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Method for Indicating Resonance Current Direction by LED

Noriyuki TOMIYAMA*

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1. Introduction

The method of audiovisually indicating the resonance of an *LCR* AC circuit has already been reported[1,2]. The method of causing an electric bulb to flicker by passing alternating current from the mains through an *LCR* parallel circuit indicates the resonance point, at which minimum current flows, when the bulb becomes dark[1]. On the other hand, the resonance experiment where a current with a frequency of several hundred kHz is passed through an *LCR* series circuit indicates the resonance point, at which maximum current flows, by means of a light bulb and loudspeaker[2]. In both cases, the resonance point is confirmable according to the intensity of light and/or sound. However, the change of direction of the resonance current cannot be distinguished directly visually or aurally.

This paper describes the result of an attempt to display the change of direction of an oscillating current at resonance by means of an LED display section in an *LCR* series circuit, and examines its practical applicability.

2. Experimental

Figure 1 shows an *LCR* series resonance drive circuit. The display section employed two ultrahigh-brightness LEDs (Toshiba Co., Ltd., TLRA135AB), as shown in Fig. 2. The LED has the following electro-optical characteristics: luminous intensity I_0=1000mcd, peak emission wavelength λ=600nm (red radiation)[3]. A 150Ω protective resistor r was con-

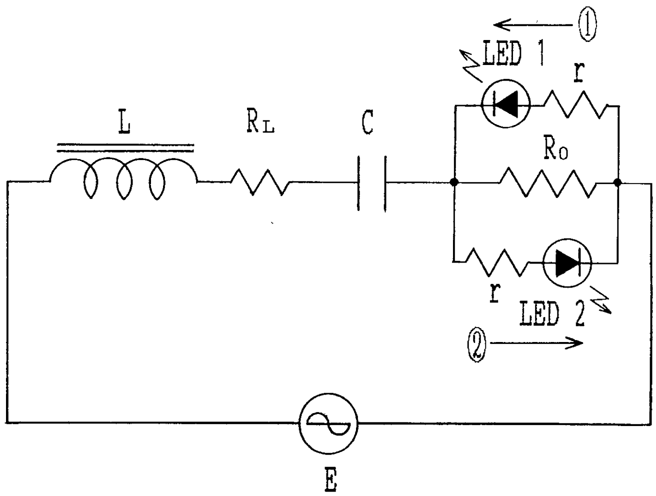


Fig. 1 Series resonance drive circuit.

* Department of Physics, Faculty of Education, Nagasaki University, Nagasaki 852, Japan

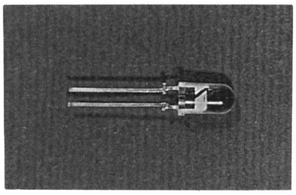


Fig. 2　LED device.

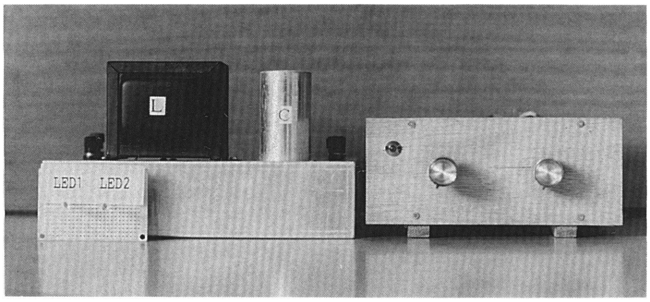


Fig. 3　External appearance.
Ultralow-frequency oscillator (right side),
LCR circuit and LED display section (left side).

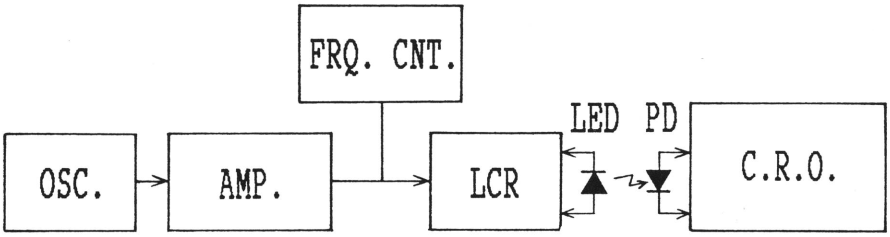


Fig. 4　Experimental set-up.

nected in series with each LED. Both LEDs had a forward resistance of approximately 15kΩ, in parallel with which a single resistor R_0 of 22Ω was connected to reduce the circuit resistance and so enhance resonance sharpness. The resulting resistance of the display section was 22Ω. Figure 3 depicts the external view of the experimental device. The choking coil L had an inductance of 5H a d. c. resistance R_L of 60Ω, while capacitors C were 10, 100, 1100, 2200 and 4400μF. Figure 4 shows schematic diagram of the experimental set-up. Signals from the ultralow-frequency oscillator were boosted by the amplifier so as to pass a sine-wave alternating current having a voltage of less than 15V (RMS) and a frequency from a few hertz to twenty-odd hertz. The current of each LED in forward bias is 20mA. The resonance frequency was read on the frequency counter when tuning had been achieved by varying the frequency so as to maximize the brightness of the LEDs by the use of each capacitor. In order to measure the time interval of light emission between the two LEDs, their light was detected by a photodiode and its output waveform was observed on an oscilloscope.

