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RF Applications of GaN For Dummies®

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Learn:

- How GaN benefits your system applications
- Why and when to use GaN
- Important design factors for GaN
- GaN's utility in multiple applications

Andrew Moore
Elias Reese

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Qorvo (Nasdaq: QRVO) is a leading provider of core technologies and RF solutions for mobile, infrastructure, and aerospace/defense applications. Qorvo was formed following the merger of RFMD and TriQuint, and has more than 6,000 global employees dedicated to delivering solutions for everything that connects the world. Qorvo has the industry's broadest portfolio of products and core technologies; world-class ISO 9001–, ISO 14001–, and ISO/TS 16949–certified manufacturing facilities; and is a DoD-accredited 'Trusted Source' (Category 1A) for GaAs, GaN, and BAW products and services. For the industry's leading core RF solutions, visit www.qorvo.com.

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Qorvo Special Edition

by Andrew Moore and Elias Reese

For Dummies
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Introduction

Gallium nitride (GaN) transistors were first demonstrated in the 1990s and are now widely available for commercial and defense applications. GaN's popularity resides in its high-current, high-voltage capabilities, which make it highly valuable for microwave applications and power switching.

GaN is the technology of choice for high-power applications in electronic warfare (EW), radar, satellites, cable TV (CATV), and cellular mobile data communications. GaN devices can operate at higher voltages and frequencies than other, commonly used materials in solid-state electronics such as silicon (Si) and gallium arsenide (GaAs). GaN devices are also highly efficient, allowing them to be used in high-power applications while conserving energy.

The unique properties of GaN make it a powerful tool in the circuit designer's kit, especially when designing for high-power, high-frequency applications. But circuit designers need to know about many important factors when employing GaN devices in their designs.

In this book, you see how and why to use GaN in your designs and some of the different forms in which GaN is manufactured and packaged. You also find out about the important design factors to consider when using GaN technology in your circuit designs, and discover several applications of GaN devices in radio frequency (RF) applications.

Foolish Assumptions

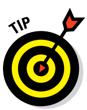
This book is written for both technical and non-technical readers. If you're an executive, salesperson, or design engineer, this book is for you. Unless of course, you're looking for a book on 19th-century Impressionism!

Icons Used in This Book

Throughout this book, we use special icons to call attention to important information. You won't see the typical cute grinning faces or other flashing emoticons, but you'll definitely want to stop and pay attention! Here's what you can expect.

This icon points out information that you'll want to put in storage, your memory, or whatever you use to keep track of important information like birthdays and phone numbers for later use.

Anything marked with this icon is targeted toward your inner geek. Who knows? You may come away with some useful knowledge to increase your nerd status.



No, this isn't the thing you do to take care of your waitresses and bartenders. You should stop and take notice because there are nuggets of knowledge that could save you some aggravation later on.

Beyond the Book

Although this book is full of good information, we could only cover so much in 24 pages! So, if you find yourself wanting more after reading this book, just go to `www.qorvo.com/gan`, where you can get to more information about Qorvo's GaN technologies and products.

Where to Go from Here

Whether you're new to electrical design and GaN technology or a seasoned design engineer looking to use GaN technology in your designs, you'll find this book useful.

Each chapter in this book stands on its own, so you can skip around if you like. If you're familiar with the topics in a chapter, go ahead and skip it. We provide cross-references to information in other chapters of the book, so you can always find what you're looking for.

Chapter 1

Why and How GaN Works in Your Design

In This Chapter

- Recognizing the cost benefits of GaN
- Exploring important design considerations
- Seeing how to add GaN devices to your circuits

Gallium nitride (GaN) devices are especially well suited for high-power applications that operate at high frequencies, such as radio frequency (RF) power amplifiers for electronic warfare (EW), radar, satellite communications, and mobile communication infrastructure. GaN offers advantages in many other RF circuit functions as well. The application in high-power amplifiers offers the greatest value and is the focus of this book. This chapter helps you learn why and how GaN works in your designs.

