Design Problem 1

(a) **Create the LTSpice Schematic of the astable multivibrator circuit.**

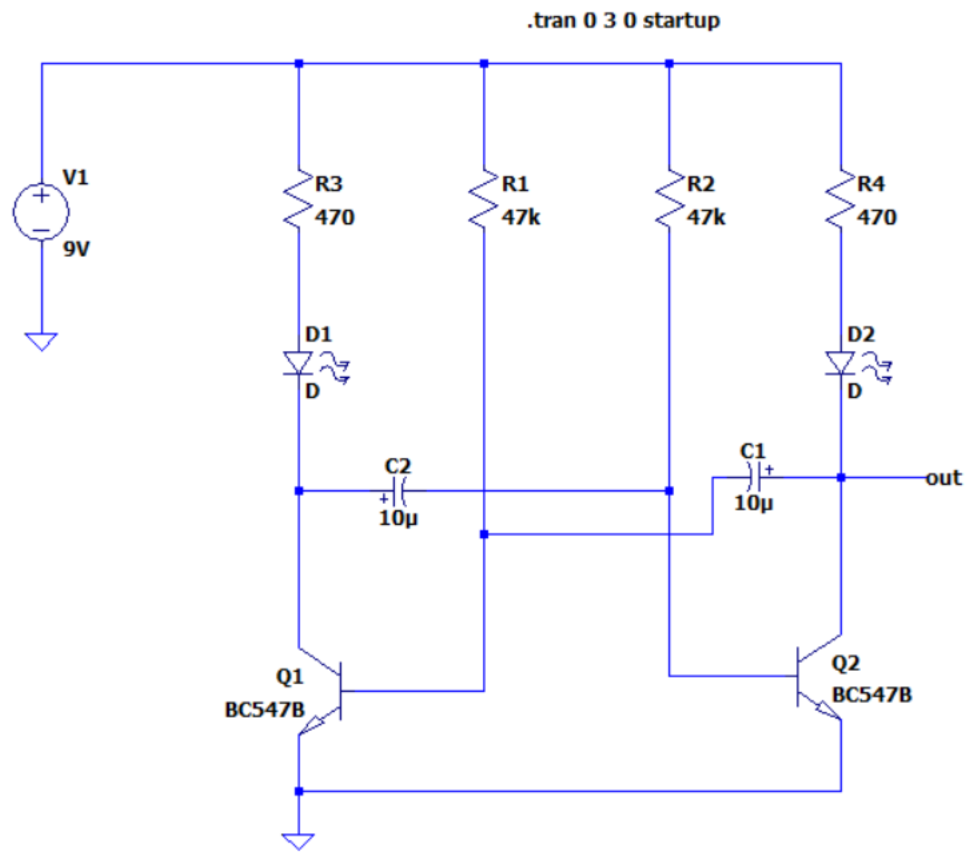

Figure 1. Circuit schematics of the astable multivibrator

(b) Amplitude of Output Waveform

- Conduct transient analysis to observe the circuit's output waveform and measure its peak-to-peak amplitude.

- Implementing in LTSpice:

  .tran 3 startup
  .meas out PP V(out)

- Result:

  peak to peak amplitude: 8.52396(V) from 0 to 10

- Utilize the .MEASURE directive to reliably identify maxima and minima of the waveform.

- Implementing in LTSpice

  .meas maxOut MAX V(out)
  .meas minOut MIN V(out)

- Result:

  maxima of the waveform: 8.52396(V)
  minima of the waveform: 0(V)

- Plot a trace of the output waveform over a time duration of 3 s.

