Chapter 9 **Multivibrator Circuit Practice**

9-1 Practice Purpose

1. To understand 555 Timer's movement theory
2. To understand 555 Timer's appliance

9-2 Practice theory

555 Timer is an integrated circuit (IC) with many functions, (including unstable operations) which is very commonly used. Its size is only half of a normal IC and it can be used as a single stable or unstable vibrator. The following is a description of its basic structure, movement theory and appliance.

9-2-1 555 Time setter

555 Timer was manufactured in 1972, by Signetics Company which has become a very popular devive. The special characteristics of 555 Timer are as follows:

(1) Uses only simple resistance, capacitor to complete extending vibration. Its extending range is wide from a few micro seconds to a few hours or so.
(2) Its operation range is big and it can cooperate with TTL and CMOS logic gates, which means that its output and input positions can work with these logic series' highs and lows.
(3) Its output sink or big supply power can automatically push control burdens.
(4) Its timing is very accurate and the temperature is stable (0.005%/ ◦C) and also it is cheap.

Due to the fast technical and manufacturing improvement of semi-conductors, there are already many companies producing similar timers.

Figure 9-1 is the block diagram of Signetics' NE555 Timer. There are three equal value resistance R_7, R_8, R_9 serial in and out between the power and receivers. According to voltage dividing theory, 2/3Vcc's voltage supplies upper comparator as its input reference power. 1/3Vcc's voltage supplies lower comparator's reference power. Upper comparator's reference power's input end is also the control voltage end. This end can change the timer period by outer power pressure. Another end is critical end (also called threshold end) which uses the comparison of outer voltage and voltage control positions to control upper comparator's output.

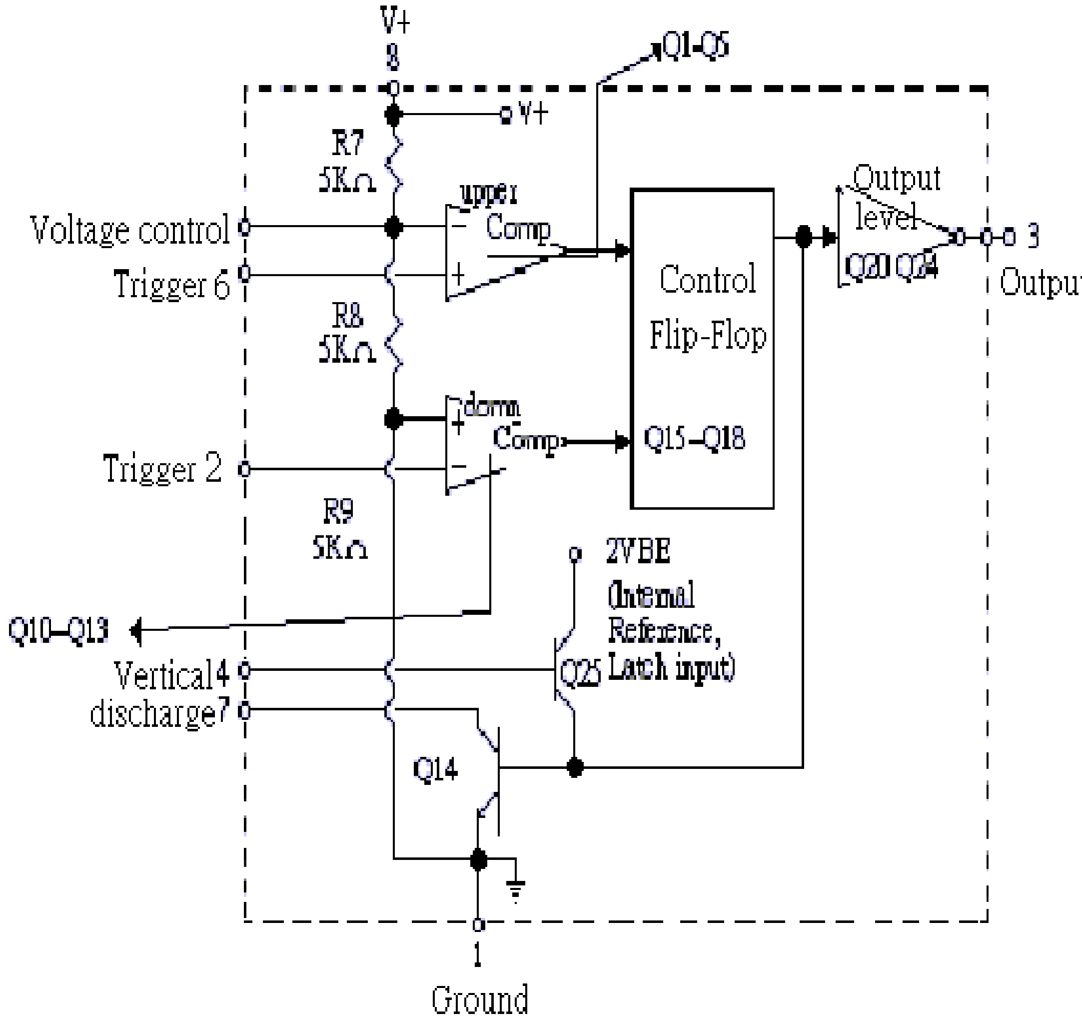


Figure 9-1 NE555 Timer structure

The other end of lower comparator is fixed at 1/3Vcc's position, the other end follows outer trigger voltage and 1/3Vcc's comparison to decide lower comparator's output.

The output voltage position caused by the input difference of two comparators affects the control flip-flop's output voltage. The high and low of voltage can be a switch of Q_14. Also, it can produce the necessary output voltage through output state's push. Q25 is the IC switch of reset.

