Article | December 14, 2020

Unique mmWave Designs And Customized Products For Satcom, Radar, EW, And ECM Systems

Source: dB Control

By Mike Lee, dB Control

Building solid state power amplifiers (SSPAs), microwave power modules (MPMs) and traveling wave tube amplifiers (TWTAs) to operate in the Ka-band, Q-band, and other high-frequency bands is far more challenging than operating at lower frequencies. Decisions and compromises affecting size, weight, and power, as well as the costs (SWaP-C), become more impactful.

This article examines some of the challenges inherent in working with high frequencies – specifically, Ka-band (continuous wave [CW] and pulsed) and Q-band (CW only). It also details how SWaP-C challenges can be overcome, dispels a few misconceptions about operating in these frequency bands, and addresses unit designers' diverse specification needs.

High Frequency Challenges

The Ka-band comprises 27 GHz to 40 GHz and includes both a commercial band and a military band. It mainly is used for satellite communications and its focused spot beams allow frequency reuse to boost satellite system capacity.

The Q-band, meanwhile, comprises 36 GHz to 46 GHz and has been applied to satellite communications, radio astronomy studies, and automotive radars. One of the Q-band's major applications is Advanced Extremely High Frequency (AEHF), a secure, satellite-based military communications band.

In addition to SWaP-C concerns, the design and construction of high-frequency devices in these applications may be affected by use environmental conditions and longer unit lead times.

Size – In part, it becomes more difficult to build products as you progress to higher frequencies because the components (e.g., waveguides and output devices) get much smaller. While SSPAs are starting to find a home in high-frequency applications, TWTs remain the more commonly used output device. However, building a TWT is labor-intensive and requires precise machining, all of which becomes more difficult as the size is reduced.

Weight – Weight is a balancing game as output devices and components get smaller and lighter as the frequency gets higher. When components shrink to fit in tighter spaces (e.g., manned or unmanned aircraft), their mass typically drops, as well. However, our experience shows that, as the frequency goes up, so do the operating voltages. Therefore, the size and weight of the power supply necessary to drive the output device increases.

Power – Power likely presents the greatest design challenge since, as you go higher in frequency, it's harder to generate greater power output. Even jumping from the Ka-band to the Q-band is a significant leap, and you can't match in Q-band the power levels achievable in Ka-band.

Part of the reason for this is atmospheric obscurants. As you operate higher in frequency, adverse environmental conditions, such as rain fade, increase — meaning the environment causes an increasing amount of attenuation. So, if you transmit 100 W through the environment, you may only achieve a fraction of that because the signal is being attenuated through the atmosphere. Thus, operators not only need sufficient power to establish a link, they need enough power to persevere through atmospheric interference (or they risk losing communications and critical data or video transmissions).

Additionally, at higher frequencies, it is more difficult to maintain a unit's power level at the point of linearity, wherein one watt of input power leads to one watt of power output. When running in a linear region, a unit does not experience distortion at the outer frequencies (i.e., damaging your neighbor's communication with your signal). Linearity — measured in spectral regrowth, intermodulation, or noise power ratio (NPR) — is particularly relevant in commercial operations for this reason.

Many amplifier customers – particularly in satcom applications – use the terms P1dB and linearity interchangeably, despite the terms not meaning the same thing. P1dB, also called the 1 dB compression point, is the output power level at which gain decreases 1 dB from its constant value (i.e., backed off 1 dB from the theoretical linear power level), and is not a good indication of linearity. Once an amplifier reaches its P1dB it goes into compression and becomes a non-linear device, producing distortion, harmonics, and intermodulation products. A P1dB spec or figure of merit is catered more towards a solid-state device, versus a TWT device.

Cost – Ultimately, the combination of high power requirements, labor-intensive manufacturing, and a small package makes up the leading-edge technology in these applications, which makes solutions more costly than similar units operating in, for example, the C-band or Ku-band.

Some customers unfamiliar with the complexity of higher frequency components may experience sticker shock upon seeing a cost number that's usually about double what they've seen at lower frequencies — depending on whether the application is in radar, communications, or other forms of transmission.

Another cost contributor is the fact that, despite the U.S. government funding of GaN solid-state solutions to operate in higher frequency bands, that technology remains immature and is subject to performance limitations. As a result, not many companies currently produce solutions in these bands at a power comparable to a TWT.

Lead Times — The added complexity of producing smaller components for high-frequency applications generally increases lead times. At lower frequencies, TWTs are built and manufactured at larger sizes, so they're easier to achieve. As the components get smaller, it is not only harder to construct each component, but fallout increases (i.e., yield decreases); you may have to build several TWTs to achieve one good unit.

For example, for dB Control, the gating item is the tube. The tube lead timing in a Ka-band unit is anywhere from 25 to 50 percent longer than that of a lower frequency unit.

Despite these challenges, TWT still is preferred to solid-state devices, as evidence does not support claims that GaN SSPAs provide an adequate solution operating at higher frequencies and greater output power levels.

Consider that current GaN devices operating in the Ka-band are very low power. For example, if a designer needs 100 W of output power to provide CW for a Ka-band unit, multiple GaN devices would have to be combined — adding to size, weight, and power draw, not to mention cost.

