CONTROLS

At Living Web Farms

An introduction to simple electrical control systems

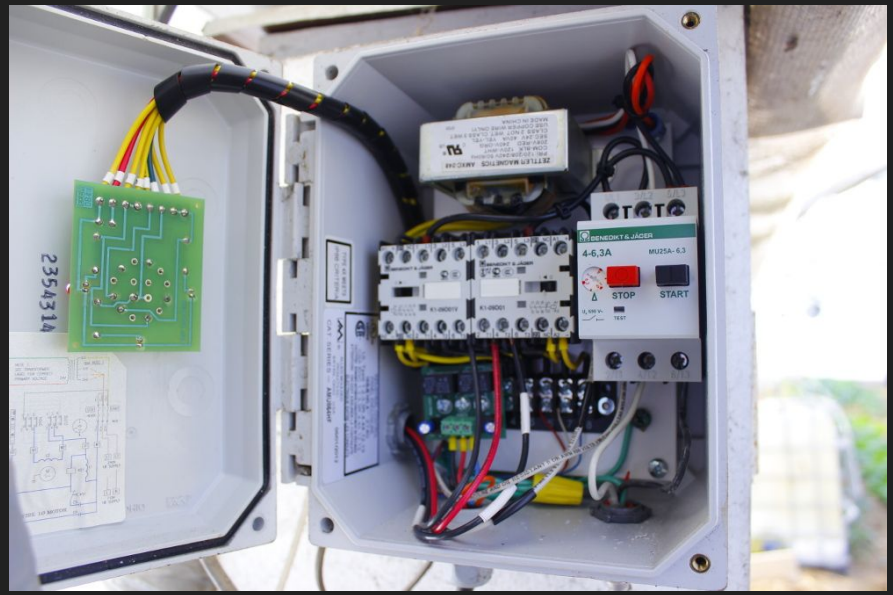
Dan Hettinger, Biochar Facility Manager

Why Learn Controls?

These systems are everywhere! And they govern a lot of the systems that make us comfortable and productive. Why not learn this practical hands-on knowledge?

Required for diagnosing failures and more informed operation of:

- Heating systems
- Greenhouse Environmental
- Automobiles and Equipment
- Appliances, Power Tools
- Your specific application

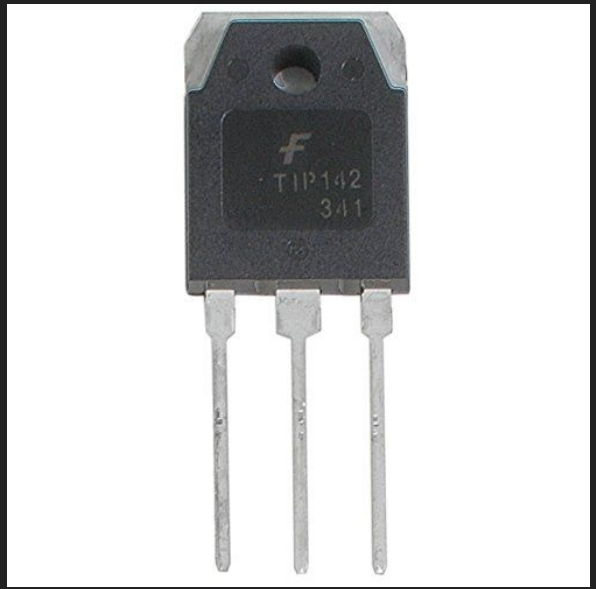


About me:

I’m definitely not an expert! Merely someone who has learned ‘the hard way’ and wants to share the knowledge with the DIY oriented community - so you can make educated decisions about the technology that surrounds you.

Ex. 1 - Oven electronic control board - would you be able to diagnose a broken solder joint? That’s all it took to repair a $200 part, without waiting days for new parts to arrive in mail.

Ex. 2 - Used Hobart 180 welder - had issues with wire feed rate. Online communities helped me locate and replace a $5 transistor. Reconditioned welders sell for $550. I got mine for $105.



What we'll cover today:

- Becoming familiar with circuits and reading wiring diagrams
- Working safely with electricity
- Using a multimeter
- Reading labels and nameplates
- Recognizing components: Switches, Relays, Transformers, etc.
- Maybe a little soldering practice?
- Discover a few common readymade controllers: Thermostats, Setpoint, Timers...
- See some operating control systems at the LWF Grandview Facility
- Become familiar with the vocabulary and supporting resources
- Gain confidence to do your own troubleshooting and repair work

Philosophy:
NOT going to cover:

- Complicated and inaccessible control programming
- Automation technology that replaces people
- Controls that make us more **dependent** farmers: wasteful, lazy, and unaware

We ARE going to cover:

- Systems that replace the most mundane, regular scheduled tasks
- Systems that help us stay safe, clean and productive
- Systems that can be shut down and manually operated
- Systems that help us become more resilient and creative people

Screenshot: www.farmbot.io

Is there a PASSIVE option?

Control circuits: A Broad Definition:

Anything that uses electricity to first sense something and act on that information

Power Source -> Switch -> Load -> Ground

A Broad Definition:

Anything that uses electricity to first sense something and act on that information

Power Source -> Switch -> Load -> Ground

Schematics and Wiring Diagrams

- Visual representation showing layout of an electrical circuit
- Map for troubleshooting
- Tool for designing, modifying existing circuit
- Pictorial or Schematic often can look very different from each other
- I like to use both for my projects:
  - Schematics for designing and understanding function
  - Pictorial for installation

