Self-Holography – Slimming Down Calibration of Large Aperture Arrays

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Why use self-holography

- Traditional calibration schemes make use of the array covariance matrix:
    - Required data volume scales quadratically.
- We propose self-holography (SH) as an alternative:
    - Uses the correlation of the individual receive paths with a reference signal obtained by the array itself.
    - Required data volume scales linearly.
- The Mid-Frequency Aperture Array (MFAA), shown on the right, is envisaged to have between 10^3 and 10^4 receive paths per station.
- At this scale it might be infeasible to use covariance matrix based methods!

But self-holography has drawbacks…

- The simplicity of SH stems from an assumption that the calibration signal measurement is completely isolated.

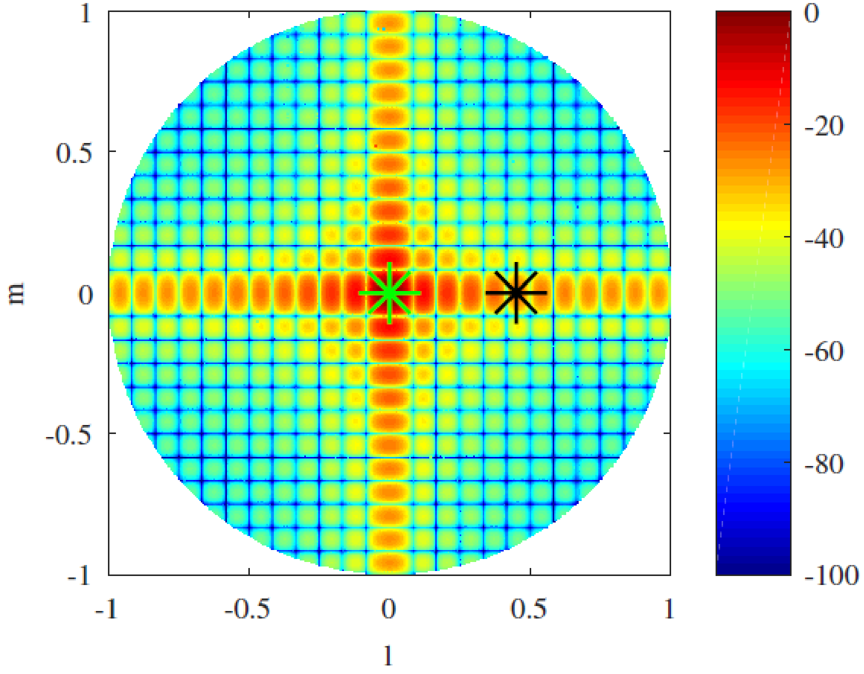
- Practically, this will not be the case so the presence of interference will impact the accuracy of the gain estimates.

- See simulation example and corresponding results on the next slide:

The impact of interference and noise – a simulation

- Source positions indicated on top of the radiation pattern (scale is logarithmic). Green and black stars indicate the calibration and interfering source respectively. The interfering source is 4 times stronger than the calibration source.

