A Novel Op-Amp Based LC Oscillator for Wireless Communications

by Ary Syahriar

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Dodi Garinto
1) Mechatronics Department
Politeknik Manufaktur Astra
2) Mechanical Engineering Department
Swiss German University
Jakarta, Indonesia
dodi.garinto@polman.astra.ac.id

Ary Syahriar
1) Electrical Engineering Department
University al Azhar Indonesia
2) Mechanical Engineering Department
Swiss German University
Jakarta, Indonesia
syahriar@uai.ac.id

Setiyo Budiyanto
Department of Electrical Engineering
Universitas Mercu Buana
Jakarta, Indonesia
sbudiyanto@mercubuana.ac.id

***Abstract*— This paper presents a novel op-amp based LC oscillator circuit design for wireless communications. This LC oscillator can be classified as a harmonic oscillator. Unlike the Hartley, Colpitts and Clapp oscillators, the resonant tank circuit of the proposed op-amp based LC oscillator is composed of only two components – single-inductor and single-capacitor, in parallel connection. Also, the LC oscillator does not use resistor components. The aim of this paper is to provide a low cost solution for sinusoidal oscillator design, particularly in low power mobile applications, where the power amplifier stage can be eliminated if the RF oscillator has enough output current and output voltage capabilities to supply the antenna load. On the other hand, the digital modulator is also integrated with the RF oscillator. The proposed op-amp based LC oscillator is analyzed and discussed using PSPICE simulation results. To verify the concept, experimental results are given. It can be observed that the simulation results are in line with the experimental results.**

Keywords*— *LC sinusoidal oscillator, Hartley oscillator, Colpitts oscillator, Clapp oscillator, Op-amp based LC oscillator

I. INTRODUCTION

In the Circuits and Systems society, sinusoidal oscillators are a popular research domain. It is interesting because many applications, such as wireless communication, biomedical, geophysical, control system, measurement, instrumentations, metal detector and dc-ac power converters require a sinusoidal oscillator circuit. In wireless communication applications, a sinusoidal oscillator is the RF source that can be modulated by digital input signal and amplified by power amplifier so that the digital information can be transmitted by antenna to the air. Generally, sinusoidal oscillators are produced using transistor-based circuits with additional LC components. It is also can be generated by op amp and LC circuits [1] [2]. Although many papers and journals discuss the sinusoidal oscillators [1] [2] [3] [4] [8], this paper only discusses the research gap on LC oscillators. Specifically, this paper is focused on op-amp based LC oscillator. In principle, according to the Barkhausen criterion, in order to achieve oscillation, the loop gain must have a level of at least unity [5].

Today's well known LC oscillators, such as Hartley, Colpitts and Clapp Oscillators are commonly used in the frequency range from some hundred kilo-Hertz to several hundred Mega-Hertz. Hartley oscillator is a type of LC oscillator which was invented by American engineer Ralph Hartley in 1915. The tank circuit of Hartley oscillator consists of three components – two inductors and single capacitor, as shown in Fig. 1(a). Three years later, in 1918, American

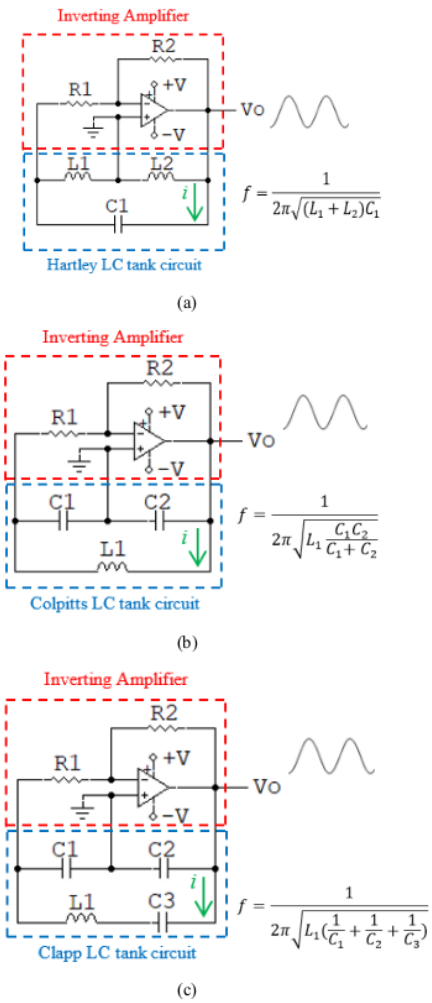

Fig. 1. Op-amp based LC sinusoidal oscillators. (a) Hartley oscillator. (b) Colpitts oscillator. (c) Clapp oscillator.