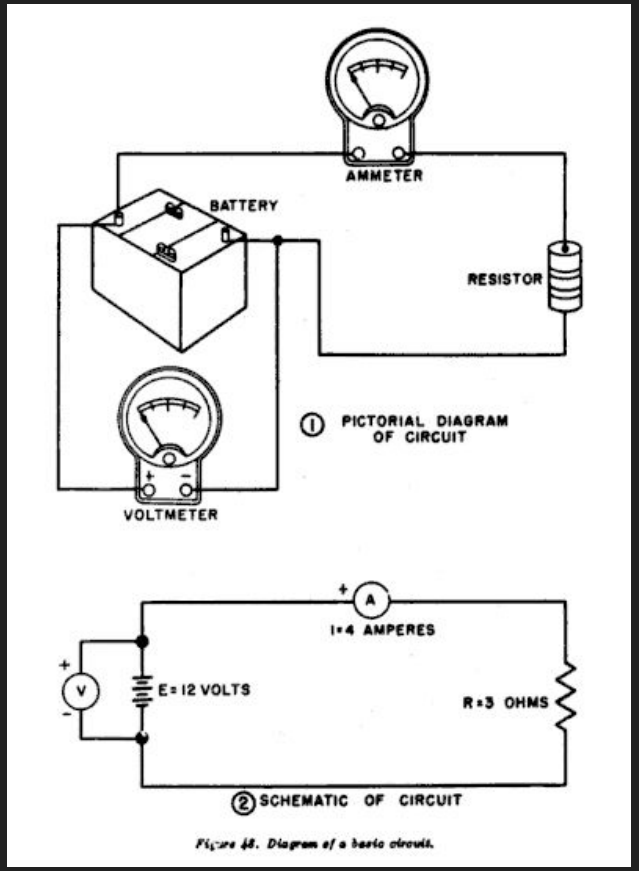
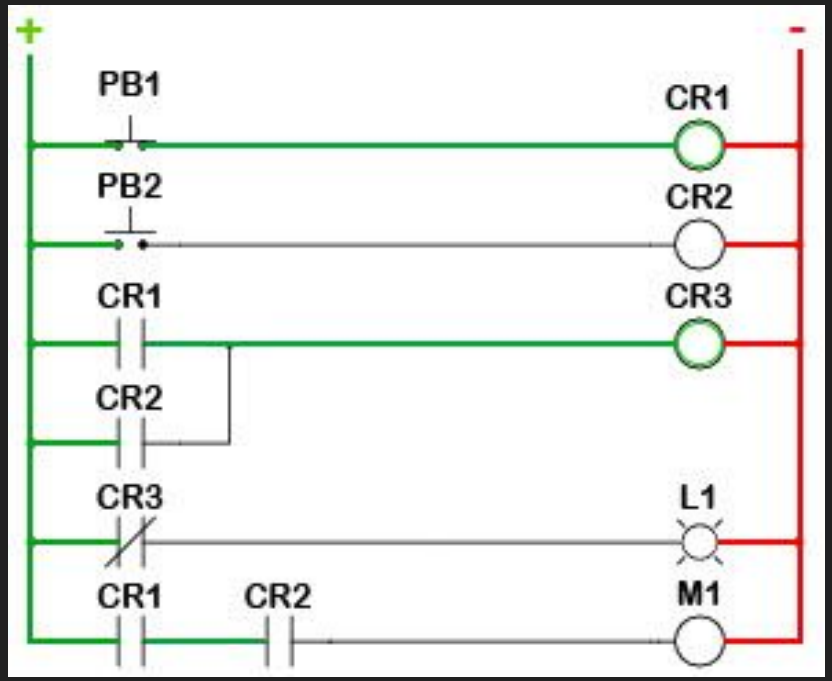
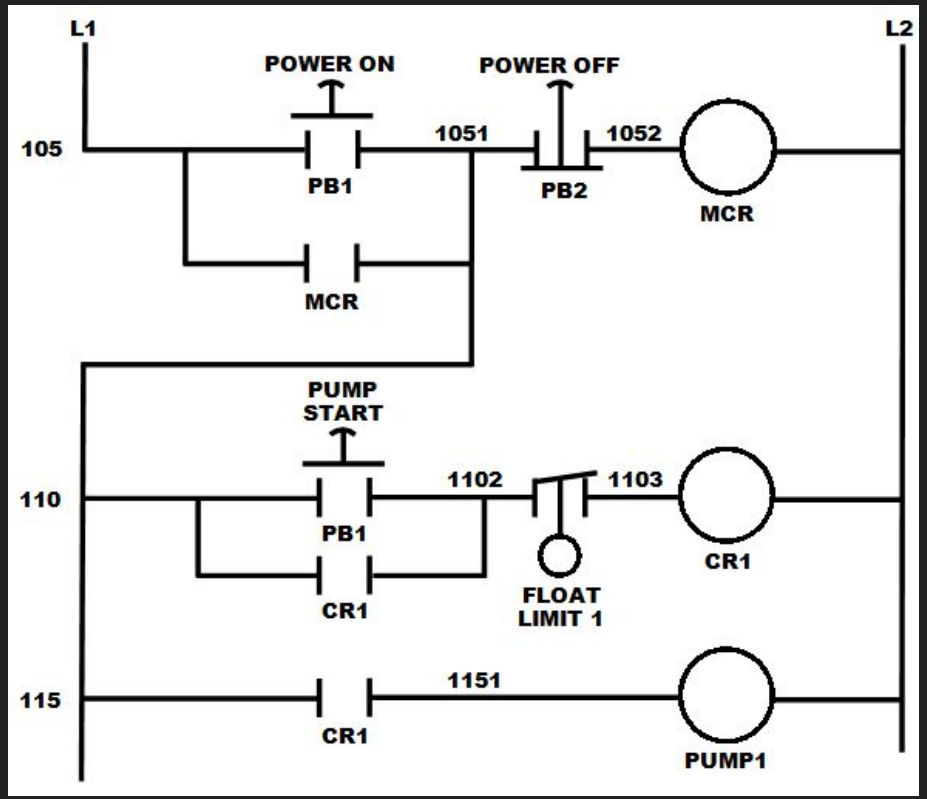


Figure 48. Diagram of a basic circuit.

