White Paper

Optimizing a GaN-on-SiC-Based RF Amplifier with Wolfspeed and RadioCarbon

Authors
Larry Hawkins
Director – Technical Marketing and Integrated Solutions and Systems, Richardson RFPD

Ryan Baker
RF Product Marketing Manager, Aerospace & Defense, Wolfspeed

April 2023

The benefits of Wolfspeed GaN-on-SiC RF amplifiers have been well-documented—they provide outstanding power density, reliability and better efficiency than their traditional GaAs-based counterparts. In this paper, a GaN-on-SiC-based RF amplifier is optimized for 4.4–5.0 GHz troposcatter applications.

System Design

This paper reviews component selection, design in a simulated environment, and implementation of the simulated circuit into hardware. The primary development goal was to produce a compact power amplifier design to be implemented into an RF front-end designed by Richardson RFPD. ***Figure 1***, below, uses a C-Band SATCOM PA as an example, outlined in a yellow box. This troposcatter PA is capable of delivering 50 W CW from 4.4 to 5 GHz and has a linearity requirement for less than 3% EVM under a peak-to-average power ratio of 10 dB.

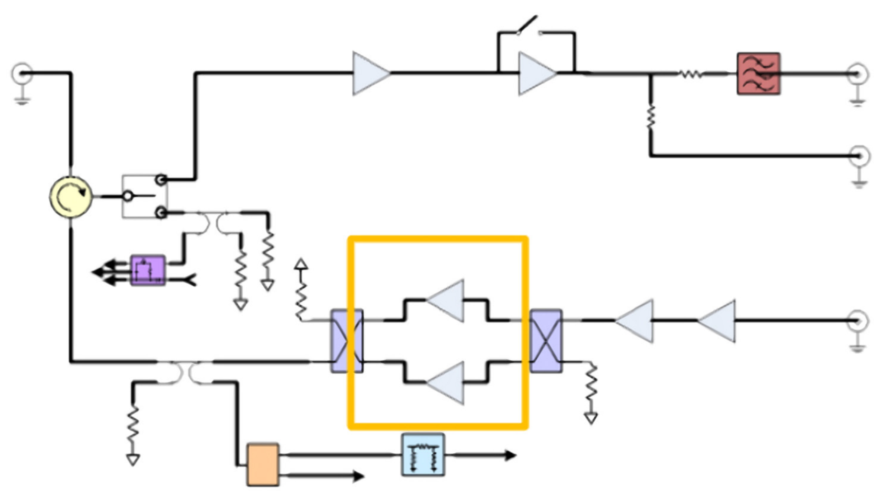

Figure 1

In order to provide the highest possible gain at the C-band, a transistor from the Wolfspeed 0.25µm foundry process: the CGHV1F025S. This is a 25 W general-purpose transistor that utilizes Wolfspeed's G40V4 process technology and is ideally suited for use in compact footprint designs. In order to achieve the desired output power, it was necessary to combine two devices in a balance architecture. The properties of the CGHV1F025S transistor, specifically its shorter gate length, allows for higher frequency operation and improved gain.

To build the design, the engineer used the Wolfspeed GaN transistor model in Microwave Office from Cadence. To simulate the PCB parasitics, lumped elements were chosen. Additionally, a thermal resistance of 7.3° C/W was used for the via farm under the transistor. In order to maintain a junction temperature below 225° C, approximately 50% efficiency is needed to achieve a case temperature of 85° C for the application.