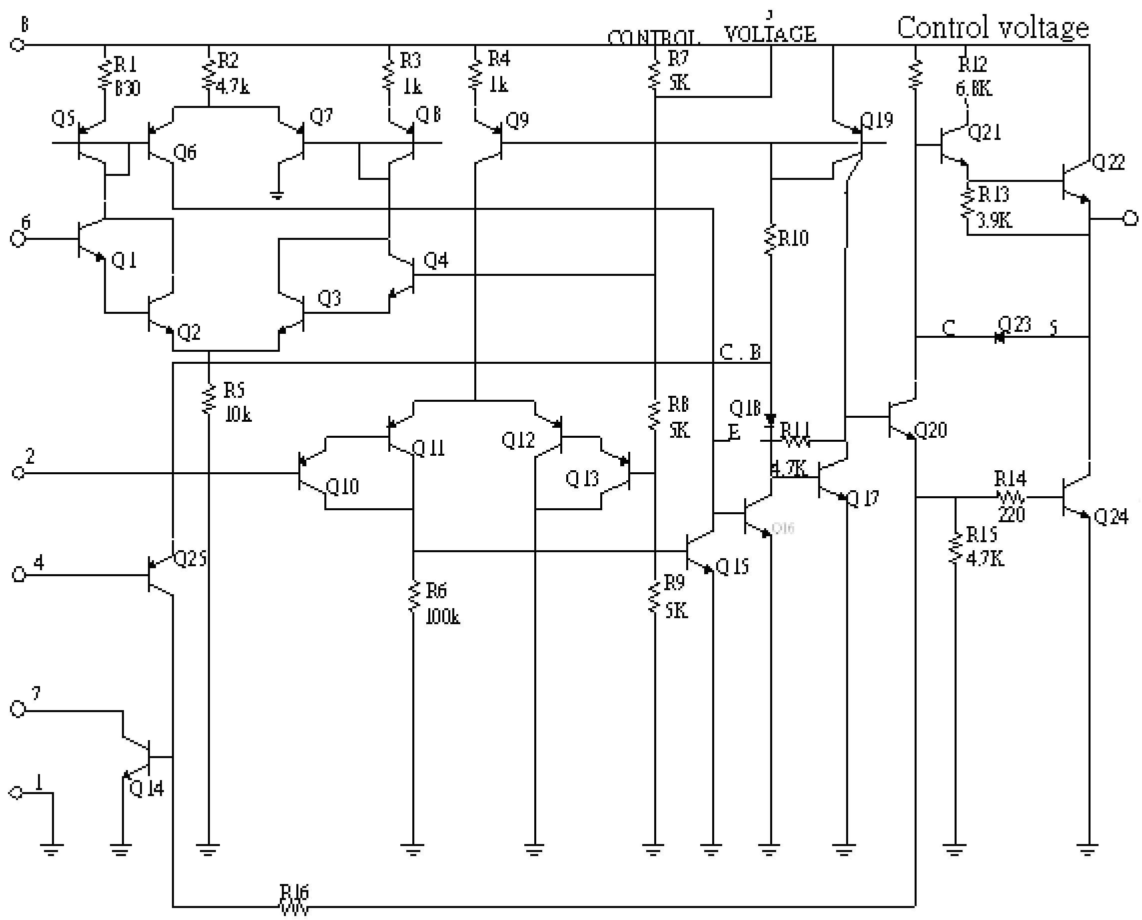


Figure 9-2 555 Timer's inner circuit

Figure 9-2 is the figure of 555 Timer's inner circuit. First of all, in the center of the figure, we find three voltage dividers R7, R8, R9. They all are 5kΩ's resistance. Therefore, Q4 is 2/3Vcc's reference voltage. Q13 is 1/3Vcc. The two voltage dividing resistances are also the two ICs' pressure voltage. From Q1 to Q8 are the eight IC upper comparators and Q10 to Q13 are the four IC lower comparators. We also realize that Q1Q2, Q3Q4, Q10Q11, Q12Q13 are Darlington pairs' amplifiers; therefore they have higher input resistance and lower input voltages. So when the comparators are connected to the outer ends, we can use a wide range timer voltage to extend the time. And these two comparators connect to Q15 IC through Q6 and Q11's outputs to push and combine the control flip-flop's Q16 and Q17.

Assume the trigger is low state (lower than 1/3Vcc), Q11 Q10 can pass. Therefore, Q15's base can get a positive position which makes Q17's output low state. So Q20 to Q24's Totem pole shows high state.

Assume threshold connects to low voltage and reaches critical voltage (over 2/3 Vcc), Q1Q2、Q6Q16pass, Q17 shows low voltage and the Totem pole is low state as well.

Assume RESET connect to low voltage (lower than 0.7V), Q25 pass. The two ends Q18's CB are both low voltage. Therefore Q17's voltage is held at low voltage. At this time, the trigger or threshold's input is ignored. Timer output is low state.

We already know Q20 to Q24's totem pole output. If Q20 IC is high position, then the timer output is low, but through Q20's positions and go through R16's resistance connecting to Q14's XXXX Q14 IC is open-collector design; this Q14's pass makes the extreme end connect timer capacitor to the ground. And the voltage discharges through Q14.
In all, 555 Timer pin functions are as table 9-1.

Table 9-1

Pin	Symbol	Meaning	Function
1	GROUND	GROUND	1. Common ground.
2	TRIGGER	TRIGGER	1. Low state movement (lower than 1/3Vcc), output is high state. 2. Start signal period, smaller than R.C timer period.
3	OUTPUT	OUTPUT	1. high voltage, about Vcc － 1.7 when Vcc = 5V, Voh = 3.3V, Vol = 0.25V, Vcc = 15V, Voh = 13.3V, Vol = 2V
4	RESET	RESET	1. Lower state (lower than 0.7) , output is low state. 2. With priority, output is lower state.
5	Control Voltage	CONTROL VOLTAGE	1. The inner voltage divider is 2/3Vcc. 2. Input control voltage range is 2V to(Vcc － 1)V,it varies. Change timer output period, especially the adjustment' s appliance. 3. If not using this pin, there is always 0.01Uf ground to reduce the noise.
6	Threshold	THRESHOLD	1. High state (over 2/3Vcc) , output is low state. 2. Coming voltage is small to make outer timer voltage reach 15M.
7	Discharge	DISCHARGE	1. Open-collector output switch. 2. When the timer output is high state, this end is ground to provide timer power. 3. When the timer output is low state, this end is ground to provide inner power.
8	Vcc	Vcc	1. Power connection 2. Power range 4.5 ～ 16V 。 3. Supply voltage is about 10mA.

