Validation of the obtained mutual coupling impedance matrix from CST model of two element array

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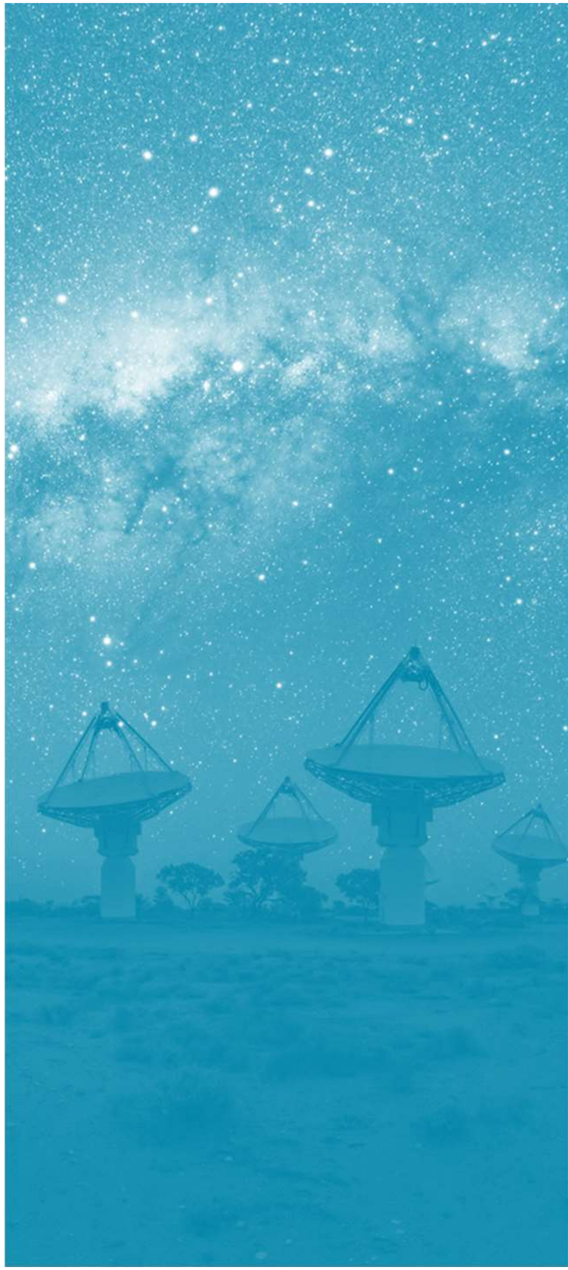
Presenter: Bahare Mohamadzade | 16/11/2022

Outline

- Mutual coupling effects on phased array performance
- Required data for calculating array sensitivity
- Two dipole models for initial analysis
- CryoPAF phased array receivers modelling and measurement results



Mutual coupling and phased array

For analysing the phased array antenna and using network theory, mutual coupling effects should be included in the design of receiving phased arrays?!

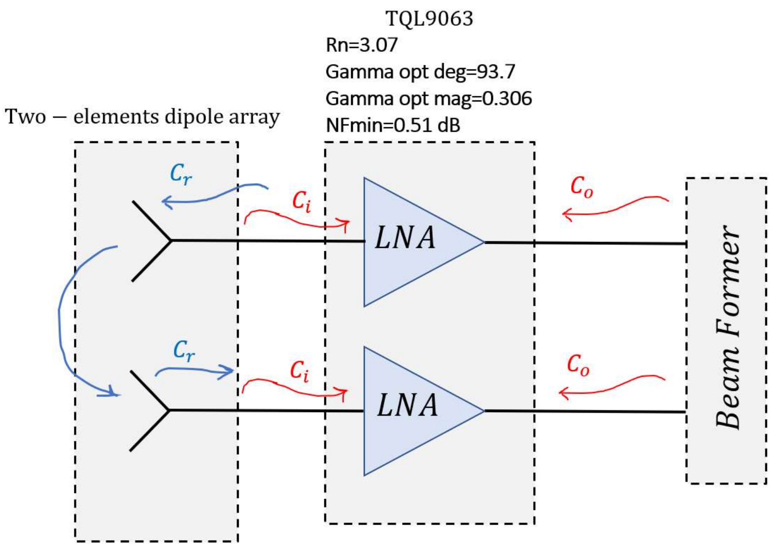
- The variation in the input impedance as a function of the scan angle, which may create errors in:
  - ❑ the desired pattern
  - ❑ direction-of-arrival (DOA) estimation
- Changing the array's interference rejection capability by increasing the sidelobe level.

