2-27-2013

Darwin's Radio Telescope: Use of Genetic Algorithms in the Optimization of Patch Antennas for Radio Astronomy

Matthew N. Rispoli

Darwin's Radio Telescope

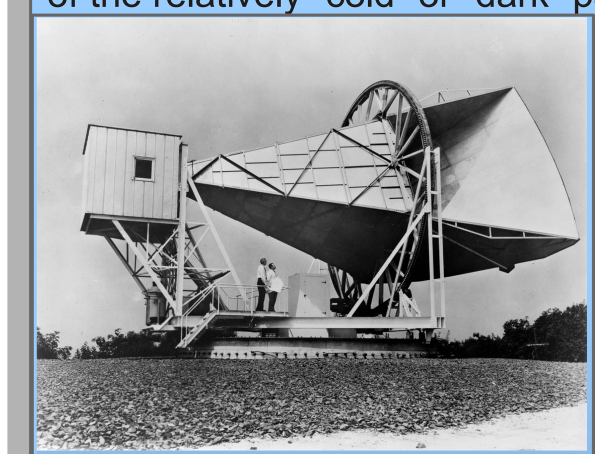
Use of Genetic Algorithms in the Optimization of Patch Antenna Arrays for Radio Astronomy

M.N. Rispoli[1], N.R. Huntoon[1], C.S. Lee[1], R. Kehoe[2], R.J. Scalise [2]

Introduction:

Radio astronomy refers to the observation of celestial objects by observing their emissions within the RF bands of the electromagnetic spectrum. Radio astronomy provides astronomers with a way to perform astronomical observation of the relatively "cold" or "dark" parts of the Universe and is characteristic of specific physical events.

Current radio astronomy uses large interferometers of parabolic dish antennas. This work uses genetic algorithms to optimize patch antennas and patch antenna arrays for a more versatile, robust, and accessible design of radio telescopes.



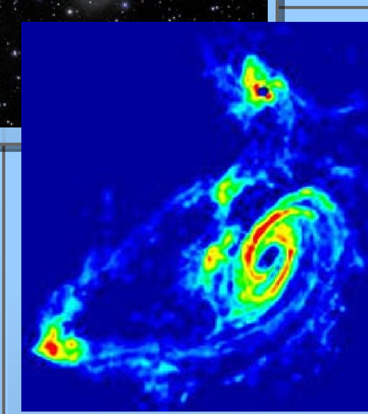


Fig.1: M81 Galaxy

Astronomical Signal:

Two Sources of celestial "signal"

- Spectral Emission
  - Neutral Hydrogen hyper-fine splitting from the spin-spin interaction of the proton and the orbital electron → λ=21cm emission.
- Blackbody Spectrum
  - Result of thermal radiation from hot object
  - Measurements correspond to the "Wien" tail of the distribution

