Development of Educational Kit for Practical Course in the Topic of Phase-Shift RC Oscillator

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Abstract—This research develops a phase-shift RC Oscillator trainer kit that can be used to give undergraduate students an understanding of one of the materials related to analog circuit practicum. The Oscillator is one of the essential subtopics to be examined thoroughly by electrical engineering students. Furthermore, the Resistor and Capacitor modules were provided separately to be connected to the trainer through jumper cables. The phase-shift RC circuit in the trainer kit used a single Op-Amp 741 while the Network model utilized an Inverting Amplifier to determine the gain which must be ≥ 29 times, therefore, feedback resistor (R_f) value should be greater or equal to 29 times of gain resistor (R_g) value. To full fill $R_f \geq 29\ R_g$, we select $R_f = 30$ kΩ and $R_g = 1$ kΩ. Two tasks in this learning media were completed by students, namely measuring the output frequency and observing the phase shift. The output signal on this trainer kit was observed using only an Oscilloscope and a frequency counter. The phase inverter of the phase-shift RC Oscillator adjusts the output signal by 180º and sends feedback to the input, therefore, there is positive feedback. Meanwhile, the trainer kit had an output frequency specification of ~649 Hz (C_1, C_2, C_3 = 100 nF, R_1, R_2, R_3 = 1 kΩ) and it shifts the phase by 60º on each RC network. Using 2 and 3 RC networks, the phase shifts were 120º and 180º, respectively. The trainer kit was packaged in a box made of acrylic with dimensions $l \times w \times h$ = 20 cm × 28 cm × 5 mm. Through a questionnaire consisting of 13 criteria, this trainer kit was declared valid, namely $r_{count} > 0.2960$ (5%) and reliable (Cronbach's alpha > 0.60, which was 0.732) to be used as a learning media based on user responses, namely students as the respondents (N = 35). In the context of technical education, this trainer kit also supports the efficient implementation of practicum without compromising the learning objectives due to the ease of operation (plug & play through jumper cables) compared to fully assembling the circuit using a project board.

Keywords—trainer kit, phase-shift RC oscillator, Op-Amp, practical course

1 Introduction

The Oscillator is one of the frequent topics presented in lectures at Indonesian universities majoring in electrical science, both educational and non-educational, through theoretical and practical lectures. Generally, there are courses related to analog electronics. This is a pulse generator circuit with certain applications in electronics. There are three types of analog Oscillator, namely Resistor – Capacitor (RC), Inductor – Capacitor (LC), and relaxation [1], [2]. Furthermore, there are various types, including phase-shift RC which has a total phase shift of 180º in the circuit [3]. This phase inverting circuit was formed by three RC circuits using single feedback. The characteristics of the RC phase-shift type include: 1) it does not require a transformer or inductor, because it is composed using three-stage resistors and capacitors; 2) each 1-stage RC has a phase difference of 60º, therefore, a three-stage RC has a phase difference of 180º; and 3) using an Inverting amplifier with gain must be ≥ 29 times, therefore it can be expressed as $R_f \geq 29R_g$.

Understanding the Oscillator characteristics requires a systematic thinking ability supported by the trainer kit. Based on Internet searches, various similar trainer kits are sold commercially in online stores, but making self-designed learning media is a top priority for the following reasons: 1) Some trainer kits are made by obscure institutions, therefore, the validity and reliability is questionable; 2) Similar media are produced abroad which makes the price expensive due to additional import costs, even though the media making up materials are available in the local market, and production costs are cheaper; 3) There is financial support, teamwork and adequate laboratory facilities for self-production; 4) teaching aids equipped with customized job sheets or referring to the latest curriculum catalog, therefore, linear with the latest learning objectives; 5) Media developed through research and development (R&D) in the target environment is claimed to be more effective in the long term. There are several processes required, namely: observation of media needs (pre-development) from interviews of lecturers and students taking the relevant courses, validation of media designs to technical trials and their feasibility; as well as 6) Media can be verified in advance by experts covering the flexibility, practicality, durability of the media, portability, and other aspects, therefore, the media is really valid to use.

Based on the literature review, it was determined that several trainer kits were developed by various researchers such as Podder, *et al.* [4], Sudira, *et al.* [5], Huriawati, *et al.* [6], Jamil, *et al.* [7], Dewanti, *et al.* [8]. When compared to similar trainer kits developed by [4]–[8], the advantage of this trainer is that students are invited to be more active in assembling resistors and capacitors to the trainer directly (hands-on lab) according to the available components to form a phase-shift Oscillator circuit. Furthermore, the output is viewed on the Oscilloscope and Frequency counter. The practicum trainer was developed to help students assemble in accordance with a series of practical experiments and design a series for enhanced understanding as well as to further increase student activity in the learning process. Therefore, it is expected that students will better understand the material delivered in class. The weakness in [4]–[8] is that the trainer does not direct students on how to assemble a series. However, they were directed on how to ascertain the output and observe how the circuit works in principle. The developed trainer can stimulate students to practice the process of assembling a circuit correctly without eliminating the main goal in learning, because one of the competencies of electrical engineering students is wiring skill, as the issue raised by [9]. The four learning objectives of this trainer kit development include enabling students to determine the working principles and characteristics of the RC phase-shift circuit (output frequency & phase shift at each RC point), to correctly design the provided circuit in accordance with the basic theory, ability to test the circuit in a practical hands-on laboratory using measuring instruments, as well as the ability to analyze and conclude the practicum results. A similar trainer kit was developed by Isminarti [10] but is more focused on the Astable Multivibrator. Moreover, Uran, et al., developed a phase-shift Oscillator that integrates with the cloud server, therefore, it is remotely accessible [11]. However, the scope of practicum and learning objectives between this research to other studies are different. The developed trainer kit focuses on measuring the output frequency and observing the phase shift in the RC network levels I, II, and III, more similar to [4].

