Next-Generation, GaN-based Power Amplifiers for Radar Applications

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Today's civilian and military radar systems rely on conventional vacuum electron devices (VEDs), gallium arsenide- (GaAs-) based amplifiers, and silicon- (Si-) based solid-state amplifiers to deliver watts to hundreds of kilowatts of pulsed and continuous wave power covering both microwave and millimeter frequencies.

Typical radar system implementations include weather observation, civilian air traffic control, high-resolution imaging along with various military radar applications such as ground penetration, ground and/or air surveillance, target tracking, and fire control. In order to perform the precise, mission-critical functions required, these radar systems need next-generation amplifiers that provide advantages in output power, bandwidth, and efficiency over conventional technology.

Gallium nitride- (GaN-) based amplifiers are just such RF components and are well suited to displace incumbent technologies near-term in L-, S-, and C-band and longer-term in X-, Ku-, and Ka-band radar systems. Designing end products using GaN-based amplifiers will help reduce the size and complexity of the overall amplifier module with ever-increasing improvement of efficiency and high-power operation of radar systems.

Figure 1: Long-range Surveillance L-Band Phase Array Radar

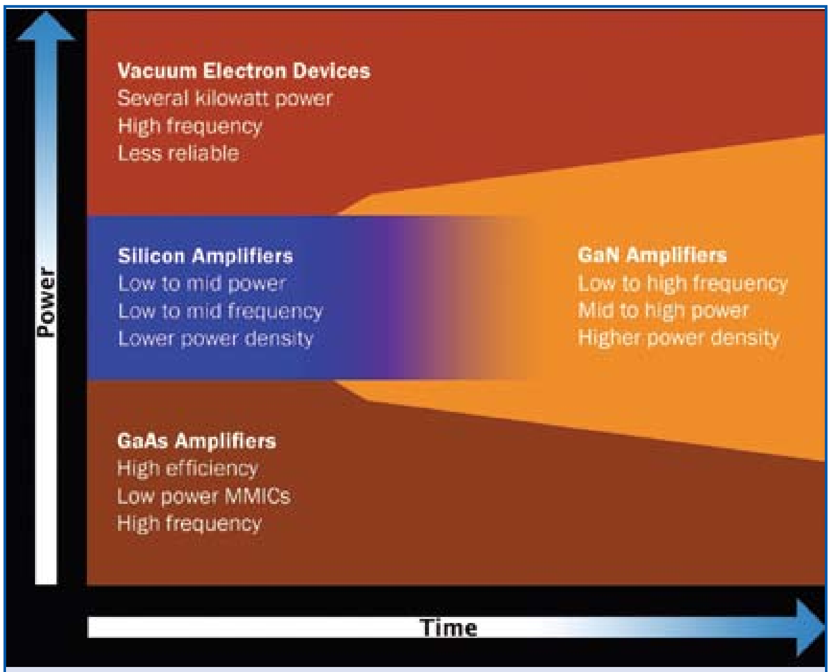

Figure 2: Radar Amplifier Technology Adoption Projections

Advancements in Radars

Radar system manufacturers continue to make advancements in order to meet the increasing demands of the environmental conditions in which these systems must operate. Several such areas of advancement within radar systems include:

1. Movement toward Active Electronically Scanned Arrays (AESA) – Mechanically scanned antennas are being displaced with electronically driven systems (AESAs) due to improvements in performance and reliability. The AESA system main advantages include its fast scanning rate and smaller form factor, the latter evolving as a result of the use of solid state devices and elimination of antenna hydraulics.
2. Increased Sensitivity – Demonstrated increased sensitivity translates to an improved detect-and-monitor capability by enabling radar systems to capture small objects previously indistinguishable with older technology.
3. Image Enhancement – Higher resolution images are being generated using advancements in computer processing and enhanced transmit and receive technologies.
4. Improved Energy Efficiency and Increased Power – Advancements in energy efficiency and power provide radar manufacturers the opportunity to reduce the size and weight of these complex radar systems.

As radar system manufacturers continue to drive the implementation of the advancements listed above, they continually push the incumbent amplifier technologies close to--and perhaps beyond--their capabilities. This has driven both radar system and components manufacturers to search for and develop alternative technologies that are better suited to meet these evolving demands.

Legacy Amplifier Technologies

Prominent military and civilian radar systems operate in the following microwave and millimeter frequency ranges: L-band (1-2 GHz), S-band (2-4 GHz), C-band (4-8 GHz), X-band (8-12 GHz), Ku (12-18 GHz), and Ka-band (26.5-40 GHz). Furthermore, power levels vary from a couple of watts to hundreds of kilowatts, depending on the amplifier utilized in the system.

