

# Multiband Digital Transmitter Techniques Using High-Efficiency GaN Switching-Mode Amplifiers

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## 1. Introduction

The size of digital baseband sections on transmitters for wireless installations such as base stations has become smaller and the operation speed has increased as semiconductor processes have become finer. However, it is very difficult to improve the efficiency of high-frequency analog sections including transmitting amplifiers. Therefore, digital transmitter architecture has been attracting attention as the next-generation transmitter architecture. In this architecture, high-frequency signals are processed to digital signals and most of the high-frequency section is operated digitally. The main characteristics of the digital transmitter architecture are as follows: (1) the transmitter is programmable and can be adapted, so it can be easily applied to multiple specifications, (2) the size of the transmitting section can be made smaller by increasing the integration and reducing the number of external parts, and (3) the efficiency can be improved by adopting the switching amplifier circuit architecture.

One main technical challenge for digital transmitters is to develop high-efficiency switching amplifier circuit technology. To use switching amplifiers on transmitters for base stations, they need to have high-efficiency and high-power characteristics in high-frequency bands. Some researchers have recently reported high-efficiency and high-power switching (class D) amplifiers that work in frequency bands near GHz by adopting GaN transistors.<sup>(1), (2), (3)</sup> This amplifier technology is expected to lead to the development of high-performance multifunction digital transmitters for base stations.

This paper describes multi-band digital outphasing transmitter architecture having switching amplifiers. It also reports on the results of prototyping a two-band digital outphasing transmitter with GaN class-D amplifiers based on the proposed architecture. The efficiency of GaN class-D amplifiers was improved by applying boot-strap driver circuits. In addition, high-efficiency and high-power operation was made possible through class-S outphasing amplification of the two class-D amplifiers by a Chireix power combiner. This type of transmitter showed excellent high-frequency characteristics when sending two frequencies (244 and

500 MHz) at the same time, raising expectations for the development of the new next-generation transmitter architecture using GaN devices.<sup>(4)</sup>

## 2. Digital Outphasing Transmitter Architecture for Non-Contiguous Concurrent Multi-Band

Figure 1 shows the block diagram of a multi-band digital outphasing transmitter with the proposed switching amplifiers. This transmitter consists of a signal processing block including a digital signal generator for multi-level (e.g.,  $q$  level) outphasing that generates signals from digital baseband signals, class-S outphasing amplifying block consisting of class-D amplifiers and a power combiner, and multi-band filter.

The signal processing block converts individual digital baseband signals ( $I_n$  and  $Q_n$ ) to high-frequency signals through digital up-conversion. Then, to enhance the efficiency of signal processing, the multi-band multi-bit bandpass delta-sigma modulation (BPDSM) forms high-linear digital signals in the level of  $(2q + 1)$ . The digital signal generator for multi-level outphasing forms and outputs two types of  $q$ -level digital signals that correspond to the  $(2q + 1)$ -level digital signals and that have an outphasing angle.

The two types of digital signals output from the signal processing block are input to each of the two class-D amplifiers constituting the class-S outphasing amplifying block and are amplified. The power combiner combines the amplified signals based on the outphasing angle. The multi-band filter removes harmonic components. The antenna outputs the signals. These processes realize a high-efficiency and high-power digital transmitter that can transmit multi-band signals at the same time.

## 3. Prototyped Results of Digital Outphasing Transmitter with Two-Dimensional Power Coding

The authors prototyped a two-band digital outphasing transmitter based on the block diagram in Fig. 1. The two frequencies of 244 and 500 MHz were selected. For low-frequency signals, the channel

bandwidth was 5 MHz and the peak-to-average power ratio was 11.0 dB. For high-frequency signals, the channel bandwidth was 10 MHz and the peak-to-average power ratio was 11.7 dB.

