Optimization of the Onboard Performance of Antenna Arrays Using The Empirical Optimization Algorithm as Implemented in the EmpOp™ Program

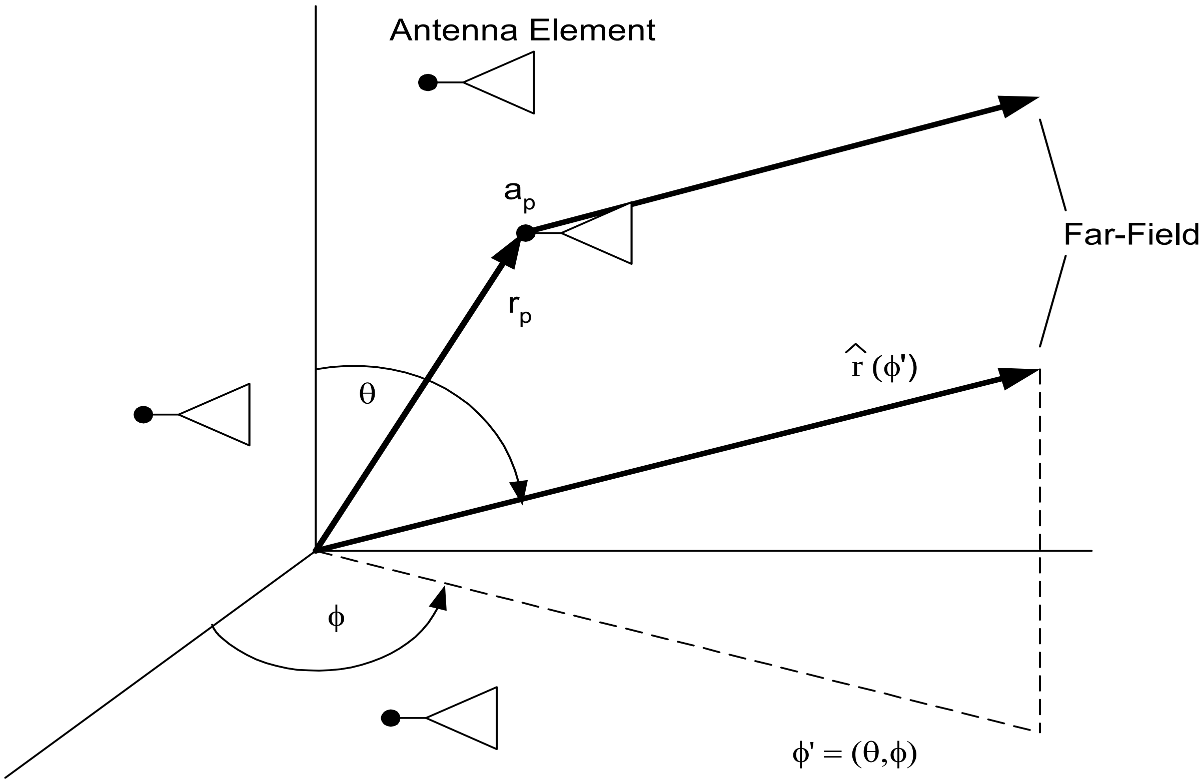
Stephen Jon Blank
Michael F. Hutt

Hutt Systems, Inc.

Empirical Optimization of Antenna Arrays, The EmpOp™ Program

- Iterative 'on-the-vehicle' performance optimization that accounts for electromagnetic coupling and scattering. Based on 'in-situ' measured or computed element pattern data.
- Synthesis of optimum element excitations and spacings, including conformal and thinned array configurations.
- Numerical optimum search to minimize normed difference between actual pattern and specified desired pattern. Applicable to:
  - Minimization of max sidelobe
  - Minimization of sidelobe power
  - Shaped beam synthesis
  - Maximization of scan angle/bandwidth product
  - Optimization of Sum/Difference patterns
- Applicable to adaptive array systems and maximization of SNR.

Antenna Configuration



The Antenna Array Problem

- Array field pattern:

$$E(\phi', a, r) := \sum_{n=1}^{N} h_n(\phi', r) \cdot a_n \cdot e^{j \cdot \frac{2 \cdot \pi}{\lambda} \cdot r_n \left(u(\phi') - u\left(\phi'_s\right)\right)}$$

- $a = (a_1, a_2, \ldots a_N)$ = vector of element excitations
- $r = (r_1, r_2, \ldots r_N)$ = vector of element locations
- $h = (h_1, h_2, \ldots h_N)$ = vector of element 'in-situ' field patterns
- Φ' = observation angle (θ, Φ)
- Φ'_s = scan angle (θ_s, Φ_s)

The Antenna Array Problem...

