Jurnal Infotel
Vol. 16, No. 4, November 2024, pp. 855–870. doi:10.20895/infotel.v16i4.1237

Research Article

Design of a 20 Mbps OQPSK Modulator Based on Multiplexers

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Received: September 02, 2024; Revised: October 23, 2024; Accepted: October 27, 2024.

Abstract: This paper describes the design and implementation of the OQPSK (Offset Quadrature Phase Shift Keying) modulator. Designing a modulator with the OQPSK modulation method, an improvement on the QPSK modulation method, is the primary goal of this project. The multiplexer, which chooses one carrier signal from four and modulates it with data bits, is the main element of this architecture. The modulator also converts two square wave pulses that are 90 degrees out of phase with one another into differential sinusoidal impulses to create the carrier signal. The clock and streaming data bit frequencies are set to 10 MHz and 5 MHz, respectively. Simulation results verify the OQPSK modulator's efficacy, demonstrating that it can generate modulated signals at a consistent 20 Mbps data transfer rate. This illustrates how well digital data is transmitted via an analog communication channel by the modulator. To sum up, the developed OQPSK modulator is a superb illustration of effective signal modulation and demodulation.

Keywords: communication network, data transfer rate, modem, modulator, OQPSK

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1 Introduction

Modems use communication channels to move data between two systems. Digital data streams are transformed into analog signals by a modulator so they can be sent via cables or phone lines. In order to match the transmission channel, this process entails changing the signal's amplitude, frequency, or phase. Stated differently, a modulator guarantees effective and low-interference data transmission [1].

Modern technology has greatly improved in speed, efficiency, and compatibility with new communication standards over the years. Digital modems that can send data at speeds ranging from kilobits per second (Kbps) to gigabits per second (Gbps) have surpassed analog modems, which at first functioned at speeds measured in bits per second (bps) [2–5].

Analog and digital modulation are the two primary forms of modulation utilized in communication systems. Each has unique traits, methods, and uses that are appropriate for particular communication requirements. Transforming analog information signals, like audio or video, into analog signals that may be sent via communication channels is known as analog modulation. This method modifies the carrier signal's amplitude, frequency, or phase, among other properties. Amplitude modulation (AM) is a common analog modulation technique. adjusts the carrier signal's amplitude in accordance with the information signal. AM radio broadcasting makes extensive use of AM [6,7]. Based on the information stream, frequency modulation (FM) modifies the carrier signal's frequency. FM radio and television broadcasts frequently use this strategy [8,9]. Phase modulation (PM): Modifies the carrier signal's phase to correspond with the data being conveyed. Numerous radio communication technologies make use of PM [10,11]. Although analog modulation works well for many broadcasting applications, the quality of transmission might be lowered by the increased susceptibility of analog signals to noise and interference. Digital modulation, on the other hand, entails transforming digital information impulses into analog signals in order to transmit them. This method uses changes in the carrier signal's amplitude, frequency, or phase to represent digital data bits. Typical methods of digital modulation include: To represent digital data bits, Amplitude Shift Keying (ASK) modifies the carrier signal's amplitude. Short-distance communications frequently use ASK [12–14]. To represent digital data, frequency shift keying (FSK) alters the carrier signal's frequency. Modems and data transmission systems frequently use FSK [15, 16]. Phase shift keying, or PSK, modifies the carrier signal's phase to match digital data bits. PSK is used to increase transmission efficiency in a variety of digital communication applications [17, 18]. Compared to analog modulation, digital modulation has advantages in terms of resilience to noise and interference. For applications like internet networks and cellular communication, more accurate and dependable data transmission is made possible by techniques like encoding and error correction in digital modulation.

The kind of signal being modulated, and the methods employed are the primary distinctions between analog and digital modulation. While digital modulation concentrates on discrete signals and is more prevalent in contemporary communication systems, analog modulation concentrates on continuous signals and is frequently employed in conventional broadcasting. Digital modulation offers greater transmission efficiency, is more resistant to interference, and frequently incorporates error correcting methods to guarantee data integrity. Selecting the best modulation strategy for a range of communication applications, from radio broadcasting to sophisticated digital data communication, is made easier by being aware of these distinctions [12].

Additional developments have been made from the three fundamental digital modulation techniquesASK, FSK, and PSK. A development of the PSK modulation technology which known as Binary Phase Shift Keying (BPSK) [19, 20], is Quadrature Phase Shift Keying (QPSK) [21, 22]. QPSK is then extended to Offset Quadrature Phase Shift Keying (OQPSK) [23–25]. The OQPSK modulator is the main topic of this paper's discussion.

