TECH BRIEF

Understanding the Phenomenon of High-Power Pulse Recovery in GaN LNAs

Custom MMIC

Introduction

The Gallium Nitride (GaN) high electron mobility transistor (HEMT) is well known for its use in microwave and millimeter-wave power amplifiers due to its high breakdown voltage and ability to handle high RF power. Recently, GaN technology has also been used to create low noise amplifiers (LNAs) in the microwave region, as the noise properties of GaN are similar to other semiconductor materials, most notably Gallium Arsenide (GaAs) [1-2]. In many microwave systems, LNAs are subject to unwanted high input power levels such as jamming signals. One of the features of LNAs made from GaN is the ability to withstand these input power levels without the need for a limiter, due to the inherent robustness of the device [2]. Indeed, this is one reason GaN LNAs are supplanting their GaAs counterparts, since GaAs LNAs typically require a front-end limiter, which adds to the cost and degrades the performance of the LNA.

Despite the ability to operate without a limiter, GaN LNAs, however, are not completely immune to the effects of high input power. The problem occurs when both a high power jamming signal and the desired signal are input to the GaN LNA, and then the jamming signal is suddenly turned off. Under this scenario, the GaN amplifier does not recover immediately, as there is some residual distortion of the desired signal before normal operation returns. This phenomenon is known as pulse recovery time and is fast becoming an important parameter with regards to LNAs in general.

Past researchers have studied pulse recovery times in GaN LNAs, although this work has been limited in scope. One study presented recovery times of less than 30 ns in some amplifiers [3-4], but these measurements only utilized a coherent jammer, and the overall number of measurements was limited. A second investigation of pulse recovery time was performed on a GaAs LNA with a limiter [5]. The limiter not only effected the small signal performance, but it also increased the recovery time when high power was applied. Further research has been performed on the degradation of GaN HEMT noise performance after exhibiting DC and RF stress, which can cause forward gate current and damage the gate device [6]. However, this work did not explicitly address pulse recovery times in LNAs. Other papers have similarly analyzed the survivability of GaN amplifiers to high input power overdrive [7-10], but again this work offers little understanding of pulse recovery times. A summary of the relevant previous work is shown below in *Table 1*.

TABLE 1: Summary of Previous Work

Reference	Jamming Signal	Frequency	Incident Power of Jammer	Duration of Jammer
[3]	Coherent	8 GHz	+39 dBm	250 ns - 3 us
[4]	Coherent	3 GHz	+20 to +33 dBm	250 ns - 3 us
[5]	Non-coherent	12 GHz (jammer) 7 GHz (signal)	+40 dBm	10 us
This work	Non-coherent	8.5 GHz (jammer) 7.5 GHz (signal)	+15 to +27 dBm	1, 2, 4, 6, 10, 100, 200, 400, 600 us

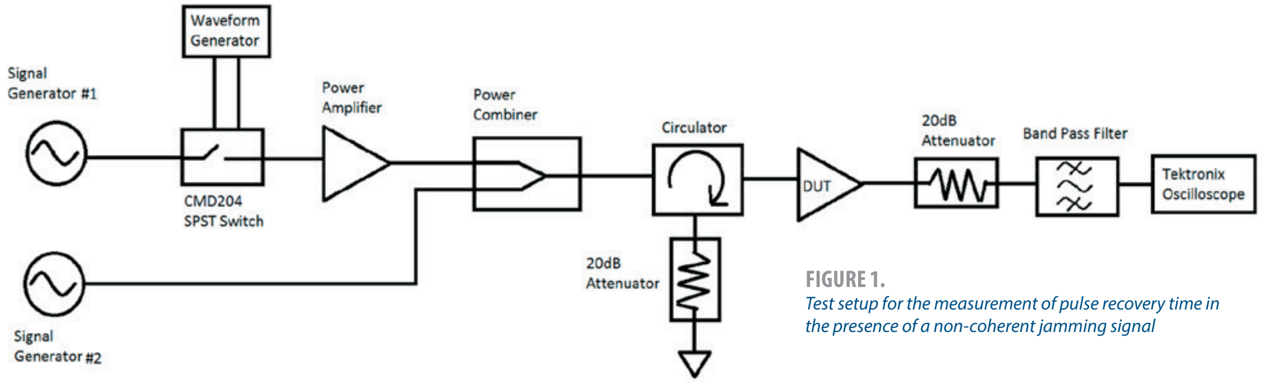

FIGURE 1.
Test setup for the measurement of pulse recovery time in the presence of a non-coherent jamming signal

