Power Transfer Over a Capacitive Interface

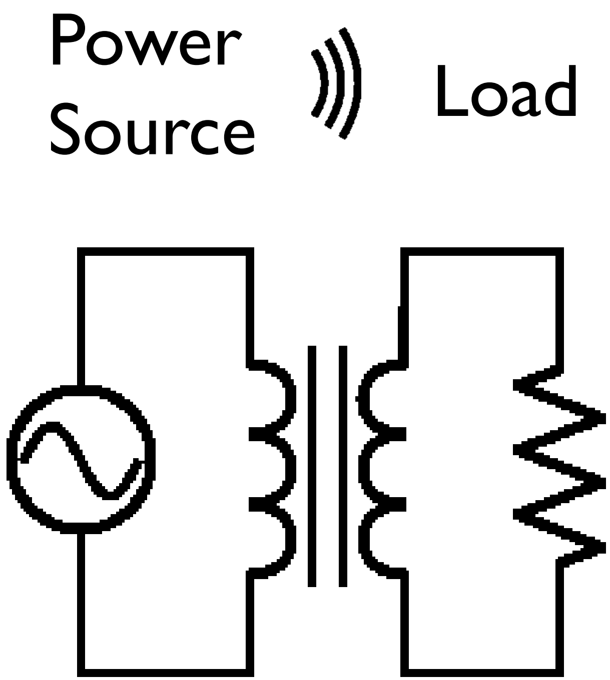
A Wireless Power Technology

Mitchell Kline
Igor Izyumin
Prof. Bernhard Boser
Prof. Seth Sanders

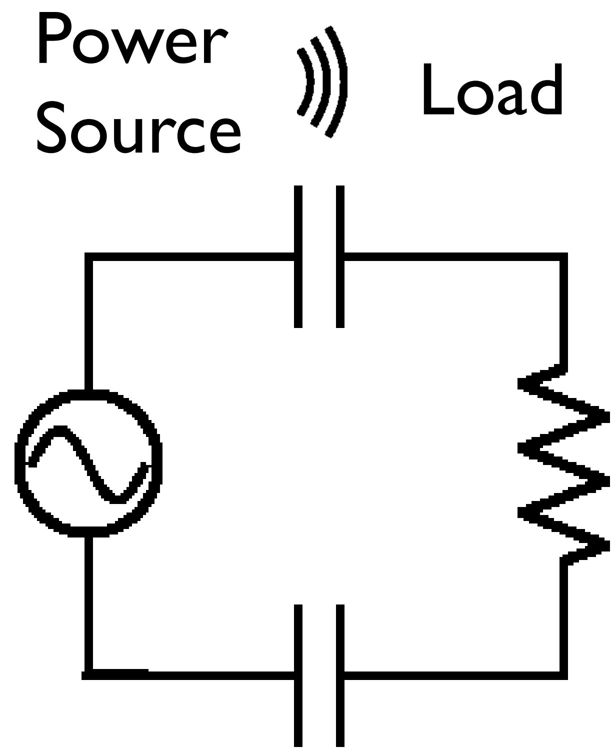
Why Wireless Power?