2 QPSK and OQPSK Modulation

By altering the phase of one channel by one bit (half a symbol), the OQPSK (Offset Quadrature Phase Shift Keying) modulation technique modifies QPSK (Quadrature Phase Shift Keying). OQPSK has a smaller bandwidth than BPSK (Binary Phase Shift Keying) modulation because, like QPSK, it uses two signal bits to represent each information symbol. This method maintains the same average error rate while halving the bit rate and using half the bandwidth of BPSK [22].

Figure 1 illustrates the general block diagram of an OQPSK modulator, which includes an even-odd data splitter, a delay cell, and a modulator (a device that modifies the carrier signal, using sine and cosine waves) with an input signal such as data, voice, or video. The modulator encodes the input signal before transmission by multiplying or mixing it with the carrier signal. The final block is a summing circuit that combines the even-modulated and odd-modulated signals, resulting in the OQPSK-modulated signal.

The OQPSK modulator employs quadrature signals, which are signals that are 90 degrees apart (sine and cosine), as the diagram illustrates. Four signal types—sine, cosine, negative sine, and negative cosine—must be produced in order to represent data bits 0 and 1. These four signals can be produced in at least four ways: In order to use a quadrature oscillator, four outputs that are 90 degrees apart are used [26,27]. Using Square Waves: This technique creates four output signals that are 90 degrees apart by first transforming square wave signals into sinusoidal forms and then passing them via four phase shifters. Using a Pair of Quadrature Waves: In this case, a balanced modulator is used to analogously modulate a pair of sine and cosine waves with odd and even data values (1V and -1V), producing four carrier signals that are 90 degrees apart [28]. The Approach Taken for This Paper: With this method, two square wave signals that are 90 degrees apart are used, and they are subsequently transformed into differential sinusoidal signals.

The block diagram can be explained as follows: Serial data from the source (D0-D7) is divided into even data (D0, D2, D4, D6) and odd data (D1, D3, D5, D7), forming pairs of bits known as dibits. For example, serial data 11001100 is divided into dibits 10, 11, 01, and 00, which correspond to even data (1010) and odd data (1010), as shown in Figure 2. This figure also illustrates the differences between QPSK and OQPSK.

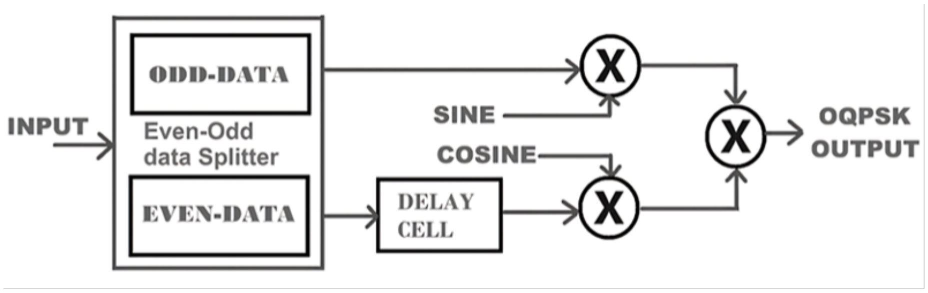

Figure 1: OQPSK block diagram.

OQPSK uses the same modulation technique as QPSK as formulated as shown below [21]:

$$S_{\text{OQPSK}}(t) = S_{\text{Odd}}(t) + S_{\text{Even}}(t) \tag{1}$$

$$S_{\text{Odd}}(t) = \begin{bmatrix} \text{If the odd bits} = 1 \longrightarrow S_{\text{Odd}} = A \cdot \cos(\omega_c t) \\ \text{If the odd bits} = 0 \longrightarrow S_{\text{Odd}} = -A \cdot \cos(\omega_c t) \end{bmatrix} \tag{2}$$

$$S_{\text{Even}}(t) = \begin{bmatrix} \text{If the even bits} = 1 \longrightarrow S_{\text{Even}} = A \cdot \sin(\omega_c t) \\ \text{If the even bits} = 0 \longrightarrow S_{\text{Even}} = -A \cdot \sin(\omega_c t) \end{bmatrix} \tag{3}$$