Measurement Test Setup

A functional description of the test setup is shown above in *Figure 1*. This setup uses two signal generators, where the first (labeled as #1) provides the out-of-band interfering signal at 8.5 GHz, and the second (#2) provides the desired continuous wave (CW) in-band signal at 7.5 GHz. The interfering RF signal from #1 is pulsed using a single pole single throw (SPST) switch controlled by a square wave with a low duty cycle. We chose to pulse the signal path, as opposed to the bias circuitry of the interferer amplifier, due to the fast rise/fall time of the SPST, which is on the order of 1.8 ns. Additionally, pulsing the power supply caused high levels of ringing to appear at the output. The interfering signal was amplified by an external power amplifier (PA) and then added to the desired signal with a passive power combiner. We utilized a circulator, terminated in a 20 dB pad and a high power 50 Ohm load, between the combiner and the device under test (DUT) in order to prevent any high power mismatch signal from reflecting back into the PA. The output of the DUT was then attenuated with an additional 20 dB pad, sent through a band pass filter with a pass band of 7.25 to 7.75 GHz, and then input into a digitizing oscilloscope. The filter attenuates the interfering signal to allow for an accurate measurement of the pulse recovery time.

Finally, we utilized two different oscilloscopes for the measurement. A Tektronix digital serial analyzer oscilloscope was used to measure the recovery time for the shorter pulse widths, while a Hewlett Packard Digitizing Oscilloscope was used to measure the recovery time when longer pulses were used.

TABLE 2: Summary of Test Conditions - Short Pulses

Interferer Power (dBm)	Pulse Width (us)	Pulse Repetition (Hz)	Interferer Energy (uJ)
17	6.00	500	0.30
15	10.00	500	0.32
23	2.00	500	0.40
20	4.00	500	0.40
17	10.00	500	0.50
27	1.00	500	0.50
20	6.00	500	0.60
26	2.00	500	0.80
23	4.00	500	0.80
20	10.00	500	1.00
27	2.00	500	1.00
23	6.00	500	1.20
26	4.00	500	1.59
23	10.00	500	2.00
27	4.00	500	2.00
26	6.00	500	2.39
27	6.00	500	3.01
26	10.00	500	3.98
27	10.00	500	5.01

The test procedure consisted of varying the pulse width and the input power of the interfering signal, while keeping the power of the desired signal constant at -10 dBm. A summary of the test conditions including pulse widths, repetition rates, and power levels of the interfering signal are presented in *Table 2* (short pulses of 1 to 10 us), and *Table 3* (long pulses of 100 to 600 us). In these tables we note the input power of the interfering signal was varied between 15 and 27 dBm, with the total energy delivered to the DUT being the important parameter of concern. All measurements with short pulses were performed on the Tektronix oscilloscope, whereas the long pulse measurements were performed on the Hewlett-Packard oscilloscope.

TABLE 3: Summary of Test Conditions - Long Pulses

Interferer Power (dBm)	Pulse Width (us)	Pulse Repetition (Hz)	Interferer Energy (uJ)
15	100.00	100	3.16
17	100.00	100	5.01
15	200.00	100	6.32
20	100.00	100	10.00
17	200.00	100	10.02
15	400.00	100	12.65
15	600.00	100	18.97
23	100.00	100	19.95
20	200.00	100	20.00
17	400.00	100	20.05
17	100.00	100	30.07
26	600.00	100	39.81
23	200.00	100	39.91
20	400.00	100	40.00
27	100.00	100	50.12
20	600.00	100	60.00
26	200.00	100	79.62
23	400.00	100	79.81
27	200.00	100	100.24
23	600.00	100	119.72
26	400.00	100	159.24
27	400.00	100	200.47
26	600.00	100	238.86

Measurement Results

In this section we present the measurements of pulse recovery time for a commercially available GaN MMIC amplifier with a 5 to 9 GHz bandwidth [11]. The amplifier was assembled into a metal housing, with 2.4 mm connectors used to interface with the test equipment. Three separate units were tested, with the results being consistent among all units. Therefore, we present the results for one unit in the interest of brevity.

We begin, in *Figure 2*, by presenting an example of a pulse recovery time measurement. In this figure, the interferer pulse is shown in magenta, whereas the desired signal is shown in red. We can see that desired signal is heavily distorted when the interferer is activated, and then recovers once the interferer is disengaged. The recovery is measured as the rise time from 10% to 90% of the signal level.

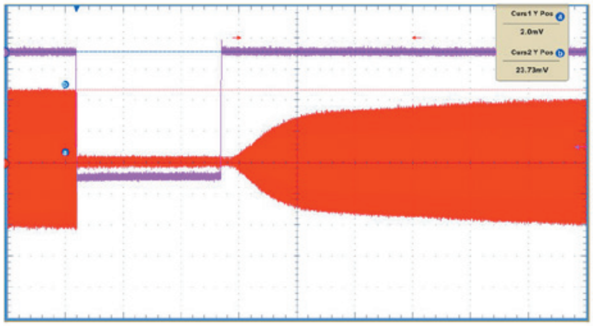

FIGURE 2.
Typical oscilloscope trace for the measurement of pulse recovery time. Desired signal in red, interferer pulse in magenta.