Figure 9-3 is LM 555 C's characteristics; from the figure we know that the usage of voltage range is wide, from 4.5V to 16V. When using higher voltage, we can push the indication or other burden. When using 5 V power, it matches TTL.

The voltage 0.5 μA needs low contacting power, the second pin (trigger end) is opening state and uses a finger to start the second pin to make output high state.

Parameters	Test conditions	LM55C			Unit
		MIN	TYP	MAX	
Electronic Voltage		4.5		16	V
Electronic current	Vcc=5V,RL=∞		3	6	mA
	Vcc=15V,RL=∞		10	15	mA
Trigger current			0.5		
Regain current		0.4	0.5	1.0	V
Regain current			0.1	0.25	mA
Critical current			0.1	0.25	μA
	Vcc=15V ISINK=100mA		0.1	0.25	V
	ISINK=50mA		0.4	0.75	V
Low state output voltage	ISINK=10mA		2.0	2.5	V
	ISINK=200mA		2.5		V
	Vcc=5V ISINK=5mA		0.25	0.35	V
	Vcc=5V Io=200mA		12.5		V
High state output voltage	Io=100mA	12.75	13.3		V
	Vcc=5V	2.75	3.3		V

Figure 9-3 LM555C characters

The current reaches 200mA when output is high state which can push an indicator and a small relay. When the current expands, the output voltage becomes low, for example, Vcc=15V, 200mA/12.5V, 100mA/13.3V, when output 200mA current, output voltage is

12.5V, output power Po=200 mA *. 12.5V=2.5W. When Vcc=5V, 100 mA /2.75V, output2.75V can sufficiently supply TTL logic 1 circuit. The sink current can reach 200mA. When the sink current expands, output voltage goes up as well. For example, Vcc=15V, 10mA/0.1V 100mA/2V 200mA/2.5V
Vcc=5V, low state input 8mA/0.35V, voltage stays below 0.35V, sink current stays below 8mA which is half of 74 series low state sink current (loL) 16mA, therefore, 555 can only have 5 input ends toward 54/74 series basic gates.

9-2-2 **Mono**stable **Vibrators**

Figure 9-4 is a monostable vibrator, R_A, C IS is charging timing element, when C_t reaches $\frac{2}{3}$ Vcc through R_t, the critical point starts to react, output becomes low state. Therefore, the discharging end reacts to discharge capacitor, meanwhile, the circuit stays the same until the trigger end is lower than 1/3Vcc; then output becomes high state and discharging end opens, Ct charges and so forth. From Ct charges until discharge stops; this is called the timing period.

$$Vc=V(1-e^{-\frac{t}{RC}}) \qquad (9\text{-}1)$$

Capacitor charges from 0V to V_{th}^{+} ($\frac{2}{3}$ Vcc), the state is changed, so

$$\frac{2}{3}Vcc=Vcc(1-e^{-\frac{t}{RtCt}}) \qquad (9\text{-}2)$$

Vcc is $\frac{2}{3}=1-e^{-\frac{t}{RtCt}}$

$$-\frac{1}{3}=-e^{-\frac{t}{RtCt}}$$

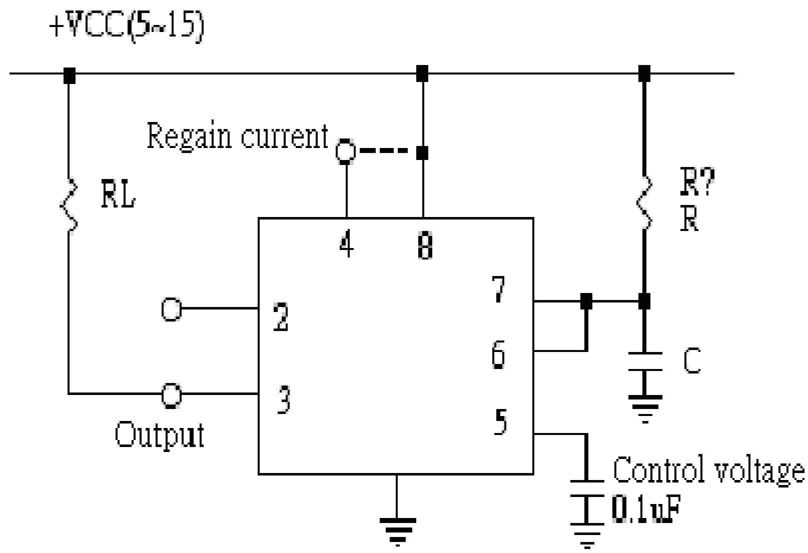
$$\frac{1}{3}=e^{-\frac{t}{RtCt}}$$

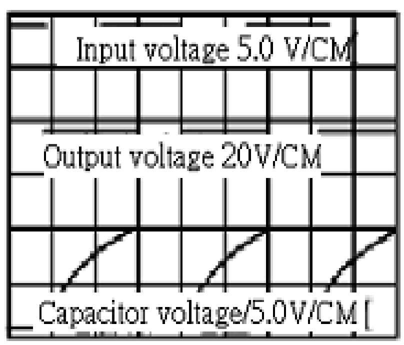
$$\ln\frac{1}{3}=\ln e^{-\frac{t}{R_tC_t}}$$

$$-\ln\frac{1}{3}=-\frac{t}{R_tC_t}$$

$$t=R_tC_t\ln 3 \fallingdotseq 1.1R_tC_t \text{ since } \ln 3 \fallingdotseq 1.1$$

The timer’s mono stable period is about 1.1. (Shown as figure 9-5).





