A Comparison of GaN vs GaAs System Performance

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Abstract

Traditionally RF power amplifiers used GaAs technology which has a well behaved and understood performance. Over the past few years GaN technology is replacing GaAs because GaN is more efficient and has a higher power density resulting in higher power MMICs and FETs.

Subject to system link budgets, we usually want to run a given amplifier as close to saturation as possible to minimize CAPEX costs. Running an amplifier closer to saturation causes many non-linear effects that can cause link performance degradation and interfere with other users.

To better understand and quantify the differences between GaN and GaAs amplifiers and the impact of this on system performance, some amplifier and system measurements will be taken. The findings will be documented in a white paper.

Introduction

Traditionally RF power amplifiers used Gallium Arsenide (GaAs) technology which has a well behaved and understood performance. Over the past few years Gallium Nitride (GAN) technology is replacing GaAs because GaN is more efficient and has a higher power density resulting in higher power MMICs and FETs.

GaAs-based amplifiers (block upconverters also known as BUCs and Solid-State Power Amplifiers also known as SSPAs) are typically specified by their P_{1dB} point. The saturated output power (P_{sat}) is usually less than 1 dB higher than P_{1dB}. GaN-based amplifiers are usually rated by their P_{sat} and sometimes using Linear Power (P_{linear}). There is confusion in the market with customers specifying different powers and it is difficult to compare GaN and GaAs devices.

Subject to system link budgets, we usually want to run a given amplifier as close to saturation as possible to minimize CAPEX costs. Running an amplifier closer to saturation causes some non-linear effects that can cause both self interference and can interfere with other users.

GaAs vs GaN

Table 1 summarizes the typical output power and power gain for GaN and GaAs MMICs and FETs. While high power FETS (GaAs and GaN) are available, their power gain is low resulting in a BUC or SSPA requiring several FETS, thus adding to cost and size. An SSPA, which is also part of a BUC, typically uses several amplification stages. Each stage must provide enough linear drive level to power the next stage without impacting the overall performance of the amplification chain. So, for example, to achieve an output of nominally 40W, an SSPA would require one MMIC as a final amplification stage or equivalently 3 or 4 FETS to produce the same gain and output power. MMICs combine the gain and output power to reduce the number of discrete stages and reduce size.   Unfortunately, the maximum output power of GaAs MMICs is about 8W and about 50W for GaN MMICS.   Using GaAs MMICs for high power BUC or SSPAs would require power combining which can add to size and cost. A combination of GaAs and GaN MMICs and FETS can be used to optimise the number of discrete amplification stages, size, gain and output power.

Table 1 Summary of Maximum Power and Gain for MMICs and FETs

Technology	**Max Rated Power**	**Power Gain**
GaAs MMIC	Up to 8 W P_{1dB}	~24 dB
GaAs FET	Up to 60W P_{1dB}	~7 dB
GaN MMIC	Up to 50W P_{sat}	~24 dB
GaN FET	Up to 80W P_{sat}	~7 dB

The GaN devices tend to be more efficient. The Power Added Efficiency (PAE) for GaAs MMICs is about half of GaN MMICs (PAE ~ 30 % for GAN and, ~15% for GaAs). GaN devices operate at higher voltages – usually 20-28V while GaAs devices operate in the 6-8V range. This higher voltage means less current for the same output power so PCBA traces can be smaller, thus saving space. Since the GaN operating voltage is closer to the standard supply voltages there is some efficiency in DC power regulation. The better efficiency of GaN technology may improve MTBF of the product as the devices are not running as hot and the parts count can be reduced.

GaAs and GaN FETS can be high power, but they are usually limited in bandwidth and have low gain especially at their rated output power. While a narrow bandwidth is acceptable for standard frequency bands, it is not a good solution for wide band applications or custom frequency bands.