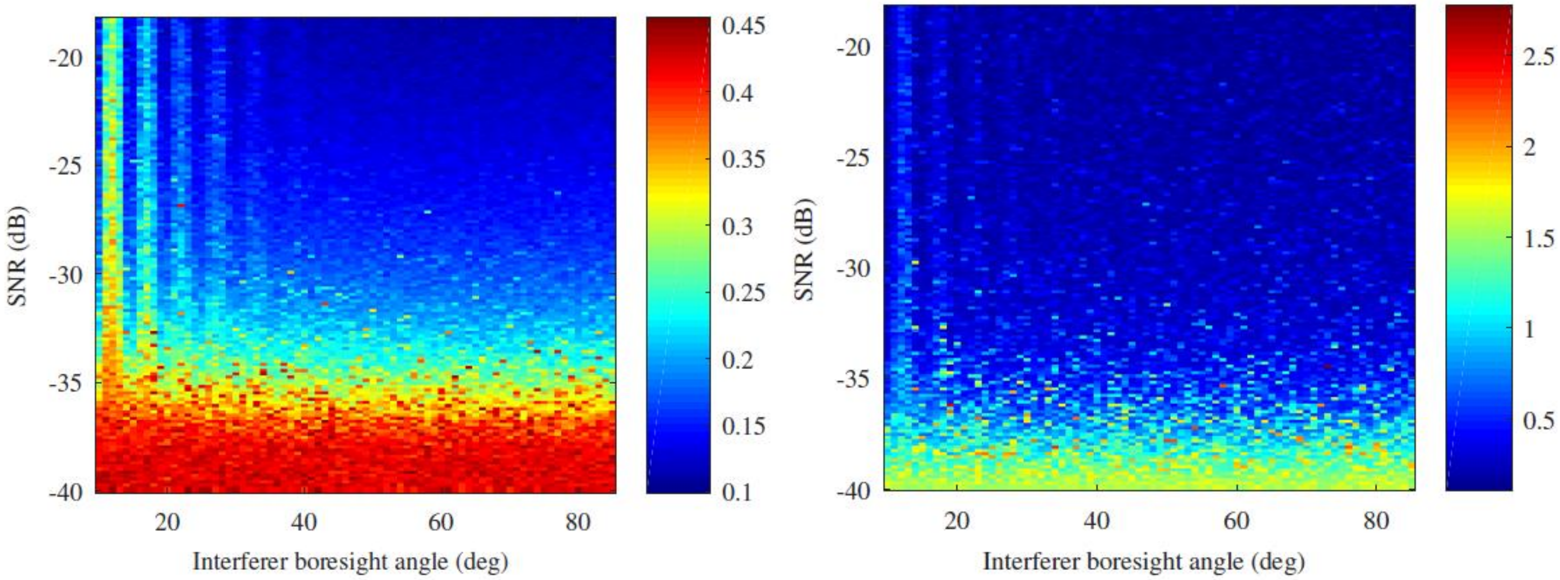
- Level of interference is varied by simply adjusting the boresight angle of the interferer (or the l-coordinate in this representation).



- Results on next slide:

The impact of interference and noise – a simulation

- Relative gain magnitude (left) and phase error (right) as a function of interferer boresight angle and the instantaneous Signal-to-Noise Ratio (SNR) of the calibration signal.



- Significant receiver noise will cause noisy gain estimates. However, for normal operating conditions, it was determined that it will not be a concern.

- Interference will cause a bias in the gain estimates.

- In the next slide, we will look at a possible solution to minimise the interference.