Trainers as a form of technology-based learning media have several essential advantages, namely 1) enhance the understanding of students concerning the material provided due to changes in viewpoints, patterns of reasoning, and behavior [12], 2) can increase active participation and the academic performance of students compared to the traditional material delivery format [13], 3) increase creativity more deeply in the related curriculum [14], and 4) assist students in concretizing abstract and conceptual material [15], [16]. Therefore, it indirectly realizes learning activities that involve all aspects owned by students through cognitive, affective, and psychomotor aspects

2 Method

2.1 Oscillator design

The phase-shift RC Oscillator trainer kit consists of three boards: main and supplementary. The mainboard is a box consisting of a single-layer PCB Oscillator with a generic Op-Amp 741 component installed. Passive components Resistors (such as R_1, R_2, R_3, R_f, and R_g) and Capacitors (C_1, C_2, and C_3) are not mounted on the printed-circuit board (PCB) as they are placed on a separate board (supplementary board). The supplementary board consists of the resistor and capacitor modules. There are two resistor boards provided, namely (1) 1kΩ & 10 kΩ and (2) 3 kΩ & 30 kΩ of resistor modules. As for the capacitor board, only one is provided, which contains 10 nF & 100 nF mylar capacitors. Each resistor value (1 kΩ, 10 kΩ, 3 kΩ, 30 kΩ) and capacitor (10 nF & 100 nF) on the board totals four pieces. In the implementation, only 30 kΩ is used as a feedback resistor (R_f) and 3 kΩ is not used. Module resistor provides a value of 3 kΩ for other trainer kits in the same package as this trainer kit, namely the Op-Amp-based Hartley – Colpitts Oscillator [17], Op-Amp-based Astable Multivibrator [18], and Op-Amp-based Wien Bridge oscillator [19].

In principle, the Oscillator works based on the *Barkhausen* stability criteria [20], where there are two important variables: 1) the gain of the op-amp (α) formed by a series of resistors R_f and gain resistor (R_g), both connected to the negative input of the Op-Amp, then 2) feedback (β) generated by the RC network coupled with the positive input of the Op-Amp. The phase-shift is a type of RC Oscillator, and determining the output frequency on the Oscillator circuit with consistent value will require feedback to the circuit, namely positive and negative [2]. Negative feedback involves feeding the output to the input signal with 180° phase-shift. Meanwhile, positive feedback involves feeding the output to the input signal with 0° phase-shift. The circuit for this trainer kit provides positive feedback.

This oscillator produces good frequency stability, however, the disadvantage is the difficulty to begin oscillation. This is because the output is generally small, therefore, the feedback is also small. The circuit in Figure 1(a) is a three-stage RC ladder network that forms the basis of a complete phase-shift RC Oscillator (Figure 1b). The value of β can be obtained through the division between R_f and R_g where the ratio of R_f and R_g must be 29 : 1 [3]. If the ratio is lower than 29, the oscillator will not oscillate. Hence, to meet this consideration, the phase-shift Oscillator trainer kit will provide R_g of 1 kΩ and R_f of 29 kΩ (2 kΩ and 27 kΩ series resistors). To reduce the use of components, a resistor on the market that is close to 29 kΩ is chosen, namely 30 kΩ. An ideal single RC network would produce exactly 60°, 120° and 180° phase-shifts. However, in reality, it is difficult to obtain exactly 60° for the phase-shift process, therefore, it requires a precise selection of resistor and capacitor values. The amount of phase-shift depends on the RC values. This local Oscillator is often used for synchronous receivers, musical instruments, and as a low-frequency generator for audio applications [21]. The output frequency formula for phase-shift RC Oscillator is expressed in Equation (1), where n is the number of RC circuit network. In this case, it uses $n = 3$ or three RC networks to shift 180° of signal where root 6 is equal to 2.45. Finally, it can be rewritten as Equation (2).

