IBEX 2006

Advanced Corrosion Principles and Control
(Part 1)

- Stray Current Corrosion
- Corrosion Surveying Considerations in Freshwater

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ABYC®
Setting Standards for Safer Boating

In Part 1 We'll Discuss:

- Stray current corrosion
  - Causes, detection, prevention
  - Is AC current a real player?
- Considerations for surveying in freshwater
  - What type of reference cell should you use?
- In Part 2, Ted Swartz will discuss various aspects of cathodic protection.

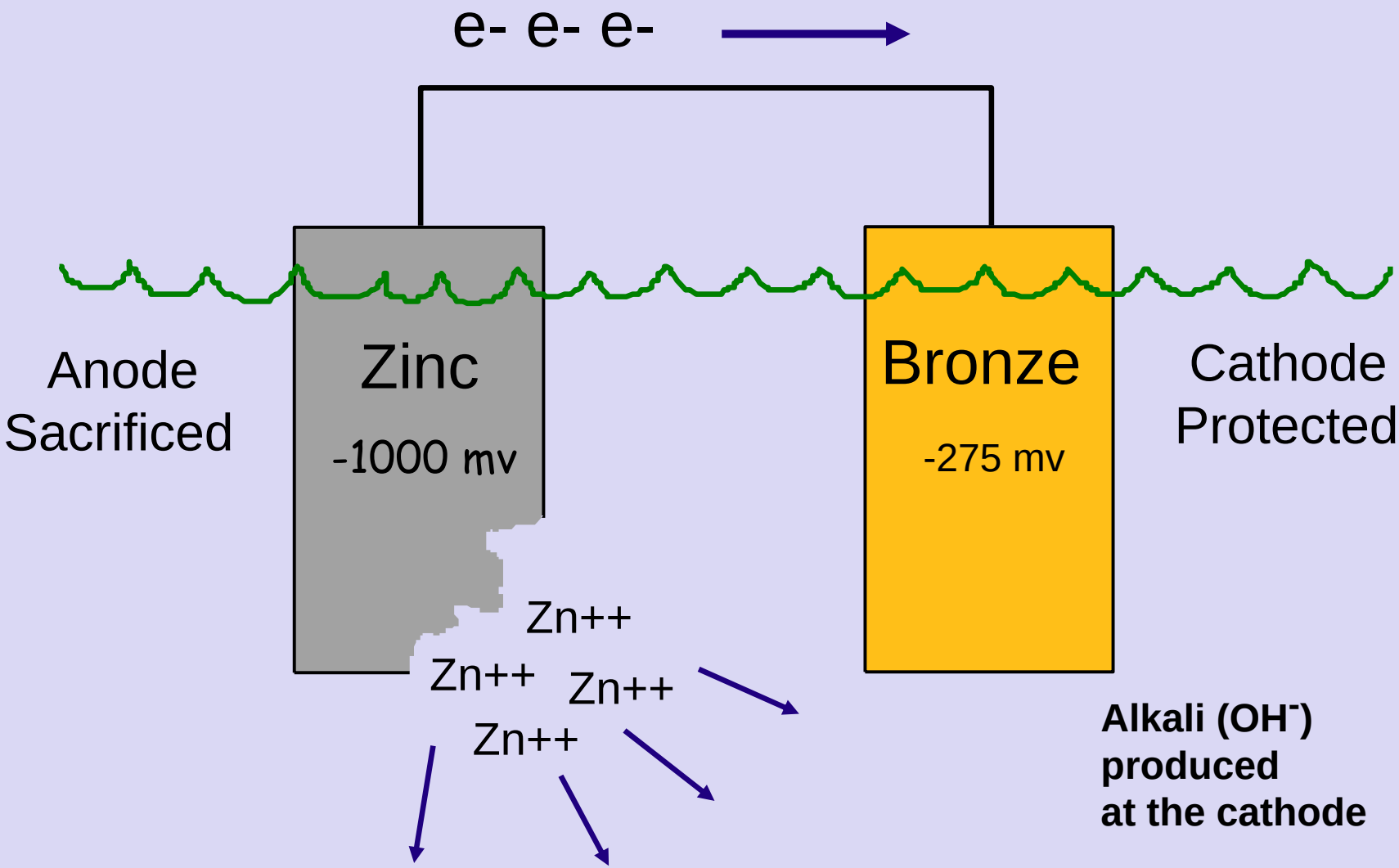
Even though it's an advanced topic…

- Here are some quick basics:
  - Bonding **keeps metals at the same potential**, and provides a delivery path for cathodic protection.
  - Galvanic corrosion: Occurs when **dissimilar metals are making electrical contact in the same electrolyte** (think long term, typically months/years).
  - Stray current corrosion: Occurs when metals are at **different potentials in an electrolyte and connected to a common source** (think hours/days/weeks, catastrophic failure).
  - **Metals driven positive** with respect to others **become the anodes** (corrode).

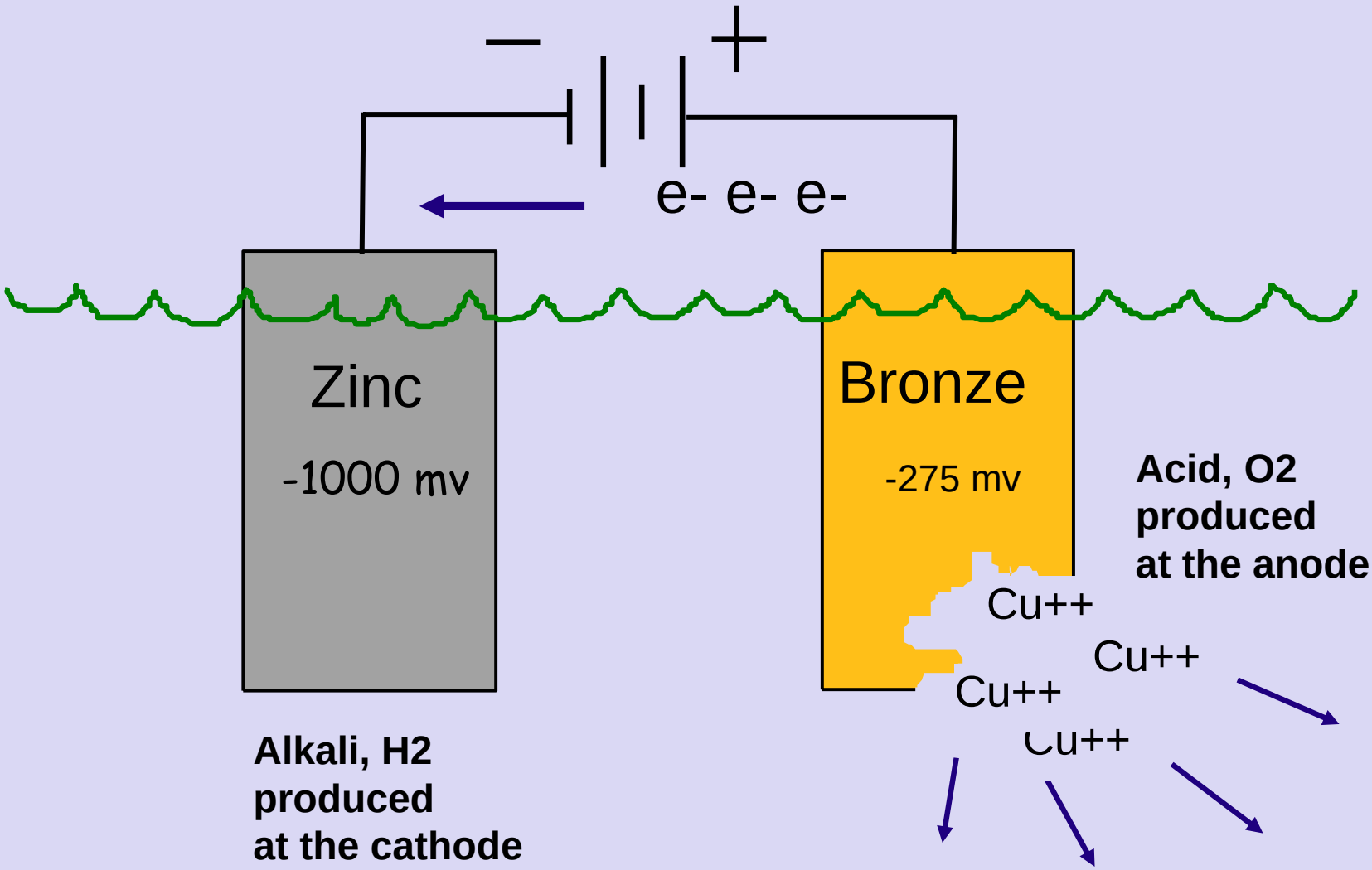
Even though it's an advanced topic…

- And a few more basics:
  - We always need **2 faults**.
    - Active electrical fault and a bonding fault (or lack of bonding)
  - Electrons flow in metals, ions flow in water.
  - The corroding area is an **anode** and is ***losing* electrons.**
  - The protected area is a **cathode** and is ***receiving* electrons.**
  - **DC is the predominant cause of underwater corrosion**, but we'll see how AC can be a player.
  - Learn to ***FOLLOW the ELECTRONS!***