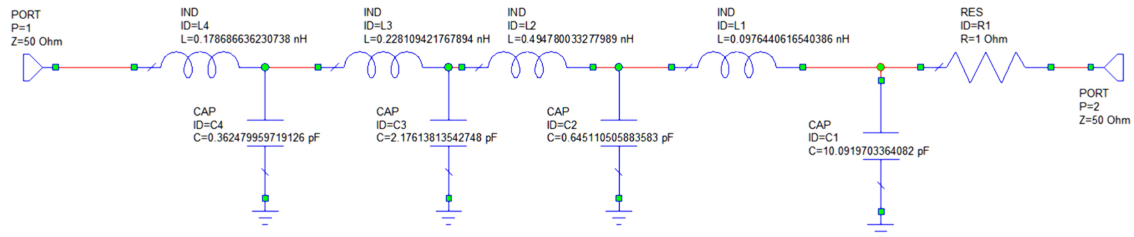

Figure 2: Input Match

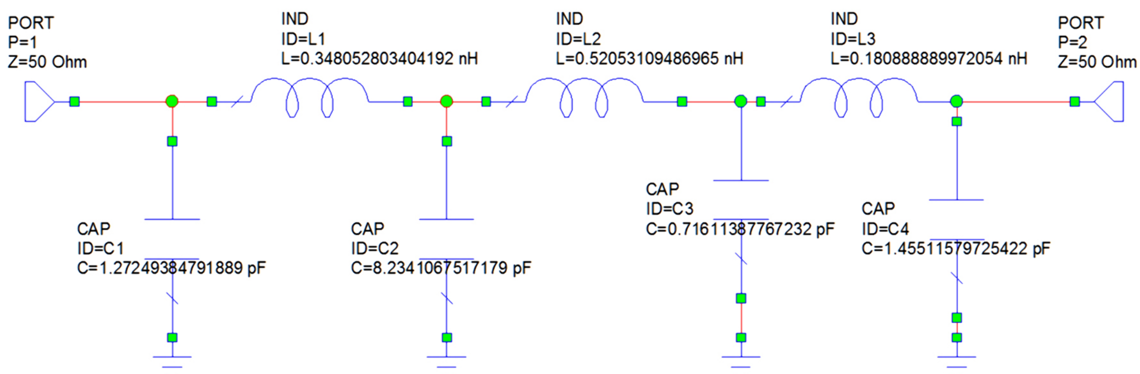

Figure 3: Output Match

By simulating both the input match (*Figure 2*) and output match (*Figure 3*) with lumped elements, the number of LC stages required to achieve the target BW was determined. This information was then converted to transmission lines. All of the resistor, inductor and capacitor component models are from the Modelithics passives library. A 1-ohm resistor was added in the gate path in order to achieve the desired stability, as is common practice in GaN transistor matching.

In the next step of the design process, these lumped elements for the I/O networks were created using transmission lines, as seen in *Figure 4*. All PCB layout items were included in the simulation.

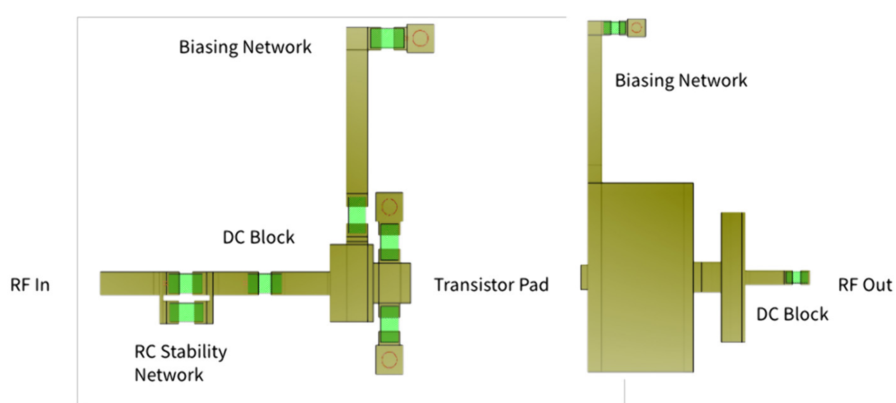

Figure 4: Matching Network PCB Layout

As previously mentioned, the two 25 W transistors were combined in order to achieve the desired power output. In this stage, the simulator pulls in the I/O matching networks, then adds the splitter and combiner networks. For the splitter and combiner, a Wilkinson topology was chosen, which provides good isolation between the two ports. They were implemented in transmission line format, to improve the manufacturability and performance uniformity (see *Figure 5*). An alternate approach would be to use a high power-handling resistor. It is essential that the stability of the design is carefully analyzed, as each transistor can impact the impedance presented to the other.

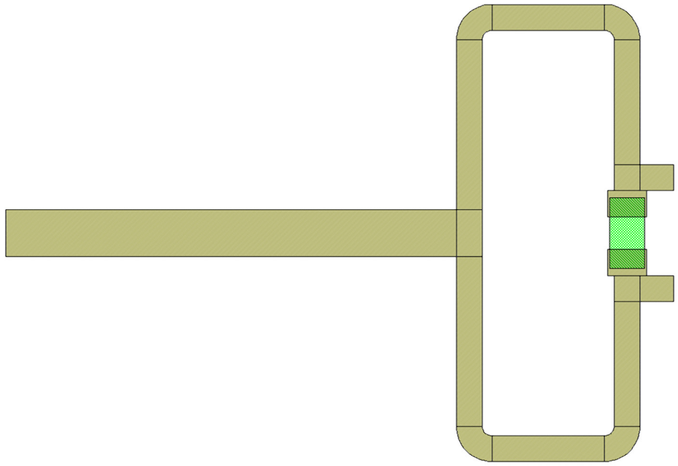

Figure 5: T-Line Combiner

Thermal Considerations

One of the most important considerations for system design is thermal performance. In fact, if a design is not thermally viable, then any other measure of performance simply does not matter. In order to help designers accurately assess the thermal performance of their systems, Wolfspeed provides an Rjc on each transistor datasheet. The Rjc indicates the thermal resistance of the die, on the back of the package, and can be used to calculate junction temperature. The equation to calculate junction temperature is as follows:

*Tj = (Dissipated Power)*Rth + Operating Temperature*

In order to keep the die in a safe operating condition, as well as allow for the device to have an MTTF of more than 1 million hours, designers should aim to keep the Tj under 225° C. To determine the thermal resistance (Rth) of its RF products, Wolfspeed uses a combination of an IR camera, which captures thermal images of the die, and an FEA (finite element analysis) simulation to model the junction temperature. With the IR camera, it is important to consider the spot size of the camera and to use actuals instead of averages of the temperature. The camera measures the topside of the die. A thermal stack is then used to arrive at the temperature of the backside of the die. The combination of these two methods paints an accurate picture of the thermal resistance of the device.

The Arrhenius plot in *Figure 6* helps depict the effects of temperature on the lifetime of a device and helps Wolfspeed to perform reliability testing at elevated temperatures in order to accelerate a failure. Note that all Wolfspeed GaN RF technologies have a mean time to failure (MTTF) of more than 10 years, even at an operation junction temperature of 225° C. This reliability, even at high temperatures, gives additional flexibility in the design. If even greater longevity is needed, the system can be designed to operate at temperatures lower than 225° C. If is is prerable to push performance higher and shorten the design life, then operating temperatures can be pushed higher.

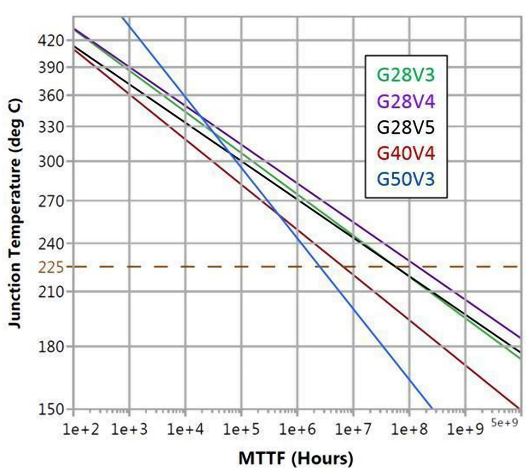

Figure 6: Junction Temperature vs. Mean Time to Failure

During the design of this amplifier, the junction temperature was monitored using the Trise port in Microwave Office. The Trise port, which is native in Wolfspeed's models, automatically includes the self-heating effects from the transistor's performance—an important but easy-to-overlook consideration.

Electromagnetic Analysis

Once the lumped element and microstrip lines result in acceptable RF performance, and any fine-tuning for stability is completed, it is recommended that the design is simulated using an EM simulator. Using EM analysis will improve the accuracy of the design, resulting in closer modeled-to-measured results. It is suggested that an EM simulator is used on the entire design.

Axiem EM offers automated meshing. Meshing is the process of dividing the design into many smaller parts in order to correctly define the physical shape of the design. This results in a more accurate response in a shorter amount of time. The EM analysis exposes any layout or simulation errors, like port errors. The precision of the analysis can be increased by defining a finer mesh; this will increase accuracy but also increase simulation time.

Modeled vs. Measured Performance

So how did the performance of the modeled system stack-up vs. measured performance? The results speak for themselves. The small signal performance (*Figure 7*) resulted in very good correlation of modeled-to-measured performance.

