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Solid state power amplifiers 101

Amplifiers come in many shapes and sizes in the satellite sector, and not all are created equal. Whether it's solid state power amplifiers (SSPAs), vacuum-tube amplifiers, magnetic amplifiers or negative resistance amplifiers, all have their pros and cons, depending on the application. Whatever the type, amplifiers are an essential component enabling satellite communications by increasing signal power. Here, we examine the differences between GaAs and GaN SSPA technology, and take a look at what's available on the market today.

The general public, and even many of us within the satellite industry, take for granted the fact that all the complicated mechanical parts required to make a satellite communications network function, just work. We trust that the engineers and manufacturers know what they're doing, but we don't worry too much about it ourselves.

However, this leads to a great deal of confusion for anyone who isn't an expert, especially when there are so many technologies available on the market to meet a single demand.

Within the amplifier field for satellite communications applications, today we're looking at two key technologies:

- **Solid state power amplifiers (SSPAs):** A series of combined field effect transmitters (FETs) amplify the RF signals. FETs are formed of semiconductor materials such as Gallium Nitride (GaN) or Gallium Arsenide (GaAs), which, through their high band gaps and electron mobility, are more useful at high frequencies than traditional materials like silicon (Si).
- **Travelling wave tube amplifiers (TWTAs):** A linear-beam vacuum tube in which the RF signal is amplified by absorbing power from a beam of electrons as it passes through the tube. Today, all TWTAs used for satellite communications feature multi-stage collectors, resulting in smaller and more efficient amplifier products.

SSPAs and TWTAs are both valid technologies for a wide range of satellite communications applications. The best choice for any solution usually depends on operating parameters like linear power, weight and annual prime power expense, although reliability, serviceability and capital cost all come into play as well. The prevailing opinion is that TWTAs provide higher output power levels for a given frequency than SSPAs, but they are larger, heavier and require higher power supplies. SSPAs, in turn, are considered ideal for lower power applications where they are often more economic. Ultimately, there is no one-size-fits-all model when deciding between SSPAs and TWTAs; each application is unique and products must be weighed on their individual merits.

Solids state power amplifiers: GaN vs GaAs

Not all SSPAs are alike. GaAs-based SSPAs have been used for more than 40 years, growing in popularity for RF/microwave applications and quickly replacing silicon-based semiconductors such as bipolar transistors and metal oxide semiconductor field effect transistors (MOSFETs). GaN-based SSPAs are much newer; they've been in action since about 2000, when the Department of Defense (DoD) developed them for improvised explosive device (IED) jammers in Iraq. The commercially developed GaN SSPAs produced in the aftermath were originally designed for low-frequency L, S and C-band satellite communications, but have since been advanced to the higher frequency X, Ku and Ka-bands. Both GaAs and GaN amplifiers have been utilised for microwave and millimetre wave electronics such as satellite, radar, communications and electronic warfare.

Power

Power is one of the key differentiators between GaN and GaAs amplifiers.

GaN operates at higher voltages than GaAs, at 24-50V and 5-20V, respectively, within the SSPAs available on the market today. As GaN/GaAs technology continues to be developed with new innovative products, these ranges may be expanded. The increased operating voltage of GaAs SSPAs results in lessened I^2R power loss from the amplifier; of course, with less power loss, OPEX costs for input power are reduced. The higher operating voltage also means that GaN SSPAs are more useful for high power applications. With the higher operating voltage, GaN has a much higher breakdown voltage at more than 100V, compared with 20-40V for GaAs, depending on the manufacturer and device.

The operating voltages of both GaN and GaAs SSPAs can be enhanced by using multiple amplifiers in push-pull, in parallel, or by combining output in transformers or networks to increase voltage by a factor of four or five. This can produce tens of Watts of power for GaAs devices, or hundreds of Watts for GaN devices.

While for many applications the ability to operate at higher powers is an advantage, the lower voltage operation of GaAs amplifiers is ideal for some mobile devices, including mobile phones. Since such devices have both lower power requirements and operate at lower frequencies, the economies of scale mean that it is typically more cost effective to use GaAs SSPAs for these applications, while extending battery life.

Temperature

There is a significant difference in operational temperature for GaN and GaAs SSPAs, which play an important role in

GaN-based SSPA/BUCs from CPI Satcom

CPI Satcom has long played a vital role in the high power amplifier industry, enabling effective satellite operations around the world. As part of its broad portfolio, CPI Satcom manufactures GaN-based SSPAs and BUCs, utilising GaN FETs instead of the traditional GaAs FETs.

