EE352 Automatic Control

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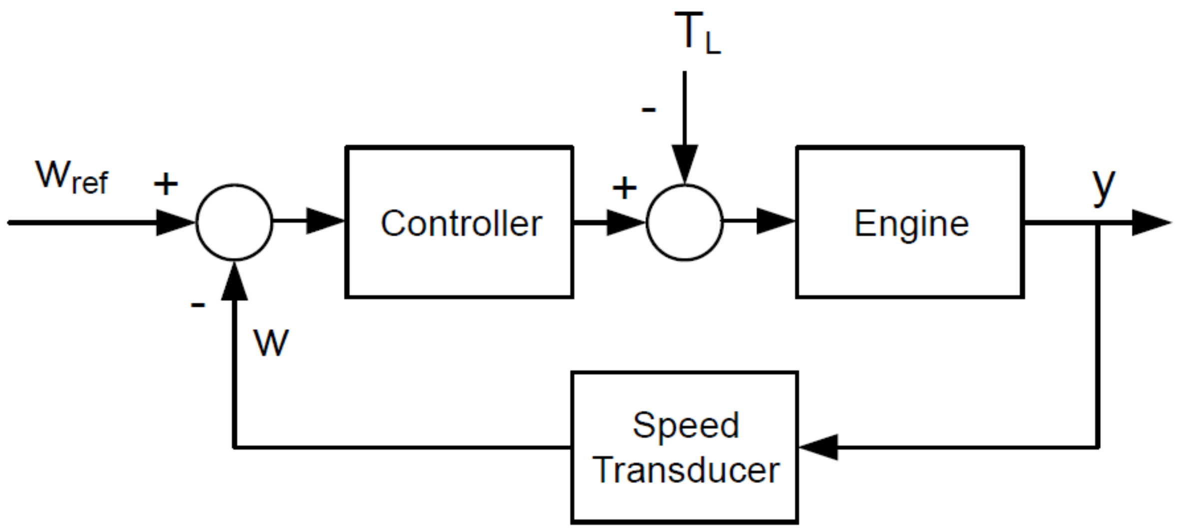
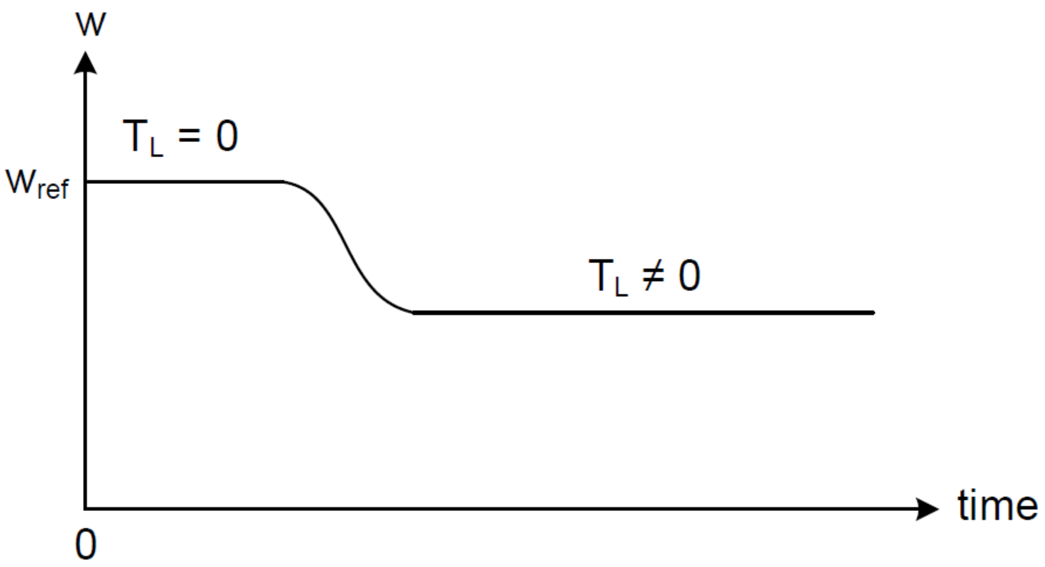
What is feedback?

