

Comparison between Quadrature- and Polar-modulation Switching-mode Transmitter with Pulse-density Modulation

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Abstract— This paper presents the performance of the quadrature modulation (QM) transmitter when compared with the (PM) transmitter. So as to evaluate the substantive power efficiency in both transmitters, the effective demodulation power efficiency (EDPE) is proposed as a novel figure of merit for transmitters. Computer simulation reveals that the EDPE for a QM transmitter is lower than that for a PM transmitter. In addition, D/U for a QM transmitter is higher than the one for PM transmitter due to lower quantization noise. As a result, the EVMs for a QM transmitter is higher than the one for a PM transmitter.

Keywords— Transmitter; Polar modulation; Quadrature modulation; Pulse density modulation; Delta-sigma modulation; Effective demodulation power efficiency

I. INTRODUCTION

Around a half of the power consumption in a mobile communication transmitter is consumed in a power amplifier. Therefore, reducing power consumption in a power amplifier is indispensable so as to save energy in mobile communications. To reduce power consumption in a transmitter, highly-power-efficient transmitters using envelope pulse-width- or pulse-density-modulation [1]-[10] have been investigated intensively so far. This type of transmitters can amplify signals linearly with keeping high power efficiency even when a backoff from the saturation power of a power amplifier is large, whereas conventional transmitters using class-A, AB, or B amplifiers cannot. In addition, the transmitters using delta-sigma modulation for pulse-density modulation [1]-[3], [5]-[10] is attractive because it can reduce quantum noise by noise shaping. Among these types of transmitters polar-modulation (PM) [2]-[5] and quadrature-modulation (QM) transmitters [6]-[10] mitigate the requirements in high-speed operation of delta-sigma (Δ - Σ) modulators compared with the transmitters using bandpass Δ - Σ modulation in pulse-density modulation [1].

The PM transmitters separate a modulated baseband signal to envelope and phase components, amplify the envelope component, and restore them at or in front of the power amplifier. However, the PM transmitter needs analog signal processing in a phase modulator that generates constant-envelope RF phase-modulated signal. In contrast, the QM transmitter is advantageous in compatibility to LSIs because all-signal processing can be done by digital circuits. However, comparison between the PM and QM transmitters has not

been performed sufficiently. In addition, the effective power efficiency from the output of the transmitter and the demodulated signal at the receiver has not yet been evaluated for the QM transmitter.

This paper presents the performance of the QM transmitter when compared with the PM transmitter. So as to evaluate the substantive power efficiency in both transmitters, the effective demodulation power efficiency (EDPE) is proposed as a novel figure of merit for transmitters. Computer simulation reveals that the maximum EDPE in a QM transmitter is lower than the one in a PM transmitter.

II. TRANSMITTER ARCHITECTURE

A. PM Transmitter

The architecture of a PM transmitter with Δ - Σ modulation for pulse-density modulation of envelope component is shown in Fig. 1. After decomposing the inputted signal into an envelope and a phase component, Δ - Σ modulation is performed to generate an envelope signal and phase modulation is performed to generate phase-modulated signal. Next, these signals are multiplied to generate the amplified signal.

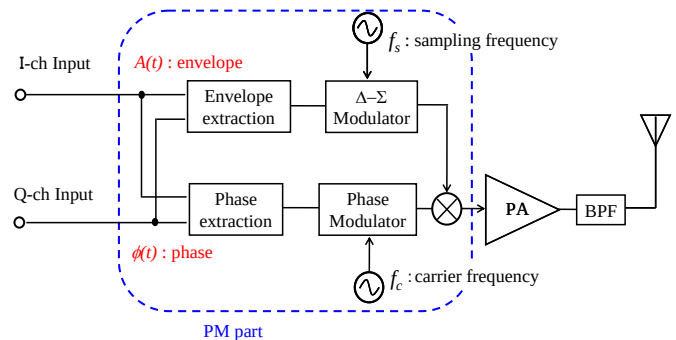


Figure 1. Block Diagram of a polar-modulation (PM) transmitter

B. QM Transmitter

The architecture of a QM transmitter with Δ - Σ modulation for pulse-density modulation of envelope component is shown in Fig. 2. To employ all-digital transmitter architecture excluding continuous phase control, digital quadrature up-