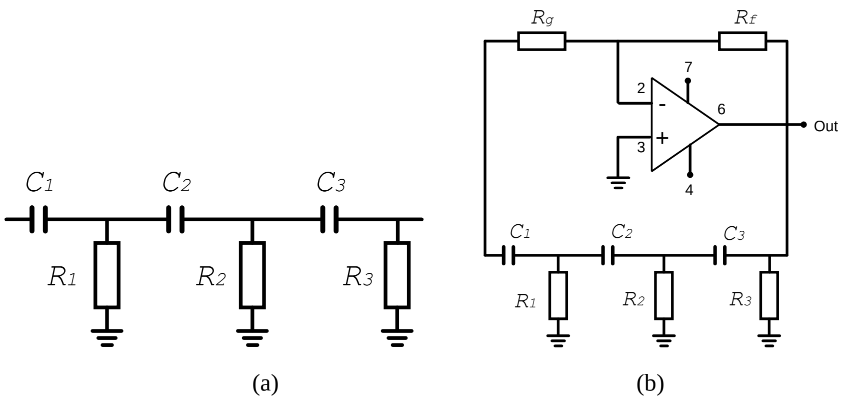


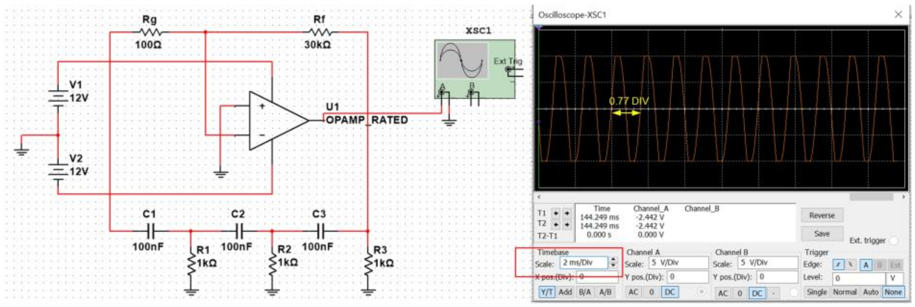
Fig. 1. (a) Base network of three-stage RC phase-shifter; (b) phase-shift RC Oscillator circuit

$$\frac{1}{2\pi RC\sqrt{2n}} \quad (1)$$

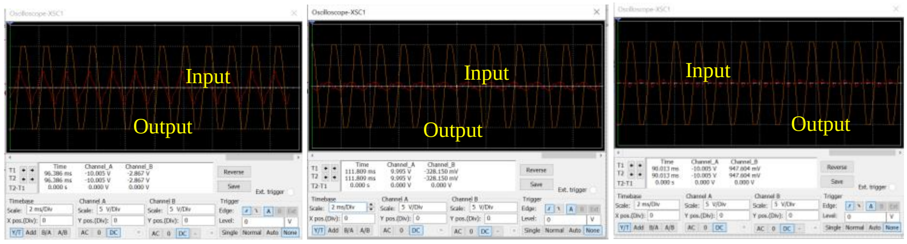
$$\frac{1}{4.9\pi RC} \quad (2)$$

The conditions for perfect oscillation are: $R = R_1 = R_2 = R_3$ and $C = C_1 = C_2 = C_3$. Furthermore, this equation is for calculating the output frequency produced by the Oscillator, if $R_1 \neq R_2 \neq R_3$ and $C_1 \neq C_2 \neq C_3$, then the manual calculation will be more complex. The RC phase-shift Oscillator uses an inverting amplifier. The frequency output can be read by seen the period (T) of the sinusoid signal on the Oscilloscope.

To ensure that the trainer kit design is in accordance with its function, an initial simulation was first carried out. Multisim® software (version 14.0) was used to measure the output frequency and to determine the phase-shift. Multisim® is SPICE-based simulation that is familiar to most students in Indonesia and has been widely used to simulate a simple electronic circuit, such as [22]. Multisim provides an Oscilloscope graphical-unit interface (GUI) with a time per division (*T/DIV*) setting and a proper division (*DIV*), therefore, it can ease the designer to search for frequencies. Besides, Multisim provides a virtual Oscilloscope with two channels: channel 1 (CH1) and channel 2 (CH2), therefore, it enables the designer to examine the phase-shift. The phase-shift comparison can be seen clearly through CH1 (output) and CH2. The CH2 was moved from RC stage I, to stage II and finally in RC stage III. The component value settings are as follows, $R_1 = R_2 = R_3 = 1$ kΩ, $C_1 = C_2 = C_3 = 100$ nF, $R_f = 30$ kΩ and $R_g = 100$ Ω instead of 1 kΩ. If we put 1 kΩ as R_g in a Multisim environment, the circuit can not oscillate so that the value of R_f should be much higher than R_g, which is $R_f = 30$ kΩ and $R_g = 100$ Ω. The simulation results of Oscillator's output frequency and phase shifter of each stage are shown in Figures 2(a) and 2(b), respectively. Furthermore, the simulation results show that the phase-shift RC Oscillator circuit based on the Op-Amp 741 model can generate a sine signal with a frequency of 649.35 Hz ($T = 1.54$ ms obtained from the multiplication between 0.77 *DIV* with 2 ms/*DIV* as the scale used) and successfully shift the signal 60º according to the theory. However, the signal of each block is little bit different peak-to-peak (V_{pp}) voltage. This is the limitation of Multisim®.



