Rejection of the Intrinsic Noise for Non-contact Temperature Measurement of an Object in a Closed Cavity

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Abstract – A novel and simple method to reject the intrinsic system noise within a non-contact absolute temperature measurement is presented. The absolute radio thermometry usually uses Dicke's radiometer with a known reference temperature source, which has a fixed impedance [1] [2]. This can be applied to the radiometer, if a constant impedance of the antenna exists [3]. However, it is not suitable for the measurement of an object with variable impedance [4]. The impedance of the antenna, including the nearfield coupled object, might change its physical conditions. Moreover, the intrinsic noise of the measurement system depends on it strongly. Using the stochastic method based on a least mean squares algorithm [5] allows a measurement and calculation of the complex noise parameters. As an extension, this method is used to calibrate the intrinsic system temperature and compensate it for the measurement. An improvement of measurements accuracy and a simplification of the measurement procedure is achieved.

Theory – The noise source of an amplifier is modelled by a current and a voltage source, which are partly correlated. The noise characterization of an amplifier can be parametrized with three coefficients, the variances of the noise current source $\mathrm{E}\left[\left|\underline{\mathrm{I}}_\mathrm{n}\right|^2\right]$, the noise voltage source $\mathrm{E}\left[\left|\underline{\mathrm{V}}_\mathrm{n}\right|^2\right]$ and the complex correlation coefficient $\mathrm{Re}\{\mathrm{E}[\underline{\mathrm{I}}_\mathrm{n}\cdot\underline{\mathrm{V}}_\mathrm{n}{}^*]\}+\mathrm{Im}\{\mathrm{E}[\underline{\mathrm{I}}_\mathrm{n}\cdot\underline{\mathrm{V}}_\mathrm{n}{}^*]\}$, corresponding to four real numbers [5]. Fig. 1 shows the diagram of the noise model of the measuring amplifier with a coupled input impedance $\underline{Z}_L$ of the measured object, which has the temperature $\underline{T_L}$ proportional to the variance of the available voltage $\mathrm{E}\left[\left|\mathrm{V}_\mathrm{L}\right|^2\right]=4\mathrm{kT}_\mathrm{L}\Delta\mathrm{f}\,\mathrm{Re}\{\underline{\mathrm{Z}}_\mathrm{L}\}$.

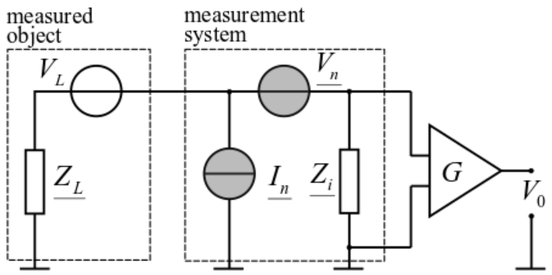


Fig.1: noise model of the measurement system

The output voltage V_o can be measured with a spectrum analyzer and calculated with equation (1).

$$V_o{}^2 = G^2\left|\frac{\underline{Z}_i}{\underline{Z}_i+\overline{\underline{Z}}_L}\right|^2\left(\begin{array}{c} 4kT_L\Delta f\,\mathrm{Re}\{\underline{Z}_L\}+E\left[\left|\underline{V}_n\right|^2\right]+E\left[\left|\underline{I}_n\right|^2\cdot\left|\underline{Z}_L\right|^2\right]- \\ -2\,\mathrm{Re}\{\underline{Z}_L\}\cdot\mathrm{Re}\{E[\underline{I}_n\cdot\underline{V}_n{}^*]\}-2\,\mathrm{Im}\{\underline{Z}_L\}\cdot\mathrm{Im}\{E[\underline{I}_n\cdot\underline{V}_n{}^*]\}\end{array}\right) \tag{1}$$

