The simultaneous correction of the spherical ($C_s$) and the chromatic aberration ($C_c$) in transmission electron microscopy (TEM) has been implemented for a broad range of beam voltages: 20-300kV [1-3]. In such an instrument the effects of the lateral and temporal incoherence of the illuminating electron beam are largely suppressed. The measured remaining focus spread for instance is by far small enough to allow information transfer beyond $g=20/nm$ - even at 300kV where $C_c$-correction is most challenging [1]. However, during the development of the corrector hardware we recognized, that an additional incoherence mechanism deteriorates the contrast of the recorded images. By careful measurements of the contrast transfer we found that an envelope function of the form $\exp[-2(\pi\sigma|g|)^2]$ perfectly matches the observations. It turned out, that an isotropic image spread $\sigma$ reduces the image contrast. Image spread can be understood as a stochastic, high-frequency image displacement during acquisition. Recently, it could be proven experimentally that the origin of this image spread is magnetic field noise (Johnson-Nyquist noise) emitted from the conducting parts around the electron beam. The thermodynamic nature of this noise was clearly demonstrated by cooling beam tubes (made from stainless steel or permalloy) from room temperature down to liquid nitrogen temperature [4].

In the experiments we measure the standard deviation $\sigma$ of this image shift. Its variance $\sigma^2$ is proportional to the product of the field correlation length $\xi$ along the path and the variance $<B^2>$ of the transversal magnetic field [4]. Here, we report on the progress we made to understand the experimental results theoretically.

Surprisingly, magnetic materials ($\mu_r>1$) introduce more integral noise than non-magnetic materials like stainless steel. Hence, we were very much interested in the common situation were magnetic material is placed outside a liner tube made from stainless steel, see Figure 1. The question arose, if the thin stainless steel tube is transparent for the stronger noise emitted from the magnetic components. Here we also report on the experiment “tube-in-tube”: A thin-walled (0.15mm) stainless steel liner tube with 3mm outer diameter is placed in a stack of permalloy tubes, see Figure 1. Beside numerical strategies, a semi-analytical approach to understand the compound system is presented, see Figures 2+3.

After all, electron optical design - especially the design of extended corrector optics - has to take into account the existence of magnetic field noise emitted from the conducting parts. We discuss scaling rules and why hexapole-type aberration correctors are collecting less image spread from thermal magnetic field noise than quadrupole-octupole-type $C_c$-correctors.

Acknowledgement:

References:
Fig. 1: Experiment to compare the thermal magnetic field noise of a thin stainless steel liner tube with the compound system. Permalloy tube fitted over a 3mm stainless steel liner tube (a), tube stack and outer holder tube (b), end view of the compound sample (c), dimensions (d), copper cooler and two samples: bare liner tube and the compound sample (e).

$$A_\varphi = J_1(r) \cdot \exp[-kz]$$

Fig. 2: Theoretical treatment by means of the fluctuation-dissipation theorem. The power-loss induced within a conducting structure by a fluctuating magnetic dipole is calculated. In rare cases with high symmetry Maxwell's equations can be solved directly by separating variables: A sheet of non-magnetic material in contact with a magnetic half-space.

Fig. 3: For thin conducting sheets (thickness t, resistivity $\rho$) a boundary-element method for a triangular mesh covered with $t/\rho$ is the preferable way to calculate the frequency spectrum of the magnetic field noise.