ISSN: 1745-5502

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VHTS systems and the amplifiers they need to succeed

The satellite landscape is changing, with smaller, lighter, higher throughput satellites being launched into lesser-used orbits like never before. The massive investment in very high throughput satellite (VHTS) systems is changing the world of satcom amplifiers forever.

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More than US$36 billion has been invested in space companies since 2000, a massive increase over the previous 20 years. Even in 2020, the year of COVID-19, space investments continued apace at nearly US$7.7 billion, while commercial revenues began to recover after slipping due to virtual stoppages in aero, cruise, and oil & gas.

Commercial revenues of US$315 billion in 2020 were down two percent from 2019's US$319 billion but expected to rise again slightly in 2021 before accelerating through 2022 and beyond according to Euroconsult.

The satellite systems and services part of the global space economy is forecast by Strategy Analytics to grow at 5.4 percent per year through 2028 to reach US$93.6 billion. And NSR expects satcom wholesale capacity revenue to double from 2022 levels up to US$26.5 billion by 2029. If the CAGR continues, the industry would generate US$50 billion annually by 2040.

While the top four traditional FSS operators (SES, Intelsat, Eutelsat and Telesat) comprise close to 60 percent of industry capacity revenue, their share has been decreasing. The top 10 ranking of service providers has seen significant turnover, as companies like Viasat, Hughes, Inmarsat, Yahsat, China Satcom, and ISRO move up. The coming online of new VHTS capacity in both geosynchronous (GEO) and low Earth orbit (LEO) constellations will further shake things up.

Traditional communications satellites in GEO orbits have demonstrated their worth for decades. While costly, they are extremely capable with long service lives. Their 35,000km altitude provides a wide field of view, enabling nearly global coverage with three satellites spaced appropriately. Technology advances have improved efficiency, flexibility, and performance, along with massively increased capacity.

HTS and VHTS systems have already caused a dramatic increase in total available throughput, and the trend will continue. With the satellite communications market projected to grow at a CAGR of >7.7 percent over the next five years to US$41.3 billion per Fortune Business Insights, Northern Sky Research (NSR) estimates the global capacity available from the HTS/VHTS satellite systems will increase at a CAGR of more than 26 percent from 2Tbps in 2018 to more than 20Tbps in 2028, when half of all VHTS/HTS capacity will be provided by NGO systems, from only about 10 percent today.

The VHTS capacity growth comes from two system types: New larger and much higher capacity geosynchronous-orbit satellites (GEO-VHTS) and LEO and medium Earth orbit (MEO) satellite constellations (non-GEO VHTS) consisting of hundreds to thousands of satellites in multiple orbital planes providing full earth or regional coverage. Over the next decade, non-GEO VHTS demand and revenue growth will be stronger than GEO-VHTS, but from a smaller starting point. GEO-VHTS will still provide half of global HTS capacity and revenue in 2029, but NSR projects that half of the total VHTS market will be through non-GEO systems by then.

VHTS GEO systems

Current and planned GEO VHTS systems, which can provide as much as 1Tbps capacity from a single satellite, are generally in Ka-band with a few in Ku-band. Many plan to add V-band feeder links to complement the dense Ka-band beam pattern that provides user coverage. Eliminating 'holes' in coverage due to gateway uplinks enables more complete user coverage and increases capacity available for user traffic. In addition, fewer total gateways are needed with the higher data rate feeder links. These V-band feeder uplinks require powerful and highly accurate antennas and very high power, high-performance V-band amplifiers to meet the link budget.

The V-band high-power amplifiers (HPAs) must provide 4.2GHz (or up to 5.2GHz to cover extension to 51.2-52.4GHz band) of operational bandwidth with very low gain variation over the band, as well as excellent phase noise if a BUC is included, and high linearity performance as measured with noise power ratio (NPR). Other requirements are to be compact, lightweight, and rugged for operation mounted very close to the feed, minimizing loss. Larger GEO gateway

Parameter	Requirement
Frequency	47.2 – 51.4 GHz [47.2 - 52.4 GHz planned]
Peak Output Power	250 Watt (54.0 dBm)
Linear Output Power (minimum at flange)	80 Watt (49.0 dBm)
Noise Power Ratio (at P_{linear})	-19 dBc
Small Signal Gain (minimum at P_{linear})	60 dB
SS Gain Variation: max across full band Any 500 MHz sub-band	< 4.0 dB peak-peak < 2.0 dB peak-peak
Size	20" (50.8cm) x 11.0" (27.94cm) x 10.3" (26.2cm)
Weight	58 lbs

Figure 1. 250W peak V-band gateway uplink TWTA (a) Requirements (b) Amplifier in production

antennas provide a lot of gain at such high frequencies, but meeting pointing requirements at 50GHz grows more difficult as antenna size and weight increase. System designers need as much linear power as they can get from the amplifiers.