3. Results and Discussion

Figure 5 shows the waveform of the drive voltage at resonance. A sine-wave alternating current is input to the circuit. To indicate the resonance point clearly, the circuit resistance must be minimized and inductance L must be maximized to produce a circuit with a high Q (for quality factor). In this circuit, Q lies within the range of 0.4 to 9 at different values of C. The larger value of C, the smaller the value of Q. The optical output of an LED is generally proportional to the current through it[4]. Each LED is brightest when the series resonant circuit is tuned, and the resonance current becomes maximum. Theory shows that the resonance current[5)]

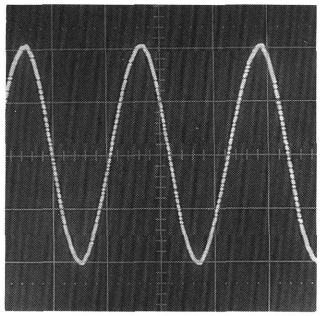


Fig. 5 Input signal waveform.
[0.1V/div., 0.2s/div., 2.3Hs.c.]

$$I = V/Z \quad (1)$$

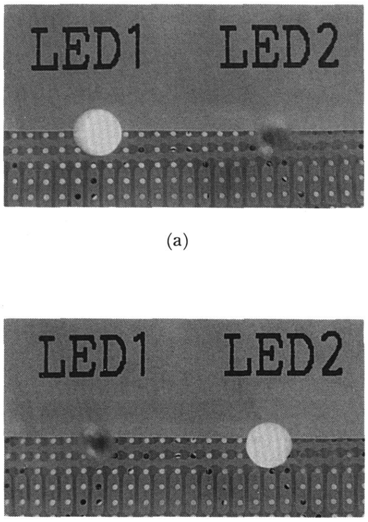
Z is the complex impedance and V is the voltage of a. c. supply. where

$$Z = \sqrt{R^2+(X_L-X_C)^2} \quad (2)$$

R is the equivalent d. c. resistance of LCR series circuit, $X_L(=2\pi fL)$ is the inductive reactance, $X_C[=(2\pi fC)^{-1}]$ is the capacitive reactance and f is the frequency. When $X_L = X_C$, then Z is a minimum. The LCR circuit will resonate and the current will have its maximum amplitude when

$$f = 1/(2\pi\sqrt{LC}) \quad (3)$$

The quantity $X_L R^{-1}(=X_C R^{-1})$ is called the Q of the circuit.

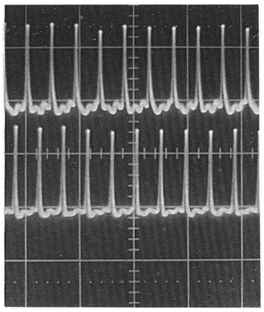


(b)

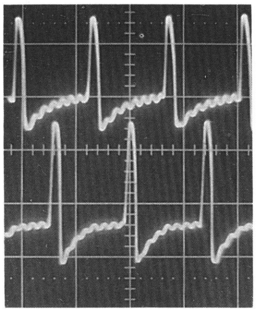
Fig. 6 On/off status of the LED light emission.

Figures 6 (a) and 6 (b) compare the on/off status of the LEDs when using the 1100μF capacitor. In (a), LED 1 is lit, and in (b), LED 2 is lit. In Fig. 1, because of rectification by the LEDs, LED 1 lights when the resonance current flows in the direction indicated by arrow ①. When the current flows in revers, as indicated by arrow ②, LED 2 lights. An ordinary electric light bulb cannot indicate the change of direction of the current, as mentioned earlier, because it does not act as a rectifier.

