# Analyzing Boatside Water-Shock Hazards

Jim Shafer
David Rifkin

IBEX, October 12, 2007

# Agenda

- Problem scope
- Grounding, Bonding, and the Code
- The physiology of an accident
- Causes of accidents
- USCG Study
- Making it safer

# Problem Scope

- Documented deaths (>40) and injuries (>100)

**ELECTRIC SHOCK DROWNINGS**

1. July 28,2007 Lake of The Ozarks, MO Twenty four year old female attempted to exit the water using a metal ladder at the end of a private dock. She apparently experienced a paralyzing electric shock which caused her to fall back into the water and drown. Several people had reported being shocked by the ladder and the dock owner had gone to shut the power off. High water had apparently submerged the dock wiring.
2. July 24, 2006 Lake Lanier, Cumming, GA. Seventeen year old boy in water near a private dock, working on a jet ski with two friends, was overcome by electric shock. Extension cord with damaged insulation caused the metal dock to become energized. Friends also shocked, and partially disabled, could not help their friend. Father of victim fought paralyzing shock and pulled unconscious son away from dock – he could not be resuscitated. Investigation planned.
3. July 14, 2006 River Street Marina, Port Huron, MI. A 20 year old man jumped, or fell, into the water from the pier behind a 29' boat, moored stern too. He became disabled as he attempted to climb onto the swim platform. Two friends attempting to pull him onboard reported being shocked. He could not be resuscitated. The next day an inspector reported 107vac in the water behind the boat – measuring points not known at this time. Investigation in progress.
4. June 24, 2006 Brady Mountain Resort, Lake Ouachita, AR. A 14 year old boy died from electric shock while swimming near a houseboat. A friend was also shocked

# Grounding and Bonding

- A vital, yet simple system
- Need established in the late 1800s
- Clearly defined and applied through out the National Electric Code
- The terms are often used interchangeably, but they are distinctly different
- Let's look at some definitions

# Grounding

A common connection to earth for:

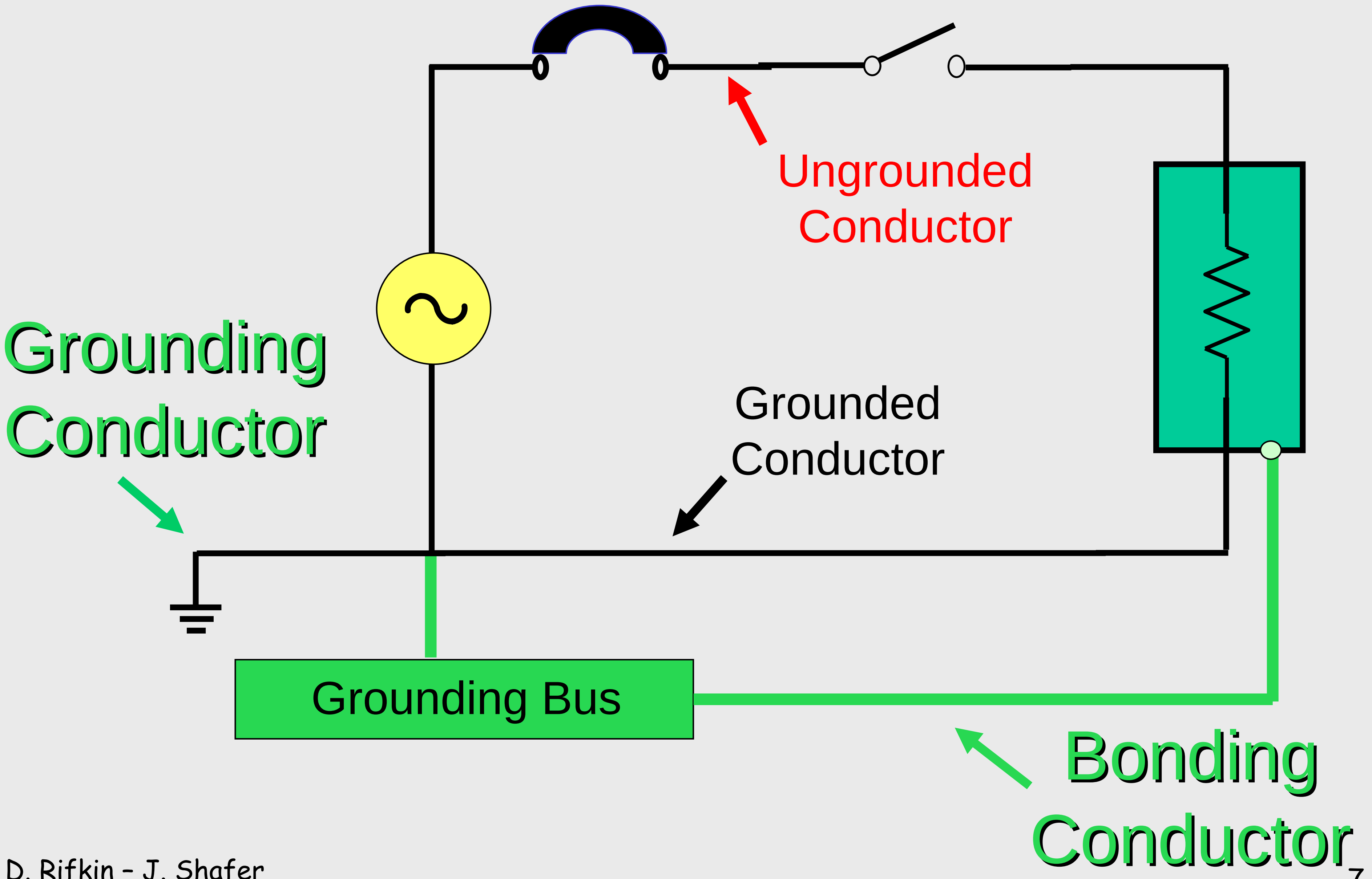
- Lightning discharge
- System voltage stabilization
- Reducing static and RF interference

# Bonding

A common connection joining metal components to:

- Provide a low impedance ground fault path to trip a circuit protection device
- Prevent dangerous voltages from appearing on metal objects
- Prevent DC stray currents
- Acts as a conduit to provide protection by cathodic protection systems