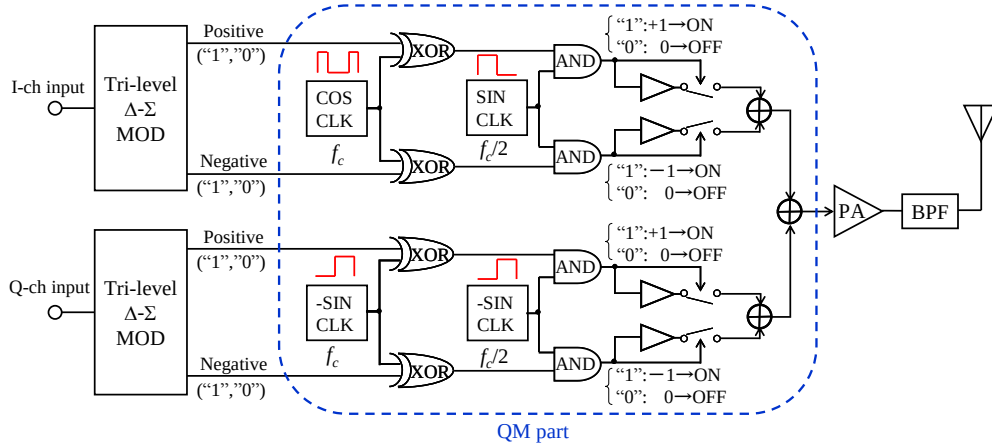


Figure 2. Block diagram of a quadrature-modulation (QM) transmitter.

conversion architecture using dual XOR for I- and Q-channel is used.

In this architecture baseband I- and Q-channel signals are converted to 1-bit digital signals using Δ - Σ modulators. Next, these digital signals are up-converted to RF with XOR gates. In QM transmitters alternate generation of I- and Q-channels is essential because simultaneous generation of I and Q signals causes overlaps of these signals and, therefore, prevents switching-mode operation of a power amplifier [6], [7], [9], [10]. To keep switching-mode operation of the amplifier the XOR gate outputs are taken AND operation with sine and minus sine clocks at a half frequency of the carriers for I- and Q-channel, respectively, with AND gates. By doing this, this transmitter generates information of I- and Q-channel alternately as shown in Fig. 3. This enables quadrature amplitude modulation (QAM) all-digittally without generated the overlaps. Next, the outputs of the AND gates for negative polarity are converted to negative signals. After that a tri-level bipolar logical sum of four outputs is taken and amplified with a switching-mode amplifier. Finally, quantization noise generated by Δ - Σ modulator at the frequency deviated from the signal frequency is removed by a band pass filter (BPF) of appropriate bandwidth.

C. Tri-level Δ - Σ modulator

The basic operation of the second-order Δ - Σ modulator used in this study is shown in Figure 4. The output voltage of the second-order Δ - Σ modulator shown in fig. 4 is expressed as

$$V(z) = U(z) + (1 - z^{-1})^2 E(z) \quad (1)$$

Noise transfer function (NTF) is expressed as

$$NTF(z) = (1 - z^{-1})^2 \quad (2)$$

Power response for noise is expressed as

$$|NTF(e^{j2\pi f})|^2 = [2\sin(\pi f)]^4 \quad (3)$$

A tri-level Δ - Σ modulator used in our study is shown in Fig. 5. Binary pulses correspond to positive and negative internal

