How Ka-band has become invaluable to the military

Satellite technology has long delivered vital capabilities to defence groups across the world, enabling secure and assured communications between forces at home and abroad. Satcom for military has a long and rich history with frequent upgrades and advancements, culminating in unparalleled efficiency.

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The introduction of Ka-band satellite communications (satcom) has changed military satcom forever – and transformed commercial satcom as well! The changes continue as we transition toward full motion video imagery and real-time sensing data enabling global remote command and control while providing full-spectrum battlespace awareness to the warriors. These require massive:

- Data generation by new and innovative sensors;
- High speed processing to transform raw sensor data into critical usable information; and
- Very high-capacity, low-latency global communications to connect warfighters with data, processing and command networks

Satcom plays a vital role in the global communications needs of current and future military structures, and the evolution of military satcom (milsatcom) is a story of ever-growing needs for data transmission driving movement to higher frequencies, larger bandwidths, and increased spectral efficiencies. That story is undergirded by advances in technology along the way that enable it to unfold.

A milsatcom history

Milsatcom has moved up in frequency consistently from L and S-bands through C, X, and Ku-bands to end up in Ka and Q-bands. This rise in frequency comes with an increase in available spectrum and is driven by the need for higher throughput with smaller antennas (Figure 1). The costs of moving higher in frequency are time and money to solve new technology challenges and greater rain fade. But with Ka and Q-bands, the multiple-GHz-wide bands of spectrum allocated are highly alluring. There is even potential on the horizon to use 5GHz of uplink spectrum in the in Q/V-band.

For milsatcom, larger spectrum allocations at higher frequencies are absolutely necessary to handle increased sensor data transmission. Defense forces worldwide need both commercial and military satellites for their milsatcom needs. Special security, resilience, or guaranteed capability requirements drove development of several key milsatcom systems which are summarized in Figure 2.

Since the mid-1960s, the US military has used X-band spectrum for Defense Satellite Communications System (DSCS) to provide up to 200Mbps capacity per satellite. This band has many constraints, including nearly adjacent transmit and receive bands that force integrators to ensure there are no RF leakage or passive intermodulation products that can wreak havoc in the receive band. While X-band remains useful, it was not enough. As data transmission needs grew, military forces around the world began relying heavily on commercial Ku-band. Expanding the Ku-band uplink from 500MHz to 750MHz barely made a dent in the military's additional needs.

Experimenting with Ka-band - Researchers predicted in the 1970s that demand for geosynchronous (GEO) orbital slots would exceed capacity for C and Ku-band satellites, which have 2° separation requirements. As Ku-band orbital slots filled, the US took steps toward Ka-band by launching the Advanced Communications Technology Satellite (ACTS) in 1993. ACTS was the first high-speed, all-digital communications satellite with

