Transformers, Reactance, Resonance and Impedance

Transformers and Turns Ratios

Capacitive and Inductive Reactance

Resonance and Impedance Matching

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Review

Two types of current:

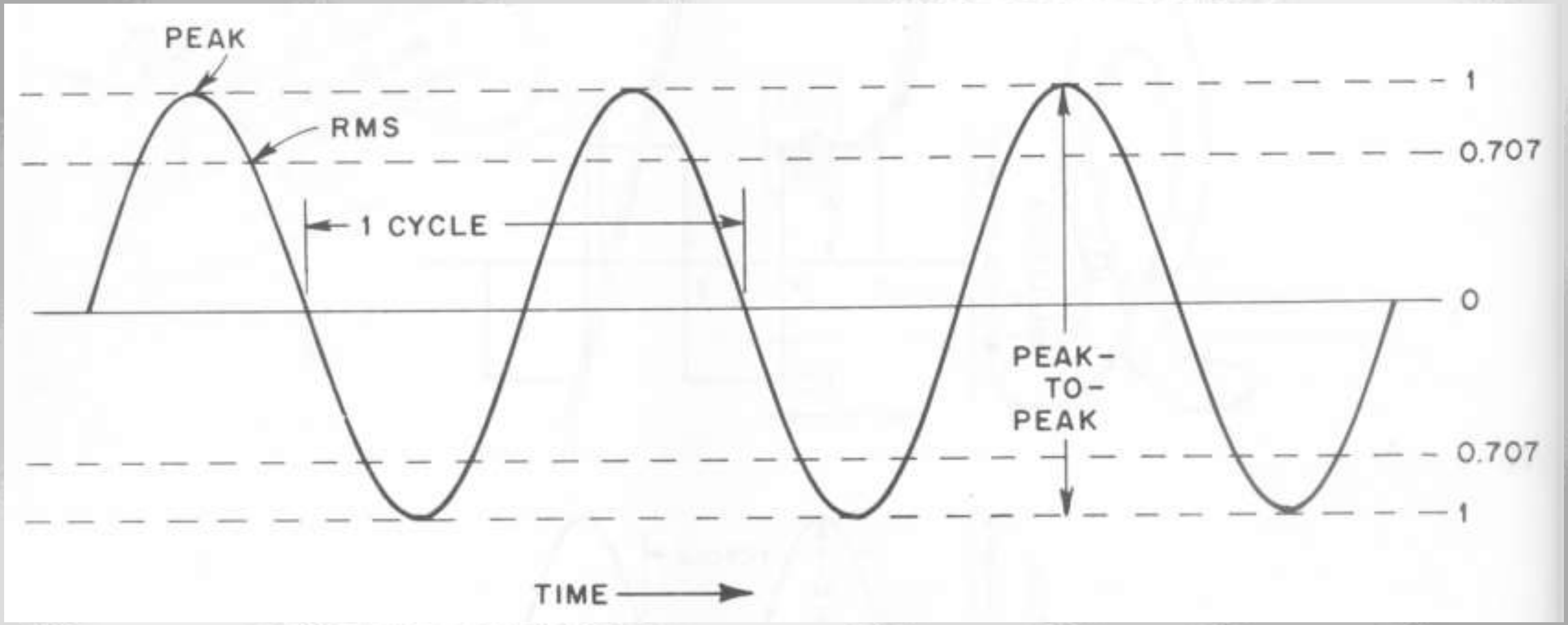
- AC – Charge movement alternates in direction.
- DC – Charge movement in one direction only.

Two fundamental principles:

- Moving charges (electrons) create magnetic fields
- Moving or changing magnetic fields cause charges (electrons) to move

Ohm's Law – E = I * R

AC Wave Vocabulary Review



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Oppositions to Current by R, L, and C

Resistance in a circuit opposes the flow of electrons the same for AC as for DC.

Inductors and capacitors in circuits store energy.

- Inductors offer low resistance in DC environment
- Capacitors offer infinite resistance in DC environment.
- Inductors oppose changes in current.
- Capacitors oppose changes in voltage.

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Voltage and Current vs. Time

When voltage is applied to a resistor, current reaches the final value immediately.

The stored energies in capacitors and inductors retard the changes in voltage or current in a circuit.

