ECE 528 – Understanding Power Quality

https://webpages.uidaho.edu/ECE/power/ECE528

Paul Ortmann
portmann@uidaho.edu
208-316-1520 (voice)

Lecture 27

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Today…

- Some HW7 questions
- Wiring for communications continued
  - Decibels
  - Determining communication system performance
- An introduction to stray voltage

References:

- *Electromagnetic Compatibility Engineering*, by Henry W. Ott
- *Technical Tidbits* posts from February 2002, March, 2002, and April 2005 on Douglas Smith's High Frequency Measurements Web Page (www.emcesd.com)

(*I recommend both if you are interested in high frequency and electromagnetic compatibility*)

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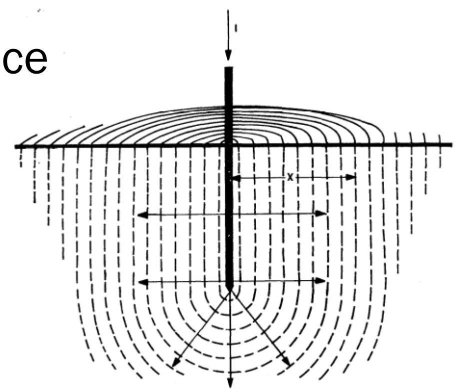
Homework 7 pointers

Problem 4 – Process

1. Find ground rod resistance, R_{rod}
2. Find ground fault current I_g, using complete ground fault current path resistance
3. Use ground fault current in voltage gradient equation
4. V_{fault} is the voltage across the ground rod or other earth connection at the ground fault location.

Calculating ground rod resistance



$$R_{rod} = \frac{\rho}{2\cdot\pi\cdot L}\cdot\left(\ln\left(\frac{4L}{a}\right) - 1\right)$$

ρ soil resistivity in Ω-m (Ohm-meters)
L rod length in meters
a rod radius in meters
(1 Ω-m = 100 Ω-cm)

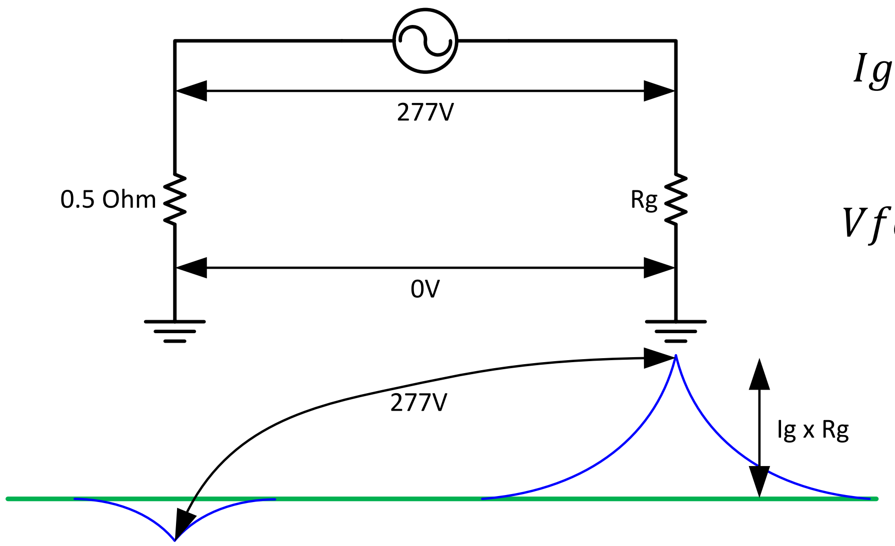
Equation is valid for L>>a

Approximate Soil Resistivity:

Wet Organic Soil:	10 Ω-m
Moist Soil:	100 Ω-m
Dry Soil:	1,000 Ω-m
Bed Rock:	10,000 Ω-m

From MIL-HDBK-419A, 1987

HW7, prob. 4



$$Ig = \frac{277V}{Rg + 0.5\Omega}$$

$$Vfault = Ig \times Rg$$

Calculating earth surface potentials near a ground rod

$$U_g(y) = \frac{I_g \cdot \rho}{2 \cdot \pi \cdot L} \cdot \ln\left(\frac{\sqrt{L^2 + y^2} + L}{y}\right)$$