Wireless Power Technology

Close-coupled wireless power transfer

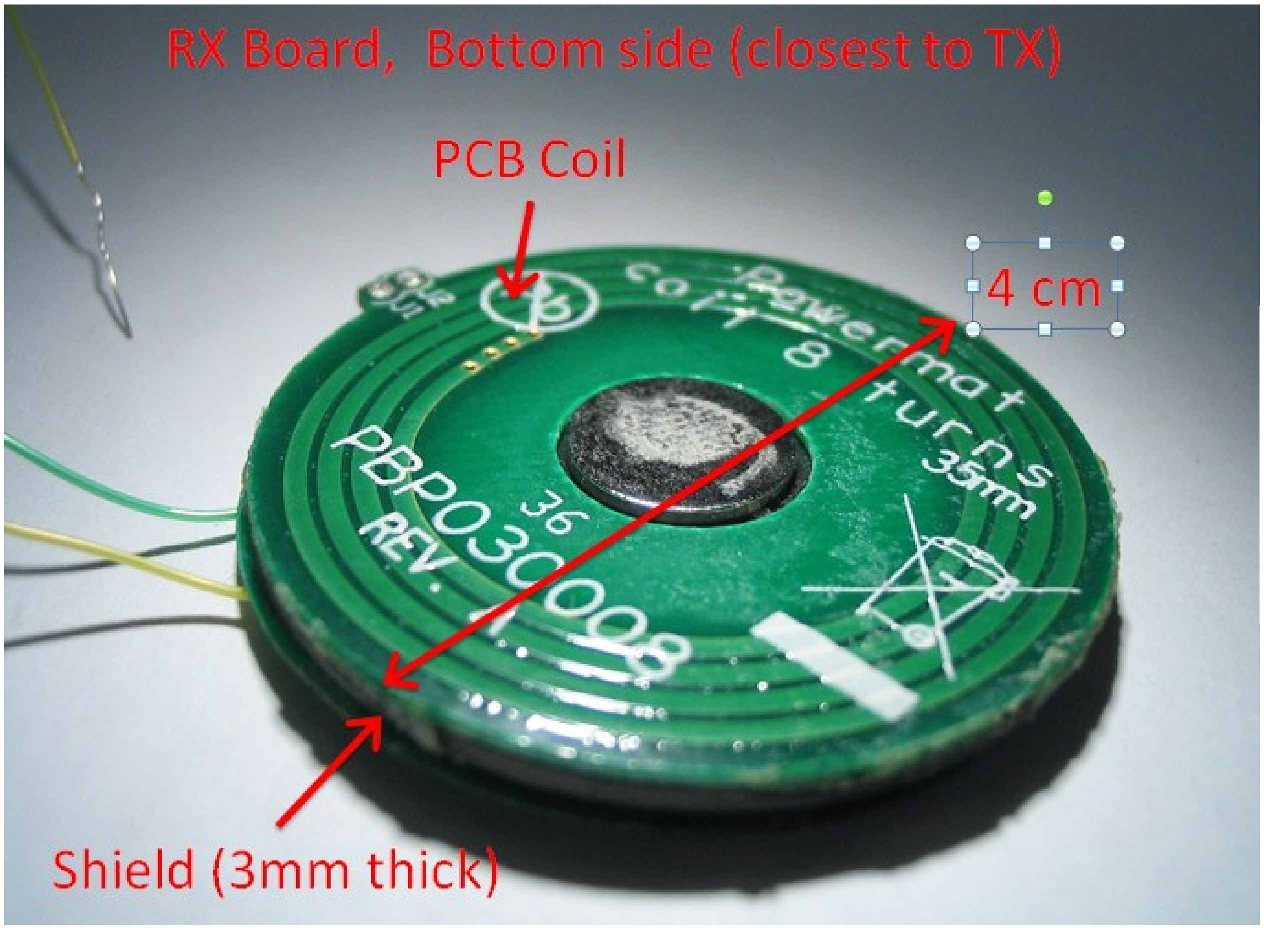


1. Inductive