The Cost Benefits of GaN

Employing GaN devices in product design can realize several cost benefits. Although GaN is often considered expensive, GaN technology can reduce costs when you know how and why to use it. You can reduce the following three main costs when using GaN:

- **Development costs:** Using GaN appropriately reduces complexity in RF circuit designs, making system development quicker and lower risk, while improving performance and reducing size. It also reduces demands on other aspects of the system, such as power and thermal management.

- **Acquisition costs:** GaN components can reduce costs in the RF subsystem. The most obvious factor is the lower cost per watt of GaN devices in high-power amplifiers. But the reduction in circuit components and size offers an even greater potential for cost savings at the system level by impacting power supply, distribution, and thermal management factors.
- **Operational costs:** The ultimate cost benefit of using GaN-based products is realized over the system's operating life. Systems designed with GaN components require less energy, weight, size, and maintenance. The designer can trade a higher level of functionality with greater size, weight, maintenance, and/or energy costs, but that trade-off is completely in the control of the system designer.

Design Considerations Common to All GaN Circuitry

Circuit and system designers must consider a variety of factors when deciding to use GaN devices in their designs. In this section, we cover some of these important considerations.

Reducing current and power losses in the power supply

GaN devices can operate at higher bias voltages, which provides several advantages at both the system/subsystem and circuit level. A higher operating voltage leads to a proportional decrease in current requirement for the circuit, presuming the power level is held constant.

Decreasing the required current for a circuit makes the system more efficient by reducing power supply distribution loss throughout the system. Minimizing that loss (which is converted to heat) reduces thermal management challenges. The bottom line: GaN improves the system-level trade-off of size, weight, and power.

Reducing temperature rise in the semiconductor

It's no surprise that semiconductors are sensitive to temperature. If the temperature becomes too high, operational reliability may be degraded. If the temperature variation is too high, maintaining required functionality becomes more difficult. Both the semiconductor's maximum and range of temperature must be controlled within the circuit and system. This thermal management function is critical in circuit and system design.

Thermal management becomes even more important in high-power RF systems because, by their nature, power losses are greater, which generates more heat. The semiconductor channel temperature (T_{ch}) must be kept low enough for reliable operation.

GaN provides distinct advantages for keeping temperatures low enough for proper operation. Most significant is that GaN provides reliable operation at a higher temperature than either gallium arsenide (GaAs) or silicon (Si). For a given T_{ch}, GaN provides orders of magnitude longer life. For example, for a 1-million-hour median time to failure (MTTF), GaN can easily operate at a T_{ch} 50°C higher than GaAs. Figure 1-1 shows an Arrhenius plot comparing the reliability performance of GaAs and GaN.

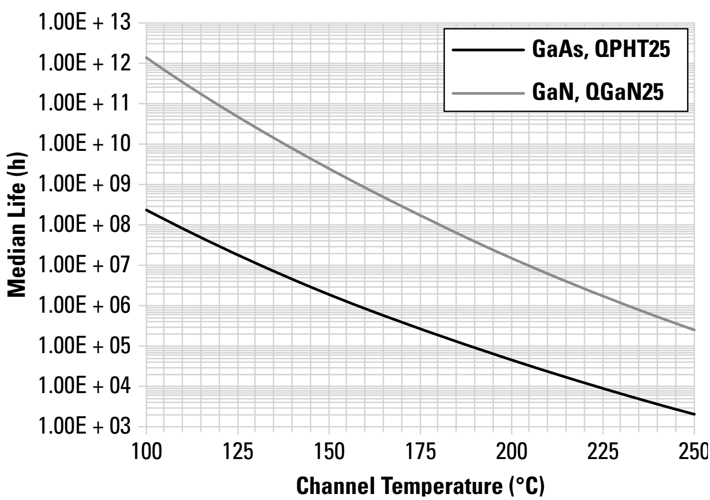


Figure 1-1: Reliability performance of GaAs versus GaN.

Silicon carbide (SiC) is the substrate of choice for GaN RF power devices. SiC provides a much higher thermal conductivity than GaAs or Si substrates. This higher thermal conductivity reduces the temperature rise in the substrate itself. The improved thermal conductivity allows for a small die size for high-power transistors. Thermal design conventions used in high-power GaAs power amplifiers are often thrown out — the conductivity of a GaAs substrate is much lower than solder or the package base. In GaAs devices, the most significant temperature rise is in the device itself. The thermal conductivity of SiC is greater than solder and most package base materials, so most of the temperature rise is often in the die attach, package base, and heat sink interface to the package base.

