

Simulation-Based Comparative Analysis of Advanced Antenna Systems for Radar Applications

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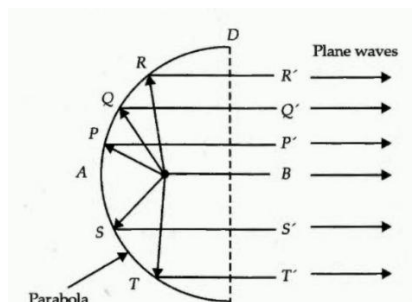
Abstract: This study provides a comparative analysis of four types of antennas—parabolic reflector, phased array with mechanical and electronic scan types, and Cassegrain antennas—focusing on critical performance metrics such as side lobe levels, gain, and efficiency. The research highlights the differences in side lobe suppression, gain, and overall efficiency across these antenna types. Parabolic reflector antennas are known for their high gain but tend to have moderate side lobe levels. Phased array antennas, which can be equipped with either mechanical or electronic scanning, offer improved side lobe suppression and higher efficiency, making them highly adaptable for various applications. Cassegrain antennas, which utilize a combination of a parabolic primary reflector and a secondary reflector, are particularly effective in minimizing side lobe levels while maintaining good gain and efficiency. These results were achieved with the help of the PREP software, a powerful simulation tool for radar system performance analysis. This analysis emphasizes the trade-offs between side lobe suppression, gain, and efficiency when selecting the most suitable antenna for different communication and radar systems, particularly for high-frequency applications. The findings suggest that antenna selection should be tailored to specific application requirements, with a focus on achieving optimal performance in terms of directivity, interference reduction, and energy efficiency.

Key Words: Parabolic reflector, Phased array, Cassegrain antenna, SLL, Gain, Efficiency.

1. INTRODUCTION:

1) PARABOLIC REFLECTOR

A parabolic reflector is an antenna or optical device that uses a parabolic shape to focus or direct electromagnetic waves into a highly directional beam. It is commonly used in satellite communications, radio telescopes, radar systems, and optical instruments. The parabolic shape reflects waves from the focus into a parallel beam or focuses incoming parallel waves to the focus. Key features include high gain, narrow beam width, and low sidelobe levels. Parabolic reflectors offer high directivity, a simple design, and versatility, making them suitable for a wide frequency range, from 30 MHz to several hundred GHz, depending on the application[1].





$$G_{dB} = 10 \log_{10} \left(\frac{4\pi A}{\lambda^2} \right)$$

Where G : gain of antenna, A : Effective aperture area of the antenna, λ : Wavelength of the signal being transmitted or received

Gain of Phased array can be given by

$$G_{\text{element}} \approx \frac{4\pi A_{\text{element}}}{\lambda^2}$$

Where A element: Effective aperture of a single element, λ : Wavelength of the signal.

Gain of Cassegrain antenna:

$$G_{dB} = 10 \log_{10} \left(\frac{4\pi A_{\text{eff}}}{\lambda^2} \right)$$

Where Aeff : Effective aperture area, λ : Wavelength of the signal, G: Gain of the antenna.

- 2. Antenna efficiency** refers to the ratio of the power radiated by an antenna to the total power inputted to the antenna. It is an important parameter in antenna design, as it indicates how effectively an antenna converts the supplied electrical power into electromagnetic radiation. The efficiency of an antenna is influenced by various factors, such as the material properties, losses in the antenna components, and the design of the antenna[2][3]..

Efficiency of Parabolic reflector and cassegrain antenna

$$\eta = \frac{G}{G_{\text{max}}}$$

Where G: Actual gain of the antenna, Gmax: Maximum theoretical gain of a perfect antenna

Efficiency of Phase array:

$$\eta = \frac{P_{\text{radiated}}}{P_{\text{input}}}$$

Where P radiated : Power radiated by the antenna, P input: Power supplied to the antenna.

