How to Teach IC Timer NE 555 for Future STEM Teachers Through Virtual Lab

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Abstract. The use of simulation can help the learner to understand complex topics, such as signals and systems. This paper presents how to teach the IC Timer (NE 555 model) for future STEM teachers. This IC is a popular active component used in various fields; it can generate square wave signals and vary the Duty cycle. This paper proposes a course consisting of eight materials; it can be taught to future STEM teachers to understand the IC Timer NE555 concept carefully. The virtual laboratory practicum was chosen as the primary approach to provide initial understanding to future teachers about the square wave generator and Duty cycle controller. Besides, virtual laboratories are the right choice in engineering courses because they can minimize the risk of damage to electronic components and measuring instruments. Once future STEM teachers pass this proposed course, they can teach students using a virtual laboratory (simulation setup) before being forwarded to a hands-on laboratory. Circuit Wizard™ is the best option as a virtual laboratory because it provides the needed properties: passive components (i.e., virtually fixed resistors, electrolytic Capacitors, and Ceramic Capacitors), Active components (IC NE555), DC Sources (e.g., Battery), and Instruments (i.e., Virtual analog Oscilloscope)

Keywords: IC Timer, NE 555, Circuit Wizard™, Virtual Laboratory, STEM Teacher

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INTRODUCTION

Several elementary school levels in Indonesia have optional extracurricular programs related to STEM in their curriculum, e.g., electronics, mechanics, physics, robotics, Etc (Dewantoro et al., 2021; Machdi & Waryani, 2019; Widiastuti et al., 2016). In an electronics extracurricular program, usually, the primary material contains the introduction of basic electronic components followed by simple projects involving electrical circuits. The teaching method should adapt to or follow increasingly advanced technology, especially within the digital revolution that has transformed the way students to learn (Caena & Redecker, 2019). Therefore, STEM teachers should always be looking for the best strategies to educate students by employing existing technologies. However, teaching with these technologies remains a challenge for STEM teachers (Yaşar et al., 2015), especially in developing countries such as Indonesia. The complex material taught to elementary students should be theoretical and practical by providing students with direct experiences in a hands-on physical laboratory or virtual laboratory (simulation). With this strategy, it can support the students' understanding (Fuada & Wibowo, 2018; Wibowo & Fuada, 2016). The simulation approach can help students simplify complex phenomena in the real world (Wahyuni & Baroroh, 2015); thus, it will make them understand an abstract concept. Later, through simulation, students can simply adjust the parameters in such an object repeatedly with minimal risk (Lin et al., 2019).

One of the STEM topics in an electronic extracurricular program taught to elementary students is a blinking LED. The applications of blinking LED have been found around us, such as street markers, decorative lights, kites, Etc (Figure 1). This circuit can blink the LED lights through pulse generated by a simple electronic circuit. There are several options to be used as a core, i.e., IC timer NE555, Astable Multivibrator circuit using Op-Amp, and flip-flop circuits using BJT or FET Transistor. The timer IC NE555 is simpler, cheaper, and easier to be implemented than Op-Amp and BJT flip-flop. The IC NE555 was invented by Hans Rudolph Camenzind (1934 – 2012) in 1971 and commercialized in 1972 (Petritoli et al., 2021); it has been widely used for various applications, e.g., as a trigger circuit for the ultrasonic transducers (Hidayat et al., 2018), timer circuit (Rajput & Singh, 2015), touch switch (Yani, 2011), and other various cases (Ardaisi, 2017;

Jamaaluddin & Wakhidian, 2019; Putra et al., 2017). Applying IC timer NE555 as a base for blinking LED circuits to elementary students is very interesting. It can attract students' interest in learning electronics circuits but teachers need to understand the basic concepts of NE555 first. The problem arises that not all STEM teachers can easily understand this IC because the application concept is relative hard. Hence, structured guidance is needed through specific courses in teacher education programs, as (Kiazai et al., 2019) revealed that teacher education programs have a significant role in mitigating challenges of implementing STEM education at school.