Voltage change in a capacitor is retarded by the electric field..

Current change in an inductor is retarded by he magnetic field.

These delays cause the opposition to AC called Reactance.

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Capacitor Voltage versus Time

At time = 0 when voltage is first applied:

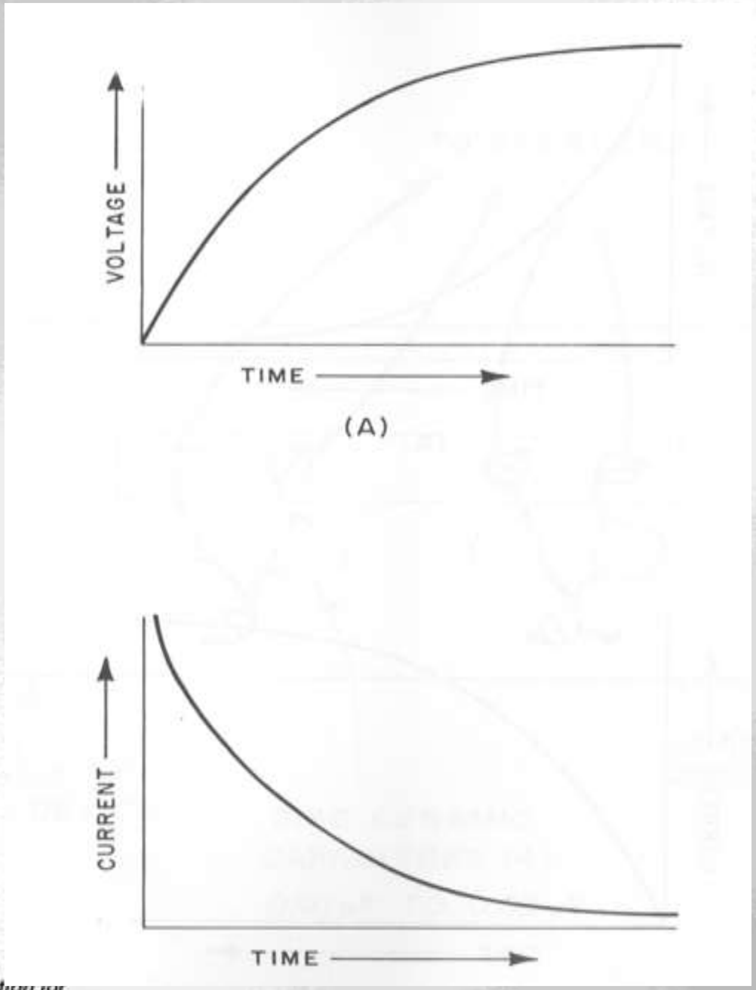
- I is very high (electrons rushing in).
- V is 0 (capacitor looks like a short circuit).

At some later time after voltage is applied:

- I is zero (capacitor will accept no more electrons).
- V is high (capacitor is fully charged).

The slow buildup of voltage causes the opposition to AC – Capacitive Reactance.