- Normalized array power pattern
  $P(\Phi',a,r) = E(\Phi',a,r)\,\tilde{E}(\Phi',a,r) / E(\Phi_0',a,r)\,\tilde{E}(\Phi_0',a,r)$

- Performance Optimization
  Find $\min_{v} \| P(\Phi',v) - P_D(\Phi') \|$

  $v = (v_1, v_2 \ldots v_N)$ = vector of variable element excitations and/or element locations.

Array Performance Optimization

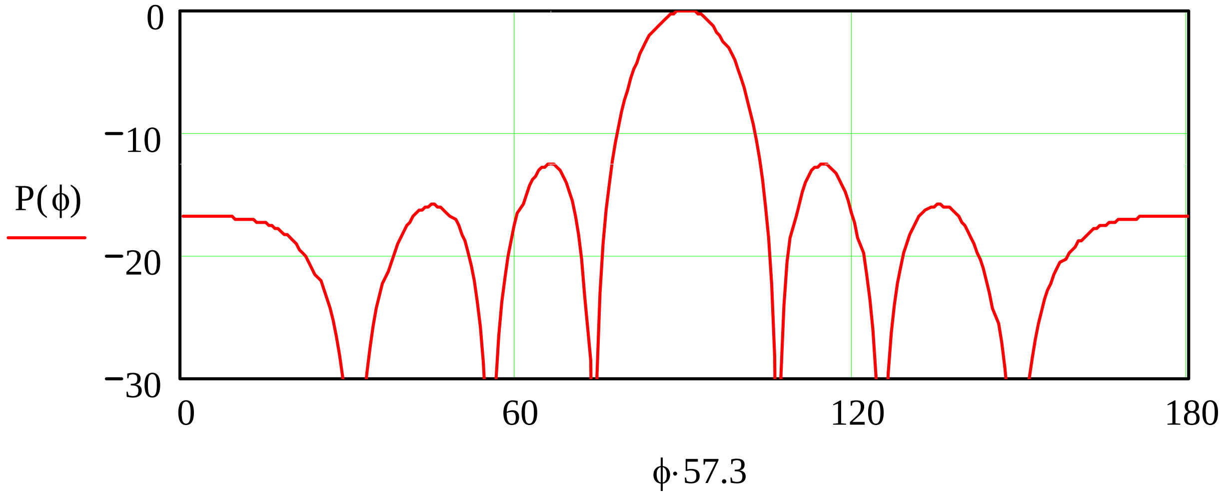
- Find $\min_{v} \| P(\Phi', v) - P_D(\Phi') \| \rightarrow v^*$
- $v = (v_1, v_2 \ldots v_N)$ = vector of variable element excitations and/or element locations.
- $P_D(\Phi')$ = desired array power pattern.
- v^* = optimum vector of element excitations and/or element locations.

Performance Function Optimization

- Find $\min_{v} \| P(\Phi', v) - P_D(\Phi') \|$
- The choice of function norm depends on the specific array performance desired.
- For minimization of the maximum array pattern sidelobe, the max norm is used, i.e.,
- Find $\min_{v} \max_{\Phi'_1 < \Phi' < \Phi'_2} P(\Phi', v)$

  where $\Phi'_1 < \Phi' < \Phi'_2$ defines the sidelobe region in angular space, and $P_D(\Phi')=0$.

