TECH BRIEF

INTEGRA
RF POWER DEVICES

Zero-in on the Best RF Transistor Technology for Your Radar's High Power Amplifier Designs

INTRODUCTION

The best solid-state, high power amplifiers (HPAs), especially those used in critical defense, aerospace, and weather-radar applications, start with the right choice of discrete or integrated RF power transistors. Several active device semiconductor technologies are available today to amplify pulsed and continuous-wave (CW) signals across narrow or wide bandwidths from HF/VHF/UHF to L-, S-, C-, and X-band frequencies and beyond. Transistors for use in RF/microwave HPAs include some well-established, legacy device technologies such as silicon bipolar and silicon VDMOS power transistors, as well as more recent power-transistor technologies such as silicon LDMOS and gallium-nitride (GaN) on silicon-carbide (GaN-on-SiC or GaN/SiC) high-electron-mobility-transistor (HEMT) power transistors. Depending upon frequency, bandwidth, and other requirements, each transistor technology offers its own set of performance benefits in terms of output power, gain, and efficiency. But evaluating the tradeoffs related to cost and value can be a daunting task. This Tech Brief is intended to give you a head start. We'll explain the key things to look for, and the advantages and disadvantages of each technology, while providing a few examples of ideal fits for certain types of applications at different frequencies, and under different waveform conditions.

Application Variances and their Impact on Initial Transistor Choices

RF power transistors are usually characterized for the type of signals that they will handle, such as CW or pulsed signals. And when amplifying pulsed signals, the range of signal conditions are the most complex, such as defined by your pulse width and pulse duty cycle.

Although different types of RF/microwave power transistors are capable of high power efficiency, no power transistor is 100% power efficient, as some DC and RF power supplied to a power transistor will inevitably be lost as heat (which also must be dissipated). Amplifying CW signals, or long-pulse-length and/or high-duty-cycle pulses, will result in more heat from one transistor technology than another and will vary when compared to handling short pulses or low-duty-cycle pulses. As a result, there is no "silver bullet" technology for all of today's high power amplification requirements. The only solution is to match up the key characteristics of a transistor type to your most important application requirements. But as you'll learn, this becomes not only a spec-to-spec comparison exercise, it also requires recognition of other system-level tradeoffs to arrive at the best combination of performance, reliability, thermal management, and total bill-of-materials (BOM) cost for your HPA.

Amplifying with Si Bipolar Transistors

The silicon bipolar junction transistor (BJT) is the oldest technology for pulsed applications, but it is not an obsolete technology. Si BJTs are still in regular manufacture and will continue to be manufactured for the foreseeable future due to the on-going demand for them. Even today, some attributes of Si BJT devices are unequalled by any other technology. For example, Si BJT amplifiers have the smallest and lowest-cost circuits and only need a single positive supply voltage. Nevertheless, newer HPA designs generally don't include Si BJT devices because of their low RF gain and their need for expensive and environmentally unfriendly BeO packages.

Integra's IB1011S1500 is an example of a Si BJT designed for IFF/SSR applications **(Fig. 1)**. This device delivers typically >1400 W output power at either 1030 or 1090 MHz with >9.8 dB gain and 48% efficiency with 10-μs, 1% duty-cycle pulses.

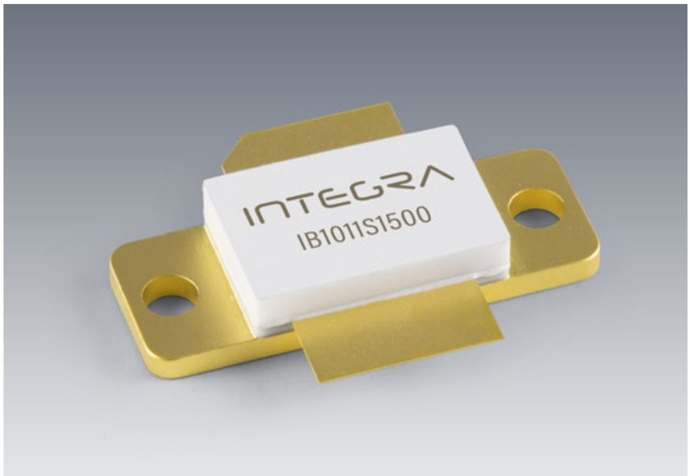

Fig. 1. Model IB1011S1500 is a silicon bipolar power transistor that is capable of 1400 W output power at 1030 or 1090 MHz with 10-μs pulse widths at 1% duty cycle.

