6.200 - Lecture 18

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:

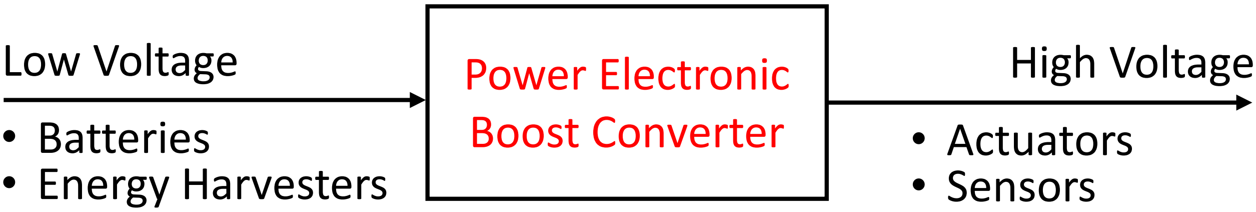
- efficiency and temperature rise;
- power density;
- regulation of output voltage or current; and
- response bandwidth in the presence of source and load variations.

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 6.222 and/or 6.622.

Boost Converter?



Low Voltage

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

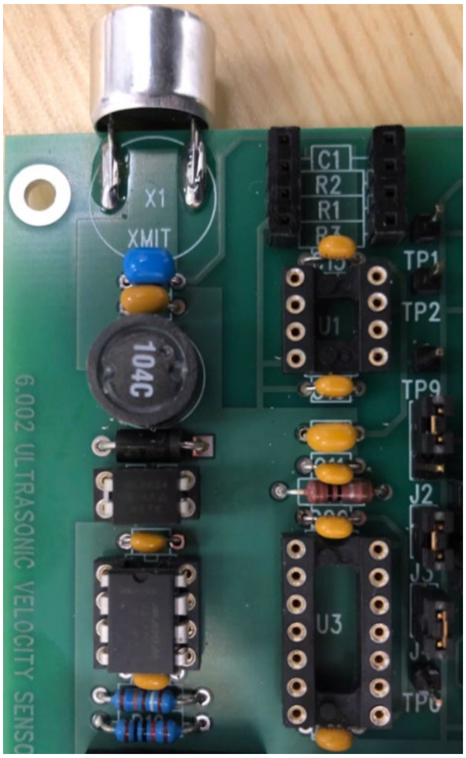
Power Electronic Boost Converter

High Voltage

- Actuators
- Sensors
