Vol 56, No 4—November 2022

ANALOG DEVICES
AHEAD OF WHAT'S POSSIBLE™
AnalogDialogue

The Internet from Space: RFIC Advances in High Capacity, Low Latency LEO Satellite User and Ground Terminals

Donal McCarthy, Director of Marketing and Business Development

Introduction

This article introduces key market trends driving low Earth orbit (LEO) satellite deployments. It will discuss the basic operation of a LEO satellite system and present some of the semiconductor RFIC advances, which are enabling the next generation of Ku and Ka band LEO user and ground terminals.

LEO Connectivity—The Path to Success

Satellite communications (satcom) is an established means to transfer voice, video, and data, and is used in a large variety of use cases across the prevailing orbitals called geostationary equatorial orbit (GEO), medium Earth orbit (MEO), and LEO. Satcom is seen as an effective means to communicate GPS for navigation, weather information, TV broadcast, voice, data, and is also used for imaging and science-based applications. However, a new wave of promised high speed internet connectivity is planned around LEO satellite constellations. This will deliver low latency, high capacity broadband connectivity for next-generation internet communications.

LEO satellites will play an important role in the continuing rollout of 5G cellular connectivity. Satellite networks are becoming more involved in the 3GPP standardization and their expected role in the networks of the future is well under development. In 2017, activities kicked off within the 3GPP standards body to understand the feasibility of satcom networks within 5G connectivity. Through releases 15, 16, 17, and 18 of the 3GPP standard, several activities were developed to support the integration of these networks. LEO satellites can provide wide area coverage to underserved areas, provide continuity of service for people on the move, connect to machine-to-machine (M2M)/Internet of Things (IoT) devices, and be a notable upgrade path for 5G in a cost-effective manner.

The next generation of LEO systems will orbit between 500 km and 2000 km above the Earth's surface and will deliver a technically superior solution to satellite networks of the past. Such proximity to the Earth means they will deliver lower latency connections, which is important for consumer or business use cases (for example, internet gaming or the control of industrial/medical equipment in real time). LEO satellites should deliver approximately 50 ms of latency (and this will improve with next-generation technology to <20 ms) vs., for example, GEO that is 700 ms.

A key enabler of LEO satellites is that their exposure to radiation is much lower due to the lower orbit. This is important as it means the expensive and sometimes prohibitive radiation hardened testing can be relaxed. This will generate economies of scale as the cost to build a LEO satellite is now drastically reduced. Less radiation means wider availability of semiconductor processes and, therefore, components for use.

Given the lower orbit, the expectation is for a much larger number of satellites deployed. The average life span for such satellites will be much shorter than previous use cases; perhaps between 5 and 8 years, after which these satellites will fall out of orbit and need to be replaced. LEO satellites must be cost-effective to launch and relaunch replacements.

All these trends are making industry watchdogs take note as the LEO broadband connectivity business case is starting to look strong. If we remember back in the 1990s, this internet venture was the goal of several companies, but it was unfortunately a failure due to the high cost of deployment and limited demand. Fast forward to today and we see remarkable advances in semiconductor technology delivering unprecedented performance and integration. Coupled with the exponential demand for high speed, low latency internet connectivity in more rural or underserved settings, and the integration of satcom into 5G standards, the LEO constellations of the future are on a much better platform for success.

At the time of writing, it is expected that users could achieve maximum downlink data speeds of 100 Mbps and this could extend to 150 Mbps in the future, which is ideal for multi-user, full-time video streaming.

One challenge with LEO is the ever-moving nature of satellites—the constellation really needs to be fully deployed to become a minimal viable service. This means that the initial outlay is high as the number of LEO satellites is greater given their lower orbit. But even so, this does not seem to be a deterrent to success now and the business case for ubiquitous coverage is strong for investors.

