Phased Array Feeds for the Large Adaptive Reflector

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Abstract

This poster establishes the design parameters of a phased array feed system for the Large Adaptive Reflector. Our investigation has found: that for an octave-bandwidth phased array the beamformer must be channelized; for a 0.8°-wide field-of-view 2000 elements are needed; for low spillover ($<$ 10K) up to 1000 elements per beam are required and $\geq$ 5 bits quantization prior to summation.

Introduction

The Large Adaptive Reflector (LAR) [4], [5], [1]

- Operate from $\sim$ 150 MHz to 10–20 GHz.
- Reflector diameter $\sim$ 200 m and focal length $\sim$ 500 m.
- Instantaneous field of view at 1.4 GHz will be 0.5 square degree.

LAR Phased Array

- Phased array feed will be used so that the field of view is fully sampled with multiple beams.
- No electrical beam steering, only mechanical.
  - ▷ Minimizes foreshortening effects.
  - ▷ Simplifies array since phase shifters not needed.
  - ▷ Coarser element spacing allowed, up to λ, before grating lobes appear in the forward hemisphere.
- Beams have a variable profile because the reflector presents an elliptical outline at the focal point.
- Focal spot size equal to $(f/D)\lambda = 2.5\lambda$.

Wide-Band Phased Arrays

- Maximum array bandwidth
  - ▷ The maximum grating-free spacing for phased arrays that are not electrically steered is $\sim \lambda$.
  - ▷ The minimum spacing is set by the distance at which mutual coupling between two adjacent elements becomes significant, typically $\sim \lambda/2$
  - ▷ *Therefore the maximum bandwidth is one octave.*

- Beamforming network
  - ▷ Conventional beamforming networks produce illumination functions that are invariant with frequency.
  - ▷ The radiation pattern of such an antenna will vary with frequency, as shown in Fig. 1.
  - ▷ Thus the beamforming network needs to be made frequency dependent, as shown in Fig. 2.
    - ◇ FIR filter divides signals into bands.
    - ◇ Separate set of beamforming weights for each band.
    - ◇ Spectral aliasing can be suppressed by using the WIDAR method [2].

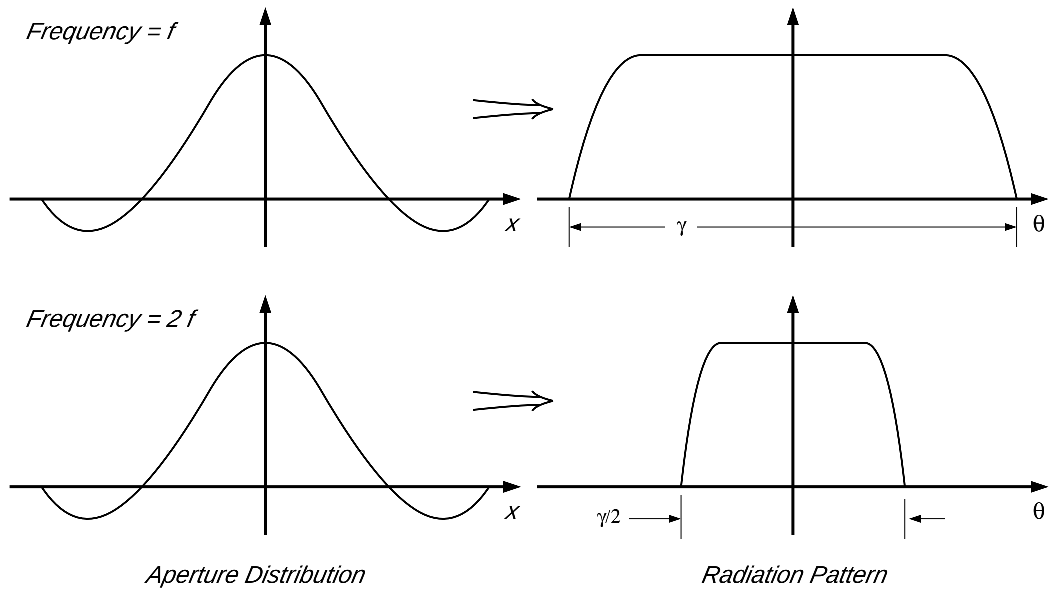

Figure 1: How a frequency independent aperture illumination produces a frequency dependent radiation pattern.

