FEATURE

Basic Electricity #8

by Ron C. Johnson

Several months (and quite a few bad jokes) ago, we set out to overview the basics of electricity: we started out by looking at electrically charged particles and their fields, electromotive force, work and energy, resistance, current and Ohm's Law. Once we had some of the terminology figured out we looked at examples of electric circuits, some components and how to determine their values, and how voltages and currents behave in series and parallel circuits. We discussed meters and how they affect the circuit being measured; voltage and current sources and then checked out alternating voltage and current. An overview of oscilloscopes came next. The last few articles were mainly concerned with capacitors, magnetics and inductors.

This will be the last segment in this particular series. We are going to continue on with capacitors and inductors together in AC circuits and show you how basic filters are made using the characteristics of these components.

If you remember from previous articles, while capacitors and inductors do not dissipate power, they do store and release energy. In AC circuits this characteristic shows up as reactance which does limit the current in a given circuit, even though it does not consume power as resistance does. We know that capacitors and inductors shift the phase of the AC voltage with respect to the current and that in inductive circuits voltage leads current by 90° while in capacitive circuits voltage lags current by 90°. In circuits which have a combination of resistance, inductance and capacitance the relationship between current and voltage can only be predicted by vectorially adding the three impedances.

In the last segment we also discussed the fact that capacitive and inductive reactances are frequency dependant—that inductive reactance increases with frequency while capacitive reactance decreases with frequency. These two frequency response characteristics are fundamentally what we use to obtain filters.

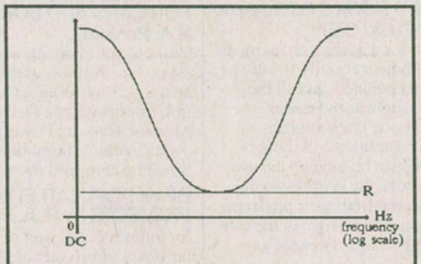

Figure 1. Frequency Vs R, X_L, and X_C

Let's take a look at the frequency response curves shown in Figure 1. As you can see the straight line labelled R for resistance does not change with frequency. X_C, which is capacitive reactance, decreases as frequency increases. X_L, which is inductive reactance, increases as frequency increases. (Note that because frequency is graphed on a logarithmic scale the responses are curved even though the relationships are directly proportional.) The three elements shown, R, X_C, and X_L, combined in various proportions and applied to a couple of basic circuits, are used to create most frequency dependant and filter circuits. These circuits are called resonant circuits because they resonate at a particular frequency in much the same way that a tuning fork resonates or oscillates at only one frequency.

SERIES RESONANCE

Figure 2 shows a series circuit similar to one we saw in our last segment. It consists of a variable frequency AC voltage source, an inductor, a capacitor and a resistor. As we have already mentioned, the individual impedances of the devices, (impedance can mean reactance or resistance, usually a combination thereof), are as shown in Figure 1. What happens to the overall frequency response of the circuit with all three combined?

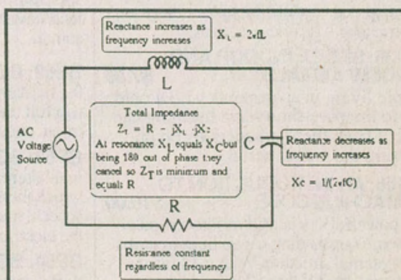

Figure 2. A Series Resonant circuit

We said in the last segment that voltage leads current in the inductor and vice versa in the capacitor and the resistor just limits the current the same at all frequencies. We also said that ultimately the level of current and its phase shift with respect to the input voltage was determined by a combination of all the components and could only really be determined using vector algebra.

So the frequency response is really a graphical representation of that current with respect to frequency. If we calculated the current flowing in the circuit for each value of the source frequency we would have the overall frequency response curve. Another way of looking at it would be to take the resistance, capacitive reactance and inductive reactance, (in other words, the total impedance) of the circuit at each frequency, and use it to find the total current, and then graph the frequency response.

