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VED IPP

AOC Issue Brief

Rethinking What We Know About Vacuum Electronic Devices

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Rethinking VED Technology

Last year, the AOC's *Journal of Electronic Defense* (JED) featured two articles highlighting advances in Traveling Wave Tube (TWTs) and other Vacuum Electronic Devices (VED).[1] Both articles discussed emerging opportunities for TWTs, especially as technology demands are pushing further out in the frequency to the Extremely High Frequency (EHF) band (30-300 GHz), or Millimeter Wave (mmW), especially above 75 GHz. The mmW band is receiving considerable attention due to the potential for next generation military technology and the 5G communications network. The propagation characteristics of mmW make it useful for cellular communications and radar because of the ability to transmit of large amounts of data, and for space-based applications since atmospheric attenuation is not a factor. Furthermore, technological advances continue to address some of the traditional limitations for TWTs, including operating life, the time required to heat the TWT cathode, and the overall power generation compared to Solid State Power Amplifiers (SSPAs), especially at higher frequencies.

The debate over TWTs versus SSPAs has been going on for decades, not simply because of the introduction of gallium arsenide (GaAs) and gallium nitride (GaN) devices, but also due to a lack of awareness about the value of TWTs, especially considering recent trends in the Spectrum Dependent Systems (SDS). When SSPA devices were introduced, they demonstrated promise over existing TWTs for their life span and ability to power certain transmit/receiver modules. The prevailing assumption was that SSPAs were a panacea for power requirements in advanced and future systems. While this assumption did not miscalculate the efficacy of SSPAs - they are better suited than TWTs for certain systems - it was myopic in its perspective about the design and development of future SDS, especially in higher frequency bands. SDS in a complex electromagnetic spectrum (EMS) environment requires operating in bands we didn't anticipate 30 years ago. SSPAs have not been able to solve challenges, especially pertaining to efficiency and heat-generation, that early assumptions anticipated. This has encouraged a fresh look into what we know about TWTs and how next generation VEDs may revolutionize amplifier technology.

The Changing Role of the EMS in Military Ops

Electromagnetic energy - what we call the EMS as an organized classification of frequencies — underpins everything we do, everywhere in the world. This includes both commercial and military applications, such as wireless communications, Command and Control (C2), Precision Navigation and Timing (PNT), Radar, and data transfer. There is an increasing realization that

[1] Journal of Electronic Defense (March 2018 Vol 41 #3 / September 2018 Vol 41 #9).

About the VED IPP

The Vacuum Electronic Devices Industry Partnership Project (VED IPP) explores how the DOD, our foreign military partners, and the global defense industrial base are in a strong and cooperative position to advance VED technology, including traveling wave tubes (TWTs), TWT amplifiers (TWTAs), Microwave Power Modules (MPMs), and other power tube technology.

Current VED IPP Partners:

Photonis Defense, Inc.
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this EMS Domain is central to commerce, global military reach, and combat mobility. In both the US and NATO, and other partner countries, the strategic significance of the EMS in modern operations is rapidly gaining high-level attention and increased funding for advanced systems and weapons.

For decades, the US and NATO enjoyed an era of clear superiority as friendly EMS capabilities far outpaced adversary EMS capabilities. Today, that advantage is quickly eroding. EMS demand, density, complexity and contest are increasing exponentially. The demand for more data at higher speeds on more efficient, reliable, and smaller systems is pushing us further out in frequency, beyond traditional Microwave bands, where there is less congestion and more opportunity to leverage signal behavior.

This rapidly shifting dynamic is leading us to rethink what we know about core component technologies, such as TWTs and Microwave Power Modules (MPMs). Today, we are in a better position to understand how certain technologies work and why they may provide better solutions than previously anticipated.

In the end, we must look beyond the TWT versus SSPA debate, but focus on the valuable attributes of both to maximize their capabilities. We need both to power the range of military technologies for unfettered maneuver across the EMS. Therefore, we must counter prevailing and false assumptions about TWTs and better understand opportunities that will drive the evolution of VEDs for the next generation. TWTs are far from obsolete. Rather we are in the early stages of a new generation of TWTs that will likely provide solutions to challenges of operating in higher frequencies we previously did not anticipate.

Rethinking Assumptions

For development of the next-generation family of VEDs to realize their potential and stimulate necessary investment, we must disprove the following prevailing and misleading assumptions through additional studies and more dedicated advocacy by government, industry and academia.

Obsolescence: As discussed previously, the notion that TWTs are not relevant in modern electronic warfare (EW) systems ignores the expanding system requirements for maneuver in the EMS today. Systems today require higher power and greater bandwidth. New generation modeling and design techniques allow VED components to meet size constraints and achieve these ultra-precise alignment standards necessary to operate in higher frequency bands.

