

## SIMULATION RESULTS

## 7.1 INTRODUCTION

In this chapter, the simulation results for the newly proposed circuits in chapter 4 using either single or two OTRA active elements are given. All the proposed circuits given in chapter 4 are designed using one or two OTRAs along with few passive components. All the proposed circuits are simulated for waveform generation by using the CMOS OTRA shown in Fig. 7.1. The CMOS OTRA shown in Fig. 7.1 is designed using Cadence 180 nm CMOS model parameters and simulated by using Spectre simulation model parameters. For simulation, the supply voltages  $\pm 1.8$  V are used for all the proposed circuits.

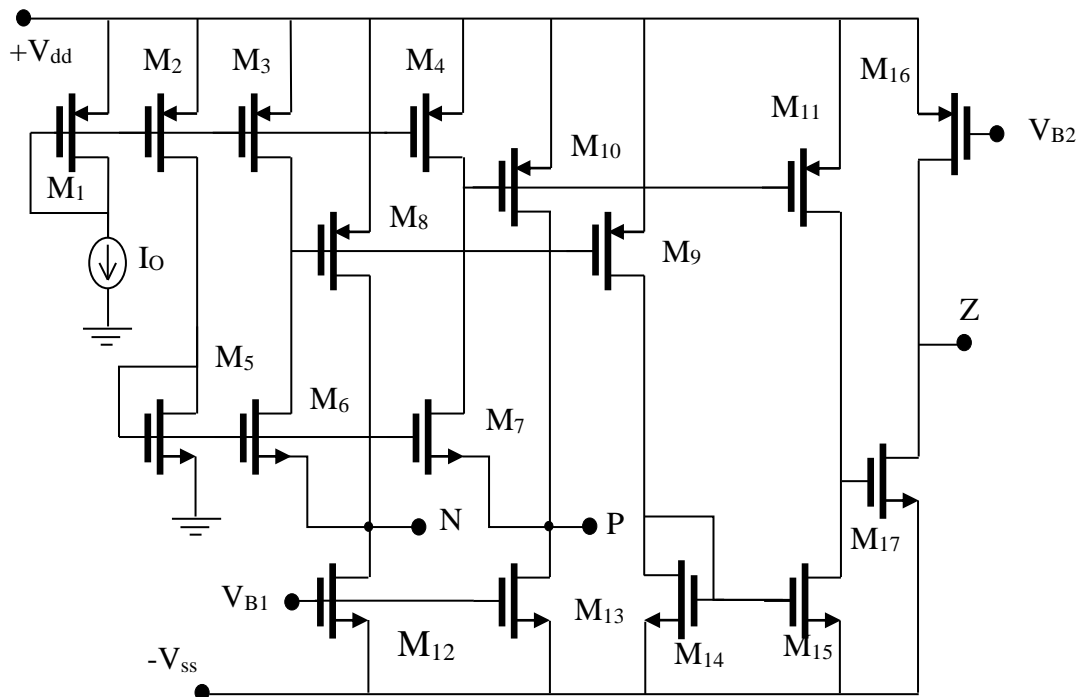


Fig. 7.1 CMOS implementation of the OTRA

The widths and lengths of transistors used for simulating the CMOS OTRA by Cadence gpdK 180nm are given in Table 7.1 and the bias current used during the simulation is  $I_0 = 80\mu\text{A}$ .

Table 7.1 Aspect ratios of CMOS OTRA shown in Fig. 7.1

Transistor	Width ( $\mu\text{m}$ )	Length (nm)
M <sub>1</sub> , M <sub>2</sub> , M <sub>3</sub> , M <sub>4</sub>	2	180
M <sub>5</sub> , M <sub>6</sub> , M <sub>7</sub>	2	180
M <sub>8</sub>	4.5	180
M <sub>9</sub>	9	180
M <sub>10</sub> , M <sub>11</sub>	40	180
M <sub>12</sub> , M <sub>13</sub>	40	180
M <sub>14</sub> , M <sub>15</sub>	33	180
M <sub>16</sub>	22	180
M <sub>17</sub>	12	180

## 7.2 GROUNDED RESISTANCE/CAPACITANCE SINUSOIDAL OSCILLATORS

### 7.2.1 SIMULATION RESULTS

The passive components for the newly proposed topologies shown in Fig. 4.3 and 4.4 are connected to the respective terminals of the CMOS OTRA shown in Fig. 7.1. All newly proposed circuits are simulated using Spectre simulation model parameters.

For the first proposed minimum component oscillator circuit shown in Fig. 4.3, the passive components  $R_1 = 10 \text{ k}\Omega$ ,  $R_3 = 1 \text{ k}\Omega$ ,  $C_2 = 100 \text{ pF}$  and  $C_4 = 1 \text{ nF}$  are connected for generating the oscillations. Fig. 7.2 represents the simulated output waveform of the first proposed minimum component oscillator circuit with a frequency of 161.5 kHz.

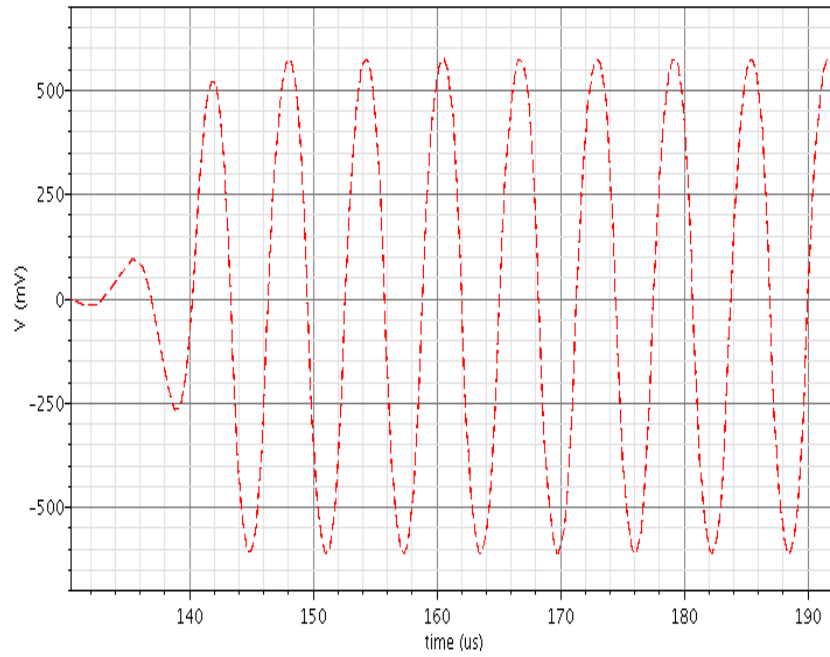


Fig. 7.2 Simulated output waveform of the proposed circuit in Fig. 4.3

The percentage of error between the simulated and theoretical oscillation frequency is 1.5 %. The frequency spectrum of the proposed circuit shown in Fig. 4.3 is shown in Fig. 7.3.

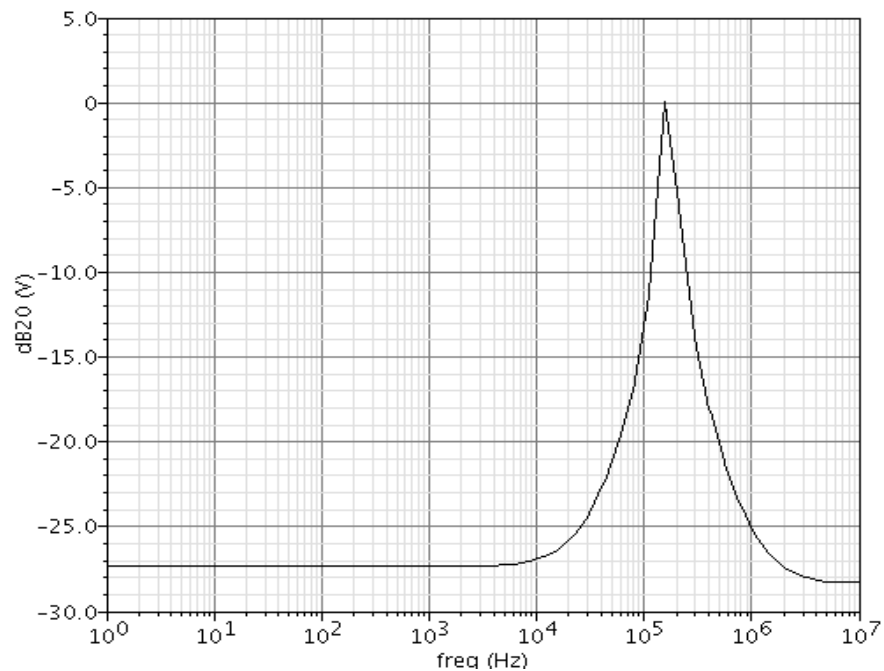


Fig. 7.3 Frequency spectrum of the proposed circuit in Fig. 4.3

The following passive components  $R_3 = 60 \Omega$ ,  $R_5 = 1 \text{ k}\Omega$ ,  $R_7 = 300 \Omega$ ,  $C_2 = 10 \text{ nF}$  and  $C_4 = 100 \text{ nF}$  are used to simulate the proposed circuit shown in Fig. 4.4 (a). Figure 7.4 represent the output waveform of the proposed oscillator circuit with a frequency of 21.8 kHz. The percentage of error between the simulated and theoretical oscillation frequency is 2.8 %.