Basic Galvanic Cell

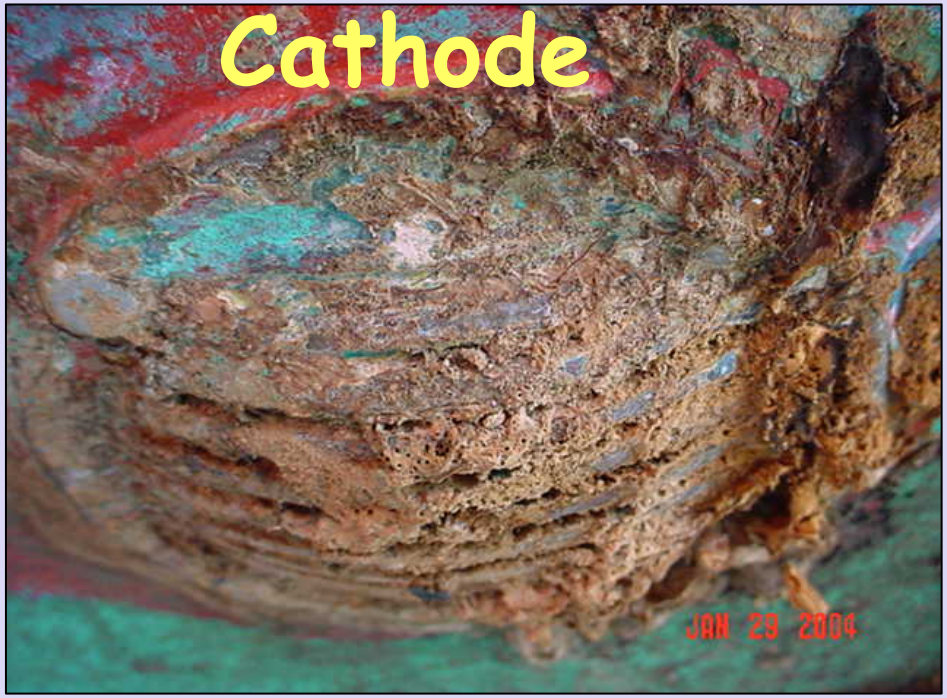


Basic Stray Current Cell



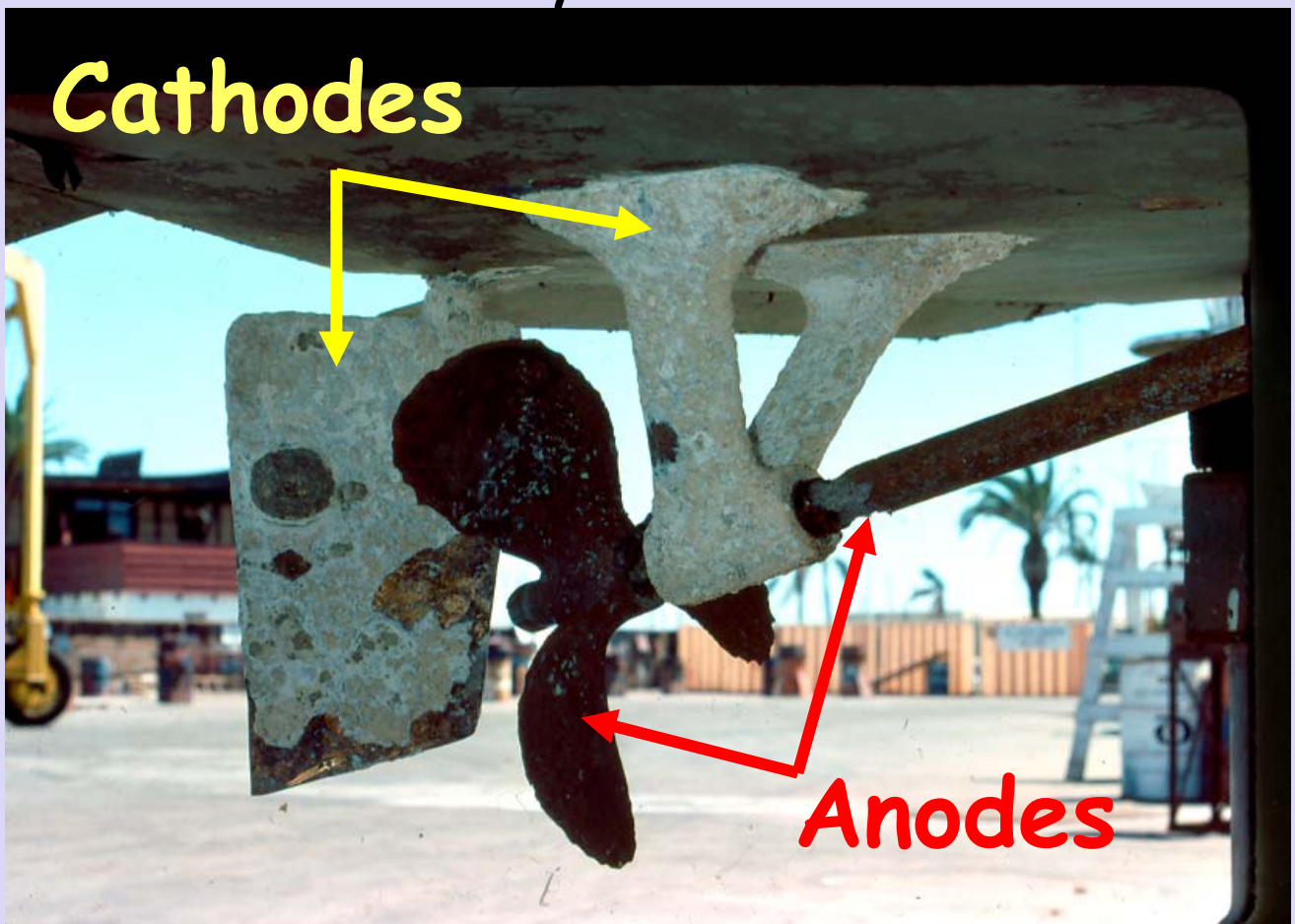
Stray Current Corrosion

- Remember, this can happen real fast.
- Trawler with fault in AC/DC refrigerator and bonding system faults.



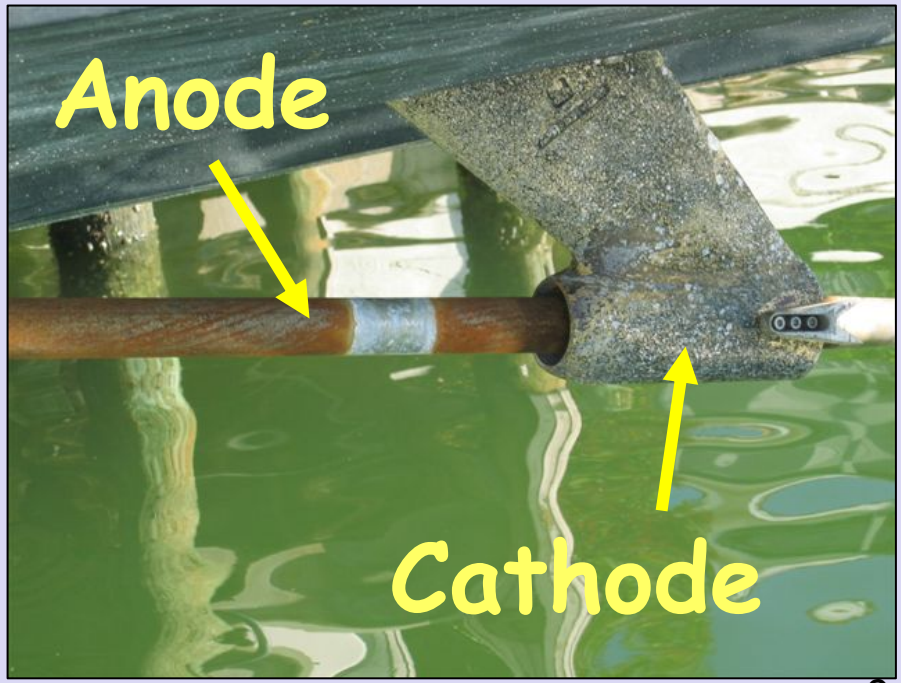
Stray Current Corrosion

- Classic appearance.
  - Calcium precipitated onto the cathode, while the anode corroded…why?



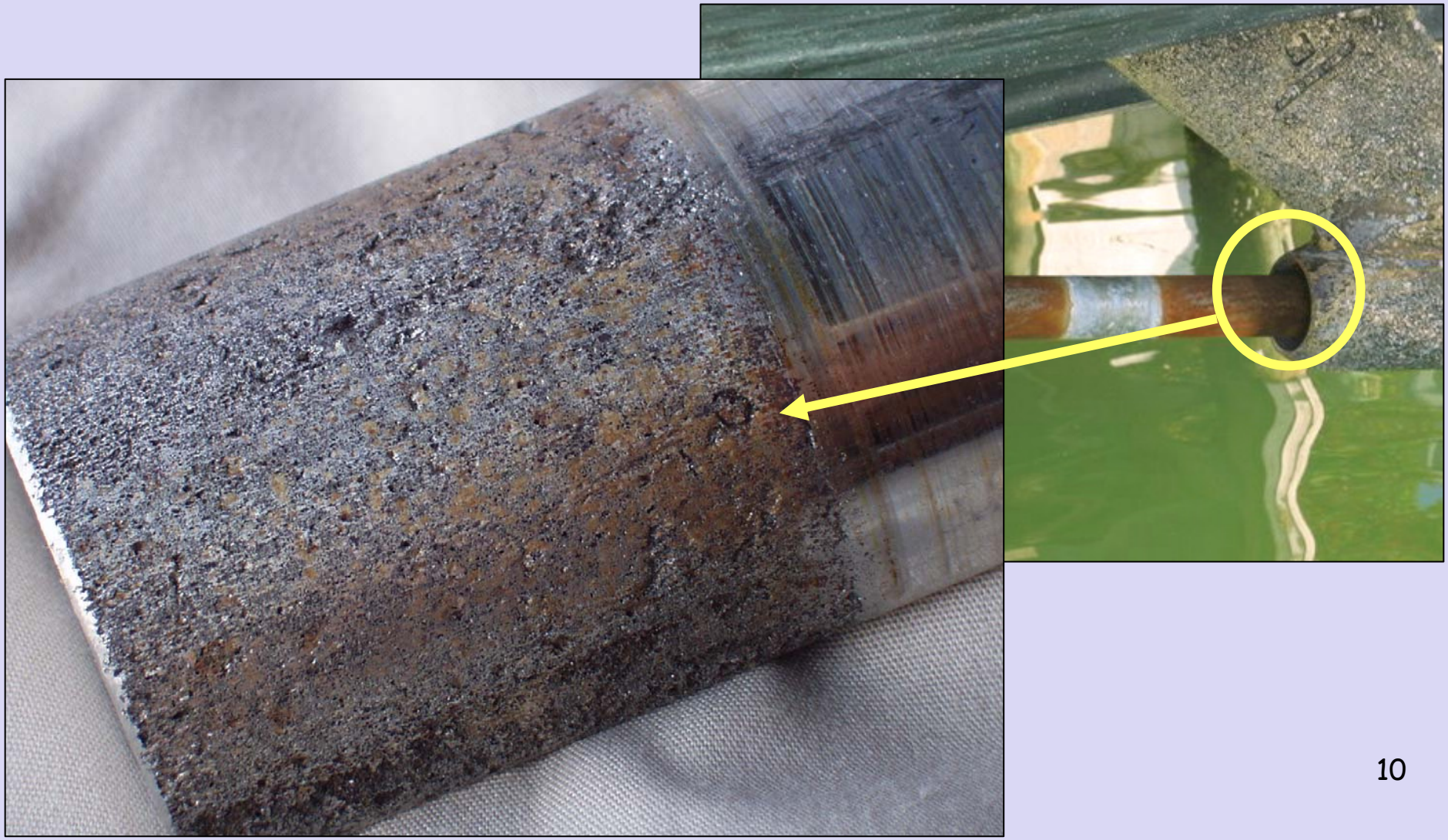
Stray Current Corrosion

- Sportfish with 2 faults
  - Alternator ground fault to engine block
  - Ungrounded ("isolated") engine block
  - Damaged in 8 hours



Stray Current Corrosion

- Sportfish with 2 faults



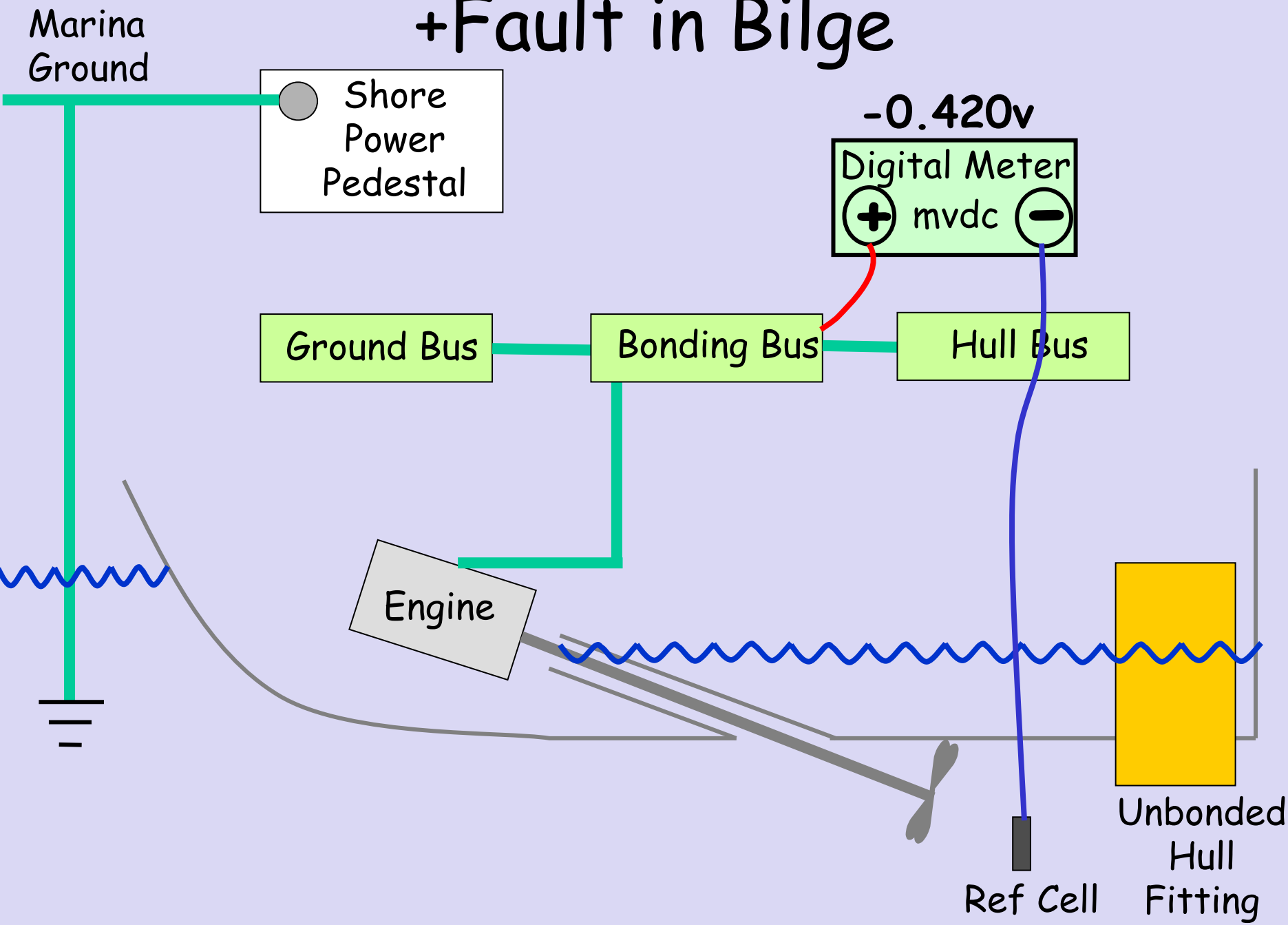
Stray Current Corrosion

- Another Sportfish with 2 faults
  - Starter positive to solenoid case
  - Ungrounded ("isolated") engine block
  - Estimated damaged in weeks