Figure 1. Illustrations of the blinking LED application

According to the literature studies, there is no published paper on how to teach IC Timer for future STEM teachers. In previous work, we have proposed a curriculum of the IC Timer NE555 course for future STEM teachers; the course was composed of 10 meetings (Dewi et al., 2021). This paper simplifies the number of course meetings from the previous proposal to streamline implementation time. Then we obtain eight meetings. The Circuit Wizard™ is still used as a material basis to simulate a simple blinking LED circuit. The proposed course's output is the future STEM teacher can understand why the LEDs can blink using a stable electrical source (battery). Later, they can understand the waveforms (e.g., square wave, sinusoid, etc.) and Pulse-Width Modulation (PWM), read the frequency generated by NE555, determine the Duty Cycle, and So on.

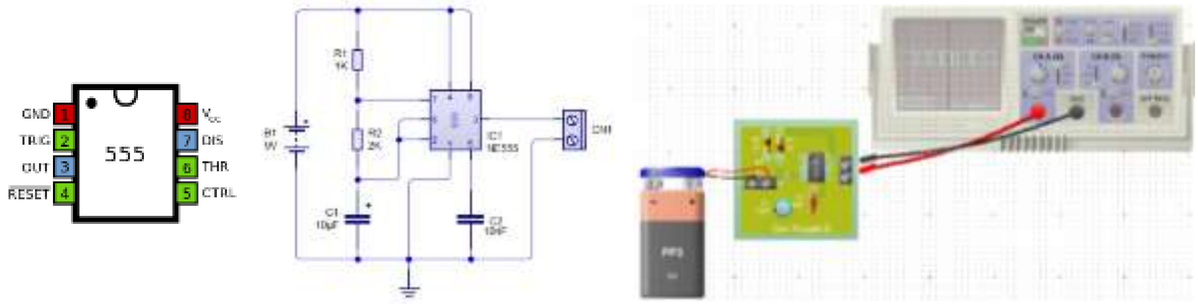
Other researchers have previously utilized similar simulation approaches. However, they used MultiSIM (Abrar, 2017), TINA PRO (Rahaman et al., 2015), Matlab – Livewire – Proteus (Fuada & Aquari, 2013), which have different graphical user interfaces (GUIs) with Circuit Wizard™ software. The Circuit Wizard™ provides an electronics laboratory that resembles the real world, including passive–active electronic components and measuring instruments. Even though the virtual laboratory mode serves limited items, it is very appropriate for this course. For this reason, Circuit Wizard™ is more suitable for use compared to the software mentioned earlier. The novelty of this study is to propose a simple learning strategy/design to teach IC Timer NE555 for future STEM teacher since there is no work to discuss in detail regarding this issue.

METHOD

The IC NE555 pin is shown in Figure 2(a); it has eight pins, i.e., 1) Ground, 2) Trigger, 3) Output, 4) Reset, 5) Control Voltage, 6) Threshold, 7) Discharge, and 8) Power Supply (VCC). In this course, the IC NE555 is set to generate the square wave signals (Astable Multivibrator configuration). The circuit is composed of several items, i.e., IC NE555, resistors and capacitors (denoted as R_1, R_2, C_1, and C_2), a single battery with 9V, and Terminal Blocks as the input and output pins, assembled under Wizard Circuit™ simulator (Figure 2b). The Astable Multivibrator circuit can trigger itself (Hidayat et al., 2018), (Tooley, 2015). The PCB version of IC Timer is then connected to a 9V battery and Virtual Analog Oscilloscope to measure the generated frequency following by its Duty Cycle (Figure 3c).

The learning process in this proposed course is fully supported by the Circuit Wizard™, which will be explained through eight meetings in the practicum session, we will describe every meeting in Section III (Results), which is: introduction of the signal shapes, theory of frequency and period in a signal, introduction of frequency measuring instrument, introduction of the IC

NE555, frequency measurement using virtual analog Oscilloscope, introduction of virtual laboratory using Circuit Wizard™, practicum step, and the last is evaluation.



(a) (b) (c)

Figure 2. (a) The NE555 – Pin diagram; (b) NE555 configured as an Astable multivibrator circuit; (c) Timer circuit using NE555 assembled in a Circuit Wizard™ consisting battery and Virtual analog Oscilloscope

RESULTS

Introduction of the Signal Shapes

The material of this meeting is similar to (Dewi et al., 2021). We introduce various signal forms to the future STEM teacher first, i.e., sinusoidal, square, Ramp, Pulse, Arbitrary, and Complex (Figure 3). However, this course is more highlights the square signal. Therefore, the circuit arranged in the simulator will be set to generate square wave signal.