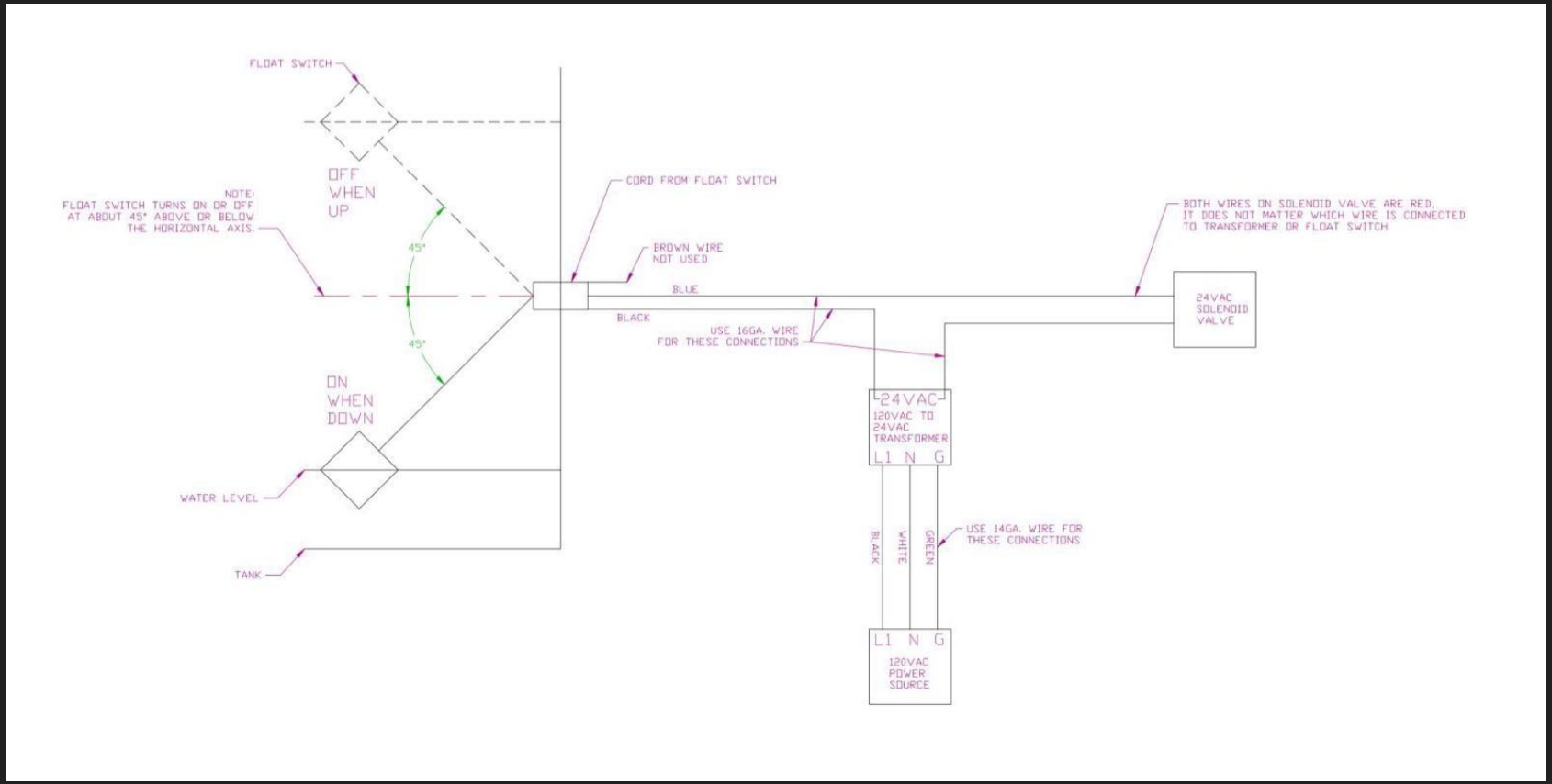
Ladder Diagrams - Schematic





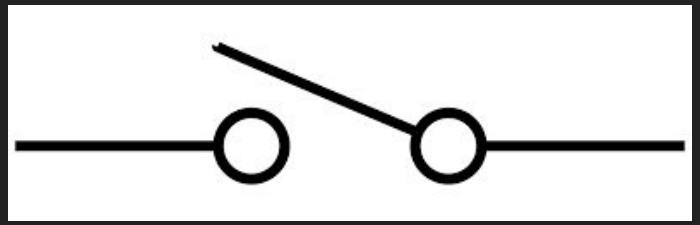
Source: library.automationdirect.com

Wiring Diagrams - Pictorial

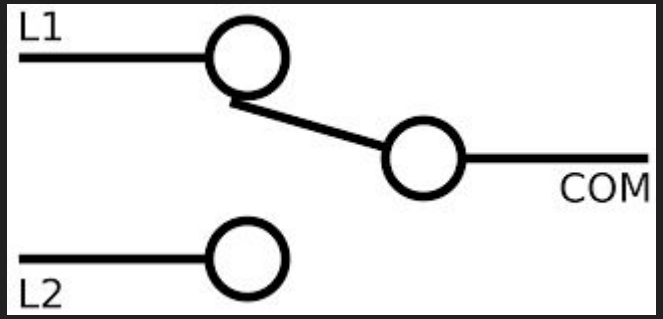


Switches

Switches

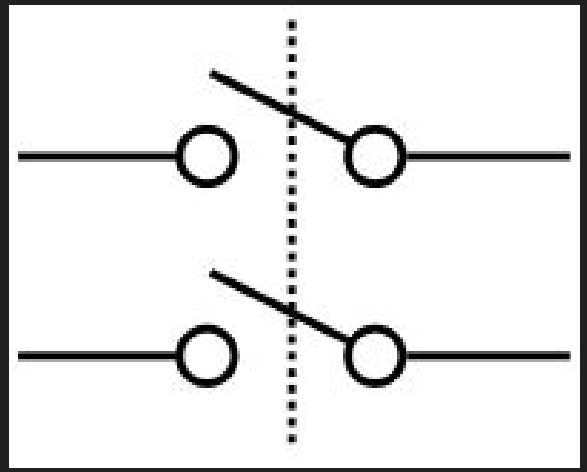


SPST - Single Pole Single Throw

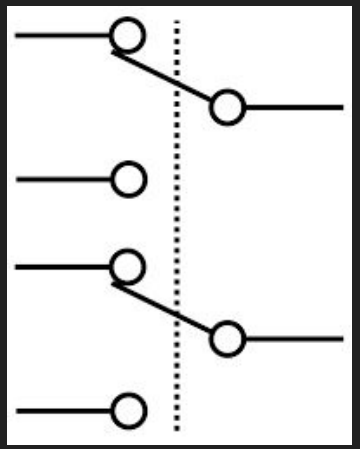


SPDT - Single Pole Double Throw

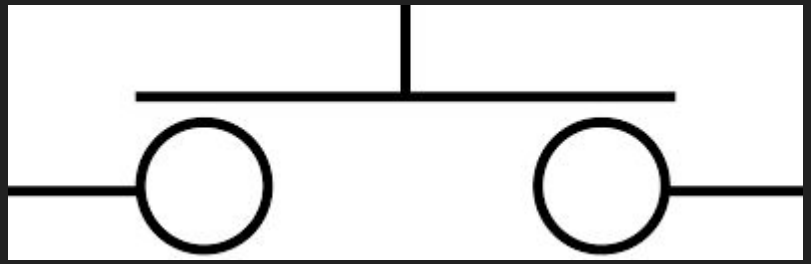
DPST - Double Pole Single Throw



DPDT - Double Pole Double Throw



Switches: Normally Open and Normally Closed

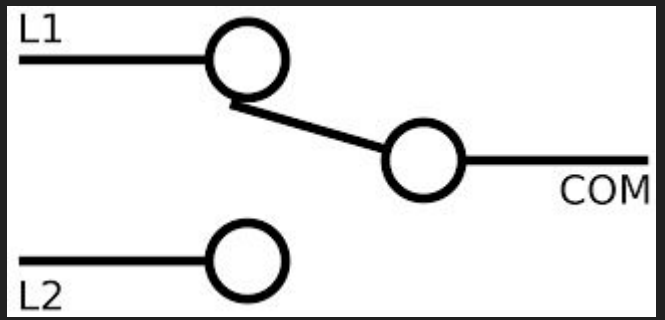


Button Switch: Normally Open

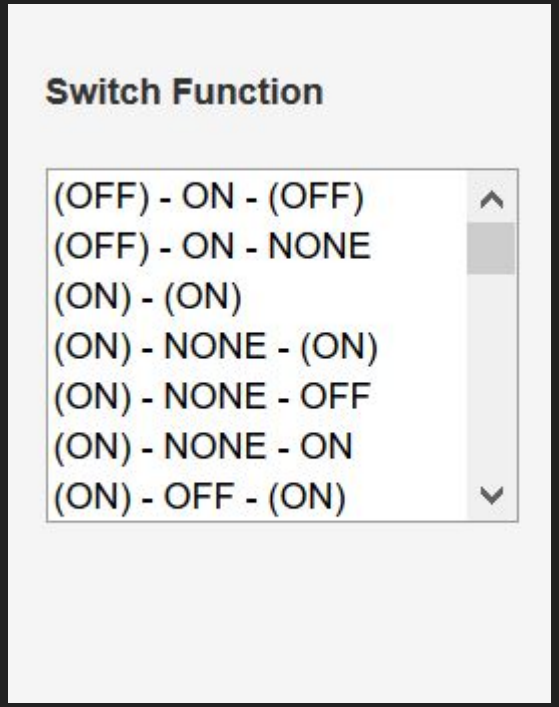
Button Switch: Normally Closed

Normally Closed N/C

Normally Open N/O

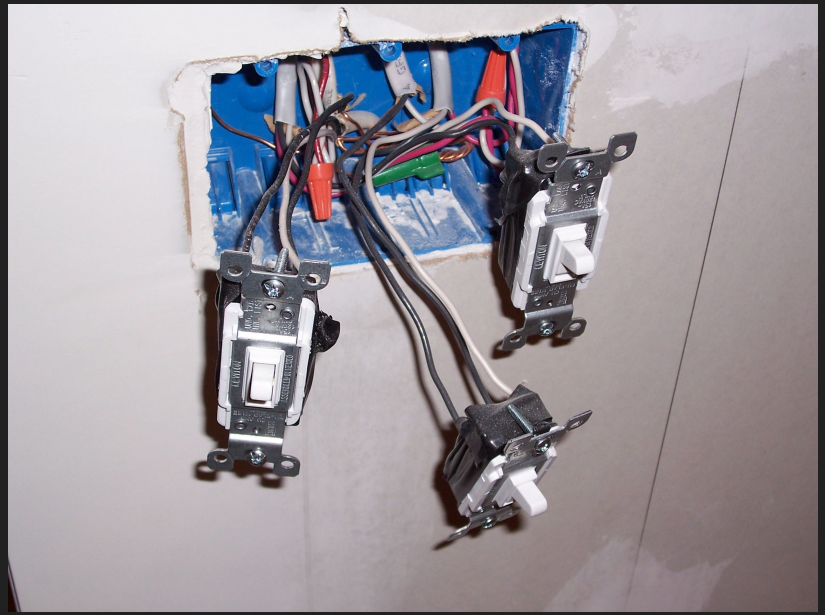


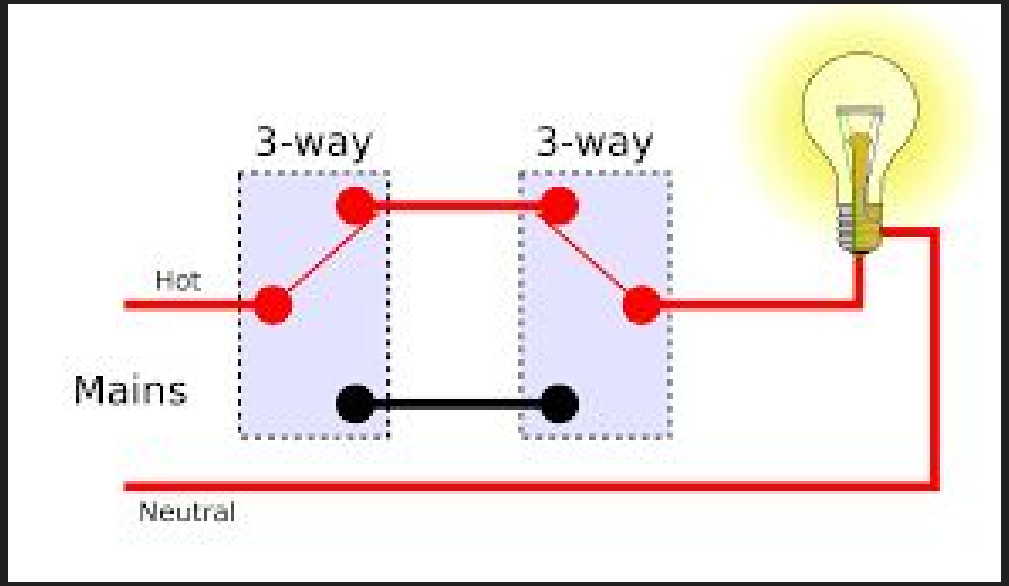
Switches: Momentary (ON) and Latching ON



