ECE4871 - Culminating Design Project

#### Evaluation Form - Technical Background Review

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/ 30 Technical Content

- Current state-of-the-art and commercial products
- Underlying technology
- Implementation of the technology
- · Overall quality of the technical summary

/ 3

#### / 30 Use of Technical Reference Sources

- Appropriate number of sources (at least six)
- Sufficient number of source types (at least four)
- · Quality of the sources
- · Appropriate citations in body of text
- Reference list in proper format

#### /40 Effectiveness of Writing, Organization, and Development of Content

- Introductory paragraph
- Clear flow of information
- Organization
- · Grammar, spelling, punctuation
- · Style, readability, audience appropriateness, conformance to standards

/ 100 Total - Technical Review Paper

# Directivity and Gain of Antennas and Applications of Parabolic Dish Antennas in Satellite Tracking and Communication

## I. Introduction

The purpose of this document is to provide a basic technical review on the current state of antenna technology centered around satellite tracking applications. In particular, the directivity and gain of parabolic dish antennas are emphasized and analyzed. In the context of ground-based satellite tracking, these two parameters are critical in being able to predict various design requirements and specifications for a given tracking system, including but not limited to: input signal variability tolerances, tracking model error tolerance, system response time, and others.

#### II. Fundamentals of Antenna Directivity and Gain

The *directivity* of an antenna can be defined as its ability to radiate in a particular direction relative to an isotropic source, which is a theoretical antenna that emits electromagnetic radiation with the same intensity in all directions [1]. The latter does not exist in practice but is widely used as the standard measuring device for quantifying the directivity of practical antennas. Antenna *gain* is directly related to directivity, in that the gain of an antenna is equal to its directivity up to a constant. This constant is the product of the dielectric and conduction losses associated with a given antenna. Furthermore, it is important to note that a physical antenna is incapable of converting 100% of the energy it receives from a power source into "information" (in the form of radiation) that can be accurately interpreted by a receiver. The quantity used to describe power losses of this kind is known as the reflection efficiency, which is used to compute what is known as *realized gain* [4]. This in unison with the fact that gain is a function of received electromagnetic power (unlike directivity from a single source, which emphasizes the directionality of transmitted radiation) demonstrates that the gain parameter takes into account realistic non-idealities associated with satellite tracking and communication.

# III. Industry Usage and Applications to Project

A variety of antennas are currently used in industry for satellite tracking. This document shall focus on a specific type known as *parabolic dish antennas*, since the primary system of interest later on will be a parabolic antenna. Parabolic antennas can be found in numerous aspects of day-to-day life, such as TV satellite dishes, cellphone communications, cellular data, and so on. At the precipice of these applications resides a fundamental minimum directivity and gain associated with these parabolic dish antennas.

According to [2], high-performance parabolic antennas maintain a high efficiency due to the geometry of the device. In particular, the component of the antenna responsible for receiving and "guiding" the data to the desired destination (otherwise known as *the reflector*) is able to operate at higher efficiencies due to the symmetric parabolic profile of the antenna [6]. Recent work done by Nagasaka, et al. [3] have demonstrated gain values (aperture efficiency) as high as 34.0 dB at 12 GHz and 38 dB at 21 GHz. Also, work done by Jablon et al. [5] demonstrated antenna gains as high as 40.5 dB at approximately 13 GHz using radar altimeter antennas, devices that are stated to be well-approximated, performance-wise, by wide dish parabolic antennas [5]. This along with constructive wave interference that occurs prior to transmission (EM waves become in phase) leads to very high directivity and high gain associated with these antennas.

In addition, as outlined in [6], parabolic antennas exist in numerous variations. One type, known as a Cassegrain antenna, is particularly efficient as a transmitting device due to the unique hyperboloid concave reflector of the structure.

Lastly, it is important to note that both the directivity and the gain of a given parabolic antenna increases as the size (usually look at diameter) of the parabolic profile increases. This is primarily due to similar effects of the antenna's physical structure that was outlined earlier. Due to the geometry-based increases in directivity and gain as well as the drop in radiated beamwidth, parabolic antennas are ideally designed for very high frequency applications in which high-frequency gain losses are prevalent.

It is fundamental for antennas utilized in satellite tracking to possess and maintain high directivities and gains in order for a designed auto-tracking system to produce models capable of meeting design specifications. For example, formulating a system that incorporates both RF design and Machine Learning algorithms to keep a grounded satellite dish locked onto a low-Earth orbit satellite would first require an antenna with a high directivity and gain. This would allow for less non-idealities to factor into the RF design process, thereby decreasing the required complexity and robustness (with respect to handling input data) of the implemented ML algorithm.

#### IV. Collaboration with VIASAT

This project is to be done in collaboration with an industry leader in antenna design, analysis, and synthesis – VIASAT. As such, the important antenna characteristics and parameters outlined in this review shall serve as an initial foundation for discussions with VIASAT moving forward.

#### V. Key Takeaways

To conclude, the numerous advantages of parabolic dish antennas in relation to satellite tracking and communication and the work collaboration with VIASAT place this research effort at the forefront of improving performance and efficiency in this area across the board. The unique characteristics and advantages of parabolic dish antennas provide a research-driven advantage within our area of interest.

## VI. References

- [1] "Antenna gain," *Antenna Gain an overview* | *ScienceDirect Topics*. [Online]. Available: https://www.sciencedirect.com/topics/engineering/antenna-gain. [Accessed: 08-Oct-2021].
- [2] E. Notes, "Parabolic reflector antenna: Dish antenna," *Electronics Notes*. [Online]. Available: https://www.electronics-notes.com/articles/antennas-propagation/parabolic-reflector-antenna/parabolic-dish-basics.php. [Accessed: 08-Oct-2021].
- [3] M. Nagasaka, S. Nakazawa and S. Tanaka, "Study on 12/21-GHz Dual-circularly Polarized Receiving Antenna for Satellite Broadcasting," 2018 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, 2018, pp. 339-340, doi: 10.1109/APUSNCURSINRSM.2018.8609229
- [4] C. Balanis, Antenna theory: Analysis and design. Hoboken, NJ: Wiley-Interscience, 2016.
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- [6] Antenna theory parabolic reflector. [Online]. Available: https://www.tutorialspoint.com/antenna\_theory/antenna\_theory\_parabolic\_reflector.htm. [Accessed: 08-Oct-2021].