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Weight Selection for Pattern Control of Paraboloidal Reflector Antennas with Reconfigurable Rim Scattering

R. MICHAEL BUEHRER
STEVEN W. ELLINGSON

Wireless @ Virginia Tech

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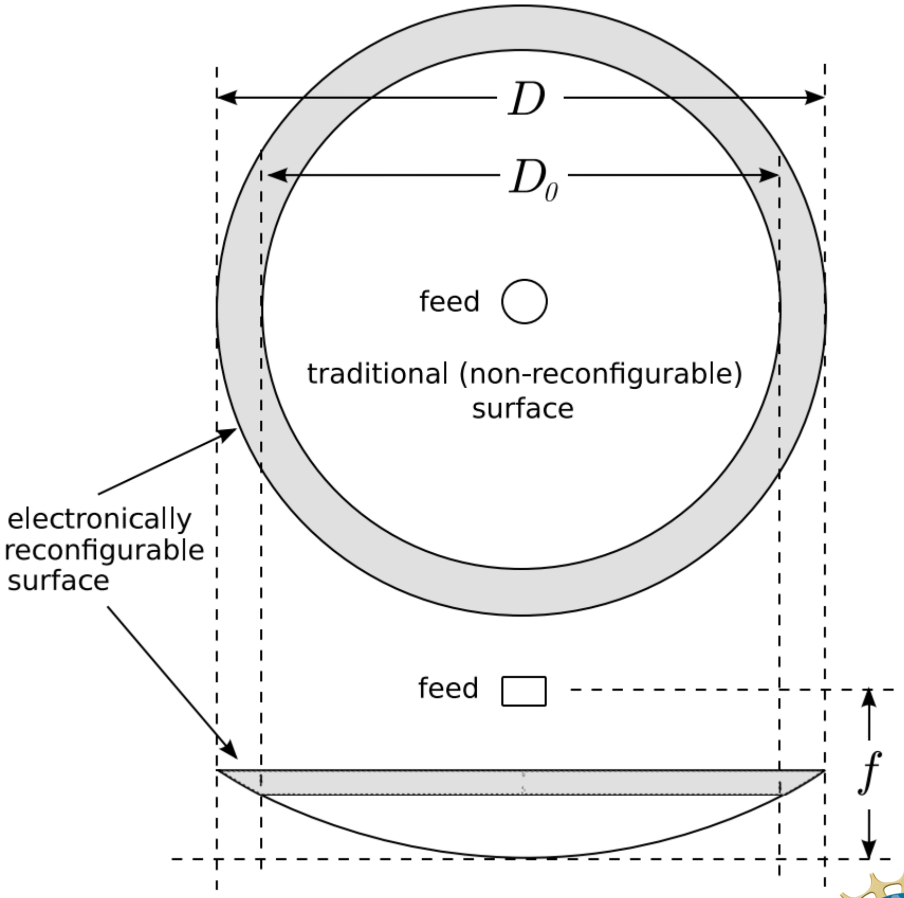
See https://www.faculty.ece.vt.edu/swe/raim/

Motivation

- Interference from satellites is a long-standing problem for radio astronomy
- Traditional methods of mitigation include avoidance (i.e., not observing) and post-observation editing (i.e., deleting afflicted portions of observations).
- Emerging and planned satellite systems will consist of thousands of satellites
- It is unclear how traditional methods of interference mitigation will fare once these systems are fully deployed.

System Model

- We are investigating the use of reconfigurable rim scattering where a large reflector is equipped with a passive reflectarray that creates a spatial null in the direction of the interferer
- **Example -** We will assume D = 18 m paraboloidal reflector operating at 1.5 GHz
- The outer 0.5 m of the reflector surface consists of 2756 contiguous reconfigurable segments.
- Each segment is a square flat plate conformal to the paraboloidal surface having side length 0 . 5λ (i.e. , an area $\Delta s = 0.25\lambda^2$).



Modifying the Received Electric Field

- Received electric field:

$$\mathbf{E}^s(\psi) = \mathbf{E}^s_f(\psi) + \mathbf{E}^s_r(\psi)$$

Due to the reconfigurable portion of the dish

Due to the fixed portion of the dish

- To cancel sidelobe at angle ψ_o we desire:

$$E_f^{s,co}(\psi_o) + E_r^{s,co}(\psi_o) = 0$$

$$E_r^{s,co}(\psi_o) = \mathbf{e}_\psi^T \mathbf{w}$$

How do we determine the weights ***w*** ?

