BANDWIDTH DEMANDS PLACE NEW STRAINS ON SATELLITE COMMUNICATIONS DESIGN

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Abstract

For the last two decades, the aerospace and defense and commercial air communities have relied on satellite communications to coordinate overseas military operations and for civilian passenger travel. With the increase in data flow and Internet of Things (IoT) applications, the need for satellite communications systems has never been so great.

More data than ever is required by soldiers and forward operating bases, as well as increased demand from unmanned aerial vehicle (UAV) technology for military operations around the world. Equally significant is the increasing demand for high bandwidth data access on commercial aircraft for both business jets and major airliners. New satellites are being launched that support higher frequencies to enable this increase in bandwidth. This article will review these technology trends, as well as solutions to achieve the required performance and fast time-to-market using commercially available and customizable architectures.

SATCOM Introduction and History

The demand for increased data rates is driving many new developments in the SATCOM world. Soldier-based SATCOM links will increase from kbps to Mbps data rates, which will enable more efficient data and video transfer. The proliferation of UAVs in the defense (and soon the commercial world), has created a new arena of SATCOM links. And the insatiable demand for data and Internet access in the commercial aerospace market is driving new developments in the K_u-band and K_a-band to support data rates up to 1000 Mbps. At the same time, supporting legacy data links, minimizing size, weight, and power (SWaP), and reducing investment in system development is driving a need to develop flexible architectures and maximize system reuse.

SATCOM systems traditionally have utilized geostationary Earth orbit (GEO) satellites—satellites that relative to the Earth's surface will stay in a fixed location. To achieve geostationary orbit, the satellite must be at a very high altitude—over 30 km from Earth's surface. The benefit of such a high orbit is that very few satellites are needed to cover a large area of ground, and transmitting to the satellite is simplified because it has known, permanent coordinates. Due to the launch cost of these systems, they are designed for long lifecycles, resulting in a stable but sometimes antiquated system.

Because of altitude and radiation challenges, additional device screening or satellite shielding is often needed. Furthermore, because the satellite is so far away, there will be significant loss with the user on the ground, impacting signal chain design and component selection. The long ground-to-satellite distance also results in high latency between the user and the satellite, which can impact some data and communication links.

Recently, many alternatives or complementing systems to GEO satellites have been proposed, with UAVs and low Earth orbit (LEO) satellites being considered. With lower orbits, these systems mitigate most of the challenges described with GEO-based systems, but at the expense of reach, with many more satellites or UAVs required for similar global coverage.

Soldier SATCOM Challenges

Effective communications and data links are critical for a fighting force to operate effectively across the globe. Although SATCOM networks are used on a variety of platforms, the soldier system is perhaps the most challenging when the missions or location makes traditional line-of-sight radio access impossible. Because these SATCOM radios need to be hand carried, SWaP is critical to the design. Additionally, these radios need to work in any physical environment—from under the tree canopy in a jungle to crowded metropolitan areas, which causes these systems to often operate in the UHF band around 300 MHz. Since the initial application was designed to operate by push-to-talk (PTT) voice, the platforms would operate a time-division duplex mode mod, allowing for significant power savings since voice bandwidths are tens of kilohertz and PTT allows the receiver and transmitter to be duty cycled.

However, future soldier SATCOM requirements are demanding much more information than secure voice, from surveillance images to updated maps and weather information. One solution to this is the Mobile User Objective System (MUOS), which still operates in the UHF band, but with dramatically increased data rate and signal bandwidths. Additionally, MUOS is a full-duplex waveform, meaning that the receiver and transmitter are simultaneously active.

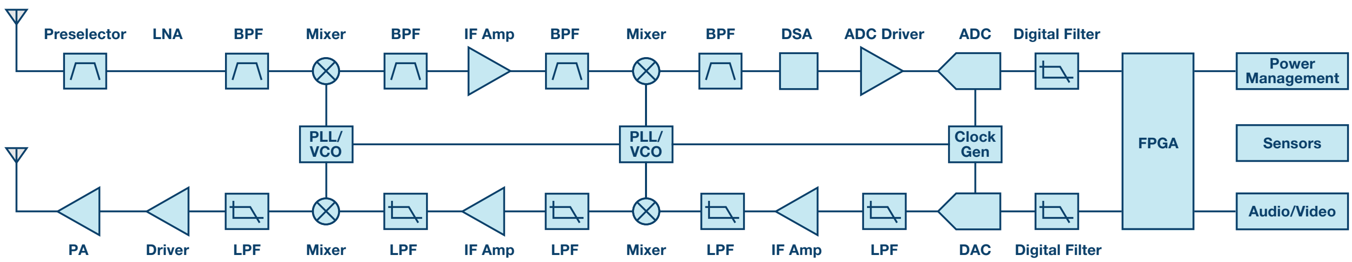

Figure 1. Traditional K_a-band/K_u-band super-heterodyne receive and transmit signal chains.