- Communication
- Distribution

Concerns

- High efficiency
- Good regulation
- Wide bandwidth



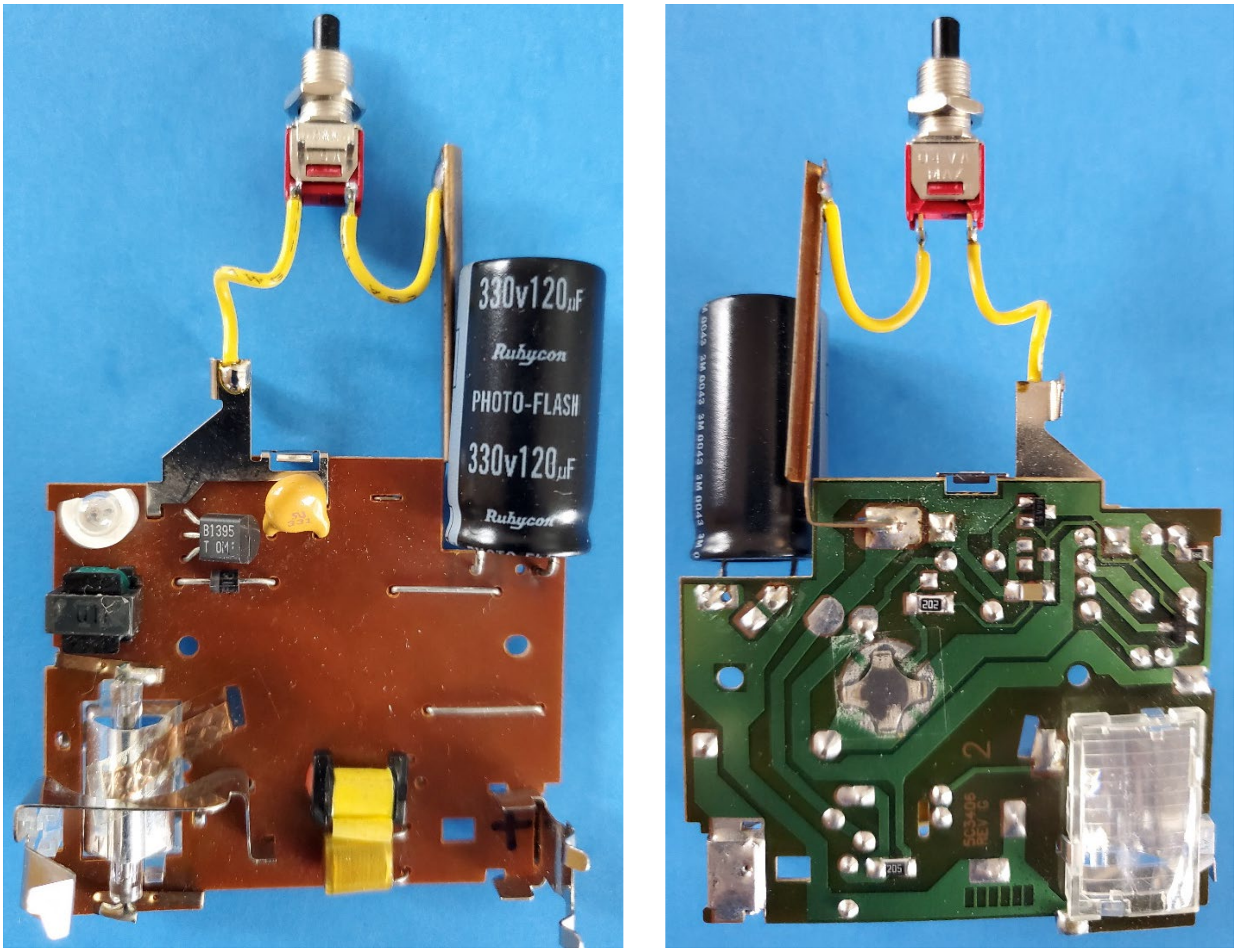
6.002 Ultrasound Boost Converter

Kodak Camera

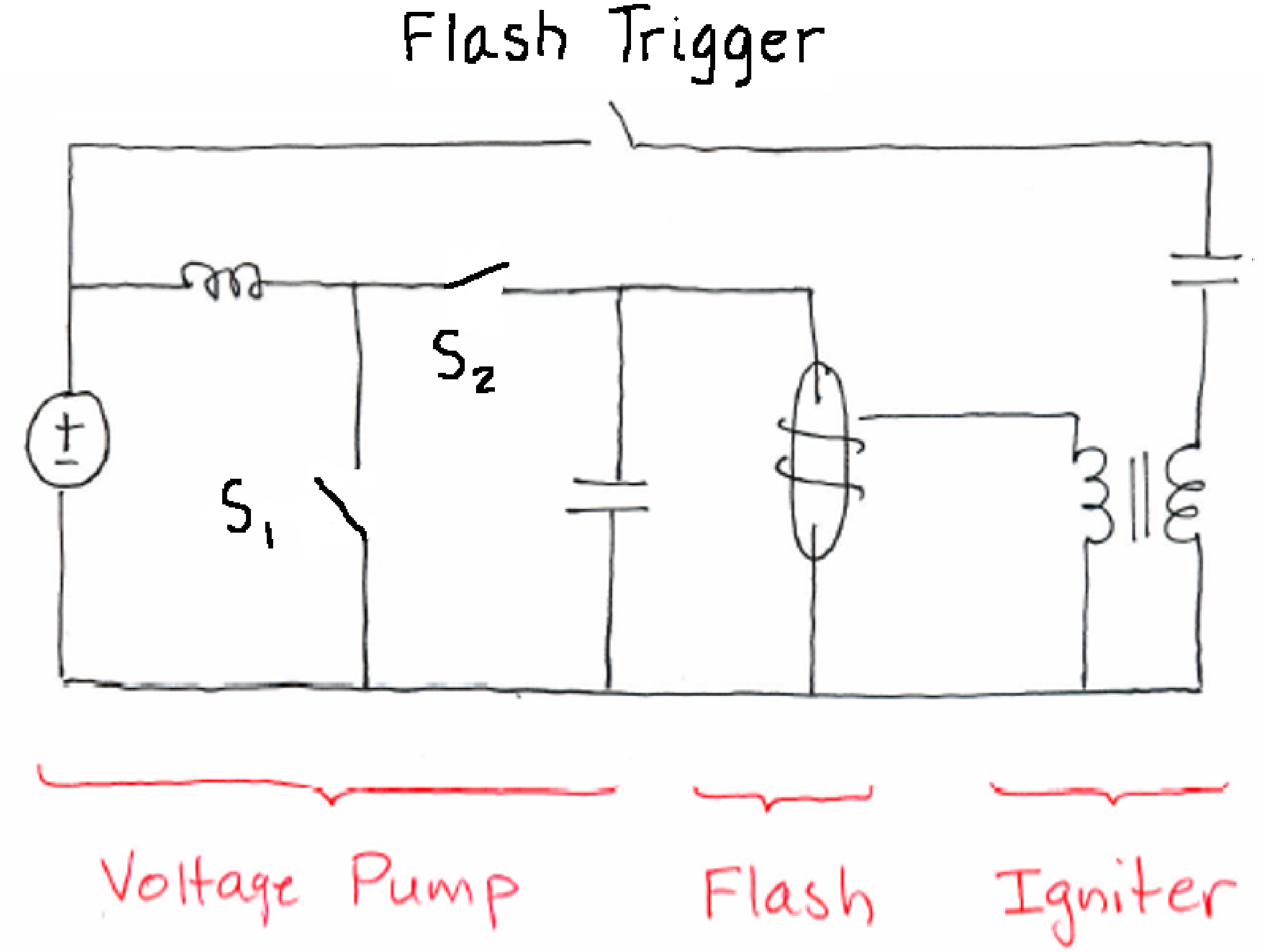
Hansen, Martin and Perreault
DOI:10.1109/TPEL.2019.2900021

