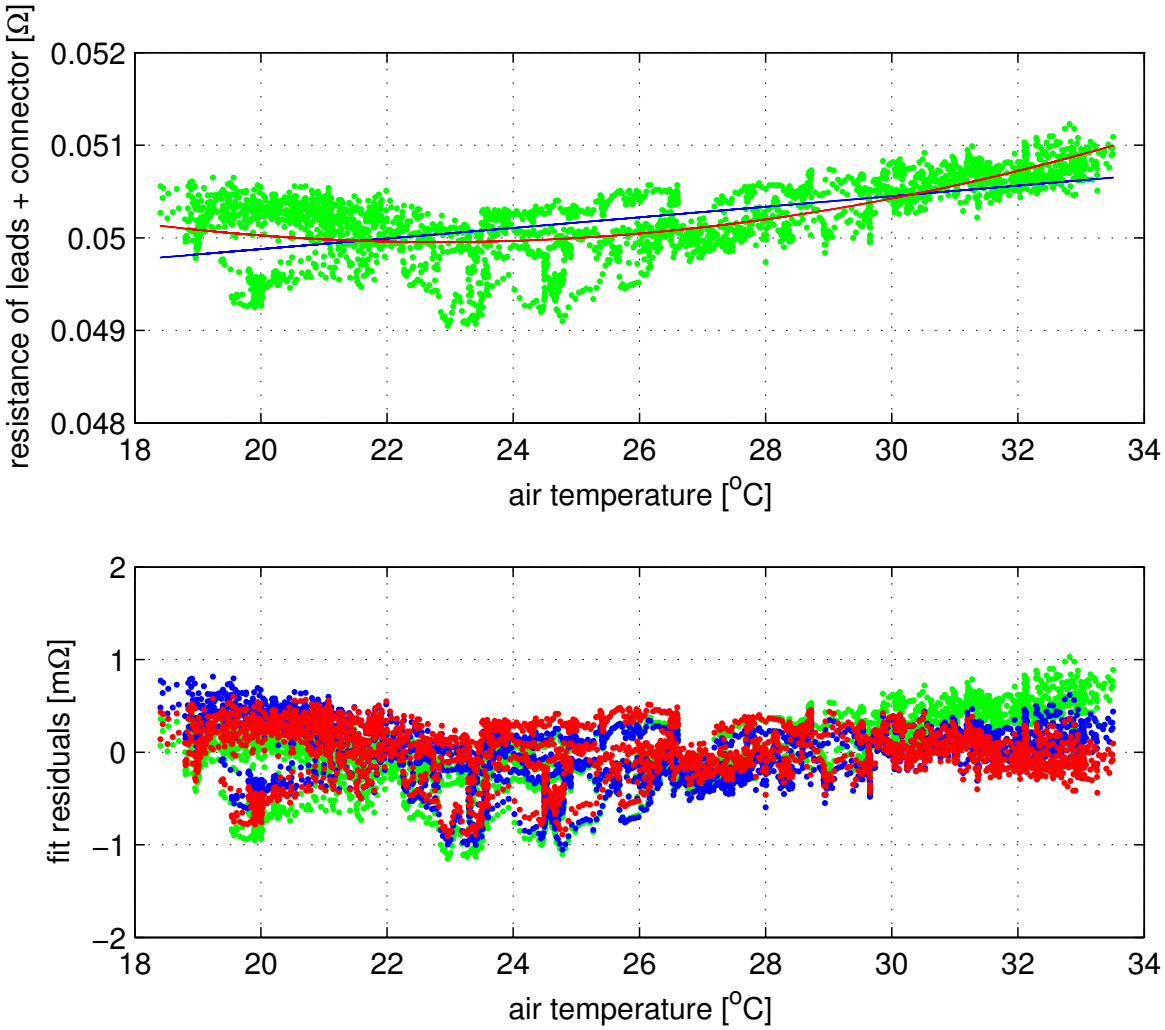

Figure: (2) Correlation of resistance with temperature. The lower panel shows the residuals after fitting a constant (green), slope (blue), and quadratic (red). If a margin of ± 1 mΩ is assumed, a simple constant value for the leads + connector of 0.05 mΩ can be used.