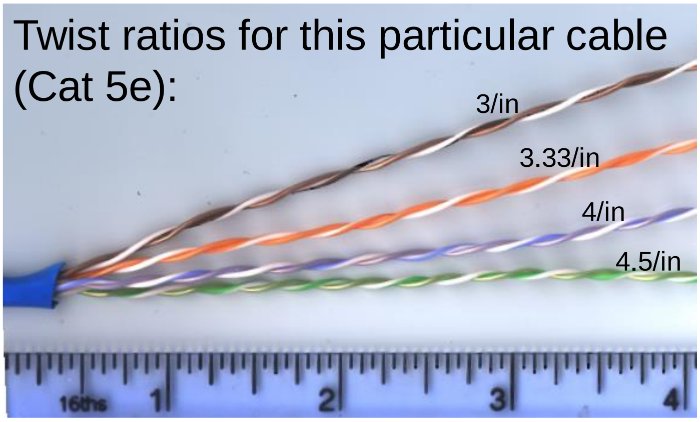
I_g = current through ground rod
y = distance from ground rod (m)

$U_g(y)$ is the voltage on the earth surface, at distance y from the ground rod, with respect to “remote” earth.

Step voltage between two points: $U_g(y_1) - U_g(y_2)$

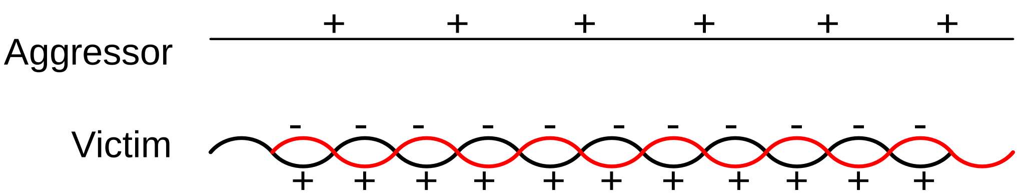
Touch voltage between ground rod and earth at distance y: $V_{fault} - U_g(y)$

Continuing from Lecture 26: Overcoming coupling: UTP – Unshielded Twisted Pair



- Construction: Cat 5e
  - #24AWG solid copper conductors
  - 4 twisted pairs
  - Varying “lays” or twist rates
  - No shield

Benefits of twisting each pair



- Capacitive coupling
  - A nearby “aggressor” circuit is creating an electric field in the area of the twisted pair
  - Twists help prevent differential voltage from developing between conductors in the pair

Benefits of twisting each pair

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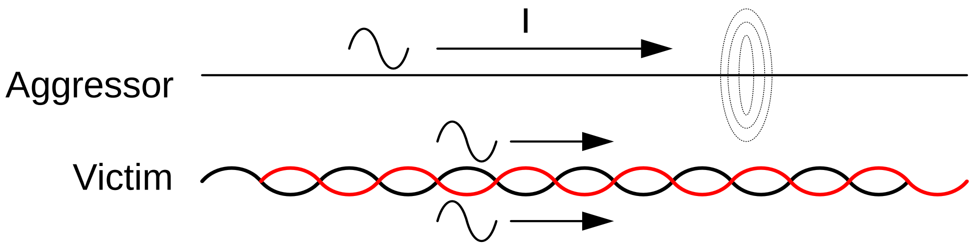

- Inductive coupling
  - A nearby "aggressor" circuit is creating a magnetic field in the area of the twisted pair
  - Twists force induced EMF to be "common mode"

