More details on inductive loads, current coasting, and flyback voltage.

Now consider turning the load off—this time with a flyback diode present.

At a particular time the switch opens.
Suppose the switch successfully stops the current.
For the inductor $v = L(di/dt)$ but as the current declines the voltage v builds up until it switches the flyback diode on. Now the voltage across the load is clamped by the diode to practically zero. This is an LR series circuit.

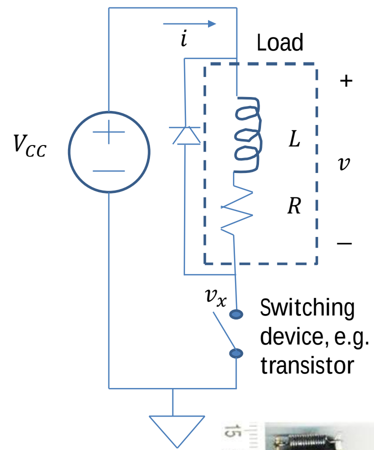
$$i(t) = \frac{V_{CC}}{R} e^{-\left(\frac{R}{L}\right)t}$$

Thus the current dies away exponentially to practically zero in a few milliseconds (typically).

KVL around the loop gives the voltage across the switch contacts.

$$-V_{CC} + 0 + v_x = 0$$
$$v_x = V_{CC}$$

Folks, this is safe!



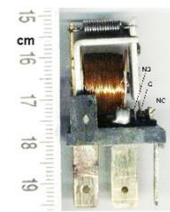


Photo: Wikimedia Commons, public domain

1

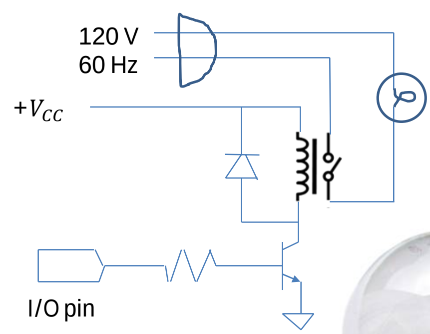
Controlling really powerful loads, AC loads, etc. using a relay.

The light bulb draws too much current and operates at too high a voltage to drive it with a transistor, so drive it with a relay.

The relay coil draws too much current to drive with a pin, so drive it with a transistor. Be sure to use a flyback diode.

The transistor needs a current limiting resistor in series with the base lead.

Notice: there is no electrical connection between the 120 V AC system and the logic system. This is a significant safety advantage that a relay can offer, regardless of power levels.



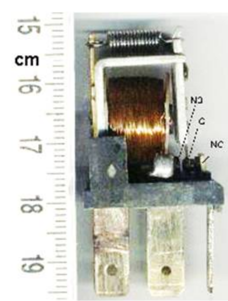


Photo of relay: Wikimedia Commons, public domain
Photo of light bulb: Wikimedia commons, CC BY-SA 3.0

2

Types of switching devices and relative advantages

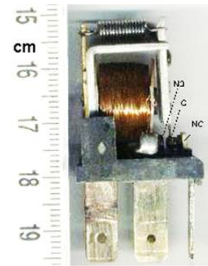
Relay
aka Contactor ("Contactor" means "big relay.")

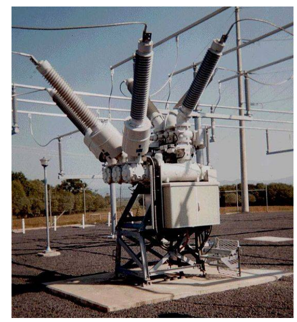
--Switching action is from "armature" (moves) to "pole" (stationary)
--Electromagnet controls on-off action.
--Coil needs quite a bit of current. MOSFET or BJT usually needed
--Practically any voltage and current rating imaginable is available.
--Physical sizes range from a grain of rice to living-room+ size.

--Slow. Small "fast" relays can maybe do 1000 cycles per second.
Common ones can do about 2 or 3 Hz but will wear out fast
Big "Contactors" might not be able to do more than 2 or 3 cy per hr.
--There is mechanical wear on the contacts, hinges, etc. Life is limited to a rated number of cycles, e.g. thousands to millions of cycles.

--Switch is nearly ideal.
Practically no on resistance, practically infinite off resistance.

--Thousands or even a million volts of ground isolation possible.
This is a very compelling reason to use a relay or contactor





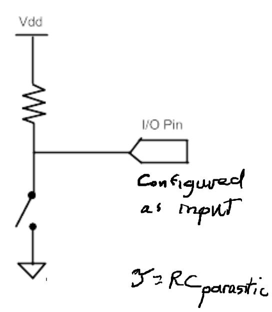
Top photo: Wikimedia Commons, public domain
Bottom photo: Wikimedia Commons, used by permission GNU Free Documentation License
Schematic: Wikimedia Commons, public domain

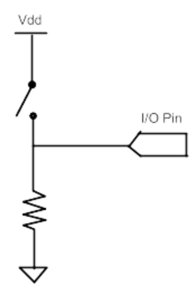
3

Digital input from a switch

Open switch (as shown) for logic-1.