Resistance of 6-dB Attenuator

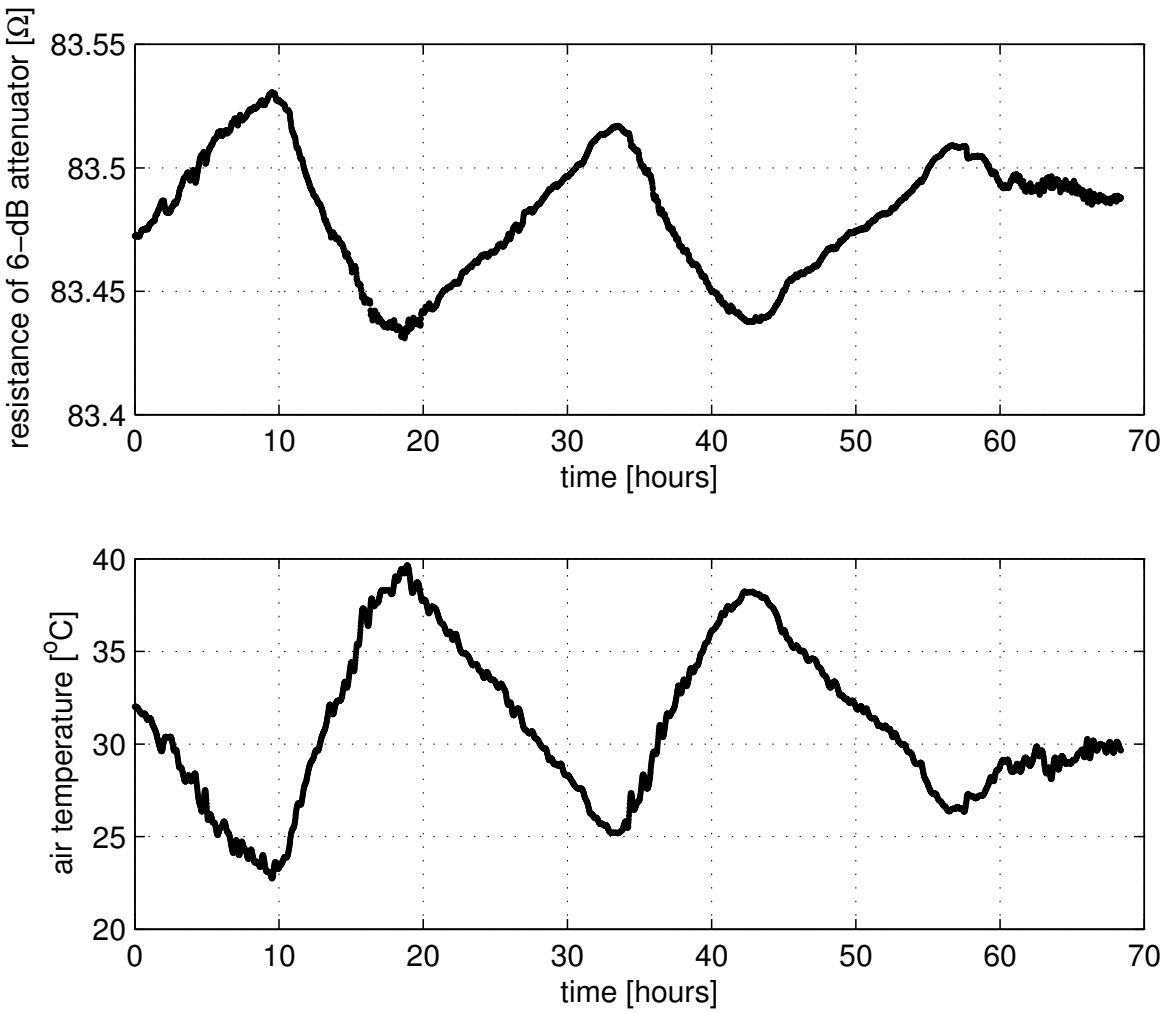

Figure: (3) Dependence of resistance of Mini-circuits 6-dB attenuator on temperature. It was measured for $\sim$ 70 hours. The resistance of cables and connector has been subtracted.

