7: Negative Feedback is Wonderful

Block Diagram

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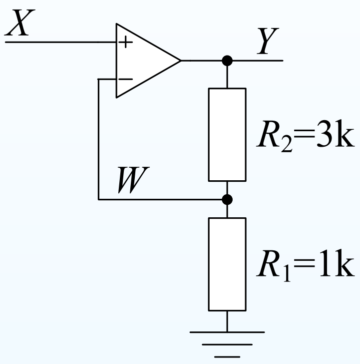

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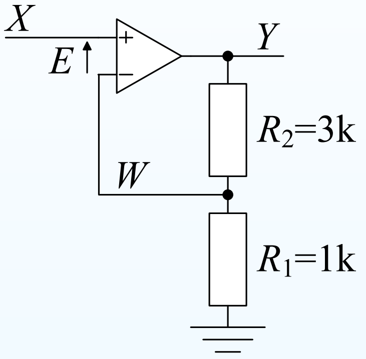

We can represent this using a block diagram:

$A = \frac{Y}{E}$: the gain of the op amp

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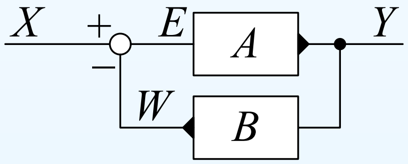
The "+" and "–" signs indicate that the feedback is subtracted from X to give an "error" signal, E.



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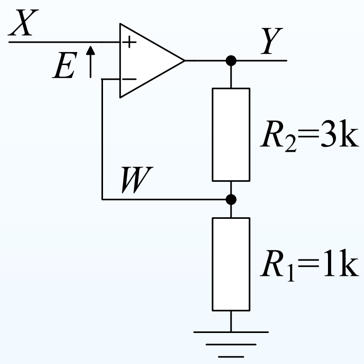

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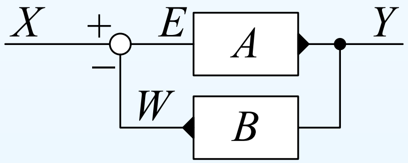

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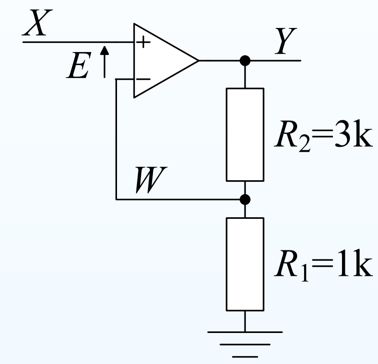

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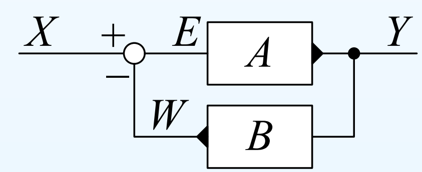

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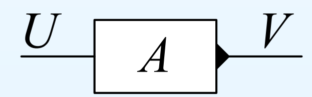
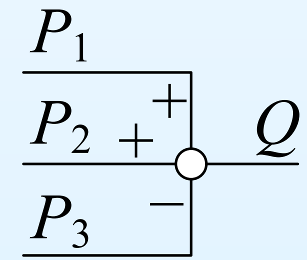


An *adder block* many inputs and one output. The signs indicate whether each input is added or subtracted: $Q = P_1 + P_2 - P_3$



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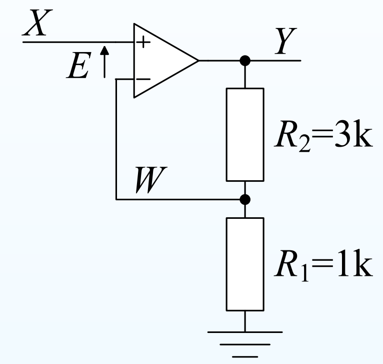

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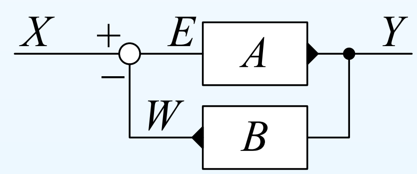

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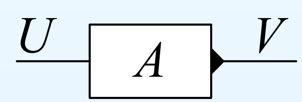

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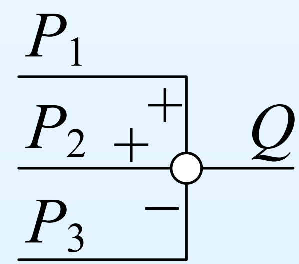
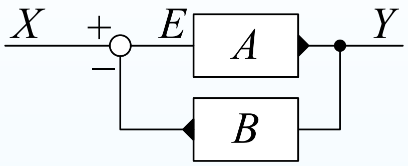


Normally, inputs are on the left and outputs are on the right.

Solving Block Diagrams

- Label inputs, output and adder outputs



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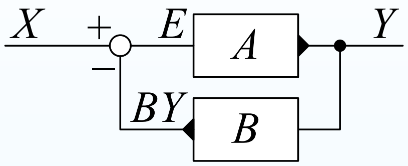

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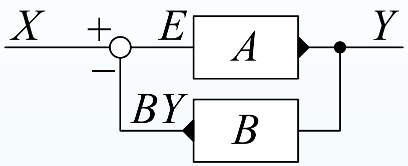

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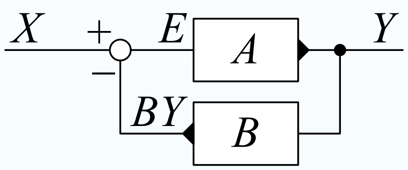