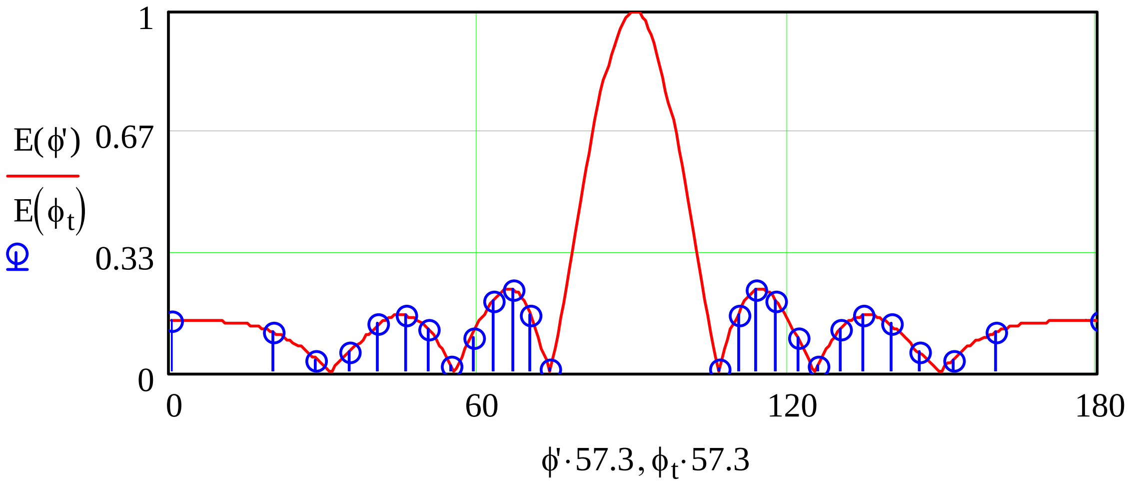
Minimize Max Sidelobe



SLmax=-12.7 dB
at ϕ=66 degrees

Minimize Sidelobe Power

- To minimize the power in the sidelobe region:
- Find $\min_{v} \sum_{\Phi'_1 < \Phi' < \Phi'_2} P(\Phi', v)$



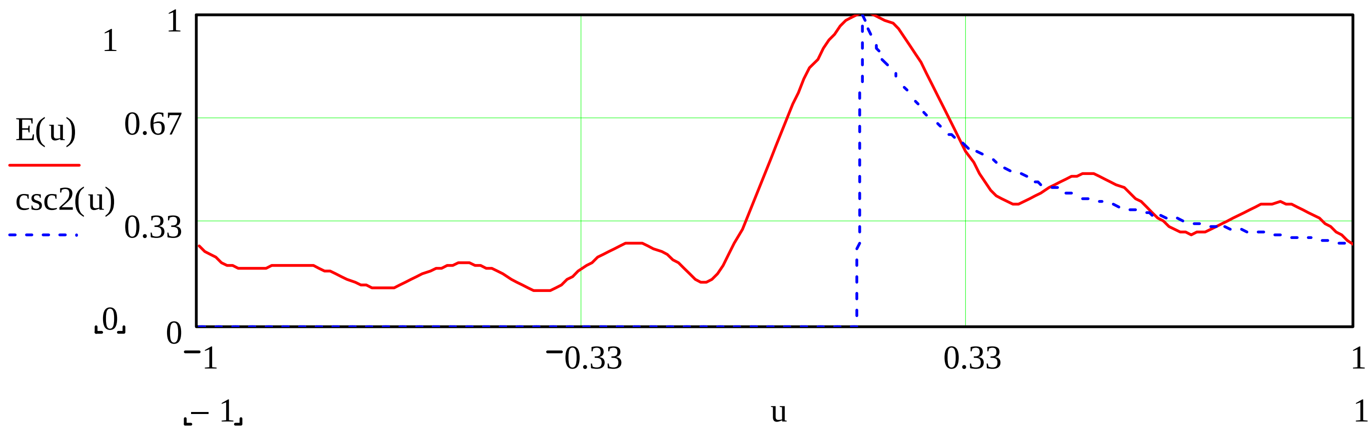
SLpower=∑ $P(f_i)$

Shaped Beam Synthesis

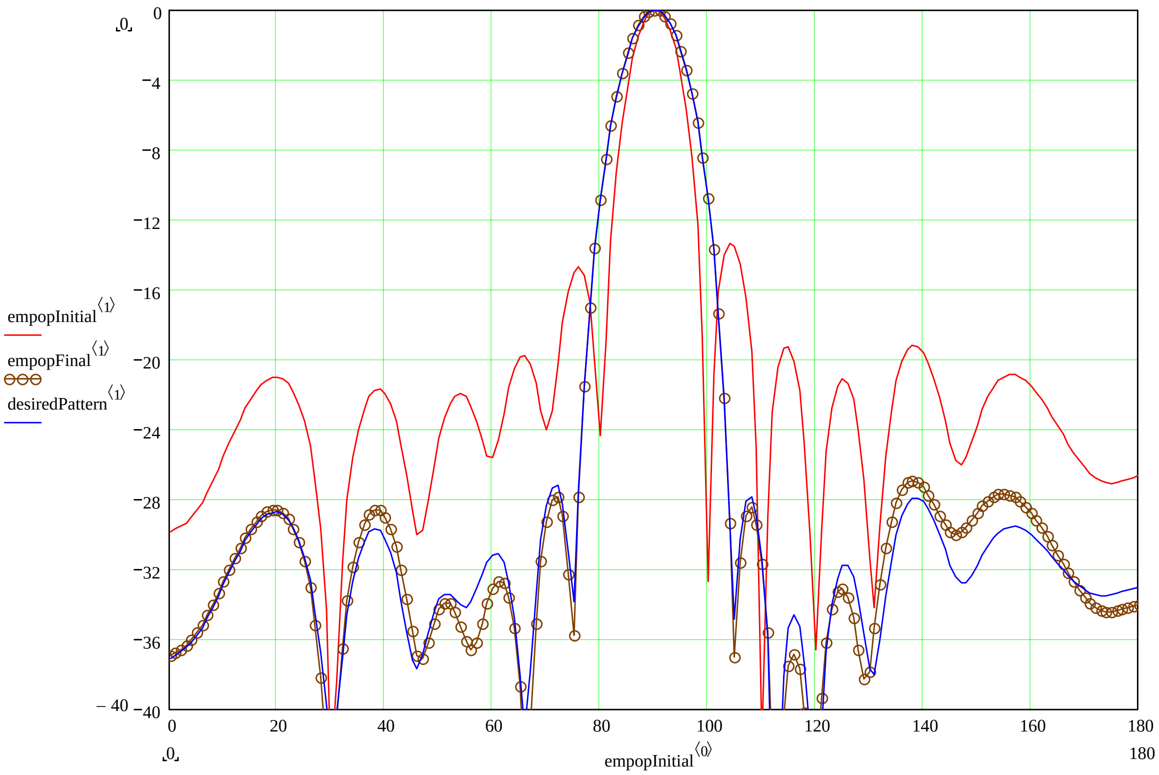
- For min-max shaped beam synthesis, the criterion statement would be:

- Find $\min_{v} \max_{\Phi'_1 < \Phi' < \Phi'_2} \left| P(\Phi', v) - P_D(\Phi') \right|$

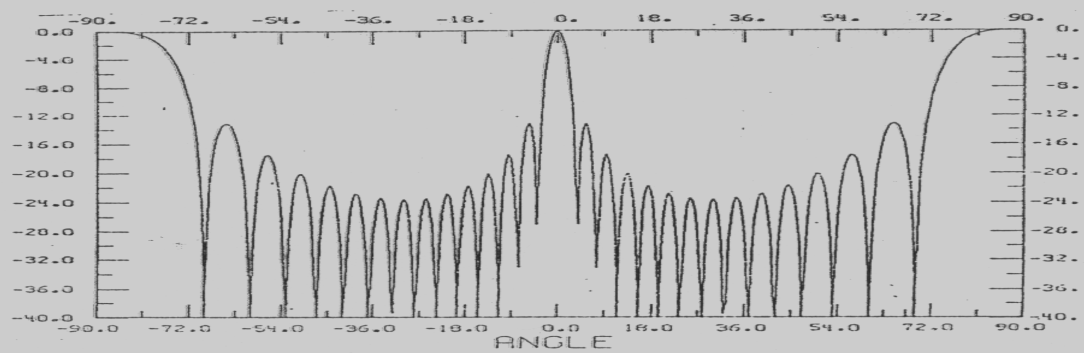
  where Φ'1 < Φ' < Φ'2 defines the region in angular space where it is desired to synthesize the pattern $P_D(\Phi')$.



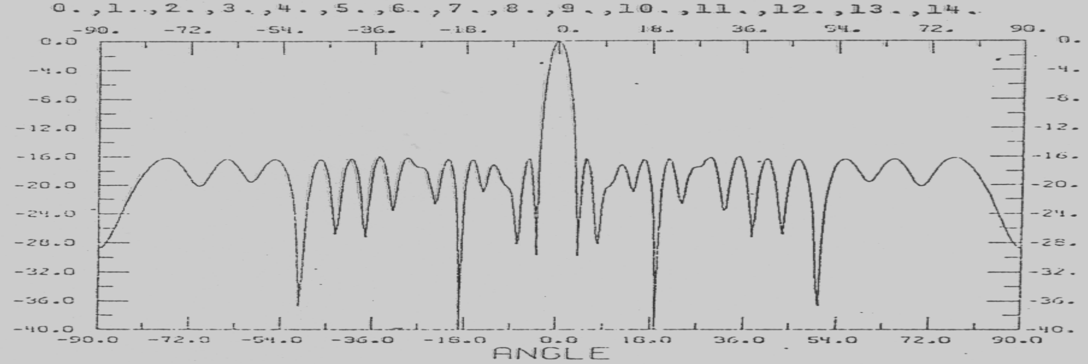
Finding Element Excitation From Given Array Pattern Data