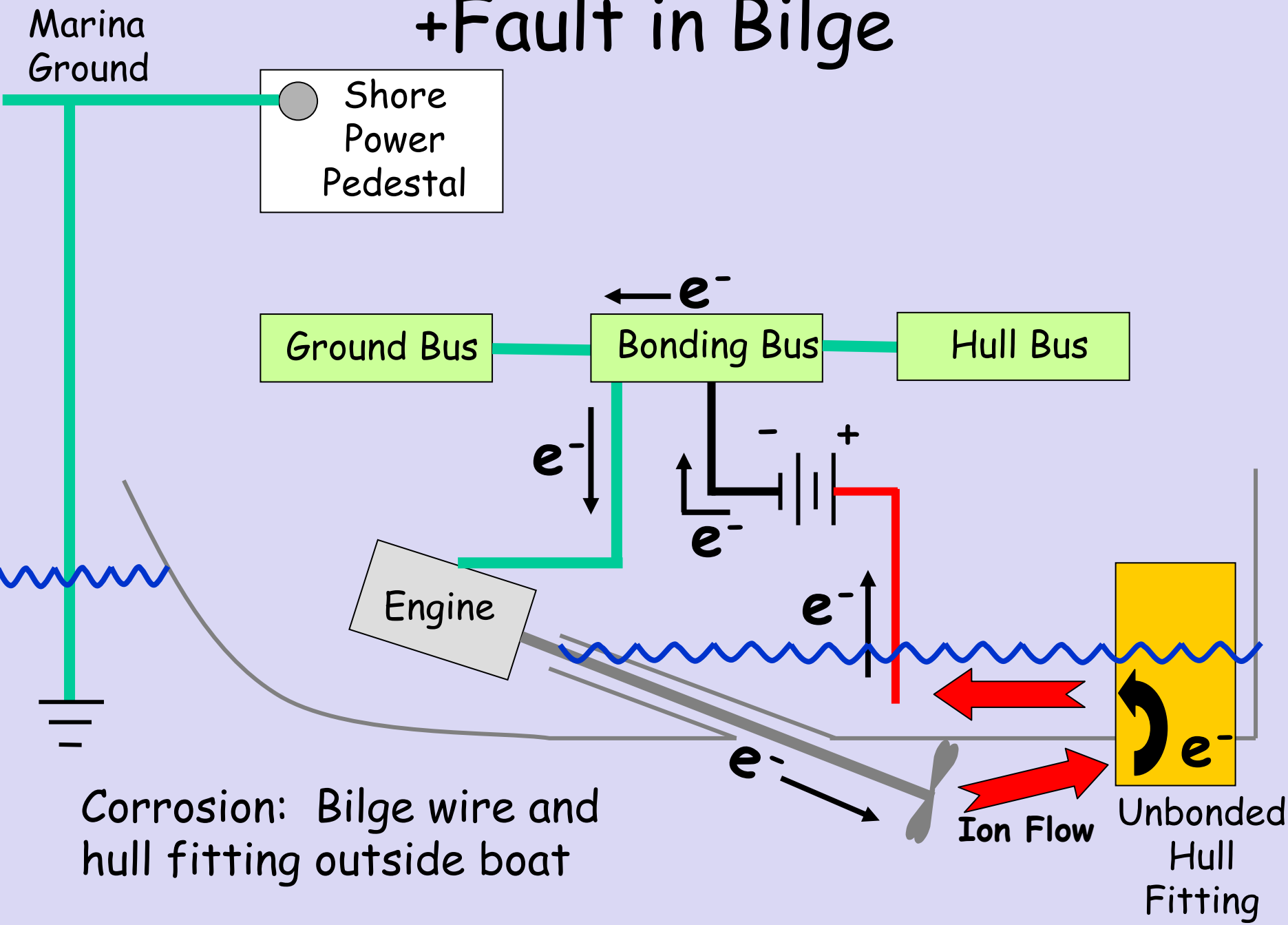
Stray Current Corrosion
Causes and Detection

- Two or more metals in the same electrolyte existing at different potentials connected to a common source (the **"holy grail"** of understanding).
- This establishes a path for current to flow (electrons in metals, ions in the electrolyte).
- Typically there is an **electrical ground fault along with a bonding problem** (on the boat with the actual fault).
- Let's analyze some scenarios, schematically.

+Fault in Bilge

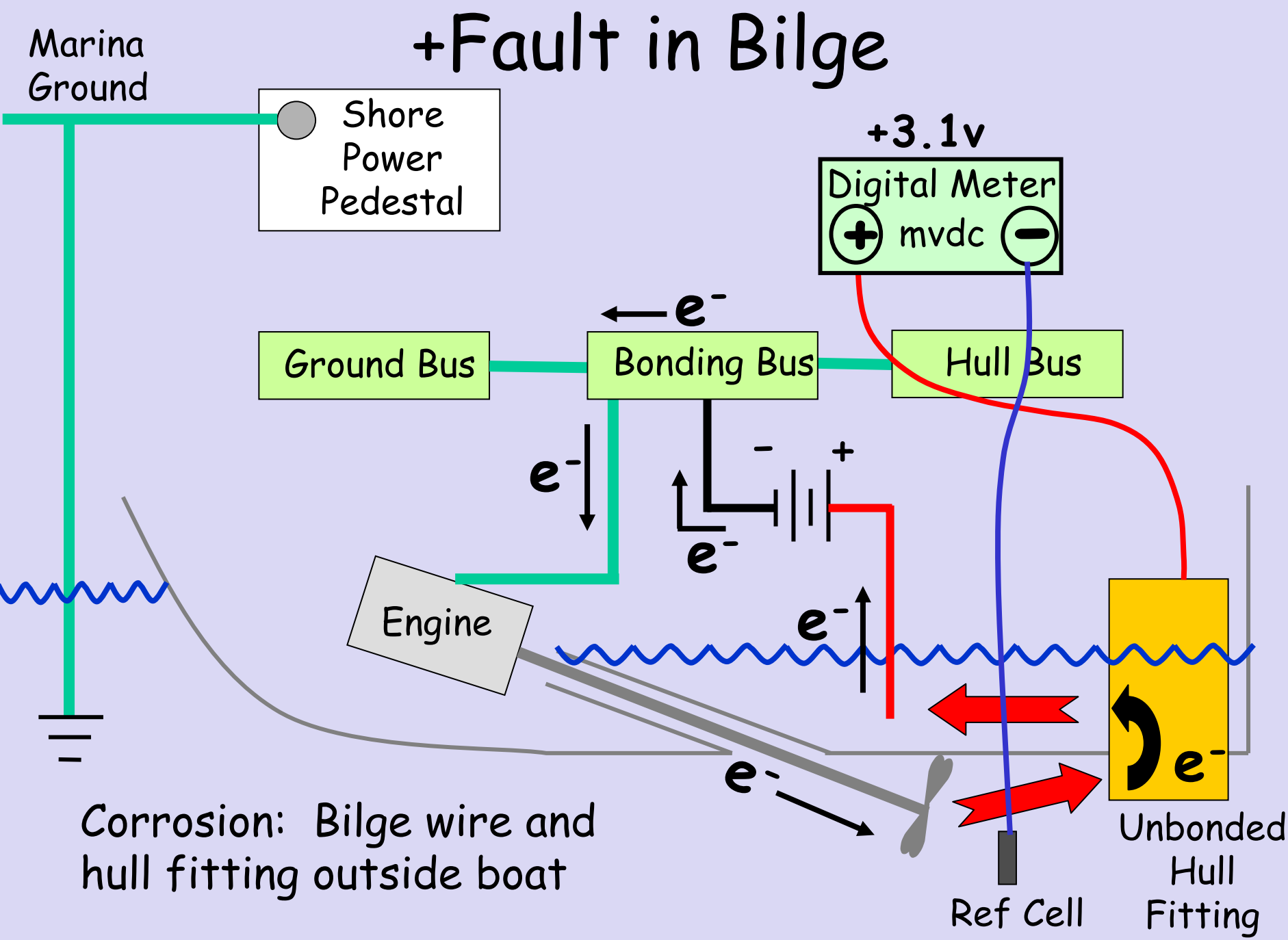


+Fault in Bilge



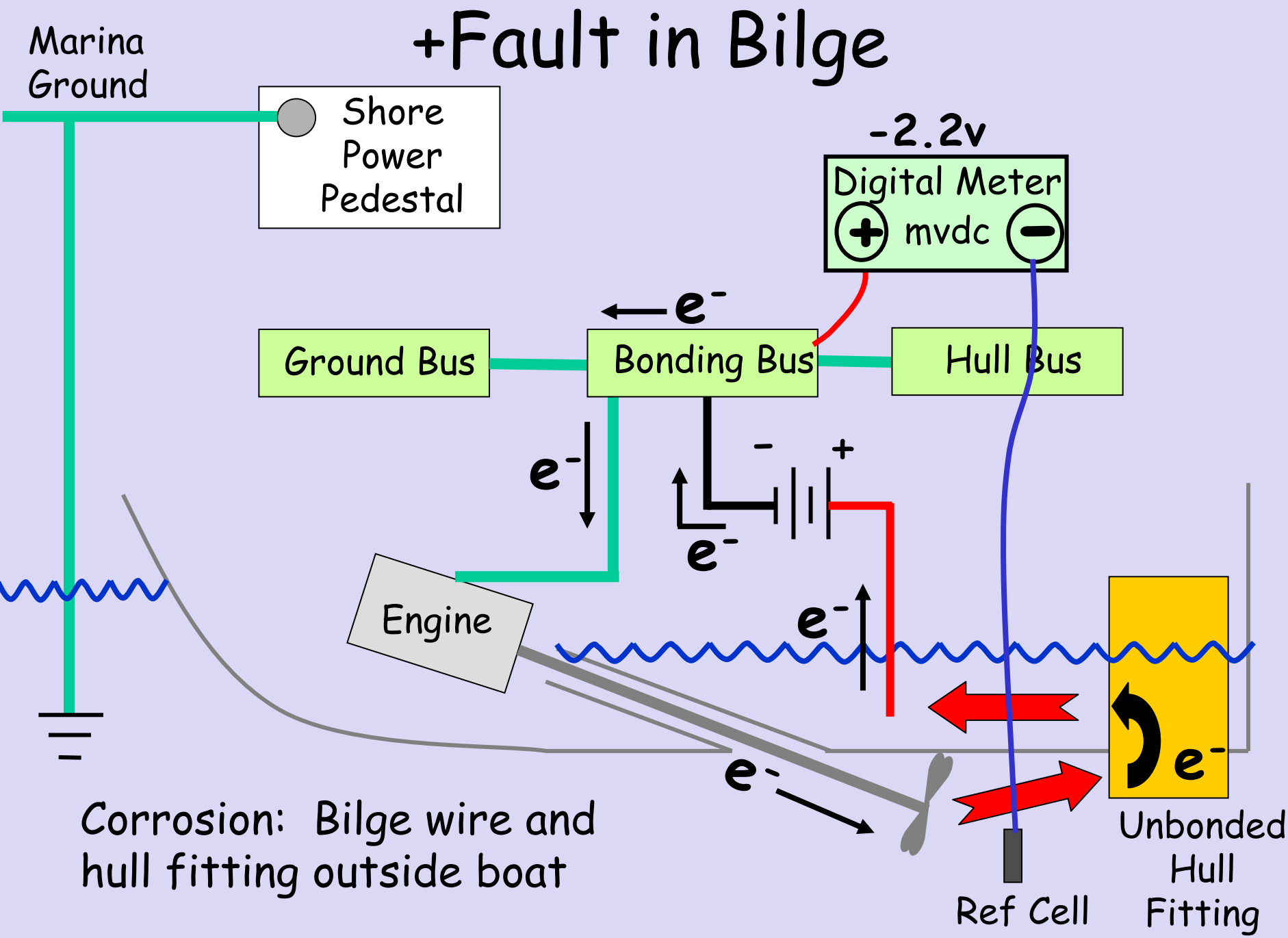
Corrosion: Bilge wire and hull fitting outside boat