TIP

Pay particular attention to the thermal management design of the high-level assembly and subsystem to accurately calculate and control the T_{ch} of the high-power GaN components. GaN enables more effective thermal management, but it places different demands on the product design to achieve it. Take advantage of the higher safe T_{ch}.

Improving efficiency and reducing size

GaN enables significant improvement in efficiency and a dramatic reduction in size at the semiconductor device level. That advantage is the first — and the easiest — to recognize. More noteworthy, though, is the dramatic improvements at the system level. Several factors improve the RF efficiency of a system:

- **Power-added efficiency (PAE):** The PAE of GaN transistors is the leading and best understood aspect of improving overall RF circuit efficiency. GaN provides superior PAE over comparably sized GaAs devices above 10 GHz and Si devices above 1 GHz.
- **Field-effect transistor (FET) cell size:** The maximum useful transistor cell size is determined by maintaining phase coherence of combining across the transistor periphery. The *power density* (power per unit periphery) of a GaN device is typically five times higher than a GaAs transistor cell at the same frequency, which allows GaN's

output power level to be five times greater than GaAs. Simply put, you can get the same power output of a GaAs transistor with a GaN transistor one-fifth the size. Size matters!

- **RF power combining:** To get the right power, designers employ RF power combining. GaN allows you to combine fewer transistors, yielding lower power losses and a smaller circuit. In RF amplifiers, the efficiency is directly improved by cutting losses in the output combining and matching networks. Both the combining and matching networks are improved by using GaN in high-power applications.

Adding GaN Devices to Circuits

You can incorporate GaN devices into circuits in a variety of physical formats. In this section, we introduce some of them.

Packaged form

GaN devices are available in many package formats for use in RF circuit design. Packages dramatically improve the ease of handling, the mechanical robustness, and ease of assembly. All levels of GaN device functionality are readily available as packaged parts, from direct current (DC) to millimeter-wave (greater than 30 GHz) frequencies.

The most common GaN product form used today is the packaged discrete power transistor in industry-standard flange and surface mount configurations, which can directly replace other power transistor technologies. Figure 1-2 shows an example of a flanged, packaged GaN transistor, the T1G2028536-FL.

The high frequency and power-level capabilities of GaN are a driving force behind advances in state-of-the-art microwave packaging. Monolithic microwave integrated circuits (MMICs) and internally matched GaN transistors designed to operate in a 50 ohm (Ω) system achieve higher power levels in the same package size as GaAs.

Figure 1-2: A flanged, packaged GaN power transistor, T1G2028536-FL.

Die form

GaN devices used in packaged products may also be available in die form. The die form gives the designer control of die attach and interconnect, enabling a compact module design and a higher-performance circuit design. The design trade-off is that handling, attaching, and interconnect to the transistors is more difficult.

Foundry service

GaN products are available from many suppliers, but few allow access to the GaN process through the foundry services that Qorvo offers (`www.qorvo.com/foundry`). Foundry service gives the designer control of every aspect of the circuit (electrical, thermal, and mechanical) in order to achieve the highest level of performance.

Chapter 2

GaN in Microwave Circuits

In This Chapter

- Investigating RF and microwave amplifiers using GaN power transistors
- Discovering GaN MMICs and RFICs
- Taking advantage of GaN in wideband power amplifiers
- Considering other GaN circuit applications: LNAs, switches, frequency multipliers, and cable TV amplifiers

In Chapter 1, we present a high-level perspective of why and how gallium nitride (GaN) is valuable in radio frequency (RF) and microwave systems. In this chapter, we dive deeper into using GaN in some circuit applications, with an emphasis on power amplifiers (PAs).

RF and Microwave Power Amplifiers

In many cases, GaN is simply the best choice for use in high-power RF and microwave amplifiers. The engineer in each of us needs to quantify "high" and elucidate "best." "Best" is a simpler concept and refers to providing superior performance at the system level: reduced development cost, risk, and time, along with increased functionality as described in Chapter 1. We quantify "high" power in the next sections.

