Non-Multiplier QPSK Modulator Using Simple Trigonometric Function

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Abstract: The quadrature phase-shift keying (QPSK) is one of the digital modulation techniques using four different phases in order to represent the data bits. Building the QPSK modulating circuit is somewhat complex because of the need of two local frequencies whose phases need to be exactly 90 degree differences. A new technique, which uses just basic Op-Amp circuits in order to create the amplifier circuit and the summing amplifier circuit and also simplifies the QPSK modulation system, is proposed. The designed amplifier circuit is controlled by data bit. Consequently, phase shifting of QPSK signal is regulated by data bit. The data bits are applied so as to control the designed amplifier circuit's gain which also regulated the QPSK signal's phases. From this reason, the proposed QPSK modulating circuit is therefore less complicate than the conventional one. Both theoretical and experimental results thus confirm that the propose technique can be realized in real world application.

Keywords — QPSK, Phase shift keying, Trigonometry

1. Introduction

At present, digital modulation plays a vital role in communications system such as satellite communications [1], television broadcastings or even mobile communications. This is because digital modulation provides high security, immunes to noise interference and requires less bandwidth. Among various types of digital modulations, e.g. amplitude shift keying (ASK), frequency shift keying (FSK), phase shift keying (PSK), or quadrature amplitude modulation (QAM), QPSK modulation is one of popular digital modulation techniques. The QPSK modulation is phase shift keying whose phase of the PSK signal can be one of the four assigned phases, i.e. $\pi/4$, $3\pi/4$, $-3\pi/4$ and $-\pi/4$ radian.

In general, the QPSK modulation is expressed in a mathematical form as written in (1).

$$s(t) = A\cos(\omega_c t - \theta_n) \tag{1}$$

where A : the amplitude of QPSK signal,
ω_c : the angular frequency of QPSK signal,
θ_n : the phase shift of QPSK signal. (n is positive integer.)

Eq. (1) is rewritten by

$$s(t) = a_n\cos(\omega_c t) + b_n\sin(\omega_c t) \tag{2}$$

where a_n is $A\cos\theta_n$, and b_n is $A\sin\theta_n$. Both a_n and b_n are voltage accordance with data bit. As QPSK modulation has 4 symbols (2 bits per symbol) includes 00, 01, 10 and 11 for 4 different phases. In order to generate QPSK, data bit need to be split and converted by using bit splitters and digital to analog converter to generate a_n and b_n. The block diagram of QPSK modulator is shown in Fig. 1.

In literature review, there are many types of modulation techniques for example the QPSK modulation using FPGA board [6-7]. There are limitations of QPSK signal from FPGA board such as frequency of carrier, program for

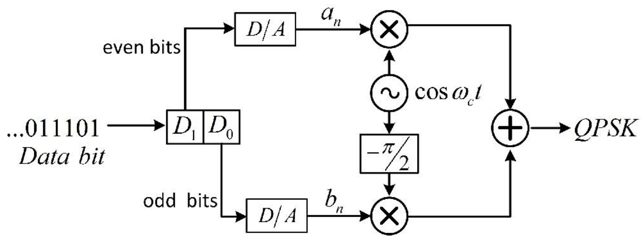


Figure 1. General block diagram of QPSK modulator

design on FPGA board. However, the limitations will be changed by FPGA technology. At the present time, QPSK modulation using FPGA board is more expensive than other methods. In 2007, the QPSK modulating circuit, based on controlling the gain of phase locked loop (PLL) to shift the phase along with external circuits, is proposed [8]. In this study, it is found that when the frequency of carrier or the reference frequency used for PLL is changed, the gain of PLL must always change according to the relations. In [9], the QPSK modulating circuit constructed by using basic electronic components, for example D-Flip flop, inverter, op-amp and BJTs, is proposed. To obtain a QPSK modulator using the aforementioned technique, two BPSK modulators are needed. However, these two modulators are made of four BASK modulators. Hence, the QPSK modulator of [9] is somewhat complicated to construct in practical.