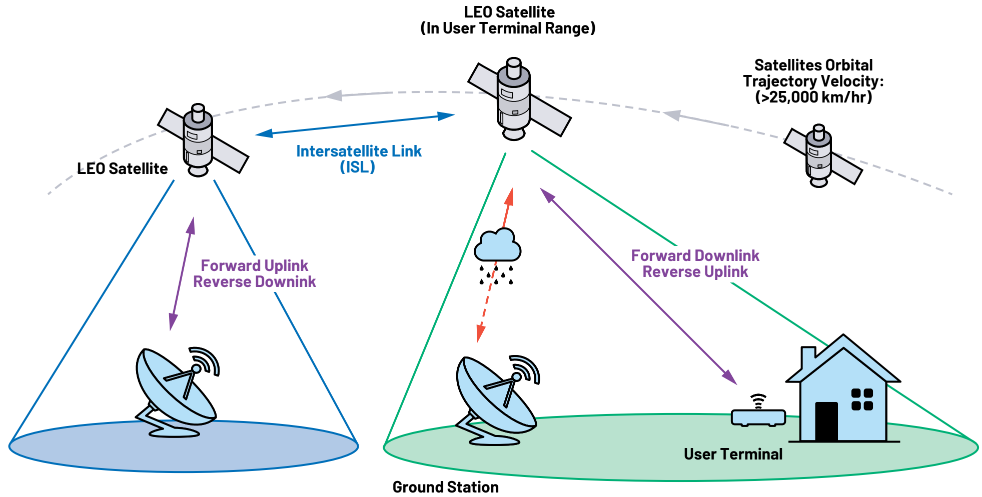


Figure 1. An example of a ground-space scenario for LEO satcom.

How Does a LEO Satellite System Work?

LEO satcom systems are made up of three major components, as shown in Figure 1.

User Terminals/User Equipment (UE)

These are the direct link between the user and the satellite and tend to be low cost, easy to setup terminals located at homes, but also can be mobile terminals (for example, maritime, satcom on the move, tactical manpack radios). User terminals leverage high levels of IC integration to simplify the bill of materials (BOM), lower cost, and maintain a small form factor.

Ground Stations/Gateway

These are the ground connections to the servers (data centers for internet connection) typically over fiber, and they link the satellite to the ground. They are deployed at fixed locations across the Earth.

Satellites

Groups of satellites are called constellations and these orbit the Earth providing simultaneous links to connect both terminals and gateways.

LEO satellites move across space and typically a single satellite will orbit the Earth in a period of 90 mins to 110 mins, referred to as the orbital period. Because of this, a user connecting to the satellite will only be in range of that satellite for a short period of time (up to 20 mins). So, the average user will be connecting to multiple satellites during normal operation. Therefore, users of the system must be handed off to other satellites that come into range, in a similar manner to a person using a cell phone in a moving car and one base station in the cellular network handing off to another. This places strict requirements on how to steer the beams to maintain the best link to the most appropriate satellite.

Another interesting evolution is how a satellite system maintains operation when it is out of range of a ground station. In Figure 1, we are showing some adverse weather that may affect the link speed to the ground station. Traditionally, satellites use bent pipe, which means the satellite must always find a link path to the Earth or some other means (aircraft) to serve as a hop back to another satellite in space, which could then be in range of a ground station. A new technique is through intersatellite links using optical or V and E band connections in space to link satellites.

Advances in User Terminal Up/Downconverters

User terminals are driving significant levels of IC integration and Analog Devices is responding to this demand by leveraging the performance and integration capability of silicon process technology. These solutions require the highest level of IC integration to enable the smallest form factor radio terminal, while maintaining the lowest power consumption and a strict adherence to the optimal cost per radio.

Up/downconverters (UDCs) are a foundational product in user terminals, and they interface the modem IF or baseband information directly to Ku band or Ka band.