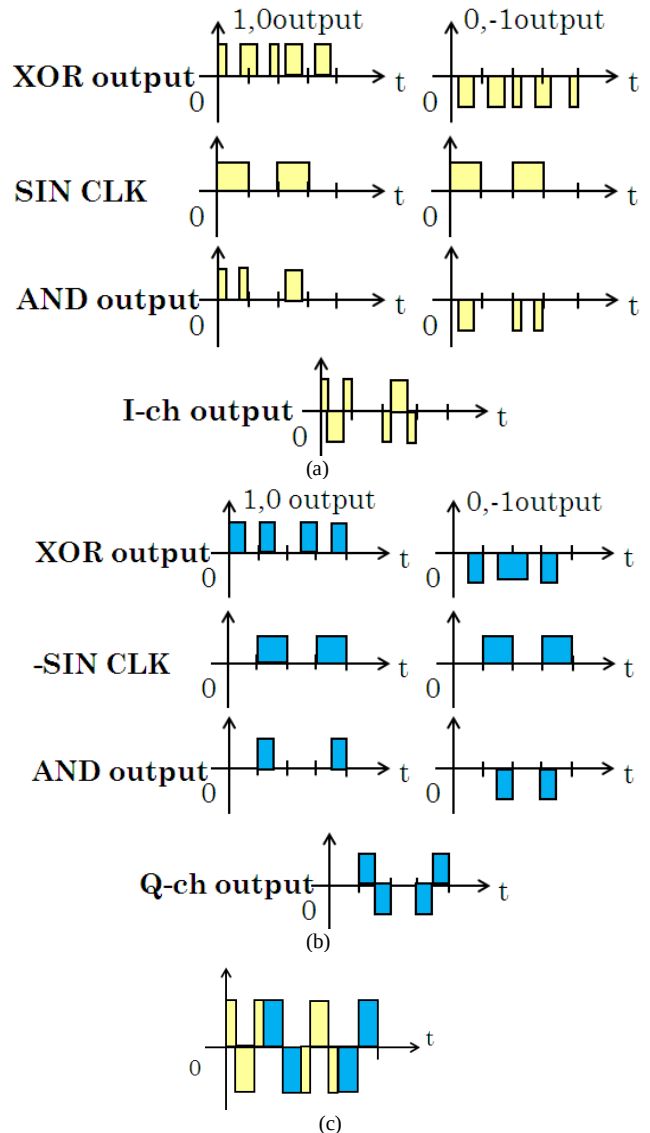


Figure 3. Alternate logic operation of a QM transmitter. (a) I- channel waveform. (b) Q- channel waveform. (c) I- and Q- channel combined waveform. In this example the I and Q signal are generated alternately in every one cycle of carriers.

This Δ - Σ modulator can represent null state for both positive and negative output. Therefore, the transmitter employing this Δ - Σ modulator can stop output power using this null state. This function is essential for low-power operation of the QM transmitter.

A. Effective Demodulation Power Ratio

$$R_{TR} = \frac{P_{RX}}{P_{TX}} \quad (4)$$
$$\eta_{dem} = \frac{R_{TR}(QM)}{R_{TP}(PM)} \quad (5)$$

Figure 6 shows the schematic diagram for the desired to undesired signal power ratio (D/U). D/U is defined as the ratio of the values of the power spectral density (PSD) in the band corresponding to the specified deviated frequency to the the center frequency of the desired band. This represents the extent of leakage to such as an adjacent channel.

$$EVM = \left[\frac{\frac{1}{N} \sum_{n=1}^N |s_{ideal,n} - s_{meas,n}|^2}{\frac{1}{N} \sum_{n=1}^N |s_{ideal,n}|^2} \right]^{\frac{1}{2}} \quad (6)$$

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D. Backoff from Saturation Power

The output power of an QM or PM transmitter with Δ - Σ modulation saturates when the Δ - Σ modulator saturates. Therefore, the backoff from the saturation power of the transmitter is defined as a backoff from the saturation level of the Δ - Σ modulator. The input saturation level of the Δ - Σ modulator is determined as the level where the output of a Δ - Σ modulator is all “1.” A backoff of 0 dB for a modulated input signal is defined as the level where the maximum magnitude of the signal input to the Δ - Σ modulator is equal to the input saturation level.

