9) $\eta = \frac{P_L}{P_{GEN}} \times 100\% = \frac{12.650132k}{12.6505701k} \times 100\% = 99.997\%$

(THIS ASSUMES AN IDEAL TRANSFORMER WITH NO LOSSES. VERY LARGE TRANSFORMERS HAVE EFFICIENCIES AROUND 90%)

10) BY ADDING 2 TRANSFORMERS, THE POWER COMPANY SAVED 309.2W − 0.438W = 308.762W
(309.2W: P_{LINE} ON p18)

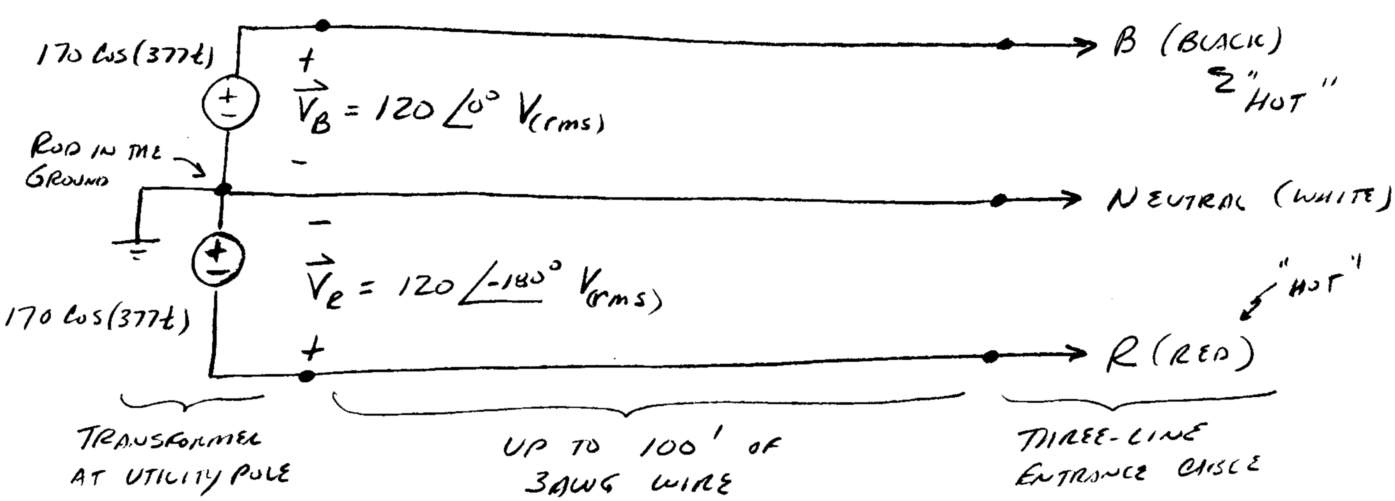
THIS REDUCED THE LOSSES BY 99.86% !

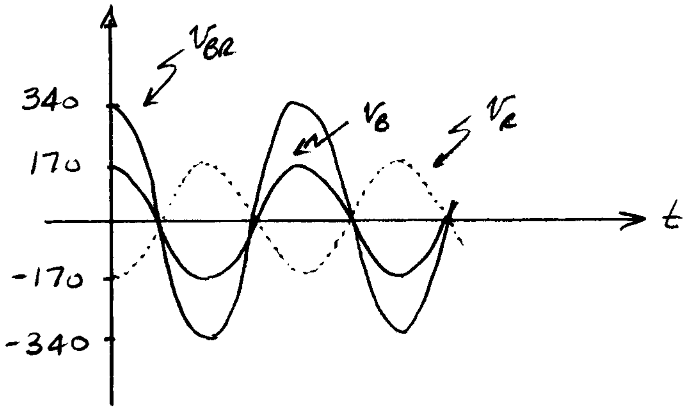
- NOW IMAGINE THE 1000' WIRE IS MANY MILES LONG. WITHOUT TRANSFORMERS THE LOSSES WOULD BE ASTRONOMICAL.