Screenshot: Mouser.com

The Three-Way Lighting Switch





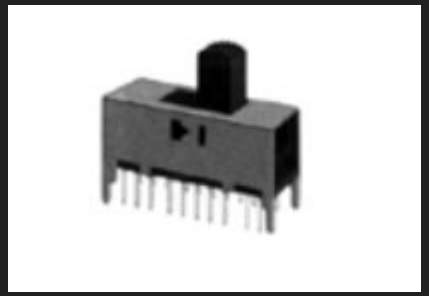
Fun with switches

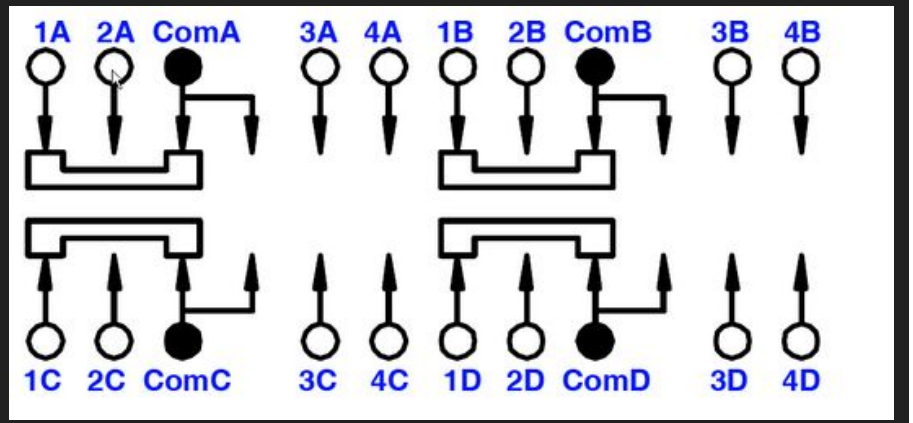
Can we have one temperature monitor look at 4 different sensors?

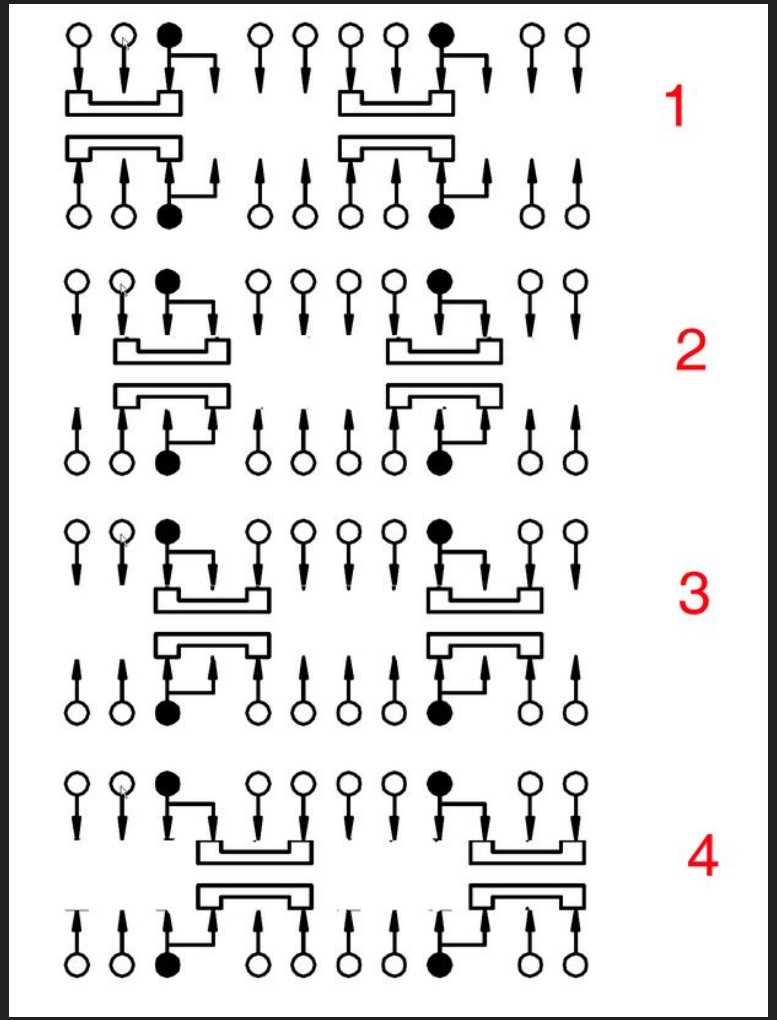
Fun with switches

SS44D04 Slide Switch

4P4T w/ 20 pins!







The Multimeter: Measuring Continuity

Measures whether two points are electrically connected: if there is *continuity*

Perform continuity test de-energized equipment

One of the most useful tests: diagnose breaks in wires, switch function, blown fuses, etc.

Part 2

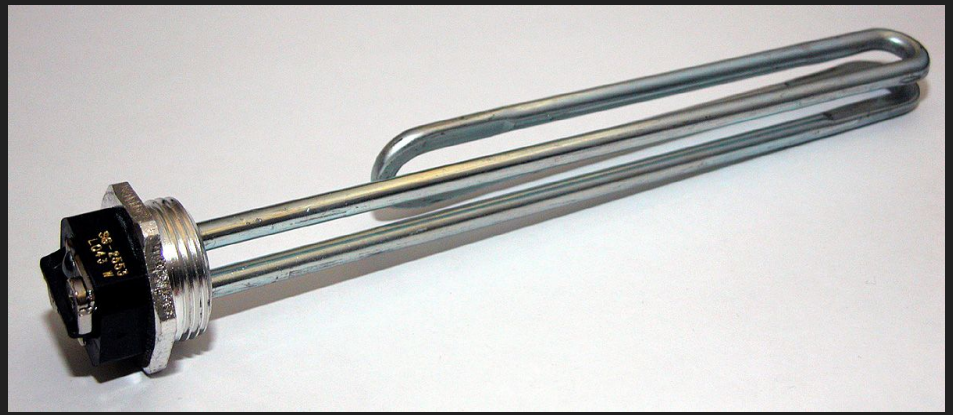
Safety, Electrical Loads, Control Voltage, And Relays

Working Safely around Electricity

- Know your environment: Dry, Well-lit, Clean
- Be awake, be aware
- Always completely de-energize, it helps to be redundant.
- Lockout/Tagout - label switches when others are present
- Redundancy of testing equipment - use a voltage tester, AND a multimeter
- Observe safety warnings, switches, disconnects - esp. after re-energizing
- Beware capacitors hold a charge
- When testing live circuits, especially high voltage:
    - One-Hand - don’t make a circuit across your chest! Know your limits!
    - Insulate from ground - this is why you see fiberglass ladders
    - Use insulated tools
    - Safety glasses
    - Know your limits!

Know your load: Resistive loads

- Convert Electricity to light and/or heat via Electrical Resistance
- Examples: Conventional light bulbs and Heating Elements
- Need to know:
  - Voltage rating (V)
  - Current demand (A) or (I)
- Watts: Volts X Amps



The Multimeter: Measuring Resistance

Resistance is measured in Ohms (Ω)

Select Ohms, and select range

Use both probes and measure resistance between two points on circuit

1 or OL indicates out of range

How many Watts?

Ohms Law:
V=IR or R=V/I or I=V/R

V= Voltage (measured in Volts)
I = Current (measured in Amps)
R = Resistance (measured in Ohms)

120V rated bulb

Measured 18 Ohms

How many Watts?

Ohms Law:
V=IR or R=V/I or I=V/R

V= Voltage (measured in Volts)
I = Current (measured in Amps)
R = Resistance (measured in Ohms)

120V rated bulb
18 Ohms resistance

Solve for 6.6 Amps
6.6 Amps x 120 Volts = **800 watt light bulb?**

How many Watts?

