IMS 2023 Microapps presentation

Comparison of Analytical Solutions and Numerical Optimization in Beamforming

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Outline of this Presentation

- General Array Feeding Challenge
- Array factor vs. Full Array analysis
- Canonical (Analytical) solutions for array excitation in Optenni Lab
  - Progressive phase shift
  - Plane wave excitation
  - Maximal gain
  - Amplitude tapering schemes
- Numerical optimization in Optenni Lab
  - Breaking free from canonical excitation schemes
- Comparison of canonical and numerical solutions in terms of **EIRP**

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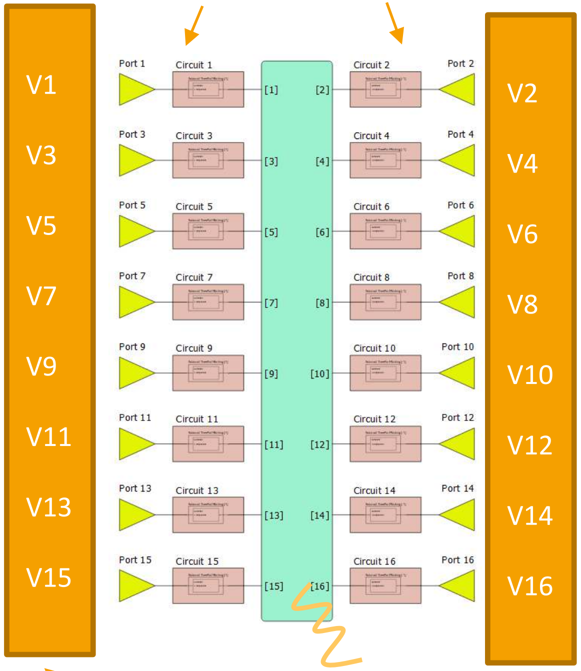
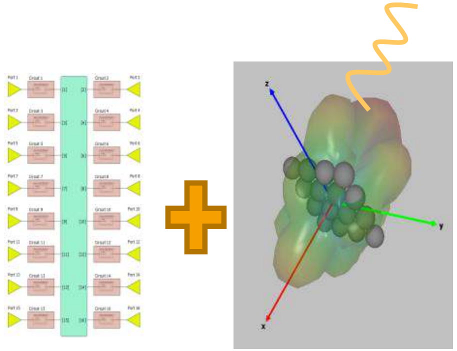
General Array Feeding Challenge

- Assuming a given physical array element structure…
- challenge is to find **excitation vectors (EV) + feeding & matching circuits**
- EVs create the wanted radiation characteristics but also alter the matching
- Power is coupled from other ports at the same frequency → active reflection coefficients, ARCs

Matching circuits

Excitation Vector (part)





Excitation Vector (part)

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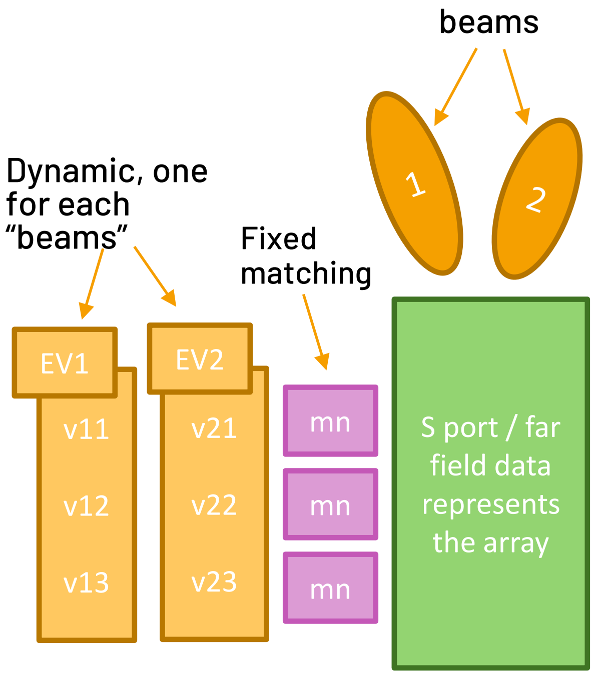
So the Challenge Is To Determine...