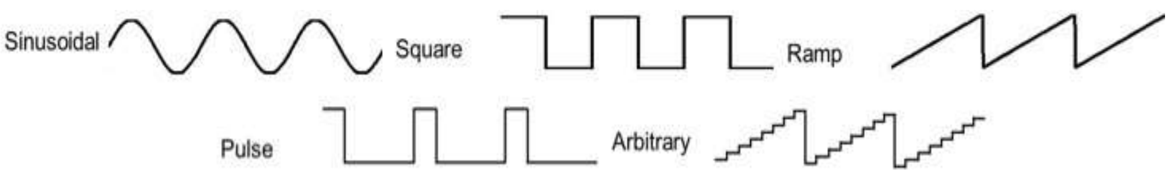


Figure 3. Different waveform signal containing sinusoid, square, ramp, pulse, arbitrary, Etc.

Theory of Frequency and Period in a Signal

Similar to (Dewi et al., 2021), in the second meeting, we introduce the frequency formula. Electrical signals have a period (denoted as T). Later, the signal's frequency (denoted as *f*) can be obtained through Equation (1). This meeting provides an understanding for the future STEM teachers about the theoretical formulas of Frequency and Period.

$$f = \frac{1}{T} \qquad (1)$$

Introduction of Frequency Measuring Instrument

To measure the frequency generated by the NE555 circuit, we can use an Oscilloscope or Frequency Counter. However, Circuit Wizard™ provides only a virtual Oscilloscope, as shown in Figure 4. In this meeting, it is expected that future teachers can understand the part of an analog Oscilloscope (e.g., DIV, T/DIV, Power button, Channel (+) input, Channel ground, V/DIV, Disp., Trigger, Etc.) and how to operate it well.

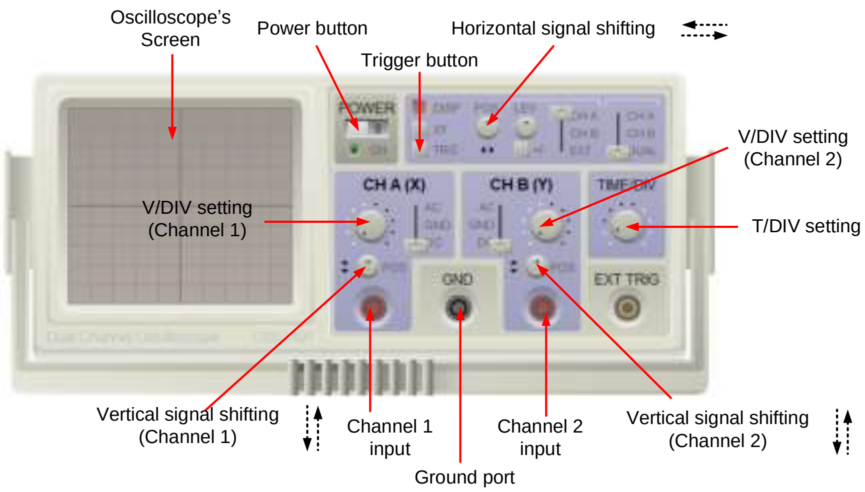
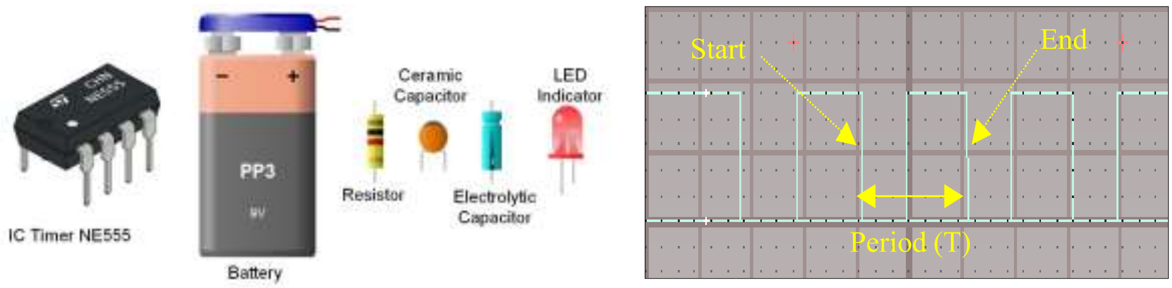