[REF] S. H. J. R. Singh H, "Mutual coupling in phased arrays: A review," International Journal of Antennas and Propagation, 2013.

Mutual coupling and phased array

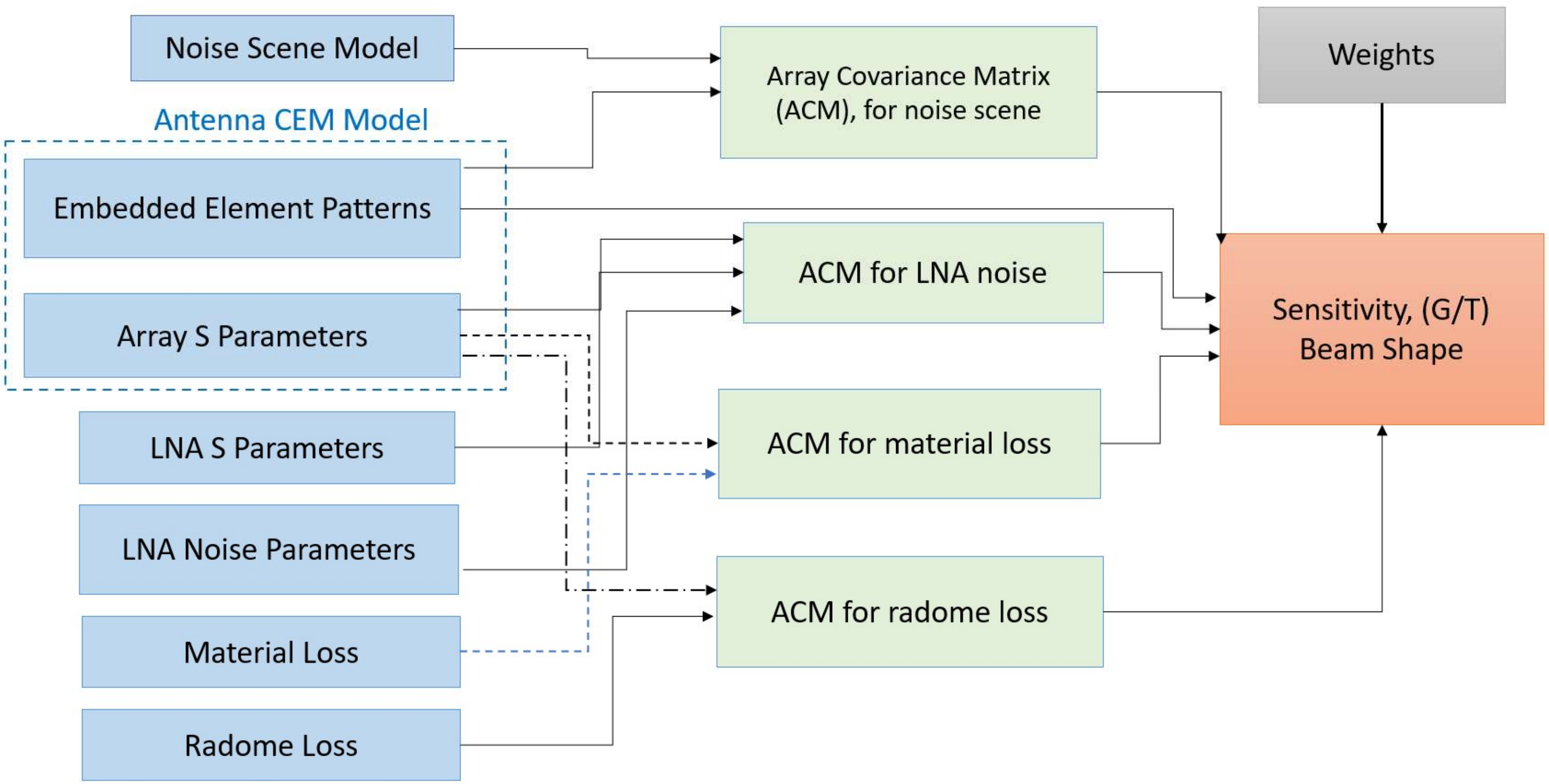
For analysing the phased array antenna and using network theory, mutual coupling effects should be included in the design of receiving phased arrays?!