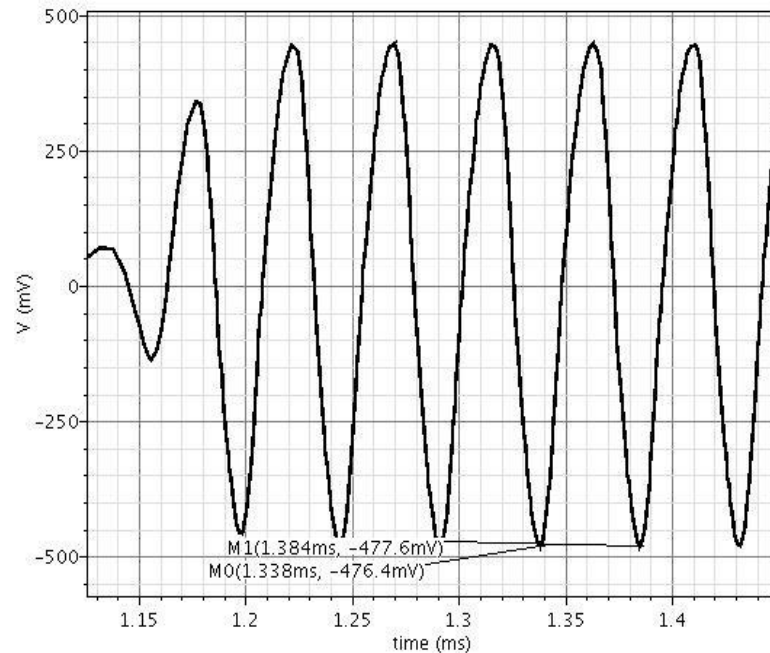


Fig. 7.4 Simulated output waveform of the proposed circuit in Fig. 4.4 (a)

The proposed circuit in Fig. 4.4 (b) is connected with the passive components  $C_1 = 100 \text{ pF}$ ,  $C_4 = 100 \text{ pF}$ ,  $C_7 = 100 \text{ pF}$ ,  $R_3 = 150 \Omega$ ,  $R_5 = 500 \Omega$  for waveform generation. The simulated output waveform of the oscillator circuit shown in Fig. 4.4 (b) is shown in Fig. 7.5. The simulated oscillation frequency for the oscillator circuit shown in Fig. 4.4 (b) is 5.3 MHz which is close to the theoretically calculated frequency of 5.78 MHz. The following passive components are chosen for generating the oscillations in the proposed circuit shown in Fig. 4.4 (c),  $R_1 = 1 \text{ k}\Omega$ ,  $R_3 = 150 \Omega$ ,  $R_7 = 15 \Omega$ ,  $C_5 = 10 \text{ pF}$  and  $C_6 = 100 \text{ pF}$ . The simulated output waveform for the proposed circuit shown in Fig. 4.4 (c) is shown in Fig. 7.6. The oscillation frequency of the waveform shown in Fig. 7.6 is at 12.9 MHz. The simulated output waveform of the proposed circuit shown in Fig. 4.4 (d) is presented in Fig. 7.7, which is obtained for the passive components  $R_2 = 500 \Omega$ ,  $R_3 = 12 \text{ k}\Omega$ ,  $R_5 = 400 \Omega$ ,  $R_7 = 2 \text{ k}\Omega$ ,  $C_4 = 100 \text{ pF}$  and  $C_6 = 10 \text{ pF}$ . The simulated oscillation frequency of the proposed circuit shown in Fig. 4.4 (d) is 2.9 MHz.

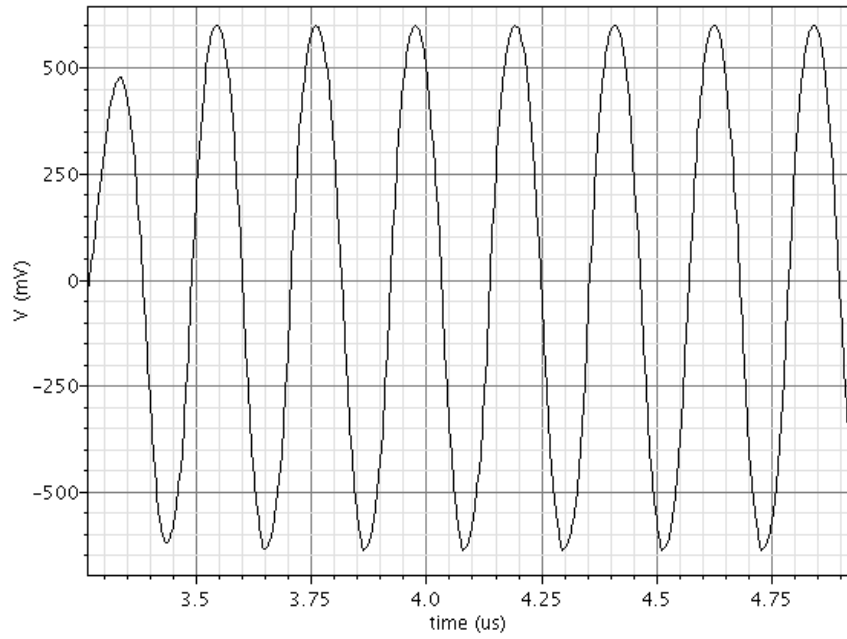


Fig. 7.5 Simulated output waveform of the proposed circuit in Fig. 4.4 (b)

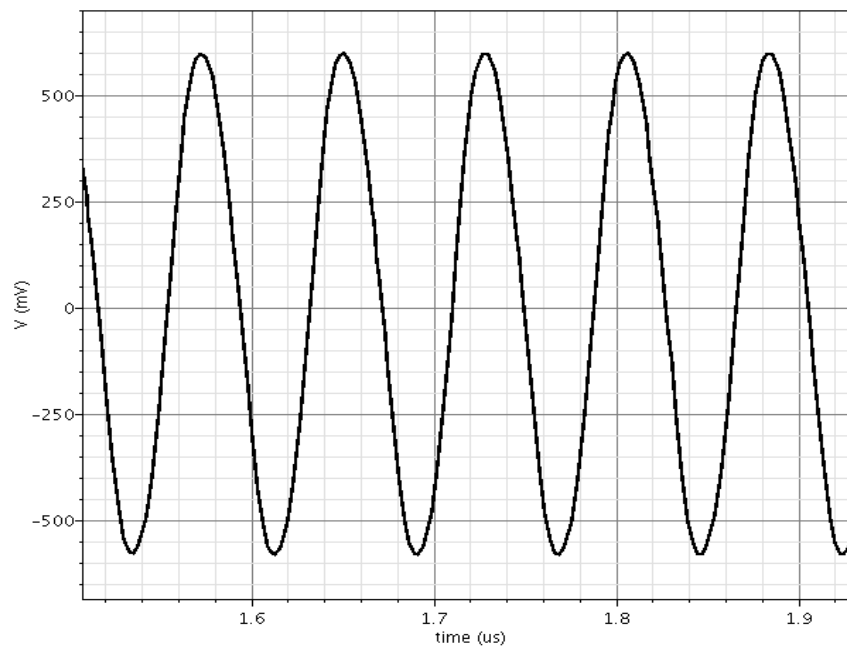


Fig. 7.6 Simulated output waveform of the proposed circuit in Fig. 4.4 (c)

The variation of oscillation frequency with respect to the passive component connected to the circuit is shown in Fig. 7.8 for the proposed circuit in Fig. 4.4 (d). For this figure, the passive components values chosen to be  $C_4 = 100 \text{ pF}$ ,  $C_6 = 10 \text{ pF}$ ,  $R_2 = 500 \text{ }\Omega$ ,  $R_3 = 12 \text{ k}\Omega$ ,  $R_5 = 400 \text{ }\Omega$  and  $R_7$  is varied from  $1 \text{ k}\Omega$  to  $12 \text{ k}\Omega$ .