Example 1



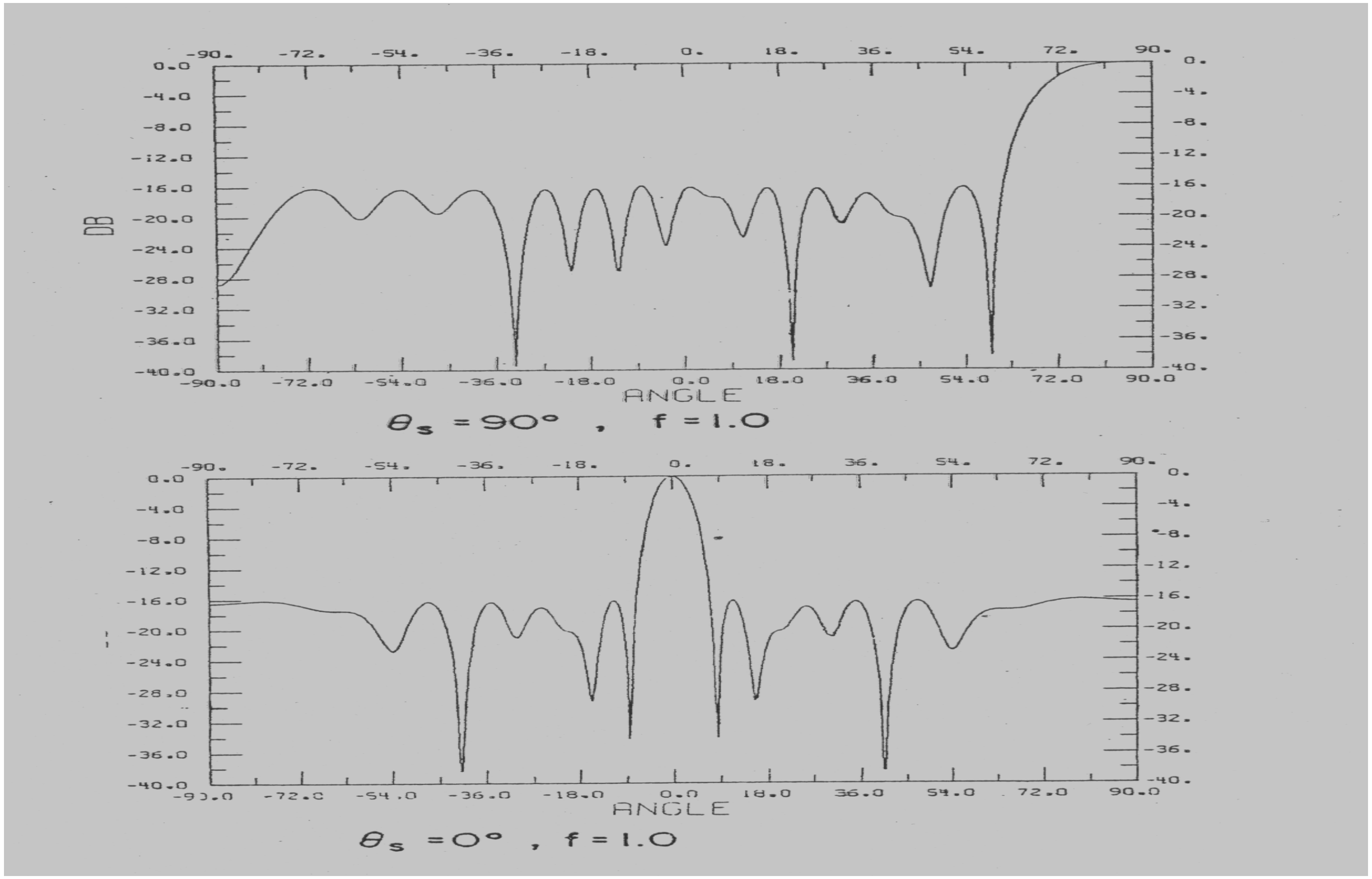
a) Reference pattern, uniform spacings (λ):
0.,1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,14.



