# Design and Fabrication of LC-Oscillator Tool Kits Based Op-Amp for Engineering Education Purpose

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### Abstract

*Tool kit is one of learning media that have important role in engineering education, the author has been finished in developing tool kit with oscillator "LC circuit" topic. This oscillator can generate a sinusoidal wave with constant frequency and amplitude. With this tool kit wish the student can develop their skill and applicated in electrical, electronic, communication circuits and systems area. In this paper, a proposed design, fabrication and testing of sine wave oscillator "LC" type (Hartley and Colpitts oscillator) has been performed using five approaches. The first approach proposed design is done theoretically using the basic theorems used to generate oscillations, such as the condition of oscillation criteria and determine the values of capacitor (C) and inductor (L) component, Secondly it is done using simulation technique (LTSpice IV), Thirdly the simulated design is implemented practically using IC OP-AMP 741 with passive elements such as resistors, capacitors and inductors by oscilloscope and frequency generator. Fourthly design the Hartley and colpitts tool kit by 2-D and 3-D, layouting the circuit by Eagle PCB design software then package into tool box which integrated each other. Finaly, the LC-oscillator tool kit was tested such as resistor, capasitor and inductor module and write the result into tables (for jobsheet data).*

*Keywords: Engineering Education, LC-Oscillator Tool Kits, Oscilator Hartley, Oscillator Colpitts*

## 1. Introduction

In the early days of engineering education, the laboratories in engineering education have to be central role, because there are have strategic function for achieving learning goals [1], a study say that the students will get knowledge not more than 5% if hearing the teacher/lecturer only, it mean that method of teaching is the least effective. Then 10% by reading, 20% by audio visual, 30% by demonstration, 50% by discussion group, 75% practice by doing and 90 % by teach others [2]. The strong experience of laboratory work helps many students to permanently memorize studied issues, especially those whom by very nature does not suit the passive lectures and study texts [3]. So, laboratories with students working in groups that the best way to teach was to "practice by doing" and "teach others".

Oscillator is one of material in workshop industrial instrument courses at State University of Malang (UM), Indonesia. This course is learn about signal generator (specific-periodic waveform such as square and sinusoidal) and its applications. The materials i.e: LC Oscillator, RC Oscillator and Relaxation oscillator. But there are no interactive media for teaching-learning activity. The focus here is on LC-oscillator: Colpitts and Hartley that created using the operational amplifiers (Op-Amps).

There are many tool kits that have been sold in the market like in Figure 1.

(a)


(b)

Figure 1. (a) Hartley Oscillator Product, available at http://www.btcinstrument.com/practicals-physics-engineering.html. (b) Colpitts Oscillator Product, available at: http://www.indiamart.com/sakyascientificinstruments/electronic-oscillators.html.

But, author must adapt the tool kit learning media with the electrical engineering department State University of Malang curriculum and its syllabus. So the author made it media by self design and model and development in instrumentation labs. State University of Malang. This tool kit is included "jobsheet" as learning material, so the students possible to learn independently [4]. The jobsheet contained manual book (practical instructrions), work procedures of the oscillators. So the psicomotoric puspose goals can be taken. With the jobsheet, students can operate LC oscillator easily by reading instructions that have been determined. Related study say that "*Achievement of learners that uses jobsheet as a practical guide is better than who do not use jobsheet*" [5].

This paper described how to design, fabrication and testing the Hartley and Colpitts oscillator tool kits (based on IC OP-AMP 741) for learning material of industrial instrumentation worklab course in Electrical Engineering Departement State University of Malang.

**LC Oscillator**

The Hartley and Colpitts oscillator is based LC work that their frequency of oscillations is determined by constants of L and C circuit. The actual of its oscillations is the resonant frequency (natural frequency) of LC tank circuit given by: 1 / (2 * phi * (sqrt (L*C))). If a large value of capasitor is used, it will take long to charge fully and also longer to discharge and if large value of inductor make current flow greather and hence time required to complete each cycle will be longer [6].