$R_A = 9.1K\Omega, C = 0.1uF, R_L = 1^{*}\Omega$

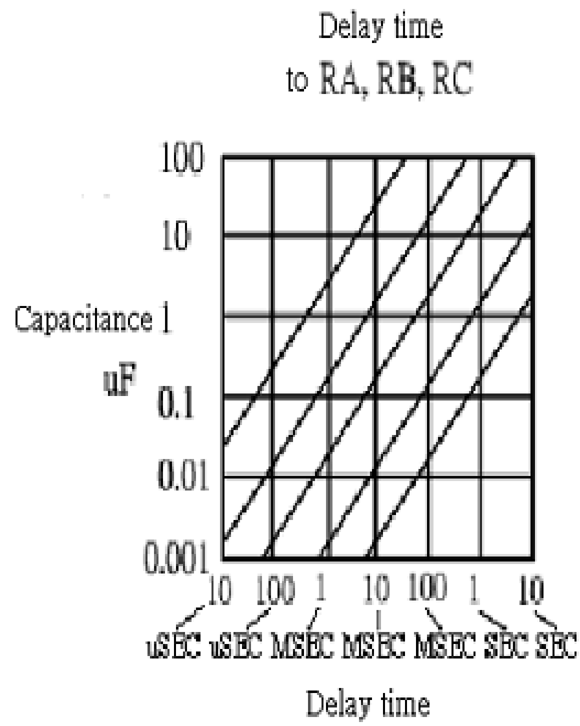


Figure 9-4 mono stable movements

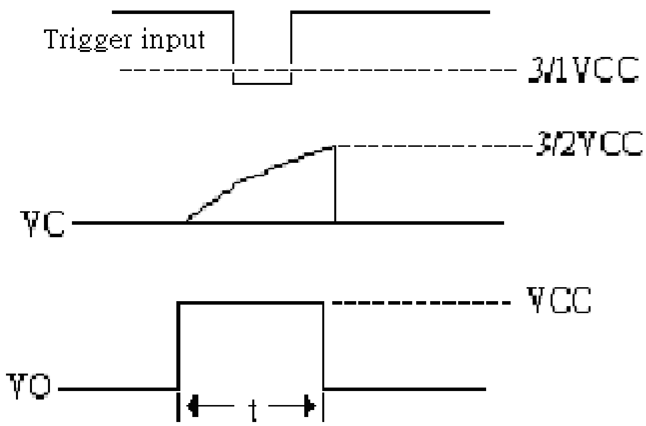


Figure 9-5 mono stable vibrator waves

From the timer period's calculation, we know that $t = 1.1R_tC_t$, but do R_t 、 C_t have range limitation? Yes, when the discharge opens, assume the minimum current of discharging and critical point is 0.25 μ A, then the capacitor's power leaking current is 0.1 μ A, the resistance is R_t, total current is I_S

$$I_S = 0.1\mu\text{A} + 0.25\mu\text{A} = 0.35\mu\text{A}$$

capacitor charging voltage $V_C = \frac{2}{3}V_{CC} = \frac{2}{3} * 15 = 10V$ (Set $V_{CC} = 15V$)

R_t capacitor's voltage V_R is

$$V_R = V_{CC} - V_C = 15 - 10 = 5V$$

R_t capacitor's max. value is $R_{t\max}$

$$R_{t\max} = \frac{V_R}{I_S} = \frac{5V}{0.35\mu\text{A}} = 14.29\text{M}\Omega$$

Therefore, we can tell that the timer capacitor has range limitations. But its range is very big. As for capacitor, it cannot be too big, otherwise, the vibration will not be working because of the extreme current. The normal capacitor is from 10kΩ to 14MΩ, the capacitor value range is between $100pF$ and $1000pF$.

9-2-3 Nonestable **Vibrators**

Nonestable vibrator, as figure 9-6, has trigger and critical point connected together and connects with timer capacitor to the ground. First, assume Ct has no electric charge, trigger reacts and makes output high state. Discharging end opens, Ct charges through R1 and Rt, the timer states, when the power reaches 2/3 Vcc, critical point reacts, the output end becomes low state. Meanwhile, it discharges to ground. Ct discharges through Rt to pin7; when discharge reaches 1/3Vcc, trigger reacts and put output back to high state. Meanwhile, the timing is over. Ct charges again and repeats each movement. Therefore there are serial wave signals.

