Time-domain distortion of a pulse-operated high-power GaN amplifier and a reduction method

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Abstract: This paper describes pulse waveform distortion by a high-power GaN amplifier and a method for reducing it in a solid-state radar that performs pulse compression. When a pulse signal is input to the amplifier, the output pulse waveform differs from the input form because of the influences of nonlinearity and transient response, which are remarkable at the time of rise and fall when the amplitude has a temporal slope. In the measurement results, the temporal slope and the pulse width increased by 79.6% and 1.5%, respectively, compared with the input waveform. On processing the received signal, these influences degraded the signal-to-noise ratio after pulse compression by about 5 dB. In the proposed method, these influences were reduced by adding a dummy signal before and after the desired signal. This method is advantageous in that it does not require the addition of a feedback circuit for distortion compensation and it is not easily influenced by changes in the signal settings and the ambient temperature.

Keywords: radar, GaN amplifier, pulse compression, nonlinearity, transient response

Classification: Sensing

References

[1] S. C. Cripps, RF Power Amplifiers for Wireless Communications, Artech House, Boston, London, 2006.
[2] H. Chen, L.-J. Jiang, X.-F. Ji, and Y.-X. Zhang, “Design of an X-band pulsed SSPA based on a cascade technique,” Proc. IEEE Int. Conf. Microw. Technol. Comput. Electromagn., pp. 152–155, May 2011. DOI:10.1109/ICMTCE.2011.5915187
[3] C. Wang, Y. Xu, X. Yu, C. Ren, Z. Wang, H. Lu, T. Chen, B. Zhang, and R. Xu, “An electrothermal model for empirical large-signal modeling of AlGaN/GaN
HEMTs including self-heating and ambient temperature effects,” *IEEE Trans. Microw. Theory Techn.*, vol. 62, no. 12, pp. 2878–2887, Dec. 2014. DOI:10.1109/TMTT.2014.2364821

[4] D. Hayashi, Y. Tsuda, and S. Kawasaki, “Pulse operation characteristics of X-band high power GaN amplifiers for the Hayabusa2 re-entry capsule tracking radar,” APMC2018, Kyoto, WE1-K01, Nov. 2018.

[5] J. E. Cilliers and J. C. Smit, “Pulse compression sidelobe reduction by minimization of Lp-norms,” *IEEE Trans. Aerosp. Electron. Syst.*, vol. 43, no. 3, pp. 1238–1247, July 2007. DOI:10.1109/TAES.2007.4383616

1 Introduction

Modern radar generally uses a semiconductor amplifier to generate the transmitted signal. Furthermore, to achieve detection performance comparable with that of a conventional electron tube, radar often uses a pulsed chirp signal as the transmitted signal and pulse compression to process the received signal. Gallium nitride (GaN) is used as the amplifying semiconductor because it has excellent thermal conductivity, band gap, and breakdown voltage and can handle higher output power compared with gallium arsenic (GaAs) in the same size.

In a GaN amplifier, the gain and efficiency (among other properties) change according to the output power [1], and gain compression in excess of 3 dB is not uncommon in high-power operation [2]. Also, any change in the power efficiency changes the amount of heat generated around the device. The change in heat generation is determined by the structure of the semiconductor and does not coincide with the envelope of the radiofrequency (RF) signal. This induces hysteresis in the GaN amplifier, known as the memory effect, and affects the linearity of the output signal [3]. Under pulse operation in which the output level changes with time, careful attention is required [4]. Techniques such as pre-distortion and feed forward can be used to reduce such distortion. However, assuming that the distortion changes with the signal settings and the ambient temperature, both those techniques require a feedback circuit.

In this study focused on solid-state radar, we measured the pulse waveform distortion in a high-power GaN amplifier and investigated its influence on pulse compression. Additionally, we propose a simple method for reducing the distortion.

2 Pulse waveform distortion of a high-power GaN amplifier and its influence on pulse compression

For the investigation, we used an X-band high-power GaN amplifier for marine radar. It was designed using a GaAs amplifier and two GaN amplifiers in series and operated with gate-bias switching for low power consumption. This amplifier had a maximum output power of 51 dBm (126 W), and gain of 61 dB at 9.41 GHz under a 4 µs pulse width and 2600 Hz repetition frequency. At this time, the gain difference from the linear region was 5 dB.

Fig. 1(a) shows two output waveforms, one at maximum output (51 dBm) in red and the other at an output of 50 dBm in green; the waveform of the amplifier
input is also shown in blue. To see any differences more clearly, normalized amplitudes are shown. In the measurements, the gate bias was also pulsed, but a sufficient margin (0.5 µs) was maintained to obtain pure RF characteristics.

This figure shows that the temporal slope of the amplitude steepened at the rise and fall compared with the input. In addition, the behavior at the edge was such that the pulse became wider. Fig. 1(b) details these comparisons numerically, wherein a number in parentheses indicates the percentage change compared with the amplifier input. At the maximum output, the temporal slope and the pulse width increased by 79.6% and 1.5%, respectively.

Fig. 1(c) shows the results of pulse compression. The pulse waveform distortion described above appeared as a degradation of the signal-to-noise ratio (SNR) upon pulse compression and deteriorated with increase of the operating range in the nonlinear region. A mismatched filter was used for the pulse compression [5].

![Graph showing pulse waveform distortion and its influence on pulse compression](image)

Fig. 1. Pulse waveform distortion and its influence on pulse compression.

### 3 Proposed method for reducing distortion

In Fig. 2(a), to understand the influence of nonlinearity, the values in Fig. 2(c) were applied to the amplifier input of Fig. 1(a). When considering only the influence of nonlinearity, the temporal slope steepened with the output power, the pulse tended to widen, but there was no delay relative to the input signal. On the other hand, when considering only the delay, phenomena such as pulse widening would naturally not be seen. This behavior was considered to be the influence of both...
nonlinearity and transient response as shown in Fig. 2(b). A symmetric transient response appeared also at the fall time in Fig. 1(a), so it was presumed that a change in the output level was involved rather than a simple delay.

Fig. 2. Consideration of measurement results and summary of proposed method.
In the proposed method, a dummy signal that is separable by processing the received signal is added before and after the desired signal. By changing the amplitude of the dummy signal according to the desired signal, the sum amplitude is held constant while transmitting the desired signal. After passing through the amplifier, the distortion appears in only the dummy signal. The desired output waveform is obtained by separating the dummy signal at the receiver. In this method, no feedback circuits are required for distortion compensation. Furthermore, because the desired signal is handled in an electrically and thermally stable region, it is hardly affected by changes in the signal settings and the ambient temperature.

4 Effect of proposed method

In this study, a non-modulated pulsed signal whose frequency differed from that of the desired signal was used as the dummy signal, and the dummy signal was removed by the band-pass filter at the receiver. Fig. 3(a) shows the comparison before and after applying the proposed method at the maximum output. In particular, the transient response was greatly improved and there was a higher degree of similarity with the input signal. However, further investigation is required to explain the slight remaining differences. Fig. 3(b) shows the results of pulse compression. The difference in characteristics was almost eliminated, and an SNR improvement of about 5 dB was obtained compared with the results in Fig. 1(c).
5 Conclusion

This paper used measurement results to describe the pulse waveform distortion at the rise and fall of the signal in a high-power GaN amplifier, showing that the distortion appeared as a deterioration of the SNR due to pulse compression. In addition, a method was proposed for reducing this distortion, and its efficacy was confirmed. Although this method involves a wider pulse, operation in the electrically and thermally stable region can be secured with no feedback circuit. In future work, we intend to study in more detail the signal specifications necessary for the dummy signal, such as the insertion timing.

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