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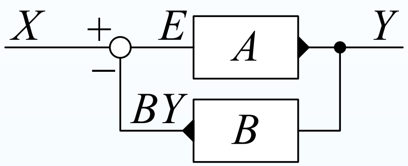

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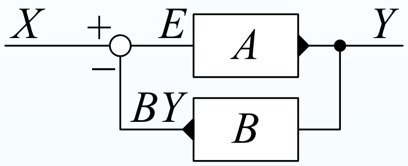

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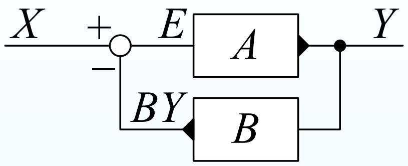

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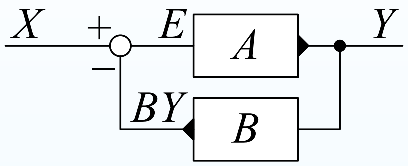

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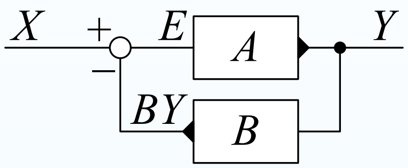

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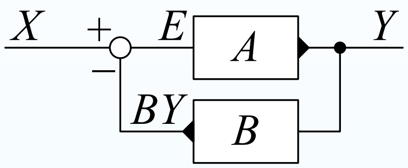

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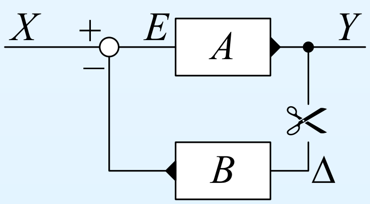
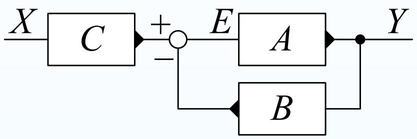
AB is called the *loop gain* of the circuit. If you break the loop at any point and inject a signal Δ after the break, this will cause the other side of the break to change by $-\Delta \times AB$.



Inverting Amplifier

Sometimes we have an additional block at the input shown here as C.



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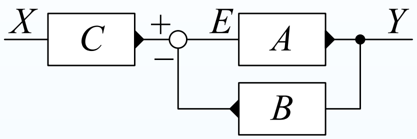

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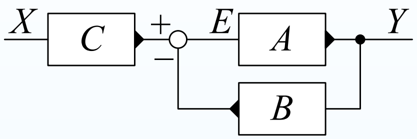

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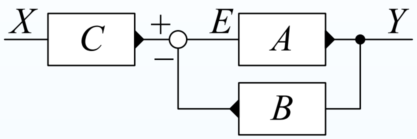

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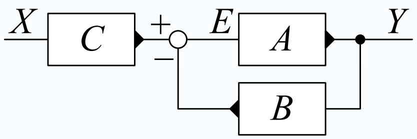

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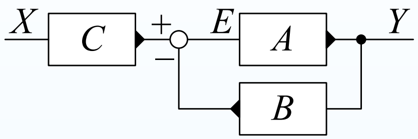

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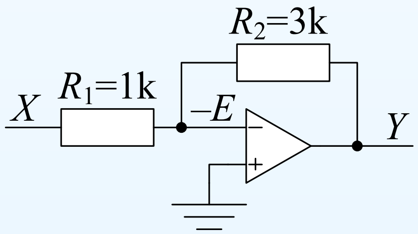

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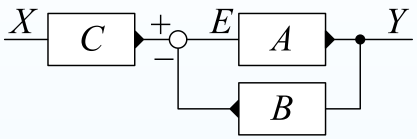

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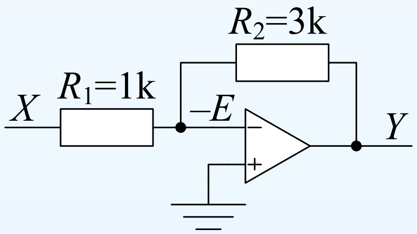

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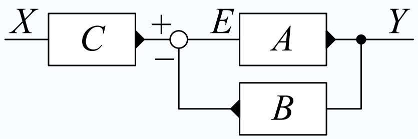

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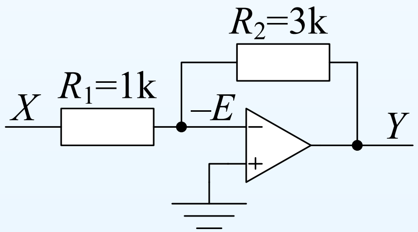

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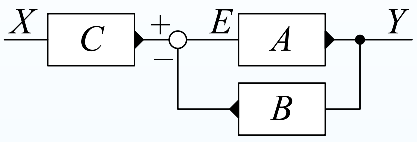

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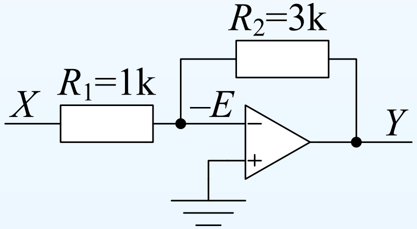

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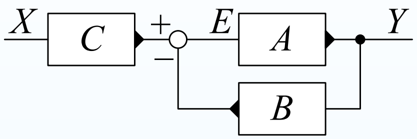

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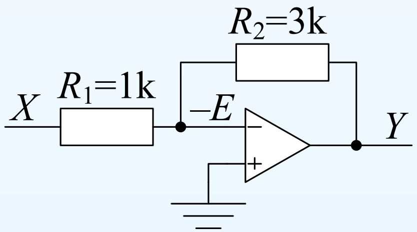

