Basic Electronics Series

Ohm’s Law and Watt’s Law

Copyright © 2023 by CMS Pitman, NJ USA - Page 2

Ohm’s Law Basics

- In an electric circuit, the three primary factors, voltage, current, and resistance are related through a concept known as Ohm’s Law.
- Ohm’s Law holds that the current flowing in a circuit is equal to the voltage applied to that circuit divided by the resistance through the circuit.

Copyright © 2023 by CMS Pitman, NJ USA - Page 3

Ohm’s Law Basics

- There are three forms in which Ohm’s Law can be expressed, all of which are simple mathematical rearrangements of the basic rule:
  - Current equals voltage divided by resistance;
  - Resistance equals voltage divided by current; and
  - Voltage equals current multiplied by resistance

Copyright © 2023 by CMS Pitman, NJ USA - Page 4

Ohm's Law Basics

- Formulaically, we use specific symbols to represent the basic values:
  - I is used for current;
  - E (and sometimes V) is used for voltage; and
  - R is used for resistance.
- These symbols are used in formulas, but are *not* always the abbreviations commonly used for these values.

Copyright © 2023 by CMS Pitman, NJ USA - Page 5

Ohm's Law Basics

- The unit of measure of current is the *ampere*, abbreviated *A.*
- The unit of measure of voltage is the *volt,* abbreviated *V*.
- The unit of measure of resistance is the *ohm,* abbreviated *Ω.*
- Each of these values is measured with a specific instrument or meter.

Copyright © 2023 by CMS Pitman, NJ USA - Page 6

Ohm’s Law Basics

- The units of measure may be modified to easily express much larger or smaller units…
  - 1 milliampere (mA) equals 0.001 amperes;
  - 1 microampere (µA) equals 0.000001 milliamperes;
  - 1 kilovolt (kV) equals 1,000 volts;
  - 1 millivolt (mV) equals 0.001 volts;
  - 1 microvolt (µV) equals 0.000001 volts;
  - 1 kilohm equals 1,000 ohms; and
  - 1 megohm equals 1,000,000 ohms.

Copyright © 2023 by CMS Pitman, NJ USA - Page 7

Ohm's Law Basics

- Current, in amperes, is measured using an *ammeter*, which is connected in series with the circuit under test.
- Voltage, in volts, is measured using a *voltmeter*, which is connected in parallel to the circuit segment under test.
- Resistance, in ohms, is measured with an *ohmmeter*, which is *always* connected only to a de-energized circuit or component.