In this paper, it is focused on developing the circuit to provide less complicate QPSK modulator by applying sum/difference angle trigonometric principle. With this simple principle, the accurate phase shifting is obtained and no phase error in the proposed technique. In addition, a digital-to-analog converter is not required resulting in the minimized circuit structure. Moreover, the proposed circuit furnishes hassle-free parameters-adjusting whilst most of phase shift techniques do require parameter-adjusting. The principle of the proposed circuit and its experimental results will be given in the following sections.

2. Principle

In this section, a brief note about the QPSK signal is reviewed mathematically. The QPSK signal is assumed that the number of phase shifts is limited to only four states. The carrier undergoes four changes in phase i.e. $\pi/4$, $3\pi/4$, $-3\pi/4$ and $-\pi/4$ radian. From (1), it can be generally shown as

$$s(t) = \cos\left(\omega_c t + (2m-1)\frac{\pi}{4}\right) \tag{3}$$

where m is positive integer. By using trigonometry property, cos(A+B)=cosAcosB-sinAsinB, eq (3) is rewritten as follows.

$$s(t)=\cos(\omega_c t)\cos\left(\frac{m\pi}{2}-\frac{\pi}{4}\right)-\sin(\omega_c t)\sin\left(\frac{m\pi}{2}-\frac{\pi}{4}\right) \quad (4)$$

Eq. (4) is recast its form to (5).

$$\begin{aligned} s(t)=\cos\left(\frac{\pi}{4}\right)&\left[\cos(\omega_c t)\cos\left(\frac{m\pi}{2}\right)-\sin(\omega_c t)\sin\left(\frac{m\pi}{2}\right)\right] \\ +\sin\left(\frac{\pi}{4}\right)&\left[\cos(\omega_c t)\sin\left(\frac{m\pi}{2}\right)+\sin(\omega_c t)\cos\left(\frac{m\pi}{2}\right)\right] \end{aligned} \quad (5)$$

From (5), let $s_1(t)=\cos(\omega_c t)\cos\left(\frac{m\pi}{2}\right)$, $s_2(t)=\sin(\omega_c t)\sin\left(\frac{m\pi}{2}\right)$, $s_3(t)=\cos(\omega_c t)\sin\left(\frac{m\pi}{2}\right)$ and $s_4(t)=\sin(\omega_c t)\cos\left(\frac{m\pi}{2}\right)$, respectively, hence

$$s(t)=\cos\left(\frac{\pi}{4}\right)\left[s_1(t)-s_2(t)\right]+\sin\left(\frac{\pi}{4}\right)\left[s_3(t)+s_4(t)\right] \quad (6)$$

From (6), the value of m is 1, 2, 3 and 4, respectively. Eq. (6) can rewrite in Table 1. where is phase shifted of QPSK signal. From Table 1, the equation shows that four QPSK signal. The QPSK signal is phase shifted to $\pi/4$ and $-\pi/4$ be generated by using summation of $\cos(\omega_c t)$ and $\pm\sin(\omega_c t)$. In addition, the output of summation can shift phase to π radian by using gain of the amplifier to be -1. The proposed block diagram of QPSK modulating is shown in Fig. 2.

From Fig. 2, the gain of the amplifier can be either 1 or -1 according to the sign of the fed data. Together with summing circuit, the proposed QPSK is accomplished. In the next section, controlling gain of input data and fabricated QPSK modulation circuit will be described.

3. The Propose QPSK Modulator

3.1 Amplifier Circuit

Based on the proposed phase shift scheme described in previous section, the summation and difference of cosine and sine function as give in Table 1 have an effect on the phase output. To apply the proposed phase shift structure for the application of QPSK modulator, the circuit is depicted in Fig. 3. The gain of amplifier circuit is controlled by analog switch, the analog switch is controlled by data bit (open if data bit = 0 and close if data bit = 1). From the operation of the designed amplifier circuit can separate work is 2 modes. The working mode is shown in Fig. 4.

