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# Exploring Monopulse Feed Antennas for Low Earth Orbit Satellite Communication: Design, Advantages, and Applications

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#### **Abstract**

**AbstrAct** systems, particularly for Low Earth Orbit (LEO) satellites. In this comprehensive review, we delve into the design principles, operational advantages, and diverse applications of monopulse feed antennas in LEO satellite communication. We explore the fundamental concepts of monopulse antenna theory, the factors influencing antenna performance, and the various configurations and implementations of monopulse feed antennas. Additionally, we discuss advanced techniques, optimizations, and emerging trends in monopulse feed antenna design and deployment for LEO satellite constellations. By elucidating the intricacies of monopulse feed antennas, this review aims to provide engineers, researchers, and enthusiasts with valuable insights into maximizing the potential of these antennas for enhancing satellite communication in LEO orbits. The layout of this designed comparator has a comparator of th Monopulse feed antennas represent a crucial component in satellite communication

been implemented, and the area of the comparator is 12.3 × 15.75 . The re-**Author's e-mail:** cid.felip@unab.cl, arangu.cedomir@unab.cl, jose.ur@unab.cl, rev. andres@unab.cl

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#### and CMOS Technology. Journal of VLSI Circuits and System Vol. 1, No. 1, No. 1, 2024 (pp. 1, 2024 (pp. 1, 2024 ( **INTRODUCTION TO MONOPULSE FEED ANTENNAS**

**IntroductIon** radiation patterns for transmitting and receiving signals to and from Low Earth Orbit (LEO) satellites.<sup>[1-16]</sup> These antennas are specifically designed to track and communicate with moving satellites in LEO orbits, ensuring reliable connectivity and data transmission for various applications, including remote sensing, Earth observation, and global internet coverage. Monopulse feed antennas are a specialized type of antenna system widely used in radar and communication applications, particularly in systems requiring precise tracking and direction-finding capabilities. These antennas are designed to generate multiple beams simultaneously with specific phase relationships, allowing for accurate and reliable tracking of targets as shown in Fig. 1. Monopulse feed antennas play a critical role in satellite communication systems by providing high-gain, directional

The term "monopulse" refers to the antenna's ability to generate and process multiple beams simultaneously, enabling precise angle measurements of incoming signals. Unlike conventional antennas that produce a

 $L$  (2)  $\sim$  (1)  $\sim$  (  $\Box$  is 112.5 mV for all  $\Box$  for all  $\Box$  $\mathbf{H} = \mathbf{H} \mathbf{H} + \mathbf{H} \mathbf{H}$  and  $\mathbf{H} = \mathbf{H} \mathbf{H} + \mathbf{H} \mathbf{H}$ we examine the design and operation of a current-based, and operation of a current-based, and operation of a cu low-power comparator. In order to gain more precision and minimize, a competent offset cancellation method has between implemented. In this comparator, super low thresholders in the comparator, super low thr MOSFETs are used. In general, in a conventional MOSFET structure, the gate capacitance tends to show a higher value. For this reason, the threshold of the MOSFETs tends tends to the MOSFETs tends tends to the MOSFETs tends tends to the MOSFETS ten to be higher. One of the techniques to obtain a super low of the techniques to obtain a super low obtain a super low of the techniques of the techniqu threshold of MOSFETS is to fabricate the MOSFETS with the MOSFETS wit lower gate capacitance. As the gate capacitance is lower capacitance is lower capacitance is lower capacitance in these types of MOSFETs, the threshold voltage will reduce a lot which will give a better headroom for design,

