Diploma of Audio Production Name________________

Analogue Fundamentals (Audio Knowledge)

Module 12

Topic 1: The Inductor (L).
Topic 2: The unit of Inductance
Topic 3: The inductor and Reaction to DC.
Topic 4: Graphing the Behavior of CR EQ Circuits.
Topic 5: The inductor and Reaction to AC.
Topic 6: Simple EQ circuits using LR circuits.

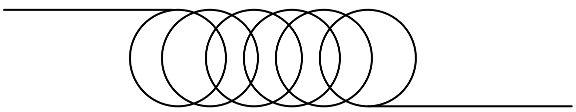
Topic 1: The Inductor (L).

The inductor is basically a coil of wire wound in a former. It is called an "Inductance" because its behaviour is that of Magnetic Inductance, Ie. Electro-magnetism.. For an inductor of any given shape, the more turns of wire it has, the more inductance it has.
An inductor, like the capacitor is capable of storing energy however this time this energy is stored as a magnetic field surrounding the coil. Again energy must be first "put in" if we are to get energy out. A current flowing through the inductor will generate the magnetic field.
An inductor exhibits the exact opposite Characteristics to that of a capacitor. That is its DC resistance is almost a short circuit or zero ohms and it opposes a change of current as distinct to that of a capacitor, which opposes the change of voltage.

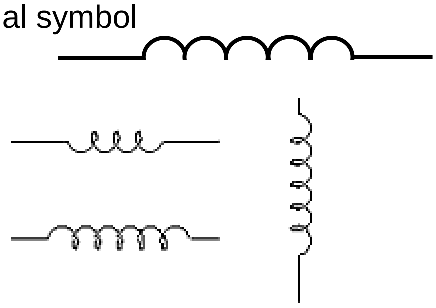
An inductor opposes the change in current because the magnetic field generated by a *change* in current generates an internal voltage that actually *opposes* the changing voltage applied.

The symbol is simply a coil with a connection at both ends.

Eg.



Usual symbol



Inductors vary in shape, size and application from tiny circuit board types to very large coils as used in high quality loudspeaker crossovers.

Topic 2 : The unit of Inductance:

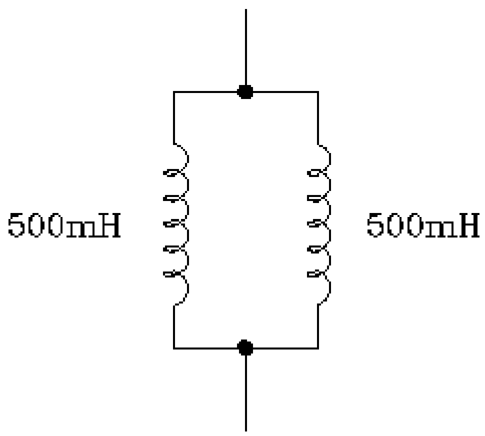
The Unit of Inductance is the **"Henry"** and the mathematical symbol is **"L".**
Again this unit is named after some chap who discovered its properties and chose the base unit because a change of 1 Ampere in 1 second will produce 1 Volt across the inductance.

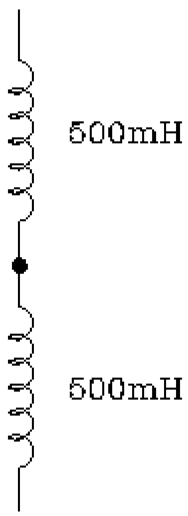
Ie. $\mathbf{V = L \times \frac{\Delta I}{\Delta t}}$ Where V is the voltage across the inductor in Volts, L is the inductor value in Henries, ΔI (Delta I) Delta means a change of so ΔI is a change of 1 Amp and Δt is a change of 1 Second.
So there you have it. Aren't you glad you asked?

In the Audio Electronics area we use Henries (H), milli-Henries (mH) and micro-Henries (µH).

Parallel and Series Connection of Inductors:

Now as the Inductor characteristics are opposite to that of a Capacitor putting them in series or parallel will be the same as that for resistors. That is series Inductors increase the effective value and parallel connections decrease the total value. If you liken putting inductors in series effectively ***increases*** the number of turns of wire this is easy to see.
So in series the total value will be always greater than the largest value and in parallel the total will be always smaller than the smallest value Inductor because the signal has an alternative path just like with parallel resistances. That is two 500mH inductors in series will give a total value of **1H** and in Parallel connection will give a total value of **250mH**.