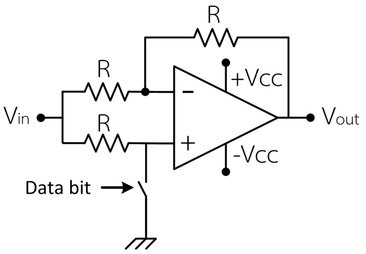
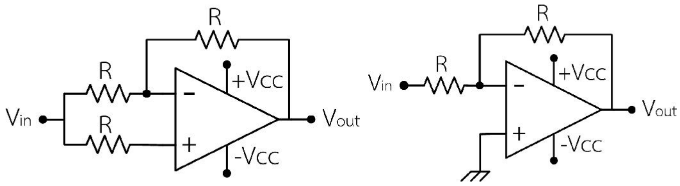


Figure 3. The designed amplifier circuit



(a) open switch (b) close switch

Figure 4. The operation of the designed amplifier circuit

In Fig. 4(a), when the logic of data bit is "0" (LOW), the status of switch is "open", a gain of amplifier is 1. Because of the equal voltage at non-inverting input and inverting input of Op-Amp, then the voltage input (V_{in}) is equal to the voltage output (V_{out}). In Fig. 4(b), the logic of data bit is "1" (HIGH), the status of switch is "close", this circuit is inverting amplifier whose gain is -1.

The proposed technique can control a gain of amplifier by logic of data bit. The QPSK modulator circuit shown in Fig. 5 is composed the amplifier circuit and the summing amplifier circuit. The circuit shown inside the dash line is the amplifier which can adjust its gain by data bit.

TABLE 1 Equation of QPSK signal

m	θ	$s_1(t)$	$s_2(t)$	$s_3(t)$	$s_4(t)$	$s(t)$
1	$\pi/4$	0	$\sin(\omega_c t)$	$\cos(\omega_c t)$	0	$\frac{1}{\sqrt{2}}\left[\cos(\omega_c t)-\sin(\omega_c t)\right]$
2	$3\pi/4$	$-\cos(\omega_c t)$	0	0	$-\sin(\omega_c t)$	$-\frac{1}{\sqrt{2}}\left[\cos(\omega_c t)+\sin(\omega_c t)\right]$
3	$-3\pi/4$	0	$-\sin(\omega_c t)$	$-\cos(\omega_c t)$	0	$-\frac{1}{\sqrt{2}}\left[\cos(\omega_c t)-\sin(\omega_c t)\right]$
4	$-\pi/4$	$\cos(\omega_c t)$	0	0	$\sin(\omega_c t)$	$\frac{1}{\sqrt{2}}\left[\cos(\omega_c t)+\sin(\omega_c t)\right]$

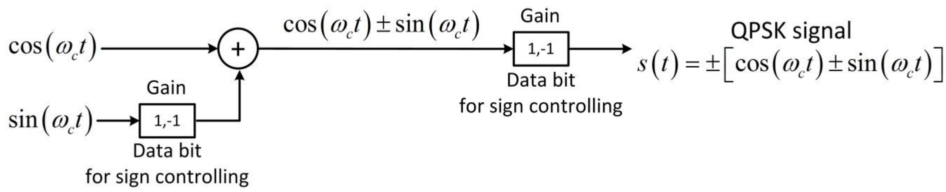


Figure 2. The proposed block diagram of QPSK modulator

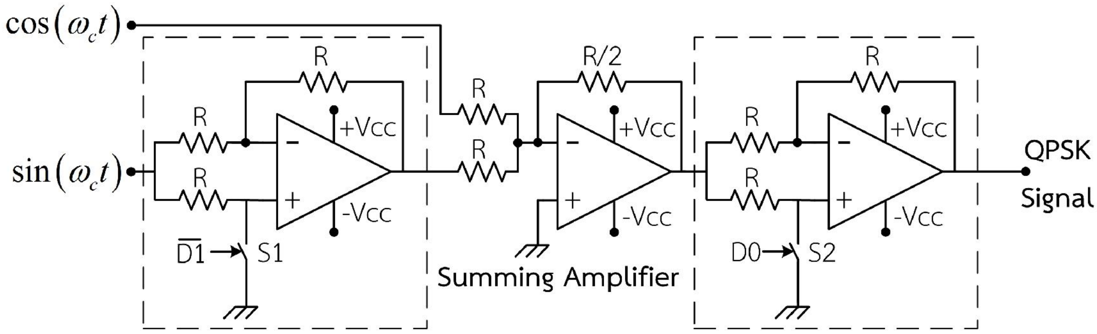


Figure 5. The proposed QPSK modulator circuit

In addition, the design of the modulation codes is given in Table 2. As shown in Table 2, the switch S1 is controlled by the inverse of D1 to obtain an even bit. Likewise, the switch S2 is controlled by D0 to acquire an odd bit.