Resistance of 6-dB Attenuator

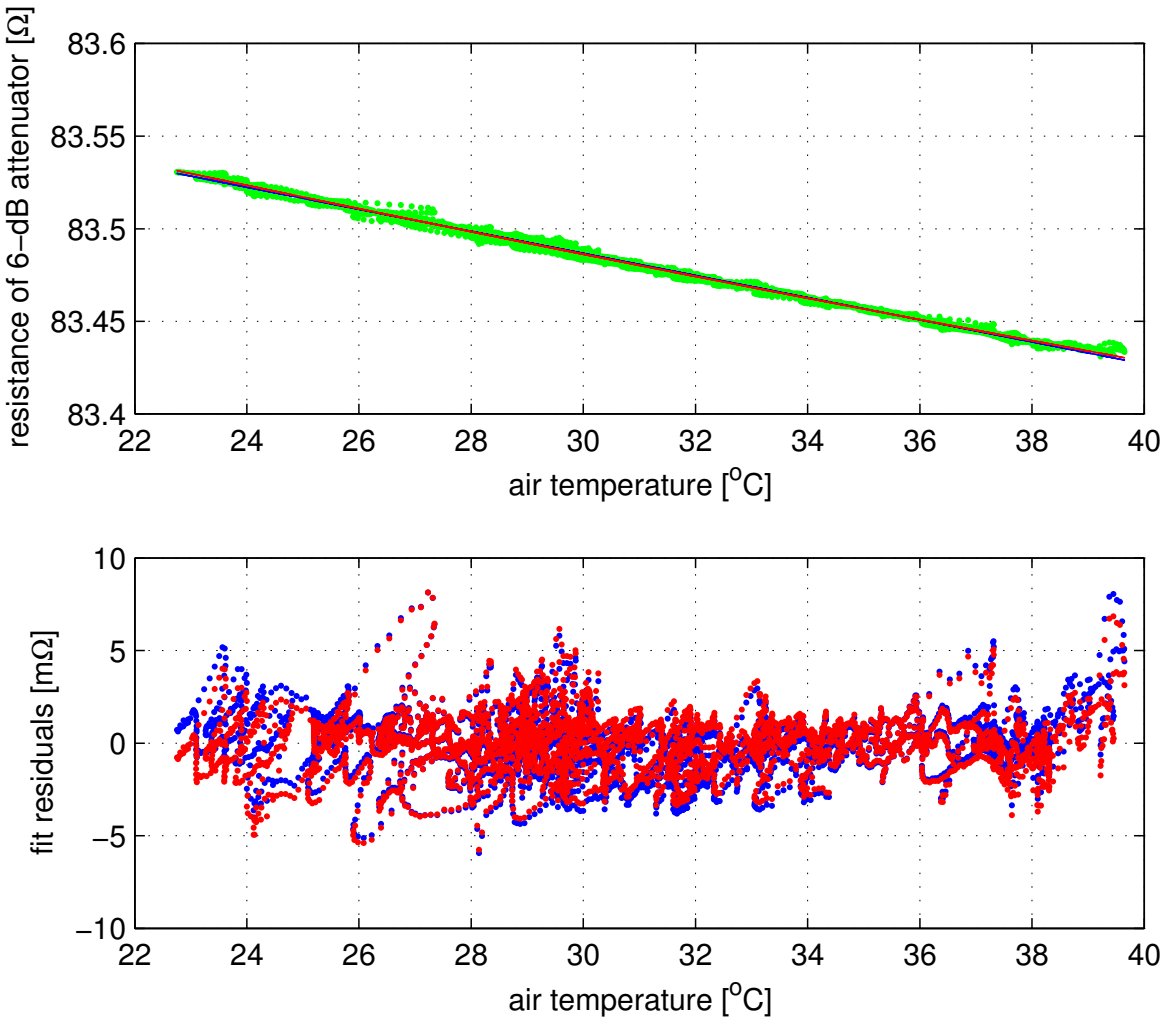

Figure: (4) Correlation of resistance with temperature. The lower panel shows the residuals after fitting a slope (blue) and quadratic (red). No improvement is observed when a quadratic model is used. Therefore, a first-order model is used and residuals of $\pm$ 8 mΩ are assumed.

