6.002 - Lecture 19

Boost Converter

- Power Electronics
- Energy Processing
- Boost Converter Example
- LC Network Review
- LC Network Application

Power Electronics

“Power electronics” does not necessarily mean “powerful electronics”. Rather it refers to electronics designed to process power/energy as opposed to electronics that process signals/information.

Power electronics concerns include:

- efficiency and temperature rise;
- power density;
- regulation of output voltage or current; and
- response bandwidth in the presence of source and load variations.

As a consequence of the concern for efficiency, power electronics involve (to first order) only ideally lossless devices:

- capacitors and inductors acting as energy stores;
- transistors and diodes acting as switches to direct energy flow;
- transformers for isolation and voltage and current transformation.

To learn more, consider 6.131 and/or 6.334.

Boost Converter?

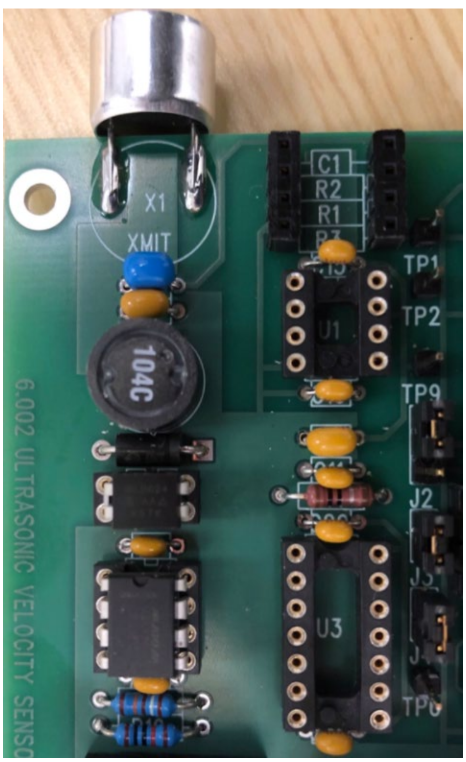
Low Voltage → **Power Electronic Boost Converter** → High Voltage

Low Voltage
- Batteries
- Energy Harvesters
  - RF
  - Solar
  - Thermal
  - Vibration
- Digital Systems