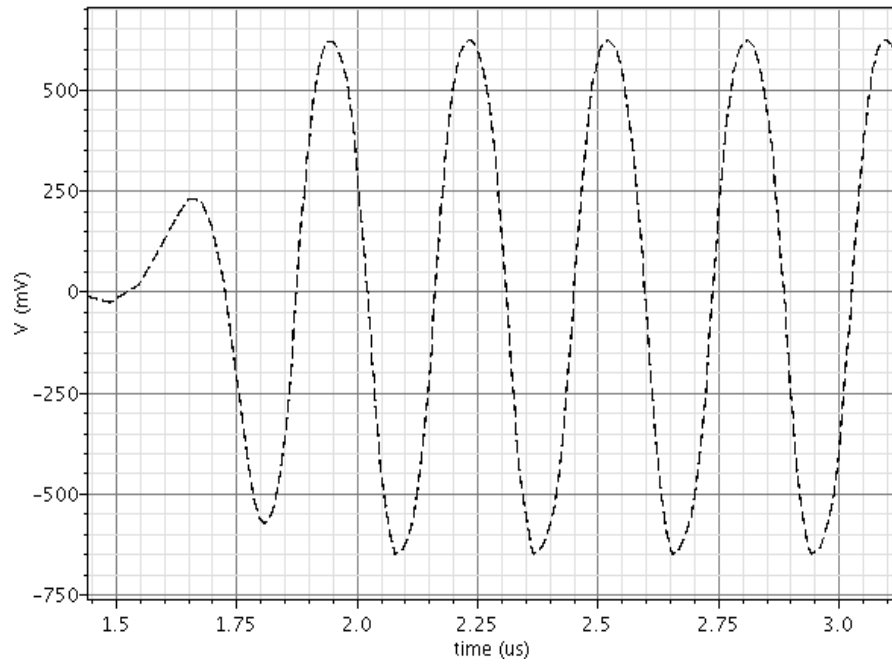


Fig. 7.7 Simulated output waveform of the proposed circuit in Fig. 4.4 (d)

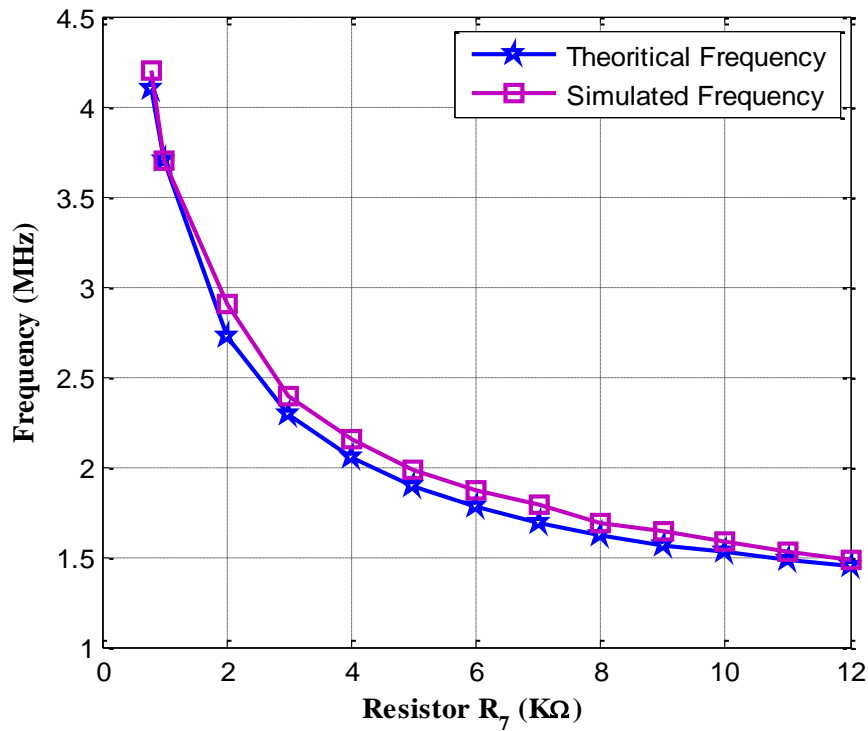


Fig. 7.8 Tunability of the proposed circuit in Fig. 4.4 (d) with respect to the resistor  $R_7$

The passive components  $R_2 = 1 \text{ k}\Omega$ ,  $R_4 = 60 \text{ }\Omega$ ,  $R_7 = 50 \text{ }\Omega$ ,  $C_6 = 100 \text{ pF}$  and  $C_3 = 10 \text{ pF}$  are used for producing the oscillations in the proposed circuit shown in Fig. 4.4 (e). The simulated output waveform of the proposed circuit is given in Fig. 7.9 with a frequency of 3.15 MHz, whereas the theoretical oscillation frequency was

calculated as 3.02 MHz. The variation of oscillation frequency for Fig. 4.4 (e) with respect to the passive component connected to the circuit is shown in Fig. 7.10. For this figure, the passive components values are  $C_3 = 10$  pF,  $C_6 = 100$  pF,  $R_2 = 1$  k $\Omega$ ,  $R_4 = 60$   $\Omega$  chosen and  $R_7$  is varied from 50  $\Omega$  to 10 k $\Omega$ .

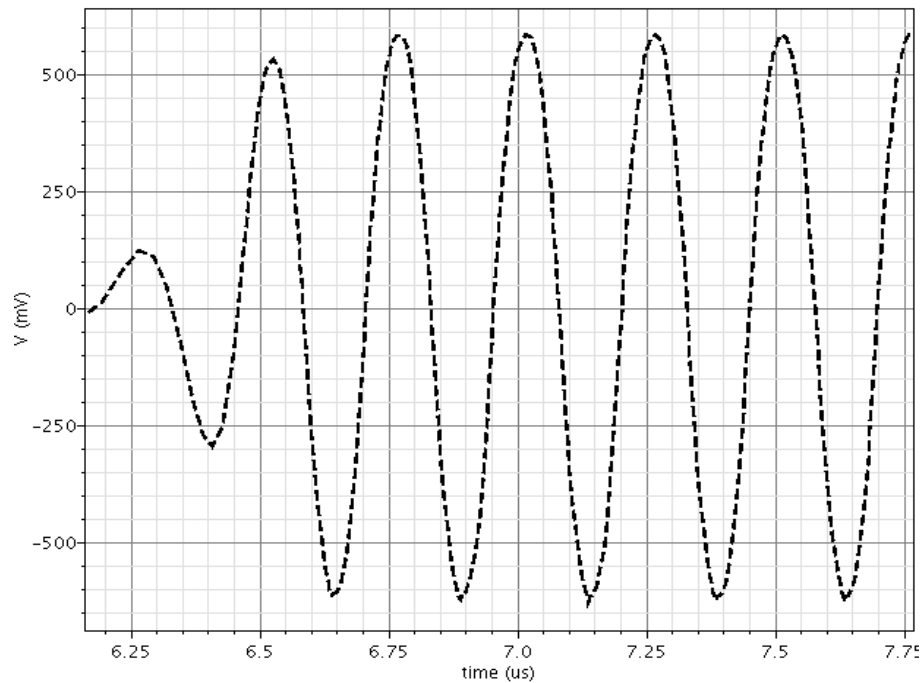


Fig. 7.9 Simulated output waveform of the proposed circuit in Fig. 4.4 (e)

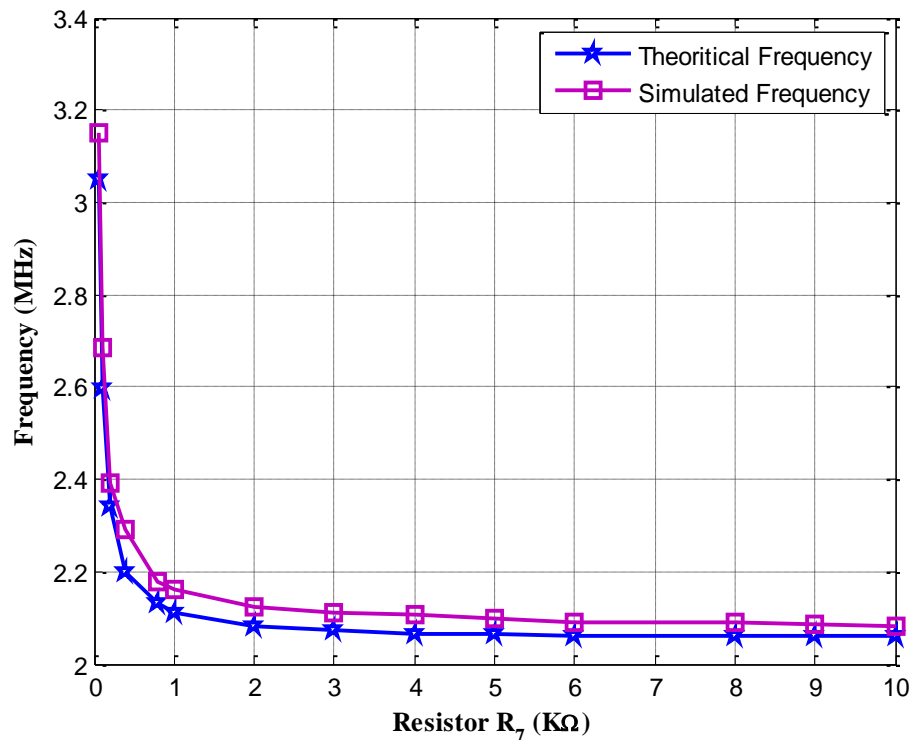


Fig. 7.10 Tunability of the proposed circuit in Fig. 4.4 (e) with respect to the resistor

$R_7$

For generating the oscillations of the proposed circuit shown in Fig. 4.4 (f), the passive component values are chosen to be  $R_3 = 100 \Omega$ ,  $R_5 = 1 \text{ k}\Omega$ ,  $R_6 = 7 \text{ k}\Omega$ ,  $R_7 = 200 \Omega$ ,  $C_2 = 100 \text{ pF}$  and  $C_4 = 10 \text{ pF}$ . Fig. 7.11 represents the simulated output waveform of the proposed circuit with a frequency of 1.3 MHz which is close to the theoretical result of 1.8 MHz. For generating the oscillations of the proposed circuit shown in Fig. 4.4 (g), the passive component values are chosen to be  $R_3 = 1 \text{ k}\Omega$ ,  $R_6 = 1 \text{ k}\Omega$ ,  $R_7 = 5 \text{ k}\Omega$ ,  $C_1 = 100 \text{ pF}$  and  $C_4 = 100 \text{ pF}$ . Fig. 7.12 represents the simulated output waveform of the proposed circuit with a frequency of 1.2 MHz which is close to the theoretical result of 1.5 MHz.

