More discussion on Active and Passive Sensors:

- ***An active sensor*** is a sensing device that requires an external source of power to operate; active sensors contrast with passive sensors, which simply detect and respond to some type of input from the physical environment.

- In the context of remote sensing, an active sensor is a device with a transmitter that sends out a signal, light wavelength or electrons to be bounced off a target, with data gathered by the sensor upon their reflection.

- Active sensors are also widely used in manufacturing and networking environments for example to monitor industrial machines or data center infrastructure so anomalies can be detected and components can be repaired or replaced before they break and shut everything down.

- ***Examples of other active sensor-based technologies include***: scanning electron microscopes, radar, GPS, x-ray, sonar, infrared and seismic. However, as can be the case with some sensors, seismic and infrared light sensors exist in both active and passive forms.

- ***A passive sensor*** is a device that detects and responds to some type of input from the physical environment.

- Passive sensor technologies gather target data through the detection of vibrations, light, radiation, heat or other phenomena occurring in the subject's environment.

- They contrast with active sensors, which include transmitters that send out a signal, a light wavelength or electrons to be bounced off the target, with data gathered by the sensor upon their reflection.

- Sensors can also be used in harsh environments and places inaccessible to people.

- ***Examples of passive sensor-based technologies include***: Photographic, thermal, electric field sensing, chemical, infrared and seismic. However, as can be the case with some sensors, seismic and infrared light sensors exist in both active and passive forms.

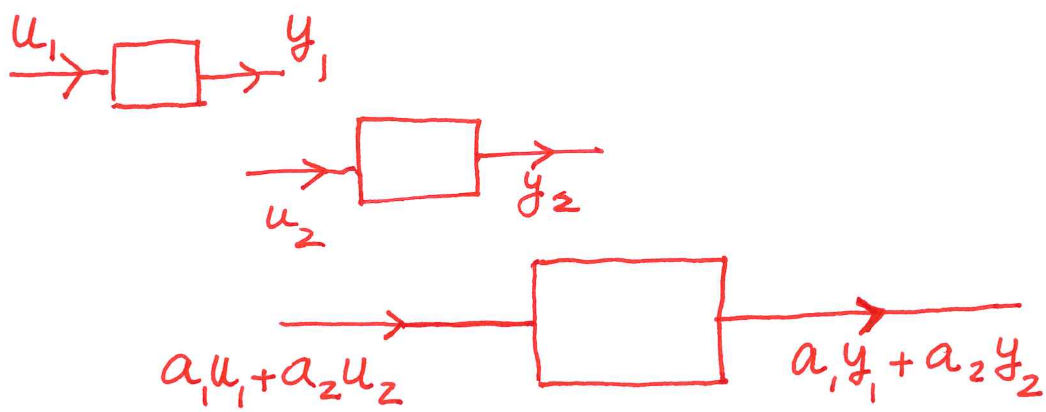
Linearizing Devices:

- Nonlinearity is present in any physical device, to varying levels.

- If the level of nonlinearity in a system (component, device, or equipment) can be neglected without exceeding the error tolerance, then the system can be assumed linear.

- Linear system is one that can be expressed as one or more linear differential equations.

- Note that the principle of superposition holds for linear systems.



Nonlinearities in a system can appear in two forms:

- 1. Dynamic manifestation of nonlinearities
- 2. Static manifestation of nonlinearities

Cases:

- The useful operating region of a system can exceed the frequency range where the frequency response function is flat. The operating response of such a system is said to be dynamic.
  - Examples include a typical control system (e.g., automobile, aircraft, milling machine, robot), actuator (e.g., hydraulic motor), and controller (e.g., proportional-integral-derivative or PID control circuitry).

- Nonlinearities of such systems can manifest themselves in a dynamic form such as the jump phenomenon (also known as the fold catastrophe), limit cycles, and frequency creation.

Solutions for dynamic manifestations of nonlinearity:

- Design changes, extensive adjustments, or reduction of the operating signal levels and bandwidths would be necessary in general, to reduce or eliminate.

Is that a good Solution?

- In many instances, such changes would not be practical, and we may have to *somehow cope with the presence of these nonlinearities* under dynamic conditions.

- Design changes might involve:

  - Replacing conventional gear drives by devices such as harmonic drives to reduce backlash.

  - Replacing nonlinear actuators by linear actuators, and

  - Using components that have negligible Coulomb friction and that make small motion excursions.

What is Coulomb Friction?

- Coulomb friction is a simplified quantification of the friction force that exists between two dry surfaces in contact with each other.

- All friction calculations are approximations, and this measurement is dependent only on the fundamental principles of motion.

- It assumes that the contact surfaces are fairly uniform and that the coefficient of friction that must be overcome for motion to begin is well-established for the materials in contact.

What about Static Manifestations:

- Making design changes and adjustments, as in the case of dynamic devices.