The frequency coverage goals of RFIC UDCs are:

- Ku band: ~10.7 GHz to ~14.5 GHz
  - Downlink (satellite to ground): 10.7 GHz to 12.7 GHz
  - Uplink (ground to satellite): 14 GHz to 14.5 GHz
- Ka band: ~18 GHz to ~31 GHz
  - Downlink (satellite to ground): 17.7 GHz to 21 GHz
  - Uplink (ground to satellite): 27 GHz to 31 GHz

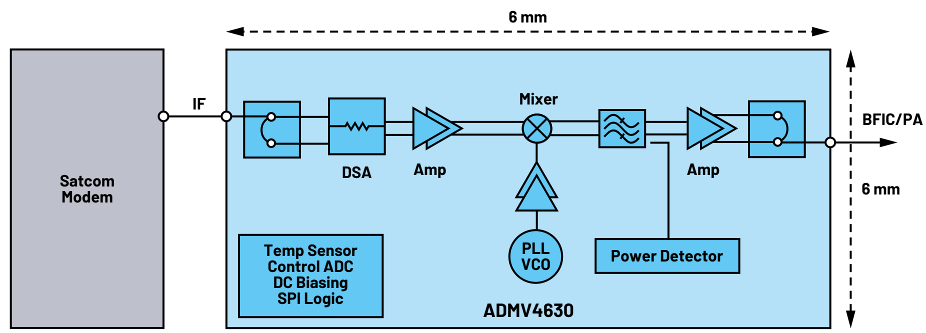
Downlink and uplink are separated in frequency so the communication from the satellite to the user terminal is using two separate frequency bands. Therefore, RFIC companies must design each user terminal up and down converter for separate bands.

Depending on uplink vs. downlink, user terminal links typically cover channel bandwidths (BW) of 125 MHz to 250 MHz and gateways cover between 250 MHz and 500 MHz. However, some deployments have a shared bandwidth capability between the user and gateway links, so the channel bandwidth is reconfigurable in the frequencies they operate.

LEO satellites are moving constantly as shown in Figure 1. Thus, the up/downconverter frequency synthesizer within the terminal must achieve fast lock times for uninterrupted connection. Synthesizers are used to assist in the frequency upconversion and downconversion. They play a vital role in enabling the terminal to connect and reconnect to different satellites during operation, as the frequency over the air changes constantly within the operational bands (that is, Ka and Ku bands) from one satellite to another.

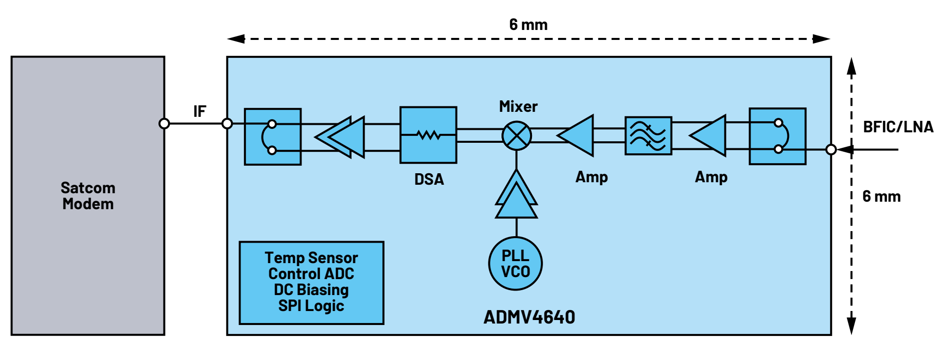
ADI has developed a family of Ku and Ka band UDCs targeting user terminals to address the size, weight, area, power, and cost (SWaP-C) problem. These UDCs contain extensive RF and IF signal conditioning such as filters, amplifiers, attenuators, PLLVCOs, and power detection. All ICs are purposely designed with the signal chain performance of a user terminal in mind. The ADMV4630/ADMV4640 are Ku band UDCs that support an IF interface to the satellite modem and are shown in figures 2 and 3 with highlights of the ICs' performance shown in the tables.

For the higher frequency Ka band, ADI has developed the ADMV4530/ADMV4540 UDCs (Figure 4 and Figure 5) that support satcom modems requiring an I/Q baseband interface. Note that the ADMV4530 upconverter is a dual-mode device, which can also support an IF interface. Designed with silicon, these solutions deliver the highest level of integration to manage the integration pressures seen in these high volume terminal applications.