(a)



60°　　120°　　180°

(b)

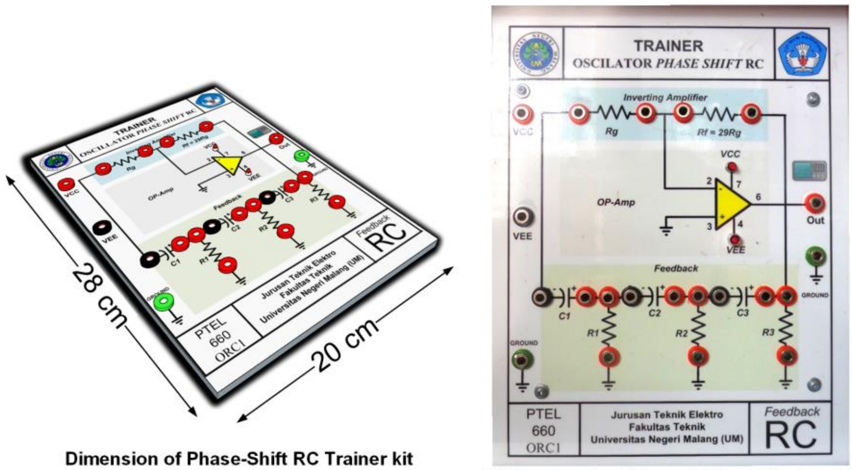
Fig. 2. (a) Simulation circuit on Multisim simulator and output frequency measurement results; (b) phase shift review results

2.2 Define the student's initial ability

The initial ability of students who will access or operate this trainer kit needs to be defined to facilitate the implementation of practical activities [1]. Furthermore, it is expected that they will immediately be able to interact and adapt to the trainer kit, thereby playing an active role in practical learning. Students are also required to understand the basics of instrumentation, physics, and mathematics, understand and master electronic passive components such as resistors and capacitors, active electronic components (IC Op-Amp), understand the operation of symmetrical power supplies, electronic circuit schematics, and be familiar with various measuring instruments such as digital/analog Multimeter, Oscilloscope, and Frequency Counter. This trainer kit can be included in the curriculum of the study program or department in certain subjects where there are prerequisites as previously mentioned. It is also highly recommended that students perform a circuit simulation first (virtual lab method) before carrying out a real practicum (hands-on method) to minimize equipment damage [23]–[25] while providing an overview of the actual practicum. This accelerates students' understanding of previously abstract material.

2.3 Implementation

The development of this trainer kit was carried out at the Power Electronics Laboratory and Digital Electronics Laboratory, G4 Building, Electrical Engineering Department, Faculty of Engineering, State University of Malang. Figure 3 visualizes the 2D design of the trainer kit and the implementation result.



Dimension of Phase-Shift RC Trainer kit

A Photograph of Phase-Shift RC Trainer kit

Fig. 3. Design and implementation of phase-shift RC oscillator trainer kit

The box trainer kit is made of white acrylic with a thickness of 5 mm and dimensions of 28 cm × 20 cm. It is made using Microsoft Visio 2003® and was then printed on glossy coated vinyl sticker paper to make it more durable. The PCB circuit was made using the Eagle® software and printed on a silver-coated fiberboard to prevent oxidation (mushrooming). Furthermore, the indicator light on the Op-Amp's positive voltage (V_{CC}) and Op-Amp's negative voltage (V_{EE}) leg connections on the Op-Amp 741 utilized a red 3 mm LED. The banana plug pins were provided as ports to be connected to the available resistor and capacitor modules through jumper cables. PCB Pad on resistors and capacitors replaced wires and connected to the banana plug that has been installed in the phase-shift RC trainer kit. The V_{CC} and V_{EE} pins were connected to the Op-Amp PCB via a ¼ Watt 1 kΩ carbonfilm resistor and a LED mounted on the board. Figure 4 is a front view design of the phase-shift RC Oscillator trainer kit and a description of its parts. This trainer kit has been registered with intellectual property rights (IPR) in Indonesia since January 14, 2020, with No. registers EC00202001570 and No. recording 000177546. Afterward, it was examined using two instruments: Analog Oscilloscope and Frequency Counter.