Power Electronic Boost Converter

Concerns
- High efficiency
- Good regulation
- Wide bandwidth

High Voltage
- Actuators
- Sensors
- Communication
- Distribution



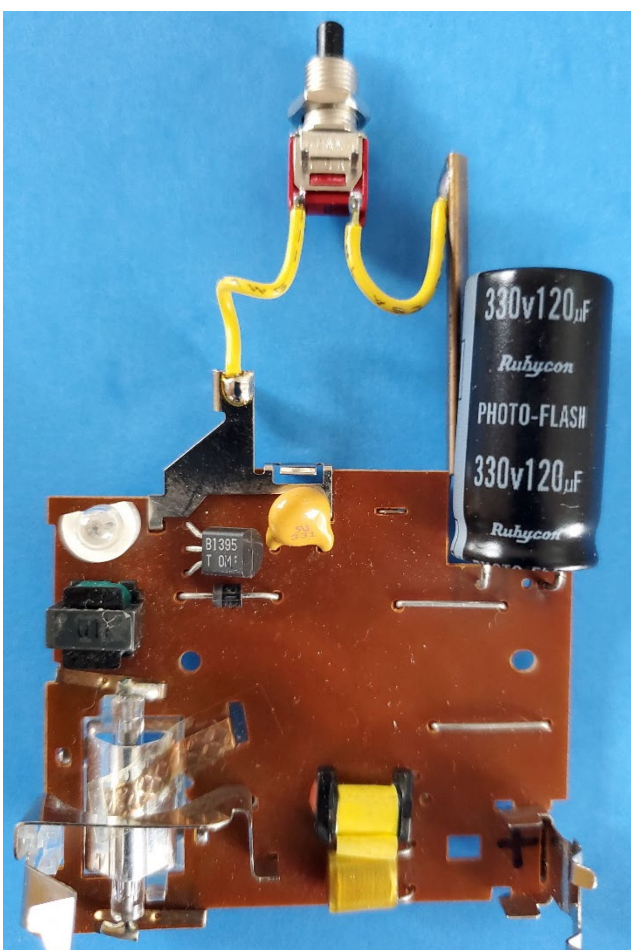
6.002 Ultrasound Boost Converter

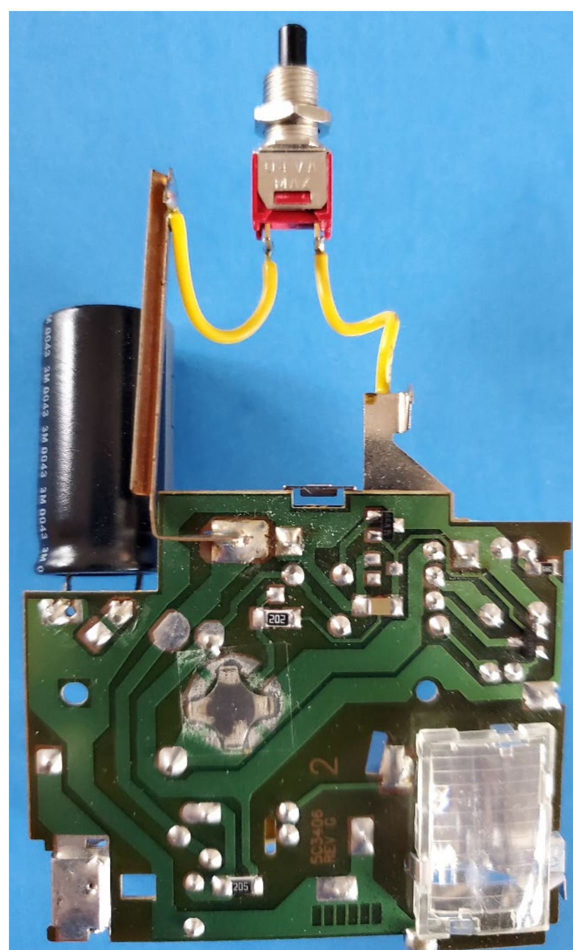
Hansen, Martin and Perreault
DOI:10.1109/TPEL.2019.2900021