The Hartley oscillator was invented American engineer "Ralph Hartley" in 1915 while he was working for the Western Electric company. The original design was tube based and he got a patent for it in the year 1920 [7]. This is an old oscillator and very popular. Using LC feedback (inductor-capasitor in a single circuit) and inverting OP-AMP mode. This oscillator commonly applied in RF (FM and AM) and the recommended frequency range is from 20KHz to 30KHz. Hartley oscillator developed by two series inductors (L1 and L2) connected with one capasitor by parallel [7] [8], like the LC tank circuit that visualized in Figure 2.
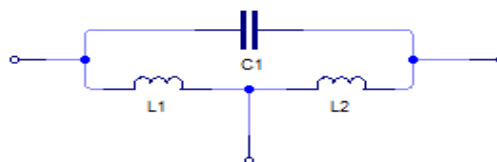


Figure 2. LC-tank circuit at Hartley Oscilator

The main advantage of using IC Op-Amp is that the gain of the Hartley oscillator can be individually adjusted using the feedback resistor (Rf) and input resistor (R1). When the Op-Amp is turned on (active), the capacitor is fully charged it starts discharging through coil L1. This charging and discharging creates a series of damped oscillations in the tank circuit and it is the

key. The voltage L2 is across 180$^o$ out of the voltage across L1 since the junction of two inductors is grounded. This phase shift is produced by L1-L2 voltage divider. For value of gain (α) and phase shift of LC feedback (β) given by,

$$\alpha\beta = 1 \tag{1}$$

β is voltage divider by L1 and L2 that given by.

$$\beta = L1 / L2 \tag{2}$$

The opamp is arranged in inverting mode and the gain can be expressed by the equation given by,

$$\alpha = 1/ L1 / L2 \tag{3}$$

$$\alpha = L2 / L1 \tag{4}$$

In equation 1 and 4 we can observe that the gain must be greater than the ratio of L1 and L2 (L1/L2). For example L2 = 16,66mH and L1 = 4,39mH. So the gain is four times or higher than it. So for solution, we can use Rf = 10KΩ or 20KΩ and Rg = 1KΩ by Inverting Amplifier. In this circuit, L1 and L2 connected series can be written "$L_T$" that equivalent series circuit $L_T$ = L1 + L2. Then for 180$^o$ phase shift formula given by

$$\omega = \frac{1}{\sqrt{L_T C}} \tag{5}$$

$$\omega = 2\pi f \tag{6}$$

With equation 5 and 6, we get frequency formula which produced by Hartley oscillator. Given by,

$$f = \frac{1}{2\pi\sqrt{LC_T}} \tag{7}$$

Equation 7 is hartley resonant frequency and used by author for reference in developing Hartley oscillator tool kit.

The Colpitts oscillator was invented by Edwin H. Colpitts, (an American engineer) in 1920. Have same contruction with Hartley that this oscillator develops by capacitor and inductor for feedback circuit [9]. This oscillator commonly applied for generating sinusoidal output signal with very high frequency. Other application [10] i.e, (1) It is frequently used for the applications in which very wide range of frequencies are involved; (2) Used for applications in which undamped and continuous oscillations are desired for functioning; (3) preferred in situations where it is intended to withstand high and low temperatures frequently; (4) The combination of this oscillator with some devices (instead of tank circuit) can be used to achieve great temperature stability and high frequency. And (5) It is used for the development of mobile and radio communications. Colpitts oscillator developed by two series capacitor (C1 and C2) connected with one inductor by parallel, like the LC tank circuit that visualized in Figure 3.
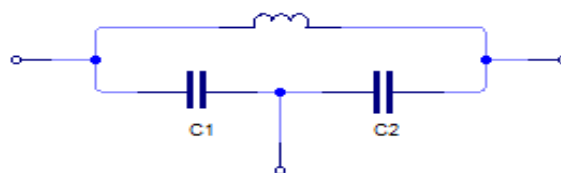


Figure 3. LC-tank circuit at Hartley Oscilator

When the Op-Amp is turned on (active), the capacitors C1 and C2 is start charging and after the capacitors get fully charged, the capacitors starts discharging through the inductor L1 in the circuit causing damped harmonic oscillations in the tank circuit. Thus, an AC voltage is produced across C1 & C2 by the oscillatory current in the tank circuit. While these capacitors get fully discharged, the electrostatic energy stored in the capacitors get transferred in the form of magnetic flux to the inductor and thus inductor gets charged. Similarly, when the inductor starts discharging, the capacitors start charging again and this process of energy charging and discharging capacitors and inductor continues causing the generation of oscillations and the frequency of these oscillations can be determined by using the resonant frequency of the tank circuit consisting of inductor and capacitors [10]. The advantage of the LC-tank configuration in colpitts oscillator is can reduce inductance, so it can improve the stability of frequency. Thus, with the same LC-tank circuit, oscillator colpitts have better stability at high frequency.