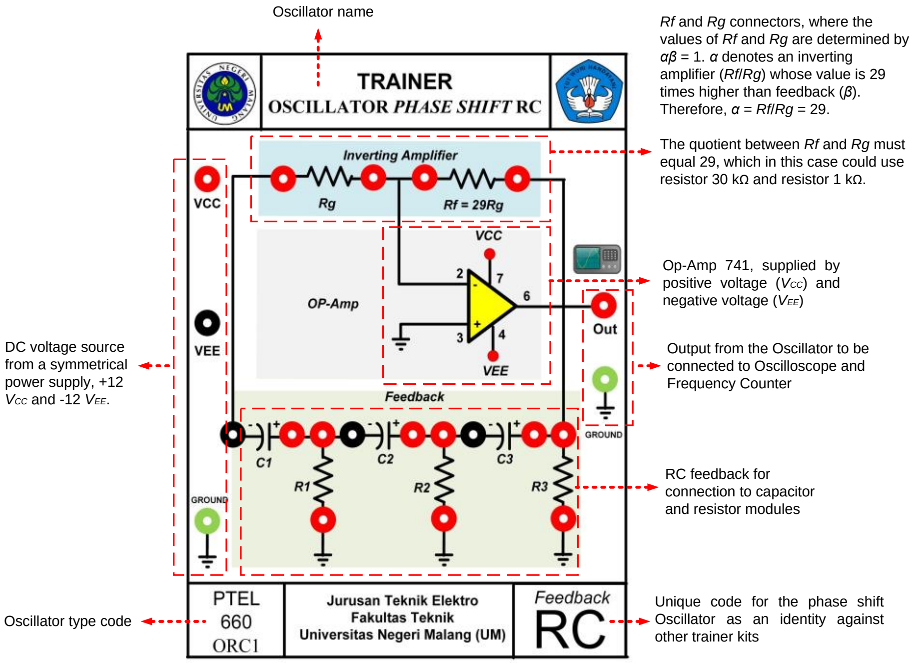


Fig. 4. Part of phase-shift RC Oscillator trainer kit

2.4 Student response methodology

The trainer kit was to be verified functionally by measuring the output frequency and phase shift at stages I, II, and III at the RC feedback point. Furthermore, students will assess this trainer kit as users.

A total of 35 students in fifth semester of the Electrical Engineering Education Study Program batch 2012 (class A & B), Faculty of Engineering, State University of Malang were selected as respondents (N = 35). Paper-based questionnaires were distributed to respondents after testing the functional trainer kit, and a total of 13 items (*Q.1 – Q.13*) were given. Respondents gave a score of 1 to 4, where 4 = strongly agree, 3 = agree, and 2 = agree and 1 = strongly disagree. The results of the Likert scale analysis were often applied by various research in Indonesia in the trainer kit validation that was developed, such as carried out by [26]. Students rate more about visuals, responsiveness to ease of use, and functionality of the trainer kit according to the questionnaire questions given (Table 1). The analysis of the validity and reliability of the instrument in this research was carried out with the help of the SPSS® (Statistical Program for Social Science) 23.0 for Windows program.

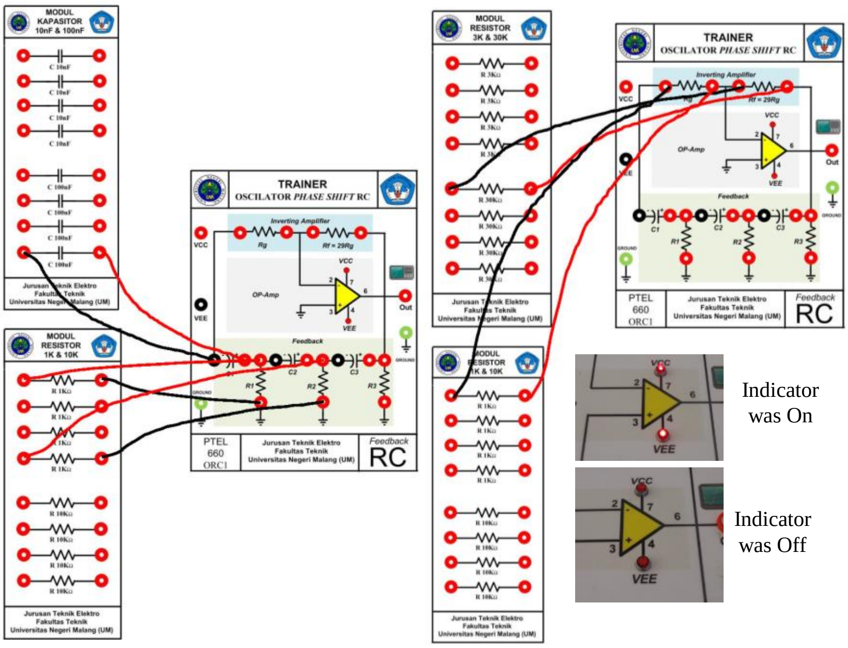
Table 1. Trainer kit questionnaire

Item	Question
Q.1	Attractive trainer design, therefore can foster learning motivation.
Q.2	The trainer is easy to use and simple to operate.
Q.3	In the trainer, there is a description of the voltage source, components, codes, types, measuring instruments, and outputs that are presented clearly.
Q.4	Trainers are packed neatly.
Q.5	The V_{CC} indicator light and the V_{EE} trainer are working properly.
Q.6	Connecting cable works fine.
Q.7	Layout/composition Circuit drawings, voltage sources, outputs, components, indicator lights on the trainer design are presented appropriately.
Q.8	The color of the banana plug on the trainer matches the polarity.
Q.9	The circuit image on the trainer clearer the understanding of the trainer usage.
Q.10	The writing on the trainer is clearly legible.
Q.11	Selection of materials on quality trainers.
Q.12	Ideal trainer size (not too small and not too big).
Q.13	Overall attractive trainer design.