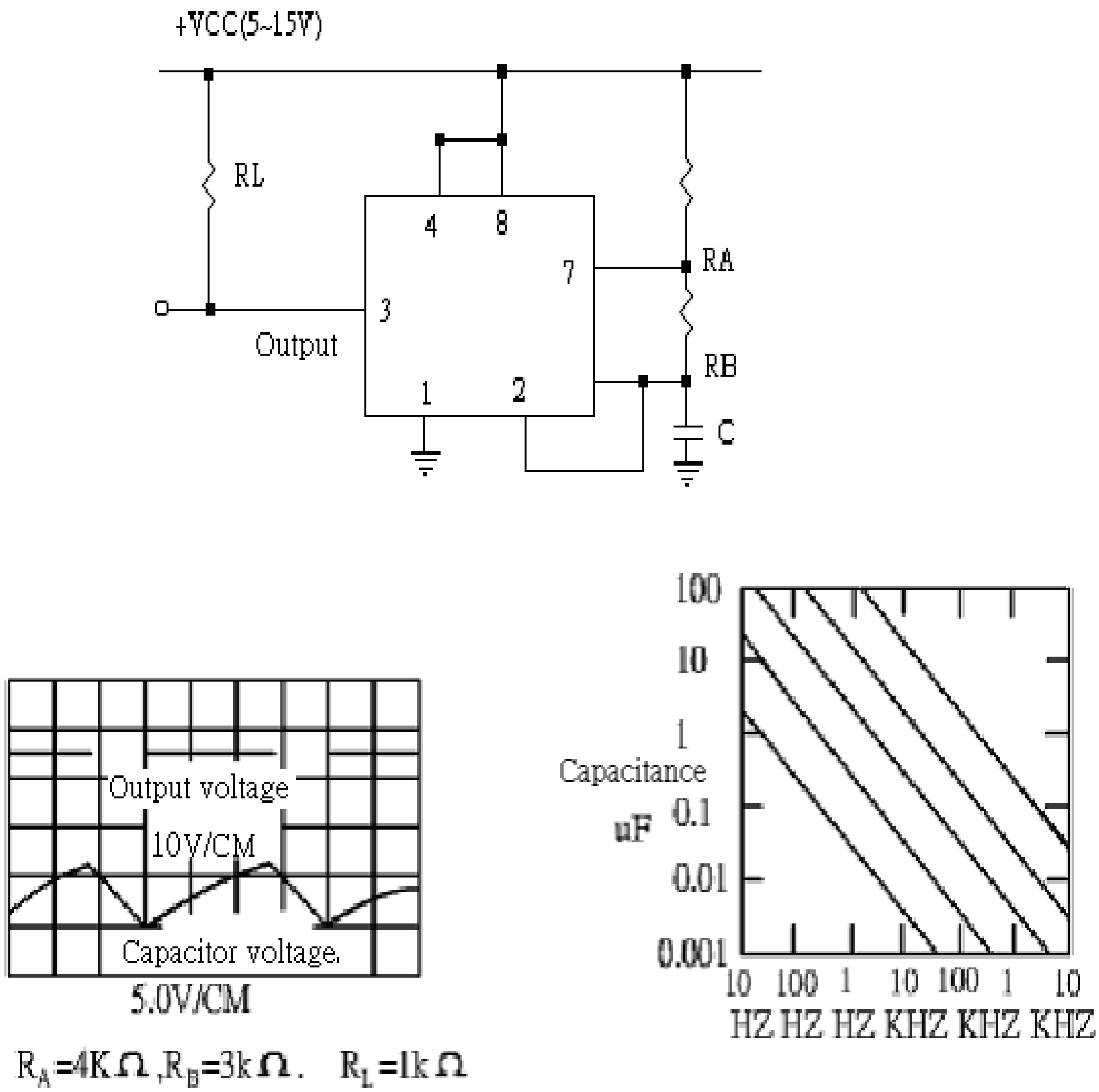


Figure 9-6

According to capacitor's charging formula (as 9-1)

$$V_C = V(1 - e^{-\frac{t}{RC}})$$

capacitor's discharging and charging are between the changes of $V_{th}^{-}(\frac{1}{3}V_{CC})$ and $V_{th}^{+}(\frac{2}{3}V_{CC})$, so

$$V_C = V_{th}^{+} - V_{th}^{-} = \frac{2}{3}V_{CC} - \frac{1}{3}V_{CC} = \frac{1}{3}V_{CC}$$

the actual current on to the capacitor is only $(V_{CC} - V_{th}^{-})$

therefore $V = V_{CC} - \frac{1}{3}V_{CC}$

when it is charging :

$$\frac{1}{3}V_{CC}(1 - e^{-\frac{t_1}{(R_t+R_1)C_t}}) \text{ due to charge through } R_t \text{ and } R_1$$

$$\frac{1}{2} = 1 - e^{-\frac{t_1}{(R_t+R_1)C_t}}$$

$$\frac{1}{2} = e^{-\frac{t_1}{(R_t+R_1)C_t}}$$

$$\ln\frac{1}{2} = -\frac{t_1}{(R_1 + R_1)C_t}$$

so $t_1 = (R_t + R_1)C_t \ln 2$ 〈$2\ln \fallingdotseq 0.693$〉

$\fallingdotseq 0.693(R_t + R_1)C_t$ (9-3)

for discharging:

$$\frac{2}{3}V_{CC} = \frac{2}{3}V_{CC}(1 - e^{-\frac{t_2}{R_tC_t}}) \text{ (Because discharging is } R_t)$$

so $t_2 \fallingdotseq 0.693R_tC_t$ (9-4)

from (9-3)(9-4)

Full period $T = t_1 + t_2 \fallingdotseq 0.693(2R_t + R_1)C_t$ (9-5)

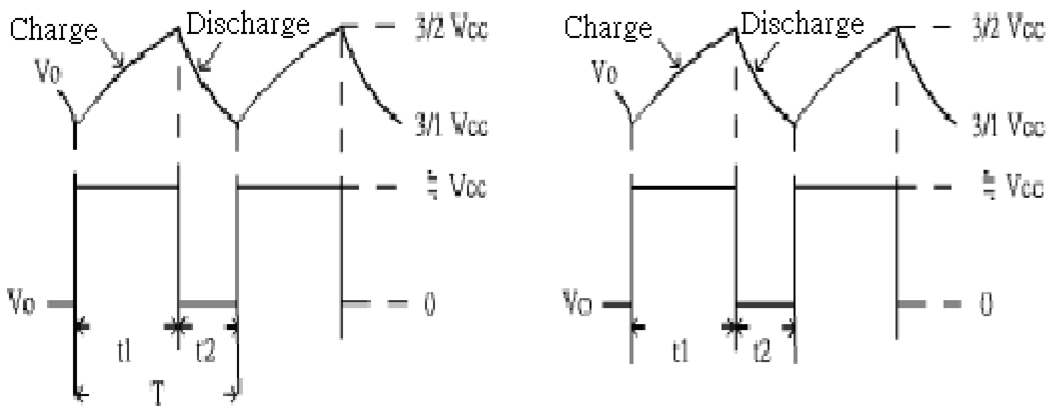
Therefore, the timer non-diagram period is about $0.693\,(2R_t + R_1)C_t$ as figure9-7(a). The full period T and partial period t_1 or t_2's ratio is called Duty Factor / DF from (9-3)(9-5)

$$DF_{(t_1)} = \frac{t_2}{T} = \frac{0.693(R_t + R_1)C_t}{0.693(2R_t + R_1)C_t} = \frac{R_t + R_1}{2R_t + R_1} \quad (9\text{-}6)$$

from (9-4)(9-5)

$$\text{DF }(t_2) = \frac{t_2}{T} = \frac{0.693R_tC_t}{0.693(2R_t + R_1)C_t} = \frac{R_t}{2R_tR_1} \quad (9\text{-}7)$$

From (9-6)(9-7), if $R_1 \fallingdotseq 0$, then DF(t_1)=DF(t_2),t_1=t_2 , Therefore, the output has a symmetry wave. as figure 9-7 (b).