When GaN is the best choice

Compared to other semiconductor technologies, GaN offers the highest combination of speed and signal level. This combination of speed and signal level is realized as

- The highest gain, signal level, and efficiency at a specific frequency
- The highest frequency, gain, and efficiency at a specific signal level

GaN processes are optimized for the highest performance over different frequency ranges. The widest range of GaN processes in the industry are available from Qorvo. Qorvo offers power transistors well suited for operation at various voltages and frequency ranges:

- Through 6 GHz at up to 65 V V_{DD} (QGaN50)
- Through 10 GHz at 48 V (QGaN25HV)
- Through 20 GHz at 40 V (QGaN25)
- Through 50 GHz at 22 V (QGaN15)

Your applications that present challenges in high power and frequency can definitely benefit from GaN technology.

TIP

High-power amplifiers (HPAs) are the dominant application for GaN technology today. When should you use GaN? A simple guideline for HPAs is to use GaN whenever it makes the most critical aspect of HPA design — the output matching network — perform best. Imperfection in this network directly reduces HPA output power and efficiency — two critical requirements for the HPA. Effectively, the imperfection is circuit loss relative to an ideal output matching network.

The following are two primary functions for the output matching network:

- Perform impedance matching between the field-effect transistor (FET) and the system impedance
- Combine the signals from all the FET cells used in the output stage transistor

Requiring less of either function provides an advantage that minimizes loss of the network. GaN helps both functions.

GaN reduces the impedance transformation ratio for HPAs because it operates at a higher voltage than gallium arsenide (GaAs). The minimum power level for which GaN becomes advantageous can be calculated from the operating voltage of the device, the transformation threshold. Figure 2-1 shows the threshold requiring transformation from the system impedance down to the optimum FET load impedance, for typical GaN and GaAs devices across a range of application frequencies.

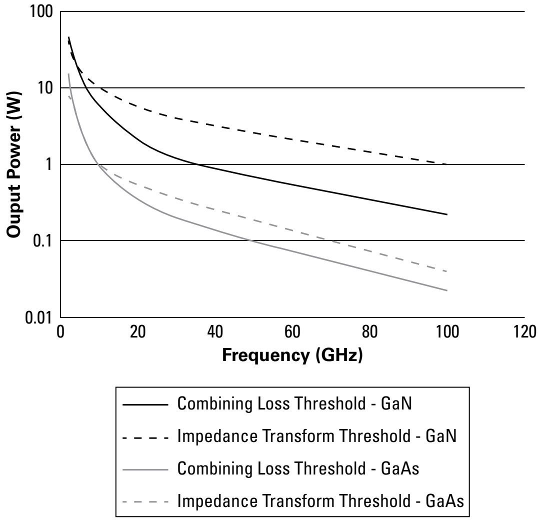


Figure 2-1: HPA design thresholds of GaN versus GaAs.

Consider an example for a 10 GHz HPA. A GaN HPA doesn't require impedance transformation until about 10 watts (W) of total output power. The GaAs HPA would require it a factor of ten lower, about 1 W. The impedance threshold varies as a function of frequency, because the FET devices that are optimized for higher-frequency ranges operate at lower voltages and lower power density.

Now, consider the second function of the output matching network that contributes to losses — combining the signal from multiple FET cells. Combining an increasing number of cells provides an increasing level of loss. The minimum power level that requires combining is shown in Figure 2-1 as the combining threshold. Generally, HPAs use as few cells as possible, and GaN provides an advantage here as well. Using the same 10 GHz example, you can see in Figure 2-1 that a typical GaN FET cell at 10 GHz can provide about 6 W of output power, while a typical GaAs FET cell would provide around 1 W of output power. A GaN HPA will have lower output combining network losses for output power requirements above the 1 W combining threshold of GaAs.

The calculations represented in Figure 2-1 use a number of simplified assumptions. The figure should serve as a guide for HPA requirements that may benefit significantly by using GaN technology, but as always, you should perform a detailed design study to reach final conclusions.

Identifying the best GaN product formats

In Chapter 1, we introduce different product formats for GaN devices. In this section, we consider design trade-offs with each.

