White Paper

Discrete Transistor, IMFET or Power Amplifier IC... Selection by Application

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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. Part I of this paper addressed the unique value proposition for each device. Now the discussion turns to applications and use cases.

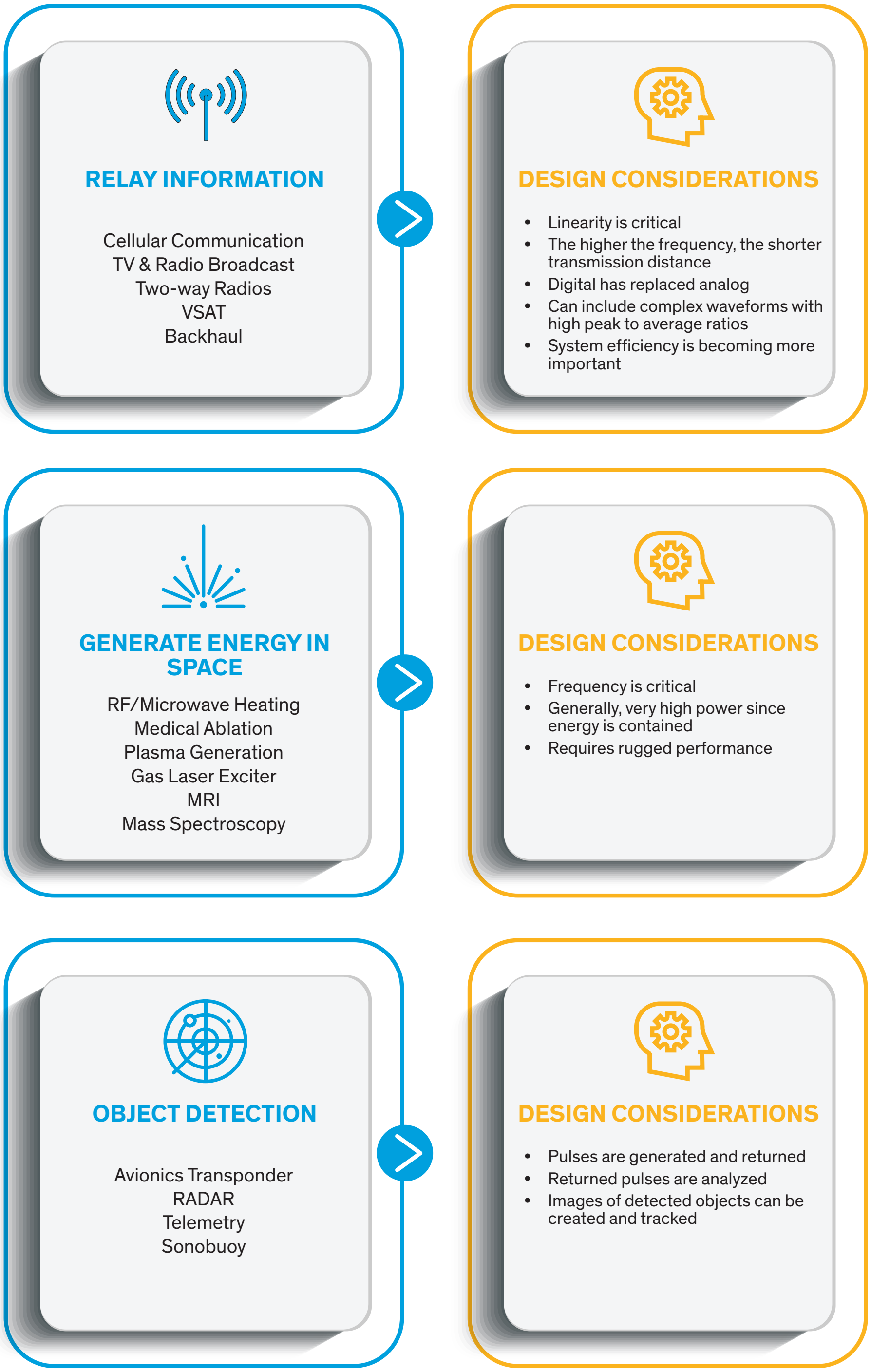
Introduction

Part I of this paper, “Discrete RF Power Transistor, IMFET, or Power Amplifier IC... Which is Best?” addressed the different RF power semiconductor device types, their differentiating features and some examples. It is important to also address applications and use cases.

RF power devices are developed via direct collaboration between component manufacturers, distributors and end users. Invariably, these devices are developed for a specific use case(s). As mentioned in the first paper, the component manufacturer analyzes the market to marry the right features and attributes with a potential customer base and expected production volume. These are typically intense deliberations.