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Hence $C = -\frac{3}{4}$ and $B = +\frac{1}{4}$ and $\frac{Y}{X} \approx \frac{C}{B} = -3$

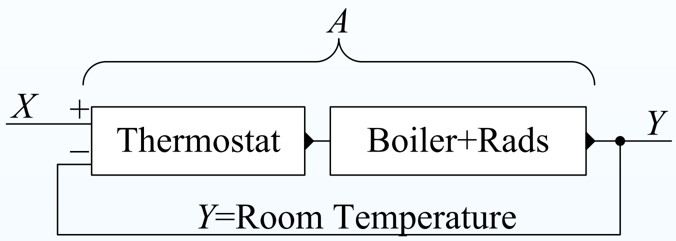
Negative Feedback Examples

Central Heating:

X: Desired temperature

Y: Actual room temperature

A: Rather complicated system of boiler and radiators



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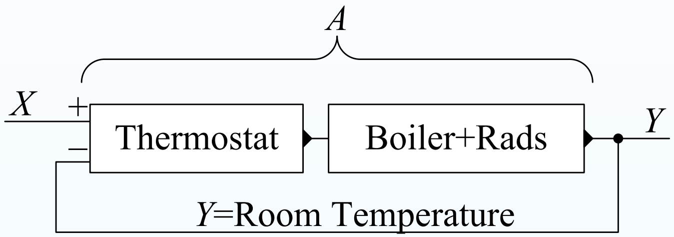
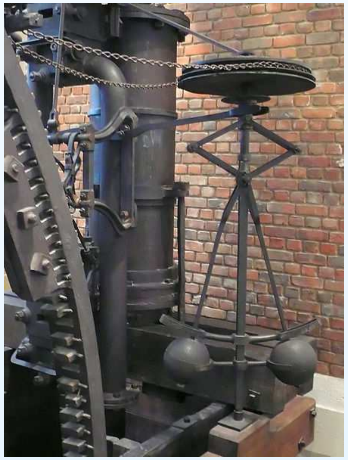


Steam Engine Governor:

X: Desired Speed

Y: Actual Speed

A: Rotational speed causes weights to fly apart (centrifugal force) which adjusts the steam supply via a throttle valve.



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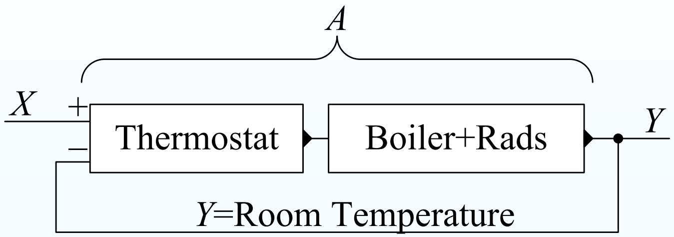

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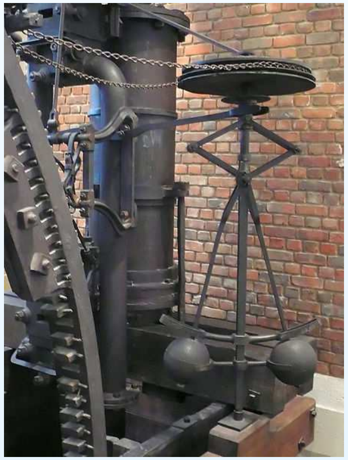

Many Other Examples:

Economics: Demand↑ ⇒Price↑ ⇒Supply↑ ⇒Supply=Demand

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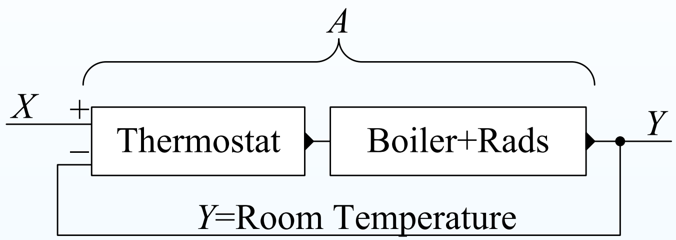

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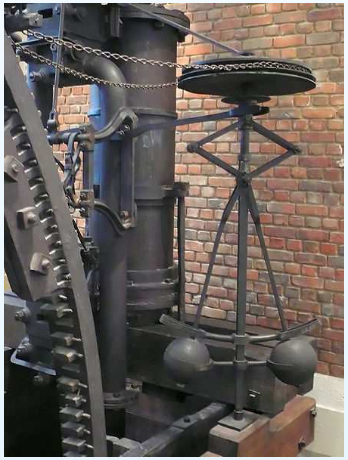

Many Other Examples:

Economics: Demand↑ ⇒Price↑ ⇒Supply↑ ⇒Supply=Demand

Biology: More rabbits ⇒Not enough food ⇒Less rabbits ⇒Enough food

Benefits of Negative Feedback

1) Gain Stabilization

The gain of a feedback system is almost entirely determined by the feedback path and not by the gain of the amplification path. This means that you can get predictable gains even when the gain of the amplification path is unknown or time-varying.

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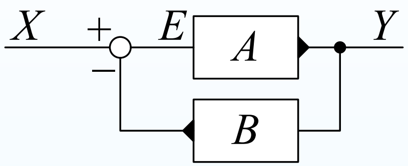
External disturbances have little effect on the output of a feedback system because the feedback adjusts to compensate for them.