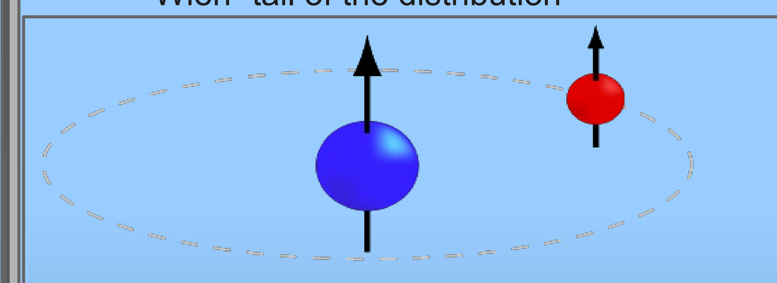


Fig.2: Excited state of neutral Hydrogen

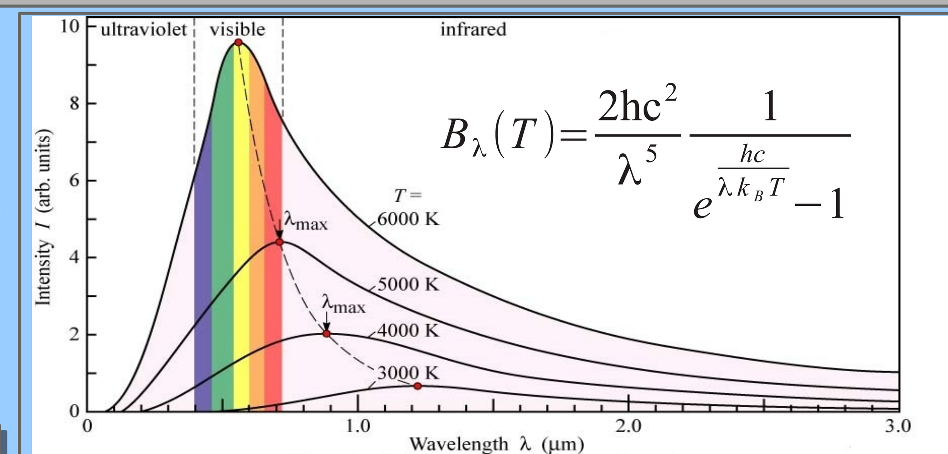


Fig.1: Blackbody Distribution

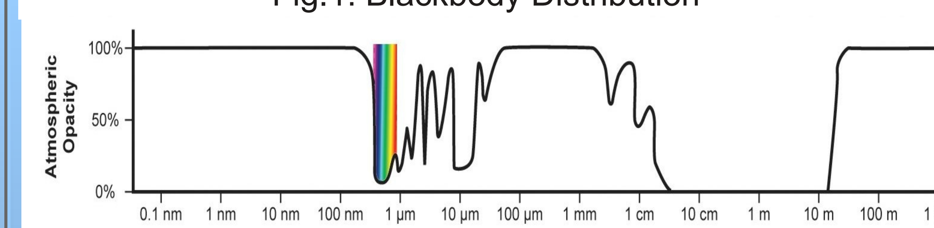


Fig.3: Atmospheric Opacity

Antenna Parameters:

Radio telescopes, like optical telescopes, require high resolution and the ability to see very faint signals. Like the size of the lens and the observed wavelength limit an optical telescope, the geometry of an antenna and the observed EM radiation limit the antenna.

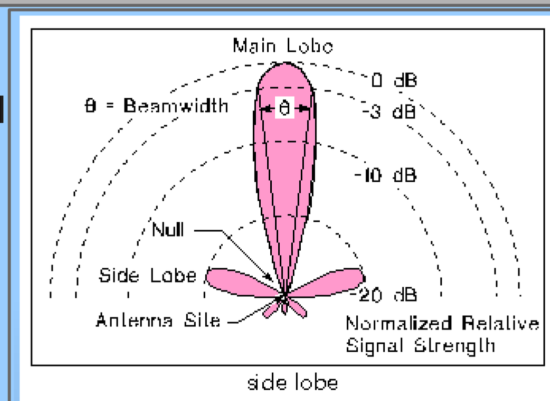


Fig.4: Schematic of Beam Pattern

Desirables for Radio Telescope:

- Narrow Beamwidth (FWHM)
- High Bandwidth (BW)
- High Efficiency
- Steerable Beam
- Low Side Lobe Level (SLL)

$$SLL=10\cdot\log(P_{SL}/P_{ML})$$

$$Eff=P_{rad}/P_{feed}$$

$$\delta\theta=1.22\lambda/D$$

Fig.5: VLA in New Mexico

Interferometry:

Exploits the phase offsets of incoming radio waves for constructive and destructive interference to shape the overall array beam. This also gives the antenna an overall larger effective area.

Arrays:

d~0.92λ, AW (11x11 array)

The arrays created were forced to be an NxN square array.