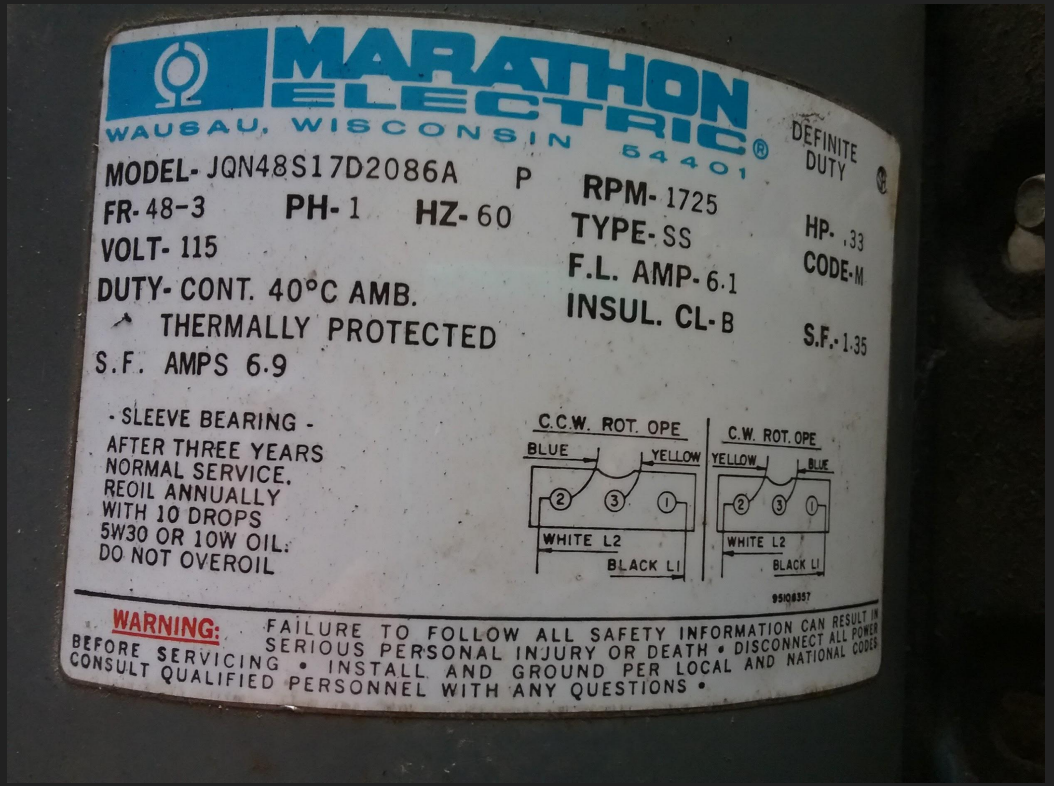
Solve for 6.6 Amps
6.6 Amps x 120 Volts = **800 watt light bulb?**

Resistance actually increases from measured 18 ohms to 240 ohms after it heats up

This 60W bulb actually uses .5 amps at 120 Volts.

Know your load: motors

- ‘Inductive’ Load
- Voltage
- Amperage
  - FLA
  - Surge/inrush current
  - SF amps
- Watts (Volts x Amps)
- Other:
  - Phase? Hz?
  - Intermittent duty?
  - Protected?
  - Reversible?



Fun with Switches: Motor Reversing

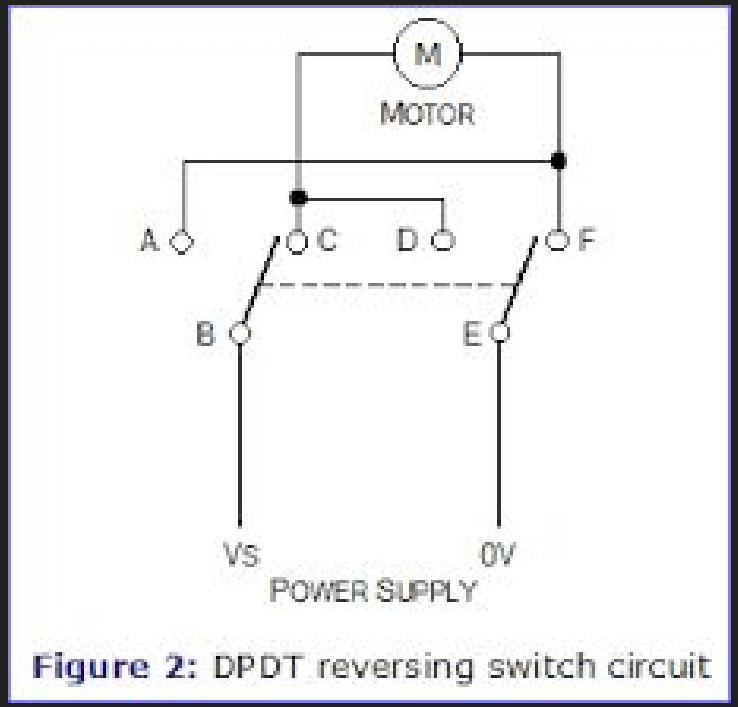
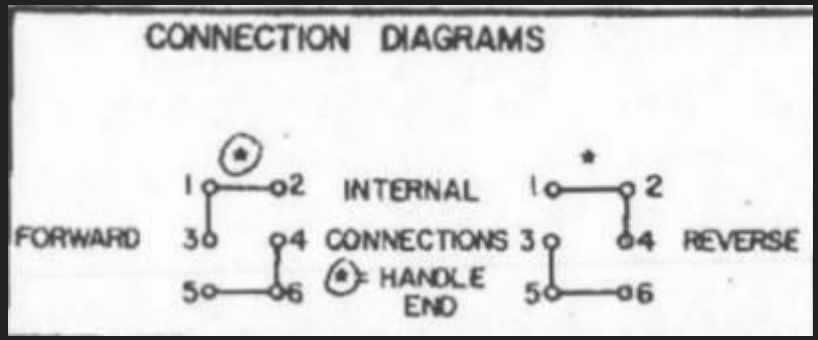


Figure 2: DPDT reversing switch circuit



Source: forum.allaboutcircuits.com

VFD: variable frequency drive

- Operate 3-phase motors from single phase source
- Primarily used for Speed control
- Reduced energy consumption when operating loads at lower speeds
- Controlled acceleration and torque
- Select a VFD that can tolerate motors max current under maximum torque demand
- Talk to an expert first

DC Power supplies


HON-KWANG
PLUG IN CLASS 2 TRANSFORMER
LISTED
69N0
E97199
LR 68048
NOM
166
NYCE
Made In China
MODEL NO : D12-50
INPUT : 120V 60Hz 15W
OUTPUT : 12VDC 500mA

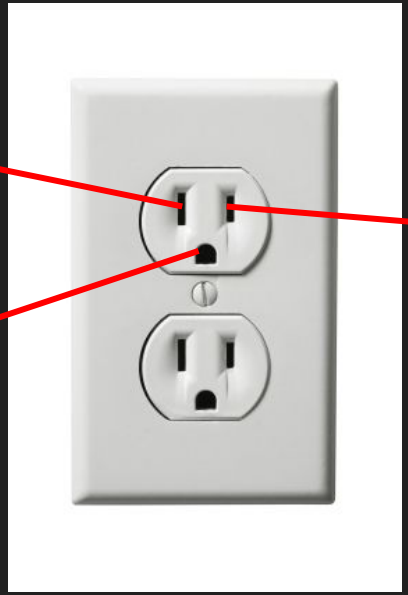
AC Power supply

For the scope of this workshop:
120V AC, Single Phase power

Two ‘legs’ combine for 240V AC

Typ. Residential and small commercial power

Each circuit - lighting, outlets, etc is protected by an overcurrent device.



Is it live? Using a multimeter to check voltage

- Select AC or DC
- Set Range at slightly higher than what you expect to measure
- Reduce range if necessary for more accurate results
- DC - Red is +, Black is -
- AC - Red/Black doesn’t matter
- Probe between two points: typically between test point and known ground
- 1 or OL indicates out of range

Be Safe! Be Redundant!