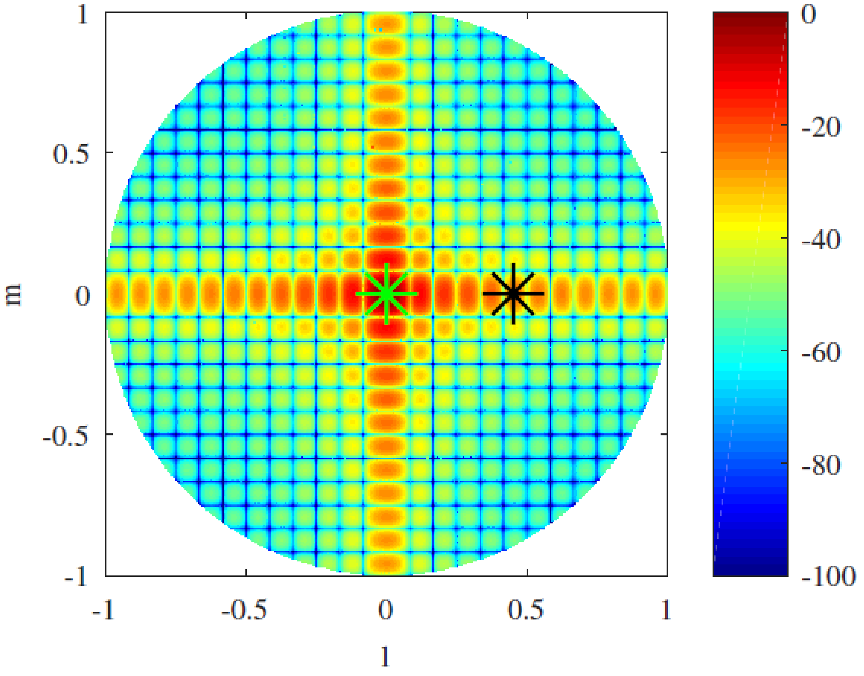
Null placement as a possible solution

- For the same simulation setup shown in the previous slides, we can minimise the interference by placing a null in the direction of the interferer.

- The effectiveness of this is determined using two dynamic simulation scenarios:

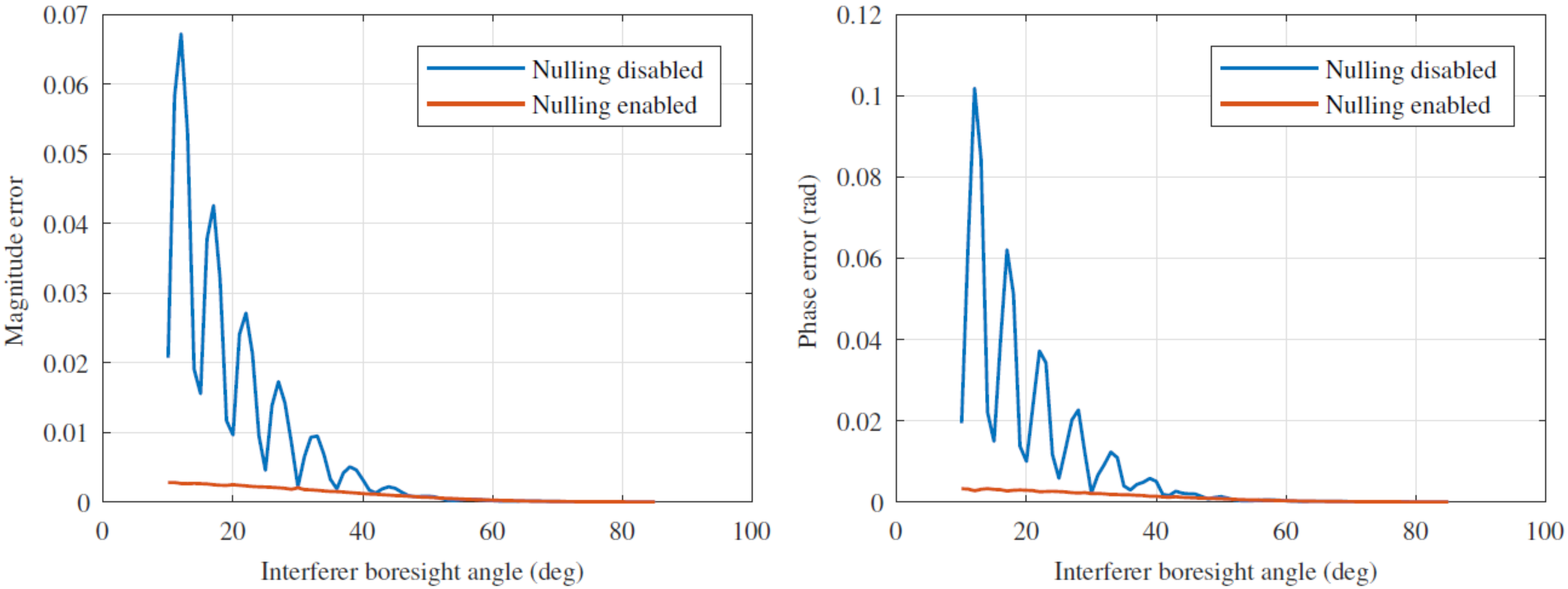
    - The boresight angle of the interferer is varied between 10 and 85 degrees while maintaining constant power.

