

Showing RLC Circuit Resonance with Electronics Workbench

Chong Chen, Walter W. Buchanan
Middle Tennessee State University/Oregon Institute of Technology

Abstract

In circuit analysis courses, RLC circuit resonance is a topic that is difficult to teach without demonstration. The physical demonstration of this topic requires several kinds of circuit components and equipment. Some of these devices may not be available in a typical engineering or engineering technology department laboratory.

This paper presents teaching RLC circuit resonance with Electronics Workbench [1], a popular circuit simulation software package. With Electronics Workbench, RLC circuit resonance can be demonstrated very easily. This software package can save both the cost of the circuit components and the time to build and modify the circuit. Using Electronics Workbench, students can change the circuit parameters to the values they want and find the voltages and currents of the circuit corresponding to these values. Therefore, they may see the conditions of RLC circuit resonance from the circuit simulation for themselves.

Introduction

For circuit analysis courses, RLC circuit resonance is a topic that is not easily accepted by students when they are taught in a classroom. RLC circuit resonance can be shown mathematically. For example, in a series RLC circuit the inductive reactance cancels out the capacitive reactance at resonant frequency. Therefore, the circuit has a minimum impedance and a maximum current at this frequency. However, it is hard to see from the formulas how the reactance and the current respond to the frequency change, when the circuit frequency is approaching the resonant frequency. It is also difficult to introduce the sensitivity of a RLC circuit and the effectiveness of the capacitance or the inductance to resonance or sensitivity.

RLC circuit resonance can be demonstrated in a laboratory. The experimental demonstration can give students a chance to see this electrical phenomena. However, the equipment used in this demonstration is not always available in all college laboratories.

Electronics Workbench, a computer circuit simulation software, has been used in many universities and technical schools. It has been used for beginning electrical engineering technology courses [2] and digital fundamental courses [3]. With Electronics Workbench, the maximum power transfer theorem and RLC circuit resonance can be demonstrated very well. Also, this does not require any laboratory equipment.

Demonstrating Series RLC Circuit Resonance

In a series RLC circuit, resonance occurs when the circuit's capacitive reactance equals its inductive reactance. The applied voltage's frequency, which causes resonance, is called resonant frequency. When a series RLC circuit is in resonance, the circuit has the following properties:

- The impedance has its minimum value.
- The current has its maximum value.
- The voltage across the capacitor equals the voltage across the inductor.
- The voltage across the resistor equals the applied voltage.
- The phase angle between the current and the applied voltage is zero degrees.

With Electronics Workbench, these properties can be used to locate a circuit's resonant frequency or be proven when the resonant frequency is located.

Let students build the circuit shown in Figure 1, where it is known that the resonant frequency of the circuit is not greater than one MHz. Therefore, the search range for the resonant frequency is from zero to one MHz. Because Electronics Workbench does not accept zero Hz of AC voltage, we may start from 0.001 Hz or any frequency that is close to zero Hz.

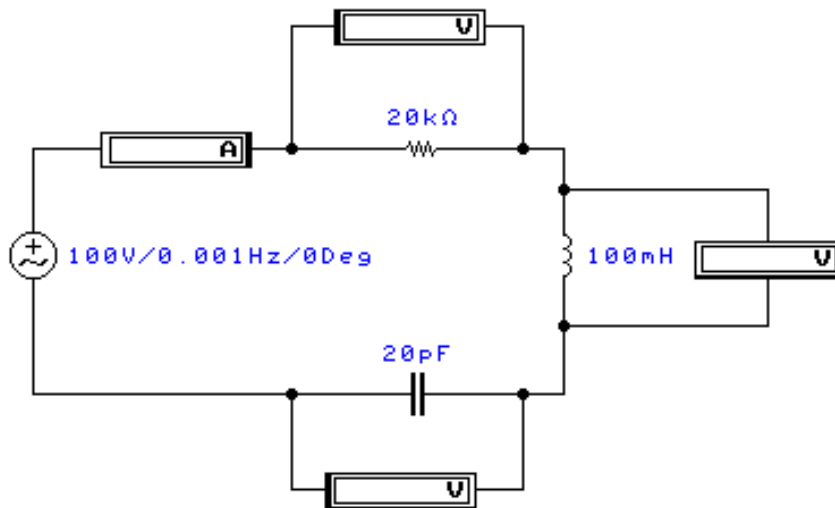


Figure 1

Keep the applied voltage in the circuit of Figure 1 at 100 Volts and set its frequency to the values in Table 1. For each checked frequency value, read and record the currents and voltages as shown in Table 1.