Figure 4. The appearance of the Virtual analog Oscilloscope on Circuit Wizard™

Introduction of the IC NE555

The Op-Amp, IC timer NE555, and BJT/FET transistor can be employed to generate square wave signals (Dewi et al., 2021). However, we still use the NE555 as the base of this course. Figure 5(b) visualizes an example of the generated square wave signal in Circuit Wizard™ setup. We can read the period of square wave signal by using Equation (2). In this meeting, it is hoped that future STEM teachers can understand the items used for square wave signal generators, *e.g.,* Battery, Capacitors, Resistors, LED, and IC NE555, as shown in Figure 5(a).

$$T = DIV \times T/DIV \qquad (2)$$



(a) (b)

Figure 5. (a) Items used for assembling the Astable Multivibrator using NE555; (b) One period of a square wave signal displayed on an analog Virtual Oscilloscope

Frequency Measurement using Virtual Analog Oscilloscope

In this meeting, the future STEM teacher is taught how to measure period and frequency by looking at the signal formed on the virtual analog Oscilloscope. Given a specific value of T/DIV, then the future STEM teacher can count how many signal boxes a period is expressed in the DIV. The number of DIV is then multiplied by the T/DIV (can be seen on the Oscilloscope screen in the lower right corner), the result is the period (T); the formula used Equation (2). To convert the period to frequency form, Equation (1) is applied. Figure 6 is an example of square wave signal with 25 ms of T/DIV and DIV = 2. The results are T = 50 ms and *f* = 20 Hz.

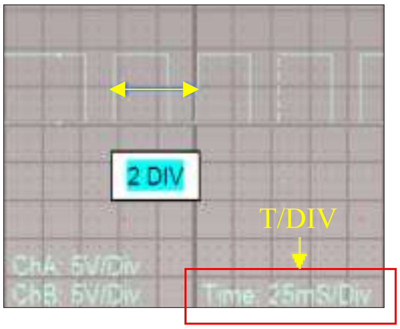
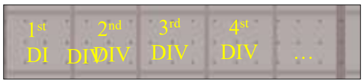


Figure 6. An example of a square wave

The frequency calculation on Virtual analog Oscilloscope can be found as follows:

1. Count the number of DIV when the signal is rising-edge (start) andfalling-edge (end)



2. Calculate the T Period=DIV x T/DIV

 = 2 x **25 ms** = 50 ms *or* 50 × 10^{-3} s

3. Calculate the *f*

Frequency $= \frac{1}{50 \times 10^{-3}} = 20$ Hz

Introduction of Virtual Laboratory using Circuit Wizard™

As mentioned above, in doing practicum, we used a virtual laboratory due to that quite simple. To operate Circuit Wizard™, we only require a personal computer. Circuit Wizard™ provides the PCB layout feature, and it can make electronic components and measuring instruments look real. The Circuit Wizard™ operation is an offline simulator and relatively easy. This software is not free access (licensed software). Hence, if there is no premium access to the Circuit Wizard™, users can use the 30 days trial version option. Another option, users can insert serial numbers that have been provided globally on the Internet. However, this is not the best option due to copyright infringement. In this course, we used the trial version. By this meeting, the future teacher will be taught the virtual worksheet and how to operate the Circuit Wizard™ properly.

Practicum Step

After the learning materials are given to the future STEM teachers, later they do the simulation through the provided worksheet. They are expected to carry out practical simulations more easily.First, they make an Astable Multivibrator circuit using IC Timer NE555 in the Circuit Wizard (Figure 1b), then converted into virtual laboratory modes (Figure 1c). The PCB of the Astable Multivibrator is connected to the Battery and Virtual analog Oscilloscope. The future STEM teachers can vary the value of resistors following the worksheet guidance. Afterward, they define the period (T) of generated square wave signal by Equation (2), then the frequency of the NE555-based Astable Multivibrator can be found by using Equation (3).