- 3. Side Lobe Level** are unwanted radiation lobes that appear outside the main lobe of the antenna's radiation pattern. They represent radiation in directions other than the desired one (main lobe), which can lead to interference or signal degradation. The sidelobe level (SLL) of an antenna refers to the relative intensity of the sidelobes compared to the main beam of the antenna's radiation pattern. In phased-array antennas, sidelobes are undesired radiation patterns at angles other than the direction of the main lobe. They are an inevitable byproduct of the array structure and excitation but can be minimized through careful design[3].

For circular apertures (like parabolic dishes), an approximate empirical relation for the first side lobe level is:

$$SLL \text{ (dB)} \approx -A \log_{10}(T)$$

Where A : constant (~20 depending on the taper function), T: the edge taper in linear scale (not dB)

The starting point for analyzing side lobes is the array factor, which for a linear array of N isotropic elements with uniform spacing d is given by:

$$AF(\theta) = \sum_{n=0}^{N-1} I_n e^{jn(kd \cos \theta + \beta)}$$

Where j_n : Amplitude excitation of the n_{th} element , k: $2\pi/\lambda$ Wave number, d :Distance between elements, θ : Observation angle, β : Progressive phase shift



The side lobes occur at angles where the array factor has secondary maxima. The SLL is the ratio of the maximum side lobe amplitude to the main lobe amplitude, typically expressed in decibels (dB) [2][7].

$$SLL \text{ (dB)} = 20 \log_{10} \left(\frac{AF_{\text{main lobe max}}}{AF_{\text{side lobe max}}} \right)$$

Where $AF_{\text{side lobe max}}$: Maximum value of the array factor in the side lobe regio, $AF_{\text{main lobe max}}$: Maximum value of the array factor in the main lobe
 Side lobe level of Cassegrain antenna

$$SLL_{\text{Cassegrain}} \text{ (dB)} \approx -A \log_{10}(T)$$

Where $A \approx 20$ (depends on the specific design), T: Edge taper ratio in linear scale (not in dB)

3. RESEARCH METHODOLOGY:

PULSE RADAR SIMULATION SOFTWARE (PREP) is a powerful, pulsed radar, simulator software designed to assist with operator training, to teach concept of radar and to use by radar engineers. A key feathers pf PREP is the integral electronic warfare capability.

PREP uses CBT to enable operator to vary radar parameters and then observe the effect on the radar screen, PREP uses standard displays and signal processing techniques[4][6][7][8][10].

Technical specification:

- Frequency: 100 MHz to 50 G Hz
- Pulse width: 100 ps to 1 ms
- PRF : 10 Hz to 50 KHz
- Maximum range: 1m to 500 km
- Receiver gain: 30 to 150 db, linear and logarithmic
- Receiver Noise factor: 1 to 50
- Signal Processing: FTC, IAGC, CFAR, STC
- Peak power: -30 to +60 dbm
- Antenna dimentions: 1cm to 100m in Azimuth and elevation
- Scan type: Mechanical or electronic
- Plumbing loss: 0.01 to 20 dB
- Switch loss: 0.01 to 5 dB

4. RESULTS:

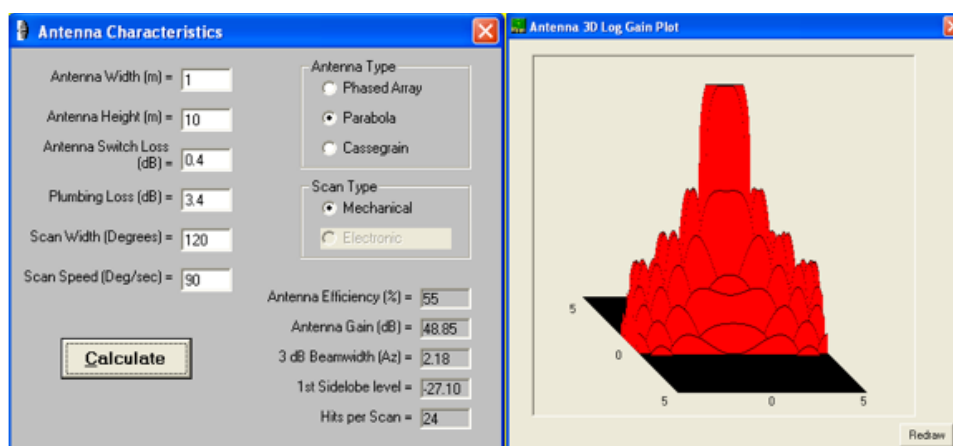


Fig. 1. SLL, gain and efficiency of Parabola antenna with mechanical scan type using Antenna width 1 meter and antenna hight 10 meter