Kodak Camera

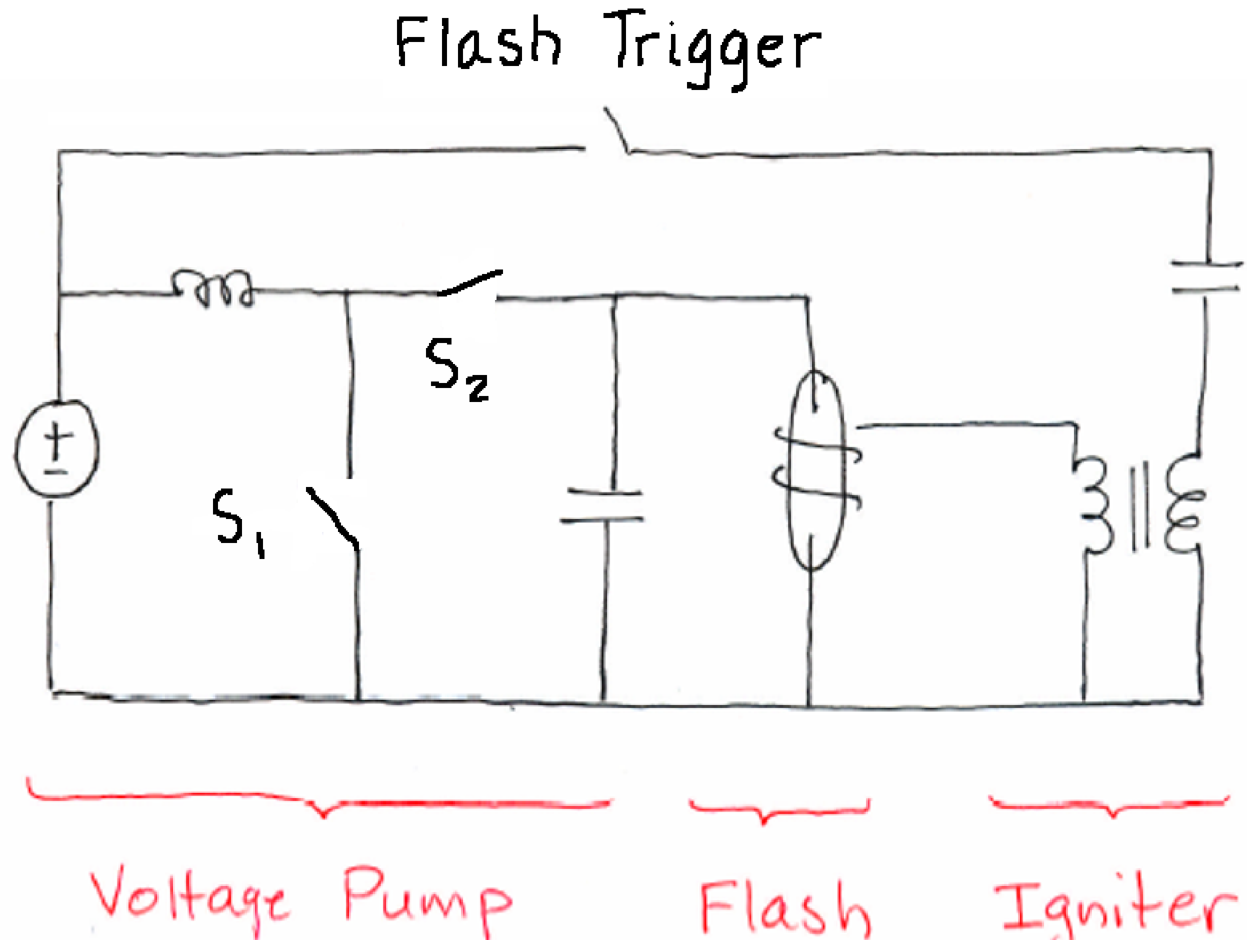
Ofori-Tenkorang,
PhD Thesis, MIT, 1997

Single-Use Camera





Simplified Camera Flash Circuit

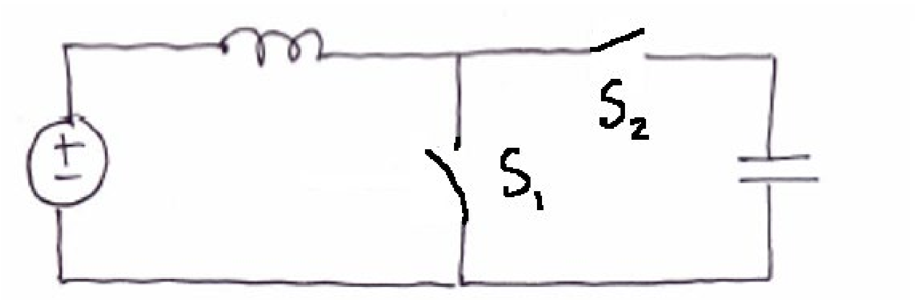


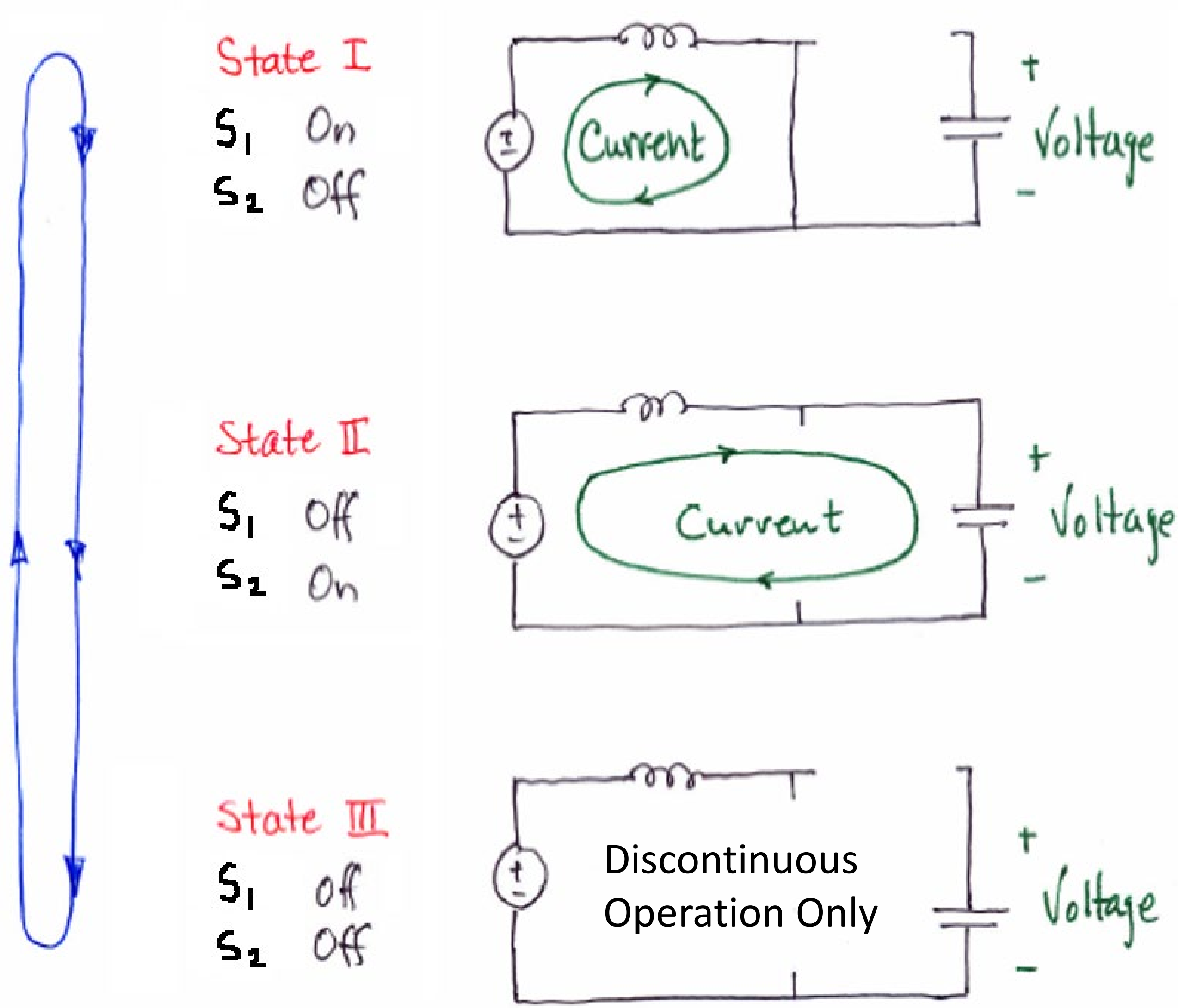
Typical Operation: 1.5 V @ Battery

300 V @ Capacitor

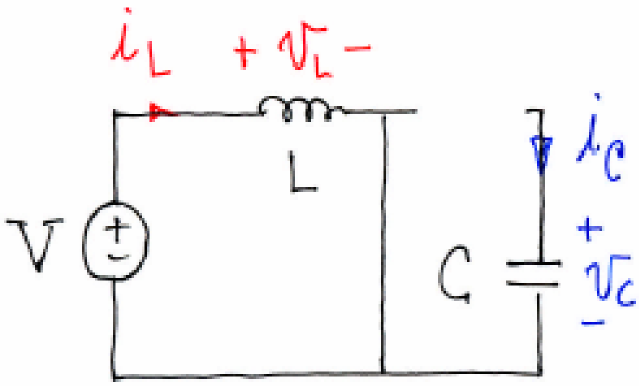
10 kV @ Igniter

Voltage Pump (Boost Converter)





State I



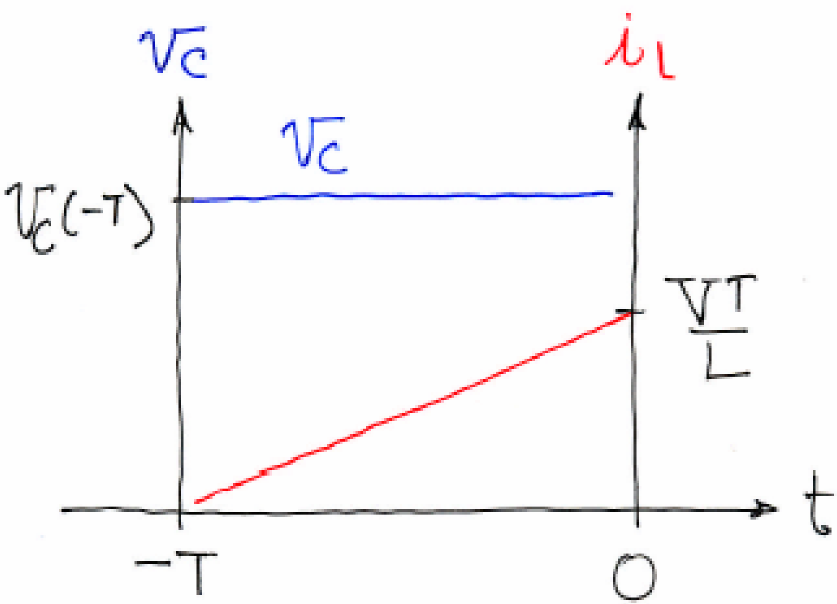
$$-T \le t \le 0$$

