PLAYBOOK

LEO Satellites: Driving the Future of SATCOM

THE SATELLITE COMMUNICATIONS (SATCOM) INDUSTRY IS EXPERIENCING RAPID GROWTH.

Overview

The SATCOM industry is experiencing rapid growth, driven by advancements in low Earth orbit (LEO) satellite technology and the increasing demand for low-latency, high-speed connectivity. With LEO constellations expected to make up 70% of the commercial satellite market by 2029, this shift presents significant opportunities for innovation across telecommunications, Internet of Things (IoT), defense and disaster recovery.

Key enablers of this transformation include active electronically scanned array (AESA) antennas and beamforming technologies, which enhance performance, agility and reliability. These systems enable seamless communication across various orbits, supporting high-speed data transmission and global coverage. Additionally, the emergence of non-terrestrial networks (NTNs) is extending connectivity to remote and underserved areas. Enabled by 3GPP Release 17 and upcoming enhancements in Release 18, NTNs support applications such as direct-to-smartphone connectivity, real-time IoT communications and emergency response.

As SATCOM technologies continue to evolve, they will play a critical role in next-generation wireless networks. Qorvo's SATCOM portfolio is positioned to meet these demands, offering scalable RF solutions that enhance connectivity for both terrestrial and space-based applications.

The LEO satellite market is skyrocketing, with projections showing it will soar from $12.6 billion in 2024 to an impressive $23.2 billion by 2029. This rapid growth, at a CAGR of 13.0%, reflects surging demand for next-generation connectivity and the race to revolutionize global communication networks.[1]

SATCOM Market Drivers

Large investments in new communications satellite constellations are driving the demand for new technologies at lower price points and more capabilities. In addition to new technologies, the growth in satellite deployments is driving the need for more power efficient, compact and reliable components used throughout the signal chain, from RF power amplifiers to low-noise amplifiers to beamforming ICs.

There are a wide range of SATCOM applications across a variety of market segments. Often these terminals have varying requirements depending on the constellation(s) on which they operate and the markets in which they address.

The four major markets include **consumer, commercial mobility, enterprise and government**. Many requirements overlap in these markets, including performance requirements, size, weight, power draw, throughput performance, cost and ruggedness. Generally, the consumer market has the least overlap as their requirements are the most unique, with very limited viability outside their intended market.

The other three markets have more significant overlap in requirements with ruggedness being a key differentiator from consumer applications. With this typically comes higher prices, ability to sustain higher power draw and often the demand for higher throughput performance. Although many requirements overlap, each market has its own unique class set of criteria as shown in Figure 1 on page 4.

THE FUTURE HAS NEVER LOOKED BRIGHTER FOR SATELLITE OPERATORS

given the record-setting number of satellite launches in recent years, the growing number of satellite-based applications and the huge capital investments being made in a host of planned space ventures.

[1] Markets and Markets LEO Satellite Market Report, May 2024.

FOUR MAJOR MARKETS OF SATCOM USER TERMINALS:

1. **Consumer:** Home internet users, vehicle and private maritime users.
2. **Enterprise:** Data centers, mid-to-large businesses and satellite-to-ground teleports.
3. **Government:** Aviation, ground mobile, maritime and ground transportable.
4. **Commercial Mobility:** Agriculture, construction, mining, maritime, aviation and ground transport.

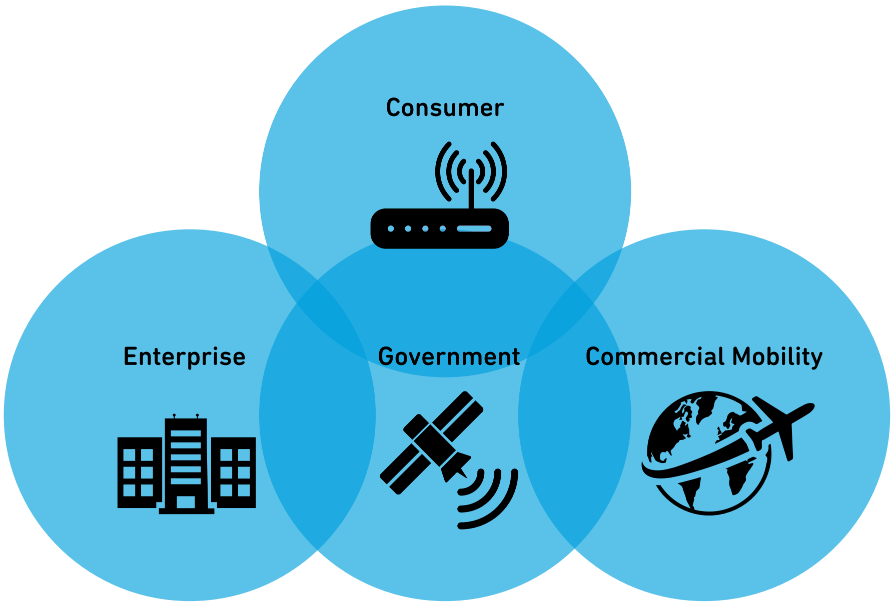


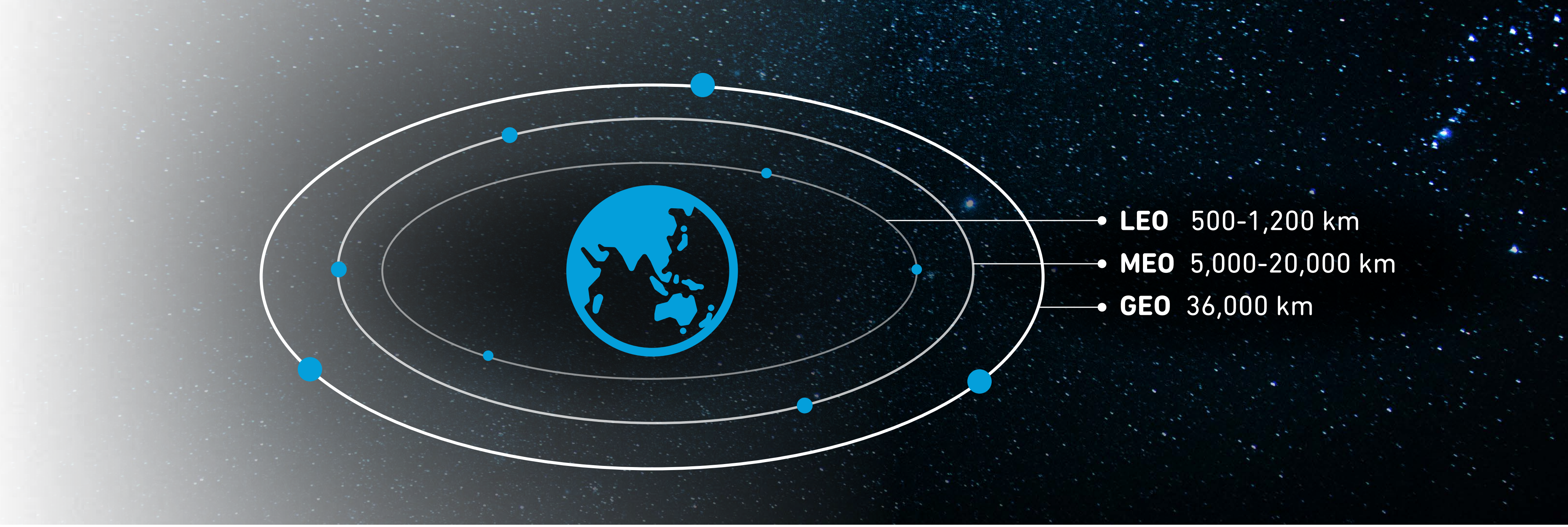
Figure 1: Primary markets have overlapping requirements for terminals dominated by enterprise, government and commercial mobility with consumer terminals nearly standing on their own.