TABLE 2 Modulation Code Design

θ	$\overline{D1}$	$D1$	$D0$	S1	S2
$\pi/4$	0	1	0	OFF	OFF
$3\pi/4$	1	0	1	ON	ON
$-3\pi/4$	0	1	1	OFF	ON
$-\pi/4$	1	0	0	ON	OFF

4. Simulation and Experimental Results

To confirm the proposed phase shifter by the summation and difference of cosine and sine function. The proposed modulator is examined by using computer simulation and laboratory experiment.

4.1 Simulation Results

The program MATLAB (Simulink) is selected for simulation. The QPSK modulator designed by the proposed technique in MATLAB is depicted in Fig. 6. The carriers are cosine and sine waves whose amplitude is 3.5 volt and frequency is 23 kHz. The data bit input D0 and D1 are square waves with amplitude 5 volt TTL, and frequency 1.15 kHz and 2.3 kHz, respectively. The simulation results of QPSK modulator as shown in Fig. 7(a) and 7(b) are the QPSK signal in time domain and the lissajous curve, respectively.

4.2 Experimental Results

In the experiment, the proposed QPSK modulator is implemented as depicted in Fig. 5. IC LM353N is used for the designed amplifier and summing amplifier circuit as well as IC 74HCT4066 is employed for analog switch in the designed amplifier circuit. The experimental results are given in Fig. 8. The 4 phases of QPSK signal are illustrated in Fig. 8(a). Additionally, the lissajous curve of the QPSK modulating signal is given in Fig. 8(b).

5. Conclusion

This paper presents the circuit for QPSK modulator. The modulator can shift phase to $\pi/4$ and $-\pi/4$ radian by using the summation of $\cos(\omega_c t)$ and $\pm\sin(\omega_c t)$ function, respectively. From the generated phase output, shifting phase π radian to either $3\pi/4$ or $-3\pi/4$ radian is obtained by only adjusting the gain of the designed amplifier circuit to be -1. In the proposed technique, phase can be shifted accurately to the designed value thus phase error does not exist. In addition, the proposed circuit furnishes hassle-free parameters-adjusting. The QPSK modulator circuit uses only Op-amp and analog switch, it is therefore less complicate than the conventional technique. The obtained results examined by using computer simulation and experiment are in accordant and can confirm the contribution of the proposed technique.

