CDIAN002: Choosing the Right GaN Device for Reliability and Robustness

Paul E. White – Component Distributors, Inc.

While Sumitomo Electric Device Innovations, Inc., SEDI, (formerly Eudyna) was the first to the marketplace with a reliable high volume GaN Power HEMT, there are many manufacturers who are offering GaN microwave power devices today. This application note will look at a few of the major factors in determining the reliability and robustness of different GaN product offerings, and will also give some perspective on the cost impact of those factors. For purposes of this paper, reliability is defined as long-term device performance and survival. Robustness is defined as the ability of the device to withstand short-term conditions that, if not properly managed, could destroy or degrade the GaN device.

When deciding which device is appropriate for a high power application, there are several key factors that need to be evaluated. These include the following:

- The nature of the driving waveform (pulsed, CW, high Peak/Average)
- VSWR conditions that result in excessive drain current (thermal issues)
- VSWR conditions that result in excessive drain voltages (breakdown issues)

DRIVING WAVEFORM – THERMAL CONSIDERATIONS

The nature of the driving waveform has a significant impact on the reliability of the selected high power GaN device. SEDI's original GaN product offering, the EGN series, was designed to operate at high levels of saturated output power, with significant overdrive. This required a die size and geometry that allowed for the heat generation to be spread across a fairly large die area while minimizing "hotspots" on the surface of the die. While this design approach proved to be a good tradeoff for CW applications, it came with a fairly large, and therefore a relatively expensive die. Based on the reliability of hundreds of thousands of high power GaN power HEMTs that have been deployed in tactical countermeasure applications at high baseplate temperatures (flange temperatures > 105°C), the design has proven to be exceptionally robust. The same die design strategy has been implemented in the design of SEDI's recently introduced SGNE series of power GaN HEMTs. The maximum channel temperature for the new SGNE090MK parts is specified at T_{ch}= 250°C, with a typical θ_{jc}= 1.2°C/W. Importantly, this device also has a nominal drain efficiency of 70% at P_{sat}, so it is very efficient. All of these factors result in a SEDI GaN HEMT that has proven to provide robust and reliable operation at high flange temperatures.

When designing a die for modest pulsed duty factor, or high peak/average (PAR) operation, the die will be under significantly less thermal distress at peak power levels than in CW saturated operation. As a result, the die geometry and therefore the die size can be compacted with the benefit of a less expensive die. While many suppliers are building GaN for radar and high PAR base station applications, these devices are NOT designed to support the thermal stresses that are associated with CW saturated or high average power operation. ***Caution should be used to match the device to the signal environment.***

VSWR – THERMAL CONSIDERATIONS

Excessive drain current will result in an eventual thermal failure of a device. This can be caused by high load VSWRs at certain phase angles. The good news is that it can be managed with good circuit design techniques that can provide for input drive fold-back, or drain bias cutoff during periods of excessive thermal stress. This problem needs to be addressed in tens of microseconds and is fairly easy to mitigate using common circuit techniques.

VSWR – BREAKDOWN CONSIDERATIONS

Unfortunately, the other adverse impact of high VSWR load impedances is that at certain phase angles of the load VSWR, a high instantaneous drain voltage will result. The worst-case condition is when the instantaneous forward voltage and reflected voltage at the drain of the device are at the same phase angle and therefore sum together at the device drain node. When added to the DC drain bias voltage, if the total voltage exceeds the maximum drain-source voltage of the device, there will be an immediate and catastrophic failure of the device. This failure will typically occur on one event. At 3 GHz, the failure will occur in about 333 picoseconds if all voltages add up instantaneously.

There are only a few options for avoiding this issue:

1.) Reduce the drain bias voltage on the device. This will also reduce the composite instantaneous drain voltage to a level that does not exceed the drain-source breakdown voltage. Unfortunately, it will also reduce the amount of output power available from the chosen device.
2.) Provide some type of circuit protection to clamp the peak instantaneous drain voltage. There are several techniques to accomplish this task, but beyond about 1 GHz, their adverse impact on RF performance makes them impractical.
3.) Provide something at the output of the amplifier that can protect against high load VSWR's (isolator, circulator, or miscellaneous circuit losses). This is a good, although expensive, option for narrowband applications. It is usually not practical when the desired operating bandwidth exceeds an octave.
4.) Use a device with exceptionally high breakdown voltage, which will not be exceeded when operating at saturated output power into an infinite load VSWR at any phase angle.