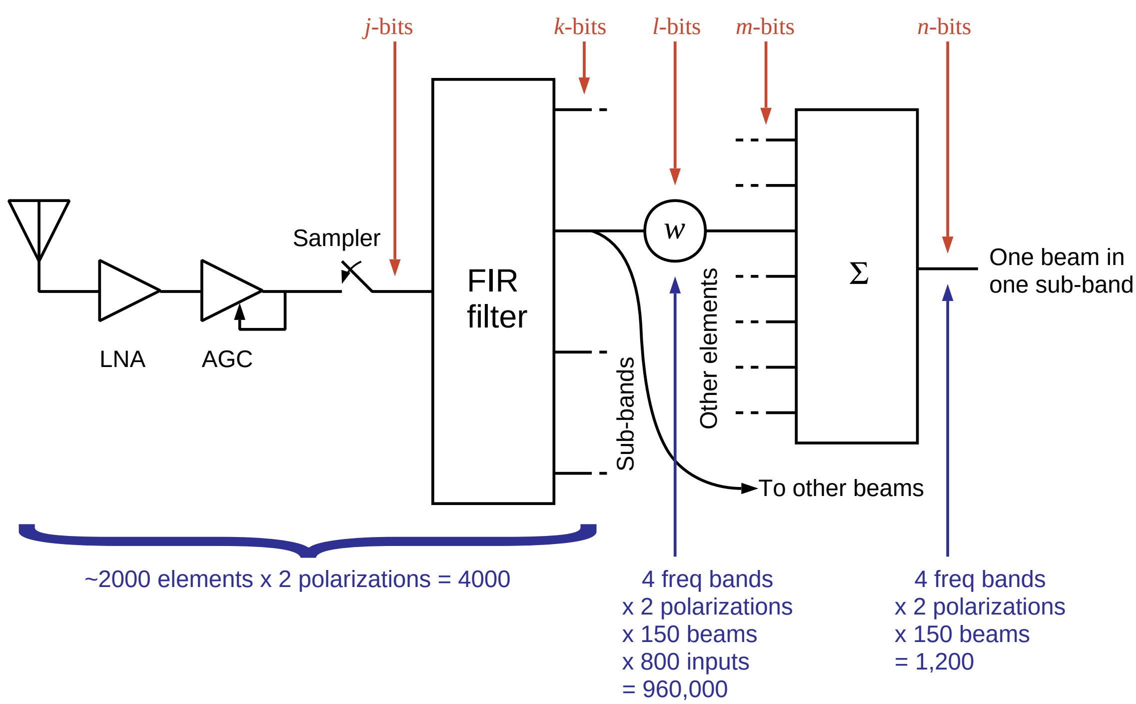

Figure 2: Wide-band beamforming network for a single receiver channel.

Simulation Software

- A software package has been written for transformations: *aperture illumination* $\Leftrightarrow$ *radiation pattern*.

- The package also contains many functions, such as the calculation of spillover noise, quantization of antenna weights, and the plotting of radiation patterns.

- The software was written in Octave [3], an interpretive language for numerical math and matrix algebra.

- Assumptions:

  ▷ reflector in the far-field zone of the array,
  ▷ coupling between the array elements is negligible,
  ▷ element pattern is uniform over the hemisphere.

- Can use either square or hexagonal grids of any size.

- Two types of beams can be specified for synthesizing an aperture illumination:

  ▷ Gaussian
  ▷ 'Flat-top', which is uniform with Gaussian skirts.

- Spillover temperature calculation
  - ▷ Ground temperature is assumed to be 300K.
  - ▷ The calculation take into account both the foreshortening of the reflector and the horizon.

Simulations and Results

- Purpose is to estimate the scale of a number of critical LAR phased array parameters:
  - ▷ the number of elements per focal spot or beam on the sky,
  - ▷ the numerical precision in the signal processing chain, and
  - ▷ the total number of elements.

- Beams used:
  - ▷ with a Gaussian beam with an edge taper of 15 dB,
  - ▷ with a flat-top function that had the flat radius set to 0.5 and tapers of 15 & 20 dB.

- Figure of merit used is the spillover noise temperature.

- Hexagonal and square grids were both examined.

Number of Elements and Combining Network Numerical Precision

- Grid spacings used:
  - ▷ hexagonal grids $\Rightarrow$ 0.9λ at the high-end of band and 0.45λ spacing at low-end,

- ▷ square grids $\Rightarrow$ 0.8λ at the high-end of band and 0.4λ spacing at low-end.

- Adjust taper on reflector so that spillover noise is 10K.

- Reduce number of elements without significantly increasing spillover.

- Vary the number of bits to find the minimum number where the performance degradation is minimal.

- Typical results shown in Tables 1–2.

