Modelling of 32-APSK Constellation Distortion and EVM in GaN Power Amplifiers From AM/AM and AM/PM Curves

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***Abstract*— This paper presents a comprehensive memoryless modelling approach to analyse the distortion characteristics of a GaN power amplifier when transmitting 32-APSK digital signals. The analysis is based on the AM/AM and AM/PM characteristics, as well as the Noise Figure (NF) of the amplifier. The simulations conducted in this study yield constellation diagrams of the output signal, and the resulting Error Magnitude Vector (EVM) is calculated to quantify the distortion's impact of source EVM and input drive level. Practical measurements were conducted on a 12-Watt GaN power amplifier operating within the frequency range of 20.2 to 21.2 GHz. The actual constellation diagrams and EVM measurements obtained from the experimental setup demonstrated a good agreement with the calculated constellation and EVM of the output. This model thus provides valuable guidance for optimizing the amplifier's operation and enhancing the overall system's performance in practical communication applications.**

***Keywords—32-APSK, EVM, AM/AM, AM/PM, nonlinearity*.**

I. Introduction

Error Vector Magnitude (EVM) is often used as a standard to test for quality of the signal that in transmitted by non-linear amplifiers [1]. Amplitude (AM/AM) and phase (AM/PM) curves versus input power of the amplifier have a direct effect on the signal distortion [2]. Their effect can be seen on the distortion of the sybol constellation when compared to the ideal constellation. Computations of EVM for a given constellation depend on ideal symbol relative input power in the constellation as well as noise figure (NF) of the amplifier [3]. This paper calculates the EVM of the output signal based on the AM/AM and AM/PM characteristics of the amplifier as well as its NF based on simulations of the resulting constellation compared to the ideal one. The results agree well with actual constellation and EVM measurements made on a 12-Watt 20.2 to 21.2 GHz GaN power amplifier. The results provide valuable guidance on how the input source EVM and drive level affect the total distortion of the 32-APSK signal at the output of the power amplifier.

II. Modeling of 32-APSK Distortion

The 32-APSK modulation constellation is composed of three concentric rings of uniformly spaced 4, 12 and 16 PSK points, respectively. We define N = Number of Symbols, and R = Symbol rate ($Msps$). We generate random 32-APSK data symbols as random integers between 0 to 32 over the range N by using three amplitude rings having 4-PSK, 12-PSK and 16-PSK points respectively. The signal time starts at 0 to N/R with steps of $1/R$, and is used to generate the modulated signal as a function of time. We call the noiseless generated 32-APSK as $original\_signal\_data$. Then we add noise to the generated 32-APSK signal by calculating the noise power from the source SNR as:

$$signal\ power = \frac{1}{N}\sum_{i=0}^{N} {x_i}^2 \quad (1)$$

where x_i is the time domain sample, and N is the signal length.

The noise power is calculated as:

$$noise\ power = \frac{signal\ power}{10^{\frac{SNR}{10}}} \quad (2)$$

Random noise at time i is generated as:

$$noise(i) = \sqrt{noise\ power}\,.(randn(i) + j.randn(i)) \quad (3)$$

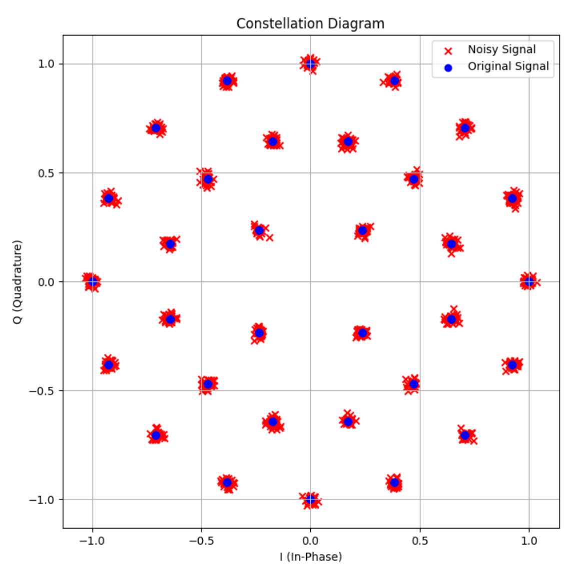


Figure 1. 32-APSK signal out of 35 dB SNR signal source resulting in EVM = 2.59%

Where $randn$ is normal distribution random number.
The noise data is the sum:

$$noise = \sum_{i=0}^{N} noise(i) \quad (4)$$

The noisy 32-APSK signal is formed by adding the $original\_signal\_data$ and the noise data of length N:

$$noisy\_signal\_data = original\_signal\_data + noise \quad (5)$$

Plotting the constellation of the original and noisy signals is shown in Figure 1.