Determining the Weights

- The optimal weights are

$$\mathbf{w}_{opt} = -E_f^{s,co}(\psi_o)\frac{\mathbf{e}_\psi^*}{||\mathbf{e}_\psi||_2^2}$$

- Disallowing amplification (i.e., phase change only):

$$\mathbf{w}_{gp} = \min_{\mathbf{w}\in\mathcal{C}^N} \left\| E_f^{s,co}(\psi_o) + \mathbf{e}_\psi^T\mathbf{w} \right\|_2^2$$

$$s.t. \quad |w_i| = 1 \qquad i = 1, 2, \ldots N$$

Determining the weight vector **w**

Bad news

- The cost function is non-convex and extremely complex.
- The search space is large – 2756 complex variables for 18m dish with 2m reconfigurable rim.

Good news

- There appear to be a large number of very well-performing local minima
- Finding a good solution is not particularly difficult – require no more than 10,000 iterations

Infinite Phase Quantization

Gradient Projection Algorithm

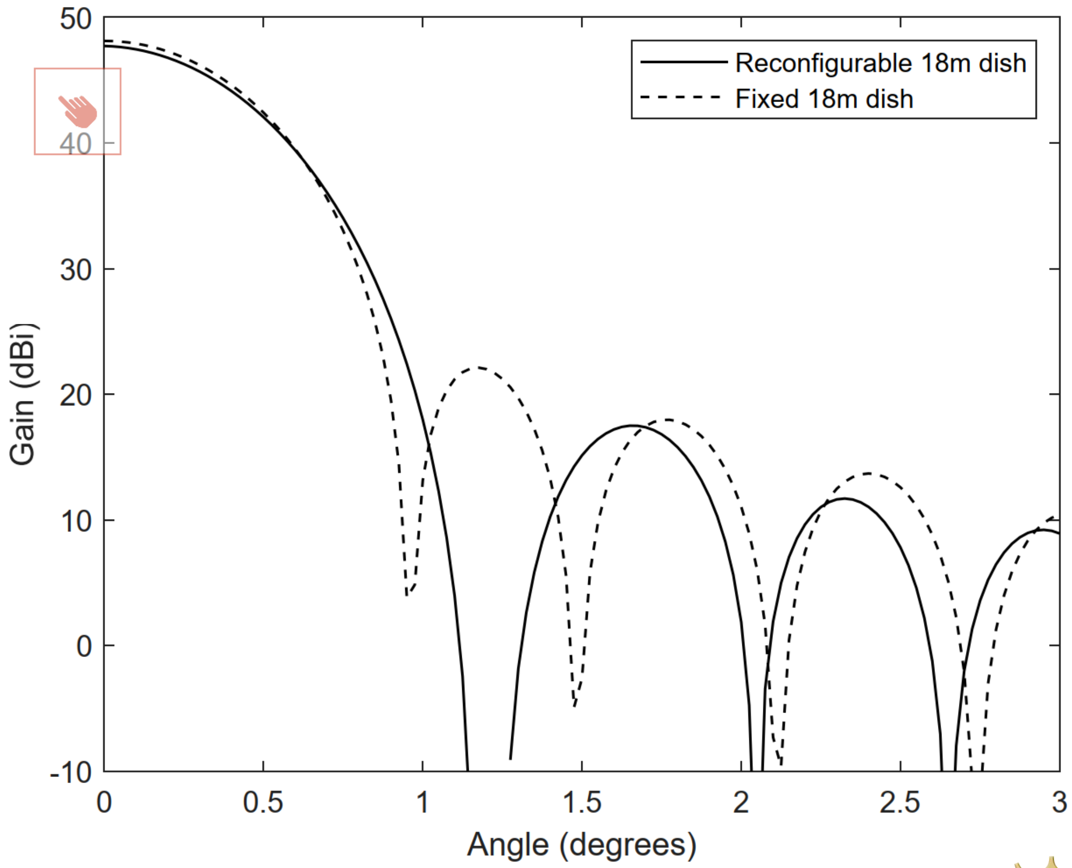
$$\tilde{\mathbf{w}}^{(k+1)} = \mathbf{w}^{(k)} + \alpha \mathbf{e}^* \left(E_f^{s,co}(\psi) + \mathbf{e}^T \mathbf{w}^{(k)} \right)$$