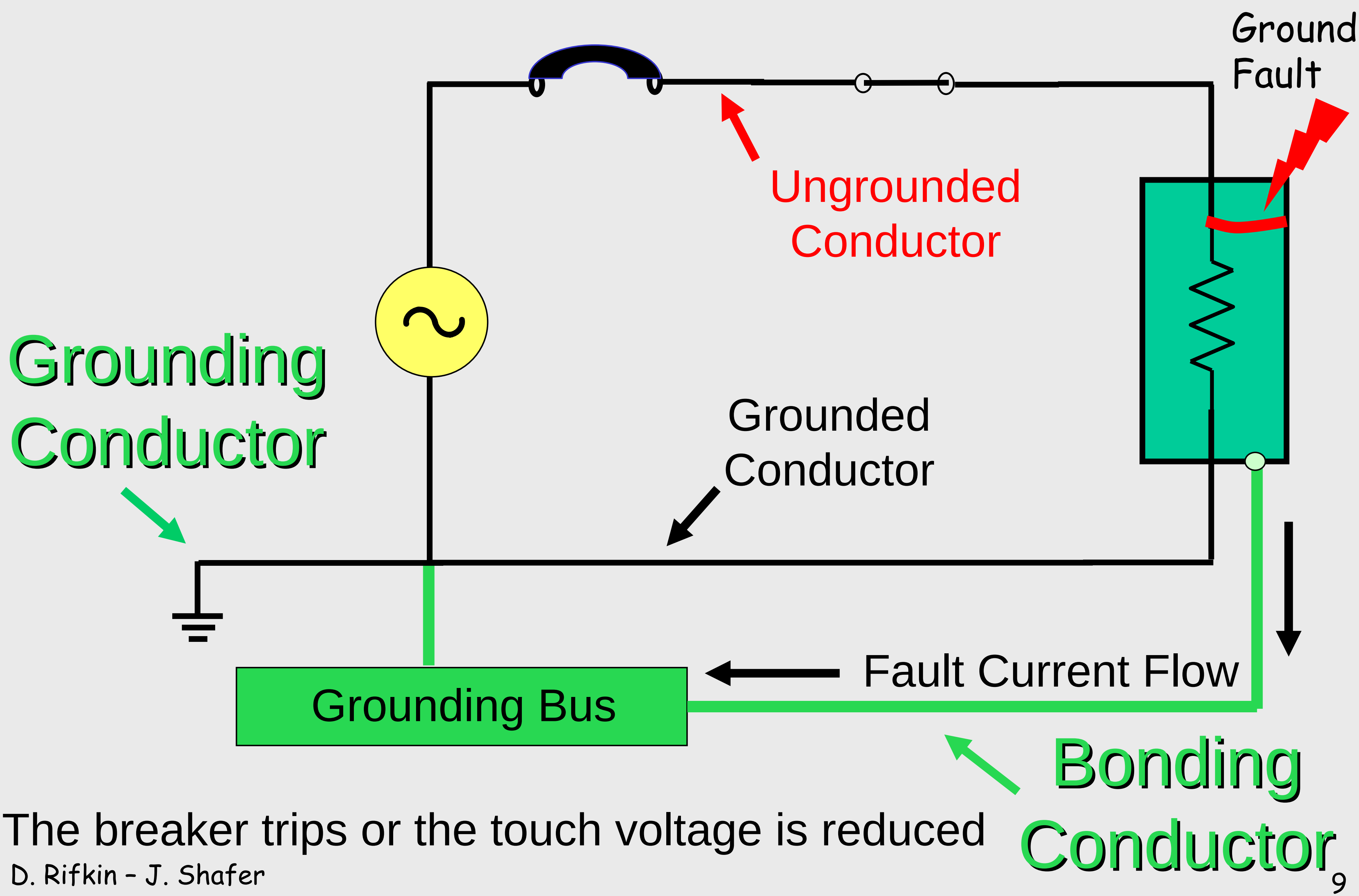
# A Very Basic System



# First, What *Is* a Fault?

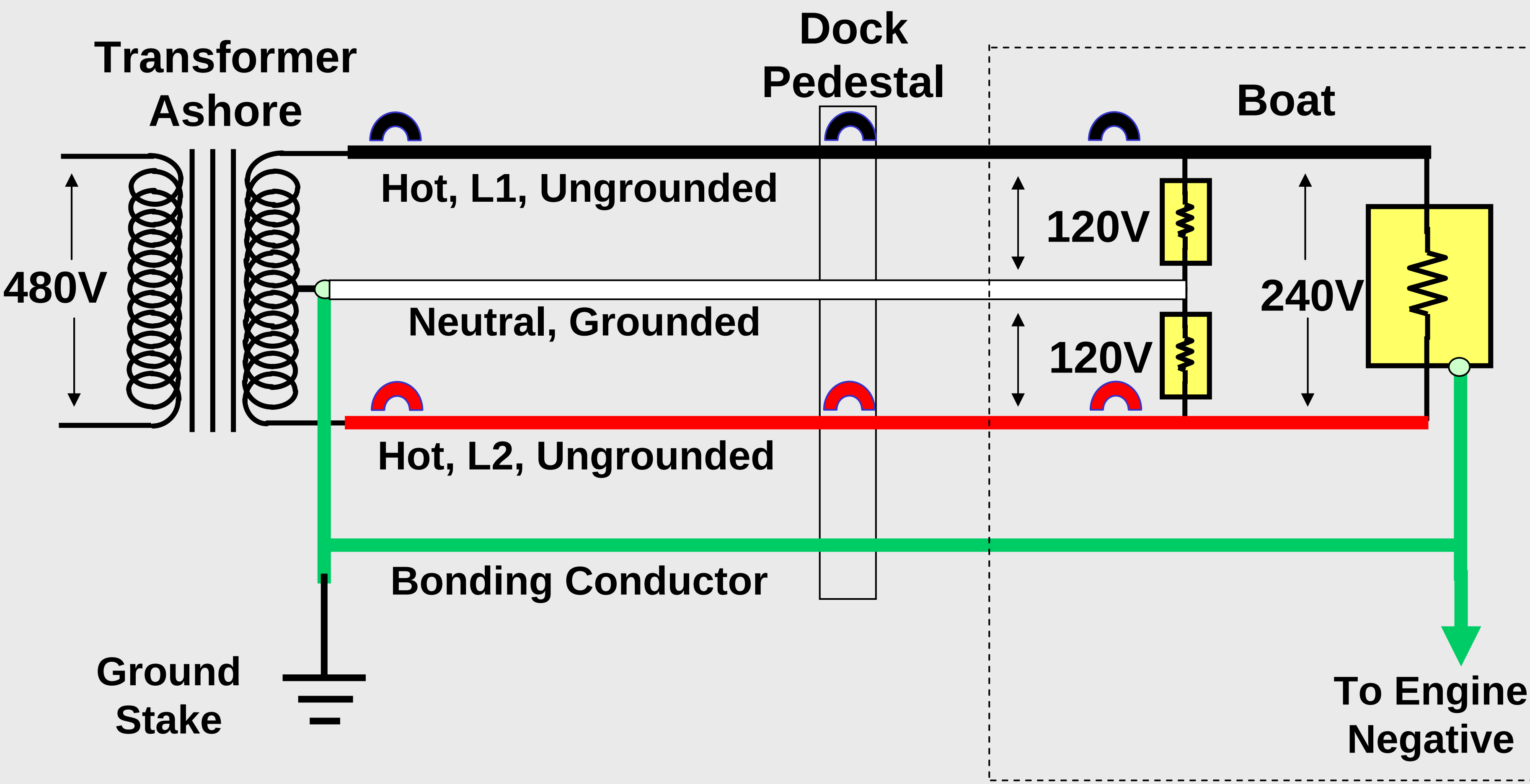
- *An AC* fault occurs when the energized ungrounded conductor contacts a metal component
- *An* undetected *AC* fault occurs when the fault current is too low to trip the circuit protection device
  - Keep in mind that the undetected fault is always the killer…

# Bonding System At Work




The breaker trips or the touch voltage is reduced

# AC Supply from Shore




Key point: Neutral and ground are only connected at a newly derived source (e.g. xfmr secondary, genset/inverter when supplying AC).

# Compatibility

- Some argue that the NEC is not applicable to boats…
- However, the basis for most if E-11 *is* the Code!
- It's vital to follow the Code's tenets, lest we reduce safety margins
- Remember that the Code, and most standards are "written in blood"; deviation is at one's own peril and the peril of the end users…

- Here's what article 250 of the NEC says:

**(4) Bonding of Electrically Conductive Materials and Other Equipment.** Electrically conductive materials that are likely to become energized shall be connected together and to the electrical supply source in a manner that establishes an effective ground-fault current path.

- Here's what ABYC, E-11 says:

AC grounding conductor (green or green with a yellow stripe) - A conductor, not normally carrying current, used to connect the metallic non-current carrying parts of AC electrical equipment to the AC grounding bus , engine negative terminal, or its bus, and to the source ground.

11.17.3.2. All exposed, electrically conductive, non-current carrying parts of fixed AC electrical equipment and appliances intended to be grounded shall be connected to the grounding conductor.

# The Physiology

- Paralysis is the cause of Electric Shock Drowning (electrocution is different)
  - A swimmer becomes paralyzed and loses the ability to stay afloat
  - The autopsy will state "drowning" as the cause
  - Unless there are witnesses or a victim's statement, electricity is not considered as a cause
- There may be hundreds more Electric Shock Drownings we never hear about
  - Databases don't breakout this type of drowning
  - We have the only listing known

# Current Effect on Humans

- The generally accepted nominal current levels:

| | |
|---|---|
| 1 ma | Tingle |
| 15 ma | Paralysis / Drowning |
| 60 ma | Heart Failure (electrocution) |
| 300 ma | Combustion |
| 10 ma | = .01 Amps |

# Typical Scenario

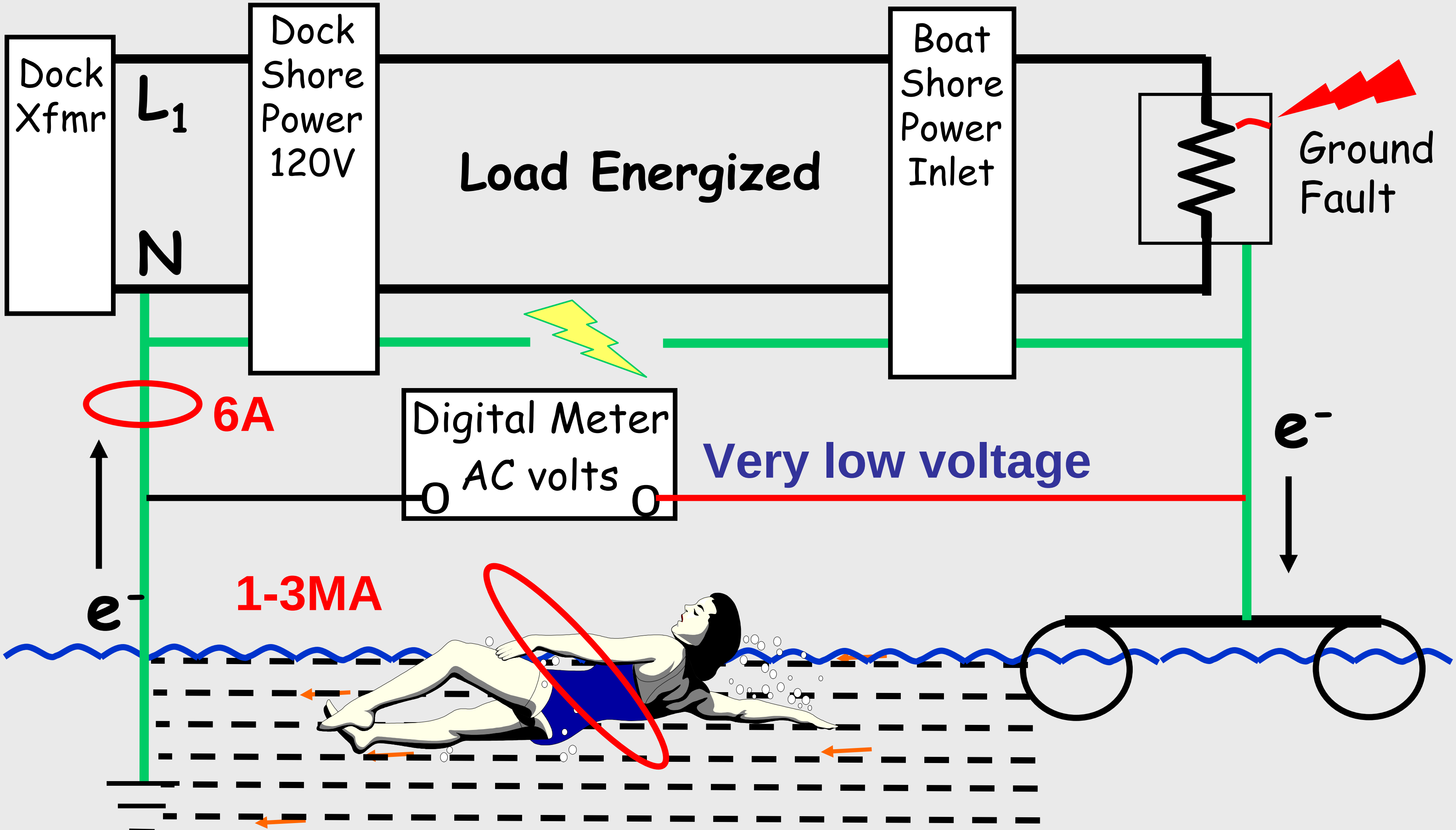
- Victim enters water, becomes disabled, and calls for help
- Rescuers may be unable to assist due feeling electrical shock themselves
- Victim's situation can worsen when seeking a "safe haven"
- Bystanders may secure power
- Rescuers attempt first aid if victim can be pulled from water
  - Victim may not remain on surface

# Electric Shock Injury

- Fresh or saltwater, what's the difference?
  - Freshwater is far more dangerous
    - All of our casualties occurred in freshwater
  - Reason is the low conductivity of the water
  - A human body is much more conductive than the typical freshwater lake or river
    - And the body is *less* conductive than saltwater
  - So, the body competes more favorably for the electric current in freshwater
  - Put another way, a much greater percentage of the current flowing in freshwater will be conducted by the body than in saltwater