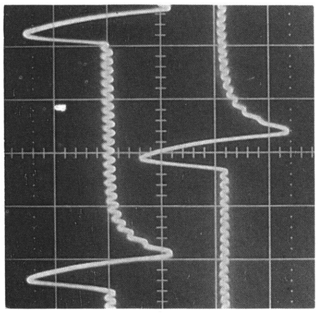
Figure 7 dipicts the light emission of each LED observed with the oscilloscope. It is easy to indicate the resonance point because of a high Q of the circuit when its capacitance is 10 or 100μF, as shown in Figs. 7 (a) and 7 (b). Since these on/off time intervals are very short, it is hard to observe the change of current visually. In the case of 1100, 2200 and 4400μF, the brightness is nearly the same for LED 1 and LED



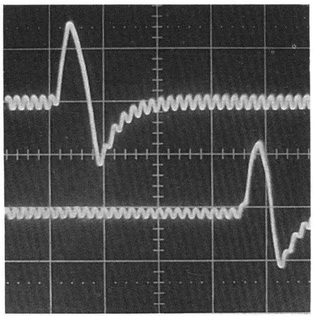
(a)　C=10μF



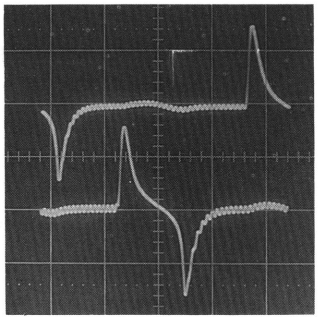
(b)　100μF



(c)　1100μF



(d)　2200μF



(e)　4400μF

Fig. 7　Light emission signal waveforms. On/off status of LED 1 (upper part) and LED 2 (lower part). [0.1V/div., 0.1s/div. for (a), (b), (c) and (d), 0.1V/div., 0.2s/div. for (e)]

Table 1.

Capacity C[μF]	Resonant frepuency f[Hs.c.]		Time interval t[s]
	Measured value	Calculated value	
10	20	23	0.025
100	6.9	7.1	0.072
1100	2.3	2.2	0.22
2200	1.4	1.5	0.35
4400	1.2	1.1	0.42

2, as shown in Figs. 7 (c), 7 (d) and 7 (e). Hence, the polarity of the capacitor does not have much influence. Because the on/off time intervals are long, as shown in these Figures, we can follow the change in direction of the current easily. Q decreases as the capacitance increases, so the exact resonant frequency is difficult to read. It appears to be best to use a capacitor of 1100, 2200, 4400μF for this circuit.

正　誤　表

教科教育学研究報告第15号の富山先生の論文で誤りがありましたので、ここに慎んで訂正させていただきます。

P13　Fig. 5　Input signal waveform.

[0.1V/div., 0.2s/div., 2.3Hs.c.] 誤

↓

2.3Hz　正

P14　Table 1.

誤

Capacity C[μF]	Resonant frepuency f[Hs.c.]		Time interval t[s]
	Measured value	Calculated value	
10	20	23	0.025

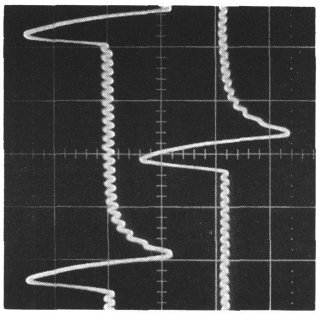
↓

正

Capacity C[μF]	Resonant frepuency f[Hz]		Time interval t[s]
	Measured value	Calculated value	
10	20	23	0.025

P14　Fig. 7

誤



(c)　1100μF

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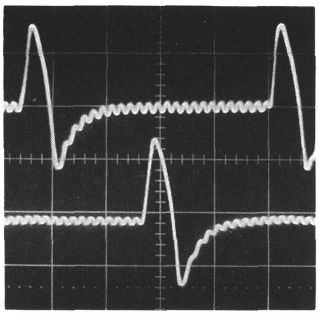

(c)　1100μF

Table 1 lists the measured values of the resonant frequency f, the calculated values according to equation (3), and the measured time intervals t between the lightings of LED 1 and LED 2. The measured value of the resonant frequency fits the calculated value. In the case of 1100, 2200 and 4400μF, during one cycle, LEDs 1 and 2 light once, slowly and alternately. Therefore, the magnitude and change of direction of the current flowing through the circuit are visually distinguishable. This means that the change of a long-period alternating current during resonance can be seen by the eye.

4. Conclusion

The change of direction of the resonance current flowing through the circuit was indicated by the flickering of light as a result of the rectification effect of an LED when a sine-wave alternating current at diffrent frequencies from a few Hz to twenty-odd Hz was passed through an LCR series resonant circuit. The author thinks this is the only method capable of allowing visual observation of the change of oscillating current by means of a simple optical circuit.

The example of series resonance taken here is a phenomenon analogous to the resonance of a piece of string or an air column in a tube. It is an important point in the teaching of physics. Therefore, this method seems to be applicable to instruments for educational experiments. The author would like to report on such teaching using such instruments on another occasion.

Acknowledgement

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