Journal of Applied Sciences

ISSN 1812-5654

ANSInet
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http://ansinet.com

Journal of Applied Sciences 5 (6): 1012-1015, 2005
ISSN 1812-5654

An Accurate Model of 555IC Astable Multivibrator

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Abstract: An accurate model of 555IC astable multivibrator circuit has been presented in this paper. The closure resistance of the discharge transistor, which was ignored in the previous analysis, has been taken into consideration in this model. The equations developed in the model are plotted in Matlab. The plot of these equations shows that when $R_A << R_B$ the discharging time becomes much larger than the charging time and the duty cycle of the output waveform becomes much smaller than 50%. These results has been found in complete agreement with experimental results for all values of R_A and R_B.

Key words: 555IC, astable multivibrator, closure resistance

INTRODUCTION

Although 555IC was introduced 30 years ago, still today is the most used IC. It has many applications such as pulse generation, precision timing, sequential timing, time delay generation, pulse width modulation, pulse position modulation and linear ramp generation[1,2]. One of its application pulse generation in which the 555IC operates as astable multivibrator is widely used in undergraduate laboratories. In the astable multivibrator mode the timer is connected to two external resistors R_A and R_B and one capacitor C as shown in Fig. 1. The duty cycle of the output waveform is controlled by the charging and discharging of the RC network[1,2]. This circuit is analysed and discussed in the data sheets of 555 IC[1,2] and almost in every electronics book which contains a chapter on oscillators[1-5]. In all these references the calculation of duty cycle is described as that when the output of the timer is high the capacitor C charges through R_A and R_B to a value $(2/3)V_{cc}$ (Fig. 2). When the output of the timer is low the capacitor C discharges through R_B and discharge transistor Q_1 to a value $(1/3)V_{CC}$. The charging time of the capacitor is given as[1-5].

$$T_C = 0.693(R_A + R_B)C \quad (1)$$

This discharging time of the capacitor is given as[1-5].

$$T_D = 0.693R_BC \quad (2)$$

The frequency of oscillation f and the duty cycle D is given as[1-4]:

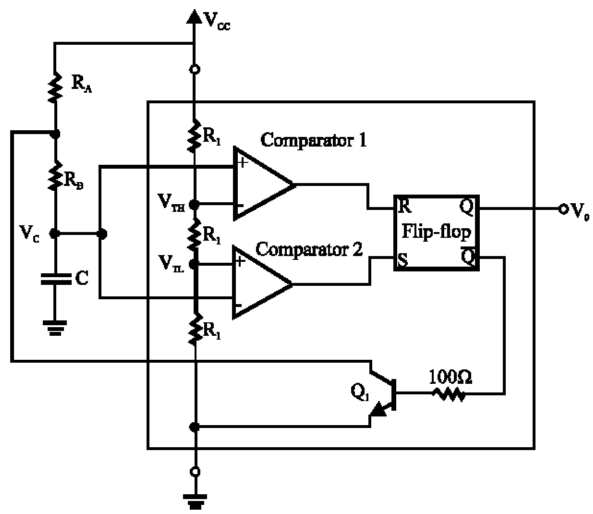

Fig. 1: 555 IC astable multivibrator circuit

$$f = \frac{1}{T} = \frac{1}{T_C + T_D} = \frac{1}{0.693(R_A + R_B)C} \quad (3)$$

and

$$D = \frac{T_C}{T} \times 100\% = \frac{R_A + R_B}{R_A + 2R_B} \times 100\% \quad (4)$$

The Eq. 4 shows that the duty cycle for this circuit is always greater than 50%. The duty cycle approaches 50% for $R_A << R_B$[1-5]. However in this research it has been found experimentally that duty cycle is less than 50% for $R_A << R_B$. This is in contradiction with the Eq. 4. Therefore expression (4) and hence (2 and 3) are not valid for $R_A << R_B$. To answer for the experimental results, a new model is derived, taking into account the closure resistance of the discharge transistor.

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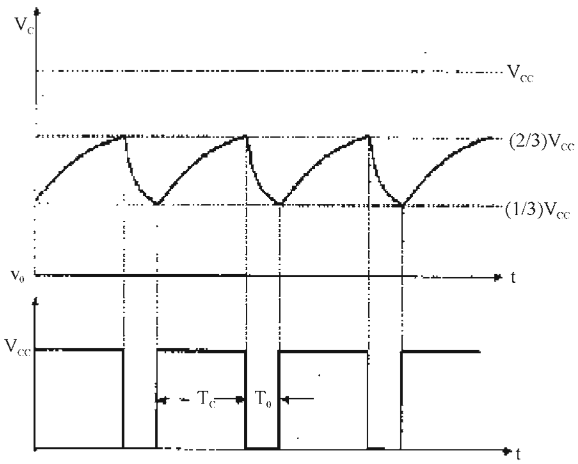

Fig. 2: Typical operating waveform of 555 IC astable multivibrator

DERIVATION OF THE MODEL

The two comparators along with RS flip-flop function as a switch at the base of the discharge transistor Q_1. Therefore the circuit of the Fig. 1 can be redrawn to the one shown in Fig. 3 which is more convenient for the calculation of the charging and discharging times.