C) RESIDENTIAL CIRCUITS AND WIRING

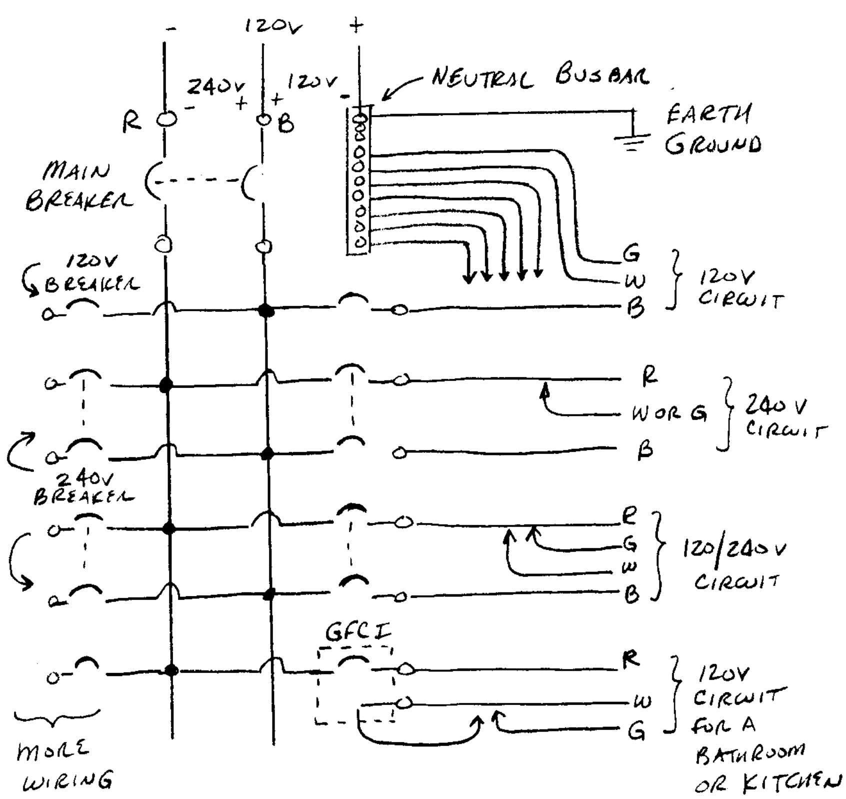
1) DUAL-VOLTAGE SERVICE ENTRANCE

- MOST HOMES HAVE A DUAL VOLTAGE AC SUPPLY PROVIDED BY A THREE-LINE ENTRANCE CABLE





AFTER PASSING THROUGH THE ELECTRIC METER THAT MEASURES ENERGY CONSUMPTION, THE ENTRANCE CABLE TERMINATES AT THE MAIN PANEL. HERE THE "HOT" LINES CONNECT TO INDIVIDUAL CIRCUITS FOR LIGHTING, APPLIANCES, AND SO FORTH, WHILE THE NEUTRAL CONNECTS TO A BUSBAR AND THUS TO THE LOCAL EARTH GROUND



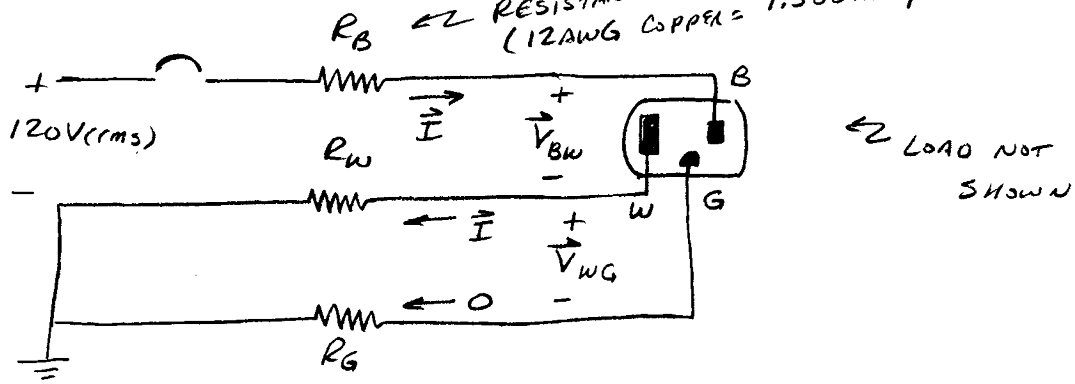
WHERE

HOT = B (BLACK) OR R (RED)

NEUTRAL = W (WHITE)

GROUND = G (GREEN)

2) WIRING AND GROUNDING



- UNDER NORMAL CONDITIONS, CURRENT FLOWS TO THE LOAD (NOT SHOWN) THROUGH ONLY THE HOT AND NEUTRAL WIRES, HENCE THE GROUND TERMINAL AT THE OUTLET IS AT ZERO VOLTS WITH RESPECT TO THE EARTH GROUND, DESPITE THE RESISTANCE R_G.