For value of gain (α) and phase shift of LC feedback (β) given by "equation 1", then β is voltage divider by C1 and C2 that given by,

$$\beta = C2 / C1 \tag{8}$$

$$\alpha = 1/ C2 / C1 \tag{9}$$

$$\alpha = C1 / C2 \tag{10}$$

In equation 1 and 10 we can observe that the gain must be greather than the ratio of C1 and C2 (C1/C2). For example C1 = 10μF and C2 = 1μF. So the gain is four times or higher than it. So for solution, we can use Rf = 10KΩ or 20KΩ and Rg = 1KΩ by Inverting Amplifier. In this circuit, C1 and C2 connected series can be written "$C_T$" that equivalent series circuit $C_T$ given by equation 11, for 180° phase shift formula given by equation 12,

$$C_T = \frac{C1 \times C2}{C1 + C2} \tag{11}$$

$$\omega = \frac{1}{\sqrt{LC_T}} \tag{12}$$

$$\omega = 2\pi f \tag{13}$$

With equation 12 and 13, we get frequency formula which produced by Colpitts oscillator. Given by,

$$f = \frac{1}{2\pi\sqrt{LC_T}} \tag{14}$$

Equation 14 is colpitts resonant frequency and used by author for reference in developing Colpitts oscillator tool kit.

Linberg investigating Colpitts oscillator family (18 topologies) based on a linear VCVS OP-AMP, by the Spice software. He use IC uA741 for Low Frequency and IC TL082 for high frequency [11]. Both, Hartley and colpitt oscillator for this tool kit are made by IC OP-AM uA741 or CN741 with Voltage Controlled Voltage Source (VCVS).


## 2. Methods

In order to obtain the goals of engineering laboratories, developing LC-Oscillator tool kit is needed to advance the practice skills of the students in industrial instrumen workshop course. The tool kit in this research is developed based on several steps for approaches, where the steps are: (1) Determining the RLC values and calculating its values into output frequency equathion that have been devined, then author develop the jobsheet but the experiment tables is empety; (2) Simulating L-C oscillator circuit using LTSpice IV. Then (3) Proving the results of

simulation into real experiment by breadbroad using IC OP-AMP 741 with passive elements such as resistors, capacitors and inductors and analyzed by oscilloscope and frequency generator. (4) Modelling the LC-Oscillator in 3D and designing into 2D using Microsoft Visio 2007, author use Eagle PCB design software for layouting oscillator circuit. Then package into tool box which integrated each other. Before it, the author select the best one of LC values. Final step is (5) testing hartley and colpitts oscillator tool kit then full filling the experiment tables, this data(s) are for practice guidance.
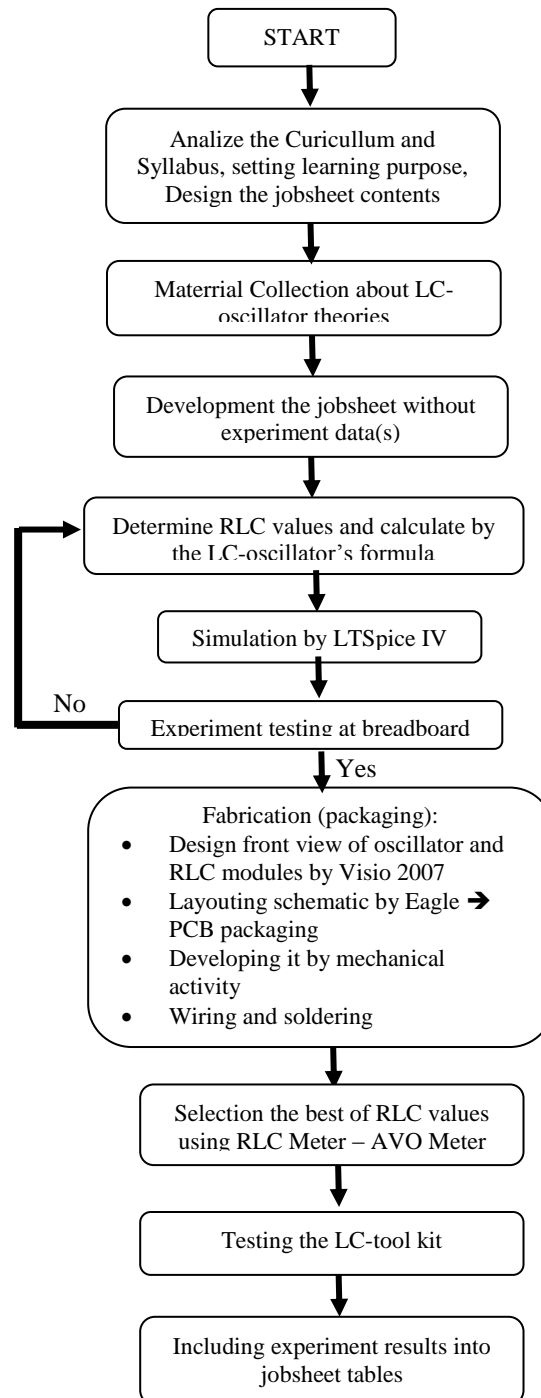