Gain Stabilization

Gain is $\frac{Y}{X} = \frac{A}{1+AB}$



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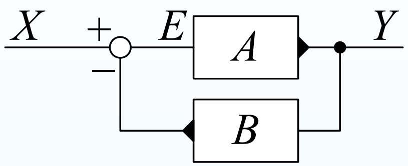

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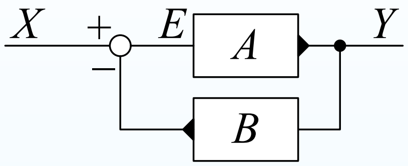

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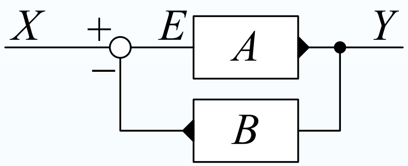

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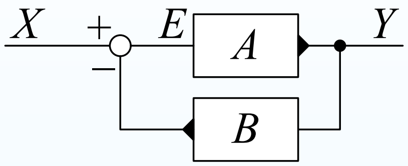

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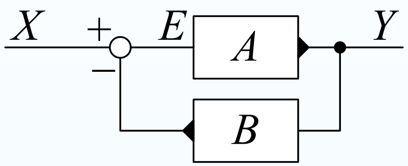

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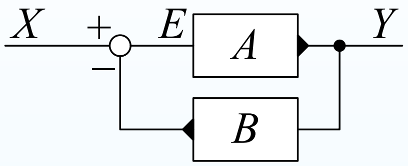

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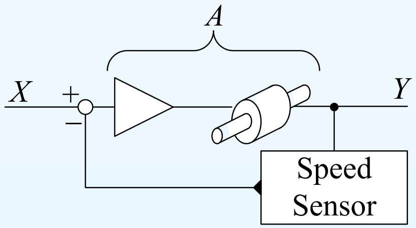

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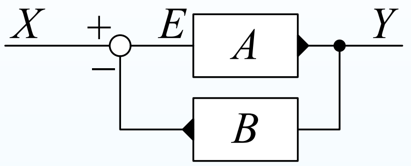

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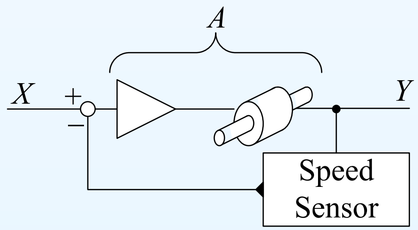

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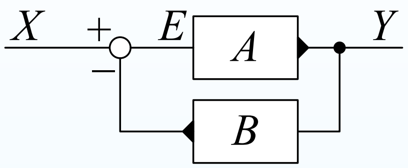

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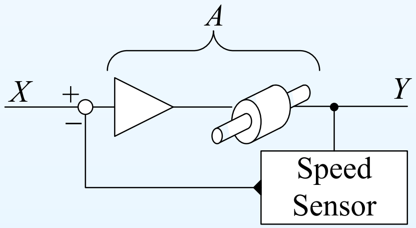

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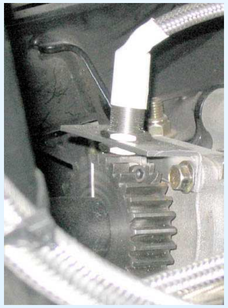
We can sense the motor speed using gear-teeth and a magnetic (Hall effect) sensor together with a circuit that converts frequency to voltage.



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+

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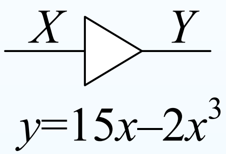

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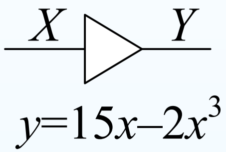

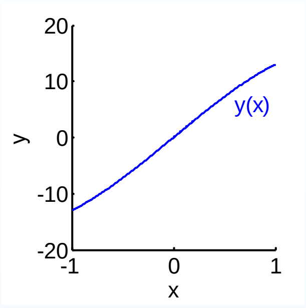

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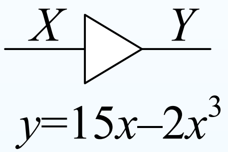

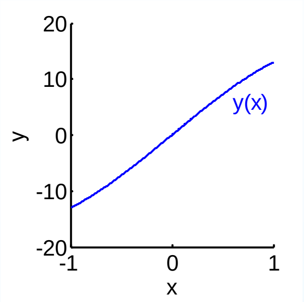

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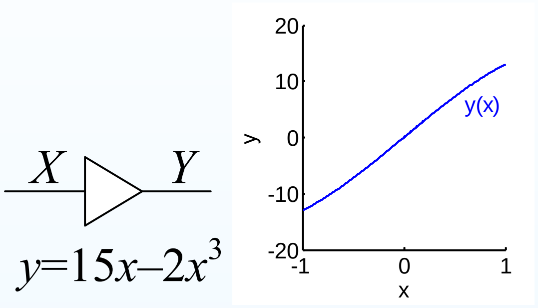

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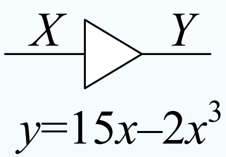

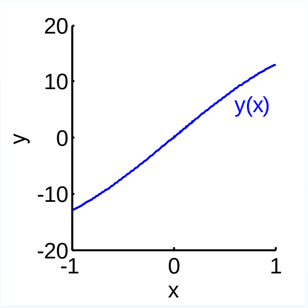

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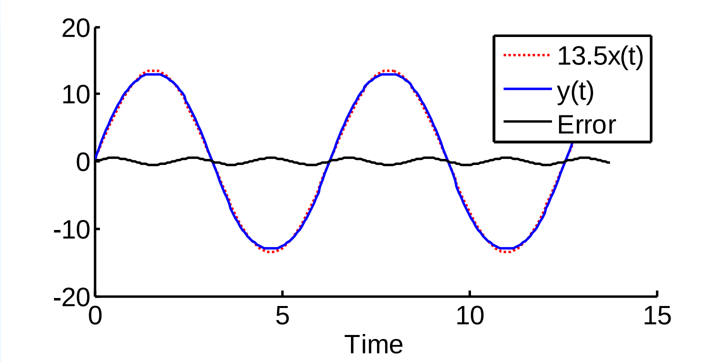
The gain is only 13.5 instead of 15 and *harmonic distortion* is added at a multiple of the original frequency.



