Impedance, Resonance, and Filters

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A Quick Review…

- Before discussing Impedance, we must first understand capacitive and inductive reactance.

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Reactance

- **Reactance** is the **opposition** to the **flow of Alternating Current (AC).**
- **Reactance** has **no effect** on the flow of **Direct Current (DC).**

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Capacitive Reactance

- **Capacitive Reactance** is the **opposition** to the **flow of AC by capacitance.**
- As the **frequency of the AC increases, Capacitive Reactance decreases.**
- The **Symbol** for **Capacitive Reactance** is $\mathbf{X_C}$**.**
- $\mathbf{X_C}$ is expressed in **ohms.**
- Even though it is expressed in ohms, **power is not dissipated by Reactance!** Energy **stored in a capacitor** during **one part of the AC cycle** is simply **returned to the circuit** during the **next part of the cycle!**

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Capacitive Reactance

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

- Where:

F = frequency in Hertz

C = capacitance in Farads

π = 3.14

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Inductive Reactance

- **Inductive Reactance** is the **opposition** to the **flow of current** in an **AC circuit** caused by an **inductor.**
- As the **frequency increases,** Inductive Reactance **also increases.**
- The **symbol** for **Inductive Reactance** is $\mathbf{X_L}$**.**
- Even though it is expressed in ohms, **power is not dissipated by Reactance!** Energy **stored in an inductor's magnetic field** during **one part of the AC cycle** is simply **returned to the circuit** during the **next part of the cycle!**

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Inductive Reactance

$$X_L = 2\pi f L$$

- Where:

  f = frequency in Hertz

  L = inductance in henrys

  π = 3.14

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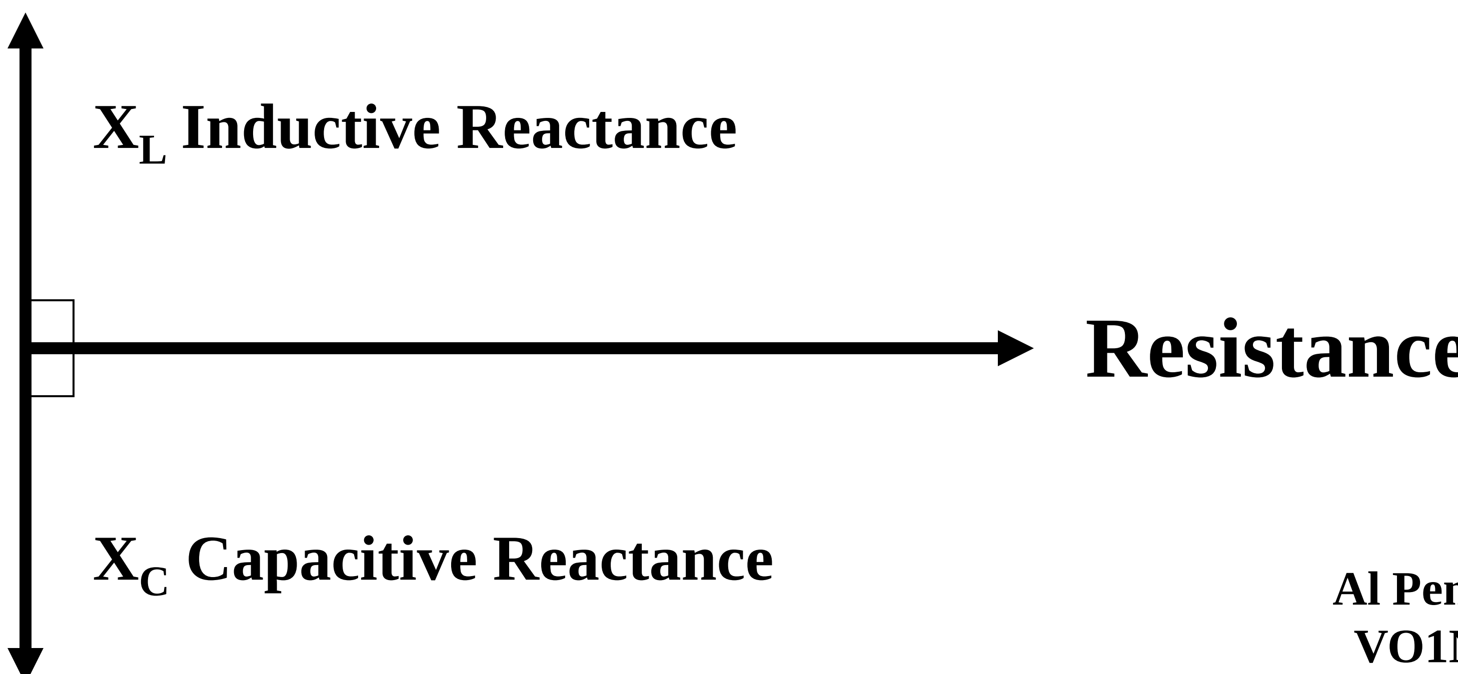
Current versus Voltage

- In a simple **resistive** circuit, the **current and voltage are always in phase.**
- For reasons beyond the scope of the Basic Course, the current and voltage are **not in phase in AC circuits** that contain **capacitance and/or inductance.**
- The **current** across a **capacitor leads the voltage by 90 degrees.**
- The **current** across an **inductor lags the voltage by 90 degrees.**

Vector Representation

- When plotted as **vectors, series circuits** containing Inductance, Capacitance and Resistance **(LCR)** can be represented as such:



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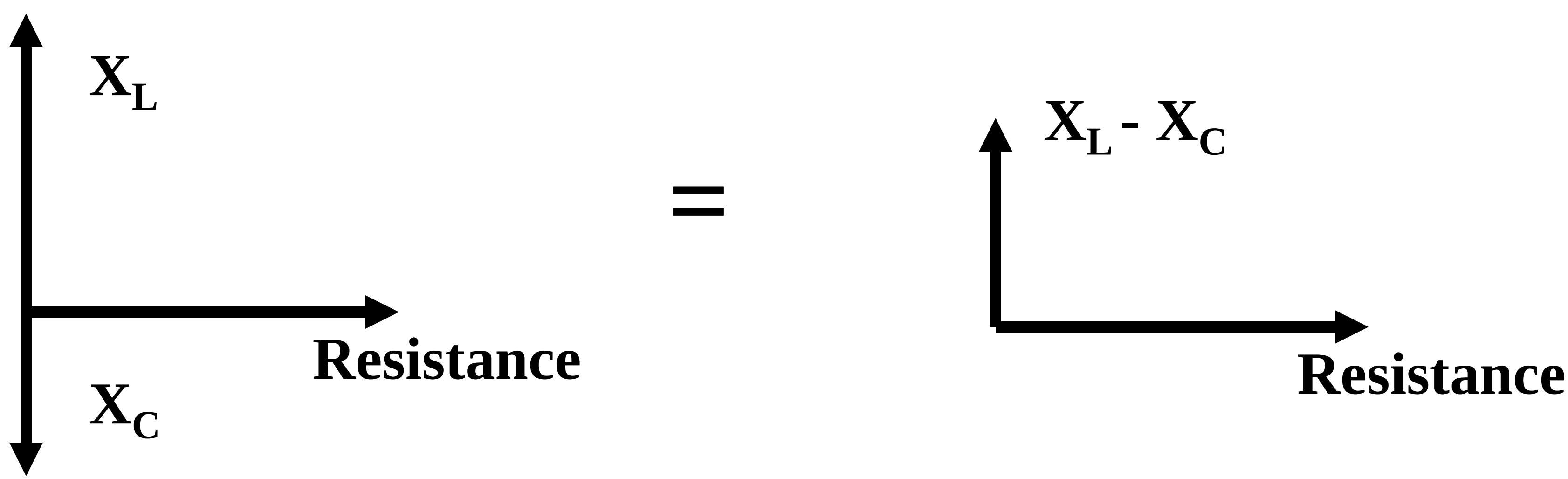
Inductive vs Capacitive Reactance

- Inductive and Capacitive Reactance **cannot** be **added together** to give an overall reactance.
- In fact, they tend to **cancel each other out.**



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Impedance

- When a circuit contains both **resistance** and **reactance,** the **opposition to the flow of AC** is called **Impedance,** abbreviated **Z.**
- Because **Resistance** and **Reactance** are **not in phase** however, we must use **vectors** to determine the **Impedance,** even if Inductive and Capacitive Reactance have partly **cancelled each other out.**

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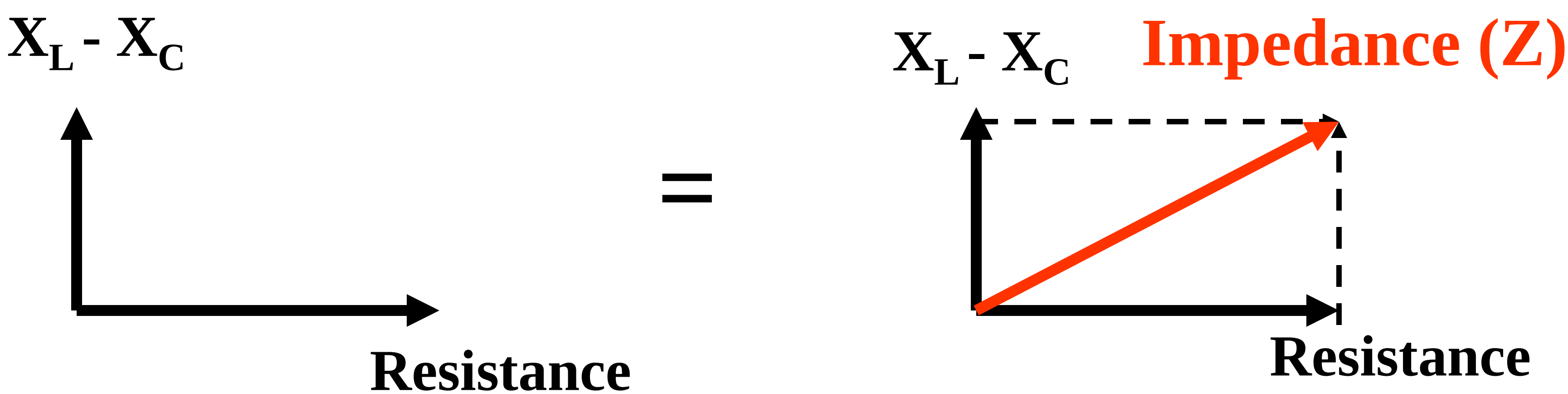
Vector Addition

Through the use of **vector addition,** the Impedance can be determined…



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LCR Circuit Impedance Formula

- Rather than plot vectors every time we need to determine impedance however, we can use a **formula:**

$$\mathbf{Z} = \sqrt{R^2 + (X_L - X_c)^2}$$

- Note that because the difference between X_L and X_C is squared, **it doesn't matter** what term is subtracted from what – you can use $\mathbf{X_C - X_L}$ if that is more convenient.