Figure 4. A method approach for developing LC-Oscillator (Hartley and Colpitts)

**Why using Spice?** Because this computer program is (a) commonly program that used for analog circuit analysis in the world (available in analog oscillator case), (b) it's free, (c) LTSpice is able to operate in regulator switching with faster than other simulation software, (d) with this program, user able to use many standard component models from various companies that have been available in various sites on the internet. (e) LTspice has been used as a tool teaching at many universities, as a tool for thesis master and dissertation doctoral research and also used for validation circuit in drafting patents purposes [13], [14], [15]. So simulation approach has behaviour such as real experiment.

## 3. Results and Analysis
## LT Spice Simulation Result

The Hartley and Colpitts oscillator circuit generally available at the "google", but the author develop fixed LC values, because there are don't need many LC modules for minimum hardware component and budget, also able to used for both tool kit oscillator (hartley-colpitts) and other tool kit (such as Astable Multivibrator dan Wien Bridge Oscillator [16]). So the simulation approach is required to match the LC value corresponding to the various oscillators practicum courses. The directly experiments were not effective, by the LTSpice simulation, the results of frequency output can be used as a reference for selecting LC value. Sample simulation result shown in Figure 5 and 6.
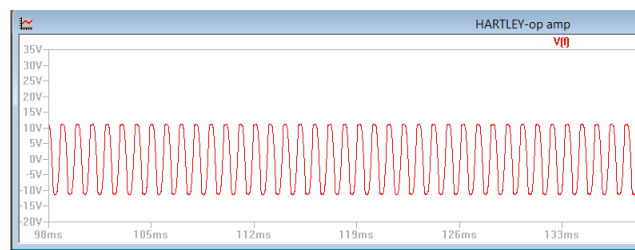


Figure 5. A Computer simulated output of Hartley Oscillator using LTSPICE by parameter:
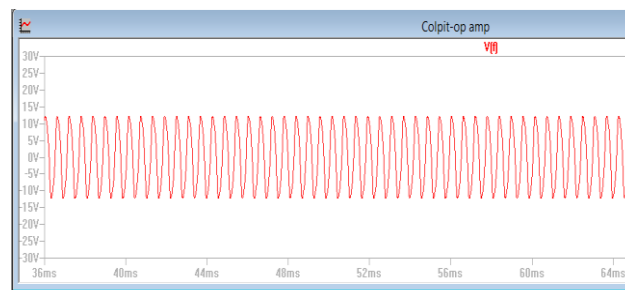L1 = 4.39mH ; L2 = 16.66mH, C = 1uF and Rf2=100 ohm



Figure 6. A Computer simulated output of Colpitts Oscillator using LTSPICE by parameter:
C1= 1uF; C2 = 1uF, L = 16.66mH

## The Hartley and Colpitts Oscillator and RLC Modules

The LC module is shown in Figure 7 with 28cm x 10cm size. Capasitor modules have function as kit which provides capacitors with fixed value i.e 10nF, 100nF, 1uF, 10nF, 100uF and 1000uF as weel as Inductor modules for providing inductors with fixed value i.e 4,39mH and 16,67mH. There are any pin connectors in several both modules; it is for connecting to the oscillator tool kit by the jumper (cables). The Hartley and Colpitts oscillator is shown in Figure 8(a) and 8(b) with 28cm x 20cm size.