Parameter	ADMV4630
RF Output Freq (GHz)	14 to 14.5
IF Input Freq (GHz)	3.0 to 5.0
Conversion Gain (dB)	19
Gain Control Range (dB)	31
OP1dB (Max Gain dBm)	11
OIP3 (Max Gain dBm)	22
Power Consumption (W)	1.7
Package Size (mm)	6 × 6

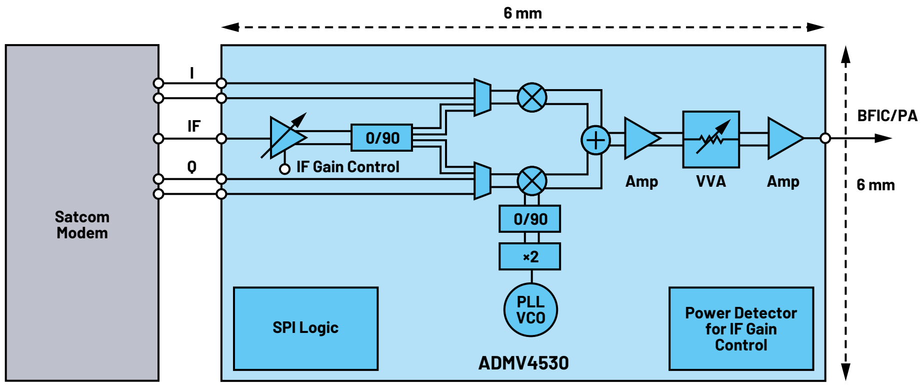
Figure 2. A highly integrated Ku band upconverter with IF interface directly from the satcom modem.



Parameter	ADMV4640
RF Input Freq (GHz)	10.7 to 12.7
IF Output Freq (GHz)	1.4 to 2.5
Conversion Gain (dB)	27
Gain Control Range (dB)	31
IIP3 LNA High Gain (dBm) LNA Low Gain (dBm)	 –6 * –1 *
Noise Figure LNA High Gain (dB) LNA Low Gain (dB)	 4.2 5.2
Power Consumption (W)	1.35
Package Size (mm)	6 × 6

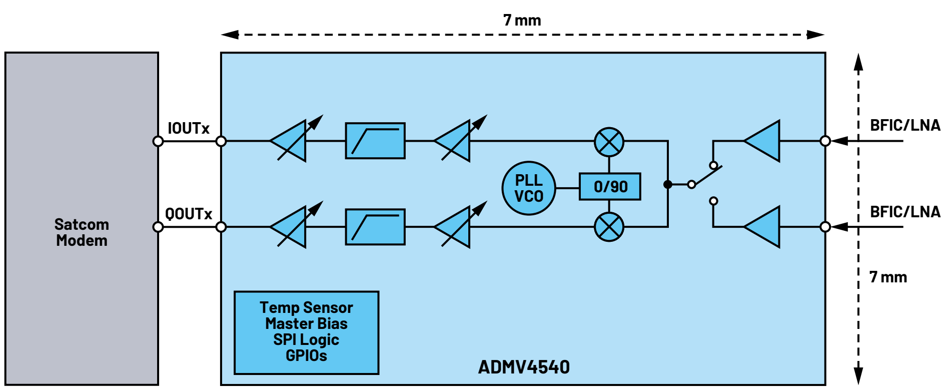
*Pin = –33 dBm/Tone

Figure 3. A highly integrated Ku band downconverter with IF interface directly to the satcom modem.



Parameter	ADMV4530
RF Output Freq	27 to 31
IF Input Freq (GHz) Baseband (I/Q) (GHz)	2 to 3 DC to 0.5
Conversion Gain (dB)	21
Gain Control Range (dB)	30
OP1dB (Max Gain dBm)	19
OIP3 (Max Gain dBm)	29
Power Consumption (W)	1.9
Package Size (mm)	6 × 6

Figure 4. A highly integrated Ka band upconverter with I/Q and IF interface directly from the satcom modem.