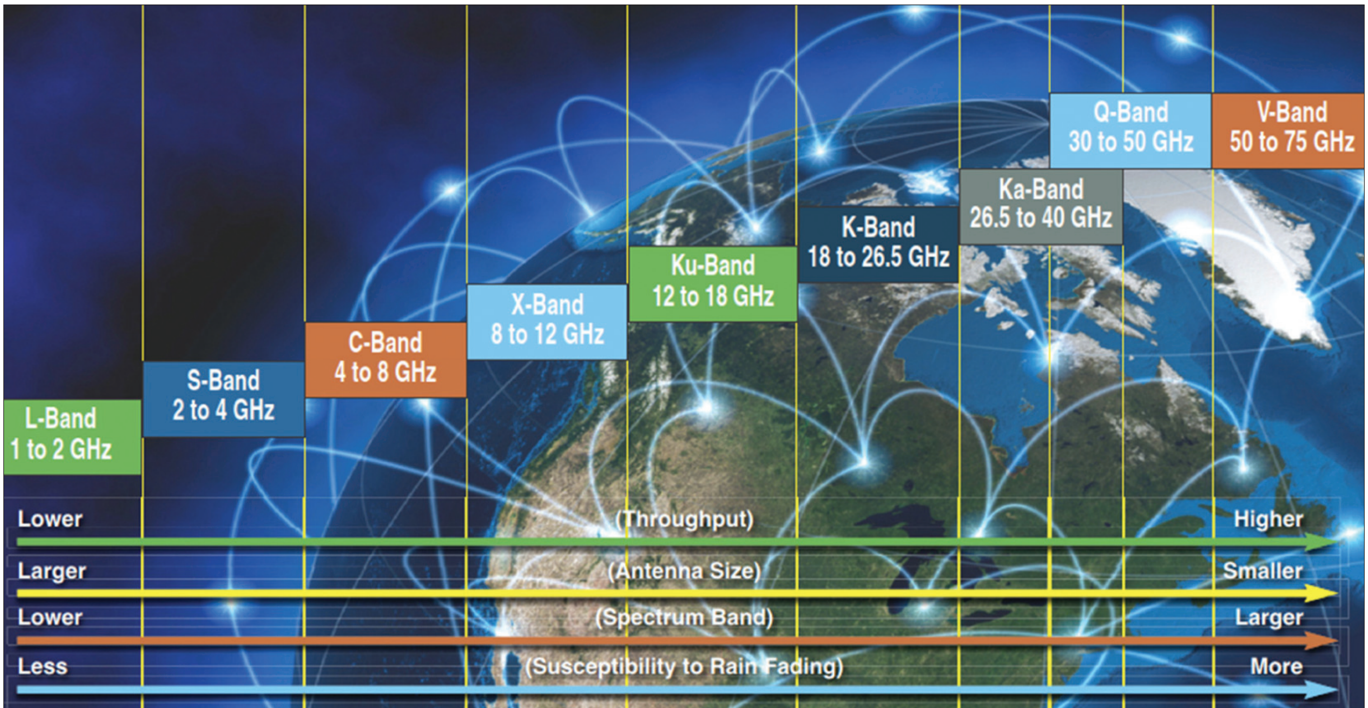

Figure 1. Higher frequency satcom bands provide greater spectrum allocation. Photo courtesy of Comtech Xicom Technology

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onboard baseband switching and operated in Ka-band. ACTS, along with Italsat, served a critical role in advancing satcom through experimentation with Ka-band RF technologies, propagation effects, and on-board switching. In 1997, a record data rate of 520Mbps TCP/IP throughput was achieved between large ground stations. In 1998, the Naval Research Lab used ACTS to achieve a Navy record 45Mbps uplink data rate for a ship at sea using a Xicom TWTA on a one-meter tracking antenna aboard a 45ft yacht. These demonstrations proved high-speed Ka-band transmission capabilities, and they enabled the commercial satcom industry to accept the technology risk of building a business at Ka-band. ACTS was decommissioned after 10 years, but industry followed with new Ka satellite launches that now dominate total capacity.

Broadcasting at Ka-band - In 1998, the US Global Broadcast System (GBS) began broadcasting critical information to military users globally over Ka payloads on two Ultra High Frequency Follow-On (UFO) satellites. GBS now also broadcasts over the Wideband Global Satcom (WGS) constellation at Ka-band. Over 1,000 GBS receive suites deployed worldwide can subscribe to large-volume products like full-motion video from unmanned aerial vehicles (UAVs), digital maps, satellite imagery, and more. This critical distribution function couldn't happen today without the UFO and WGS Ka-band payloads.

Moving up to Q-band - The US identified a need to provide the US President, Defense Secretary, and armed forces with reliable satcom for strategic command and control, and the Military Strategic and Tactical Relay (MILSTAR) program was born. MILSTAR incorporated adaptable anti-jam and low probability-of-intercept/detection (LPI/LPD) technologies with nuclear survivable designs to provide 2.4kbps peak speeds (Block I), and 1.5Mbps (Block II), for the most strategic command communications. This author's first project after college at TRW was simulating and analyzing adaptive antenna-nulling algorithms for the eventual MILSTAR antenna. When launched in 1994, MILSTAR became the most sophisticated, secure, robust, protected satcom network in the world, but with 1.5Mbps peak user data rate, there were limitations.

Advancing Protected Satcom - The US military worked with the UK, Canada, Australia, and the Netherlands on the next generation protected satcom, the Advanced Extremely High Frequency (AEHF) satellite system, a joint service system providing survivable, global, secure, protected, jam-resistant communications for high-priority military assets. AEHF is backward compatible with MILSTAR, operating at 44GHz uplink/20GHz downlink, but increases peak user data rates to 8.2Mbps. The sixth satellite launched in March 2020, completing global coverage from 65°N to 65°S. AEHF added to MILSTAR's role by increasing data rates and bandwidth, providing the US and allies an advanced, highly-resilient protected satcom constellation.