Close switch for logic-1.





Typical resistor value is 10 kohms up to 100 kohms.
Higher values save power.
Lower values give faster logic transitions.

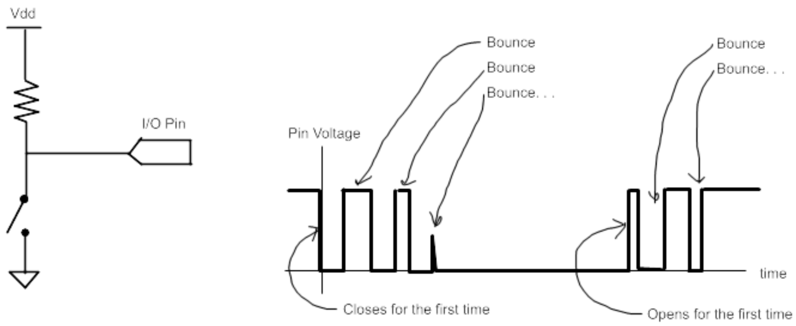
4

Digital input from a switch

Bouncing typically lasts 1 to 100 ms. Most switches bounce for about 10 to 30 ms.

Switch bounce is a factor.

Humans feel that pushbuttons act sluggishly if they do not respond within 30 to 70 ms. (A few people can notice a 30 ms delay. Practically everyone will notice a 70 ms delay.)



Monkey Debouncing: https://www.youtube.com/watch?v=Nj-Q8FQxHhU

5

Debounce Techniques--must choose one

Software--read multiple times, accept the value after it has been stable a prescribed amount of time (one to thirty ms typically).

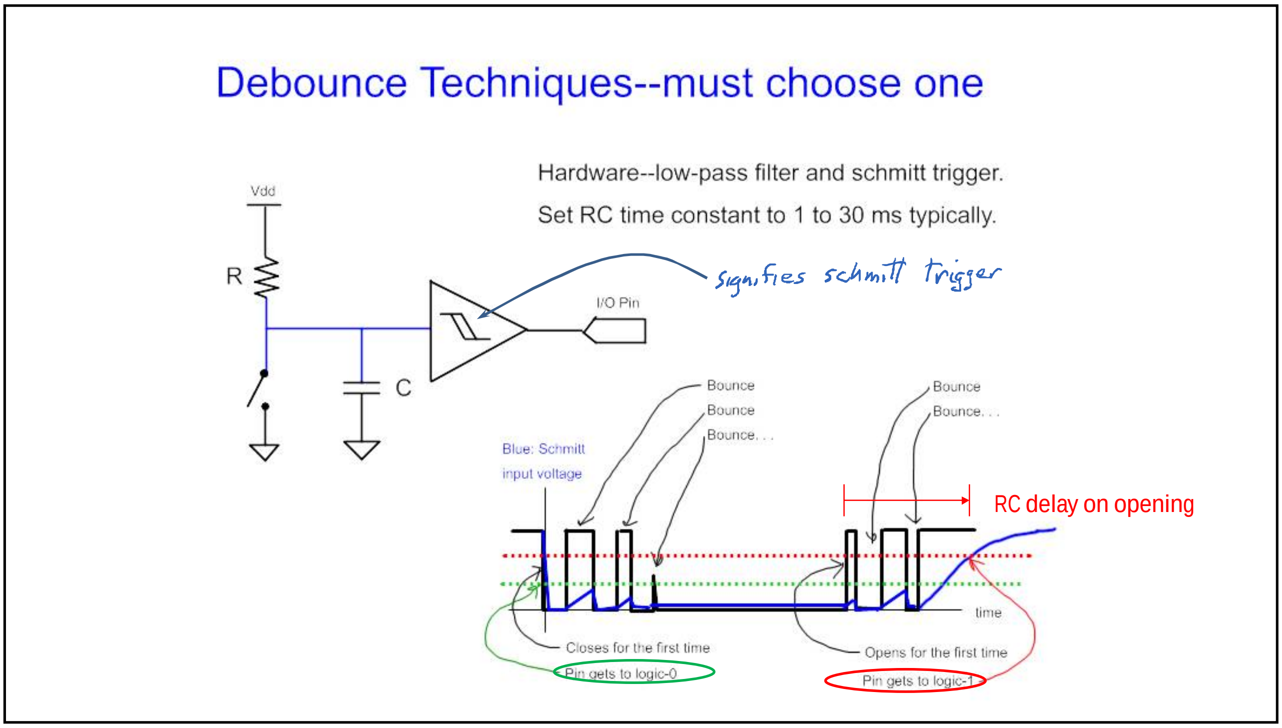
Pseudo code:

```
Procedure read_the_switch(value)
start timer
old = read(switch)
while timer <10 ms
  new = read(switch)
  if new not equal old
    old = new
    restart timer
  end if
end while
return(old)
```