The constellation(s) with which the systems operate can also drive required performance capabilities and requirements. Orbits can be divided into two categories: traditional geostationary Earth orbit (GEO) and non-geostationary orbit (NGSO). NGSO includes low Earth orbit (LEO), medium Earth orbit (MEO) and highly elliptical orbit (HEO), all of which bring unique terminal performance requirements.

The LEO mega-constellations are projected to provide **100x increase in bandwidth** from the legacy GEO satellites with reduced latency by 10x, while serving significantly more users.

MEO satellites also provide lower latency, higher throughputs and service more users than GEO, but with less global footprint than LEO. HEO satellites are being used to fill the "gaps" in GEO and MEO systems, providing higher latitude and polar coverage.

MEO satellites, like GPS, are commonly used for navigation. MEO satellites have their advantages, but like GEO satellites, they do have high launch and maintenance costs. Both GEO and MEO satellites serve a purpose, but they come at the cost of latency and data speeds. Figure 2 on page 5 describes the coverage areas for each of the satellite types.



Parameter	LEO: 500-1,200 km	MEO: 5,000-20,000 km	GEO: 36,000 km
Altitude	Very low	Low	High
Earth Coverage	Small	Large	Very large
Satellites Required	Thousands	Six	Three
Data Gateways	Local numerous	Regional flexible	Few fixed
Antenna Speed	10-minute fast tracking	1-hour slow tracking	Stationary

Figure 2: LEO, GEO, MEO satellite coverage areas. LEO satellites have ushered in a new era of global connectivity and data accessibility.

LEO satellites offer distinct advantages over their geostationary and medium Earth orbit counterparts. They provide low-latency (30 times more responsive than GEO) and high-speed internet connectivity to remote and underserved regions of Earth. LEO satellites require hundreds to thousands of units to cover the Earth's surface, enabling a cross-linked mesh network. This mesh networking not only improves global coverage but also improves connection reliability – for example, if one satellite goes offline, another one can step in to support any signal loss. Currently, most LEO satellite deployments are driven by private companies and government agencies. Companies like SpaceX, OneWeb, Amazon's Project Kuiper and Telesat have invested heavily in LEO satellite deployment. This has ushered in a new era of global connectivity and data accessibility.

SATCOM ORBITS DEFINED

- **GEO:** 35,786 km above Earth. Application connection:
  - Telecommunication, broadcasting, weather forecasting, remote sensing, navigation.
- **MEO:** 5,000-20,000 km above Earth. Application connection:
  - Telecommunication, GPS and other navigation applications.
- **LEO:** 500-1,500 km above Earth. Application connection:
  - Latency critical applications, financial transactions, autonomous vehicles, remote video surgery.

Satellites play a big role in connecting the world. As shown in Figure 3, they do two main things: talk directly to Earth supporting multiple end user terminals across various industries and backhaul that data to Earth either directly or through inter-satellite links (ISLs). With more LEO satellites being launched, communication is getting even faster and covers more area, making it easier to send information from space to Earth with less delay.

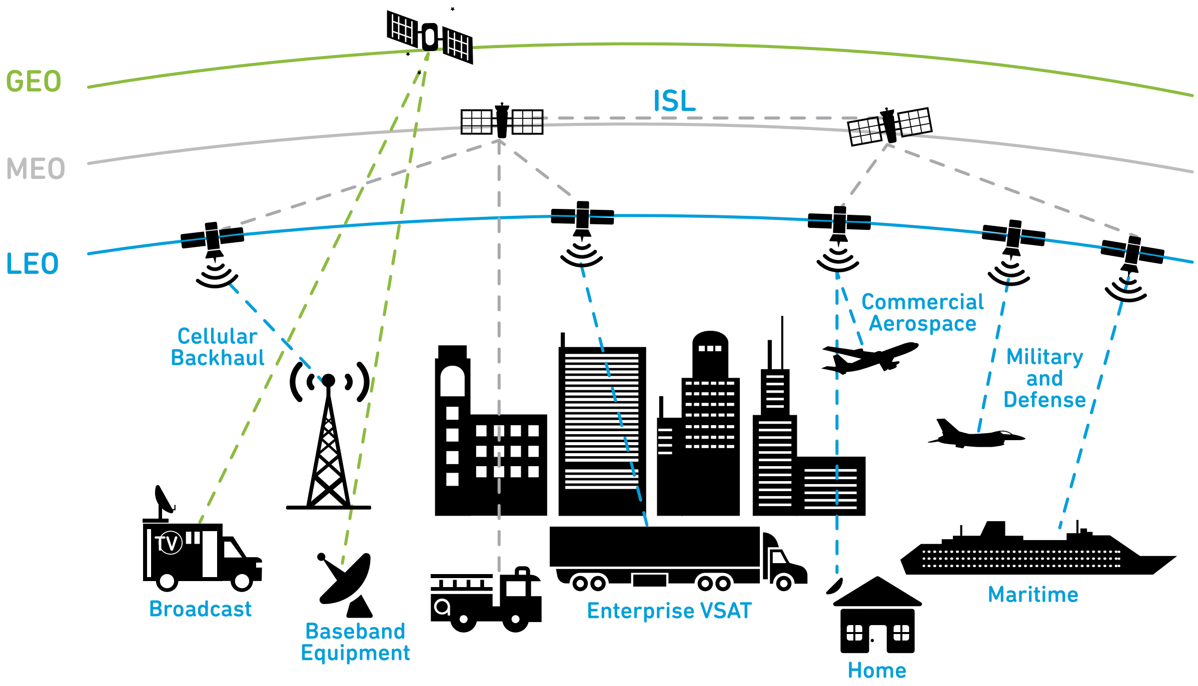


Figure 3: Satellite networks, including terrestrial ISL. The LEO mega-constellations are projected to provide 100x increase in bandwidth from the legacy GEO satellites with reduced latency by 10x, while serving significantly more users.

Looking at the top 4 LEO constellations in consideration today, Amazon (Project Kuiper), Eutelsat OneWeb, Starlink and Telesat, together, they plan for a combined total of over 30,000 satellites when the constellations are fully deployed. The aggregate data capacity of these constellations is staggering, especially compared to the current capabilities of the GEO satellites. As of March 2025, 8,712 communications satellites were in orbit, an increase of over 200% since December 2020, dominated by the LEO launches of OneWeb and Starlink.

A comparison of the constellation sizes is shown in Table 1. This massive growth in capacity combined with a growing demand in the government and commercial mobility markets is leading to a 6-12% CAGR of growth through 2030. In 2021, the market was $3,877 million and is projected to be over $6,000 million by 2028[2]. This demand and growth mean great opportunities for terminal manufacturers who can develop, manufacture and certify terminals at a reasonable price.