- CURRENT FLOWING THROUGH R_B AND R_W CAUSE THE NEUTRAL TERMINAL TO BE AT $\vec{V}_{WG} = \vec{I} R_W$ VOLTS WITH RESPECT TO EARTH GROUND AND THE AVAILABLE VOLTAGE $\vec{V}_{BW} = 120\angle 0^\circ - \vec{I}(R_B + R_W)$.

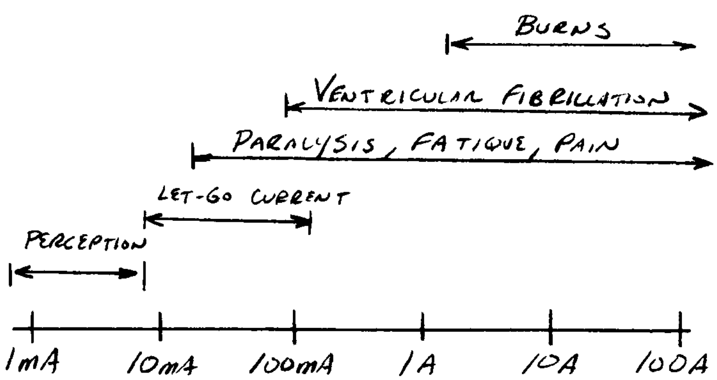
- ALSO THE RESISTANCE OF THE ENTRANCE CABLE (3AWG COPPER = 197 μΩ/FT) INCREASES THIS LOADING EFFECT EVEN FURTHER. THUS HOME APPLIANCES MUST BE DESIGNED TO OPERATE OVER A RANGE OF VOLTAGES, TYPICALLY 110 − 120 V(rms)

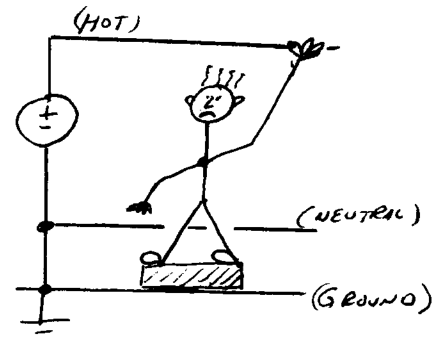
3) Electrical Safety

– The circuit theory of this subject is simple:

$$i = \frac{V}{R}$$

where unfortunately R is you!





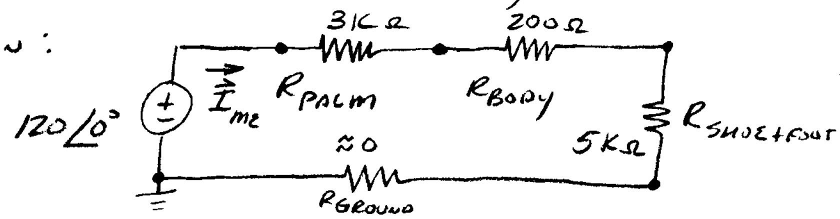
Condition (area in situ)	Resistance	
	Dry	Wet
Finger touch	40K - 1 MΩ	4K - 15KΩ
Hand holding wire	15K - 50KΩ	3K - 6KΩ
Palm touch	3K - 8KΩ	1K - 2KΩ
Hand around drill handle	1K - 3KΩ	100 - 1.5KΩ
Foot immersed in water		100 - 300Ω

Human body, internal, excluding skin = 200 - 1000Ω

Material	Resistance
Rubber gloves or shoes	> 20MΩ
Leather sole, dry, including foot	100K - 500KΩ
Leather sole, wet, including foot	5K - 20KΩ

EXAMPLE: WHAT WOULD YOU EXPERIENCE IF YOU WERE STANDING ON MOIST GROUND WITH LEATHER-SOLED SHOES AND YOU UNWITTINGLY GRAB HOLD OF A 120 V(rms) WIRE?