Since these products are aimed at specific use cases, it is relevant to investigate the typical applications and look at how RF power semiconductor types (discrete transistor, IMFET, MMIC amplifier) may be suited for these systems. The applications reviewed in this paper include avionics and radar, land mobile radio, electronic warfare, Satcom, wireless infrastructure, and industrial, scientific and medical (ISM).

The ultimate equalizer is the market, thousands of designers coming together with component manufacturers with their use cases.



RELAY INFORMATION

Cellular Communication
TV & Radio Broadcast
Two-way Radios
VSAT
Backhaul

DESIGN CONSIDERATIONS

- Linearity is critical
- The higher the frequency, the shorter transmission distance
- Digital has replaced analog
- Can include complex waveforms with high peak to average ratios
- System efficiency is becoming more important

GENERATE ENERGY IN SPACE

RF/Microwave Heating
Medical Ablation
Plasma Generation
Gas Laser Exciter
MRI
Mass Spectroscopy

DESIGN CONSIDERATIONS

- Frequency is critical
- Generally, very high power since energy is contained
- Requires rugged performance

OBJECT DETECTION

Avionics Transponder
RADAR
Telemetry
Sonobuoy

DESIGN CONSIDERATIONS

- Pulses are generated and returned
- Returned pulses are analyzed
- Images of detected objects can be created and tracked

Figure 1: RF Power Uses

Communications

Relaying information is usually associated with mass communication systems like cellular infrastructure and television and radio broadcast systems, but this can also include private radio or land mobile/two-way radio systems, as well as satellite communications. Although these systems are quite different, they share common RF amplifier design considerations.

Amplifier linearity is critical. It takes a highly linear amplifier to transmit complex, modulated waveforms of communication data. More recently, efficiency has also become quite important—it is no longer sufficient to operate a highly linear yet inefficient communications transmitter. Another consideration is that the transmission distance is inversely proportional to the operating frequency. As the operating frequency increases, the transmitted power decreases and vice-versa.

As mentioned in part I of this paper, cellular infrastructure applications represent the single largest available market for RF power semiconductors, so component manufacturers dedicate the most resources to this space. Unique for this application is that design cycles are extremely fast, from 6 to 12 months, and the production cycles are also short, usually lasting no more than three years. Doherty is the system architecture of choice for this application. It combines a main and peak amplifier to offer both high linearity and efficiency, albeit over a relatively narrow signal bandwidth. For high-power Macro BTS, discrete transistors rule the final stage amplifier. A good example of a final output stage discrete transistor is the A2G35S200-01SR3 from NXP, which provides 40 W average output power and 15 dB gain from 3.4 GHz to 3.6 GHz. Wolfspeed's GTRA364002FC-V1 (See Figure 2, below) is a dual-path Doherty transistor that provides 400 W peak saturated power, 14 dB gain, and 60% efficiency from 3.4 GHz to 3.6 GHz.

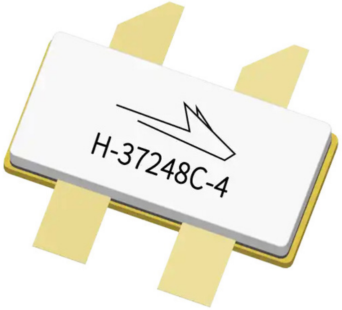


Figure 2: Wolfspeed's GTRA364002FC-V1
dual-path Doherty transistor

The integrated, multistage MMIC amplifiers for cellular tend to be low-power drivers. A good example is NXP's A3I35D025WNR1, which is a dual-stage LMDOS amplifier providing 3.4 W average power and 29 dB gain from 3.2 GHz to 4.0 GHz. Massive MIMO (mMIMO) is an alternative approach to broad coverage of a Macro BTS, which does offer unique characteristics. It is a distributed architecture that is of an assembled array of low power transmit/receive elements, 32 and 64 being the most common. Since the power is low and there are a high number of items to integrate into the system, highly integrated MMIC devices are of value. Examples of this include the NXP A3M35TL039, which is a LDMOS Doherty amplifier IC that offers 7 W average output power, 40% efficiency and 50 ohm input and output.

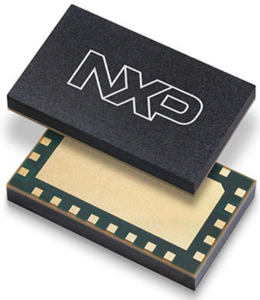


Figure 3: NXP A3M35TL039 LDMOS Doherty amplifier IC

There are times where system designers need to develop products faster than component manufacturers can design the appropriate RF power semiconductors, so there is a normal tension between the use of discrete transistors and integrated amplifiers, depending on the needs of the day. IMFETs are not feasible in wireless infrastructure. There are too many frequency bands to manage and too much optimization required for a generic single-stage gain block to be of much use.