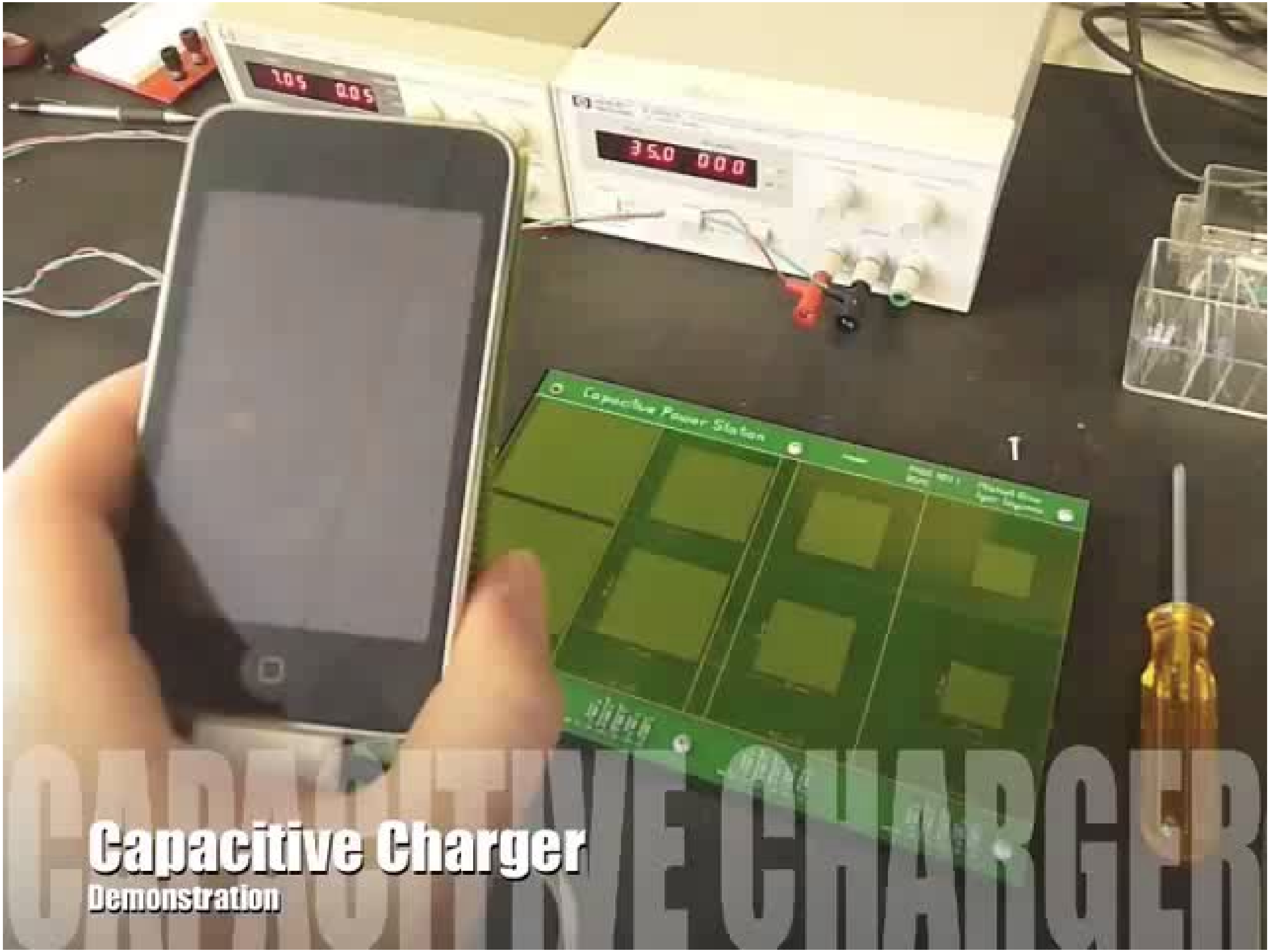


2. Capacitive

The Powermat



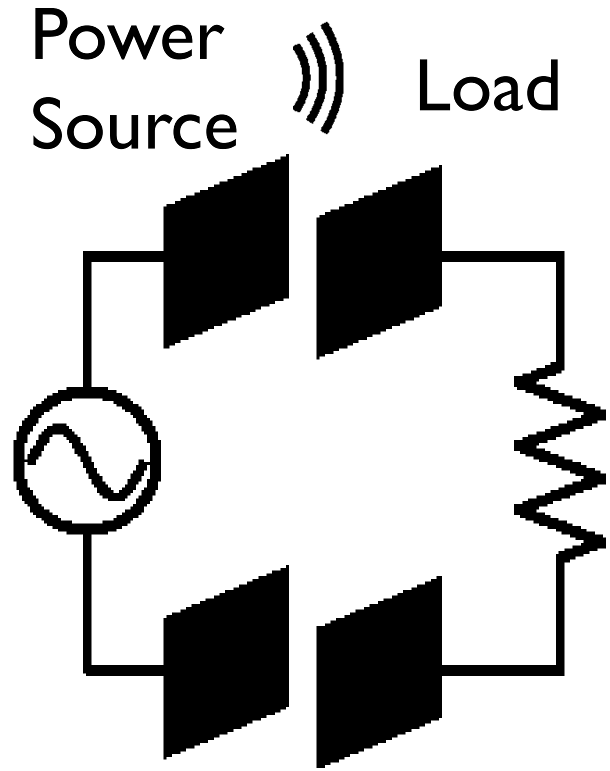
- 60% efficiency
- shield
- up to 1cm gap