Si LDMOS

Si LDMOS is a newer technology than Si bipolar and has found widespread use in high-linearity communication applications as well as in broadband CW amplifiers. It is also a great choice for pulsed applications up to L-band. (L through S-band LDMOS transistors are available, their performance is inferior to that available from GaN HEMT devices at this frequency). Si LDMOS is well-suited to long-pulse and/or high-duty-cycle applications because of its very low thermal resistance per Watt which also contributes to its excellent VSWR-withstand characteristics. The limiting factor of Si LDMOS, however, is that if offers inferior power efficiency to either Si bipolar or GaN HEMT.

ILD1011L950HV from Integra is an excellent example of a state-of-the-art Si LDMOS transistor for L-band avionics applications **(Fig. 2)**. This transistor typically delivers 1100 W at 1030 MHz under the demanding Mode S ELM waveform (48 x {32 μs on, 18 μs off}, 6.4% long-term duty cycle) with 16 dB gain and 55% efficiency. Unlike similar devices from other manufacturers, a unique feature of this device is that it is a single-ended rather than push-pull transistor. Consequently, it requires a smaller, less-expensive, and simpler circuit since no balun is required. This type of added functionality is also something you should be looking for when comparing datasheets.

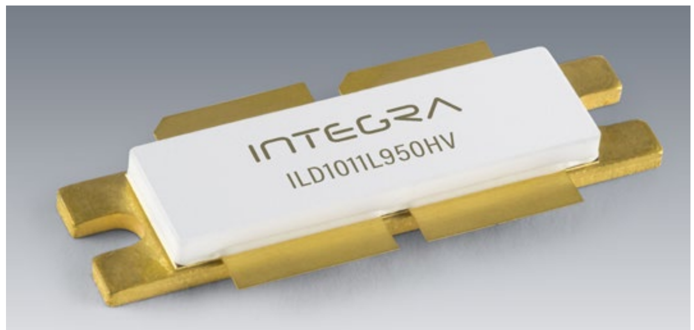

Fig. 2. Model ILD1011L950HV is a silicon LDMOS power transistor with 1100 W pulsed output power under Mode S ELM for IFF/SSR applications at 1030 MHz.

Going for GaN

GaN HEMTs are the latest in RF and microwave power transistor technology. They are quickly gaining favor for many applications because of their high gain and high power levels at S-band and above. GaN power transistors are most often produced on a silicon carbide (SiC) substrate which offers excellent heat extraction for enhanced long-term reliability.

GaN HEMTs are ideally suited to high power pulsed applications and their power density requirements (as compared to CW applications) as the ability to design on a SiC substrate allows for optimal cooling. Because of this superior power density, your output capacitance per Watt will be much lower. This enables you to conduct harmonic tuning at the output with efficiencies >85%—even at kW power levels. The much lower capacitance per Watt is also what enables these devices to operate to much higher frequencies than possible with LDMOS. One disadvantage of GaN HEMTs, however, is that they are depletion-mode devices, which means not only that they require both positive and negative voltage supplies, but the gate voltage must also be applied before the drain voltage. To address this pitfall, Integra incorporates gate pulsing and sequencing (GPS) circuitry in their pallets and test fixtures, which minimizes this issue and its impact on your BOM dramatically.

IGN1011L1200 is an example of a state-of-the-art GaN HEMT device **(Fig. 3)**. This transistor typically delivers >1250 W

Fig. 3. Model IGN1011L1200 is a GaN-on-SiC power transistor capable of 1250 W pulsed output power under Mode S ELM for IFF/SSR applications at both 1030 and 1090 MHz.

output power at both 1030 and 1090 MHz for IFF/SSR applications using the same circuit (a consequence of the low capacitance per Watt) along with 17 dB gain and an exceptionally high 85% efficiency under Mode S ELM waveform (48 x {32 µs on, 18 µs off}, 6.4% long-term duty cycle).

