Seelab Introduction (Expt 9)

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This report presents the results of a series of electronics experiments conducted using SeeLab, a hardware-software integration tool. The experiments included analyzing the output characteristics of an NPN transistor, studying the performance of different 555 multi-vibrator circuits, validating Faraday's and Lenz's laws, and observing the emf dependence on the velocity of a falling magnet. The experiments were designed to explore various concepts in electronics and demonstrate the capabilities of SeeLab as a flexible and versatile tool for hands-on learning and experimentation. The results obtained provide insights into the behavior of electronic circuits and validate fundamental electromagnetic principles.

I. EXPERIMENTS

- Transistor characteristics
- Astable multivibrator with IC 555
- EM induction to determine magnetic moment are mandatory

II. THEORY

The ExpEYES-17 board is powered and interfaced with a computer's USB port, and it can be programmed using Python. It serves as a versatile tool with multiple functionalities, including a low-frequency oscilloscope, function generator, programmable voltage source, frequency counter, and data logger. The accompanying software enables monitoring and control of voltages at various terminals. Additionally, other parameters such as temperature, pressure, etc., can be measured by converting them into electrical signals using appropriate sensor elements.

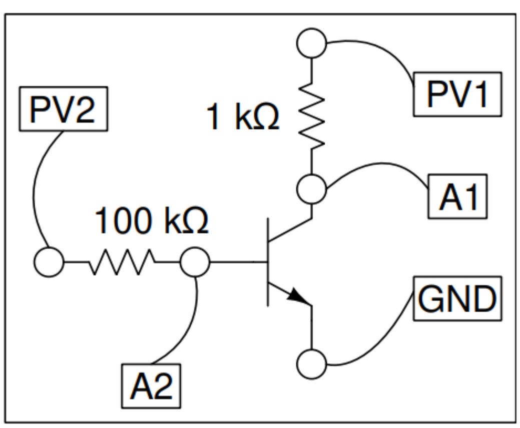

FIG. 1: circuit diagram to study transistor characteristics

A. NPN Transistor Output characteristics (CE)

The transistor functions by using a small current in one circuit to control a larger current in another circuit. The common emitter configuration is widely used in many applications. By studying the relationships between voltages and currents at different terminals, we can understand the transistor's operation. We plot the output characteristics by measuring the collector voltage against the collector current in a common emitter configuration, varying the base current. The collector current is determined from the voltage across a $1k\Omega$ resistor in the collector circuit.

The software controls the base current by adjusting the voltage at one end of the $1k\Omega$ resistor, with the other end connected to the transistor base. The base current value is calculated using the formula: $Ib = \frac{V_{PV2}V_{A2}}{100\times10^3} \times 10^6 \mu A$, where V_{PV2} is the voltage at PV2 and V_{A2} is the voltage at A2. If A2 is not connected, the code assumes $0.6V$ at the base to calculate the base current.

B. Astable multivibrator

A Multivibrator is a circuit that oscillates between a "HIGH" and "LOW" state, typically with a 50% duty cycle, meaning it has equal "ON" and "OFF" times. In sequential logic circuits, the state change may occur on the rising edge, falling edge, or both of the clock signal. On the other hand, stable pulse generation circuits do not have stable states, but rather continuously switch between two states, resulting in a train of square wave pulses at a fixed frequency. These concepts are important in understanding the behavior of multivibrators and pulse generation circuits, and play a significant role in digital electronics and circuit design.

The IC 555 is a popular integrated circuit with 23 transistors, two diodes, and 16 resistors, offering stability and affordability for timer and multivibrator applications. It can operate in mono/bi-stable or astable mode depending on external connections, generating single pulses or continuous pulse trains. Its versatility and characteristics make it widely used in modern electronics.