Optimized Parameters from array:

- (FWHM)=4.8 deg.
- SLL= -14.35dB
- Max(|AF|)~4500

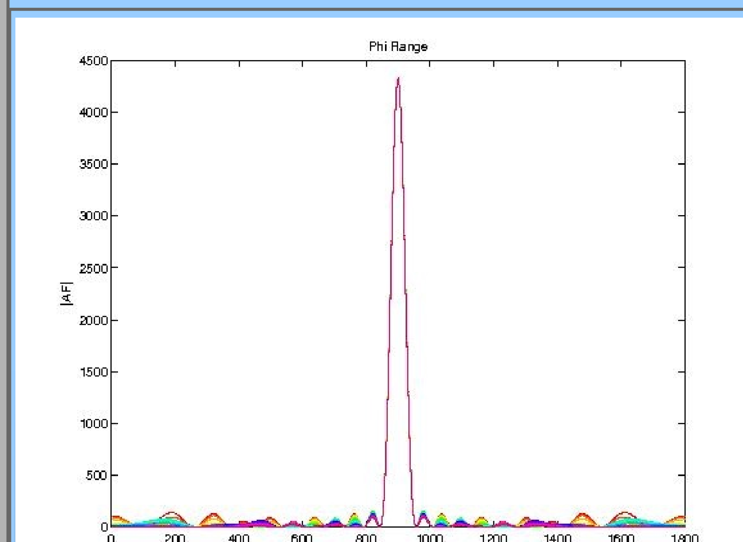


Fig.6:AF with multiple φ plots

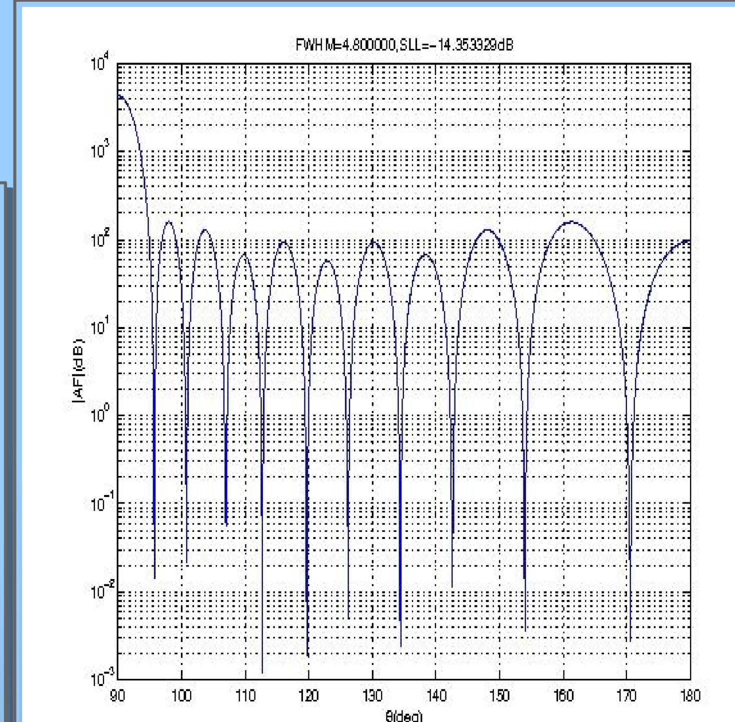


Fig.7: 10xLog(AF)