Copyright © 2023 by CMS Pitman, NJ USA - Page 8

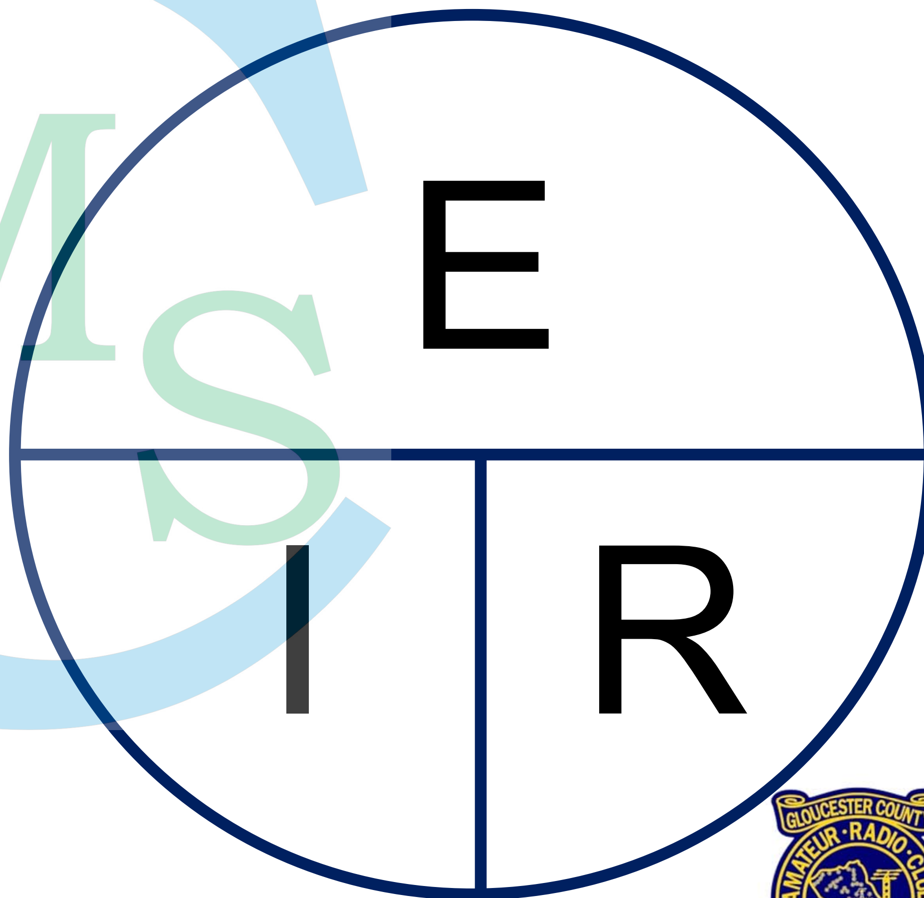
Ohm's Law Equations

- The three forms of Ohm's Law, stated using the symbolic representations for the values, are as follows:
  - $I = E / R$
  - $R = E / I$
  - $E = I \times R$
- If we know two of the values, we can easily calculate the third value.

Copyright © 2023 by CMS Pitman, NJ USA - Page 9

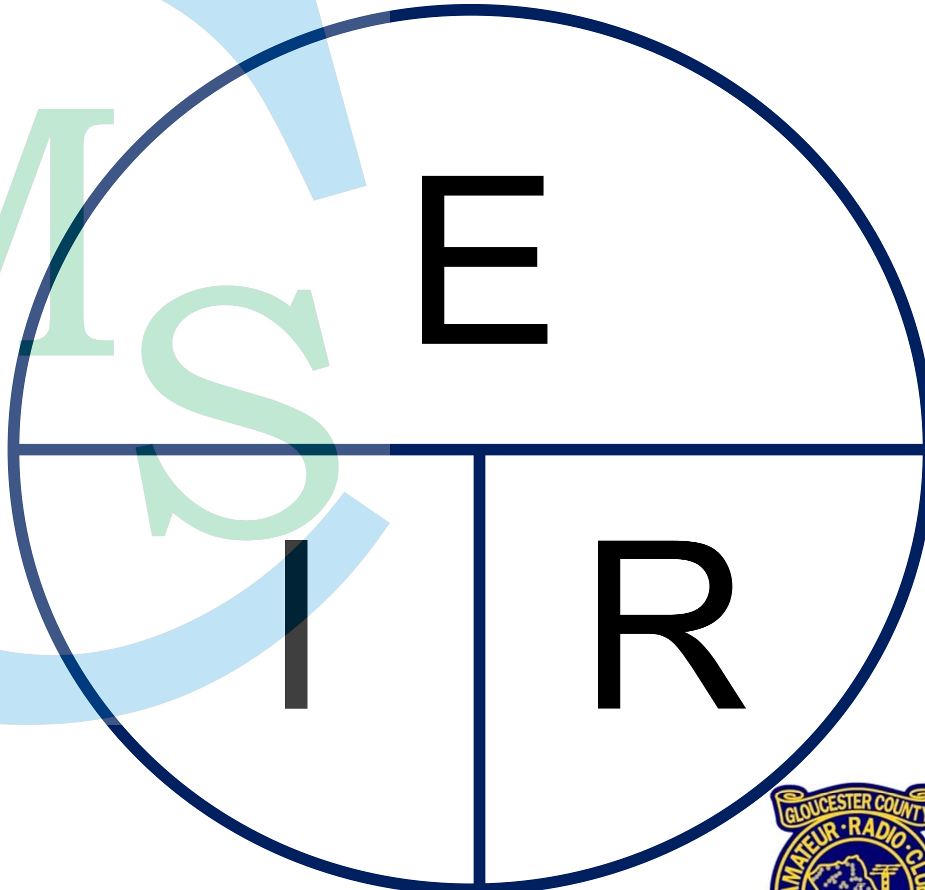
Ohm’s Law Wheel

- The Ohm’s Law wheel helps us to remember the equations by showing the equation parts in a graphical form, and the graphic gives us the equations if we cover one part.