A Python program was written to implement the analysis described above and to plot the scatter diagram and calculates from it the EVM. The program accepts at its input the number of symbols N , symbol rate R, and the signal-to-noise ration of the input signal SNR, the AM-AM and AM-PM characteristics of the amplifier, and the amplifier's Noise Figure NF.

The AM-AM characteristics of the Solid State Power Amplifier (SSPA) is measured and then using curve fitting is represented as per Figure 2. Nominal input power in this case is 0 dBm but can be driven up to 3 dBm into compression.

The AM-PM characteristics of the SSPA is also measured and curve fitted to be represented as in Figure 3. The phase changes with input drive level. Nominally the amplifier is operated at 0 dBm but can be driven up to 3 dBm yielding output power of about 41 dBm (12-Watts).

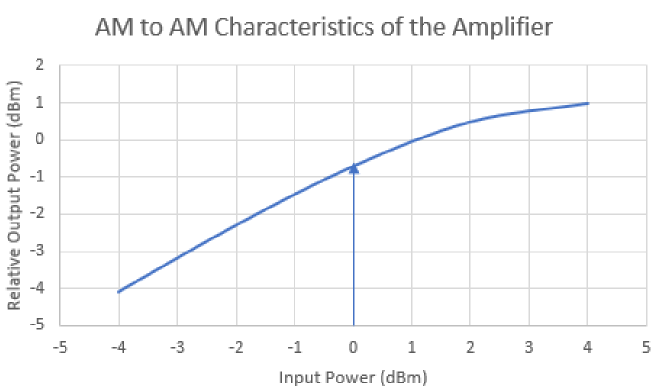


Figure 2. AM/AM characteristics of the GaN Solid State Power Amplifier (SSPA).

Taking into account the AM-AM, AM-PM characteristics and NF of the SSPA (7 dB) we obtain the constellation shown in Figure 4. Notice the effect of amplitude compression is shown on the amplitude of the constellation points especially at the outer ring, and also the effect of phase rotation due to phase change of the SSPA with input drive level.

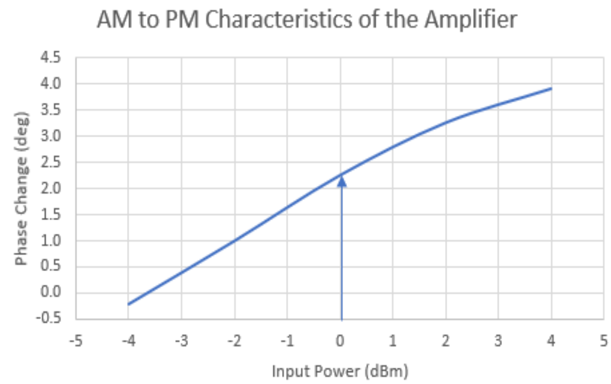


Figure 3. AM/PM characteristics of the GaN SSPA

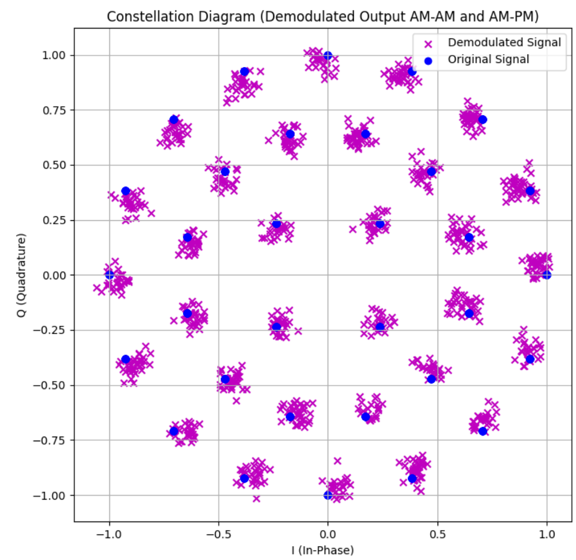


Figure 4 . Constellation diagram of 32-APSK signal out of the SSPA taking into account AM/AM, AM/PM and 7 dB NF of the SSPA resulting in EVM = 7.87%.