Alternatively, TV and radio broadcast transmitters differ from 5G wireless infrastructure in two important aspects. First, the power levels are extremely high, because broadcasters transmit hundreds of miles. Second, the design and production cycles can last several years, and new transmitters are only designed when a significant technology improvement is achieved. UHF TV broadcasters were some of the first to adopt LDMOS technology in the mid 1990s to take advantage of the high gain and linearity of the devices. Although UHF broadcast transistors have been improved since then, similar LDMOS devices are still used today.

A similar event happened in 2011 for FM transmitter OEMs, as Freescale introduced a new line of very high power density semiconductors that could provide 1.25 kW in a single device. Existing transmitters at the time were combining four 300 W RF MOSFETs, so there was considerable value in reducing devices, matching networks and combiners. The 1.25 kW MRFE6VP61K25HR6 is still in production today, although new versions like the MRF1K50HR5 and MRFX1K80HR5, that provide 1.5 kW and 1.8 kW, respectively, have been added to the portfolio.

TV and radio transmitters may seem, on the surface, like ideal candidates for IMFETs, because the transmit frequencies are defined and the output power can exceed tens of kilowatts, as will be address for avionics and radar, below. However, the production volumes for such devices are relatively low, which makes it difficult to justify developing devices for this specific use case. Furthermore, the FM and UHF TV transmitting frequencies are below 1 GHz and are adjacent to other high power RF applications of industrial, scientific, and medical. Therefore, the most appropriate solution for the market is for designers to rely on discrete, unmatched transistors and optimize an impedance matching network for each end use. This enables a small number of devices to be used in a multitude of applications. Customers have several discrete solutions to meet their needs, and although the overall optimization may take longer with a discrete transistor, the development cycles are in step with time-to-market dynamics.

Land mobile/private mobile radio is an interesting application. The system is like a wireless cellular network, in that there is a base station as well as subscription-level handheld devices. Handheld LMR radios are akin to cellular handsets, but there are also mobile/trunked radios that are powered by marine or car batteries. The voltage rail requirements are the main differentiator between LMR and most other applications, because they are powered by batteries. LMR handsets tend to run between 5 VDC and 7.2 VDC from portable batteries, and LMR mobile radios run 12–15 VDC from traditional car batteries.

Although the market is relatively small, LMR system developers were fortunate that easy-to-use, multistage RF power amplifier modules were available. Based on low-cost silicon MOSFET transistors, LMR handsets and mobile radios were easy to develop and low-cost. While there are still PA modules available today, the number of models has declined. Few competitors have emerged with alternatives, so the bulk of devices available today for LMR are discrete LDMOS transistors. Since LMR handsets are produced in very large volumes, the component manufacturers have released two-stage MMIC amplifiers. For instance, the AFIC901N from NXP is a two-stage LDMOS amplifier with +30 dBm output power and is optimized from 1.8 MHz to 1000 MHz. Although the device is not impedance-matched to 50 ohms, NXP has designed the part to be easily optimized for common LMR frequency bands, 136–174 MHz, 350–520 MHz and 760–870 MHz. It may be tempting to consider a 50-ohm GaN MMIC amplifier for LMR to cover all bands from 136 MHz to 870 MHz. While some GaN devices are available, they are prohibitively expensive for an LMR handset. For mobile radios, several 13 V LDMOS transistors are available from 15 W to 75 W output power, which will cover all mobile applications. Good examples of these include the AFT05MS031NR1, which is a 136–520 MHz, 31 W LDMOS transistor.

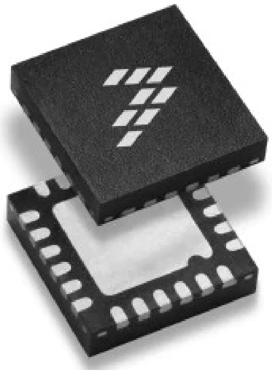


Figure 4: **NXP AFIC901N** two-stage LDMOS amplifier

Satellite communications is growing rapidly from the dramatic increase in space and satellite commercialization. Satellite communication uplinks are primarily in Ku- and Ka-band, with some C-band and X-band. Taking a moment to discuss die process technologies, the Satcom market has recently migrated from GaAs FET to GaN devices, taking advantage of the higher power density, gain and efficiency of GaN. Even more interesting than the die processing technology change is the shift from IMFETs and discrete transistors to multistage MMIC amplifiers. Due to the size of the market, as well as standard system requirements, GaN multistage MMIC amplifiers for the final PA stage of Satcom systems are presently available. These ICs have multiple gain stages and are matched to 50 ohms, which simplifies deployment. A good example is the Wolfspeed CMPA1C1D080F, which offers 80 W saturated power and 25 dB gain from 12.75 GHz to 13.5 GHz. A Ka-band example is Microchip's ICP2840, which is a three-gain stage power amplifier that provides 9 W saturated power and 24 dB gain from 27.5 GHz to 31.0 GHz.