+Fault in Bilge



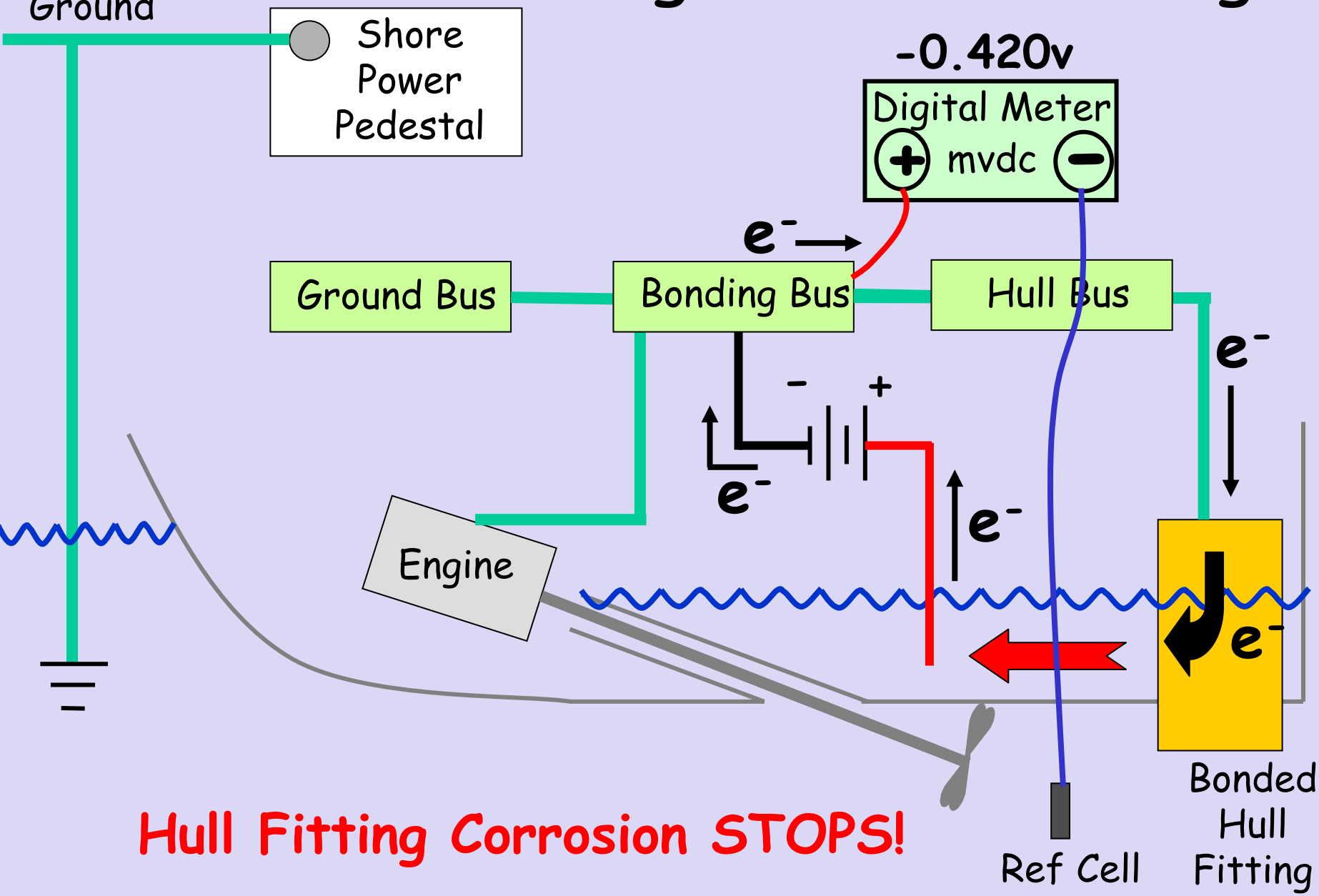
Corrosion: Bilge wire and hull fitting outside boat

+Fault in Bilge



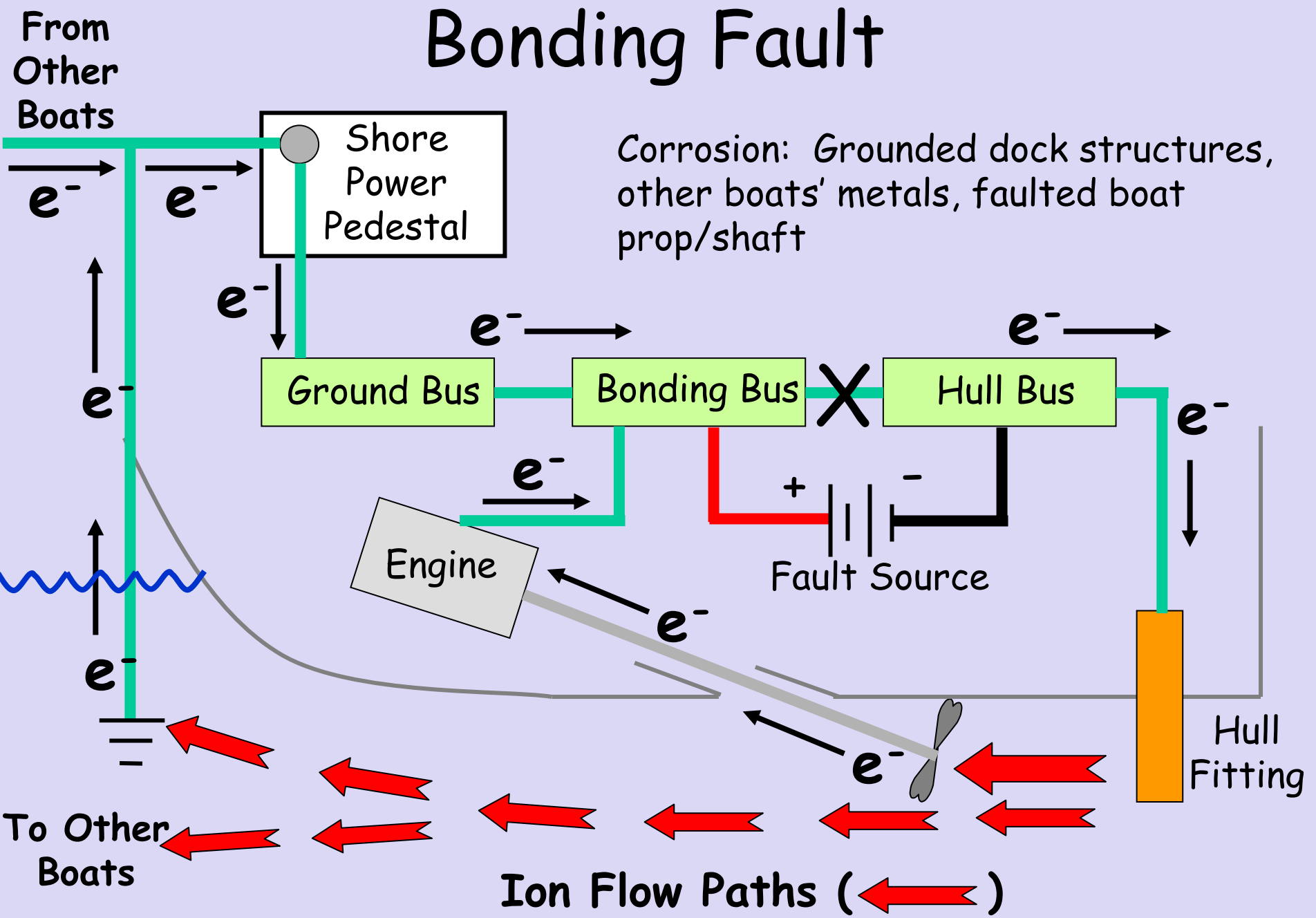
Corrosion: Bilge wire and hull fitting outside boat

+Fault in Bilge, With Bonding

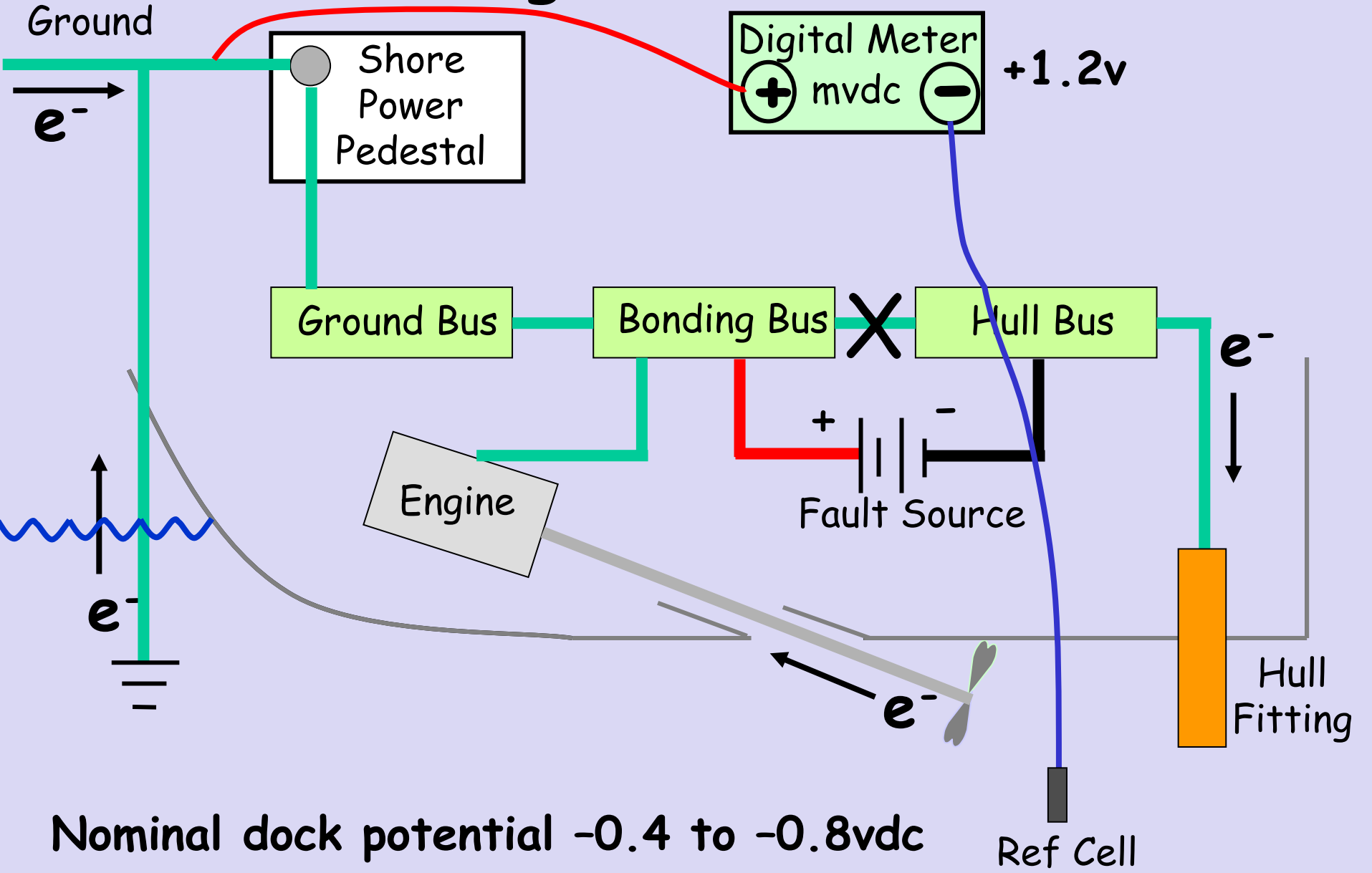


Hull Fitting Corrosion STOPS!