Low Voltage Controls

Inherently safer because of lower voltages

Smaller wires: more economical, easier installation

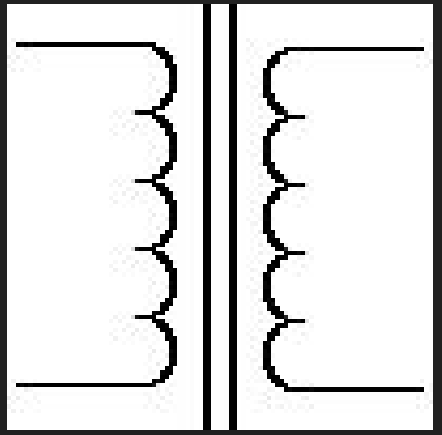
Typical residential applications: doorbells! Thermostats

24Vac typical. NEC specifies 49V or less AC as ‘Low Voltage’

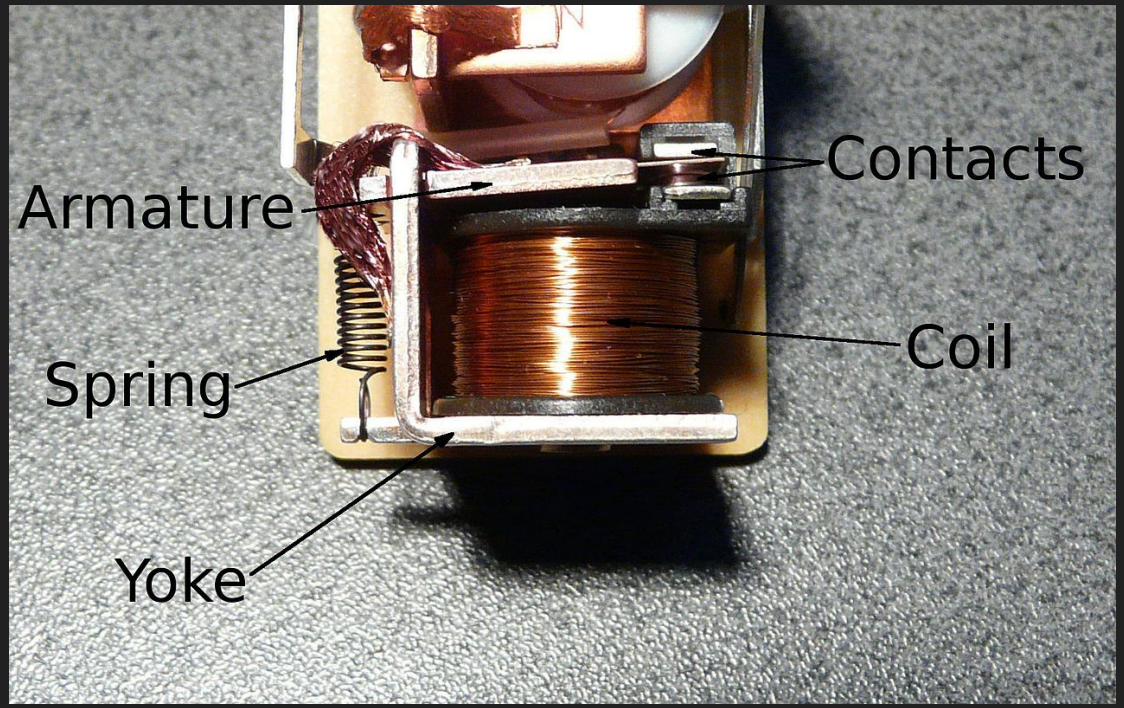
Further applications: specialty switches, timers, thermostats and humidity controls.. The list goes on!

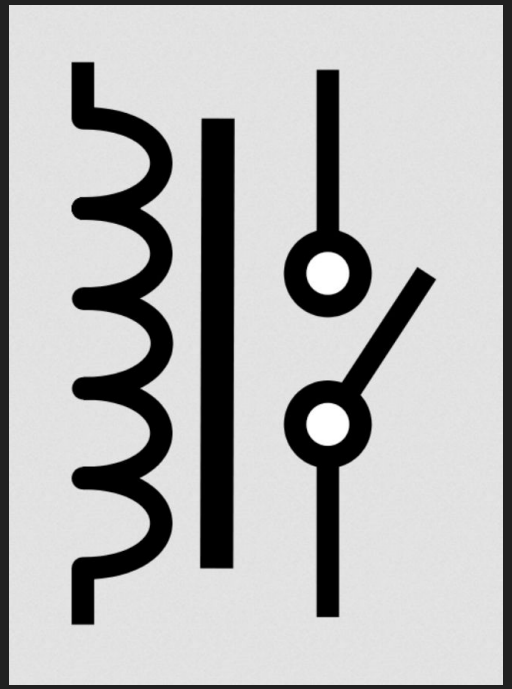
Transformers

- Labeled by Primary and Secondary windings.
- 40 VA rated 24VAC ‘Doorbell’ transformers are very common for control voltage
- Pri: 120V, Sec: 24V
- We’ll use ‘Step-Down’ transformers
- Step-up transformers: microwaves, spark transformer



Relays!