    - The boresight angle of the interferer matches the first sidelobe of the array while its power is varied.



Results: interferer with variable position

- Mean relative gain magnitude (left) and phase error (right) as a function of interferer boresight angle with nulling enabled and disabled.



- With nulling disabled, errors follow the sidelobe pattern of the array as expected.

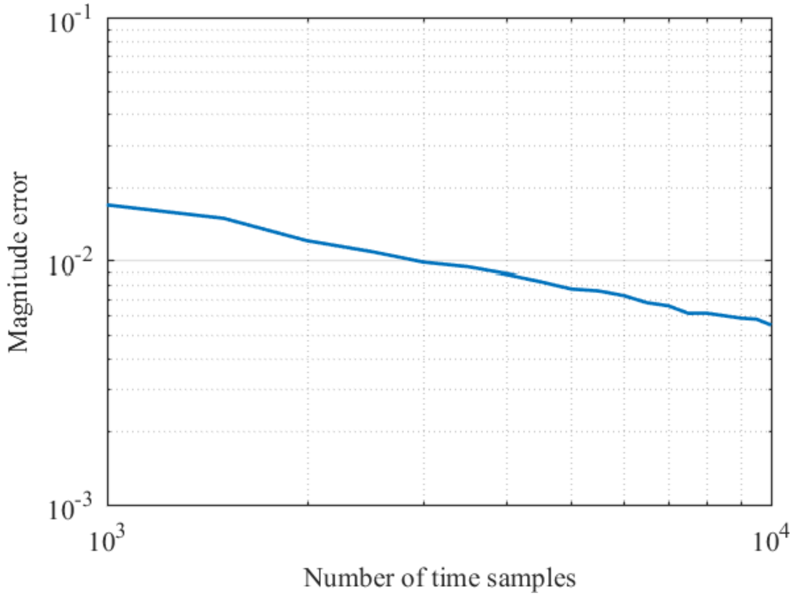
- With nulling enabled, errors are proportional to the embedded element pattern (EEP). This is due to the power received by the individual elements in the array, which is unaffected by nulling.

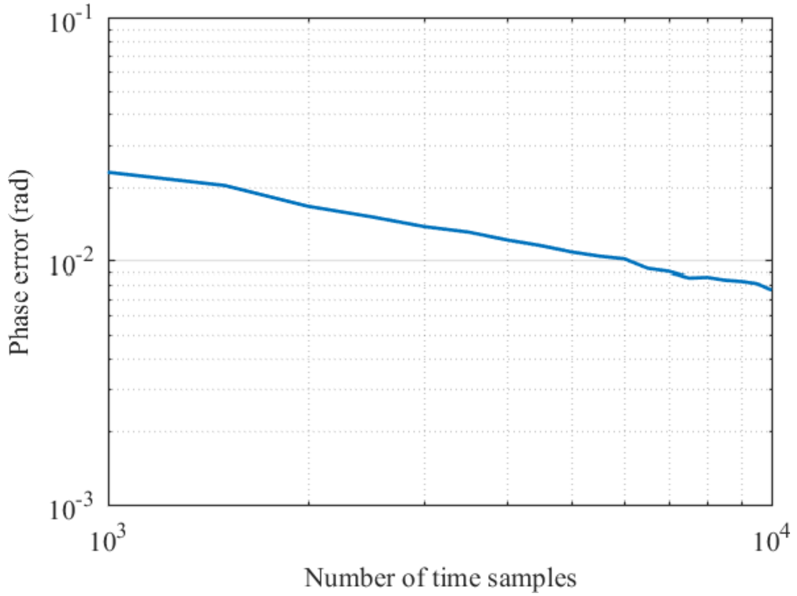
Additional insight: interferer with variable position

The simulation was based on finite length, noise-like signals, which means that the remaining error (with nulling enabled) will decrease with an increase in signal length.