When the switch 'S' is open the transistor Q_1 is in off state and the capacitor will charge through R_A and R_B. The charging time T_C is same as given by Eq. 1. When the switch 'S' is closed the transistor Q_1 will be in saturation state and it will behave as a closed switch with a small closure resistance $R_{CE(Sat)}$. Therefore the transistor can be replaced by a closure resistance $R_{CE(Sat)}$ as shown in Fig. 4. The closure resistance $R_{CE(Sat)}$ of the discharge transistor is the slope of the I_C verses V_{CE} and is given as[4]:

$$R_{CE(Sat)} = \frac{\Delta VCE_{(sat)}}{\Delta I_C} \tag{5}$$

where, $I_C = I_1 + I_2$

From the I_C-V_{CE} characteristics of the discharge transistor the closure resistance was found to be approximately 10 Ω from 1 to 90 mA and beyond 90 mA the closure resistance starts increasing and when it becomes equal to $R_A/2$ the oscillator stops oscillating. The discharging time of the capacitor is calculated by considering the circuit shown in Fig. 4. The complete response of the circuit shown in Fig. 4 is sum of natural response and forced response. The natural response can be evaluated by setting $V_{CC} = 0$ and finding the Thevenin resistance faced by the capacitor

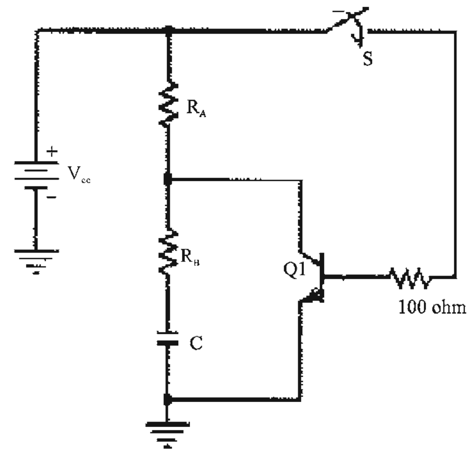

Fig. 3: Equivalent switching circuit

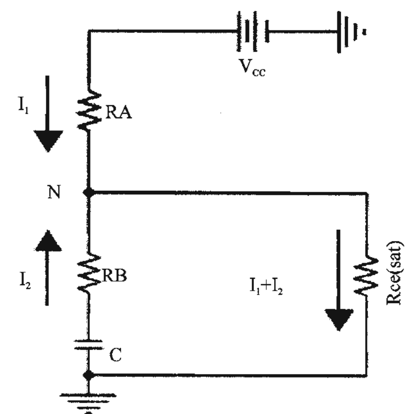

Fig. 4: Equivalent circuit when output of timer is low

$$R_{eq} = R_B + \frac{R_A R_{CE(Sat)}}{R_A + R_{CE(Sat)}} \tag{6}$$

and

$$V_{Cn} = A\exp(\frac{-t}{R_{eq}C}) \tag{7}$$

Now to evaluate the forced response the capacitor is treated to be open circuit and the forced voltage V_{Cf} are given as:

$$V_{Cf} = \frac{R_{CE(Sat)} V_{CC}}{R_A + R_{CE(Sat)}} \tag{8}$$

The complete response is:

$$V_C = \frac{R_{CE(Sat)} V_{CC}}{R_A + R_{CE(Sat)}} + A\exp(\frac{-t}{RC}) \tag{9}$$

Applying initial condition $V_C = \frac{2}{3}V_{CC}$ at t = 0

$$A = \frac{2}{3}V_{CC} - \frac{R_{CE(Sat)}}{R_A + R_{CE(sat)}}V_{CC} \quad (10)$$

Using Eq. 16 into 15:

$$V_C = \frac{R_{CE(Sat)}V_{CC}}{R_A + R_{CE(Sat)}} + \left(\frac{2}{3}V_{CC} - \frac{R_{CE(Sat)}}{R_A + R_{CE(Sat)}}V_{CC}\right)\exp(\frac{-t}{RC})$$