The formula demonstrates that if the input data is even and has a logic value of 1, it will be modulated by the in-phase carrier signal ($\sin(\omega t)$). If the data has a logic value of 0, it will be modulated by the in-phase carrier signal with a 180-degree phase shift, which is $-\sin(\omega t)$. For odd data, if the input data has a logic value of 1, it will be modulated by the quadrature carrier signal ($\cos(\omega t)$). If the data has a logic value of 0, it will be modulated by the quadrature carrier signal with a 180-degree phase shift, which is $-\cos(\omega t)$. In practice, a signal value with logic 0 is replaced with -1V to achieve the 180-degree phase shift of the carrier signal. Ultimately, the modulated odd and even signals are combined using an op-amp summing circuit to create the OQPSK signal. The differences between QPSK and OQPSK can be seen in Figure 2. This phase shifting is done to avoid simultaneous changes in pairs of bits, which can occur in QPSK. Due to the timing alignment of $S_{\text{Odd}}t$ and $S_{\text{Even}}(t)$ in QPSK, phase changes occur only once every two clocks, every two bits, or one symbol. The phase change can reach a maximum of 180 degrees if there are simultaneous changes in $S_{\text{Odd}}t$ and $S_{\text{Even}}(t)$. In contrast, in OQPSK modulation, bit changes occur every single clock because the changes in $S_{\text{Odd}}t$ and $S_{\text{Even}}(t)$ are balanced.

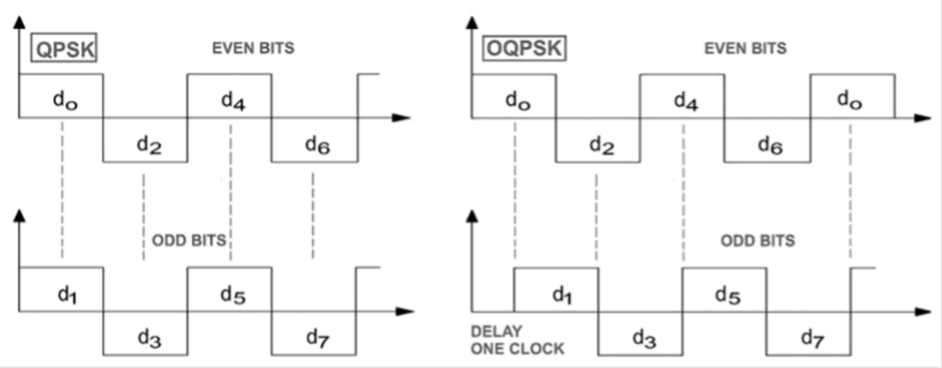

Figure 2: OQPSK The difference between the sequence of even and odd data in QPSK and OQPSK.

Therefore, in OQPSK, the maximum carrier phase change is limited to 90 degrees because only one-bit change (half a symbol) can occur at a time. This limitation helps avoid a 180-degree phase change, preventing the signal envelope from dropping to zero and reducing the likelihood of nonlinear amplification generating high-frequency side lobes. As a result, OQPSK can potentially achieve lower spectral occupancy compared to QPSK. However, the signal spectrum of OQPSK is identical to that of QPSK because both signals occupy the same bandwidth.

The differences in phase transitions or bit changes between QPSK and OQPSK are illustrated in Figure 3. The arrows in the figure show the direction of bit transitions. In QPSK, the symbol/bit ’00’ can change to ’01,’ ’10,’ or ’11,’ whereas in OQPSK, the symbol/bit ’00’ can only change to ’10’ or ’01,’ and vice versa. In QPSK, a pair of bits can

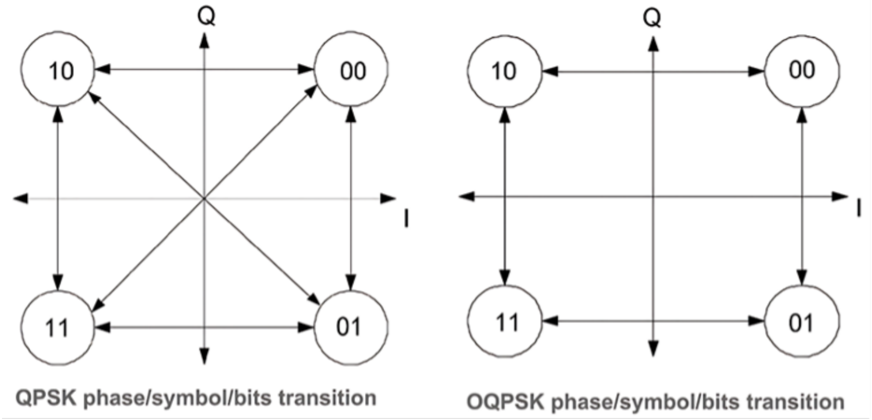

Figure 3: Difference in phase transitions/symbol/bits between QPSK and OQPSK.

change simultaneously, leading to transitions such as from ′00′ to ′11′ or from ′10′ to ′01.′ These transitions can result in a 180-degree phase shift, which can create sharp angles that may complicate data recovery at the receiver. In contrast, such abrupt phase shifts are not possible in OQPSK, as it limits phase transitions to 90 degrees to prevent sharp angles and ensure smoother data transmission.