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LCR Circuit Impedance Example

- Resistance = 120 Ohms
- X_L = 40 Ohms
- X_C = 130 Ohms

- Z = Sqr Root [$R^2 + (X_C - X_L)^2$]

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  = Sqr Root [$(120)^2 + (130 - 40)^2$]

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LCR Circuit Impedance Example

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- Z = Sqr Root [$R^2 + (X_C – X_L)^2$]
  = Sqr Root [$(120)^2 + (130 – 40)^2$]
  = Sqr Root [14400 + 8100]

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  = Sqr Root [$(120)^2 + (130 - 40)^2$]
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  = 150 Ohms

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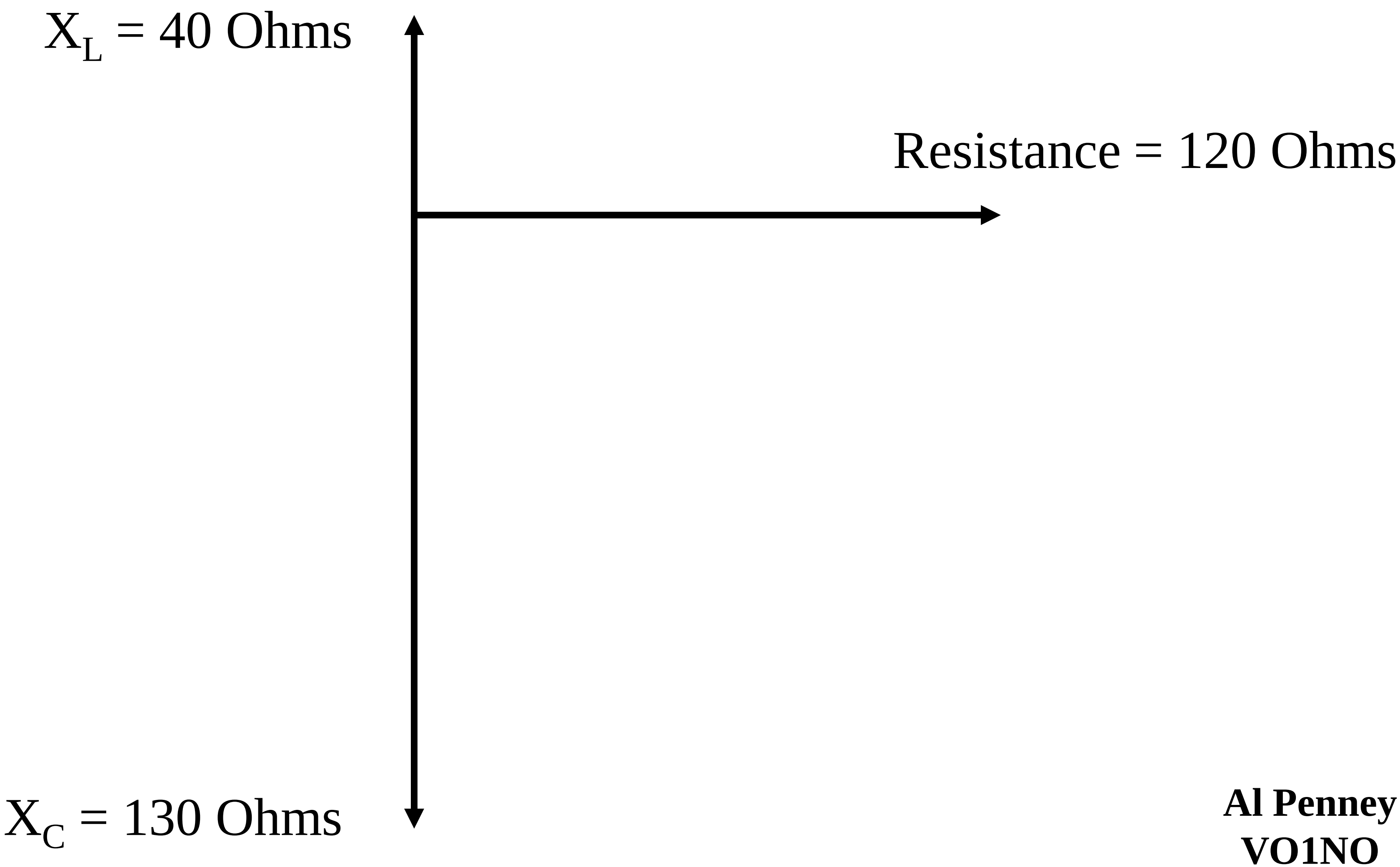
LCR Circuit Impedance Example



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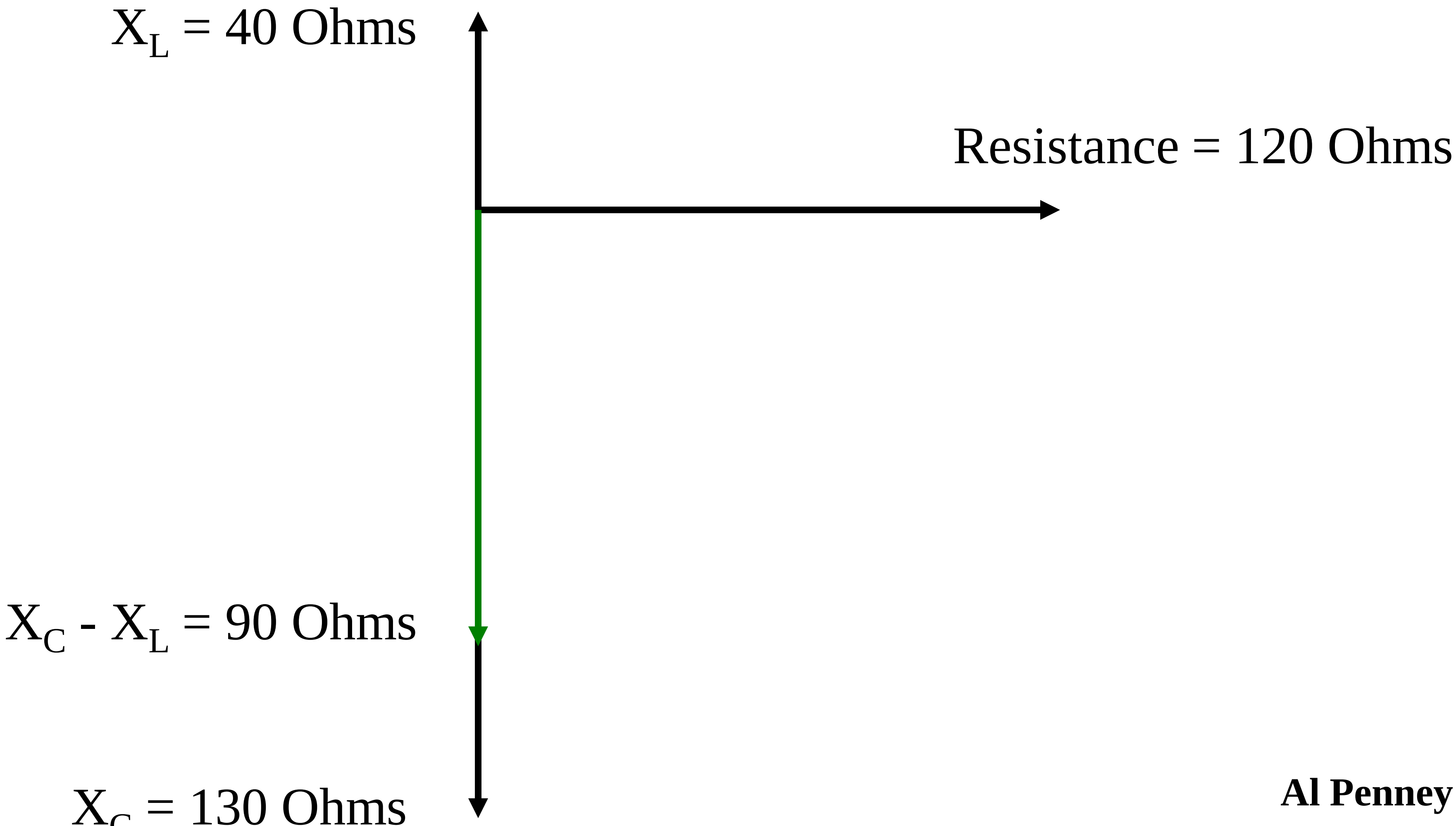
LCR Circuit Impedance Example



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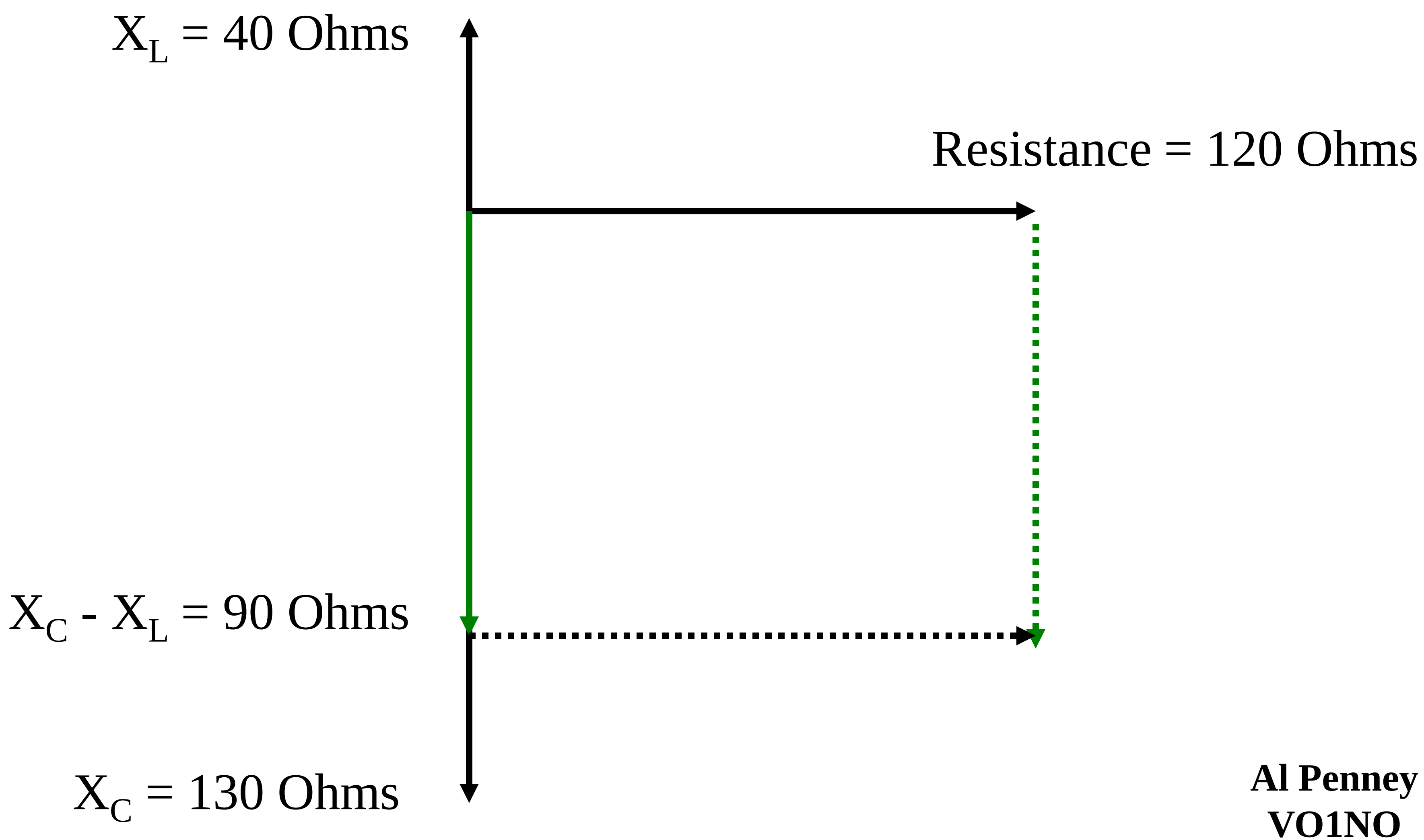
LCR Circuit Impedance Example