While GaN devices have many advantages, they do not behave the same as the GaAs devices:

a) GaN devices have softer compression than GaAs devices
b) GaN devices have more variation over temperature than GaAs devices

The soft compression means P_{1dB} is usually further backed off from saturation in a GaN device than a GaAs device. The soft compression can be problematic in some systems with open loop power control and may require additional dynamic range of the IF input to reach the desired operating point.

P_{sat} vs. P_{1dB} vs. P_{linear}

P_{sat}, P_{1dB} and P_{linear} are all used in BUC/SSPA literature. GaAs-based products are usually rated as P_{1dB}, while GaN products are usually rated as P_{sat} with a P_{linear} point often mentioned. Each of these output power definitions indicate something different. P_{sat} is the saturated output power – the maximum power achievable. P_{1dB} is the output power where the gain of the BUC/SSPA is 1 dB lower than a small signal gain. P_{linear} is the output power where a specific set of requirements are met such as spectral regrowth or two-tone intermodulation products. While each are an output power, only P_{linear} directly provides a measure of intersystem interference.

System Requirements

To reduce CAPEX, operators use the lowest power BUC/SSPA they can, based on system link budgets. Regardless of BUC/SSPA technology, the maximum available output power is P_{sat}. Also, regardless of BUC technology, the closer one operates to P_{sat}, the more non-linear effects arise causing both inter- and intra-system interference. Some measurements of inter- or intra-system interference are:

a) Adjacent Channel Power Ratio (ACPR)
b) Two-Tone Intermodulation (TTIM)
c) Amplitude Deviations to Phase Deviation (AM-PM)
d) System Bit Error Rate (BER)

ACPR

ACPR is sometimes called spectral regrowth and is often specified by satellite systems or satellite networks as a requirement. Table 2 summarizes some ACPR requirements:

Table 2 Summary of ACPR Requirements

System	ACPR or Spectral Regrowth
Intelsat (IESS 308)	Spectral Regrowth < -26 dBc
Eutelsat (EESS 502)	EIRP in adjacent channel < 12 dBW /4 kHz
MIL-STD-188-164	Spectral Regrowth < -30 dBc

Some satellite networks can tolerate higher spectral regrowth.

TTIM

Closely related to ACPR is intermodulation, Two-tone intermodulation is often specified as a requirement with the most common requirement of TTIM < -25 dBc (MIL-STD-188-164).

AM-PM

AM-PM is a measure of phase deviations caused by amplitude deviations and is especially important for phase modulated signals. AM-PM is less likely to be used as a requirement for satellite operators, but is often used by network operators.

BER

The system BER is a good indication of self interference and ultimately is the measure of system health.

Comparison of System Performance

To compare the system performance using GaN and GaAs technologies, two similarly rated BUCs are compared. Performance at several operating points are contrasted. The specific BUCs used were:

a) Norsat Atom series 40W GaAs – rated as 40W P_{1dB}
b) Norsat Atom series 40W GaN – rated as 40W P_{sat}

For the specific BUCs measured, the P_{sat} for the GaN BUC was 46.3 dBm and the P_{sat} for the GaAs BUC was 47.1. All measurements were taken at 14.125 GHz and at room temperature. In all cases the rated power (P_{sat} or P_{1dB}) exceeds the stated value. The measurements and results should be considered typical and could change from BUC to BUC.

Gain

In Figure 1, the gain vs. input power for a GaN and GaAs BUC are compared.