3 Circuit Design

This section will discuss the circuits designed to generate the clock, carrier wave, odd and even dividers, and the final circuit, which is composed of a summation and two multiplexers.

3.1 Bit rate

In OQPSK modulation, the clock frequency of the modulator is directly related to the bit rate of the modulated signal. The bit rate is defined as the number of data bits transmitted per second (bps). In OQPSK, the bit rate determines how quickly digital information is converted into a modulated analog signal, while the clock frequency refers to the rate at which the signal is transmitted or received. In digital modulation such as OQPSK, the clock frequency typically denotes the sampling frequency of the digital signal being modulated.

In OQPSK modulation, each symbol consists of two modulated data bits. Consequently, the symbol frequency is half the bit rate because each symbol carries two bits of information. Therefore, the relationship between the clock frequency (which, in this context, often refers to the symbol frequency) and the bit rate is given by:

$$\text{Clock frequency} = \frac{\text{Bit Rate } (Rb)}{2} \tag{4}$$

To design a bit rate of 20 Mbps, the required clock frequency for the OQPSK modulator is 10 MHz.

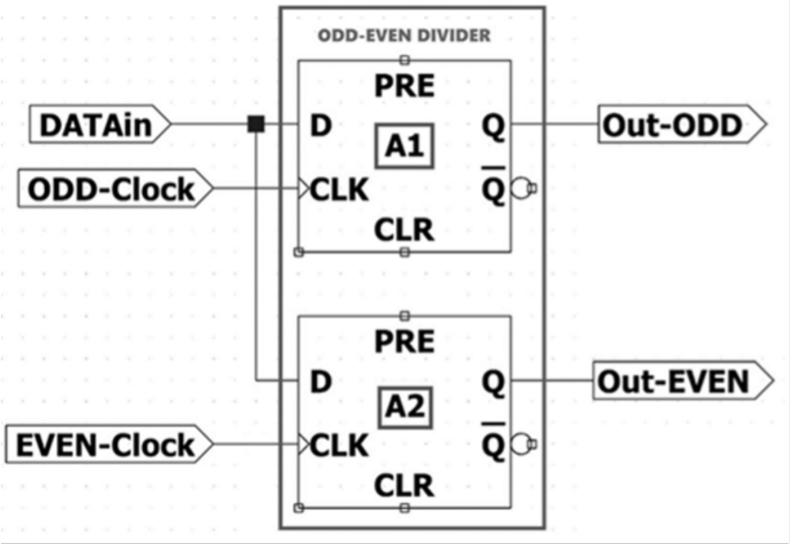

Figure 4: Odd-even data bits splitter.

3.2 Odd-Even data bits splitter

The circuit shown in Figure 4 splits incoming serial data into two streams: even and odd data bits. It uses two D flip-flops to separate the data into even and odd categories. An inverter is placed on the clock line for the odd data stream to delay the odd clock by one clock cycle. The clock operates at a frequency of 10 MHz, which is half the period of the symbol/data frequency, i.e., 5 MHz.

3.3 Carrier Signal

Figure 5 shows the circuit block that generates carrier signals in the form of sine, cosine, negative sine, and negative cosine waves. This circuit uses two D flip-flops, with a delayed clock for the second D flip-flop (even clock), to produce quadrature square wave signals that are phase-shifted by 90 degrees. These square wave signals are then processed through a circuit block that converts them into differential sinusoidal signals, with each one phase-shifted by 180 degrees. Using two square-to-sine converters, the circuit generates four sinusoidal signals, each phase-shifted by 90 degrees, to match the transitions of the OQPSK signal.

There are several methods to generate quadrature signals. One method involves using an oscillator to produce quadrature sinusoidal signals. Another method converts square wave signals into sinusoidal waves, followed by phase-shifting to generate four signals differing by 90 degrees. A third method involves a pair of quadrature sinusoidal signals (0 degrees and 90 degrees) that are modulated analogically with even and odd data using a balanced modulator, resulting in four carrier signals phase-shifted by 90 degrees. The fourth method, described in this paper, uses two square wave signals phase-shifted by 90 degrees, which are then converted into differential sinusoidal waves. The conversion of