- Radioastronomy applications are highlighting the need to understand high-sensitivity array performance.



Required data for calculating sensitivity

First step: obtaining the mutual impedance matrix and the embedded element patterns. Therefore, an accurate numerical analysis of the array over the band of interest is required.



Purpose of this work

Challenge:

- Numerical analysis model of a large and dense phased array antenna including the LNAs and all the beamforming weights of interest in a reasonable time or within memory constraints
- ensuring the correct use of the CEM tool, and if it represents the parameters required for an accurate full-array model

Solution:

- An analytical model of the array mutual impedance matrix is compared with the same from the CEM tool.

Analysing model for calculating the mutual coupling effects

A simple two-element half-wave dipole array is chosen for this work as an analytical model is readily available and it is very fast to simulate in the CEM tool. The mutual impedance between these two dipoles and the self-impedance of a single antenna is calculated from the following formulas.

- $\boldsymbol{Z_{12} = \frac{jZ_0}{4\pi\,(\sin k_0 l)^{\,2}} \int_{-l}^{+l} (A + B - (2\cos k_0) l * C)\,(\sin k_0 (l - |l_m|)\,dl_m}$
- $\boldsymbol{Z_{11} = \frac{jZ_0}{4\pi\,(\sin k_0 l)^{\,2}} \int_{-l}^{+l} (A' + B' - (2\cos k_0) l * C')\,(\sin k_0 (l - |l_m|)\,dl_m}$

$$A = \frac{e^{-jk_0(\sqrt{[(l-l_m)^2+s^2]})}}{\sqrt{[(l-l_m)^2+s^2]}},\; B = \frac{e^{-jk_0(\sqrt{[(l+l_m)^2+s^2]})}}{\sqrt{[(l+l_m)^2+s^2]}},\; C = \frac{e^{-jk_0(\sqrt{[(l_m)^2+s^2]})}}{\sqrt{[(l_m)^2+s^2]}}$$

$$A' = \frac{e^{-jk_0(\sqrt{[(l-l_m)^2+(d/2)^2]})}}{\sqrt{[(l-l_m)^2+d/2^2]}},\; B' = \frac{e^{-jk_0(\sqrt{[(l+l_m)^2+(d/2)^2]})}}{\sqrt{[(l+l_m)^2+d/2^2]}},\; C' = \frac{e^{-jk_0(\sqrt{[(l_m)^2+(d/2)^2]})}}{\sqrt{[(l_m)^2+d/2^2]}}$$

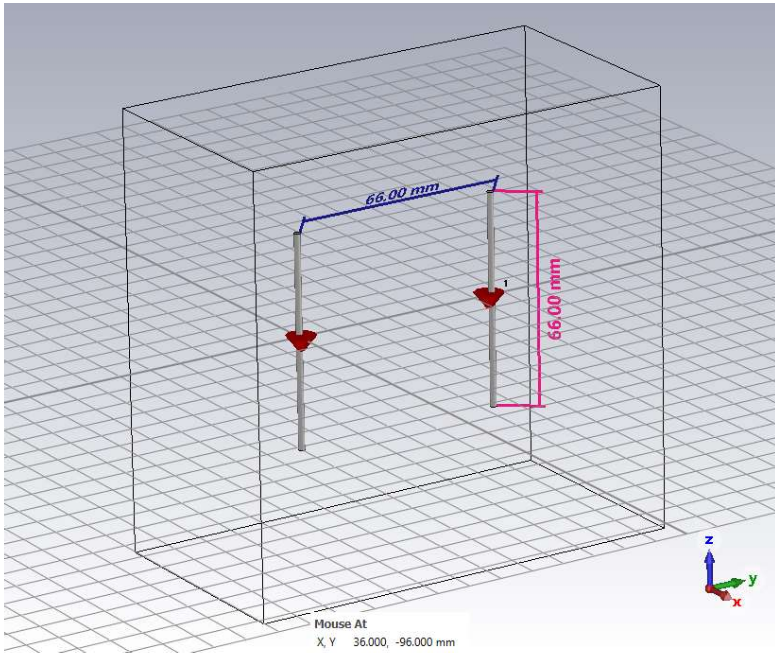


Fig 3: Two-element dipole array in CST simulation environment.