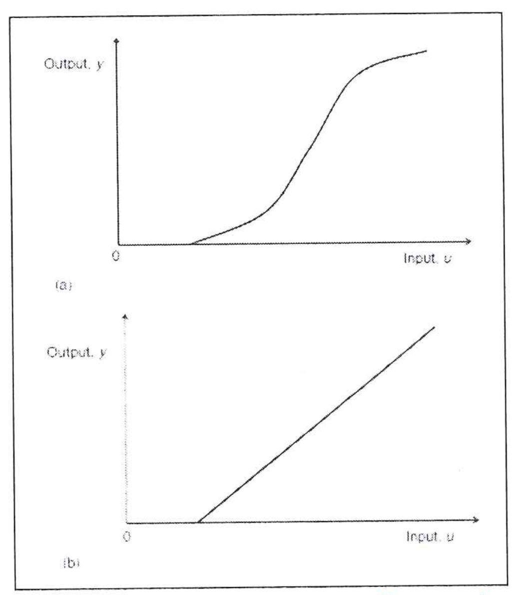
- Since the response is static, and since we normally deal with an available device (fixed design) whose internal hardware cannot be modified,

- We should consider ways of linearizing the input/output characteristic by ***modifying the output*** itself.
    - Linearization using digital software
    - Linearization using digital (logic) hardware
    - Linearization using analog circuitry

- **In the software approach to linearization:**
    - Output of the device is read into a digital processor with software-programmable memory
    - ***And the output is modified*** according to the program instructions.

- **In the hardware approach:**
    - Output is read by a device with ***fixed logic circuitry for processing (modifying)*** the data.

- **In the analog approach:**
    - A ***linearizing circuit is directly connected at the output of the device***, so that the ***output of the linearizing circuit is proportional to the input*** to the original device.



Simple Curve: Add DC

DC component will convert the characteristics into Linear form given by: $y = ku$

This method is called offsetting: Can't use for More Complex Curves.

Software based linearization:

Assuming that the nonlinear relationship between the input and the output of a nonlinear device is known, the input can be computed for a known value of the output.

In the software approach of linearization, a processor and memory that can be programmed using software (i.e., a digital computer) is used to compute the input using output data.

non-Linear charactri's given by

$$y = f(u) : u \to \text{device input}, \quad y \to \text{device output}$$

Assuming one-one Relation, Inverse Equation

$$u = f^{-1}(u)$$

Analysis:

- Flexible - Linearization algorithm can be modified (e.g., improved, changed) simply by modifying the program stored in the RAM.
- Highly complex nonlinearities can be handled by the software method.
- Relatively slow.

Linearization by Hardware Logic:

- Hardware logic method:
  - Linearization algorithm is permanently implemented in the IC form using appropriate digital logic circuitry for data processing and memory elements (e.g., flip-flops).

- However, ***algorithm and numerical values of parameters*** (except input values) cannot be modified without redesigning the IC chip, because a hardware device typically does not have programmable memory.

- Difficult to implement very complex linearization algorithms –Mass chip production, initial chip development cost? Testing for our needs only?

- Lack of Flexibility - A digital linearizing unit with a processor and a read-only memory (ROM), whose program cannot be modified, also lacks the flexibility of a programmable software device.

Table Look up: Fast, Accurace $\propto$ Amount of stored data
Memory Intensive; Increased Accuracy Vs. Speed & Memory Requirements.

Analog Linearizing Circuitry

Three types of analog linearizing circuitry can be identified:

- Offsetting circuitry
- Circuitry that provides a proportional output
- Curve shapers

Offsetting circuitry:

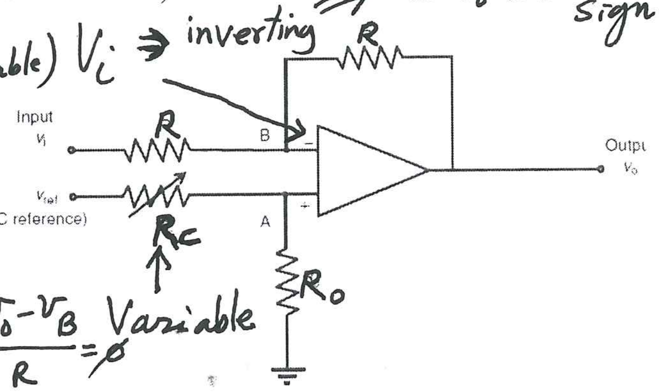
- An offset is a nonlinearity that can be easily removed using an analog device.
- Adding a dc offset of equal value to the response, in the opposite direction. Deliberate addition of an offset in this manner is known as offsetting.
- The associated removal of original offset is known as offset compensation.
- Example:
  - Results of ADC and DAC can be removed by analog offsetting.
  - Constant (dc) error components, such as steady-state errors in dynamic systems due to load changes, gain changes, and other disturbances, can be eliminated by offsetting.

Easiest Approach - Use Summer Op-Amp (Add or subtract)

V_{ref} : Provides offsetting Voltage (Variable) V_i ⇒ inverting ⇒ input will appear in V_o with reversed sign.