### 3.1 Class-S outphasing amplifier

Figure 2 shows the circuit diagram of the class-S outphasing amplifying block consisting of class-D amplifiers and a Chireix power combiner. The class-D amplifiers have GaN transistors that feature two types of characteristic (high-speed operation and high voltage resistance). They were integrated on a chip as shown in Fig. 3. The chip size is  $1.6 \times 0.9$  (mm<sup>2</sup>). A class-D amplifier consists of a switching circuit including two transistors ( $M_1$  and  $M_2$ ) and driver circuit connected to the gate sides of  $M_1$  and  $M_2$ . The driver circuit of the gate terminal of  $M_1$ , in particular, needs to supply high-voltage amplitude highly efficiently from near the threshold

voltage to the drain voltage ( $V_{DD}$ ). By applying a bootstrap driver circuit with a capacity for charging and discharging voltage, the circuit can be used under a condition where the drain power supply of the driver circuit on the  $M_1$  side ( $V_{DDH}$ ) is lower than  $V_{DD}$ . As a result, the power consumption of the entire class-D amplifiers can be reduced.

### 3.2 Digital outphasing transmitter

The authors prototyped a two-band digital outphasing transmitter. Figure 4 is a photograph of the class-S outphasing amplifying block included in the digital outphasing transmitter. Figure 5 shows the results of evaluating the digital outphasing transmitter. The power supply voltage ( $V_{DD}$ ) of the class-D amplifier was 35 V and the outphasing angle was limited to a range from 0 to 45 degrees. The results of the evaluation were a maximum drain efficiency of 59%, maximum overall