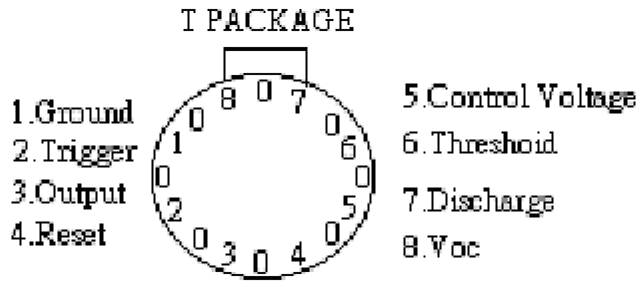
t1=0.693(Rt+R1)Ct
t2=0.693 Rt Ct
T =0.693(2Rt+R1)Ct
(a) none-symmetry

t1 = t2≒0.693 Rt Ct
T =2t1=2t2=1.386 Rt Ct
(b) symmetry

Figure9-7None stable output waves

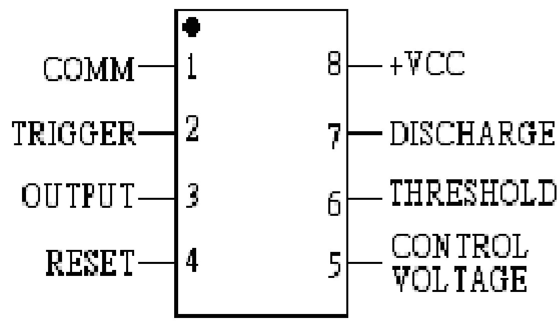
9-2-4 The usage of 555 Timer

The package of 555 Timer usually has a metal shell TO-99 and 8 pins dual inline packages/ DIP. As figure 9-8 shows, 555 timer's total power consumption is 600mw, if there is a radiator on the packaging shell, then it can tolerate higher sink or push current. The voltage's max. value is 18V, no more than this. Usually it works below 15V. Also, when it comes to welding it is better to use 25W, lower voltage steel to weld and the welding time should not be too long.
Furthermore, there are still some other outer pins and specifications like figure 9-9 and the elements of 555 timer, such as NE556 is two 555 timers which is packed on the time chip's timer. Also, such as Intersil Company's ICL8250, ICL8260 and Exar Company's XR-2240, XR-2250's programmable timers. Their main movement theory is similar to 555; the only difference is that they have inner timer which allows the output timing to follow the outer pins connecting to the output end. And that expands more functions of 1-255RtCt, 1-99RtCt or 1-59RtCt. As figure 9-10 shows.