System	GEO	Kuiper	OneWeb	Starlink	Telsat
Frequency	Ku & Ka	Ka	Ku	Ku	Ka
Number of Satellites in Orbit	563	2	660	8,050	0
Number of Planned Satellites	700 by 2030 (~15-20 per year)	3,232	7,088	20,000	300
Altitude (km)	35,786	590-630	1200	540-570	1,015-1,320
Latency (ms)	560	~30	~40	~30	~40-50
Satellite Life (Years)	–	7	~5	5-7	10-12
Capacity at Full Plan	3 Tbs	~30-32 Tbs	~50 Tbs (~7.5 Gbps/Sat)	~75 Tbs (~17 Gbps/Sat)	~12 Tbs (~20-50 Gbps/Sat)
Target Markets	Consumer, Enterprise, Mobility, Gov	Consumer, Enterprise, Mobility, Gov	Enterprise, Mobility, Gov	Consumer, Enterprise, Mobility, Gov	Consumer, Enterprise, Mobility, Gov

Table 1: Top 4 LEO Satellite Constellations.[3]

[2] Market Research.com Satellite Communication Terminal Market Forecast to 2028, January 2022.

[3] Jonathan McDowell, astronomer at the Harvard-Smithsonian Center for Astrophysics and leading watcher of most things orbital. March 8, 2025.

Frequency Spectrums for Satellite Communications

Most satellite deployments are L to Ka-band. However, there are more modern satellites moving toward higher frequency bands like Q/V and E spectrums, as shown in Table 2. To serve 5G non-terrestrial network application, 3GPP also allocated NTN bands. Table 3 shows both the current NTN bands in L&S band as well as the newly proposed bands in the K and Ka band.

SATCOM Frequency Band	Downlink Frequency GHz	Downlink Bandwidth GHz	Uplink Frequency GHz	Uplink Bandwidth GHz	Description
L-Band	1.535-1.56	0.025	1.635-1.66	0.025	Provides real-time visibility to monitoring the status of equipment for a remote location and machine-to-machine communications
S-Band	2.5-2.54	0.04	2.65-2.69	0.04	Used for weather radar, surface ship radar and NASA communications, satellite television, mobile broadband services, radio broadcasting and inflight connectivity
C-Band	3.4-4.2	0.8	5.8-6.725	0.925	Provides voice and data transmissions from ship to shore
X-Band	7.25-7.75	0.5	7.9-8.4	0.5	Used for SATCOM, military SATCOM and radar applications
Ku-Band	10-13	3	14-18	4	Used for SATCOM, fixed satellite services and broadcast satellite services
Ka-Band	17.7-21.2	3.5	27.5-31	3.5	Used for SATCOM, military SATCOM, 5G telecommunications
Q/V-Band	37.5-42.5	5	42.5-51.4	8.9	Used for voice, data and video communications
E-Band	71-76	6	81-86	5	Provides very high throughout satellite communications

Table 2: Allocated frequency spectrum for SATCOM communications.

NTN Bands

NR Operating Band	Uplink Operating Band Base Station Receive User Equipment Transmit	Downlink Operating Band Base Station Transmit User Equipment Receive	Duplex Mode	Region	Nicknames
	FDL_low-FDL_high	FDL_low-FDL_high			
n255	1626 MHz-1660.5 MHz	1525 MHz-1559 MHz	FDD	All	MSS L-Band
n256	1980 MHz-2010 MHz	2170 MHz-2200 MHz	FDD	All	MSS S-Band

Proposed 3GPP NTN FR2-1 for K-Band and KA-Band (VSAT)

NR Operating Band	Uplink Operating Band Base Station Receive User Equipment Transmit	Downlink Operating Band Base Station Transmit User Equipment Receive	Duplex Mode	Region	Nicknames
	FDL_low-FDL_high	FDL_low-FDL_high			
n510	17.7 GHz-20.2 GHz	27.5 GHz-28.35 GHz	FDD	All	MSS K & Ka-Band
n511	17.7 GHz-20.2 GHz	28.35 GHz-30 GHz	FDD	All	MSS K & Ka-Band
n512	17.7 GHz-20.2 GHz	27.5 GHz-30 GHz	FDD	All	MSS K & Ka-Band

Table 3: Current and proposed NTN bands.

The Integration of Satellites in the 5G Network

There's a growing adoption globally of broadband internet services offered by large LEO satellite constellations. This interest, along with the integration of satellite networks into the 5G ecosystem, is further propelling satellite market growth.

Moreover, cellular communications are becoming part of the satellite ecosystem. The introduction of 3GPP 5G wireless technology in Release 17[4] has made it possible to adapt 5G systems for NTNs. NTNs aim to expand network coverage worldwide, especially in rural and remote areas, and facilitate direct connections between mobile devices, the IoT and commercial autonomous vehicles to satellites. This integration enables the satellite industry to leverage the 5G ecosystem's economy of scale.

The 3GPP Release 17 specified both 5G new radio (NR) NTN and 4G IoT NTN, as described in Figure 4. It focuses on utilizing satellite transparent payload architecture and User Equipment (UE) with GNSS capabilities. Figure 4 shows the expected use cases for 5G NTN.

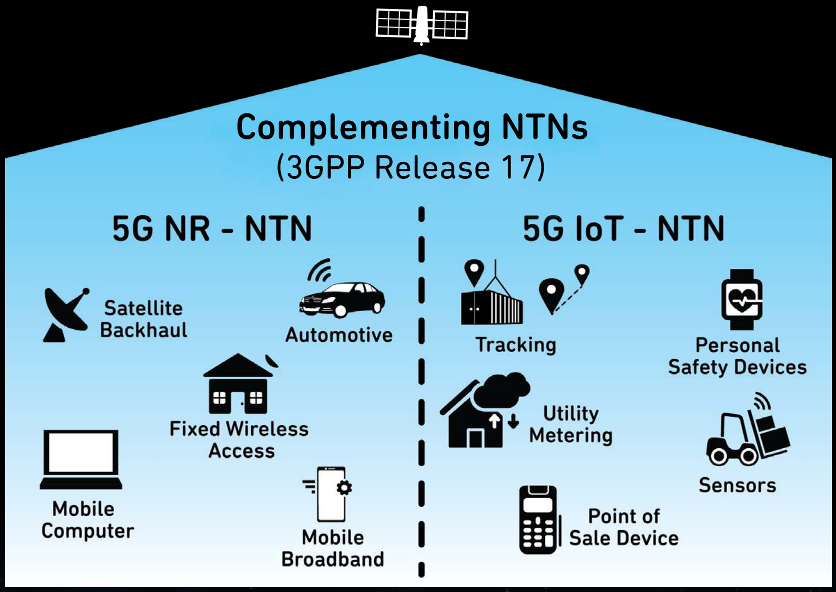


Figure 4: NTN 5G NR and IoT use cases that complement each other.

Additional 5G NTN uses include:

- Under-covered areas such as agriculture, mining and forestry.
- Disaster communications when land communication networks are damaged.
- Broadcasting information over a very wide area.

[4] 3GPP Release 17

Advancing Communication: The Role of LEO Satellites in the Wireless Expansion

In the previous section, we explored the many aspects of the satellite marketplace and began to touch upon the impact it's having on 5G NR cellular and IoT networks. In this section we dig a bit more into this convergence of satellite mesh with NTNs and how they are changing the communication landscape of tomorrow.