engineer Edwin H. Colpitts proposes the opposite structure of Hartley Oscillator to improve the sinusoidal waveform and to increase the stability at high frequencies. The tank circuit of

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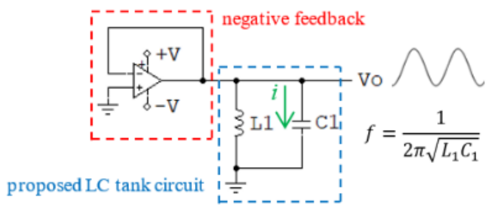
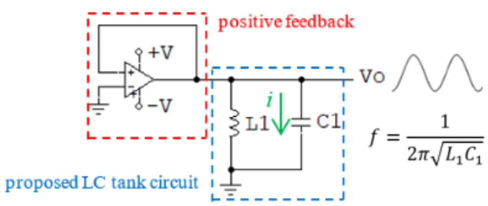
Colpitts oscillator also consists of three components – two capacitors and single inductor, as illustrated in Fig. 1 (b). To change the oscillation frequency, the value of inductance and capacitance of both Hartley and Colpitts oscillators can be tuned. For a long time, thirty years later, Colpitts oscillator is modified by James Kilton Clapp in 1948 using additional capacitance in series with inductor. The resonant LC tank circuit of Clapp oscillator consists of four components – three-capacitors and single-inductor to meet the requirement regarding variable frequency oscillator, as depicted in Fig. 1 (c). However, it can be perceived that the Hartley, Colpitts and Clapp oscillators, also many patents that concerned on op-amp based LC oscillator circuit design utillize relatively excesive components [1] – [8].

II. Proposed LC Oscillator Circuits

In this paper, a novel LC oscillator using single op-amp and single LC circuit is proposed. Unlike the Hartley, Colpitts and Clapp oscillators, the resonant tank circuit of the proposed LC oscillator is composed of only two components – single-inductor and single-capacitor, in parallel connection, as presented in Fig. 2. Moreover, unlike Fig. 1, resistors R1 and R2 are not required by the proposed negative or positive feedback in op-amp.



(a)



(b)

Fig. 2. Proposed op-amp based LC oscillator circuit using (a) Negative feedback and (b) Positive feedback.

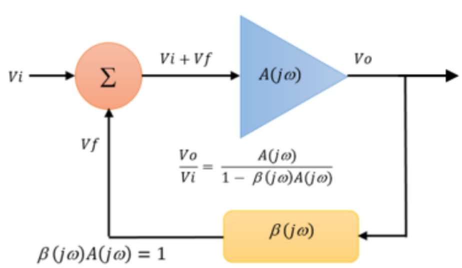


Fig. 3. The simplified feedback circuit modeling

In principle, sinusoidal oscillator is an unstable circuit system which produce a continous sinewave oscillation because the Barkhausen criterion is satisfied, as shown in Fig. 3, where the loop gain = 1 = unity and there is no input signal [5].

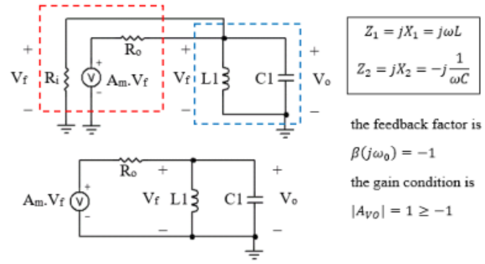


Fig. 3. Circuit modeling of the proposed Op Amp-based LC oscillator with unity loop gain