In *Figure 3*, we present the pulse recovery times versus input energy under short pulse conditions. We note the recovery time appears to increase monotonically with increasing input energy, though the relationship appears to be nonlinear. Indeed, we curve fit the data to a radical function. The form of this function is given below in Eq. 1, where y is the pulse recovery time, x is the input energy, C is a constant, and m is the radical order. $y = C \times \sqrt[m]{x}$ (1)

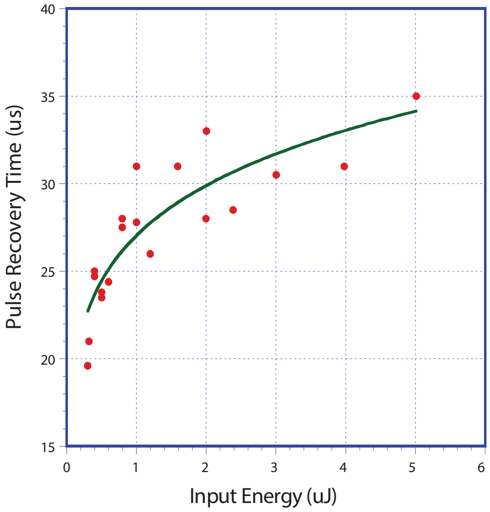

FIGURE 3.
Recovery time versus input energy for short pulses (<= 10 us).

One feature of this equation is that it predicts a recovery time of 0 us when the incident energy is 0 uJ. For the short pulses results as shown in *Figure 2*, C = 27, and m = 0.145.

In *Figure 4*, we next present the pulse recovery times versus input energy under long pulse conditions. We note the recovery time increases monotonically with increasing energy, and follows the same trend as the short pulses, with the same governing trend as described by Eq. (1). However, the fitted results give different constants in Eq. (1) for the long pulses, with C = 0.224 and m = 0.53.

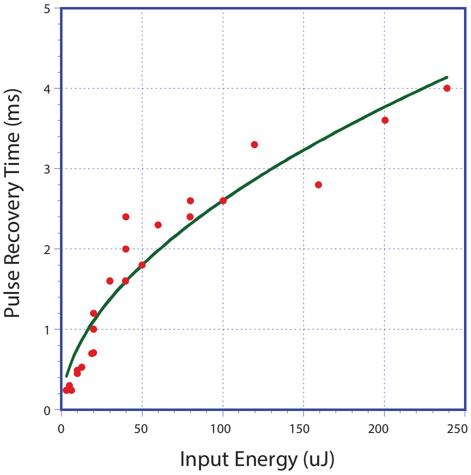

FIGURE 4.
Recovery time versus input energy for long pulses (>= 100 us).

In considering the results for short pulses versus long pulses, we did notice that the recovery time was not solely dependent on the incident energy. Indeed, there were two sets of short pulse and long pulse measurements with the same incident energy, but much different recovery times. These results are presented below in *Table 4*.

Table 4: Summary of Short and Long Pulse Recovery Measurements with Equal Incident Energies

Interferer Power (dBm)	Pulse Width (us)	Interferer Energy (uJ)	Interferer Action (uJ-us)	Recovery Time (us)
15	100.00	3.162	316.228	240
26	10.00	3.981	39.811	31
17	100.00	5.012	501.187	300
27	10.00	5.012	50.119	35

In this table, we note that the longer pulses with lower power had a much longer recovery time than the shorter pulses with higher power, even though they had near identical incident energy. Therefore, it appears that pulse recovery time, while being dependent on incident energy, is also dependent on the incident action (energy times duration, uJ-us) of the interfering signal. This is an interesting phenomenon we will explore in future work.

Conclusion

In this paper we presented a methodology for measuring the pulse recovery times of GaN low noise amplifiers in the presence of high power, out-of-band jamming signals. Pulse recovery time is becoming an important metric for assessing system performance. In our examination of a commercially available 5 to 9 GHz GaN LNA, we considered jamming signals that operated under short pulse (< 10 us) and long pulse (> 100 us) conditions. We found that in each case, the recovery time was mathematically related to the input energy through a radical relationship. However, the pulse recovery time also appears to be a function of the input action (uJ-us), as short and long pulses with the same incident energy had recovery times that were different by an order of magnitude. In the future, we will explore this phenomenon through more measurements of GaN low noise amplifiers.

Next Steps

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"On the Measurement of Pulse Recovery Times in Gallium Nitride Low Noise Amplifiers" by Nicholas Novaris, Paul Blount, and Charles Trantanella of Custom MMIC. Copyright (c) 2017 European Microwave Association.

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