According to Doug Slaton, Marketing Product Manager at CPI Satcom, historically, the frequency and bandwidth of SSPAs was dictated by the manufacturers of FETs, but this has all changed in recent years as manufacturers have become capable of producing FETs in almost every frequency. This is a great benefit to military satellite service users in particular, since GaN devices are more efficient than GaAs devices, allowing for smaller footprints, lighter weight and higher practical power levels than the older technology.

A key product in CPI Satcom's portfolio is its Ka-band 160W SuperLinear GaN SSPA/BUC, available either purely as an SSPA, or with an L-band to Ka-band BUC option with multiplexed 10MHz and 50MHz reference added on. The SSPA was designed as a solid, easily-maintained and highly efficient product with ample thermal margin. It provides high linearity excellent AM/PM, phase noise and spectral regrowth performance, and contains a digitally-controlled attenuator. Output frequencies of 27.5-30.0GHz, 30.0-31.0GHz, or 27.5-31.0GHz are attainable, with minimum gains of 64dB and maximum gains of 70dB at small signal.

Demonstrating mindfulness of the Size, Weight and Power (SWaP) requirements that are so important to customers today, CPI Satcom's Ka-band SuperLinear 160W GaN SSPA measures just 445 x 242 x 221mm, and weighs 21.4kg. With the BUC option included, the device is a little larger at 445 x 318 x 221mm and marginally heavier at 22.7kg.

"While accommodating these often contradictory requirements can be a difficult assignment, industry manufacturers have answered the challenge with many product offerings, including the increased use of the latest solid state technology," said Doug Slaton.

their differing applications. GaN SSPAs can operate at much higher temperatures than GaAs devices without degradation. The thermal conductivity of GaN at 1.7W/cm^{-K} is more than three times greater than that of GaAs at 0.46W/cm^{-K}. High thermal conductivity results in a low temperature increase during electricity conduction; thus, GaN SSPAs can operate at much higher power levels than GaAs analogues. A GaAs SSPA will rapidly degrade at 175 degrees C, for example, while a GaN amplifier will continue to operate for millions of hours even at 350 degrees C for today's most advanced SSPAs.

The increased operational temperatures withstood by GaN SSPAs affords a couple of options during the manufacturing process. For one, the heat sink can be reduced in size since waste heat generation is reduced, resulting in an overall SSPA size reduction. Another option is to allow the GaN SSPA to operate at an elevated temperature, or else to come to a balance between the two differentials. Finally, if the SSPA is placed near the antenna to reduce RF losses during operation, it can be run even cooler or made smaller still.

Reliability

GaN amplifiers are considered inherently more reliable than GaAs SSPAs by most in the industry, with a significant order-of-magnitude boost in terms of mean time to failure (MTTF) hours, which translates to reduced OPEX costs for maintenance and down-time. This belief is held even by companies that produce both GaAs and GaN devices, such as Communications and Power Industries LLC (CPI).

The higher power density of GaN (4-8W/mm) compared to GaAs (05.-1.5W/mm) means that GaN can dissipate heat more rapidly from its container than GaAs. This is very important when it comes to product longevity and reliability, since prolonged exposure to high temperatures has a negative effect on electrical components.

However, as GaN SSPAs have smaller parts than their GaAs analogues, most GaN SSPA manufacturers have opted to produce smaller amplifier packages for GaN devices, affording amplifiers that have similar thermal margins to GaAs products, resulting in amplifiers of comparable reliability. In CPI's *'High Power Amplifier Selection For Satellite Uplinks: A CPI Technology Focus'* article, the author concludes: "Thus, in practice, GaN SSPA reliability is approximately the same as that for GaAs versions."

Efficiency

The crystal lattice structure and the advantageous electron mobility properties it imparts onto GaN compared with GaAs mean that GaN SSPAs are inherently more efficient than GaAs SSPAs.

We've already outlined that, due to the reduced loss of I^2R power during conduction, less voltage will provide the same overall power when using a GaN amplifier compared with GaAs. For instance, C-band GaN SSPAs have up to 48 percent efficiency, compared to 25-30 percent for GaAs SSPAs. This means that the cubical volume of the power supply can be reduced by a factor of two. OPEX costs are reduced as a result.