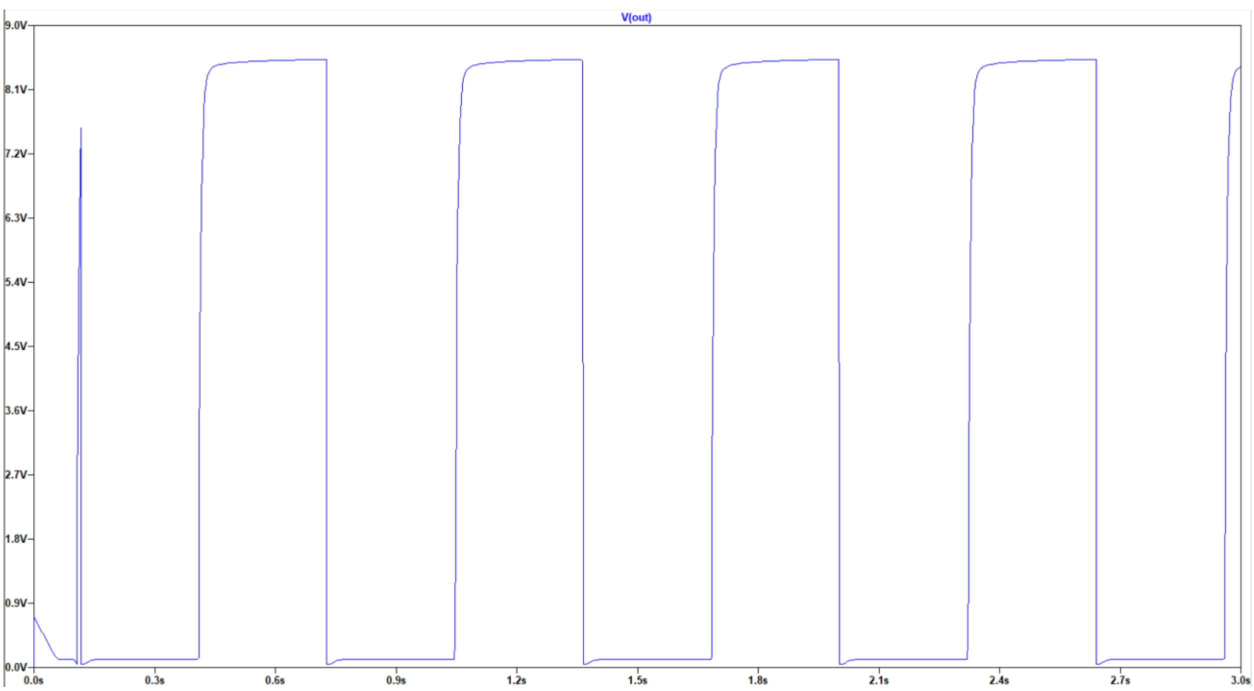

Figure 2. Output waveform over a time duration of 3s

- Discuss the relationship between the output signal and the LEDs in the circuit.

- Discussing:

    Comparing Figure 2 and Figure 3 (below), in stabilization period, we noticed that the voltage output signal and current LED 1 are in the same phase, nevertheless, voltage output signal and current LED 2 are different phase.

    Looking at Figure 3, when LED 1 turns on, LED 2 turns off and otherwise. Therefore, at the specific time (in stabilization period), only 1 LED activates.

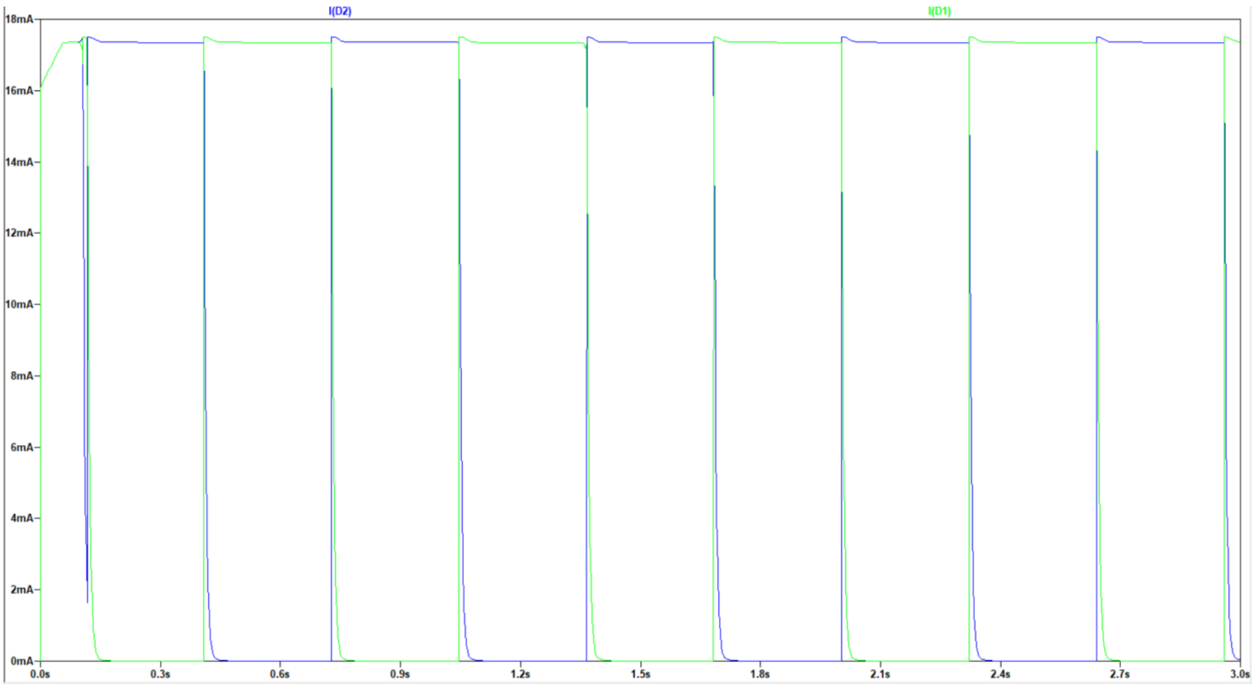

Figure 3. LED 1 current (green line) vs LED 2 current (blue line) over a time duration of 3s

(c) Frequency of Oscillation

- Determine the period and the frequency of the output waveform. Use the .MEASURE directive to analyze the output waveform.

- Implementing in LTSpice:

```
.tran 0 3 0.3 startup
.meas TRAN t1 FIND time WHEN V(out)=7 TD=0 RISE=1
.meas TRAN t2 FIND time WHEN V(out)=7 TD=0 RISE=2
.meas TRAN period PARAM (t2-t1)
.meas TRAN frequency PARAM 1/(t2-t1)
```

- Explanation:

  When observing Figure 2, we recognize that waveform starts to stabilize and appear periodically from time = 0.3s. Then, we measure voltage output signal when >=7(V) first time, and when <=7(V) first time. Next, we find period that is the interval time between 2 measurements, and frequency is 1/period.

- Simulate the multivibrator circuit with different capacitor values for C1 and C2. What are the frequencies of the oscillations with both capacitors being 4.7 µF and 20 µF, respectively?

