Electrical Safety

Ying Sun's Lecture Notes

Electrical hazards	Ventricular fibrillation	Macroshock – external source Microshock – internal source (bypassing the skin resistance)
	Burns	Resistive heating of tissues
	Chemical burns	Electrolyte imbalance caused by prolonged DC exposure

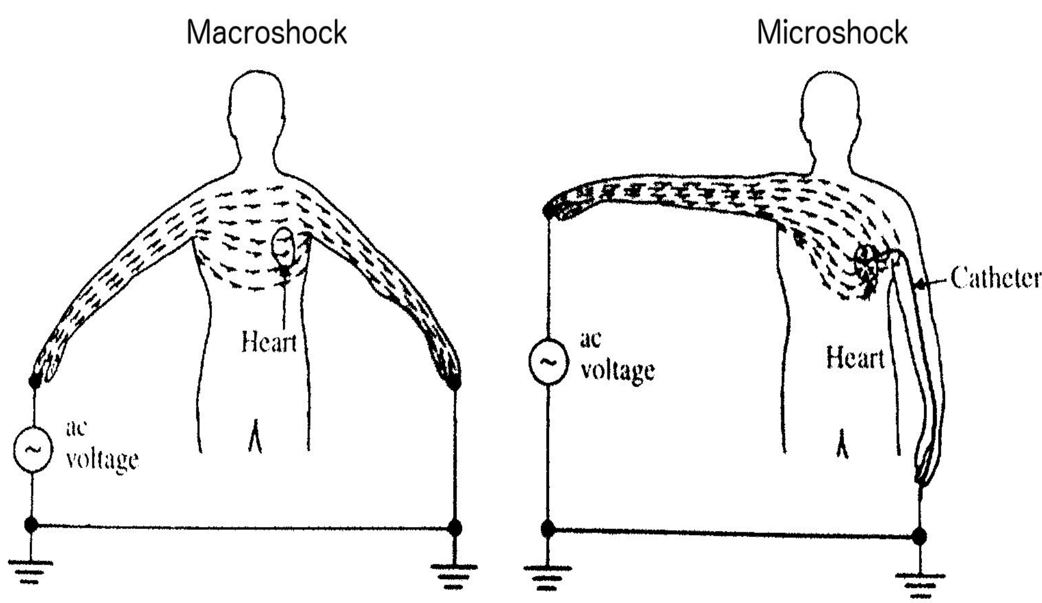
In early 1970's, Dr. Carl Walter and Ralph Nader (an attorney and consumer activist) stated that accidental electrocutions claim 1200 patients a year during medical procedures. However, there is no documented evidence of such electrical hazards to date. Reference: Malcolm G. Ridgway. "The Great Debate on Electrical Safety – In Retrospect" in Clinical Engineering Handbook, Joseph F. Dyro, Ed., ISBN: 978-0-12-226570-9.

<u>Macroshock – human experiments doing in the 1970's</u>

60 Hz AC current applied externally through AWG8 copper wires for 1-3 s (see I-Fig.14.1, p.639)

Perception threshold ---------------------------------- 1 mA (RMS value)
Maximum harmless ---------------------------------- 5 mA
Let-go current -- 10 mA
Ventricular fibrillation -------------------------------- 100-300 mA
Sustained myocardial contraction ------------------ 1 A
Burns -- 5 A

Ventricular fibrillation threshold	Macroshock	100 mA
	Microshock	100 μA



Dry skin vs. wet skin

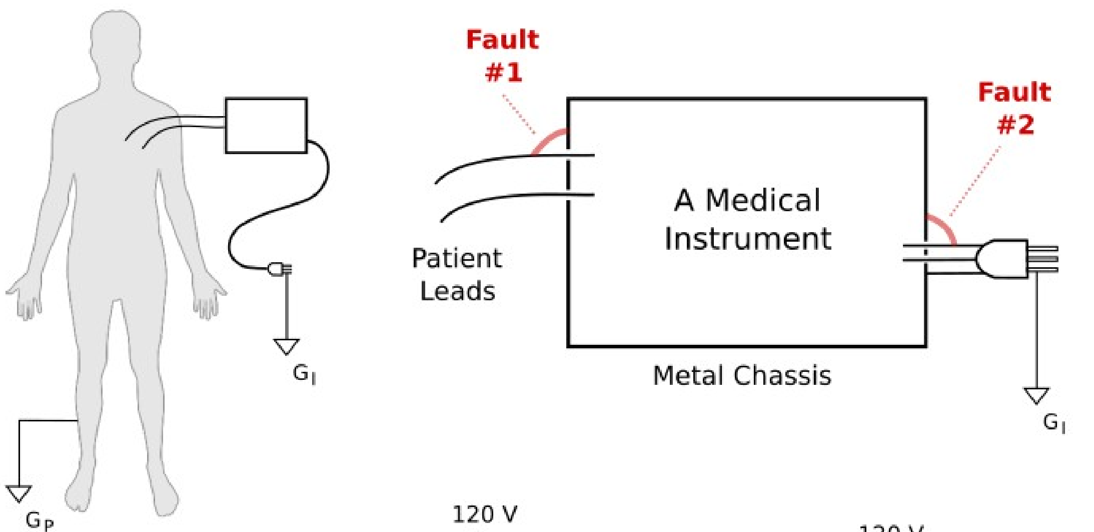
Skin resistance	Dry skin	~100 KΩ
	Wet skin	~1 KΩ