Generating RF Energy in Space

In this context, "space" refers not to outer space, but a defined space such as a cavity. There are several interesting specialty RF power applications that generate RF energy for industrial, scientific and medical purposes. Industrial uses range from CO2 gas lasers, which use an RF amplifier to excite the gas and fire the laser, as well as RF generators for igniting plasma for chemical vapor deposition (CVD) process in the fabrication of semiconductors. There are also multiple medical uses, such as tumor ablation and MRI. Scientific use cases of RF power amplifiers include mass spectroscopy and particle accelerators (e.g., synchrotron). Finally, there has been significant development in the field of solid-state microwave heating at 2.45 GHz for industrial as well as consumer use.

While these applications are varied, they tend to share many common characteristics. For one, the power levels tend to be high, from hundreds of watts to even tens of kilowatts. Also, many of these applications are dealing with non-ideal loads which require high device ruggedness. They also share frequency of operation. There are several unlicensed bands, referred to as the ISM bands for industrial, scientific and medical use, that range from 13.56 MHz to 2.45 GHz. See Table 1, below, for a listing of common ISM bands for RF power uses.

Center Frequency	**Band**	**Typical Application**
13.56 MHz	ISM	RF / Plasma Generator
27.12 MHz	ISM	CO^2 Laser Exciter
40.68 MHz	ISM	Induction Heating
63.9 MHz	1.5T MRI	MRI Coil
81.36 MHz	ISM	CO2 Laser Exciter
127.8 MHz	3.0T MRI	MRI Coil
298.2 MHz	7.0T MRI	MRI Coil
433.92 MHz	ISM	RF Heating
869 MHz	ISM	RF Heating
915 MHz	ISM	RF Heating
2.45 GHz	ISM	RF Heating

Table 1: Common ISM bands for RF power uses

Like the broadcast transmitters referenced earlier, ISM application designers would benefit greatly from IMFETs, but with these applications being relatively low volume, discrete transistors are generally the device of choice. The component manufacturers have developed several high power density devices that are also rugged and suitable for applications over a wide frequency band. The discrete transistors are inherently narrowband devices, which suits the applications, as most high-power ISM use cases are also narrowband. The rugged LDMOS transistors from NXP are good examples, as mentioned earlier in the FM transmitter section.

The final application for generating RF energy in space is the use of a wideband jammer, which is an electronic warfare application. Wideband jammers are high power RF transmitters that are intended to interfere with enemy communications and tactical equipment, such as missile guidance. This application needs highly saturated power over a wide band. Efficiency is useful but not as important. As opposed to communications, jammers do not transmit a modulated signal, so linearity is not critical. Above 6 GHz, high power GaAs MMICs were used, but the higher power density of GaN is better suited from DC to Ka-band. Initially, discrete transistors were used because the component manufacturers were behind the system developers. Fortunately, GaN transistors are inherently broadband. Over time, the component manufacturers caught up to the system designers, and several wideband devices, including octave and multi-octave MMIC power amplifier ICs, were made available. A good example is the Wolfspeed CMPA0060025F1, which offers 25 W saturated power and a minimum of 17 db gain from DC to 6 GHz.

Figure 5: Wolfspeed CMPA0060025F1

Detecting Objects

One of the broadest uses of RF power amplifiers is detecting objects, and the best examples of this include avionics and radar applications. Avionics transponders generate an amplified electrical response when "interrogated" by a ground station or another aircraft. These are often used for collision avoidance via air traffic control in civilian applications or Identify Friend or Foe (IFF) military applications. Avionics transponders use an RF amplifier to transmit the interrogator signal from the ground station to aircraft, or transmit the identifying code from aircraft to ground station. Operating in the L-band frequency range of 960–1215 MHz, avionics transponders range from 250 W to multiple kW power levels but are generally transmitted in short pulses.