[Ref 1] R. E. Collin, Antenna and radiowave propagation, McGraw-Hill College, 1985.

[Ref 2] S. J. Orfanidis, Electromagnetic waves and antennas, Rutgers University, 2004.

Results and discussion

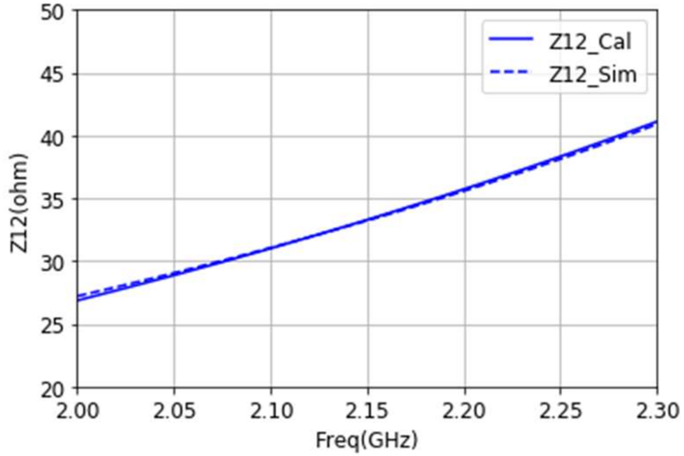


Fig 4: Simulated and calculated mutual impedance

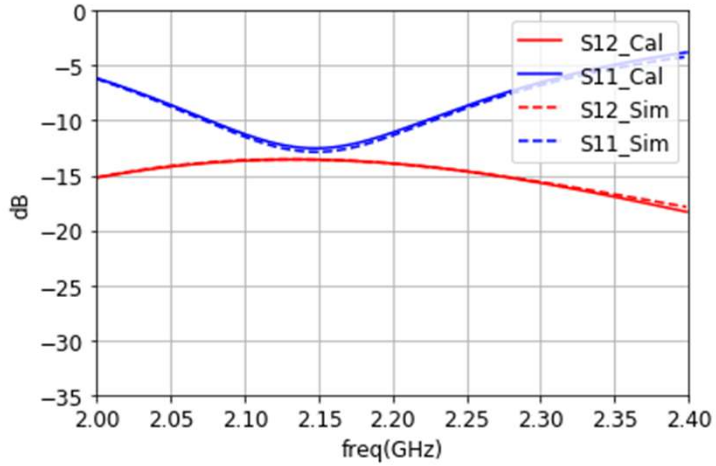


Fig 5: Simulated and calculated reflection and transmission coefficients

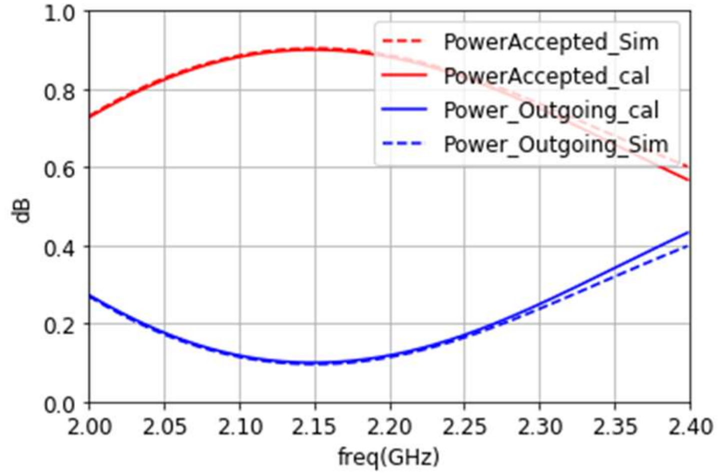


Fig. 6: Simulated and calculated power accepted, and outgoing

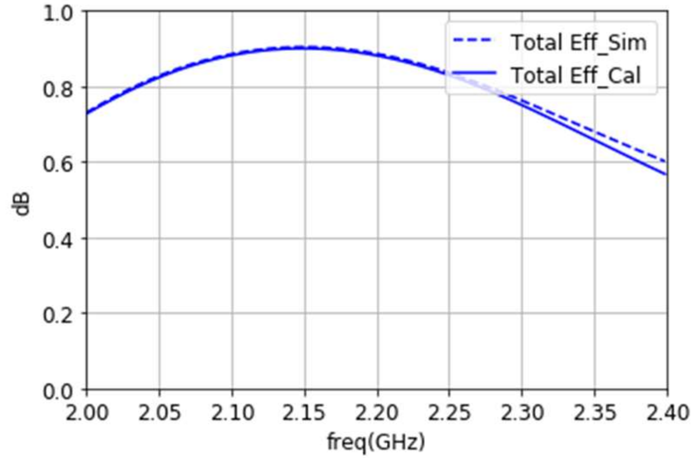


Fig. 7: Simulated and calculated total efficiency

Calculating ACM based on network theory