Bonding Fault

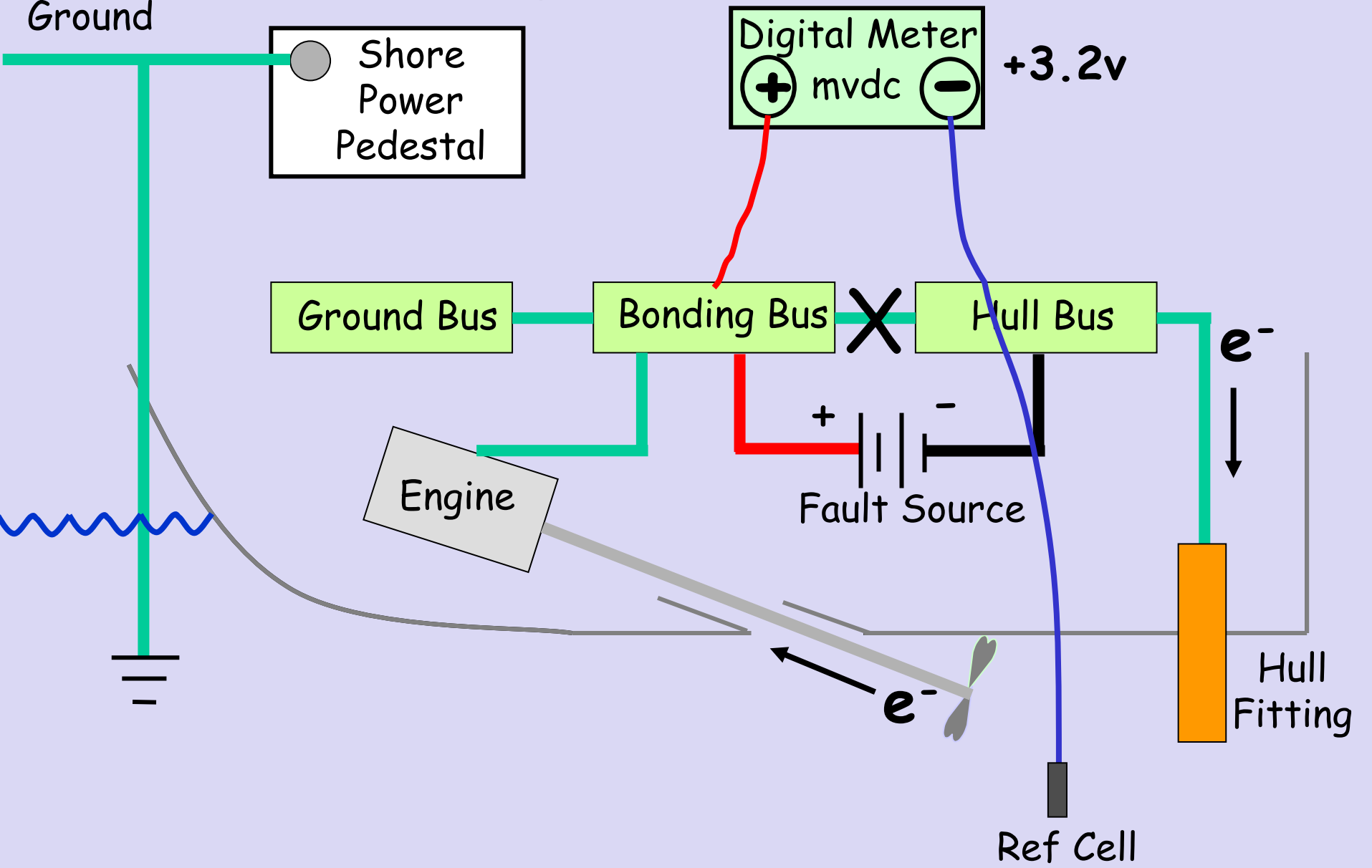


Bonding Fault Potentials

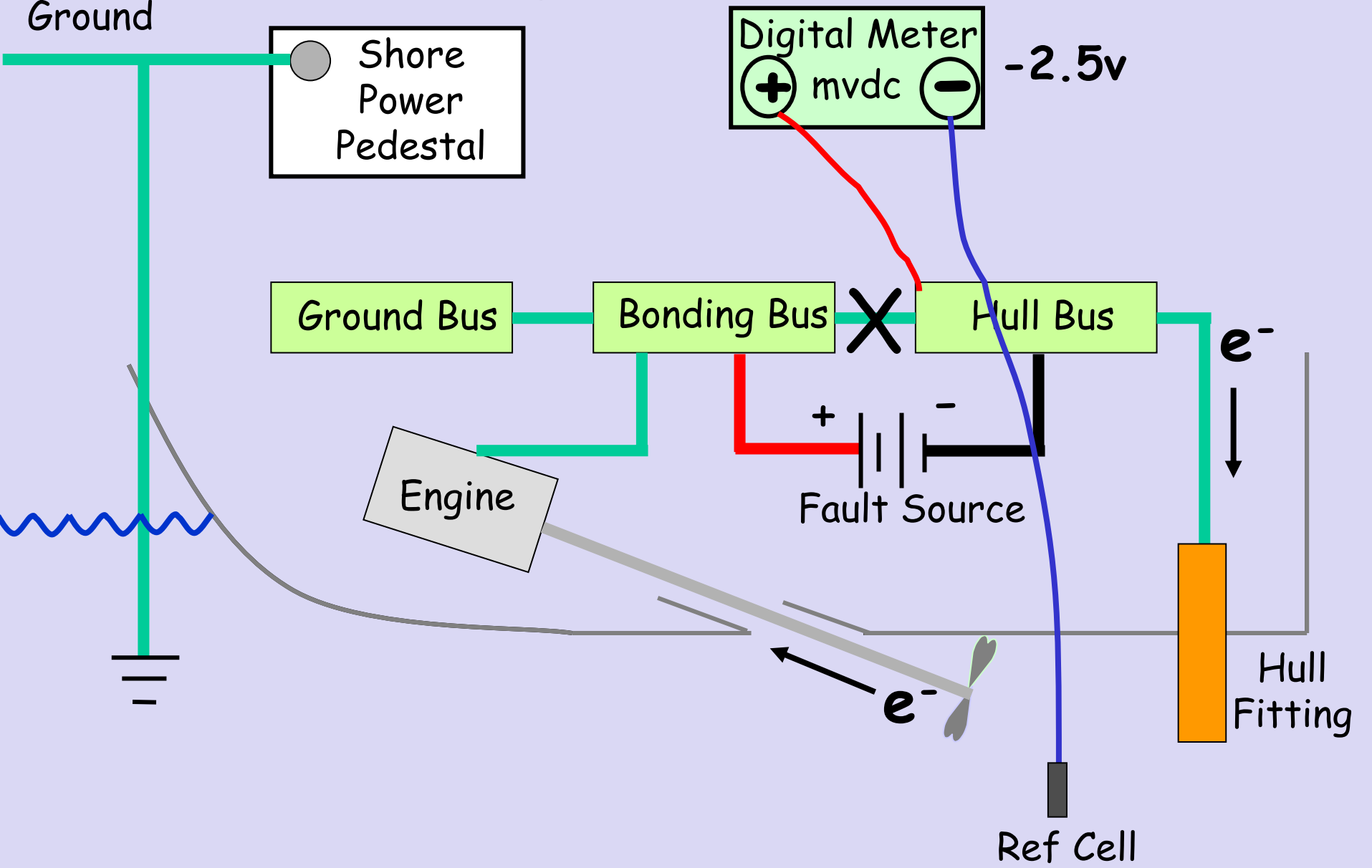


Nominal dock potential –0.4 to –0.8vdc

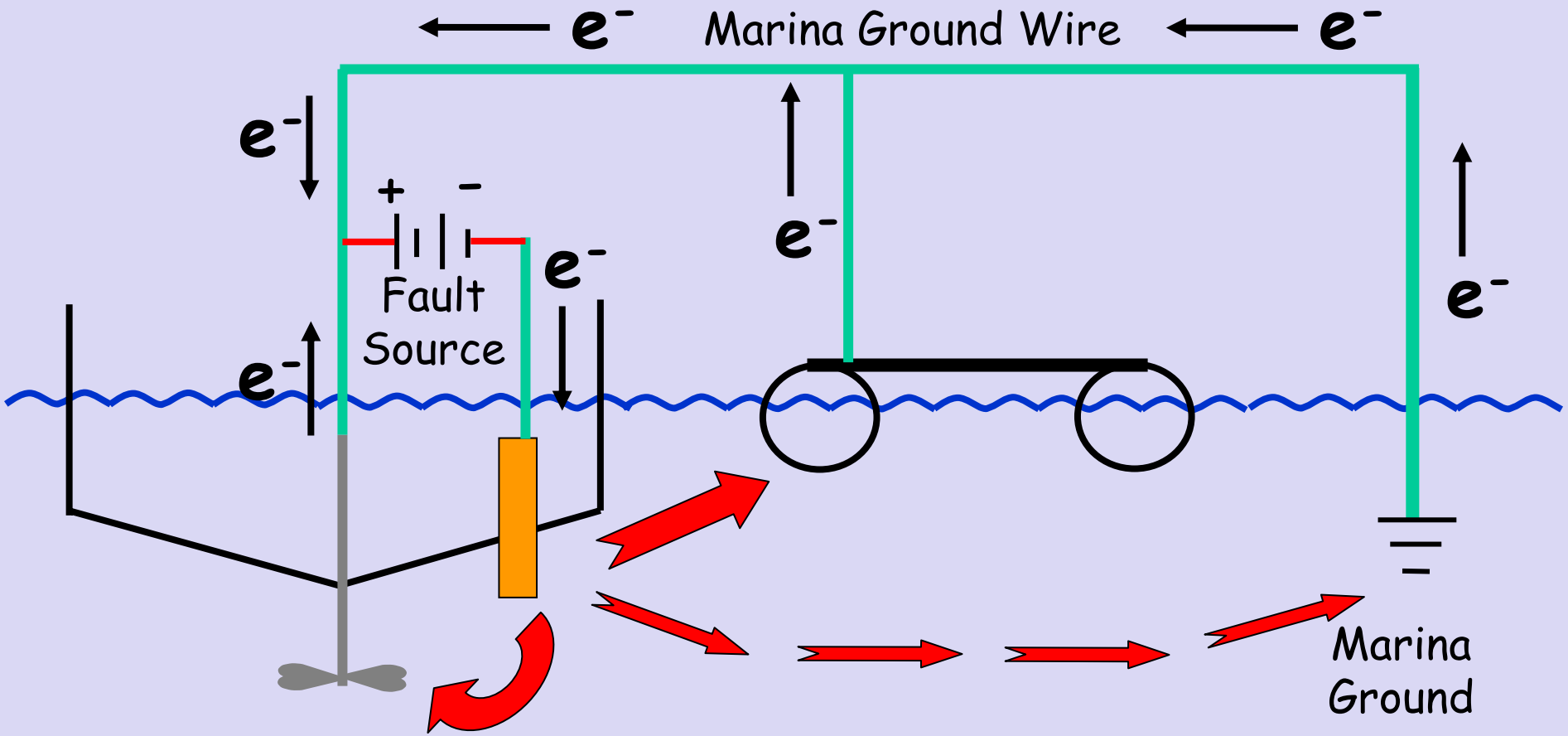
Bonding Fault Potentials



Bonding Fault Potentials

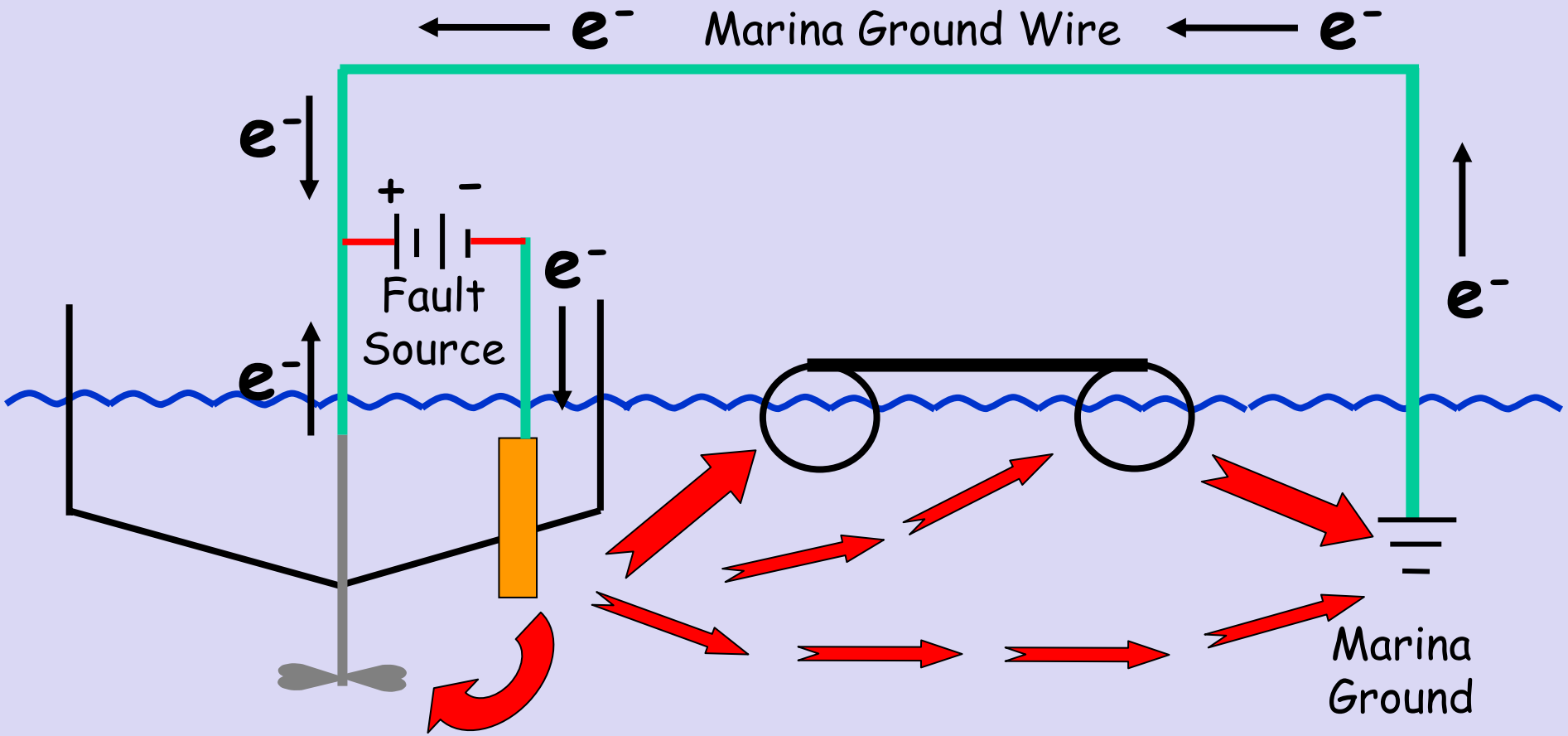


Other boats on shore power…



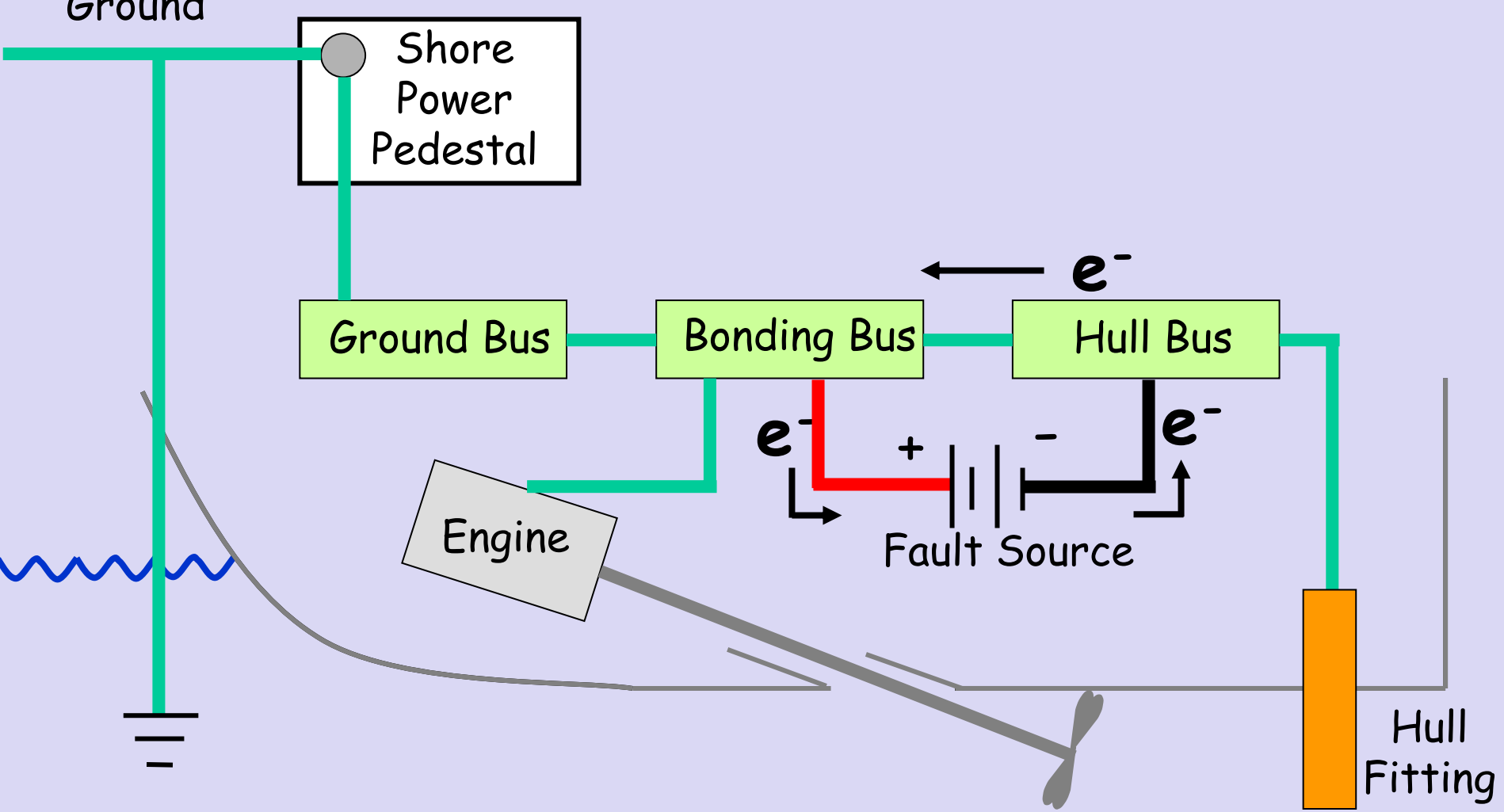
Corrosion: Prop/shaft, pontoons, dock structures

And boats not on shore power?



Corrosion: Prop/shaft, pontoons, dock structures

Without Bonding Fault

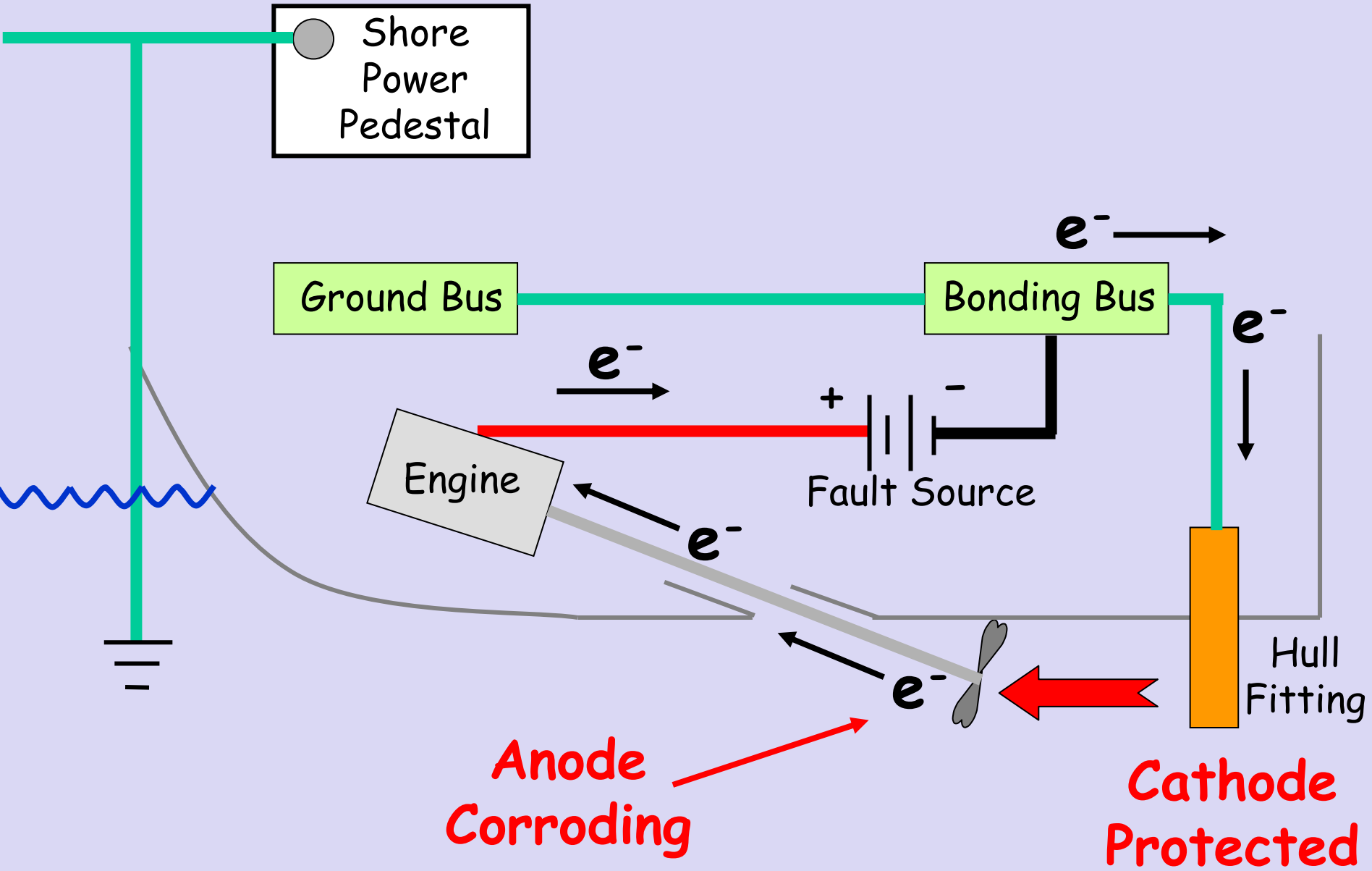


All U/W Fittings at Same Potential
Stray Current Corrosion STOPS!

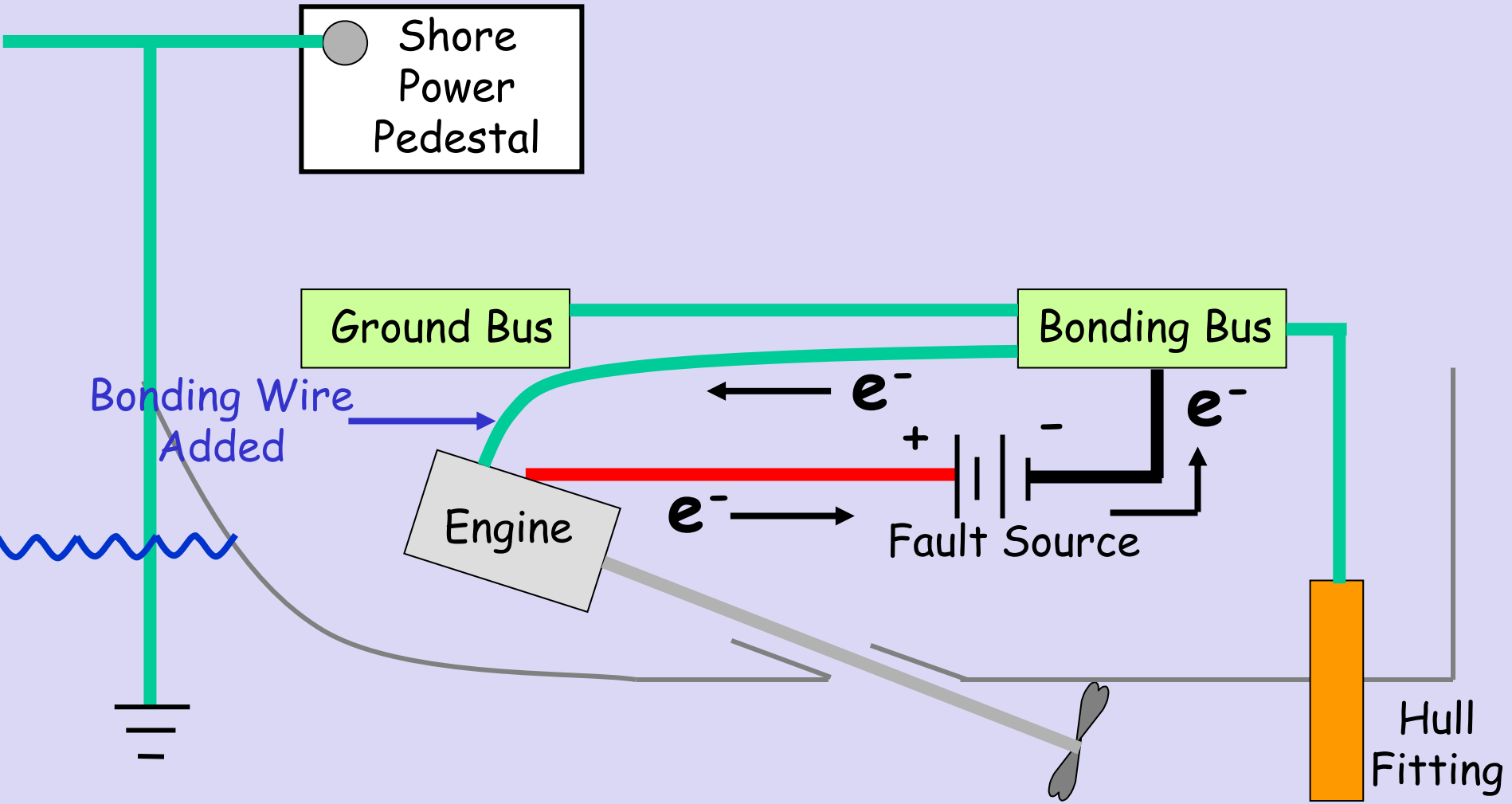
The "Isolated" Engine Block

- Engine manufacturers using **electronic controls** specify the block should not be used as a conductor.
- This requires using:
  - **Isolated starters and alternators** (2-wires)
  - **Isolated sending units** (2-wires)
- However, this does not mean that the block should be unbonded!! Four major engine manufacturers have told us that **these applications still require the blocks to be *bonded***.
  - Use a cable of same AWG as alternator output cable.
  - Simply **treat the block as any hull fitting and bond it**.
  - This will **minimize likelihood of stray current damage** and **make the boat safer** for personnel inside and out.