This can be explained by the contribution of the off-diagonal entries to the diagonal (autocorrelation) entries of the array covariance matrix, which will reduce as the signal length increases. This effect is referred to as self-noise.

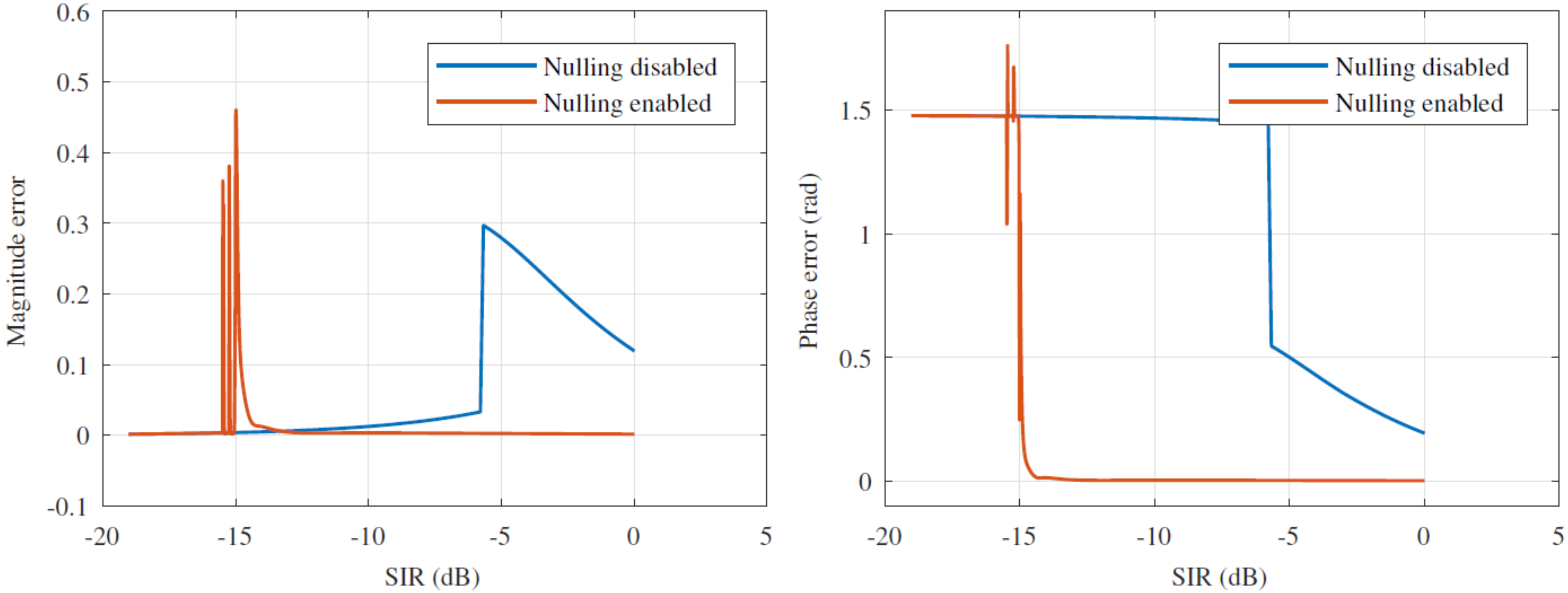
The results below illustrate this effect by showing the mean gain estimation error as a function of signal length for an interferer that has a fixed location:





Results: interferer with constant position, but variable power

- Mean gain magnitude (left) and phase error (right) as a function of the Signal-to-Interference Ratio (SIR) of the incident signal with nulling enabled and disabled.