Parameter	ADMV4540
RF Input Freq (GHz)	17 to 22
Baseband 1 dB BW (I/Q) (GHz)	DC to 0.5
Max Conversion Gain (dB)	>50
Gain Control Range (dB)	>50
IIP3_High Gain (dBm)	–3**
Noise Figure (dB)	5 at max gain
Power Consumption (W)	3.2
Package Size (mm)	7 × 7

**Pin = –30 dBm Composite Input

Figure 5. A highly integrated Ka band downconverter with I/Q interface directly to the satcom modem.

Higher Performance Terminal UDCs

Some applications within the terminal market are performance driven and have less restrictions on their size and lowest cost design goals. They have the freedom to use discrete RFIC solutions. Keeping components in separate packages allows for a mixture of process technology including MESFET, pHEMT, BiCMOS, and CMOS ICs to optimize any design requirement. Discrete design allows for many types of performance vs. size trade-offs, giving maximum flexibility in the design process. Designers can create higher performance radios giving higher output power and supporting wider bandwidths. Furthermore, a higher receiver sensitivity to improve dynamic range and improved spurious performance can be achieved. It should be noted that ground stations/gateways also fall into this category of solutions. Gateways are larger in size and certainly not driven by the same integration demands at the terminal level. Gateways leverage different process technology to bring the most performance-optimized solution to the market. At ADI, we continue to expand the portfolio of discrete solutions to address the use cases. Figure 6 illustrates a discrete high performance solution.

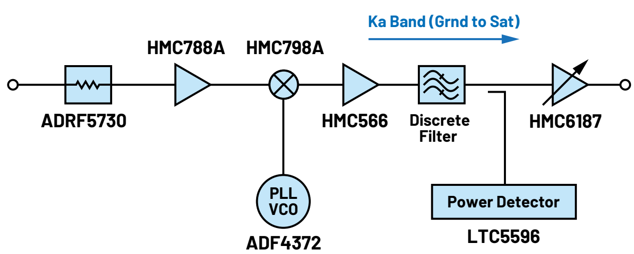


Figure 6. A functional diagram of a discrete HMC798A Ka band user terminal.

Lowering the Cost of User Terminals Using Electronic Steerable Antenna

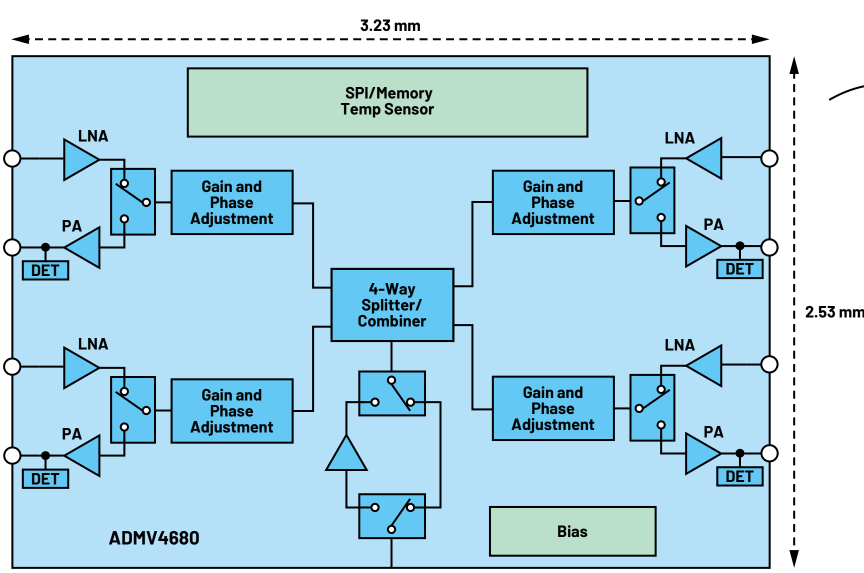
Companies are focusing on lowering the cost of deployment of user terminals by removing the expensive installation cost traditionally associated with a professional contractor who mounts the equipment and locates the satellite position. This is achieved by combining the antenna along with all the electronics (for example, phase-shifting elements, RFIC UDCs) required to process the communication link in a single outdoor unit (ODU). The ODU is the antenna array that resides outside the home and is aimed at the sky. An indoor unit (IDU) is connected to the ODU and functions as a traditional router (wired or wireless) to supply internet connectivity to the user (for example, PC or phone).