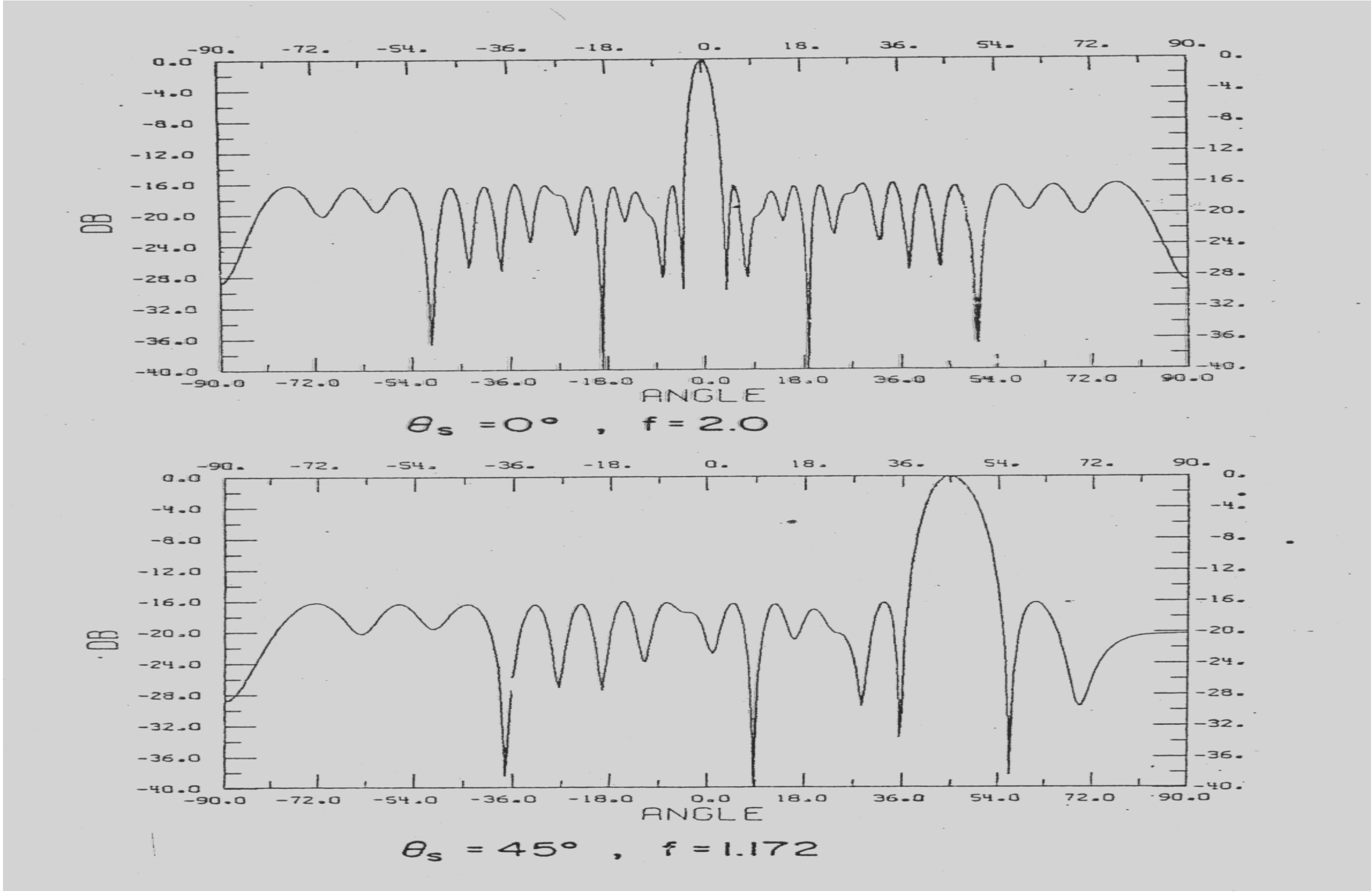
b) Optimized pattern, nonuniform asymmetric spacings (λ):
0., 1.842, 2.716, 3.786, 4.634, 5.556, 6.442, 7.430, 8.332, 9.160, 9.998, 10.908, 12.406, 13.216, 14.

Array Patterns – Thinned linear array of 15 isotropic elements, uniformly excited.