Fig.1 :A Compact Monopulse Feed for **STRACKING ANTENNAS** 

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**ISHRAT AND AND RESIGNATION**<br> **ISHEAR.** 2: Design and development of Rx only X-band  $A^z$ **Feed with monopulse feature**

single beam, monopulse feed antennas generate multiple beams with precise phase differences, facilitating the **the motion of the motion of the motion** Monopulse Antenna determination of the direction of incoming signals. cadence,

now  $\frac{1}{2}$  and  $\frac{1}{2$ consumption of the comparator is 48.7. The layout of this designed comparator has **1. Array Geometry** One of the primary features of monopulse feed antennas arrival information. This is achieved by comparing the relative amplitudes and phases of the signals received by different elements of the antenna array. By analyzing  $\overline{\mathbf{r}}$  the phase differences between the signals, monopulse arrival of incoming signals, even in the presence of noise and interferenceas shown in Fig. 2. is their ability to provide high-accuracy angle-offeed antennas can accurately determine the angle of

systems for tracking moving targets, such as aircraft, (ULAs),  $\frac{1}{2}$ natty, monopulse feed antennas are utilized in satellite communication Monopulse feed antennas find extensive use in radar missiles, and satellites. They are also employed in communication systems for directional beamforming and beam steering applications. Additionally, monopulse systems, phased array antennas, and radio astronomy.

In summary, monopulse feed antennas play a crucial role m measure target and communication systems, sharting<br>precise tracking of targets and accurate directional pressed stating of targets and according an economic. beamforming. Their doncey to provide angle or arrival mormarism. Comparison. Comparators are widely used in various applications, ranging from military surveillance m carcele approaches, ranging romanication served and according to commercial satellite communication. commercial sacelitic communication. in modern radar and communication systems, enabling

#### **DESIGN PRINCIPLES OF MONOPULSE FEED ANTENNAS**  $\alpha$  is comparator of set voltage. The comparator is comparator is comparator in obtaining  $\alpha$

The design of monopulse feed antennas is based on the principles of antenna theory, including radiation pattern shaping, impedance matching, and feed network optimization. Key design include the antenna geometry, feedhorn configuration, radiation pattern requirements, and polarization characteristics.<sup>[17-24]</sup> Monopulse feed antennas are typically designed to provide high-gain, narrow-beam radiation patterns considerations



**Monopulse Antenna**

hing signals.<br>And resolution, and resolution, and resolution, is built on 45  $\mu$  flip CMOS and 45  $\mu$  CMOS and 45  $\mu$ with low sidelobe levels to maximize signal strength se feed antennas and minimize interference. Designing monopulse feed curacy angle-of- antennas requires careful consideration of several key y comparing the principles to achieve accurate and reliable performance  $\frac{1}{2}$  signals received to reduce the communication systems is shown in Fig. 3 signals received in radar and communication systemsas shown in Fig. 3.<br>ray By analyzing

ine the angle of  $\tau$  the geometry of the artenna array plays a crucial rol in the angle-layout simulations of the antenna array plays a crucial role presence of noise **Author's e-mail:** ishratzahanmukti16@gmail.com, **ebad.eee.cuet@gmail.com, kou-**specific geometries, such as uniform linear arrays so employed in arrays, are often used to achieve desired beam shapes al beamforming and directional properties.<br>... in determining the radiation pattern and beamforming capabilities of monopulse feed antennas. Arrays with (ULAs), uniform rectangular arrays (URAs), or planar

#### **2. Element Spacing**

affects the antenna's beamwidth, directivity, and parameter comparator resolution is 112.5 model in the desired beamwidth and resolution FIT CONVERTER WITH A 1.8V SUPPLY VOLTAGE. IN THIS WORK, IN THIS WORK, IN THIS WORK, IN THIS WORK, IN THIS WASHINGTON. we examine the design and operation. The spacing between antenna elements in the array sidelobe levels. Optimal element spacing is determined

#### **1. Phase Shifting.** In order to gain more precision of  $\theta$ and minimize, a competent of set can competent of set can competent of set can compute

Precise phase shifting of the signals between antenna elements is essential for generating multiple simultaneous beams with specific phase relationships. Phase shifters, such as analog or digital phase shifters, are used to control the phase of signals in monopulse feed antennas. The MOSFETS with the

#### **in the Tapering of MOSFETS, the three threshold voltage will be the threshold voltage will be the three three t**

Amplitude tapering, or weighting, of the signals  $\frac{1}{2}$  across the antenna array helps to shape the radiation pattern and improve the antenna's sidelobe levels .<br>and beam efficiency. Tapering techniques, such as Taylor, Dolph-Chebyshev, or Gaussian weighting, are commonly employed to achieve desired performance characteristics.