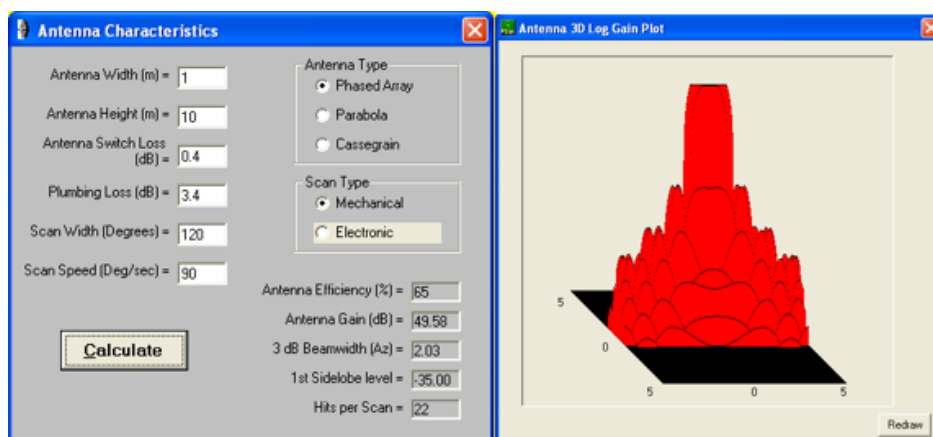


Fig. 2. SLL, gain and efficiency of Phase array antenna with mechanical scan type using Antenna width 1 meter and antenna height 10 meter

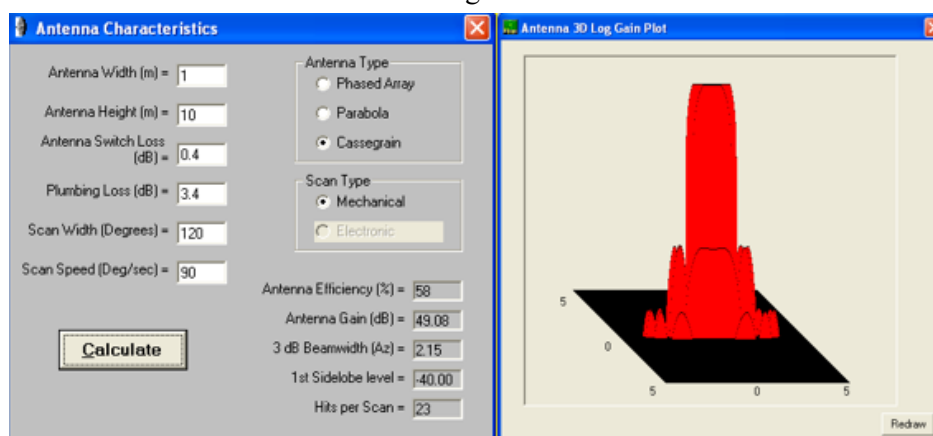


Fig. 3. SLL, gain and efficiency of Cassegrain antenna with mechanical scan type using Antenna width 1 meter and antenna height 10 meter