# Electric Shock Drowning

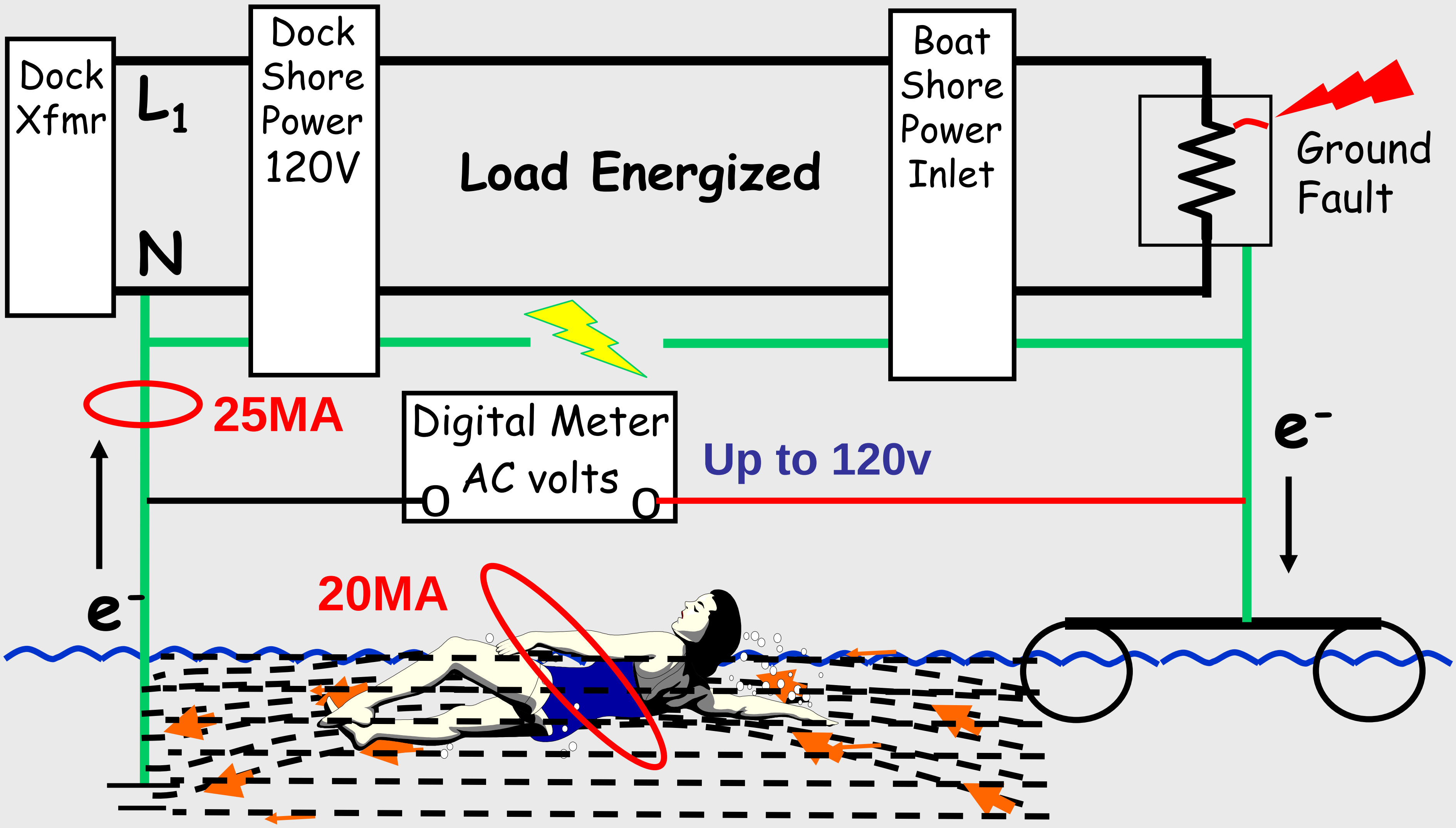
## Saltwater




**Swimmer Feels Low Current Density**

# Electric Shock Drowning

## Freshwater




**Swimmer Feels High Current Density**

- Does this mean we are not concerned with faults in saltwater? No!
- The same undetected fault in saltwater will cause more current to flow at the fault
  - More current means more heat which increases the likelihood of a fire when compared to the same fault in a freshwater situation
- In freshwater we get lower currents but much higher voltage gradients, and these gradients are what is dangerous

# Lethal Potentials

- It is recognized that a voltage gradient of 2v per foot is considered potentially fatal
  - Consider a boat prop elevated to 20v which is 10 feet from a grounded dock ladder
  - The gradient is 20v/10feet = 2v per foot
- Look at an average human being
  - Body impedance about 1000 ohms
  - Hand to hand distance of 6 feet
  - At 2v per foot, the total voltage felt is 12v
  - Ohm's law tells us that 12v/1000ohms = 12ma
  - This 12ma can cause paralysis and drowning

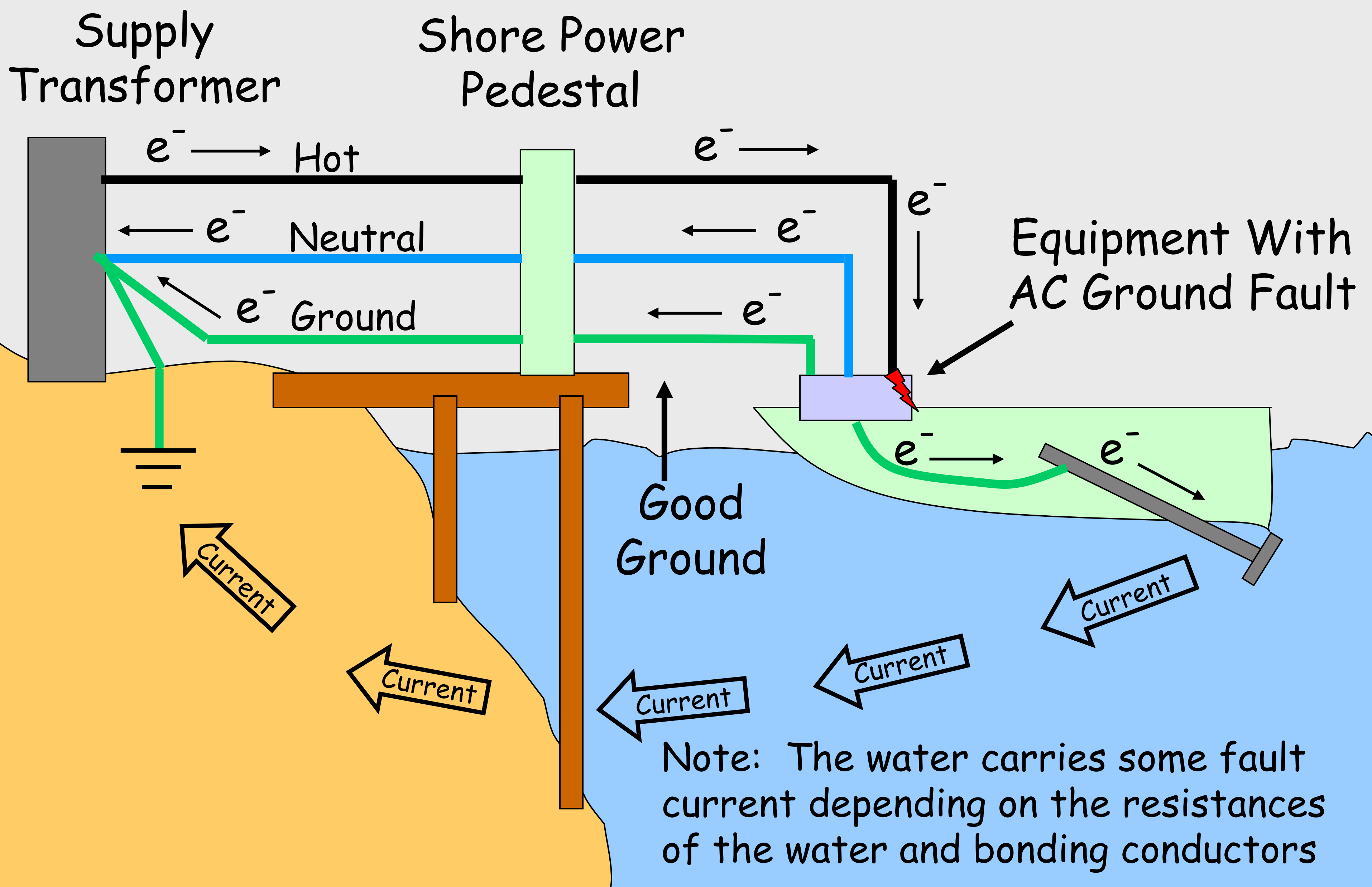
# So, What Causes These Accidents?