Figure 2. Key Milsatcom systems from 1960s to present. Photo courtesy of Comtech Xicom Technology

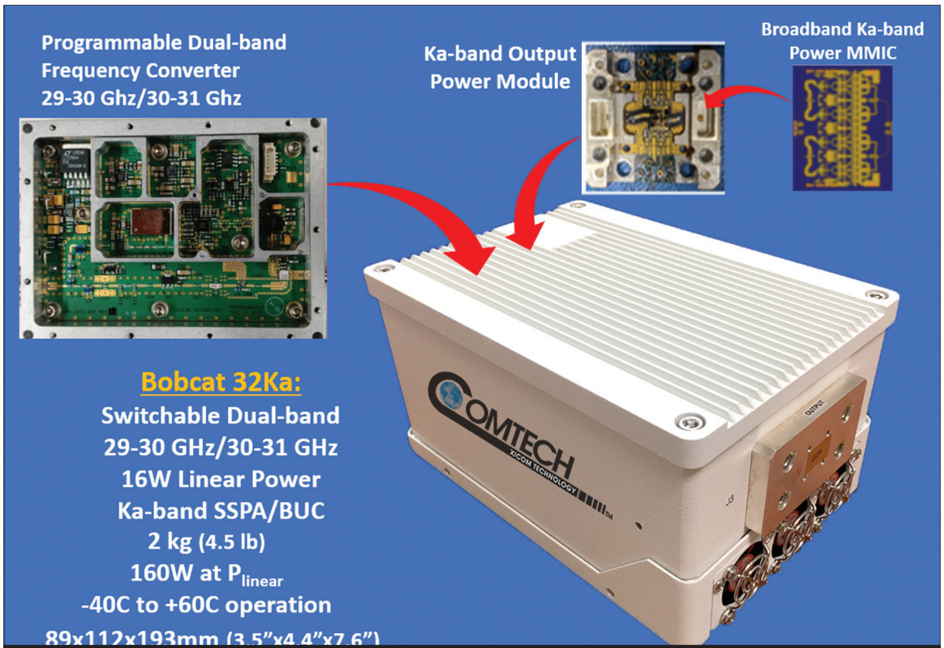

Figure 3. Switchable dual-band Ka SSPA/BUC for transportable terminals in 2 kg package. Photo courtesy of Comtech Xicom Technology

Military leads the way to Ka - While AEHF created protected satcom, military use of commercial Ku-band for bandwidth-hungry surveillance missions around the world was gobbling up capacity. The US began looking at Ka-band for relief. Available uplink bands of 27.5-30GHz for commercial satcom and 30-31GHz for government/military use were very wide and largely empty. Proposed high-throughput commercial Ka-band systems were still experimental, and many weren't proposing global coverage. The US decided on a military Ka-band solution. Use of 30-31GHz uplink and 20.2-21.2GHz downlink allocated for government/military was one of the first real high data rate uses of Ka-band satcom besides direct broadcast.

Gap-filler goes global - The Wideband Gapfiller Satellite (WGS) system, later renamed Wideband Global Satcom system, first launched in 2007, expanding capacity for the US and its allies. WGS was developed as an international network with users including US military services, White House Communications Agency, US State Department, and international partners Australia, Canada, Denmark, Luxembourg, New Zealand, the Netherlands, the Czech Republic and Norway. WGS provided X- and Ka-band capacity far beyond any the military had before with 2.4-3.6Gbps data transmission rate/satellite. The 1GHz of spectrum available for military use at K/Ka-band, plus frequency reuse with Ka spotbeams, yielded massive increases in milsatcom transmission capacity. WGS-1 provided more capacity than the entire DSCS constellation.