Figure 1 summarizes the key requirements for the new V-band HPAs based on currently available capability of 250W peak RF power. Higher power will be needed in the future; TWTA development is continuing toward higher power levels as well as creating phase-combined systems using the 250W peak TWTAs, which can enable as much as 125W of combined linear power.

The first commercially available V-band TWTA has been developed and is currently in significant production (Figure 1 b). It is a 250W peak TWTA providing 80W of linear RF power at the output flange as defined by an NPR of -19dBc while drawing 1,200W prime power.

In addition to V-band gateway uplink amplifiers, operators continue to need high power Ka-band uplink amplifiers. Until recently, Ka-band HPAs that can cover the full 3GHz commercial Ka-band were limited to TWTAs providing 500W of peak power. Some operators need even higher peak power and linear power, and new 550W and 650W peak TWTAs are now available options for 0.4-1.1dB more linear power in the same size package as the 500W unit. This can offer solutions for integrators who need additional power without impacting existing terminal design and interfaces.

Some operators are satisfied with the 500W peak TWTA's linear power but would like to have SSPAs. These 160W linear power SSPAs are planned but remain under development despite the market demand. The performance and physical difference between the existing 500W peak TWTA, and each of these options (with the SSPA estimated) is shown in Figure 2.

VHTS LEO systems

Many LEO VHTS systems are currently planned to operate at Ka-band, V-band, or a combination of both in orbits from 500-2,000km from Earth, offering faster communications (lower latency from lower altitude orbit) and providing even higher bandwidth per user than GEO VHTS systems – and any other last mile technology except true 5G. Higher frequencies enable higher data rates, smaller antennas, narrower beams, and greater security. A number of LEO systems will be built to offer global, low-latency, low cost/bit switched connectivity for existing and new applications - providing services competitive with terrestrial telecom to crack open up the much larger telecom market.

Investment firms had more than US$2.3 trillion on hand

V-band Systems

V-band satcom, also called Q/V-band as it straddles the Q- and V-bands, uses 47.2-52.4GHz spectrum for satcom uplinks (with a keep out band from 50.2-50.4GHz for EESS) and 37.5-42.5GHz for downlinks. The higher frequency of V-band signals makes them more susceptible to rain fade than Ku- or Ka-band but can be used for LEO systems with a high degree of built-in geographic diversity. The 5GHz spectrum now allocated at V-band makes it the widest available satcom uplink band.

Hughes, Viasat, OneWeb, SpaceX, Telesat, O3b, and Mangata have plans to launch thousands of satellites for stand-alone V-band systems or as part of Ku- and Ka-band HTS systems with V-band payloads.

Initially, V-band will be used by companies with Ka GEO HTS to provide high-capacity feeder links, freeing up valuable capacity for users in beams where gateways are located and reducing the total number of gateways required – lowering the system's cost/bit.

NSR has forecast cumulative 2023-2030 revenue greater than US$12.6 billion for capacity sales and leases and US$23.8 billion in service revenues from V-band global enterprise VSAT, consumer broadband, and backhaul markets.

Several satcom service providers have already made major V-band commitments, including: Eutelsat, who has launched an experimental payload and ordered the next-generation KONNECT VHTS satellite system planned for service starting in 2022; Hughes, who is incorporating V-band feeder links into their next VHTS Jupiter satellite; and OneWeb, who recently received approval to add 1,280 V-band satellites to its previously approved Ku/Ka constellation, half of which must be launched within six years.

Parameter	500W pk TWTA	550W pk TWTA	650W pk TWTA	160W lin SSPA
Frequency	27.5 - 30.0 GHz	27.5 - 30.0 GHz	27.5 – 30.0 GHz	27.5– 30.0 GHz
Rated Peak/Sat Output Power	500W (57.0 dBm)	550W (57.4 dBm)	650W (58.1 dBm)	400W (56.0 dBm)
Linear Output Power (at flange)	160W (52.2 dBm)	182W (52.6 dBm)	215W (53.3 dBm)	160W (52.2 dBm)
Noise Power Ratio (at P_{linear})	-19 dBc	-19 dBc	-19 dBc	-19 dBc
Power Draw (at P_{linear})	1000W	1100W	1250W	1750W *
Weight (typical)	58 lbs (26.3 kg)	58 lbs (26.3 kg)	58 lbs (26.3 kg)	65 lbs (29.5 kg) *