- It is the process of using a known measurable parameter, to correct an error between reference input and the system output or to improve the overall performance of the system.
- Feedback is said to exist when there exists a closed sequence of cause and effect.
- In most of the cases, it is a more complex process than just reducing the error because once the feedback is introduced it can influence many other characteristics of the system such as
  - Stability,
  - Bandwidth,
  - Overall gain,
  - Disturbance rejection
  - etc.

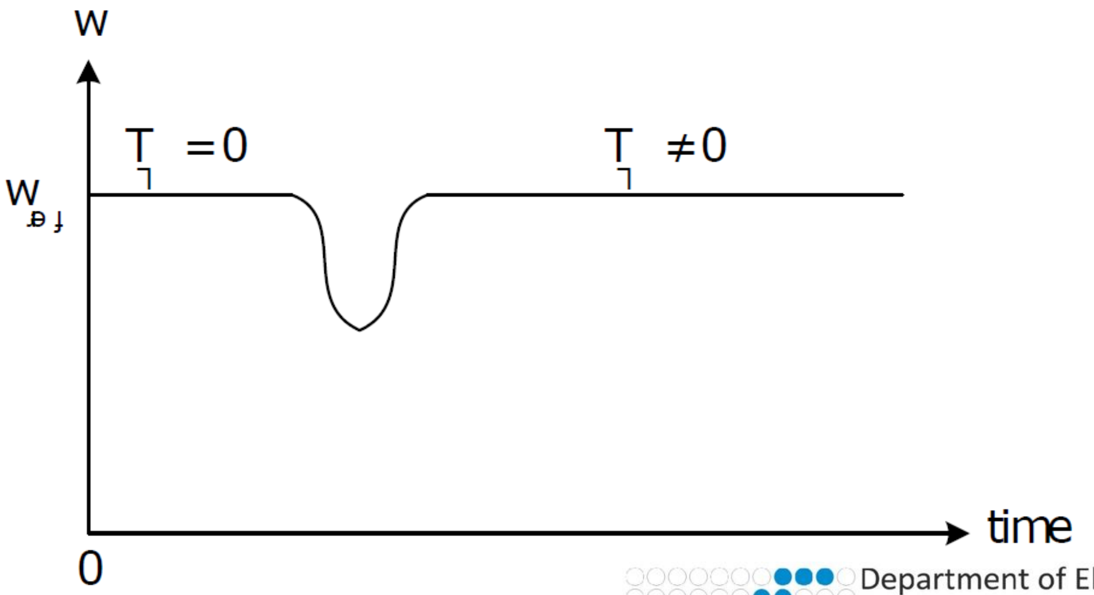
Response without/with feedback



Without feedback



With feedback



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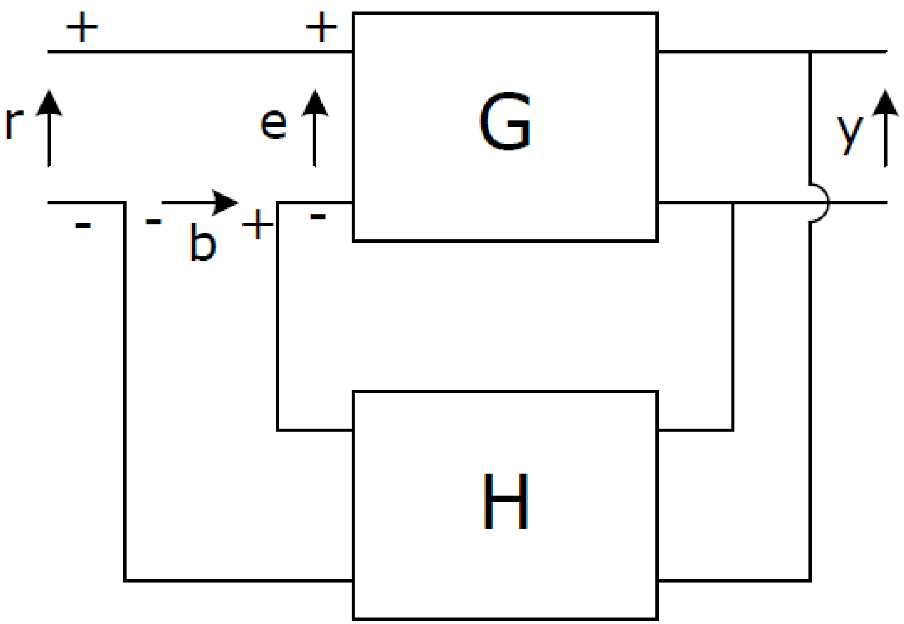
Feedback in Systems



- Consider the Two Port Network, where
  - *I.* *r* = input signal
  - *II.* *y* = output signal
  - *III.* *e* = error signal
  - *IV.* *b* = feedback signal,
  - *V.* *G* and *H* represent gains of the forward path and the feedback path respectively.