Presently, there are several incumbent technologies used to develop amplifier solutions for radar systems. The most common types are:

Vacuum Electron Devices (VEDs): VEDs consists of travel wave tubes (TWTs), klystrons, magnetrons, gyrotrons, and cross field amplifiers (CFA). Devices are capable of working in the megahertz range up to hundreds of gigahertz and vary in power from watts to hundreds of kilowatts. Most of these VED technologies have been used over the past 70 years, and are complex modules to manufacture that require unique materials and skill sets. VED market share is susceptible to replacement by next-generation technologies that offer comparable power levels, at target frequencies, with robust, solid-state reliability.

GaAs-based Amplifiers: GaAs-based amplifiers are well-known devices currently used as pre-driver, driver, and, even, final-stage amplifiers for radar applications that require high-efficiency and that operate in microwave and millimeter frequency ranges. GaAs-based amplifiers operate from supply voltages ranging from 5V to 28V. The technology's power density limitations require power combining and, in some cases, drive their exclusion from being used in higher-power radar applications. Radar manufacturers continue to look at advancements in alternative semiconductor technologies for increased bandwidth, power, and efficiency benefits.

Si-based Amplifiers: Si-based solid-state amplifiers are typically fabricated using a combination of silicon bipolar and laterally diffused metal oxide semiconductor (LDMOS) technologies. These technologies are best known to operate with supply voltages of 28V with recent improvements allowing 50V operation. Furthermore, LDMOS technology works well in UHF and VHF frequencies up to around 3.5 GHz. Multi-die modules can offer power levels up to 1000 W at 1 GHz; however, typical power levels are usually in the <200 W range. Lastly, intrinsic parasitic capacitance characteristics of LDMOS limit the frequency and bandwidth performance as well as its power-handling capabilities. These limiting performance characteristics can be hindrances to radar system manufacturers, particularly when they are attempting to address desired improvements in efficiency and power handling.

Next-Generation Amplifiers

Gallium nitride (GaN) is recognized as the key, next-generation amplifier technology for radar systems manufacturers. GaN-based amplifiers have recently been deployed in select radar systems for military applications. The design activity and adoption rate is increasing each year as more GaN-based RF component suppliers enter the market with production-ready, reliable products. Radar system manufacturers recognize the distinct advantages of the wide band-gap GaN technology—higher voltage and broader bandwidth performance combined with high drain efficiency. GaN offers significant, recognized advantages over existing Si and VED technologies for applications operating in frequency bands <6 GHz.