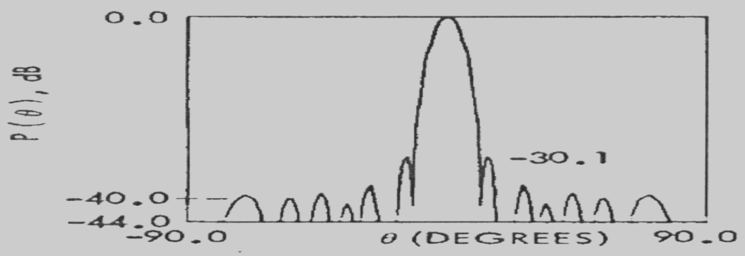
Example 2



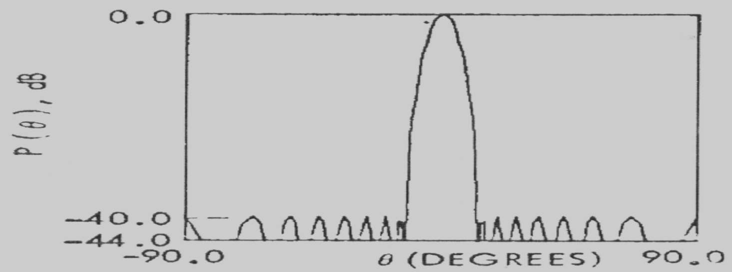
Example 3



Example 4



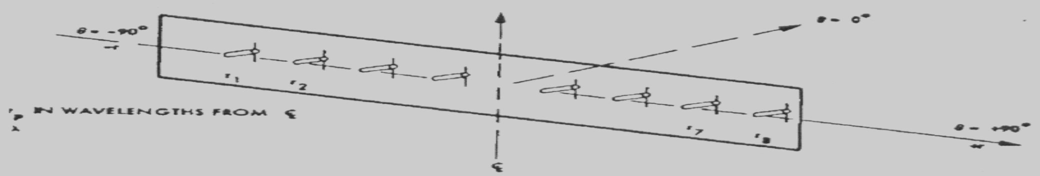
Unifomly spaced array, 16 isotropic elements, -40dB Chebychev distribution and coupling
x = (.25, .75, 1.25, 1.75, 2.25, 2.75, 3.25)



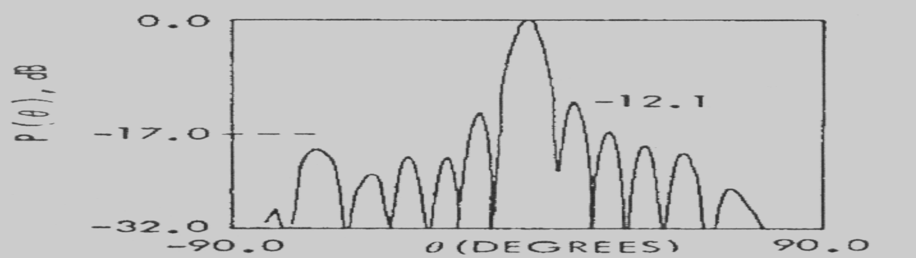
Optimum nonuniformly spaced array, 16 isotropic elements -40dB Chebychev distribution and coupling,
x^3 =(.23, .70, 1.18, 1.68, 2.18, 2.70, 3.20)

Fixed excitation: a = (1, .9358, .8178, .6638, .495, .3356, .1996, .1171)

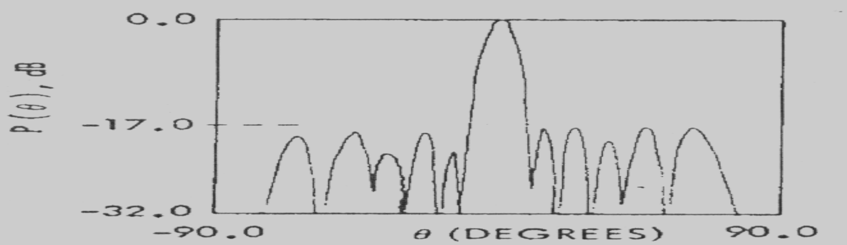
Example 5



Experimental dipole array, $r_1=0$, $r_8=5.25$.