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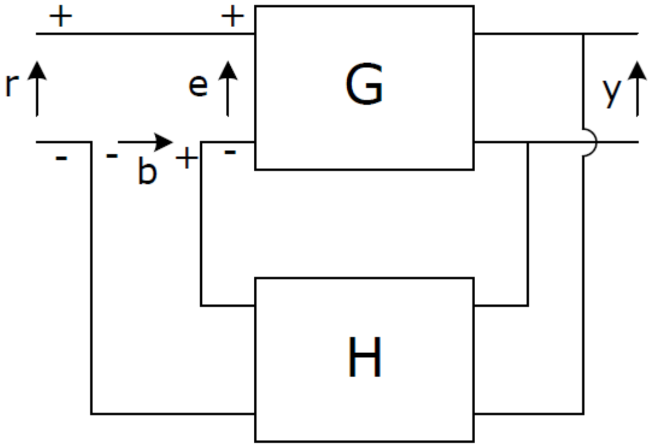
Effect of feedback on the **overall gain**



- If the system does not use feedback, then the overall gain is $G = \dfrac{y}{r}$
- But with the introduction of feedback $e = r - b$

  the overall gain becomes $M = \dfrac{y}{r} = \dfrac{G}{1 + GH}$
- When $GH > 0$, $M < G$ and vice versa.
- Hence depending on the sign of *GH*, feedback may increase or decrease the overall gain.
- In a practical systems, both *G* and *H* can be functions of frequency.
- Therefore, magnitude of
  - $(1 + GH) > 1$ in one frequency range while
  - $(1 + GH) < 1$ in another frequency range.

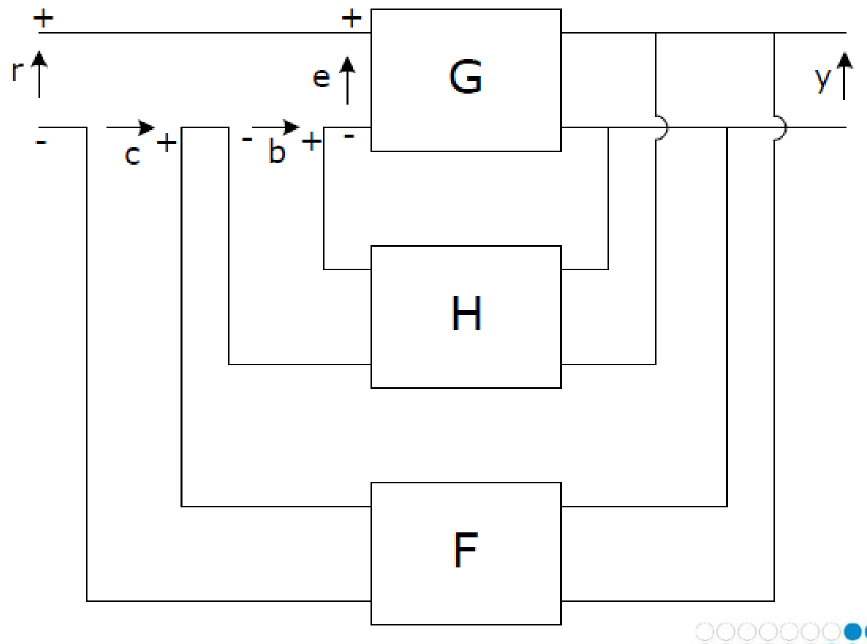
Effect of feedback on the stability

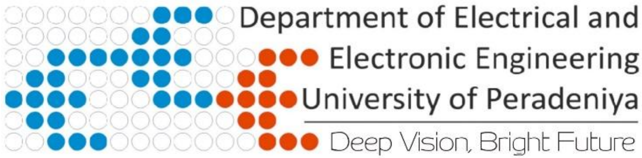
- **Stability** - system will be able to follow a finite bounded input command without producing an unbounded output (BIBO stability).
- A system is said to be unstable if its output goes out of control.
- To investigate the stability, for example if $GH = -1$ then the output is infinite for any finite input and the system is unstable.
- Hence feedback can make a system unstable which was originally stable.
- Example?