Differential communication signal and common mode noise

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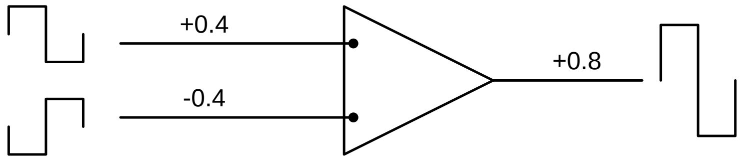
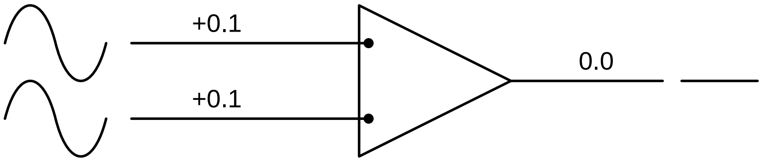
- At the receiver, the differential signal is extracted



- The common mode noise is cancelled



Other benefits of twisting the signal pairs

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- Signal cables can be the aggressor too:
  - One signal pair could be the aggressor for other signal pairs in the same cable or other nearby signal cables
  - Twisting the pairs minimizes the capacitive coupling to other nearby circuits
- Different twist ratios
  - Helps minimize “crosstalk” - the coupling of signals from one twisted pair to another, either in the same cable or other nearby cables

Benefits of twisting: Minimizing crosstalk

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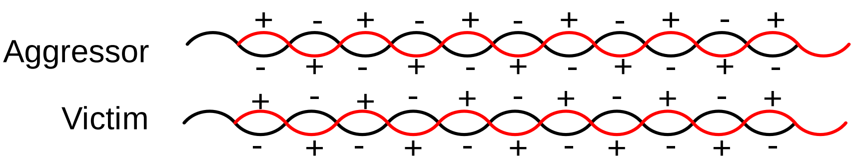
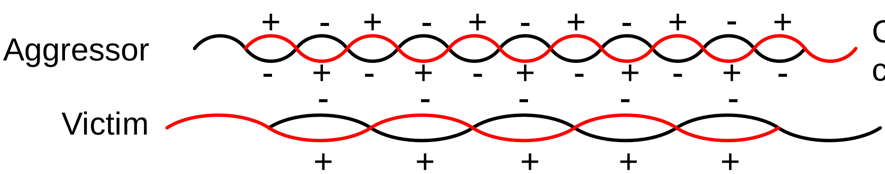
- Same twist ratio



Note capacitive coupling

- Different twist ratios



Capacitive coupling cancels

Some communications terminology

- The decibel - dB
  - Used to compare power ratios

$$dB = 10\log\frac{P_2}{P_1}$$

The result may be multiplied by -1 based on the context.

  - Try it!
    - Express a 100:1 (P_2:P_1) power ratio in dB
    - What if the ratio is 1:100 (P_2:P_1) instead?
    - Express a 0.5:1 (P_2:P_1) power ratio in dB

The decibel in communication circuits

- Used to measure loss of signal strength
- Used to measure interference from neighboring communication circuits
- Used to compare different circuit configurations
  - With voltage or current ratios, remember that power is a function of voltage or current squared:

$$P = \frac{V^2}{R} \qquad \log A^n = n\log A \qquad dB = 20\log\frac{V_2}{V_1} \qquad dB = 10\log\frac{P_2}{P_1}$$

- Try it: V_1=5V, V_2=1V, what is the ratio in dB?
- Try it: P_1=25W, P_2=1W, what is the ratio in dB?

Installation issues

- Delay skew
  - Different twist ratios result in each pair being a slightly different length
  - Signals on one pair may take longer to travel from one end of the cable to the other than signals on another, less-twisted pair
  - May be an issue with long cables and high-resolution video signals

Installation issues

- Maintaining twist ratios
  - Cable bends and terminations can untwist the pairs
  - Some manufacturers fuse the insulation between pairs to keep conductor separation to a minimum
  - Bends need to be gradual, and twist ratios need to be maintained into connectors

Installation issues

- Nearby power conductors
  - The NEC requires a minimum spacing of 2 inches between power and communication circuits
  - Generally, avoiding close, long parallel runs of power and signal cables is sufficient to avoid problems

Some communication cabling terms (calculations are in dB, i.e. -20log(ratio) *Don't just use the ratio!*)