- In every case, 2 faults are required (important concept)
  - First, there has to be an electrical fault to the bonding system
  - Second, there has to be a missing or poor bonding connection between the energized metal and the source
  - In all cases, the fault has not caused a circuit protective action (undetected)

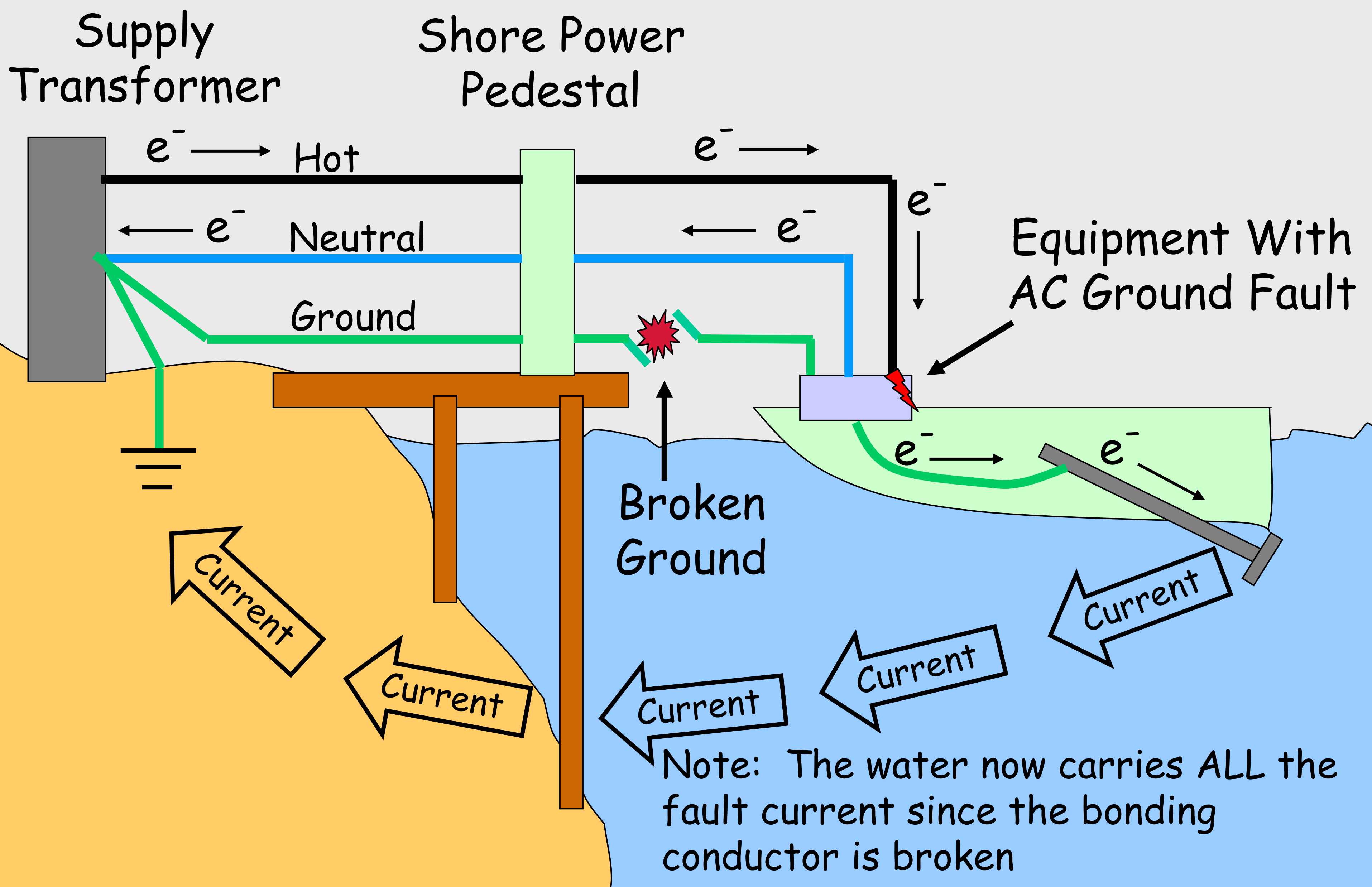
- The fault current seeks all paths back to the source and travels in any and all parts of:
  - The marina/boat bonding (green) wires
  - The water
- The path that has the lowest resistance will carry the most current

- When fault current flows back to the source in the water, it represents a danger to anyone in the water
- Remember, in freshwater, the exposure to an electric current can easily be lethal
- It depends on a several factors:
  - Magnitude of fault
  - Water conductivity
  - Surface area of energized metals
  - Surface area of the grounded metals
  - Condition of bonding system (marina & boats)
  - Resulting voltage gradient

- The worst case is a fault with a complete failure of the bonding connection (the 2nd fault, i.e. no return path)
  - This causes all the fault current to flow in the water
- A lower fault current enters the water if the bonding system is carrying some current
  - Note that saltwater represents a bonding path which can be as good, or better then the bonding conductor in the electrical system
- Let's look at it pictorially




Note: The water carries some fault current depending on the resistances of the water and bonding conductors

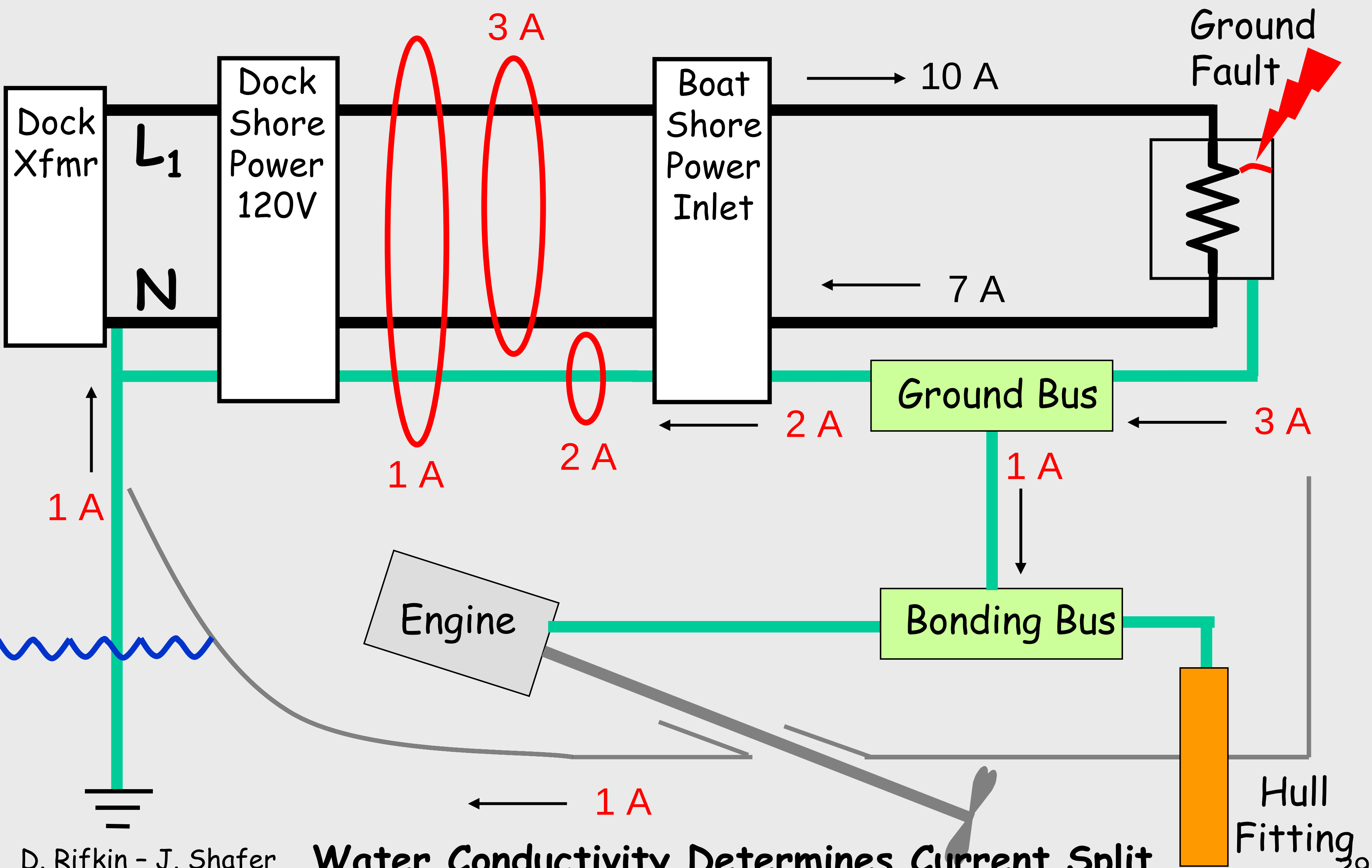


Supply Transformer
Shore Power Pedestal
e-
Hot
e-
Neutral
Ground
e-
e-
e-
Equipment With AC Ground Fault
Broken Ground
e-
e-
Current
Current
Current
Current
Current
Note: The water now carries ALL the fault current since the bonding conductor is broken

- Can you find the 2 faults here which killed a mother and daughter on Lake Cumberland in May of 2002?
- This plug was wired by the husband/father

- How can we test for current leaking into the water?
- An AC clamp meter that can resolve to 2 decimal places will do the trick
- While running as many AC loads as practical clamp the whole shore cord
- Any reading represents the current that is missing (i.e. not coming back in the shore cord)
- This missing current can only be going one place, into the WATER
- Where is this current coming from?