- Receiver system has been represented as a cascade of networks
- T_{sys} calculation is based on power wave and scattering parameters.
- data that can be easily obtained from CEM simulations, and the noise model of LNAs
- addresses the challenge of the complexity of accounting common- and differential-mode noise by using differential elements in receivers

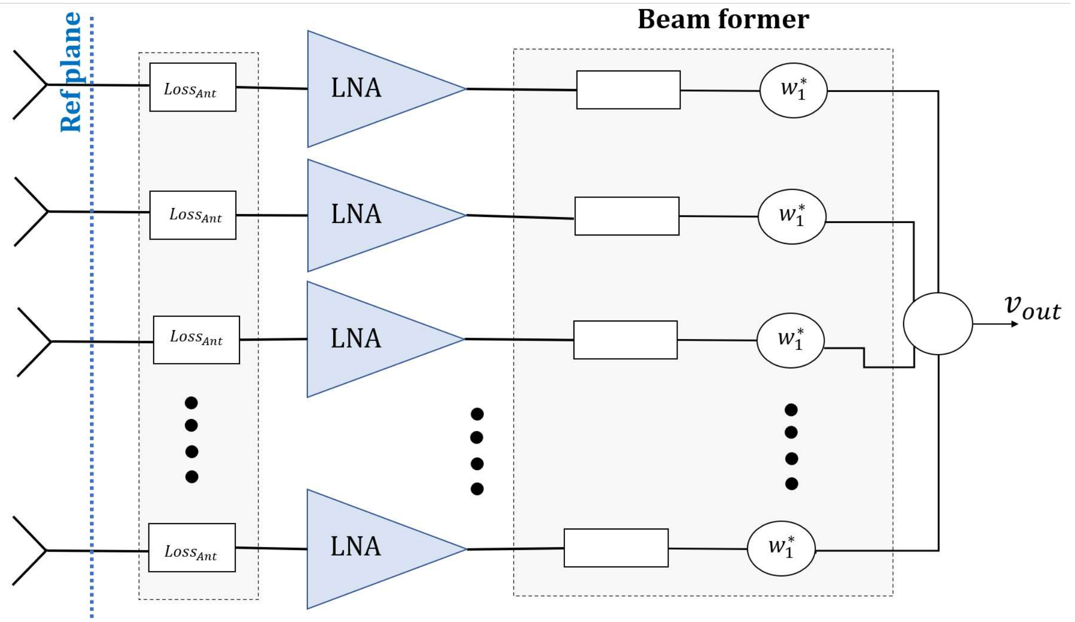


Fig. 10. Generalized representation of aperture array receiver

Calculating ACM, REF [A]

- Open circuit-loaded voltages at the array element ports or terminals.
- The array element voltages at different reference planes are related by a linear transformation