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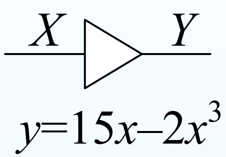

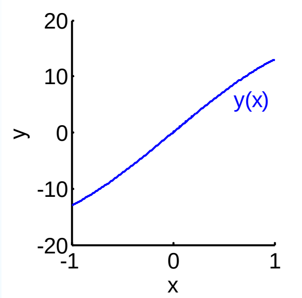

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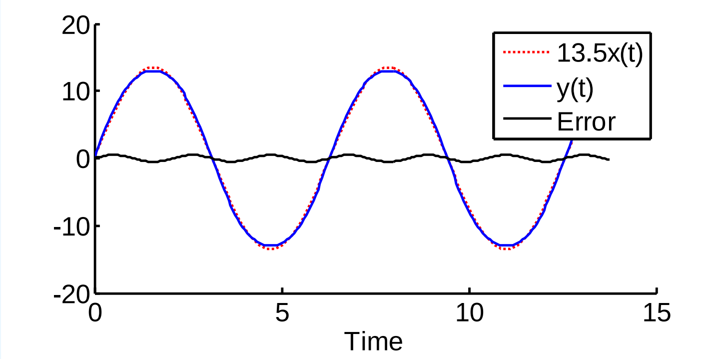

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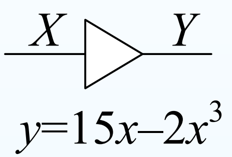

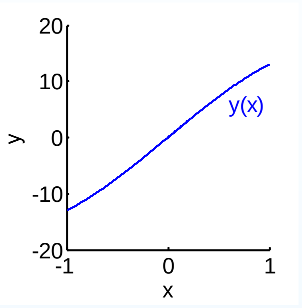

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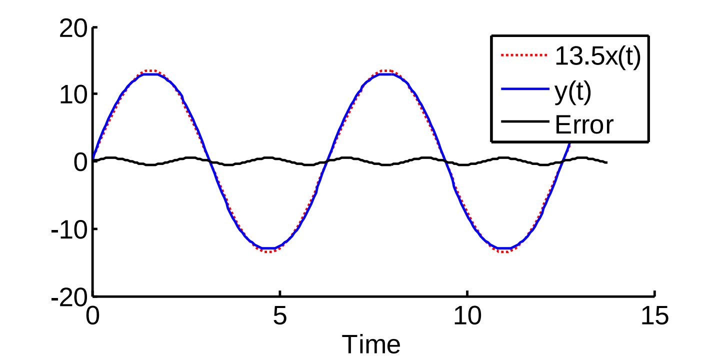

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Use feedback to reduce distortion

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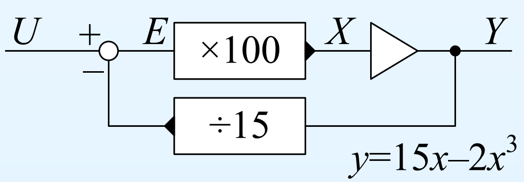

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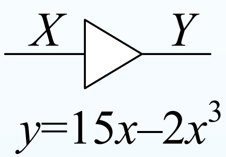

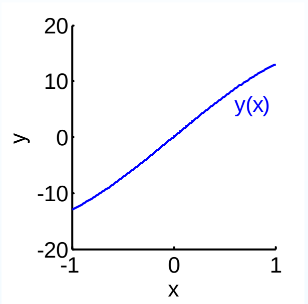

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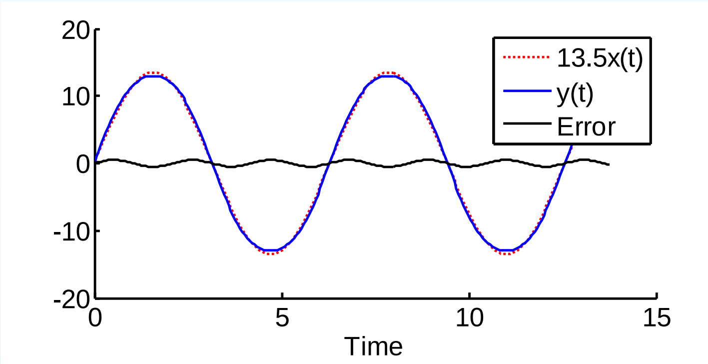

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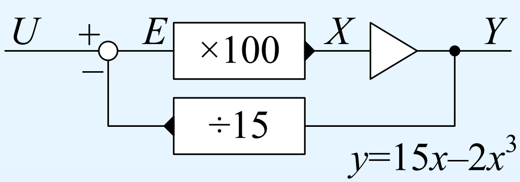

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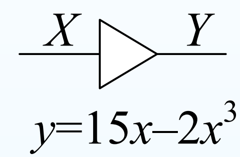