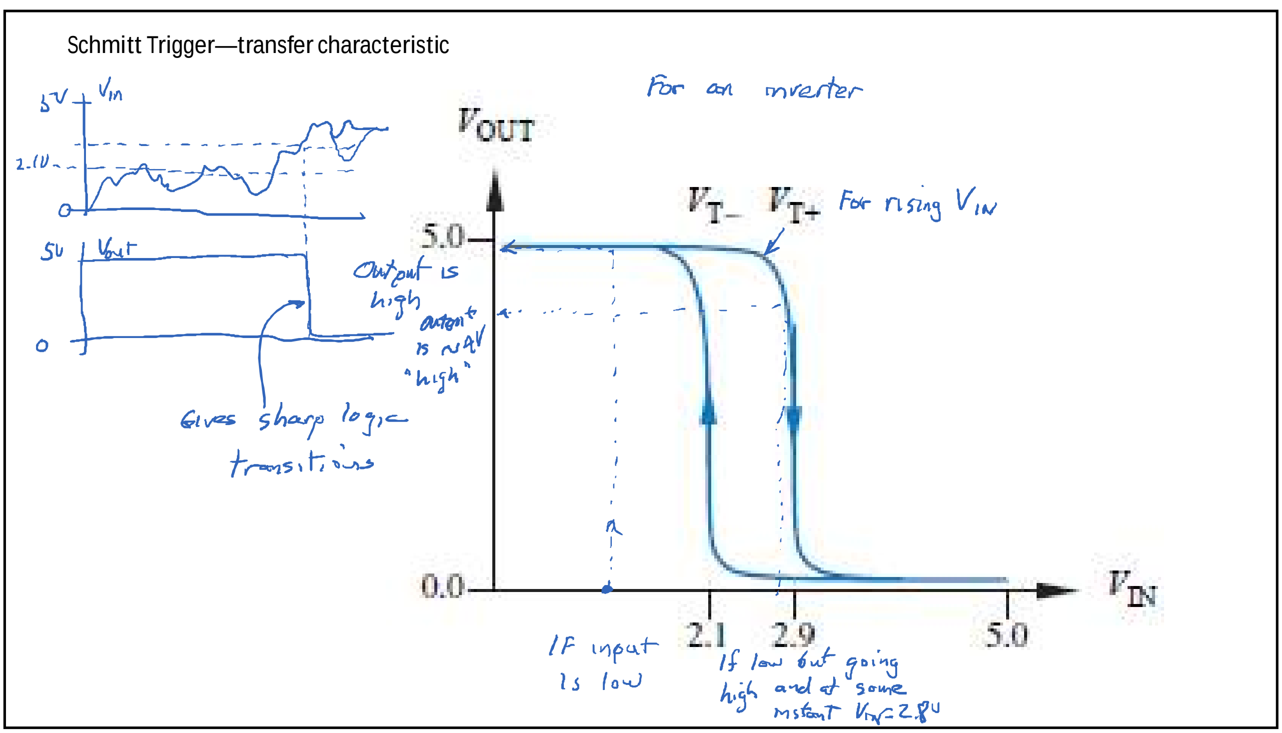
This, and variations of it to prevent the loop from hanging, is the most popular technique. It imposes a delay between the mechanical action of the switch and the ability of the software to recognize the intent of the action.

Note a risk: If switch chatters forever (vibration?) the while loop will hang.

6


Debounce Techniques--must choose one
Hardware--low-pass filter and schmitt trigger.
Set RC time constant to 1 to 30 ms typically.
signifies schmitt trigger
Vdd
R
C
I/O Pin
Bounce
Bounce
Bounce. . .
Bounce
Bounce. . .
Blue: Schmitt input voltage
RC delay on opening
time
Closes for the first time
Pin gets to logic-0
Opens for the first time
Pin gets to logic-1

7


Schmitt Trigger—transfer characteristic
For an inverter
5V
Vin
2.1V
0
5V
Vout
0
Output is high
output is ~4V "high"
Gives sharp logic transitions
VOUT
5.0
0.0
VT−
VT+
For rising VIN
VIN
2.1
2.9
5.0
If input is low
If low but going high and at some instant VIN=2.8V

8

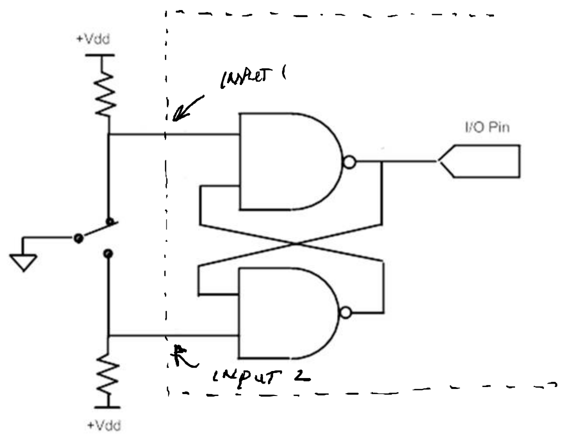
Debounce Techniques--must choose one

Both of the previous techniques cause significant delay.
In cases where that matters, try this:

Best technique if fast action is needed.