As mentioned earlier, LEO constellations will have many satellites that move in and out of the ground terminal field of view so it's far more efficient to use the electronic steerable antenna (ESA) as it can enable high directivity by electronically steering the transmit and receive beam of energy in the direction of the satellite. Thereby, the best link is maintained from one satellite to another with near instantaneous switching between satellites as the satellites move in and out of view of the user terminal. In fact, the ESA is almost a requirement when you think of the orbital period and the number of satellites that need to be connected to during the normal course of operation.

To address this challenge, ADI has developed the Ku band beam forming integrated circuit (BFIC) technology. The ADMV4680 is a silicon solution designed for user terminals, allowing for half-duplex channels to independently control the gain and phase of the signal. What is remarkable is that the size of this IC is only 8.2 mm^2 as shown in Figure 7.

The core to the development of BFIC technology to minimize overall radio cost is system and array expertise. Mechanical assembly and PCB design, which includes stack up and number of layers, are part of the radio cost driver. When the BFIC is developed with the mechanical and PCB designs in mind, a minimum overall radio cost is created. At ADI, we work closely with customers and have in-house PCB experts to help with this. In fact, the IC design and final configuration is part of the system trade-off study.

Adopting the ESA to both track the LEO satellites and optimize the link speed allows for low cost setup and typically these are plug and play. The ESA and the migration to more integrated ODUs are radically simplifying the deployment and lowering the cost of the system. The ESA is also enabling a flatter panel and aesthetically pleasing designs.



Parameter	ADMV4680
RF Frequency Range Transmit Receive	 14 to 14.5 10.7 to 12.7
Rx Noise Figure (dB)	<2
Tx OP1dB (dBm)	9
T/R Switching Time (µs)	1
Pwr Det Range (dBm)	–15 to +10
Power Consumption (W) Tx Mode Rx Mode	 <125 mW/ch <95 mW/ch
Package Size (mm)	3.23 × 2.53

Figure 7. A highly integrated, half-duplex, Ku band, 4-channel beamforming IC.

It's worth noting that in the case of highest performance terminal applications, a dual parabolic steered antenna is used. In these cases, cost and aesthetics are not a primary driver and overall performance is the focus. When it comes to consumer and cost-conscious small enterprise solutions, ESA is by far the best way to achieve the lowest radio cost while meeting system design goals.

Conclusion

LEO internet connectivity is a new and exciting domain and the race for space is on the minds of most governments and internet providers today. As the world continues to become more connected, LEO will play an important role in 5G by further enhancing the connectivity of the 3GPP standard from space to rural locations. The RFIC integration requirement on user terminals is becoming more challenging and ADI is continuing to develop solutions and roadmap ICs in this domain.

References

Cajaj, Shkelzen. "The Parameters Comparison of the 'Starlink' LEO Satellites Constellation for Different Orbital Shells." *Frontiers in Communications and Networks*, Vol. 2, May 2021.

Darwish, Tasneem, Gunes Karabulut Kurt, Halim Yanikomeroglu, Michel Bellemare, and Guillaume Lamontagne. "LEO Satellites in 5G and Beyond Networks: A Review from a Standardization Perspective." *IEEE Access*, Vol. 10, March 2022.

Hall, Brad. "Need More Bandwidth for the Ka Band? Here Are Three Options." Analog Devices, Inc., November 2017.

King, Yasmine. "New Age of the Commercial Space Satellite." Analog Devices, Inc.

About the Author

Donal McCarthy is the marketing and business development director for the Microwave Communications Group at Analog Devices in Cork, Ireland. Donal holds a B.E.E. degree from the University College Cork, an M.B.A. degree from Boston College, and a marketing degree from Irish Management Institute in Dublin. Donal held various roles including design engineer at MACOM, field sales engineer and marketing roles at Hittite, and marketing manager and director roles at ADI.