### **5. Feed Network Design**

The design of the feed network, including the distribution of power and phase to individual antenna elements, is critical for achieving uniform radiation patterns and beamforming capabilities. Careful attention must be paid to impedance matching, signal distribution, and power handling capabilities of the feed network components.

#### **16. Polarization a high-speed operation operation operation operation operation operation operation operation**

to gain a lower static & dynamic power dissipation and a The polarizatio0n of the antenna elements and the transmitted signals must be carefully matched to the polarization of the incoming signals for optimal performance in radar and communication systemsas shown in Fig. 4.

By carefully considering these design principles, engineers can optimize the performance of monopulse feed antennas to meet the specific requirements of their intended applications, ensuring accurate and reliable tracking and direction-finding capabilities. comparator with high accuracy and low offset. The comparator with  $\sim$ 

#### **OPERATIONAL ADVANTAGES OF MONOPULSE FEED ANTENNAS**

Monopulse feed antennas offer several operational advantages for LEO satellite communication systems, **ArchItecture of compArAtor** including:

provide high-gain, directional radiation patterns, enabling efficient communication with LEO satellites over long distances.<sup>[25-28]</sup> The narrow beamwidth and 1 depicts the block diagram of the proposed comparator. High Gain and Directivity: Monopulse feed antennas



Fig. 4: Monopulse radar



**Fig. 5: The More Feedhorns The Better** digital output in the comparator. We know the comparator.

a very high gain. We make the OTA stage by connecting high directivity of monopulse antennas facilitate precise satellite tracking and signal reception, even in challenging propagation conditions. High gain and directivity are essential characteristics of antennas, particularly in applications requiring longrange communication, precise signal focusing, and efficient use of transmitted poweras shown in Fig. 5.

High gain refers to the ability of an antenna to concentrate its radiated power in a specific direction, resulting in increased signal strength and coverage in that direction. Antennas with high gain are capable of transmitting or receiving signals over longer distances compared to antennas with lower gain. Gain is typically measured in decibels (dB) and is calculated as the ratio of the power radiated in a specific direction to the power radiated by an isotropic radiator (i.e., a theoretical antenna radiating equally in all directions).

Directivity, on the other hand, refers to the concentration of radiated power in a particular direction relative to an isotropic radiator. It quantifies the ability of an antenna to focus its radiation pattern in a specific direction. Directivity is also expressed in decibels and is calculated as the ratio of the radiation intensity in the direction of interest to the average radiation intensity over all directions.

Both high gain and directivity are desirable characteristics in antennas for applications such as long-distance communication, radar systems, satellite communication, and point-to-point links, where maximizing signal strength and focusing transmission/ reception in specific directions are critical for reliable and efficient operation.

allowing them to accurately track moving satellites Fig. 4: Monopulse radar **Fig. 4: Monopulse radar** across the sky. The monopulse tracking technique Tracking and Pointing Accuracy: Monopulse feed antennas feature inherent tracking capabilities,

enables continuous tracking of satellite position and orientation, ensuring reliable communication and data transmission during satellite passes. Tracking and pointing accuracy are critical aspects of antenna systems, particularly in applications such as radar, satellite communication, and tracking systems, where precise positioning of the antenna is essential for accurate signal acquisition, tracking, and communication.