Conducting electricity more efficiently means that GaN SSPAs also provide a greater level of RF efficiency; RF loss is always introduced to the circuit as the number of combined

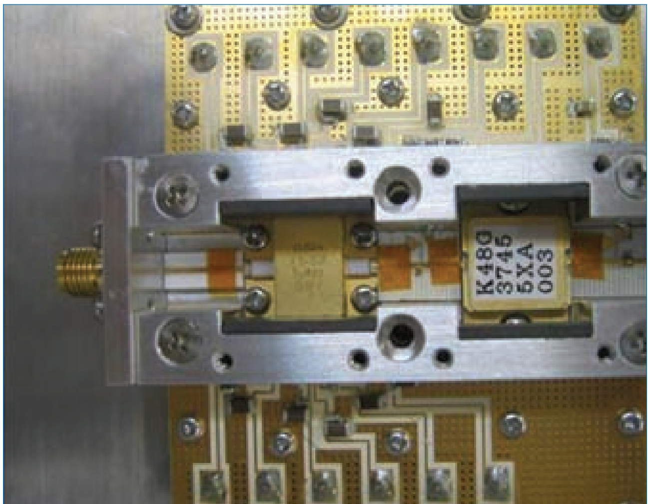


Photo courtesy of Mitsubishi

FETs increases, so the fewer that are required to achieve the same function, the more efficient the amplifier.

GaN SSPAs are significantly smaller than their GaAs counterparts. Not only are the physical GaN parts manufactured smaller, but the accompanying heat sinks can be made smaller, as previously noted. In this case, the smaller products cost less to manufacture and ship, resulting in significant CAPEX savings.

Cost

Cost is a very important factor when it comes to amplifiers, and one of the few areas where GaN falls behind GaAs.

GaN is significantly more expensive than GaAs, as the raw materials and production process are quite costly. In 2016, GaN was estimated to cost 2-3 time as much as GaAs. The cost structure stands to improve once larger quantities of GaN are being manufactured as demand grows, however, it will never fall to the same level as GaAs.

In terms of performance, the best solution is to grow GaN transistors on GaN substrates, however, the crystals are slow-growing, making it an expensive process. Today, most manufacturers of GaN SSPAs grow GaN transistors on more cost-effective substrates, such as Si or silicon carbide (SiC); there is some debate about which offers the best performance. Even with an alternate substrate material, GaN SSPAs still take 3-4 months to produce.

However, this price differential is not expected to be a major deterrent to many companies that use SSPAs, while some don't expect there to be much of a price difference at all in the long-term. "As usage of GaN devices increase, we would expect price erosion over time, whereas the shrinking of the GaAs market will force price increases. So, in the medium to long term, price will not act as a barrier to migrating to GaN technology," said L. Job Moore, CFO and VP of Western European Sales at AnaCom, Inc. "Even in the short term, from what we have seen in a limited sample size, cost differences between GaN and GaAs should not be a major factor in adopting the new technology. In fact, if one looked at the total cost picture, GaN related savings in material cost, shipping and other cost reductions stemming from smaller, lighter units possible using GaN devices would probably be more than enough to offset any current GaN cost disadvantage versus GaAs."

Today's SSPA market

The global power amplifier market is today undergoing a major state of change with competing technologies boosting innovation and prompting significant market growth.

While the GaAs amplifier market generates several billions of dollars each year, the GaN market is much smaller. However, that market is growing as GaN production costs fall and demand increases as products gain in popularity. GaAs is expected to remain strong for small signal monolithic microwave integrated circuits (MMICs) and low-noise amplifiers, in addition to low power amplifiers like those used in mobile phones, but industry sources believe that GaN amplifiers will ultimately replace TWTAs for satellite and radar applications.