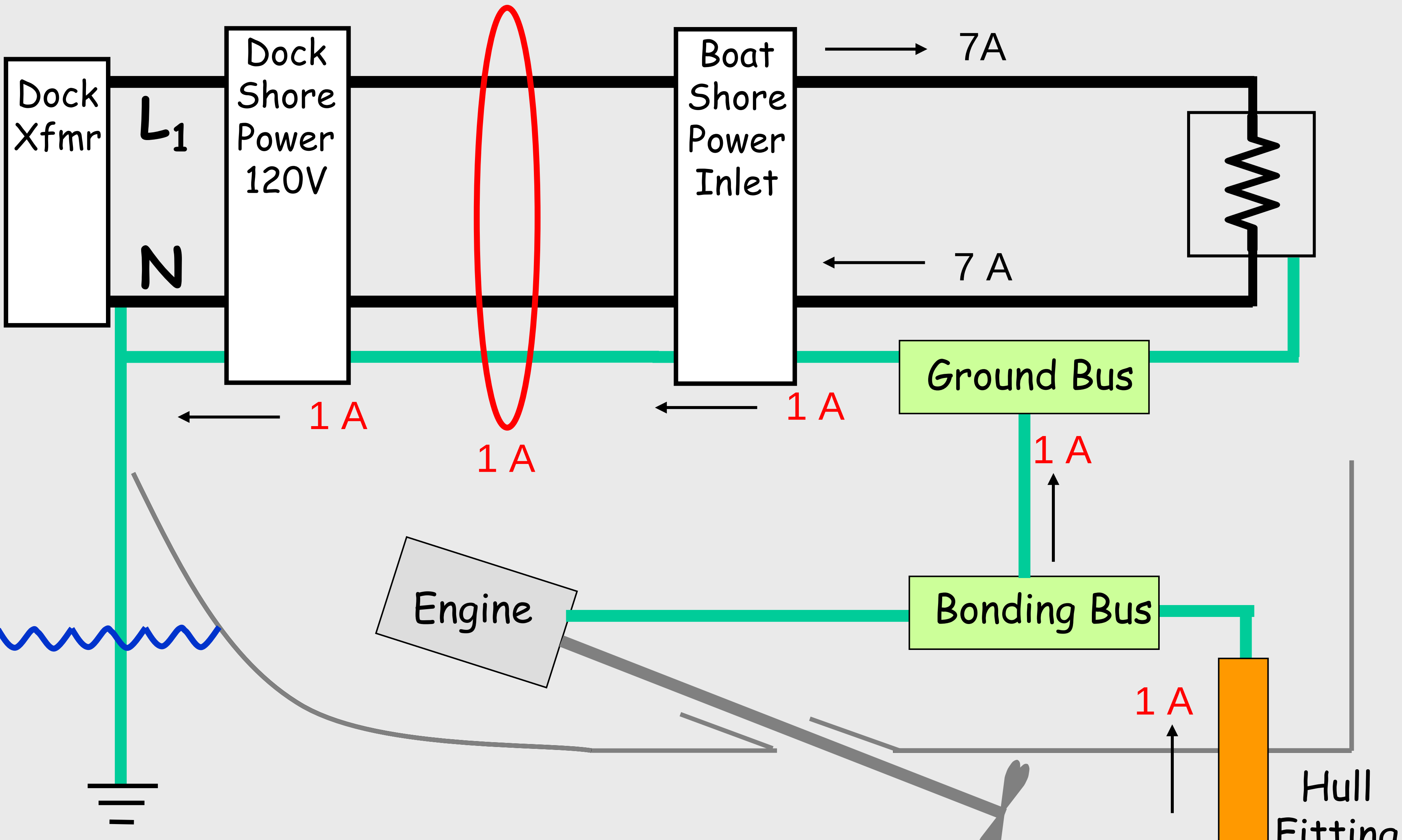
# 3A Fault Current Paths






**Water Conductivity Determines Current Split**

# No Fault, Ground Current

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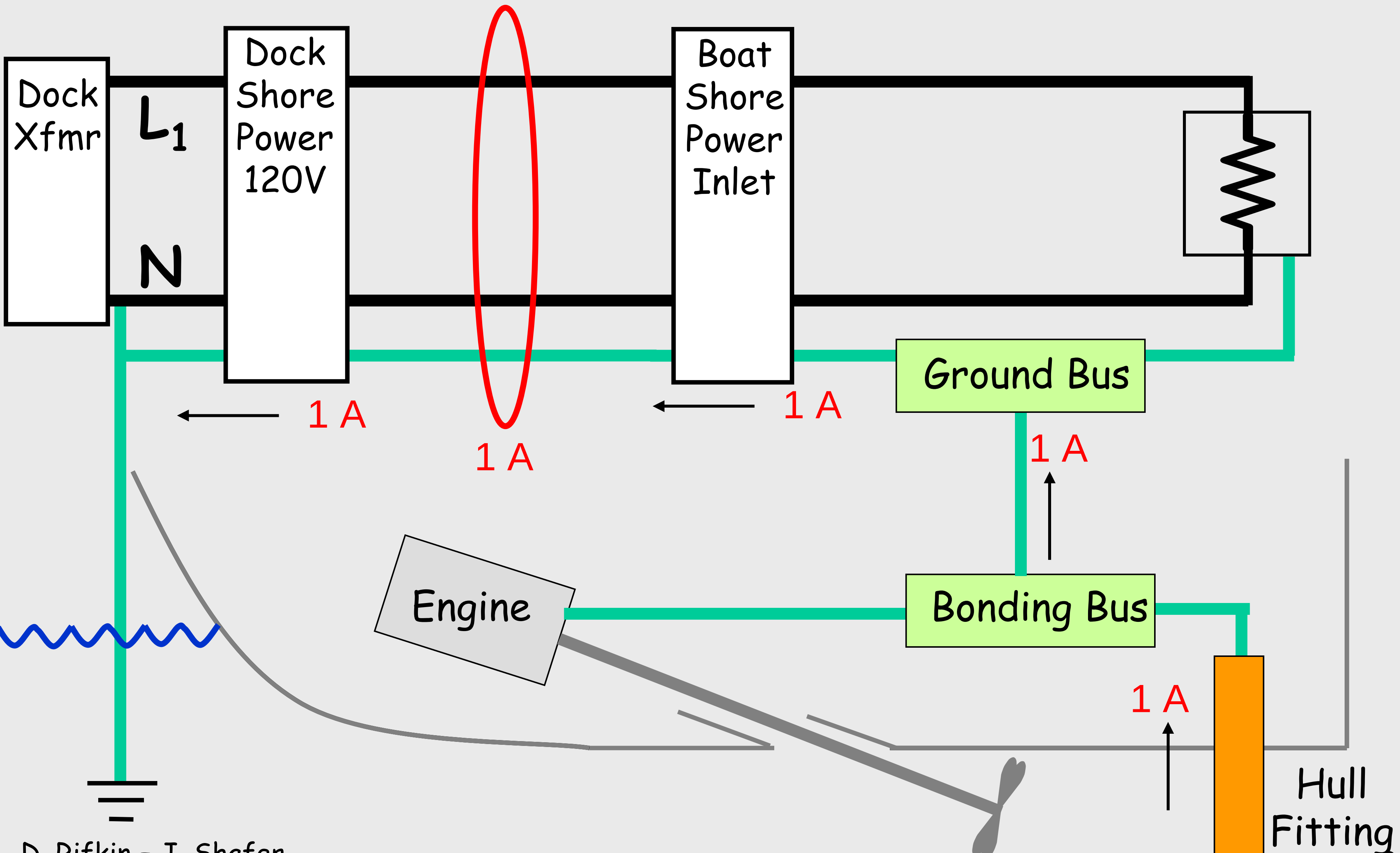
# Pedestal Breaker Off, Ground Current

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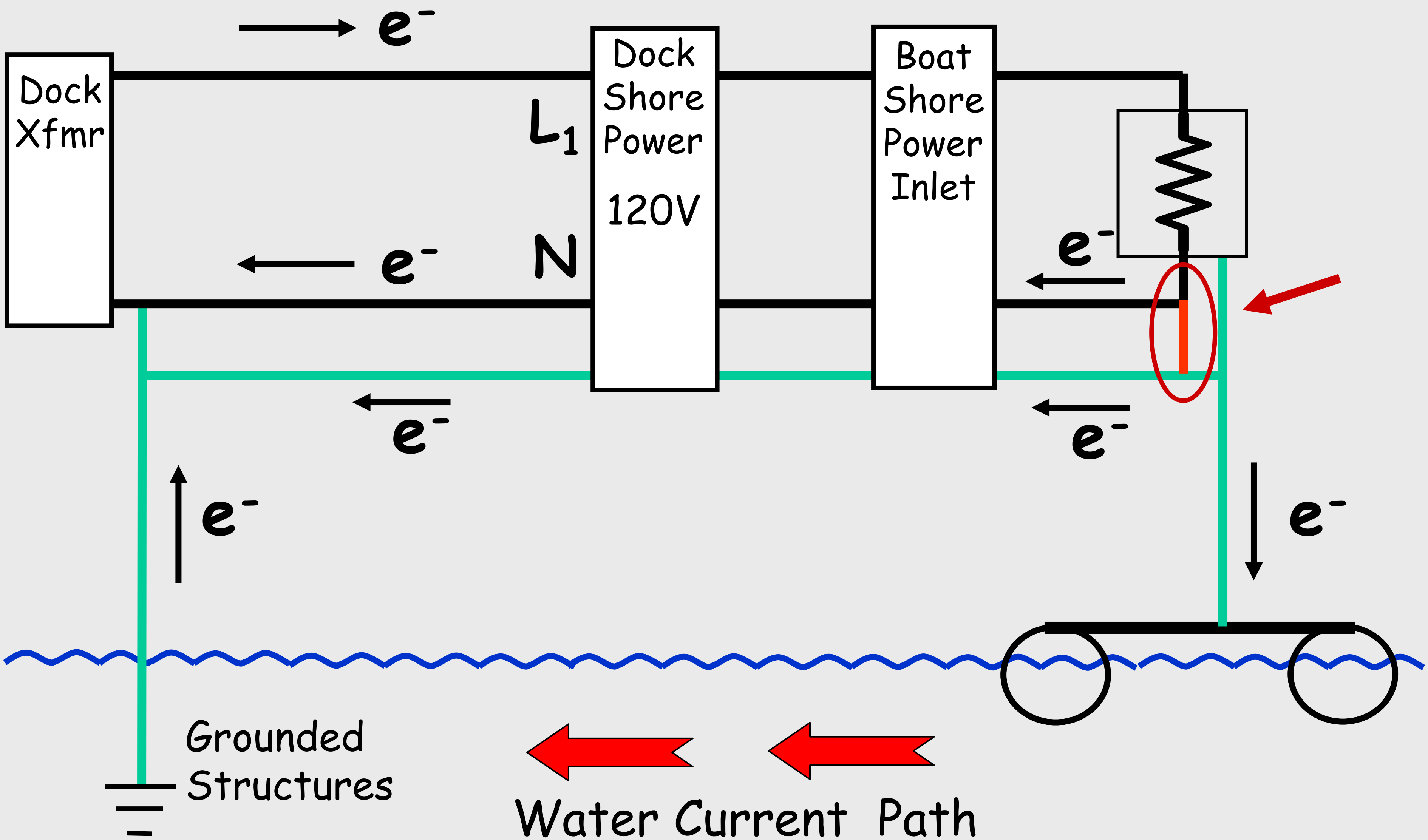
# Other Scenarios

- There are many other ways current can be introduced in the water
- One of them is a prohibited connection between ground and neutral. ABYC says:

11.5.3.2.1. The shore power neutral is grounded through the shore power cable and shall not be grounded on board the boat.