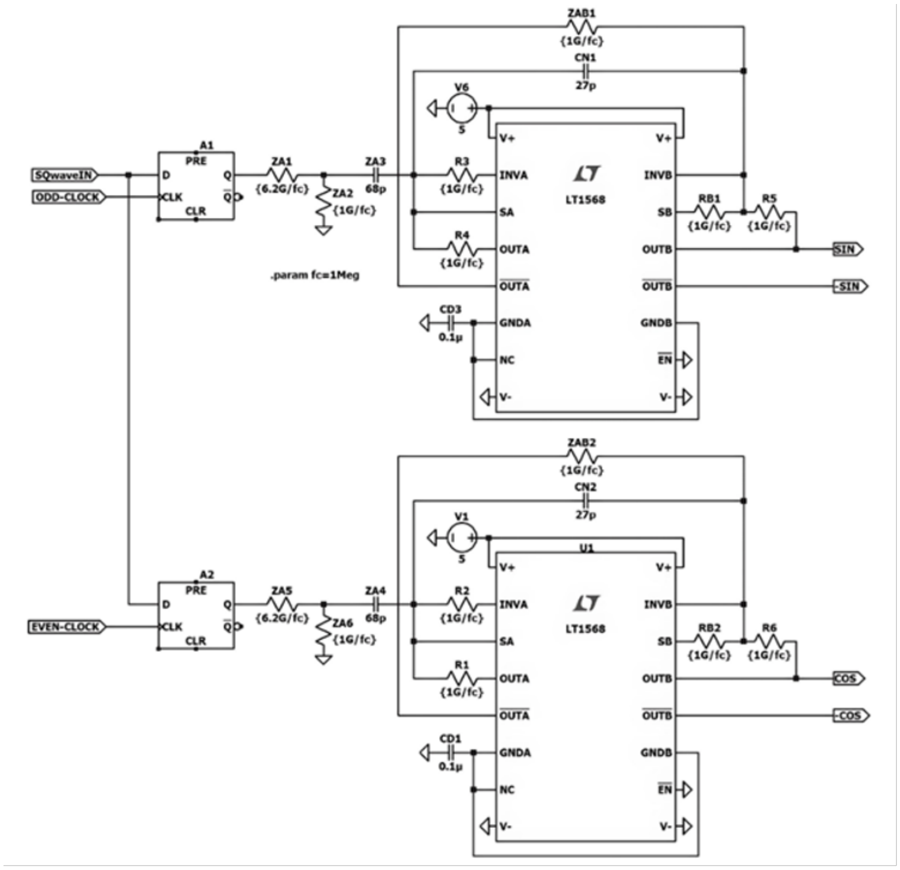

Figure 5: Sine – Cosine signal generator.

square wave signals into sinusoidal waves is done using a commercially available IC filter, specifically the LT1568 in this paper.

3.4 Multiplexer and Summing Amplifier

Figure 6 illustrates the schematic for the multiplexer and summing amplifier circuit block. The data and carrier signals are combined using a multiplexer IC, which selects the appropriate carrier signals (sine, cosine, negative sine, and negative cosine waves) based on the data input (even or odd). When the even data is 1, the multiplexer selects the 0-degree carrier ($\sin(\omega t)$); for a value of 0, it outputs the 180-degree signal ($-\sin(\omega t)$). Similarly, for odd data, a value of 1 selects the 90-degree signal ($\cos(\omega t)$), while a value of 0 results in the 270-degree signal ($-\cos(\omega t)$). The summing operational amplifier (OpAmp) in the final circuit block is essential for combining the in-phase and quadrature signals to generate the OQPSK-modulated signal.

Figure 7 illustrates the pin configuration and truth table for the CD503 IC in option A mode (with input data connected to pin 11). According to the figure, when $A = 0$, the carrier signal applied to pin ax (pin 12) is routed to pin ax0ay (pin 14) as the output. Conversely, when $A = 1$, the carrier signal applied to pin ay (pin 13) is routed to pin ax0ay (pin 14) as the output. When the input data is connected to pin B (pin 10), the input pins are bx (pin 2) and by (pin 1), and the output is directed to pin bx0by (pin 15). This paper omits the use of a balanced modulator, opting instead for a multiplexer to simplify implementation on an FPGA.