Although the previous results are straightforward, it is of interest to analyze the op-amp oscillator ac model where its output resistance is R_o. The open-loop gain is:

$$A_V = \frac{V_O}{V_f} = \frac{A_{VO}Z_R}{Z_R + R_O} \tag{1}$$

Where,

$$Z_R = \frac{Z_1Z_2}{Z_1 + Z_2} \tag{2}$$

The feedback factor is

$$\beta = \frac{V_f}{V_O} = -\frac{Z_1}{Z_2} \tag{3}$$

Hence the loop gain is

$$\beta A_V = -\frac{A_{VO}Z_R}{Z_R + R_O}\frac{Z_1}{Z_2} = -\frac{A_{VO}\left(\frac{Z_1Z_2}{Z_1+Z_2}\right)}{\left(\frac{Z_1Z_2}{Z_1+Z_2}\right) + R_O}\frac{Z_1}{Z_2}$$

$$= -\frac{A_{VO}{Z_1}^2}{Z_1Z_2 + R_O(Z_1+Z_2)}$$

$$\beta A_V = -\frac{-A_{VO}{X_1}^2}{-X_1X_2 + jR_O(X_1+X_2)}$$

Setting the loop gain equal to one shows that

$$X_1 + X_2 = 0 \tag{4}$$

and the loop-gain condition is

$$-\frac{-A_{VO}{X_1}^2}{-X_1X_2} = -\frac{A_{VO}X_1}{X_2} = 1 \tag{5}$$

Or

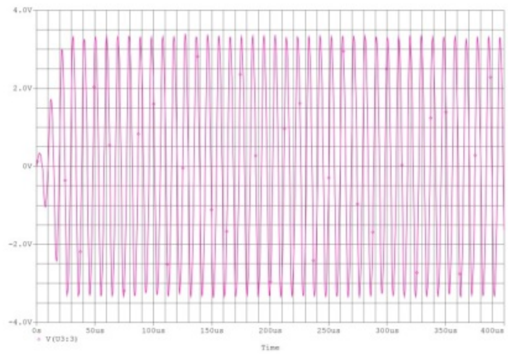
$$\boxed{A_{VO} = -\frac{X_2}{X_1} = 1} \tag{6}$$

III. Simulation and Experimental Results

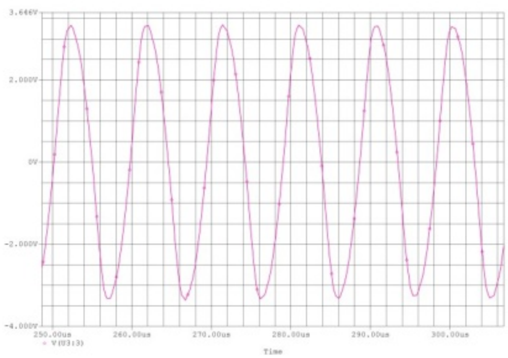
Regarding the negative feedback in op-amp of Fig. 2(a), the output signal is the same as the inverting input, which result in a unity loop gain. Due to the thermal noise, a small signal that exist at the output stage cause oscillation occured at the LC tank ciruit and amplified by op-amp until a steady state condition is achieved. Table I indicates the parameters of Fig. 2(a). PSPICE simulation results confirm that, as shown in Fig. 4(a) and 4(b), the start-up and steady state conditions of sinusoidal waveform can be generated by the circuit of Fig. 2(a) using op-amp LM318. The measured sinewave frequency based on the simulation result is about 103 kHz. The amplitude of the sinusoidal waveform is about +3.3 V and -3.3V peak to peak.

TABLE I. PARAMETERS OF THE PROPOSED LC OSCILLATOR IN FIG. 2

Component:	***Parameter:***
Voltage source +V, -V	5 V dc, -5 V dc
Inductor L1	22 uH
Op-amp (a), (b)	LM318, LM7171
Capacitor C1	0.1 uF
Output frequency f	107 kHz (calculated)



(a)



(b)

Fig. 4. (a) Start-up condition of sinusoidal waveform that generated by LC oscillator of Fig. 2(a). (b) The sinusoidal waveform at steady state.

To increase the output frequency, the inductor L1 and capacitor C1 can be adjusted to smaller values while considering the LM318 specification. According to the experimental result, the LC oscillator of Fig. 2(a) with LM318 is also working with single supply voltage +5 V. The amplitude of sinusoidal waveform is about +2.3 V and -2.3 V peak to peak, as can be observed in Fig. 5.