Figure 7. Capacitor and Inductor module



(a)                                                          (b)

Figure 8. Top display of LC-oscillator (a) Hartley; (b) Colpitts

        The advantanges of this kit i.e, (1) the manual book is available for practical guides, so it allows students to learn independently without lecture or lecture assistant. (2) Values of RLC can be modified by replacing the RLC values by jumper; students see the table in jobsheet for practical instruction. (3) The LC-oscillator tool kit have been validated by the expert (domain: media and material), so the quality(s) determined [17]. LC-oscillator that have been designed and developed have special specification as follows in Table 1,

Table 1. Specification of Hartley and Colpitts oscillator which have been developed

| Variables | Description |
|---|---|
| Kuantitas produk | <ul><li>Oscilator Hartley    (1 kit)</li><li>Oscilator Colpitts (1 kit)</li><li>R Module 1KΩ & 10KΩ  (1 kit)</li><li>R Module 2KΩ & 20KΩ  (1 kit)</li><li>C module 10nF & 100nF (1 kit)</li><li>C module 1 uF & 10 uF (1 kit)</li><li>C module 100 uF & 1000 uF (1 kit)</li><li>Inductor module 1000Wdg & 500 Wdg1 (1 kit)</li><li>Jumper *trainer* oscilator 1 buah</li></ul> |
| IC | IC OP-AMP 741 |
| Maximum Voltage for VCC / VEE | +12 Volt / s -12 Volt |
| Warna nyala /ukuran Led indicator | merah/ 3mm |
| Warna pin banana plug | VCC :  Merah; VEE : Hitam ; GND : Hijau |
| *Body*. | *Full Acrylic* |
| Stiker | Vynil susu + Glossy |
| *Printed Circuit Board* | *Fiber* lapis Silver |
| Spesifikasi resistor | Resistor tetap /metalfilm/0,5Watt |
| Jenis kapasitor | Kapasitor mylar dan *electrolit* V. Maks +25V DC |
| Rentang frekuensi | Oscilator Hartley: 35Hz s.d 11KHz Oscilator Colpitts:  1KHz s.d 4KHz |

**RLC's Module Testing**

    LC compoent that provide in electronic markets are "C" class (not for military and space purpose), despite of new condition, there are any high deviation value. So before L and C components are packaged, the authors select a lot number of L and C components using RLC-meter. After LC's components defined, the author packaging it. Author testing LC values again, may values of component are decreasing by solder's temperature. Wish, LC values is low deviation with real values. In Figure 9 is sample testing,
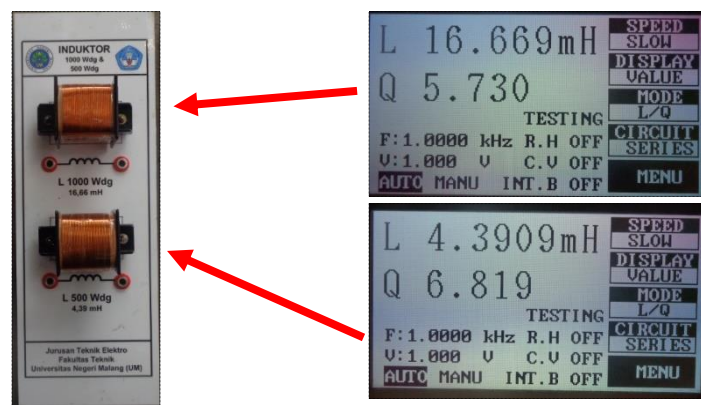


Figure 9. A labolatory tested inductor value using RLC-meters; L1000Wdg is 16.66mH; 500Wdg is 4.39mH

**LC-Toolkits Testing Result**

The measuring devices and media that used for testing the Hartley dan Colpitts oscillator as follows: Digital AVO meter, Oscilloscope, frequency counter, RLC modules, LC-Tool kit (Hartley and Coolpits), Simetric power supply (+V, GND, -V), jumper and the jobsheet. The testing result presented in Table 2 and 3 with variables i.e; feed back resistor (Rf) = 20KΩ and gain resistor (Rg) = 1KΩ (Note: β = -Rf/Rg ➔ 20/1 = 10),