Packaged versus die form

Packaged devices provide the greatest ease of use for most applications. The most obvious advantage to packaged devices is ease of assembly. Another key benefit is that signal combining for the FET cells is already accomplished within the package. In addition, thermal management is sometimes the most difficult and often overlooked challenge of a successful design with GaN. The less obvious, but arguably most valuable, advantage of a packaged product is that it addresses the first three levels of thermal design: die, die attach, and heat spreader.

Packaging is available for all forms of GaN devices: transistors, prematched transistors, and monolithic microwave integrated circuits (MMICs). GaN foundry access can also include packaging with highly integrated suppliers, such as Qorvo.

Die-form devices provide the greatest design flexibility and performance capability, but they come with some trade-offs: a longer and more difficult design process, more difficult assembly, and limited supplier availability. Die form can be the better choice when designs require the highest degree of performance and size reduction.

Power transistors

The most common format for designing with GaN is the power transistor. Packaged power transistors are available in a wide range of industry-standard and custom-packaged formats. Qorvo offers an extensive range of transistor power levels (`www.qorvo.com/go/discrete-transistors`). Packaged power transistors offer great flexibility, easy assembly, and short design cycles for GaN amplifiers. One example of a 285 W power transistor is the T1G2028536-FL, shown in Figure 1-2.

The power transistor's flexibility is used not only in conventional single-ended amplifiers, but also in other circuits, giving specific functional advantages. Some examples of circuits that use power transistors are balanced amplifiers, push-pull amplifiers, Doherty amplifiers, and more. The Doherty HPA is especially well suited to GaN devices due to its sensitivity to the high gain of the transistor. High-efficiency linear PAs for communication systems often benefit from using Doherty amplifiers (`www.qorvo.com/go/defense-gan`).

Power transistors in die form are well suited for designs requiring a higher level of performance and more compact custom circuit assemblies. Using transistor dies enables incorporation within a custom package, module, and a smaller area. A transistor die eliminates the parasitic elements that come with packages, so you can realize higher bandwidth and performance and improved circuit repeatability. The trade-off, however, is the additional difficulty in handling, attachment, interconnect, and thermal design.

Figures 2-2 and 2-3 illustrate a packaged power transistor and a power transistor die, respectively.

Internally matched transistors

Internally matched field-effect transistors (IM FETs) are sometimes referred to as "fully matched transistors" and are generally available in packaged form. Internally matched transistors are matched to the system impedance (typically 50 ohms [Ω]), for a specific frequency range. However, the biasing networks are not included and IM FETs are limited to a single stage of gain. The IM FET requires minimal board design; only biasing circuitry for the amplifier must be implemented.

The IM FET may provide excellent performance because all RF-matching networks are optimized over a fixed frequency range and implemented very close to the intrinsic transistor. The trade-off of using an IM FET is reduction in application flexibility; it's specifically designed for a limited frequency range.

Figure 2-2: A packaged 55 W, 28 V, DC–3.5 GHz, GaN RF power transistor, T2G4005528-FS.

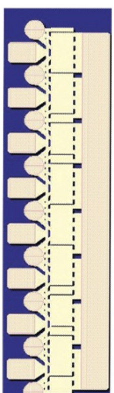


Figure 2-3: A 50 W, 12–32 V, DC–18 GHz, GaN RF power transistor die, TGF2023-2-10.

MMICs and RFICs

MMICs and radio frequency integrated circuits (RFICs) provide the highest level of functional performance and size reduction in microwave circuitry. In addition to PAs, MMICs are used for low-noise amplifiers, driver amplifiers, switches, mixers, multipliers, signal control, and many other functions. For this reason, MMICs have been widely used in GaAs technology over the past three decades and, to a lesser extent, in other compound semiconductors and silicon. Recent progress in silicon transistor speed has led to increasing use in small signal-level RFICs and, ultimately, MMICs.

The same fundamental advantages of GaN that we mention earlier in this chapter also apply to MMICs. GaN offers improved performance in operating voltage, operating frequency, and thermal characteristics. Relative to Si specifically, GaN's reduced substrate losses are a significant advantage. Consequently, GaN is the best technology choice for applications that have critical requirements for high power levels, high-frequency operation, high dynamic range, and small size. Additionally, GaN's higher bias voltage reduces the current level, which is an important advantage in MMICs beyond just higher power levels. The current often dictates the width of conducting lines; GaN's reduced line-width requirements contribute to a reduced die size and better performance in the impedance matching network.