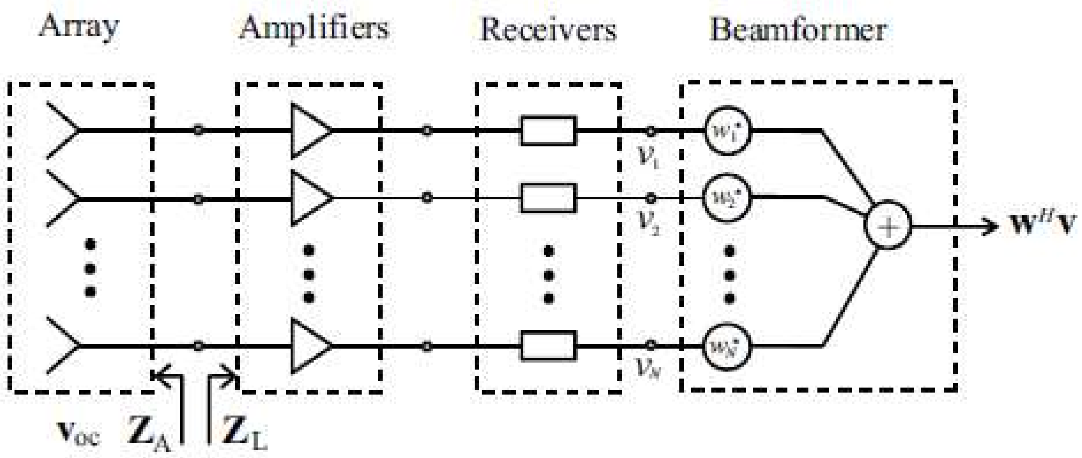


Fig. 9. Generalized representation of aperture array receiver

[A] K. F. Warnick , R. Maaskant, M. V. Ivashina, . D. B. Davidson and . B. D. Jeffs, Phased arrays for radio astronomy, remote sensing, and satellite communications, Cambridge University Press., 2018.

Calculating receiver noise temperature

- An isotropic radiation field with an equivalent temperature of 5K.
- Lossless array
- Mismatch between LNAs and antenna arrays are included

Theta Scan (deg)	Tsys	
	S-parameters	REF [A]
5	51.95	51.94
10	52.07	52.06
30	55.89	55.69

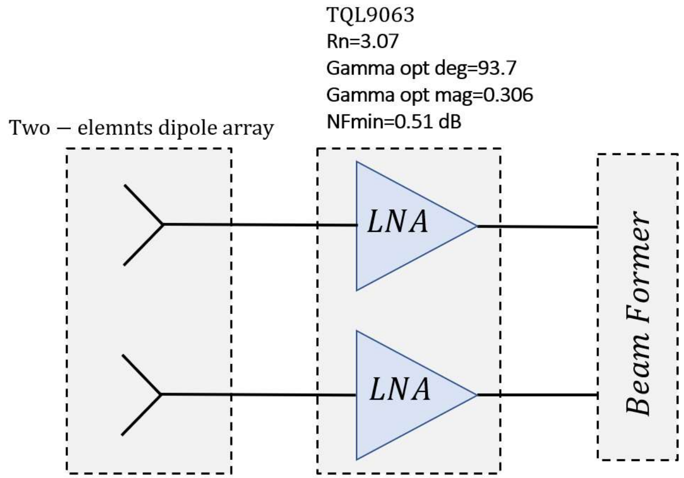


Fig 11: block diagram of a simple receiver for calculating Tsys

[A] K. F. Warnick , R. Maaskant, M. V. Ivashina, . D. B. Davidson and . B. D. Jeffs, Phased arrays for radio astronomy, remote sensing, and satellite communications, Cambridge University Press., 2018.