$\frac{V_{out}}{V_{in}}$ **Attenuation:** The loss in signal power between the sending and receiving end

$$Attenuation = -20 \cdot log\left(\frac{V_{out}}{V_{in}}\right)$$

$\frac{V_{xtalk\_near\_end}}{V_{in}}$ **NEXT:** (Near end crosstalk) the sending end signal power on one pair that appears at the sending end on any other pair in the cable

$\frac{V_{xtalk\_far\_end}}{V_{in}}$ **FEXT:** (Far end crosstalk) the sending end signal power on one pair that appears at the receiving end on any other pair in the cable

Some communication cabling terms (calculations are in dB, i.e. -20log(ratio))

$$\frac{V_{xtalk\_far\_end}}{V_{out}}$$

ELFEXT: Equal Level FEXT – The receiving end signal power on one pair that appears on any other pair in the cable at the receiving end

$$\frac{V_{reflected}}{V_{in}}$$

Return Loss: The amount of sending end signal power that is reflected back on the same pair – due to manufacturing variations or flaws in the signal conductors

Cat 5e performance standard at 100MHz

	Connectors	Channel
Attenuation	0.4 dB	24 dB
NEXT	40 dB	30.1 dB
FEXT	35 dB	-
ELFEXT*	-	17.4 dB
Return Loss	18 dB	10 dB

Channel - The link (cable and connectors) between the local and remote equipment
*ELFEXT (Equal Level FEXT) = FEXT – Attenuation
FEXT and Attenuation are measured, ELFEXT is calculated

Understanding Stray Voltage – a brief introduction

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- Stray Voltage:
  - *A <u>voltage resulting from the normal delivery or use of electricity</u> that may be present between two conductive surfaces that can be simultaneously contacted by members of the general public or animals. Stray voltage is not related to electrical faults.*
- Contact Voltage: (Discussed in lecture 24 and 25)
  - *A <u>voltage resulting from electrical faults</u> that may be present between two conductive surfaces that can be simultaneously contacted by members of the general public or animals. Contact voltage can exist at levels that may be hazardous.*

Both definitions from IEEE Std. 1695-2016

Understanding Stray voltage: Sources and loads

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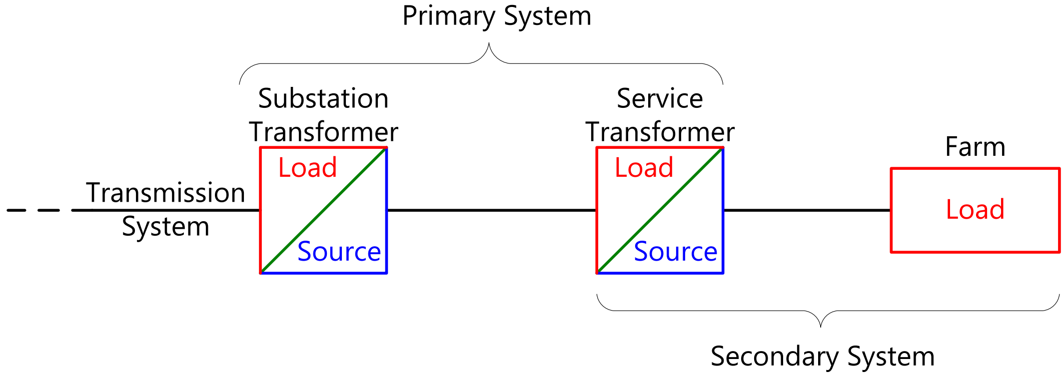
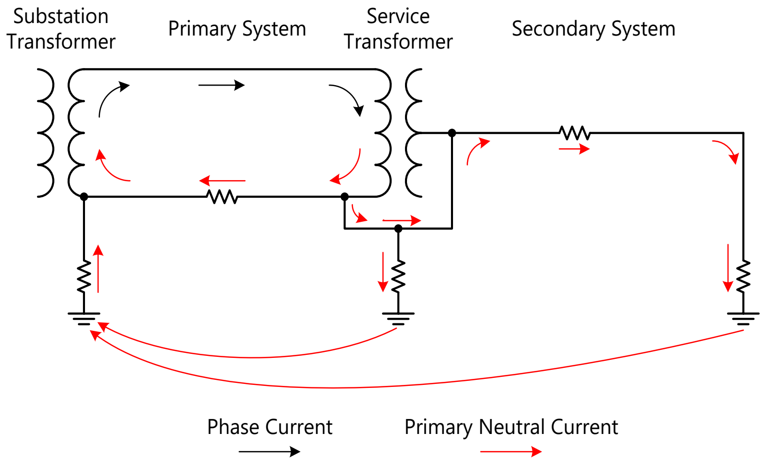