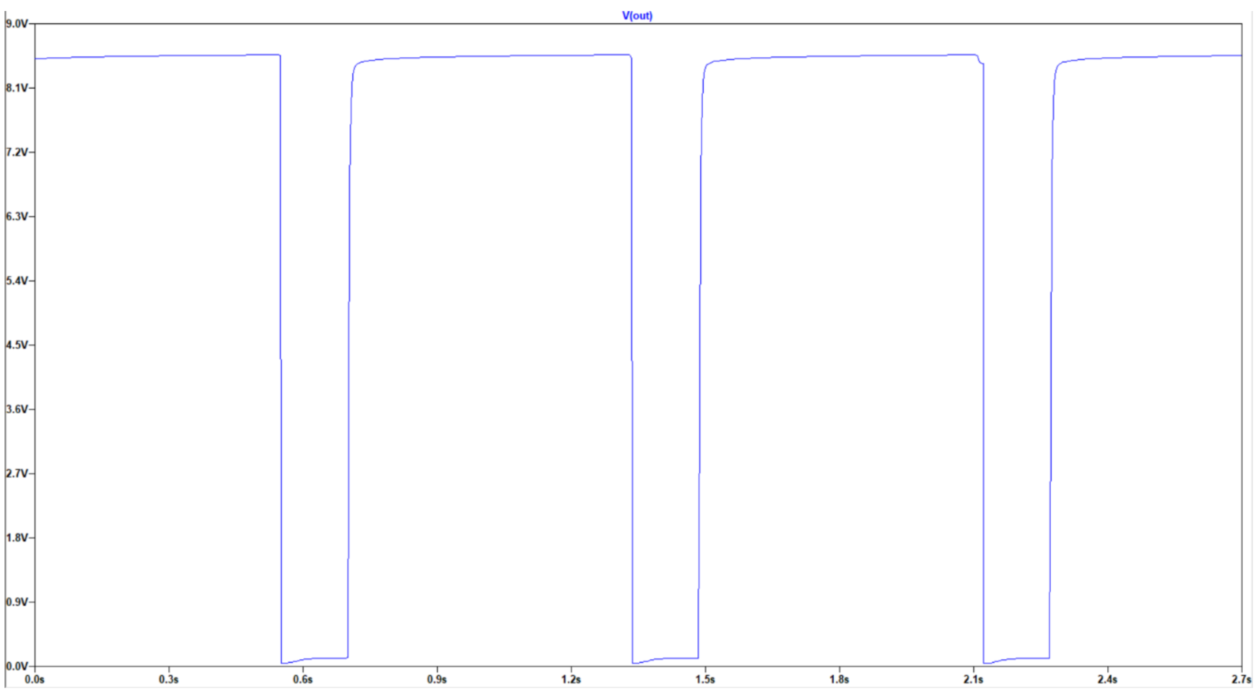

Figure 4. Output waveform with C1=4.7 µF and C2 = 20 µF

- Simulate the multivibrator circuit with different resistor values for R1 and R2. What are the frequencies of the oscillations with both resistors R1 and R2 being 22 kΩ and 100 kΩ, respectively?

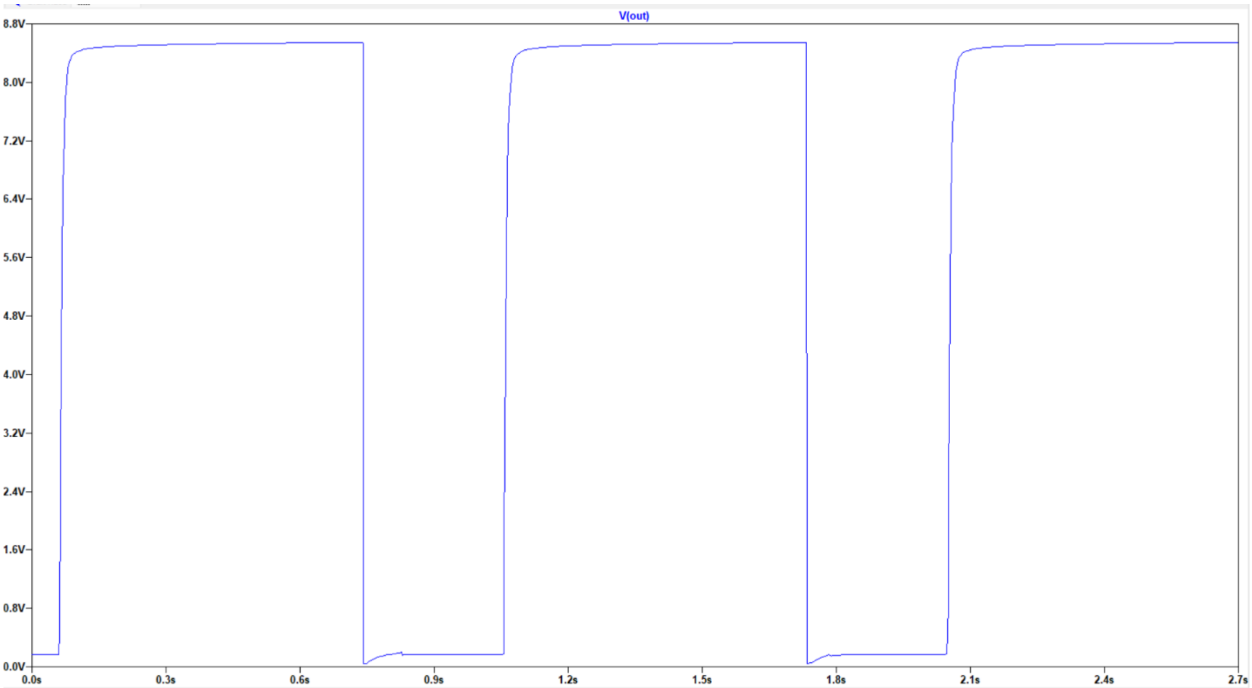

Figure 5. Output waveform with R1=22k and R2 = 100k

- Discuss the relationship between frequency, resistance, and capacitance.