SEDI has consistently offered the highest V_{ds} maximum voltage rating in the industry. The SGNE GaN devices are specified at V_{ds} maximum = 200V. Historical data has shown that this value is conservative relative to actual demonstrated breakdown voltage. These parts also operate at 50V drain bias voltage. Based on the EGN series historical performance, these devices have proven to be incredibly robust and reliable in a battlefield environment when operated as much as 15dB into compression at a +105°C flange temperature while being operated into an infinite VSWR at all phase angles.

DEVICE GATE LENGTH – RELIABILITY AND ROBUSTNESS VS. GAIN AND FREQUENCY RANGE

Many of the devices on the market today have gate lengths of 0.25 - 0.45 microns. As designers seek higher frequency bands of operation (>Ku band), gates as short as 0.1 microns are surely in the future. Shorter gate lengths will have a higher frequency of operation, and somewhat higher gain at lower frequencies.

But shorter gate lengths have a few negative tradeoffs. Firstly, more gain is not necessarily better below 3 GHz. Too much gain has adverse implications for stability of the amplifier. Secondly, smaller structures are generally more fragile. They cannot handle very high instantaneous current densities. One must remember that when a device is driven into compression, the schottky gate begins to operate into forward conduction. A longer gate will be able to handle higher current densities when operated in hard saturation. Finally, the shorter gate length naturally leads the device designer to compact the die as much as possible. GaN material is expensive, and wafer real estate is precious. However, a significantly compacted die is much more challenged thermally when used with a saturated CW or high average power signal.

The original EGN series of SEDI devices had a gate length of 0.8 microns. The SGNE series of SEDI devices uses a 0.65 micron gate. As a result, the SEDI EGN and SGNE devices tend to be amongst the most robust and reliable in the industry.

SUMMARY

The power amplifier designer is encouraged to evaluate the design environment carefully before selecting a device. Thermal distress, input signal conditions, and anticipated load VSWRs all have dramatic impact on the reliability of the end product. A device designed for high PAR or pulsed operation, is probably not the right choice for a CW jammer or FM/FSK radio requirement. An uncontrolled operating environment where good load VSWRs cannot be guaranteed may result in poor device reliability. SEDI's GaN power HEMT offerings continue to provide premium performance in harsh operating conditions, and with 8 years of proven experience, they have a reliability track record that is unmatched in the industry.

About the Author

Paul White has been involved in the microwave industry since 1969. After graduating from Lehigh University with a BSEE, he worked as a microwave engineer at Westinghouse Electric in Baltimore. In 1974 he moved into a sales and marketing position for Hewlett Packard until 1980 when he became a partner in Applied Engineering Consultants, Inc., a manufacturers representative firm.

In 1987, Mr. White founded Chesapeake Microwave Technologies, Inc., focused on the design and manufacture of microwave power amplifiers. With the sale of Chesapeake Microwave to Andrew Corporation in 1999, Mr. White became Andrew's Chief Technologist for active products.

In 2002, Mr. White co-founded and was the Co-Managing Director of Integrated Defense Systems, Inc. (IDSI). IDSI was one of the early adopters of GaN device technology, bringing GaN based high power amplifiers into the battlefield environment in 2005. Over the next 3 years, IDSI consumed several hundred thousand GaN power devices for use in broadband high power applications for military tactical countermeasure and defense communications systems. After the sale of IDSI in 2008 to General Dynamics, Mr. White retired from full time employment.

Today he remains involved in the microwave industry sitting on five corporate boards. Mr. White is also actively involved as a board member for several non-profit organizations. Today he resides on Longboat Key, FL where he and his wife Vicki continue to enjoy boating, flying, and spending time with their 4 children and 8 grandchildren.

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