Figure 2-4 dramatically illustrates GaN's advantages by comparing two Ka-band HPA MMICs — one GaAs, one GaN — delivering more than 6 W at 30 GHz. You can see that the GaAs MMIC is quite a bit larger (the images are to scale), which highlights the impact of combining level thresholds of GaAs and GaN. The GaN MMIC uses a simple four-way combining

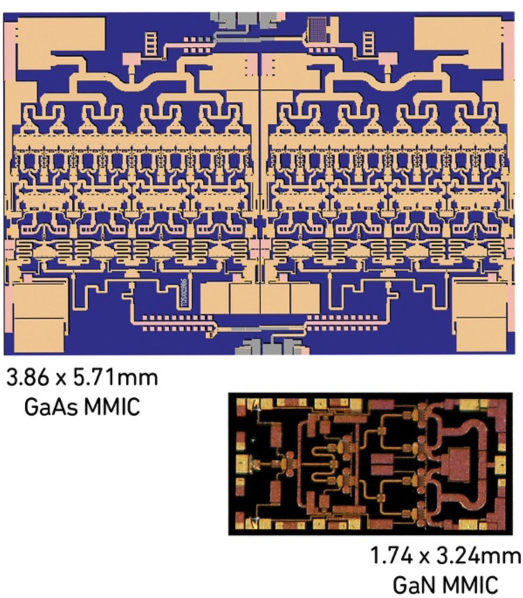


Figure 2-4: A comparison of a GaN versus GaAs Ka-band HPA MMIC.

output matching network to deliver 6 W of output power at 30 GHz. The GaAs MMIC uses a very complex, 32-way combining network to deliver about the same power level. That's not only a great reduction in size, but also a reduction in matching losses that enables higher power-added efficiency (PAE).

For a fun exercise, grab a metric ruler and visualize the size of the MMICs in Figure 2-4. The GaAs MMIC is slightly bigger than the eraser on a pencil, but at 1.74 x 3.24 mm, the GaN MMIC is even smaller than an uncooked grain of rice!

The industry has been moving from predominately die to packaged MMICs for a number of years. GaN MMICs accelerate that trend. Packaged GaN MMICs are easier to incorporate in product designs because of their thermal interface control. The high thermal flux density of GaN can be even more critical at the MMIC integration level where multiple stages and channels of amplification are possible. Packaged GaN MMICs also include the next two critical levels in thermal design and management: die attach and thermal spreader.

Wideband Power Amplifiers

The term *wideband* is a relative term and is interpreted quite differently across the RF/microwave industry. In nearly every application, however, *wideband* means wider than simple, existing solutions. Two primary factors limit bandwidth: the bandwidth of the impedance transformation network and the intrinsic bandwidth limitations of the transistor. In practice, the advantages of GaN that give it superior bandwidth capability for HPAs are an advantage in nearly every high-power RF and microwave circuit.

HPAs at RF and lower microwave frequencies (less than 6 GHz) are generally designed with impedance transformation networks that dominate the operating bandwidth. The optimum impedance load of high-power transistors is well below 50 Ω so the amplifier design must provide impedance transformation up to 50 Ω.

For a simple illustration, consider the ideal transistor with no reactive parasitic components. To realize a 100 W output power with a 40 V supply voltage, it must operate into an 8 Ω load. Thus, the amplifier matching network must transform 50 Ω down to 8 Ω. If the supply voltage is 10 V, the matching network must transform down to 0.5 Ω. That is a much more difficult circuit design problem. A fourfold increase in operating voltage changed the impedance transformation ratio by 16. The 40 V and 10 V operating voltages in this example are typical X-band devices using GaN and GaAs, respectively. The simple conclusion: Designing HPAs using GaN is easier, has lower risk, and yields better performance.