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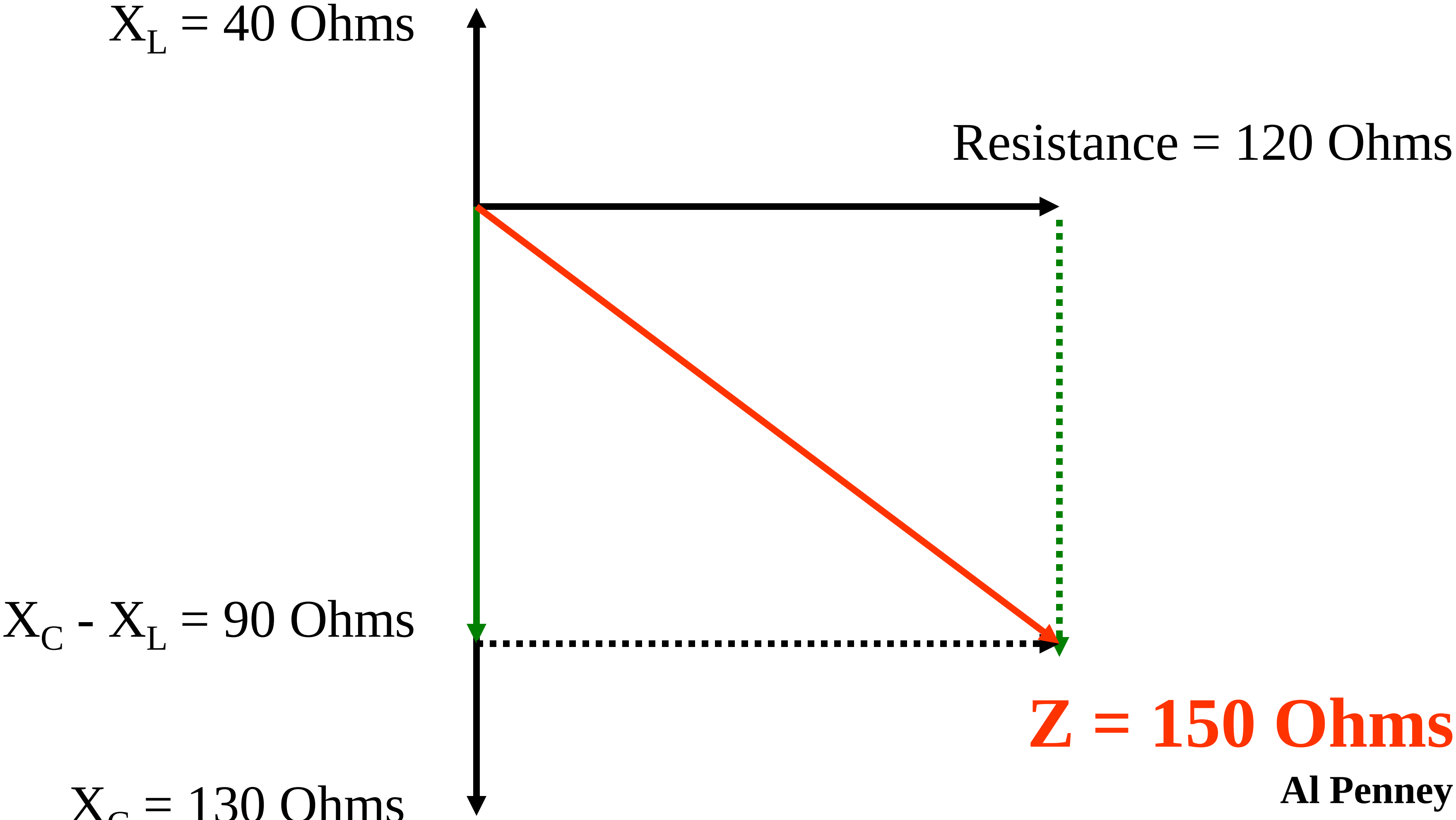
LCR Circuit Impedance Example



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Impedance Matching

- Many electronic devices and circuits (speakers, microphones, antennas, transmission lines, amplifiers etc.) have their own **characteristic impedance.**
- When interconnecting these devices and circuits, **maximum power transfer** will take place if the various **impedances are matched.**

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Matching with Transformers

- **Transformers** are often used to **match impedances** which are primarily **resistive.**
- This is especially true for **antenna and transmission line systems.**
- Take the matching transformer **(Balun – BALanced to UNbalanced)** used to match 300 Ohms to 75 Ohms in TV systems.

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300 – 75 Ohm Balun

- These **matching transformers** are widely used for TV systems, and consist of a **small ferrite core** with **two windings.**
- In addition to the **impedance transformation,** it also converts between a **balanced** system and an **unbalanced** system.

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Number of Turns

- Different impedances can be matched quite easily by adjusting the number of turns using the following formula:

$$Z_S / Z_P = N_S^2 / N_P^2$$

Or…

$$N_S / N_P = \sqrt{Z_S / Z_P}$$

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Number of Turns - Example

- Z_S = 300 Ohms, Z_P = 75 Ohms

$$N_S / N_P = \sqrt{Z_S / Z_P}$$

$$N_S / N_P = \sqrt{300 / 75} = \sqrt{4} = 2$$

- The **turns ratio** is 2:1 ie: for **every turn** on the **primary** winding, there are **two** on the **secondary** winding.
- The actual number of turns depends on the core material.

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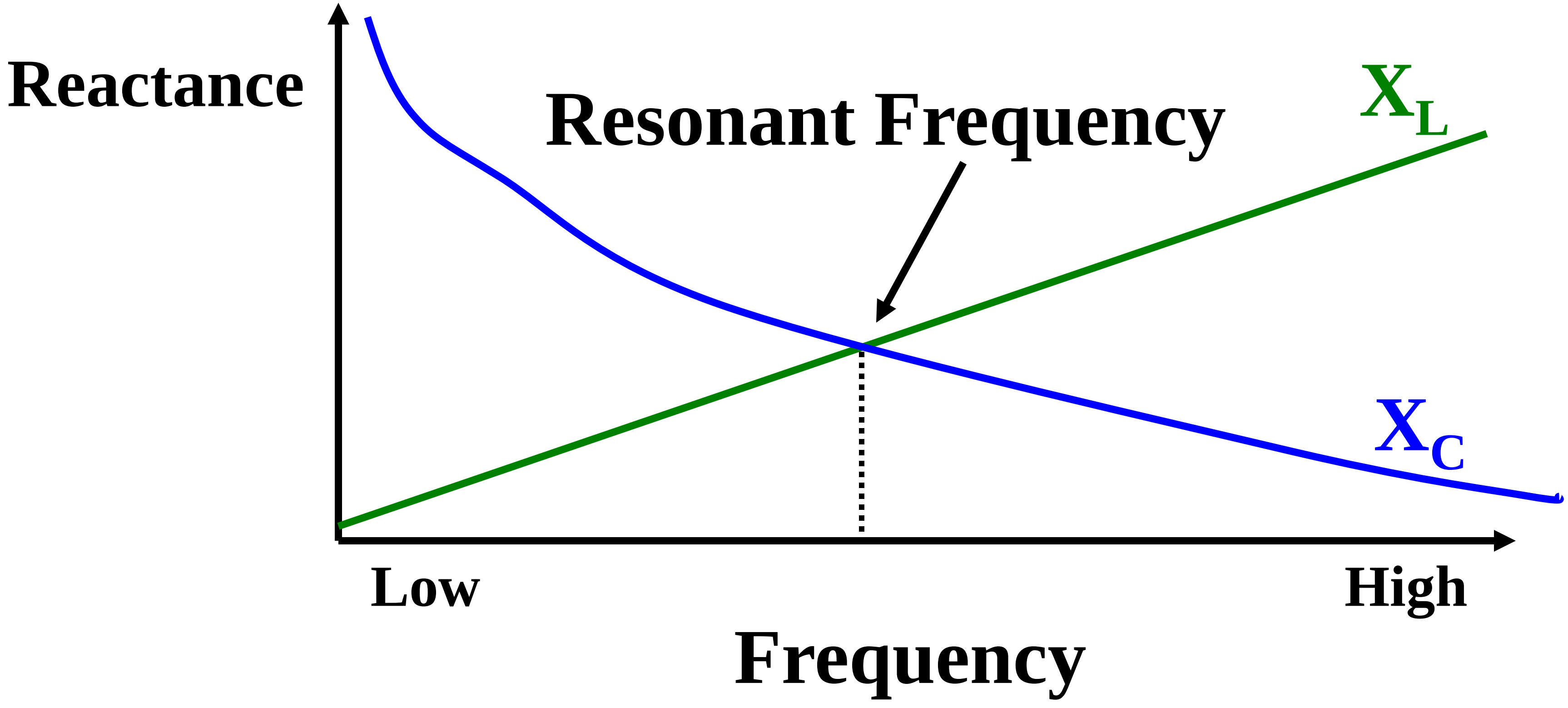
Resonance