So what is it in the case of a series circuit like in Figure 2?

At low frequencies capacitive reactance is very high, while inductive reactance is low and resistance is a constant value. Because X_c is high very little current flows. As the frequency of the source is increased capacitive reactance decreases, as can be seen from Figure 1, and while inductive reactance increases, it is still at a fairly low value a the middle of the graph. At high frequencies X_c is very low but at that point X_L is high so the total impedance is again very high and current flow is minimal. At about the middle the graph X_c and X_L are equal, but keep in mind that we have said that inductive and capacitive reactances have a phase shift attached to them: capacitive reactance is -90° while inductive reactance is +90° which makes them 180° out of phase. Because they must be added vectorially, they cancel each other out, and at that point, which is called resonance, the reactive component is zero, leaving only the resistance to limit the current in

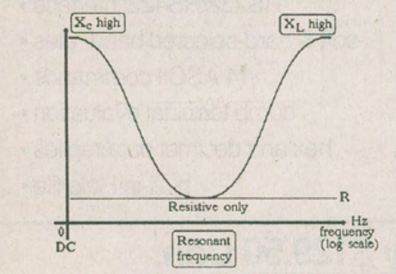

Figure 3. Series Resonant response

the circuit. See Figure 3. Naturally the opposition to current flow at this point is at a minimum and so current is maximum at resonance. In addition, there is no phase shift between the voltage source and the circuit current because the reactive components have cancelled each other out.

PARALLEL RESONANCE

A series circuit is only one basic configuration in which you will see resonant circuits. The other main circuit, as we have seen in past segments,

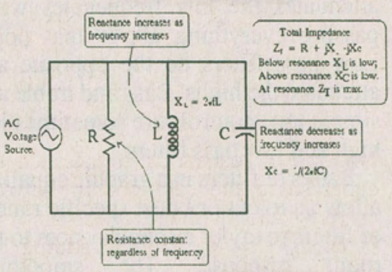

Figure 4. A Parallel Resonant circuit

is the parallel circuit. Figure 4 shows a parallel resonant circuit in which the resistance, inductance and capacitance are connected in parallel with, in this case, a variable frequency current source. In this circuit the individual components behave in exactly the same way as before, but because they are in parallel we obtain a different result.

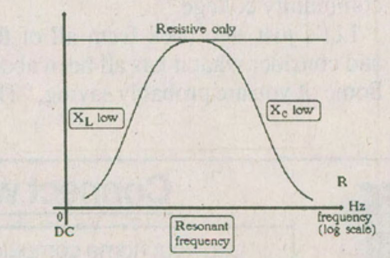

Figure 5. Parallel Resonant response

As is shown in Figure 5, at low frequencies X_L is low and X_c is high. If we measure the voltage across the parallel circuit, because X_L is low, the overall impedance of the three components in parallel is low and the voltage will be low. At high frequencies the opposite is true: X_L is high but X_c is low so, again the parallel impedance is low and the voltage across the circuit is low. At some point in the middle, however, where X_c equals X_L (and they are 180° out of phase) the reactive components again cancel each other out leaving only the resistive component. At this point the overall impedance of the circuit (which is R only) will be at its maximum and therefore the voltage across it will be maximum.

So for a series resonant circuit, at the resonant frequency, the circuit impedance is low and current flow is maximum. For a parallel resonant circuit, at the resonant frequency, the circuit impedance is maximum and the voltage output is maximum. For both types of circuit, at resonance the capacitive and inductive reactive components are equal and 180° out of phase and therefore cancel each other out making the circuit purely resistive and the phase shift in the circuit is zero. The actual frequency of resonance is determined by the values of the capacitive and inductive components.

QUALITY FACTOR

We said that the resonant frequency was a function of what inductive and capacitive component values were chosen. What about the resistor shown in the resonant circuits? What effect does it have on the frequency response curve?