ORDER PART NOS.SE555T/NE555T

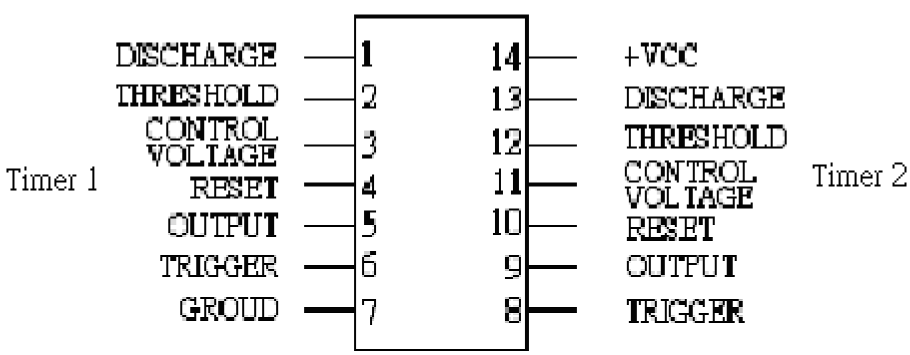
(a) Model TO=99



ORDER PART NOS.SE555V/NE555V

(b) Model DIP

Figure 9-8 555 TIMER OUTLOOK

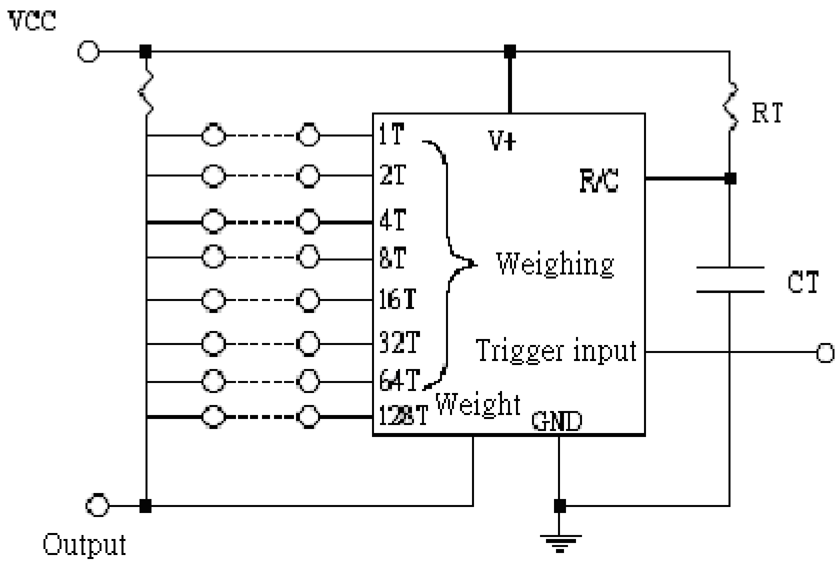


556 dual timer

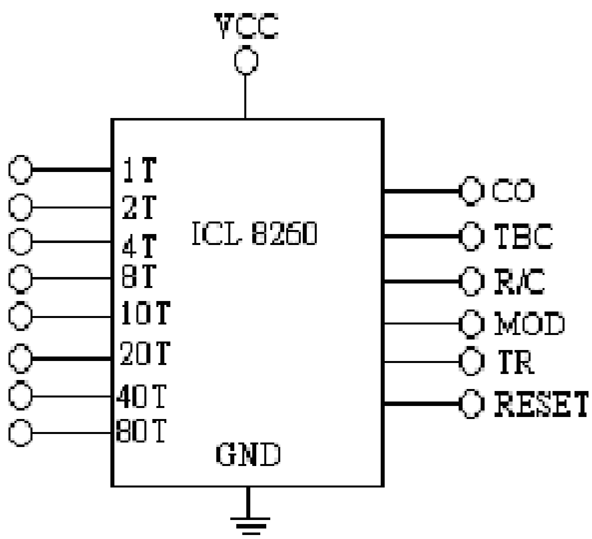
SUPPLY VOLTAGE (+Vcc)	18V max. value +5V to +15V
OUTPUT VOLTAGE LOGIC 0	0.35V max.value Vcc=5V@10mA
	0.75V max. value Vcc=15V@50mA
	2.5V max. value Vcc=15V@200mA
Output voltage logic1	12.5V typical value Vcc=5V@200mA
	3.3V typical value Vcc=5V@100mA

Min. TRIGGER wave period is 1us

Figure 9-9 555 and 556 timer’s outer pins and normal specification description



(a) Binary program model



(b) BCD program model

Figure 9-10 programmable timers

9-3 Practice items

9-3-1 Nonstable Multi-vibrators

Experiment steps

1. Nonstable multi-vibrator circuit, as figure 9-11.

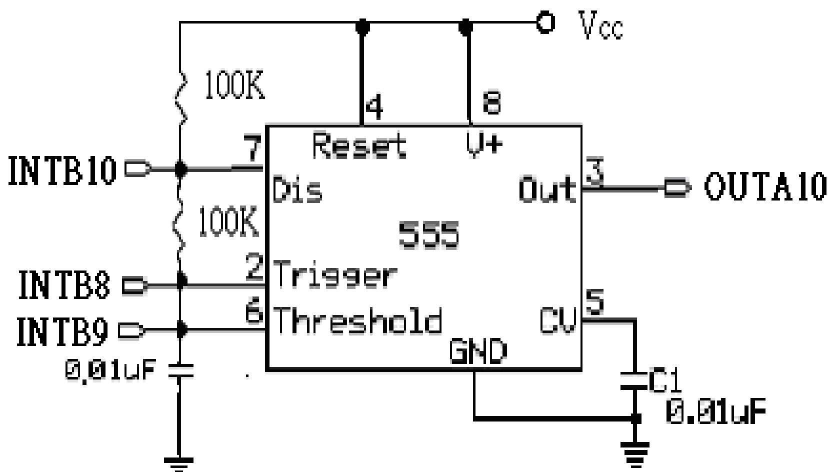


Figure 9-11

2. Input: Connect PIN2 to CON3 B8
Connect PIN6 to CON3 B9
Connect PIN7 to CON3 B10
Connect CON21 to CON19 100K resistance
Connect CON21 to CON16 100K resistance
Connect CON17 100K resistance to CON3 INB8
Connect CON21 to CON18 0.01u capacitor

Output: Connect PIN3 to CON2 A10
Connect CON2 A10 to CON13 SP1

4. Observe SP1's output sound changes after finished connecting. Change 0.01u capacitor to 0.1u capacitor and observe the output sound changes of SP1. The sound differences mean the different frequencies.

5. Record sound changes in the table:

Capacitor	0.01uf	0.1uf
Sound changes		

Table 9-2

9-3-2 555 Timers

Experiment steps

1. 555 timer circuit, as figure 9-12.

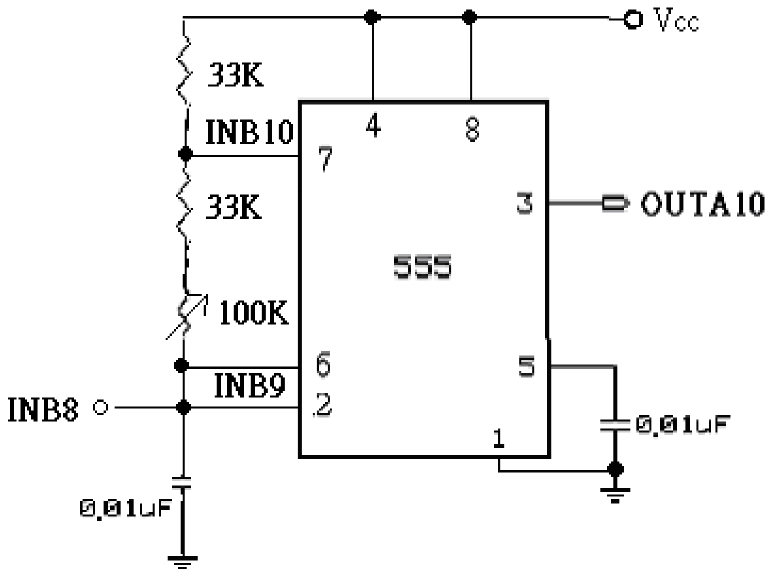


Figure 9-12

2. Input: Connect PIN2 to CON3 B8
   Connect PIN6 to CON3 B9
   Connect PIN7 to CON3 B10
   Connect B8, B9, B10 to CON21
   Connect CON21 to CON19 33K resistance
   Connect CON21 to CON16 33K resistance
   Connect CON17 33K resistance to CON16 100k variable resistance
   Connect CON17 100k to CON3 B9
   Connect CON21 to CON18 0.01u capacitor

   Output: Connect PIN3 to CON2 A10
   Connect CON2A10 to CON13 SP1
3. Observe SP1's output sound changes after finished connecting. Change 0.01u capacitor to 0.1u capacitor and observe the output sound changes of SP1. The sound differences mean the different frequencies.
3. Record sound changes in the table:

