Recommendation Of RLC Circuit and Its Uses in Electronic Devices

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Abstract. This paper introduces RLC circuit, which is a circuit with resistor, inductor, and capacitor. This paper will introduce the different types of RLC circuit and will show the uses of them in electronic devices. Equations are used to express the relationship of the different elements in the circuit, and theories are introduced to prove some equations. In addition, figures can also show the different types of connections of RLC circuit, including theoretical series and parallel connection and connection that will come in use in electronic devices. This first part of article will enable people to understand what RLC circuit is, the second part will use equations to prove certain theories, and the third part of the article will introduce how RLC circuit is used in radios, and the different ways of connection which cause the circuit to receive waves, and filter waves. The final part will conclude all the parts mentioned in the article.

Keywords: RLC Circuit; Electronic devices; Ohm's law; Quantity factor.

1. Introduction

RLC circuit is a complex circuit mainly used for signal processing. The special electronic component inside this circuit allows it to store and release energy, separate potential or current, and conduct waves et cetera. The electronic components of RLC circuit can be considered as linear elements, as the resistor inside the circuit follows Ohm's law, the relationship between the inductor and capacitor and the current also fallow certain linear relationship. The benefit of using RLC circuit is it have differential equation when connected in series, so the numerical value of the components can be calculated. The RLC circuit satisfies the following differential equation:

$$D_t^2 I(t) + \frac{R}{L} D_t I(t) + \frac{1}{LC} I(t) = \frac{1}{L} E(t), \tag{1}$$

in which R is resistance, L is inductance, and C is capacitance in circuit, and $I(t)$ and $E(t)$ are the current and source voltage, respectively [1].

The RLC circuit with capacitor, inductor, and resistor can be solved by the general solution above, and the uses of RLC circuit in electronic devices can also be calculate and put in certain use. RLC circuit also differs from normal resistor circuit for it have impedance rather than resistance. For normal resistor circuits, the total resistor equals to sum of each individual resistor, however in RLC circuit, the total impedance Z have the formula: $Z = Z_R + Z_L + Z_C$ [2]. As the impedance of resistor Z_R is the resistance R. The impedance of inductor Z_L depends on frequency f of AC current and inductance L, and it have the equation $Z_L = j2\pi fL$. The impedance of capacitor Z_c depends on frequency f of AC current and capacitance C, and it have the equation $Z_C = \frac{1}{j2\pi fC}$ [3].

2. Theory of RLC Circuit

2.1. Constitute

RLC circuit is constitute of resistors, inductors, and capacitors. The different types of connection of RLC circuit have diverse impacts. Series RLC circuit is the series connection of resistor, inductor, and capacitor. This kind of circuit can form resonance at special frequencies. At these frequencies, the impedance of circuit will become pure resistance, and the current and voltage response will be slightly increased. Parallel RLC circuit is the parallel connection of resistor, inductor, and capacitor. This kind of connection can also create resonance at special frequencies. At these frequencies, the current and voltage response will also be slightly increased. These RLC circuits are shown in Fig. 1. Resonant RLC circuit is the connection of resistor, inductor, and capacitor is connected in a certain kind of way to form a resonant system. At certain frequencies, the impedance can reach minimum when series connected, or maximum at parallel connected, so the current or the voltage response can be enhanced. Equations of RLC circuit discharge are given by:

$$I(t) = I_0 e^{-\frac{Rt}{L}}, V(t) = V_0 e^{-\frac{Rt}{L}}. \quad (2)$$

As $I(t)$ represents the current at time t, I_0 is initial current, $V(t)$ stands for the voltage at time t, V_0 is the initial voltage, and t is time [4].

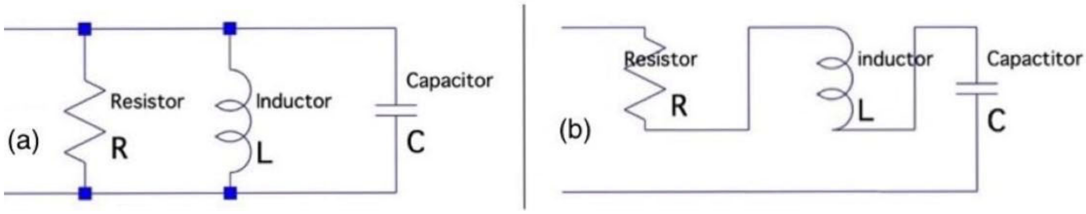

Fig. 1 The RLC circuit connected in (a) parallel and (b) series.