Unmanned Aerial Vehicles and Commercial Aviation

Airline and business jet passengers are demanding Internet connectivity as they travel across the globe. Air carriers are looking to increase data links to the cockpit, while the potential for IoT system monitoring and reporting is requiring high data rate SATCOM platforms with hundreds or even thousands of Mbps data links.

Until now such high bandwidth data links have been predominantly provided when the aircraft is over land, using a system of ground-based installations to provide the link to the aircraft. For full transcontinental coverage, SATCOM is the only effective way of providing connectivity with Inmarsat's L-band coverage, for example. In the future, to achieve the required bandwidths, the frequency of operation must move to the K_u-band or K_a-band. While these high frequencies can provision the required bandwidth, there are still design challenges and it will be inevitable that systems must support legacy data links.

UAVs face similar challenges. The advanced defense focused UAVs are required to operate around the globe with remote piloting, possibly from a different continent. These requirements drive a need for high bandwidth datalinks to support video, control, and advanced payload data, potentially saturating the existing communications infrastructure. With commercial UAVs also set to have expanded coverage in the future, global network high bandwidth connectivity will pose the same SATCOM challenges as in commercial aviation.

K_u-Band/K_a-Band and LEO Systems

Inmarsat is in the process of offering users the ability to use its GEO satellites with a K_a-band data link to address some of the challenges described above. From an architectural standpoint, this provides a solution to bandwidth shortfalls but introduces new challenges for the design engineer. Figure 1 illustrates a typical super-heterodyne receive and transmit signal chain for operation in the K_a-band and K_u-band. These systems often required two, and sometimes even three, stages of analog upconversion and downconversion, each requiring a synthesizer, amplification, and filtering that drives up system SWaP. However, to fit within the existing airliner infrastructure and power distribution system incorporating such signal chains for all the possible data links may be untenable.

Although this is clearly a simplified schematic, assuming each function is implemented using a discrete device, the SWaP implications are clear. The large number of components, power consumption, and isolation challenges means the printed circuit board (PCB) will be large. And because of the high frequency routing, more RF appropriate PCB material may be needed, significantly impacting cost. With a need to continue to support the L-band frequency of operation, the SWaP and design effort challenges are compounded.

LEO satellites potentially offer some relief. These operate at a much lower altitude—roughly 1 km off earth's surface—but at this altitude they are not stationary, and in fact sweep across Earth's surface, with an orbital cycle of roughly 30 minutes. The low altitude reduces the launch cost, and with a less harsh environment potentially less screening and shielding is needed. And critically, the low altitude means less propagation delay. But the primary difficulty for a LEO system is that the satellite is only within range of the user for fairly short bursts, necessitating the use of handoffs.

UAVs may also be a solution to the problem with some platforms being considered as a means to extend internet coverage. The UAV can provide low latency high bandwidth links, similar to LEOs, but now with the benefit of being relatively stationary. However, the cost vs. coverage of this implementation may be challenging for global applications.

Solving the SATCOM Dilemma

Although the SATCOM challenges outlined above seem daunting, many new advanced solutions are available to mitigate the challenges, reduce the SWaP, or provide signal architectures that can be partially reused or leveraged between systems.

For high bandwidth UHF SATCOMs such as MUOS, new continuous time sigma-delta (CTSD) band-pass analog-to-digital converters (ADCs) provide RF sampling solutions. For example, the AD6676 is an IF receiver subsystem integrating the ADC, analog gain control (AGC), and digital downconversion. CTSD ADCs enable the noise floor to be traded for bandwidth, providing system flexibility as well as an inherent band-pass filter response, which reduces the external filtering requirements. Because the AD6676 can directly sample the MUOS downlink, front-end mixing stages and synthesizers are eliminated, with the signal chain reduced to a low noise amplifier and simple passive filter.

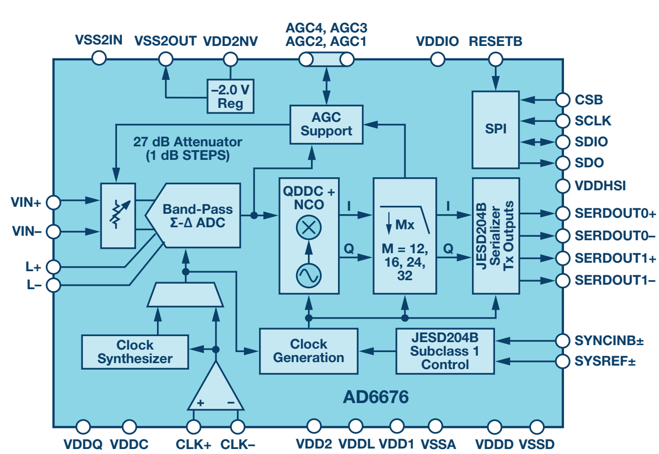

Figure 2. AD6676 receiver subsystem architecture.