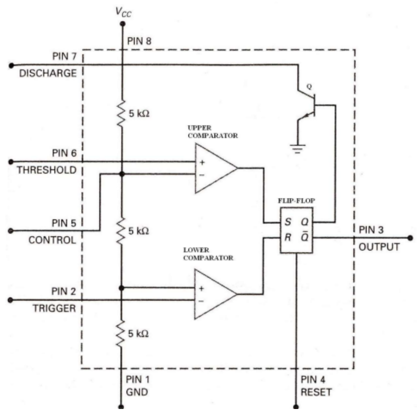

FIG. 2: Functional block diagram of IC 555

These circuits exhibit instability in any state and trigger output changes after specific time periods. As a result, they generate continuous square/rectangular waveforms with characteristics determined by the values of external resistors and capacitors.

The circuit diagrams in Figure 4 and Figure 5 depict the design of astable multivibrator using IC 555, with typical component values. The astable function is achieved by charging or discharging a capacitor through resistors connected to either V_{cc} or GND. The switching between charging and discharging modes is controlled by a resistor divider (R1-R3), two comparators, and an RS flip-flop within the IC 555. The upper and lower comparators generate positive pulses when the voltage across the capacitor (V_C) exceeds $\frac{2}{3}V_{cc}$ or falls below $\frac{1}{3}V_{cc}$, respectively. These positive pulses then set or reset the Q output.

The astable multivibrator generates a continuous square or rectangular waveform with a duty cycle of 50% or more. The charging and discharging of the capacitor is controlled by the resistors and capacitors connected to the IC 555, which determine the frequency and duty cycle of the output waveform. The resistor values of R1 and R2, along with the capacitor value, determine the frequency of the output waveform, while the resistor values of R1 and R3 determine the duty cycle. By adjusting these resistor and capacitor values, the frequency and duty cycle of the output waveform can be varied to suit the desired application.

- The time for charging C from $\frac{1}{3}$ to $\frac{2}{3}$ V_{cc} (i.e, ON Time $= 0.693(RA + RB) \cdot C$)
- The time for discharging C from $\frac{2}{3}$ to $\frac{1}{3}$ V_{cc}, (i.e., OFF Time $= 0.693RB \cdot C$)

To get the total oscillation period, adding the two:

$$\begin{aligned} T_{osc} &= 0.693(RA + RB)C + 0.693(RB)C \\ &= 0.693 \cdot (RA + 2 \cdot RB) \cdot C \end{aligned} \tag{1}$$

$$f_{osc} = \frac{1}{T_{osc}} = \frac{1.44}{(RA + 2RB) \times C} \tag{2}$$

$$Duty - cycle = \frac{RA + RB}{RA} + 2 \times RB \tag{3}$$

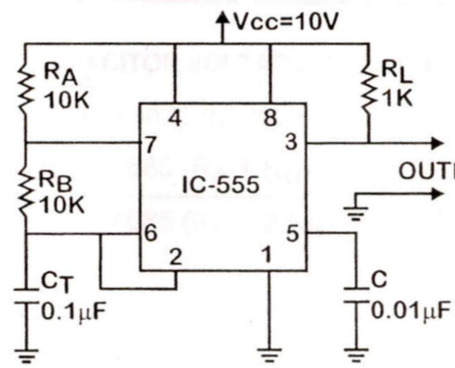

FIG. 3: Astable multivibrator circuit with duty cycle less than 50%

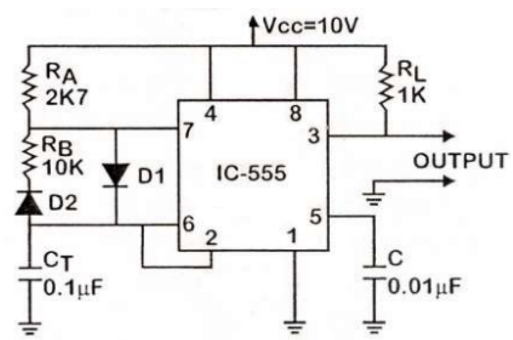

FIG. 4: Astable multivibrator circuit with duty cycle variable from 0 to 100%

C. EM induction

Faraday's law of EM induction states that anytime the flux connected with a coil changes, an emf is induced in the coil; the direction is determined by Lenz's law and is proportional to the rate of change in flux linkage. Thus, the coil develops an eddy current as a result of this emf. Moving a magnet back and forth across a coil can alter the flux flowing through it. Here, we talk about the scenario when the coil is fixed and the magnet is lowered through it. Unless there is some additional mechanism, air resistance and gravity forces will cause the magnet's velocity to vary. If we drop the magnet vertically along the z-direction keeping the coil at the origin,