The EVM is calculated as:

$$EVM\ (\%) = 100 * \frac{\sqrt{\frac{1}{N}\sum_{i=0}^{N}[original\_signal\_data(i) - noisy\_output\_data(i)]^2}}{\sqrt{\frac{1}{N}\sum_{i=0}^{N}[original\_signal\_data(i)]^2}} \quad (6)$$

Where $noisy\_output\_data(i)$ is the 32-APSK signal out of the SSPA after distortion at instant i.

III. Various Cases

The above simulations were repeated at various source EVM values as well as various input drive level values to inpect the impact of those values on the output distortion of the 32-APSK signal. Figures 5 to 8 show the resulting constellation diagrams and EVM calculations for each case as per eq. (6).

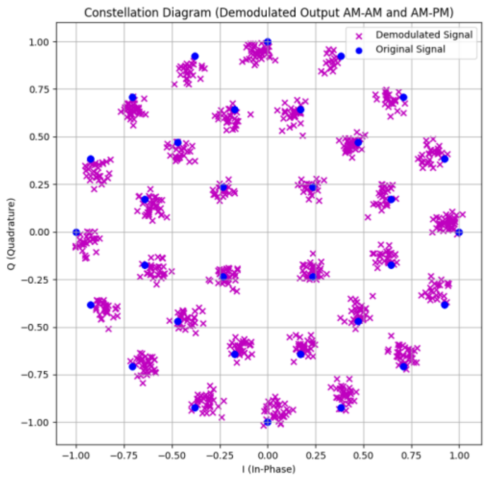


Figure 5. Source EVM = 2.6%, 1 dBm input power. Resulting EVM = 9.43%

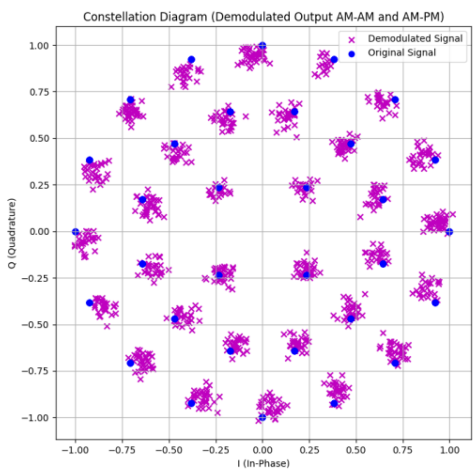


Figure 6. Source EVM = 2.6%, 2 dBm input power. Resulting EVM = 9.98%

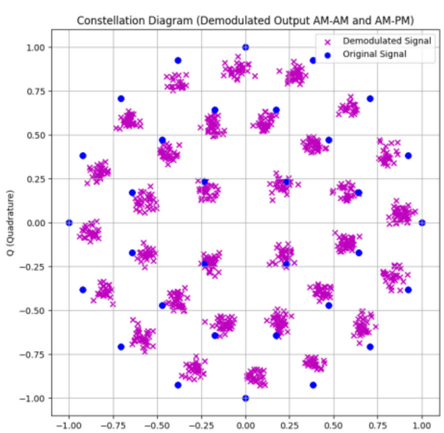


Figure 7. Source EVM = 2.6%, 3 dBm input power. Resulting EVM = 14.17%.