- Result:

Number.	R1(Ω)	R2(Ω)	R3(Ω)	R4(Ω)	C1(F)	C2(F)	Period(s)	Frequency(Hz)
1	47k	47k	470	470	10µ	10µ	0.637797	1.5679
2	47k	47k	470	470	**4.7µ**	**20µ**	0.784898	1.27405
3	**22k**	**100k**	470	470	10µ	10µ	0.829781	1.20514

Table 1. Relationship between frequency, resistance and capacitance

- Dicussing:

Observing table 1 (above), C1xR1+C2xR2 (at 1st measurement) < C1xR1+C2xR2 (at 2nd measurement) < C1xR1+C2xR2 (at 3rd measurement) and period (at 1st measurement) < period (at 2nd measurement) < period (at 3rd measurement). Hence, period is proportional to (C1xR1+C2xR2). Hence, frequency is inversely proportional to (C1xR1+C2xR2).

(d) Duty cycle

- Simulate the multivibrator circuit and measure the duty cycle of the output waveform. Use the .MEASURE directive to determine the duty cycle.

- Implementing in LTSpice:

```
.tran 0 3 0.3 startup
.meas TRAN t1 FIND time WHEN V(out)=7 TD=0 RISE=1
.meas TRAN t2 FIND time WHEN V(out)=7 TD=0 RISE=2
.meas TRAN t1_down FIND time WHEN V(out)=7 TD=0 FALL=1
.meas TRAN period PARAM (t2-t1)
.meas TRAN duty_cycle PARAM ((t1_down-t1)/(t2-t1))*100
```

- Vary the component value of C2 and observe the effect on the duty cycle. What are the duty cycles and the frequencies of the oscillations with C2 being 4.7 μF and 15 μF, respectively (keeping the value of C1 = 10 μF)?