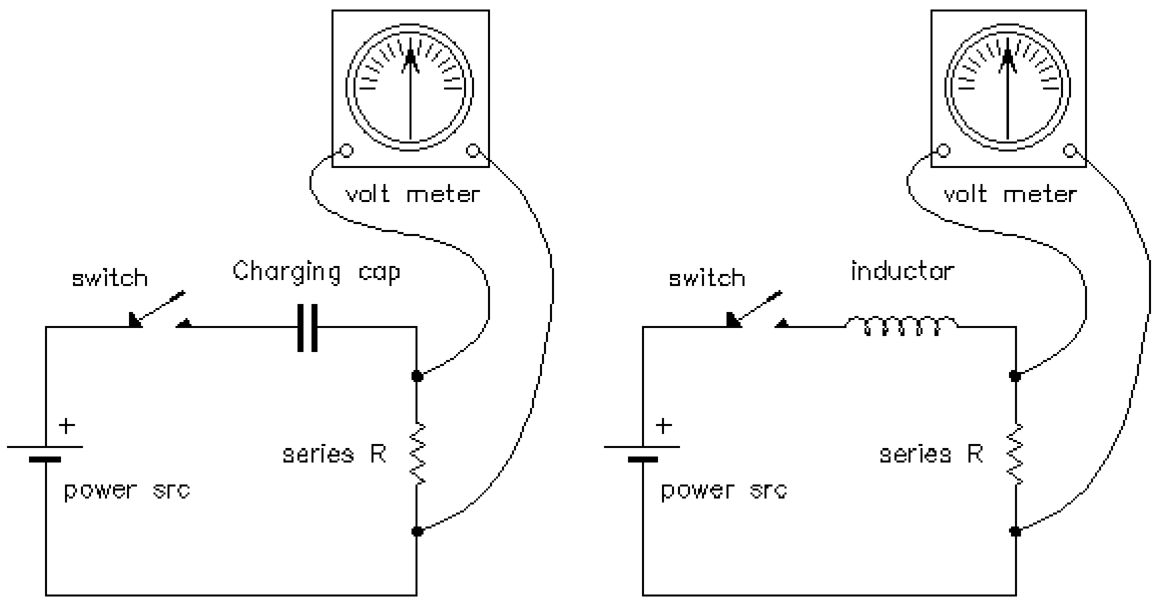
It is not a very common practice to connect inductors in parallel or series for that matter and if they are they are usually the same values so working out the total inductance is a relatively simple exercise.
The same rules apply as for resistors in parallel and series; i.e. the sum for series and product divided by the sum for two only in parallel or the reciprocal method for 3 or more in parallel.

Topic 3: The inductor and Reaction to DC.

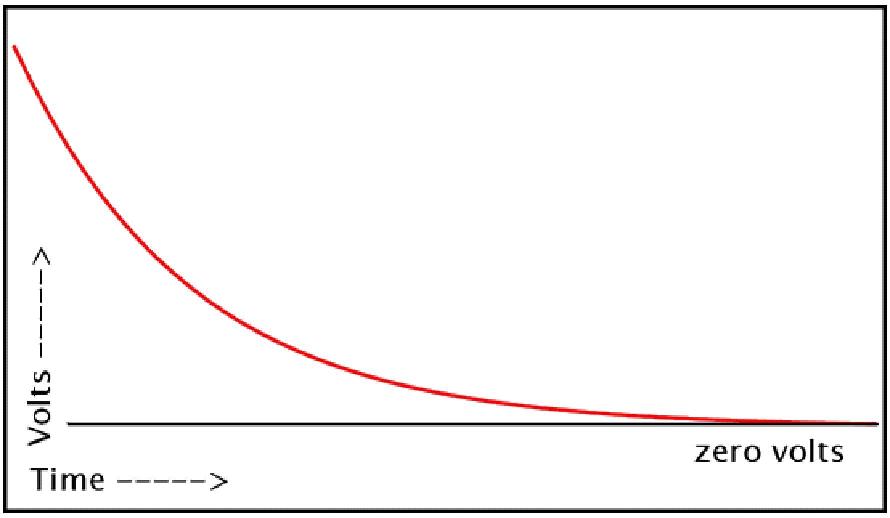
If we apply a DC voltage to an Inductor it will take a finite time for the circuit current to build up to its maximum determined by the resistance in the circuit. The instant we apply a DC voltage to an Inductor it will appear as an open circuit and no current will flow and therefore the supply voltage will appear across the inductor. When the DC is applied to the inductor the current produces a magnetic force which actually ***opposes the change in current*** that is producing it. It appears as a very high resistance to the voltage over it. So in this sense we can say that an Inductor opposes a change in current as distinct from the capacitor which opposes a change in voltage.