  - As long as the neutral and bonding conductors are in good condition there will be little water current
  - But degrade the neutral and lose the bonding connection, and it becomes lethal in freshwater
- Let's look at a sketch

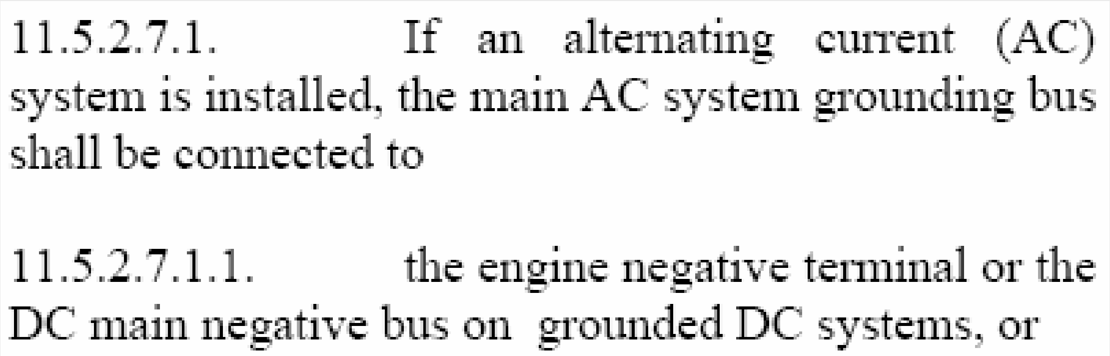
# Ground-Neutral Connection



- Making a test to check for a G-N connection is easy:
  - Unplug the boat, close the main circuit breaker
  - Use a multimeter to measure resistance between ground and neutral
  - Must be > 25kohm (usually reads infinite)
  - From ABYC E-11:

> 11.8.3. The total impedance of polarity indicating and protection devices connected between normal current carrying conductors (grounded [white] conductor and ungrounded [black] conductor) and the grounding conductor shall not be less than 25,000 ohms at 120 volts, 60 hertz at all times.

- Another dangerous condition is an AC to DC connection (short circuit)
  - ABYC standards require AC and DC conductors to be isolated by sheathing if run together
  - If the DC system becomes energized with AC, and the AC-DC ground bond is missing (also required by ABYC), the water path carries all the fault current



11.5.2.7.1. If an alternating current (AC) system is installed, the main AC system grounding bus shall be connected to

11.5.2.7.1.1. the engine negative terminal or the DC main negative bus on grounded DC systems, or

  - Tragically, this caused several of the deaths in our drowning list

Standards were violated resulting in the death of this little boy, including the lack of separation of AC and DC conductors. The required connection between AC Service and DC grounding systems was also absent.

## Is Your Boat Or Marina on Unsafe Ground? *Electric Shock Drowning*

By Deputy Joe Graziano

On August 1st, 1999, 8-year old Lucas Ritz was swimming along a dock in a marina in the Willamette River's Multnomah Channel. He was wearing a life jacket and swimming near other supervised children. He was under the watchful eyes of his mother who walked along the dock beside him as he swam. Lucas then gasped loudly and rolled onto his back, apparently unconscious. His Type II life jacket performed correctly and rolled him onto his back so that his face was out of the water. Other children swam towards Lucas to offer assistance, only to be forced away by a strong tingling sensation. Lucas' mother jumped in and was nearly immobilized the instant she hit the water. Despite this she was able to pull Lucas out of the water. CPR was rendered and the paramedics soon arrived. Lucas was transported to Emanuel Hospital where he was pronounced dead at 6:30PM.

Lucas Ritz was 8 years old when he died from electrocution while swimming in a Portland marina.

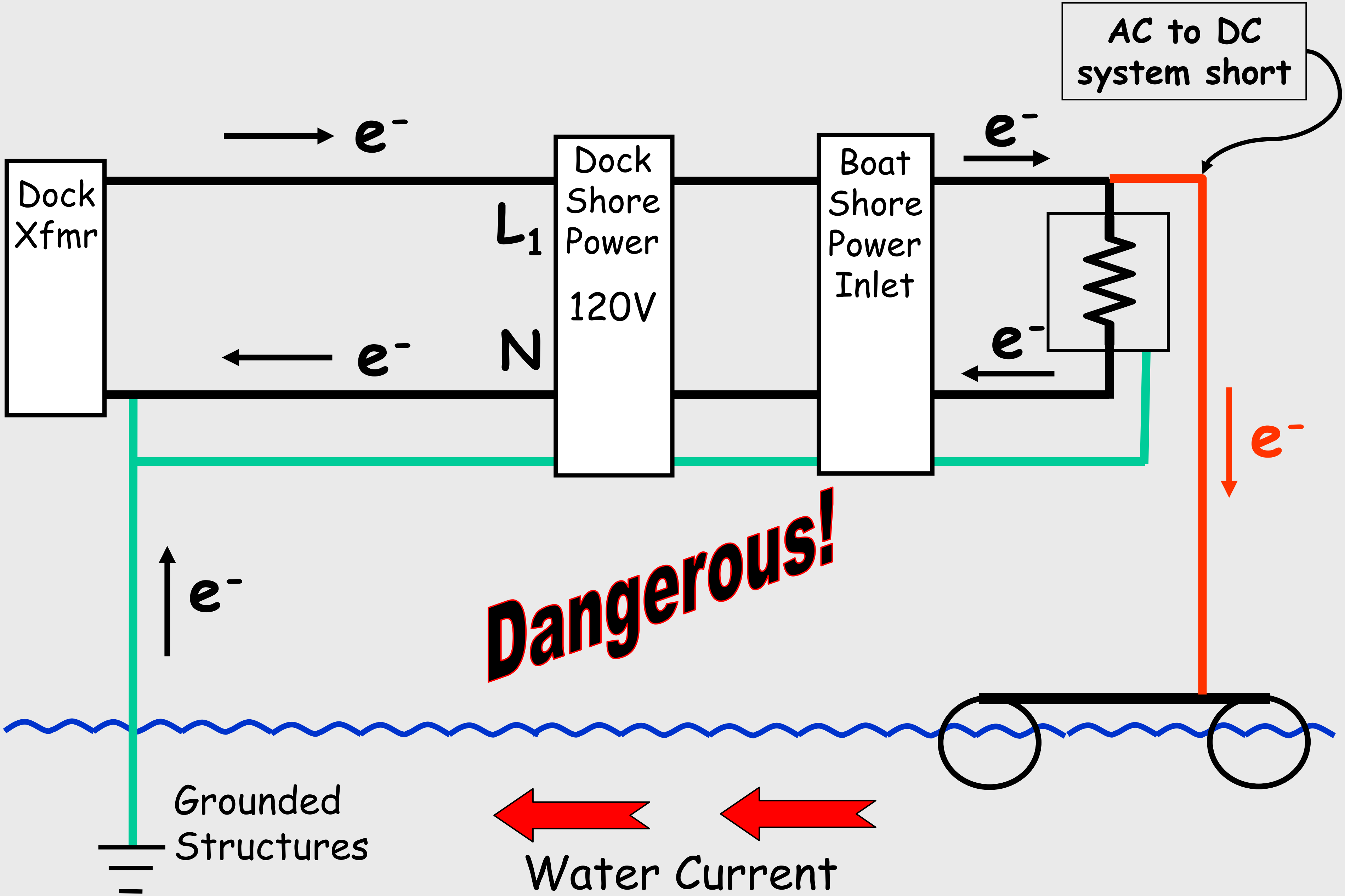
During the initial investigation it was believed that he simply drowned. Yet statements by Lucas' mother and the other children present led Lucas's father to believe that electricity was the cause. A subsequent check of the water revealed a lethal dose of electrical current emanating from an electrical short on a docked boat. Lucas did not drown. He was electrocuted.

This electrical current had caused temporary paralysis to Lucas' mother when she hit the water. This nearly prevented her from swimming and could have caused her to drown. This type of drowning is known as *Electric Shock Drowning*. It leaves no burn marks or other bodily clues on the victim. Generally, witness and/or victim statements are the only indicators of an electric shock drowning.

**How Common is *Electric Shock Drowning*?**

The exact statistics are unknown. Until about five years ago there was virtually no data on the subject. The various government agencies I've contacted have

# AC to DC Short, No AC-DC Grounding Connection

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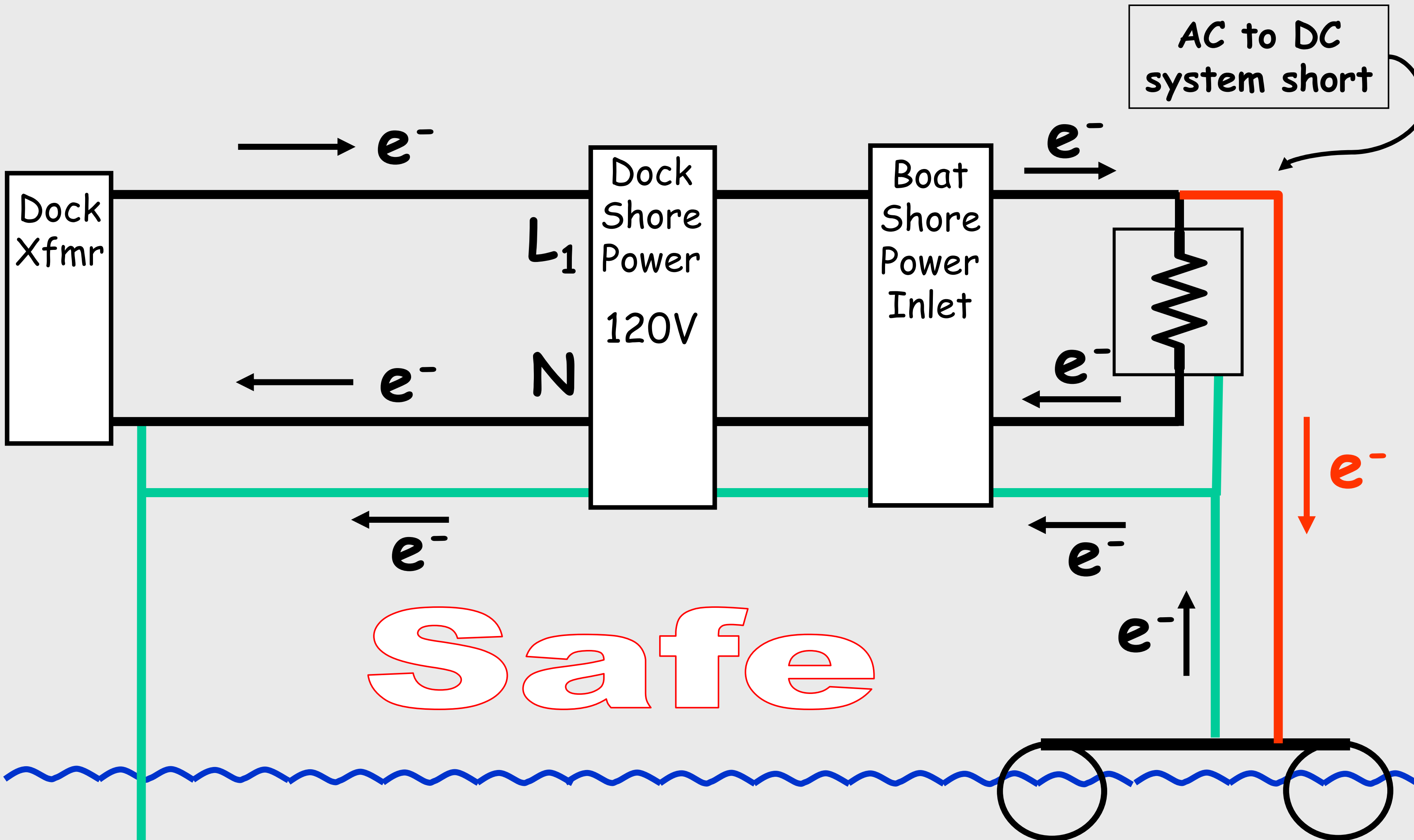
# AC to DC Short, With AC-DC Grounding Connection