NTN satellites function as relays to extend wireless coverage and capacity of terrestrial networks. These networks provide communication services for emergencies, disasters and other services such as IoT network devices. Moreover, companies are offering agreements to add satellite connectivity to the latest high-end smartphones. Enabling global two-way emergency messaging, low-cost internet services to remote locations, remote texting and other phone-based communications, all powered by LEO satellite networks.

Moreover, the 3GPP's Release 17 adds new 5G satellite network uses, covering GEO, MEO and LEO satellite technologies. The 5G NTN NR satellite network includes two communication links – one between the satellite and users and the other between the satellite and the ground station connected to the data network on Earth. It will provide both NTN-IoT and 5G NR communications – linking smartphones and other 5G enabled devices to the NTN service network.

Advancements in 5G NR NTN and Satellite Technology

As shown in Figure 5 below, GEO satellites, positioned at 35,000 km above the Earth, have a latency of 280 milliseconds (ms), whereas LEO satellites, orbiting at altitudes between 500 to 1,200 km, can reduce latency to just 6 to 30 ms. Therefore, the maximum one-way propagation delays from UE to LEO satellites have a much shorter delay than their MEO and GEO counterparts.

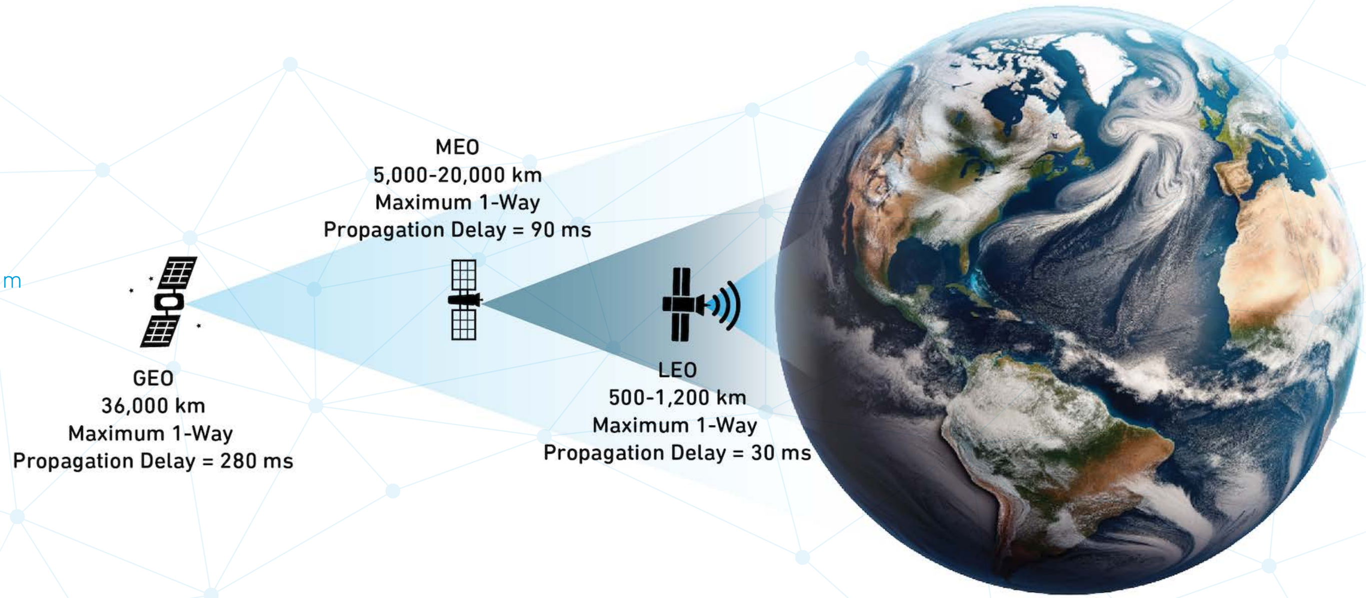


Figure 5: 3GPP-TS 22.261 maximum one-way propagation delays from UE to satellite comparison.

The 5G NR NTN architecture, incorporating satellite technology, promises global cellular wireless connectivity. The 3GPP Release 17 focuses on enhancing 5G NTN and IoT NTN services worldwide, it also introduces low latency direct-to-cellular services, improving speeds to tens of Mbps in the sub-6 GHz band.

Additionally, Release 18 aims to improve coverage and mobility by using frequencies above 10 GHz, specifically the Ku and Ka bands. This allows speeds of hundreds of Mbps, benefiting smaller AESA antennas, such as those used by SpaceX's Starlink. These advancements boost speeds, support disaster recovery efforts and extend coverage to remote areas previously unreachable by traditional networks.

As discussed in the previous section, detailed in table 3, the evolution of 5G NTN under 3GPP standards involves expanding the spectrum to include the L, S, K and Ka bands, enhancing uplink coverage and supporting mobility services. Release 18 specifically targets the introduction of three new NTN bands above 10 GHz (n510, n511 and n512) to further refine the 5G NTN design for improved performance and broader accessibility.

Another key objective of NTN networks is to enhance the efficiency of the limited radio frequency spectrum, which often becomes congested. Recent technology studies are finding better ways to manage this congestion, like using time division duplexing (TDD) for space networks, a change from the usual method that assigns different paths for sending and receiving signals. The use of TDD bands as shown in Table 4, helps mobile carriers free up more space on the busy under-6 GHz spectrum. These improvements are pushing satellite technology forward, making it smarter and more in line with ground-based networks.

Band Details	Band	Uplink (GHz)	Downlink (GHz)	Duplex
Existing 3GPP FR2 Bands	n257	26.5 to 29.5	26.5 to 29.5	TDD
	n258	24.25 to 27.5	24.25 to 27.5	TDD
	n259	39.5 to 43.5	39.5 to 43.5	TDD
	n260	37 to 40	37 to 40	TDD
	n261	27.5 to 28.35	27.5 to 28.35	TDD
	n262	47.2 to 48.2	47.2 to 48.2	TDD

Table 4: Future TDD NTN bands are pushing satellite technology forward, making it smarter and more in line with ground-based networks.

3GPP NTN GOALS:

Release 17: Enhancing 5G NTN and IoT NTN services.

Release 17: Introduce low latency direct-to-cellular services in the sub-6 GHz band.

Release 18: Improve coverage and mobility by using frequencies in the Ku and Ka-bands allowing speeds of hundreds of Mbps, benefiting smaller AESA antennas.

Comparison of One-Way and Two Way Satellite Communications

Satellite communications are categorized into one-way and two-way systems. One-way communication involves signals being transmitted from the satellite to the ground, utilized in services such as GPS, satellite TV and radio. In contrast, two-way communication facilitates interactive signal exchange between satellites and ground stations, supporting internet services and phone calls. Figure 6 illustrates the differences between one-way and two-way communications involving Earth stations and a satellite.

As shown, one-way communications (left) like direct broadcast satellite (DBS) services, traditionally rely on GEO satellites. GEO satellites match the planet's rotation and only orbit Earth's equator. From the ground perspective GEO satellites appear in a fixed position in the sky. GEO satellites are a type of geosynchronous orbit (GSO), and both are used in telecommunications and Earth observation.