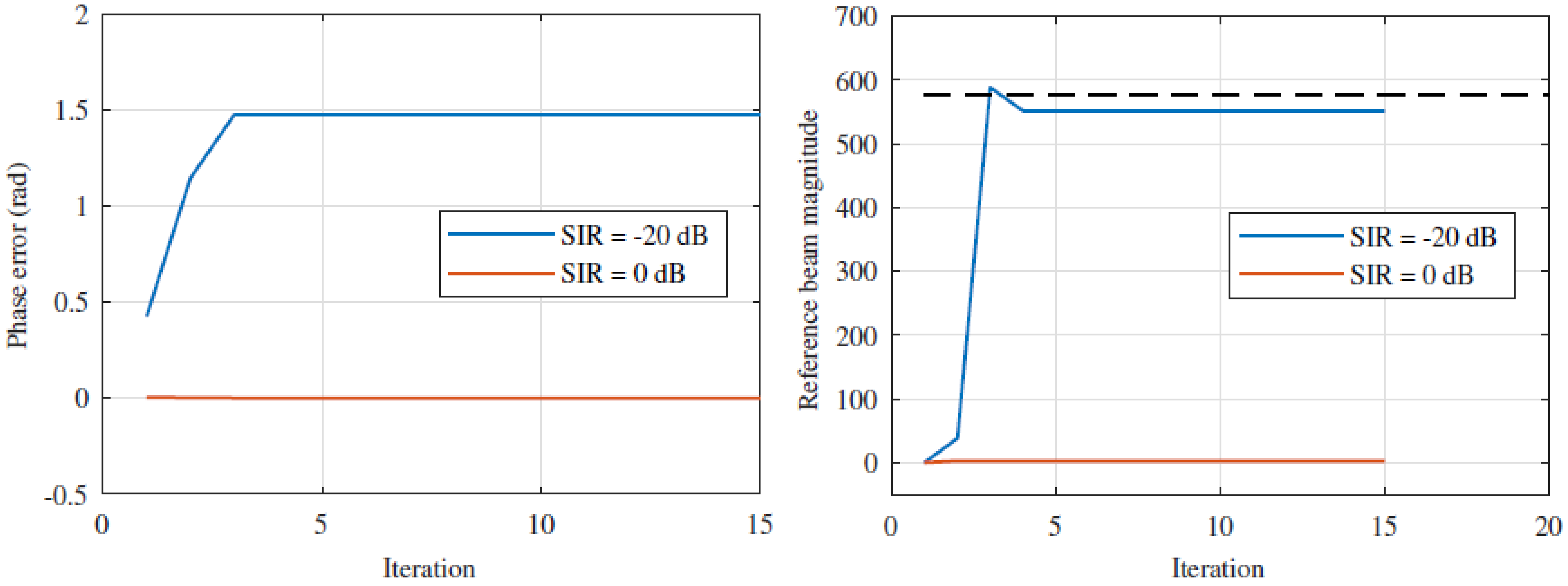


  - Nulling disabled: The estimation error increases as the interfering power increases until a discontinuity is encountered. This is the point where the calibration procedure switches to the interfering source because of its dominant power. An example is shown in the next slide that illustrates this effect.

  - Nulling enabled: Highly effective in reducing the impact of the interferer. However, after increasing the interfering power beyond a certain point, the same is observed as above.

Results continued: interferer with constant position, but variable power

- Mean phase error (left) and array beam magnitude towards interferer (right) as a function of solving iteration. When the SIR is low, the calibration procedure quickly breaks down. The right-hand plot confirms that the array beam is pointed at the interfering source after the breakdown.



- The array beam magnitude when beamformed to the interferer is indicated by the dashed line

Results continued: interferer with constant position, but variable power

- The exact point of the discontinuity with nulling enabled is dependent on the initial gain errors and the length of the signal measurement.