Capacitor Voltage and Current vs. Time

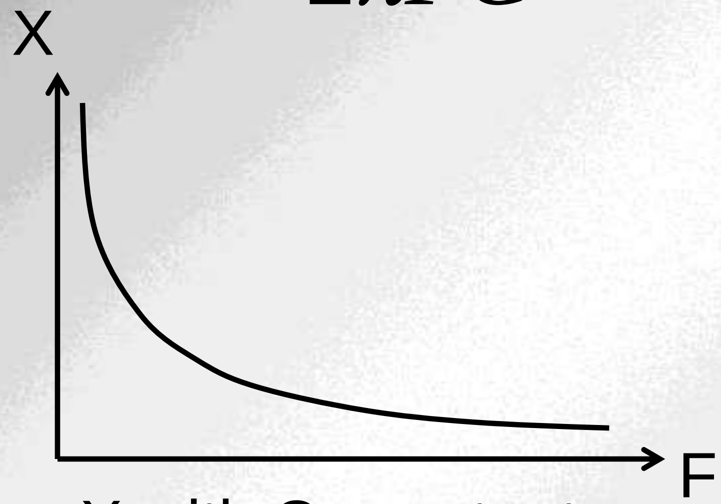


Capacitive Reactance vs. F and C

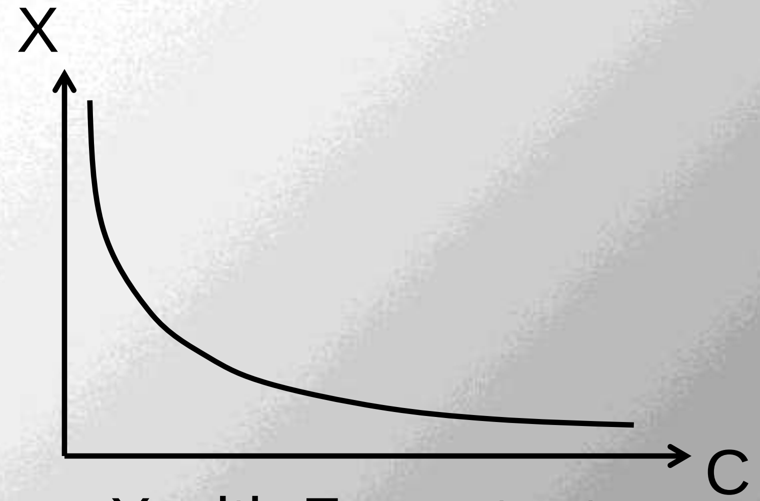
The formula to calculate capacitive reactance is:

$$X_C = \frac{1}{2\pi FC}$$

X in Ohms, F in Hz, C in Farads



X with C constant



X with F constant

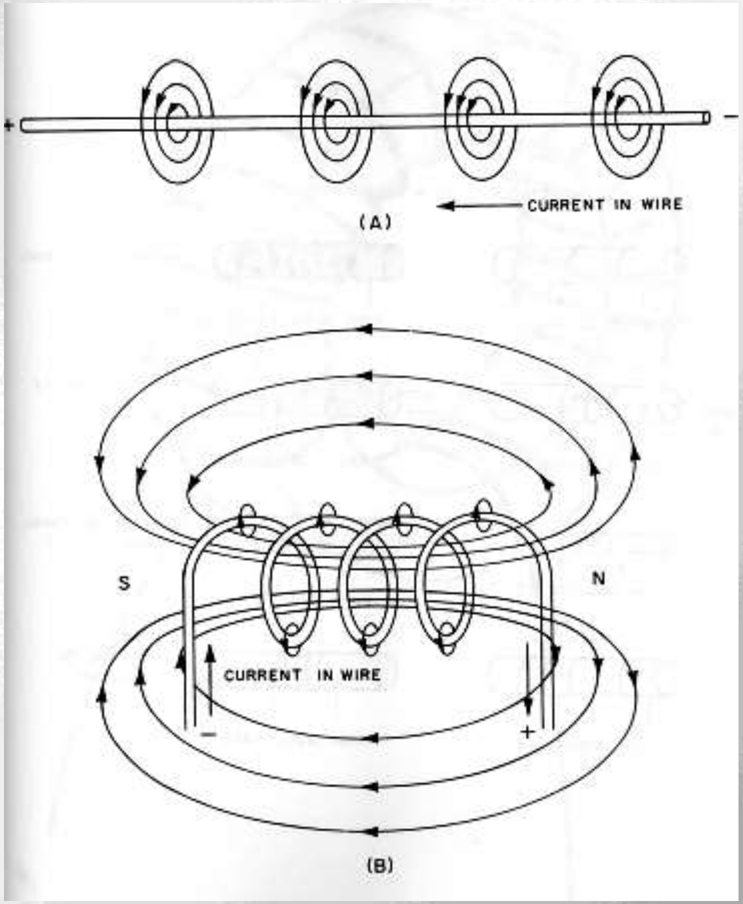
Points About Capacitive Reactance

- Capacitive reactance is the result of the stored energy in the electric field opposing a change in voltage.
- Capacitive reactance decreases as:
  - The frequency increases.
  - The capacitance increases.

$$X_C = \frac{1}{2\pi FC}$$ X in Ohms, F in Hz, C in Farads

The Inductor (Review)

- Inductance
  - Coil of wire.
  - Stores energy in a magnetic field
- Value of inductance depends on:
  - Number of turns.
  - Spacing of turns.
  - Size of the wire.
  - Material of the core.