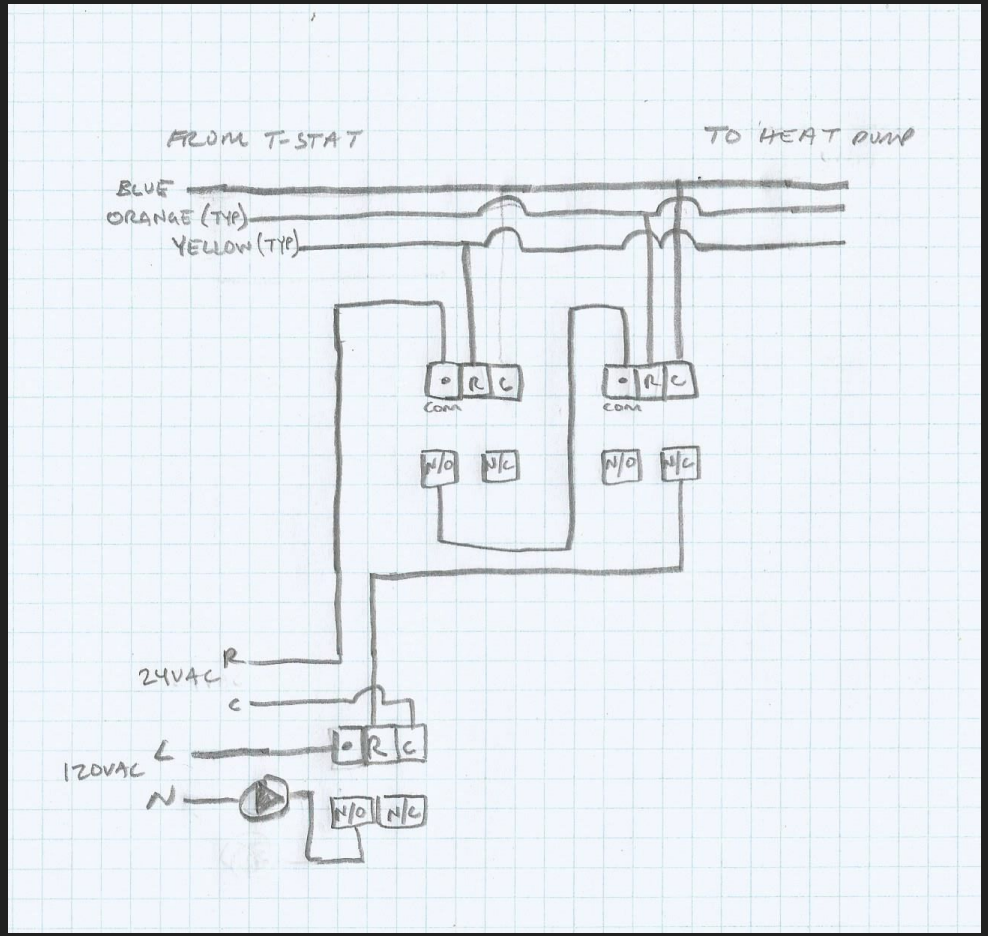


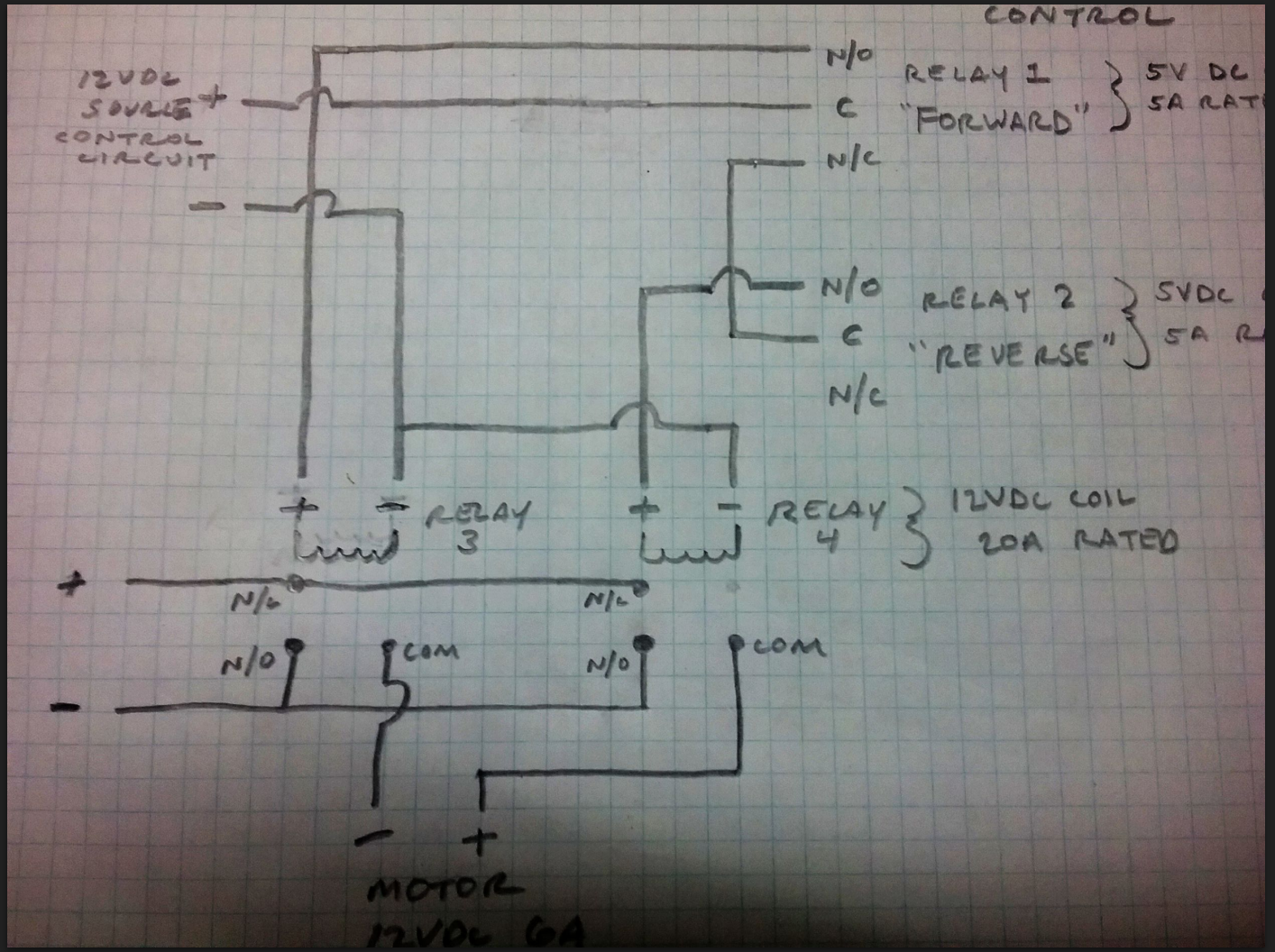



12V/ INT


SONGLE
10A 250VAC 10A 125VAC
10A 30VDC 10A 28VDC
SRD-12VDC-SL-A

Fun with Relays




CONTROL
12VDC SOURCE
CONTROL CIRCUIT
+
−
N/O
C
N/C
RELAY 1
"FORWARD"
5V DC
5A RAT
N/O
C
N/C
RELAY 2
"REVERSE"
5VDC
5A R
+
−
RELAY 3
+
−
RELAY 4
12VDC COIL
20A RATED
+
−
N/C
N/C
N/O
COM
N/O
COM
−
+
MOTOR
12VDC 6A

Solenoids, SSRs, Contactors: similar, but different

Solenoid: refers to electromagnetic action

Used in relays and valves

Source: Adafruit.com

Solid State Relay: functions same as mechanical relay, with no mechanical parts.

Reliable, fast, and capable of switching at much lower voltages

Source: sparkfun.com

Contactor: electromagnetic action, reserved for large load switching.

Typ. as large motor starter w/ modular design - add thermal, more contacts, 3-phase switching.

Source: Omega.com

Part 3

Circuit Protection and Ready-Made Controllers

Using a multimeter: recap

https://www.youtube.com/watch?v=SECWePatYjY

Using a multimeter: Measuring Amperage

‘Clamp’ meter is necessary for anything but the smallest current measurements

Select AC or DC, Select Range

Affordable AC clamp meters are common: very useful

Affordable DC clamp meters are harder to find: useful for troubleshooting battery systems: solar, auto, etc

Overcurrent Protection

- Protect people and equipment from fire and electric shock
- Designed to fail, when current exceeds it's interrupting rating
- Built-in 'weak link'

Select a fuse based on:

- Voltage Rating. System voltage must be less than rated voltage on fuse.
- Overload protection: ballpark 125% or 150% of normal operating current. Ex. 10A motor? Use 15A protection. 'Fuse protects the wire" see: 'ampacity'
- Use Time delay fuses for inductive loads (motors, transformers, coils)
- Use Fast Acting fuses for resistive loads (heaters, incandescent bulbs)
- Interrupting rating: find an electrician. Err on the high side.
- Lesson learned? **Best to replace blown fuses w/ identical fuse or Get Help**

Wire Sizing: Ampacity

The Maximum current carrying capacity of a conductor (wire)

Larger wires: higher ampacity

Pay attention to the details:

- Wire insulation
- # of wires bundled together
- Wire material: Cu or Al

Wire Size and Amp Ratings

	Copper			Aluminum	
Wire Gauge Size	60°C (140°F) NM-B, UF-B	75°C (167°F) THW, THWN, SE, USE, XHHW	90°C (194°F) THWN-2, THHN, XHHW-2, USE-2	75°C (167°F) THW, THWN, SE, USE, XHHW	90°C (194°F) XHHW-2, THHN, THWN-2
14	15	15	15	---	---
12	20	20	20	15	15
10	30	30	30	25	25
8	40	50	55	40	45
6	55	65	75	50	55
4	70	85	95	65	75

Undersized wires means risk of Fire! Do not go this alone!

When doing repairs - replace with same wire or larger!

Pay attention to wire type: UV rated? Direct Burial rated?

‘Ready-made’ Controllers

Combine sensing element and relay switching for simple automated controls

Look for input voltage and amperage requirements

Look for ratings at switch: voltage, and maximum switching amps

Pay attention to environmental ratings: Can it be used in humid environment? Etc.

Electronic or mechanical action? Will it store presets if power goes out? - Pay attention to these details found in the spec sheet or brochure.

Following are a few of my low-cost favorites we use around Living Web Farms

PECO TF115-001

- Simple and Rugged, Affordable
- NEMA 4x housing: can be sprayed (not submerged) with water
- Operable at multiple voltages
- Bimetallic sensor req’s no outside power source
- Not very accurate, especially at low temps
- Great greenhouse thermostat
- SPDT operation:
  - Normally open and Normally Closed contacts
  - Switch for heating or cooling operation

Programmable Thermostats

- Typically powered with 24 volts
- More sophisticated operation
- May be multiple relays packed in there
- May offer remote temperature sensor
- Unconventional installation?
  - Pay attention to environmental ratings
  - Not likely to withstand humid environments over time

Setpoint Controllers: Ranco ETC-111000

- Single-Stage Temperature Control
- Comes in many voltage options
- Open on Rise (close on fall)
  - Heating applications: switch opens at setpoint point or above
- Close on Rise (open on fall)
  - Cooling applications: switch closes at setpoint or above
- Programmable Differential
  - Range where no action is taken
  - Overcome ‘short cycling’
  - Typically low mass heating systems have higher differential

- Open on Rise (close on fall)
  - Heating applications: switch opens at setpoint point or above
- Close on Rise (open on fall)
  - Cooling applications: switch closes at setpoint or above