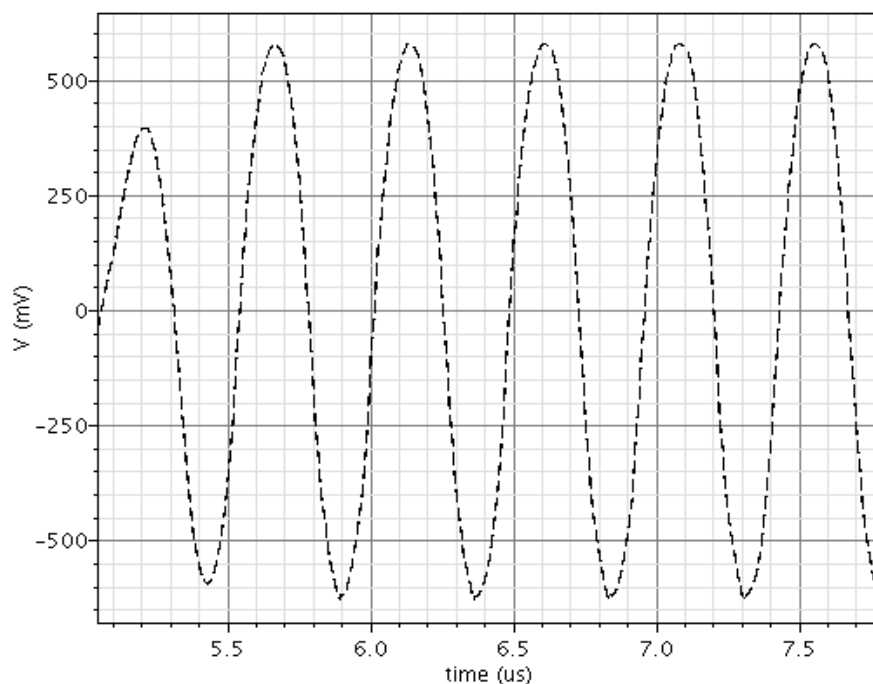


Fig. 7.11 Simulated output waveform of the proposed circuit in Fig. 4.4 (f)

The proposed circuit in Fig. 4.4(h) is constructed with passive components  $C_1 = 10 \text{ nF}$ ,  $C_3 = 100 \text{ nF}$ ,  $R_2 = 100 \Omega$ ,  $R_4 = 1 \text{ k}\Omega$ , and  $R_5 = 4 \text{ k}\Omega$  to generate the oscillations. The corresponding waveform at the output terminal of the proposed circuit is shown in Fig. 7.13. The simulated output waveform frequency for the proposed circuit is 14 kHz, which is very near to the theoretical value of 14.2 kHz.

The passive components values  $C_1 = 10 \text{ nF}$ ,  $C_2 = 100 \text{ nF}$ ,  $R_3 = 100 \Omega$ ,  $R_4 = 1 \text{ k}\Omega$  and  $R_5 = 5 \text{ k}\Omega$  are used to produce the oscillations in the proposed circuit shown in Fig. 4.4(i). The corresponding output waveform is shown in Fig. 7.14 at 16.5 kHz.



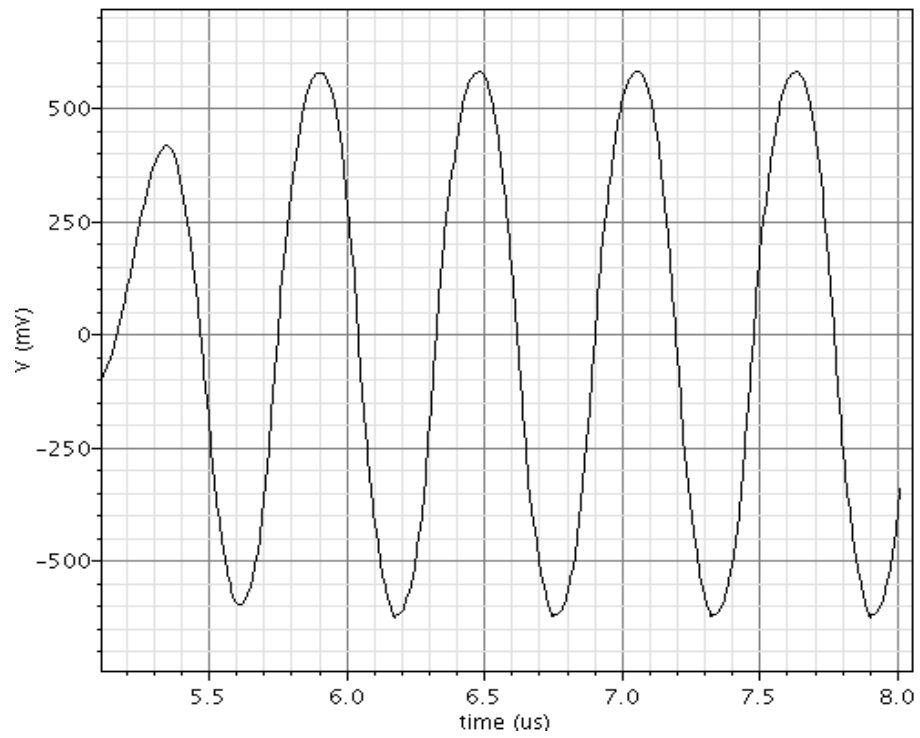


Fig. 7.12 Simulated output waveform of the proposed circuit in Fig. 4.4 (g)

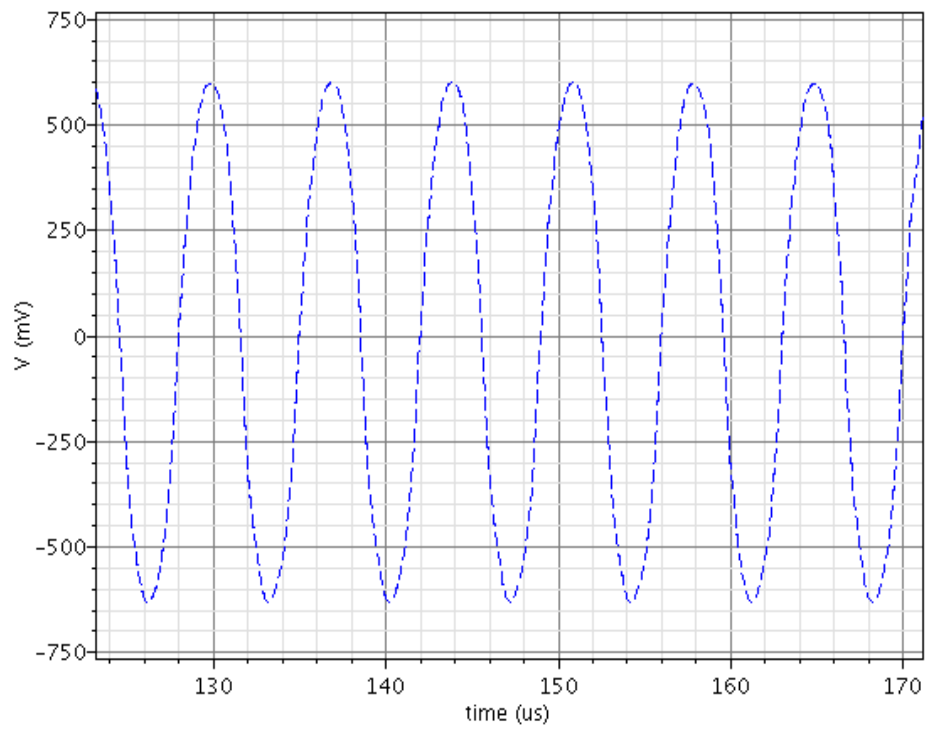


Fig. 7.13 Simulated output waveform of the proposed circuit in Fig. 4.4 (h)