*Figure 2. Ka-band gateway uplink TWTA and SSPA comparison. *Estimate based on preliminary design concept* ●●●

to spend as of early 2020. Estimates for deploying an operational LEO system range from US$5-10 billion, with annual operating costs very high; satellite replacement costs alone total US$1-2 billion for a large constellation with five-year life spans. Even though competition for capital initially held these proposals back, all that money looking for higher returns has enabled several systems to move forward simultaneously. SpaceX raised US$1.9 billion in 2019 and may IPO its Starlink subsidiary, which has now launched over 1,700 satellites with 950 of them operational in the nearly completed first 'shell' of coverage now being used for user beta testing. OneWeb, after leaving bankruptcy with investments from the UK government and Softbank, attracted strategic investments from Hughes and Eutelsat, and has now launched 218 of the planned 648 satellites. They will need to raise an additional US$2.0-2.5 billion to complete the US$6-7 billion constellation. Telesat LEO is moving ahead after receiving investment and service commitments from the Canadian government and has awarded its space contract. Amazon, with US$55 billion in reserves, is self-funding its 3,236 satellite constellation with US$10 billion investment as the only large tech player to do so, although Facebook, with reserves of US$55 billion, is rumored to have filed plans through a proxy. Apple with its US$100+ billion in reserves, is considering similar ventures, and multiple filings have been made by others.

With a LEO constellation, global coverage requires a very large number of spacecraft. This concept requires major changes in satellite operations, manufacturing, and the supply chain. LEO orbits are much tougher on satellites, and the average life span for LEOs is expected to be about five years.

Ground segment costs could determine the success of most LEO systems; Starlink will require 123 ground-station locations and ~3,500 gateway antennas to achieve maximum throughput from its initial 4,400 satellite constellation. Gateways for GEO satcom systems are expensive - ~US$1-2 million. LEO gateways have significantly lower power requirements, but the large quantity needed means gateway costs have to be much lower than current approaches for the business case to work.

Compared to GEO systems, there are myriad new requirements on the LEO ground terminal, including horizon-to-horizon tracking antennas, rapid switching between satellites and gateways, and lightweight, efficient, reliable, and low-cost amplifiers that mount on rapidly tracking antennas at dozens to hundreds of gateways. These solid-state power amplifiers (SSPAs) need to be produced in higher volume at lower cost in the power levels needed, from 5W for user terminals up to 100W or more of linear power for gateways.

For customer premise equipment (CPE), residential customers typically pay approximately US$100-200 to purchase it or pay US$10-20 in monthly rental fees. ESA antenna cost has to be cut by at least an order of magnitude for this to work… but the volume could drive the solution. Starlink and OneWeb have filed blanket license requests for 1 million and 1.5 million user terminals, respectively, with the FCC. Amazon's filing proposes connecting tens of millions of users around the world. With this market to drive the development, it could happen much more quickly. Really, the key to succeeding for LEO systems is reducing cost across the entire network. If the CPE cost can be brought down to the US$300-$500 range, McKinsey analysts believe that annual growth of more than 60 percent can be achieved in business to business (B2B) satcom capacity demand (Figure 3).

For gateways in new LEO systems, the extreme optimization of the network leads to more complex modulation/coding (mod/cod) schemes, placing new demands on the RF equipment. Transmission of multiple simultaneous complex carriers with rapid band and frequency