For the series RLC circuit, according to Ohm's Law, voltage = (current)× (total resistance), and according to Kirchhoff's first Law, the current in series circuit is equal at any point. As the total voltage is the sum of voltage of all components, the potential difference of each component is (current)×(resistance of a component). Divide current from both sides of the equation, the total resistance is found to be.

$$R_T = R_1 + R_2 + R_3 + \cdots \quad (3)$$

As R_1, R_2, R_3, are the resistance of each resistor in the circuit, R_T is the total resistance in the circuit. Since V = $L\frac{di}{dt}$, V is the electromotive force on the inductor, L is inductance, $\frac{di}{dt}$ is the derivative of current to time. As the inductors are connected in series, there is no change of current, so $\frac{di}{dt}$ is constant. The total electromotive force is equal to the sum of all other electromotive force in a series circuit, one can get the total inductance:

$$L_T = L_1 + L_2 + L_3 + \cdots . \quad (4)$$

As L_1, L_2, L_3, are the inductance of each inductor in the circuit, L_T is the total inductance in the circuit. Since $C=\frac{Q}{V}$,as C is capacitance, Q is the amount of free charge, V is voltage. When connected in series, the amount of free charge Q is constant, so C is inverse proportional to V. As the total voltage is the sum of voltage of all components, total V_T=V_1+V_2+V_3+…, so $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$ +…. This implies that the total capacitance:

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots}. \quad (5)$$

As C_1, C_2, C_3, are the capacitance of each capacitor in the circuit, C_T is the total capacitance in this circuit.[5]

For the parallel RLC circuit, the total resistance:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots}. \quad (6)$$

As R_1, R_2, R_3, stands for the separate resistance of each resistor in the circuit, R_T is the total resistance in this circuit. The total inductance:

$$L_T = L_1 + L_2 + L_3 + \cdots. \tag{7}$$

As L_1, L_2, L_3, are the inductance of each inductor in the circuit, L_T is the total inductance in this circuit. The total capacitance:

$$C_T = C_1 + C_2 + C_3 + \cdots \tag{8}$$

As C_1, C_2, C_3, are the capacitance of each capacitor in the circuit, C_T is the total capacitance in this circuit [5].

2.2. Energy Conservation of RLC Circuit

In capacitor, the energy in capacitor will increase when charging, as voltage increase, the energy will translate from circuit to capacitor. The energy will decrease when discharging, as voltage decrease, the energy will translate from capacitor to circuit. As current passes through inductor, there will be energy stored in inductor, electrical energy transfer from circuit to inductor. As current decrease to a certain point, the magnetic field energy stored in inductor will translate to electrical energy and released to circuit. Heat energy will also be translated by electric energy when current passes through the resistor. The energy transfer in capacitor and inductor will cause oscillation. Equation of energy conservation in RLC circuit

$$E = \frac{1}{2}LI^2 + \frac{1}{2}CV^2 \tag{9}$$

As E is the total energy in the circuit, L is inductance of circuit, I is current, C is capacitance in circuit, V is voltage [6].

2.3. Oscillating Process of RLC Circuit

RLC circuit can create steady oscillating signal at specified conditions, the current or voltage will change from positive to negative periodically. To start the vibration, there must be an initial stimulate, such as outside signal or noise. The oscillation will start as the circuit generates enough energy. As the circuit starts to oscillate, the capacitor and inductor will store and emit energy separately, and the current and voltage will change periodically. The frequency is related to the resistor, inductor, and capacitor. The oscillate will continue without damping, but there are many kinds of damping in most circuits to cause the attenuation of oscillation. To ensure the oscillation, the circuit normally needs an energy make up system to provide the energy loss from damping [7]. Equation of frequency in series RLC circuit is:

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{10}$$

As f is oscillation frequency, L stands for the inductance of the circuit, C stands for the capacitance of circuit.

Equation of frequency in parallel RLC circuit:

$$f = \frac{1}{2\pi RC}. \tag{11}$$

As f is oscillation frequency, R stands for the resistance of the resistor, C stands for the capacitance of circuit.

Equation of the Quality factor Q:

$$Q = \frac{1}{R}\sqrt{\frac{C}{L}} \tag{12}$$

As R is the resistance of the resistor, L stands for the inductance of inductor, C stands for the capacitance of circuit [8].

3. Application of RLC Circuit in Electronic Device

Nowadays RLC circuit can be used in numerous items, such as mobile phones, radios, computers, medical devices, and TVs.

3.1. Changing Channel in Radio

Normally the different channels in radios are changing the value of capacitor in series RLC resonance circuit. Different value of capacitor will result in the different resonant frequency, the radio will then capture and enhance different channel signals. This use of RLC circuit is used in phones, TVs, and some other electronic device [9].

In Fig. 2, it is a circuit to filter waves. This circuit can only allow certain wave frequency to pass, the other frequency waves will be weakened. It can be used in radio to select the frequency of waves that is needed.