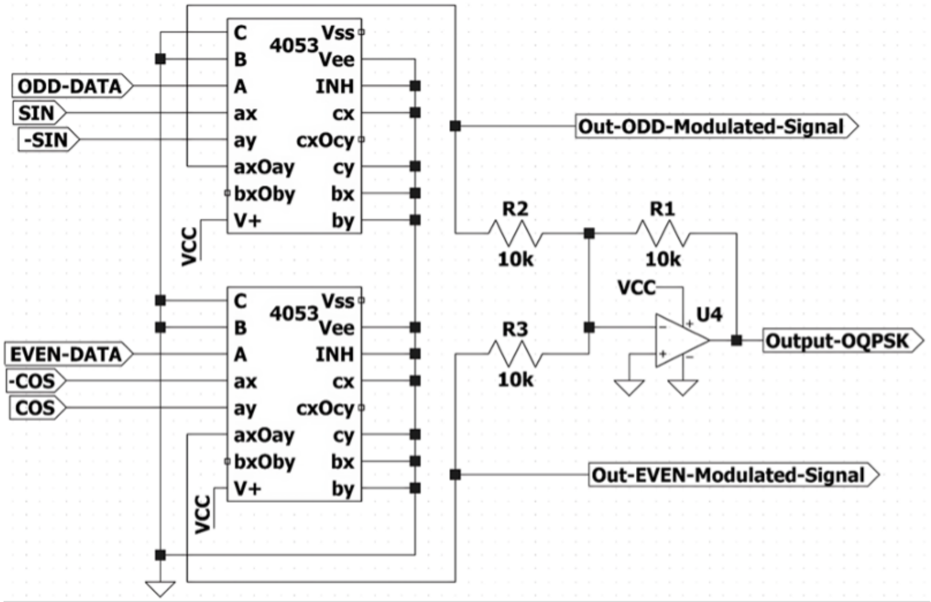

Figure 6: Multiplexer and summing amplifier.

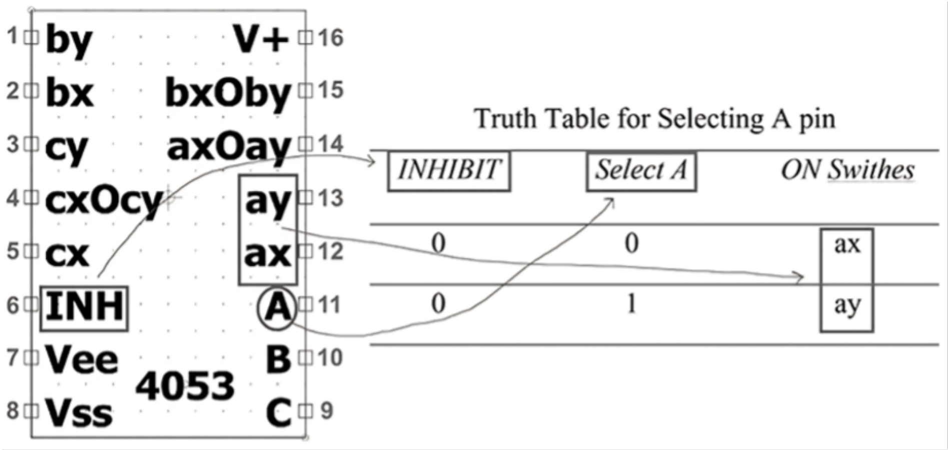

Figure 7: Pin configuration and truth table of CD5043 Multiplexer.

4 Results

The simulation results of the designed circuits will be reported in this section.

4.1 The simulation results of the even-odd divider

The output signals from the even-odd data bit splitter circuit are shown in Figure 8 and 9. Figure 8 illustrates that the circuit is functioning correctly by dividing the data bit sequence 11001111 (D0-D7) into even data bits 1011 and odd data bits 1011. Similarly, when the data bit sequence is changed to 11001011, the even data bits become 1011, and the odd data bits become 1001. This demonstrates that the data bit splitter circuit is operating properly. The even and odd data bits operate at half the frequency of the original data, specifically 2.5 MHz.

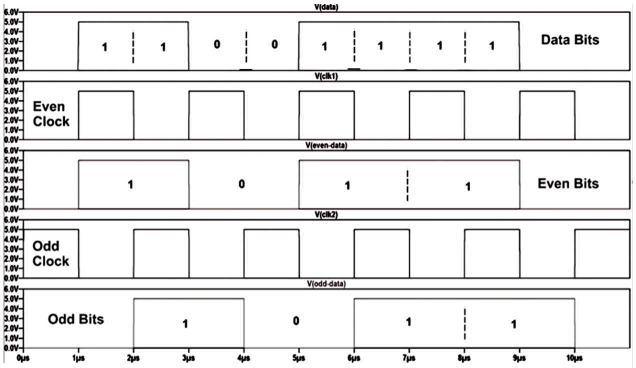

Figure 8: Odd and even data bits splitter output using input 11001111.

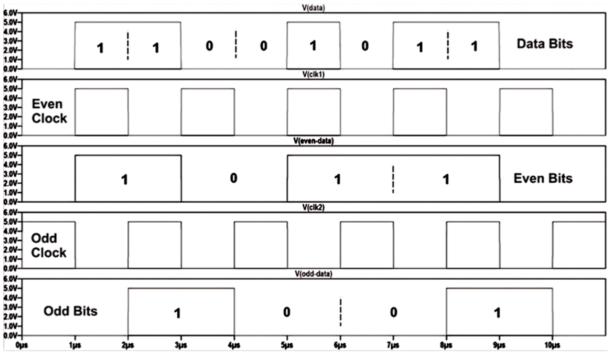

Figure 9: Odd and even data bits splitter output using input 11001011.