But, requires extra hardware.

(Or use two input pins and emulate the latch with software—still extra hardware.)



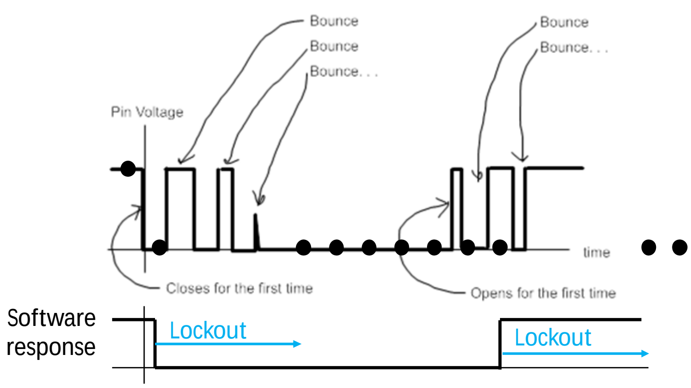
9

Debounce Techniques--must choose one

There are various other debouncing techniques.

In hardware: Various RC filters are possible.
Various arrangements of diodes can augment RC filters
Specialized "switch debounce" buffers are available.

In Software: "Lock-out" strategies. These respond to the very first change, then ignore the switch for the bounce interval.



10

Sensors

Most sensors are detecting quantities that are fundamentally. . .

continuous in time and. . .

continuous in value (or magnitude).

Converting such signals to digital is amazingly full of pitfalls for the novice. (Nontrivial task.)

https://pixabay.com/photos/wind-sock-wind-direction-anemometer-4027894/
https://pixabay.com/illustrations/thermometer-summer-heiss-heat-sun-4767443/
https://pixabay.com/photos/odometer-speedometer-dash-dashboard-1285292/

11

Sensors—Linearity (or lack thereof)

In most situations it is ideal if. . .
the digital representation of an analog physical quantity is linearly related to the analog quantity.

Let $f\big(x(t)\big)$ represent the digital value of the analog physical quantity $x(t)$
here t is the independent variable, often time, but it can be distance or anything else, at least in theory.
Ideally we usually desire

$$f\big(x(t)\big) = ax(t)$$

where a is a constant scalar of proportionality.
This is a *linear* relationship using the conventional definition of "linearity iff superposition applies."

12

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where a is a constant scalar of proportionality.
This is a *linear* relationship using the conventional definition of "linearity iff superposition applies."

Often the digital version of the signal will offset by some constant value, a bias.

$$f(x(t)) = ax(t) + b$$

This may appear to be a linear equation (by a high-school definition saying that this very equation is the definition)!
But the " $+\ b$" portion of the equation causes superposition to fail. This this is technically not a linear relationship.
This equation is mathematically known as an *affine function*.

Every linear function is also an affine function (with $b = 0$).

However, since the bias is constant, it can usually be accounted for in software, giving affine relationships almost equal usefulness as linear equations. (Hence perhaps the lack of distinction of this matter at the high-school level.)

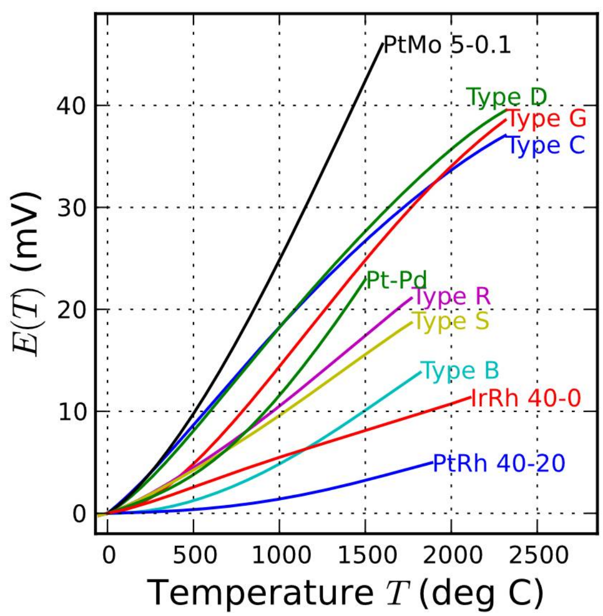
13

Sensors—Linearity (or lack thereof)

Example: Thermocouples

The relationship between temperature and voltage produced by a thermocouple is shown here for various types of thermocouples.

Clearly some are more linear than others.



https://commons.wikimedia.org/wiki/File:High_temperature_thermocouples_reference_functions.svg

14

Sensors—Linearity (or lack thereof)

Example: Thermocouples

The relationship between temperature and voltage produced by a thermocouple is shown here for various types of thermocouples.

Clearly some are more linear than others.