Table 2. Testing result data of the Oscillator colpitts

| No | LC values in LC Module | | | Theories calculate (*Frequency*) | Osciloscope | | Frequency Counter | |
|---|---|---|---|---|---|---|---|---|
| | L (mH) | C1 | C2 | | Freq | Time | Freq | Time |
| 1 | 16,66 | 1 µF | 100 nF | 4,043 KHz | 3,846 KHz | 0,26 ms | 3,952 KHz | 0,253 ms |
| 2 | 16,66 | 1 µF | 1 µF | 1,744 KHz | 1,667 KHz | 0,6 ms | 1,76 KHz | 0,567 ms |
| 3 | 16,66 | 10 µF | 1 µF | 1,2946 KHz | 1,250 KHz | 0,8 ms | 1,302 KHz | 0,767 ms |
| 4 | 16,66 | 10 µF | 10 µF | 550,99 Hz | 555,5 Hz | 1,8 ms | 577,7 Hz | 1,73 ms |
| 5 | 4,39 | 1 µF | 100 nF | 7,9618 KHz | 7,4074 KHz | 135 us | 7,42 KHz | 135 us |
| 6 | 4,39 | 1 µF | 1 µF | 3,4025 KHz | 3,33 KHz | 3 ms | 3,42 KHz | 0,2917 ms |
| 7 | 4,39 | 10 µF | 1 µF | 2,5195 KHz | 2,5 KHz | 0,4 ms | 2,5152 KHz | 0,3975 ms |
| 8 | 4,39 | 10 µF | 10 µF | 1,0759 KHz | 1,112 KHz | 0,9 ms | 1,130 Khz | 0,8849 ms |

Table 3. Testing result data of the Hartley colpitts

| No | LC values in LC Module | | | Theories calculate (*Frequency*) | Osciloscope | | Frequency Counter | |
|---|---|---|---|---|---|---|---|---|
| | L1 (mH) | L2 (mH) | C | | Freq | Time | Freq | Time |
| 1 | 4,39 | 16,66 | 10 nF | 10,989 KHz | 10,526 KHz | 95 us | 11,05 KHz | 90,47 us |
| 2 | 4,39 | 16,66 | 100 nF | 3,469 KHz | 3,4482 KHz | 0,85 ms | 3,545 KHz | 0,82 ms |
| 3 | 4,39 | 16,66 | 1 µF | 1,0989 KHz | 1,176 KHz | 0,85 ms | 1,178 KHz | 0,8484 ms |
| 4 | 4,39 | 16,66 | 10 µF | 349,9 Hz | 344,8 Hz | 2,9 ms | 350,2 Hz | 2,85 ms |
| 5 | 4,39 | 16,66 | 100 µF | 109,89 Hz | 116,2 Hz | 8,6 ms | 115,48 Hz | 8,66 ms |
| 6 | 4,39 | 16,66 | 1000 µF | 34,69 Hz | 35,7 Hz | 2,8 ms | 35,79 Hz | 27,94 ms |

According to Table 2, if we compared by theories calculate, the less difference value are shown in fourth test (4,51Hz by oscilloscope and 26,71Hz by frequency counter) and seventh test (4,51Hz by oscilloscope and 19,5Hz by frequency counter). Then the most large difference are shown in fifth test (561,8 Hz by oscilloscope and 541,8Hz by frequency counter) and sixth test (72,5Hz by oscilloscope and 20Hz by frequency counter). In Table 3 it shown that the less difference value are at second testing (20,8Hz by oscilloscope and 76Hz by frequency counter), fourth testing (2,1Hz by oscilloscope and 3,1Hz by frequency and sixth testing (11Hz by oscilloscope and 11Hz by frequency counter). Then the largest differences are shown in once testing (463Hz by oscilloscope and 65Hz by frequency counter), third testing (775Hz by oscilloscope and 799Hz by frequency counter) and fifth testing (63Hz by oscilloscope and 55Hz by frequency counter).

There are differences value of measuring by oscilloscope and by frequency counter, because both have different in accurary (oscilloscope accuracy = 1,2 or 1/5 and frequency counter accuracy = 0,00001 atau 1/10$^5$). Oscillocope display effective value then frequency counter display real result). Why real report and theory are different?, we are know that at actual condition, there are various tolerance in RLC components

Figure 10. Testing the LC-Oscillator in Basic Electronic Labolatory State University of Malang (UM), Indonesia

## 4. Conclusion

It is clear to design, fabricate and test of Hatley and Colpitts oscillator using IC OP-AMP 741 as LC oscillator material topic on industrial instrumentation worklab subject at Electrical Engineering State University of Malang (UM), Indonesia. These tool kit are dedication for education purpose with several advantanges. For develop it the author solve with 5 approaches, i.e: (1) theoretically using the basic theorems of both oscillator, (2) Simulation, (3) implemented practically, (4) design by 2-D and 3-D, layouting the circuit and then packaging, (5) testing the tool kit. For support in learn LC-Oscillator, Author develop other product i.e: jobsheet and manual book. Hartley and Colpitts oscillator can produce sinusoidal signal that determined by inductor (L) and capacitor (C) component. If one of L or C value are modivied, the output frequency value of oscillator are different with before condition. This tool kit have been used in learning activities at State University of Malang and for future scope, it possible for massal production and implemented at Electronic Departement of Vocational High School in this country.