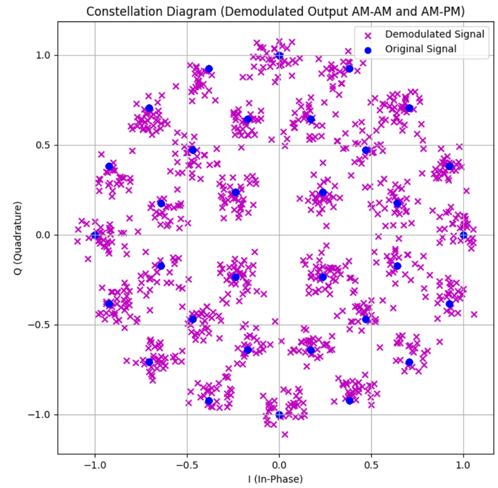
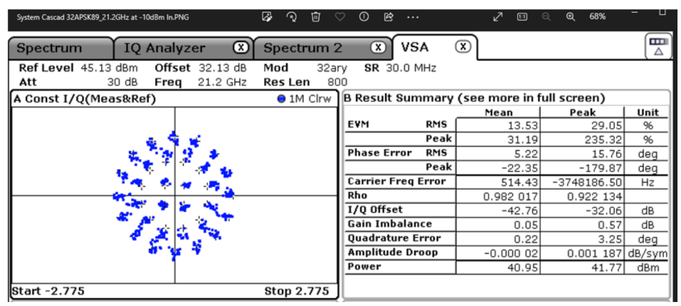


Figure 8. Source EVM = 4.5%, 0 dBm input power. Resulting EVM = 12.06%.

IV. MEASUREMENTS

The SSPA amplifier was tested at 21.2 GHz with output power of 40.95 dBm (input power of 3 dBm) which corresponds to the case of Figure 7 above yielding a measured RMS mean EVM of 13.53% as seen in Figure 9. The calculated EVM was 14.17 from Figure 7 which shows good agreement with the measurement.



		Mean	Peak	Unit
EVM	RMS	13.53	29.05	%
	Peak	31.19	235.32	%
Phase Error	RMS	5.22	15.76	deg
	Peak	-22.35	-179.87	deg
Carrier Freq Error		514.43	-3748186.50	Hz
Rho		0.982 017	0.922 134	
I/Q Offset		-42.76	-32.06	dB
Gain Imbalance		0.05	0.57	dB
Quadrature Error		0.22	3.25	deg
Amplitude Droop		-0.000 02	0.001 187	dB/sym
Power		40.95	41.77	dBm

Figure 9. Measured constellation and EVM for SSPA at 21.2 GHz and input power of 3 dBm yielding mean output power of 40.95 dBm.

To demonstrate the effect of compression, two configurations were tested as follows: The first case is when the final stage is driven by a medium power driver, and the second case when the final stage is driven by another high-power final stage. As expected, when compression is large the EVM also gets large, whereas when the compression is small then the EVM is less. Figure 10 shows the EVM versus output power for the first case, while Figure 11 shows the EVM versus output power in the second case.

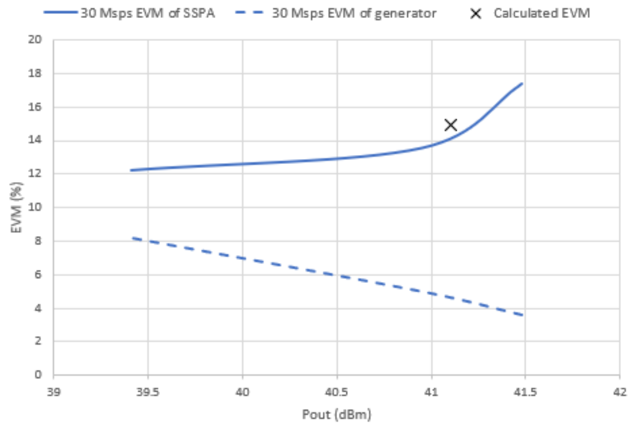


Figure 10. Measured and calculated EVM versus output power when the final stage is driven by a medium power driver.

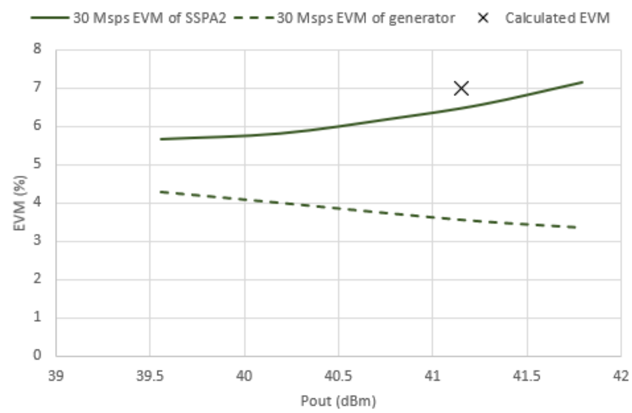
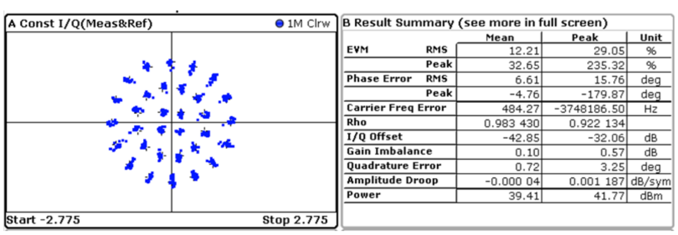