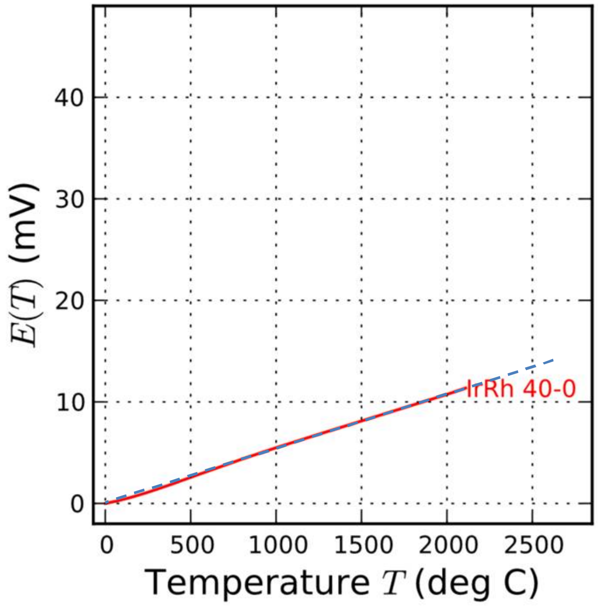
Looking at just the curve for the IrRh 40-0 t-couple, Observe two points and create a linear equation:
The two points are $T = 0, E(0) = 0$ and $T = 2000$ C and $E(2000) = 11$ mV

Let $a = \frac{11 \text{ mV}}{2000 \text{ C}}$ and then $E(T) = aT$

A linear model of the sensor.

Usually we want to find the temperature from the voltage. No problem. . . We love linearity.

$$T = E(T)/a$$



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15

Sensors—Linearity (or lack thereof)

Example: Thermocouples

The relationship between temperature and voltage produced by a thermocouple is shown here for various types of thermocouples.

Clearly some are more linear than others.

Looking at just the curve for Type G. . .
If we restrict our use to temperatures between about 750 C and 1750 C we can use an affine model.
Two points: $T = 750$ C, $E(T) = 10$ mV and
$T = 1750$ C, $E(T) = 30$ mV
Two-point formula of a line:

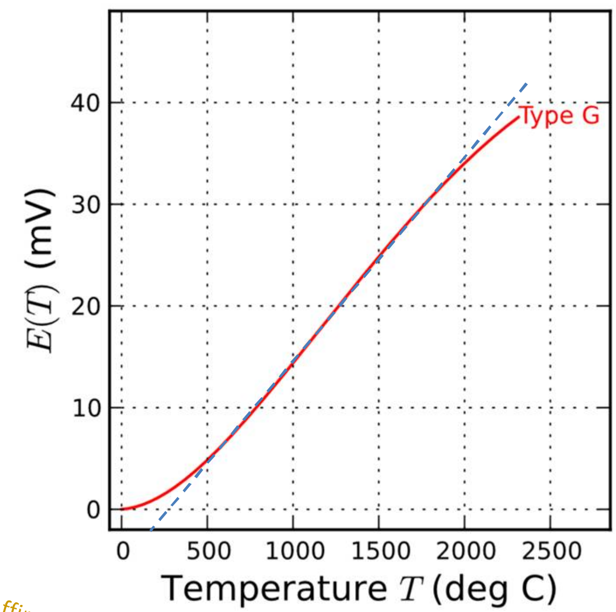
$$y = \frac{y_2 - y_1}{x_2 - x_1}(x_{-x_1}) + y_1$$

$$E(T) = \frac{T - (750\text{ C})}{(50\text{ C/mV})} + (10\text{ mV})$$

or

$$T = \left(50\frac{\text{C}}{\text{mV}}\right)[E - (10\text{ mV})] + (750\text{ C})$$

Affine is fine too.



https://commons.wikimedia.org/wiki/File:High_temperature_thermocouples_reference_functions.svg

16

Sensors—Linearity (or lack thereof)

Example: Thermocouples

The relationship between temperature and voltage produced by a thermocouple is shown here for various types of thermocouples.

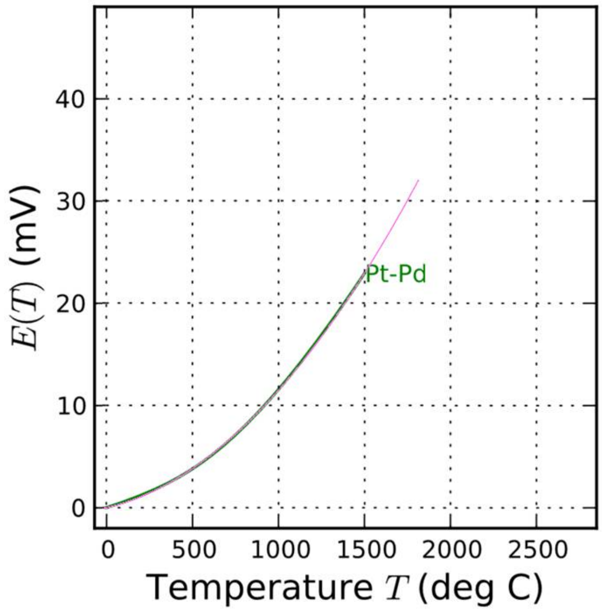
Clearly some are more linear than others.