- ...EVs that create the required radiation characteristics
  - Beams / EIRP
  - Sidelobe levels
  - Nulls
  - Polarization etc etc
- ... so that the matching due to ARCs is acceptable, and
- ... and so that the power output/dynamic range of the amplifiers generating the EVs is reasonable
- A complexity management challenge!
- **Optenni Lab makes it a breeze!**



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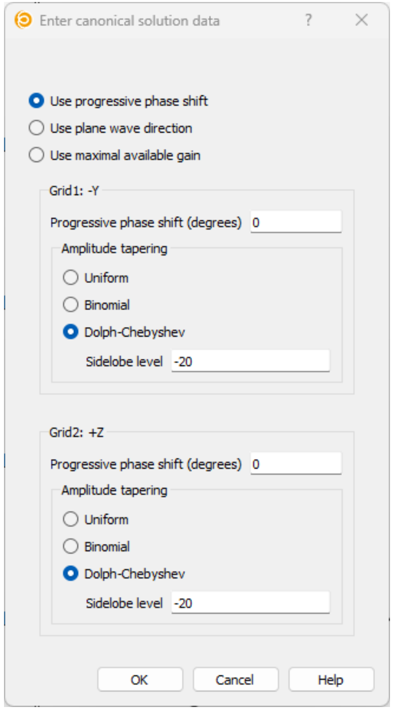
Two Approaches: Array Factor vs. Full Array Analysis

- Array factor analysis
  - Radiation is a multiple of single element and array factors
  - The radiation pattern of a single antenna element is used
  - The pattern is replicated to other elements in the array grid
  - The S parameters and coupling between the elements are ignored

- Full array analysis
  - All the radiation patterns of the array are used
  - The full S parameter matrix is used, including coupling terms
  - For any excitation, matching and termination condition the performance of the array is calculated exactly in Optenni Lab (no new EM simulation needed)
  - In this presentation, all results are from Optenni Lab & based on **full array** analysis

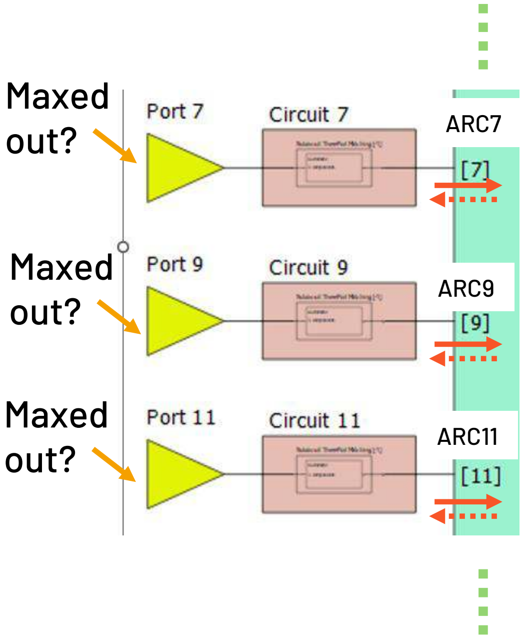
Canonical solutions in Optenni Lab

- Excitations with progressive phase shift between the elements (in two dimensions)
  - EVs phased at fixed intervals
- Excitation from a plane wave from a given direction
  - Theoretical phases of an ideal plane wave at the element locations
- Maximal available gain to a given direction
  - Can be computed with closed-form equations
- Amplitude tapering schemes to reduce side lobes
  - Binomial minimizes the sidelobes but creates highly uneven power distribution over EVs
  - Dolph-Chebyshev creates sidelobes of equal height



EIRP Of An **Array** – An Elusive Concept

- EIRP (effective isotropic radiated power)
  - hypothetical power that would have to be radiated by an isotropic antenna to give the same signal strength as the antenna in a given direction
- EIRP = Gain(theta, phi) * IncidentPower
- But, remember that for arrays,
  - IncidentPower is a **sum** of incident powers at the array's ports
  - Amplifiers of ports have a maximum power that **limit the dynamics** of the **tapering**
  - Active reflection coefficients → **how much power really gets radiated?**



EIRP Of An **Array** – An Elusive Concept (continued)

- Expected the effects of the amplitude tapering are:
  - Side lobe levels are reduced
  - Realized gain is reduced
  - EIRP can be dramatically reduced
- **Optenni Lab makes this complexity a lot more manageable**