The avionics transponders market is relatively large, and there is a common frequency band and power level per system, but there is enough differentiation that discrete transistors are the most used devices today. A good example is the GTVA101K42EV-V1 from Wolfspeed, which provides 1.4 kW peak power, 17 dB gain and 68% efficiency from 960 MHz to 1400 MHz. While there are not many MMIC amplifiers available today for avionics, NXP developed an interesting option for airborne vehicles. The AFIC10275GNR1 is a two-stage LDMOS amplifier IC that provides 250 W peak power and 32 dB gain from 978 MHz to 1090 MHz. Although the part is 50-ohm input-matched only, the chip also includes integrated ESD protection and quiescent current temperature compensation with enable/disable function.

Figure 6: NXP AFIC10275GNR1 two-stage LDMOS amplifier IC

Radar is quite similar to avionics transponders, but instead of a communications-style interrogation and reply dynamic, radar systems send pulsed energy and process the returned signals that have bounced off objects. Radar is the single largest market for RF power semiconductors after cellular communications, so there is a lot of innovation in this space. Traditionally, radar transmits very high-power pulses, but for some of the same reasons as the cellular market, system developers are shifting to distributed power via phased array radar AESA systems. Instead of a single, high-power transmitter, a phased-array antenna can consist of hundreds or even thousands of relatively low-power transmit/receive elements. This has created the need for integrated MMIC amplifiers, which is why today, radar developers have access to all three device types—discrete transistors, IMFETs and MMICs.

The highest power devices today remain discrete transistors. A good example is the NXP AFV141KHR5, which is a 50 V LDMOSFET offering 1 kW power from 1.2 GHz to 1.4 GHz. Another example from Wolfspeed is the GTVA107001FC-V1, which is a GaN HEMT offering 500 W peak power from 2.9 GHz to 3.5 GHz. Like discrete transistors, IMFETs are intended as final-stage devices of the amplifier lineup. Today IMFETs are available from S-band to X-band. Two examples from Wolfspeed are the CGHV31500F and CGHV96100F2. The CGHV31500F provides 500 W and 12 dB gain from 2.7 GHz to 3.1 GHz, and the CGHV96100F2 provides 100 W and 12 dB gain from 8.4 GHz to 9.6 GHz. Multistage MMIC amplifiers have several uses in radar. They can be used as driver stage as well as final stage, including phased array systems. MMIC amplifiers also cover a wide frequency range, from S-band to Ka-band. A good example for an S-band MMIC is the Wolfspeed CMPA2935250S, which provides 250 W peak power from 2.9 GHz to 3.5 GHz. For Ka-band, Microchip offers the ICP2840, which is a three-stage MMIC amplifier that provides 9 W peak power from 27.5 GHz to 31 GHz.

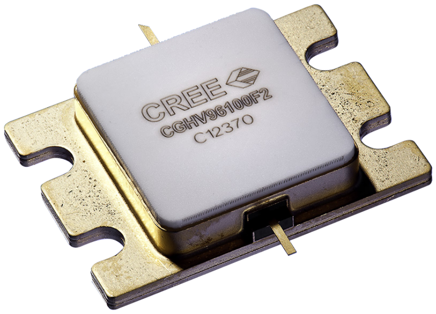


Figure 7: Wolfspeed CGHV96100F2

Summary

Selecting the right RF power semiconductor for a given application depends on several factors, including electrical, mechanical, cost and availability, as well as balancing performance and time-to-market tradeoffs. Multiple device types with different levels of integration provide system developers with latitude to decide which is best for specific needs. Fully discrete solutions offer the most flexibility but generally take the longest to productize, while IMFET and MMIC amplifiers are generally easier to design but remove some ability to innovate. Summary *Table 1* references all of the applications mentioned in this paper, in addition to the RF power semiconductor technology available today.

Function	Application	RF Semiconductor Technology
Communications	Cellular	MMIC or Discrete
	TV and Radio Broadcast	Discrete
	Land Mobile Radio	MMIC or Discrete
	Satcom	MMIC or Discrete
RF Energy	RF Generators	Discrete
	RF Heating	Discrete
	EW/Jammers	MMIC or Discrete
Object Detection	Avionics Transponders	MMIC or Discrete
	Radar	MMIC, Discrete, IMFET
	Sonobuoy	Discrete
	Telemetry	Discrete

Summary Table 1: Primary use cases and design considerations for RF power amplifiers

But the ultimate equalizer is the market—thousands of designers coming together with component manufacturers with their use cases. And while it may seem at times that the available RF power semiconductor technologies are not distributed equally for all use cases, it is evident that all applications have benefited in terms of quality, pricing and even technological advancements, thanks in large part to leading applications like cellular infrastructure and radar.

Footnotes and Sources:

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

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 www.richardsonrfpd.com.

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