Applying final condition $V_C = \frac{1}{3}V_{CC}$ at $t = T_D$

$$\frac{1}{3}V_{CC} = \frac{R_{CE(Sat)}V_{CC}}{R_A + R_{CE(Sat)}} + \left(\frac{2}{3}V_{CC} - \frac{R_{CE(Sat)}}{R_A + R_{CE(Sat)}}V_{CC}\right)\exp(\frac{-T_D}{RC})$$

or

$$\frac{R_A - 2R_{CE(Sat)}}{2R_A - R_{CE(Sat)}} = \exp(\frac{-T_D}{RC}) \quad (11)$$

Solving Eq. 17 for T_D:

$$T_D = RC\ln\left(\frac{R_{CE(Sat)} - 2R_A}{2R_{CE(Sat)} - R_A}\right) \quad (12)$$

Use of Eq. 12 into 18, yields:

$$T_D = \left(R_B + \frac{R_A R_{CE(Sat)}}{R_A + R_{CE(Sat)}}\right)C\ln\left(\frac{R_{CE(Sat)} - 2R_A}{2R_{CE(Sat)} - R_A}\right) \quad (13)$$

Figure 5 shows the plot of Eq. 13 in MATLAB. The Fig. 5 shows that the discharging time of capacitor is increases exponentially with decrease in the resistance R_A. Equation 13 is valid only for, $R_{CE(Sat)} \le R_A/2$. This is due to the reason that when $R_{CE(Sat)} \le R_A/2$ then Eq. 13 becomes negative which is not possible and also at $R_{CE(Sat)} \le R_A/2$ the forced voltage across the capacitor becomes larger than $1/3V_{CC}$ and oscillation stops. The duty cycle of the waveform is given as:

$$D = \frac{0.693(R_A+R_B)}{0.693(R_A+R_B) + \left[\left(R_B + \frac{R_A R_{CE(Sat)}}{R_A + R_{CE(Sat)}}\right)\ln\left(\frac{R_{CE(Sat)} - 2R_A}{2R_{CE(Sat)} - R_A}\right)\right]} \quad (14)$$

Figure 6 and 7 shows the plot of Eq. 14 in MATLAB. The Fig. 6 illustrate that the duty cycle of the wave form decreases exponentially with the decrease in the resistance R_A.

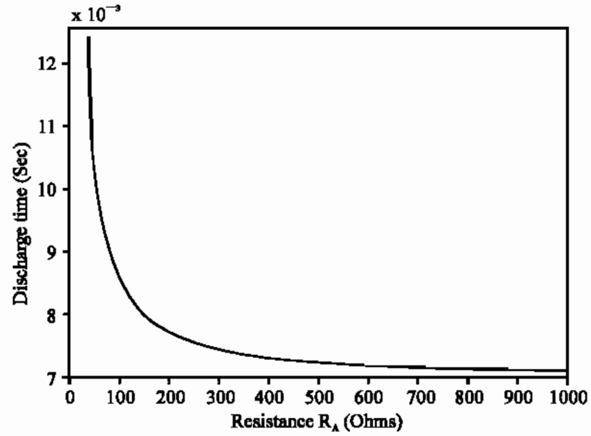

Fig. 5: Plot of Eq. 13 (C = 0.1 uF, $R_{CE(Sat)}$ = 10 Ω, R_B = 100 kΩ and R_A= 40→1000 Ω)

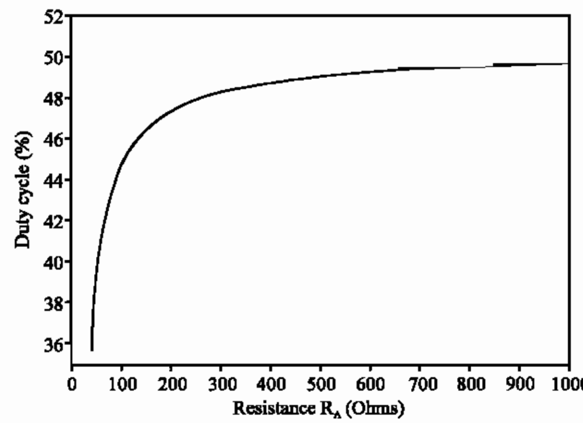

Fig. 6: Plot of Eq. 14 ($R_{CE(Sat)}$ = 10 Ω, R_B = 100 kΩ and R_A= 40 Ω→1000 Ω)