$$i_L(-T) = 0$$

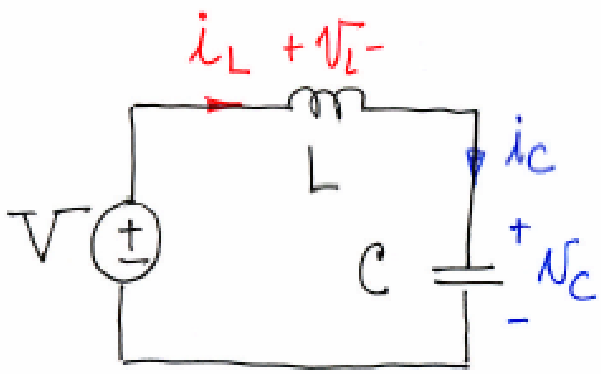
$$v_C(-T) = \text{Given}$$

$$V = v_L = L\frac{di_L}{dt} \Rightarrow i_L(t) = \frac{V}{L}(t+T)$$

$$0 = i_C = C\frac{dv_C}{dt} \Rightarrow v_C(t) = v_C(-T)$$



State II



$0 \le t \le$ Diode Turn Off

$i_L(0)$ = Given

$V_C(0)$ = Given

$$V = LC\frac{d^2 v_C}{dt^2} + v_C \quad \& \quad i_C = C\frac{dv_C}{dt}$$

$$v_C = V + A\sin\left(\frac{t}{\sqrt{LC}}\right) + B\cos\left(\frac{t}{\sqrt{LC}}\right)$$