Ofori-Tenkorang,
PhD Thesis, MIT, 1997

Single-Use Camera



Simplified Camera Flash Circuit

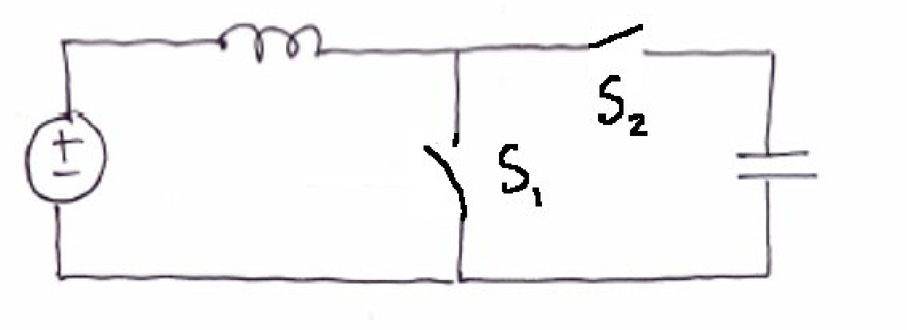


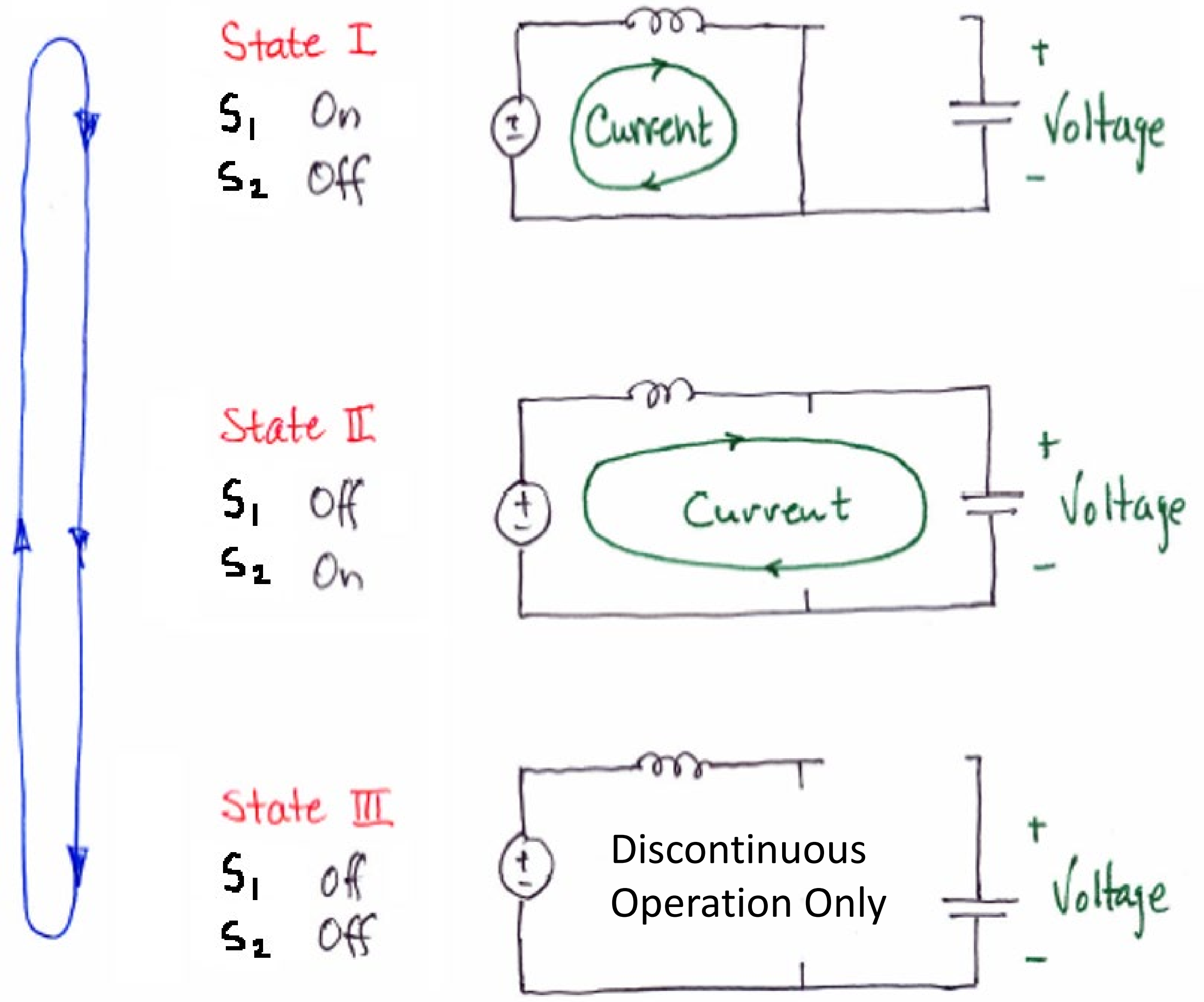
Typical Operation: 1.5 V @ Battery

300 V @ Capacitor

10 kV @ Igniter

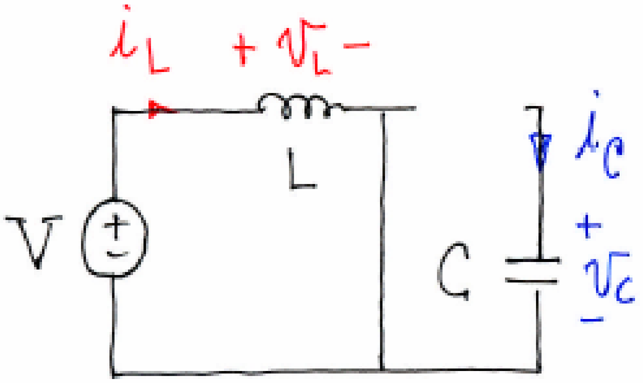
Voltage Pump (Boost Converter)