Effect of feedback on the **stability** contd.,

- If a certain system is originally unstable, feedback can be used to stabilize it.
- For example to stabilize the system with *GH = -1*, let us introduce another feedback loop
- Let the gain in the secondary feedback path be *F*, then

$$\frac{y}{r} = \frac{G}{1 + G(F + H)}$$





Effect of feedback on **sensitivity**

- Physical properties change with the environmental conditions and time.
- For example, the winding resistance of an electric motor changes as the temperature of the motor rises during its operation.
- In general, a good control system should be very insensitive to such parameter variations while being sensitive to inputs or input commands.
- Assume that G varies over the time.

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Effect of feedback on **sensitivity** contd.,

- Then, the Sensitivity of the overall system gain with respect to the variation of *G* can be defined as

$$S_G^M = \frac{\partial M / M}{\partial G / G} = \frac{\partial M}{\partial G} \frac{G}{M}$$

- With $M = \dfrac{G}{1 + GH}$ $\quad S_G^M = \dfrac{1}{1 + GH}$
- In the open loop system $S_G^M = 1$
- But in a closed loop system, by making *GH* very large, provided the system remains stable, the S_G^M can be made smaller.
- However since *GH* is generally a function of frequency,
  - $(1 + GH) > 1$ in one frequency range while
  - $(1 + GH) < 1$ in another frequency range.

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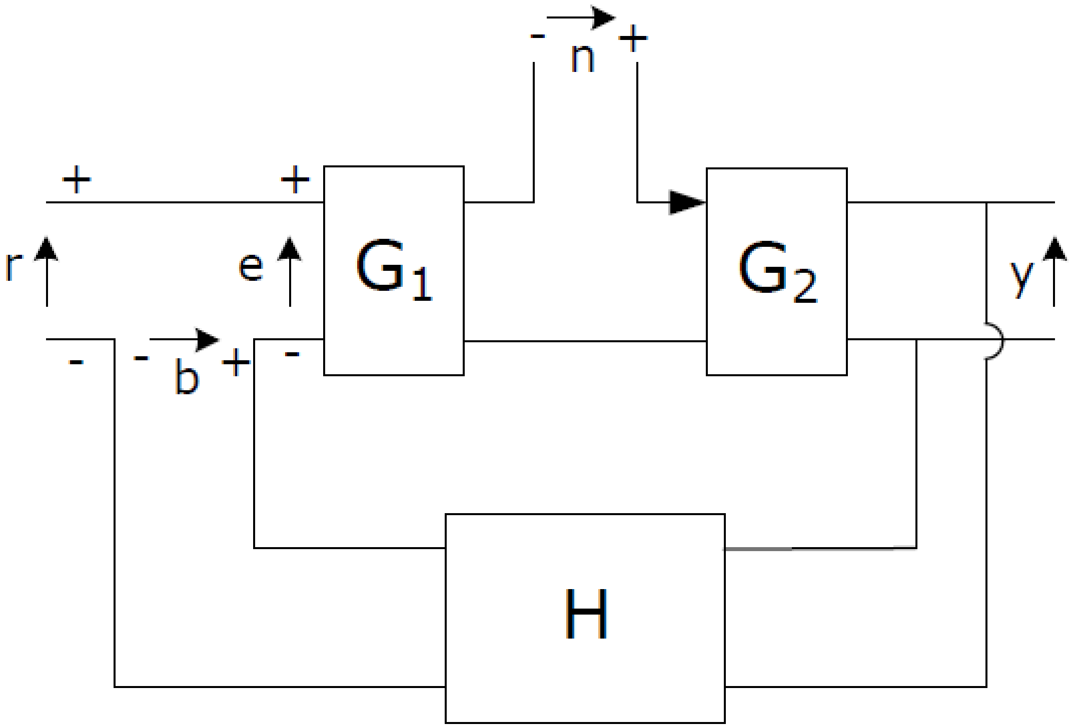
Effect of feedback on **external disturbance or noise**