$$i_L = C\frac{dv_C}{dt} = \sqrt{\frac{C}{L}}A\cos\left(\frac{t}{\sqrt{LC}}\right) - \sqrt{\frac{C}{L}}B\sin\left(\frac{t}{\sqrt{LC}}\right)$$

$$v_C = V + \sqrt{\frac{L}{C}}\,i_L(0)\sin\left(\frac{t}{\sqrt{LC}}\right) + (v_C(0) - V)\cos\left(\frac{t}{\sqrt{LC}}\right)$$

$$i_L = i_L(0)\cos\left(\frac{t}{\sqrt{LC}}\right) - \sqrt{\frac{C}{L}}(v_C(0) - V)\sin\left(\frac{t}{\sqrt{LC}}\right)$$

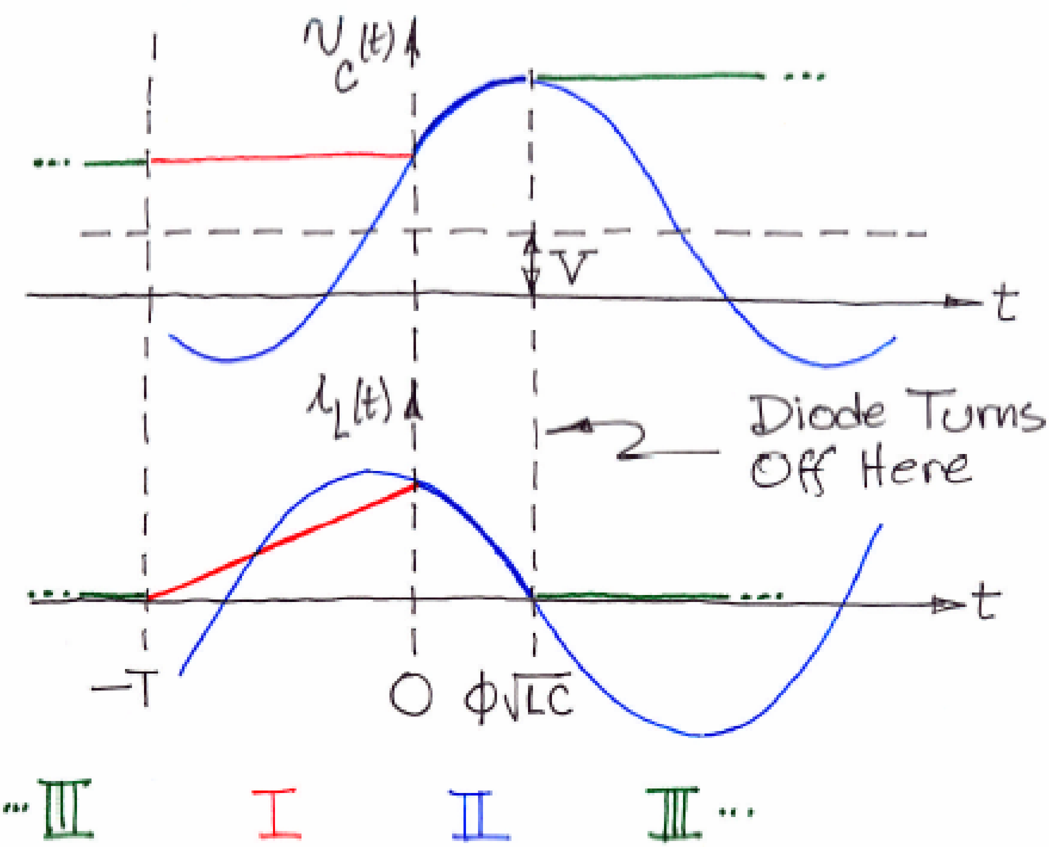
All States Together

State II Review:

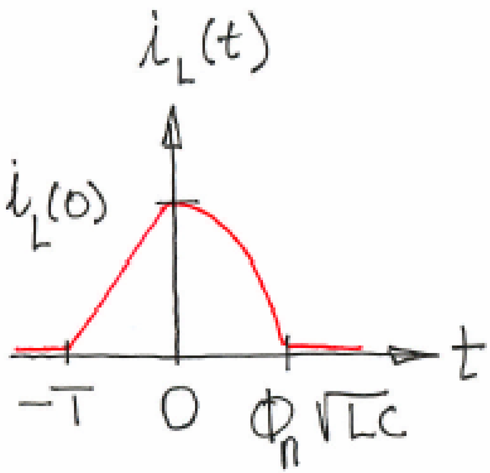
ϕ = Positive (the brace over the $\tan^{-1}$ term)