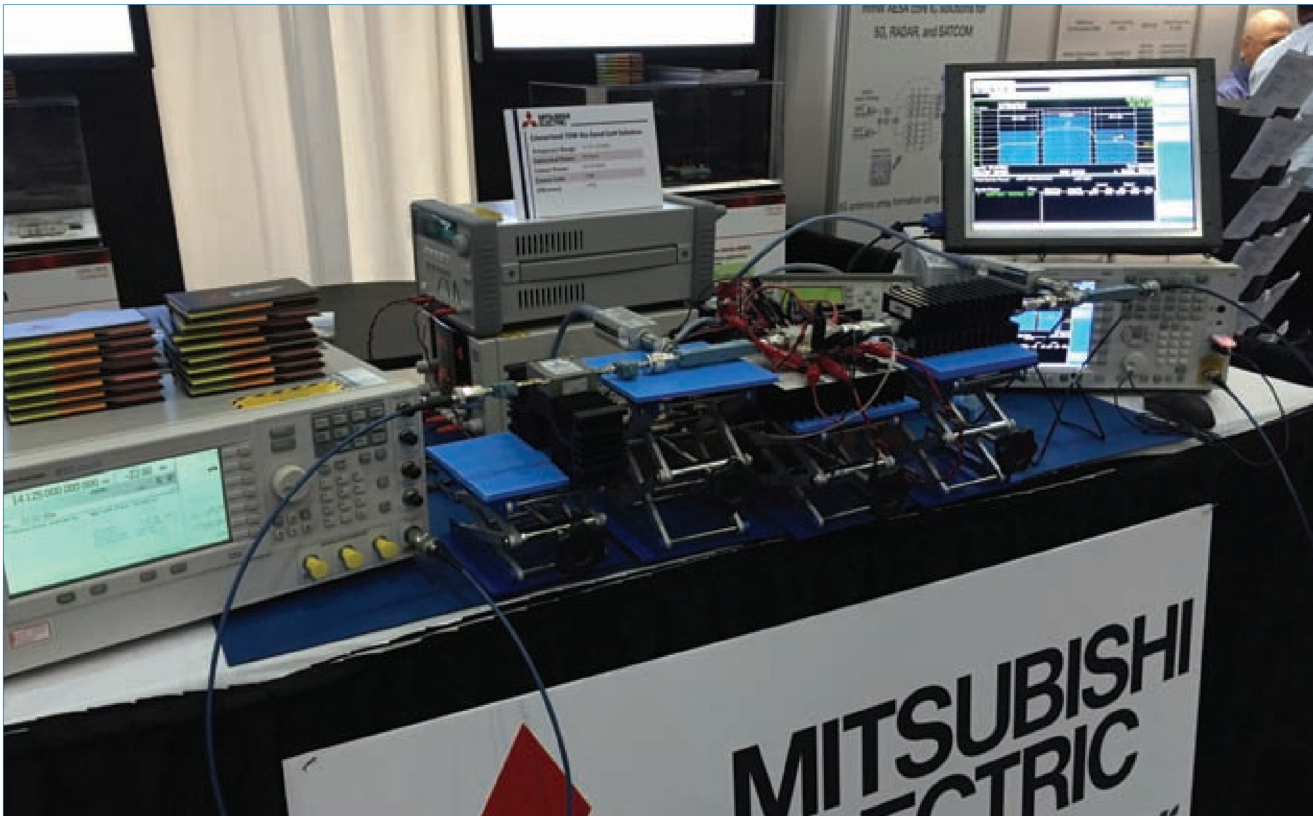
Technavio's *'Global Power Amplifier Market 2016-2020'* states that the global power amplifier market is estimated to increase with a CAGR of 14 percent during the reporting period. Growth is expected to stem from the development of multi-band and multi-mode mobile computing devices that incorporate wireless communications systems such as LTE, GPS, Bluetooth and wireless local-area networks, which have all boosted demand. The report names the current top three emerging trends as:

- Increasing wafer size: Manufacturing costs can be reduced by 20-25 percent by increasing the wafer diameter from 50mm to 150mm, as has been witnessed for GaAs wafers. The industry is now moving towards 200mm wafer technology, with pilot production expected at the end of 2018. With bigger wafers, GaAs technology will be able to compete directly with Si wafers by price.
- Adoption of complementary metal-oxide-semiconductor (CMOS) technology by start-ups: While most power amplifiers are produced using GaAs technology, CMOS power amplifiers provide a lower-cost alternative. Companies such as ACCO Semiconductor are raising funds to expand research in this area.
- Growing need for high-speed amplifiers in defence: SSPAs and TWTAs are the only power amplifiers capable of operating at terahertz frequencies, which enable more efficient spectrum use, a high priority for defence and military groups that need to connect more and more mobile devices.

Key market players

Mitsubishi Electric is a key player in the global SSPA market. The company produces five GaN amplifiers, and is continuing to expand its portfolio to meet the growing demand for higher power outputs and the growth in Ku-band satellite communications systems.