A matching network of the same complexity can achieve a wider bandwidth with the lower impedance transformation ratio required by GaN. The wider bandwidth circuit requires no more area using GaN. Alternatively, realizing the same bandwidth using GaN's lower transformation ratio requires a lower complexity circuit consuming less area. In short, a designer using GaN devices has a better trade space to work with. For example, a GaAs high-power transistor amplifier may achieve an instantaneous bandwidth of 50 MHz at 2 GHz, while a GaN transistor of the same power level may realize 200 MHz bandwidth with the same matching network complexity.

The second factor providing an advantage for GaN transistors is their intrinsic bandwidth capability. Theoretically, the maximum bandwidth using a lossless matching network is substantially higher than the example given in the previous paragraph. The intrinsic output impedance of power transistors is well represented by a parallel resistor/capacitor (RC) network. The maximum instantaneous bandwidth that can be achieved is limited by the well-established Bode–Fano limit with an infinite matching network complexity.

TECHNICAL STUFF

The *Bode–Fano limit* states that there is a general limit on the bandwidth over which an arbitrarily good impedance match can be achieved in the case of complex load impedance. This limit is related to the ratio of reactance to resistance and to the acceptable degree of mismatch to the load.

GaN can increase this instantaneous bandwidth due to its higher current density and lower parasitic capacitance. The practical bandwidth for providing excellent power match may be greater than 10 GHz for a process like Qorvo's QGaN15. Realizing bandwidth approaching the theoretical limitations requires very small dimensions between the transistor and matching networks; these small dimensions are only available in an MMIC implementation.

If you take advantage of GaN's other benefits, your circuit designs can achieve higher amplifier bandwidths with modest compromise. The TGA2573-2, shown in Figure 2-5, is an example. Distributed amplifiers can be used for multiple decade bandwidth amplifiers such as optical modulator drivers. In these amplifiers, the advantage of GaN is, once again, its higher operating voltage. A typical high-power distributed amplifier's output power is limited by the square of the supplied voltage for a fixed load impedance of, for example, 50 Ω. When you compare a GaN amplifier operating at three times the bias voltage of a comparable GaAs amplifier, the GaN amplifier provides about nine times the output power of the GaAs device!

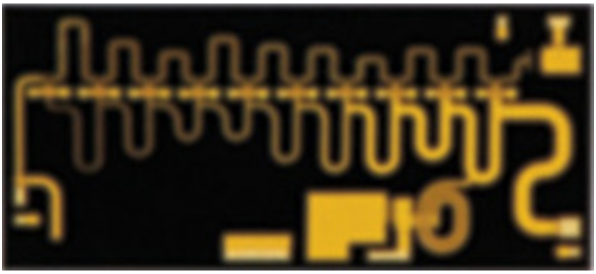


Figure 2-5: A 10 W, 2–18 GHz, GaN power amplifier MMIC, TGA2573-2.

Other GaN Circuit Applications

Besides the circuit applications previously mentioned in this chapter, there are other circuit applications of GaN technology. We won't cover all of them in this short book describing GaN, but we will mention a few just to whet your appetite.

Low-noise amplifiers

GaN provides comparable noise figure performance to GaAs FETs, allowing similar noise figure performance for a low-noise amplifier (LNA). The advantage of GaN is the ability to handle much higher signal levels without damage. This is useful for applications where high incident signal levels require a limiter before the LNA. The limiter incurs loss, degrading the system noise figure. A GaN LNA may eliminate the limiter, improving the system noise figure.

An example of an LNA is the TGA2612-SM, shown in Figure 2-6.

Figure 2-6: A 6–12 GHz GaN low-noise amplifier, TGA2612-SM.

High-power switches

GaN is well suited to RF switching applications. The high breakdown voltages combined with low on-resistance and off-state capacitance enable dramatic increases in power handling. GaAs FET switches are widely utilized throughout the RF industry, but they're typically used for power levels on the order of a few watts or less. GaN FETs are able to use the same circuit architectures to handle power levels on the order of tens of watts. This can be implemented on the same MMIC as HPAs, LNAs, and other signal control circuitry.

An example of a high-power switch is the TGS2353-2-SM, shown in Figure 2-7.

Figure 2-7: A 0.5–18 GHz high-power GaN SPDT reflective switch, TGS2353-2-SM.