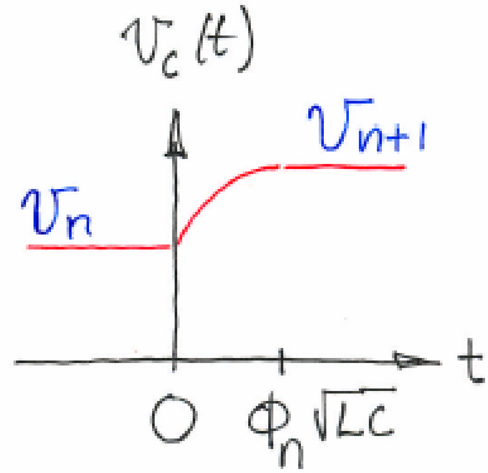
$$v_C(t) = V + \sqrt{\left(v_C(0)-V\right)^2 + \frac{L}{C} i_L^2(0)}\;\cos\left(\frac{t}{\sqrt{LC}} - \underbrace{\tan^{-1}\left(\sqrt{\frac{L}{C}}\,\frac{i_L(0)}{v_C(0)-V}\right)}_{\phi}\right)$$

$$i_L(t) = -\sqrt{\frac{C}{L}\left(v_C(0)-V\right)^2 + i_L^2(0)}\;\sin\left(\frac{t}{\sqrt{LC}} - \tan^{-1}\left(\sqrt{\frac{L}{C}}\,\frac{i_L(0)}{v_C(0)-V}\right)\right)$$



(Lossless) Cycle Analysis





$$v_{n+1} = V + \sqrt{(v_n - V)^2 + \frac{L}{C} i_L^2(0)}$$

$$= V + \sqrt{(v_n - V)^2 + \frac{V^2 T^2}{LC}}$$

$$(v_{n+1} - V)^2 = (v_n - V)^2 + \frac{V^2 T^2}{LC} \qquad (v_0 - V)^2 \equiv 0$$

$$v_n = V + V\sqrt{\frac{nT^2}{LC}}$$

Cycle Analysis Via Energy

Conservation: $\Delta W_C = -\Delta W_B + W_L$

Capacitor: $\Delta W_C = \frac{1}{2} C v_{n+1}^2 - \frac{1}{2} C v_n^2$

Inductor: $W_L = \frac{1}{2} L i_L^2(0)$

Battery: $-\Delta W_B = \bar{V} \Delta Q$

Charge: $\Delta Q = C v_{n+1} - C v_n$

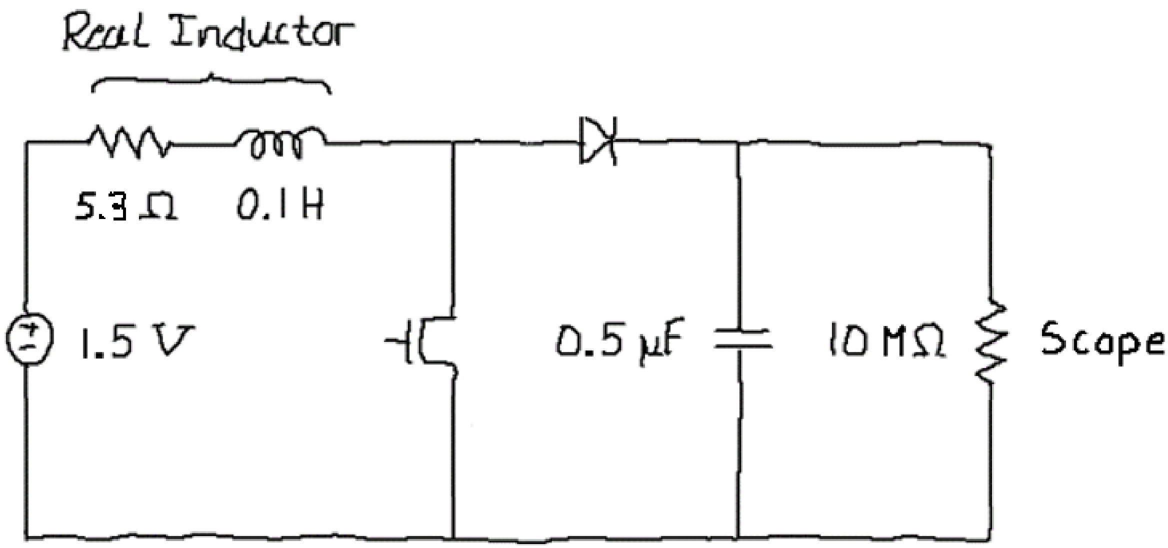
$$\frac{C}{2} v_{n+1}^2 - \frac{C}{2} v_n^2 = C \bar{V} v_{n+1} - C \bar{V} v_n + \frac{L}{2} i_L^2(0)$$