- These are the minimum number of elements; more inputs are needed to:

  - ▷ track residual motions of airborne platform
  - ▷ allow smooth hand-off from one network to the next to accommodate field rotation.

Zenith Angle	Frequency	Elements	Bits
0°	low-band	331	5
	high-band	91	6
60°	low-band	817	5
	high-band	271	6

Table 1: Results for Gaussian beam with a 15 dB taper on a hexagonal grid.

Zenith Angle	Frequency	Elements	Bits
0°	low-band	289	5
	high-band	81	5
60°	low-band	1089	4
	high-band	289	6

Table 2: Results for Gaussian beam with a 15 dB taper on a square grid.

Total Number of Elements

- Calculated for 1.4 GHz, which will be the top of the octave-wide band.

- The telescope field of view will be one-half-square-degree with a field diameter of 0.8°, shown by the inner large circle in Figure 3.

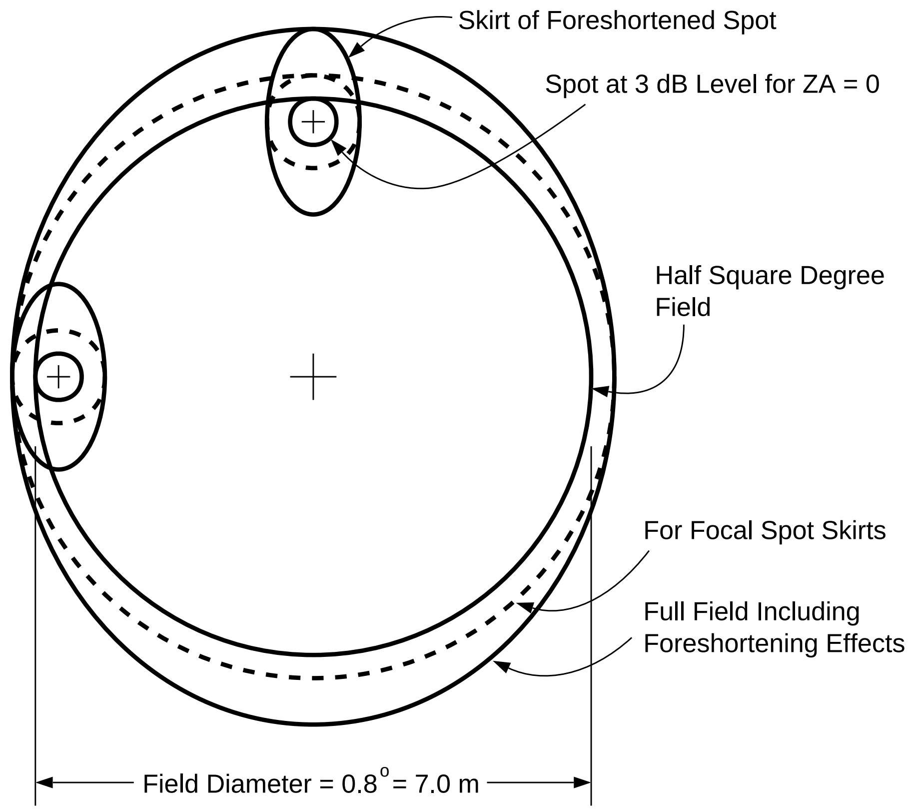

Figure 3: Boundaries of beams and overall field projected onto focal plane.

Perimeter	Diameter		Number of Elements	
			Hexagonal	Square
3 dB	33.2 λ	7 m	1237	1353
skirt	39.6 λ	8.3 m	1765	1925
ZA $=$ 60°, elliptical	39.6 λ $\times$ 45 λ	8.3 m $\times$ 9.5 m	1999	2185
ZA $=$ 60°, circular	45 λ	9.5 m	2263	2477

Table 3: Size and number of elements for various phased array perimeters.

Conclusions

- Wide-band phased arrays require a frequency-dependent beamforming network.
- For hexagonal grids the spacing varies between 0.45λ and 0.9λ .
- The useful range of spacings for a square grid is from 0.4λ to 0.9λ.
- There is a modest savings in the total number of elements if a hexagonal grid is used.
- A square grid may be chosen for other reasons, such as antenna type or fabrication method.
- For low spillover $\sim$1000 elements/beam at the low-frequency end of the band and $\sim$200 at the high-end.
- Quantization to 5-bits prior to the summing operation in the beamforming network usually provides adequate performance, although a conservative design should use 6-bits.

- At 1.4 GHz, the phased array will have the dimensions 8.3 m $\times$ 9.5 m for a 0.5 square-degree field-of-view.

- The phased array will contain 2000 elements for a single polarization.

References

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