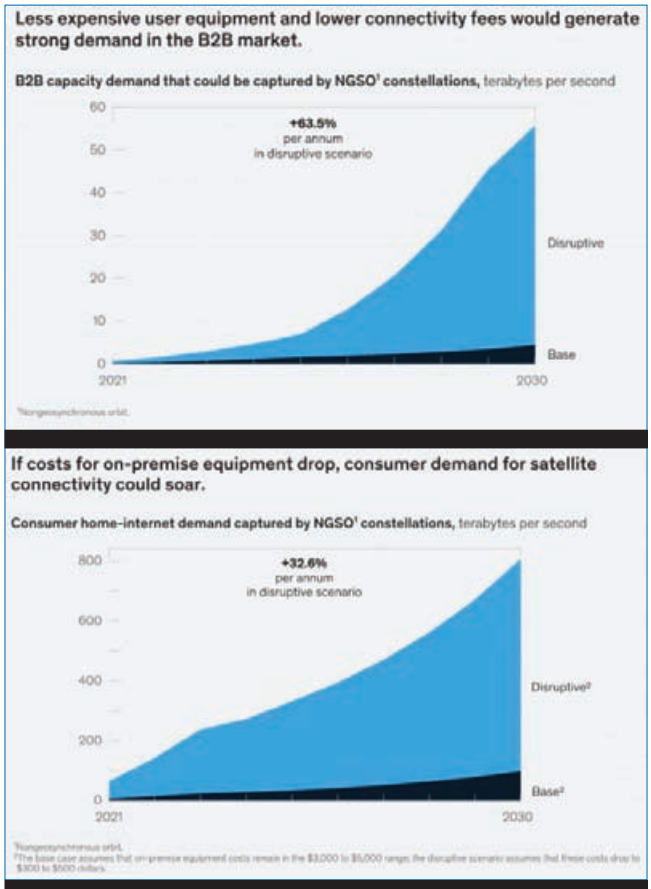

Figure 3. Low-cost CPE and low connectivity costs could drive radical growth in capacity demand for both (a) business to business and (b) residential consumers [McKinsey 2020] ●●●

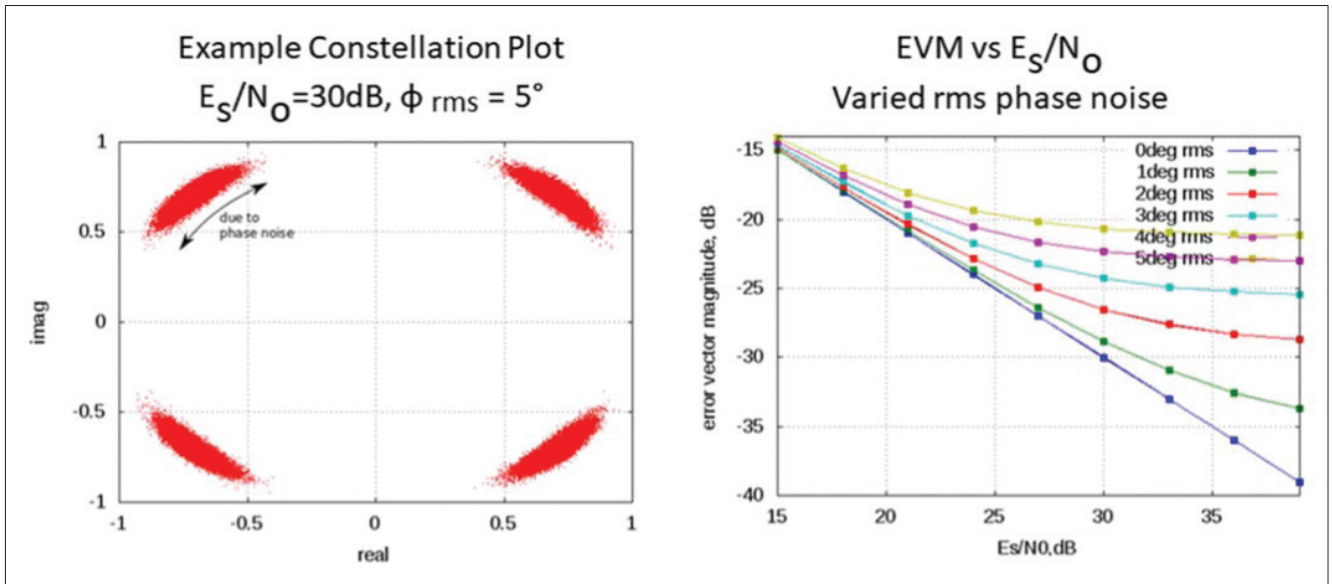

Figure 5. Phase jitter impact on error vector magnitude (EVM) (a) example constellation with 30 dB Es/No and 5° rms phase noise (b) impact of varying rms phase noise on EVM ●●●

switching means gain and phase variations must be kept extremely low, as well as phase noise. The need to maximize the power per modulated carrier to optimize transmission means that the linearity and linear power density (efficiency) of the amplifier is critical. The unit must be reliable as it is likely to be placed in unmanned or lightly manned locations, Finally, the cost per linear watt must absolutely be minimized for the business case to succeed. Cost, performance, efficiency, reliability, manufacturability – these must all be optimized for the system to be financially viable.