- In electronic circuits, a special condition exists when **Inductive** and **Capacitive Reactance** are **equal** to each other **($X_L = X_C$).**
- When that happens in Series LCR circuits, **X_L and X_C cancel** each other out, leaving only Resistance to oppose the flow of AC current.
- This condition is know as **Resonance,** and occurs at **only one frequency,** known as the **Resonant Frequency (F_R).**

Resonant Frequency



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Resonant Frequency

- At Resonance, $\mathbf{X_C = X_L}$ so

$$X_C = \frac{1}{2\pi f C} = X_L = 2\pi f L$$

- With a little mathematical wizardry, we can rearrange that equation to determine the **Resonant Frequency** $\mathbf{F_R}$ as follows…

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Resonant Frequency

$$F_R = \frac{1}{2\pi\sqrt{LC}}$$

- Where:

  F_R = Resonant Frequency in Hertz

  L = Inductance in henrys

  C = Capacitance in Farads

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Resonance is not <u>always</u> a good thing however…

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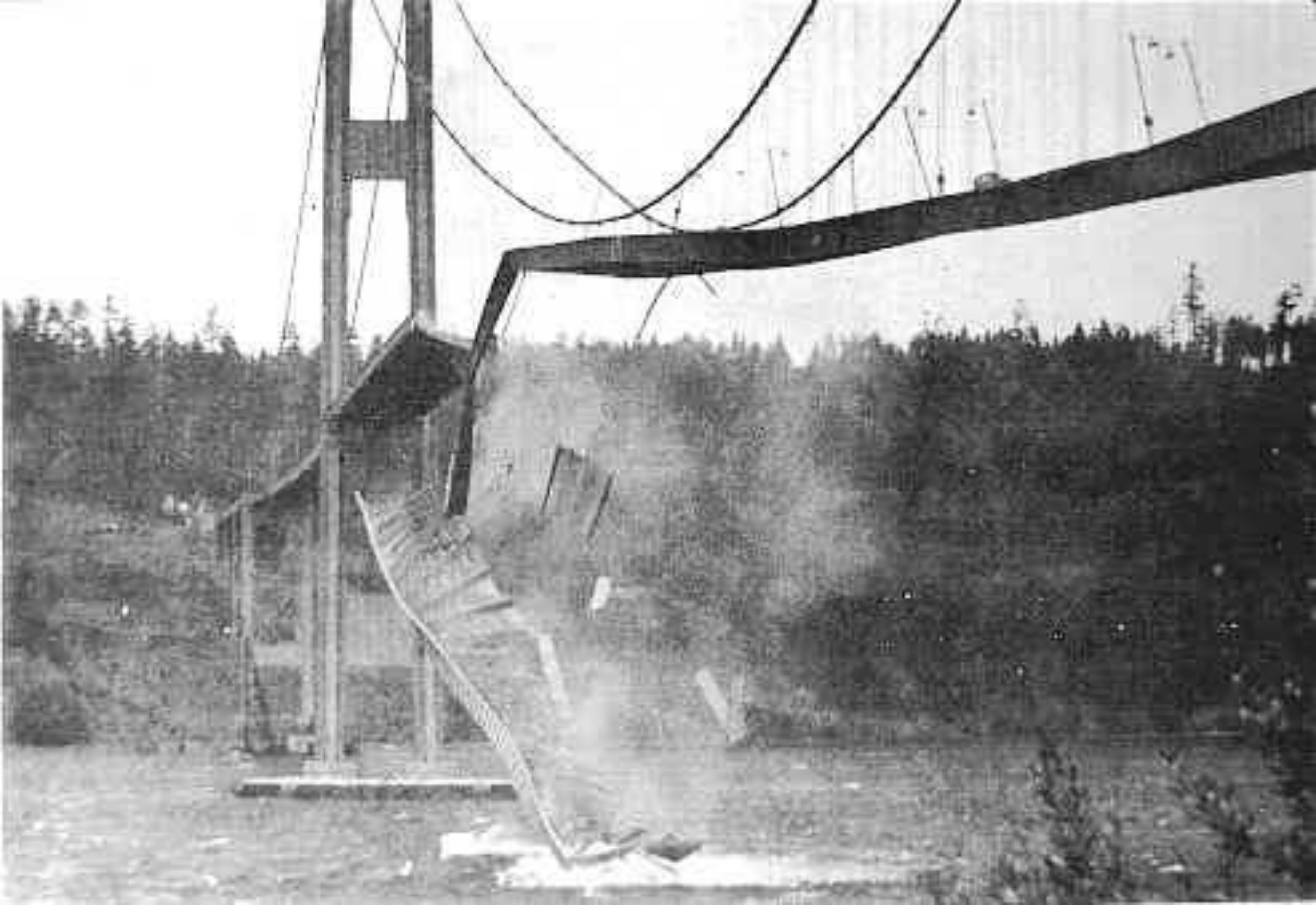

Tacoma Narrows suspension bridge

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Tuned Circuits

- Circuits containing **Capacitors and Inductors** are often referred to as **Tuned Circuits.**
- They have **many uses** in electronics – every time you tune a radio, you are varying the **resonant frequency** of a **tuned circuit.**

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Series LCR Circuit

- When a **Series LCR** circuit is in **Resonance, current** in that circuit is at its **greatest** (the **Impedance** is at its **lowest**).
- There are **two ways** to achieve **Resonance** in **Series LCR** circuits:
  - **Vary the applied frequency** until we find the point where $X_C = X_L$.
  - Keep the frequency constant and **vary the value of the capacitance or inductance,** or both, until $X_C = X_L$.

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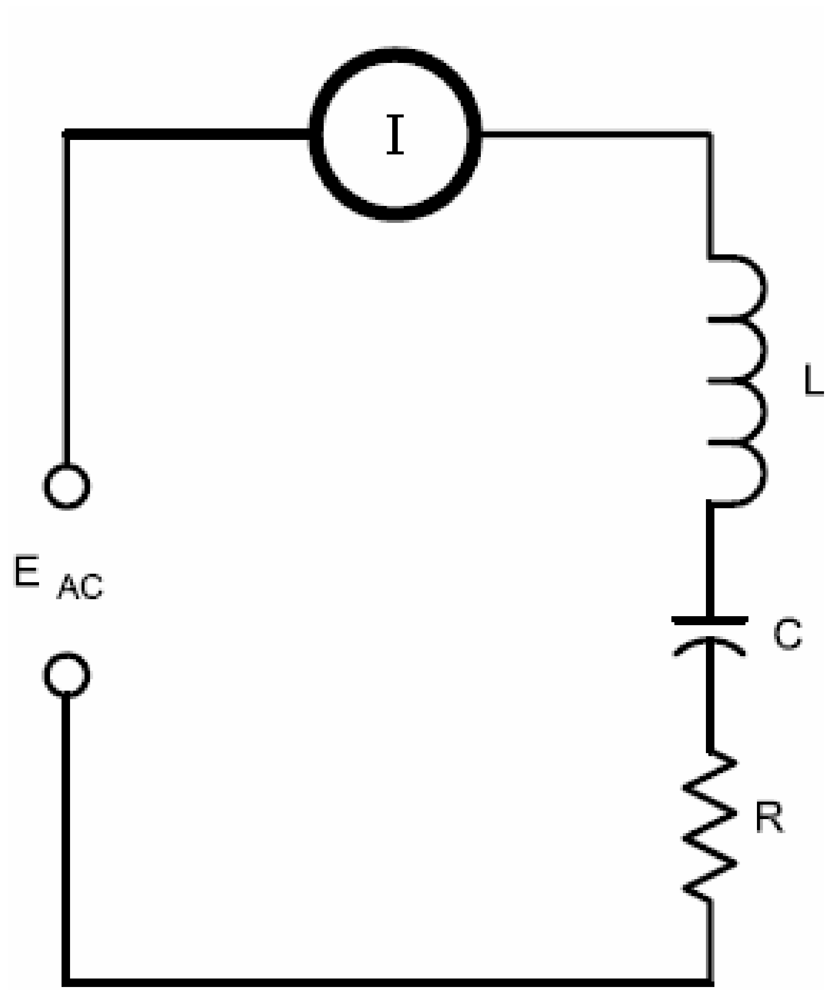
Series LCR Circuit



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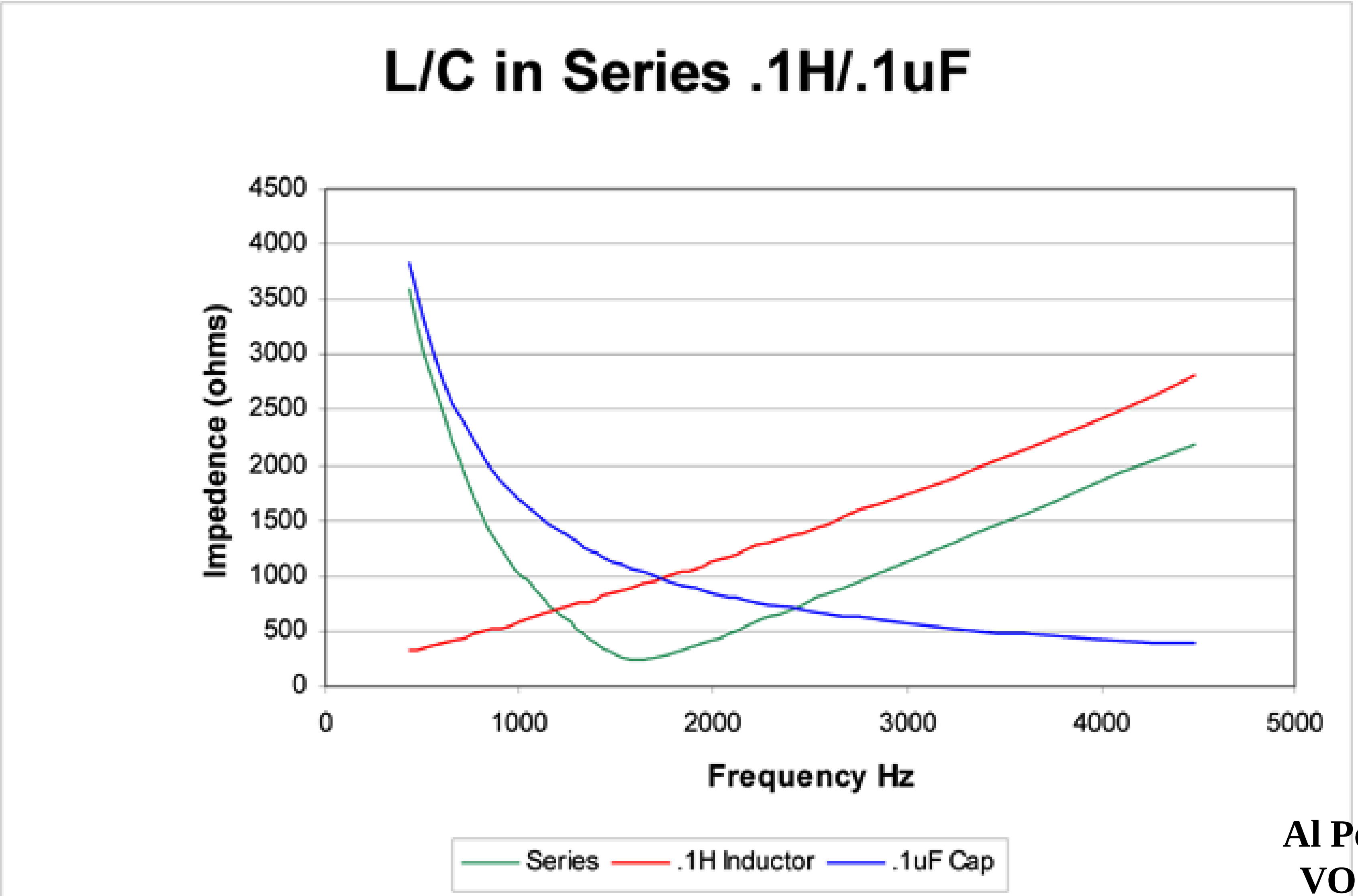
Series LCR Circuit Impedance