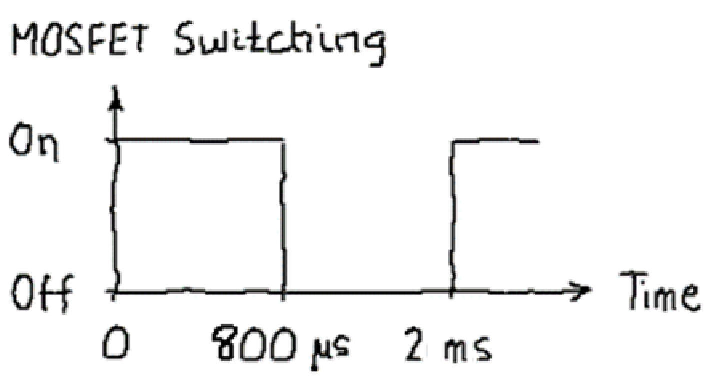
$$v_{n+1}^2 - 2\bar{V} v_{n+1} + \bar{V}^2 = v_n^2 - 2\bar{V} v_n + \bar{V}^2 + \frac{L}{C} i_L^2(0)$$

$$(v_{n+1} - \bar{V})^2 = (v_n - \bar{V})^2 + \frac{L}{C} i_L^2(0)$$

... As Before!

Demo

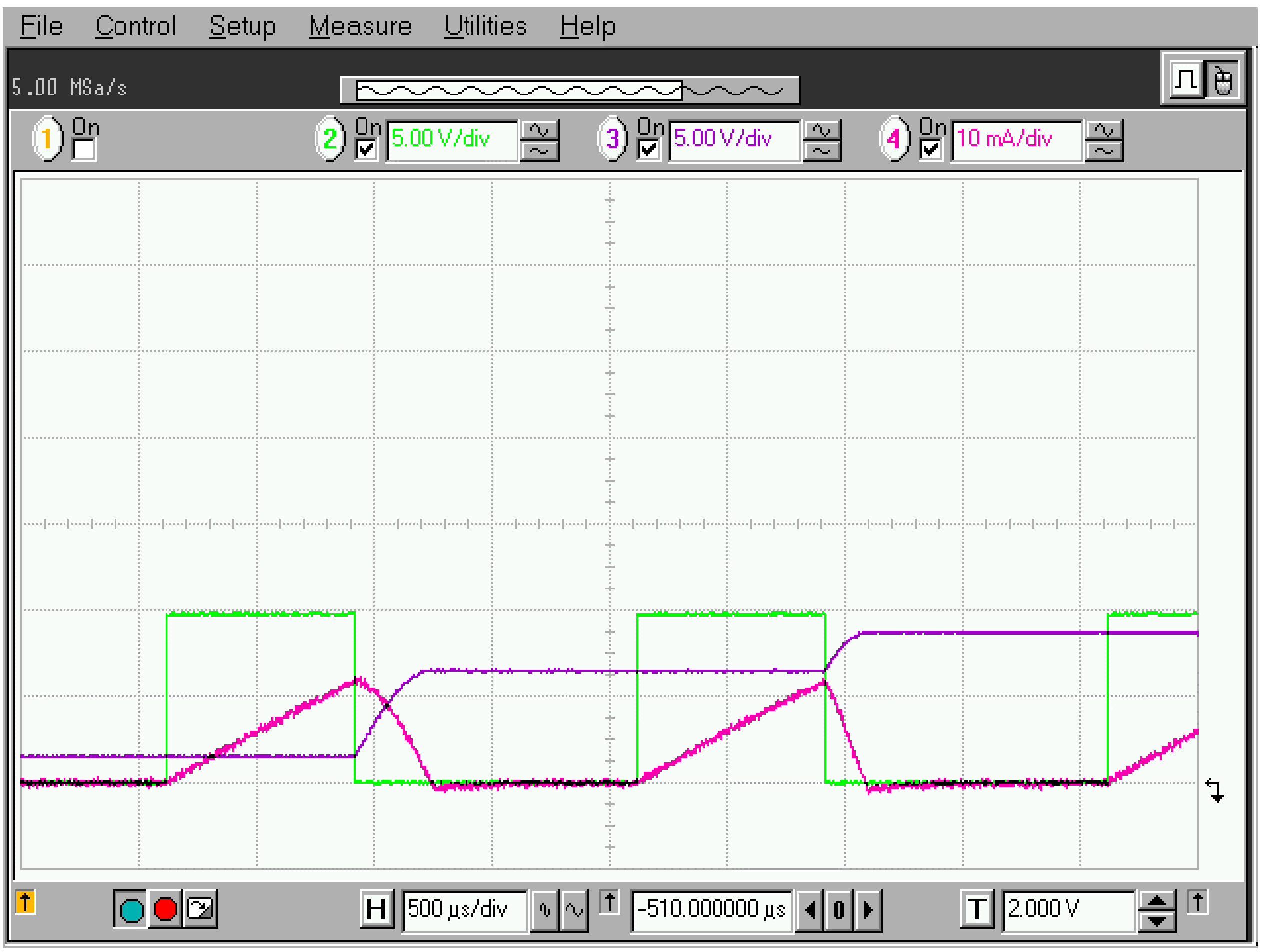




- Transistor Rating = 50V
- Capacitor Rating ≥ 100V
- Diode Rating ≥ 100V
- Inductor Rating = ?