Islaming accurately follow a moving target or maintain and one common approach *1-3Dept. of EEE, Independent University, Bangladesh, Dhaka, Bangladesh* alignment with a stationary target. This is crucial satellites, where the antenna must continuously adjust such as the spectrum agincy of the antenna positioning and the outlined of suppress signals based on their system, the responsiveness of tracking algorithms, and a spatial characteristics. **KEYWORDS:**  for applications such as radar tracking of aircraft or its position to maintain a clear line of sight with the target. The accuracy of tracking is determined by factors such as the speed and agility of the antenna positioning Tracking accuracy refers to the ability of an antenna the stability of the antenna platform.

communication, where the antenna must precisely **being the solutane of the state of temperature of the state of** point towards a satellite in orbit to establish a reliable ractors sach as the precision of the antenna positioning and inacting<br>mechanism, the accuracy of pointing control algorithms, incomin including the mechanical structure, positioning **IntroductIon** Additionally, factors such as environmental conditions, also play a crucial role in ensuring accurate tracking and  $s_{\rm min}$  and input and input analog signal with a reference signal with a reference signal,  $s_{\rm min}$ Pointing accuracy, on the other hand, refers to the ability of an antenna system to accurately direct its beam towards a specific target or location in space. This is essential for applications such as satellite communication link. Pointing accuracy is influenced by factors such as the precision of the antenna positioning and the stability of the antenna structure [29]-[34]. Achieving high tracking and pointing accuracy requires careful design and optimization of the antenna system, mechanism, control algorithms, and feedback systems. antenna calibration, and signal processing techniques pointing.

Tracking and pointing accuracy are fundamental requirements for antenna systems in a wide range of applications. By optimizing the design and implementation of the antenna system and employing advanced tracking and pointing techniques, engineers can achieve precise and reliable performance, enabling the successful operation of radar, communication, and tracking systems in diverse environments and conditions.

**\*** Interference Rejection: Monopulse feed antennas exhibit superior interference rejection characteristics, minimizing the effects of co-channel 1/2 LSB. When the reference voltage and supply voltage are interference and adjacent satellite interference. Interactive called a system calculate interactives.<br>The narrow beamwidth and high sidelobe suppression of monopulse antennas reduce the impact of

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enables continuous tracking of satellite position external sources of electromagnetic interference, racking and pointing accuracy are critical aspects in antenna systems, particularly in environments<br>f antenna systems, particularly in applications in where electromagnetic interference (EMI) and noise satellite communication, and tracking<br>
can degrade signal quality and compromise system<br>
re precise positioning of the antenna Implemented in 45 percentual terms of the antenna<br>In ability of an antenna system to suppress or mitigate<br>In the suppress or mitigate enhancing communication reliability and signal quality. Interference rejection is a critical capability where electromagnetic interference (EMI) and noise performance. Interference rejection refers to the unwanted signals and noise while maintaining sensitivity to desired signals.

> If sight with the comparachieved using techniques such as beamforming, mined by factors and steering, and adaptive array processing, which enna positioning selectively enhance or suppress signals based on their can operate on a nominal supply of 1.8 V. The comparator of 1.8 V. The comparator of  $\alpha$ One common approach to interference rejection is spatial filtering, where the antenna system is designed to suppress signals arriving from specific directions or angles associated with interference sources. This can spatial characteristics.

> ecompensate for the offset voltage, we found a decent voltage and vol andered approach to interference rejection involve I, letels to the frequency filtering, where the antenna system is  $r$  at  $r$  and  $r$ ratety direct its equipped with filters or frequency-selective elements  $\epsilon$ duon in space.  $\epsilon$  that attenuate interference signals at specific frequencies ich as satellite the passing desired signals relatively unaffected.

> is influenced by such as digital signal processing (DSP) algorithms and **How to cite this article: Mukti IZ, Khan ER, Biswas KK**. 1.8-V Low Power, High-Res-desired signals and interference. These algorithms can ccuracy requires adaptively adjust the antenna system's parameters to antenna system, minimize interference while maximizing signal-to-noise Additionally, advanced signal processing techniques, machine learning algorithms, can be employed to analyze incoming signals in real-time and distinguish between ratio.