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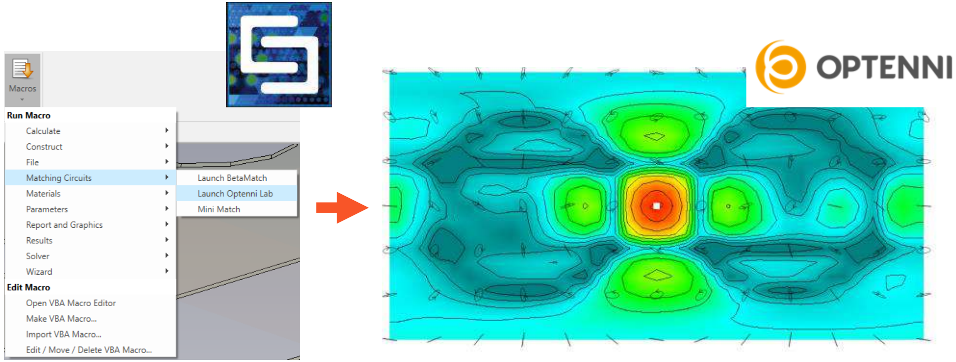
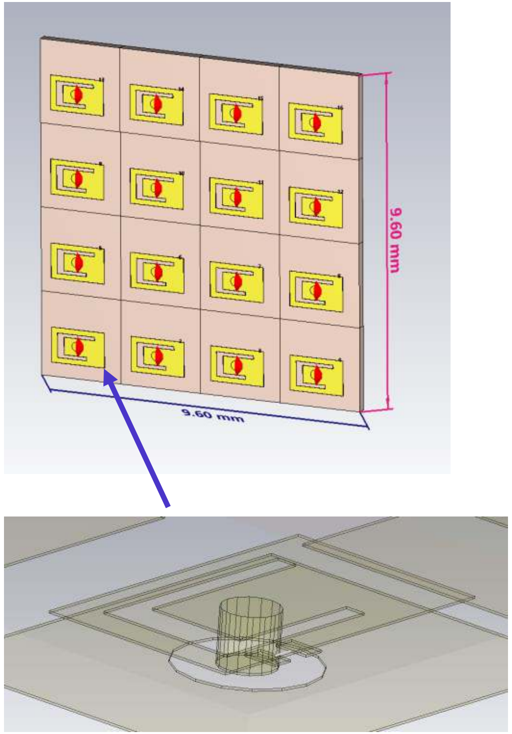
Example – A Compact mm Wave 4x4 Array

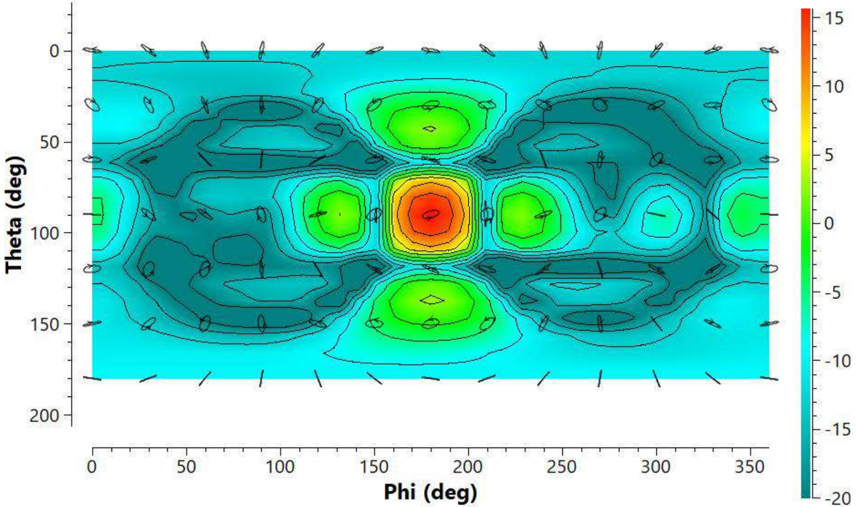
- Let's analyze the 16 port structure in 3D EM (here, Dassault/CST MWS)
  - Compute radiation patterns and 4x4 S parameter system
  - Push the results to Optenni Lab from CST's **Home > Macros > Optenni Lab**