- A control system should be insensitive to noise and other disturbances and sensitive only to the desired inputs.
- The impact of noise on the performance is greatly depends on node where it gets injected to the system.
- For $G = G_1G_2$ consider the noise incorporated two port network



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Effect of feedback on **external disturbance or noise** contd.,

- With no feedback, i.e. *H = 0* and with no command input, i.e., *r = 0*, the output $y = G_2 n$
- When there is feedback, i.e., $H \neq 0$ and when there is a command input, i.e., $r \neq 0$, $y = G_2\big(n + G_1(r - Hy)\big)$
- With noise present, i.e., $n \neq 0$ and with no command input, i.e., r = 0, the output is $y = \dfrac{G_2 n}{(1 + G_1 G_2 H)}$
- With feedback, the noise available at the output can be changed by a factor $\dfrac{1}{(1 + G_1 G_2 H)}$

Types of feedback control systems

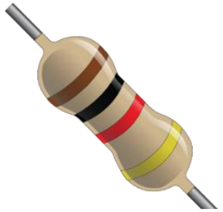
- Depending on the purpose, there are many ways of classifying control systems.
- According to the method of analysis and design:
  - Linear Systems
  - Nonlinear Systems
  - Time Variant Systems
  - Time Invariant Control Systems
- According to the type of signals used:
  - Continuous Data Systems
  - Discrete Data Systems
- According to the main purpose of the system:
  - Torque Control Systems
  - Velocity Control Systems
  - Position Control Systems

Linear and Nonlinear systems

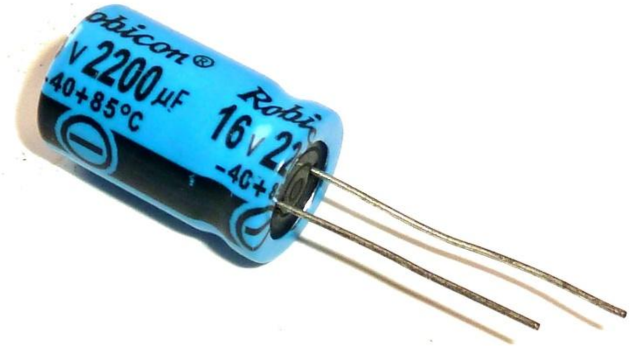
- When the magnitudes of signals in a control system are limited to ranges in which the system exhibits linear characteristics, the system is said to be linear.
- The best evidence to guarantee linearity of the system is that its inputs and outputs must obey the **Theory of Superposition**.
- That is for a SISO system, if $y_1(t)$ and $y_2(t)$ are the outputs for the input signals $x_1(t)$ and $x_2(t)$ respectively, then any linear combination of the inputs should maintain the same linear relationship in the output, i.e., for $\alpha \neq 0$ and $\beta \neq 0$ if the input is $\alpha x_1(t) \pm \beta x_2(t)$, then the output should be $\alpha y_1(t) \pm \beta y_2(t)$.
- Examples