SOLUTION:



⇐ USING LOWEST VALUES FROM PREVIOUS TABLE

$$\vec{I}_{ME} = \frac{120\angle 0^\circ}{3K + 200 + 5K} = \frac{120\angle 0^\circ}{8.2K\angle 0^\circ} = 14.6m\angle 0^\circ \; A(rms)$$ ⇐ DANGEROUS*

(WITH RUBBER SOLE SHOES $120\angle 0^\circ / 20M\angle 0^\circ = 6\angle 0^\circ \mu A(rms)$ ⇐ NOT NOTICEABLE)

BUT DON'T TRY IT!

*NOTE†: SKIN RESISTANCE FALLS RAPIDLY AS CURRENT PASSES THROUGH THE POINT OF CONTACT BECAUSE THE CURRENT BREAKS DOWN THE PROTECTIVE, DRY, OUTER-SKIN LAYER. THIS MAKES IT IMPORTANT TO BREAK THE CONTACT WITH THE LIVE CONDUCTOR AS SOON AS POSSIBLE. SINCE THE VOLTAGE AT THE POINT OF CONTACT USUALLY REMAINS CONSTANT AND SINCE THE RESISTANCE DECREASES, THE CURRENT CAN SOON RISE TO LETHAL LEVELS.

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† "GUIDE TO ELECTRONIC MEASUREMENTS AND LABORATORY PRACTICE" BY STANLEY WOLF, PRENTICE-HALL 1983.

4) Grounding Appliances and Tools

- If the neutral is at approximately 0V, why is the ground pin needed?

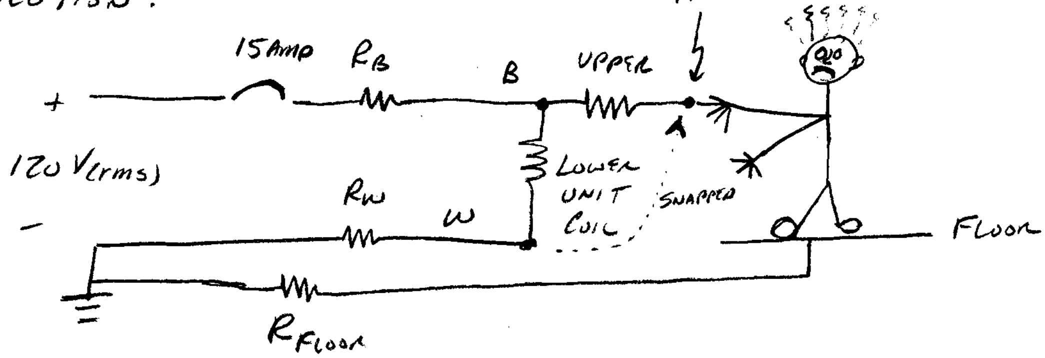
a) Example

Many homes have kitchen appliances which have 2-prong plugs.

Suppose such a home had a waffle iron plugged-in and the upper-heating element snapped and fused itself to the metal frame. There is a 50-50 chance that the heating element was connected to the white (neutral) wire. Suppose, further, that this is the case.

After some time your waffle mix isn't cooking and putting your hand over the metal frame you realize that it is cool. So you touch it to really see if it's cool. What happens?

Solution:

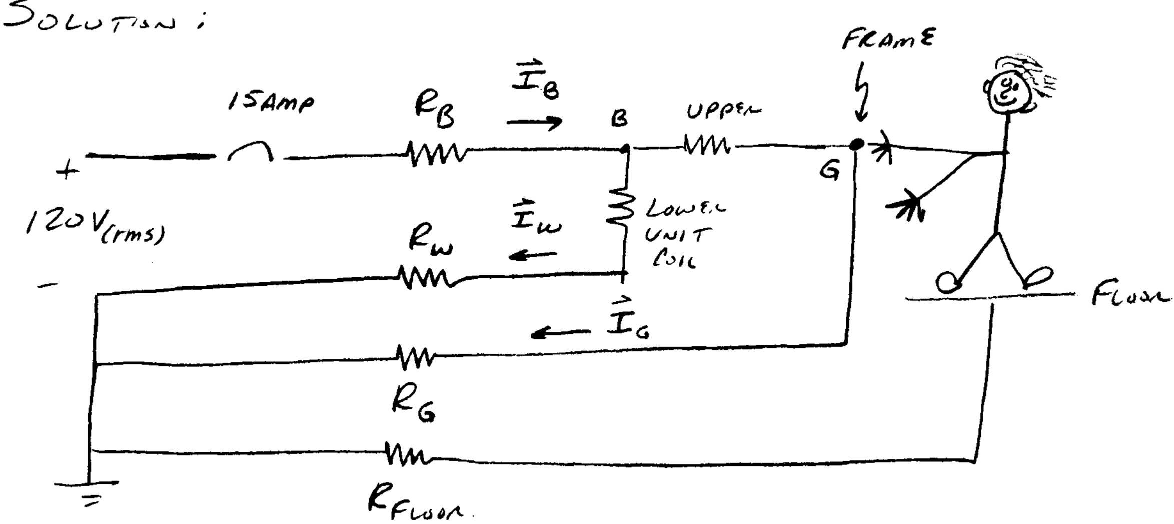


YOUR BODY PROVIDES A PATH FOR CURRENT. YOU MAY EXPERIENCE A SERIOUS SHOCK DEPENDING ON THE RESISTANCE $R_{FLOOR+SHOES}$. THE 15-AMP BREAKER WON'T TRIP BECAUSE YOUR MINIMUM BODY RESISTANCE IS AROUND 200Ω RESULTING IN A CURRENT, $\frac{120\ V(rms)}{200\Omega} = 600mA(rms)$

b) EXAMPLE

SUPPOSE THE SAME SCENARIO OCCURS BUT NOW WITH A 3-PRONG PLUG WHERE THE METAL FRAME OF THE WAFFLE IRON IS CONNECTED TO GROUND.

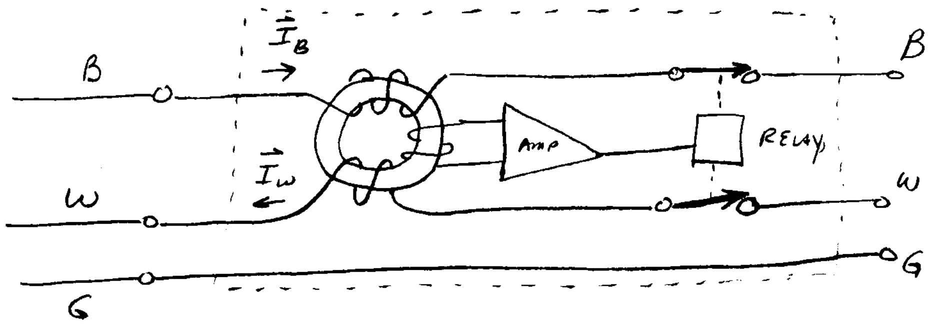
SOLUTION:



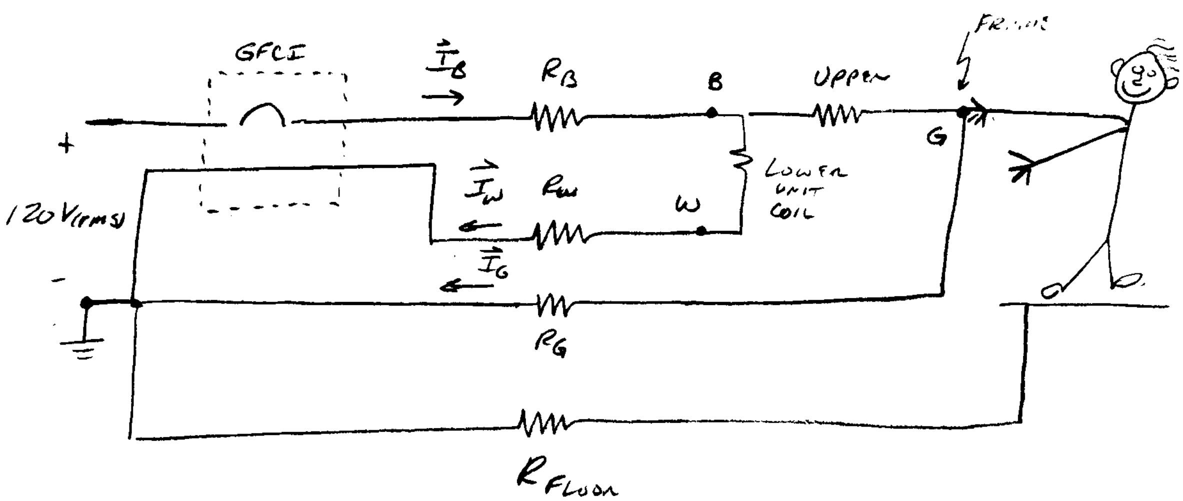
$R_{UPPER} \gg R_B + R_G$, SO MOST OF THE 120V(rms) IS DROPPED ACROSS R_{UPPER} AND $\vec{V}_G \ll 120V(rms)$