Its latest product, the MGFK48G3745, a 70W GaN high electron mobility transistor (HEMT) designed for Ku-band satellite Earth station applications, was announced at EDI CON in September 2016. At the time, it was the highest power output GaN HEMT available on the market. The MGFK48G3745 features individual transmitter components that can be configured independently during manufacture, eliminating the need for on-site configuration and reducing



Mitsubishi Electric US, Inc. - At EDI CON in September 2016, Mitsubishi Electric US, Inc. presented a hands-on live demonstration of its latest cutting edge GaN technology. A "mini-lab" was set up at the company's booth showcasing its latest linearized 2-stage 70W Ku-band evaluation board. With improved gain and efficiency compared to earlier process generations, this compact design provides 40-45 watts of linear power with more than 30dB gain and combined efficiencies >20% across the 13.75-14.5GHz band, allowing customers the ability to design more competitive, highly scalable SSPA and BUC products.

development times. Speaking with *Satellite Evolution*, Kyle Martin, VP and General Manager of Mitsubishi Electric US, Inc., commented that GaN offers several advantages over GaAs for SATCOM SSPA applications: "A paradigm shift is taking place in the market whereby we are seeing a tangible increase in the amount of VSAT designs being developed with GaN. There are four primary reasons for transitioning from GaAs to GaN.":

- higher power density,
- better high-frequency performance,
- higher efficiency, and
- increased reliability.

Martin highlighted the implications of higher power density as a key differentiator between the two technologies. "Because GaN transistors produce between 2x to 10x greater power density than GaAs, fewer transistors can be used to generate a given output power. This translates to more compact, simpler designs with lower BOM count," said Martin. Additionally, the fewer RF transistors, the lower the RF loss: "Loss generally increases in a circuit as more FETs need to be combined together. GaN operates at much higher voltages than GaAs: This feature both reduces I^2R power losses of the final product while raising the transistor's natural output impedance. Higher output impedance leads to better efficiency and bandwidth as fewer external matching components are required to raise the output impedance to 50ohms."

The implications of better high-frequency performance are also a major game-changer for SSPAs. "Although the output power of all transistors drop off as frequency increases, the output power for a given size GaN transistor is superior to GaAs, primarily due to lower parasitic capacitance between the gate and source (Cgs) and between the drain and source (Cds). This translates to GaN devices having the ability to deliver higher output power for a given frequency than GaAs. As an example, an equivalent-sized GaN transistor can deliver higher power for Ku and Ka-band SATCOM applications than GaAs," explained Martin.

Reliability is a very important factor throughout the satellite sector to ensure always-on communications, so the increased reliability provided by GaN SSPAs is a significant step forward. "A significant order-of-magnitude reliability boost (in MTTF hours) is obtained by moving from GaAs to GaN," noted Martin. "This leads to significant cost reduction in maintenance and downtime. A GaN transistor channel can run hotter than a GaAs channel. This allows a designer to either reduce the heat sink and product size even more or operate the product in more demanding temperature extremes."

Going forward, Mitsubishi Electric will continue its GaN

SSPA development ahead of its GaAs technology. "Due to the benefits GaN offers vs. GaAs, we are placing more emphasis on developing new high-power GaN transistors than on GaAs. We envision that GaN will play an increasing role in SSPAs while GaAs adoption declines," said Martin.

Advantech Wireless is another major player, with a vast portfolio of indoor and outdoor GaAs and GaN amplifiers. "Ka-band solid state technology is part of Advantech Wireless' product development road map since 2000, when we developed the first worldwide Ka-band terminal to be Mil certified by the precursor of what we now know as WGS. GaN technology allows us to reach power levels that were not possible before, and to serve customers that are looking for solutions in this fast-growing market segment," said Cristi Damian, VP Business Development at Advantech Wireless.

The company's latest addition came in September 2016, when it launched its second generation GaN technology based on 125-200W Ka-band UltraLinear SSPA/BUC products. Designed to operate in harsh outdoor conditions, the new SSPB-4010Ka series amplifiers were designed for Ka-band LEO and GEO satellite uplink applications, providing higher power and higher reliability. Meeting MIL-STD-188-164A and WGS, the new SSPAs have 100-200W power output and convert L-band signal Ka-band from 27.5-31GHz (in bands).