Xicom Puma GaN Ka SSPA rearview ●●●

Ka-band LEO gateway SSPAs must provide 2.5GHz of operational bandwidth with very low gain variation over the band and good linearity performance as measured using noise power ratio (NPR). The converters must have excellent phase noise performance, and phase jitter must be very low to minimize error vector magnitude (EVM). They also have to be compact, lightweight, and rugged to mount on a rapidly moving tracking antenna. Key requirements for the new Ka-band SSPAs include:

System Need	Amplifier Requirement	Design Approach
Smallest antenna size meeting G/T for lowest terminal cost	High power from amplifier in small package	*Use highest-power Ka-band GaN chips available*
Minimize impact on pointing performance	Lightweight with high power density	*Use high efficiency GaN chips and highly integrated design*
Provide maximum throughput with high availability	High linear power with excellent RF performance over wide range of operational modes, low EVM	*Include linearizer, design for wide output power range, incorporate calibration, minimize phase noise, jitter*
Cover multi-GHz RF band with commercially available 1 GHz or newer 1.5 GHz modems	Seamless multi-band switching across 2.5-3.5 GHz while maintaining power levels	*Programmable multi-band switchable L-band upconverter with auto-calibration per band*
Operate close to feed on rapidly tracking antenna	Challenging environment with varied temperature profile	*Rugged design with thermal margin in lightweight package*
Operate in remote gateways without onsite support	High reliability, low to no maintenance	*Design with high margin, extensive pre-release testing, strong quality program*
Low cost gateway to support system business case	Low cost, high volume production	*Design to cost, incorporate multiple high volume mfg sources, cooperative material procurement w/ suppliers*

Figure 4. Key Ka-band SSPA requirements for new LEO systems ●●●

Two of the critical requirements that are far more stringent that typical satcom systems include rms phase noise and error vector magnitude (EVM). Phase error performance can have a large impact on quality of transmitted multi-carrier waveforms, as shown in Figure 5. Figure 5 (a) shows the impact of five degrees of rms phase noise, or phase jitter, on

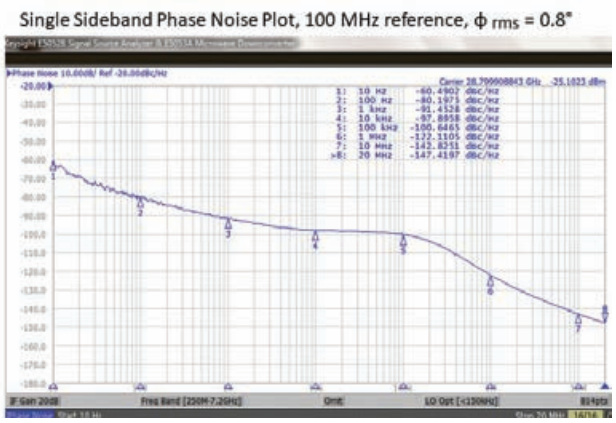

Figure 6. Ka-band phase noise for high performance SSPA/ BUC with 100 MHz reference

a quadrature constellation. There is significant smearing of the received signal, which would impact achievable link data rate – the modem would have to adjust the mod/cod and transmit data rate to maintain BER performance. Figure 5 (b) shows the impact on the error vector magnitude (EVM) of differing levels of rms phase noise, or jitter. Each dB of phase jitter has a significant impact on the EVM, and thus on system optimization.

By using a lower phase noise, higher frequency reference (i.e., 100MHz), compared with traditional systems using 10MHz reference, much lower rms phase noise can be achieved. Using a high quality 100MHz reference, 0.8dB integrated rms phase noise is achieved with the Ka-band converter under test (Figure 6).

The result is minimal impact on EVM; less than 3 percent EVM was measured on this 48dBm Psat unit at output power of 42dBm. In other systems, EVM values of 10 percent or even 15 percent are considered acceptable; for these LEO systems, EVMs <5 percent are needed to avoid impacting the modem's ability to manage the link effectively and optimize capacity.

A range of Ka-band SSPAs continues to be developed in the industry to meet these new requirements; Comtech Xicom for example is offering a 52dBm (160W) rated power Ka-band SSPA/BUC which provides 63W of linear power with -19dBc NPR. The 48dBm (63W) linear power unit provides <2.5dB gain variation over the full band and draws only 800W AC prime power. The unit measures 14"x7.8"x19", weighs 17kg, and is shown in Figure 7.

With rapid change occurring in the satcom industry, demand for new and innovative amplifiers to address operator and terminal integrator requirements will continue evolving. The technology to support these is ready, and the satcom amplifier industry is working hard to use the latest technology to provide the best solutions for each system's unique needs.

Figure 7. Ka-band 63W linear GaN SSPA for new LEO system gateways