6.302 Feedback Systems

Recitation 24: Feedback Applications
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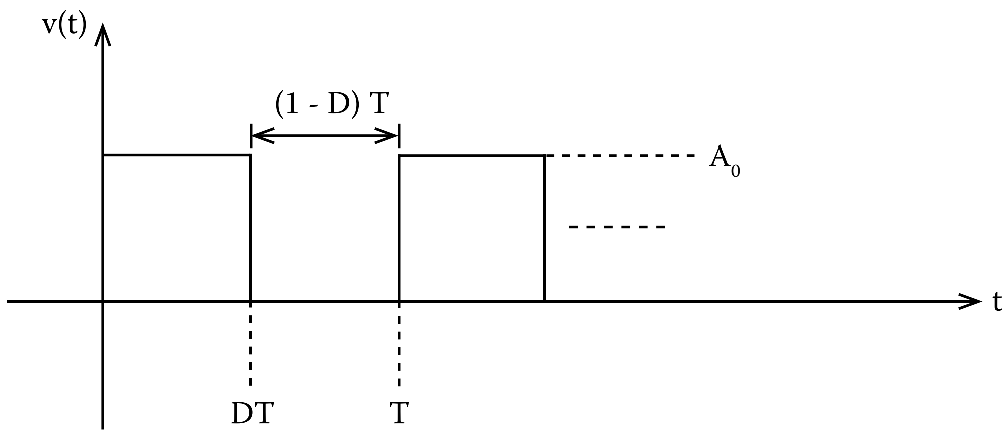
We've been talking about how feedback is used successfully in countless different applications. We've said before, and I repeat here, it is astounding that the same feedback theory that helps stabilize an inverted pendulum helps us control op-amps. Or motors. Or magnetic levitation systems. The list goes on and on.

We're going to explore a couple more applications. But before we do, our traditional class exercise.

CLASS EXERCISE

Consider the following voltage wave form:



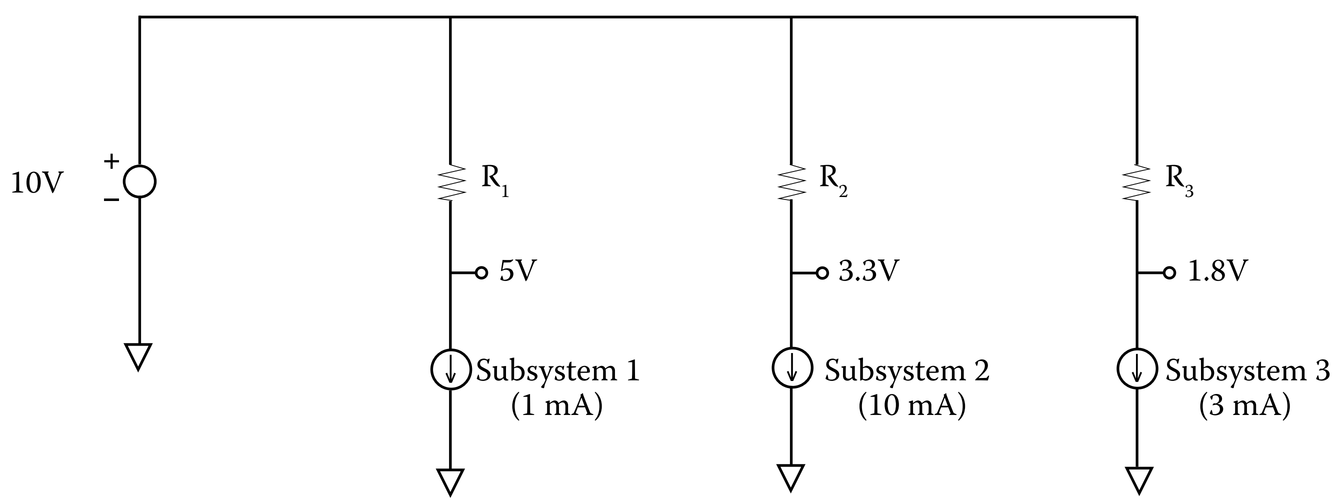
$0 \le D \le 1$

Compute the average, or DC, value of the waveform.

In the waveform that you just analyzed, the parameter "D" is called the duty cycle. Modulating, or changing, the duty cycle in order to achieve a certain DC value is a common control technique. It is called pulse width modulation, or PWM.

One of the places PWM is useful is in voltage conversion. Often on a battery-powered device like a cellular phone, different parts of the system require different supply voltages. How might we solve this problem?

One way



Total power draw: 14 mA x 10V = 140mW

Total power lost in resistors:

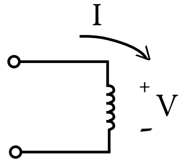
$$
\begin{array}{r}
(10V - 5V) \cdot 1mA \\
(10V - 3.3V) \cdot 10mA \\
\underline{+(10V - 1.8V) \cdot 3mA} \\
96.6mW
\end{array}
$$

70% of power lost in voltage conversion.

<u>UNACCEPTABLE</u>.

How can we do better? Not clear at this point, but a good start might be using components that are purley lossless.

Inductors:

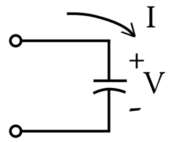


$$V = IZ = Ij\omega L = I\omega L e^{j\pi/2}$$

$$\langle P \rangle = \tfrac{1}{2}\,\mathrm{Re}\{VI^*\} = \tfrac{1}{2}\,\mathrm{Re}\{I^2\omega L e^{j\pi/2}\} = \tfrac{1}{2} I^2\omega L\,\mathrm{Re}\{\cos 90^\circ + j\sin 90^\circ\} = 0$$

Inductors might help.