In case of positive feedback in op-amp of Fig. 2(b), the output signal is connected directly to the non-inverting input without supplementary resistors. This LC oscillator also fullfils the Barkhausen criterion which result in a unity loop gain. Fig. 6 describes the PSPICE simulation result of the proposed LC oscillator using LM7171. Unlike LM318, the op-amp LM7171 can not produce sinusoidal output waveform using negative feedback. Based on experimental result, the LC oscillator with op-amp LM7171 only produces a small signal with amplitude of less than +1 V and -1 V peak to peak if it is designed in a negative feedback configuration. On the other

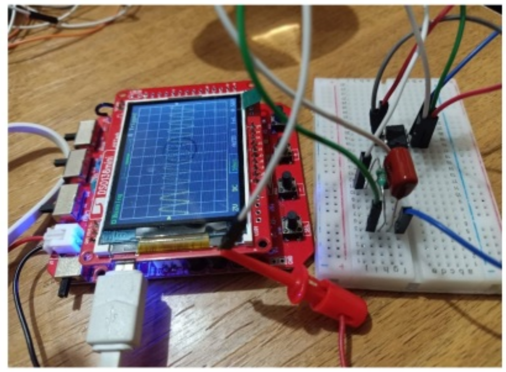


Fig. 5. Experimental result of the LC oscillator in Fig. 2(a) with LM318 and single supply voltage +5V

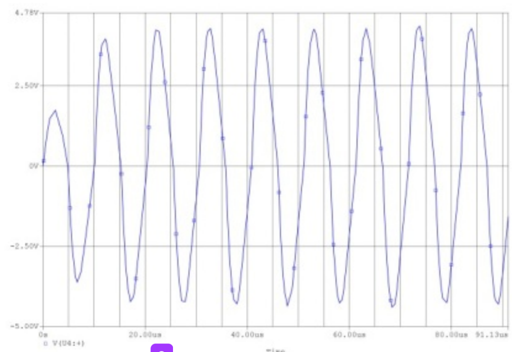


Fig. 6. Start-up and steady state transient response of the proposed LC oscillator of Fig. 2(b) using LM7171.

hand, the LM7171 doesn't work with single supply +5 V. The proposed LC oscillator based on op-amp LM7171 of Fig. 2(b) is straightforwardly verified by experimental result, as shown in Fig. 7. It can be observed that the sinusoidal amplitude can achieve around +4 V and -4 V peak to peak. It is interesting to use Op Amp with a better performance and smaller inductance and capacitance values to achieve higher frequency.

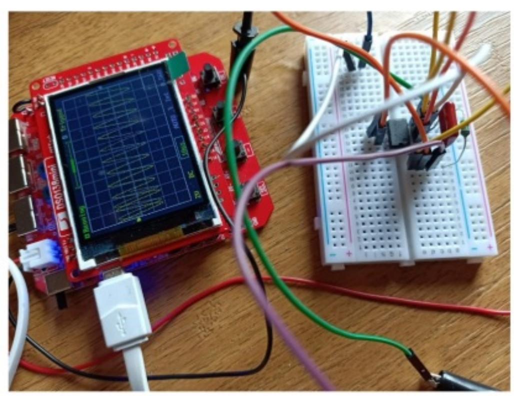
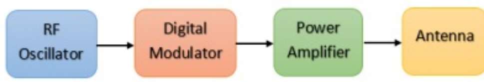
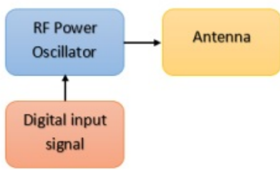


Fig. 7. Experimental result of the proposed op-amp based LC oscillator in Fig. 2(b) using Op Amp LM7171 with supply voltage of +5 V and -5 V

Fig. 8(a) illustrates today's wireless communication transmitter in a simple block diagram and Fig. 8(b) shows the proposed wireless communication transmitter block diagram. In wireless applications, it is necessary that the op-amp based LC oscillator has enough output current and output voltage capabilities to connected directly to the antenna load so that the digital information can be processed efficiently in the



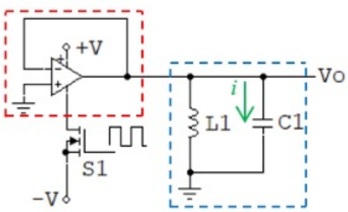
(a)



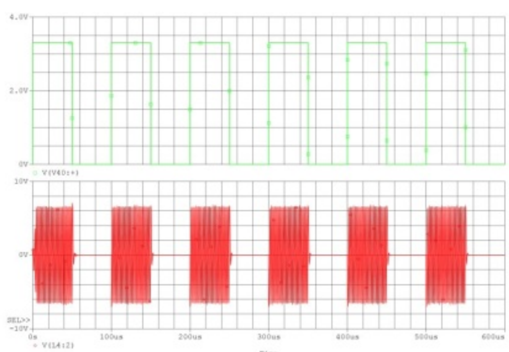
(b)