WGS keeps advancing - WGS Block I (satellites 1-3) provide 2.4Gbps peak capacity/satellite and include Ka-band GBS augmentation, adding new information broadcast capabilities and supporting two-way communications over GBS. Block II (4-6) incorporate RF bypass capability for airborne intelligence, surveillance, and reconnaissance (ISR) platforms requiring ultra-high bandwidth. WGS Block II Follow-On (7-10) add limited protected services for users with modems having anti-jam capability. Two more satellites, (11/12), are under development with narrower spotbeams for stronger connections, providing twice the capability and enhanced security.

The start of commercial Ka-band - Commercial Ka-band's early start was uneven, as companies launched small Ka-band payloads on Ku-band satellites to keep their slots. Several companies began work on large Ka-band satellites for GEO slots to cover the populated land masses. Traditional satcom service providers held back until they saw future revenue slipping away to upstart competitors with high capacity, low cost/bit, and no legacy customers to support. Early North American successes starting in 2005 using the 29.5-30.0GHz uplink included WildBlue's competitively priced consumer internet access and DirecTV's popular HD programming. These systems and others, like Eutelsat's KaSat, Avanti's Hylas, and Thaicom's IPSTAR, were commercial Ka-band trailblazers.

The military starts to switch bands - With commercial Ka-band growing, military users became interested in switching between the government/military band (30-31GHz uplink) and the adjacent commercial band (29.5-30GHz or 29-30GHz uplink) during operations. If you're on a congested network, switching to another network is a highly appealing option to military users. The dual-band terminal must be real-time switchable, meet performance requirements for both systems, and not grow too large, heavy, or costly. Broadband antennas can cover both bands, and 1GHz-wide modems are available. Dual-band switchable frequency converters and broadband solid-state power amplifiers (SSPAs) that meet gain flatness and linear output power across 2GHz are key technologies. Current broadband amplifier devices and programmable converter chips enable design for very compact form factors like 16W WGS linear output power with field-commandable band-switching in rugged 2kg packages (Figure 3).

GEO HTS widens Ka - Commercial Ka-band's early years were followed by major industry investments in High Throughput Satellites (HTS) for GEO orbits that push Ka-band on-orbit capacity into the Tbps. HTS GEO capacity will keep growing through 2030, with quadrupling revenues. These HTS systems use the full 27.5-30.0GHz uplinks, but with varying frequency plans such as a single 2.5GHz band with a new broadband modem, multiple overlapping 1GHz bands, and asymmetrical plans with varying sub-band bandwidth and spacing. Broadband antennas and feeds are available that meet performance over the wider band; the tougher challenge was custom multi-band switchable frequency converters for each system while meeting amplifier linearity and tight gain variation over 2.5GHz. With military users' desire to add the 30-31GHz uplink, upconverters may need to have 4-5 sub-bands with 3.5GHz wide amplifiers. Flexible SSPA/BUC designs with programmable/adjustable building blocks are critical to addressing the myriad frequency plans. Changing frequency plans in multi-band switchable BUCs must be simple and fast to meet short development timelines.

Ka-band LEO demands More - Recent industry focus is on non-GEO systems, including low Earth orbit (LEO) and medium Earth orbit (MEO) constellations that must launch 10s to 1000s of spacecraft to cover the globe with fast-moving satellites orbiting much nearer Earth's surface than GEOs. These LEO systems cost more to launch and maintain than GEO with shorter lifetimes and many more gateways, but much lower latency. LEO systems with intersatellite crosslinks (ISLs) have a big advantage in fewer 'hops' for low latency and higher network efficiency. They're also advantaged for aero and marine mobility markets and produce massive network capacity – 20+ Tbps by 2030. SpaceX's Starlink, OneWeb, Telesat's Lightspeed, Amazon's

Single-Sideband Phase Noise (dBc/Hz)

Frequency Offset	IESS	w/ 10MHz Reference	w/ 10MHz Reference and X5 Multiplier	w/ 100MHz OCXO Reference	100 MHz OCXO Improvement over 10 MHz	100 MHz OCXO Improvement over 10 MHz and X5 Multiplier
10Hz	-30	-46	-50	-62	16dB	8dB
100Hz	-60	-68	-75	-81	13dB	6dB
1kHz	-70	-80	-82	-93	13dB	11dB
10kHz	-80	-90	-85	-97	7dB	12dB
100kHz	-90	-96	-95	-101	5dB	6dB
1MHz		-120	-123	-132	12dB	9dB
10MHz		-126	-123	-143	13dB	20dB