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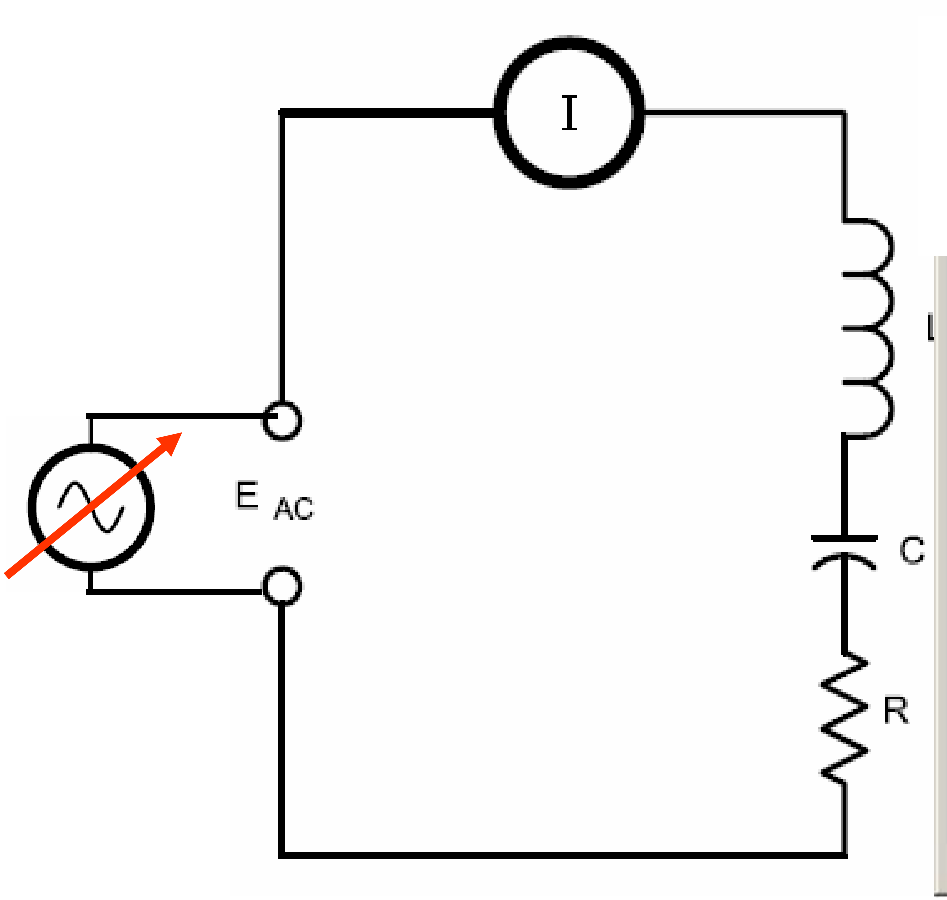
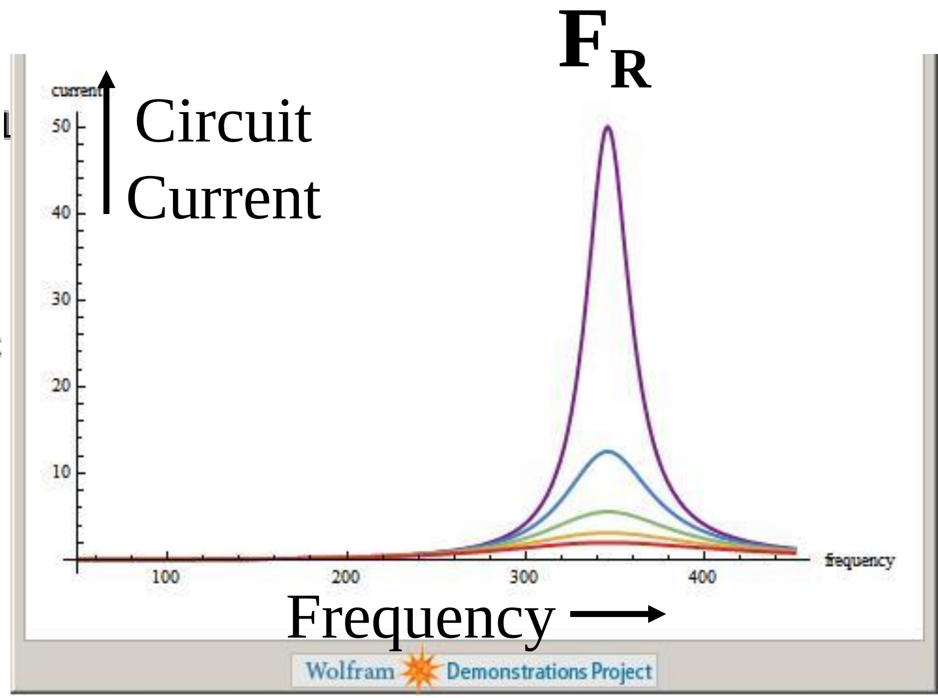
Varying the Frequency





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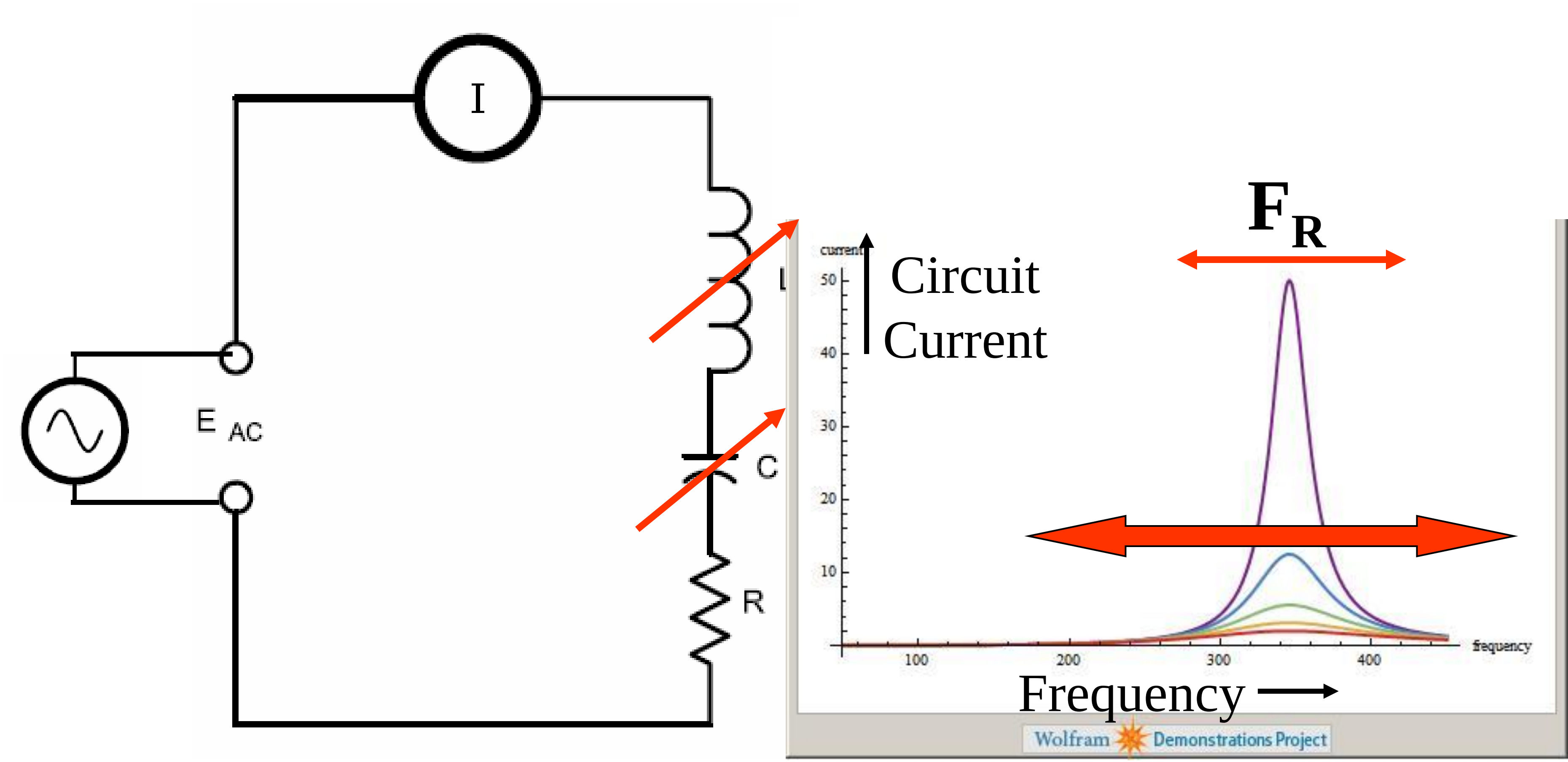
Varying Capacitance or Inductance