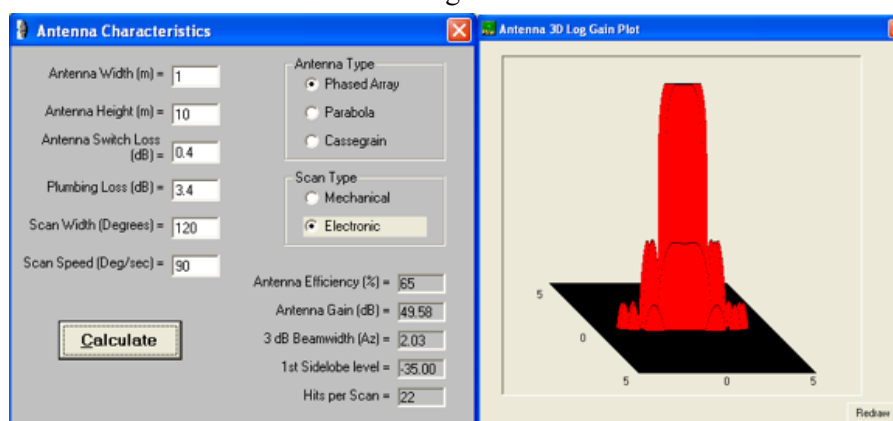


Fig. 4. SLL, gain and efficiency of Phase array antenna with Electronic scan type using Antenna width 1 meter and antenna height 10 meter

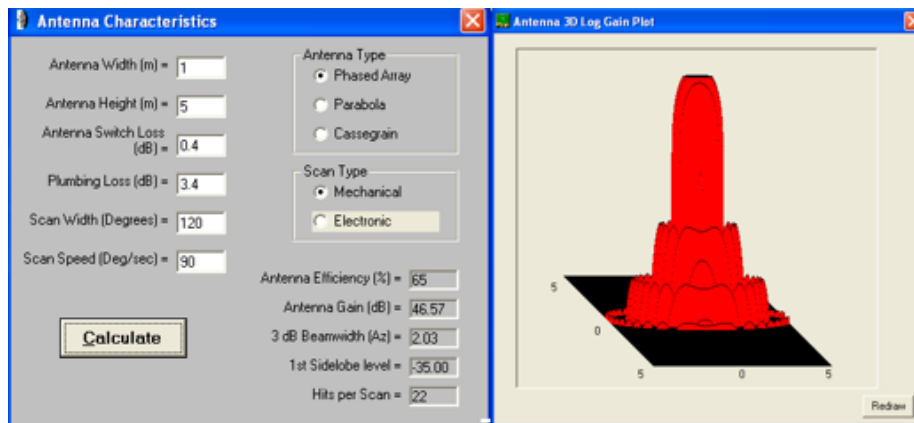


Fig. 5. SLL, gain and efficiency of Phase array antenna with Mechanical scan type using Antenna width 1 meter and antenna height 5 meter

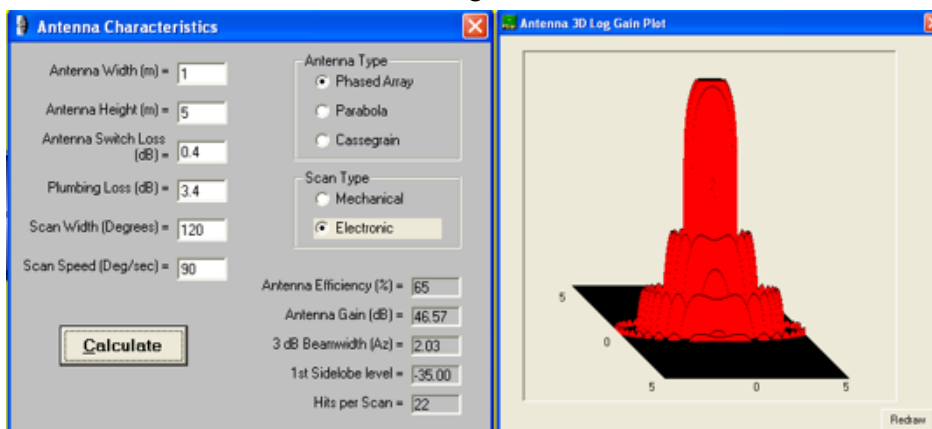


Fig. 6. SLL, gain and efficiency of Phase array antenna with Electronic scan type using Antenna width 1 meter and antenna height 5 meter