Discontinuous Operation Only

State I



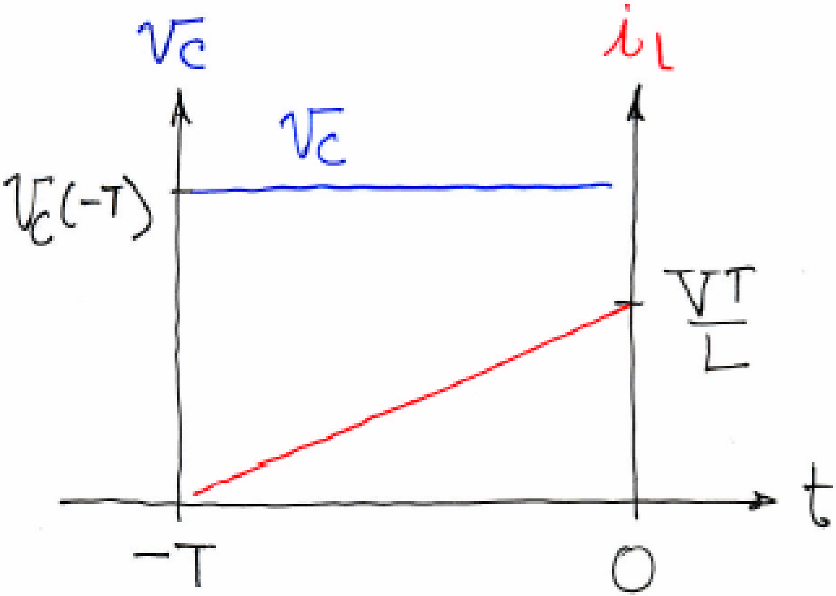
$-T \le t \le 0$

$i_L(-T) = 0$

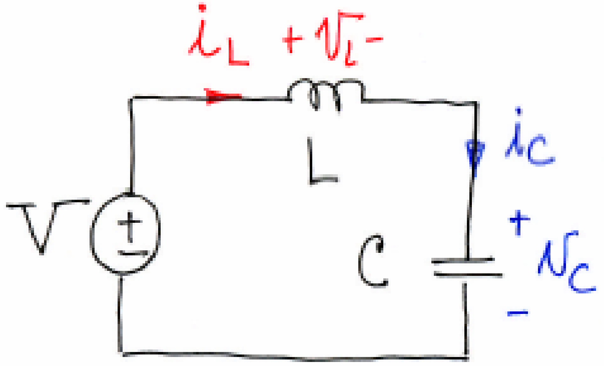
$v_C(-T) = \text{Given}$

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

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



State II



$0 \le t \le$ Diode Turn Off

$i_L(0)$ = Given

$v_C(0)$ = Given

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

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

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

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

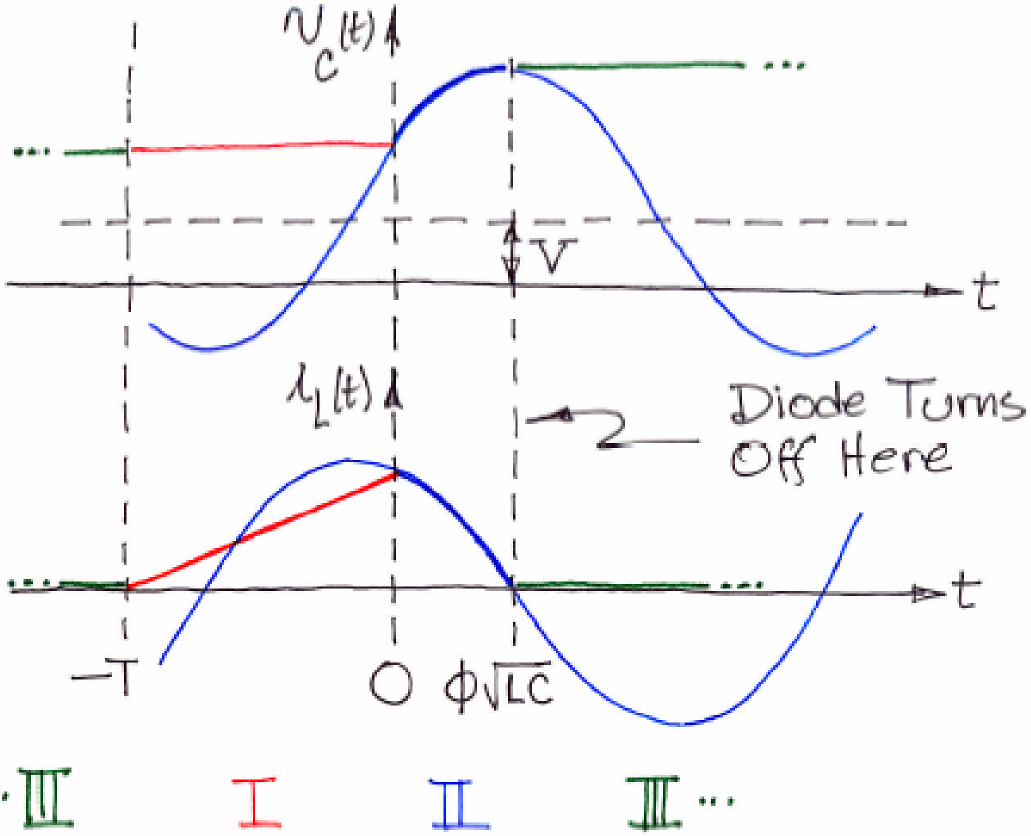
$$i_L = i_L(0)\cos\left(\frac{t}{\sqrt{LC}}\right) - \sqrt{\frac{C}{L}}\left(v_C(0) - V\right)\sin\left(\frac{t}{\sqrt{LC}}\right)$$