Common linear systems in Electrical Engineering

- Resistor $$v_R(t) = Ri_R(t)$$



- Capacitor $$v_C(t) = \frac{1}{C}\int_0^t i_C(t)dt$$



- Inductor $$v_L(t) = L\frac{di_L(t)}{dt}$$

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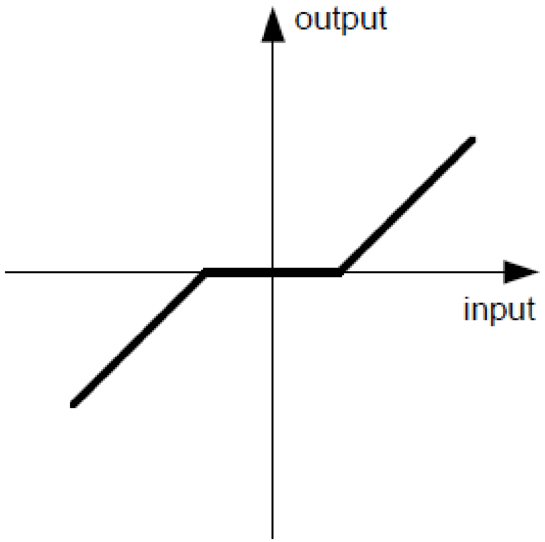
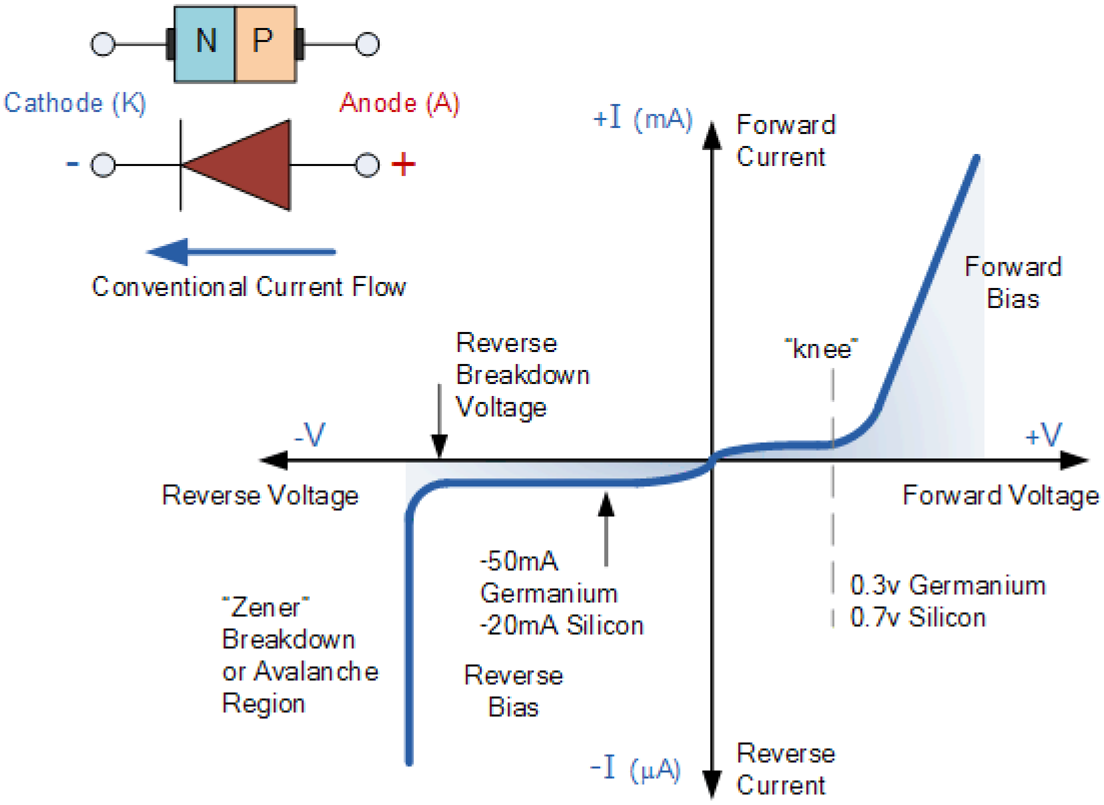
Nonlinear systems

- If a system does not obey Theory of Superposition, then it is a nonlinear system.
- Some common nonlinearities are

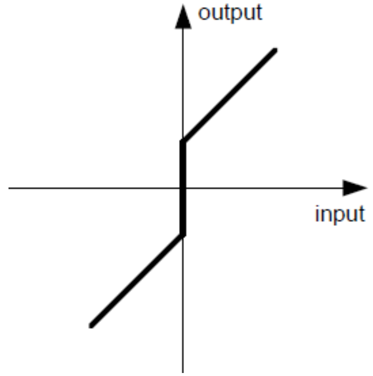
  Deadband: found in electronic components such as diodes, transistors and mechanical components such as gear train backlash, etc.