Capacitive Power Station
CAPACITIVE CHARGER
Capacitive Charger
Demonstration

BSAC

Capacitive Power Transfer

Simple
Inexpensive
Thin

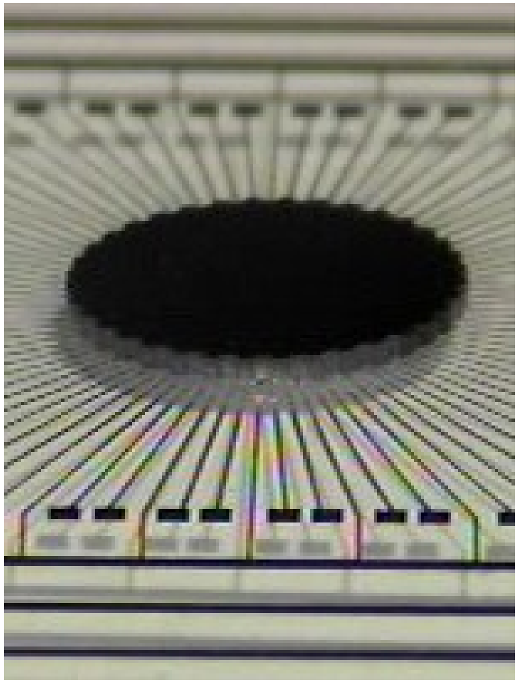


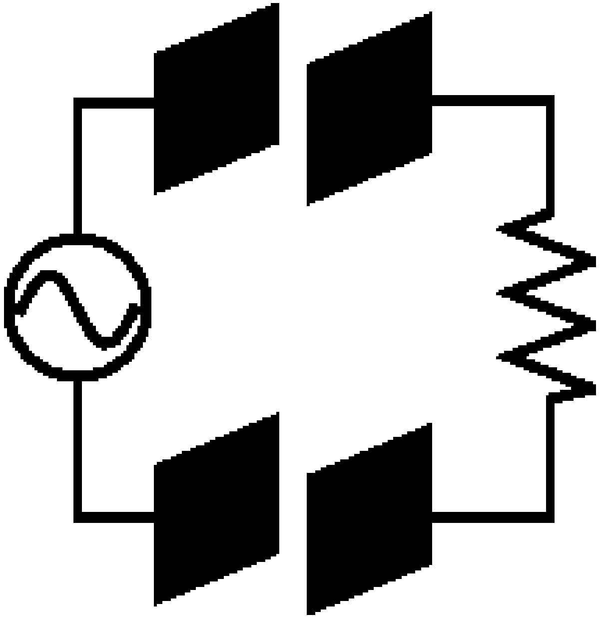
What We Want

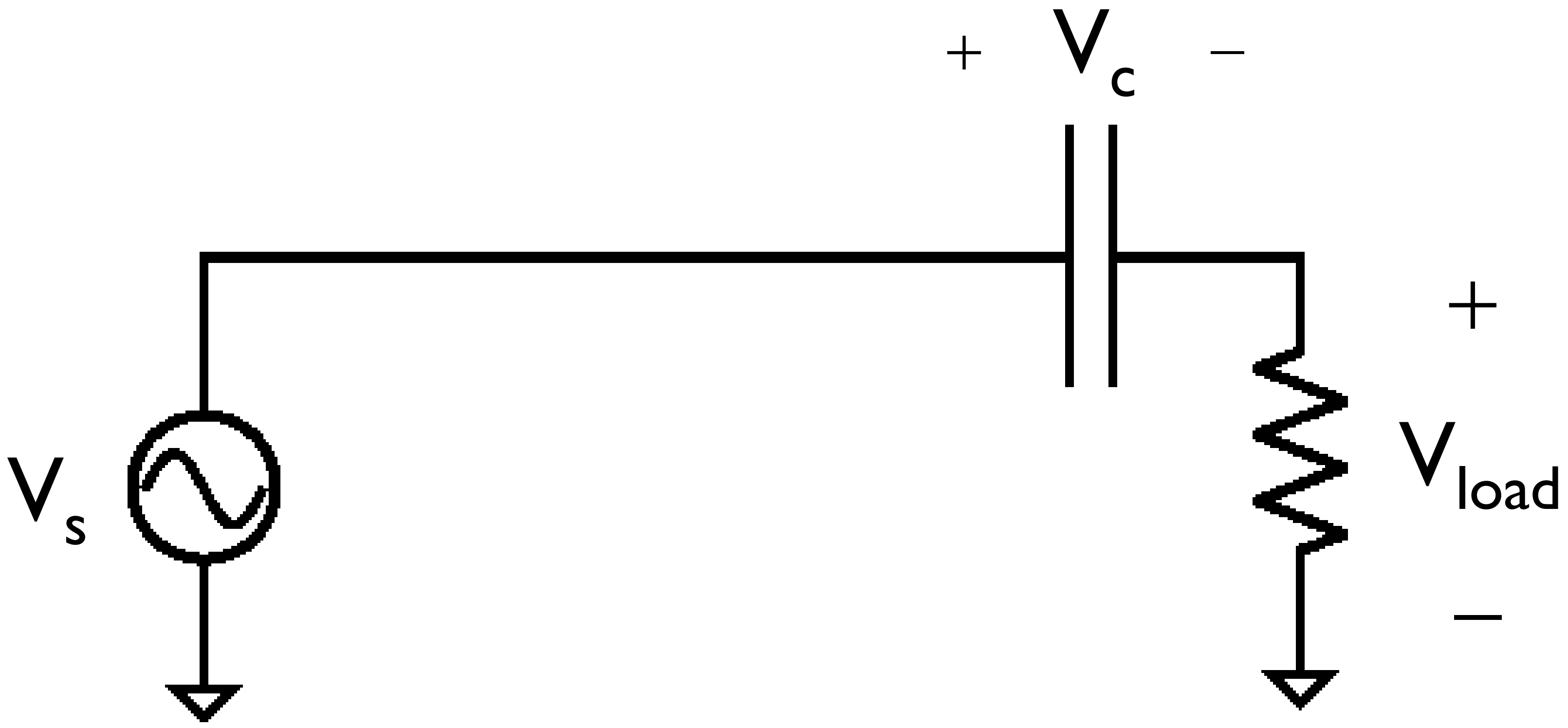