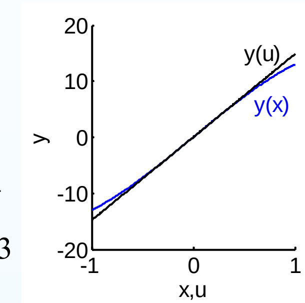

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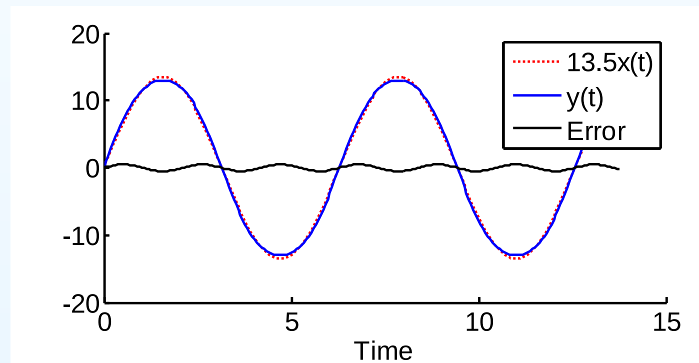

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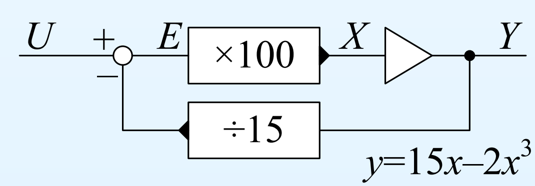

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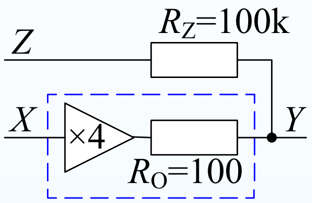

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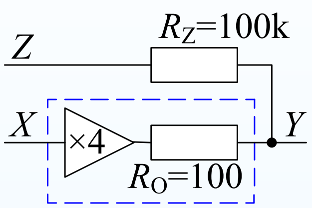

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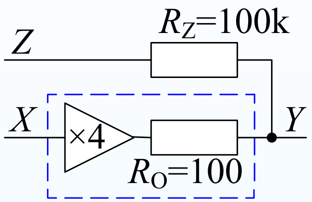

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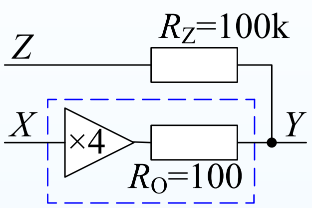

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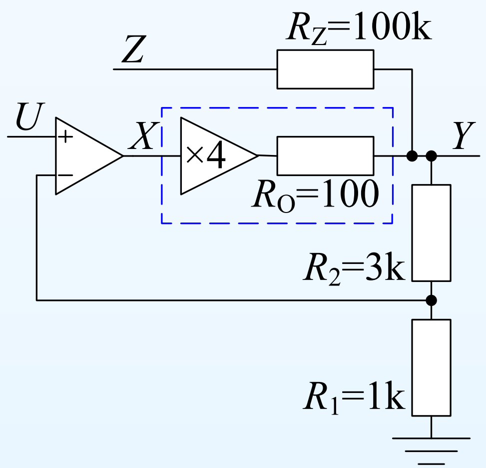

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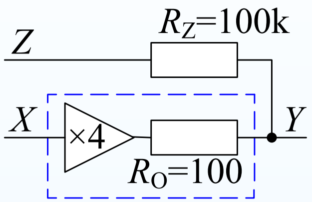

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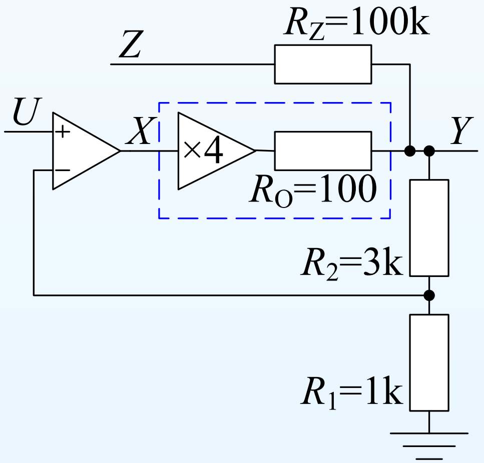


Interference Rejection

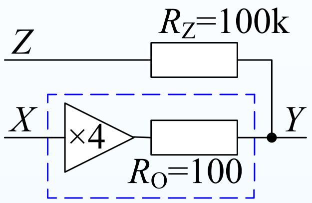
The amplifier output, Y, is affected by interference, Z.

$Y =$ average of $4X$ and Z weighted by conductances:

$$Y = \frac{\frac{1}{R_O}4X + \frac{1}{R_Z}Z}{\frac{1}{R_O}+\frac{1}{R_Z}} = 3.996X + \frac{1}{1001}Z$$

Z is often much bigger than X (e.g. mains @ 230V).

R_O is amplifier *output resistance*.



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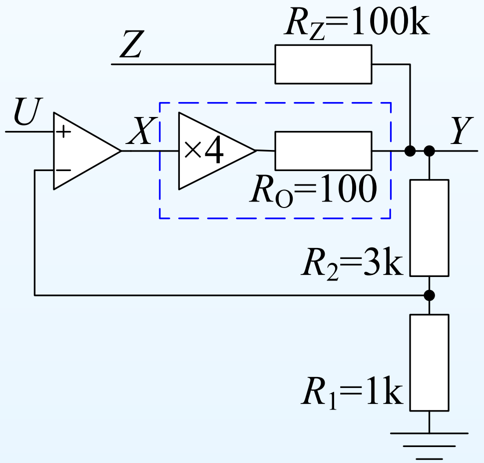

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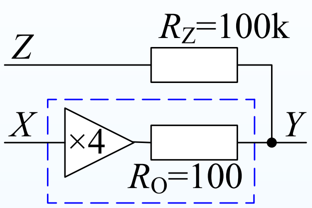