## References

[1] Brian Surgenor and Kevin Firth. "The Role of the Laboratory in Design Engineering Education" Article available at http://library.queensu.ca/ojs/index.php/PCEEA/article/viewFile/3848/3845. Last accessed on November 11, 2015. 2011: 287-293.
[2] Singhal AC, Bellamy L and Mc Neill B. "A New Approach to Engineering Education". Arizona State University, Arizona. 1997: 88.
[3] M. Ozvoldová and. P Ondrusek. "Integration of Online Labs into Educational Systems" *International Journal of Online Engineering*. 2015; 11(6), http://dx.doi.org/10.3991/ijoe.v11i6.5145
[4] Daryanto. "Menyusun Modul: Bahan ajar untuk persiapan guru dalam mengajar". Yogyakarta: Gava Media Publishing. 2013.
[5] Destiyanto. "Pengaruh Penggunaan Jobsheet Terhadap Prestasi Belajar Peserta Didik Pada Mata Diklat Praktik Las Dasar Di SMK Negeri 2 Klaten" Bachelor thesis on Engineering Faculty State University of Yogyakarta, Indonesia. 2012.
[6] Gottlieb, Irv. "Practical Oscillator Handbook" Linacre House, Jordan Hill, Oxford: The Newness publisher. 2004: 8.
[7] Jojo (2009). "Hartley Oscillator". Article available at: http://www.circuitstoday.com/Hartleyoscillator. Last accessed on Agust 2014

[8] Storr, W. (2014). "The Hartley Oscillator". Article available at http://www.electronics tutorials.ws/oscillator/Hartley.html. Last accessed on Agust 2014

[9] Storr, W. (2014). "The Colpitts Oscillator". Article available at http://www.electronicstutorials.ws/oscillator/colpitts.html. Last accessed on Agust 2014

[10] Agarwal, T. "Colpitts Oscillator: Working and Applications". Article available at http://www.elprocus.com/colpitts-oscillator-circuit-working-and-applications/. Last accessed on November 8, 2015

[11] Lindberg, K Murali and A Tamasevicius. "*The Colpitts Oscillator Family*". Proceedings NWP-2008, *International Symposium: Topical Problems of Nonlinear Wave Physics*. 2008: 47-48

[12] Pradana S, Adhi S Widyawan. "*Pemanfaatan LTspice dan DesignSpark PCB untuk Simulasi Rangkaian dan Perancangan PCB*". Proceeding Seminar Ilmu Pengetahuan Teknik. 2013: 130-135

[13] Joel D Hewlett and Bogdan M Wilamowski. "SPICE As A Fast And Stable Tool For Simulating A Wide Range Of Dynamic Systems". *International Journal of Engineering Education*. 2011; 27(2): 217–224

[14] S Fuada and FT Aquari. "Square Wave Generator Circuit Analysis Using Matlab Approach". *International Journal of Engineering Sciences and Research Technology*. 2013; 2(2).

[15] Rajender K and Krishan K. "PSPICE and MATLAB/SimElectronic Based Teaching of Linear Integrated Circuit: A New Approach". *International Journal of Electronics and Electrical Engineering*. 2015; 3(1): 34-37.

[16] Fuada, Syifaul. "*Pengujian Trainer Osilator Wien Bridge dengan Menggunakan Osciloskop dan Frekuensi Counter*". Prosiding SENTIA 2014-Politeknik Negeri Malang. 2014; 6: A-32 – A36.