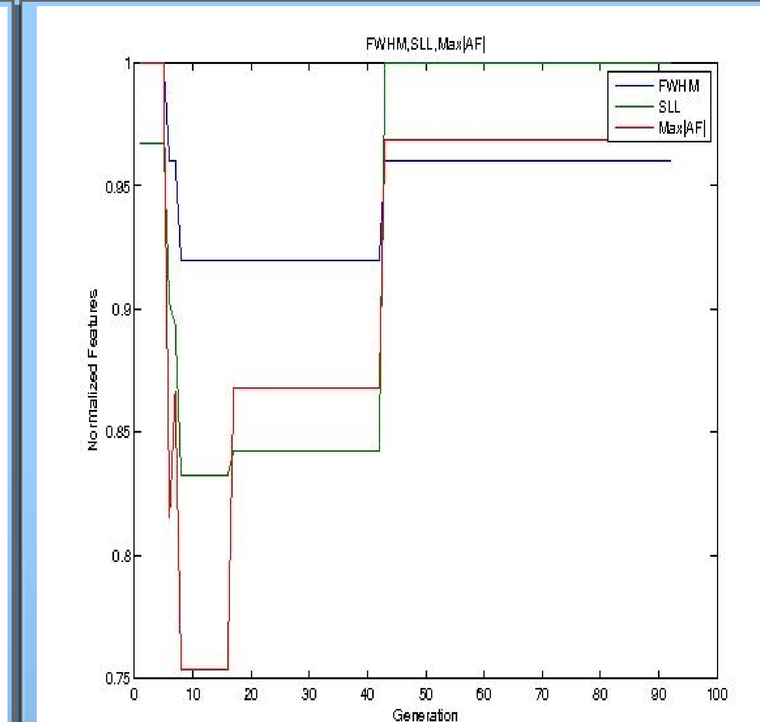
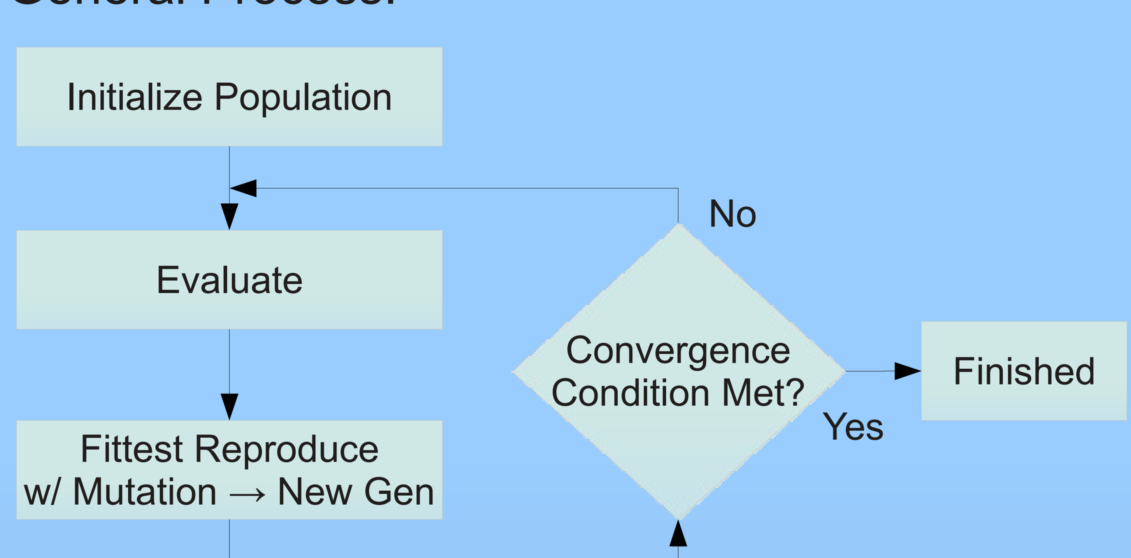


Fig.8: Parameters by generation

Genetic Algorithms:

Genetic algorithms are a subset of evolutionary algorithms that describe a simulated population of devices by parameters labeled as "genes." These genes are then used as instructions to simulate the described devices and the theory of evolution is used to determine the fitness of the described device, its survival, and ability to pass on traits to a new population of devices. Genetic algorithms have several very important benefits when it comes to device design due to the simple principle that governs them and their ability to find global maximums and non-intuitive optimal solutions.

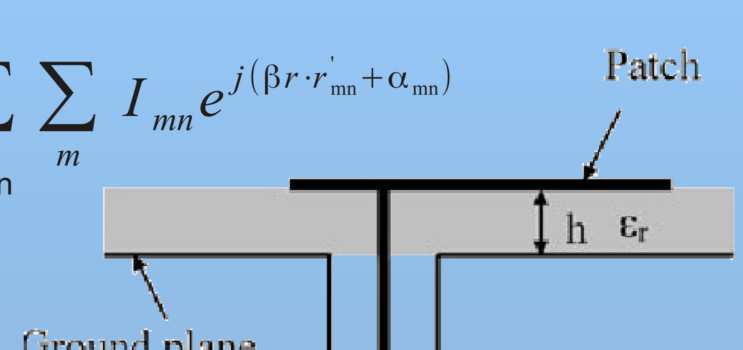
General Process:



Genes:

$$AF(\theta,\phi)=\sum_n\sum_m I_{mn}e^{j(\beta r\cdot r'_{mn}+\alpha_{mn})}$$

Array Factor Definition



Schematic of Patch Antenna

Process and Simulation:

Genetic Algorithm:

- Written in MATLAB
- Dynamic mutation rates
- Roulette Wheel genetic crossover

Arrays:

- MATLAB used to simulate AF
- MATLAB run on SMUHPC nodes through Condor
- Optimize spacing and element weighting

Patches:

- FDTD Method (MEEP)
- Near Field to Far Field (NF2FF) in MATLAB
- MEEP output computed on SMUHPC Nodes
- Optimize dielectric constant, spacing, and patch geometry

Fitness Functions:

Since there is no known global maximum, nor a restriction on the "goodness" of the antenna, the fitness function is defined as a linear combination of minimal desired quantities for the array and antenna separately. The fitness function is also defined so that the smaller the number, the more "fit" the member of the population.

Array Fitness Function:

$$Fit_i=W_{dir}\cdot(\theta_{i,max}-\frac{\pi}{2})+W_{max}\cdot P_i(\theta_{i,max},\phi_{i,max})+W_{FWHM}\cdot FWHM_i+W_{SLL}\cdot SLL_i$$

- $W_{dir}=1$
- $W_{max}=-1/N^2$
- $W_{FWHM}=1.22\cdot\lambda/((N-1)\cdot d)$
- $W_{SLL}=1/10$

$$N=Number\ of\ Elements\ along\ axis$$
$$d=spacing\ between\ array\ elements$$

Patch Fitness Function:

$$Fit_i=W_{dir}\cdot(\theta_{i,max}-\frac{\pi}{2})+W_{eff}\cdot Eff+W_{FWHM}\cdot FWHM_i+W_{SLL}\cdot SLL_i+W_{BW}\cdot BW_i$$

- $W_{dir}=1$
- $W_{eff}=-1/(0.7)$
- $W_{FWHM}=1$
- $W_{SLL}=1/6$
- $W_{BW}=-1/(0.3)$

Patches:

The optimization of the patch antennas are currently underway and therefore an optimized patch antenna cannot be displayed. However, the random nature of the population initialization can be displayed by mapping the surface of the patches and the "cookbook" patch antenna being used for evaluation are displayed below to exhibit the nature of the continued research and optimization.