> > Overall, interference rejection techniques play a crucial systems in challenging electromagnetic environments. By effectively rejecting interference, antenna systems can maintain signal integrity, improve system performance, and enhance overall reliability in various applications, including communication, radar, navigation, and sensing .<sup>[35-43]</sup> role in ensuring the reliable operation of antenna

#### **Types and Configurations of Monopulse Feed Antennas**

Monopulse feed antennas are available in various types and configurations to suit different LEO satellite communication requirements. Common types of monopulse feed antennas include:

**\*** Cassegrain Antennas: Cassegrain antennas consist duce given reflector and a sub-reflector of a parabolic main reflector and a sub-reflector positioned in front of the main reflector. The monopulse feed is typically located at the focal point of the rece is cypready to<br>cated at the recent point of the main reflector, providing high-gain, narrow-beam radiation patterns with excellent pointing accuracy and tracking performance. Cassegrain antennas are a type of reflector antenna commonly used me communication and radar systems mision manipulated. are essential. The Cassegrain antenna consists of a primary parabolic reflector and a secondary subreflector, arranged in a specific configuration to achieve the desired radiation pattern.<sup>[44-48]</sup> in communication and radar systems where high

In a Cassegrain antenna, the primary reflector is a mediated on international parabolic dish that focuses incoming electromagnetic parameter and that desired increasing eterming. But the secondary three-state in them power, where the secondary subreflector end concrete the presence of the content of power discrete. reflector, redirecting them in the desired direction. traditional comparator to the latched and hysteresis-By carefully adjusting the size and positioning of the based comparator. The designing the designing of the secondary subreflector, Cassegrain antennas can achieve precise beam control and high gain. realized in a 22nm FDS of a 22nm FDS of process with a 0.8V supply. The 0.8V supply. T

One of the main advantages of Cassegrain antennas is their compact design, which allows for efficient use of space and easy integration into various systems. Additionally, Cassegrain antennas offer excellent efficiency and low sidelobe levels, making them wellsuited for applications requiring high-quality signal transmission and receptionas shown in Fig. 6.

voltage, high resolution, and low power performance of the Cassegrain antennas find wide applications in satellite communication, radio astronomy, radar systems, and and compact size are highly valued. Overall, Cassegrain ancernial represent a versatile and enecenve solution for achieving high-performance communication and radar systems in a wide range of applications. wireless networks, where their high gain, beam control, antennas represent a versatile and effective solution for

• Gregorian Antennas: Gregorian antennas feature a concave main reflector and a convex sub-reflector, arranged in a dual-reflector configuration. The monopulse feed is placed at the focal point of the main reflector, enabling precise beam shaping and



**Fig. 1:** Block diagram of the suggested Comparator **Monopulse FeedFig. 6: Design of a Compact Multielement** 

**A. Operational Transconductance Amplifier** tracking capabilities for LEO satellite communication. Gregorian antennas are a type of reflector antenna commonly used in satellite communication and radio astronomy applications due to their high gain, low  $\frac{a}{b}$  and  $\frac{b}{c}$  different different control. Named after the French mathematician and astronomer Albert Gregorian, these antennas consist of a primary parabolic reflector and a secondary hyperbolic<br>Conventional of voltage. reflector, arranged in a specific configuration to sidelobe levels, and excellent beam control. Named achieve optimal performance.

In a Gregorian antenna, the primary reflector is a .<br>waves onto a focal point. The secondary reflector, which is hyperbolic in shape, is positioned at a specific distance behind the primary reflector and directs the focused waves towards the feed horn or receiver. By carefully parabolic dish that focuses incoming electromagnetic designing the shapes and positions of the primary and secondary reflectors, Gregorian antennas can achieve precise beam control and high gain.

One of the main advantages of Gregorian antennas is their ability to achieve extremely low sidelobe levels, which reduces interference and improves signal quality in communication and radio astronomy applications. Additionally, Gregorian antennas offer excellent efficiency and can operate over a wide range of frequencies, making them well-suited for various satellite communication and radio astronomy missions.

in a wide range of applications. Overall, Gregorian antennas represent a versatile and effective solution for achieving high-performance communication and radio astronomy systems, providing reliable and efficient signal transmission and reception

Comparator • Shaped-Beam Antennas: Shaped-beam antennas utilize advanced beamforming techniques to shape the radiation pattern according to the coverage requirements of LEO satellite constellations. The monopulse feed is integrated with beamforming networks and phased array elements to steer the beam electronically and adaptively track multiple satellites simultaneously. Shaped-beam antennas are specialized antenna systems designed to produce radiation patterns with specific shapes or characteristics tailored to the requirements of particular applications. Unlike traditional antennas with omnidirectional or directional radiation patterns, shaped-beam antennas generate beams that are customized to cover specific areas or volumes of interest.