All States Together

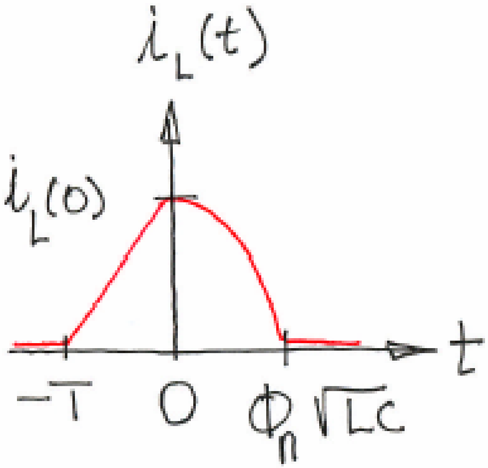
State II Review:

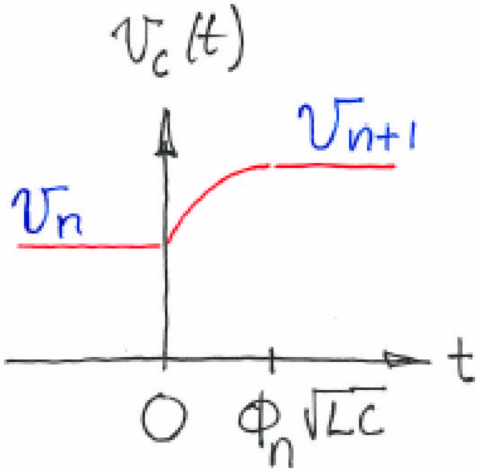
$$v_C(t) = V + \sqrt{(v_C(0)-V)^2 + \frac{L}{C} i_L^2(0)}\ \cos\left(\frac{t}{\sqrt{LC}} - \overbrace{\tan^{-1}\left(\sqrt{\frac{L}{C}}\,\frac{i_L(0)}{v_C(0)-V}\right)}^{\phi\ =\ \text{Positive}}\right)$$

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



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

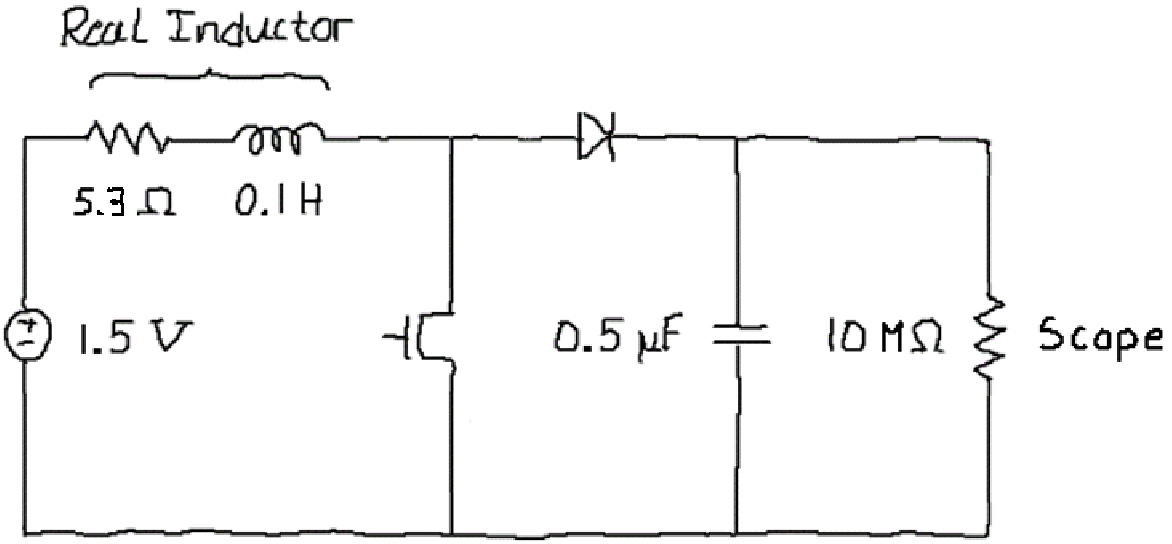
$$\frac{C}{2} v_{n+1}^2 - \frac{C}{2} v_n^2 = C \bar{V} v_{n+1} - C \bar{V} v_n + \frac{L}{2} i_L^2(0)$$