Hmm. . . Could try a parabolic model.
Need three points
T = 0, $E(T)$ = 0; T = 500 C, $E(500)$ = 4 mV; T = 1500 C, $E(1500)$ = 23 mV
Do a parabolic curve fit.
https://mycurvefit.com/

$E(T) = 0.004333333T + 0.000007333333T^2$
Where T is in C and $E(T)$ is in mV.

Now use the quadratic formula to solve for T given E
Let a = 0.000007333333, b = 0.004333333

$$T = \frac{-b + \sqrt{b^2 + 4aE}}{2a}$$



It's getting messy

https://commons.wikimedia.org/wiki/File:High_temperature_thermocouples_reference_functions.svg

17

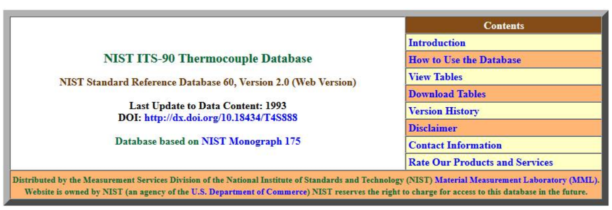
Sensors—Linearity (or lack thereof)

Example: Thermocouples

The relationship between temperature and voltage produced by a thermocouple is shown here for various types of thermocouples.

Clearly some are more linear than others.

In addition to the formulaic relationships so far discussed, there is the strategy of using a lookup table. These have been standardized by governments. In the USA, see NIST's thermocouple database.
https://srdata.nist.gov/its90/main/


NIST ITS-90 Thermocouple Database

NIST Standard Reference Database 60, Version 2.0 (Web Version)

Last Update to Data Content: 1993
DOI: http://dx.doi.org/10.18434/T4S888

Database based on NIST Monograph 175

Contents
- Introduction
- How to Use the Database
- View Tables
- Download Tables
- Version History
- Disclaimer
- Contact Information
- Rate Our Products and Services

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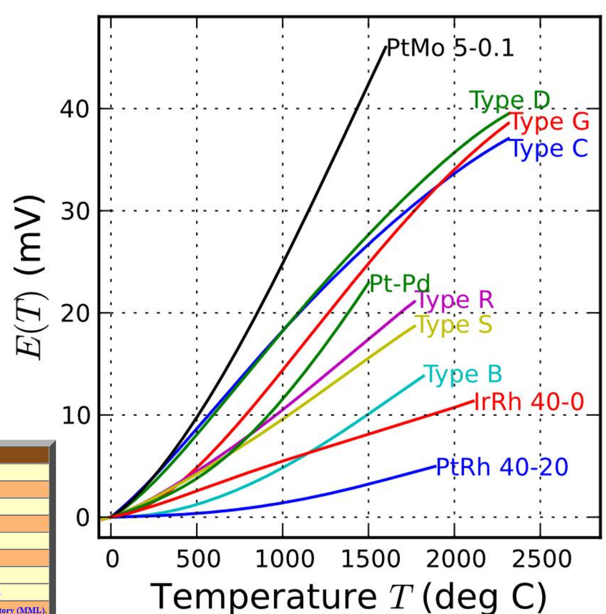
Website is owned by NIST (an agency of the U.S. Department of Commerce) NIST reserves the right to charge for access to this database in the future.



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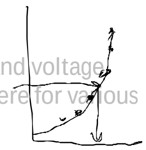
18

Sensors—Linearity (or lack thereof)

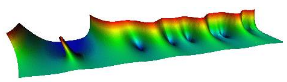
Example: Thermocouples



The relationship between temperature and voltage produced by a thermocouple is shown here for various types of thermocouples.

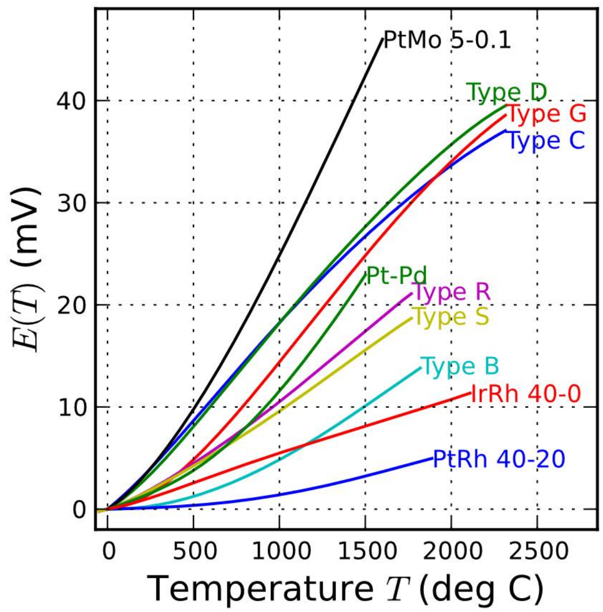
Clearly some are more linear than others.