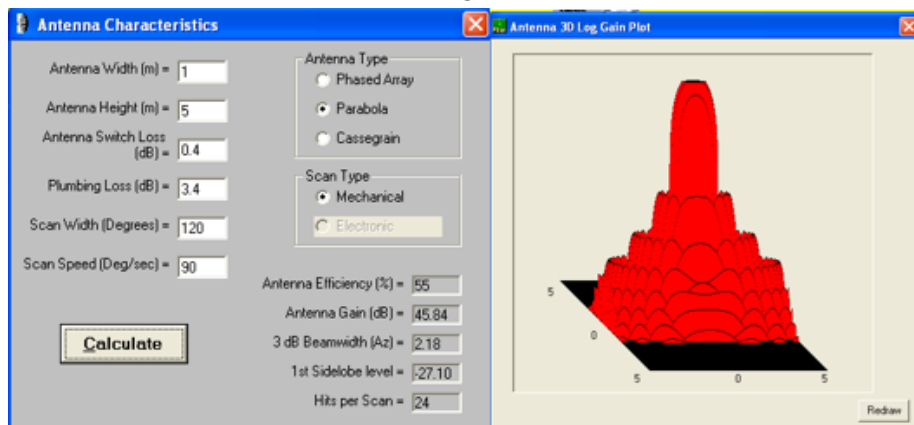


Fig. 7. SLL, gain and efficiency of Parabolic reflector with Mechanical scan type using Antenna width 1 meter and antenna height 5 meter

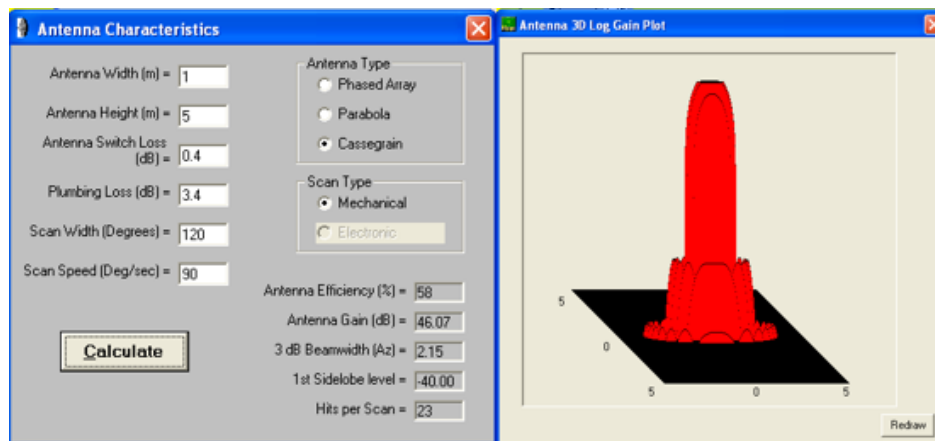


Fig. 8. SLL, gain and efficiency of Cassegrain with Mechanical scan type using Antenna width 1 meter and antenna height 5 meter

4. COMPARATIVE ANALYSIS OF RESULTS:

Sr no	Type of antenna	Height of antenna in meter	Width of antenna in meter	1 st Side lobe level	Gain in dB	Efficiency in percentage
1	Parabola reflector	10	1	-27.10	48.85	55
2	Parabola reflector	5	1	-27.10	45.84	55
3	Phase array with mechanical scan type	10	1	-35	49.58	65
4	Phase array with mechanical scan type	5	1	-35	46.57	65
5	Phase array with Electronic scan type	10	1	-35	49.58	65
6	Phase array with Electronic scan type	5	1	-35	46.57	65
7	Cassegrain	10	1	-40	49.08	58
8	Cassegrain	5	1	-40	46.07	58

5. CONCLUSION:

- Phased array antennas, particularly with electronic or mechanical scanning, show the best side lobe suppression and high efficiency.
- Parabolic reflectors provide high gain and moderate side lobe levels but are outperformed in terms of side lobe suppression and efficiency by phased arrays and Cassegrain antennas.
- Cassegrain antennas, while providing the lowest side lobe levels and good gain, come with higher complexity and potentially higher cost, making them ideal for applications where low interference and high performance are paramount, such as in satellite communications or high-frequency radar systems.

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