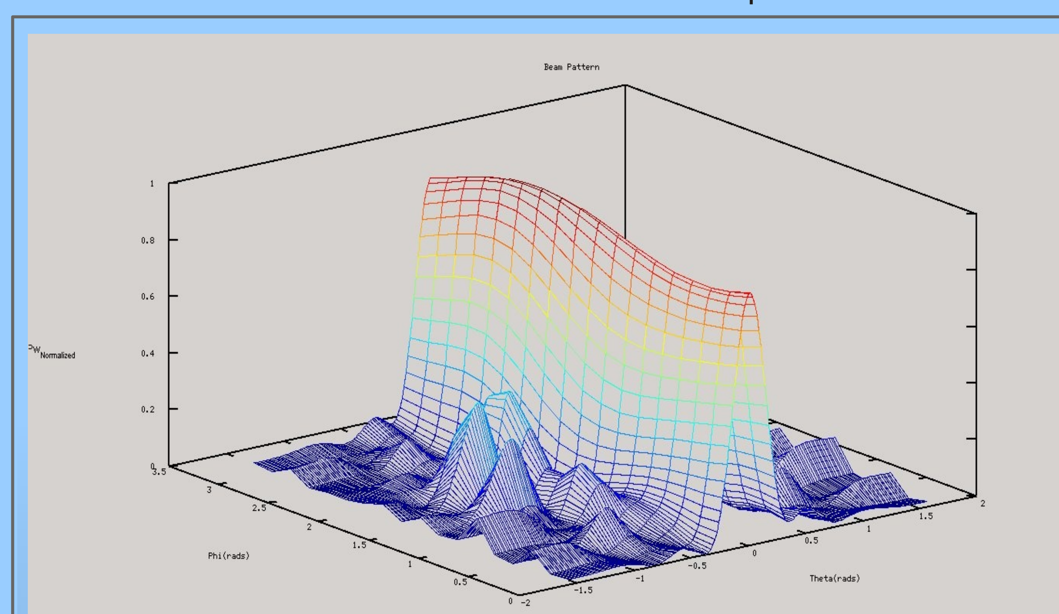


Fig. 9: 3D Beam Pattern (Not a Polar Plot)

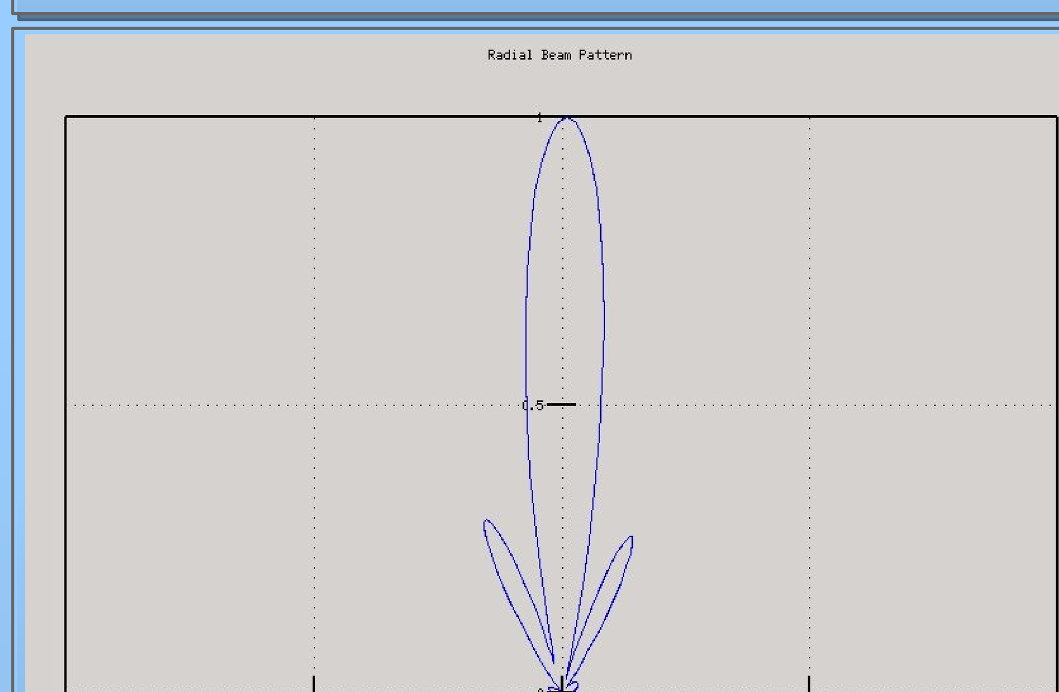


Fig. 10: Polar Plot of Beam Pattern (in θ)

Fig. 11: patch antenna Initial geometry

Summary:

- Genetic algorithms can appropriately optimize patch antenna arrays
- for radio astronomy
- Array parameters and patch parameters are optimized separately
- Extension to physical feasibility can be achieved by restricting parameter space
- Radio telescopes can be built out of subarray and array patch antenna combinations for high resolution ~ diffraction limit.

Continued Work:

- Continued optimization of patch antenna geometry (currently in progress)
- Extension from 2D optimization to 3D conformal surface optimization
- Continue revisions on optimization code for dynamic mutation rates
- Continue adjustments on genetic cross over rates for quicker convergence
- Reduction in simulation time by dynamic changes in resolution for areas of interest
- Include physical realizability costs as part of fitness function

Acknowledgements:
Lyle Engineering School—Electrical Engineering

Contact: Matthew Rispoli
mrispoli@smu.edu

1 SMU, Electrical Engineering

2 SMU, Physics