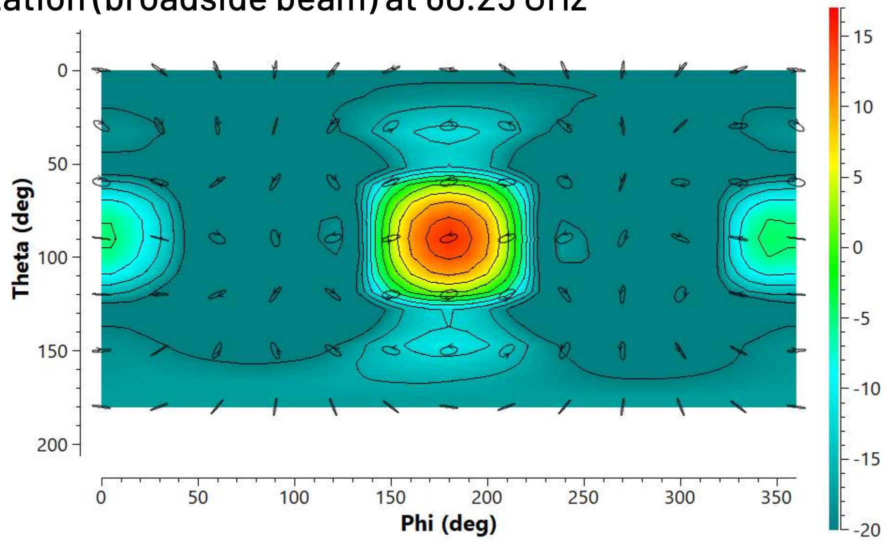




Two Canonical Solutions for the 4x4 Array

Both figures have uniform excitation (broadside beam) at 60.25 GHz





No tapering
Max gain 16.4 dBi
Max EIRP 58.4 dBm (every P_g = 30 dBm)
Side lobe level -13.7 dB (2.7 dBi)

Dolph-Chebyshev tapering
Max gain 15.3 dBi
Max EIRP 53.1 dBm (max P_g = 30 dBm, min P_g = 17 dBm)
Side lobe level -19.4 dB (-4.2 dBi)

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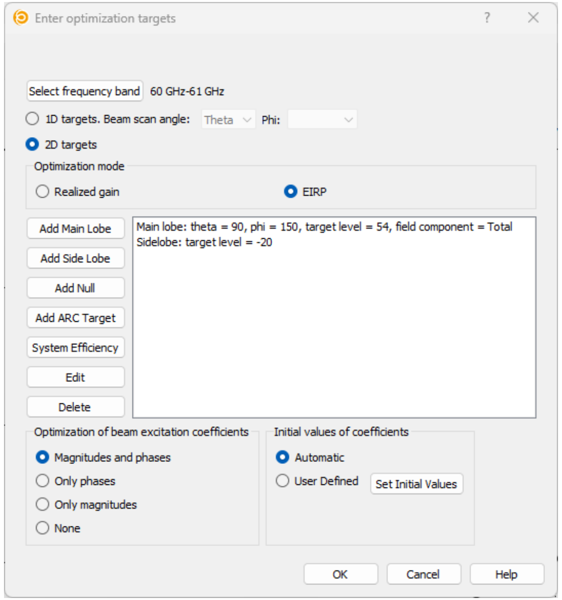
Numerical Beam Optimization in Optenni Lab

- Numerical beam optimization offers many possibilities of controlling beam properties
  - Main lobe direction and beamwidth
  - Side lobe levels
  - Nulls, polarization
  - Control of active reflection coefficient
  - Control of system efficiency
- The optimizer can vary
  - the magnitudes and phases of the beam,
  - only phases, or
  - only magnitudes
- Optimization can be done for the realized gain or for EIRP
- **Optenni Lab sets you free from the canonical / analytical solutions**