The duty cycle illustration is shown in Figure 7. The duty cycle compares the time when the signal rises-edge (T_{on}) to the period (T). Duty Cycle 50% means, T_{on} is equal to half of 1 signal period. Duty Cycle 25% means, T_{on} is equal to a quarter of the signal period, and so on. This signal can be called as PWM. To find out the Duty Cycle, the future STEM teachers can use Equation (4). During the simulation, the future STEM teachers can discuss and ask educators if they face a problem. After the calculation was complete, the future STEM teachers perform the simulation following by results analysis. The simulation result is a square signal as shown in Figure 8 with different R_2 values setting and fixed value setting of Resistor I (R_1 = 1 kΩ) and Capacitors (C_1 = 10 µF & C_2 = 10 nF). Compared to the mathematical calculation (Equation 3), the resulting frequency measured from the virtual Oscilloscope has a difference, but it is very small (Table 1). Increasing R_2 will increase the T_{on} and decrease the Duty cycle, down to 50%.

$$T = 0{,}693\ (R_1 + 2R_2)\ C_1 \quad (2)$$

$$f = \frac{1}{0{,}693\ (R1 + 2R2)\ C1} \text{ or } \frac{1{,}44}{(R1 + 2R2)\ C1} \quad (3)$$

$$D = \frac{((R1 + R2)\ x\ 100\%)}{R1 + 2R2} \quad (4)$$

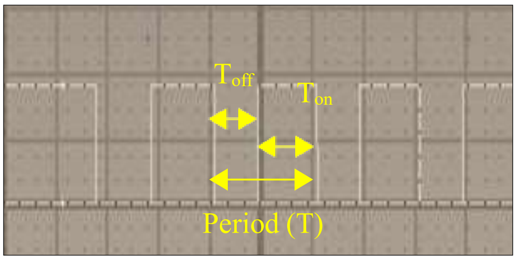


Figure 7. An illustration of the Duty Cycle of the square wave signal

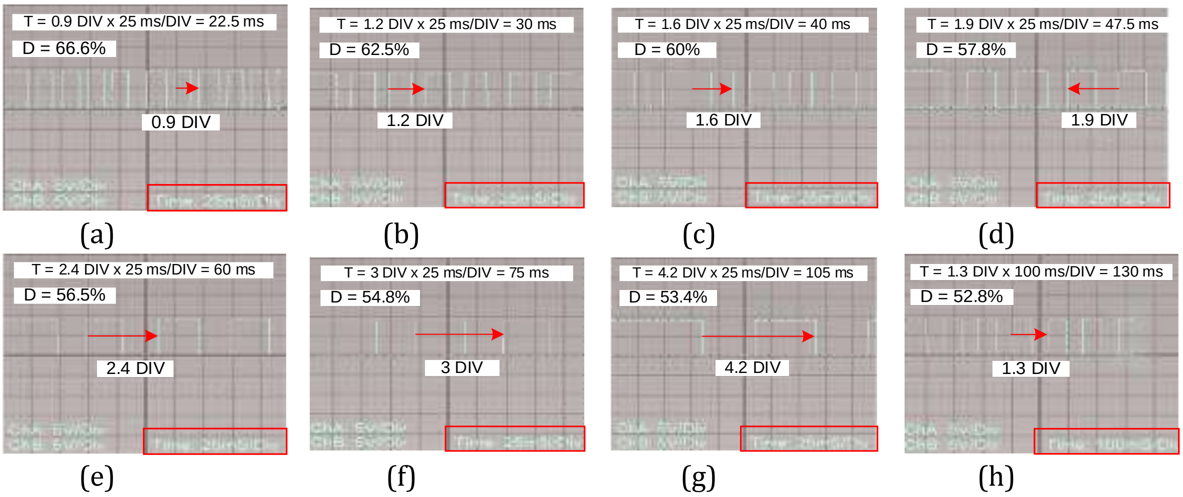


Figure 8. The results of the seventh meeting activities finished by the future STEM teachers: (a) T = 22.5 ms, *f* = 44.4 Hz; (b) T = 30 ms, *f* = 3.3 Hz; (c) T = 40 ms, *f* = 25 Hz; (d) T = 47.5 ms, *f* = 21 Hz; (e) T = 60 ms, *f* = 16.6 Hz; (f) T = 75 ms, *f* = 13.3 Hz; (g) T = 105 ms, *f* = 9.5 Hz, and (h) T = 130 ms, *f* = 7.6 Hz