R_c : Compensator (Variable)

Current balancing Equation: Node-A



Node-A

$$\frac{V_{ref} - V_A}{R_c} = \frac{V_A}{R_o}$$

(1) — $$V_A = \left(\frac{R_o}{R_o + R_c}\right) V_{ref}$$

Node-B

$$\frac{V_i - V_B}{R} + \frac{V_o - V_B}{R} = 0$$

OR

$$V_o = -V_i + 2V_B \quad \text{— (2)}$$

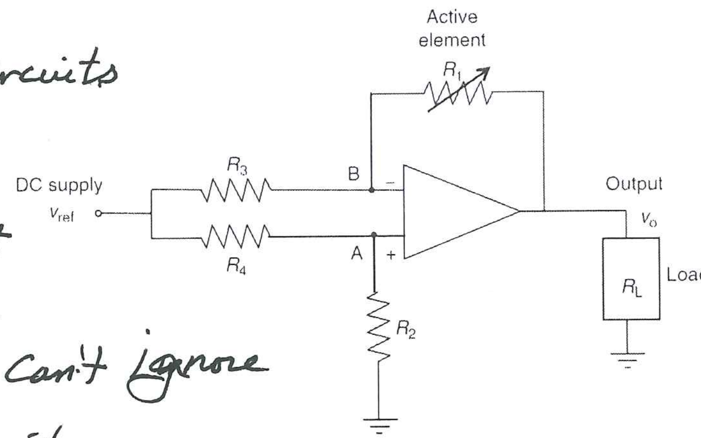
Since $V_A = V_B$ for op-Amp we can substitute (1) into (2)

$$\therefore \quad V_o = -V_i + \frac{2R_o}{(R_o + R_c)} V_{ref}$$

Can be reversed @ input or connecting to other circuitry and recovering

offsetting term by chosing R_c.

Proportional-Output Circuitry:



- Recall $\frac{\delta v_o}{V_{ref}}$, $\frac{\delta R}{R}$ in bridge Circuits
- If $\delta R << R$: Non linear Circuits can be linearized without introducing large errors.
- If δR is not Small Vs R: Can't ignore

Solution: Linearize the circuit.

Node-A | **Node-B**

$$\frac{V_{ref}-V_A}{R_4}=\frac{V_A}{R_2} \; ; \qquad \frac{V_{ref}-V_B}{R_3}+\frac{V_o-V_B}{R_1}=0$$

$$\frac{V_{ref}}{R_4}-\frac{V_A}{R_4}=\frac{V_A}{R_2} \; ; \qquad \frac{V_{ref}}{R_3}-\frac{V_B}{R_3}+\frac{V_o}{R_1}-\frac{V_B}{R_1}=0$$

$$V_A=\left(\frac{R_2}{R_2+R_4}\right)V_{ref} \; ; \qquad V_B=\frac{R_1 V_{ref}+R_3 v_o}{R_1+R_3}$$

Since $v_A=v_B$.

$$\frac{R_1 V_{ref}+R_3 V_o}{(R_1+R_3)}=\frac{R_2}{(R_2+R_4)}V_{ref}$$; Cross Multiplying

$$\frac{R_2(R_1+R_3)}{R_2+R_4}v_{ref}=R_1 V_{ref}+R_3 V_o$$

$$R_3 V_o=\frac{R_2(R_1+R_3)}{R_2+R_4}V_{ref}-R_1 V_{ref}$$

$$R_3 V_o=\frac{(R_2R_1+R_2R_3-R_1R_2-R_1R_4)V_{ref}}{R_1+R_4}$$

$$\therefore\; V_o=\left(\frac{R_2R_3-R_1R_4}{R_1+R_4}\right)V_{ref}$$; Similar to wheatstone bridge output.

Wheatstone Equation 2.88 (text) $v_o = v_A - v_B = \frac{R_1 v_{ref}}{(R_1+R_2)} - \frac{R_3 v_{ref}}{(R_3+R_4)} = \frac{(R_1R_4 - R_2R_3)}{(R_1+R_2)(R_3+R_4)} v_{ref}.$

$$V_0 = \frac{R_2R_3 - R_1R_4}{R_3(R_2+R_4)} v_{ref}$$

$V_0 = 0$ if $R_1 = R_2 = R_3 = R_4 = R$ (in beginning).

∴ Circuit is balanced

Let's change R_1 by δR

$$\delta V_0 = \frac{R^2 - (R+\delta R)R}{R(R+R)} v_{ref} - 0$$

$$\text{or } \delta V_0 = \frac{R^2 - R^2 - R\delta R}{2R^2} v_{ref}$$

$$\frac{\delta v_o}{v_{ref}} = -\frac{R\delta R}{2R^2} = -\frac{\delta R}{2R}.$$

$$\therefore \frac{\delta v_o}{v_{ref}} = -\frac{1}{2}\frac{\delta R}{R}$$

Clearly $\delta v_0 \propto \delta R$

Sensitivity $(\frac{1}{2})$ is twice that of wheatstone $(\frac{1}{4})$ with one active element.