Resistance of 10-dB Attenuator

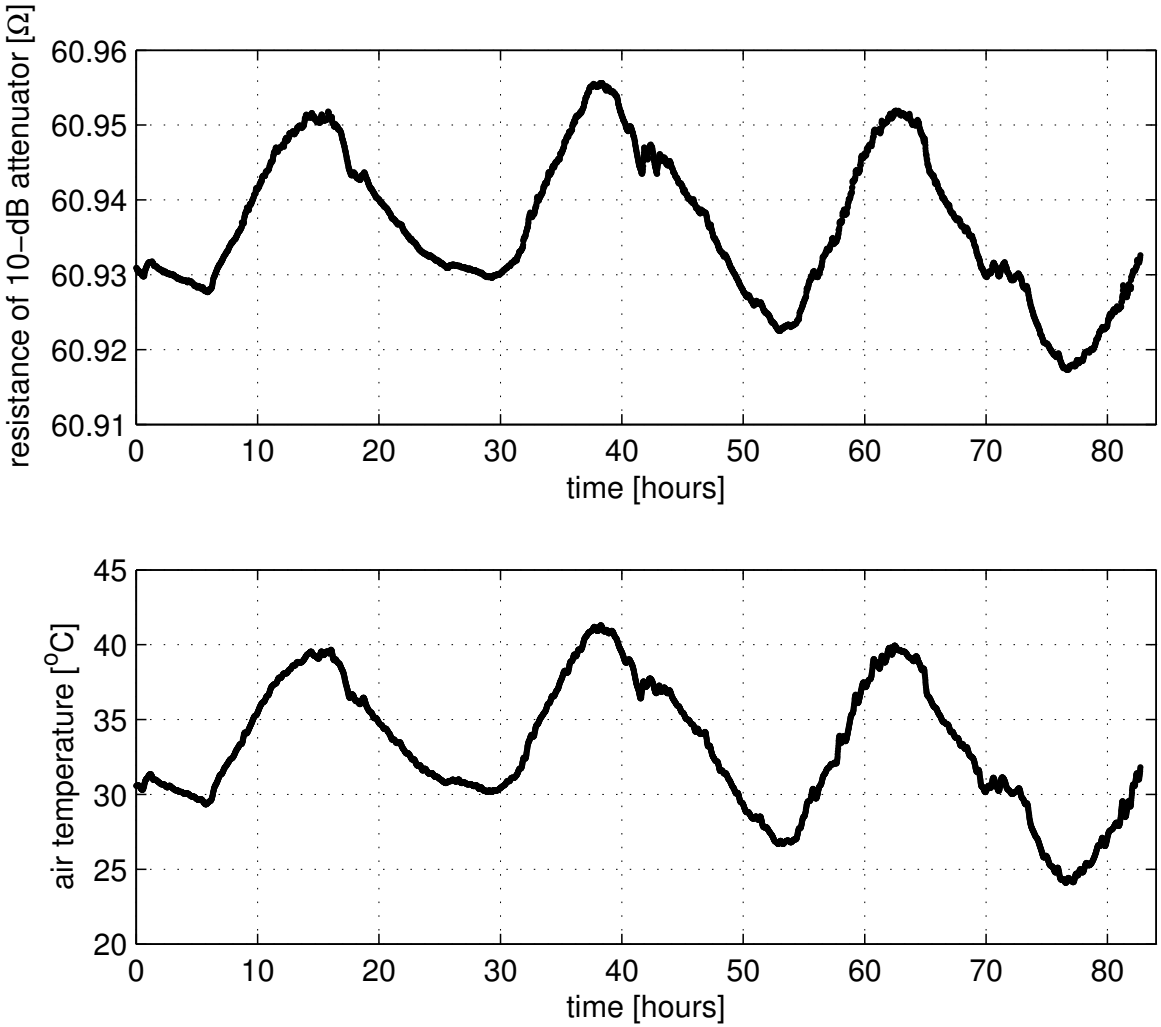

Figure: (5) Dependence of resistance of Mini-circuits 10-dB attenuator on temperature. It was measured for $\sim$ 83 hours. The resistance of cables and connector has been subtracted.