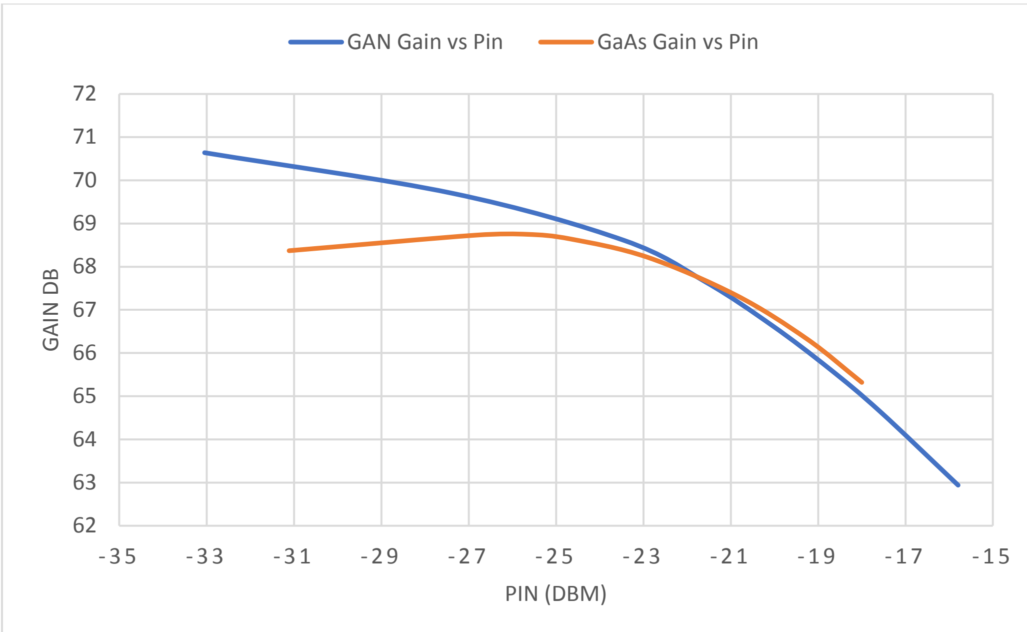

Figure 1 Gain vs. Input Power for GaAs and GaN BUC

The chart shows the soft compression of the GaN BUC. Table 3 summarizes the key output power ratings and shows the relative back-off from P_{sat}. P_{linear} is defined as the output power where the spectral regrowth is -30 dBc.

Table 3 Common BUC Power Ratings and Their Output From saturation

	Back-off from P_{sat} (dB)	
	GaN	**GaAs**
P_{sat}	0	0
P_{1dB}	4.8	0.8
P_{linear}	2.4	2.3
$P_{reference}$	9.6	10

As can be seen back-off from P_{sat} for P_{1DB} is much larger for the GaN device as would be expected with soft compression. Also, the GaAs P_{1dB} is less than 1 dB backed off from P_{sat} also as expected. Despite the large difference in P_{1dB} back-off, the P_{linear} back-off is almost the same. $P_{reference}$ is a typical low signal output and should not be affected by non-linearities seen closer to saturation

ACPR

Table 4 compares the P_{out} and back-off from P_{sat} of the GaN and GaAs BUC at several ACPR. In this table, P_{linear} is defined as the output power where spectral regrowth is -30 dBc using 2.6 MSps. The ACPR can be different at different symbol rates.

Table 4 P_{out} and Output from Saturation for Different ACPR

	GaN			GaAs			
	P_{out} (dBm)	BO from P_{sat} (dB)	ACPR (dB)	ACPR (dB)	BO from P_{sat} (dB)	P_{out} (dBm)	
$P_{reference}$	36.8	9.6	-39	-40	9.9	37.2	**$P_{reference}$**
P_{1dB}	41.5	4.8	-36				
P_{linear}	44.0	2.4	-30	-30	2.3	44.8	**P_{linear}**
	44.7	1.6	-26	-25.7	0.8	46.3	**P_{1dB}**
	45.5	0.8	-23	-23.3	0.2	46.9	**P_{2dB}**
	45.8	0.6	-20				

As expected the ACPR at the GaN P_{1dB} is much better than the ACPR at the P_{1dB} point of the GaAs BUC since it is much further backed off from saturation. The ACPR worsens faster as back-off from saturation is reduced for the GaN vs. GaAs BUC. Table 5 highlights P_{out} for GaN vs. GaAs BUCs at ACPR of -30 dBc and at an ACPR of -26 dBc.