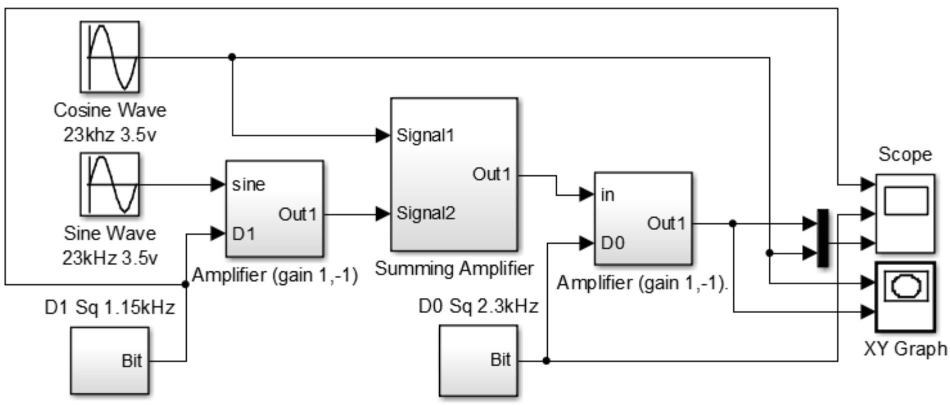
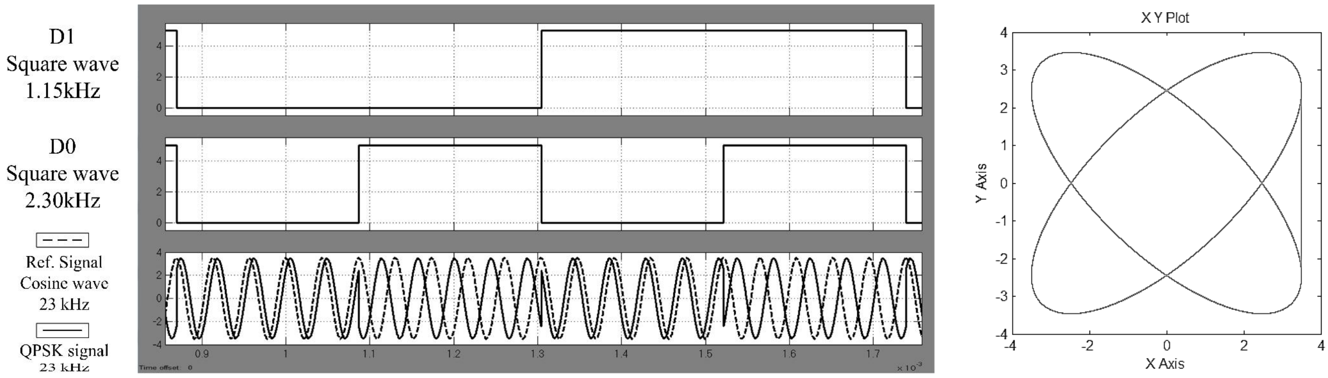


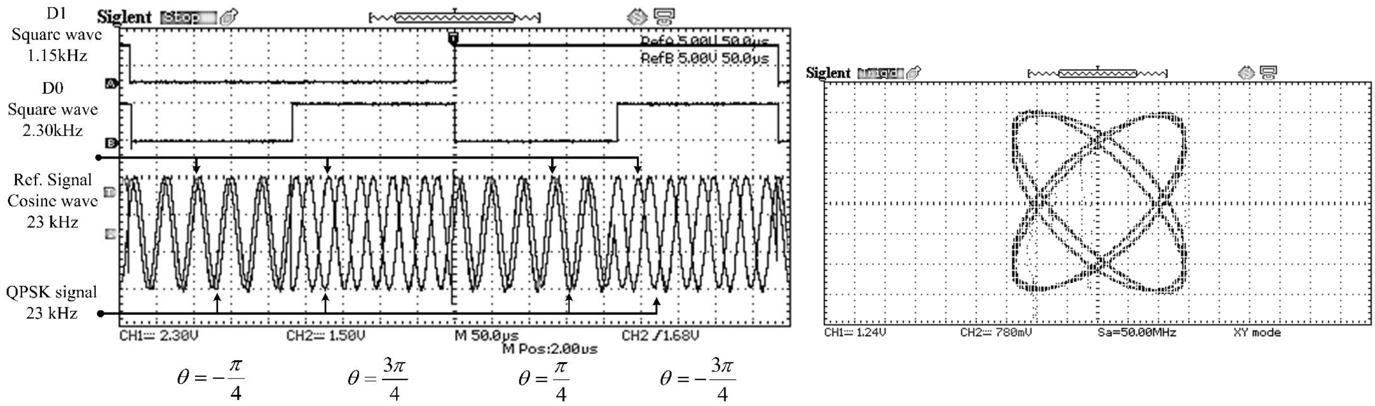
Figure 6. Block diagram of the QPSK modulator in computer simulation (MATLAB)



(a) The data bit signals : D1 (top), D0 (middle), the reference signal (cosine) and the QPSK signal (bottom)

(b) The lissajous curve of the QPSK modulation signal

Figure 7. The QPSK signal of the proposed QPSK modulator using computer simulation



(a) The data bit signals : D1 (top), D0 (middle), the reference signal (cosine) and the QPSK signal (bottom)

(b) The lissajous curve of the QPSK modulation signals

Figure 8. The QPSK signal of the proposed QPSK modulator using laboratory experiment

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