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Inductor Voltage and Current

- At time = 0 when voltage is first applied:
  - Voltage across inductor is very high.
  - Current through inductor is 0.
- At some later time after voltage is applied:
  - Current through inductor is maximum.
  - Voltage across inductor is very low.
- Inductors have a low opposition to DC and a higher opposition to AC.

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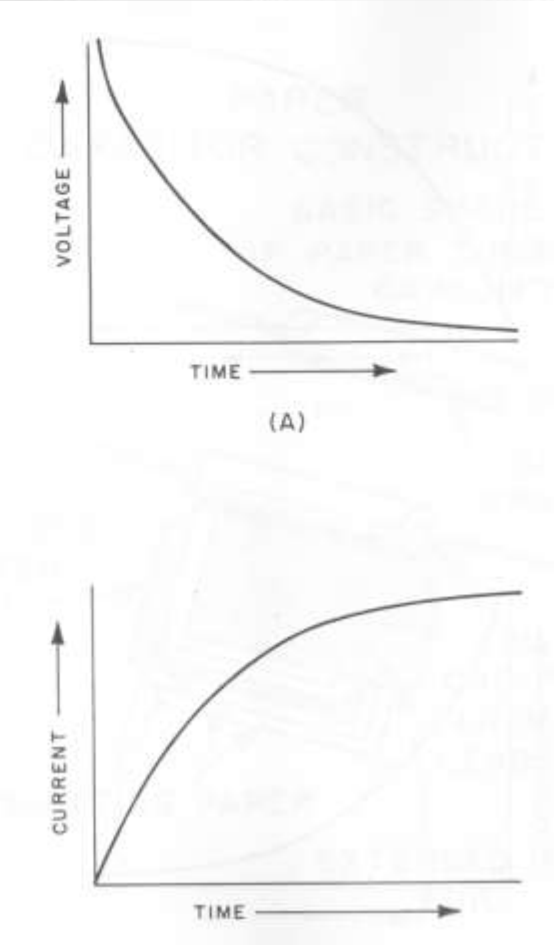
Inductor Current versus Time

As the current builds up in the inductor, a magnetic field develops which opposes the flow of additional electrons .

- The changing magnetic field causes Inductors to oppose a change in current.
- The slow buildup of current causes the opposition to AC – Inductive Reactance.

Inductor Voltage and Current vs. Time



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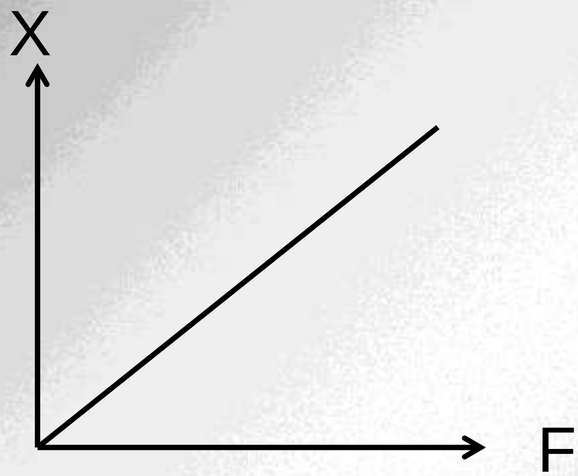
Inductive Reactance vs. F and L

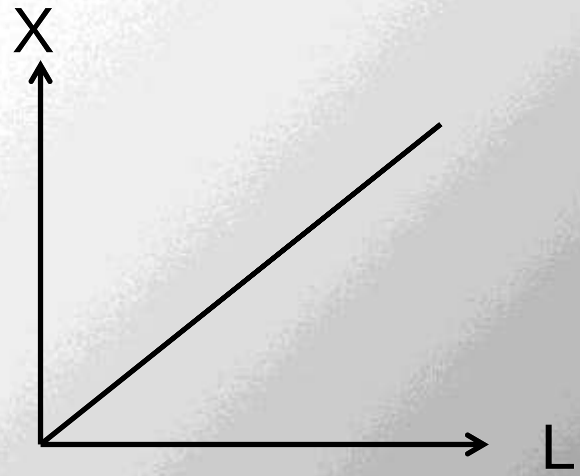
The formula to calculate Inductive is:

$$X_L = 2\pi FL$$

X in Ohms, F in Hz, L in Henrys



With constant L



With constant F

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Points About Inductive Reactance