THE BREAKER MAY STILL NOT TRIP AND YOU MAY FEEL A LITTLE SENSATION.

c) EXAMPLE – GROUND-FAULT CIRCUIT INTERRUPTER (GFCI)



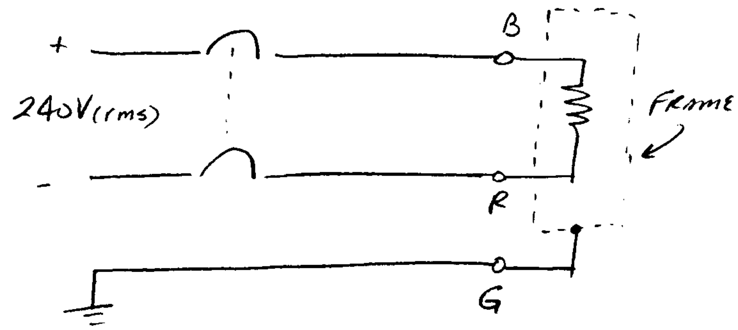
IF $|\vec{I}_B - \vec{I}_W| > 5\,mA(rms)$, THEN THE RELAY OPENS BOTH LINES AND DOES SO IN LESS THAN $\frac{1}{40}$ SEC. THIS IMBALANCE BETWEEN THE HOT AND NEUTRAL CONDUCTORS INDICATES A GROUND FAULT POSSIBLY THROUGH THE CONDUCTIVE PATH OF A HUMAN BEING



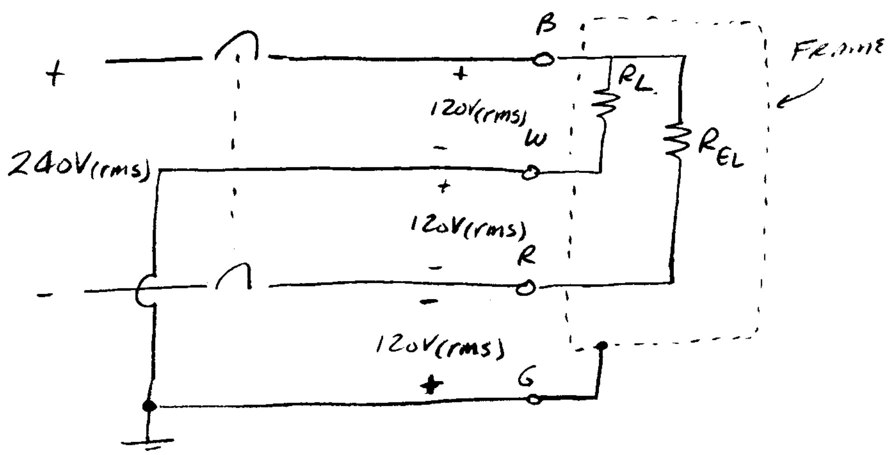
SINCE $\vec{I}_B \neq \vec{I}_W$, THE GFCI TRIPS AND $\vec{V}_G$ IS NOW ZERO. THE SAME IS TRUE IF A 2 PRONG PLUG IS USED.