$$z = -z_0 + 0.5gt^2$$

$$v = gt$$

where z_0 is the initial position of the magnet. Here g is the acceleration of the magnet. On passing through the coil, g decreases due to eddy current damping. Eddy current damping is responsible for the time delay in magnets falling through a long conductor. If the coil is short, we can neglect this. So the emf will be:

$$emf = -N\frac{d\phi}{dt}$$

$$emf = -N\frac{d(BA)}{dt}$$

The coil's induced voltage can be expressed as $V = -NAB\sin(\theta)$, where A is the coil's area, N is the number of turns of the coil, and B is the magnetic field produced by the small cylindrical bar magnet at the coil's center. The magnet, with a dipole moment m, can be considered as a current-carrying loop with n turns if its length is small.

$$m = nIA = nI\pi R^2$$

where R is the radius of the cylindrical magnet. We know that the field along the axis of the circular coil at distance x is given by:

$$B = \frac{\mu_o m}{2\pi}(R^2 + x^2)^{-3/2}$$

thus emf is given by:

$$emf = \frac{3\mu_o m}{2\pi}NA(R^2 + x^2)^{-5/2}xv$$

where v is the velocity of the magnet, thus for non-constant velocity emf is given by,

$$emf = \frac{3\mu_o m}{2\pi}NA(-z_0+0.5gt^2)(gt)(R^2+(-z_0+0.5gt^2)^2)^{-5/2}$$

$$\begin{aligned} emf = \frac{3\mu_o m}{2\pi}&NA(-z_0 + 0.5gt^2)gt \\ &\times (R^2 + (-z_0 + 0.5gt^2)^2)^{-5/2} \end{aligned} \tag{4}$$

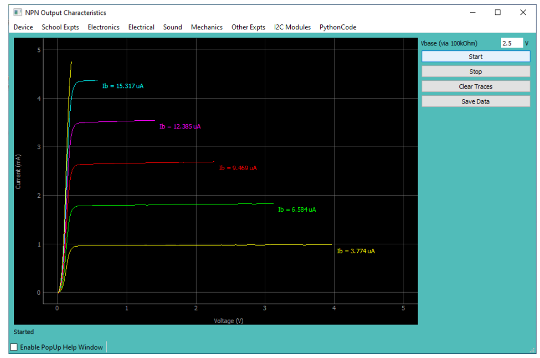

FIG. 5: Transistor charecterictics

III. OBSERVATION AND CALCULATION

A. Transistor charecteristics

The transistor characteristics for the given NPN transistor is shown Figure 5.

B. Astable multivibrator with IC 555

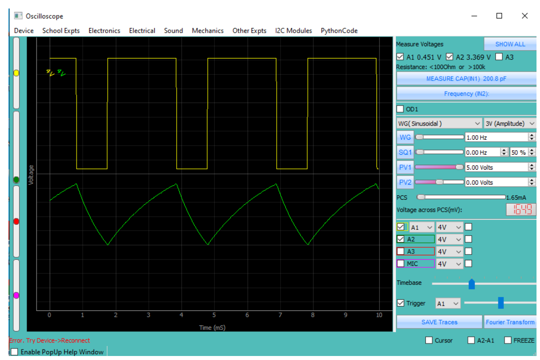

FIG. 6: voltage vs time graph for Astable multivibrator with duty cycle less than 50%