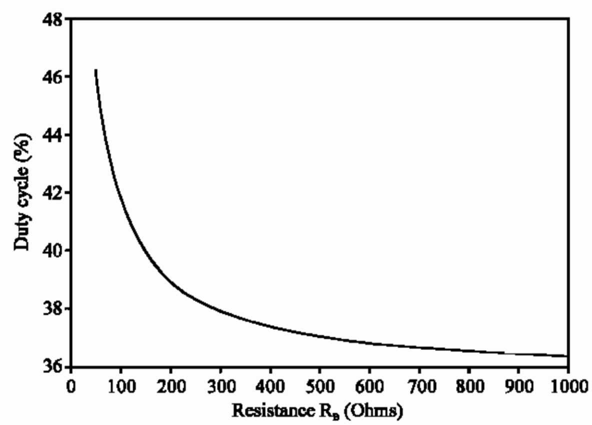

Fig. 7: Plot of Eq. 14 ($R_{CE(Sat)}$ = 10 Ω, R_A = 40 kΩ and R_B= 50 Ω→1000 Ω)

RESULTS AND DISCUSSION

In experiment the parameter of the Astable multivibrator circuit shown in Fig. 1 was set to as: V_{CC} = 5V, R_B = 100 kΩ, C = 0.1 uF and R_A was varied from 10 kΩ to 33 Ω. The experimental results are presented in Fig. 8-10, which shows the waveform at the output of the timer (upper) and at the pin 7 (lower), for R_A = 1 kΩ, R_A = 47 Ω and for R_A = 33 Ω, respectively. The results shows that the duty cycle is slightly less than 50% and this is in agreement with the theoretically results presented in Fig. 6. The experimental results shown in Fig. 8-10 are completely in agreement with theoretical results presented in Fig. 6 and 7. It was found that as long as $R_A \geq 40$ Ω, the closure resistance $R_{CE(Sat)}$ is 10 Ω. At R_A = 33 Ω the closure resistance is increase to 15 Ω and therefore using this value in expression (14), the corresponding duty cycle can be obtained.

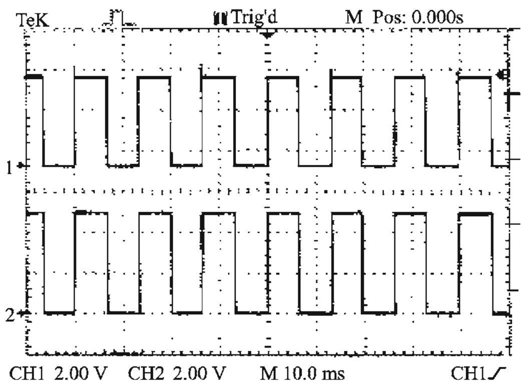

Fig. 8: Output Waveform (upper) and waveform at the pin 7 (lower); RA = 1 kΩ, R_B = 100 kΩ, $R_{CE(Sat)}$ = 10 Ω and C = 0.1 uF

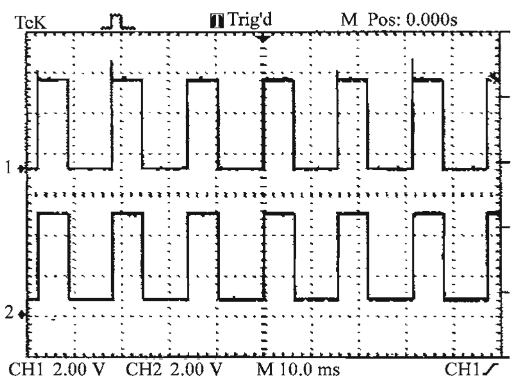

Fig. 9: Output Waveform (upper) and waveform at the pin 7 (lower); RA = 47 kΩ, R_B = 100 kΩ, $R_{CE(Sat)}$ = 10 Ω and C = 0.1 uF

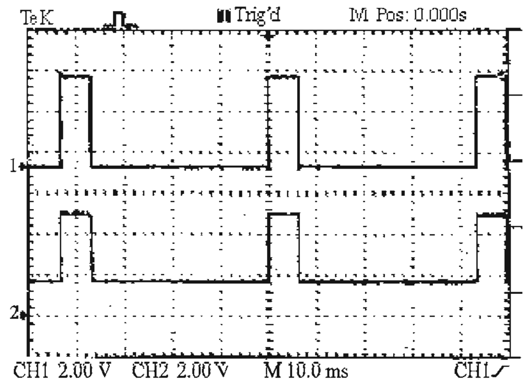

Fig. 10: Output Waveform (upper) and waveform at the pin 7 (lower); RA = 33 kΩ, R_B = 100 kΩ, $R_{CE(Sat)}$ = 15 Ω and C = 0.1 uF

CONCLUSIONS

In this paper it has been presented successfully that the previous model of 555 IC astable multivibrator circuit of Fig. 1 is invalid for $R_A \ll R_B$. This failure is due to ignorance of the closure resistance of the discharge transistor in that model. Hence taking in account the closure resistance of discharge transistor a new model has been developed. This presented model is valid for all values of R_A and R_B and is completely in agreement with experimental results.

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