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White Paper

Discrete Transistor, IMFET or Power Amplifier IC... Which is best?

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October 2021

The global RF power semiconductor market is presently valued at approximately $1.5 billion[1]. These devices provide the RF amplification for a wide variety of applications, from MRI to broadcast transmitters, radar systems and cellular base stations. Choosing the right component category is critical to developing amplifier systems that meet performance, size, cost and time-to-market requirements, and there are multiple options to consider. This paper covers component construction options avaialble for all RF power amplifier technologies, including but not limited to GaN.

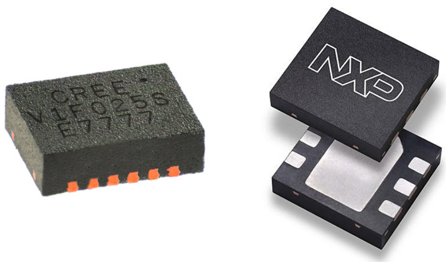
There are three broadly available RF power semiconductor devices—discrete transistors, impedance matched field effect transistors (IMFETs), and MMIC amplifier ICs. Each device has a unique value proposition that will be addressed in this paper.

How much integration do you need? Defining discrete transistors, IMFETs and MMIC amplifiers

Discrete transistors

Discrete transistors are single gain-stage devices with input and output terminals either unmatched or partially matched[2], meaning external impedance matching circuits are required on the printed circuit board to optimize the transistor in an amplifier circuit. By leaving circuit optimization to the system designer, the circuit design complexity is high, but the designer can optimize a circuit for their needs. Use cases for discrete transistors are therefore broad, as multiple applications can potentially use the same discrete transistor but with different matching.

Two examples of discrete RF power transistors are the Wolfspeed CGHV1F025S and the NXP A3G26D055NT4. The CGHV1F025S is an unmatched, single-stage GaN on SiC transistor with 25 W saturated output power. It is usable from DC-15 GHz. The NXP A3G26D055NT4 is also an unmatched, single-gain stage GaN on SIC transistor, but it offers 55 W saturated output power from 100-2690 MHz. Neither device can cover the entire frequency range in a single application, but they can be used in multiple narrow and wideband applications. This makes them extremely versatile devices.



The Wolfspeed CGHV1F025S (left) and the NXP A3G26D055NT4 (right)

Higher integration can add value,

but it generally comes at a cost—and not only in terms of price.

IMFETs

Another option is an impedance matched field effect transistor, often referred to as an "IMFET." An IMFET is similar to a discrete transistor in that it is also a single gain-stage device, but in this case the component manufacturer has added 50-ohm impedance matching elements inside the device for ease of use. Component manufacturers create this functionality by adding integrated passive devices (IPDs) to manage the impedance transformation to 50 ohms. IPDs are specialized but are generally low-cost to develop and easy to integrate within the packaged transistor. The benefit of IMFETs over discrete transistors is obvious—by having a 50-ohm input and output, the amplifier designer is not tasked to develop an external impedance matching network, which saves time and PCB space. IMFETs are the most useful for applications that require combining several devices to obtain extremely high peak output power levels.

The best examples of this use case are pulsed radar systems. Two excellent examples of IMFETs are the Wolfspeed CGHV59350F (See ***Figure 1***, below) and CGHV96100F. The CGHV59350F is a 400 W peak power GaN on SiC transistor covering C-band radar (5.2–5.9 GHz). The CGHV96100F is a 100 W peak power GaN on SiC transistor covering X-band radar (7.9–9.6 GHz). Both devices offer a single gain stage and include 50-Ohm input and output matching to enable high power amplifiers over 1 kW.

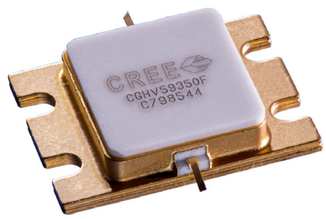


Figure 1: Wolfspeed CGHV59350F

Power Amplifier ICs

The final option is that of an RF MMIC power amplifier IC. The MMIC amplifier brings further integration and functionality in a single device. MMICs have the benefit of 50-Ohm matching for the input and/or output, like the IMFETs, but they typically also contain multiple gain stages. Discrete transistors and IMFETs, by contrast, are single gain-stage devices and will require the developer to add a driver stage and possibly a pre-driver stage to complete the RF amplifier lineup. By incorporated two or more gain stages in a single device, the amplifier development is further simplified and offers the additional benefit of shrinking the overall design. While impedance matching and multiple gain stages are commonly available in MMIC amplifier ICs, other features include dual path/Doherty amplifier configuration, high video bandwidth, temperature sensing and compensation, and even integrated couplers or power detectors. In fact, NXP recently announced integrated gate bias controllers in their 5G-ready power amplifier modules (PAMs) for massive MIMO applications.[3]

Two good examples of MMICs include NXP's AFIC10275GNR1 and A3M37TL039T2. The AFIC10275GNR1 is a dual gain-stage, 250 W peak power RF amplifier covering 978–1090 MHz. Intended for pulsed avionics transponder applications, the device has internally matched input of 50 Ohms, integrated ESD protection and temperature compensation. The NXP A3M37TL039T2 is an integrated Doherty amplifier IC that delivers 7 W average power from 3.6–4.1 GHz, with internal input- and output-matching of 50 Ohms. The device's integrated Doherty combiner results in a highly efficient Doherty amplifier with a single input and output, making this an extremely easy device to use.

