Antenna Design for Geosynchronous SATCOM at Arctic Latitudes

Dr. Jonathon Cheah
Eric Robinson
Shelley Johnson
Matthew Murray
Overview

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- MITRE Prototype Antennas
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Summary

- Geosynchronous satellites are utilized for key communications infrastructure.
- Communication with geosynchronous satellites at high latitudes is challenging due to near-horizon line-of-sight.
- Conventional SATCOM antennas are designed for use at mid-latitudes and are insufficient for Arctic use.
- MITRE has designed, prototyped, and fielded specialized antennas which address these challenges.
SATCOM Background

• Geosynchronous satellites orbit the earth at the same rate the earth spins

• Geostationary satellites placed above the equator appear static from the ground
  • Ground communications terminals can point antennas directly at the satellite and do not require tracking

• To a ground user on the equator, the satellite appears to be directly overhead

• To a ground user at the poles, the satellite is near or below the horizon
Antenna Background

- Antennas radiate and receive electromagnetic energy wirelessly

- Energy is not radiated equally in all directions; it is often focused in a particular direction or sector
  - The distribution of the radiated energy is described the *antenna gain pattern*

- One analogy for the gain pattern is that of different light sources
  - The sun illuminates equally in all directions
  - A lantern illuminates to the sides, but not above or below
  - A spotlight shines a beam of focused light in one direction

![Example 2D Gain Pattern](image)

![Example 3D Gain Pattern](image)
Commercial Antenna Shortcomings

- Commercial terminal antennas for geosynchronous SATCOM are primarily designed for use in the mid-latitudes
  - Gain patterns are focused upwards, with little coverage close to the horizon, resulting in poor performance at Arctic latitudes
  - SATCOM antennas need to be “circularly polarized,” which is difficult for omnidirectional conventional antennas
- High-gain pointing antennas are available, but they require careful steering
  - Difficult at high latitudes due to satellite geometry
  - Unfeasible for mobile terminals (ships and vehicles)
  - Impractical due to harsh deployment conditions

Commercial SATCOM antennas are insufficient at Arctic latitudes, especially for use on mobile vehicles
Visualization of Antenna Elevation Angles: Conventional SATCOM Gain Pattern

Near-Zenith Satellite (Mid-Latitudes)
- Good gain near zenith
- Poor gain near horizon

Near-Horizon Satellite (High-Latitudes)
Insufficient for SATCOM at Arctic latitudes
Visualization of Antenna Elevation Angles: Directional SATCOM Gain Pattern

- Good gain near horizon in one direction
- Requires adjustment as terminal moves

Pointed beam is not ideal; requires adjustment as platform moves
Visualization of Antenna Elevation Angles:
MITRE Omnidirectional Antenna Gain Pattern

MITRE antenna covers the whole horizon; no pointing needed

• Good gain across the whole horizon
MITRE Antenna Development

• MITRE has been conducting research to understand these constraints and design antennas to address them

• In 2017, two prototype antennas were deployed to Utqiagvik, AK (Barrow), for geosynchronous SATCOM
  • Highest latitude city in the United States
  • Geosynchronous test satellites approximately 5-10° above the horizon

• In 2019, two prototype antennas were deployed on the USCGC Healy for its yearly Arctic voyage
  • Geosynchronous test satellites approximately 0-30° above the horizon
  • Azimuthal bearing to test satellite changes significantly based on ship heading
2017 Utqiagvik Helix Antennas

- Large Helix (low risk) fabricated from coaxial cable
- Small Helix (high risk) fabricated from flexible printed circuit board
- Designed to be easily deployed by a single user on a tripod; no aiming or complex setup required
2017 Utqiagvik Prototype Antenna Testing

- Tested in Utqiagvik/Barrow, AK, at a latitude of 71.29°
- Spectrum measured with Rhodes-Schwartz PR100
  - Average signal-to-noise ratio of +4 dB recorded for geosynchronous satellite waveform
- Data recorded with USRP E310 SDR
  - Post-processing utilized to identify specific satellites and confirm reception

Successful data collection proved out initial MITRE antenna concept
For the 2019 USCGC Healy Arctic voyage, new MITRE antenna prototypes were designed and deployed on the icebreaker

- A two-element “Cloverleaf” style antenna array was designed for optimal performance and ease of fabrication
- No matching network required, high power handling, and temperature insensitive

Two operational modes are being tested:
- Raw data collection
- Transmit and Receive mode, where a radio is used to test communications capabilities

Revised design to Cloverleaf Antenna to enable performance on harsh Arctic ocean voyage
Cloverleaf Antenna Measurement

- Performance was validated with antenna measurements
  - Gain patterns were measured over uplink and downlink bands
  - Antenna bandwidth was also measured for full array and individual antennas
Measured RHCP Gain Patterns, Elevation Cut

- Cloverleaf antennas designed to be omnidirectional with 3 dB of peak gain in free space

Good agreement between simulated and measured results
USCG Healy Platform Simulations

- Two antennas were fielded on the USCG Healy to maximize coverage
- The ship alters the gain pattern due to reflections
- Simulations were used to choose optimal antenna mounting locations
  - Statistical analysis produced the optimal combination of two antenna locations to maximize coverage

~95% horizon coverage predicted

Simulation model used to select optimal mounting locations
USCG Healy in Port at Dutch Harbor, AK
Aft and Starboard Cloverleaf Antennas Installed
USCGC Healy Results to Date

• The antenna is performing better than modeled and tested
• The data collected will be analyzed for performance and correlation of operational use
• We expect a public release report Spring 2020
Conclusions and Future Work

- MITRE is providing ongoing research to address communications challenges in the Arctic
  - First test of specialized high latitude antennas in Barrow, AK, in 2017
- For 2019, a new Cloverleaf antenna was developed to enable shipborne geosynchronous SATCOM at high-latitudes
  - Hardware was designed, fabricated, and tested
  - Currently deployed on the 2019 USCGC Healy Arctic voyage
  - Successful transmission and reception to date at high latitudes
- In 2020, we will develop recommendations and standards for high-latitude geosynchronous SATCOM antenna design
  - Transition standards to industry to facilitate commercially available antennas
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- Matt Murray and Chris Schmidt (MITRE test staff aboard USCGC Healy)
Questions?
Backup Slides
Elevation to Geosynchronous Constellation
Nearest Satellite Arctic Coverage

- MITRE T823 SATCOM modelling tool was used to compute the elevation angles to the geosync constellation from high terminal latitudes
  - North of 65° N, elevation ranges from 0° to 15°
- Line-of-Sight coverage extends as high as 78° N
  - 2015 experiment on the Healy indicated reception as far as ~83° N, indicating that Beyond Line-of-Sight propagation is also possible

Credit: Ben Babineau, MITRE T823 SATCOM Tool
Antenna Electronics with Enclosure

• Long coaxial cables are used to connect the antennas outside the ship to the test equipment inside

• Antenna electronics boxes were mounted alongside the antennas
  • Contain signal filters and amplifier in order to maximize the recorded signal quality

• Fabricated with off-the-shelf components; tested at MITRE Bedford over temperatures as low as -30° C
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