Reliability: Early studies of device reliability between TWTs and SSPAs do not provide an accurate picture of limitations of either technology. When parameters are equal and consider the number of devices and the expected operating temperatures, TWTs and TWT amplifiers (TWTAs) are not only more reliable than originally thought, but more reliable than SSPAs in key performance criteria. One definitive study by Boeing in 2006 concludes that "the wealth of reliability data . . . indicates the observed FITs (Failures in Time) on TWTAs are significantly lower than their SSPA counterpart."[2] The study also shows TWTAs delivered more power and that there is a lack of evidence in support of the "graceful degradation" of SSPAs. Furthermore, beyond the study, advances in manufacturing and process technology have resulted in significant improvements for device Mean Time Between Failure (MTBF).

Efficiency: Advances in VED efficiency has improved not just in the mmW band, but also at low (1.3 GHz) frequencies especially if the requirements are narrow band for scientific applications. For military applications, the issue is not efficiency at low frequencies, but the volume of devices and the manufacturing capacity to meet demand. Additionally, the power versus heat-generation equation greatly favors TWTAs and allows them to exhibit 30-40 percent return, meaning that greater power can be produced by a TWT when compared to SSPAs with the same cooling system.

Opportunities on the Horizon

The overall advances in VED technology and ongoing research, most notably in reliability and efficiency of devices, have opened doors to new opportunities that will likely ensure that VEDs will remain an important component technology for the next 30 years.

Millimeter Wave: According to the JED article, "The Domain of the Tube - Millimeter and Beyond," mmW is in increasingly high demand for next generation military applications that require greater through put on data links.[3] TWTs can readily meet the power and linear amplifier requirements of operating in mmW bands. As our adversaries also continue to invest in systems that operate at higher frequencies, we need solutions to these emerging threats that most SSPAs cannot support today.

Best of Technologies: To move beyond the narrow TWT versus SSPA debate, advances in both technologies have led to reliable and mature Microwave Power Modules (MPM) technology, which offers a "best of the technologies" approach that uses the strengths of vacuum, solid state and compact power supply technology in an optimized integrated package. This combination of technologies in one system was unheard of 30 years ago, but we better understand today that the advancement of one technology does not imply the obsolescence of another.

Improved Materials and Component Technologies: The development of the synthetic (or CVD) diamond, advanced cathodes, micro machining and additive manufacturing each offer new approaches for increased VED capability. Specifically, DARPA through its Innovative Vacuum

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[2] TWTA Versus SSPA: A Comparison of On-Orbit Reliability Data; IEEE Transactions on Electron Devices, Vol. 52, No. 5, May 2005.
[3] Journal of Electronic Defense (March 2018 Vol. 41, No. 3).

Electronic Science and Technology (INVEST) program has been researching cold-cathode TWTs, a revolutionary advancement in which a thermionic emitter is not electrically heated, thereby bypassing the need to heat electrons in a vacuum tube to 1000° C. to operate. This will dramatically increase efficiency and reliability while eliminating the time to "fire up" the TWT because it will operate at ambient temperature.

Recommendations/The Way Ahead

Advocacy: The opportunities awaiting the global VED industrial base are promising, but not without obstacles to realization. For advances to continue, we need leadership, resources, and intellectual capital. The faulty assumptions discussed previously have interfered with the stability and growth of the industrial base. If what we know about VEDs today represented "new technology," we might be viewing them as the next great break-through. Through greater education and awareness, we must move beyond the myths to reinvigorate sustained investment and growth in VEDs.

Supply Chain: Additionally, policy makers in governments must provide more focus and visibility on VED supply chain challenges, particularly those that can adversely affect critical military systems. There is not only a dwindling global manufacturing base for TWT devices, but also certain materials and rare earth elements (REEs) are in limited supply.[4] For example, the United States relies entirely on imports of REEs, primarily from China. Thus, while peer competitors, such as China and Russia recognize the benefits of VED technology and are investing heavily in this area, the US has no rare earth mining production and must increasingly rely on imports, mostly from China for certain materials. Development of improved materials can solve some of this challenge, but we must understand that the industrial base supporting TWTs is not nearly as strong as it was. Realizing the opportunities on the horizon requires immediately addressing supply chain vulnerabilities.

Intellectual Capital: Finally, we need to stimulate the intellectual capital in the VED sector through initiating new collaborative efforts between academia, industry and government to encourage graduates and researchers to enter the field of vacuum electronics. Vacuum electronics is not drawing enough interest from the next generation of engineering students. Both government agencies and component manufacturing companies must strengthen recruitment and retention programs to attract the best engineers and physicists from the US and abroad.

Conclusion

The VED IPP will continue to drive attention to the opportunities and challenges facing the global VED industrial base. The most recent studies reveal that we haven't been thinking about VED as the evolutionary technology it truly is. Far from being obsolete, VEDs may become preferred, if not essential, component technology for future systems, especially in higher frequency bands that require more power and greater efficiency. Until then, what we do know is that using the "best of technology" approach renders the prevailing TWT versus SSPA debate

[4] Rare Earth Elements: The Global Supply Chain. Congressional Research Service (R41347), September 30, 2010.

counterproductive. We need to realize that there is room for both and integration can open up new possibilities in the development of next-generation technology.

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