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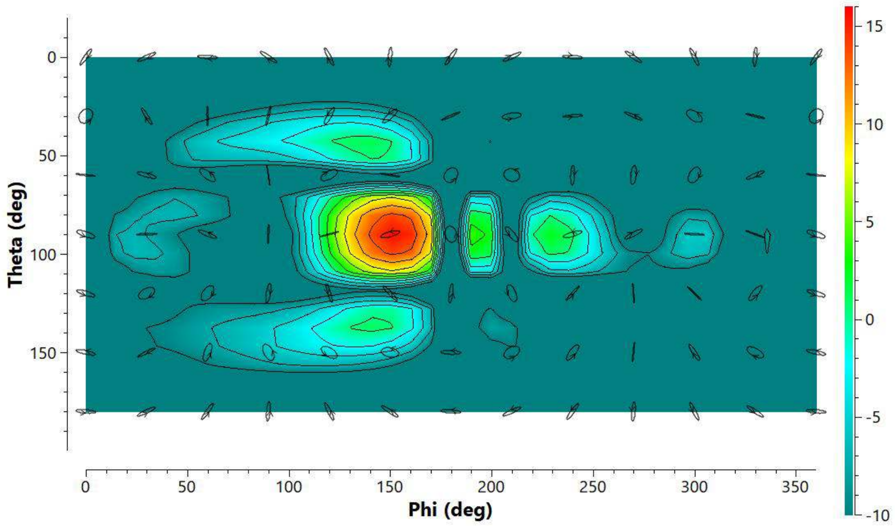
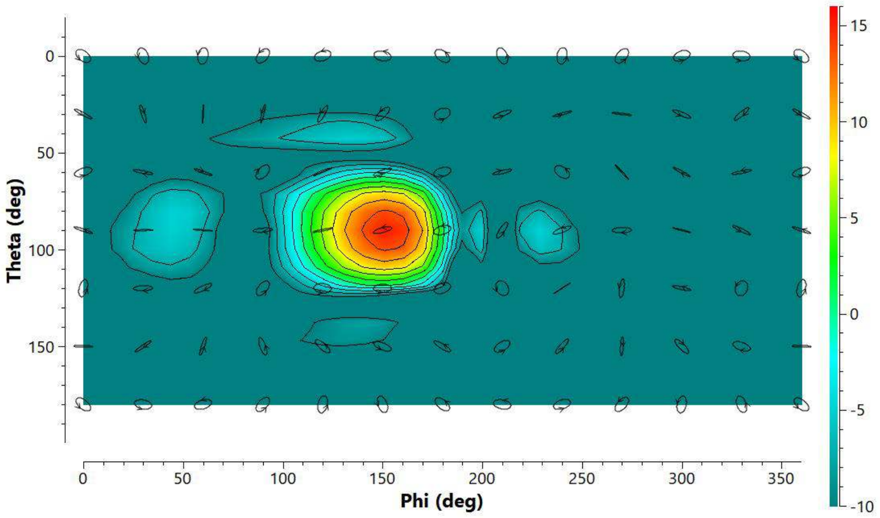
Numerical Optimization Viewed Through Antenna Gain





Maximize gain to theta=90, phi=150
→ Realized gain 15.7 dBi (P_g = 28.8 - 30 dBm)
→ Side lobe level -11.7 dB (4.0 dBi)

Add a side lobe target to the max.gain target
→ Realized gain 15.2 dBi (P_g = 21.6 - 30 dBm)
→ Side lobe level -20.0 dB (-4.8 dBi)

Thus, in terms of gain, main beam drops 0.5dB, but the sidelobe level can be decreased over 8dB

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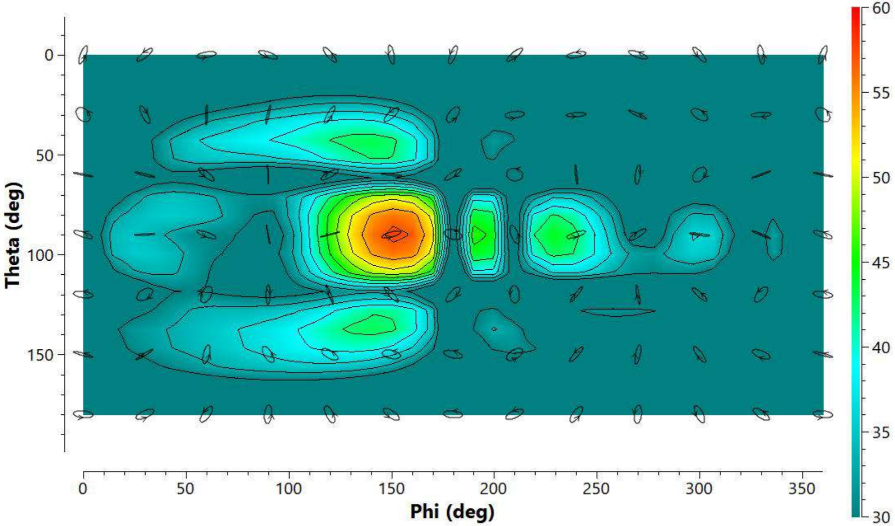
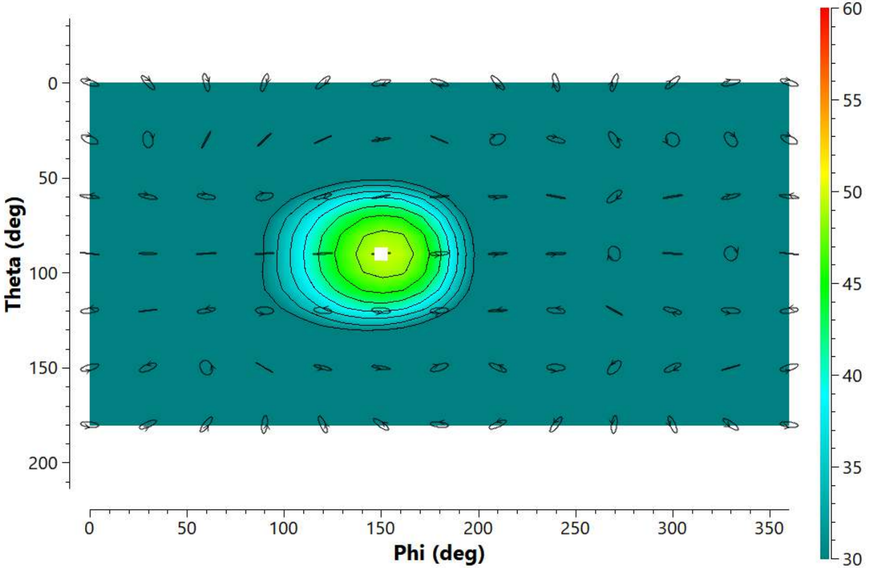
Numerical Optimization Viewed Through EIRP