Ohm's Law Wheel

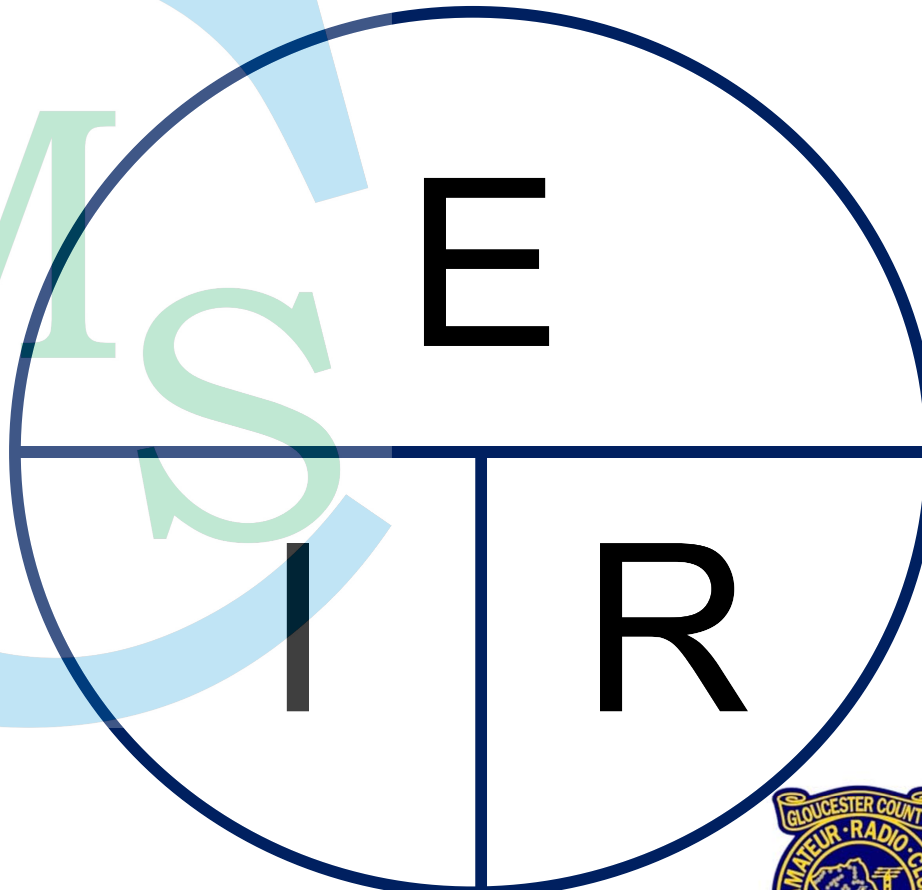
- If we cover the part that we need to solve for, the remaining parts will then be displayed in the form of the appropriate equation for finding the missing part.



Copyright © 2023 by CMS Pitman, NJ USA - Page 11

Ohm’s Law Wheel

- Cover the E and get I next to R ($E = I \times R$).
- Cover the I and get E over R ($I = E / R$).
- Cover the R and get E over I ($R = E / I$).
- This is a handy tool that is easy to use and to remember.