Fig. 8. (a) Today's wireless communication transmitter in a simple block diagram. (b) Proposed wireless communication transmitter block diagram

transmitter stage. In other words, the power amplifier stage can be eliminated to reduce the complexity and to increase the overall efficiency of the transmitter system. Fig. 9 depicts the proposed LC oscillator with additional switch S1 to perform a digital modulation technique using on off keying modulation. In principle, switch S1 is driven by digital input signal to



(a)

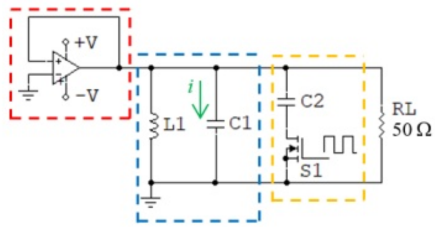


(b)

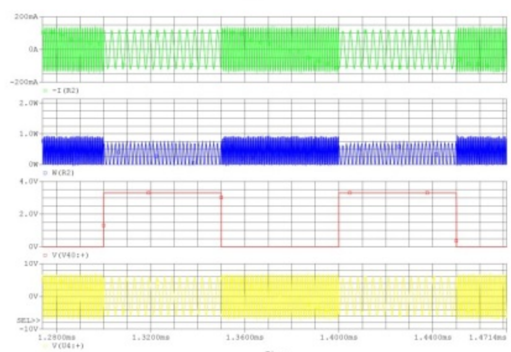
Fig. 9. (a) Proposed LC oscillator with additional switch S1 to perform on off keying modulation. (b) Simulation result confirms that on off keying modulation can be achieved.

modulate the RF source or sinusoidal signal that generated by this circuit. As shown in Fig. 9(b), a binary 1 is characterized by the present of RF signal and a binary 0 is characterized by no signal. The LC oscillator of Fig. 9(a) uses LM318 with L1 = 10 uH and C1 = 0.01 uF. The supply voltage is +9V and -9V.

Fig. 10(a) describes the proposed op-amp based LC oscillator with frequency shift keying modulation and additional antenna load 50 Ω. Fig 10(b) shows the simulation results when the switch S1 is turned ON and turned OFF by digital input signal. The parameters of Fig. 10(a) are L1 = 2.2 uH, C1 = 0.01 uF, C2 = 0.1 uF and the op-amp = LM7171. The supply voltages are +9 V and -9 V. The frequency modulation is illustrated by the Fourier spectrum in Fig. 10(c). To increase the output RF power of the LC oscillator, high output current and output voltage capabilities of the op amp is



(a)



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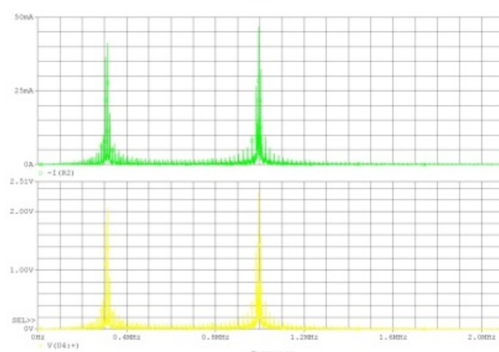
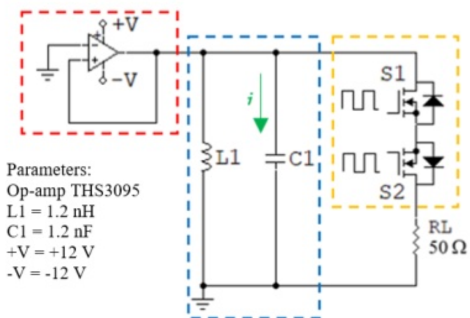


(c)