Frequency (kHz)	1×10^{-6}	100	200	300	400	500	600	700	800	900	1000
Current (mA)	0.001	3.82	1.13	0.613	0.430	0.334	0.274	0.233	0.203	0.180	0.161
V_R (V)	0.020	76.4	22.7	12.2	8.61	6.69	5.49	4.66	4.05	3.59	3.22
V_L (V)	6.3×10^{-7}	240	142	115	108	105	103	103	102	102	101
V_C (V)	100	304	45.1	16.2	8.56	5.32	3.64	2.65	2.02	1.59	1.28

Table 1

It can be seen in Table 1 that the voltage V_L is less than the voltage V_C when the frequency is 100 kHz or less, and V_L is greater than V_C when the frequency is 200 kHz or more. From the property (c) as noted above, the resonant frequency must be between 100 kHz and 200 kHz.

Next, read and record the current and voltages for the frequency values, which are equally separated between 100 kHz and 200 kHz, in Table 2. It can be seen that the resonant frequency should be between 110 kHz and 120 kHz.

Frequency (kHz)	100	110	120	130	140	150	160	170	180	190	200
Current (mA)	3.82	4.91	4.53	3.49	2.70	2.18	1.83	1.58	1.39	1.25	1.13
V_R (V)	76.4	98.2	90.7	69.7	54.0	43.6	36.6	31.6	27.9	25.0	22.7
V_L (V)	240	340	342	285	237	206	184	169	158	149	142
V_C (V)	304	355	301	213	153	116	91.0	74.0	61.6	52.3	45.1

Table 2

We may repeat this and work out the values shown in Table 3 and Table 4. From Table 4, it is noted that V_L and V_C have the same value at both 112.5 kHz and 112.6 kHz. Therefore, we cannot use the properties of a resonant circuit to find its resonant frequency more accurately. However, we may say that this RLC circuit's resonant frequency is 112.5 kHz or 112.6 kHz. The actual resonant frequency of the circuit can be found with the calculation:

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{0.1 \times 20 \times 10^{-12}}} = 112,539 \text{ Hz}$$

The error is 61 Hz, if 112.6 kHz is chosen as the resonant frequency. This error is less than 0.1% of the actual resonant frequency.

Frequency (kHz)	110	111	112	113	114	115	116	117	118	119	120
Current (mA)	4.91	4.95	4.97	4.97	4.96	4.92	4.87	4.80	4.72	4.63	4.53
V_R (V)	98.2	99.0	99.4	99.5	99.1	98.4	97.3	96.0	94.4	92.6	90.7
V_L (V)	340	345	350	353	355	355	355	353	350	346	342
V_C (V)	355	355	353	350	346	340	334	326	318	310	301

Table 3

Frequency (kHz)	112.0	112.1	112.2	112.3	112.4	112.5	112.6	112.7	112.8	112.9	113.0
Current (mA)	4.97	4.97	4.97	4.98	4.98	4.98	4.98	4.98	4.98	4.97	4.97
V_R (V)	99.4	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5
V_L (V)	350	350	351	351	351	352	352	352	353	353	353
V_C (V)	353	353	353	353	352	352	352	351	351	351	350

Table 4

The properties (a), (b), and (d) at the beginning of this section can be proven with the resonant frequency in Table 4. The phase angle between the current and applied voltage can be observed with the oscilloscope in Electronics Workbench. With Tables 1 to Table 4, the responses of the current and voltage to the frequency can be seen very clearly. It can also be seen from Table 2 that the cutoff frequencies of this circuit, at which the current of the circuit is 70.7% of its maximum value, are a little less than 100 kHz and a little less than 130 kHz.

Conclusions

Electronics Workbench is a useful circuit simulation software for demonstrating RLC circuit resonance. There are no limitations on the values of components used. The students can see the responses of the currents and voltages to the circuit frequency. They may also spot the cutoff frequencies of a RLC circuit from the simulation.

Bibliography

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CHONG CHEN

Dr. Chen is an associate professor in Department of Engineering Technology and Industrial Studies, Middle Tennessee State University. He received B.S. degree from Hebei Institute of Technology in China, M.S. degree from Tianjin University in China, and Ph.D. degree from University of Kentucky, all in Electrical Engineering. Dr. Chen teaches electric circuits, electronics, controls, and industrial electricity. He is a P.E. in the State of Tennessee.

WALTER W. BUCHANAN

Dr. Buchanan is Professor of Electronics Engineering Technology and Dean of the School of the Engineering and Industrial Technologies at the Oregon Institute of Technology. He received his BSE and MSE from Purdue University, and his Ph.D. and J.D. from Indiana University. Walt is a P.E. and is Assistant Vice Chair for Programs of ETD. He has written over 50 papers, and is an Alternate Member of TAC /ABET and member of IEEE's CTAA.