- Inductive Reactance is due to the stored energy in the magnetic field opposing a change in current.
- Inductive reactance increases as:
  - The frequency increases.
  - The inductance increases.

$$X_L = 2\pi FL$$ X in Ohms, F in Hz, L in Henrys

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Impedance

Impedance is the total opposition to AC current. We can state Ohm's Law for impedance as I = E / Z

- Symbolized by the letter Z
- Measured in Ohms
- Includes both resistance and reactance
- May be stated as a value and angle, i.e. 100 /_45^{o}
- May be stated as R + jX, i.e. 10 + j20

Combining X_C with X_L in Series

Capacitors and Inductors have opposite effects so X_L and X_C oppose each other.

The equivalent reactance in series will be the difference: $X_L - X_C$.

- When X_L is larger, the equivalent is inductive.
- When X_C is larger, the equivalent is capacitive.
- When $X_L = X_C$, the reactance is zero and the circuit is **Resonant** to that frequency.

A series LC circuit has minimum opposition at the resonant frequency.

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Some effects of Resonance

Resonant circuits can be used as filters to accept or reject frequencies.

Real inductors and capacitors have physical size and shapes which cause parasitic inductances and capacitances.

- The leads of a capacitor make an inductance in series with the capacitor making a series resonant circuit at some frequency.
- The windings of an inductor have capacitance between turns which make resonant circuits within the windings.

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Transforming Impedance

The impedance determines the value of AC Current for a given AC Voltage.

Transformers may be used to transform or match the impedance of the load to the source.

When the Load impedance does not match the design impedance of the source, the source will not deliver its designed output power.

- i.e., An amplifier designed for a 50 Ohm load operates most efficiently when connected to a 50 Ohm antenna.

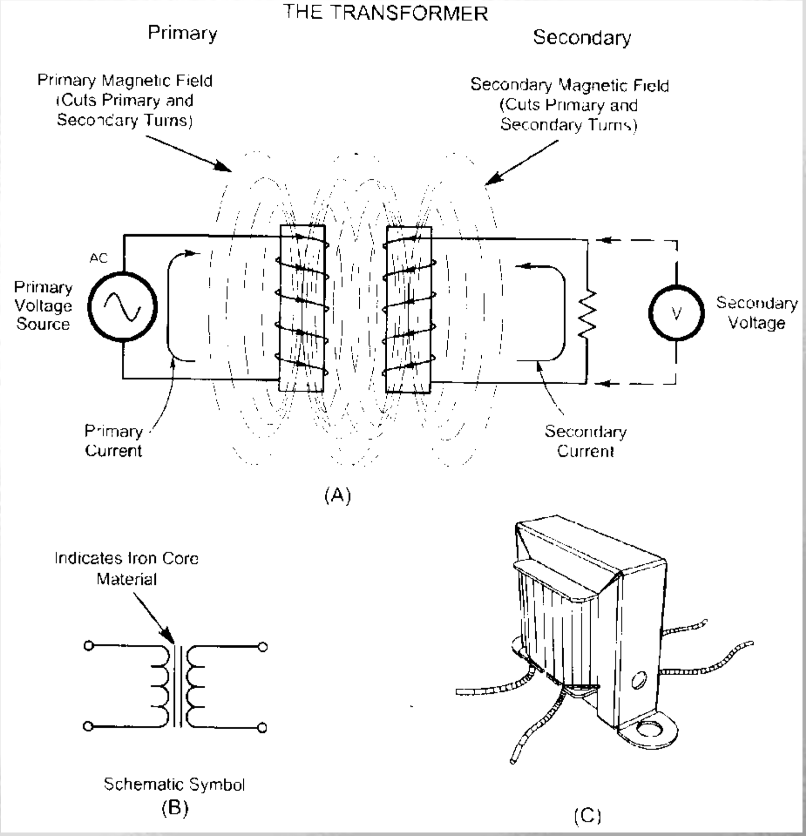
The Transformer

Two inductors with a common magnetic field.