Table 5 P_{out} for ACPR of -30 dBc and -26 dBc

	P_{out} (dBm)		
	ACPR = -30 dBc	ACPR = -26 dBc	TTIM < 25 dBc
GaAs	44.8	46.2	43.8
GaN	44.0	44.7	43.3

While the GaN P_{out} corresponding an ACPR of -30 dBc is lower than the GaAs BUC, but the output back-off from saturation is almost the same. The corresponding GaN P_{out} for an ACPR of -26 is about 44.7 dBm, while the GaAs P_{out} is about 46.2 dBm. The output from saturation is larger for the GaN than the GaAs

MIL-STD-188-164 offers two definitions of P_{linear}, TTIM and spectral regrowth. The spectral regrowth definition is used for single-carrier systems. For multi-carrier systems P_{linear} is defined as the minimum P_{out} for spectral regrowth < -30 dBc and P_{out} for TTIM < 25 dBc. The P_{linear} resulting from these two definitions is slightly different. Table 6 compares the P_{linear} output powers for the various definitions and technology. The symbol rate for the ACPR is 2.6 MSps and the TTIM tone spacing is 2.6 MHz.

Table 6 Comparison of P_{linear} using ACPR and TTIM

	Plinear (dBm)	
	ACPR	TTIM
GaAs	44.8	43.8

GaN	44.3	43.3

AM-PM

Table 7 summarizes the AM-PM performance at several output powers for the GAN and GaAs.

Table 7 Summary of AM-PM for Various Output Power

	GaN			GaAs		
	P_{out} (dBm)	**Back-off from Saturation (dB)**	**AM-PM (deg/dB)**	**P_{out} (dBm)**	**Back-off from Saturation (dB)**	**AM-PM (deg/dB)**
$P_{reference}$	36.8	9.6	1.0	37.2	10.0	0.8
P_{linear}	44.0	2.4	1.2	44.8	2.3	1.8
P_{1dB}	41.5	4.8	0.9	46.3	0.8	4.4

Performance up to P_{linear} is similar between the two technologies. At higher output powers, closer to saturation, AM-PM increases rapidly.

BER

The BER was measured for various output powers for the GaN and GaAs BUCs. Output powers from $P_{reference}$ to about 46 dBm were tested. In each case the signal and noise power were adjusted to maintain a constant Eb/No of 4.0 dB as reported by the modem. The signal used was QPSK with a rate ½ Viterbi FEC. There was little difference in the BER between the lowest output powers and the highest. There was little difference between the GaN and GaAs BUC performance.

Conclusions

The test results show similar performance between GaN and GaAs BUCs for most parameters except ACPR and TTIM. The P_{sat} of a 40W P_{1dB} GaAs BUC is up to 1 dB higher. So, a GaAs BUC rated at 40W P_{1dB} will have a P_{sat} of up to 50 W.

Review of ACPR and TTIM performance of GaAs and GaN based on back-off from saturation shows that both GaN and GaAs behave similarly up to P_{linear}. In the example above, P_{linear} for both BUCs is about 2.3-2.4 dB below saturation. Above P_{linear} the GaN ACPR degrades more quickly with output power. At the point where ACPR is -26 dBc, the GaAs BUC is about 0.9 dB from saturation, while the GaN BUC is 1.6 dB below saturation.

If you assume that the operating point of the GaAs BUC is the rated P_{1dB}, the ACPR is about -26 dBc, the equivalent operating point of the GaN device rated at P_{sat} will be about 1.6 dB below this for a QPSK system.

Neither GaN nor GaAs is technology “better” than the other, it depends upon the unique requirements of each application to determine the best technology for the job. Norsat has a line of both GaN and GaAs BUCs to ensure we have the best solution available for all customers and applications.

References

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[3] IESS 308, Performance Characteristics for Intermediate Data Rate Digital Carriers Using Convolutional Encoding/Viterbi Encoding and QPSK Modulation, Rev 11, 10 March 2005