Copyright © 2023 by CMS Pitman, NJ USA - Page 12

Ohm’s Law Example 1

- Solve for the current in milliamperes for a circuit where 12 volts applied across a resistance of 470 ohms…
  - $I = E / R$
    - $I = 12V / 470\Omega$
    - $I = 0.02553A$
    - $I = 25.53mA$

Copyright © 2023 by CMS Pitman, NJ USA - Page 13

Ohm's Law Example 2

- Find the resistance in a circuit where a current of 275 milliamperes flows when 7.5 volts are applied.
  - $R = E / I$
  - $R = 7.5V / 275mA$
  - $R = 7.5V / 0.275A$
  - $R = 27.27\overline{27}\Omega$

Ohm's Law Example 3

- What is the voltage applied in a circuit in which 1795 milliamperes is flowing through a resistance of 2.7kΩ?
  - $E = I \times R$
  - $E = 1795mA \times 2.7k\Omega$
  - $E = 1.795A \times 2700\Omega$
  - $E = 4{,}8465.5V$

Copyright © 2023 by CMS Pitman, NJ USA - Page 15

Power

- When a current flows through a resistive circuit, work is done in that the current flow through the resistor causes the resistor to radiate some amount of heat.
- The work that is done can be measured, and the rate at which the work is done is known as *power.*
- Power, in general, is abbreviated *P.*

Copyright © 2023 by CMS Pitman, NJ USA - Page 16

Power

- Power is a function of voltage and current, and can be calculated using the equation
  POWER = CURRENT x VOLTAGE.
- As before, we can symbolize the current and voltage to give us POWER = I x E.
- This equation is a representation of Watt's Law.
- The unit of measure of power is the *watt.*
- One watt is the amount of power consumed when a current of one ampere is moved by a voltage of one volt.

Copyright © 2023 by CMS Pitman, NJ USA - Page 17

Power

- Also as before, the watt is often expressed in other forms to show exceptionally large or very small levels of power:
  - 1 milliwatt (mW) equals 0.001 watts
  - 1 microwatt (µW) equals 0.000001 watts
  - 1 kilowatt (kW) equals 1,000 watts
  - 1 megawatt (MW) equals 1,000,000 watts