Picking the Right Transistor Technology

The requirements of an application, such as waveform type, frequency, bandwidth, and output-power level, will determine the type of performance needed by your power amplifier and its power transistors. At lower frequencies all the transistor technologies discussed above are viable candidates and the choice of which to use will depend upon what's most important to you. At S-band and above, GaN HEMTs on SIC are really the only choice. In between, your challenge to balance cost vs. performance becomes trickier and we advise starting with leaning towards those solutions already defined by the industry as being ideally suited for either pulsed or CW designs. **Table 1** summarizes the advantages and disadvantages of the three transistor technologies considered.

Comparison of RF Power Transistor Technologies for Pulsed Radar Applications

Attributes	Si-bipolar	Si LDMOS	GaN/SiC
Power density (W/unit area)	High	Medim	Very high
Efficiency	High	Lowest	Very high
Gain	Lowest	High	Very high
Capacitance/W (low value needed for highest power and widest bandwidth)	Medium	Medium	Low
Broadband matching capability	Difficult	Difficult	Simplest
Bias circuitry complexity	Lowest	Medium	Highest
Typical bias voltage	28-60 V	28-50 V	24-50 V
Maximum frequency	S-band	C-band	Up to Above 10 GHz
Transistor thermal characteristics under pulsed conditions	Fair	Good	Good
VSWR withstand	Poor	Best	Average
Technology maturity	High	High	Medium
Price ($/W)	Medium	Lowest	Medium
Green credentials	Poor (needs BeO package)	Excellent	Excellent

Conclusion

How the specifications for your choice in RF power transistors are prioritized will depend on the ultimate performance and budget requirements of your HPA design. And the most expensive transistors could very well be worth the investment in what they return to your total build costs. Frequency range and bandwidth, and whether the amplifier will be handling pulsed or CW signals are your first decisions, but those requirements will only help narrow down the best power transistor technology and the device for the job so much. Understanding the impacts throughout your HPA's block diagram are essential and identifying bonus features and smart design choices your transistor supplier has made can become make or break differences.

In the end, what it all really comes down to, is deciding early-on how far your Radar signal must travel, at what frequency, and with what level of resolution. This will determine how far you're willing to stretch the budget of your power transistor devices in your block diagram. Get the price/performance tradeoffs right, and you'll have the power you need to be a disruptor in the radar industry.

The transistors detailed above are just a few examples of an extensive portfolio of devices available from Integra in all three semiconductor technologies. Devices are available with and without internal impedance matching and in different package styles. In addition, many of these power transistors are also available as integrated PCB assemblies, RF Power Modules, or "pallets". These integrated low-profile boards include RF matching, power-supply circuitry, and control circuitry (**Fig. 4**) to ease the integration into your RF power amplification system even further.

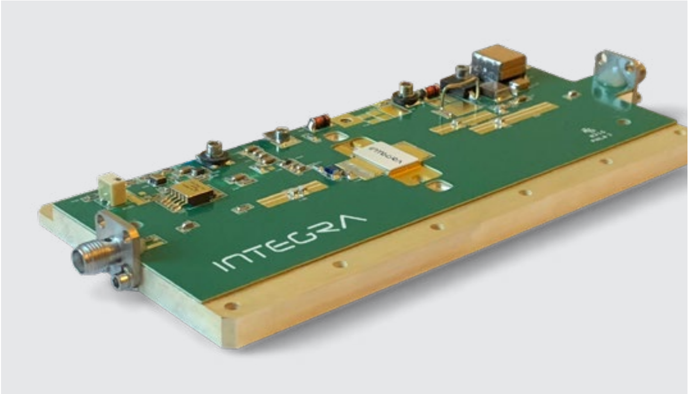

Fig. 4. Low-profile RF Power Modules, or "pallets" include RF matching, power-supply circuitry, and control circuitry to ease the integration of a power transistor into a power amplifier design.