Initial experiment pattern, eight dipoles
$x^0=(.75, 1.5, 2.25, 3, 3.75, 4.5)$

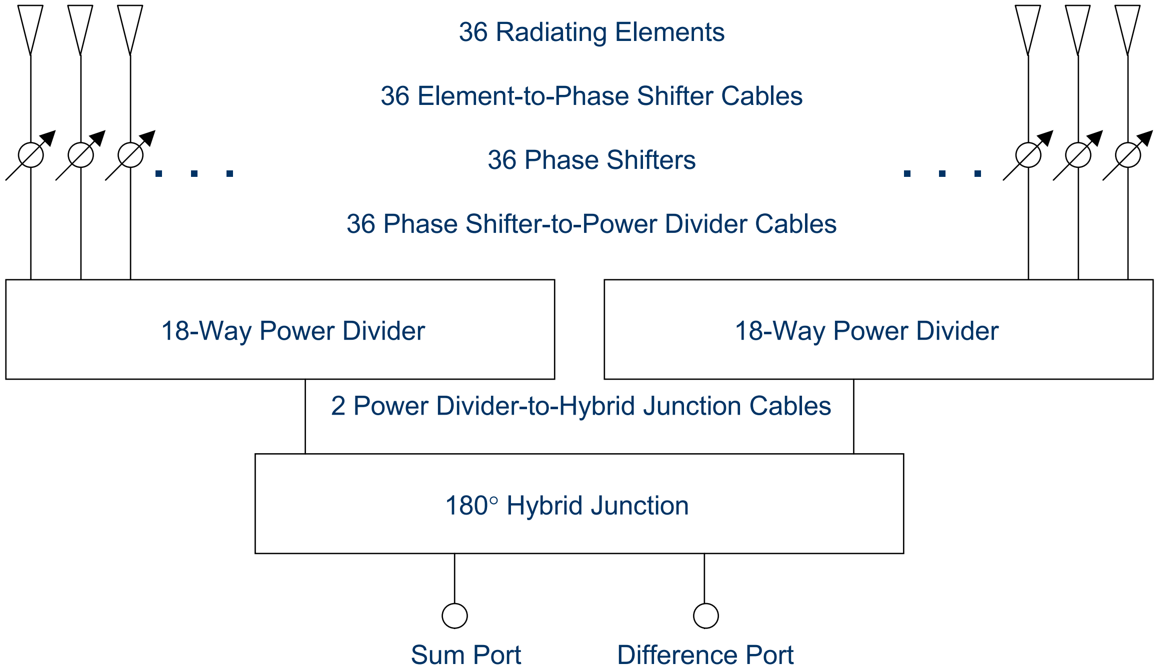


Optimized experimental pattern, eight dipoles.
$x^2= (.88, 1.68, 2.34, 2.9, 3.56, 4.33)$

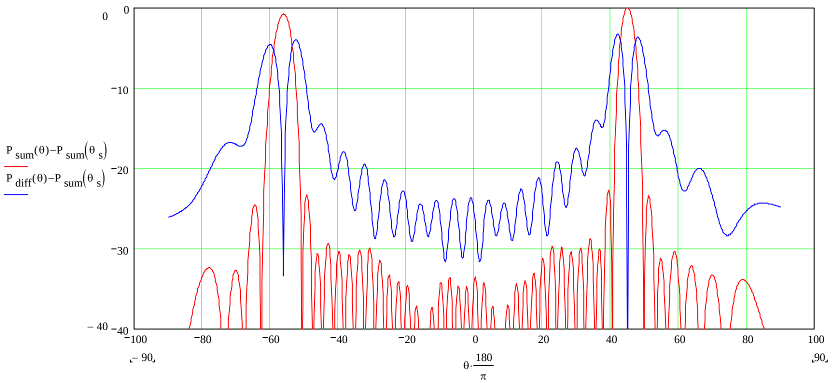
Sum/Difference Pattern Optimization

- Application to monopulse radar performance optimization.
- Performance objective example:
  Determine the optimum array parameters that will ensure that the difference pattern sidelobe level not exceed the sum pattern sidelobe level, as the pattern is scanned ± 45°.

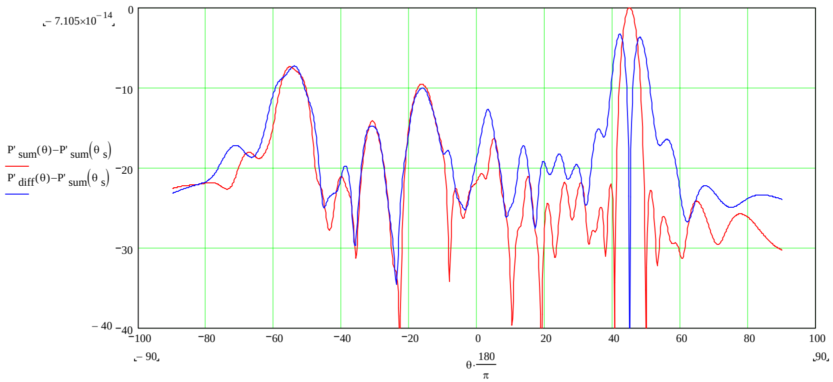
Monopulse Array System Block Diagram



Array Sum and Difference Patterns

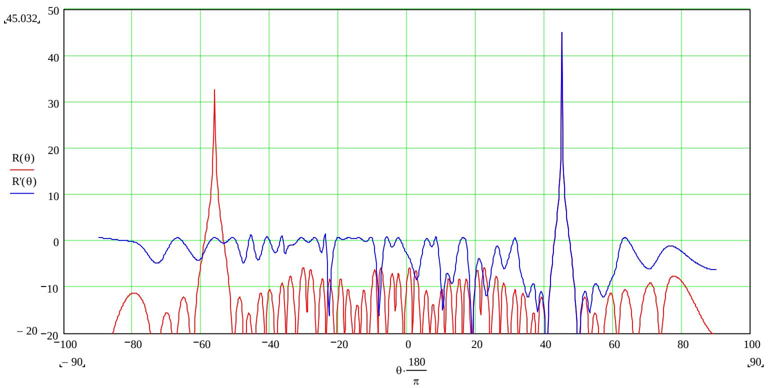


Initial



Optimized

Ratio



Applications of EmpOp™

- Synthesis of "on-the-vehicle" performance optimization of antenna arrays using EmpOp™ in conjunction with NEC to account for scattering and coupling between the array elements and the nearby structure.
- Determination of array excitations from measured pattern data.
- Optimization of array performance over a range of scan angles and frequency bandwidth.
- Synthesis of optimum element excitations and spacings, including conformal and thinned array configurations.