- Iron core makes for stronger coupling.
- Coupling depends on orientation & spacing.

Transforms:

- Voltage and Current.
- Impedance.



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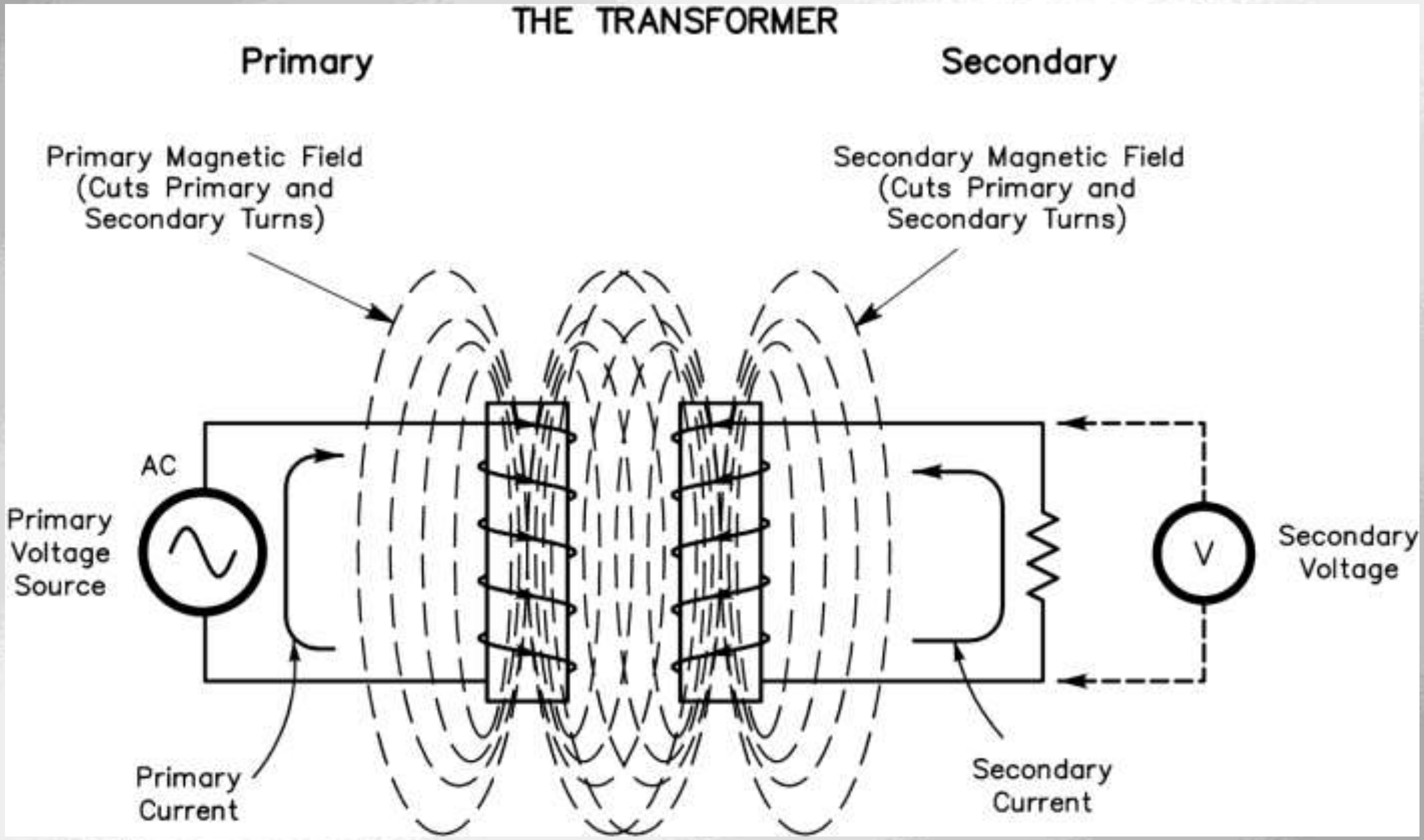
How a Transformer Works