The increased reliability of GaN SSPAs is a big selling point for Advantech Wireless: "We work with semiconductor device researchers and manufacturers to make sure we remain on the forefront of commercialising GaN in increasingly high frequencies and power levels. The benefit to our customers has been the drastic increase in high power amplifier reliability resulting from using GaN devices; we find that bringing a two-three-fold increase in reliability to our customer has been well received and has justified our continued investment in the product line," commented Steve Richeson, SVP Global Sales at Advantech Wireless to *Satellite Evolution*.

Like Mitsubishi Electric, Advantech Wireless ultimately sees GaN replacing GaAs technology: "As GaN has evolved over the last decade and continues to evolve in terms of yield and performance, we see GaN completely replacing GaAs over time. The value in increased reliability from GaN versus GaAs is a compelling reason to use GaN whenever possible," said Richeson. Looking to the future, Advantech Wireless expects to see a great deal more change in the SSPA market. "As GaN development follows a predictable technology curve, we expect to continue to see advances in both power level and frequencies supported by GaN devices. We expect a significant market demand in replacing TWTAs at DBS and Ka-band frequencies, just as we are seeing in the C-band and Ku-band market today."

Comtech Xicom also produces a range of GaAs and GaN antenna-mounted, rack-mounted and airborne SSPAs for the satellite communications sector, in addition to a wide collection of TWTAs. The company's latest product, the XTSLIN-100X-B1, is a GaN SSPA that builds upon the success of its legacy XTS-100X GaAs SSPA. The XTSLIN-100X-B1 is a 100W fully integrated antenna mount SSPA unit that complies with MIL-STD-188-164. Measuring 17.3x26.7x43.2cm and weighing 32lb, the XTSLIN-100X-B1 provides 'the most linear output power available in a package this size,' and was designed for challenging outdoor conditions. The SSPA features forced air cooling to provide reliable operation over extended temperature ranges of -40 to +60 degrees C.

Meanwhile, RF solutions provider Qorvo launched a family of hybrid GaN/GaAs amplifiers optimised to extend the reach and address the explosion of higher data throughput required for the point-to-point radio link market in 2015. The TGA2752-SM, TGA2753-SM and TGA2760-SM amplifier family, the first hybrid products on the market, to deliver up to 16W of output power, and have the following key features:

- TGA2752-SM: Operates from 7.1-8.5GHz, suitable for point-to-point radio and C-band linear satellite communications, available in 7x9x0.9mm QFN package.
- TGA2753-SM: Operates from 5.9-7.7GHz, suitable for point-to-point radio and C-band linear satellite communications, available in 7x9x0.9mm QFN package.
- TGA2760-SM: Operates from 9.5-12GHz, suitable for point-to-point radio, available in 8x10x2mm laminate package.

"Wireless infrastructure customers increasingly require higher power amplifiers to expand data throughput and enable longer point-to-point connections," said Gorden Gook, General Manager of Qorvo's Transport business unit. "Qorvo's newest hybrid GaN/GaAs power amplifier product portfolio draws upon 30 years of leadership in advanced GaAs and GaN process technologies to help advance the commercial wireless infrastructure market."

No one size fits all solution

When it comes to SSPAs, it's clear that there's no one size fits all solution. With the market in a great state of change as new technologies are launched and further developed, and falling prices making alternative solutions more cost-effective, it's down to the buyer to educate themselves to the best of their knowledge to find the best solution for their needs.

AnaCom, which works closely with Mitsubishi Electric to deliver all the benefits of GaN technology while minimising the problems that can occur in VSAT networks, agrees that there is room for both GaAs and GaN SSPAs on the market.

"The GaN amplifier market came on strong a couple of years ago as many industry analysts were predicting that GaN technology would completely replace GaAs technology due to its inherent advantages. Unfortunately, these early reports did not take into account the disadvantages that early GaN devices exhibited, especially linearity-related issues. Reports on the imminent death of GaAs were premature," AnaCom's Moore told Satellite Evolution. "AnaCom now believes that there is room for both GaN and GaAs devices in the VSAT power amplifier market. For BUC's with P1dB of roughly 50W and below, GaAs devices work perfectly well. BUC sizes and weights are very reasonable using GaAs in the lower power region, and linearity related problems are non-existent. Units with a Psat of 80W and above represent GaN-based device's sweet spot. These higher-powered units make significant use of GaN's advantages. Coupling this with the eventual mitigation of early problems will result in a swift capture of the mid to high-powered market by GaN technology."