IV. EVALUATION BY COMPUTER SIMULATION

Computer simulations were performed for evaluating the EDPE, PSD, D/U, and EVM for a PM and a QM transmitter. Figure 8 and Table I shows the simulation setup and parameters. Figure 9 shows the dependence of EDPE on backoff. The EDPE for a QM transmitter is about 30% lower than that for a PM transmitter over a backoff of between 0 and 20 dB. This is due to the power loss caused by cancellation in vertical component of the original baseband signal as described in Sec. III.A.

Figure 10 shows the power spectral density (PSD) for a QM and PM transmitter. The D/U values for 12.5 and 25 MHz offset are shown in Fig. 11. The D/Us for a QM transmitter at 12.5- and 25-MHz offset are respectively 12-18 and 8-9 dB higher than that for a PM transmitter. This is due to the wider bandwidth of the envelope signal than the I and Q signals [8]. Accordingly, the QM transmitter is advantageous in higher D/U.

Figure 12 shows the signal constellation after demodulation for a backoff of 0 dB for both transmitters. The EVMs for a QM and PM transmitter are 42 and 34 dB, respectively. Both transmitters have enough high EVM for a backoff of 0 dB. Higher EVM for a QM transmitter is at least partly due to the lower quantization noise in the bandwidth of the roll-off filter in the demodulator.

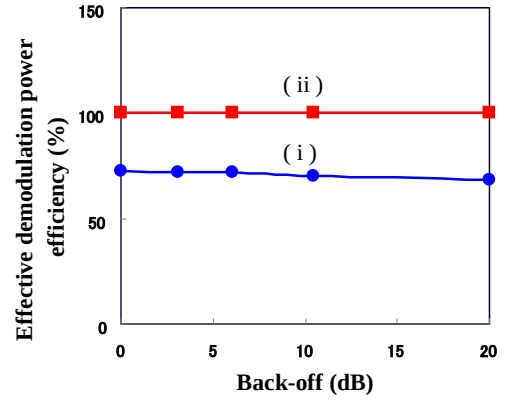


Figure 9. Dependence of effective demodulation power efficiency (EDPE) on the backoff from the saturation power, for (i) QM and (ii) PM transmitter (as a reference).

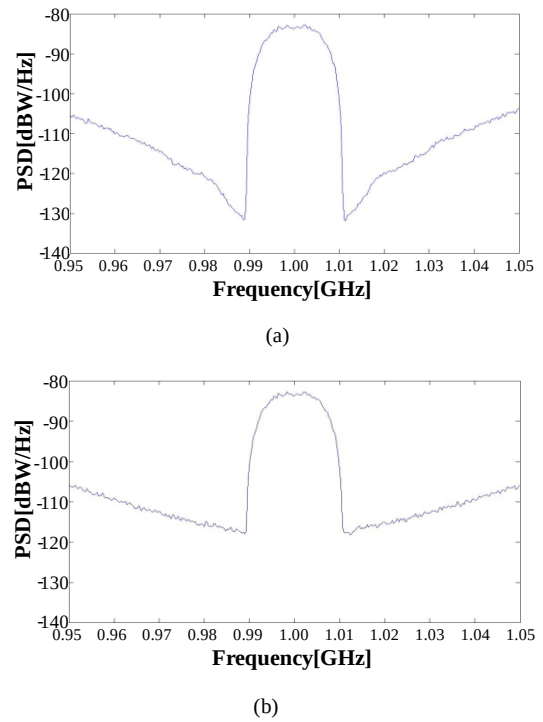


Figure 10. Power spectral density (PSD) at the output of (a) QM and (b) PM transmitter.