Further, signal loss compounds as components are added, as does heat generation, degrading efficiency and, potentially, reliability. A TWT solution comprises one output device that is able to produce more output power with greater efficiency.

Finally, note that the commonly held belief solid state is more reliable than TWT depends on the application. For example, a system running on the ground may benefit more using solid-state devices. A system running on a ship might lead to a toss-up decision between solid state and a TWT.

But, on an airborne platform, a TWT offers a significant reliability advantage due to the operating conditions: high shock, altitude, vibration, and temperatures. High temperatures, in particular, are detrimental to solid-state devices, whereas TWTs are designed to run at elevated base temperatures for long periods of time.

Thus, don't be fooled by metrics like mean time between failures (MTBF), often touted as indicative of reliability for solid-state devices. A solid-state device offers a higher MTBF than a TWT because a TWT has multiple components and a higher parts count. However, MTBF doesn't equate to device longevity.

Consider that a battery may have a MTBF of 1 million hours (theoretically, and performing under ideal conditions); realistically, that battery is more likely to last a few hours.

Trust dB Control's Expertise

dB Control has been building Ka-band amplifiers for more than 14 years and has provided products for military applications – operating in harsh environments – for more than 30 years. In that time, dB Control has:

- Become proficient in designing and building modulators, as well as integrating them into our solutions (i.e., to handle pulsed wave applications, such as radar, or some EW tasks).
- Familiarized itself with its customers' application demands: what is needed if the unit is to operate at 50,000 feet, or 70,000 feet? What about performance in a pressurized aircraft cabin versus a non-pressurized cabin?
- Perfected winding its own transformers, a vital component of high-voltage power supplies. dB Control uses both proprietary methods and materials in the encapsulation of high-voltage system sections. Absent encapsulation, the proper potting materials or procedures, power supply circuits risk arcing and causing component or system failure, and can become very large in size.

Every dB Control product, from the component level and sub-assembly level all the way up to the amplifier level, is subjected to environmental stress screening before it is shipped.

While numerous vendors perform environmental stress screening, no others combine in-house transformer winding plus full encapsulation, as well as the experience to execute the appropriate testing and ensure the tightest of electrical tolerances specified down to the component level.

As to whether one should seek commercial off-the-shelf (COTS) units or custom components, the application guides the answer.

Excellent high-frequency TWTs are available off the shelf, but most operate at fairly standard frequencies. Customization becomes relevant when a customer, depending on their project needs, asks for more power, a slightly higher or lower frequency, a broader bandwidth, or guarantees for a certain linearity (applies to MPMs, as well).

Custom orders require an understanding of the “stat weight” afforded to different unit specifications within the user’s application. First, the vendor has to offer the frequency range and the power needed. Other parameters then vary. For example, in a satcom application, linearity is a key concern. In ECM, EW, or radar applications, weight and efficiency will be key concerns, because the solution may be mounted on an airborne platform.

Conclusions

dB Control mmWave amplifiers currently are used in communication, radar, ECM, and EW systems — a broad range of products compared to competitors. Challenges exist to working in all of these bands and application areas, and rich experience not only teaches us how to overcome those hurdles effectively, it allows us to apply the lessons learned across different technologies.

At its core, dB Control is an amplifier manufacturer specializing in the high-voltage power supply. We are output device agnostic – whether it’s a vacuum tube or solid-state output device, we aim to choose the most viable solution for the application and customer’s needs.

If you have questions about designing for the Ka-band and Q-band, or want to discuss how dB Control can assist in your project, the author may be reached at mlee@dbcontrol.com, or visit dB Control online.

About The Author

Mike Lee is the Director of Sales and Marketing at dB Control. He has more than 25 years of RF and microwave experience developing new relationships with companies whose specs require high-power TWTAs, SSPAs, MPMs, power supplies, contract manufacturing services, or repair depot services. Prior to joining dB Control, Lee worked at Comtech Xicom Technology and IBM – where he received a U.S. Patent for his electrical circuit design. He earned a Bachelor of Engineering in Electrical Engineering from The City College of New York.

About dB Control

Established in 1990, dB Control Corp., a subsidiary of HEICO Corp., supplies mission-critical, often sole-source, products worldwide to military organizations, as well as to major defense contractors and commercial manufacturers. The company designs and manufactures reliable high-power TWT Amplifiers (TWTAs), microwave power modules (MPMs), transmitters, and high-voltage power supplies with modulators for radar, electronic countermeasures (ECM), and datalink applications. dB Control is ISO 9001:2015 certified and also offers specialized contract manufacturing, transformer winding and testing, full vacuum encapsulation, pressure cure, conformal coating, and repair depot services from its modern, 40,000-square-foot facilities in Fremont, CA.

In 2019, dB Control acquired TTT-Cubed. The acquisition adds the following to the company’s product offerings: Instantaneous Frequency Measurement (IFM) Units, Frequency Locked Oscillators (FLO), Digital Control Units (DCUs), Antenna Control Units (ACU), and Integrated DCUs. More information about dB Control is available by calling (510) 656-2325 or emailing info@dBControl.com.