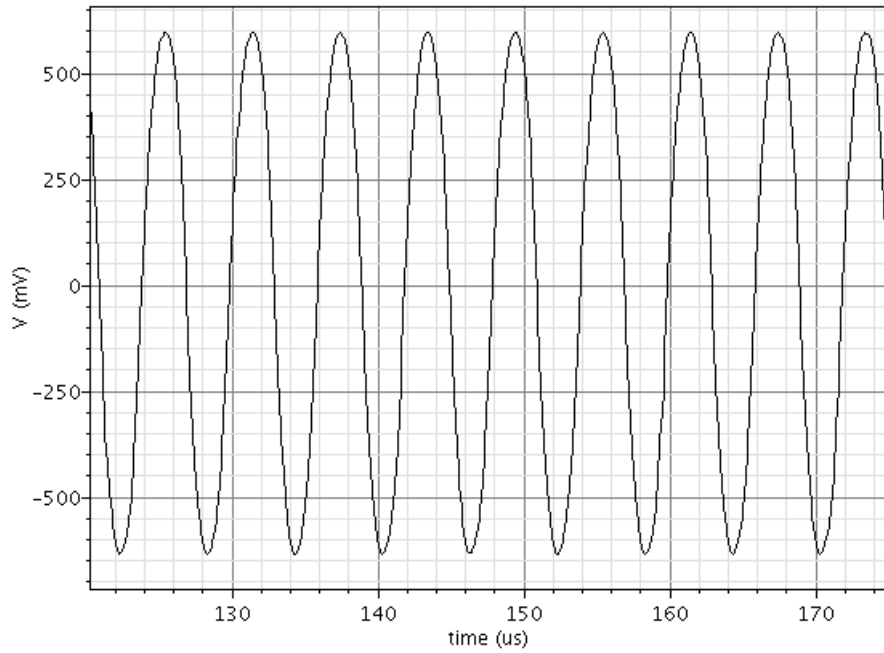


Fig. 7.14 Simulated output waveform of the proposed circuit in Fig. 4.4 (i)

The following passive component values are chosen to simulate the proposed circuit in Fig. 4.5 (a),  $R_1 = 100 \Omega$ ,  $R_2 = 1.2 \text{ k}\Omega$ ,  $R_3 = 600 \Omega$ ,  $R_4 = 5.5 \text{ k}\Omega$ ,  $C_2 = 100 \text{ pF}$  and  $C_3 = 100 \text{ pF}$ . Fig. 7.15 represents the simulated output waveform of the proposed circuit in Fig. 4.5 (a) with a frequency of 3.1 MHz.

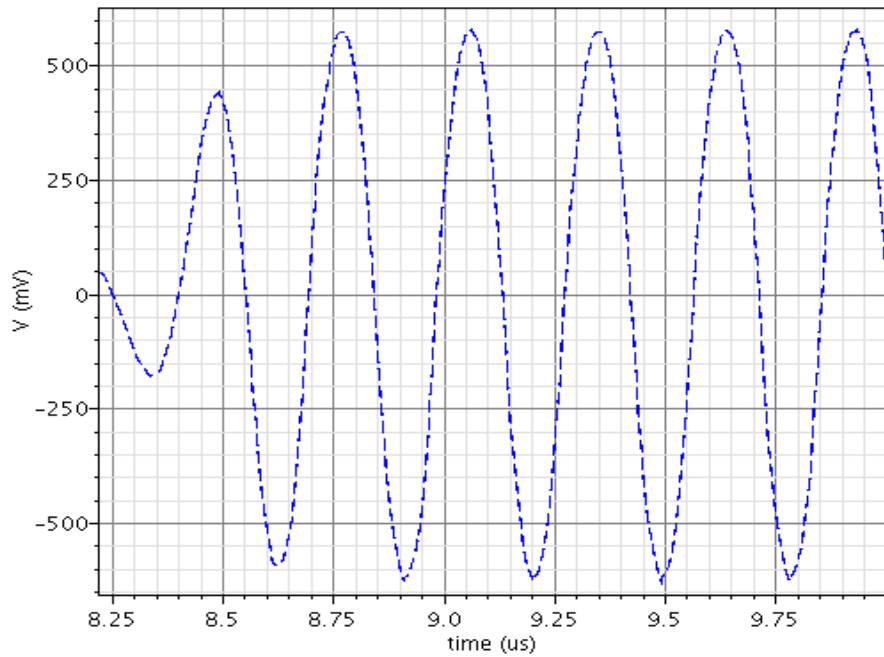


Fig. 7.15 Simulated output waveform of the proposed circuit in Fig. 4.5 (a)

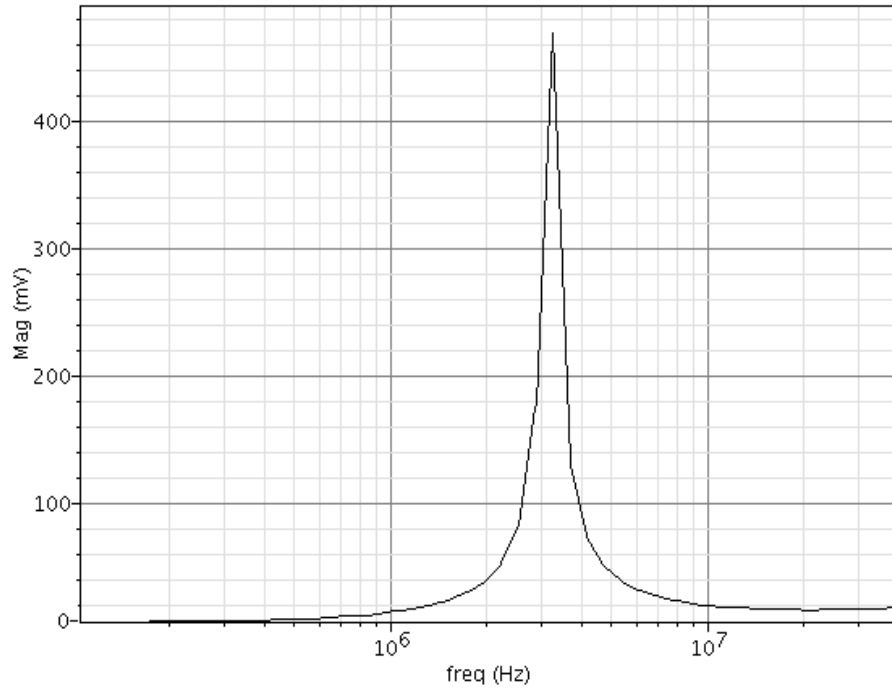


Fig. 7.16 Frequency spectrum of the proposed circuit in Fig. 4.5 (a)

The simulated frequency in Fig. 7.15 is very close to the theoretical frequency of 3.21 MHz. The frequency spectrum of the proposed circuit in Fig. 4.5 (a) is shown in Fig. 7.16.

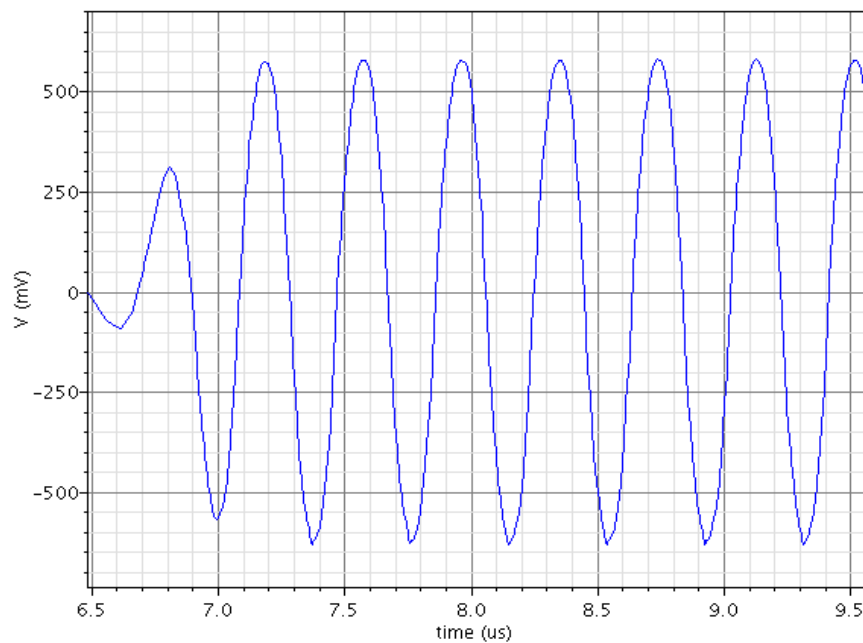


Fig. 7.17 Simulated output waveform of the proposed circuit in Fig. 4.5 (b)