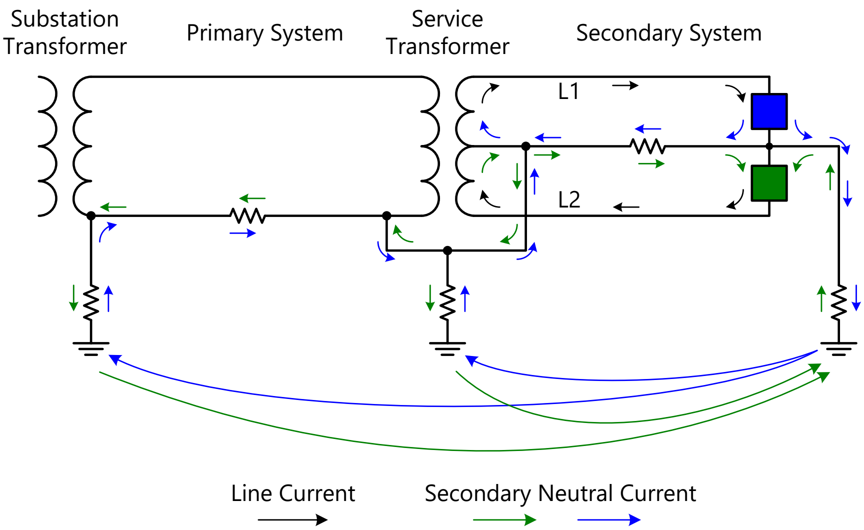
Current circulates between a source and load.
Understanding stray voltage requires understanding the flow of <u>neutral</u> currents between the sources and loads.

Primary neutral current flow

Important observations:
"Source" is the substation transformer and "load" is the service transformer.
However, primary system neutral current also flows on the secondary system because the neutrals of both systems are connected.
All conductors and earth grounds have impedance.
According to Ohm's Law, there will be a voltage across each impedance in the grounding system.

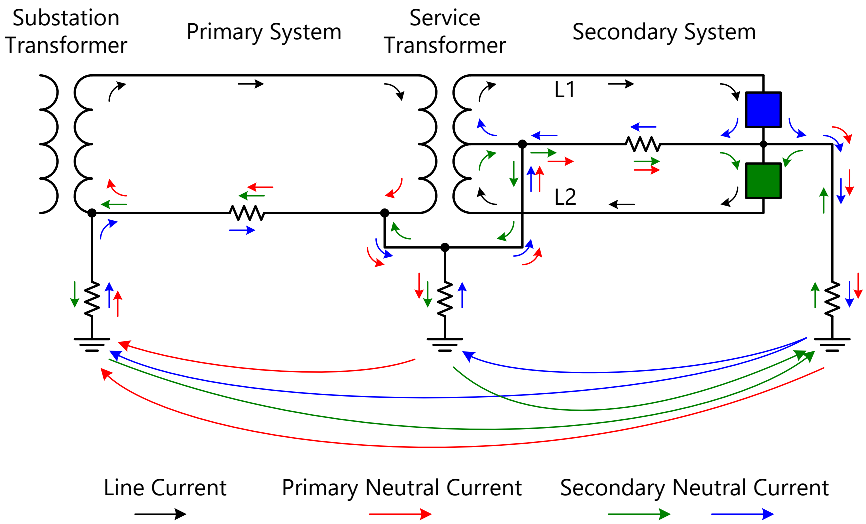


Secondary neutral current flow



Important observations:
"Source" is the service transformer and "load" is the customer's equipment.
However, secondary system neutral current (due to load imbalance) also flows on the primary system.