Frequency multipliers

Frequency multipliers are circuits that generate an output signal with a frequency that is a *harmonic* (multiple) of the input frequency. Some applications of frequency multipliers are wireless communications, very-small-aperture terminal (VSAT), point-to-point radio (PtP), space, and test equipment. Qorvo produces frequency multipliers that cover a frequency range of 8 GHz up to 77 GHz.

GaN will work exceedingly well in these applications for the same reasons GaN excels in amplifiers — its ability to operate with higher voltages and higher frequencies, while using a small circuit area.

Cable TV

As in other applications needing higher speed and large signal levels, GaN's intrinsic characteristics are excellent for key components within cable TV (CATV) infrastructure systems. CATV systems are used extensively in the world's information communication networks, and the increasing demand for data and information transport means CATV components also need higher speed and higher output power — benefits that GaN can provide inherently.

Initial CATV infrastructure deployed in the 1970s and 1980s used silicon driver amplifiers. Those CATV driver amplifiers moved to GaAs technology in the 1990s because GaAs enabled increased data rates through higher signal bandwidth and power levels. GaN provides additional increases in speed and signal level relative to GaAs. Today's highest performance CATV driver amplifiers use GaN devices to provide the highest linear output power over the widest bandwidth in the industry.

An example of a CATV amplifier employing GaN technology is the RFPD3210, shown in Figure 2-8.

Figure 2-8: A 1.2 GHz, GaN-GaAs power doubler amplifier in an industry-standard hybrid package, RFPD3210.

Chapter 3

Ten Keys to Success Using GaN

In This Chapter

- Taking advantage of GaN's high operating voltage
- Choosing the best product format
- Exploiting the system implications to the greatest extent
- Employing thermal modeling to evaluate design reliability

In this chapter, you find ten keys to success using gallium nitride (GaN) in your circuit designs to achieve the power and frequency needed for your applications.

- **Use GaN for high frequency and high power.** GaN devices have the unique ability to operate at a much higher voltage than other semiconductor microwave devices, allowing them to be used in higher-power applications. GaN devices can produce higher power with less current, reducing the power loss on the board and improving the thermal management of the system.
- **Take advantage of the flexibility of product availability.** GaN is available in both packaged and die form for power transistors and monolithic microwave integrated circuits (MMICs). Partially matched transistors and fully matched transistors are available in packaged form. Each format has its own trade-offs that the designer should carefully consider. Because GaN is available in several formats, it can be used to meet almost any requirement.
- **Include thermal management in the next-level assemblies.** When designing systems with high power levels, thermal management is extremely important. The outstanding thermal conductivity of GaN helps thermal

management. Conversely, the very high power densities realized in GaN place additional stress on system thermal management. Consider this element of design from the beginning.

- **Coordinate circuit trade-offs with system design.** GaN circuits will result in system-level capability improvements and trade-offs. Recognize that impact and optimize the circuit trade-offs with the system design to realize the full benefit of GaN's capabilities.
- **Consider temperature dependence.** GaN devices can operate at much higher temperatures than many other semiconductor materials, so they're great for applications that require high-temperature operation. The large range of safe operating temperatures also places special emphasis on accommodating the device's temperature dependence in your circuit design.
- **Take advantage of the operating voltage flexibility.** GaN's flexibility of operating voltage allows you more options to achieve the desired power and frequency while being able to implement a simpler circuit design to get the desired performance.
- **Take advantage of GaN's high power density and low parasitics.** Consider the high power density of GaN when you need to maximize output power and minimize circuit surface area.
- **Reduce the number of stages using higher gain and power.** The higher usable gain provided by GaN devices allows the designer to reduce the number of stages required. Take full advantage to minimize the circuit area in conjunction with reduced field-effect transistor (FET) area available using GaN.
- **Use GaN's high signal-level capability for dynamic-range requirements.** The ability of GaN to operate at a higher voltage for a given frequency allows you to use a high signal level for designs that require a high dynamic range.
- **Evaluate reliability of the design with thermal modeling.** GaN devices have a longer median time to failure (MTTF) than other semiconductor devices. For a given channel temperature (T_{ch}), GaN has beyond an order of magnitude improvement in MTTF. Thermal modeling is critical to establish an accurate T_{ch} and MTTF.