Calibration of Radio Astronomical Phased Arrays

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The radio astronomical community is currently developing or building several new radio telescopes. For most of these telescopes, survey speed is one of the key system specifications. Survey speed is a measure of how fast a given part of the sky can be mapped out down to a given sensitivity level and can either be improved by expanding the field-of-view (FOV) or increasing the sensitivity. Phased arrays can provide a large FOV and are therefore used in most new radio telescopes, either as aperture array or as phased array feeds.

Accurate calibration of all signal paths in a radio telescope array is required to achieve optimal performance and to create maps with a dynamic range exceeding 1:100. In terms of calibration, the use of phased array technology poses new challenges. First of all, the number of signal paths in the system increases by three orders of magnitudes for a system like LOFAR and even four orders of magnitude for the SKA compared to current radio telescopes. Secondly, the chance that environmental conditions, such as ionospheric propagation conditions, differ for distinct lines-of-sight within the FOV is larger for a wide FOV than for a small one. Calibration of radio astronomical phased array thus poses a daunting parameter estimation task. In this tutorial, I give an overview of available calibration techniques and how these help to solve the calibration challenges that lie ahead.

The calibration problems for distinct radio telescope systems can be categorized in four scenarios based on the size of the array and the field-of-view of the elements. This determines whether direction dependent effects need to be taken into account and, if so, whether they can be assumed identical to all elements in the array or different for different elements. Depending on the scenario that fits a given instrument, a specific approach to calibration is required.

The processing in new radio telescope systems is typically split into several levels such that the total data rate at each level remains manageable. At each processing level, the total amount of information is reduced, for example by beam forming the received signals to the field of interest. It is generally impossible to correct deterioration of the signal due to imperfect system calibration in the lower levels of the processing hierarchy at higher levels. This hierarchical processing structure thus reflects on the calibration scheme of the telescope in the sense that some form of calibration is required at each level and thus that the telescope needs a corresponding calibration hierarchy. In this presentation, I focus on the lower levels of this hierarchy since most of the novelty of the introduction of phased array technology comes in at that level.