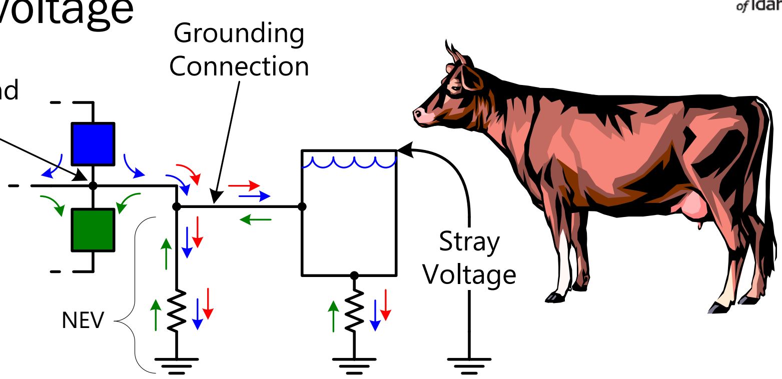
Primary and secondary neutral current flow



<u>Important observations:</u>
Primary and secondary neutral currents can add or subtract.
All of the resulting voltages are the normal result of current flowing through impedance. Nothing is broken here.

From NEV to stray voltage

A small portion of the primary and secondary neutral current can travel through the grounding system, resulting in voltages between conductive surfaces, like the earth and a heated metal water trough



Stray voltage mitigation: Primary system

- Two approaches
  - Reduce current on the grounding system
    - Increase voltage of primary system
    - Use 3-phase primary systems and balance the loading
  - Reduce impedance of the grounding system
    - Use large, short, service neutral conductors
    - Increase the size of the primary neutral conductors
    - Increase the primary system grounding

Stray voltage mitigation: Secondary system

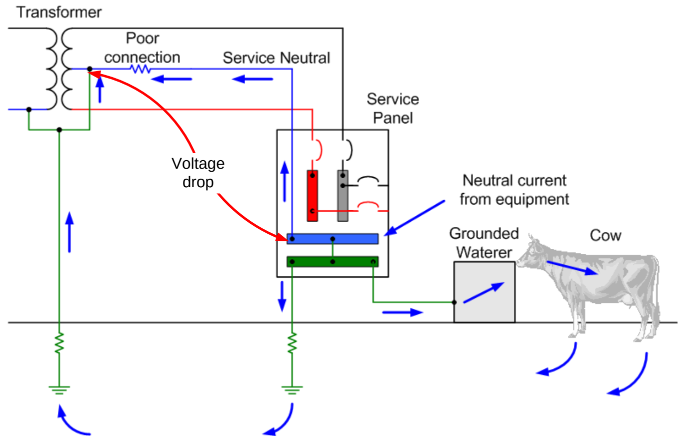
- Two approaches
  - Reduce current on the grounding system
    - Balance the load on split single-phase systems
    - Use 3-phase services and equipment
    - Use a single neutral-to-ground bond at the service point with separate neutral and grounding conductors to all downstream locations (NEC)
  - Reduce impedance of the grounding system
    - Large, short service neutral conductors
    - Extensive bonding of conductive equipment (NEC)
    - Equipotential planes in animal confinement areas (NEC)

Stray voltage mitigation: Secondary system

A poor connection, or a long, small neutral conductor, forces more neutral current into the earth at the service panel, raising NEV at the building service panel and raising the corresponding stray voltage.

Using three-phase loads or loads connected line-to-line avoids neutral current.

An equipotential plan would put the cow's standing surface and the waterer at the same potential, eliminating the voltage between them. The NEC requires equipotential planes.



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Stray voltage summary

- There is normally a very small voltage between different grounded objects or grounded objects and the earth.
- Primary and secondary grounding systems are interconnected – changes to one will impact the other.
- After a careful investigation to determine the source of some stray voltage and the circuit parameters, there are steps we can take to mitigate stray voltage using normal electrical principles.

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Coming up…

- PQ recorders, instruments and tools
- Recorder location and the impact on what we record
- Wiring and grounding summary
- Your chance to evaluate your instructor
- Final exam