Figure 11. Measured and calculated EVM versus output power when the final stage is driven by another high power final stage.

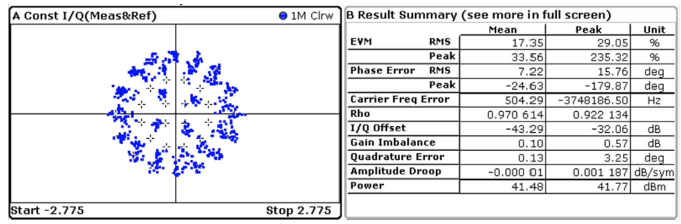
The effect of AM-AM compression results in scatter diagram that is spread more diametrically, in addition to memory effects that are not taken into account in our model, and when AM-PM becomes significant then phase rotation also becomes apparent in the scatter diagram as shown in Figures 12 and 13.



		Mean	Peak	Unit
EVM	RMS	12.21	29.05	%
	Peak	32.65	235.32	%
Phase Error	RMS	6.61	15.76	deg
	Peak	-4.76	-179.87	deg
Carrier Freq Error		484.27	-3748186.50	Hz
Rho		0.983 430	0.922 134	
I/Q Offset		-42.85	-32.06	dB
Gain Imbalance		0.10	0.57	dB
Quadrature Error		0.72	3.25	deg
Amplitude Droop		-0.000 04	0.001 187	dB/sym
Power		39.41	41.77	dBm

Figure 12. Scatter diagram at output power of 39.41 dBm where AM-AM effect is more pronounced than AM-PM.

Our model can be improved in the future by adding feedback to simulate memory effects.



		Mean	Peak	Unit
EVM	RMS	17.35	29.05	%
	Peak	33.56	235.32	%
Phase Error	RMS	7.22	15.76	deg
	Peak	-24.63	-179.87	deg
Carrier Freq Error		504.29	-3748186.50	Hz
Rho		0.970 614	0.922 134	
I/Q Offset		-43.29	-32.06	dB
Gain Imbalance		0.10	0.57	dB
Quadrature Error		0.13	3.25	deg
Amplitude Droop		-0.000 01	0.001 187	dB/sym
Power		41.48	41.77	dBm

Figure 13. Scatter diagram at output power of 41.48 dBm where both AM-AM and AM-PM become significant.

V. CONCLUSION

This paper shows how the 32-APSK gets impacted by AM/AM, AM/PM as well as NF of the SSPA. Memory effects are not considered in this effort. It is seen that the more the amplifier gets more into compression the higher the EVM gets as per the AM/AM and AM/PM characteristics. When the AM-AM curve is dominant the scatter diagram spread more diametrically, and when AM-PM becomes more significant then rotational scatter of the symbols becomes evident as well. It is also shown how the final EVM is impacted by signal source EVM which causes the output EVM to increase with increase in the source EVM. Good agreement between measured and calculated constellation and EVM for a 20.2 to 21.2 GHz SSPA was shown with varying input power yielding output power up to 41.2 dBm. Other measurements were taken for two cases when compression was large and when it was moderate and the resulting scattered plots as well as EVM were compared to the prediction made by this analysis showing good agreement. This memoryless model thus, as implemented by a Python program, provides valuable guidance for predicting the amplifier's nonlinearity impact on the symbol distortion for 32-APSK waveform and the resulting EVM, which helps in defining linearity requirements for a particular power amplifier to meet specific EVM goals that guarantee the overall system's performance will be met for a particular communication channel application. Our model can be improved by adding feedback to include memory effects in the future.

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