If you are doing the table-lookup method, then you should also know about various strategies for interpolation between table givens. Linear interpolation is considered poor relative to the accuracy tables should be able to give you. Use a higher –order method. Again, NIST is a standard resource for this. https://dlmf.nist.gov/



NIST Digital Library of Mathematical Functions

NIST's mathematical resources were pioneered by Abramowitz and Stegun.
https://en.wikipedia.org/wiki/Abramowitz_and_Stegun
Available in Dordt's library, QA3.U5, lower level shelves.



https://commons.wikimedia.org/wiki/File:High_temperature_thermocouples_reference_functions.svg

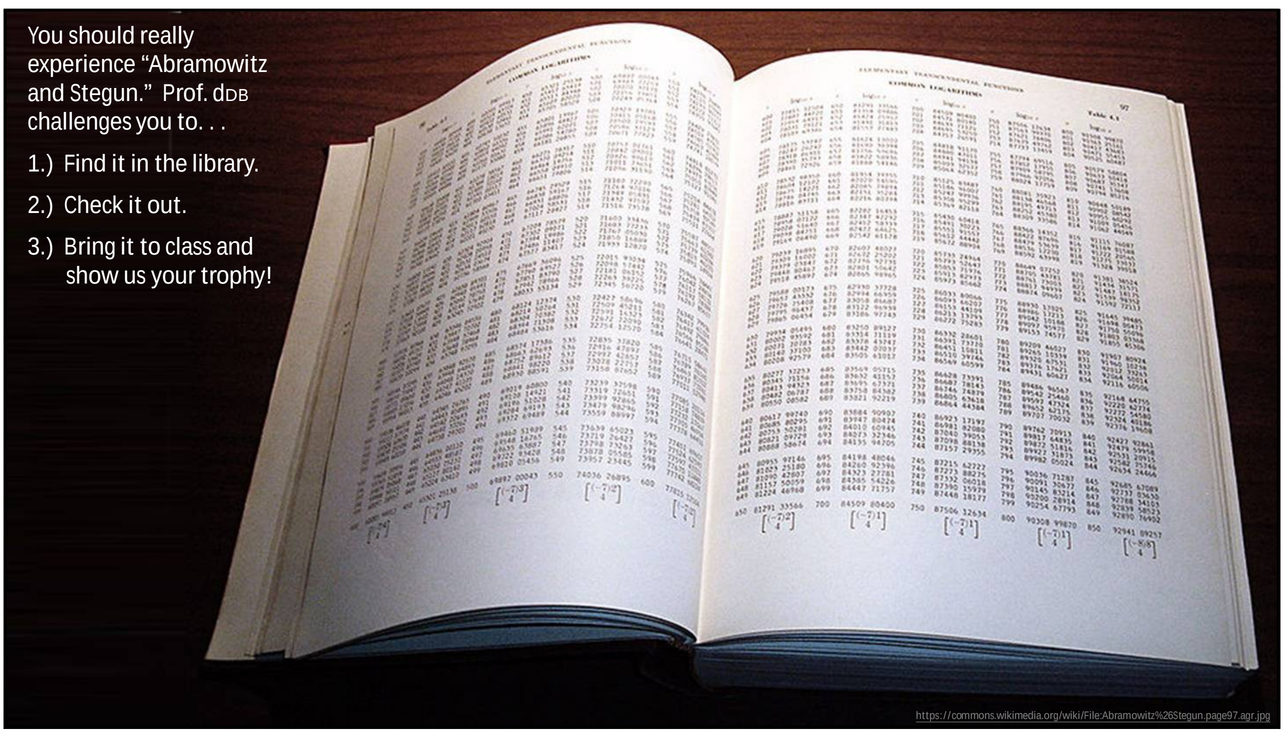
19

You should really experience "Abramowitz and Stegun." Prof. dDB challenges you to. . .

1.) Find it in the library.

2.) Check it out.

3.) Bring it to class and show us your trophy!



https://commons.wikimedia.org/wiki/File:Abramowitz%26Stegun.page97.agr.jpg

20

Sensors—Linearity (or lack thereof)

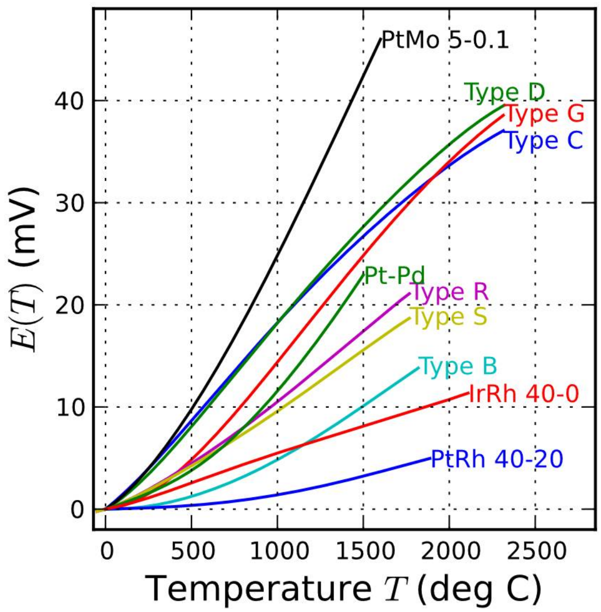
Example: Thermocouples

The relationship between temperature and voltage produced by a thermocouple is shown here for various types of thermocouples.