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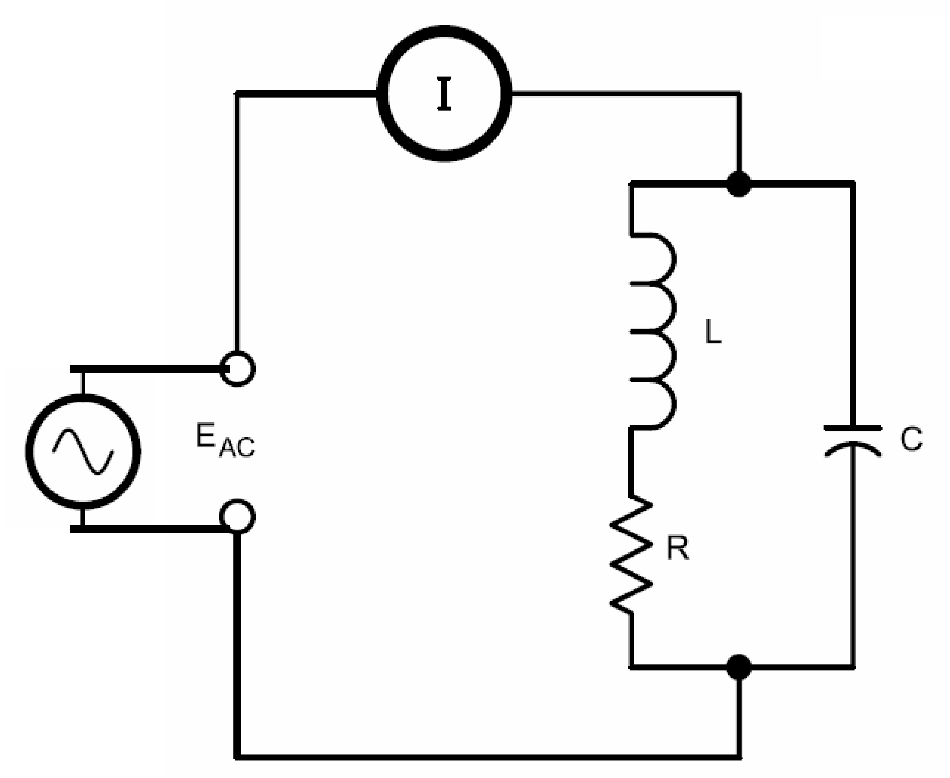
Parallel LCR Circuits



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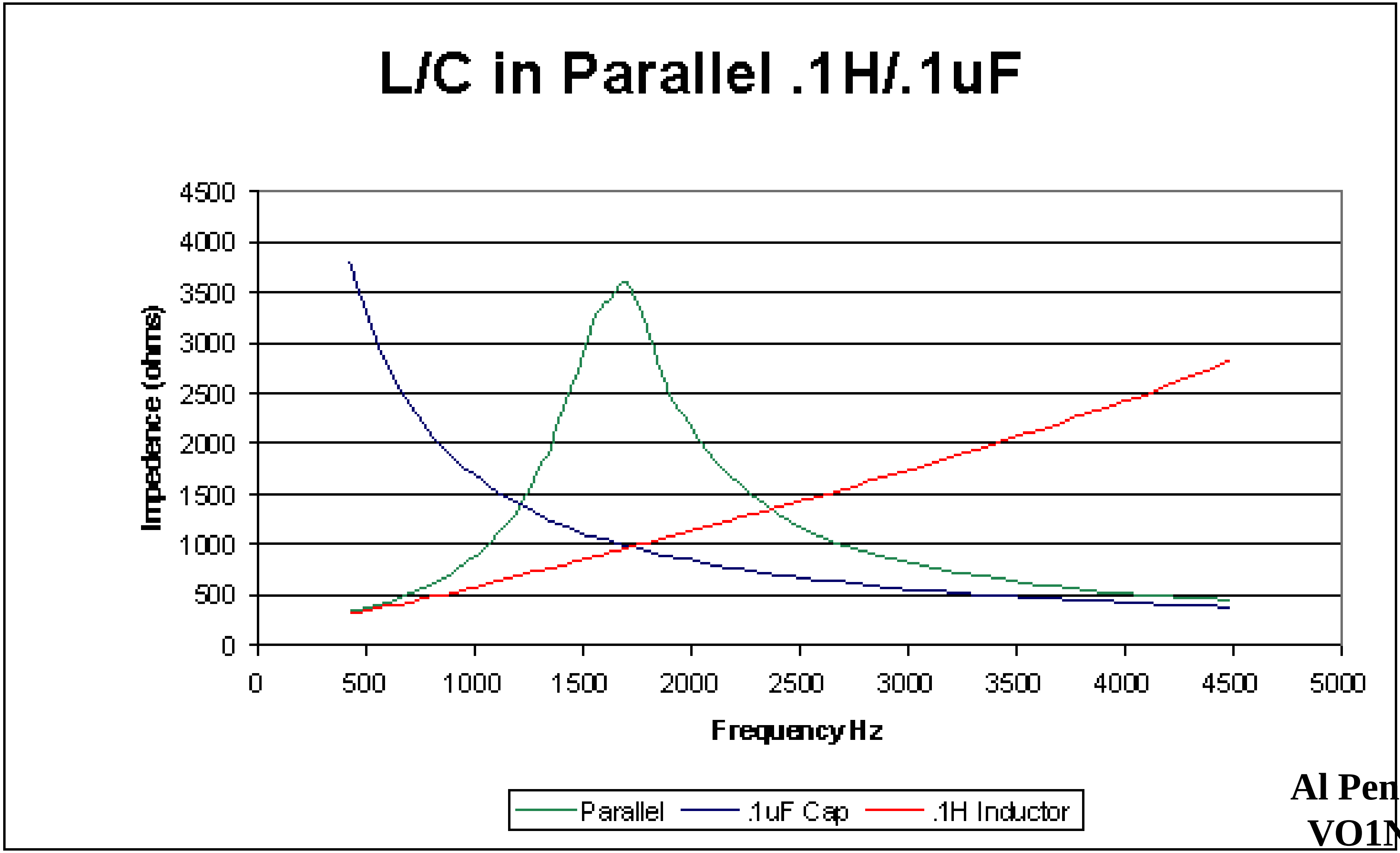
Parallel LCR Circuits

- In a **Parallel LCR Circuit**, the **current** is **lowest at Resonance** (the **impedance** is at its **highest).**
- Parallel LCR circuits are used to **reject a specific frequency** while allowing all others to pass.

Parallel LCR Circuit Impedance



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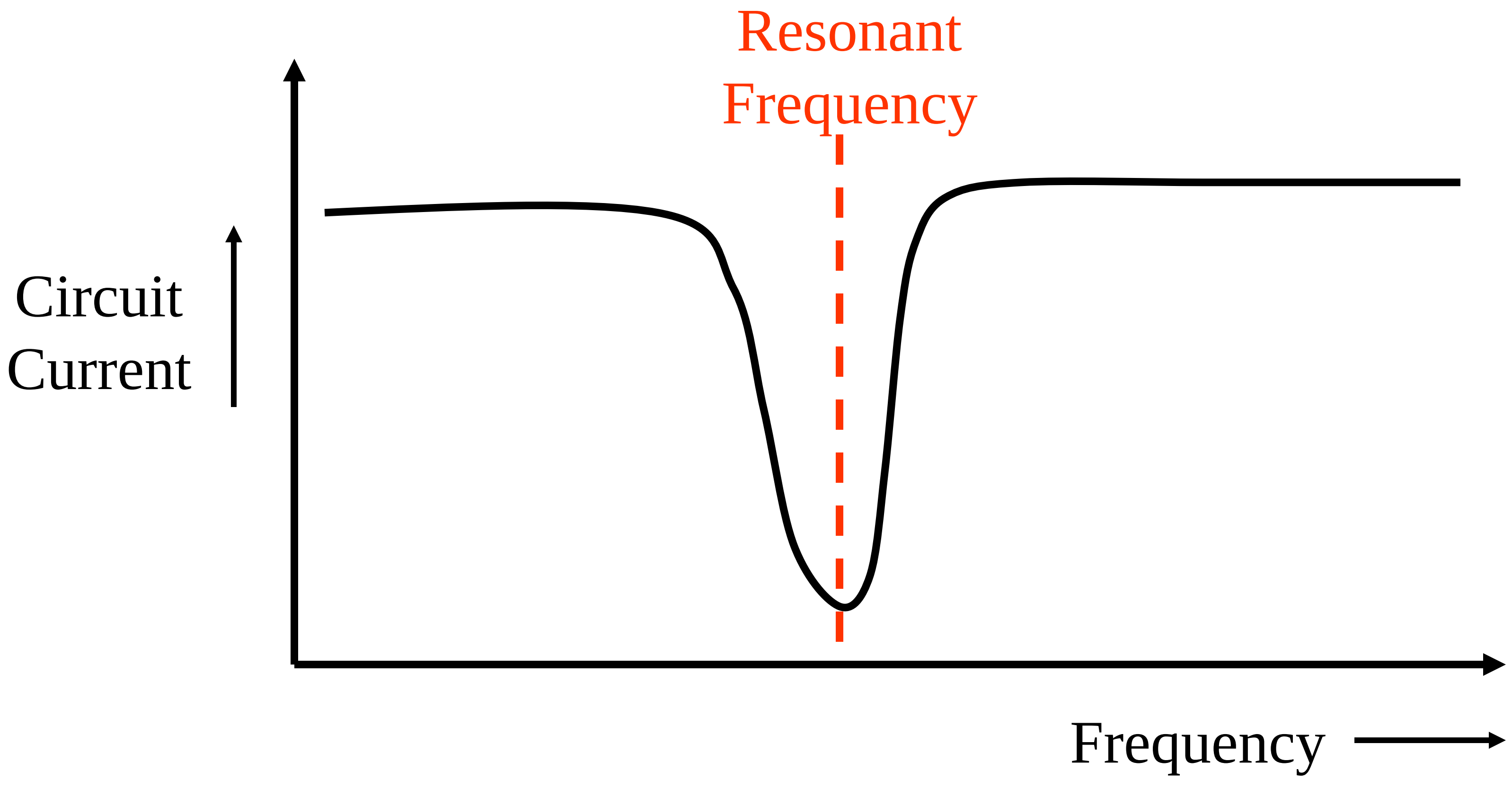
Parallel LCR Circuit Current



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Circuit Quality

- In a **resonant series LCR circuit,** energy is stored **alternately** in the **electric field of the capacitor,** and then the **magnetic field of the inductor.**
- This causes a **current** to flow **between them.**
- Anything that **removes energy** from this circuit **broadens the range of frequencies** affected by the circuit, but **increases the impedance** at the **resonant frequency.**

Circuit Quality

- The **“Q”, or Quality** of a series LCR circuit is defined as the **ratio** of either $\mathbf{X_C}$ **or** $\mathbf{X_L}$ to the **resistance** in the circuit.
- **Below** resonance **“Q” =** $\mathbf{X_C / R}$
- **Above** resonance **“Q” =** $\mathbf{X_L / R}$
- At resonance $X_C = X_L$
- A “Q” of **100** is **high**, while a “Q” of **10** is **low**.