Voltage vs. Turns Ratio

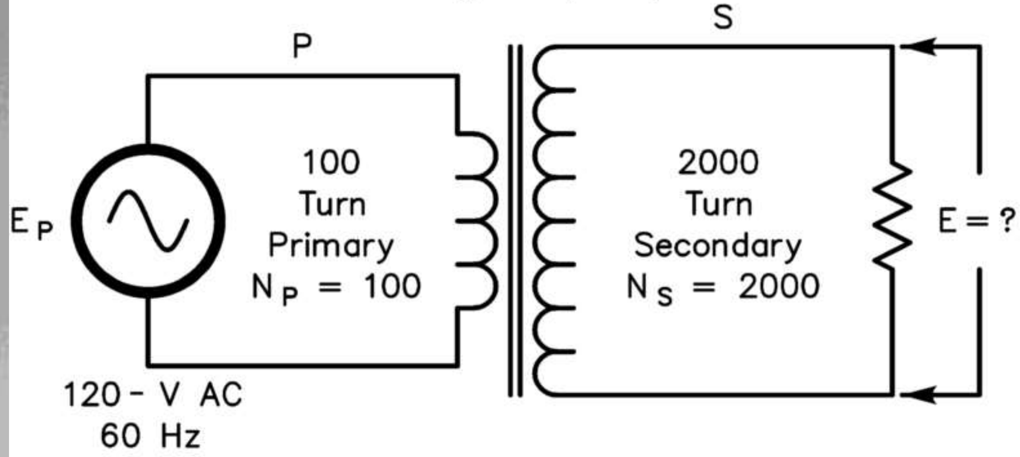
The ratio of primary turns to secondary turns equals the ratio of primary voltage to secondary voltage.

- Step up (Secondary voltage is higher)
- Step down (Secondary voltage is lower)

$$\frac{E_S}{E_P} = \frac{N_S}{N_P}$$

E = Voltage
N = Number of Turns
S = Secondary
P = Primary

Voltage Step - Up

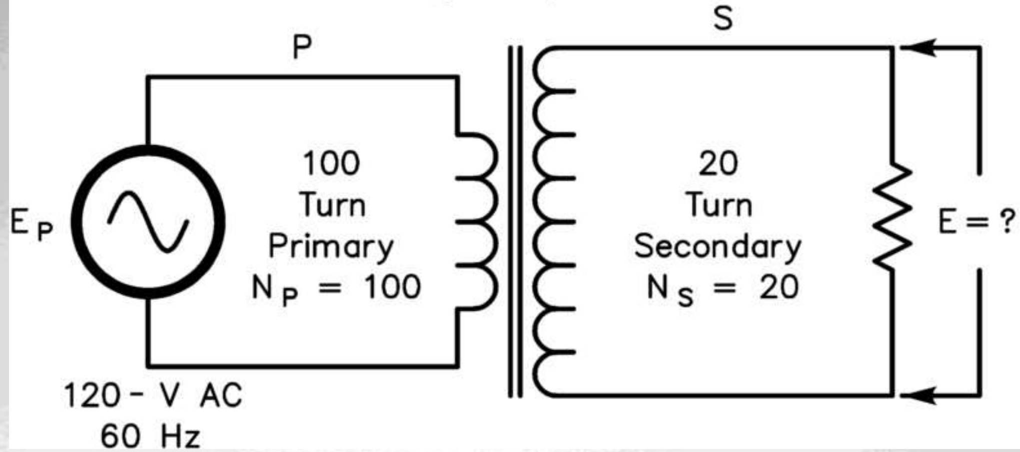


Turns Ratio 20: 1

$$E_S = \frac{N_S}{N_P} \times E_P = \frac{2000}{100} \times 120$$

$$= 2400\ \text{V}$$

Voltage Step - Down



Turns Ratio 1: 5

$$E_S = \frac{N_S}{N_P} \times E_P = \frac{20}{100} \times 120$$

$$= 24\ \text{V}$$

Transforming Impedance

The ratio of the number of turns in the primary to the number of turns in the secondary determines the impedance change

- Step up – Secondary impedance is higher.
- Step down – Secondary impedance is lower.