One common application of shaped-beam antennas is in satellite communication systems, where coverage Felip Cide, et al. : Exploring Monopulse Feed Antennas for Low Earth Orbit Satellite Communication: Design Advantages, and Applications

required. By shaping the radiation pattern to match the footprint of the satellite's coverage area on the Earth's signals to designated locations with minimal interference and wasted power.

Shaped-beam antennas are also used in radar systems for  $\begin{bmatrix} \text{Sine} \\ \text{Sine} \\ \text{Sine} \end{bmatrix}$  and reconnaissance applications. Interest, such as moving angles of regions of potential  $\Delta_{\text{ulto-tracking}}$ *i* and improve overall system performance. surveillance, tracking, and reconnaissance applications. By shaping the radar beam to focus on specific areas of interest, such as moving targets or regions of potential

**Rigning shaped-beam antennas involves d** ding reduction, pactern endrocerristics to define the desired comparator is desired coverage and performance objectives. Advanced electronically steerable antennas, are often employed was electronically technique to implement shaped-beam capabilities and enable Designing shaped-beam antennas involves careful optimization of the antenna's geometry, feed system, antenna technologies, such as phased array antennas and dynamic beam shaping and steering.

a wide range of applications in aerospace, defense, Overall, shaped-beam antennas play a vital role in modern **DOI:** customized coverage and improved performance for communication, radar, and sensing systems, providing telecommunications, and beyond.

#### **SATELLY ADVANCEMENTS AND OPTIMIZATION TECHNIQUES**

and optimization have led to improved performance, Recent advancements in monopulse feed antenna design efficiency, and reliability. These include:

- **IntroductIon** feeds, and multiband feeds, enhance the efficiency and bandwidth of monopulse feed antennas. These feedhorn designs optimize the coupling efficiency between the feed and the main reflector, improving antenna gain and radiation characteristics. Advanced Feedhorn Designs: Innovations in feedhorn design, such as corrugated horns, scalar
- **\*** Feed Network Optimization: Optimization of the feed network, including feed phase shifters, power consumer consumer consumer and reduced noise in the reduced noise level and reduced noise level and reduced noise level and reduced noise and re couplers, and hybrid junctions, enhances the<br>comparator is completed in obtaining of pearmorning capabilities and tracking accuracy of monopulse feed antennas. Advanced feed network monoparator is a suite using comparator which which is made using CMOS technology, which is a substantial of the comparator of the c architectures enable adaptive beam steering,<br>architectures enable adaptive beam steering, potarization diversity, and interretence interaction for LEO satellite communication systemsas shown in  $\overline{E}$ .  $\mathbf{c}_1$  is accuracy shown accuracy show beamforming capabilities and tracking accuracy of polarization diversity, and interference mitigation Fig. 7.
- **100 Compact Antenna Solutions: Developments in compact** antenna solutions, such as microstrip arrays, planar waveguides, and printed circuit antennas, enable



#### ray antennas and **Fig. 7: Target tracking architecture of monopulse technique**

miniaturization and integration of monopulsefeed The designed comparation and the designed comparation of the designed comparation of  $\alpha$ . tal role in modern **antennas** into small satellite platforms and CubeSat consumption of the compact antenna designs offer lightweight,<br>stems providing beens, providing low-profile solutions for space-constrained applications reformance for performance for in LEO satellite constellations.