3 Results and discussion

3.1 Technical testing

For testing, a symmetrically regulated power supply was required for producing +12V and -12V outputs which was then connected to the trainer kit phase-shift RC inputs, namely ports V_{CC} for +12V input, V_{EE} for -12V input, and *GND* for connecting to ground power supply. This voltage was the power supply for the generic Op-Amp 741 in the trainer kit. The two indicator lights (LED 3mm) lit up when properly connected. Furthermore, the power was turned off first and the connection of the resistor and capacitor modules to the trainer was carried out through jumper cables. In this case, $C_1 = C_2 = C_3 = 100$ nF and $R_1 = R_2 = R_3 = 1$ kΩ is chosen. while R_g is chosen as 1 kΩ and $R_f = 30$ kΩ. Therefore, the gain obtained was 30 which fulfilled the phase-shift RC requirement, namely $\alpha \geq 29$ [3]. An Analog Oscilloscope (GW INSTEK GOS-620FG 20 MHz) and a Frequency Counter (GW INSTEK GFC-8010H 120 MHz) are connected to the output ports of the phase-shift RC Oscillator trainer kit. The connection of the resistor and capacitor module to the feedback section (three-stage RC network) is shown in Figure 5(a). Figure 5(b) illustrates the procedure for connecting the resistor module to the amplifier section (R_f and R_g) and illustrates the indicator LED lights off or on.



(a) (b)

Fig. 5. Wiring procedure for α and β of the phase-shift RC Oscillator

Figure 6 is the measured output frequency on an analog oscilloscope. *T/DIV* is selected 0.5 ms and $DIV = 3.1$. Therefore, $T = 1.55$ ms or frequency output (f) = 645.16 Hz. The readings on the analog oscilloscope were carried out manually by looking at the *T/DIV* and *DIV* [27], [28]. Meanwhile, on the frequency counter, the output frequency and period values were directly displayed, namely, $T = 1.54$ ms and $f = 649$ Hz (Figure 7). With the settings $V/DIV = 2$ and $DIV = 3$, therefore, the peak-to-peak voltage of the output signal was 6 V_{pp}. The calculation of the output frequency is close to the theory in Equation (2), which is 649.9 Hz. According to the test, technically, the phase-shift RC Oscillator trainer kit has succeeded in producing a frequency in form of a sine wave which value is determined by three-stage RC as feedback, R_g, and R_f. Therefore, functionally and technically it can be used as a medium of learning. Table 2 compares the results of theoretical calculations, simulations (using Multisim 14.0), real measurements on an Analog Oscilloscope, and Frequency Counter, where the results are in line with [3].

The results of the output frequency measurement using an Oscilloscope and a Frequency Counter are not exactly the same, as there was a 3.84 Hz difference. Both were then compared with the mathematical calculations of Equation (2). The difference between theoretical calculations and Oscilloscope readings was 4.74 Hz. Meanwhile, between theoretical calculations on the Frequency Counter, the difference is 0.9 Hz. The value shown on the Frequency Counter is closer to theoretical calculations because the

Oscilloscope's accuracy is only 0.2 *DIV* or 1/5 concentration, while the frequency counter has an accuracy of up to 0.00001 or $1/10^5$ [1], [19].

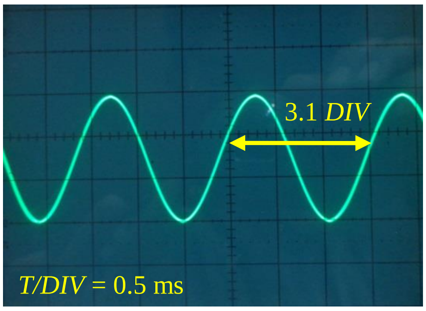
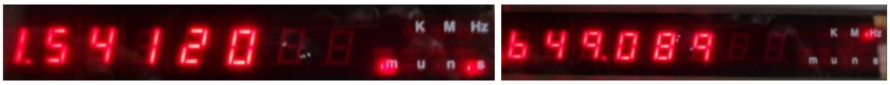


Fig. 6. Output frequency displayed by analog oscilloscope



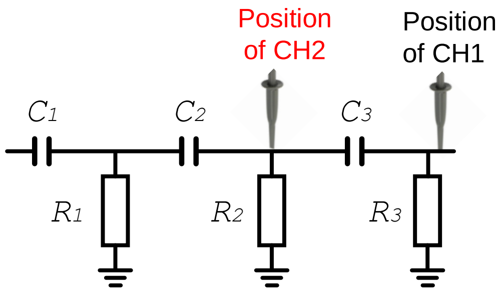
(a) (b)

Fig. 7. Output frequency displayed by frequency counter: (a) period mode, T = 1.54 ms; (b) mode frequency, f = 649 Hz

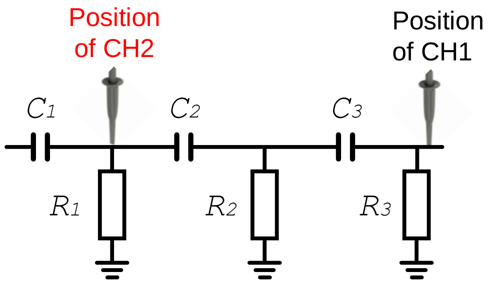
Table 2. Output frequency measurement summary