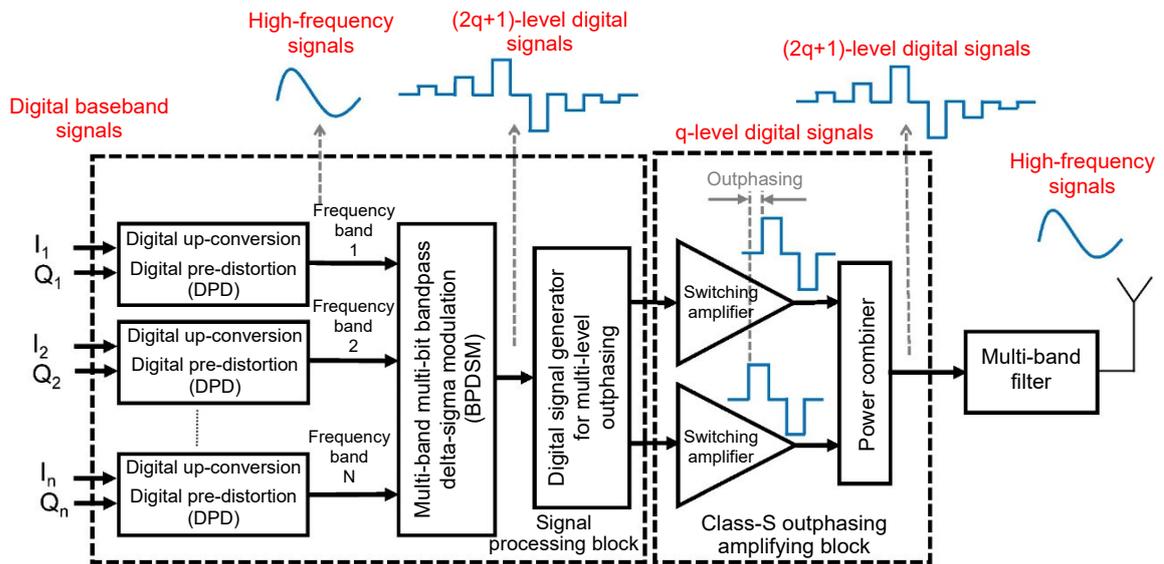


Fig. 1 Architecture of multiband digital outphasing transmitter

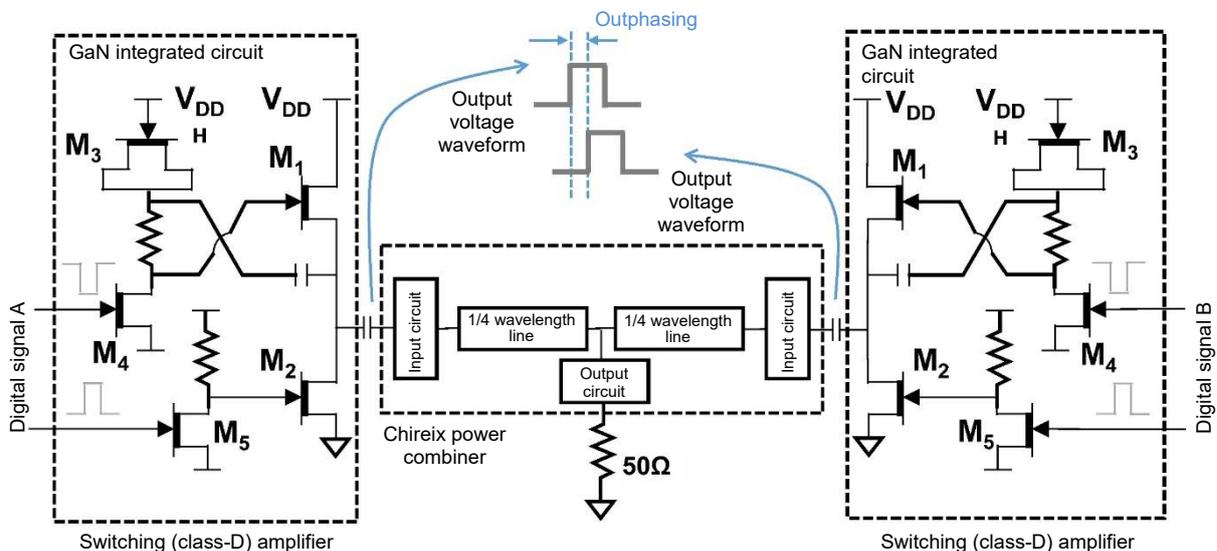


Fig. 2 Circuit of class-S outphasing amplifier block

efficiency of 50%, and maximum output power of 38.0 dBm, thus achieving high efficiency and high power. It has also been confirmed that even when the output power was reduced, the high-efficiency characteristics were retained. Figure 6 shows the results of evaluating the output spectra of the digital outphasing transmitter. Figure 6(a) shows the results when the frequency of the

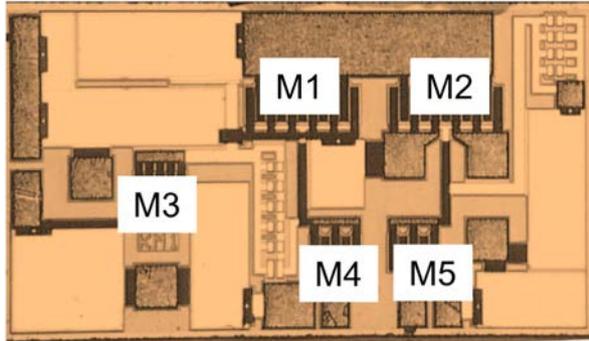


Fig. 3 Chip photograph of GaN switching amplifier

signals was 244 MHz and the channel bandwidth was 5 MHz. Figure 6(b) shows those when the frequency of the signals was 500 MHz and the channel bandwidth was 10 MHz. The adjacent-channel leaking power for the case in Fig. 6(a) was -37 dBc and that for the case in Fig. 6(b) was -30 dBc. Thus, it has been confirmed that the transmitter has excellent distortion characteristics and can transmit two frequencies at the same time.

#### 4. Conclusion

This paper reported the results of prototyping a two-band digital outphasing transmitter with class-D amplifiers. The evaluation results show that the transmitter has excellent high-efficiency and high-power characteristics and that the architecture is effective for digital transmitters for base stations that will require higher efficiency and more functions in the future. The results also indicate the potential for developing new GaN devices.