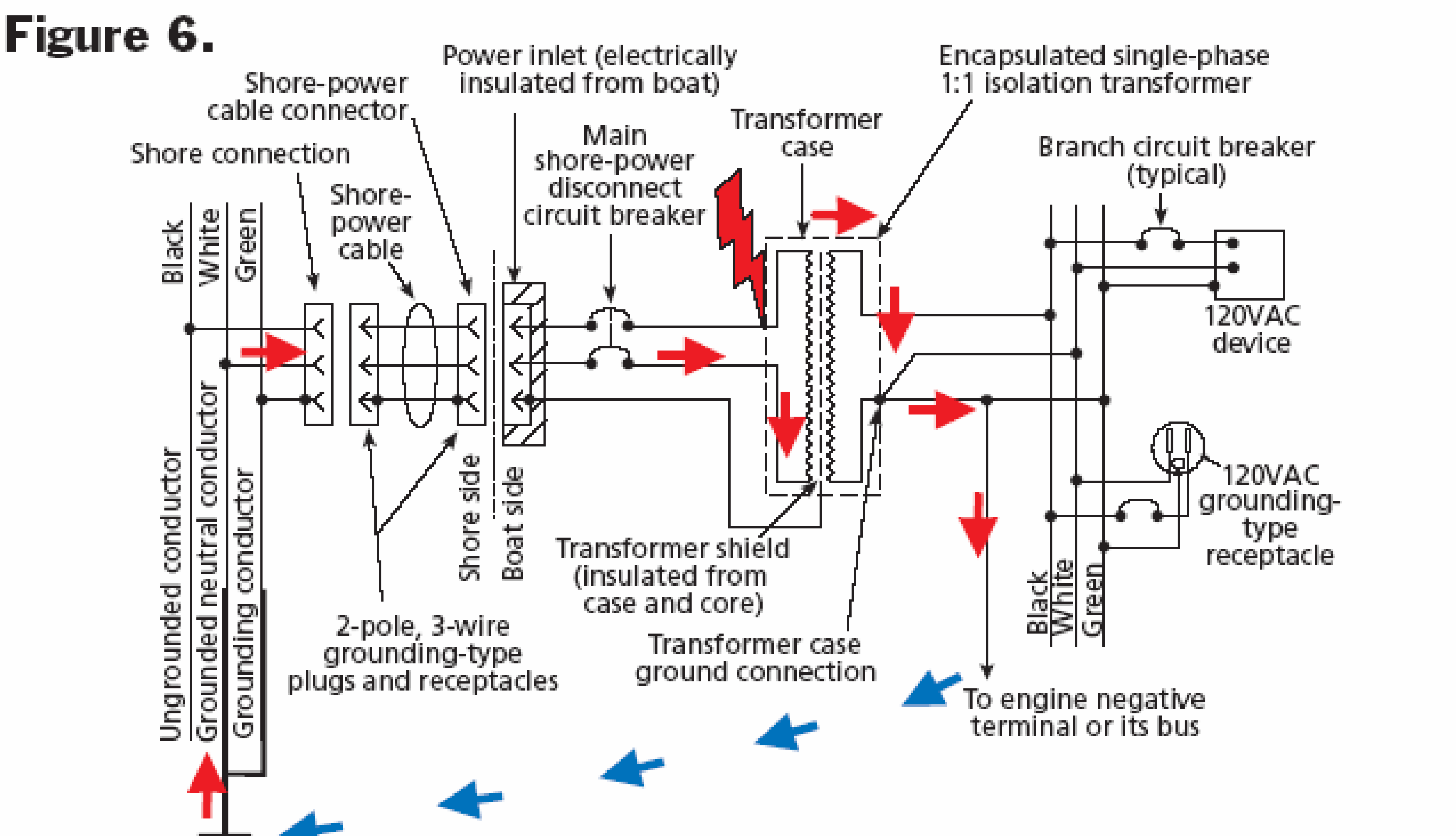

Grounded Structures

Minimal water current leakage if grounding system in good condition.

- Testing for the AC to DC grounding connection is also easy:
  - Unplug the boat
  - Use a multimeter and measure resistance between the AC and DC grounding buses (can use a receptacle ground and engine negative)
  - Should be less than 1 ohm to be assured of a good connection

# Transformers; Isolation Invites Water Path

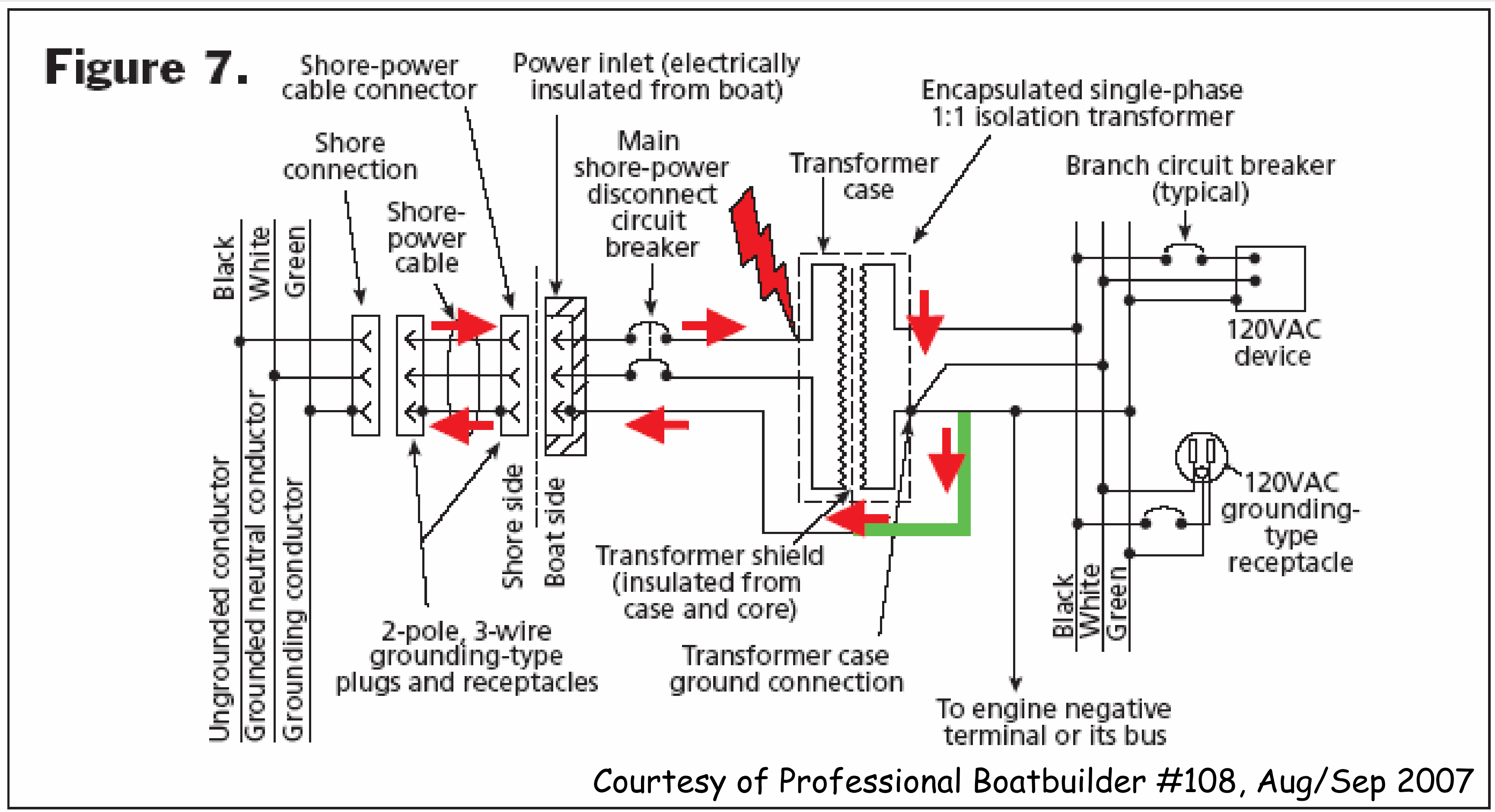
- A fault without bonding results in water path
- Current will seek its source ashore