$$\mathbf{w}^{(k+1)} = \mathcal{P}\left(\tilde{\mathbf{w}}^{(k+1)} \right)$$

$$\mathcal{P}(\mathbf{x}) = e^{j \angle \mathbf{x}}$$

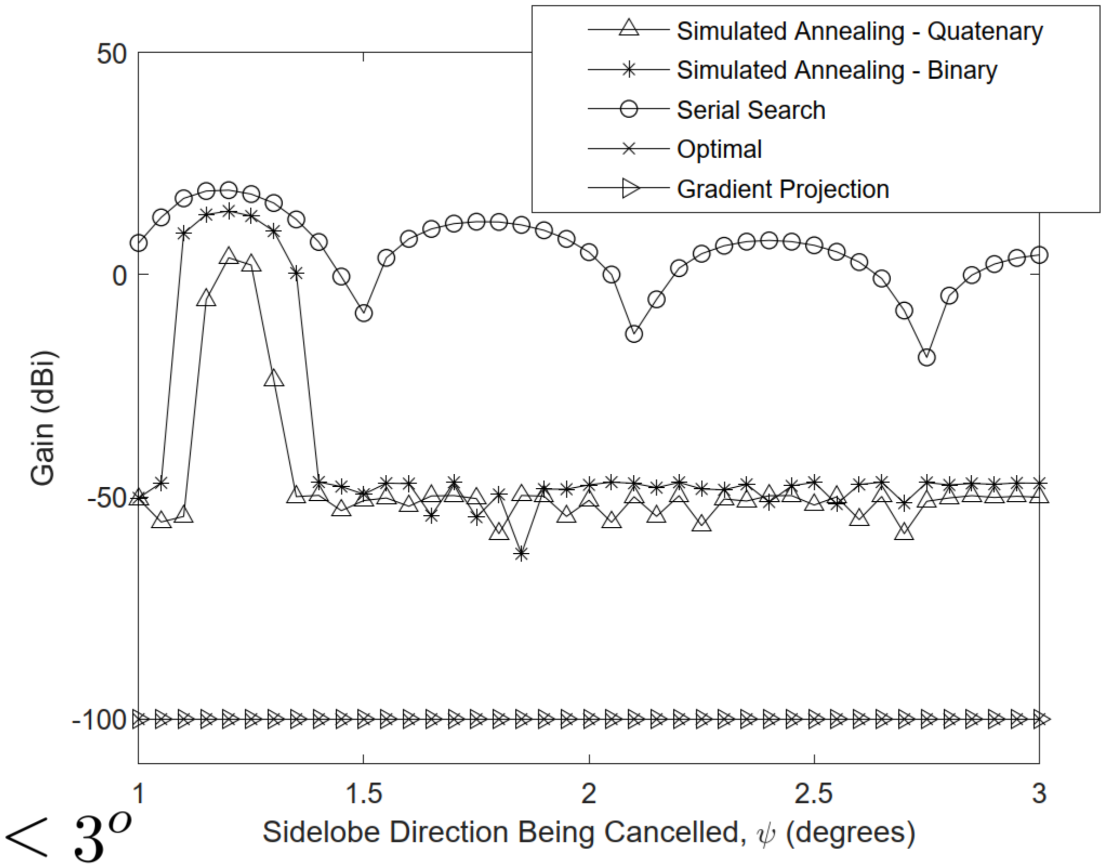
18m dish, 0.5m reconfigurable rim

Null direction ψ_o = 1.25°



Quantized Weights

- Algorithm: Simulated Annealing
- Quantizing phase to *K* values requires a search over space of K^{2748} vectors
- There appear to be a very large number (at least 1000's) of (good) local minima
- RIGHT: Gain achieved for $1^o \leq \psi \leq 3^o$