Copyright © 2023 by CMS Pitman, NJ USA - Page 18

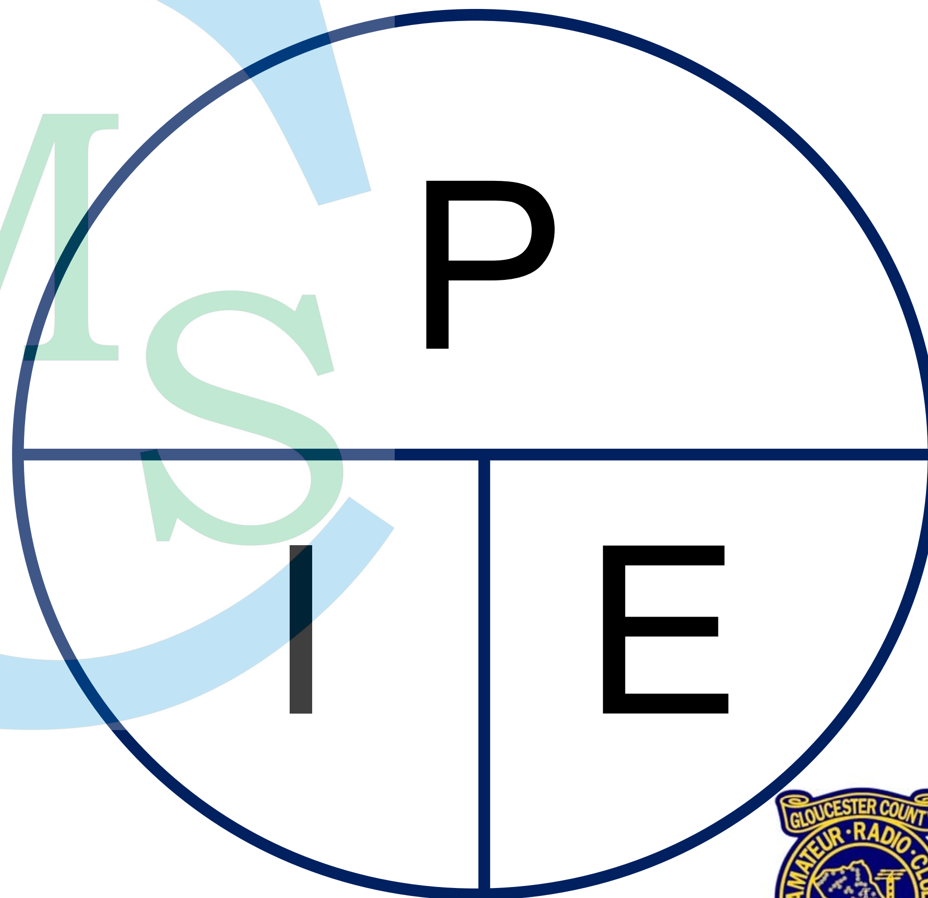
Power

- The watt is abbreviated *W* and is measured by a device called a *wattmeter.*
- Also as before, the equation for power can be rearranged mathematically as follows:
  - P = I x E
  - I = P / E
  - E = P / I
- As before, we have a memory aid for Watt's Law that is very familiar by now.

Copyright © 2023 by CMS Pitman, NJ USA - Page 19

Watt's Law Wheel

- As with the Ohm's Law wheel, the Watt's Law wheel will give us the equation for any of the equation's parts by covering the part for which we need to solve.