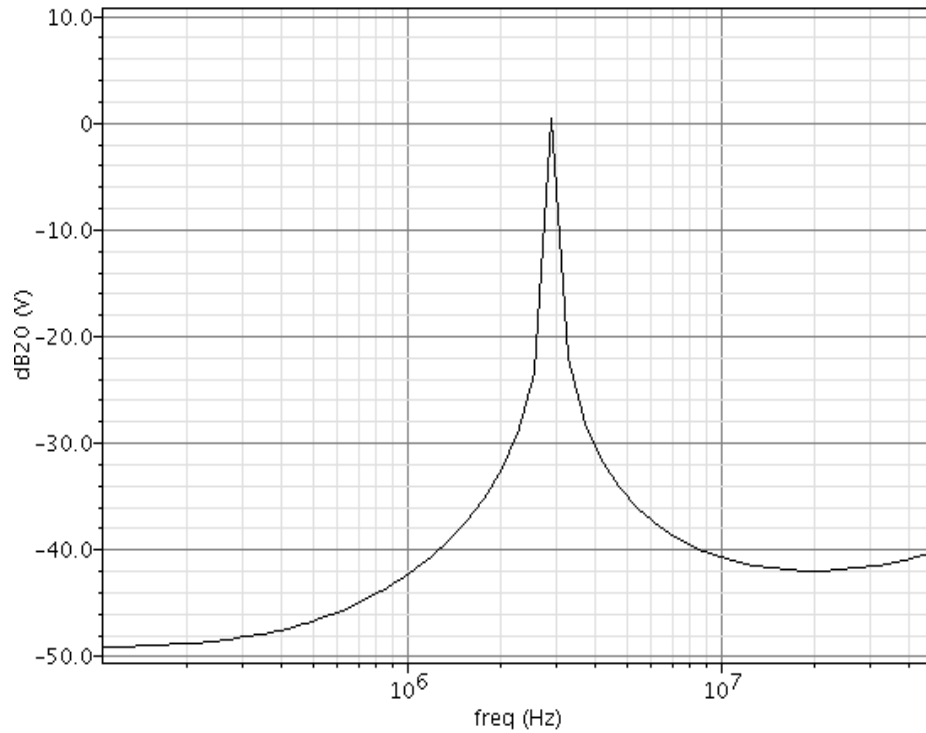


Fig. 7.18 Frequency spectrum of the proposed circuit in Fig. 4.5 (b)

The passive components values  $R_1 = 100 \Omega$ ,  $R_2 = 1.2 \text{ k}\Omega$ ,  $R_3 = 600 \Omega$ ,  $R_4 = 5.5 \text{ k}\Omega$ ,  $C_1 = 100 \text{ pF}$  and  $C_3 = 100 \text{ pF}$  are chosen to simulate the proposed circuit in Fig. 4.5 (b). Fig. 7.17 represents the simulated output waveform of the proposed circuit in Fig. 4.5 (b) with a frequency of 2.9 MHz. The simulated frequency in Fig. 7.17 is very close to the theoretical frequency of 3.21 MHz. The frequency spectrum for the proposed circuit in Fig. 4.5 (b) is shown in Fig. 7.18.

## 7.3 QUADRATURE SINUSOIDAL OSCILLATORS

### 7.3.1 SIMULATION RESULTS

The following passive components values are chosen to simulate the proposed circuit in Fig. 4.6,  $C_2 = 10 \text{ nF}$ ,  $C_4 = 100 \text{ nF}$ ,  $R_3 = 100 \Omega$ ,  $R_5 = 1 \text{ k}\Omega$ ,  $R_4 = 7 \text{ k}\Omega$  and  $R_1 = 200 \Omega$ . Fig. 7.19 represents the simulated output waveform of the proposed quadrature oscillator circuit with a frequency of 16.8 kHz. The variation of oscillation frequency with respect to the passive component  $C_2$  is shown in Fig. 7.20. For Fig. 7.20, the following passive component values are chosen  $R_1 = 200 \Omega$ ,  $R_3 = 100 \Omega$ ,  $R_4 = 7 \text{ k}\Omega$ ,  $R_5 = 1 \text{ k}\Omega$ ,  $C_4 = 100 \text{ nF}$  and  $C_2$  is varied from 1 nF to 10 nF.

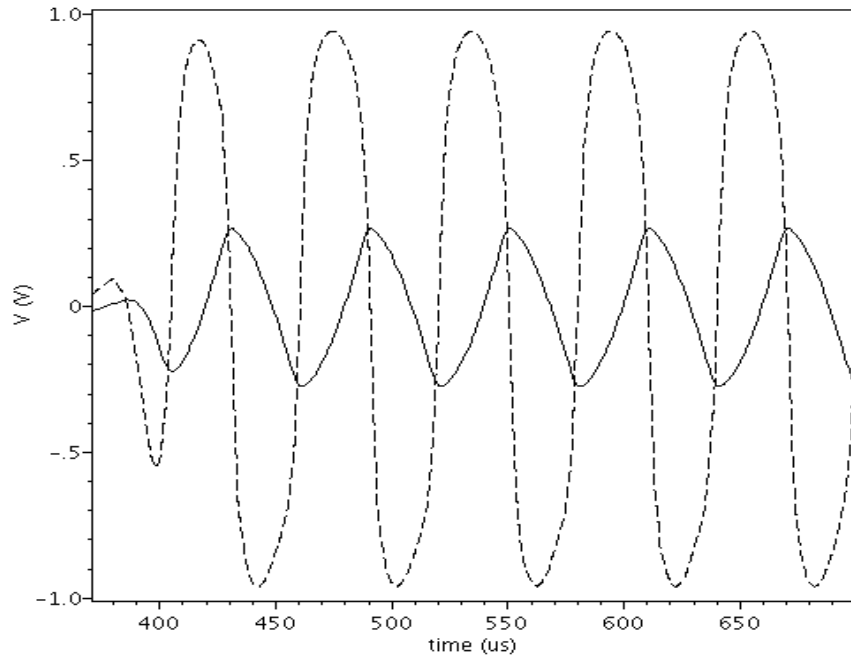


Fig. 7.19 Simulated output waveform of the proposed quadrature oscillator circuit in Fig. 4.6

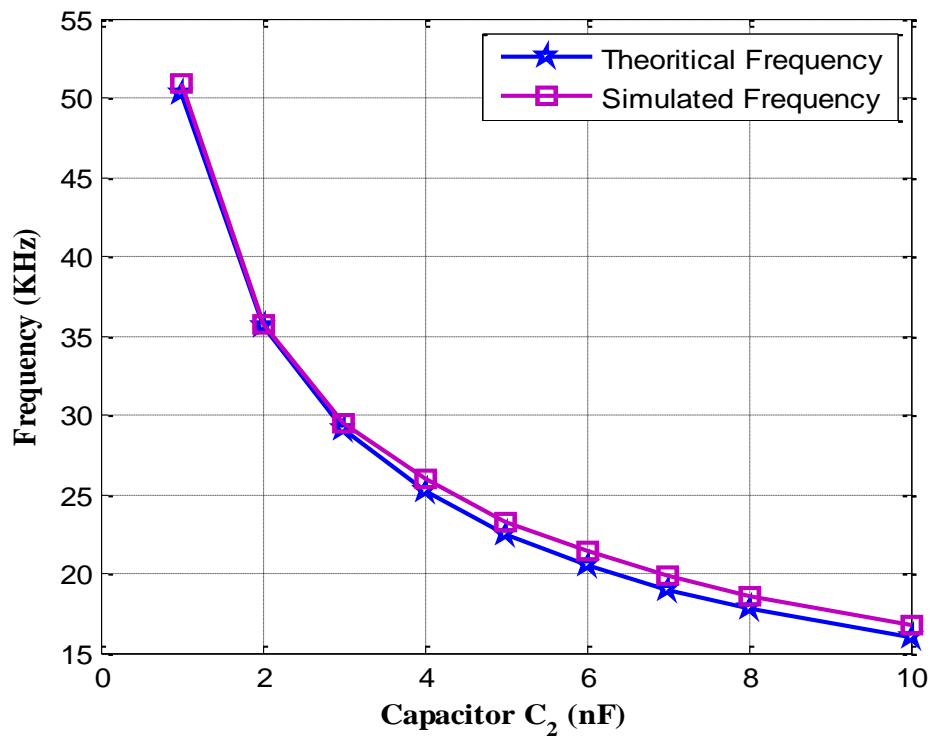


Fig. 7.20 Tunability of the proposed circuit in Fig. 4.6 with respect to the capacitor  $C_2$

The proposed circuit in Fig. 4.7 is connected with the passive components values,  $R_1 = 9 \text{ k}\Omega$ ,  $R_2 = 500 \Omega$ ,  $R_3 = 1 \text{ k}\Omega$ ,  $R_5 = 100 \Omega$ ,  $C_1 = 100 \text{ pF}$  and  $C_4 = 100 \text{ pF}$ . The simulated output waveform with a frequency of 2.4 MHz is shown in Fig. 7.21.