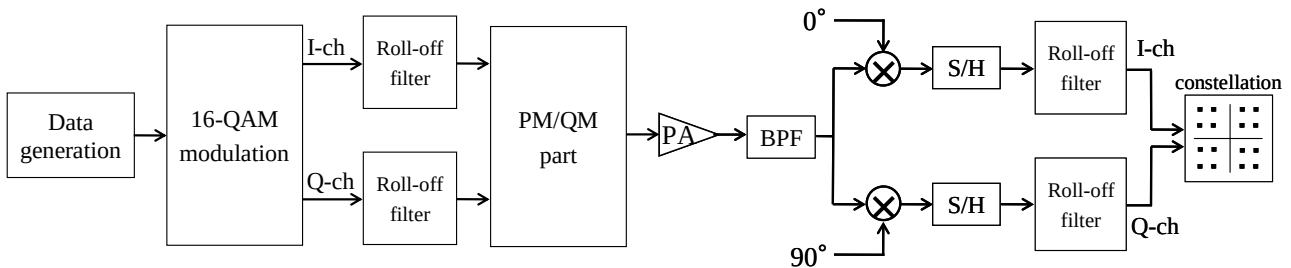


Figure 8. Simulation setup.

TABLE 1. SIMULATION PARAMETERS

Modulation		16QAM
Symbol rate		12.5 Msymbol/s
Roll-off filter	Type	Root raised cosine
	Roll-off factor	0.7
	Length of impulse response	16 symbols
Δ - Σ modulator	Order	2 nd
	Over-sampling ratio	40
Carrier frequency		1 GHz
RF sampling rate		100 Gsample/s
BPF	Type	Butterworth
	Order	2 nd
	Bandwidth	0.5 GHz (0.75-1.25 GHz)

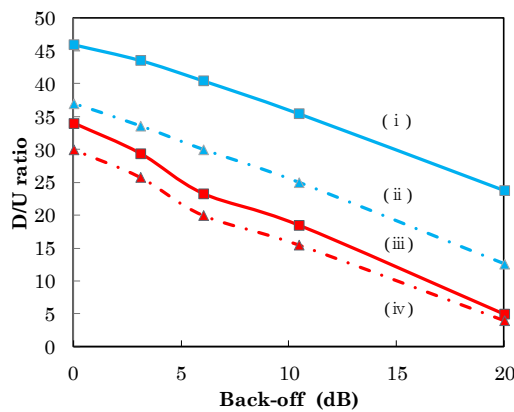
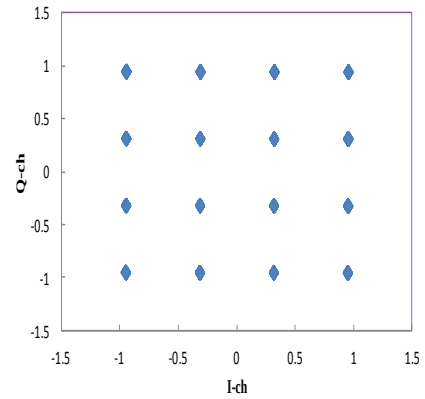


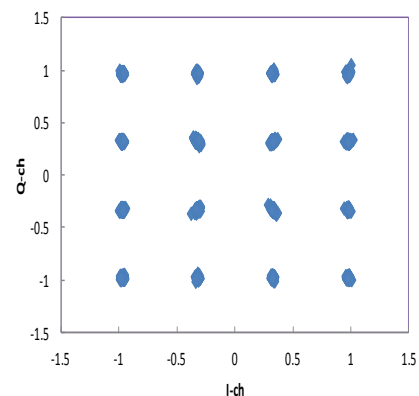
Figure 11. Dependence of D/U on backoff for (i) QM transmitter with 12.5 MHz offset, (ii) QM transmitter with 25 MHz offset, (iii) PM transmitter with 12.5 MHz offset, and (iv) PM transmitter with 25 MHz offset.

V. CONCLUSION

Computer simulation was performed to compare the performance of the QM and the PM transmitter. The EDPE is proposed as a novel figure of merit for transmitters to represent the power efficiency in vector combining of transmitted signal at the received baseband filter used for band limitation. Computer simulation showed that the EDPE for a QM transmitter is much lower than that for a PM transmitter. In addition, D/U for a QM transmitter is higher than the one for PM transmitter when the frequency offset is small due to the lower quantization noise. The EVMs for QM transmitter is higher than the one for PM transmitter for a backoff of 0 dB at least partly due to the lower quantization noise.



(a)



(b)

Figure 12. Signal constellation after demodulation for a backoff of 0 dB for (a) QM and (b) PM transmitter.

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