Copyright © 2023 by CMS Pitman, NJ USA - Page 20

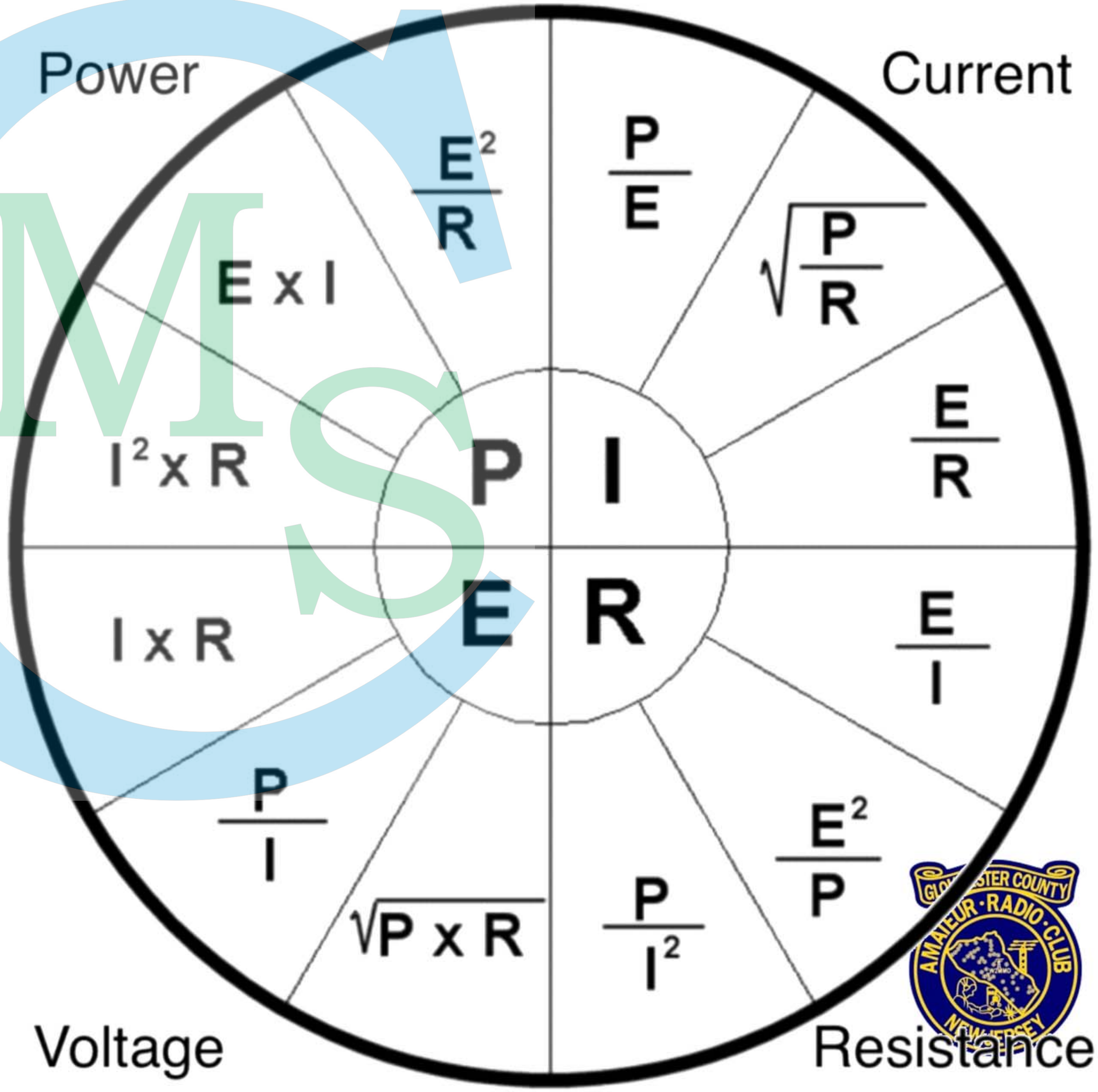
Power

- Sometimes, we will have to solve for power having been given the resistance instead of either the current or the voltage.
- Some additional useful rearrangements of the equations are:
  - $P = I^2 \times R$ ($P = I \times E$, and $E = I \times R$, so $P = I \times I \times R$)
  - $P = E^2 / R$ ($P = I \times E$, and $I = E / R$, so $P = E \times (E/R)$
- Other forms of Watt's Law equations exist.

Copyright © 2023 by CMS Pitman, NJ USA - Page 21

Ohm’s & Watt’s Laws Wheel

- This combined wheel shows all of the possible forms of the Ohm’s Law and Watt’s Law equations, broken apart in quadrants by the factor for which we need to solve.



Copyright © 2023 by CMS Pitman, NJ USA - Page 22

Watt's Law Example 1

- How much power in kilowatts is consumed in a circuit in which 21 amperes flows under a voltage of 100 volts?
  - $P = I \times E$
  - $P = 21A \times 100V$
  - $P = 2100W$
  - $P = 2.1kW$

Copyright © 2023 by CMS Pitman, NJ USA - Page 23

Watt's Law Example 2

- How much current is flowing in a 250V circuit in which 7.5MW is consumed?
  - $I = P / E$
  - $I = 7.5MW / 250V$
  - $I = 7{,}500{,}000W / 250V$
  - $I = 30{,}000A$

Copyright © 2023 by CMS Pitman, NJ USA - Page 24

Watt's Law Example 3

- What is the voltage of a circuit in which 48 watts are consumed and a current of 8 amperes is flowing?
- $V = P / I$
- $V = 48W / 8A$
- $V = 6V$

Copyright © 2023 by CMS Pitman, NJ USA - Page 25

Watt's Law Example 4

- What is the milliwatt power consumption of a 15V circuit with a resistance of 1.8kΩ?
  - $P = E^2 / R$
  - $P = 15V^2 / 1.8k\Omega$
  - $P = (15 \times 15) / 1800$
  - $P = 225 / 1800$
  - $P = 0.125W$
  - $P = 125mW$

Copyright © 2023 by CMS Pitman, NJ USA - Page 26

Watt's Law Example 5

- How many kilowatts are consumed in a circuit having 470Ω resistance and a current flow of 375mA?
  - $P = I^2 \text{ x } R$
  - $P = 375mA^2 \text{ x } 470\Omega$
  - $P = 0.375 \text{ x } 0.375 \text{ x } 470$
  - $P = 66.09375W$
  - $P = 0.0661kW$

Copyright © 2023 by CMS Pitman, NJ USA - Page 27

AC Variations of Watt's Law

- Up to this point, all of the examples that we have seen involved DC circuits.
- I order to understand these concepts when AC is involved, we must first understand the DC equivalent of an AC voltage.
- As DC flows through a resistance, a given amount of measurable heat is produced.
- We are interested in that amount of heat.