Parameter		10 MHz reference with X5 multiplier	100MHz low phase noise OCXO	100 MHz OCXO Improvement	100 MHz OCXO % Improvement
Random Phase Jitter	sec RMS	1.10E-13	8.42E-14	2.56E-14	23%
Random RMS Noise	rad RMS	0.0200	0.0153	0.0047	23%
Random RMS Noise	deg RMS	1.146	0.879	0.267	23%
Random EVM	dB	-33.975	-36.286	2.311	-
Random EVM	% RMS	2.001	1.534	0.467	23%
Random Residual FM	Hz	1.15E+05	8.17E+04	3.37E+04	29%

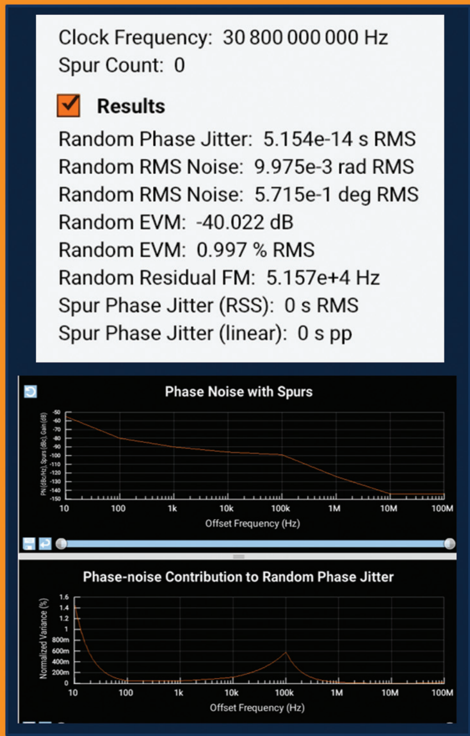

Figure 4. LEO Ka systems need SSPA/BUCs with better Phase Noise, Jitter and EVM performance to meet Spectral Efficiency Goals. Photo courtesy of Comtech Xicom Technology

Kuiper, and SES's mPower are all proceeding with satellite procurement and ground terminal development, each pushing the limits of possibility for an efficiency/cost edge. Complex, higher-order modulation and coding used to maximize spectral efficiency and drive down system cost/bit demand pretty dramatic tightening of RF component requirements including lower phase noise, phase jitter, error vector magnitude (EVM), and gain variation for SSPA/BUCs (Figure 4), all while radically driving down cost with high volume given the large number of gateways and very large number of users.

Enhancing Ka-band for the military - Surveillance demands have heightened since the US withdrew from the Open Skies Treaty in May 2020. UAV capabilities continually increase, improving imagery and monitoring for pre-emptive strikes, surveillance, and remote real-time decision-making. Defense departments and contractors worldwide are investing heavily in ISR capability, which just keeps driving up high-speed satcom requirements. The US Navy is outfitting the P-8A Poseidon surveillance aircraft with high-speed satcom to support enhanced surveillance. Airborne ISR platforms are looking beyond X-band, Ku-band, and standard Ka-band (27.5-31GHz) at alternative Ka-band spectrum to add capacity and enhance security. Non-standard Ka-band frequencies will require new terminal designs. New RF chipsets and output combining structures are needed for the amplifiers. Efficiency improvements are critical to enable these higher data rates for extended unmanned flights. Power amplifiers must be more efficient and located very close to the antenna to minimize RF losses. Split box designs, with the power amplifier mounted on the antenna and multi-band block upconverter located elsewhere, reduce required SSPA linear output power, but demand operation in challenging cabin-external environments (Figure 5).

The impact of Ka-band satcom is accelerating, and military satcom users will benefit from both technology advances and new system architectures coming online now and over the next few years. A lot of new capacity built at much lower cost/bit can be applied to transmission of critical military communications if governments can figure out how to work with commercial enterprises that build and operate these systems. Today's government/military users must seek flexibility and adaptability in networks and user terminals along with the performance and protection they have always demanded. **GMC**

Figure 5. Multiple-band Enhanced Ka SSPA/BUC for ISR platform is split to increase EIRP and efficiency. Photo courtesy of Comtech Xicom Technology