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

S = Secondary
P = Primary
N = Number of Turns
Z = Impedance

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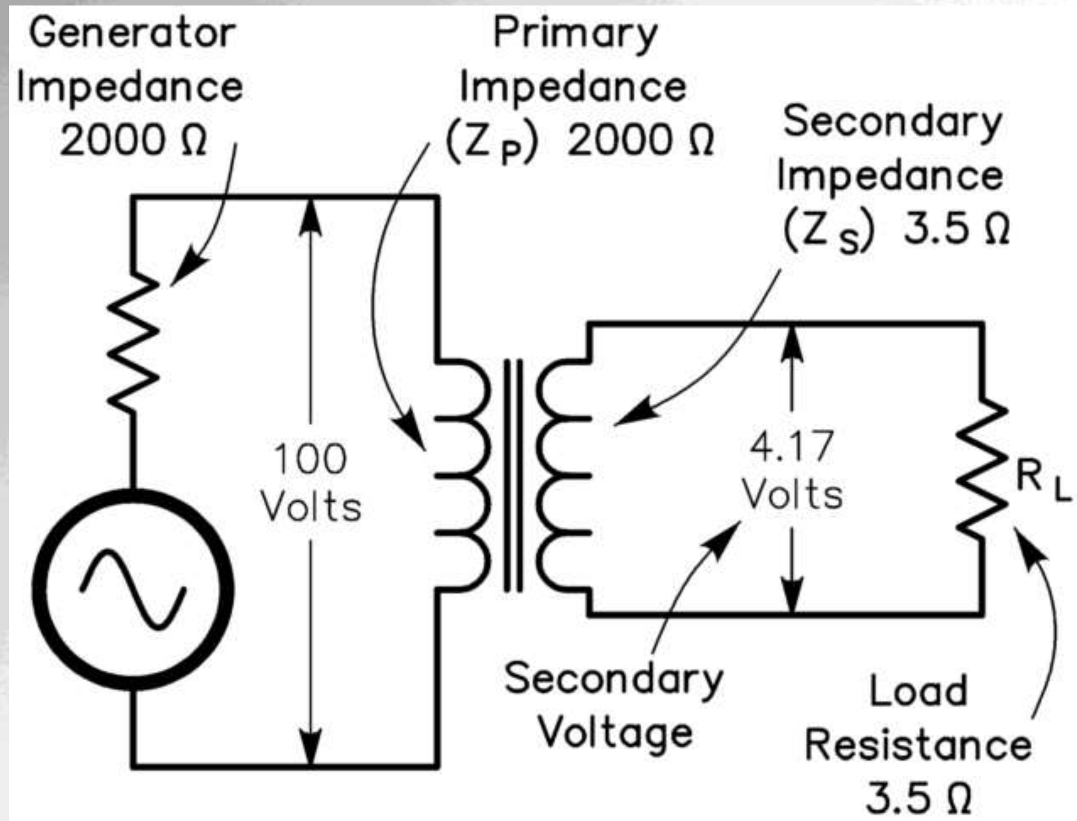

$$\frac{N_P}{N_S} = \sqrt{\frac{Z_P}{Z_S}} = \sqrt{\frac{2000}{3.5}} = \sqrt{571} = 24$$

Your Turn

2250 turns in the primary, 500 turns in the secondary, 120 volts AC applied to primary. What is the output voltage?

– Answer: 26.6

An amplifier designed for a 600 Ohm Load is to be connected to 4 ohm speakers. What is the turns ratio of the impedance matching transformer required?

– Answer: 12.2

Impedance Matching in RF circuits

The Maximum Power Transfer Theorem says that maximum power is transferred to a load if the load impedance equals the generator impedance.

- RF power amplifiers are usually designed to deliver maximum power to a small range of load impedances.
- The load impedance sometimes has to be transformed to the design impedance.

Impedance Matching in RF Circuits

A commonly designed load impedance for power amplifiers is 50 Ohms.

- The tubes or transistors in the amplifier usually need a higher or lower impedance load.
- Inside the amplifier, LC networks or transformers are used to transform from 50 Ohms to the tube or transistor required load value.
- Common LC networks are called Pi and T.
- Transformers for RF are made with Iron or Ferrite Torroid cores.

For Next Week:

- Study Chapter 4-20 – 4-38
- Review Suggested Questions in Chapter 4-1 – 4-20.
- Make up and solve Series and Parallel Resistor problems. Use Calculator.
- Make up and solve Series and Parallel Capacitor problems. Use Calculator.