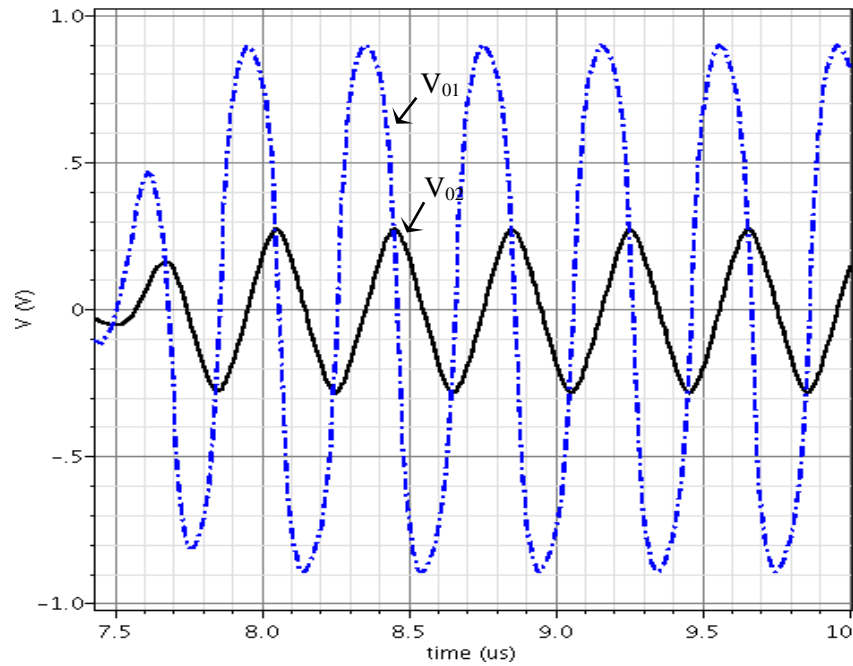


Fig. 7.21 Simulated output waveform of the proposed circuit in Fig. 4.7

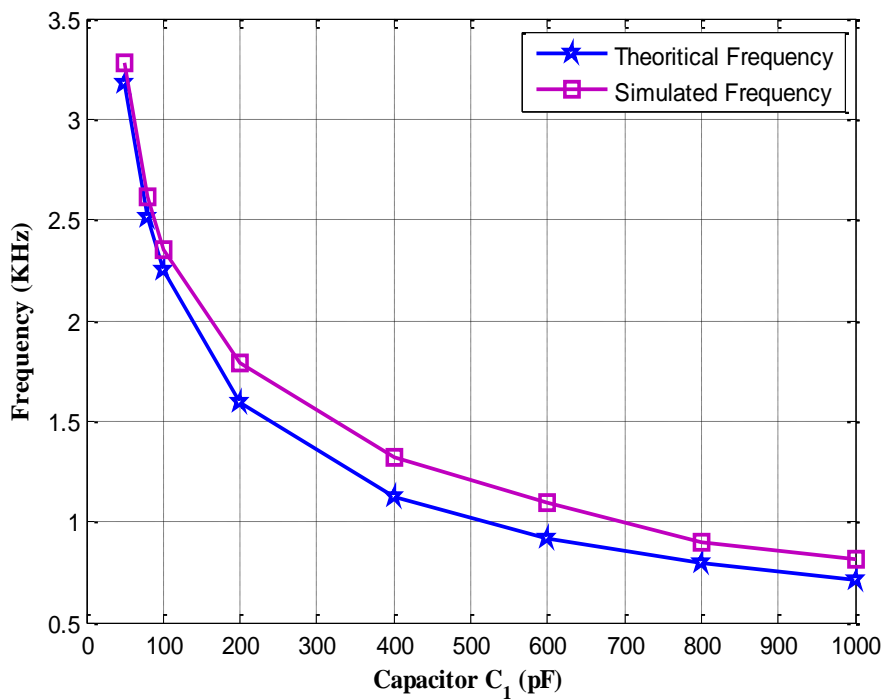


Fig. 7.22 Tunability of the proposed circuit in Fig. 4.7 with respect to the capacitor  $C_1$

The variation of oscillation frequency with respect to the capacitor  $C_1$  is shown in Fig.7.22. For this plot, the capacitor is varied from 50 pF to 1nF. The output voltages  $V_{01}$  versus  $V_{02}$  is shown in Fig. 7.23.