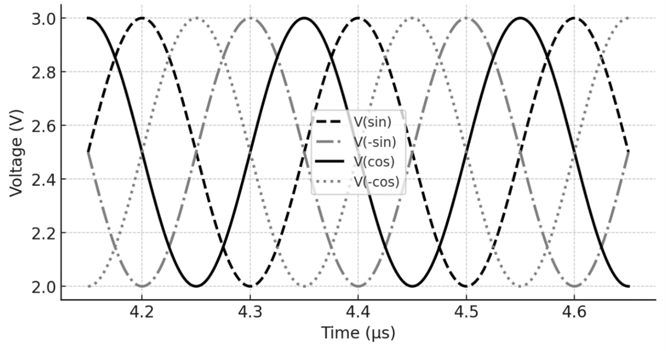

Figure 10: Carrier signal waveform.

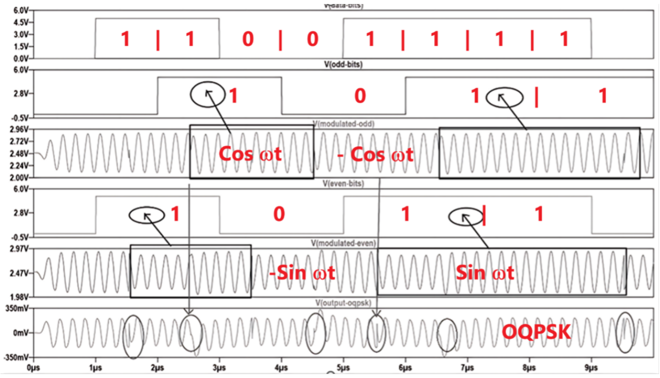

Figure 11: OQPSK modulator output waveform.

4.2 The Simulation results of the carrier waveform block

Figure 10 displays the output signals from the carrier wave block, showing that each signal is phase-shifted by 90 degrees as intended. This phase shift results in the formation of sine, negative sine, cosine, and negative cosine signals. The carrier wave operates at a frequency of 5 MHz.

4.3 The simulation results of Multiplexer and summing amplifier block

Figure 11 displays the results of modulating the even and odd data signals using the initial data pattern 11001111. Notably, there is a 180-degree phase difference between logical zero and one, similar to the outcome seen in BPSK modulation. After modulation, the two signals are combined using an Op-Amp summing amplifier, resulting in the anticipated OQPSK-modulated signal. From top to bottom, Figure 11 illustrates the transmitted data, the splitter's odd and even data streams, the odd and even modulated signals, and the final OQPSK-modulated waveform. The image clearly shows that a change in the bit from 1 to 0 or from 0 to 1 results in a 180-degree phase shift. Additionally, it illustrates the summation of the odd and even bit signals, which produces the modulated OQPSK signal.

5 Discussion

5.1 Key Findings and Overview

This study presents the design and simulation of an OQPSK (Offset Quadrature Phase Shift Keying) modulator, demonstrating successful implementation of a system capable of transmitting data at 20 Mbps. The implementation of even-odd data splitting to keep carrier phase changes within 90 degrees and the use of multiplexers to create modulated signals are important components of the design that successfully prevent the signal deterioration frequently observed in QPSK systems that experience 180-degree phase shifts. Through simulation, the accuracy and stability of the suggested OQPSK modulator were confirmed by using a 10 MHz clock frequency and a 5 MHz data bit frequency for carrier generation.

5.2 Interpretation of Findings and Theoretical Implications

By addressing phase continuity, the concept provides a workable solution to the drawbacks of QPSK modulation by reducing the likelihood of 180-degree changes, which can cause signal distortion. By incorporating a more straightforward hardware design that makes use of multiplexers, this study improves upon current modulation theory, specifically the expansion of Quadrature Phase Shift Keying (QPSK) to OQPSK. In addition to lowering circuit complexity, this method increases the modulator's adaptability to various applications, including FPGA-based communication systems.

The paper advances modulation theory by showing how signal quality can be improved by using multiplexers and avoiding simultaneous phase changes. In the context of communications systems, where preserving signal integrity under diverse transmission situations is essential, this discovery is critical. As the theory is refined, the work highlights how signal modulation techniques can develop to strike a balance between simplicity and efficiency, especially when used in hardware design.