Comparing capacitors & inductors:

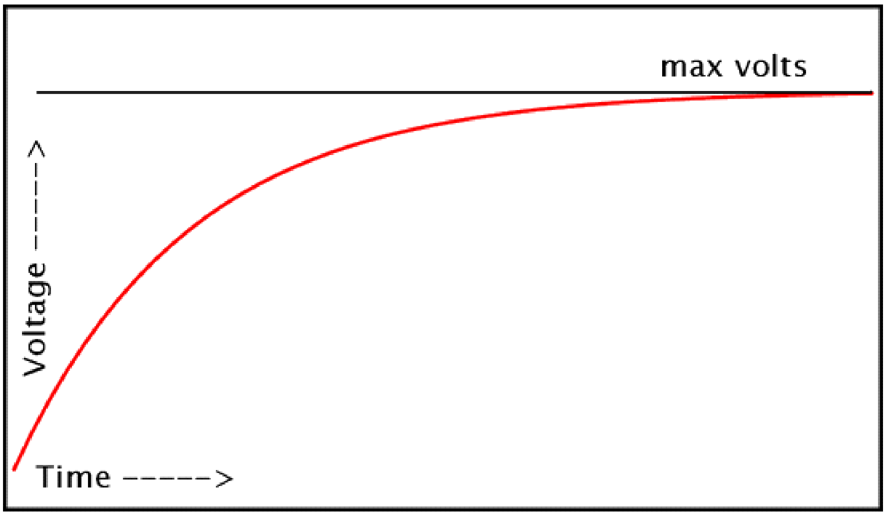
Consider the two different charging circuits below; and what would happen if we measured the voltage over the 'series R' resistor:



If we looked at the voltage over the 'series R' resistor in the 1st diagram, it would look like the diagram on the next page: the capacitor ***accepts*** the flow of current quickly at first, but slows exponentially, until there is no current flow.



If we looked at the voltage over the 'series R' resistor in the 2nd diagram using an inductor, it would look like this: the inductor ***resists*** the flow of current, but this effect decreases exponentially and eventually the DC flows through unhindered. **Note that in both cases we are measuring the voltage changes over the *series resistor*.**



We still use the Universal Time Curves to describe the operation of a series Inductance Resistance circuit but this time on the charging cycle the rising curve is the circuit current. A series LR circuit also takes 5 time constants to reach it fully charged condition.

And the Formula.

Time Constant (TC) = $\frac{L}{R}$ Where L is in Henries and R is in ohms and TC is in seconds. Can also be expressed as: $\tau = \frac{L}{R}$