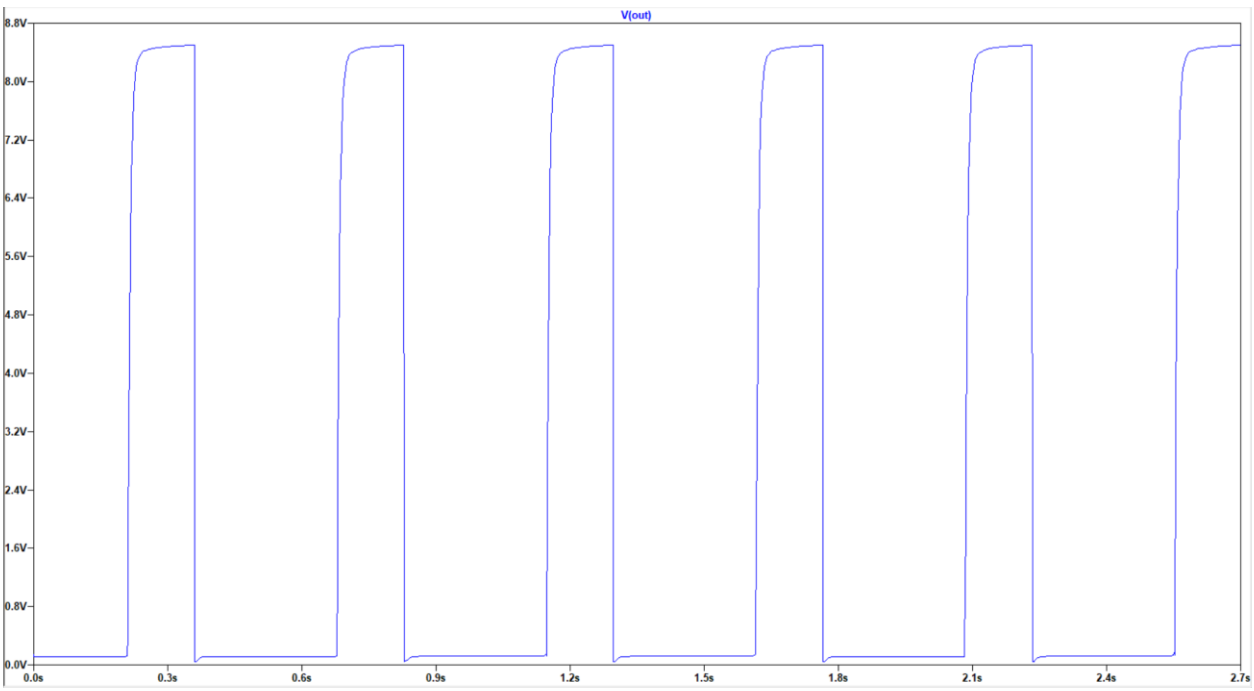

Figure 6. Output waveform with C2 = 4.7 μF

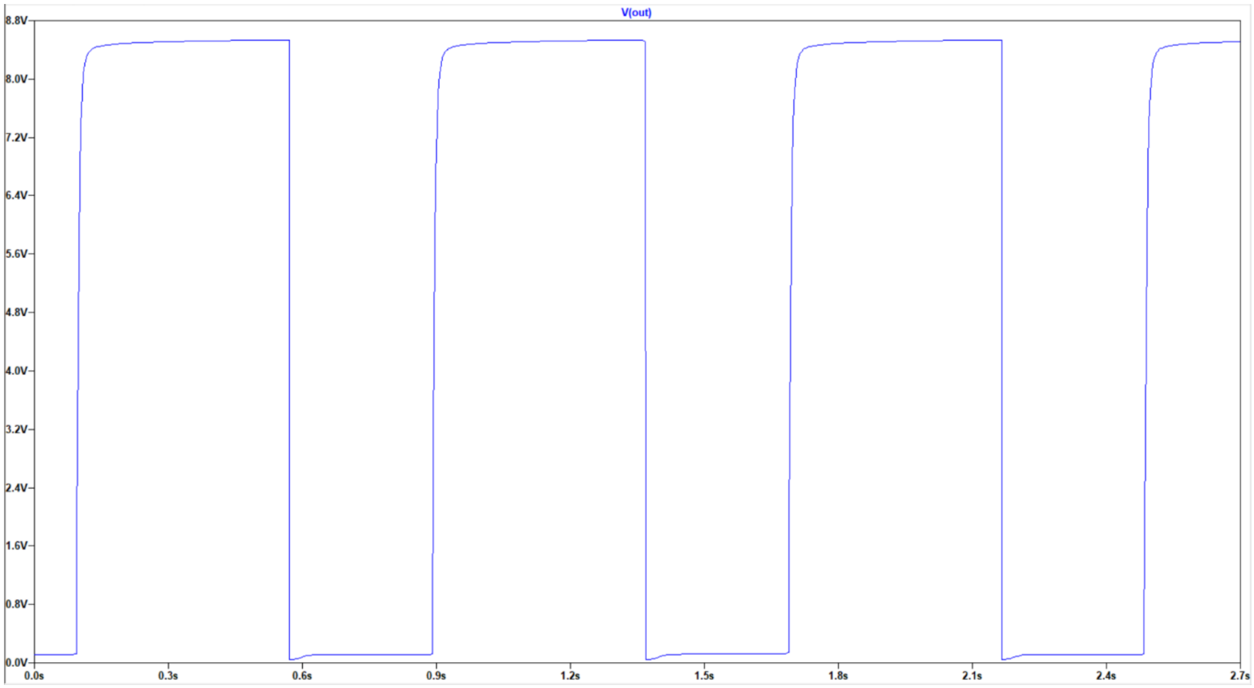

Figure 7. Output waveform with C2 = 15 µF

- Discuss how to achieve a desired duty cycle and the trade-offs involved.

- Results:

Number.	R1(Ω)	R2(Ω)	R3(Ω)	R4(Ω)	C1(F)	C2(F)	Frequency(Hz)	Duty cycle(%)
1	47k	47k	470	470	10µ	10µ	1.5679	48.5939
2	47k	47k	470	470	10µ	**4.7µ**	2.13493	30.1282
3	47k	47k	470	470	10µ	**15µ**	1.25452	58.833

Table 2. Relationship between duty cycle, resistance and capacitance

- Discussing:

  Observing table 2 (above), we can conclude that duty cycle increases when the value capacitor increases. If we want to achieve a desired duty cycle, we vary the value of capacitor C2 and keep the value of other components unchanged.

(e) Rise- and Fall- Time Analysis

- Analyze the rise- and fall-time of the circuit's output waveform.
- Implementing in LTSpice:

```
.tran 0 3.3 0.3 startup
.meas TRAN low_value_trans PARAM (maxOut/100*10)
.meas TRAN high_value_trans PARAM (maxOut/100*90)
.meas TRAN rise_t_low FIND time WHEN V(out)=low_value_trans TD=1.5 RISE=1
.meas TRAN rise_t_high FIND time WHEN V(out)=high_value_trans TD=1.5 RISE=1
.meas TRAN fall_t_low FIND time WHEN V(out)=low_value_trans TD=1.5 FALL=1
.meas TRAN fall_t_high FIND time WHEN V(out)=high_value_trans TD=1.5 FALL=1
.meas TRAN rise_time PARAM (rise_t_high-rise_t_low)*1000
.meas TRAN fall_time PARAM (fall_t_low-fall_t_high)*1000
```

- Simulate the multivibrator circuit with different resistor values for R3 and R4. What are the rise- and fall-times of the square wave with both resistors R3 and R4 being 220 Ω, 470 Ω, 2.2 kΩ, and 4.7 kΩ, respectively?