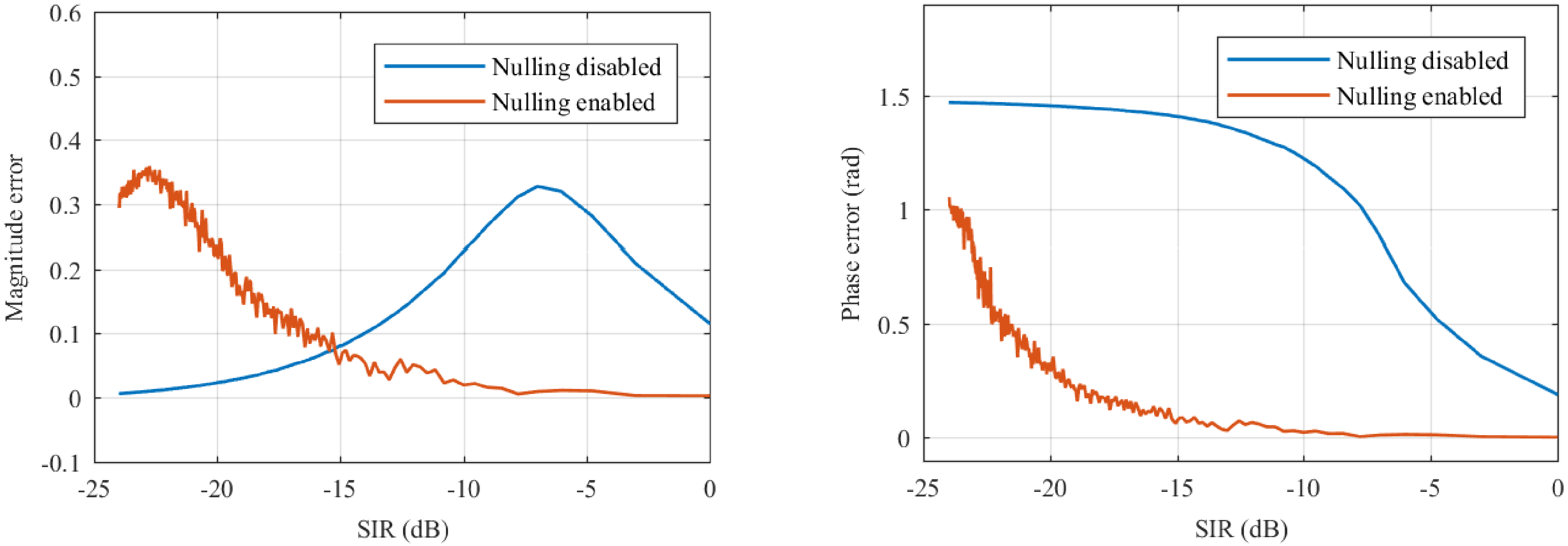
- That is because the initial gain errors reduce the suppression of the interferer while the self-noise effect, which increases with a reduction in signal length, limits the accuracy of the first solving iteration.

- A large enough estimation error after the first iteration will cause the array beam to distort and lose focus on the calibration source. Since the simulation is set up to use the same signal measurement in each solving iteration, further solving iterations will only distort the beam further, causing gain errors that increase with iteration.

- Using a new signal measurement with each iteration dampens this effect. See results on next slide:

Results continued: interferer with constant position, but variable power

- Mean gain magnitude (left) and phase error (right) as a function of the SIR of the incident signal:



- Using a new signal measurement with each iteration helps to stabilise the beam. The array maintains focus on the source so the remaining bias is caused by the interference only.

- In this case the estimation error increases steadily as a function of decreasing SIR until it locks onto the interferer.

Conclusions

- It was shown that nulling is highly effective in improving the performance of self-holography. The plot on the right shows a comparison of the SIR of the array output signal (with nulling enabled and disabled) as a function of the SIR of the signal that is incident on the array.

- Even better performance expected when increasing the array size.

- Only one interferer was considered, which is mostly unrealistic when considering a real environment.

- However, this work is aimed at arrays that are planned to be built in radio-quiet environments with RFI monitoring equipment that provides spatial information on any interference that might arise.

- Spatial information provided by the RFI monitoring equipment can then be used for spatial filtering. A good example of this type of RFI is overhead aviation traffic.

- Lastly, nulling can also be used to suppress the signals from other bright astronomical signals that might be detrimental to the calibration measurement.