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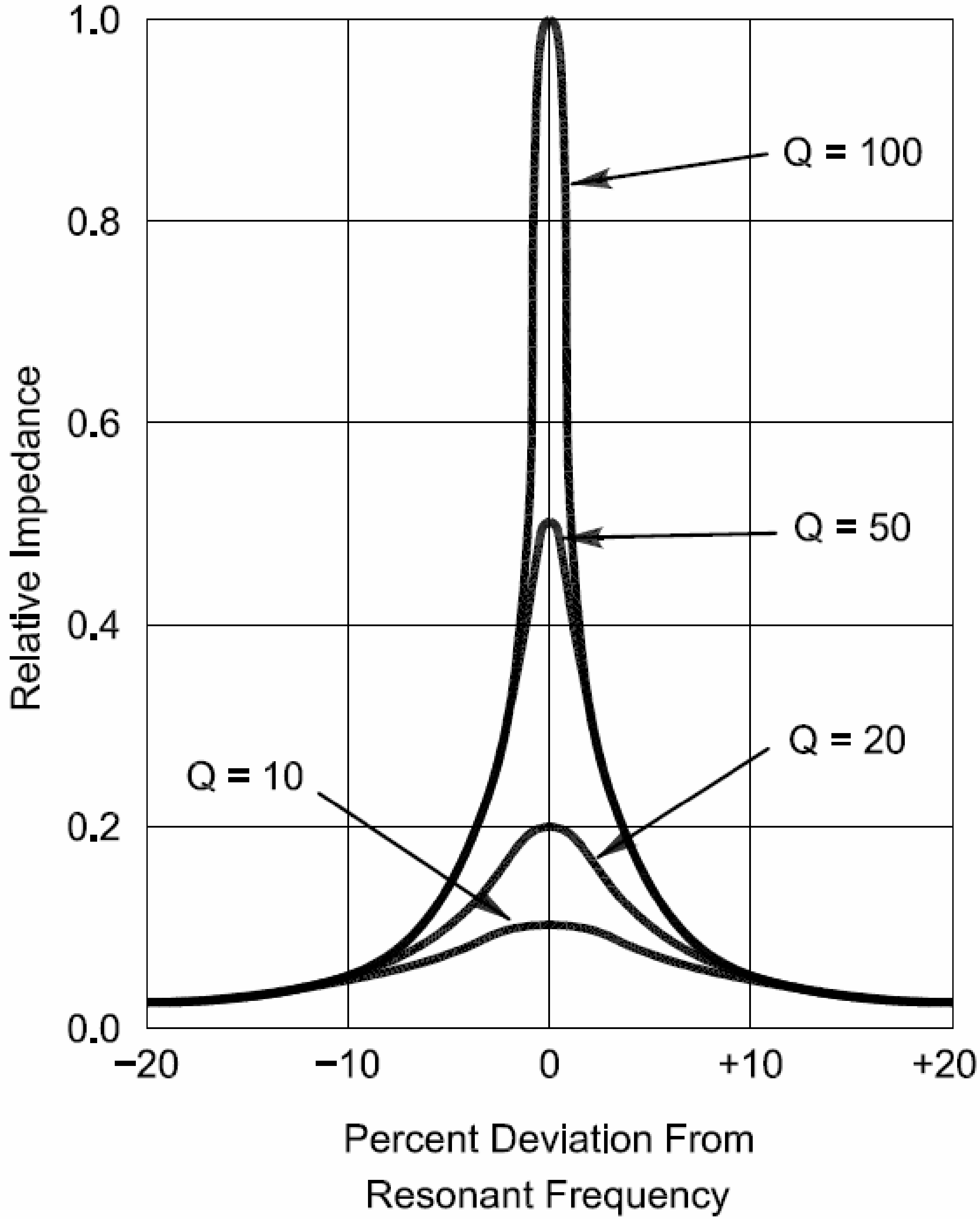

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Filters

- By the proper selection of capacitors and inductors, it is possible to design **Filters** that can **pass desired frequencies**, and **reject unwanted frequencies.**

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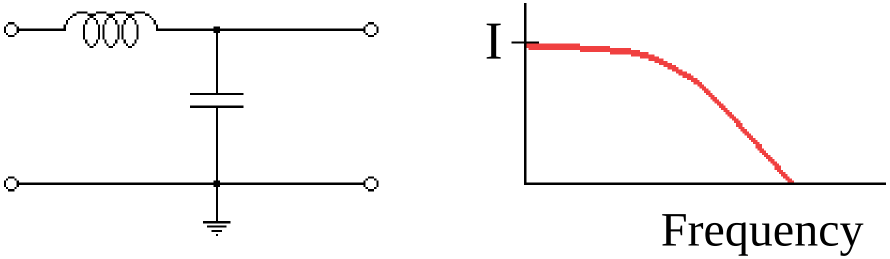
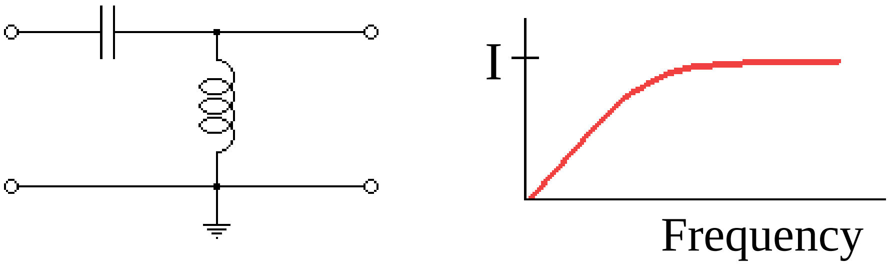
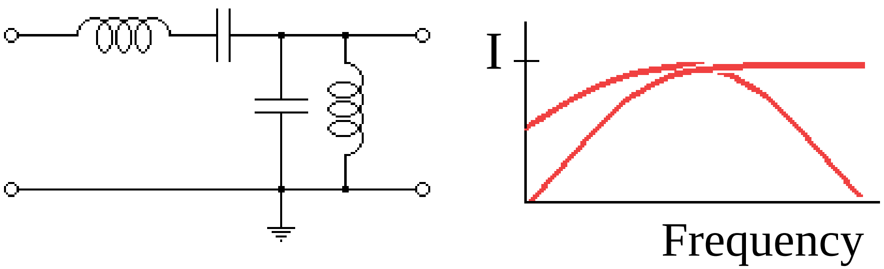


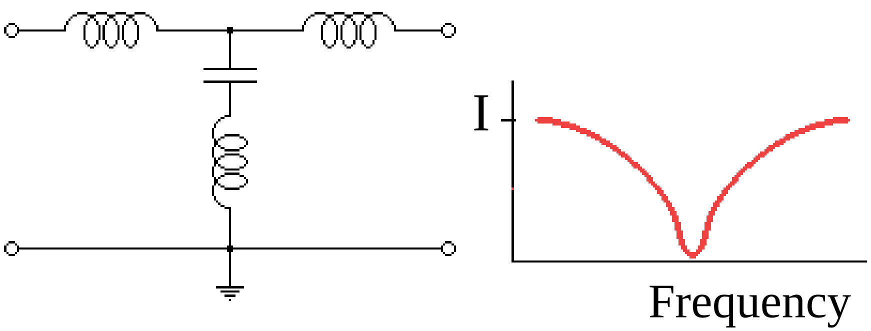
Low Pass Filter



High Pass Filter



Band Pass Filter



Notch Filter

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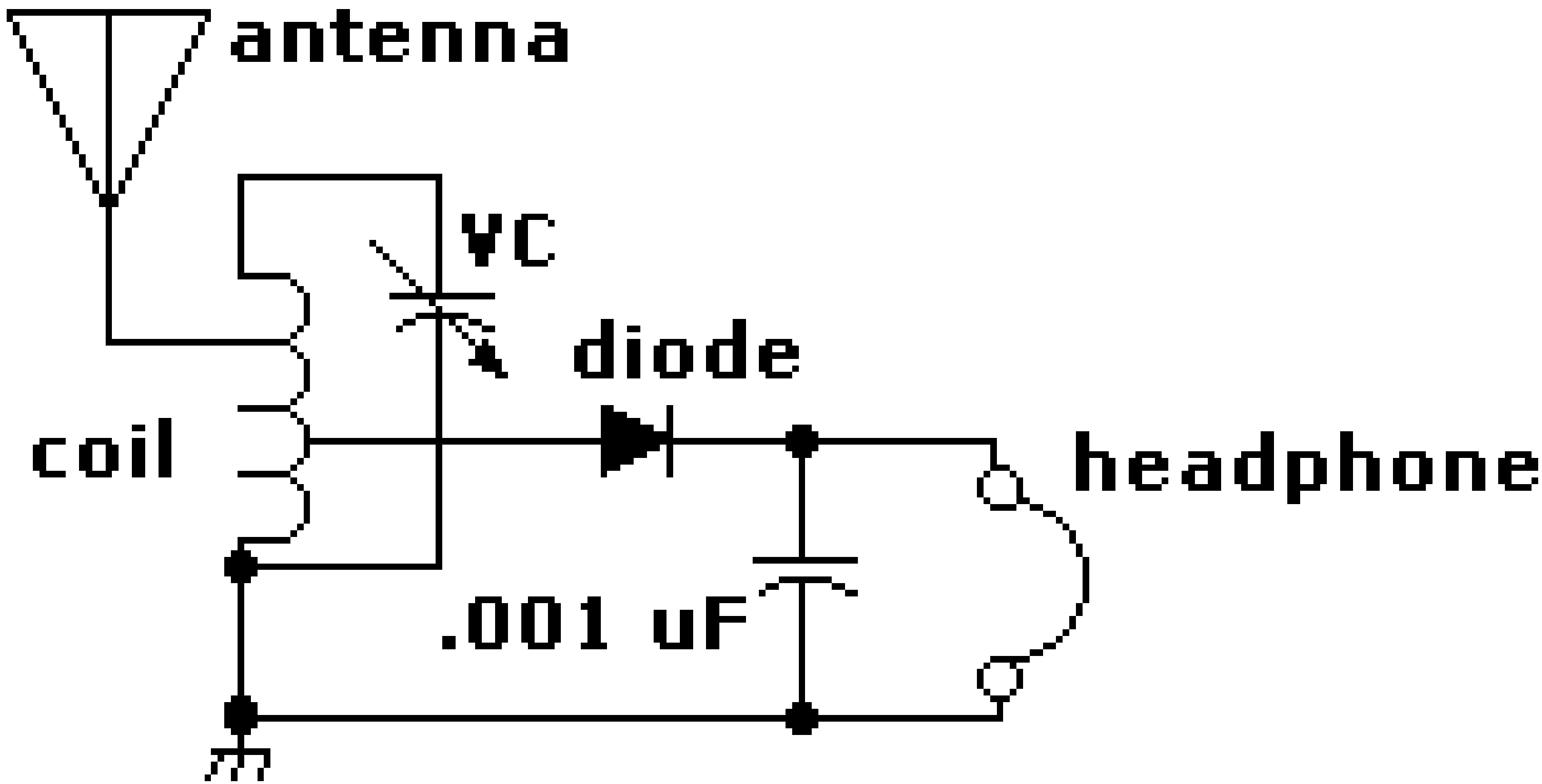
Crystal Radio Tuned Circuit