Courtesy of Professional Boatbuilder #108, Aug/Sep 2007

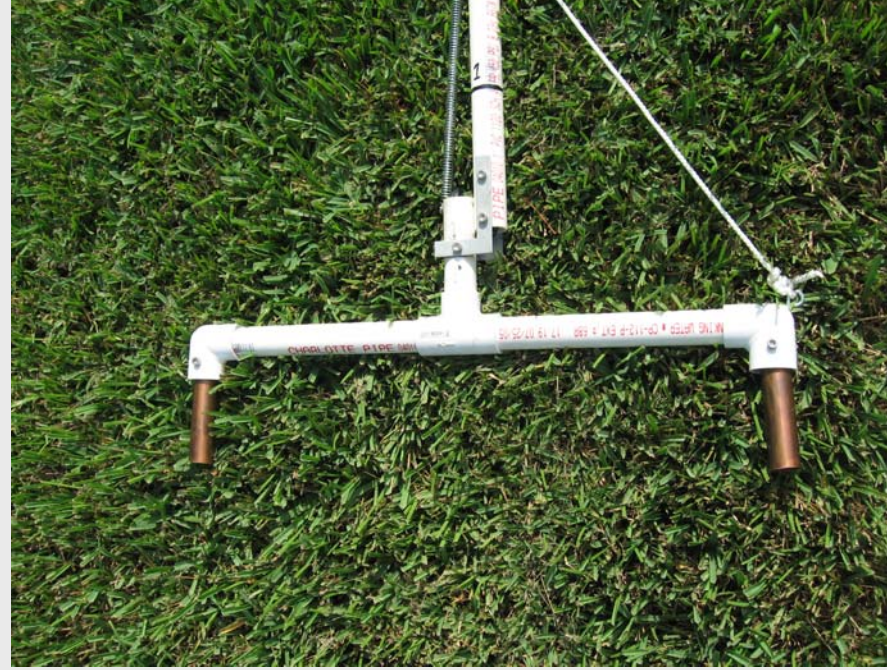
# Polarization Prevents Water Path

- With bonding the water path is eliminated
- Due to effective fault clearing path (green)



# The USCG Study

- The purpose was to find causes of accidents and recommend ways to make the marina environment safer
- We visited freshwater marinas nationwide over the past year
- Faults were introduced and the resulting electric fields measured around each boat
- Metal and FRP boats were tested in various propulsion and mooring configurations
- Here's some photos and sample page of actual data




NO
WAKE

USCG FY 2007 Safety Grant
In-Water Shock Mitigation

# Field Strength/Voltage Data Form, pg 1

Investigators: Jim Shafer, David Rifkin

Test number: LOM-FRP-IB-BI, 5/17/07, 0800 Date: 5/17/2007 Marina/Location Lake Ocoee Inn and Marina, Benton OH

Vessel Name: Diamond Jim Type: Houseboat Hull Material/Coating, if metal: FRP

Make/Model: 1979 Carlcraft Dock #: A Slip #: 42 Pedestal #: 42 Water flow at dock: 0 kts

Mooring: **Wharf:** ☐ S / ☐ P Side to **Slip:** ☑ Bow In/ ☐ Bow Out **Tee Dock:** ☐ S / ☐ P Side to

Length/Beam: 40'/12' ft **Prop:** ☑ Inboard ☐ Inboard Outboard ☐ Outboard ☐ Sail : ☐ Single ☑ Double

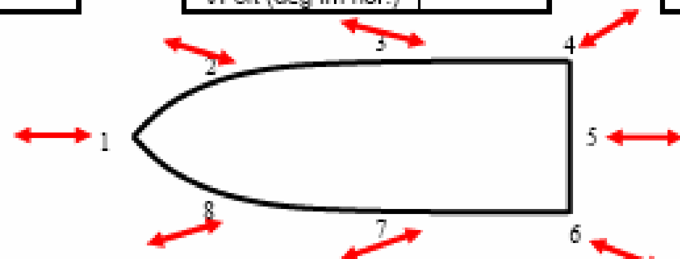
Power: ☐ 50A/240V ☐ 30A/120V ☑ 2-30A/120V ☐ 50A/240V to 2-30A Other: ______

| 2 | Bkgd | Fault |
|---|---|---|
| HF1ft(V) | 0.003 | 0.288 |
| HF3ft(V) | 0.003 | 0.280 |
| HF5ft(V) | 0.003 | 0.270 |
| V3ft(V) | 0.027 | 1.700 |
| VF3ft(V) | 0.003 | less |
| VF3ft (deg fm hor.) | | 0 |

| 3 | Bkgd | Fault |
|---|---|---|
| HF1ft(V) | 0.003 | 0.740 |
| HF3ft(V) | 0.003 | 0.750 |
| HF5ft(V) | 0.003 | 0.743 |
| V3ft(V) | 0.032 | 4.900 |
| VF3ft(V) | 0.003 | less |
| VF3ft (deg fm hor.) | | 0 |

| 4 | Bkgd | Fault |
|---|---|---|
| HF1ft(V) | 0.003 | 7.200 |
| HF3ft(V) | 0.003 | 8.300 |
| HF5ft(V) | 0.003 | 5.600 |
| V3ft(V) | 0.020 | 17.800 |
| VF3ft(V) | 0.003 | less |
| VF3ft (deg fm hor.) | | 0 |

| 1 | Bkgd | Fault |
|---|---|---|
| HF1ft(V) | 0.003 | 0.173 |
| HF3ft(V) | 0.002 | 0.177 |
| HF5ft(V) | 0.002 | 0.164 |
| V3ft(V) | 0.026 | 1.150 |
| VF3ft(V) | 0.003 | less |
| VF3ft (deg fm hor.) | | 0 |




| 5 | Bkgd | Fault |
|---|---|---|
| HF1ft(V) | 0.003 | 13.500 |
| HF3ft(V) | 0.003 | 14.700 |
| HF5ft(V) | 0.003 | 7.800 |
| V3ft(V) | 0.014 | 22.000 |
| VF3ft(V) | 0.003 | 15.400 |
| VF3ft (deg fm hor.) | | 30 d a |

| 8 | Bkgd | Fault |
|---|---|---|
| HF1ft(V) | 0.002 | 0.232 |
| HF3ft(V) | 0.002 | 0.224 |
| HF5ft(V) | 0.002 | 0.216 |
| V3ft(V) | 0.023 | 1.820 |
| VF3ft(V) | 0.002 | less |
| VF3ft (deg fm hor.) | | 0 |

| 7 | Bkgd | Fault |
|---|---|---|
| HF1ft(V) | 0.002 | 0.846 |
| HF3ft(V) | 0.002 | 0.830 |
| HF5ft(V) | 0.003 | 0.750 |
| V3ft(V) | 0.025 | 5.800 |
| VF3ft(V) | 0.003 | less |
| VF3ft (deg fm hor.) | | 0 |

| 6 | Bkgd | Fault |
|---|---|---|
| HF1ft(V) | 0.003 | 9.000 |
| HF3ft(V) | 0.003 | 8.500 |
| HF5ft(V) | 0.003 | 5.600 |
| V3ft(V) | 0.021 | 19.000 |
| VF3ft(V) | 0.003 | less |
| VF3ft (deg fm hor.) | | 0 |

| Difference Voltages | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| HF1ft (V/ft) | 0.085 | 0.143 | 0.369 | 3.599 | 6.749 | 4.499 | 0.422 | 0.115 |
| HF3ft(V/ft) | 0.088 | 0.139 | 0.374 | 4.149 | 7.349 | 4.249 | 0.414 | 0.111 |
| HF5ft(V/ft) | 0.081 | 0.134 | 0.370 | 2.799 | 3.899 | 2.799 | 0.374 | 0.107 |
| V3ft(V) | 1.124 | 1.673 | 4.868 | 17.780 | 21.986 | 18.979 | 5.775 | 1.797 |
| VF3ft(V/ft) | less | less | less | less | 7.699 | less | less | less |

Bonding system: ☑ Intact Pedestal Impedances w/SureTest: H 0.03 N 0.1 G 0.03 ohms

Test Current: 2.2 A Voltage for Test Current 117.5 V Water Type: ☐ Salt ☐ Brackish ☑ Fresh

Salinity: 0.029 g/l TDS: 0.046 ppt pH: 8 Temp: 70F

Conductivity: 0.064 ms/cm@1ft 0.058 ms/cm@3ft 0.057 ms/cm@5ft Water path (Ω): 53.41

- Here's the field strength table blown up from the data page
- Note the lethal conditions around this boat, particularly at the stern and quarters (positions 4, 5 and 6)

| Difference Voltages | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| HF1ft (V/ft) | 0.085 | 0.143 | 0.369 | 3.599 | 6.749 | 4.499 | 0.422 | 0.115 |
| HF3ft(V/ft) | 0.088 | 0.139 | 0.374 | 4.149 | 7.349 | 4.249 | 0.414 | 0.111 |
| HF5ft(V/ft) | 0.081 | 0.134 | 0.370 | 2.799 | 3.899 | 2.799 | 0.374 | 0.107 |
| V3ft(V) | 1.124 | 1.673 | 4.868 | 17.780 | 21.986 | 18.979 | 5.775 | 1.797 |
| VF3ft(V/ft) | less | less | less | less | 7.699 | less | less | less |

# Making It Safer

- Here are some general recommendations from our study:
  - Install Ground Fault Protection (GFP) circuit breakers for the boat's main shore power disconnect
  - Maintain a good bonding connection between the marina grounding system and a boat's underwater metals
    - Note that this necessitates wiring transformers as polarization vice isolation systems (see Professional Boatbuilder #108, Transformers, for more info)
  - Test for and eliminate prohibited neutral-ground bonds on boats

- Periodically test boats for fault current leakage into the water
  - Equipment is available for installation in marinas to monitor for these faults 24/7
  - More information may be found at www.marinaguard.net
- Be guided by NFPA-303-2006
- Never allow homemade or damaged shore cords
- Electrical work should only be accomplished by certified marine electricians
  - Residential electricians do not always understand the unique situation presented by the marine environment
- Never swim around boats using shore power!

# In Conclusion:

- It always takes 2 faults:
  - An electrical fault to ground
  - Loss of or degraded bonding connection
- When that fault does occur:
  - A good bonding system will clear the fault or reduce touch potentials
  - The use of Ground Fault Protection technology is a great safety enhancement, **but it never takes the place of that good bonding system**

# Contact Info


- James Shafer
  kp2r@bellsouth.net
  www.marinaguard.net

- Capt. David Rifkin
  qualitymarinesvcs@comcast.net
  www.qualitymarinesvcs.net