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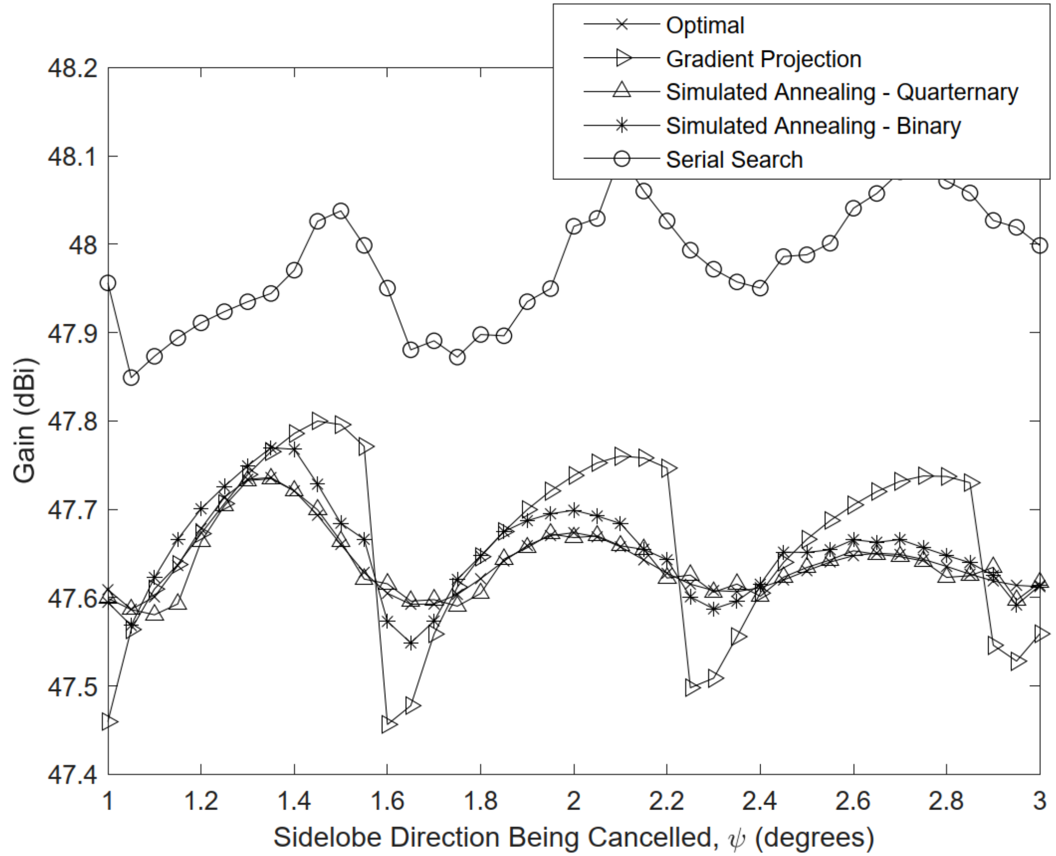
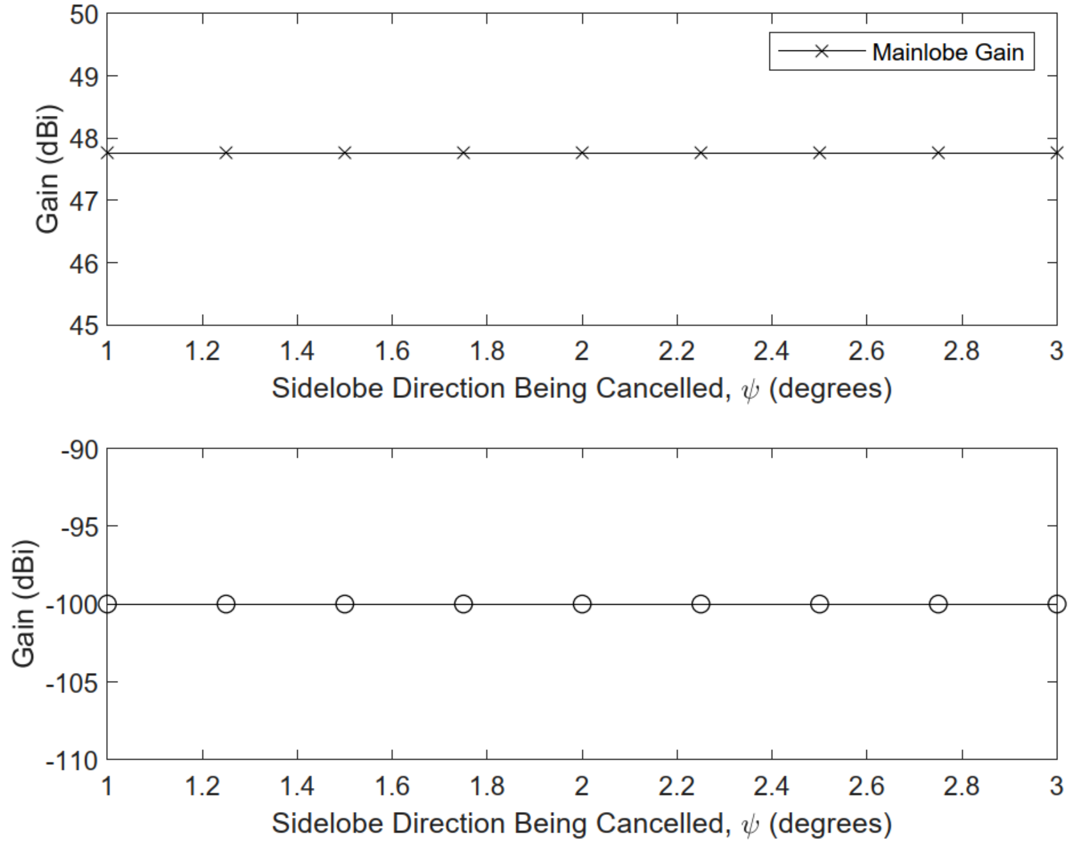
Main Lobe Variation – Infinite Quantization