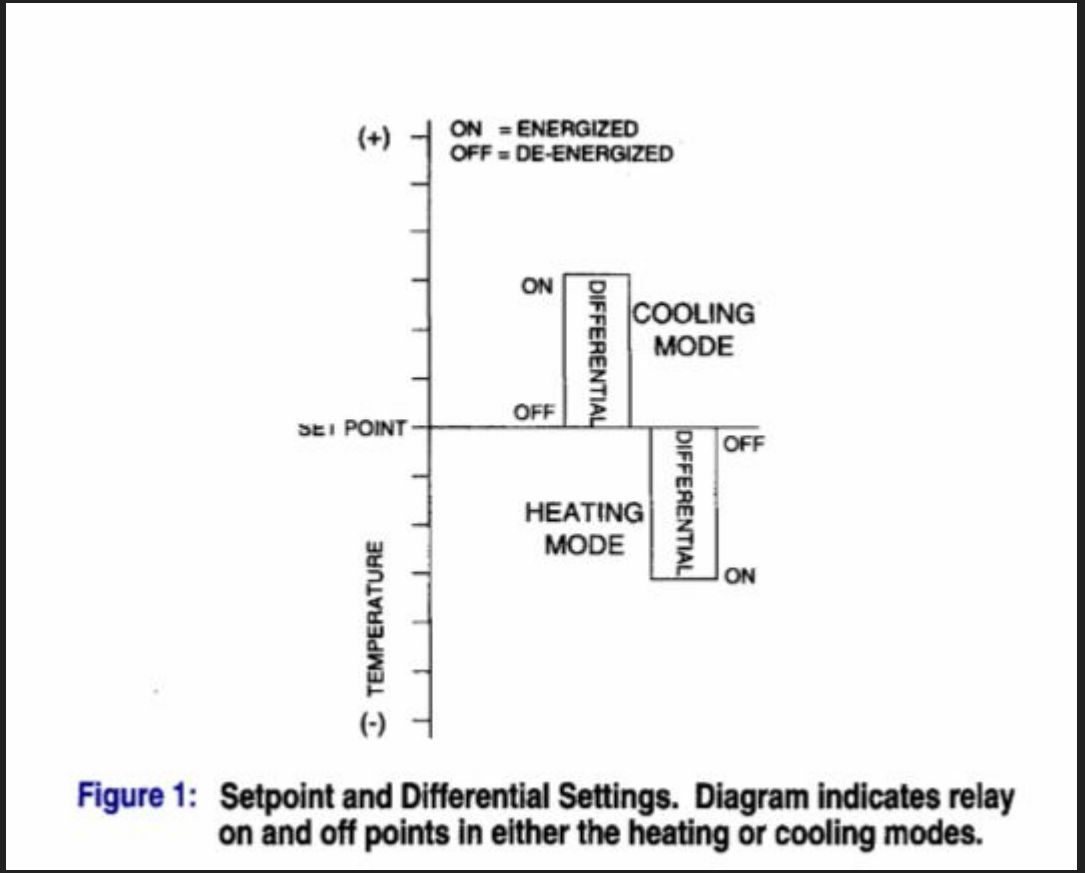


Figure 1: Setpoint and Differential Settings. Diagram indicates relay on and off points in either the heating or cooling modes.

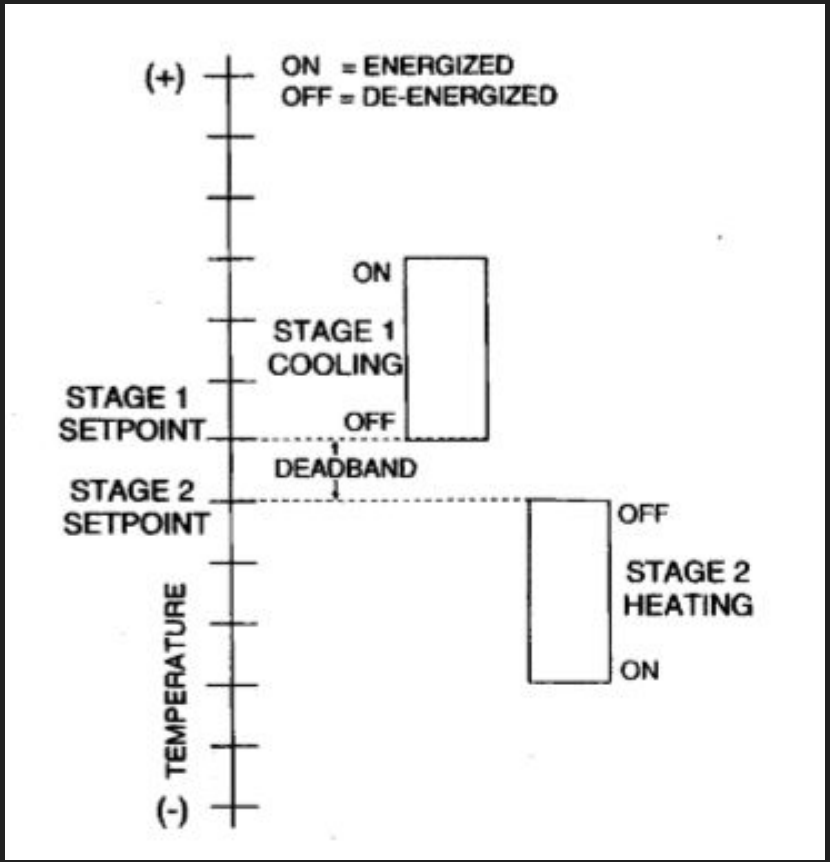
Screenshot: Ranco ETC111000 Installation Manual

2 stage setpoint control: Ranco 211/212 series

2 relay outputs for operating two devices

Huge variety of applications

Still limited to single sensor



Humidistat

Similar operation as Thermostat, switching is usually based on **relative humidity** (temperature compensated).

Willhi WH1463: very cheap, pre-wired outlet

1%-100% Relative humidity, accurate to 1%

Remote sensing option

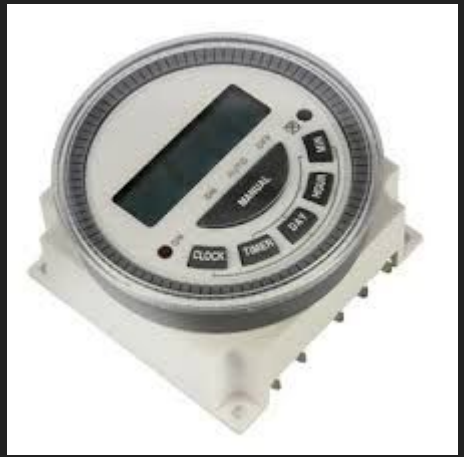
Humidify/Dehumidify option

Timers: TM-619 Programmable clock timer

- Up to 8 different programmable on/off settings
- Optional power sources: 12VDC, 24,120,240VAC
- Range from hours and seconds.
- Battery backup, retains programs and current time

Examples:

- Used to limit operation of humidity controlled ventilation fans in our solar kiln
- Used to operate compost tumbler: on for only 5 seconds, twice a day.
- Commonly used for animal feed dispensing, security, chicken coop door



Timers: Peltec 102

Repeat Cycle (recycle) timer

Single Relay, n/o and n/c contact

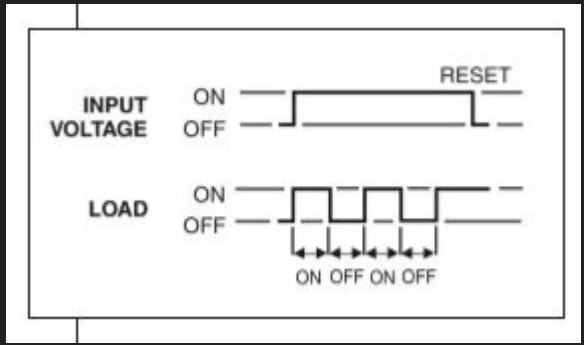
Universal input voltage in single unit

Separate programmable on and off time

Range from .1 seconds to 100 days

Example:

- Buzzer control on overheat/overflow alarm
- Spray bar control on germination trials



Specialty Controllers: some of my favorites

- Differential Temperature controller
  - Mostly used for solar heating applications
  - We use these for controlling pumps that draw heat from our storage tanks, in our biochar facility heating system.
- PID
  - For “continuously modulated control”
  - Common DIY applications are paired with resistive heating for constant temperature control
- Honeywell R8184N
  - Oil Burner ignition control: will shut down process in the absence of light (no flame)
  - We use these on our Pyrolysis oil burner mods
- Rain Bird SMRT-Y Soil Moisture Sensor Kit
  - Interrupts 24V signal to irrigation solenoid, if soil is already at a user-defined moisture setpoint
  - Simple, robust, and doesn’t require internet connections like other ‘smart’ irrigation controllers

Big League Controls: Microcontrollers, PLC + Beyond

Arduino Microcontrollers: electronics prototyping platform

Very Affordable components, huge network of online help

Programmable in C+ via open source Arduino IDE software

PLC: Programmable Logic Controllers

Workhorse of industrial automation

Typically proprietary hardware/software with ladder logic programming

AutomationDirect.com has affordable units with lots of training videos