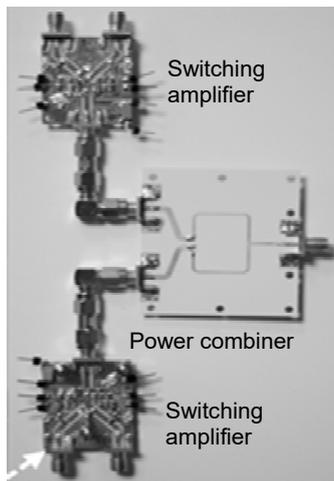
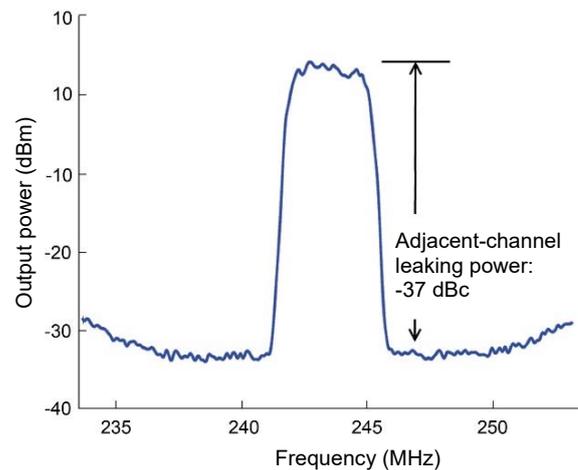


Fig. 4 Prototyped class-S outphasing amplifier block



(a) 244 MHz frequency, 5 MHz channel bandwidth

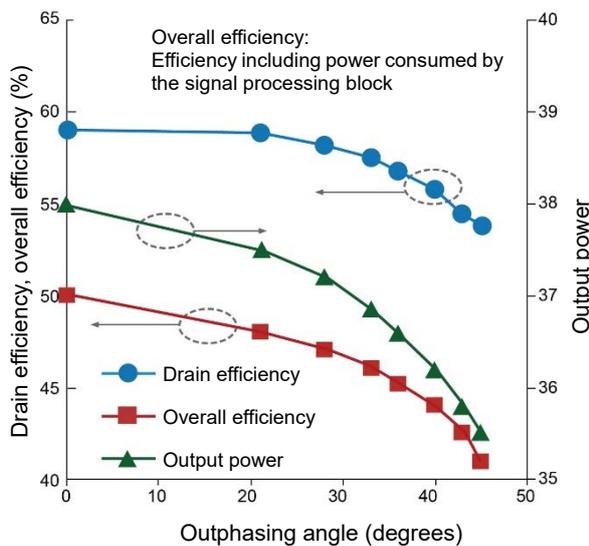
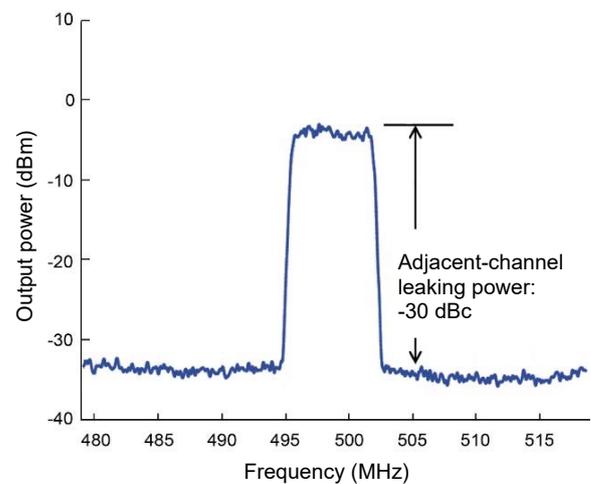


Fig. 5 Measured results of digital outphasing transmitter



(b) 500 MHz frequency, 10 MHz channel bandwidth

Fig. 6 Measured output spectrum of digital outphasing transmitter

## 5. References

- (1) Hori, S., et al.: Linear and Efficient Digital Transmitters for Future Mobile Communication, IEEE International Microwave Symp. Workshop (2017)
- (2) Andreas, W., et al.: Digital Transmitters for the Wireless Infrastructure, IEEE International Microwave Symp. Workshop (2017)
- (3) Nakamizo, H., et al.: Over 65% PAE GaN Voltage-Mode Class D Power Amplifier for 465 MHz Operation Using Bootstrap Drive, IEEE Radio Wireless Symp. (2015)
- (4) Sung, W. C., et al.: Concurrent Multiband Digital Outphasing Transmitter Architecture Using Multidimensional Power Coding, IEEE Trans. Microw. Theory Tech., Vol. 63, 598–613 (2015)