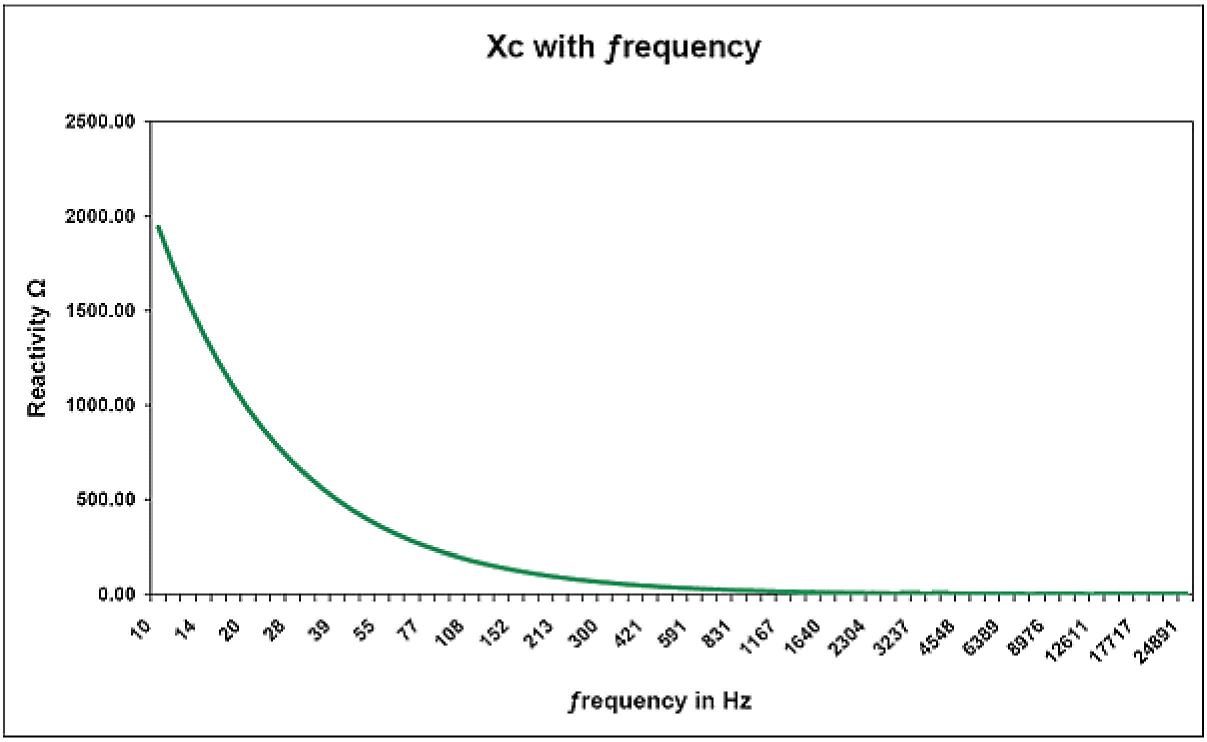
It is not so practical to "time" these circuits as we did with capacitors because we would need very large inductances and small resistors and this would make the circuit current to high when the inductor is charged.

Topic 4: Graphing the behaviour of CR EQ circuits:

Because a capacitor charges up with a time constant determined by the value T = RC, it passes AC signals through by way of the plates charging and discharging. The larger the capacitor value (in Farads), the more easily these AC signals pass through ***at any given frequency.*** Remember the formula for the reactive capacitance of a capacitor?

$$X_c = \frac{1}{2\pi F C}$$

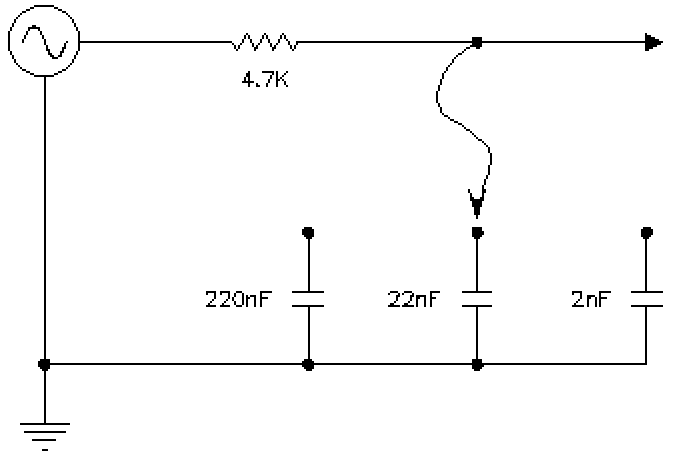
Where F = ƒrequency of the AC signal and C = the value of the cap in Farads. If we plotted a graph of Xc (in this case 8.2uF) with increasing frequency (logarithmically) from 10 Hz upwards, it looks like this:



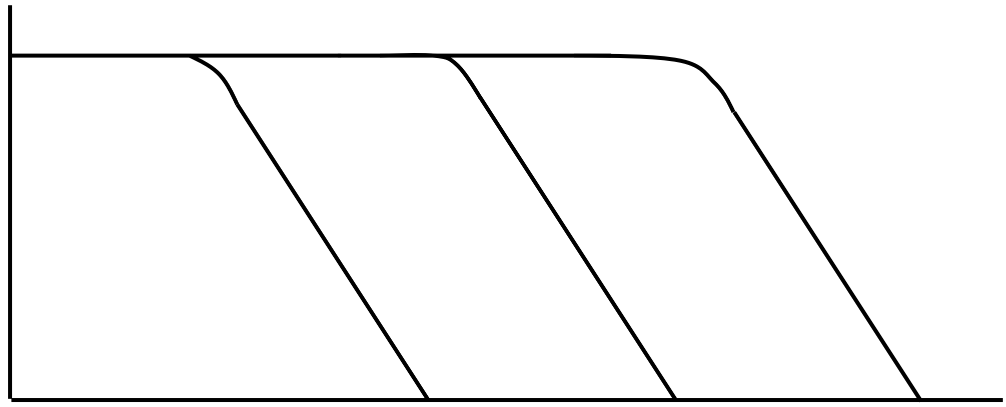
By re-arranging the formula for $\mathbf{X_C}$ we can predict the "turnover" frequency for any given combination of **R** & **C**. i.e. when the capacitive reactance of a cap is the same value as the series resistor, we can substitute $\mathbf{X_C}$ for **R.** E.g.

$$X_C = \frac{1}{2\pi f C} \quad \therefore \quad f = \frac{1}{2\pi R C}$$

… the result is that the attenuation will be –3dB at this point.

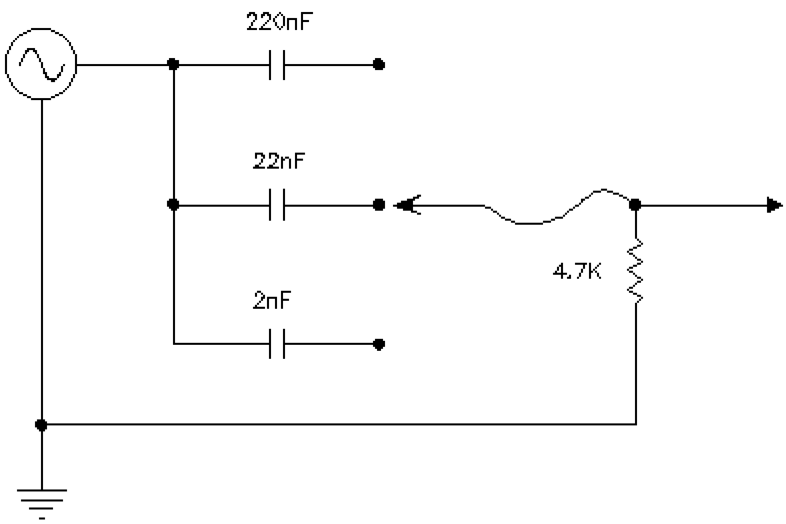


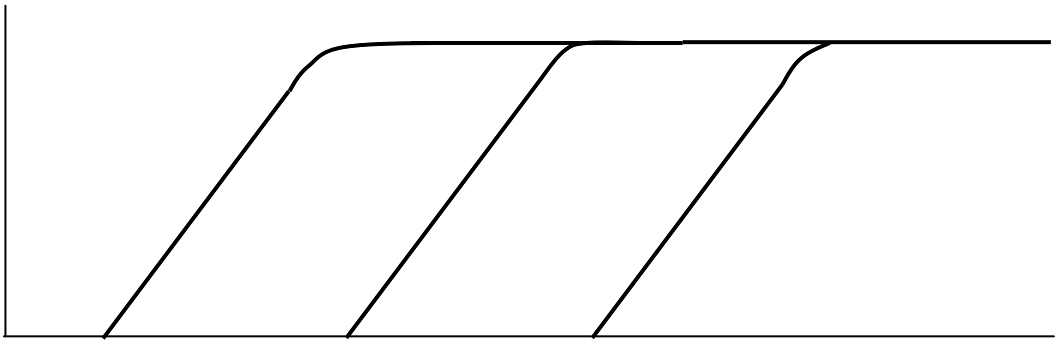
With this in mind look at the expected behaviour graphs below in relation to the above circuit.



Mark on the graph which Capacitor results in the curve as shown above along with the turn over frequency.

In the circuit below, we have changed the position of the resistor and Capacitor.





Mark on the graph which Capacitor results in the curve as shown above along with the turn over frequency.