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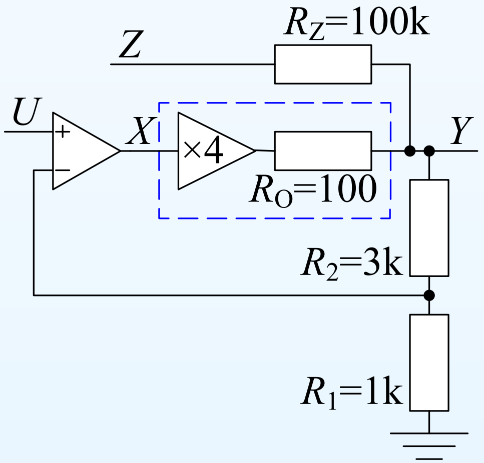

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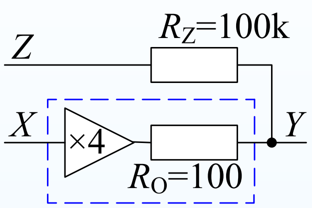

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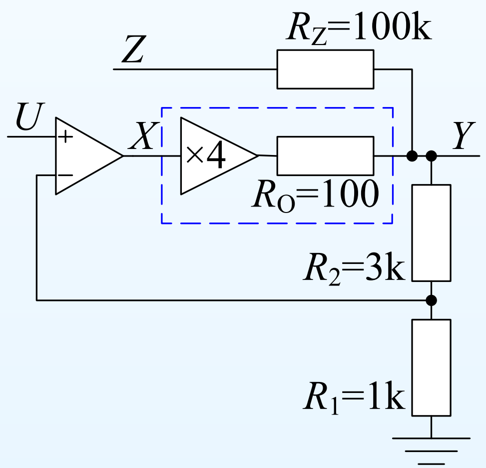
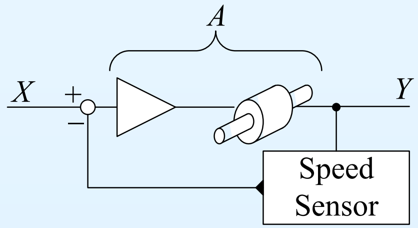


"Interference" includes any external influence that may affect the output.
E.g. the mechanical load changing on a motor or an opened window in a heating system.



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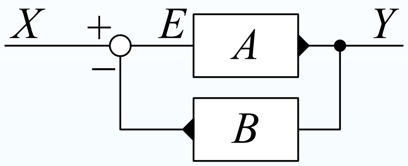

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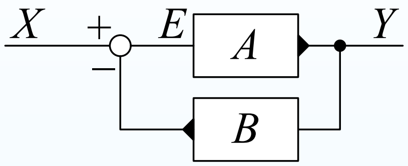

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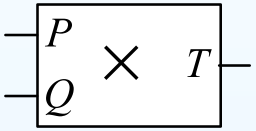

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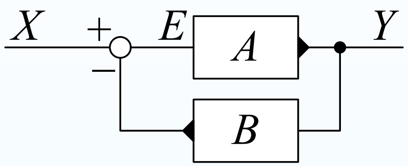

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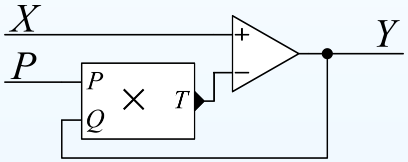

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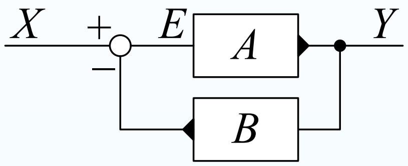

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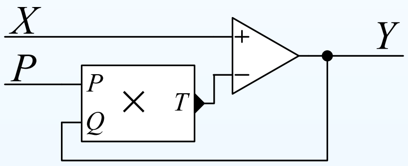

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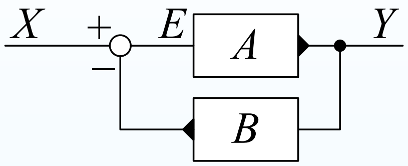

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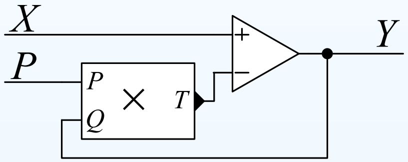

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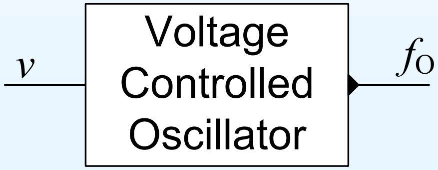

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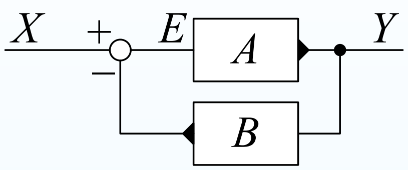

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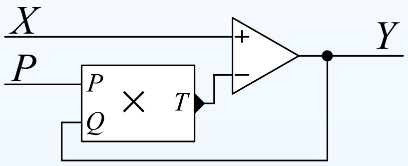

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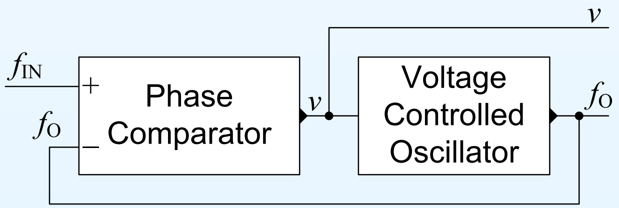

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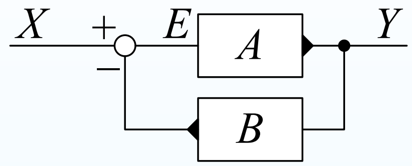