Clearly some are more linear than others.

The main point:

You need to understand the sensor at hand.
Understand your model too.
Model it appropriately in the software.



https://commons.wikimedia.org/wiki/File:High_temperature_thermocouples_reference_functions.svg

21

Sidebar item: Decibels

Coming up—characteristics of analog sensors.
In some contexts the units of *decibels* are used with analog quantities.

Def'n: A *bel* is the base-ten log of the ratio of two amounts of power.

Example
Cell phone speaker: 0.1 W of power when streaming loud music.
Rock concert: 100 kW of power to the loudspeakers.
(need a generator on an 18-wheeled trailer.)

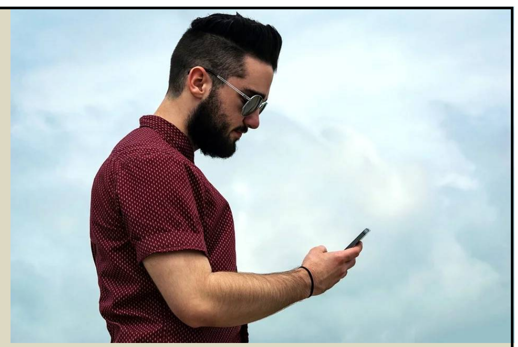
$$\log_{10}\left(\frac{100000}{0.1}\right) = \log(1000000) = 6 \text{ B}$$

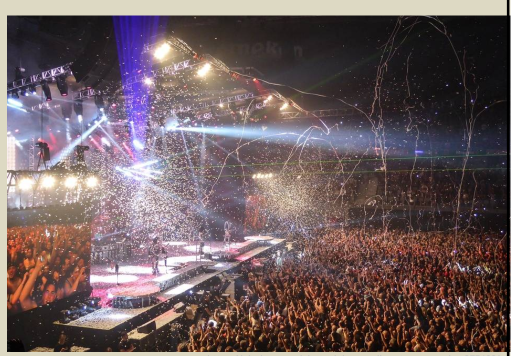
The rock concert requires 6 bels more power.

Def'n: A decibel is 1/10 of a bel.

$$10\log_{10}\left(\frac{100000}{0.1}\right) = 60 \text{ dB}$$

The rock concert requires 60 dB more power.





https://pixabay.com/photos/phone-cell-customer-service-875488/
https://pixabay.com/photos/concert-music-rock--n--roll-819149/

22

Sidebar item: Decibels

Decibel represents a *power* ratio.

If the units are watts, BTU/hr, horsepower, (any unit of *power*) and numerator and denominator have the same units, then. . .

$$\text{Ratio in dB} = 10\log_{10}\left(\frac{P_1}{P_{ref}}\right)$$

But very often the units are not watts!

Say the units are volts.

We know that $P = VI$ and that $I = V/R$ thus $P = V^2/R$

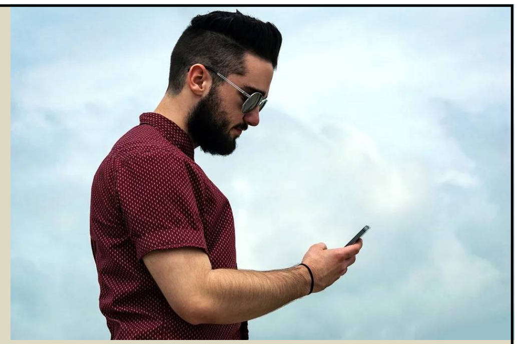
Put that in the decibel formula!

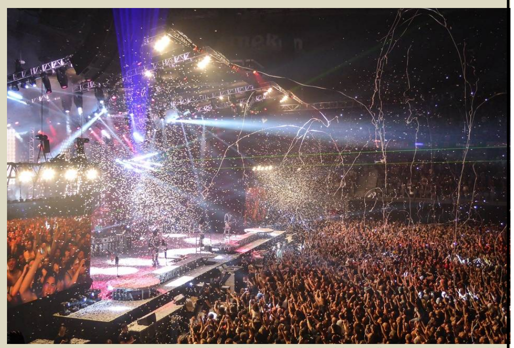
$$\text{Ratio in dB} = 10\log_{10}\left[\frac{(V_1^2)/R)}{(V_{ref}^2/R)}\right] = 20\log\left(\frac{V_1}{V_{ref}}\right)$$

This works with practically all signal units that are NOT POWER.

Thus, if units are power, use 10 $\log_{10}(power\ ratio)$

If units are not power, use 20log_10$(not\ a\ power\ ratio)$





https://pixabay.com/photos/phone-cell-customer-service-875488/
https://pixabay.com/photos/concert-music-rock--n--roll-819149/

23