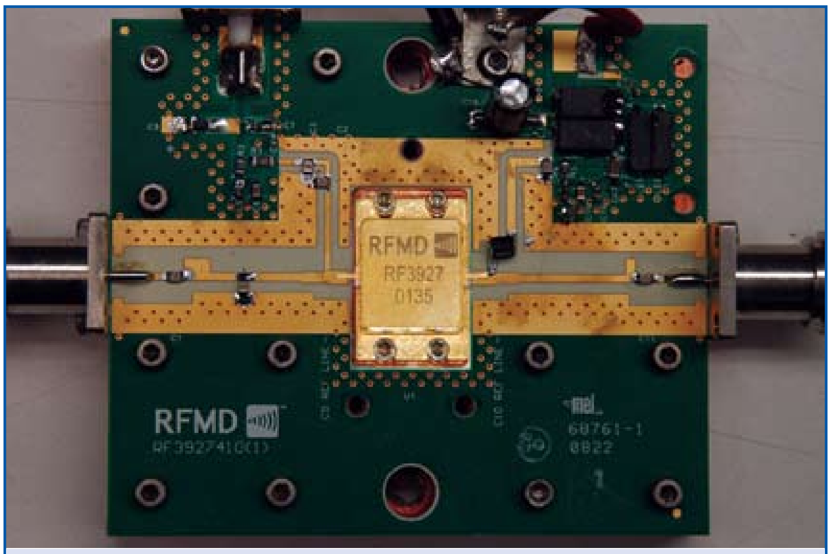

Figure 3: Typical 50-ohm Match Applications Circuit

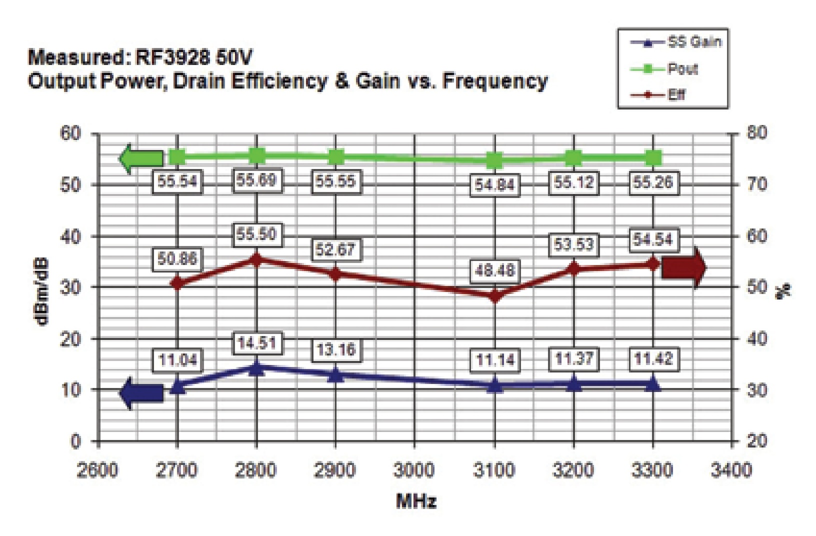

Figure 4: RF3928 Peak Output Power, Peak Drain Efficiency, and Small Signal RF Performance from 2.7 to 3.3 GHz

Most recently, there has been increased activity from U.S. and Japanese GaN manufacturers, specifically in the areas of higher frequency radar applications (>10 GHz) as well as targeting improvements in bandwidth, power output, and efficiency. As a result these higher frequency GaN-based solutions are encroaching on design slots typical secured by GaAs-based amplifiers and VEDs.

RFMD®: Tailoring GaN for Radar Systems

GaN is a relatively new semiconductor technology, however several well-established RF companies have invested considerable time and money to develop robust, reliable semiconductor technology products with GaN that target multiple markets. Radar systems for both civilian and military applications are ideally suited based on GaN's exceptional pulsed and continuous wave (CW) performance. RFMD's first-generation GaN technology will be released as a 50V process with power density >5W/mm and respectable power gain performance up to 6 GHz. Currently, RFMD is developing a family of high-power, high-efficiency, broadband amplifiers that are targeted toward L-, S-, and C-band radar applications.

Figure 3 shows a typical RFMD solution including the partially matched power transistor, bias network, and on-circuit board matching elements. The package is a hermetically sealed bolt-down package for optimal thermal contact. The package houses the GaN transistor die, splitting and combining networks, and matching and stabilization circuitry.

The impedance at the package pin for the device is typically 15 to 25 ohms. This higher impedance allows the circuit board matching elements to remain compact, as shown in Figure 3. Features such as wide dimension and low impedance matching traces common in Si-based solutions can consume significant amounts of circuit board area, but, fortunately, are not required in this GaN-based approach. Some radar applications use several devices combined in parallel to achieve multi-kilowatt amplifiers, and in this case RFMD's GaN-based solutions solve the significant issues of module size and cost by eliminating the aforementioned matching traces.

RF3928: 300W at S band

RFMD's RF3928 was originally designed for operation from 3 to 3.5 GHz and provides over 300 W of pulsed peak power, with peak gain greater than 10 dB and peak drain efficiency of 40% to 50% over the stated frequency range.

Previously (1) RFMD has shown that this amplifier topology configuration is very flexible and can achieve wide-bandwidth operation (17% bandwidth) while providing high-output power and efficient operation. Figure 5 presents board-tuned performance for the RF3928 at the lower band (2.7 to 3.3 GHz). Of note, achieving this performance at the lower than originally targeted frequency range only required minor changes to the and circuit board bias network with no change to the circuit elements internal to the package.

For the 2.7 to 3.3 GHz band, the RF3928 achieves output power of 304 to 370 W while maintaining greater than 10 dB peak gain. Additionally, peak drain efficiency is between 48% and 55%. Small signal gain ranges from 11 to 14.5 dB. Gain ripple at peak output power is typically 1 dB over the entire bandwidth. All measurements were taken under pulsed conditions using a 100 µsec pulse at 10% duty cycle. Power droop across the pulse width is typically 0.2 dB indicating that the thermal properties of the GaN device and package are not performance limiting.

RF300ML110: 500W at L band

RFMD is currently developing an amplifier to provide high power at L-band frequencies. The RF300ML110 uses the same circuit topology and package as the RF3928, however it is specifically targeted to provide high-power performance from 0.9 to 1.4 GHz, while being optimized for 1.2 to 1.4 GHz. Although this amplifier is in the prototype phase of development, early evaluation of non-linear, model-based performance is included in Figure 5.

The simulation predicts that the RF300ML110 should provide high output power from 0.9 to 1.4 GHz (at 35% bandwidth). The amplifier targets greater than 400 W of output power over the entire stated frequency band, and it is specifically optimized for greater than 500 W of output power from 1.2 to 1.4 GHz. Small-signal gain is expected to range from 15 to 20 dB, and peak drain efficiency to range from 45% to 55%.