Resistance of 10-dB Attenuator

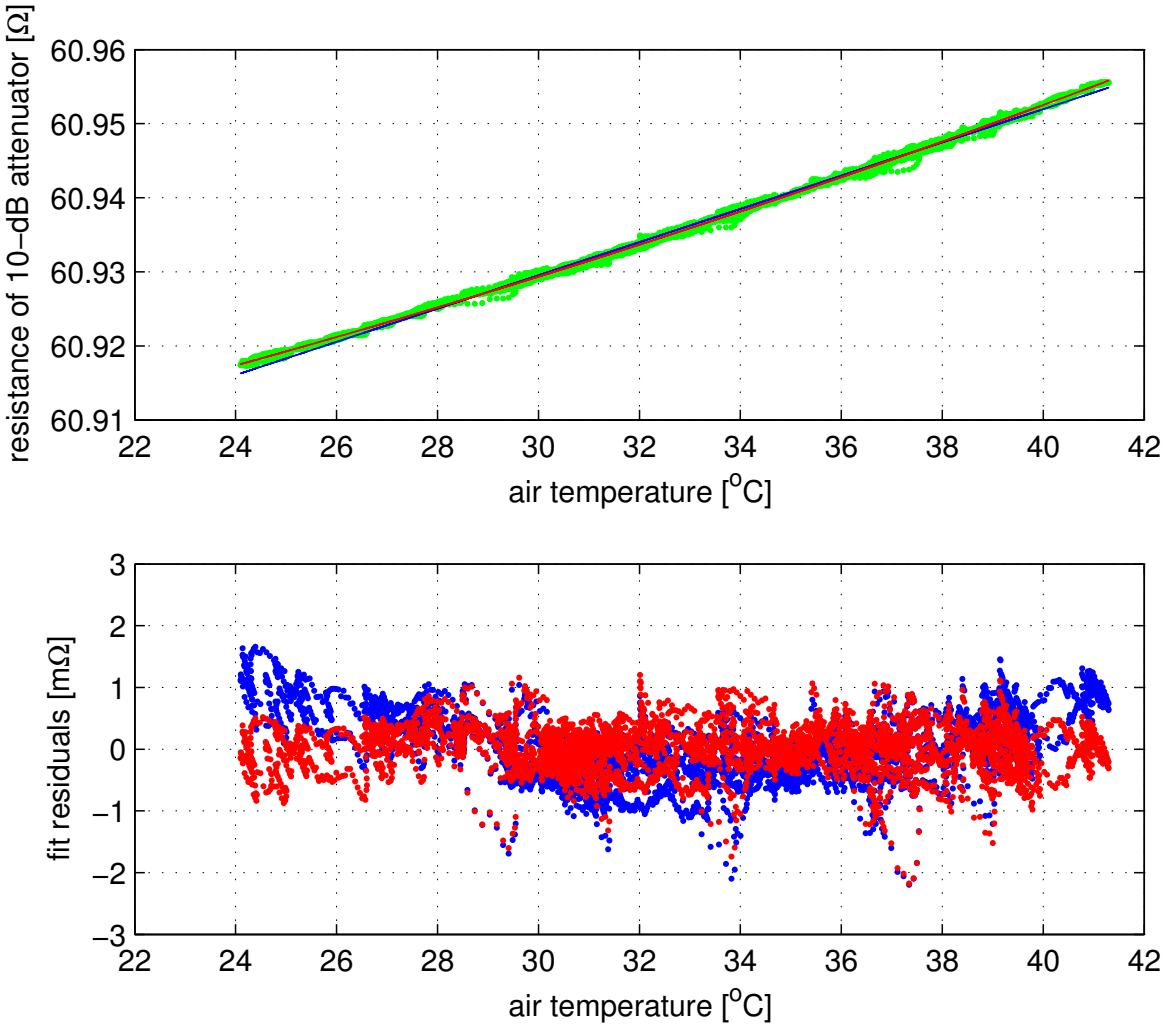

Figure: (6) Correlation of resistance with temperature. The lower panel shows the residuals after fitting a slope (blue) and quadratic (red). Improvement is noticed when a quadratic model is used. Therefore, a second-order model is used and residuals of $\pm$ 2 mΩ are assumed.