Non-geostationary orbit (NGSO) refers to a type of orbit used by satellites where it is not stationary relative to the surface of the Earth. NGSOs orbit the Earth at a lower altitude than GEO satellites and complete an orbit in a much shorter time. NGSOs constantly move across the sky and can provide better coverage for mobile satellite services and improve global connectivity. There are several types of NGSO orbits, including LEO, MEO and HEO – with LEO being the closest to Earth.

Two-way LEO satellite architectures further enhance the overall satellite communications. These two-way satellite communications advance beyond the old one-way "bent-pipe" approach, incorporating technologies like AESA antennas. The bent-pipe architecture behaves like a repeater, while the two-way architecture moves beyond this one-way communications style. These advanced systems are crucial for enhancing communication between ground and satellite.

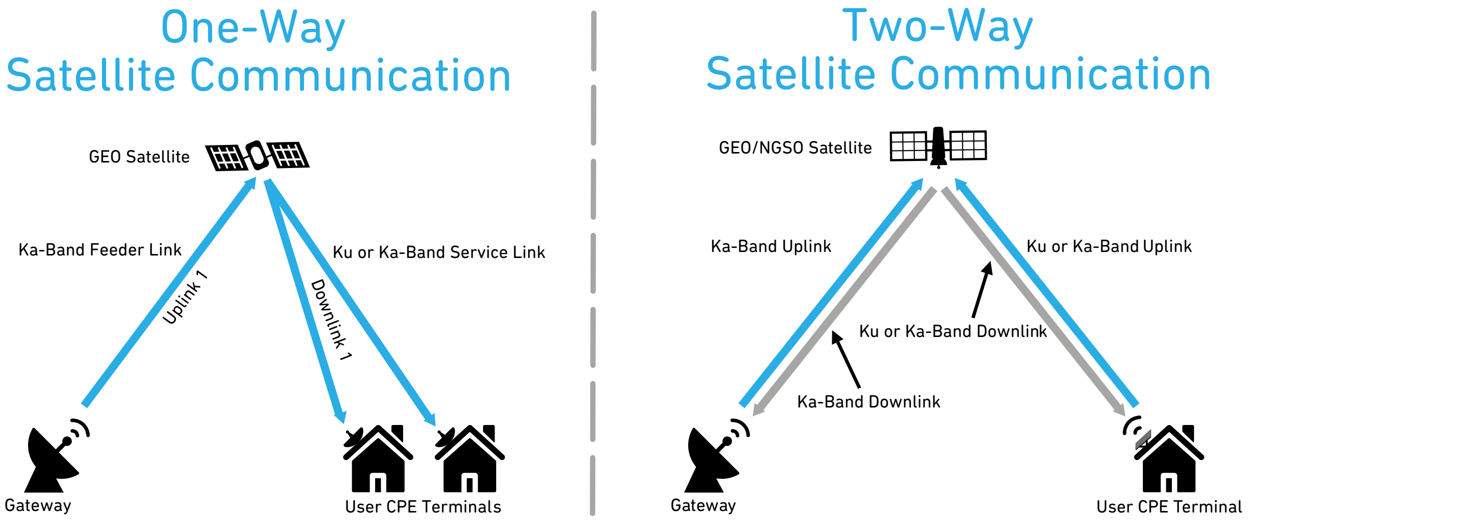


Figure 6: Example of one-way and two-way satellite use cases. Two-way architectures are crucial for enhancing communication between ground and satellite.

NTN Transparent and Regenerative Architectures

The new generation of ground-station systems is moving towards flexible and interconnected infrastructures with smaller flat panel user terminals, like cellular networks. To integrate satellite access networks into 5G, 3GPP TR38.821 introduced two types of satellite-based NG-RAN architectures: transparent and regenerative.

As shown in Figure 7 (left), the transparent payload architecture, the 3GPP 5G NR base station (gNB) is on the Earth, while the satellite plays the role of the bent-pipe repeater. In transparent payload communications, RF filtering, frequency conversion and amplification are performed on the satellite. In the regenerative payload architecture shown in Figure 7 (right), full gNB or part of gNB is implemented on the satellite. Therefore, in regenerative payload communications, the RF filtering, frequency conversion and amplification, demodulation, coding/decoding, switching or routing and modulation are done on the satellite. This is like having all or part of the gNB traditional ground base cell site function on board the satellite. These regenerative system architectures used for LEO satellites have many advantages over the traditional bent-pipe transponders. This is the architecture of the future as the current LEO constellations have their own proprietary waveforms and on-board processing systems.

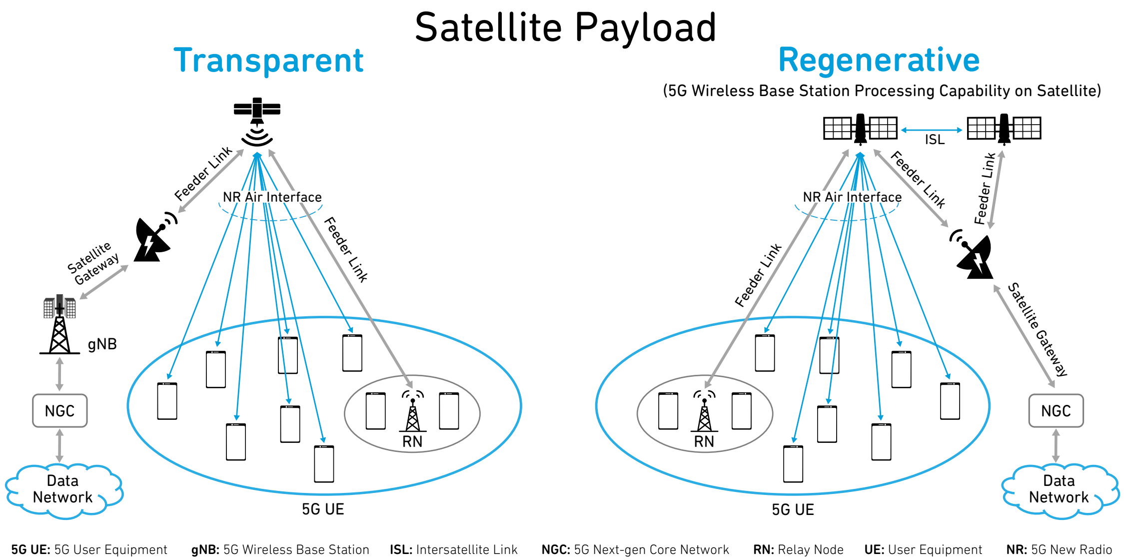


Figure 7: Satellite payload transparent and regenerative networks. Regenerative satellite architectures offer significant advantages in terms of performance, flexibility and efficiency, making them ideal for modern, data-intensive applications

AS DEMAND FOR CONNECTIVITY INCREASES

satellites will serve areas outside highly networked cities for purposes such as connection on the move, critical emergency services, edge networking and connected devices (IoT).

Satellite Technologies

Satellite communications is a growth market, both for the satellites in orbit and the associated ground terminals. Both require a broad range of RF signal chain components, from low noise amplifiers (LNAs) and RF power amplifiers (PAs). Other key components include filters and switches. As demand for LEO SATCOM advances, so does the focus on the satellite's size, weight and power attributes. Also, the availability of lightweight fixed and portable SATCOM user terminals is driving the industry to deliver creative answers to existing technologies, such as antennas.