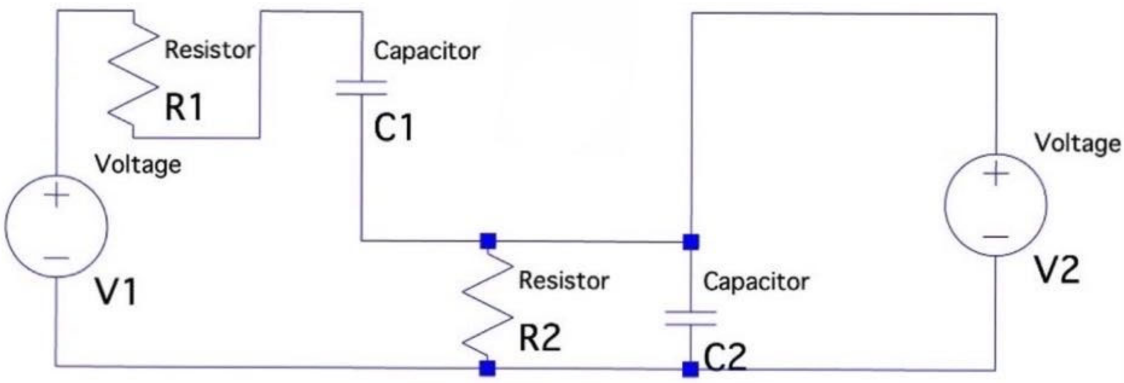

Fig. 2 circuit of wave filter.

In Fig. 3, this is a simple example of the use of RLC circuit in radio. As wave of different frequency is captured by the antenna (the component with L2), then the current will be inducted from L2 to L1. As a certain frequency which cause the greatest current in circuit, then there will be a high potential difference formed around capacitor. To change the channel of radio, one can change the capacitance C and choose to receive another wave frequency.

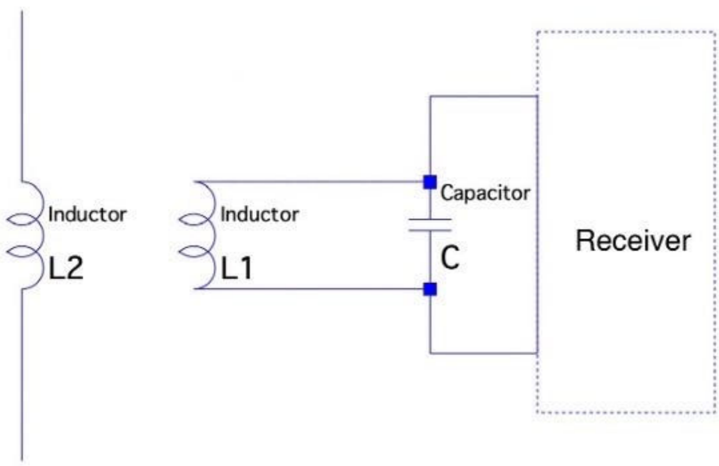

Fig. 3 the circuit of radio receiver

3.2. Induction Cooker and Flash Lamp

The induction cooker uses the electromagnetic induction principle to heat food. The RLC circuit can change the induced circuit into magnetic field, and create induced current in the bottom of cooker, so it can he heated. The different value of resistor, inductor, and capacitor can change the frequency and magnitude of circuit and change the temperature of cooker [10].

The creating of short, strong light by the use of camera needs RLC circuit. The light is created by electric arc as a circuit discharge. The inductor and capacitor in RLC circuit can control the speed and amount of discharge in a circuit. As inductor decrease fast, the current will increase, if the capacitor also discharges quickly, then the large amount of electric energy will create an arc.

4. Conclusion

RLC circuit is a circuit that can be used and calculated easily. This is because the electronic components of the circuit can be considered as linear components, and there is a differential equation above for the general solution of the circuit. This makes the circuit easy and distinct, which is easy to use. For the special structure of resistor, inductor, and capacitor, they allow the circuit to charge and transfer electric energy into magnetic energy, and the circuit can be used to oscillate and filter waves. There are two kinds of RLC circuit, series and parallel connected. The series connected have the benefit of impedance being small, so the voltage can be very big, and the circuit is voltage resonance. For parallel connected RLC circuit, the current of the circuit will be small, so impedance will be quite big, this enables the circuit to be current resonance. Relationship of total resistance, total inductance, and total capacitance between each component in series and parallel are also proved and explained in section two above. Therefore, the relationship of the total resistance and total inductance in series RLC circuit, is equal to the total inductance and total capacitance in parallel RLC circuit. The relationship of the total capacitance in series RLC circuit is also equal to the resistance of parallel RLC circuit.

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