Resistance of Match

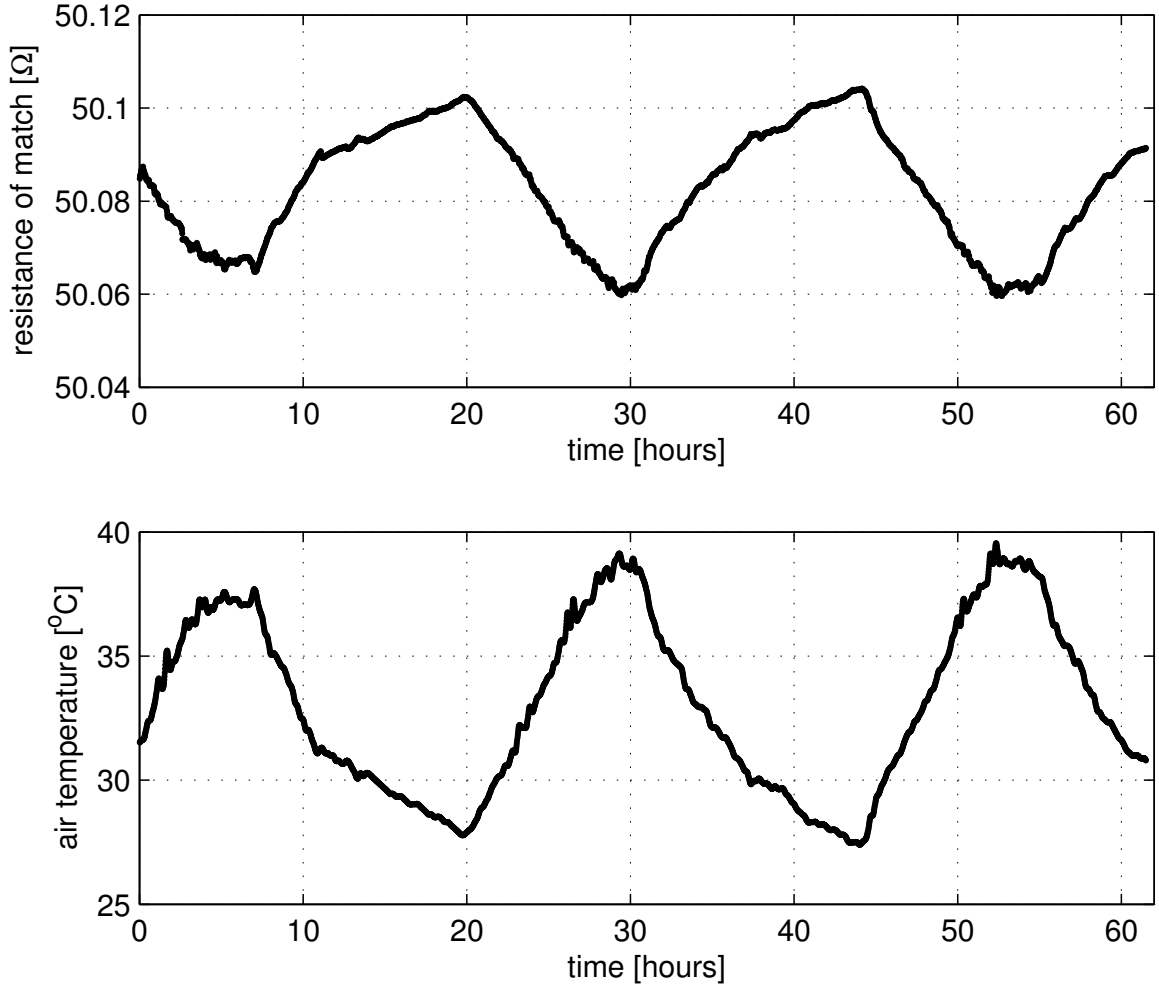

Figure: (7) Dependence of resistance of *match* on temperature. It was measured for $\sim$ 60 hours. The resistance of cables and connector has been subtracted.