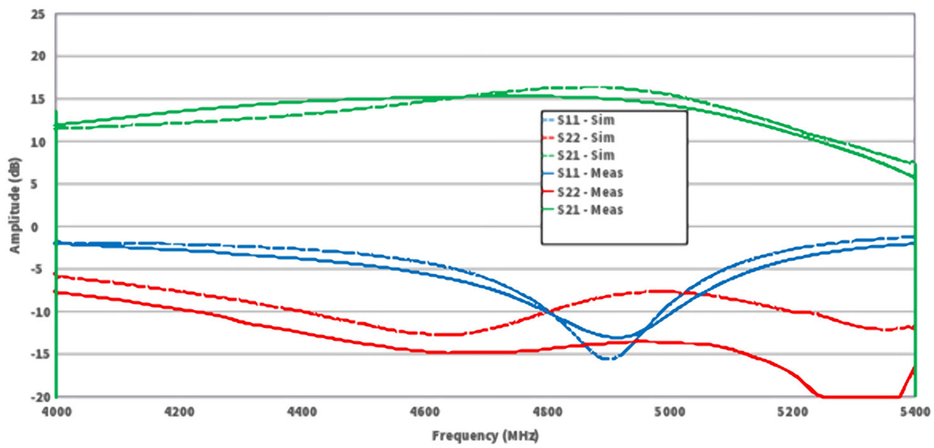

Figure 7: Small Signal Measured vs. Modeled

The large signal model (*Figure 8*) showed 10 dB of power gain, 50 W and ~57-58% DE. This model is slightly pessimistic for drain efficiency.

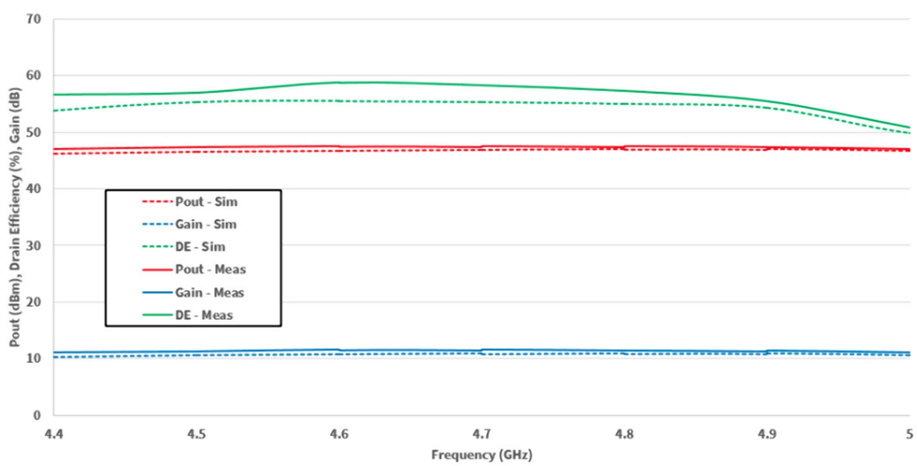

Figure 8: Large Signal Measured vs. Modeled

RichardsonRFPD
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Wolfspeed

Wolfspeed RF Amplifier and RadioCarbon Implementation

Richardson RFPD has been promoting the concept of Design Accelerators. Design Accelerators are hardware development platforms that reduce customers' time-to-market. In addition to off-the-shelf, orderable hardware, Design Accelerators also provide licensable design files, software and design services. Some of these accelerators can be used as-is in production as OEM modules, while others are intended as reference designs which customers may modify. The Wolfspeed GaN-on-SiC RF amplifier shown in this article was used to develop the Richardson RFPD RadioCarbon platform. The RadioCarbon RF front end can be modified for other bands and use cases, through a third party. The RadioCarbon RF front end can work independently or can be integrated with radio systems that include digital pre-distortion (DPD), which enables an "out of the box" communication system to quickly develop software, algorithms or waveforms, thereby accelerating designs and decreasing time-to-market.

About Richardson RFPD

Richardson RFPD, an Arrow Electronics company, is a global leader in the RF, wireless, IoT and power technologies markets. It brings relationships with many of the industry's top radio frequency and power component suppliers. Whether it's designing components or engineering complete solutions, Richardson RFPD's worldwide design centers and technical sales team provide comprehensive support for customers' go-to-market strategy, from prototype to production. More information is available online at richardsonrfpd.com.

About Wolfspeed

Wolfspeed (NYSE: WOLF) leads the market in the worldwide adoption of Silicon Carbide and GaN technologies. We provide industry-leading solutions for efficient energy consumption and a sustainable future. Wolfspeed's product families include Silicon Carbide materials, power devices and RF devices targeted for various applications such as electric vehicles, fast charging, 5G, renewable energy and storage, and aerospace and defense. We unleash the power of possibilities through hard work, collaboration and a passion for innovation. Learn more at www.wolfspeed.com.

In Person

Richardson RFPD
630 262 6800
800-737-6937 (U.S. Toll Free)

Wolfspeed
919-313-5300
800-533-2583 (U.S. Toll Free)

Via Email

larry.hawkins@richardsonrfpd.com
ryan.baker@wolfspeed.com

Online

richardsonrfpd.com
wolfspeed.com

RichardsonRFPD
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