Table 1. Observation result of the Astable Multivibrator using NE555 conducted by the future STEM teachers

No	R_2 (kΩ)	R_1 (kΩ)	C_1 & C_2	*f* Calculation of NE555 (Hz)	*f* Oscilloscope (Hz)	Difference (Hz)	Duty Cycle
1.	1			48	44.4	3.6	$=\frac{(10^3 + 10^3)\ x\ 100)}{10^3+(2x10^3)} = 66.6\ \%$
2.	1.5			36	33.3	2.7	$= \frac{(10^3 + 1{,}5\ x\ 10^3)\ x\ 100)}{10^3+(\ 2x\ (1.5x10^3))} = 62.5\ \%$
3.	2		10 µF & 10 nF	28.8	25	3.8	$= \frac{(10^3 + 2\ x\ 10^3)\ x\ 100)}{10^3+(\ 2x\ (2x10^3))} = 60\ \%$
4.	2.7			22.5	21	1.5	$= \frac{(10^3 + 2{,}7\ x\ 10^3)\ x\ 100)}{10^3+(\ 2x\ (2.7x10^3))} = 57.8\ \%$
5.	3.3			18.9	16.6	2.3	$= \frac{(10^3 + 3{,}3\ x\ 10^3)\ x\ 100)}{10^3+(\ 2x\ (3.3x10^3))} = 56.5\ \%$
6.	4.7			13.8	13.3	0.5	$= \frac{(10^3 + 4.7\ x\ 10^3)\ x\ 100)}{10^3+(\ 2x\ (4.7x10^3))} = 54.8\ \%$

No	R_2 (kΩ)	R_1 (kΩ)	C_1 & C_2	*f* Calculation of NE555 (Hz)	*f* Oscilloscope (Hz)	Difference (Hz)	Duty Cycle
7.	6.8			9.8	9.5	0.3	$= \frac{(10^3 + 6.8\ x\ 10^3)\ x\ 100)}{10^3 + (\ 2x\ (6.8x10^3))} = 53.4\ \%$
8.	8.2			8.2	7.6	0.6	$= \frac{(10^3 + 8.2\ x\ 10^3)\ x\ 100)}{10^3 + (\ 2x\ (8.2x10^3))} = 52.8\ \%$

Evaluation

At this stage, the course participants are expected to understand well the Astable Multivibrator circuit concept and apply it significantly using virtual tools and materials. They can build an Astable Multivibrator circuit using NE555 in Circuit Wizard™ and change other parameters, such as R_1, C_1, and C_2. Afterward, they will observe what is the impact in changing these parameters to frequency output & Duty Cycle. In this meeting, educators can evaluate the future STEM teacher by validating the simulation result and the depth analysis level.

CONCLUSION

This article is a curriculum simplification of the previous proposal (8 from 10 meetings). The course's participant in this paper is a future STEM teacher. This course provides understanding to future STEM teachers about teaching the blinking LED concept through a simulation approach. The blinking LED utilizes IC NE555. It is expected that future STEM teachers can adapt this proposed course to their students in the future. There are eight meetings used in this course, where the 1st to 4th is the same with (Dewi et al., 2021), i.e., 1) Introduction of the Signal Shapes; 2) Theory of Frequency and Period in a Signal; 3) Introduction of Frequency Measuring Instrument; 4) Introduction of the IC NE555; 5) Frequency Measurement using Virtual Analog Oscilloscope; 6) Introduction of Virtual Laboratory using Circuit Wizard™; 7) Practicum Step; and 8) Evaluation. Since this paper is a proposal, therefore the implication to the society is still questionable. For this reason, in future work, we will open this course in Indonesia; everyone who is a future STEM teacher can follow this proposed course.

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