While the resistance does not affect the centre frequency of the resonant response it does have an effect on what is called "quality factor." Quality factor is a number which indicates how selec-

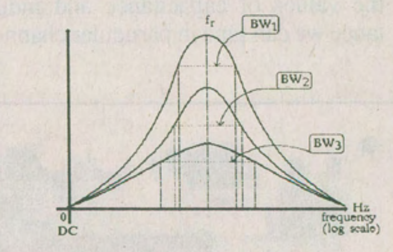

Figure 6. Three different quality factors

tive the circuit is. Figure 6 shows three different resonant responses superimposed on each other, all centred on the same frequency but with different quality factors. In order to determine the bandwidth (range of frequencies passed) of the circuit we use what are called the half-power points on the response curve. Half-power points are the point on the curve where the amplitude of the frequency at that point would deliver half as much power to a load as the centre frequency would. If you work it out mathematically you would find that half-power corresponds to .707 times the peak voltage or current. These points are shown on the graph for each response curve. You can see that as the quality factor increases (highest response) the half-power points become closer together. This causes the bandwidth of the frequencies passed by the circuit to become smaller or more selective. Generally we consider more selective filter circuits to be more desirable because we have better control over a small band of frequencies. Quality factor applies to both series and parallel resonant circuits.

The question now becomes: how does all of this apply to circuits we may work with as hobbyists or beginners in electronics? The important thing here is to understand in a qualitative way why capacitors, resistors and inductors are put together in certain combinations to create circuits which are frequency dependant. At various times in this magazine and other sources you will see filter circuits which are used for various purposes.

Bandpass filters are one kind of frequencies dependant circuit that we have already looked at. They pass a certain range of frequencies while blocking out all others. Bandpass filters are the main type of filter used in radio and television receivers and by changing the values of capacitance and inductance we can tune in particular channels or stations which broadcast at a known frequency while rejecting all the others. While the circuits employed to maximise the quality factor and other filter requirements can become complex, the basic circuit concepts are the same as we have discussed.

We can also build high pass or low pass filters by leaving out either the capacitor or inductor and increasing the gain of the circuit using amplification. An example of a high pass filter would be the rumble filter on your stereo. It attenuates the low frequencies while passing everything above that point. Low pass filters do the opposite and attenuate the highs. Bass and treble and simple tone controls are sometimes just high and low pass filters.

Banks of filters in a graphic equalizer allow us to cut or boost specific ranges of filters to taylor a sound system to the room response. The smoothing capacitors in DC power supplies are really just low pass filters, designed to attenuate all frequencies above DC.

Well, that about wraps it up for this area of basic electricity. That is not to say that we have covered everything to the depth that we could have but, as we set out to do, we have overviewed the subject in a qualitative way. If you want to dig deeper into the mathematics behind this stuff you would do well to take an evening class at a technical school or community college.

Let's just step back from all of this and consider what it has all been about. Some of you are probably saying, "This has been an eight part series and we still haven't talked about semiconductors, integrated circuits or any of that good stuff." That is true but having familiarized yourself with the basics, you will find that this stuff will support the more advanced information and you will understand it better.

For instance: Knowing the difference between a voltage source and a current source, what their individual characteristics are, the practical considerations of internal resistance and maximum power transfer helps you to understand why DC power supplies are designed the way they are, input and output impedance in audio amplifiers, speaker loading, how batteries work and why they behave the way they do when they are partially discharged. Series and parallel networks are used continuously in transistor circuits, speaker combinations, digital circuits and lots of other areas. Capacitance and inductance is used, again, in power supplies, timing circuits and filters. Magnetism is used in tape recorders, relays, televisions and industrial electronics.

So where do we go from here?

In subsequent issues I'll be starting a series on semiconductors, considering the theory, some practical applications, and the minimum amount of math required to enable you to design your own basic circuits. To make things a little more interesting I'll give you some simple circuits to set up on a breadboard so you can see for yourself how they work. ❒