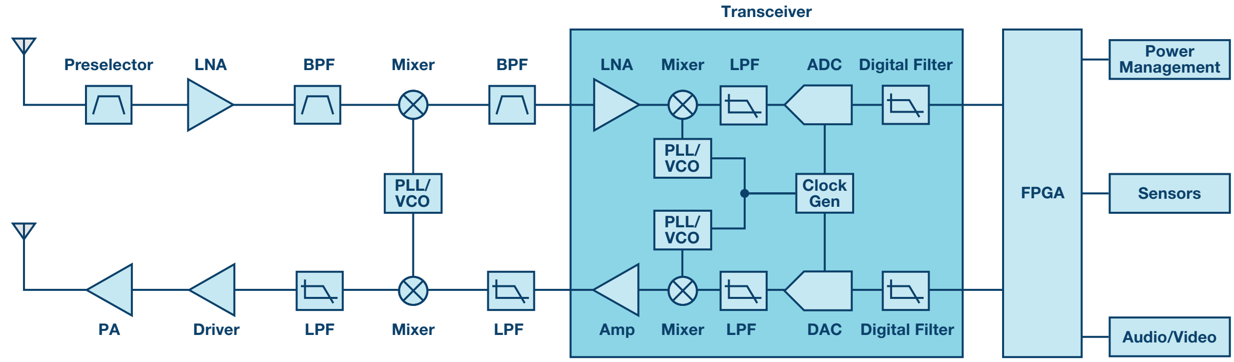

Figure 3. Integrated IF receiver-based K_a-band/K_u-band receive and transmit signal chains.

However, as MUOS uses full-duplex mode, the power consumption of the power amplifier (PA) also becomes critical. With handheld SATCOM radios needing to transmit at power levels between 1 W and 10 W, new gallium nitride (GaN) amplifier devices like the HMC1099 provide increased power efficiency and when combined with additional linearization techniques, such as digital predistortion (DPD), they provide attractive SWaP solutions for these systems

For K_u-band and K_a-band systems, new, more integrated architectures provide SWaP and signal chain simplification as well as potentially supporting significant system reuse between the L-band and K_a-band. Figure 3 illustrates the potential savings that the AD9361 RF transceiver can provide when utilized as an IF converter, eliminating the second upconversion and downconversion stages, amplifiers, and filters, as well the ADCs and DACs.

The RF transceiver is typically used as an agile direct conversion radio, which allows it to be used as part of an L-band solution. When used in this manner, it provides significant commonality across these platforms and maximizes the reuse of software and firmware. The aggregated SWaP is also reduced, consuming only 1.1 W for most applications, and packaged in a 10 mm × 10 mm footprint.

In addition, new PLL and VCO devices such as the ADF5355 provide very wideband, high performance, low SWaP frequency sources. Available in a 5 mm × 5 mm package, the ADF5355 provides a low power, high performance LO source that can sweep from VHF all the way to 13.6 GHz—providing an ideal solution for common platform designs.

Finally, for future LEO systems, beamsteering architectures will be critical to ensure the efficiency of the link. Although analog beamforming solutions using digital phase shifters such as the HMC247 provide today's solutions, as converter technology becomes more integrated and increased signal processing becomes more available in lower power devices, digital beamforming becomes a very attractive architecture. In this approach, the RF signal chain is kept identical across the array, and the beam is created in the digital domain. A key difficulty for digital beamsteering is managing the size, timing, and power across multiple ADC or DAC devices. Any time or process skew across devices will have an impact on the quality of the beam. New devices like the AD9681 greatly simplify digital beamsteering design. Having up to eight ADCs all use an identical voltage reference and clock source improves the beam quality, and the integration of the devices creates a smaller package with lower power consumption.

Summary

For the last several decades SATCOM has played an increasing role in commercial and military communication and data systems. But the insatiable demand for bandwidth across the globe creates new challenges for future aerospace and defense SATCOM designs, requiring new architectures and system designs. Whether the goal is extending soldier battery life, fitting into a small UAV payload, or supplying Internet on your next flight, the SWaP of SATCOM radios will become more and more critical. New high linearity IF subsystems, multichannel, high resolution ADCs, integrated RF transceivers, and VCO and PLL combinations will provide low SWaP solutions to the next generation of SATCOM radios.

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