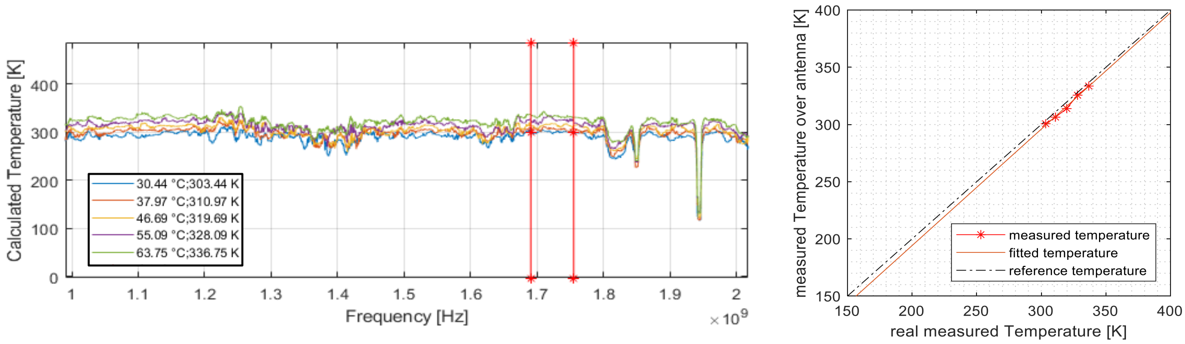
where k is the Boltzmann constant, Δf the measurement bandwidth and G the gain of the amplifier. For impedance matching we have to measure the input impedance of the amplifier $\underline{Z}_i$ and the coupled impedance $\underline{Z}_L$ using a network analyzer previously. As the three noise coefficients and the coupled impedance $\underline{Z}_L$ are independent of each other, the characterization of the noise coefficient is carried out by using a set of arbitrary but known input impedances at known temperatures. In order to obtain the four mentioned numbers a calibration with at least four arbitrary impedances needs to take place. In our case, we used 10 different calibration impedances covering a large range of the complex Z-plane. For the calculation of the noise coefficients a least mean square algorithm was used according to the method described in [5]. This leads to more accurate values of the noise coefficients as the dependence of the noise sources from the input impedance is better represented. Using this method, the system noise temperature is determined by:

$$T_{sys} = \frac{E\left[\left|\underline{V}_n\right|^2\right] + E\left[\left|\underline{I}_n\right|^2 \cdot \left|\underline{Z}_L\right|^2\right] - 2\,\mathrm{Re}\{\underline{Z}_L\}\,\mathrm{Re}\{E\left[\underline{I}_n \cdot \underline{V}_n^*\right]\} - 2\,\mathrm{Im}\{\underline{Z}_L\}\,\mathrm{Im}\{E\left[\underline{I}_n \cdot \underline{V}_n^*\right]\}}{4k\Delta f\,\mathrm{Re}\{\underline{Z}_L\}} \tag{2}$$

The temperature of the object can be calculated by subtracting system noise temperature from the total noise temperature of the spectrum analyzer:

$$T_{obj} = \frac{P_m \cdot Z_0}{4k_B \Delta f\,\mathrm{Re}\{\underline{Z}_{ant}\} \cdot G^2 \cdot \left|\frac{\underline{Z}_i}{\underline{Z}_i + \underline{Z}_L}\right|^2} - T_{sys} \tag{3}$$

Experiment and result – The calibration of the amplifier for the impedance measurement was carried out first. The 10 known impedance terminations, which are made of different lumped elements, were hooked on the input of the amplifier at known room temperature. Afterwards an object consisting of a thermally controlled hose with salt water was set to 5 different temperatures. Fig. 2 (a) shows the results of the calculated temperature according to (3). Fig. 2 (b) shows the average temperature in the marked range of 1.69–1.76 GHz.



(a) (b)

Fig.2: Calculated temperatures of the measured salt water

The offset of the fitted temperature line shows a low deviation in comparison to the measured reference temperature, describing a correct evaluation of the intrinsic noise level of the system. From Fig. 2 (a) it can be seen that different frequency ranges show slightly different temperature offsets, indicating that a fully compensation of the system noise is not possible for all input impedances.

Conclusion – Compared to the traditional characterization of the intrinsic noise, this method allows a system noise calibration without disassembling the measurement setup at any time between the temperature measurements. The accuracy for the temperature measurement will improve, if more calibration impedances are in use. An automated calibration procedure can be realized using e.g. a mechanical multiplexer. In combination with an in-situ measurement of the object impedance, the system performance could be significantly enhanced.

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