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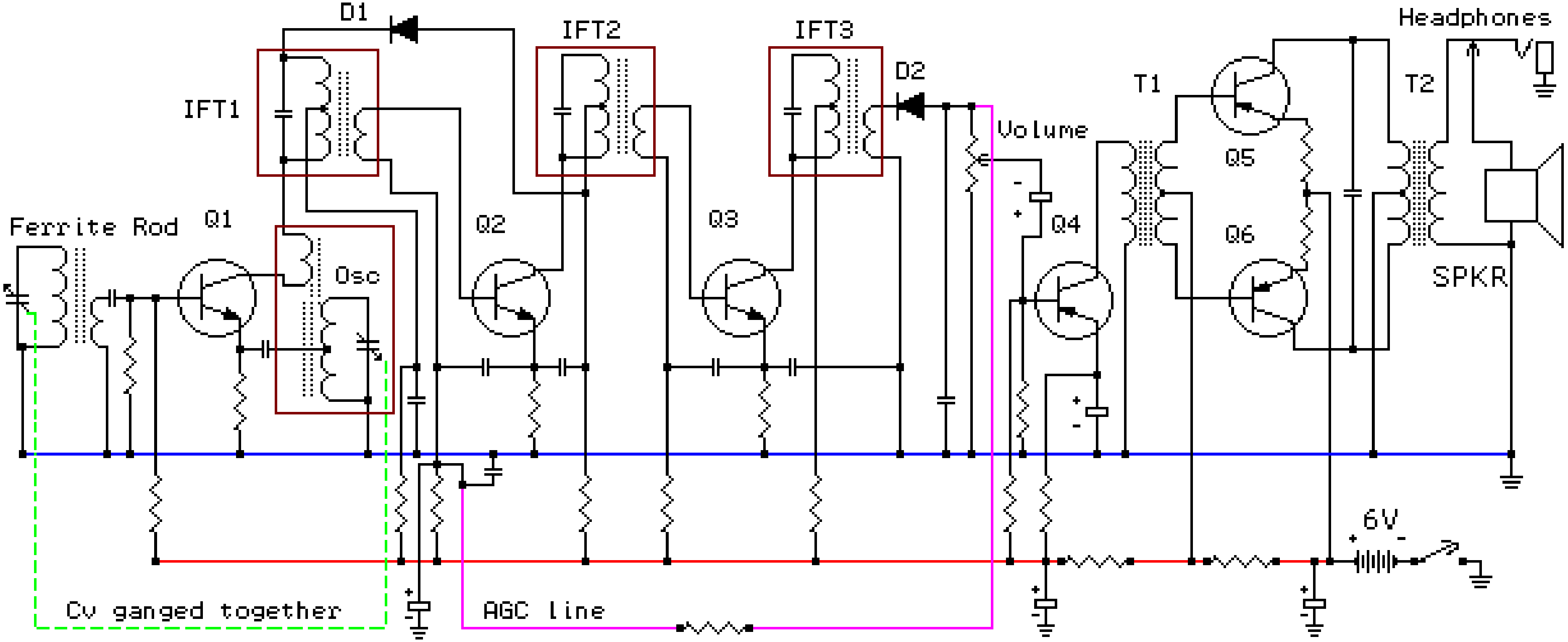
6 Transistor Radio



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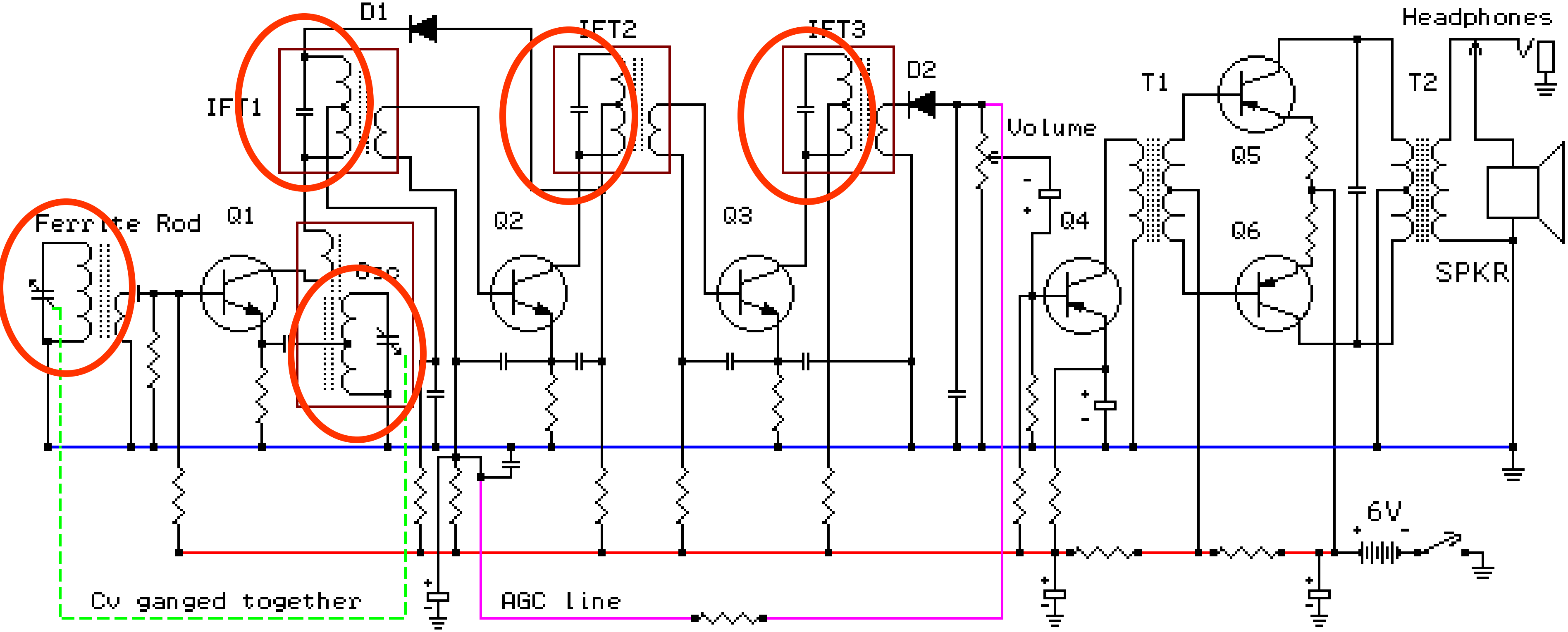

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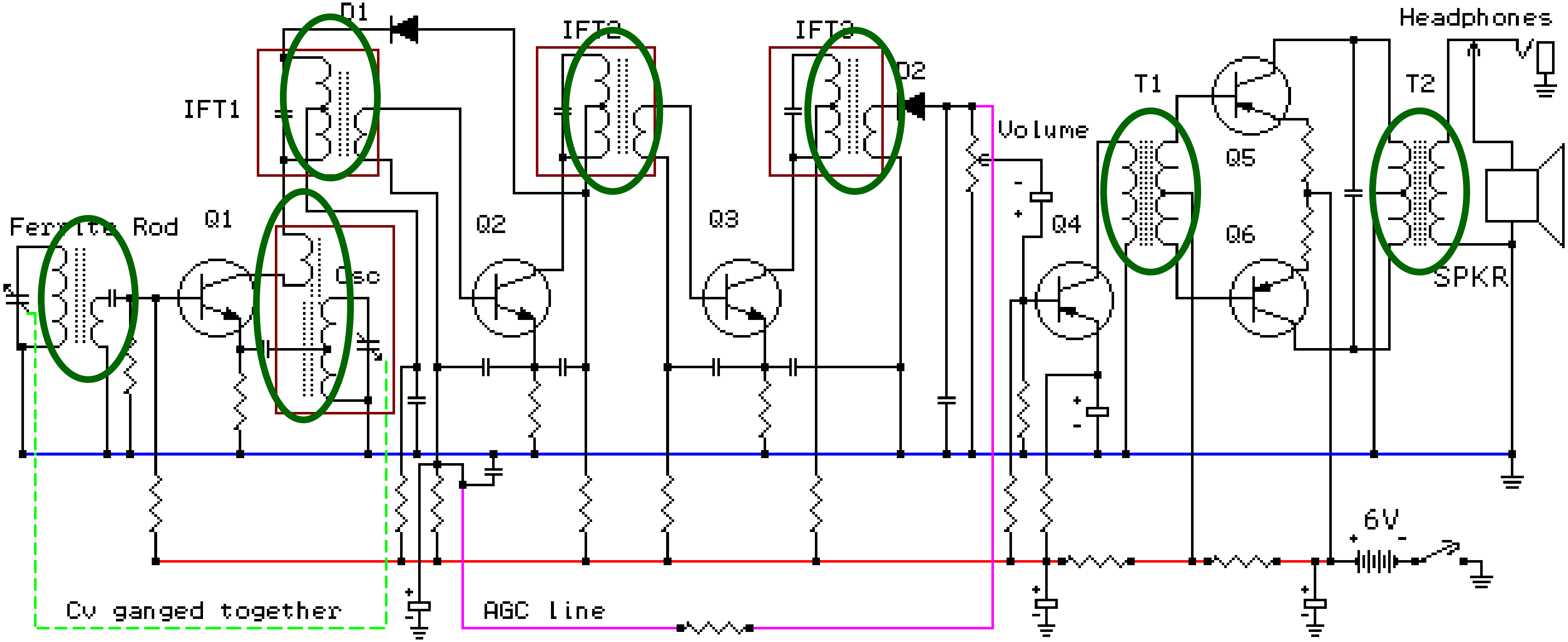

Transformers

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