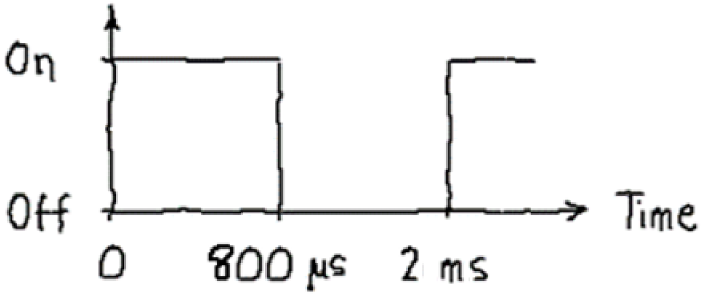
$$v_{n+1}^2 - 2\bar{V} v_{n+1} + V^2 = v_n^2 - 2\bar{V} v_n + V^2 + \frac{L}{C} i_L^2(0)$$

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

... As Before!

Demo

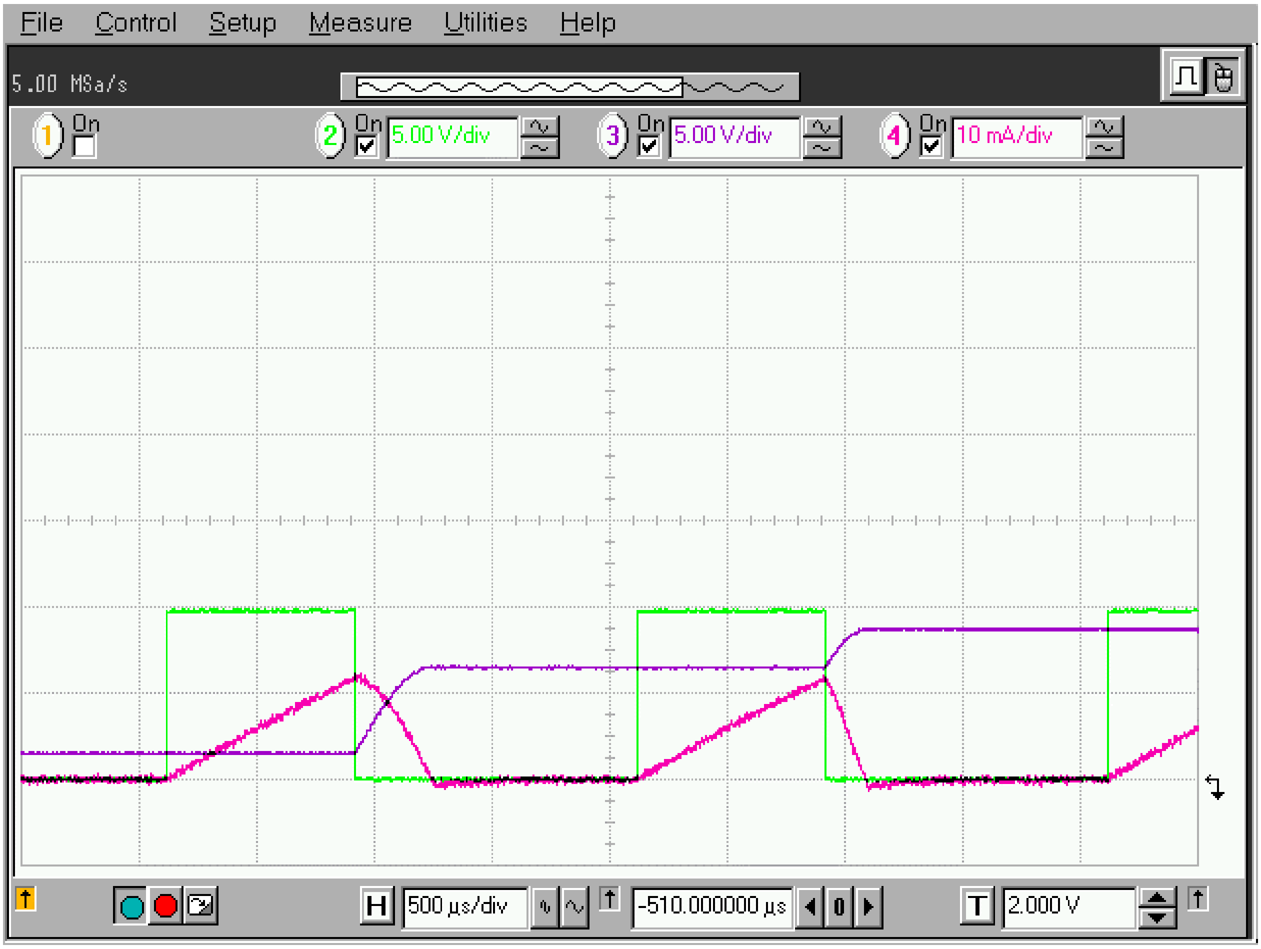



MOSFET Switching