R_1, R_2, R_3	C_1, C_2, C_3	Theory	Simulation	Oscilloscope	Frequency Counter
1 kΩ	100 nF	649.9 Hz	649.35 Hz	645.16 Hz	649 Hz

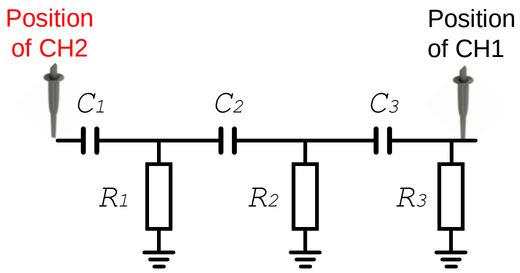
Furthermore, the trainer kit verified whether the phase-shift RC circuit shifts by 60° at each point of the single-stage RC circuit. The experimental connection was not changed, as only one channel Oscilloscope was required to be connected to the RC point. Therefore, CH 1 was connected to the trainer kit output while CH2 is positioned varied according to Figure 8(a) to Figure 8(b). In this case, the connection to the Frequency Counter is disconnected. The test results are shown in Figure 9. The test shows that the signal shifts 60° on a level I RC network, shifts 120° on a level II RC network, and 180° on a level III RC network. The measurement results showed that the signal successfully shifted 60°, 120°, and 180°. This result is in accordance with the performance of the trainer kit developed by [4]. Although not exactly the shift towards theory, the test was concluded to be successful. The phase-shift position depends on the RC values of the Oscillator.



(a) 60º

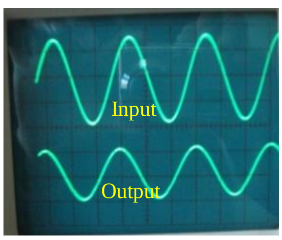


(b) 120º

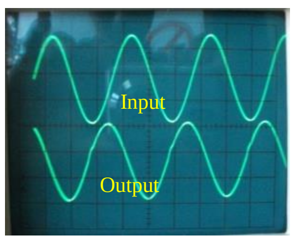


(c) 180º

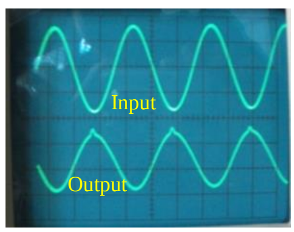
Fig. 8. Observation of phase shift at each point of the RC network



(a) 60º



(b) 120º



(c) 180º

Fig. 9. Testing the phase shift, the upper signal output frequency on the oscillator and the lower signal is the RC network of each stage: (a) setting *V/DIV* = 1 & *DIV* = 3.1, (b) setting *V/DIV* = 0.2 & *DIV* = 3.1, (c) setting *V/DIV* = 0.1 & *DIV* = 2.3

3.2 Student response

Table 3 is the validity result using SPSS® software. The determination of r_{count} *df-2* to be 30 because N = 35, where r_{count} = 0.2960 (5%) and 0.4093 (1%). In the validity test, the data is believed to be valid if $r_{count} > r_{table}$ in the product-moment. However, the item is declared invalid if $r_{count} < r_{table}$ in the product-moment. Based on Table 4, the results of the instrument validity test showed that all items are valid. Furthermore, there are 11 items with validity test results above a significance value of 1%, namely *Q.1, Q.2, Q.3, Q.4, Q.6, Q.7, Q.8, Q.9, Q.10, Q.11*, and *Q.12*. For *Q.13*, items related to the overall design have a significance value of 5%. This questionnaire is also believed to be reliable if Cronbach's alpha value is higher than 0.60 (>.6). Based on the output reliability statistics table, the result was 0.732. Therefore, it was deduced that the questionnaire is reliable (Table 3). The level of reliability obtained was also classified as high (strong) because it includes the interval of 0.60 – 0.799 [29], [30].

Table 3. Validity test

Item	r_{count}	r_{table} (5%)	r_{table} (1%)	Criteria
Q.1	0.608*	0.2960	0.4093	Valid
Q.2	0.568*	0.2960	0.4093	Valid
Q.3	0.567*	0.2960	0.4093	Valid
Q.4	0.623*	0.2960	0.4093	Valid
Q.5	0.402	0.2960	0.4093	Valid
Q.6	0.642*	0.2960	0.4093	Valid
Q.7	0.664*	0.2960	0.4093	Valid
Q.8	0.469*	0.2960	0.4093	Valid
Q.9	0.666*	0.2960	0.4093	Valid
Q.10	0.568*	0.2960	0.4093	Valid
Q.11	0.420*	0.2960	0.4093	Valid
Q.12	0.459*	0.2960	0.4093	Valid
Q.13	0.353	0.2960	0.4093	Valid