Resistance of Match

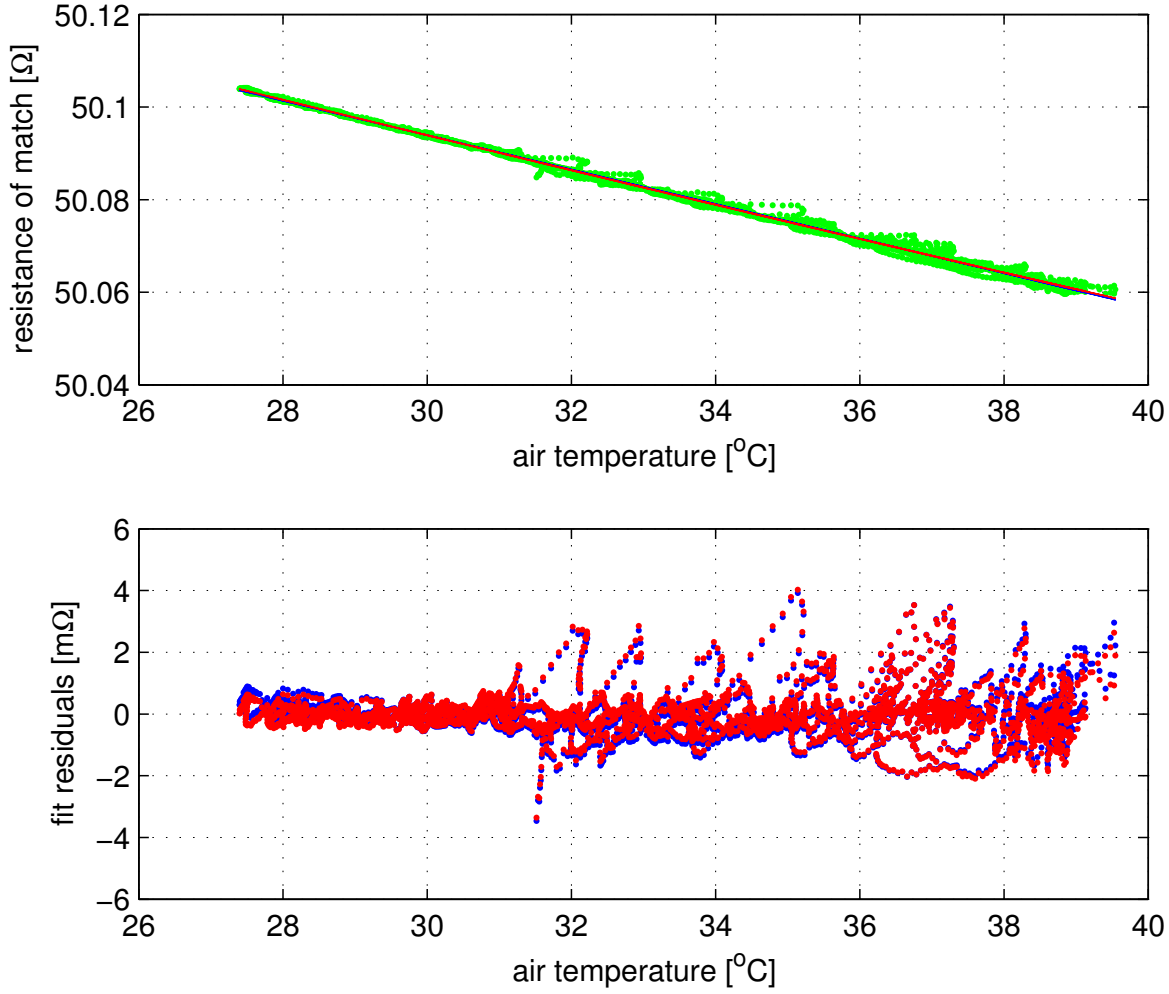

Figure: (8) Correlation of resistance with temperature. The lower panel shows the residuals after fitting a slope (blue) and quadratic (red). No improvement is noticed when a quadratic model is used. Therefore, a first-order model is used and residuals of $\pm$ 4 mΩ are assumed.