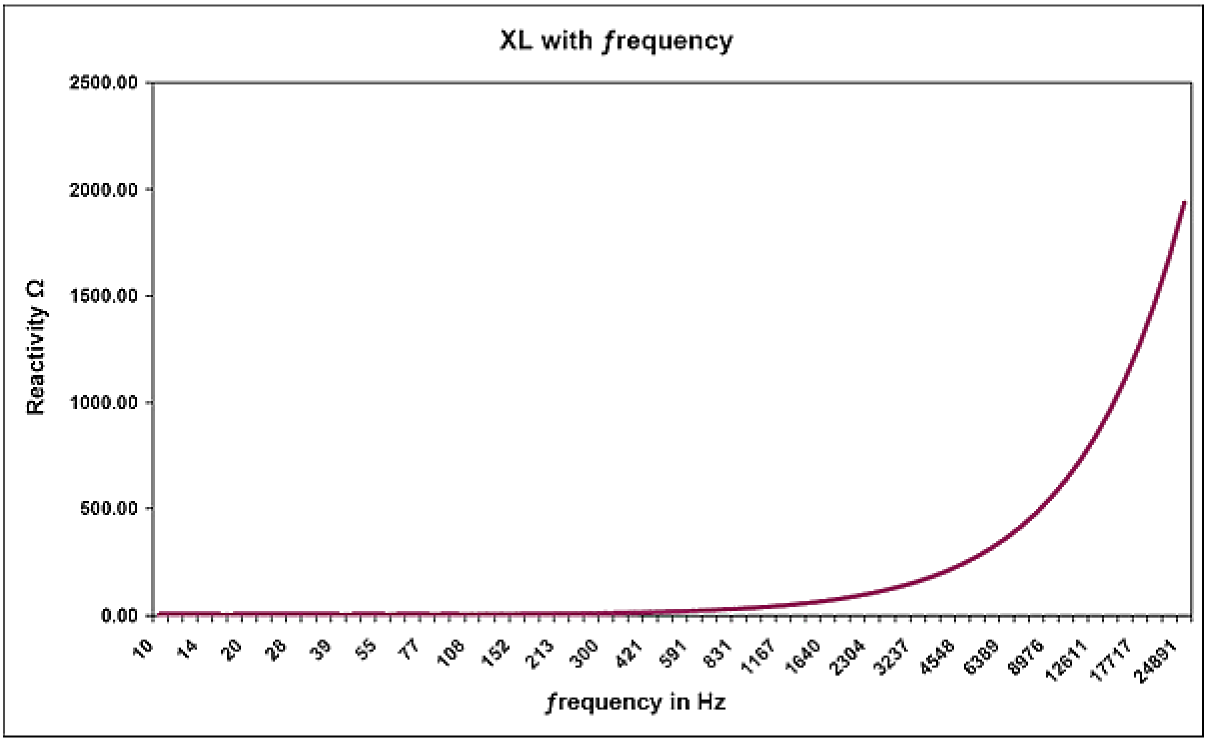
A demonstration with some music will hopefully reinforce this aspect of CR EQ circuits.. So lets put on the Gunners.
You will need to describe how the sound appears to you with each capacitor in both the circuits.

Topic 5: The inductor and Reaction to AC. (Sine waves)

Just as in the capacitive circuit the inductor's resistance will vary depending on the input frequency. So we say it "reacts" to changing input frequencies but this time the resistance increases as the frequency increases. This resistance is really **"<u>Inductive Reactance</u>".**

The formula for inductive reactance is: $\mathbf{X_L = 2\pi f L}$

…where f = the frequency of the AC signal and **L** = the value of the inductor in Henries. If we plotted a graph of X_L (in this case 2 milliHenry) with increasing frequency (logarithmically) from 10 Hz upwards, it looks like this:



We can calculate the actual value of inductive reactance for any given inductor if we know its value and the frequency of the input sine wave.

Formula: $\mathbf{X_L = 2\pi f L}$

Where $\mathbf{X_L}$ is Inductive reactance in ohms, f is the frequency in hertz and **L** is the value of the inductor in Henries. Now this $\mathbf{X_L}$ increases in a linear fashion with increasing frequency.