The Entrance of AESA and Beamforming

The growth of SATCOM user terminals is responsible for a major shift in antenna technology.

Traditional parabolic (dish type) antenna limitations are unable to keep up with current requirements, leading a transition to electronically steered antennas such as AESA or phased-array types. AESA antennas can change the direction of their signal electronically, without needing to move physically, offering a big improvement over the mechanically steered antennas' agility. Moreover, AESA can create and send out its signals, using beamforming techniques for fast and accurate beamsteering adjustments. This enables connectivity to satellites in any orbit with fast handoff between satellites.

As shown in Figure 8 below, user CPE terminals are the direct link between the user and the satellite. These units are lower cost, easy to set up and can be stationary or mobile (i.e., mobile SATCOM, maritime, etc.). They use AESA antennas to integrate various technologies into a more compact and lightweight design. This includes beamforming technology for agile tracking and steering, and they also utilize readily available commercial off-the-shelf (COTS) components. Moreover, they support faster data transmission methods.

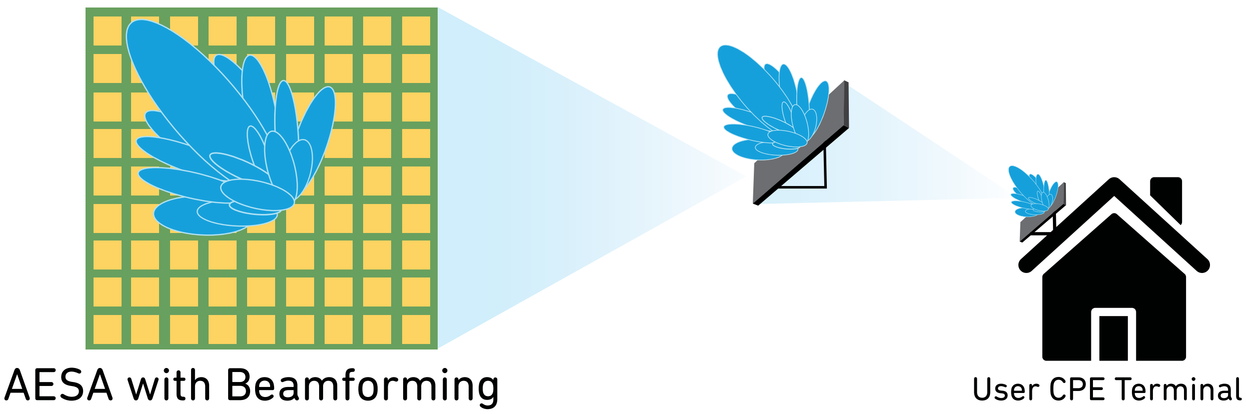


Figure 8: AESA beamforming terminal. AESA technology improves the speed in which data can be sent and the efficient use of the available frequencies. This makes internet connections faster, reaching wider areas and provides more dependable service, even in remote locations.

The Role of Beamforming and AESA Antennas in SATCOM Communications

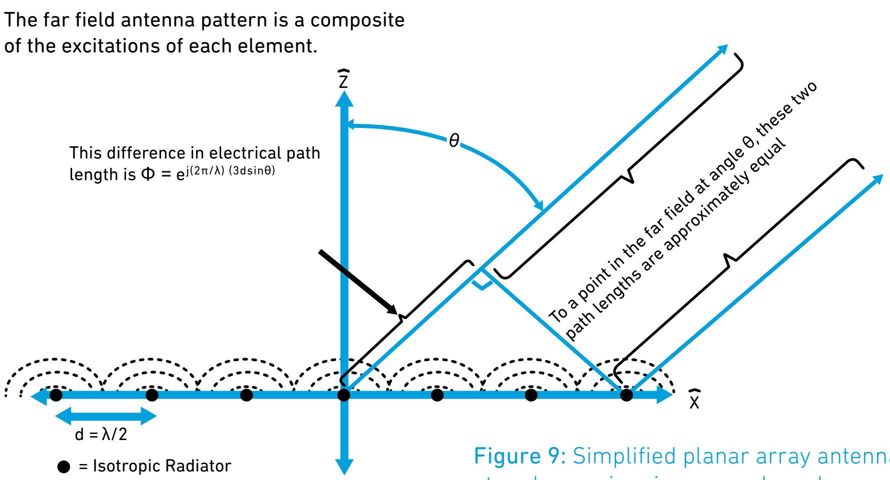
In the previous sections, we explored the many aspects of the satellite marketplace and introduced ways in which beamforming and AESA technologies are advancing satellite NTN. This section delves into how beamforming and AESA antennas are shaping satellite communication design trends and benefiting engineers in the field.

Beamforming is a signal processing technique used in antenna arrays for directional signal transmission or reception. This technology is crucial in wireless communication systems as it improves signal power, leading to enhanced performance and efficiency.

Beamforming along with multiple-input multiple-output (MIMO) and AESA are foundational technologies in modern wireless communication, offering significant benefits in terms of signal quality, network efficiency and user experience. Their applications span from mobile networks and Wi-Fi to satellite communications and radar, making them a critical tool in the advancement of wireless technologies.

What is an AESA or Active Antenna?

An active antenna, also known as a phased array antenna, consists of multiple stationary elements fed coherently. To form an electronic beam, each element is energized by the appropriate phase, then a beam can be formed coherently in the far field for the desired direction. It uses variable phase control at each element to scan a beam to specific angles in space, as shown in Figure 9 below. This electronic beam steering, with no moving parts, is managed by ICs at each radiating element.



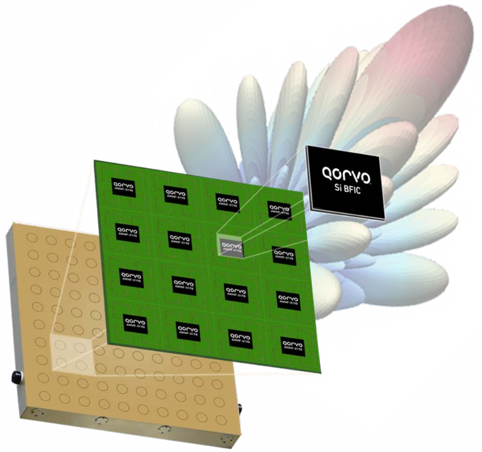


Figure 9: Simplified planar array antenna with a row of isotropic radiators. Active antennas can steer beams in microseconds and support multiple, simultaneous, independently steerable beams.

Active antennas with beamforming ICs have the advantage known as a soft failure mechanism, which means that the failure of a few elements typically has little impact on overall performance. Moreover, these AESA beamforming antennas can steer beams in microseconds and support multiple, simultaneous, independently steerable beams. With no mechanical parts, they are low-profile and reliable. Additionally, they can steer nulls and have high degrees of freedom to block interferers and jammers, enabling precise radiating aperture patterns.