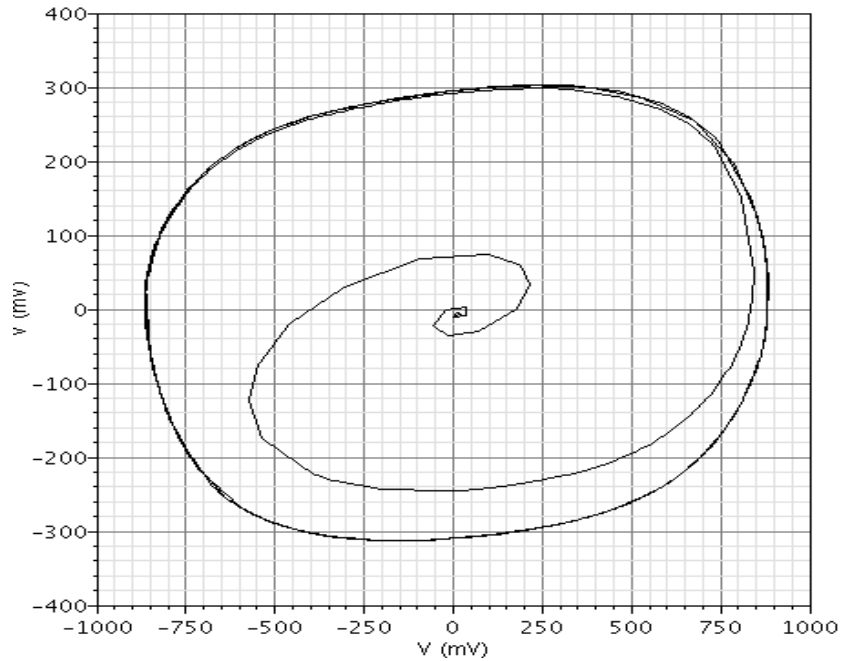


Fig. 7.23 Outputs  $V_{01}$  Vs  $V_{02}$  of the proposed circuit in Fig. 4.7

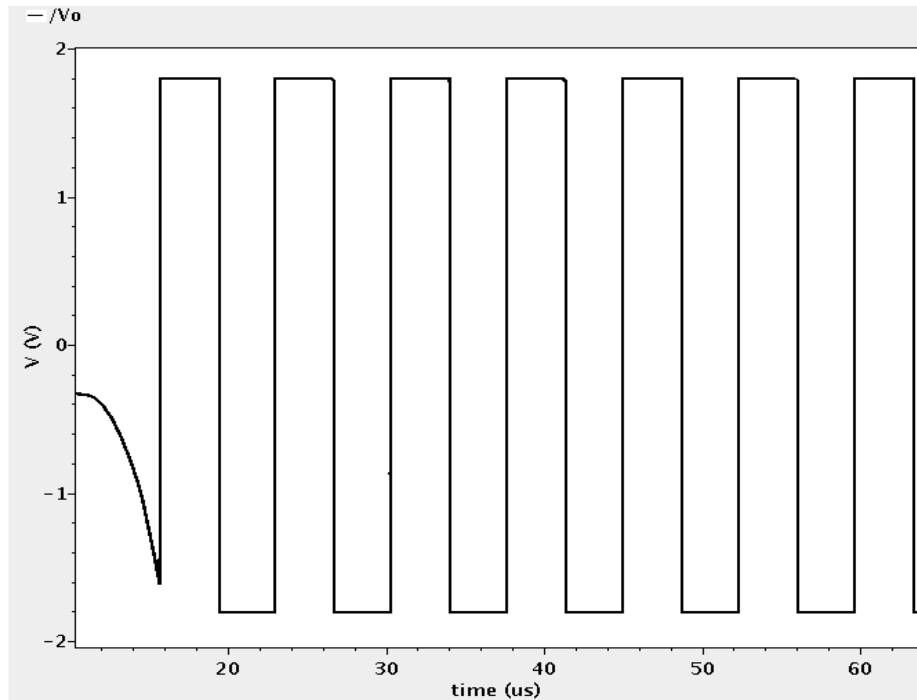
## 7.4 SQUARE WAVEFORM GENERATORS

### 7.4.1 SIMULATION RESULTS

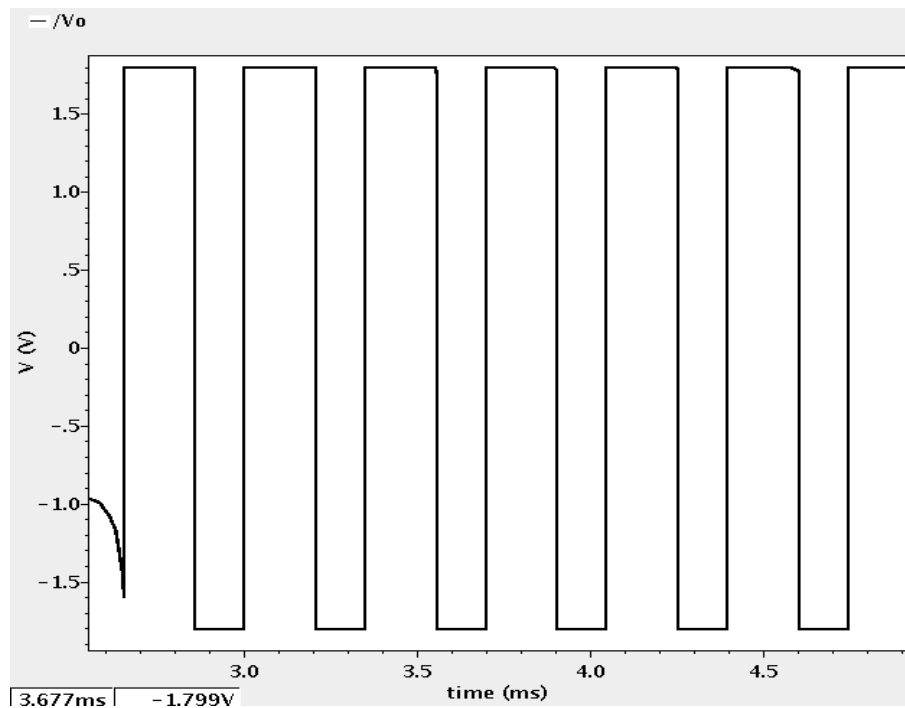
The simulated output results of the proposed square waveform generator circuits are given in Fig. 7.24. For generating the square-wave of the first proposed circuit in Fig. 4.8 (a), the required time period or frequency is chosen first. Then the ratio of  $R_1/R_2$  is taken care of and the value of capacitor  $C$  is arbitrarily determined from the time period or frequency expression given in equation (5.46) or (5.47). For the proposed circuit shown in Fig. 4.8 (a), the required time period is chosen as  $0.71 \mu\text{s}$ . The passive components chosen for the proposed circuit shown in Fig. 4.8 (a) are  $R_1 = 15 \text{ k}\Omega$ ,  $R_2 = 1.5 \text{ k}\Omega$  and  $C = 10 \text{ pF}$ . However, with this circuit the on-duty and off-duty cycles are fixed as shown in Fig. 7.24 (a). For the second proposed circuit in Fig. 4.8 (b), the values of resistors  $R_1 = R_{11} = R_{12}$ ,  $R_2$  and capacitor  $C$  are derived from the above process as stated in fixed duty cycles.

Then the resistors  $R_{11}$  and  $R_{12}$  are tuned independently to set the required on-duty and off-duty cycles. If resistor  $R_{11}$  is chosen greater than the resistor  $R_{12}$ , then the on-duty cycle is more than the off-duty cycle. These values will be ( $R_{12} > R_{11}$ ) reversed to set the off-duty cycle more than the on-duty cycle. The required time

period is chosen as 0.32 ms. The passive components  $R_2 = 1.5 \text{ k}\Omega$ ,  $R_{11} = 1.5 \text{ k}\Omega$ ,  $R_{12} = 5 \text{ k}\Omega$  and  $C = 0.1 \text{ nF}$  are used to simulate the proposed circuit with 60% on duty cycle and 40% off-duty cycle. The corresponding simulated output waveforms for the second proposed circuit are given in Fig. 7.24 (b) and (c).

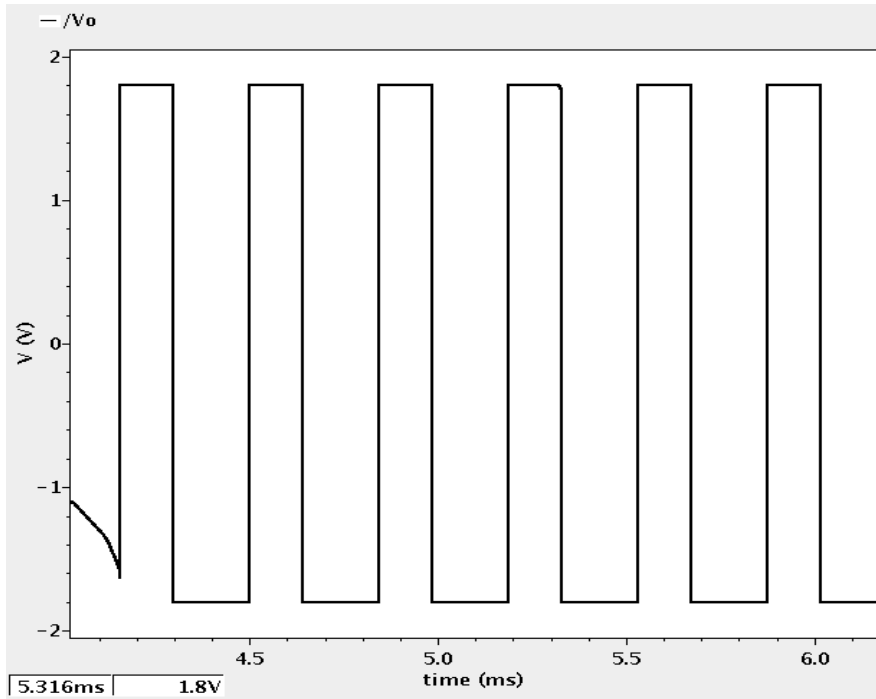


(a) Output waveform of the first proposed circuit ( $T_{ON} = T_{OFF}$ )



(b) Output waveform of the second proposed circuit ( $T_{ON} > T_{OFF}$ )





(c) Output waveform of the second proposed circuit ( $T_{ON} < T_{OFF}$ )

Fig. 7.24 Output waveforms of the proposed square-wave generators

The tunability of time period with respect to resistor  $R_2$  is shown in Fig. 7.24. For the tunability plot, the passive components  $R_1 = 15 \text{ k}\Omega$  and  $C = 1 \text{ nF}$  are used,  $R_2$  is varied from  $200 \Omega$  to  $3 \text{ k}\Omega$ .

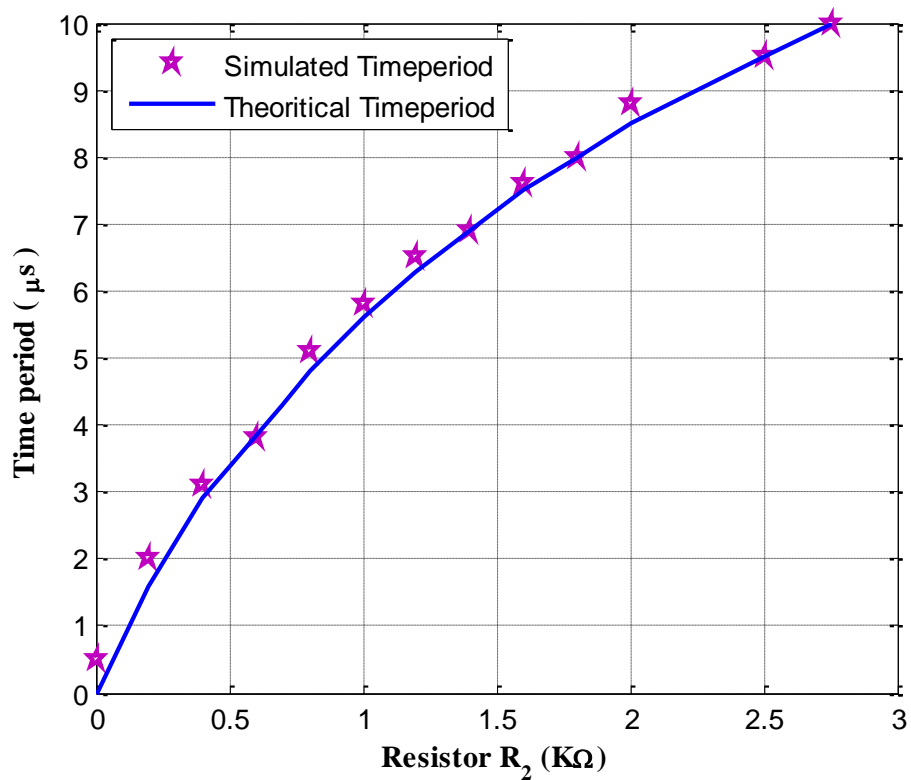


Fig. 7.25 Tunability of time period against resistor  $R_2$

## **7.5 SUMMARY**

The simulation results are presented in this chapter to validate the mathematical analysis given in chapter 5. All the proposed circuits are simulated using Spectre simulation model parameters with a supply voltage of  $\pm 1.8$  V. The simulated output waveforms of all the proposed circuits are presented in this chapter. For all the proposed circuits the passive component values are given to validate the theoretical analysis. The simulation frequencies of all the proposed circuits are matched with the theoretically calculated frequencies from chapter 5.