5.3 Comparison with Existing Literature

The results are consistent with earlier research showing how effective OQPSK is in minimizing signal envelope fluctuations and spectrum regrowth. Mu et al. (2024), for example, investigated pulse shaping filters in OQPSK to preserve a constant envelope for improved spectral efficiency. This is supplemented by the current study, which provides a reduced design that improves signal quality in a similar way but focuses on hardware optimization instead of spectral approaches.

In comparison to other designs, such as those using balanced modulators, this study introduces a notable simplification using multiplexers. The impact of this simplification is significant because it reduces the complexity and cost of the modulator without compromising the modulation performance. This positions the study as a contribution to the body of work that seeks to make high-speed digital communication systems more accessible and scalable.

However, unlike studies that push the boundaries of high data rates beyond 20 Mbps (e.g., studies exploring higher-order modulations like 64-QAM or OFDM), this work maintains a relatively modest data rate of 20 Mbps, which is well-suited for applications requiring reliability over extreme speed. This divergence from high-speed, high-complexity designs highlights the study's focus on robustness and simplicity in environments that prioritize signal integrity over data throughput.

5.4 Limitations

While the design and simulation results are promising, the study is limited by its scope, which is confined to simulation without hardware validation. Real-world factors such as noise, component mismatches, and environmental variability could affect the performance of the modulator in practical implementations. Additionally, the design is currently optimized for a specific data rate and modulation scheme, limiting its applicability in systems requiring higher flexibility or adaptability to varying communication standards.

The simplification brought about by the multiplexer-based method is another drawback. When trying to expand the system to greater data rates or more sophisticated modulation methods, including adaptive modulation approaches that dynamically modify the modulation order based on channel circumstances, this approach may pose scaling issues even though it simplifies the hardware.

5.5 Future Research

To verify the resilience of the OQPSK modulator, future studies should concentrate on both hardware implementation and real-world testing. A better grasp of the modulator's limitations may be obtained by examining its performance under various noise levels, interference, and multipath effects. Confirming the modulator's practical usefulness will require implementing it on platforms like FPGA, ASIC, or other hardware systems. Optimizing the modulator for low-power consumption is a crucial research direction that will make it more appropriate for power-sensitive applications such as Internet of Things systems and mobile devices. Involving experiment with various materials or architectures in can be explore to boost efficiency.

Future studies could further enhance the modulator's capabilities while preserving spectrum efficiency and satisfying the needs of modern communication by examining higher data rates and scalability. Using more complex modulation techniques, including adaptive modulation, could potentially increase its use in high-speed communication networks.

Furthermore, the modulator should incorporate error correcting methods to enhance data integrity and dependability, particularly in high-interference settings. Investigating how error correction might improve signal performance under these noisy circumstances could greatly support the deployment of the system in practice.

6 Conclusion

In summary, the design and modelling of a multiplexer-based 20 Mbps OQPSK modulator were reported in this study. The modulator uses quadrature square waves that are transformed into sinusoidal signals to efficiently distinguish and modulate even and odd data bits. By producing OQPSK signals with the anticipated phase shifts and data rates, simulation results verified that the system achieves its goals. The study emphasizes the potential of OQPSK modulation in contemporary communication systems because of its benefits over QPSK in terms of phase change and lower spectrum occupancy. By providing a framework for additional research into scalable, high-efficiency modulation techniques, the modulator design's success advances the field of communication technology. Future research efforts will concentrate on real-world issues including power efficiency, noise resilience, and higher data rate applications, which require more work.

Acknowledgments

The authors would like to thank Universitas Gadjah Mada's Department of Electrical Engineering and Information Technology for funding this work in 2024 through departmental grant monies (Penelitian Hibah Departemen, PHD).

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List of Abbreviations

A : Amplitude of the carrier signal
AM : Amplitude Modulation
ASK : Amplitude Shift Keying
Bps : Bits Per Second
BPSK : Binary Phase Shift Keying
CDMA : Code Division Multiple Access
CD503 : A specific integrated circuit used in multiplexing
$\cos\omega t$: Cosine wave carrier signal (representing quadrature signal)
D0-D7 : Data bits (representing serial data stream)
D flip-flop : D-type Flip-Flop
FM : Frequency Modulation
FPGA : Field-Programmable Gate Array
FSK : Frequency Shift Keying
Gbps : Gigabits Per Second
IC : Integrated Circuit
Kbps : Kilobits Per Second
LT1568 : A specific integrated circuit used for filtering
Mbps : Megabits Per Second
MHz : Megahertz
Op-Amp : Operational Amplifier
OQPSK : Offset Quadrature Phase Shift Keying
PM : Phase Modulation
PSK : Phase Shift Keying
QPSK : Quadrature Phase Shift Keying
$\sin\omega t$: Sine wave carrier signal (representing in-phase signal)
VLSI : Very-Large-Scale Integration