Capacitor	0.01uf	0.1uf
Sound changes		

Table 9-3

9-3-3 Monostable Multi-vibrators

Experiment steps

1. Monostable multi-vibrator circuit, as figure 9-13

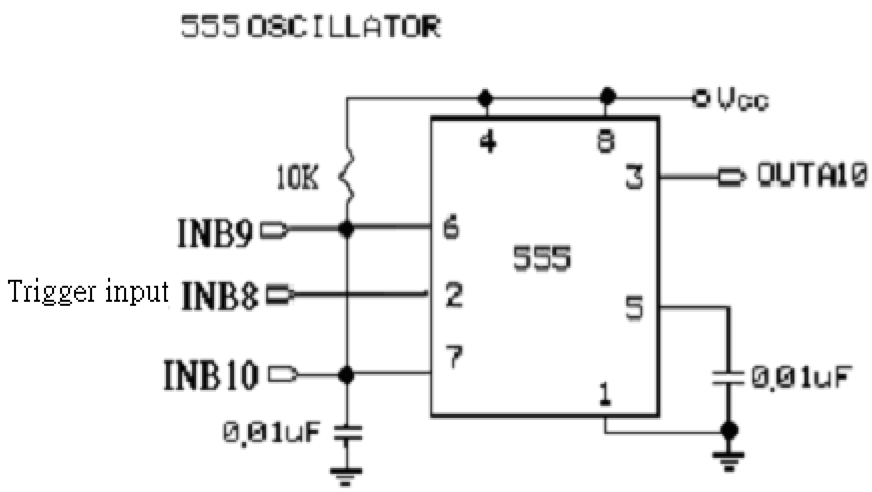


Figure 9-13

2. Input: Connect PIN2 to CON3 B8
Connect PIN6 to CON3 B9
Connect PIN7 to CON3 B10
Connect B9, B10 to CON21
Connect CON21 to CON18 0.01u capacitor
Connect CON21 to CON16 10K resistance
Connect CON17 10K resistance to CON9 V_H

Output: Connect PIN3 to CON2 A10
Connect CON2A10 to CON13 SP1

3. Observe SP1's output sound changes after finished connecting. Change 0.01u capacitor to 0.1u capacitor and observe the output sound changes of SP1. The sound differences mean the different frequencies.

4. Record sound changes in the table:

Capacitor	0.01uf	0.1uf
Sound changes		

Table 9-4

9-3-4 Bistable Multi-vibrators

Experiment steps

1. Bistable multi-vibrator circuit, as figure 9-14

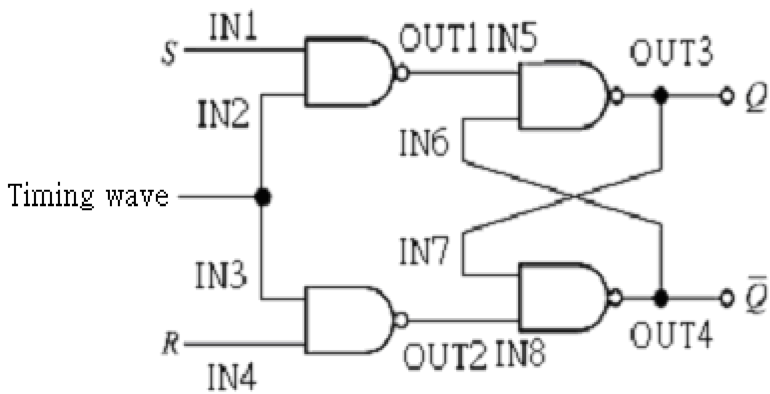


Figure 9-14

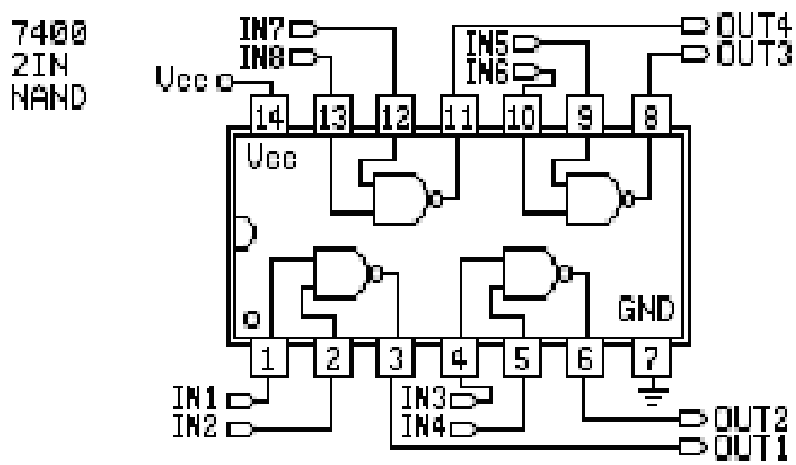


Figure 9-15

2. Refer to figure 9-15 7400 2 input NAND gate circuit Connection, as figure 9-14.

3. Input:	Connect CON7 S1 to CON1 IN1
	Connect CON5 1Hz to CON1 IN2 IN3
	Connect CON7 S2 to CON1 IN4
	Connect CON4 OUT1 to CON1 IN5
	Connect CON1 IN6 to CON4 OUT4
	Connect CON1 IN7 to CON4 OUT3
	Connect CON4 OUT2 to CON1 IN8
Output:	Connect CON4 OUT3 to LED DISPLAY CON15 Q1
	Connect CON4 OUT4 to LED DISPLAY CON15 Q2

4. Switch S1, S2, as table 9-5. 0 means low logic, LED off. 1 means high logic, LED on.

5. Record LED changes in table 9-5.

CK	S(S1)	R(S2)	Q	$\overline{Q}$
1	0	0		
1	0	1		
1	1	0		
1	1	1		

Table 9-5

9-4 Questions & Discussion

1. What is the advantage of 555 timer?
2. What are the types of vibrators?