Operation

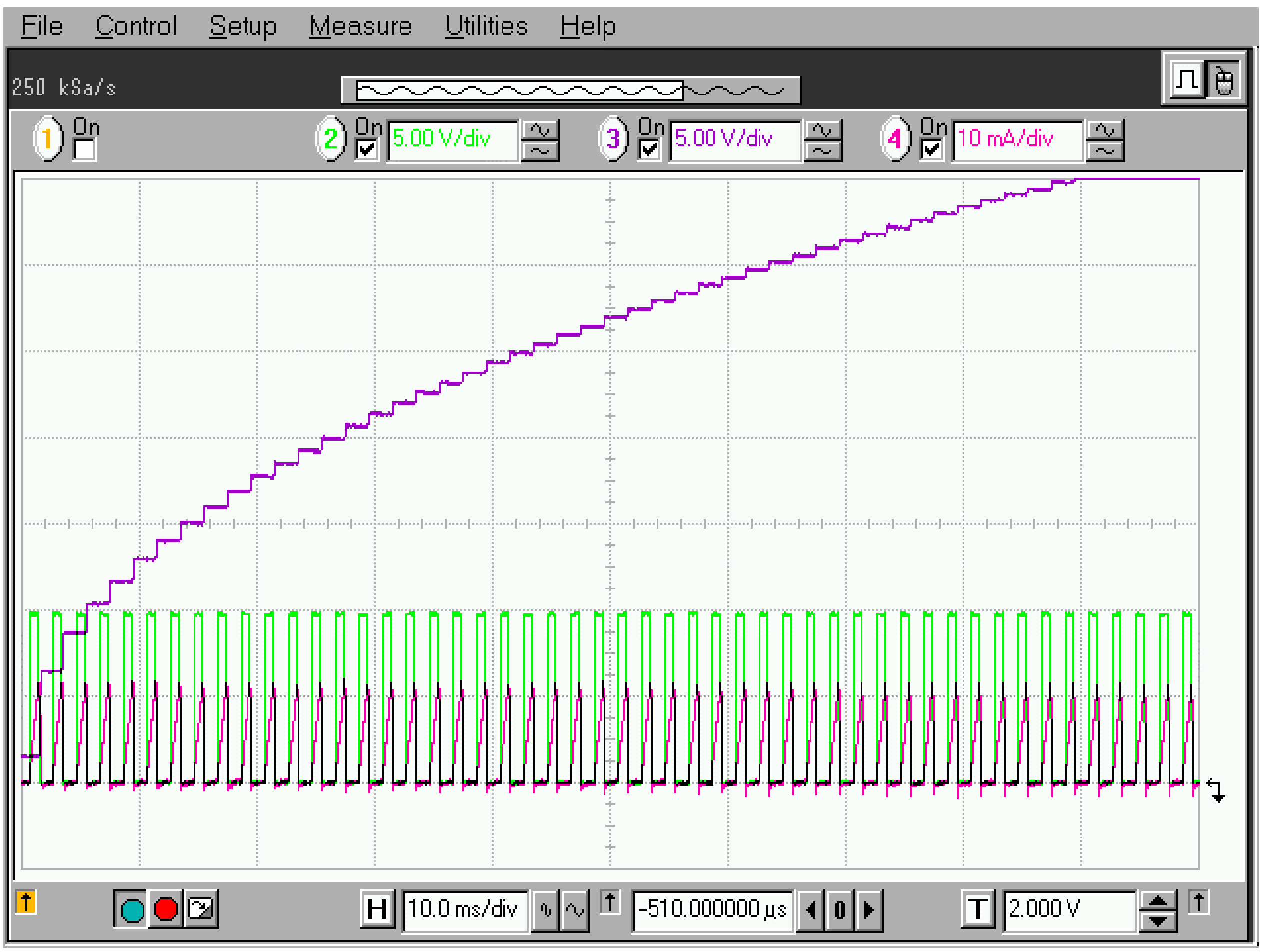
First two switching cycles



Green: S1 switch state (high = on and low = off)
Red: inductor current (10 mA/division)
Purple: capacitor voltage (5 V/division)

Operation

First fifty switching cycles



Green: S1 switch state (high = on and low = off)
Red: inductor current (10 mA/division)
Purple: capacitor voltage (5 V/division)

Simulation

This simulation omits all losses:
inductor, scope, transistor and diode.