Design and Analysis of Corner Reflectors for the Acconeer XM125 Radar Sensor

Abstract

This paper examines the design of corner reflectors to optimize the performance and accuracy of the Acconeer XM125, a 60 GHz pulsed coherent radar sensor. Three reflector shapes—parabolic, flat plate, and trihedral corner—are analyzed for their radar cross-section (RCS), beam characteristics, and suitability within a constrained setup. A parabolic reflector is proposed for its focusing potential and compared to flat plate and trihedral alternatives to determine the best choice for enhancing signal quality and data collection.

1. Introduction

The Acconeer XM125 radar sensor operates at 60 GHz, offering a 2.5 mm range resolution and a wide field of view (FoV) due to its integrated antenna (Acconeer, 2023). However, its omnidirectional pattern can dilute signal strength for small or low-reflectivity targets. A corner reflector can increase the radar cross-section (RCS) and improve signal-to-noise ratio (SNR), enhancing measurement precision. This paper evaluates parabolic, flat plate, and trihedral corner reflectors to identify the optimal design for the XM125.

2. Reflector Design Considerations

2.1 Requirements

- Maximize RCS to boost reflected signal strength.
- Enhance SNR for accurate detection of small targets.
- Fit within a compact space (e.g., <50 mm dimensions).
- Use lightweight, radar-reflective materials (e.g., aluminum).

2.2 Reflector Shapes

1. **Parabolic Reflector**:
    - **Description**: A curved dish focusing radar waves into a narrow beam, with the XM125 at the focal point.
    - **RCS**: High when aligned, approximately $\sigma \approx \pi D^2/(4\lambda^2)$, where D is the diameter and λ is the wavelength (5 mm at 60 GHz)
    - **Advantages**: Concentrates energy, improving SNR and aiding precision.
    - **Challenges**: Needs precise alignment; harder to fabricate.
2. **Flat Plate**:
    - **Description**: A planar surface reflecting waves directly back when perpendicular to the radar beam.
    - **RCS**: $\sigma = (4\pi A^2)/\lambda^2$, where A is the area
    - **Advantages**: Simple to make; predictable reflection.
    - **Challenges**: Narrow angular response; no focusing effect.
3. **Trihedral Corner**:
    - **Description**: Three orthogonal planes form a corner, reflecting waves back over a wide angle.
    - **RCS**: $\sigma = (12\pi a^4)/\lambda^2$, where a is the side length.
    - **Advantages**: High RCS; wide FoV (up to 90°).
    - **Challenges**: Bulkier; no beam focusing.

2.3 Parabolic vs. Other Shapes

- **Focusing**: The parabolic reflector focuses energy into a tight beam, boosting SNR by ~10-15 dB (estimated from antenna gain, Balanis, 2012). Flat plates and trihedral corners scatter energy without concentration.
- **Angular Response**: Trihedral corners reflect consistently across a 90° FoV, ideal for omnidirectional use, while parabolic and flat designs require alignment.
- **Size Efficiency**: A 4 cm diameter parabolic dish (~12 cm³ volume) offers high RCS with less bulk than a trihedral corner (e.g., ~27 cm³ for a = 3 cm with similar RCS).

3. Design Implementation

3.1 Parabolic Reflector

- **Dimensions**: Diameter = 4 cm, depth = 1 cm (focal length ≈ 1 cm).
- **Material**: Thin aluminum foil (0.1 mm), reflective at 60 GHz.
- **RCS**: $\sigma \approx \pi(0.04)^2/(4\times0.005^2) \approx 50\ m^2$ (theoretical peak).
- **Fabrication**: Molded from foil or 3D-printed with a conductive coating.

3.2 Flat Plate

- **Dimensions**: 4 cm x 4 cm square.
- **Material**: Aluminum sheet.
- **RCS**: $\sigma \approx (4\pi(0.04)^2)/0.005^2 \approx 20\ m^2$.
- **Fabrication**: Cut from stock material; minimal processing.

3.3 Trihedral Corner

- **Dimensions**: Side length a = 3 cm.
- **Material**: Aluminum panels.
- **RCS**: $\sigma \approx (12\pi(0.03)^4)/0.005^2 \approx 30\ m^2$.
- **Fabrication**: Assembled from three cut pieces; moderate complexity.

4. Performance Analysis

- **Parabolic**: Offers the highest SNR due to focused energy, ideal for precision tasks like small-target detection. Alignment is critical but manageable with fixed positioning.
- **Flat Plate**: Provides moderate RCS but loses effectiveness if misaligned; lacks focusing for enhanced resolution.
- **Trihedral**: Delivers high RCS across a wide angle, best for static setups needing omnidirectional reflection, but no SNR boost.

The parabolic reflector outperforms in directed signal enhancement, critical for detailed data collection, while the trihedral excels in versatility and the flat plate in simplicity.

5. Conclusion and Recommendation

The parabolic reflector is recommended for the XM125 due to its superior SNR and energy focusing, optimizing radar performance for precise applications. A 4 cm diameter design balances RCS and size, using aluminum foil for cost-effective fabrication. While trihedral corners offer wide-angle reflection and flat plates simplicity, the parabolic shape best enhances data quality within the XM125’s constraints. Future testing should validate theoretical RCS and explore alignment stability.

References

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