Isolated Engine Block Fault



Isolated Engine Block Fault



Potentials in water are equal; Corrosion Stops!

Stray Current Prevention

- An **intact bonding system** is the best defense.
- This **keeps all underwater metals at the same potential**, preventing current flow between them.
- Good bonding will **not prevent stray current damage initiated from another boat**.
- However, **good bonding does provide a safety margin** from electrical shock for people in the boat and in the water (also lightning protection).

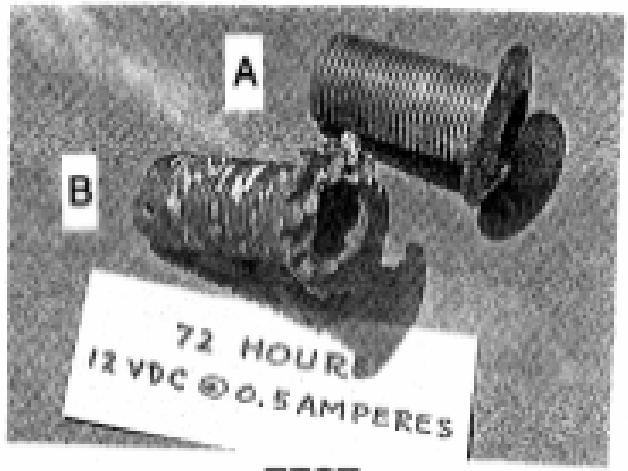
AC Stray Current Corrosion

- Well documented in the AC pipeline industry.
  - At levels less than **20-40A/M^2, there is negligible corrosion in a year.**
  - At <100A/M^2, corrosion rate will be less than 0.1mm/year.
  - These studies involved **alloy steels.**

- Robert Loeser (Seaworthy, October 1996) compared damage to a bronze fitting caused by equal amounts of AC and DC current.
  - **DC destroyed the hull fitting** in 72 hours.
  - **AC did no detectable damage.**

METAL FAILURES

STRAY CURRENT CORROSION
AC COMPARED TO DC



TEST

BRONZE THRU-HULL FITTING IN SEAWATER:

A) SUBJECTED TO .62 AMPS AC CURRENT FOR 1,000 HOURS — NO MEASURABLE DAMAGE.

B) SUBJECTED TO .5 AMPS DC CURRENT FOR 72 HOURS — COMPLETE COMPONENT FAILURE.

CONCLUSION: STRAY AC CURRENT NOT A MEASURABLE FACTOR IN INDUCED CORROSION IN THIS TEST.

TEST BY, ROBERT LOESER, 1996

HARBOR MARINE SERVICE

Summary by Jim Shafer

AC Stray Current Corrosion

- Recent incident involving **severe aluminum corrosion** was caused by a large AC ground fault in a marina supply cable.

- **30A was measured in the shore cable grounding wire** of the first boat on the dock.
  - Only this boat had an **aluminum drive**, aluminum anodes had just been replaced. Owner noticed stalagmites and bubbling from his new anodes (they were ruined in a few days but no damage to boats with stainless/bronze).

- Given the outdrive is approx $1M^2$, and anodes and scrapes represent about 10% bare aluminum, the **current density was around $300A/M^2$**.

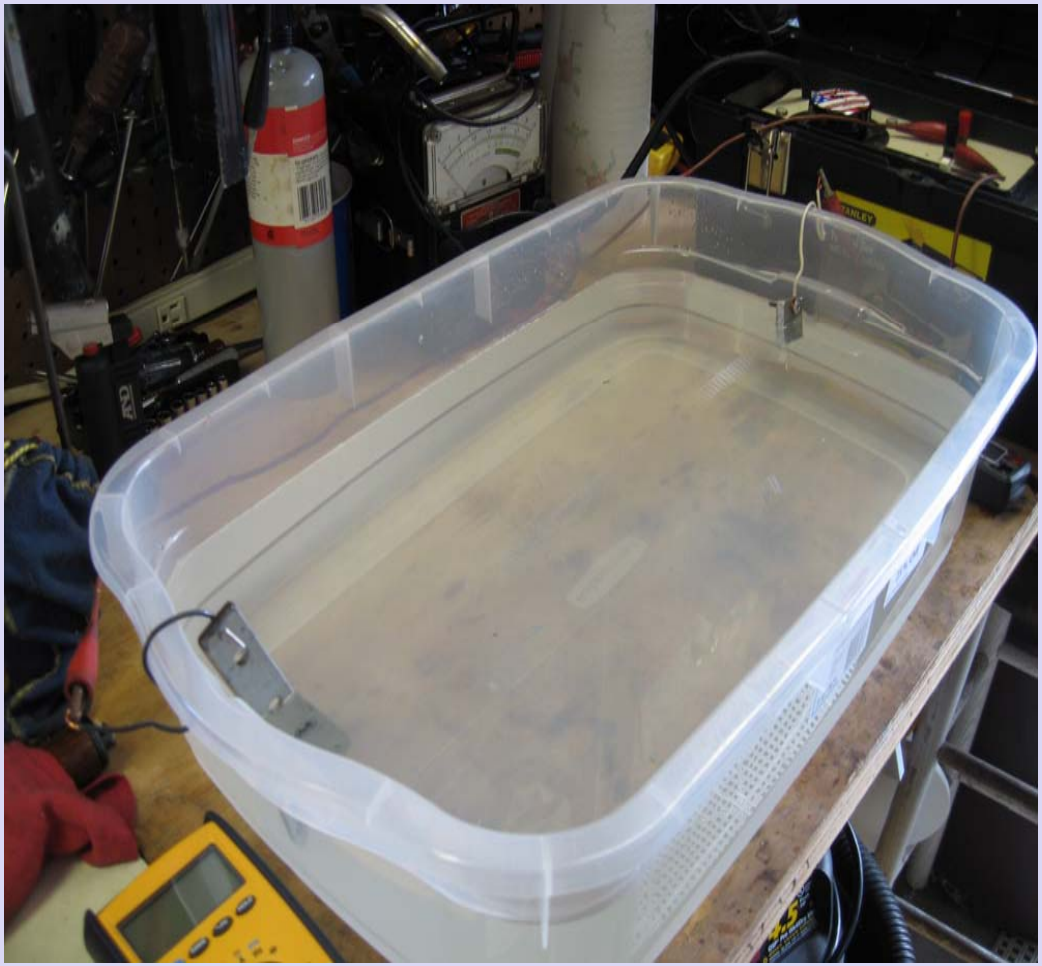
AC Stray Current Corrosion

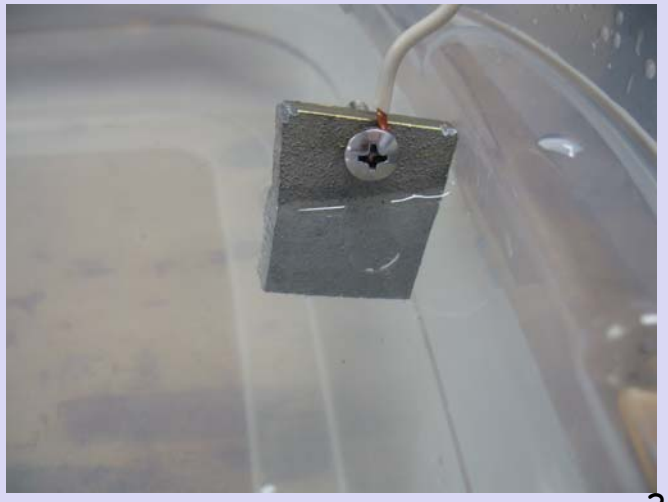
- A study done by James Williams , Northern States Power Company (Feb 1966) showed that **AC will cause about 40% of the damage as a like amount of DC will cause in *aluminum***.

- In iron, copper, and lead, the same AC current will cause only about **1% of the damage** caused by DC current.

- Look at the pictures from our own experiments which support the above finding.
  - The painted surface was undamaged at low densities.