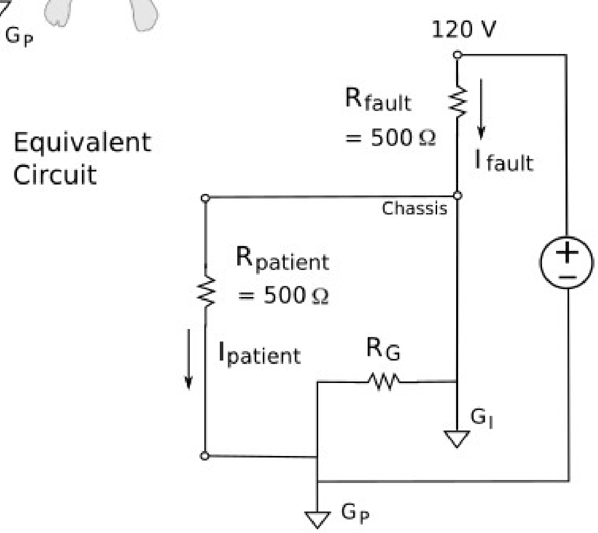
For a macroshock situation, V-fib threshold is 100 mA.

$$V = I \times R = 100\ \text{mA} \times 100\ \text{K}\Omega = 10\ \text{KV} \quad \text{(dry skin)}$$
$$= 100\ \text{mA} \times 1\ \text{K}\Omega = 100\ \text{V} \quad \text{(wet skin)}$$

General guideline for medical instrumentation

- Chassis-to-ground resistance ≤ 0.1 Ω
- Chassis-to-ground current ≤ 100 μA
- Patient lead current ≤ 50 μA (such as ECG skin electrode)
- Isolated patient lead current ≤ 10 μA (such as cardiac catheter)





$$I_{fault} = \frac{120\ \text{V}}{500\ \Omega + 500\ \Omega \,//\, R_G}$$

$$\approx \frac{120\ \text{V}}{500\ \Omega} = 240\ \text{mA}$$

$$I_{patient} = 240\ \text{mA}\ \frac{R_G}{500\ \Omega + R_G}$$

To make sure that $I_{patient} < 100\ \mu A$ (microshock situation):

$$R_G < \frac{0.1\ \text{mA}}{240\ \text{mA} - 0.1\ \text{mA}} \times 500\ \Omega$$

$$R_G < 0.2\ \Omega$$

- Ground-loop resistance standard ≤ 0.1 Ω

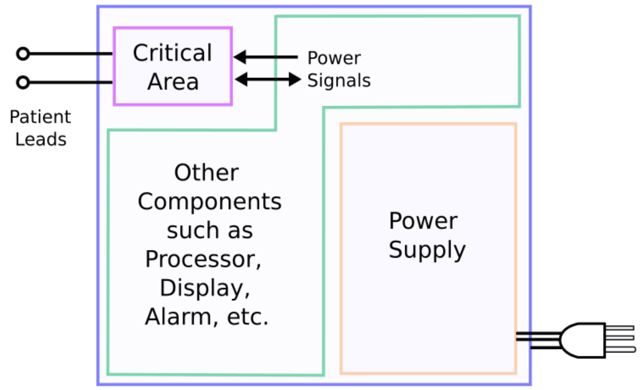
Double-fault analysis: an example

	PROBABILITY	RISK CATEGORY
Fault #1	1%	Minor
Fault #2	1%	Minor
Fault #1 + #2	0.001%	Catastrophic

This topic is related to *Rick Management*, which will be discussed in more detail later.

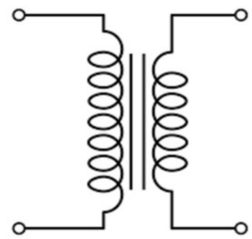
Physical layout inside a medical instrment

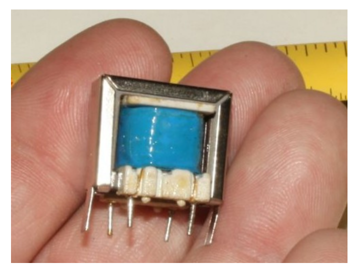
Patient leads are connected to a clearly identified "critical area" inside the instrument. The critical area should be close to the patient leads and away from the power supply. The power going into and the signals in and out of the critical area need to be electrically isolated. This means that there cannot be any direct conductive wire going into the critical area.



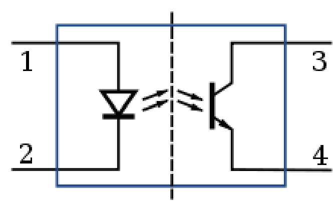
Electrical isolation of the critical area

1) Signal transformer: Analog signals can be transferred in or out of the critical area via a signal transformer, which provide an AC coupling through the magnetic field. A signal transformer has good linearity.





2) Optocoupler: Signals can also be coupled through light transmission. An optocoupler uses an LED as a source; The light tranvels through a dielectric interface and is detected by a photo transistor. Generally speaking, the optocoupler does not have good linearity and is useful to send binary (on/off) signals.



3) DC-to-DC converter: In additional to the signals, the power also needs to be electrically isolated. A DC-to-DC converter uses the DC input to drive an oscillator. The AC power goes through a transformer and then is rectified and regulated to a DC output or outputs. The schematic on the right shows a simple circuit <http://rsrelectronics.com/t_dc-dc.htm>.