#### **Author's e-mail:** ishratzahanmukti16@gmail.com, **ebad.eee.cuet@gmail.com, kou-Applications of Monopulse Feed Antennas in LEO SATELLITE COMMUNICATION**

d antenna design LEO satellite communication systems, including: Monopulse feed antennas find diverse applications in

- extempt of VLSI Christian of Circuits and System Vol. 2023, No. 1, 2021 (pp. 1, 2021) and System Vol. 2021, 20 applications. These antennas provide high-resolution links for capturing and transmitting Earth imagery and environmental data. used in Earth observation satellites for imaging, remote sensing, and environmental monitoring data transmission and real-time communication
	- Telecommunication: Monopulse feed antennas serve as the backbone of LEO satellite constellations for global internet coverage and broadband communication services. These antennas provide high-speed data links and seamless connectivity for terrestrial users, aircraft, ships, and remote communities in underserved regions.<sup>[49]</sup>
	- \* Scientific Research: Monopulse feed antennas support scientific research missions in astronomy, astrophysics, and space exploration. These antennas enable communication with scientific payloads, telescopes, and instruments aboard LEO satellites, facilitating data collection, telemetry, and command saturations. Subsequently doing that the length  $\sim$

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• Navigation and Positioning: Monopulse feed antennas play a crucial role in satellite navigation and positioning systems, such as GPS (Global Positioning **related related** *related related related***</del> <b>***related related related***</del> <b>***related related related related related***</del> <b>***related related related related related related* and timing signals for terrestrial receivers, enabling accurate positioning, navigation, and timing synchronization worldwide. System) and GNSS (Global Navigation Satellite

#### Future Directions and Emerging Trends

Emerging trends and future directions in monopulse feed antenna research and development include:  $\tau_{\rm eff}$  comparation  $\tau_{\rm eff}$  comparation with a high-speed operation  $\tau_{\rm eff}$ 

- **\*** Millimeter-Wave Communication: Exploration of millimeter-wave frequencies for LEO satellite communication offers higher data rates, wider bandwidth, and reduced latency for next-generation satellite networks. Monopulse feed antennas are being developed for millimeter-wave communication bands to support future LEO satellite constellations and space-based services.
- **Quantum Communication:** Integration of quantum a cancellation technique involving dynamic latches.[6] communication technologies, such as quantum communication commodists, such as quantum into LEO satellite communication systems enables med LED satellite communication systems chaptes<br>secure, ultra-fast data transmission and encryption. voltage, high resolution, and low power performance of the Monopulse feed antennas play a role in quantum monoparse recommendial play a rote in quantum desired that can be used to commit<br>quantum networking experiments.
- **ArchItecture of compArAtor** Z **Inter-Satellite Links:** Advancements in intersatellite communication (ISC) technologies enable direct communication between LEO satellites within a constellation, bypassing ground-based infrastructure. Monopulse feed antennas with electronically steerable beams support ISC linksfor scanness data and satellite coordinationas shown in Fig. 8. seamless data exchange, constellation management,



**Ground-Station Satellite Tracking Applications Fig. 8: Compact Multielement Monopulse Feed for**  **•** Artificial Intelligence (AI) and Machine Learning: Integration of AI and machine learning algorithms into monopulse feed antenna systems.  $I$ trialites autonomous operation, auaptive amplifiers in which differential inputs are present. The beamforming, and predictive maintenance. primary distinction distinction between  $\epsilon$ antenna performance, mitigate interference, and optimize resource allocation in dynamic satellite communication environments. enables autonomous operation, adaptive AI-driven optimization techniques enhance

#### **CONCLUSION**

 $\mathbf{r} = \mathbf{r} \cdot \mathbf{r}$ satellite communication systems, providing highgain, directional radiation patterns for tracking and communicating with moving satellites. By understanding the design principles, operational advantages, and Monopulse feed antennas play a pivotal role in LEO emerging trends in monopulse feed antenna technology, engineers and researchers can leverage the potential of these antennas to enhance satellite communication in LEO orbits. Continued research and innovation in monopulse feed antenna design, optimization, and integration will drive advancements in LEO satellite constellations, enabling global connectivity, spacebased services, and scientific exploration. Through collaborative efforts and interdisciplinary approaches, monopulse feed antennas will continue to shape the future of satellite communication and space-based applications in the LEO environment.

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