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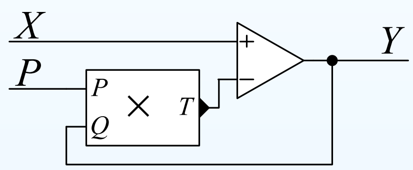

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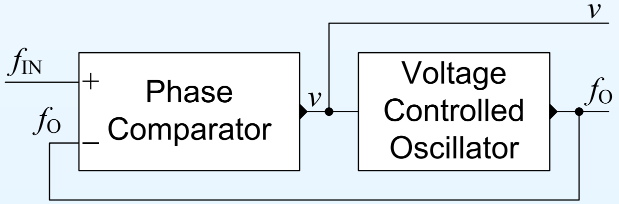

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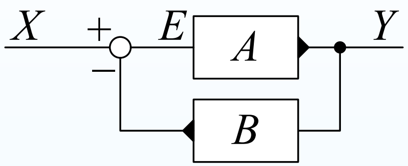

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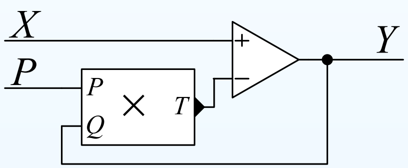

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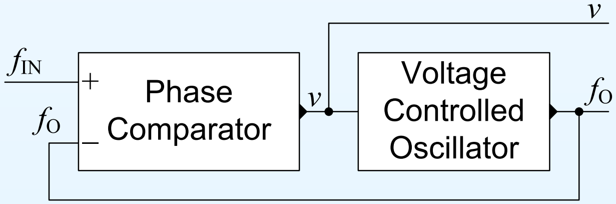

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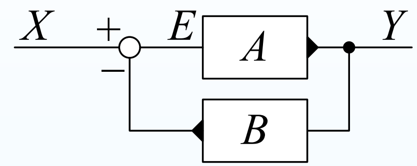

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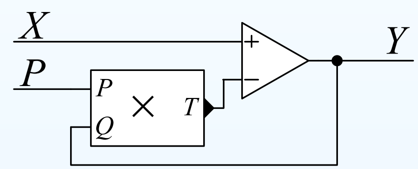

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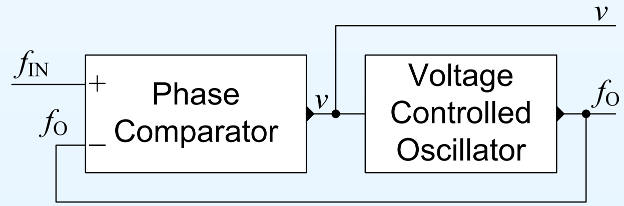

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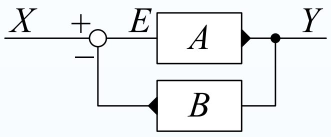
Used in FM radios and in many other circuits.

Instability

The biggest problem of feedback systems is the possibility of instability.



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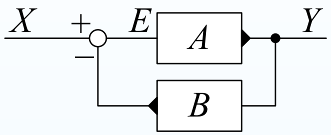

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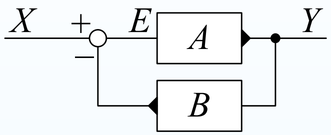

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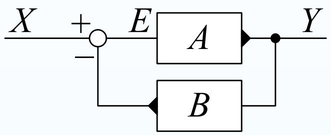

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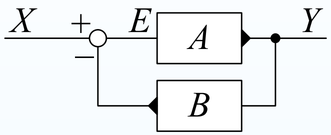

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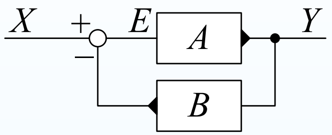

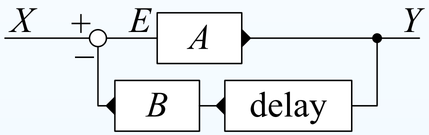

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For a sine wave, a delay anywhere within the loop of half a period (e.g. 0.5 ms for 1 kHz) is the same as multiplying by -1.

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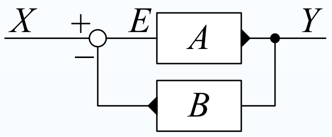

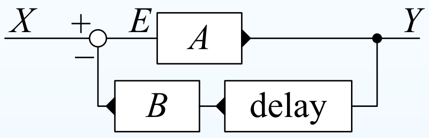

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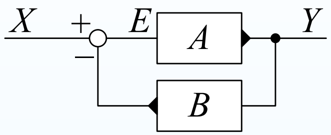

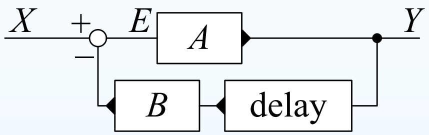

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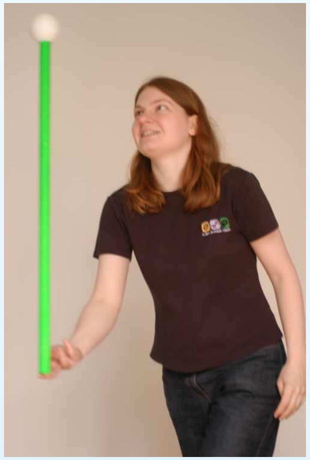
Quite a common problem: steering a boat, walking when drunk, balancing a stick.



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- The precise value of A does not matter as long as it is big enough because the gain is determined by the feedback, B.
- It makes no difference if A varies with time or with signal amplitude (i.e. A is non-linear).

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- Must make sure that as frequency increases, the loop gain falls below 1 before the phase shift reaches $-180°$.