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

Operation

First two switching cycles



5.00 MSa/s

2 5.00 V/div

3 5.00 V/div

4 10 mA/div

500 μs/div

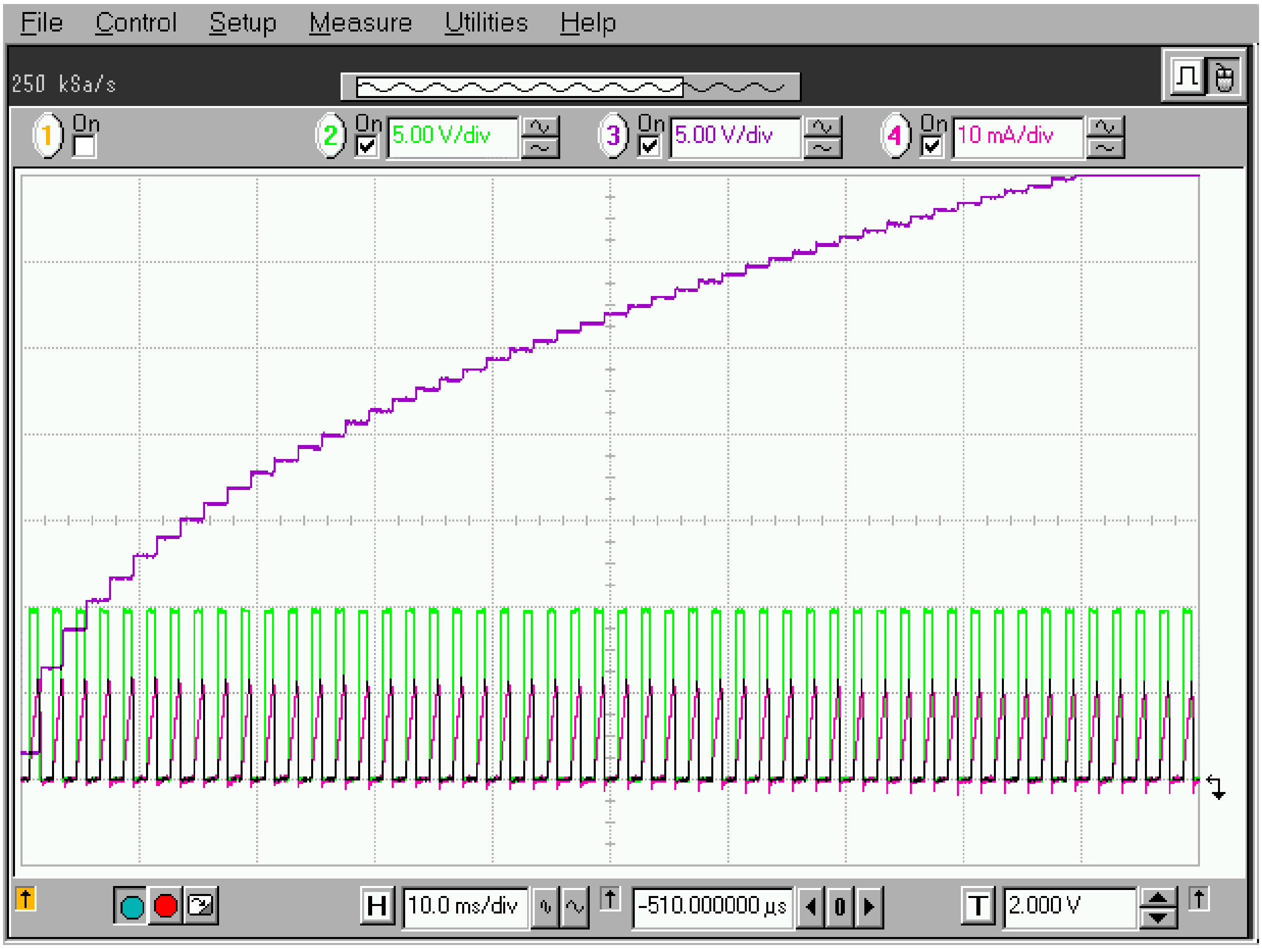
-510.000000 μs

2.000 V

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.