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Tuning an antenna array to perform as a sensitive single dish

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Abstract. We propose a method to maximize the signal-to-noise ratio for incoherent/coherent array observations using a radio interferometer.

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1. Introduction

An interferometer can be used as a single dish by adding-up signals from individual antennas corrected for geometric delays, for the purpose of enhancing the signal-to-noise ratio (SNR) for pulsar observations. Signals can be added with random phases (incoherent array mode) or in phase (phased array mode). At the Giant Meterwave Radio Telescope (GMRT), both modes are used regularly for pulsar observations. Pulsar observations in either mode lead to very high data rates, making it impractical to record individual antenna data streams (ADS) for post-processing. Therefore, prior to the actual pulsar observation, an observer needs to decide upfront the ADSs that (s)he would like to add-up without compromising on signal quality. Quality of an ADS is assessed using OFF-ON-OFF-... measurements relative to a strong calibrator source. Confounds in this assessment are the unknown but smooth trends due to gain variation, unpredictable shifts, and artifacts such as outliers due to radio-frequency interference (RFI). What would help an observer make this decision is well-tuned methods that will (a) measure the SNR robustly in presence of confounds; (b) rank ADSs based on quality; and (c) find a subset of ADSs that will yield the best overall SNR when added up.

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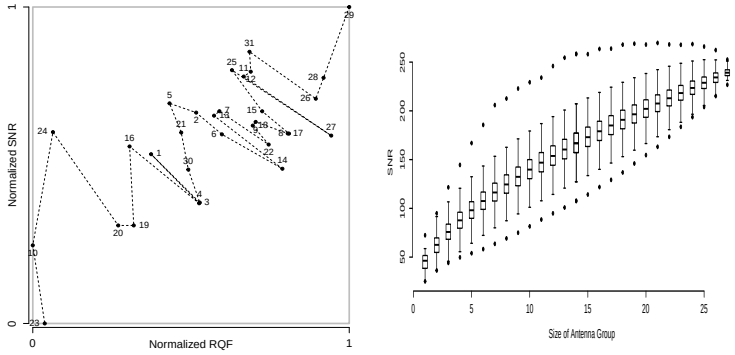

Figure 1. Left panel: An ADS ranking scheme. Right panel: Group SNR distributions. See text for details.

2. Methods

To quantify the quality of an ADS, we use two measures of signal quality of an ADS, namely, the signal-to-noise ratio,

$$\text{SNR} = (\text{on-source signal level} - \text{off-source signal level})/\text{off-source noise level}, \quad (1)$$

and the response quality measure (RQF),

$$\text{RQF} = \text{distance}(\text{ measured ADS response profile, ideal response profile })^{-1}, \quad (2)$$

which is motivated by the fact that for OFF-ON-OFF observations in an ideal world, we expect to see a sharp hat-shaped response profile for the signal. Larger the RQF, better the quality. Since the data may be contaminated with outliers, it is important to estimate both the quantities in the numerator of Eq. 1 using a robust measure of the signal level (e.g., the median). Similarly, in presence of unknown trends, the denominator is better estimated by the difference estimator of variance (Rice 1984; Beran 2000). ADSs can be usefully ranked using these two measures. To maximize the overall SNR, we perform a brute-force combinatorial search over all possible ADS combinations of k antennas at a time: this is computationally feasible for sufficiently small-sized antenna arrays such as the GMRT.

3. Results

Our data (not shown) consisted of OFF-ON-OFF response profiles for the 30 GMRT antennas with respect to the calibrator source 3C48. Figure 1 (left) shows the quality ranking of the 30 ADSs from the best (top right) to the worst (bottom left). This worst 3 ADSs (23, 10, 24) had visibly strong trends, sudden shifts, and RFI artifacts (not shown). Figure 1 (right) shows distributions (as boxplots) of the overall SNR of an

antenna group as function of the group size, with the extreme values indicated with solid dots. While group SNR shows an aggregate $\sqrt{\text{group size}}$ behaviour, the highest group SNR is attained for a group size in the 15-20 range. This implies that that the common decision to add-up all the ADSs together is not optimal.

4. Conclusion

In this report, we show how the quality of an ADS can be assessed using the SNR and RQF measures. For a GMRT ON-OFF-ON dataset, we perform a brute-force combinatorial search over all possible ADS combinations to maximize the overall SNR. Interestingly, we show that adding-up signals from all the ADSs does not yield the best overall SNR: For the GMRT data set used, the best overall SNR is attained for an ADS combination of size in the 15-20 range.

References

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