Table 4. Reliability test

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	*N* of Items
.732	.844	14

The trainer kit produced through this research constitutes one of the solutions on how to provide media capable of turning generally abstract material into useful appliances, including analog electronics which involve a discussion of signal generators. An Oscillator circuit can simply be composed of only a few components, in the case of a phase-shift RC circuit, namely a resistor, a capacitor, an Op-Amp [1], a single BJT Transistor [31], or a single Transistor MOSFET [32]. However, more understanding is required for students to master the overall competencies that include several sciences at once, such as mathematics, physics, and electronics by paying attention to the three main aspects of learning (cognitive, affective, psychomotor) [33]. With the availability of this adequate trainer kit, the implementation of the practicum becomes more qualified and optimal [34]. This is because it saves time in assembling and testing circuits. Furthermore, due to several practicum activities (hands-on labs) related to electronics found in the Department of Electrical Engineering, which still utilize conventional methods that are less practical, namely assembling components on the project board with lots of jumper cables. For students with a below-average ability and level of understanding of the material, it seems difficult to adapt and the time becomes longer. Student errors occur due to rushing to complete the practicum because of the limited time duration. Therefore, several crucial steps were missed, including theoretical calculations, recording and documenting the results, and conducting preliminary analysis, because much time was spent on assembling the circuit on the project board. Students also have difficulty doing troubleshooting if an error occurs in practice due to much cable usage. The long duration of troubleshooting makes the use of practicum time allocation less qualified. Practical problems using jumper cables and project boards are often the main issue of ineffective practice implementation and become the basis for developing trainer kits for researchers in Indonesia, as has been carried out by [35]–[38].

The incomplete implementation of the learning process may affect the subsequent learning process and advanced courses. This trainer kit has been developed with its own design and has helped solve the problem that is generally faced by electronics laboratories in developing countries such as Indonesia. This problem is primarily the limited use of learning media because the procurement of imported trainer kits tends to be expensive [39], and not necessarily in accordance with the expectations of lecturers and learning objectives that have been designed according to the existing curriculum [23], [40], [41]. The operation of this trainer kit is easy, where students only provide a trainer kit, resistor module, capacitor module, measuring instruments (Oscilloscope & Frequency Counter), and asymmetric power supply. The wiring process is still present, but neater and more concise because the Oscillator circuit is available in the trainer kit where students just need to adjust the resistor and capacitor module pins to other pins. This is performed according to the guidelines provided and does not require assembly from scratch. The Oscillator circuit is very sensitive to the quality of wire connections. In several previous experiments done by author, namely assembling the Oscillator circuit on the project board with jumper cables, it is proven that the Oscillator did not produce any signal. This was due to the cable not being properly connected to other components on the project board. In the previous experiment, it was that the project board was often used, therefore, the hole points were loose due to the jumper cable being exposed to friction. Furthermore, if the output sinusoid signal displayed by the oscilloscope becomes unstable and even disappears, then it is necessary to check the connections one by one.

This trainer kit uses a female pin and a strong male – male cable, therefore, it provides a good connection (maximum bond) between components in the phase-shift RC Oscillator circuit. Students can also see the V_{CC} and V_{EE} indicator lights if the connection of the symmetrical power supply to the trainer kit is correct or not reversed. Wiring activities are still used when using this trainer kit to enhance the student learning experience in terms of wiring abilities. Through the phase-shift RC Oscillator trainer kit, it is also expected that students will not only get theoretical explanations from lecturers but explore their knowledge through practical experience. Students connect the available modules, prove the results against the theory, and carry out an analysis according to what has been learned, to draw conclusions and suggestions. This is in accordance with the definition of the trainer kit itself in that the trainer is one of the practical learning media that can facilitate students in proving the characteristics of a series they have learned through assembling, measuring, analyzing, and concluding activities with reference to the learning objectives [42]–[46]. As an implication, the learning outcomes increase, as been proven by [47].

4 Conclusion and future work

The learning process with abstract material characteristics such as the Oscillator topic requires a trainer kit to concrete it, therefore, students understand and experience the learning process well. The phase-shift RC Oscillator trainer kit has been successfully developed through a series of activities, namely design, simulation, implementation, functionality verification, and assessment of students as target users. Furthermore, this trainer kit is a practical tool where there are several components of resistors and capacitors in a module that are assembled or connected to the main module (phase-shift RC Oscillator), therefore, the circuit can work according to its function (generating a perfect sinusoid signal). Functional verification for the task of frequency output measurement was carried out through the Analog Oscilloscope and Frequency Counter. Meanwhile, testing for the phase-shift task was only reviewed using the Analog Oscilloscope. The results showed that the Oscillator produced sinusoidal outputs at angles of 60^o, 120^o and 180^o on three-stage RC. The trainer kit can be directly integrated with the mini digital Oscilloscope in one kit to reduce the use of jumper cables, but the activity of connecting the resistor and capacitor modules should still be carried out. This helps to preserve the user experience in the wiring process. Resistor and capacitor modules with a more varied value is required, therefore, it does not only produce one kind of output frequency. Furthermore, the questionnaire must involve several other important aspects, aside functionality, operational ease, and visuality.

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