Maximize EIRP to theta=90, phi=150
→ EIRP 57.7 dBm (every P_g = 30 dBm)
→ Side lobe level -11.8 dB (45.9 dBm)

Add a side lobe target to EIRP target
→ EIRP 51.9 dBm (P_g = 16 - 30 dBm)
→ Side lobe level -19.7 dB (32.2 dBm)

Thus, in terms of EIRP, main beam drops almost 6dB when the sidelobe level is decreased approx. 8dB

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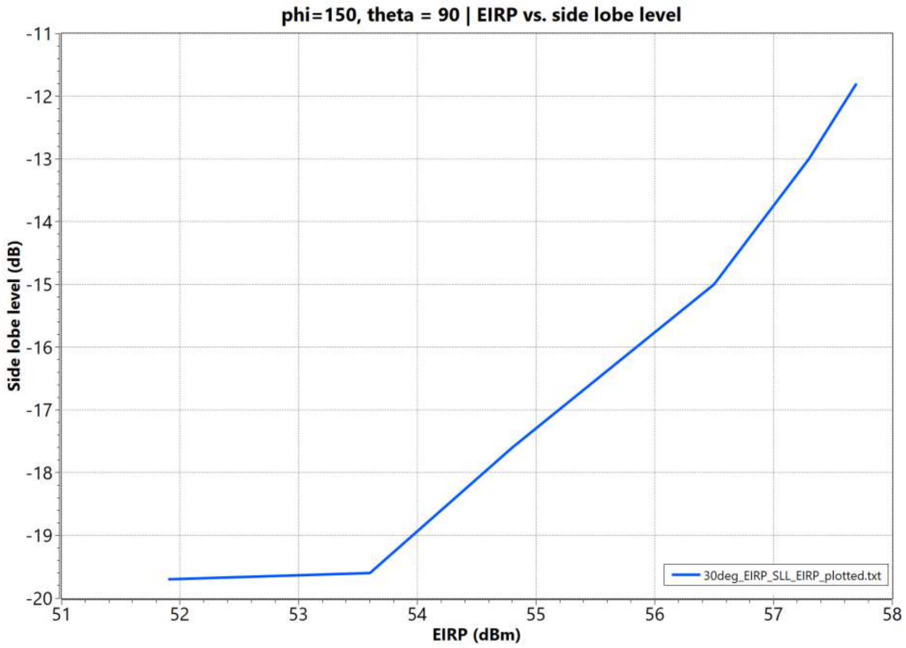
Engineering EIRP and Side Lobe Level

- By changing the target levels, a sequence of Pareto-optimal compromises between the EIRP and side lobe level can be obtained
- As an example, see graph on the right
- Such graphs are a tremendous help for **engineering** array antennas



Conclusions

- In array beamforming optimization, canonical solutions are fast to compute and lead to good initial guesses for optimization
- Numerical beam optimization enables the control of the main beam properties, side lobe levels, active reflection coefficients and EIRP
- Many of the beam optimization goals are contradictory: e.g. maximization of EIRP and minimization of side lobe levels
- By varying the weights of the optimization criteria, various compromises between the contradictory goals can be obtained
- Optenni Lab lets you take complete control of the array feeding and matching challenge
- Turn messy guesswork of array design into engineering with Optenni Lab

More information:

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