5) Other Wiring Configurations

a) 240 V(rms) Load (Electric Heating Unit)



b) Dual Voltage Load (Electric Range with 240 V(rms) Elements and 120 V(rms) Lights)



R_{EL} =

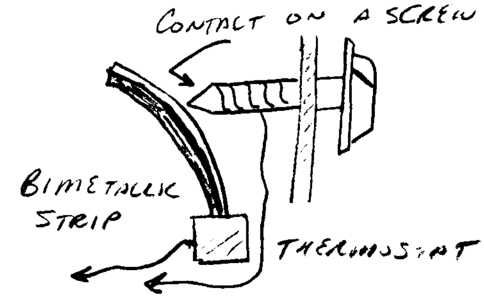
26Ω (Large surface)

45Ω (Small surface)

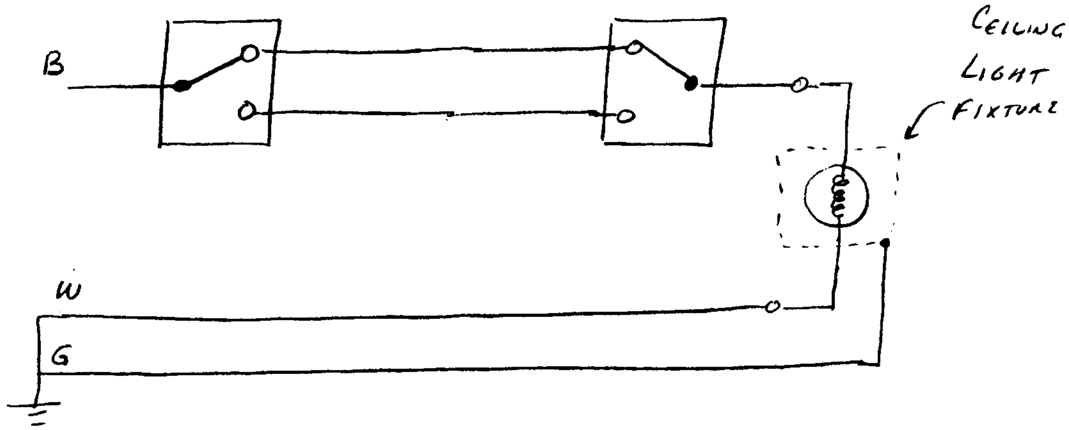
24Ω (Baking)

16Ω (Broil)

A Bi-metallic Element is used to regulate the time the heating element is connected to the 240 V(rms)

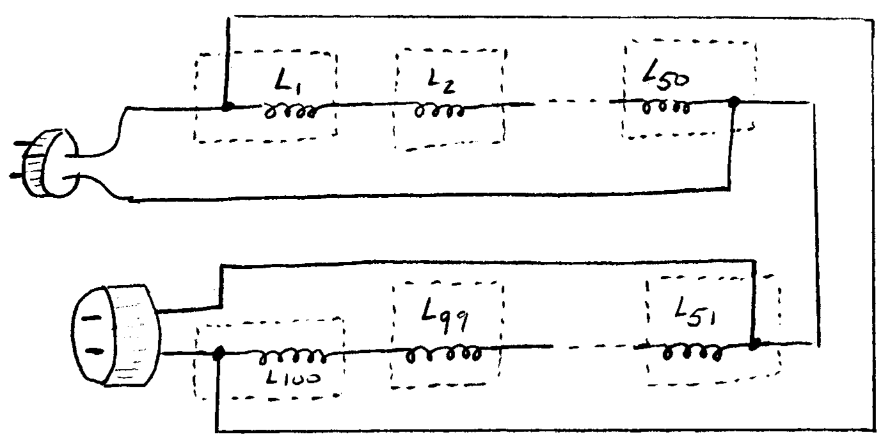


c) 3-WAY SWITCHES



- WE HAVE A COMPLETED CIRCUIT ONLY WHEN BOTH SWITCHES ARE UP OR DOWN; AND FLIPPING EITHER SWITCH OPENS THE CIRCUIT

d) CHRISTMAS TREE LIGHTS (100-MINATURE BULBS)



4 LIGHTS HAVE 3 WIRES GOING INTO THE PLASTIC BASE

96 LIGHTS HAVE 2 WIRES GOING INTO THE PLASTIC BASE

- EACH BULB IS APPROX. $\frac{1}{2}$W AND HAS A $\frac{120}{50} = 2.4V_{(rms)}$ DROP
- IF ONE BULB BURNS OUT, 50 LIGHTS ARE OUT.
- A FLASHER IS A BULB WITH A BI-METALLIC ELEMENT IN IT