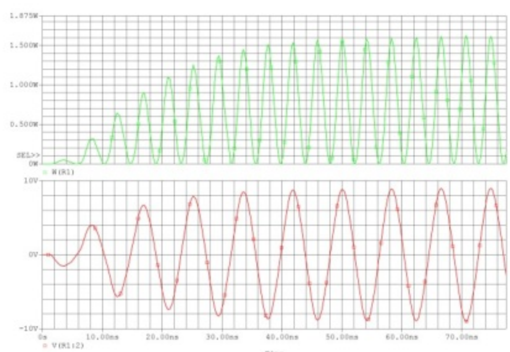
Fig. 10. (a) The op-amp based LC oscillator using FSK modulation and antenna load 50 Ω. (b) Simulated voltage and current level at RL load using LM7171. (c) The frequency spectrum.

required so that the power amplifier stage as shown in Fig. 8(a) can be pruned. Nevertheless, the frequency shift keying modulation that shaped by C2 and S1 configuration introduces switching loss when the switch is turned ON. This switching loss can be mitigated using fast rise and fall times of the S1.

To achieve a very high sinusoidal frequency, a better op-amp performance is required. Op-amp THS3095 has a better performance compared to op-amps LM318 and LM7171. Fig. 11(a) shows the proposed op-amp based LC oscillator using THS3095 with bidirectional-switch on off keying modulation



(a)



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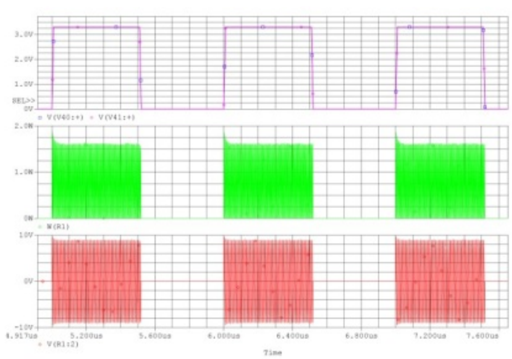

(c)

Fig. 11. (a) Proposed op amp based LC oscillator with bidirectional-switch on off keying modulation technique. (b) Start up and steady state conditions. (c) Simulated voltage and power levels at RL 50 Ω.

technique. Fig. 11(b) depicts the startup and steady state conditions in relation to the RF power at antenna load 50 Ω. Fig. 11(c) illustrates the simulated on off keying mechanism regarding the voltage and power levels at RL 50 Ω. When the bidirectional-switch S1 and S2 are turned OFF at the same time, the op-amp produces RF source in light load condition. When the bidirectional-switch S1 and S2 are turned ON at the same time by digital input signal, the RF power is delivered to the antenna load and transmitted to the air to symbolize a binary 1. Fig. 12 shows the frequency spectrum with low harmonic contents in relation to the current and voltage amplitudes at the antenna load 50 Ω. It means a better sinusoidal waveform of the proposed LC oscillator circuit based on op-amp THS3095 with 120 MHz frequency is created, as can be seen in Fig. 11(b).

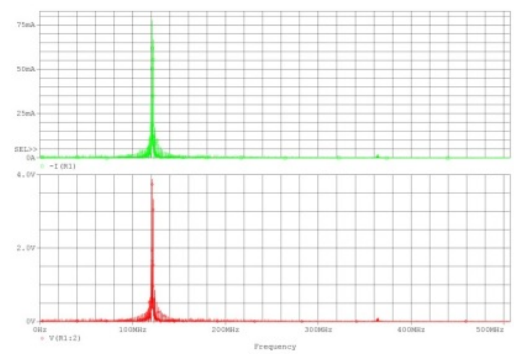

Fig. 12. The Fourier spectrum shows the RF frequency with low harmonic contents in relation to the current and voltage amplitudes.

IV. Conclusion

The op-amp based LC oscillator circuit with single op-amp, single-inductor and single-capacitor was presented in this paper. Various op-amp performances were discussed and compared. The concept of RF power oscillator without power amplifier stage for wireless communication transmitter was introduced to shorten the chain of RF power processing and to increase the overall efficiency of the transmitter system. Also, the proposed LC oscillator with integrated on off keying and frequency shift keying modulations were presented and analyzed. The PSPICE simulation results confirm that the proposed op-amp based LC oscillator can produce sinusoidal waveform for wireless communications. The experimental results using op-amp LM318 and LM7171 were also given and in-line with the simulation results. In future works, transistor-based LC oscillator with the same structure will be investigated. It is interesting to demonstrate this LC oscillator using a better op-amp performance to achieve a microwave frequency with higher output current and output voltage capabilities so that it can be connected directly to the antenna load without a power amplifier stage.

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