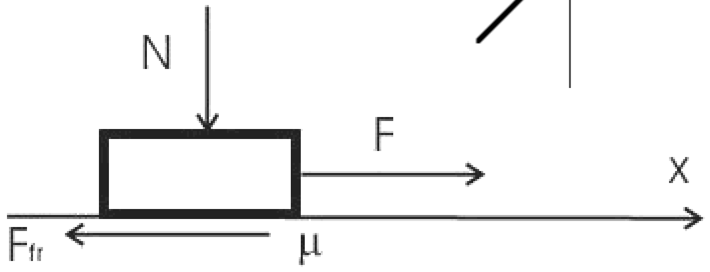




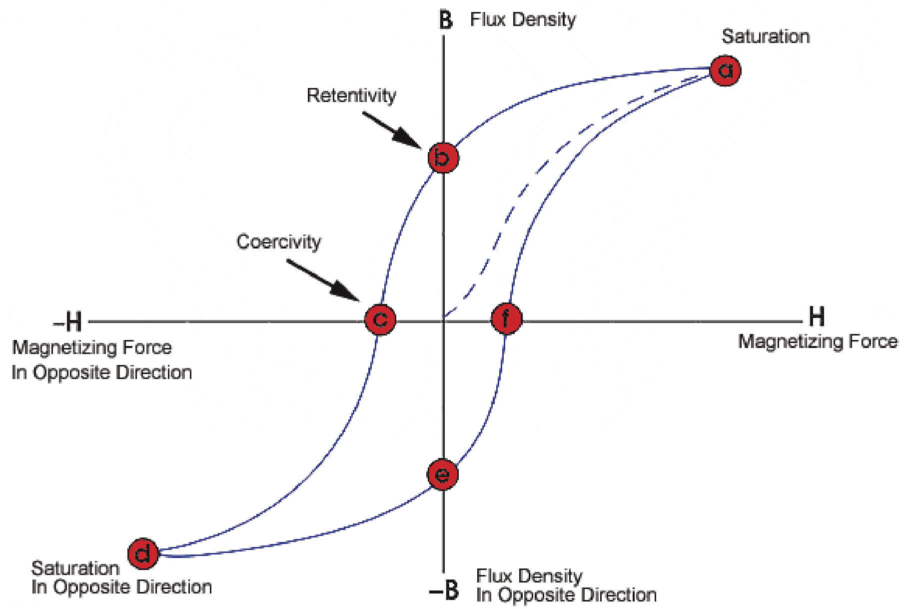
Nonlinear systems contd.,

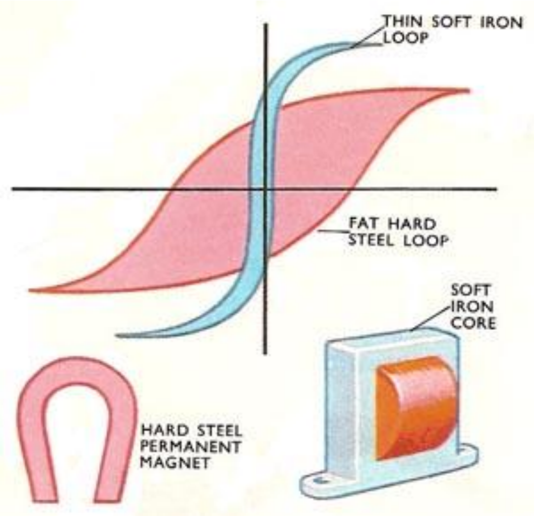
- Some common nonlinearities are
  - **Coulomb region**: found mostly with Coulmb friction

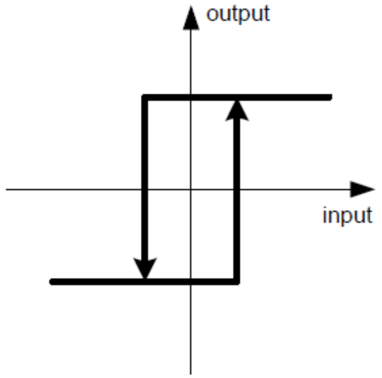




  - **Hysteresis:** found in places such as electronic logic circuits, magnetization curve (BH loop) of materials, etc.







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Time Invariant vs. Time Variant Systems

- **Time Invariant System**: dynamic response of a control system remain constant over the time during its operation.
- Most practical systems are **Time Variant** over a long time range.
- Mathematical expression of time invariance:
  - If $y(t)$ is the output of a system for an input $x(t)$, and if the system is time invariant, then for a time shifted input $x(t-\tau)$ it should give the output as $y(t-\tau)$.

This course deals with **L**inear **T**ime **Invariant** (LTI) systems