Calculating a couple of values of X_L

1/. Given a 100mH inductor and a Frequency of 1 KHz, find X_L

$\mathbf{X_L = 2\pi f L}$ which = 2 x 3.14 x 100mH x 1000Hz = 628Ω

2/. Given a 2H inductor and a Frequency of 1 KHz, find X_L

$\mathbf{X_L = 2\pi f L}$ which = 2 x 3.14 x 2H x 1000Hz = 12.5KΩ
Now we can use this increasing resistance to “steer” certain frequencies to different parts of a circuit.

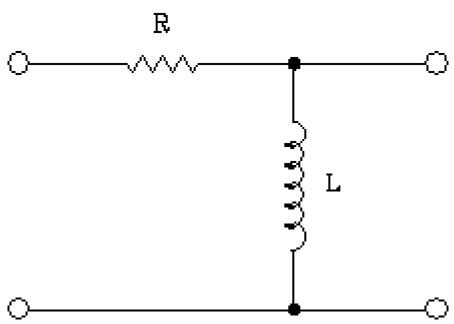
What Happens when we apply a Square wave to a LR series Circuit?

Remember **a** Square wave is really just 2 levels of DC, which are continuously changing. Something quite interesting happens and that is when the input square wave returns to zero we get a reverse voltage across the inductor.. This is due to the collapsing magnetic field inducing a voltage into the coil of reverse polarity to that which caused the build up of the field in the first place.
If we apply some different waveforms to the input of the circuit we can again change their shape. Good for creating different sounds..

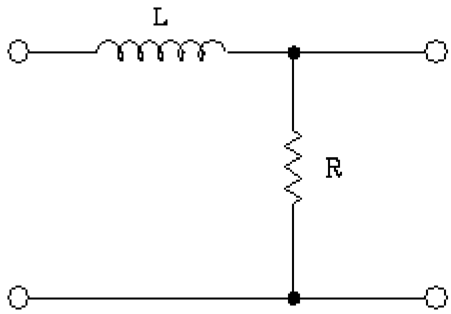
Topic 6: Simple EQ circuits using LR circuits.

We can use this changing resistance to make some simple EQ circuits as we did using series CR circuits.
Before analysing the circuits we need to keep in mind that at very low frequencies the inductor is almost a short circuit and at very high frequencies it is almost an open circuit.

So looking at the following circuit:

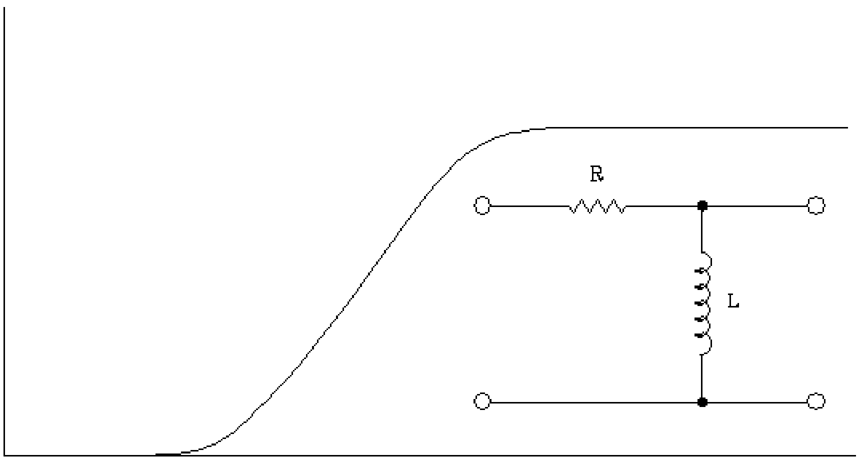


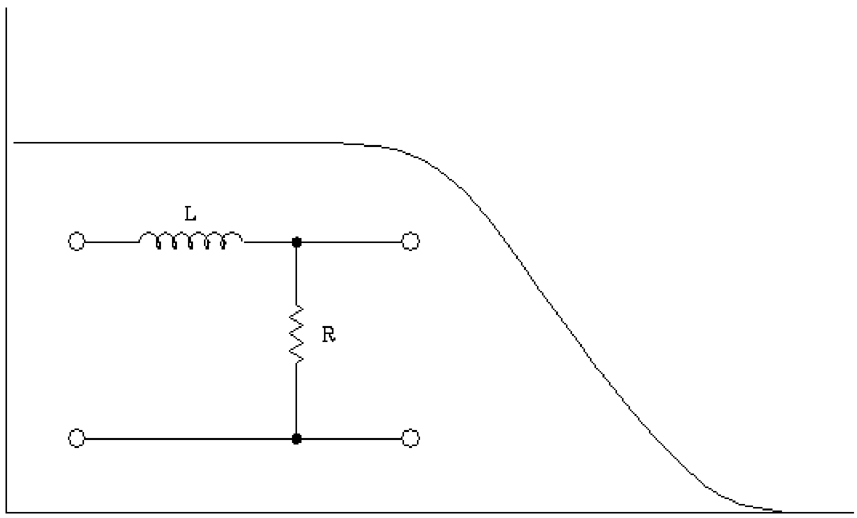
This circuit must be a _______pass filter because ____ frequencies are bypassed to ground.



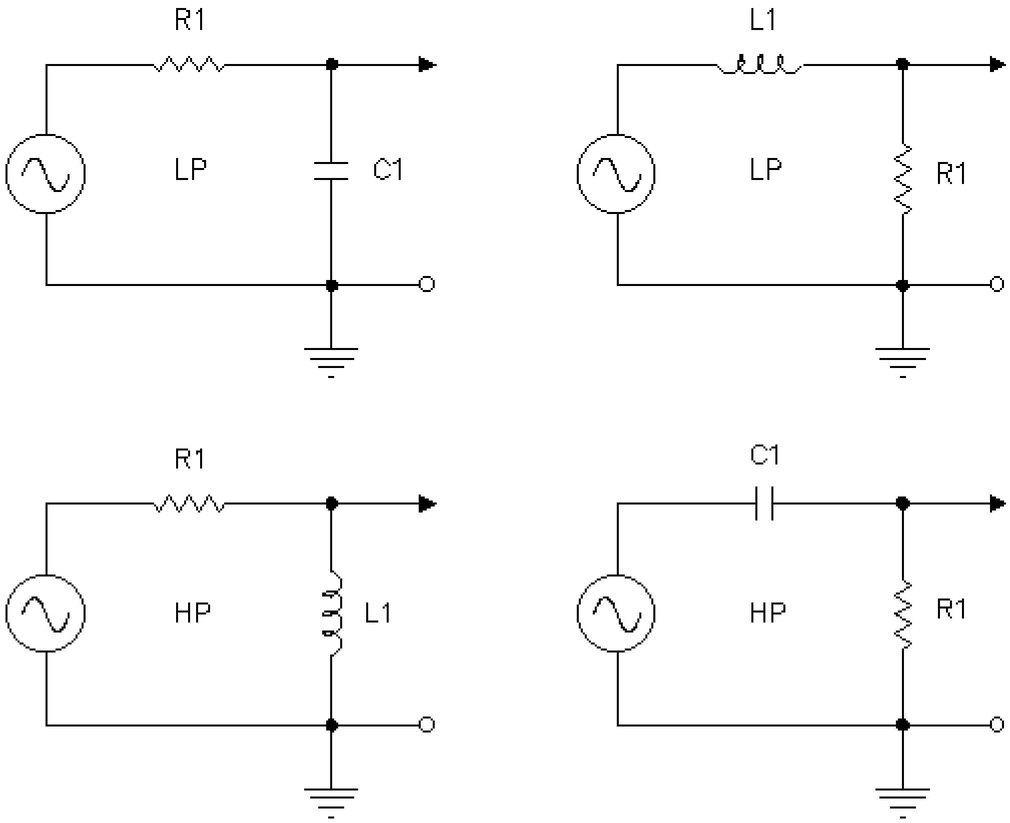
And the circuit above must be a _____ pass filter because ______ frequencies encounter a high resistance between the input and the output.

If we know the value of the resistor and the inductor we can accurately predict the point when the input signal frequency begins to roll off.
Frequency response graphs.





Comparing simple filters using capacitors & inductors:



The ones at the top are Low Pass (**LP**) filters.

The ones on bottom are High Pass (**HP**) filters.

Why don't we build up these circuits and listen to sound output when they are placed in series with the signal or maybe a demo will suffice.

But how do the inductor circuits (L/R) compare with the CR EQ circuits? What is the major difference between the two?

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