For most NTN communications, antennas operate at mmWave in the GHz frequency ranges, like 24, 26, 28, 37 or 39 GHz. These high frequencies have short wavelengths, allowing many antenna elements to fit into a compact, highly directive aperture, offsetting high path loss, as shown in Figure 9 on page 15. The highly directive beams also offer spatial diversity, enabling multiple beams to reuse the same frequency spectrum, which significantly increases system capacity.

What is Beamforming?

Beamforming can be executed in an analog or digital format, depending on the system requirements. We'll dig more into the individual architecture types later.

Beamforming involves manipulating the phase and amplitude of the signal at each radiating element in the array. This technique causes signals at specific angles to experience constructive interference, while others experience destructive interference. This results in the RF energy being "focused" in specific directions, creating a beam-like pattern, as shown in Figure 10. In this figure, we can see the steered beam in the antenna array creates a main lobe at a given angle and minimizes the side lobes. Beamforming increases the signal-to-noise ratio (SNR) at the receiver end, reduces multipath fading and minimizes interference from other directions.

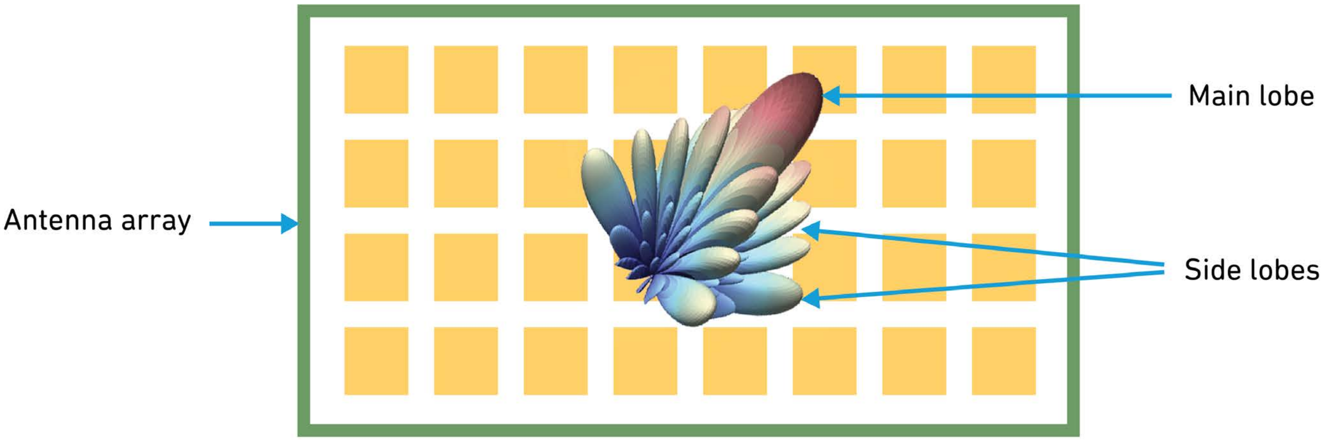


Figure 10: Beamforming signal lobes in an AESA antenna. The signal beam is steered using phase shifters of TDUs.

AESA antennas can steer the signal beam using either phase shifters or TDUs, each with its tradeoffs. For systems operating with a larger instantaneous bandwidth, TDUs may be a better choice to avoid beam distortion, known as squinting, as shown in Figure 11 below. However, for lower operating bandwidth systems, phase shifters are sufficient and are the most broadly implemented solution. Note, there are also architectures that incorporate both TDU and phase shifters into the same system. This also helps reduce squinting.

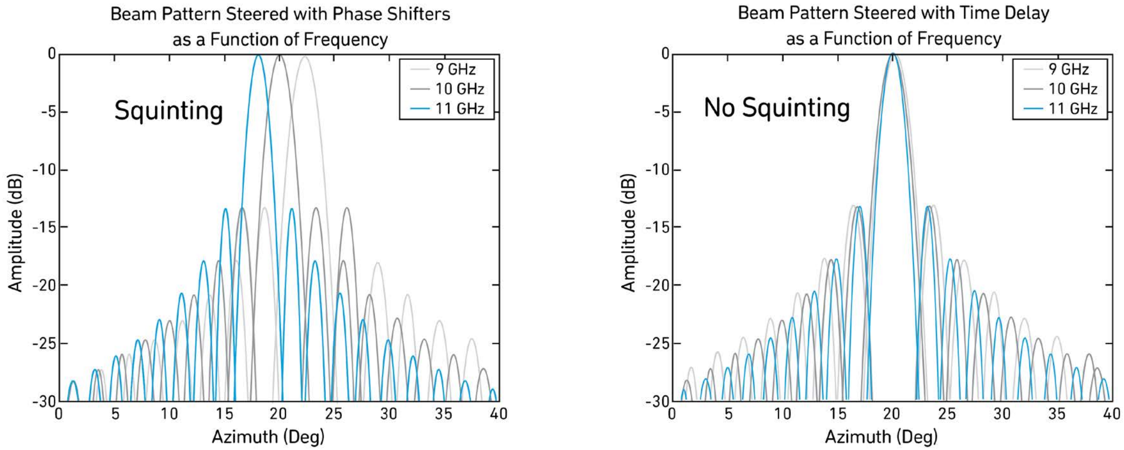


Figure 11: Beam squinting/distortion.

TDUs exhibit a constant phase slope over frequency range and therefore, remove beam squinting effects. While phase shifters exhibit constant phase over the operating frequency range; therefore, a phase shifter setting may result in different beam steering angles for different frequencies. Which is the reason phase shifters work best for narrower system bandwidths.

Phase shifters electrically steer a beam by approximating time delay, resulting in an optimal beam at the center frequency. However, phase shifting can cause understeering at the maximum operating frequency and oversteering at the minimum operating frequency. Phase shifter architectures are significantly more cost effective and thus more commonly used.

Ultimately, both methods work but engineers must make tradeoffs for the best implementation. First by evaluating the array size and instantaneous bandwidth requirements to determine if phase shifters are sufficient. Second, by evaluating whether a hybrid solution is sufficient where phase shifters are used at the elements and TDU is implemented behind some subset of elements within a larger array. If the instantaneous bandwidth and/or array size is large enough, TDUs may be required at every antenna element.

BEAMFORMING ENHANCES SIGNAL QUALITY AND EFFICIENCY

by directing electromagnetic energy, which is crucial for mobile networks, Wi-Fi and satellite communications.

Today's systems offer precise and reliable beam steering to improve network performance, signal coverage and data throughput in modern communications.

Types of Beamforming

Three general beamforming architectures are used in active antennas: analog beamforming, digital beamforming and hybrid beamforming. This section describes each approach from a high level and then compares the pros and cons of each approach.

Analog Beamforming: Requires an RF signal adjustment at each antenna element to steer the beam in the desired direction. This is simpler, often cheaper and lower power but less flexible compared to digital beamforming.

Digital Beamforming: Each antenna element is connected to its own digital signal processor. The beam is formed and steered by digitally manipulating the signals. This can allow for more precise control and the ability to form multiple beams simultaneously from the same array. This is practical only at low frequencies, such as S-band, where the lattices are large and there is plenty of room to place the required hardware on the array.

Hybrid Beamforming: Combines both analog and digital techniques, often used in systems where a purely digital approach would be too costly or complex and is popular in 5G mmWave networks. This technique mitigates the complexity inherent to using digital beamforming and reduces the RF chain components, thereby simplifying the overall system.