Capacitors:



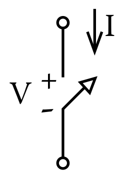
$$V = I \cdot \frac{-j}{\omega C} = \frac{I}{\omega C} e^{-j\pi/2}$$

$$\langle P \rangle = \tfrac{1}{2}\,\mathrm{Re}\{VI^*\} = \tfrac{1}{2}\,\mathrm{Re}\{VI^*\} = \tfrac{1}{2}\,\mathrm{Re}\left\{\frac{I^2}{\omega C} e^{-j\pi/2}\right\} = \tfrac{1}{2}\frac{I^2}{\omega C}\,\mathrm{Re}\{\cos 90^\circ - j\sin 90^\circ\} = 0$$

Capacitors might help.

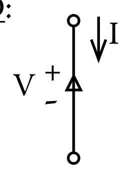
<u>Perfect Switches</u>

When switch is <u>OPEN</u>:



I = 0, V can be anything, ⇒ I · V = 0 always.

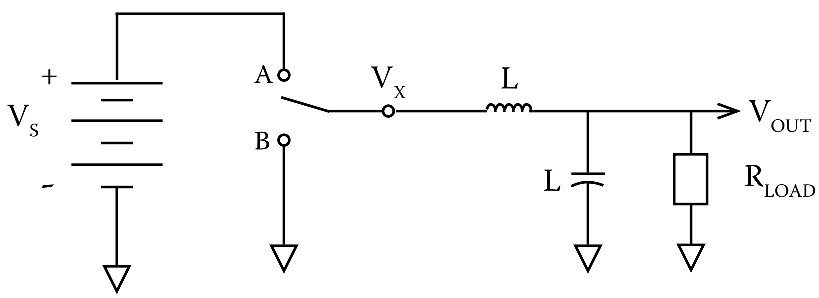
When switch is <u>CLOSED</u>:

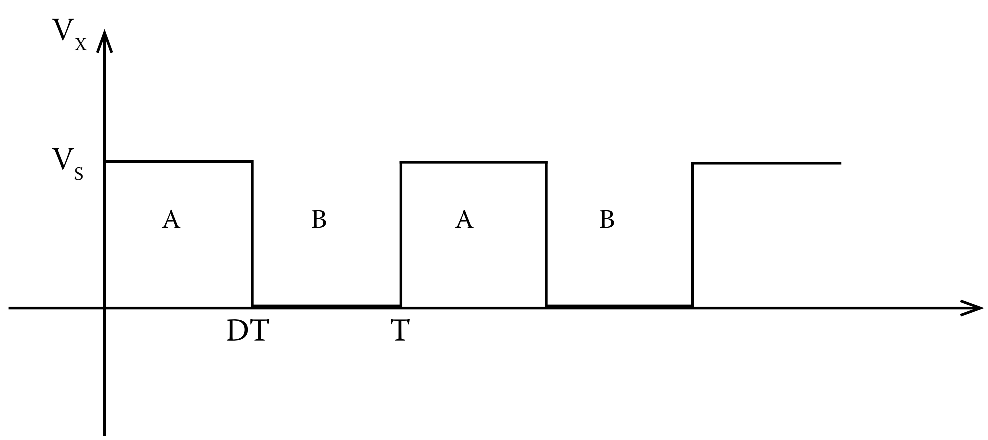


I can be anything, V = 0 ⇒ I · V = 0 always

Switches might help.

Using inductors, capacitors, and switches is in fact how we do efficient power conversion.





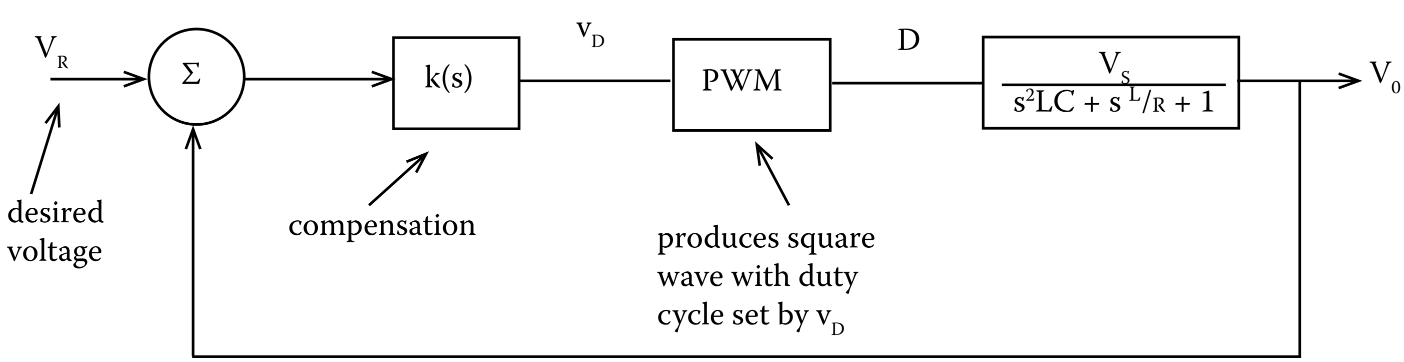
The inductor and capacitor form a low-pass filter, allowing us to extract the DC value of V_x.

1) $V_X = DV_S$

2) $$V_0 = \frac{1}{s^2LC + s\,L/R + 1} V_X$$

↳ $$V_0 = \frac{V_S}{s^2LC + s\,L/R + 1} \cdot D$$

So if we have a way of generating a variable-duty-cycle square wave, a feedback switching power converter might look something like this:



This is a very efficient way to generate voltages from a fixed supply.

↳ It is also <u>yet</u> <u>another</u> system that feedback theory helps us design.