CryoPAF CEM ACM calculation based on S-matrices

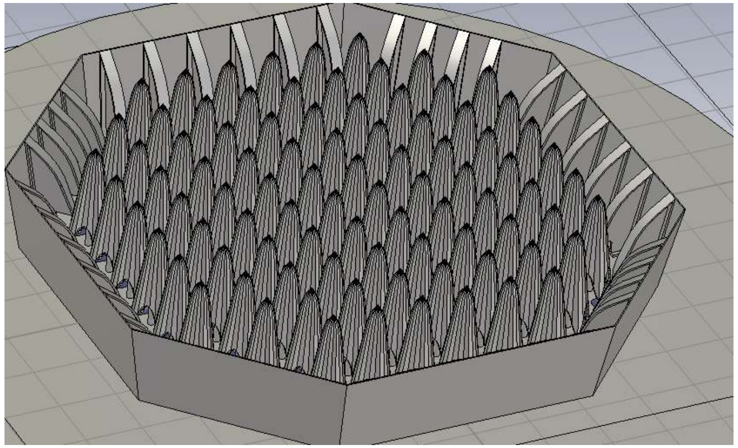


Fig. 12. 3D model of the 196 ports antenna array in CST

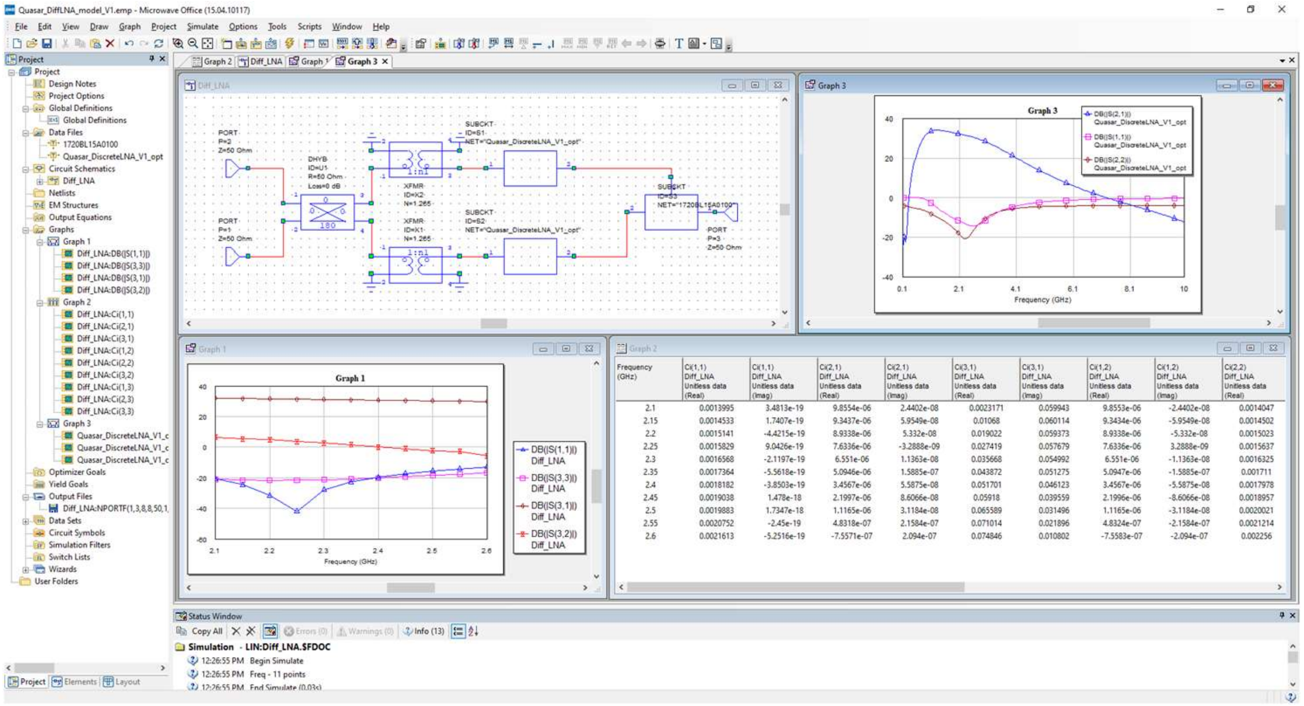


Fig. 13. LNA noise model in AWR

CryoPAF ACM measurement

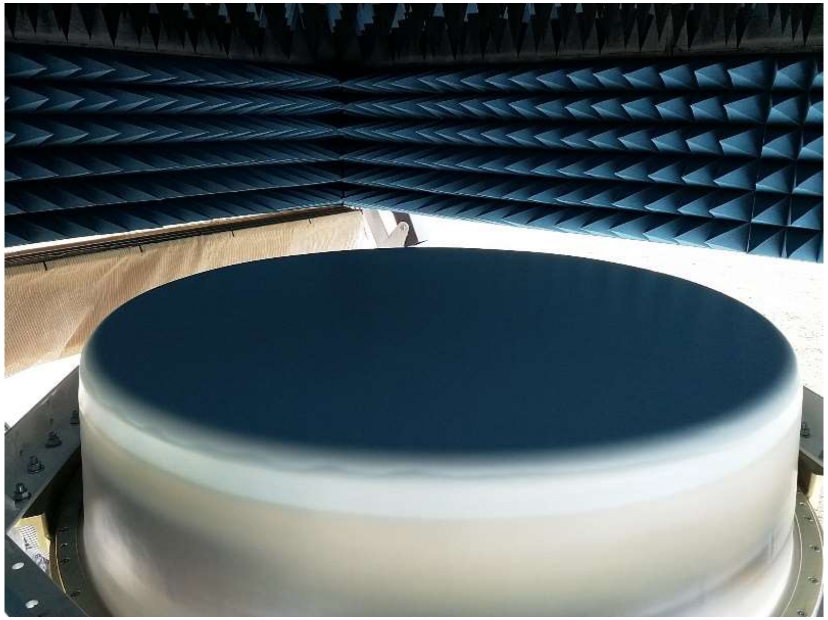
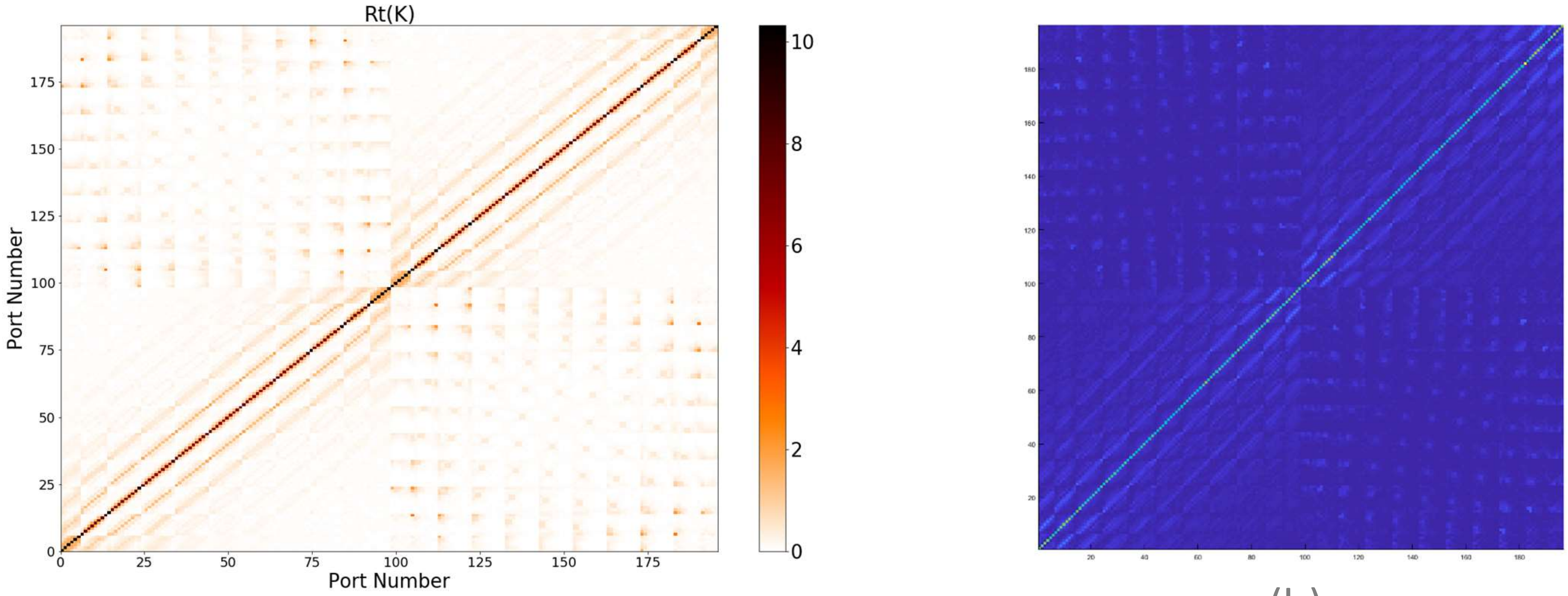


Fig. 14. Noise Temperature measurement from Absorber Y-Factor

CryoPAF ACM calculation



(a)

(b)

Fig. 15. noise covariance matrix for cryoPAF phased array antenna from (a) calculation (b) measurement

CONCLUSION:

1- Two dipole model

2- Calculating Tsys from two proposed models to compare

3- Testing the proposed model with measurement results for cryoPAF phased array antenna

Confirming the correctness of our modeling process for a simple array has reassured us as we move further with the large array analysis.

FUTURE PLAN:

Beamforming algorithm for maximum SNR

Thank you

Questions and Suggestions are Welcome

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