[17] Fuada S. "Pengujian Validitas Alat Peraga Pembangkit Sinyal (Oscillator) untuk Pembelajaran Workshop Instrumentasi Industri". *Presented at National Seminar of Education 2015, Ponorogo Muhammadiah University.* Ponorogo, East Java. 2015
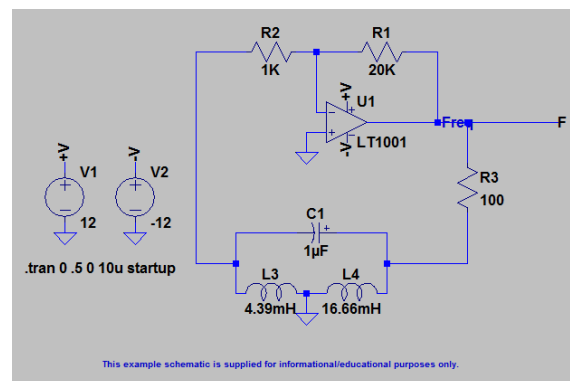
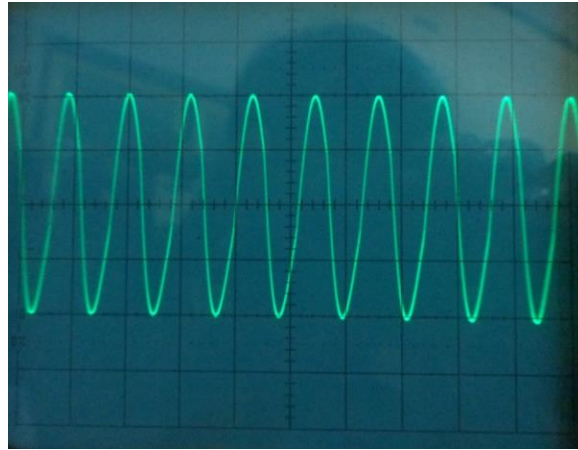## APPENDIX



Figure 11. LTSpice schematic of Hartley oscillator
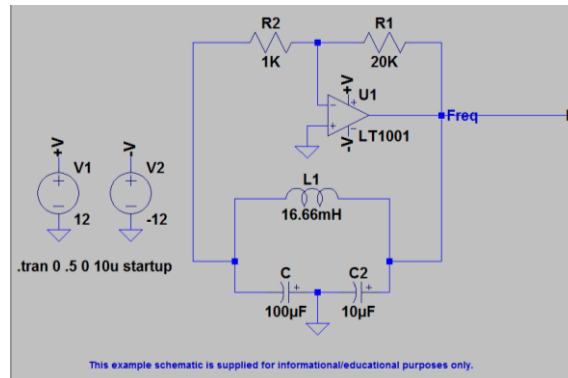
Figure 12. LTSpice schematic of Colpitts oscillator



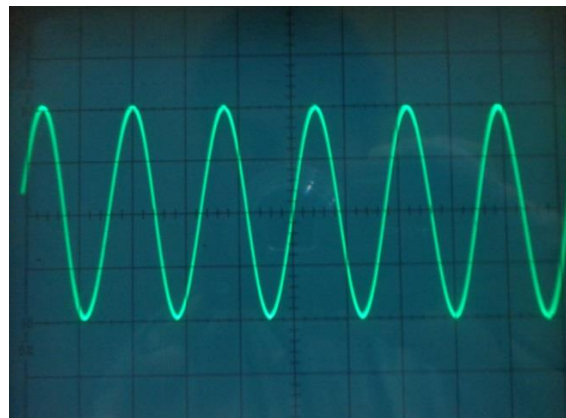Figure 13. Output of Colpitts Oscillator using Oscilloscope by parameter:
C1= 1uF; C2 = 1uF, L = 16.66mH



Figure 14. Output of Hartley Oscillator using Oscilloscope by parameter:
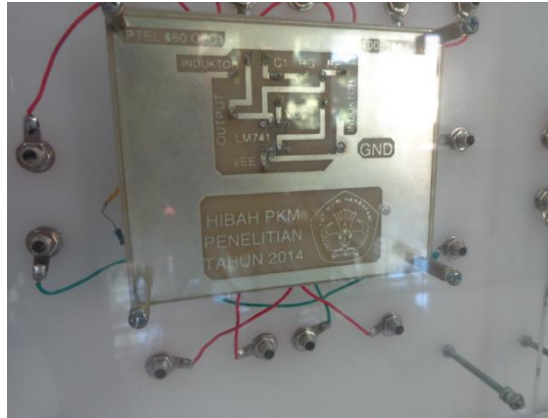L1 = 4.39mH; L2 = 16.66mH, C = 1uF and Rf2=100 ohm

Figure 15.The PCB of LC-Oscillator



Figure 16. The indicator V+ and V- of LC-Oscillator