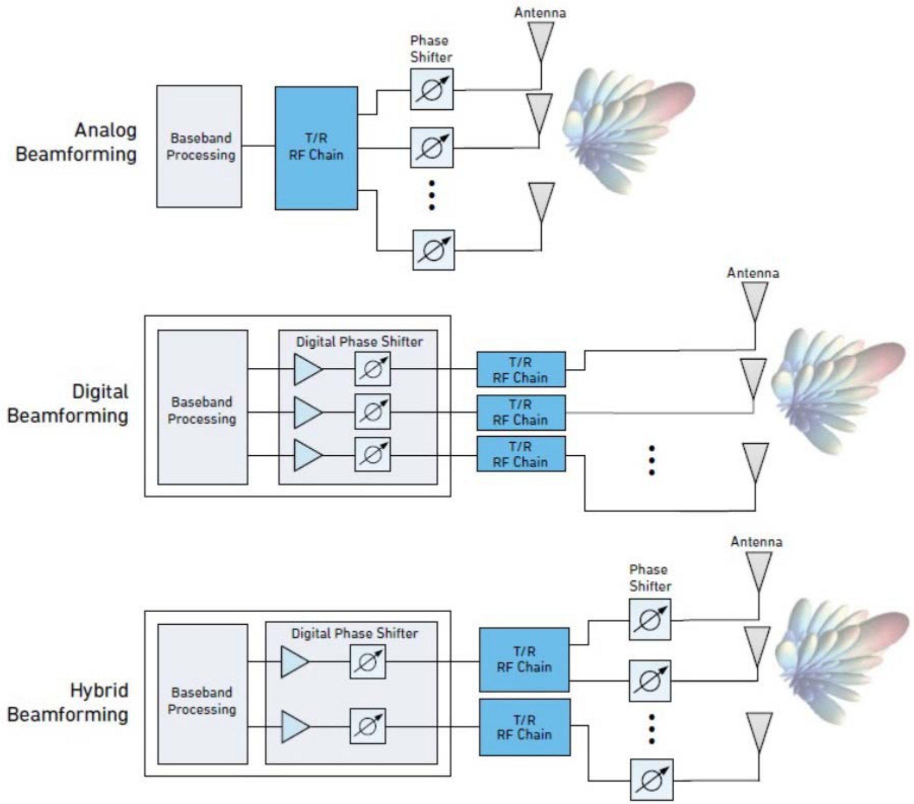


Figure 12: Comparison between analog, digital and hybrid beamforming architectures.

Parameter	Analog	Digital	Hybrid
Phase Shift Control	Analog phase shifters	Digital signal processing	Combination of analog and digital
Carrier Bandwidth	Narrower	Widest	Wider
Complexity	Lower complexity	Higher complexity	Moderate complexity
Cost	Lowest	Highest	Moderate
Power Consumption	Lowest	Highest	Moderate
Application	Broadest market	Exquisite market	High-performance market

Table 5: Comparison of beamforming types.

A Brief Look at Beamforming Wireless Applications

The wireless marketplace is beginning a move towards more beamforming SATCOM applications, to provide higher throughput enabled by wider bandwidth frequencies. In cellular networks, beamforming can be used to improve bandwidth efficiency and coverage by enabling base stations to focus signals on individual users, reducing interference and increasing data rates. In Wi-Fi networks, beamforming can be used to enhance signal quality and range, particularly in crowded environments with many user devices. Moreover, satellite communications, using beamforming is shaping the coverage area of satellite signals, allowing for targeted broadcasting and communication with specific regions. In radar system applications, beamforming is enhancing resolution and range by focusing transmitted pulses in the direction of interest improving the detection of objects.

QORVO'S SATCOM RESOURCES

Qorvo is your trusted partner for satellite communications. We bring innovation and scale to SATCOM applications. Our system level support and broad portfolio of solutions for both user terminals and LEO/GEO/MEO satellites are connecting the world through space.

Webinars:

- Innovations in Satellite Communications & Emerging ESA Technologies
- Key Components for LEO Satellite Systems
- Navigating the SATCOM User Terminal Trade Space

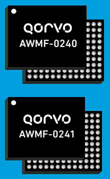
Sponsored eBook:

- RF Technology Trends for LEO Satellite Systems

Additionally, you can find more information on this subject by visiting our SATCOM solutions page, or email us at beamforming-sales@qorvo.com.

GROUND APPLICATIONS

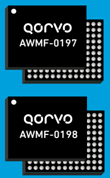
Flat Panel Arrays



Ku-Band

Rx: 10.7 to 12.75 GHz; Tx: 13.75 to 14.5 GHz

Ku-Band Quad Beamformer ICs
AWMF-0240 NEW, AWMF-0241 NEW
AWMF-0146, AWMF-0147
New Quad 4x2 Tx and Rx integrated ICs advancing efficiency and performance.
Recommended Rx Gain Stage: CMD264P3
Recommended Tx Driver: CMD264P3

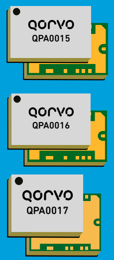


Ka-Band

Rx: 17.7 to 21.2 GHz; Tx: 27.5 to 31.0 GHz

Ka-Band Quad Beamformer ICs
AWMF-0197, AWMF-0198
Quad 4x2 Tx and Rx highly integrated ICs simplifying active antenna design.
Recommended Rx Gain Stage: QPA2626
Recommended Tx Driver: QPA2628

SATCOM Terminals



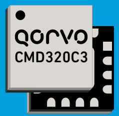
Ku-Band

Rx: 10.7 to 12.75 GHz; Tx: 13.75 to 14.5 GHz

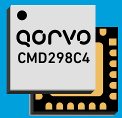
8, 15 or 25W GaN Tx Power Amplifiers
QPA0015, QPA0016, QPA0017
SMT package

Ka-Band

Rx: 17.7 to 21.2 GHz; Tx: 27.5 to 31.0 GHz
25W GaN Tx Power Amplifier
QPA2212D



Ultra-Low Noise Rx Amplifier
CMD320C3
Market leading NF=1.07 dB, 18 dB gain with no external DC blocks or RF matching required. Low power dissipation.



GaAs Rx Low Noise Amplifier
CMD298C4
Market leading NF=1.07 dB, 18 dB gain with no external DC blocks or RF matching required. Low power dissipation.

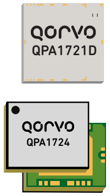
SPACE APPLICATIONS

Space Payload

Ku-Band

Rx: 13.75 to 14.5 GHz; Tx: 10.7 to 12.75 GHz

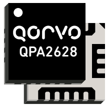
17.5 or 35W GaN Tx Power Amplifiers
QPA1006D, QPA1009D



Ka-Band

Rx: 27.5 to 31.0 GHz; Tx: 17.7 to 21.2 GHz

20 or 30W GaN Tx Power Amplifiers
QPA1721D, QPA1724



GaAs Rx Low Noise Amplifier
QPA2628
Market leading NF=1.6 dB, 23 dB gain with no external DC blocks or RF matching required.

GaAs Rx Low Noise Amplifier
QPA2735
Market leading NF=1.3 dB, 25.5 dB gain with no external DC blocks or RF matching required.

Visit qorvo.com/go/satcom for more information