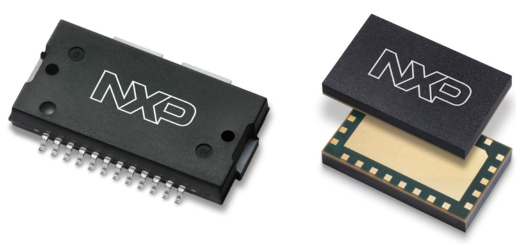


Figure 2: NXP AFIC10275GNR1 (left) and A3M37TL039T2 (right)

It should be noted that although MMICs can greatly ease system development, there are downsides to adopting them. For one, the price may include unneeded or unwanted features. MMIC amplifiers are significantly more expensive than single-stage transistors and IMFETs. Furthermore, MMICs limit the ability of the amplifier designer to innovate, as the component supplier has made multiple performance tradeoffs for the sake of integration. For instance, with the advent of electronic countermeasures for aerospace and defense applications, wideband power amplifiers have been developed for network jammers. It is quite common to find MMIC amplifier ICs covering 500–2500 MHz or even 6–18 GHz. However, as these devices have been developed for jamming applications, they have been optimized for gain flatness and efficiency but not necessarily linearity and cost—so they are not always suitable for every narrowband application within their frequency range.

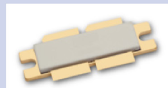
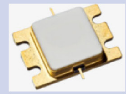
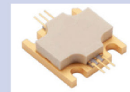
Attribute	Discrete Transistor	IMFET	MMIC
Image			
Gain Stages	1	1	2-3
50Ω Matching	None, Input only	Input/Output	Input only or Input/Output
Integration	Low	Medium	High
Versatility	High	Low	Low
Ease of use	Low	Medium	High

Table 1: Comparison of RF power semiconductor devices

If integration is better, why do component suppliers offer discrete transistors at all? The economics of RF power component development.

Component manufacturers are constantly balancing customer needs against technological capabilities and market realities. The use cases for RF amplifier systems, and therefore RF power devices themselves, are highly varied. Developers of land mobile radios, radar systems, RF generators, MRI equipment, and 5G communications equipment all have different needs that span electrical, mechanical and even cost requirements. Integrating RF power devices into multi-stage amplifiers is an expensive endeavor. Even if development of a specific custom MMIC is achievable, it does not necessarily mean a customer is willing to pay for the benefits. Furthermore, while higher integration can add value, it generally comes at a cost—and not only in terms of a higher price, though that is also true. When component manufacturers integrate more functionality into a device, they are tailoring the device for a very specific use case.

Several factors are considered to determine if development of a MMIC amplifier is appropriate. An application that spans a common frequency band and uses a common amplifier system architecture, in addition to common output power and voltage requirements, can be an excellent candidate for an integrated MMIC. In trying to align these attributes, however, the opportunities for integrated MMICs begin to shrink towards a small number of specific use cases. Ultimately, the available market for such a device needs to be large enough to justify development, and the customer base needs to appreciate the value of a highly integrated and more expensive device.

RF power device selection and finding the right balance.

As mentioned above, the integration of RF power devices can offer strong value, but it can also bring significant design tradeoffs that will not fit all applications. Therefore, it is the job of the system developer to balance the tradeoffs. Discrete RF power transistors are unmatched, miniature, single gain-stage devices that are the most versatile and can be used in almost all use cases. However, to develop an amplifier lineup with discrete transistors, physical space is needed for multiple power devices, biasing and off-chip impedance matching. Sufficient time and expertise is also needed in order to develop the circuit and still meet time-to-market requirements. IMFETs can simplify and shrink the circuit, but they cover specific use cases—for example, avionics and radar. MMIC amplifiers offer the benefit of ease-of-use and miniaturization, but the features must match the specific use case. Part 2 of this paper will address evaluating the best technology for the application and use case.

Footnotes and Sources:

1. Data provided by Eric Higham from Strategy Analytics. Contact Strategy Analytics for further details.

2. In this reference "partial match" could mean two different things. It could refer to either the input or output being matched to 50 Ohms, though it is usually the input. It is also a term used to describe silicon LDMOS RF power transistors. When LDMOS transistors were introduced in the 1990s, there were significant improvements over silicon bipolar junction transistors, which were the leading RF power device technology at the

time. However, the first available RF LDMOS transistors had extremely low characteristic impedance compared to bipolar junction transistors, which made them harder to impedance-match to 50 ohms. LDMOS suppliers listened to the customers and added “partial” matching inside the device with lumped elements and eventually IPDs. This partial matching increased the characteristic impedances to be closer to that of bipolar transistors, but these were not matched to 50 ohms like IMFETs. LDMOS suppliers to this day reference “internal impedance matching” or “partial matching” on datasheets, even though the devices are not matched to 50 Ohms, and silicon bipolar junction transistors are rarely used.

3. NXP Brings GaN to 5G multi-Chip Modules for Energy-Efficient Mobile Networks (June 28, 2021)

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