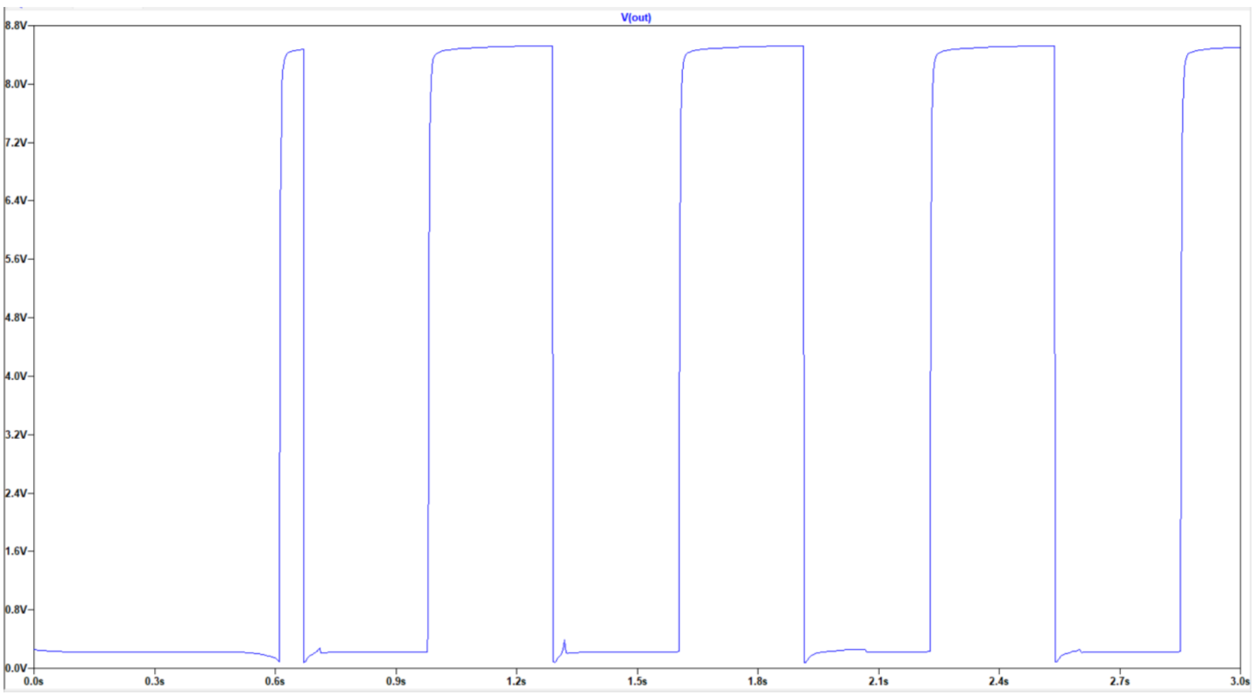

Figure 8. Output waveform with R3 = R4 = 220 Ω

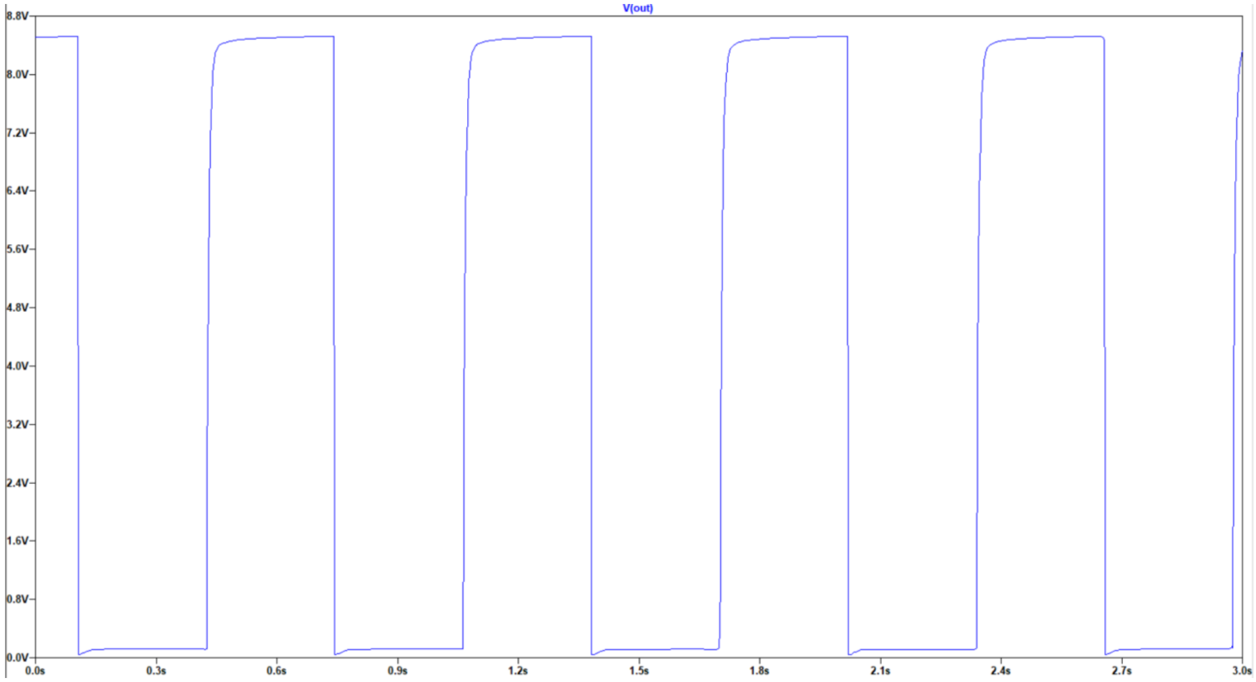

Figure 9. Output waveform with R3 = R4 = 470 Ω

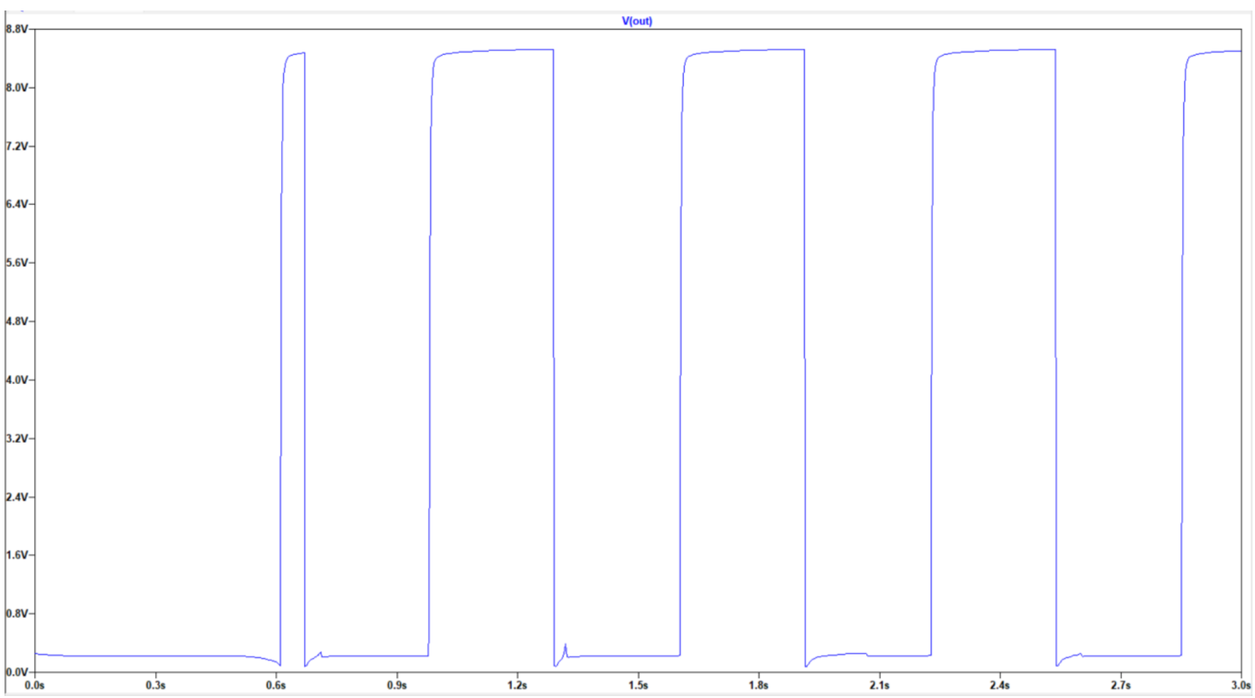

Figure 10. Output waveform with R3 = R4 = 2.2k Ω

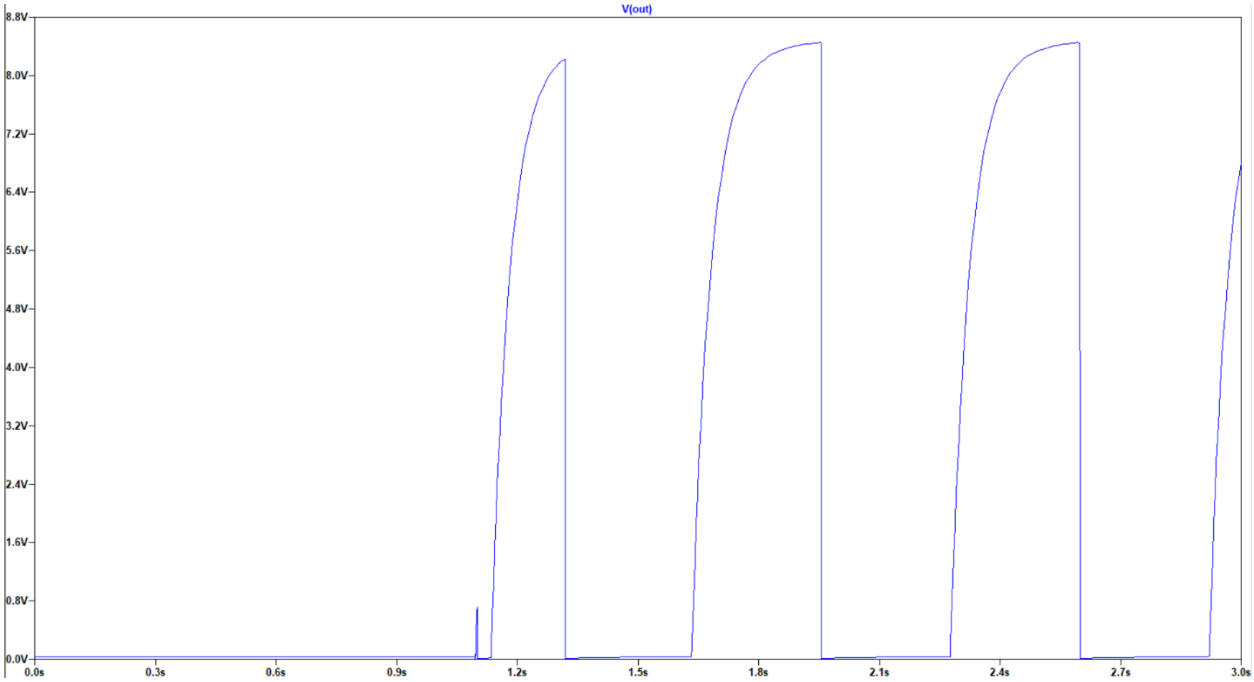

Figure 11. Output waveform with R3 = R4 = 4.7k Ω

Number.	R1(Ω)	R2(Ω)	R3(Ω)	R4(Ω)	C1(F)	C2(F)	Rise-time(ms)	Fall-time(ms)
1	47k	47k	**220**	**220**	10µ	10µ	5.80581	1.96274e-06
2	47k	47k	470	470	10µ	10µ	12.1365	2.63428e-06
3	47k	47k	**2.2k**	**2.2k**	10µ	10µ	52.6257	7.9217e-06
4	47k	47k	**4.7k**	**4.7k**	10µ	10µ	108.061	1.51519e-05

Table 3. Relationship between rise-time, fall-time, resistance and capacitance

- Discuss your observations regarding rise- and fall-times of the multivibrator circuit.

- Discussing:

Observing Table 3 (above) The value of resistor is proportional to rise-time and is inversely proportional to fall-time.

Rise-time is many times as large as fall-time.