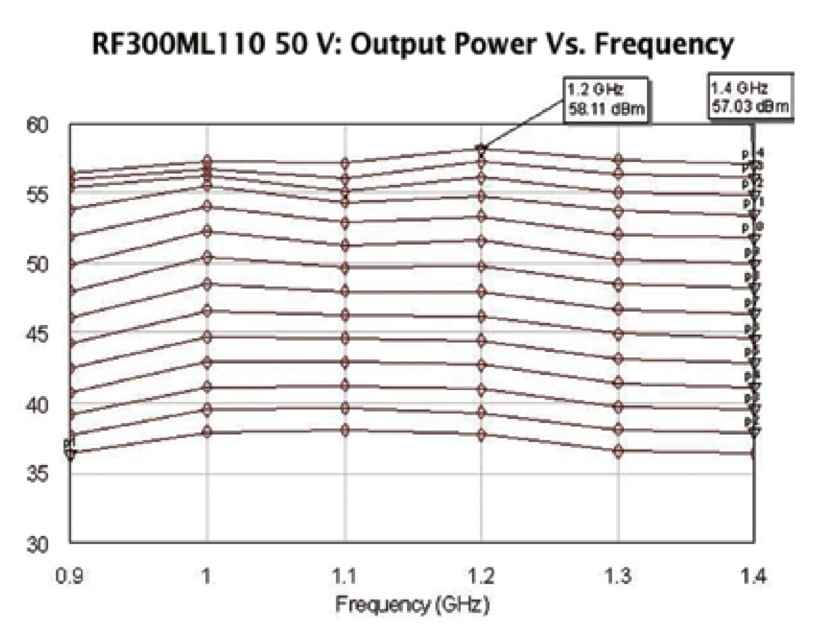

Figure 5: RF300ML110 Peak Output Power RF Performance from 0.9 to 1.4 GHz

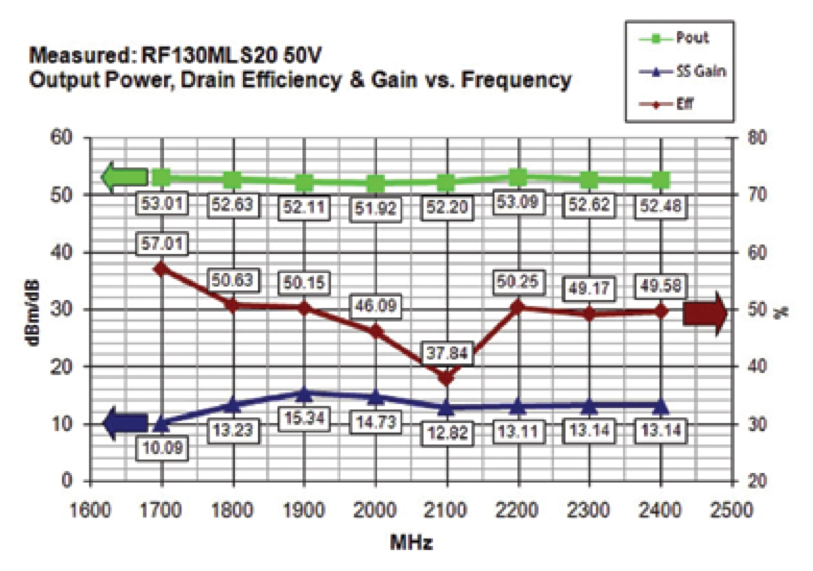

Figure 6: RF130MLS Peak Output Power, Peak Drain Efficiency, and Small-Signal RF Performance from 1.7 to 2.4 GHz

RF130MLS20: 150W at L-band

RFMD's RF130MLS20 provides a lower cost, high-power output solution for L-band operation. This part incorporates in-package pre-matching in a bolt-down, high-thermal conductivity package.

Figure 6 provides measured data on the performance of this part under the same pulsed conditions previously discussed. The RF130MLS20 achieves between 150 and 200 W peak output power over the entire 1.7 to 2.4 GHz range (at 29% bandwidth) while maintaining greater than 10 dB gain at peak power. Peak drain efficiency ranges from 37% to 57% and small-signal gain ranges from 10 to 15 dB. Gain variation at peak output power is typically 1.3 dB.

Summary

Enabling wider bandwidth operation, while maintaining efficient high-power performance, will allow for the simplification of high-power radar systems. To address this need, RFMD is expanding its portfolio of high-power, matched amplifiers targeting next-generation military and civilian radar applications. These GaN-based amplifiers are designed to allow system designers to address multiple bands with a singly-matched amplifier implementation. These GaN-based solutions reduce the size and complexity of the overall multi-kilowatt amplifier, resulting in unmatched benefits to the end customers—minimized space and lower lifetime operational costs.

References

[1] K. Krishnamurthy, M. J. Poulton, J. Martin, R. Vetury, J. D. Brown, J. B. Shealy, "A 250W S-Band GaN HEMT Amplifier", Compound Semiconductor Integrated Circuit Symposium, 2007. CSIC 2007. IEEE 14-17 Oct. 2007, pp. 1 – 4

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