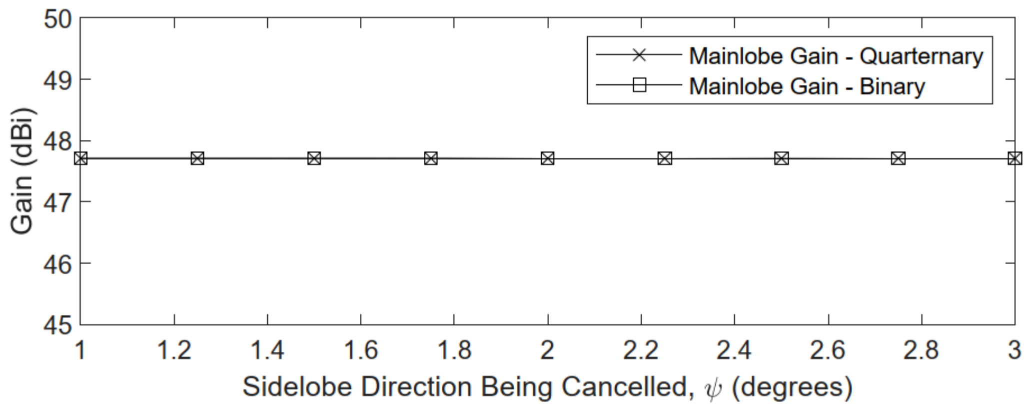
Unconstrained Main Lobe

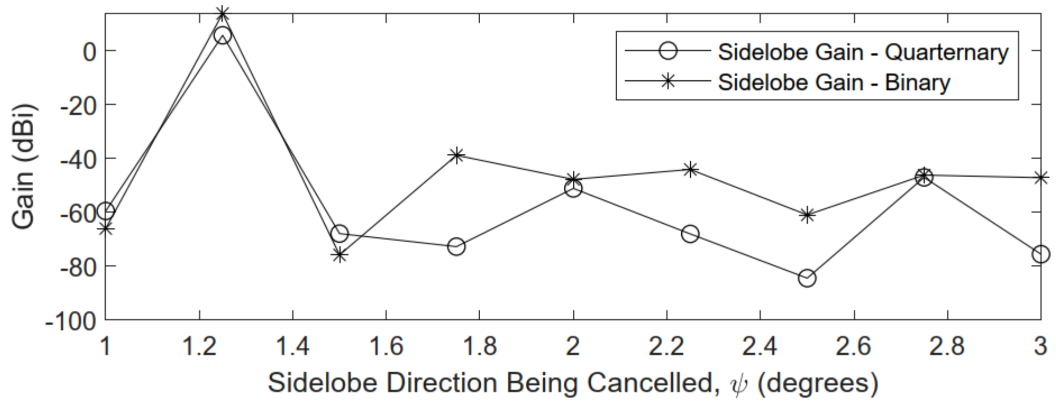


With Constraints

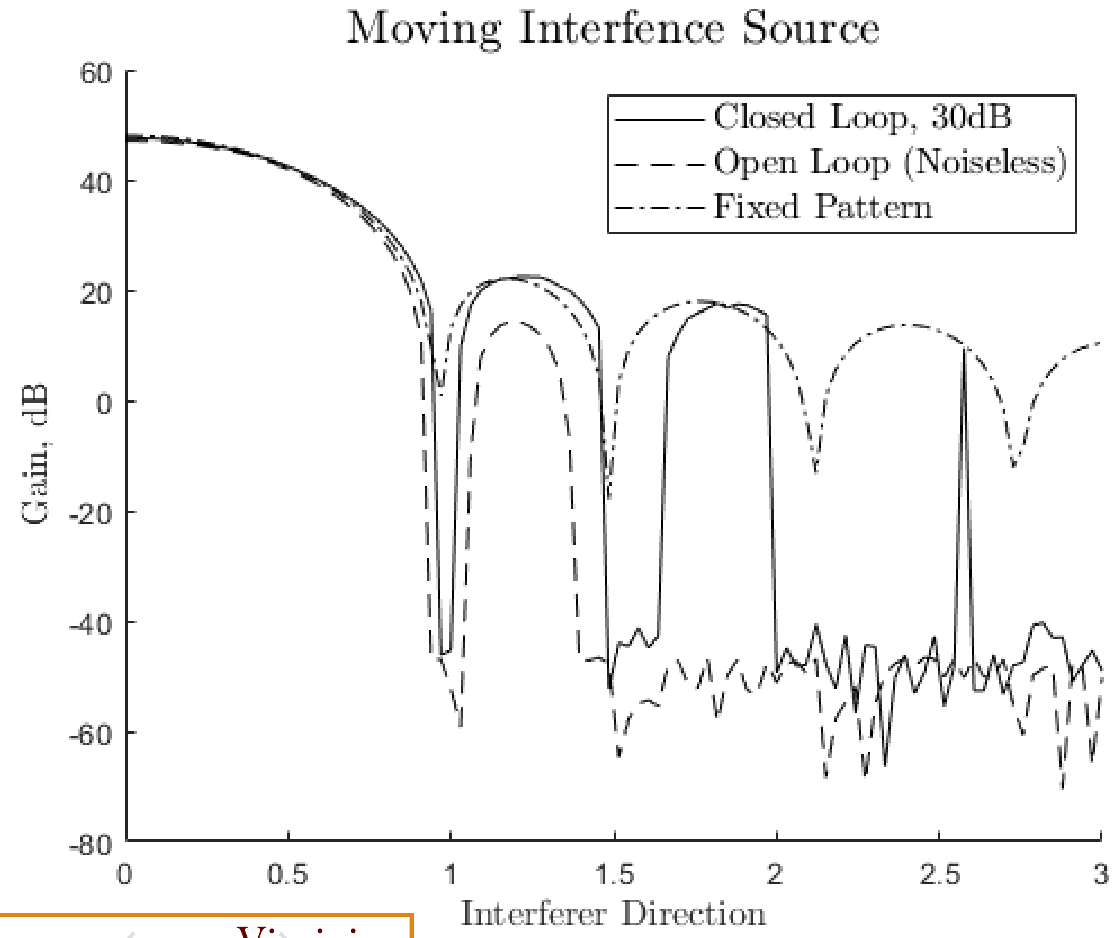
Main Lobe Variation – Quantized Weights

- Mainlobe constraints can also be applied in the quantized weight case
- Search is more complex, thus there is more variation





Initial “Real-Time” Closed-loop Simulation



- Initial work assumed we know the pattern – open-loop search for weights
- Without knowledge of the pattern we must use a real-time (closed-loop) search
- LEFT: Gain of reconfigurable rim antenna as source moves from 0 to 3 degrees. Binary weights; INR = 0dB; integration over 1000 samples, angular velocity = 0.8deg/sec

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Conclusions

- In this work we have shown that with phase-only reconfigurable patches placed on the rim of a parabolic reflectarray antenna nulls can be placed in the pattern
- Despite the large search space and complex cost function, good weight vectors can be found relatively quickly (thousands of iterations)
- Infinite phase quantization yields arbitrarily low sidelobe gains.
- Binary and quarternary weights appear to be more limited, but also perform well
  - For our example antenna, only the first sidelobe is problematic.
- Initial results for "closed-loop" solution provided promising results.

QUESTIONS?