Copyright © 2023 by CMS Pitman, NJ USA - Page 28

AC Variations of Watt's Law

- While DC is constant and continuous, AC varies continually between some positive peak and some negative peak.
- In an AC sine wave, the average voltage of this wave is zero, as the wave spends as much time above zero as it does below zero, and in the same proportions (pattern).
- Thus, we need a different way to measure AC voltages.

Copyright © 2023 by CMS Pitman, NJ USA - Page 29

AC Variations of Watt's Law

- The solution is the AC voltmeter, which measures a property of AC known as its *Root Mean Square*, or *RMS* voltage.
- This is the AC voltage that will produce the same heating effect as the equivalent DC voltage in a resistance.
- RMS voltage is equal to 70.7% of the peak voltage of an AC sine wave.

Copyright © 2023 by CMS Pitman, NJ USA - Page 30

AC Variations of Watt's Law

- The full AC sine wave, as stated earlier, swings both positive and negative across the zero line, and is thus called a *peak-to-peak voltage,* or V_{P-P}.
- RMS voltage is calculated using only one half of the full peak-to-peak sine wave, or the *peak voltage (V_P).*
- Thus, the formula for RMS voltage becomes

$$V_{RMS} = V_P \text{ x } 0.707$$

Copyright © 2023 by CMS Pitman, NJ USA - Page 31

AC Variations of Watt's Law

- In certain disciplines, such as in amateur radio, we are interested in the power represented by an AC signal waveform, possibly as seen on an oscilloscope.
- In radio, we call this waveform the signal's envelope, and we are interested in the *peak envelope power*, or *PEP.*
- PEP is calculated by the formula

$$PEP = {V_{RMS}}^2/R$$

AC Variations of Watt's Law

- In that formula, $PEP = V_{RMS}{}^2/R$, the R represents the load resistance, which is normally the characteristic impedance of the radio's antenna system, usually shown as Z_L.
- In order to calculate the PEP, two factors must be known…
  - The voltage; and
  - The load impedance (resistance).

Copyright © 2023 by CMS Pitman, NJ USA - Page 33

AC Variations of Watt's Law

- The voltage may be given in one of three forms, two of which will require some manipulation in order to solve the equation:
  - $V_{P\text{-}P}$ or peak-to-peak voltage, which we must first convert to peak voltage (V_P) and then to RMS voltage (V_{RMS});
  - V_P, which must be converted to V_{RMS}; or
  - V_{RMS}, which is ready to use in the equation.

PEP Example 1

- Calculate the PEP of a waveform having a peak-to-peak voltage of 140 volts and a load impedance of 50Ω.
  - $PEP = V_{RMS}{}^2/L_Z$ or $V_{RMS}{}^2/L_Z$
  - $PEP = ((140\ /2)\ x\ 0.707)^2/50$
  - $PEP = (70\ x\ 0.707)^2/50$
  - $PEP = 49.49^2\ /\ 50$
  - $PEP = 2{,}449.2601\ /\ 50$
  - $PEP = 48.985202W$

PEP Example 2

- What is the PEP of a waveform with a peak voltage of 120V and a load impedance of 75Ω?
  - $PEP = (120 \text{ x } 0.707)^2/75$
  - $PEP = 84.84^2 / 75$
  - $PEP = 7{,}197.8256 / 75$
  - $PEP = 95.971008W$

Copyright © 2023 by CMS Pitman, NJ USA - Page 36

PEP Example 3

- Find the PEP of a waveform having an RMS voltage of 70.7V and a load impedance of 50Ω.
  - $\text{PEP} = 70.7^2/50$
  - $\text{PEP} = 4998.49\ /\ 50$
  - $\text{PEP} = 99.9698\text{W}$

Copyright © 2023 by CMS Pitman, NJ USA - Page 37

Summary

- While there are many applications for this information, it all remains simple arithmetic.
- The Ohm's Law and Watt's Law equations are easily drawn from the wheels if they are not remembered.
- The RMS voltage equation is most easily remembered by thinking of Boeing's first jet airliner, the 707… $V_{RMS} = V_P \times 0.707$
- The PEP equation, while not really a part of Ohm's Law and Watts's Law, is a useful application of some of this information.

Questions?