theoretically, $f = 720Hz$, Duty cycle=50%
observed, $f = 476.19Hz$,

$$\text{Duty cycle} = \frac{T_1}{T_1 + T_2} = 67\%$$

theoretically, f=389.1Hz, Duty cycle=72.9%
observed, f=381Hz,

$$\text{Duty cycle} = \frac{T_1}{T_1 + T_2} = 80\%$$

C. EM induction

From Equation 4 we have

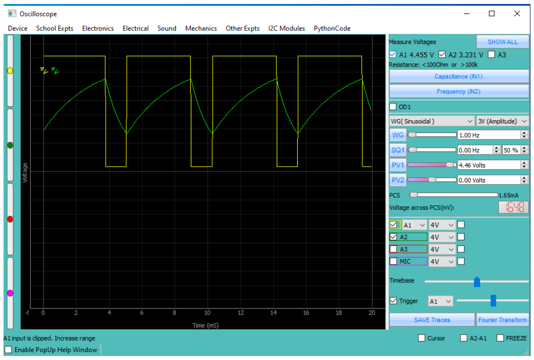

FIG. 7: voltage vs time graph for Astable multivibrator with duty cycle more than 50%

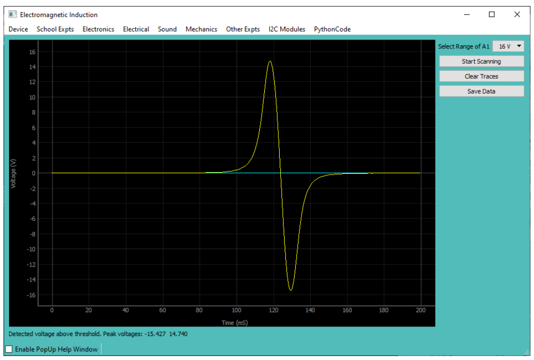

FIG. 8: Emf versus time graph for a vertically dropping magnet

We know that: $z_o = \frac{\text{length of coil}}{2} = 0.01m$

Also given: $N = 3000$ $t = 115ms$ $emf = 14.740V$ $R = 0.002m$

Thus, $m = 0.2161Am^2$

IV. ERROR ANALYSIS

In $IC555$ multivibrator circuit the observed value of frequency and duty cycle is different from the theoretical value. For the circuit with a duty cycle less than or equal to 50%.

There may be several reasons for the high error in the observed values of frequency and duty cycle in the circuit using IC555. One possible reason is the difference between the actual values of resistors and capacitors used in the circuit and the ideal values assumed during calculations, which can affect the frequency and duty cycle. Another factor could be a loose connection or instability in the circuit, resulting in variations in the observed values.

$$\delta f = 33.8\%$$

$$\delta(\text{duty cycle}) = 25.3\%$$

For a circuit with a duty cycle of more than 50%.

$$\delta f = 2.05\%$$

$$\delta(\text{duty cycle}) = 9.7\%$$

Similarly, the calculated magnetic moment may also have errors. Other forces such as air resistance and Lenz force, which are neglected in the calculations, could contribute to the error. Additionally, inaccuracies in the measured values of resistance (R) and distance (z) used in the calculations can also lead to errors in the magnetic moment value.

In summary, the high error in the observed values of frequency, duty cycle, and magnetic moment may be attributed to various factors, including differences in actual component values, circuit instability, neglected forces, and inaccuracies in measured values.

V. CONCLUSION

1. The NPN characteristics graph showed expected results, with the collector current remaining constant for a given base current, independent of the collector voltage above the threshold voltage of the Base-collector region.

2. The Multi-vibrator555 graph also matched the expected behavior in both cases, although there were slight errors in observed frequency and duty cycle values due to resistance and capacitance tolerances.

3. The EM wave graph exhibited two opposite peaks at different times, with the second peak being larger than the first peak. This indicates that the induced emf depends on the velocity of the magnet, with a higher moment of the magnet resulting in a larger emf. Negligible effects from Lenz's law and buoyant force were observed, and the magnetic moment of the magnet was calculated to be $0.2161Am^2$.

[1] project Phonix, expeyes-17 manual, Website (2022), https://csparkresearch.in/assets/pdfs/expeyes17.pdf.