(f) Design

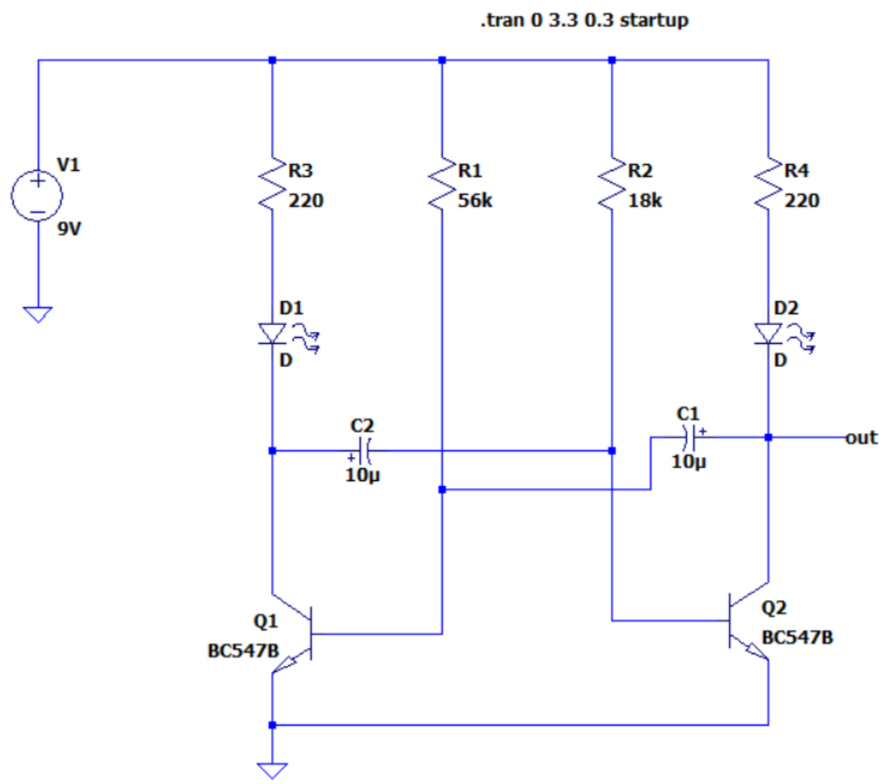

Figure 12. Circuit schematics of the astable multivibrator

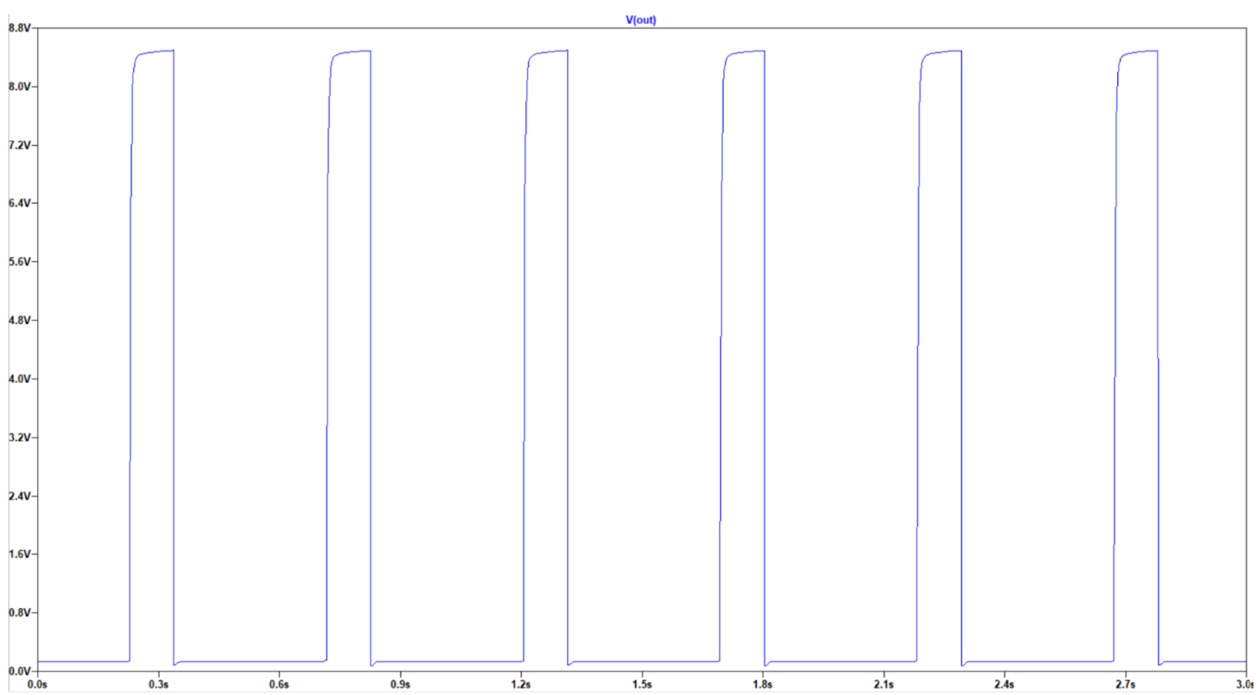

Figure 13. Output waveform over a time duration of 3(s)

R1(Ω)	R2(Ω)	R3(Ω)	R4(Ω)	C1(F)	C2(F)	Rise-time(ms)	Duty cycle(%)	Frequency(Hz)
56k	**18k**	**220**	**220**	10µ	10µ	5.58809	21.4593	2.04754

Table 4. values calculated by LTSpice with specific resistors and capacitors