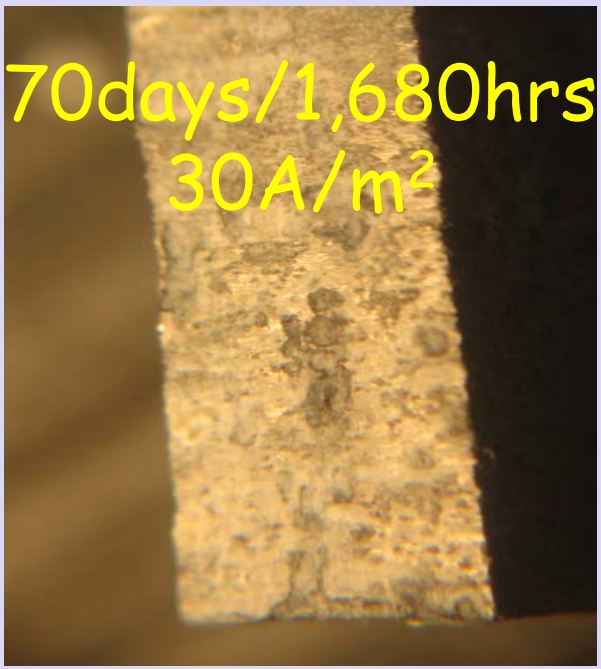
Test Setup



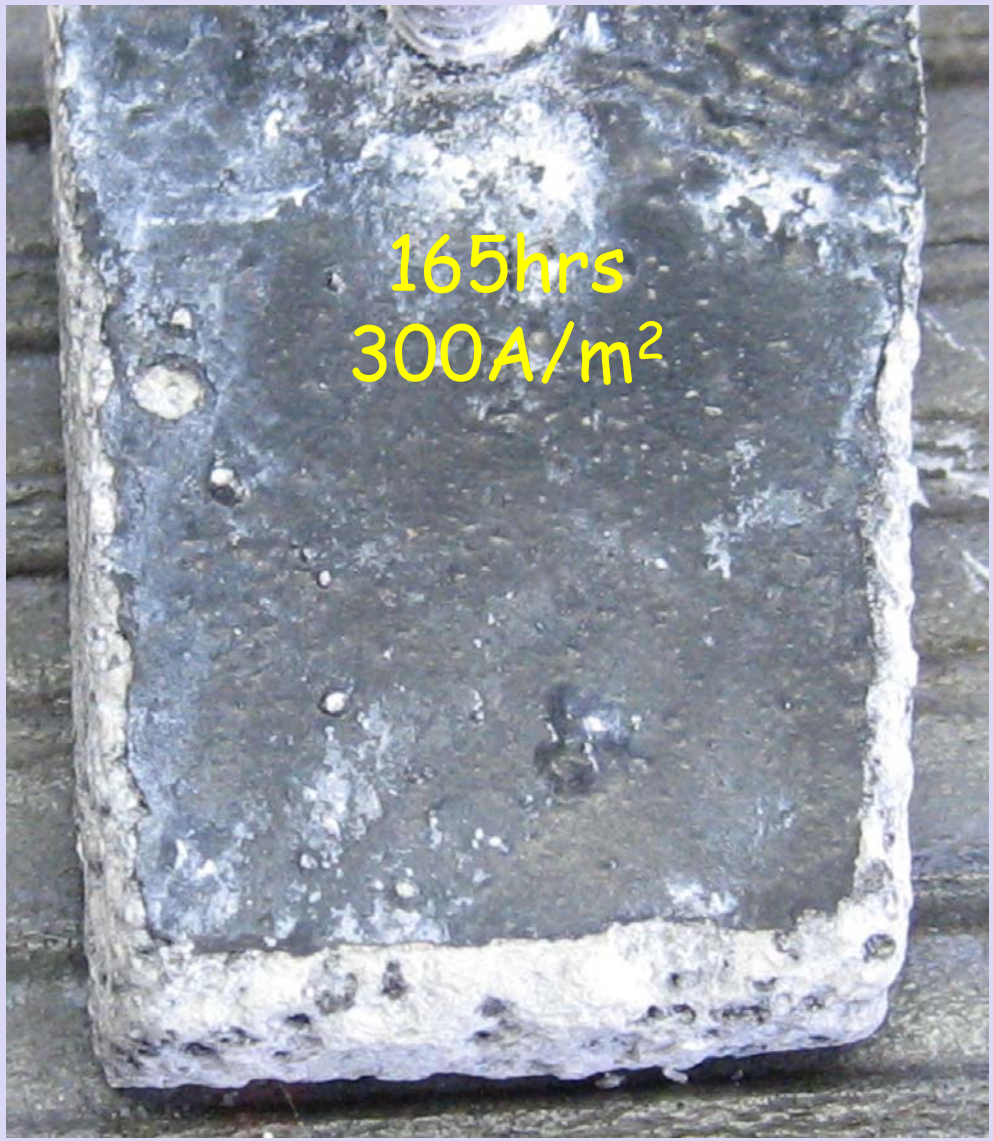


Face of Coupon

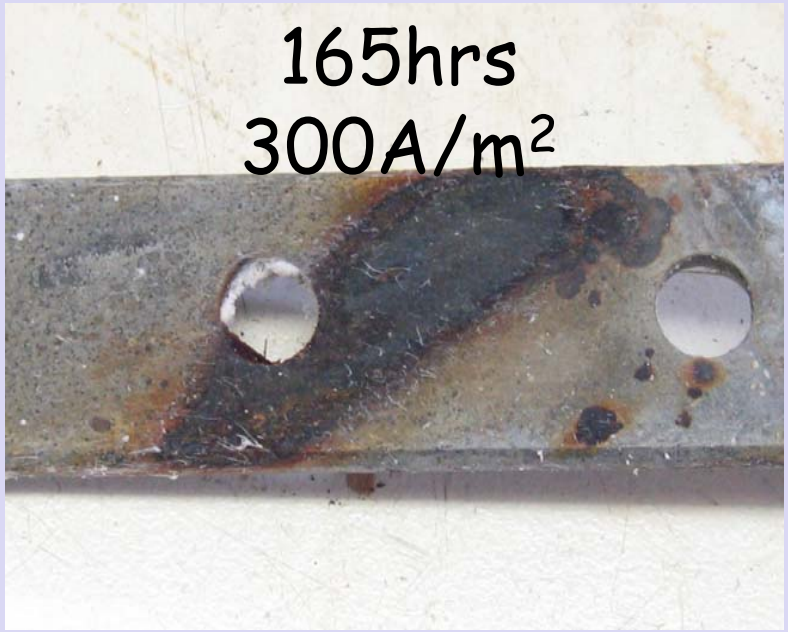
Leading Edge



Painted Face




0days/0hrs


165hrs
300A/m2


31days/744hrs
30A/m2


70days/1,680hrs
30A/m2

STEEL

AC Stray Current Corrosion

- **So, where does this AC current come from?**
  - Electrical ground faults on a boat
  - Illegal ground-neutral connections
  - Ground-neutral currents from the power grid

- **AC current leaking into the water is not uncommon.** For stern drives, this can represent a relatively high current density (30A/M^2 or more).
  - Measuring amps is not common; milliamps to hundreds of milliamps is quite common.

AC Stray Current Conclusions

- **AC stray current has little effect** on steels and copper alloys, even at relatively high levels.
- **Aluminum is susceptible to AC stray current** damage, even at levels which will not harm steels and other alloys.
- **Corrosion rate is slow at 30A/M²** (which equates to about 3A leakage into the water, single outdrive).
  - The rate is extremely slow at hundreds of MA leakage.
  - The corrosion rate increases exponentially with increasing current density.
- **Negligible weight loss at 30A/M²**, 5% at 300A/M²
- **It may contribute to long term damage to aluminum** components which was solely attributable to galvanic activity in the past.

Corrosion Survey in Freshwater

- All the **principles are identical** to saltwater.
  - The goal is to **determine the hull potential** to see if underwater metals are being protected (details provided at IBEX 2005).
  - The **200mv rule** still applies.
  - I **treat brackish water like saltwater**.
    - When salinity is near zero, and conductivity approaches that of tap water, I use freshwater techniques.

Corrosion Survey in Freshwater

- For freshwater, **a different cell** is required
  - One choice is a **Copper Sulfate** cell (as opposed to the Silver-Silver Chloride cell used in saltwater)
  - Copper sulfate cells are **designed for freshwater** (never use in saltwater!)
  - **Silver chloride cells won't read right in freshwater** (I have 4 of them and they all read significantly different in freshwater)
- Galvanic series tables are **referenced to a particular reference cell**.
  - The partial table on the next slide is from ABYC E-2, and is used directly only with a silver chloride cell.

Corrosion Survey in Freshwater

TABLE I - GALVANIC SERIES OF METALS IN SEA WATER WITH REFERENCE TO SILVER/SILVER CHLORIDE REFERENCE CELL [Sea water flowing at 8 to 13 ft./sec.(except as noted), temperature range 50°F (10°C) to 80°F (26.7°C)]

NOTE: Metals and metal alloys are listed in the order of their potential in flowing sea water as determined in tests conducted by a nationally-recognized corrosion research laboratory.

(ANODIC OR LEAST NOBLE)	CORROSION-POTENTIAL RANGE IN MILLIVOLTS
Magnesium and Magnesium Alloys	-1600 to –1630
Zinc	-980 to –1030
Aluminum Alloys	-760 to –1000
Cadmium	-700 to –730
Mild Steel	-600 to –710
Wrought Iron	-600 to –710
Cast Iron	-600 to –710
13% Chromium Stainless Steel, Type 410 (active in still water)	-460 to –580
18-8 Stainless Steel, Type 304 (active in still water)	-460 to –580
Ni-Resist	-460 to –580
18-8, 3% Mo Stainless Steel, Type 316 (active in still water)	-430 to –540
Inconel (78%Ni, 13.5%Cr, 6%Fe) (active in still water)	-350 to -460
Aluminum Bronze (92% Cu, 8% Al)	-310 to -420
Nibral (81.2% Cu, 4% Fe, 4.5% Ni, 9% Al, 1.3% Mg)	-310 to –420
Naval Brass (60% Cu, 39% Zn)	-300 to –400
Yellow Brass (65% Cu, 35% Zn)	-300 to –400
Red Brass (85% Cu, 15% Zn)	-300 to –400
Muntz Metal (60% Cu, 40% Zn)	-300 to –400
Tin	-310 to –330
Copper	-300 to –570
50-50 Lead- Tin Solder	-280 to –370
Admiralty Brass (71% Cu, 28% Zn, 1% Sn)	-280 to –360

Corrosion Survey in Freshwater

- Therefore, **a conversion must be made** when using a cell other than the one listed as the reference in your galvanic series table.
- The following information and **table in E-2** gives the conversion values between all standard reference cells.

E-2.Ap.TABLE II - CORRECTION FACTORS FOR REFERENCE ELECTRODES

Potential values of reference electrodes referred to Standard Hydrogen Electrode (S.H.E.), the standard to which other more convenient references are related:

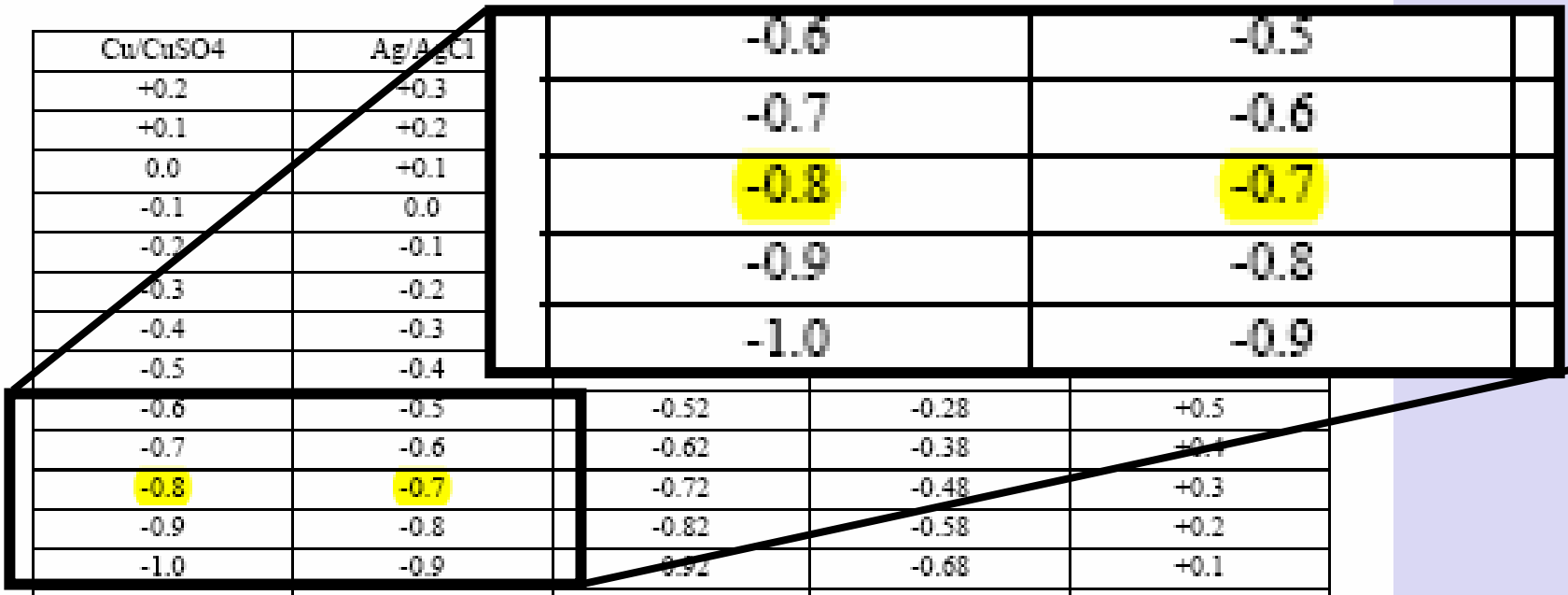
HALF-CELL		POTENTIAL VOLT
1. Tenth Normal Calomel	TNCE	+0.333
2. Copper-Copper Sulfate	Cu/CuSO4	+0.316
3. Normal Calomel	NCE	+0.280
4. Saturated Calomel	SCE	+0.241
5. Silver/Silver Chloride	Ag/AgCl	+0.222
6. Standard Hydrogen Electrode	S.H.E.	0.000
7. Zinc	Zn	-0.778

Corrosion Survey in Freshwater

E-2.Ap.TABLE II - CORRECTION FACTORS FOR REFERENCE ELECTRODES (cont.)

REFERENCE/SENSING ELECTRODES POTENTIAL IN SEAWATER COMPARED TO

Cu/CuSO4	Ag/AgCl			
+0.2	+0.3			
+0.1	+0.2			
0.0	+0.1			
-0.1	0.0			
-0.2	-0.1			
-0.3	-0.2			
-0.4	-0.3			
-0.5	-0.4			
-0.6	-0.5	-0.52	-0.28	+0.5
-0.7	-0.6	-0.62	-0.38	+0.4
-0.8	-0.7	-0.72	-0.48	+0.3
-0.9	-0.8	-0.82	-0.58	+0.2
-1.0	-0.9	-0.92	-0.68	+0.1
-1.1	-1.0	-1.02	-0.78	0.0
-1.2	-1.1	-1.12	-0.88	-0.1
-1.3	-1.2	-1.22	-0.98	-0.2
-1.4	-1.3	-1.32	-1.08	-0.3
-1.5	-1.4	-1.42	-1.18	-0.4
-1.6	-1.5	-1.52	-1.28	-0.5
-1.7	-1.6	-1.62	-1.38	-0.6
-1.8	-1.7	-1.72	-1.48	-0.7
-1.9	-1.8	-1.82	-1.58	-0.8
-2.0	-1.9	-1.92	-1.68	-0.9
-2.1	-2.0	-2.02	-1.78	-1.0



Corrosion Survey in Freshwater

- Ted Swartz uses a **zinc reference cell** for both fresh and saltwater applications. I am currently testing one of these.
- **Some other tools** you can use…
  - Conductivity meter (saltwater 50ms/cm, tap water 0.2-0.6ms/cm)
  - Salinity meter

Corrosion Survey in Freshwater

- Reference Cell Placement
  - In freshwater, place the reference cell as close as practical to the metal being tested.
  - The further away the cell is placed, the lower the potential reading will be due to the low conductivity of freshwater.
    - For example, if interested in the running gear, put the cell at the stern. Move it forward to test the bow thruster.
    - Not a concern on typical yachts in saltwater due to the high conductivity, but recommend still putting the cell near the most critical metals (like a stern drive) as a matter of practice.

Feel free to contact me if you have any questions:

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Elliott Bay, Seattle

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