1 **Small**

2 Efficient

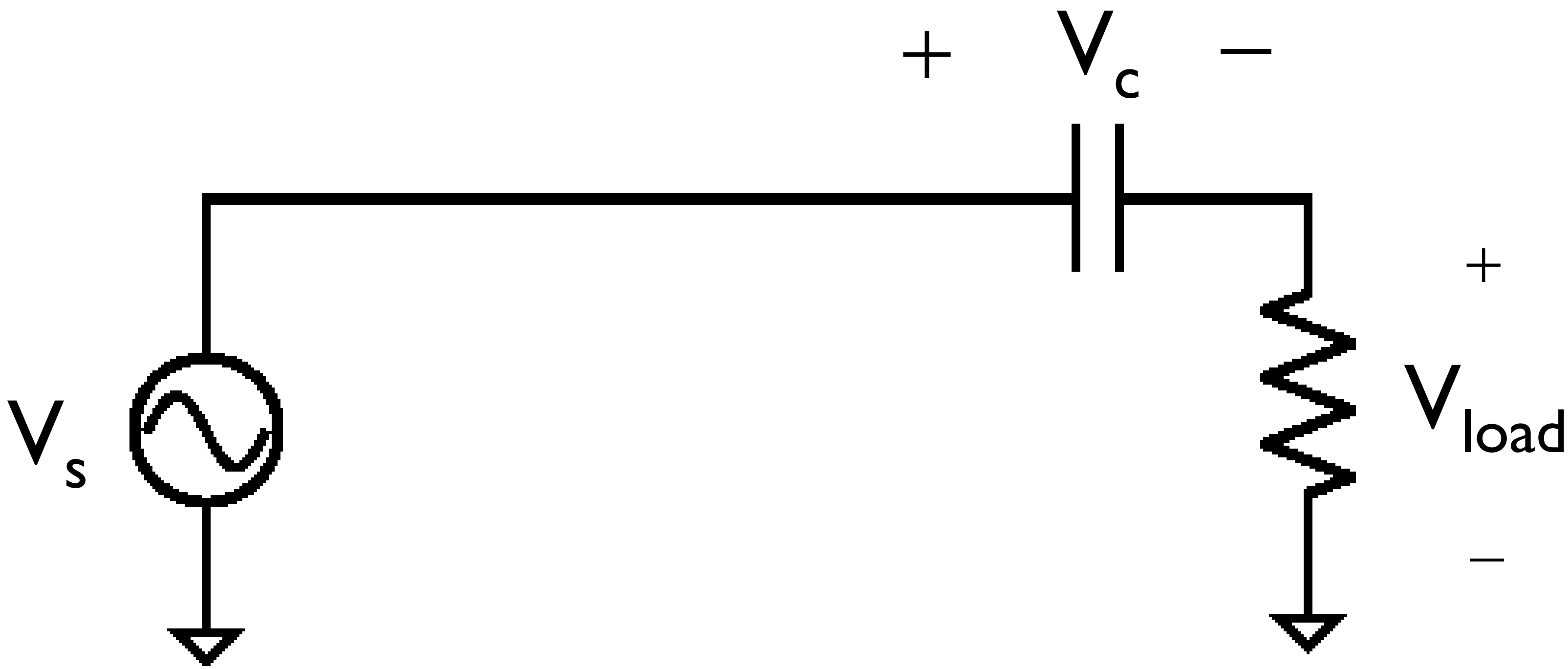
3 Robust



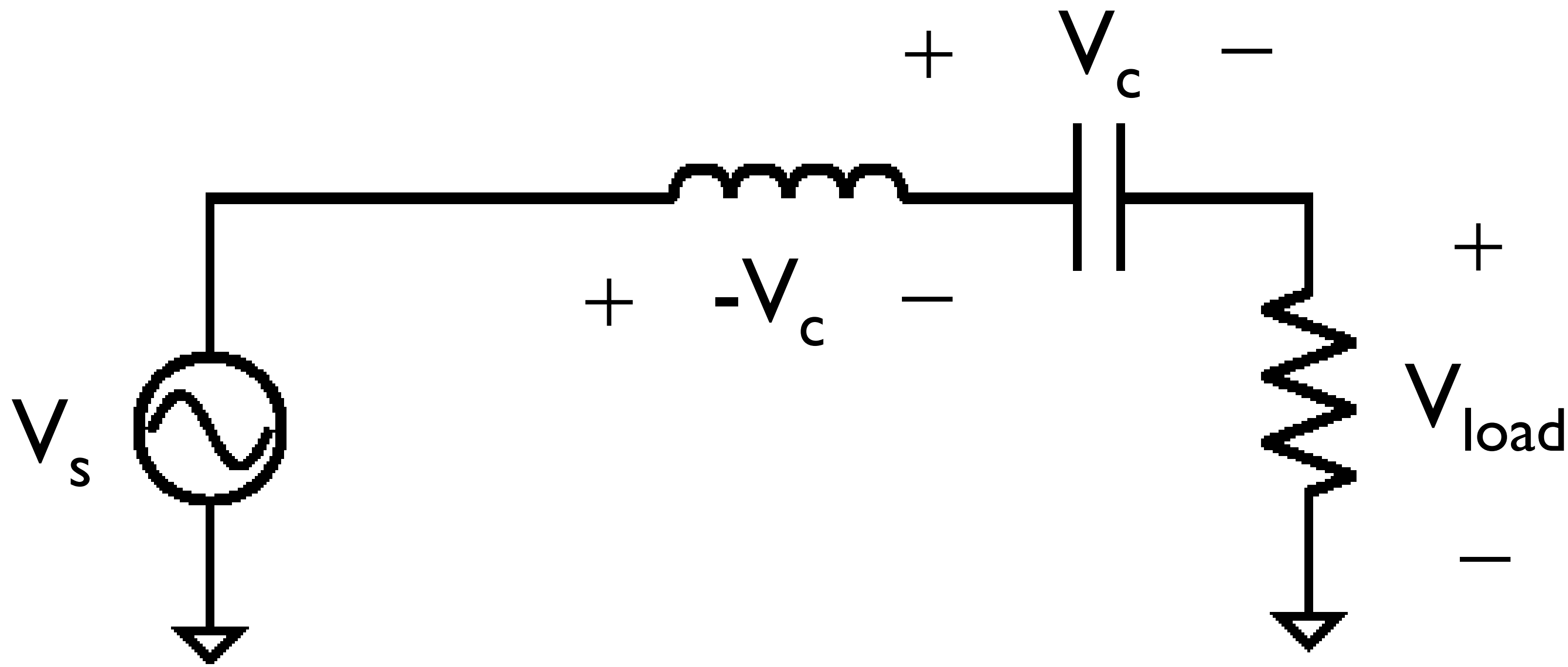




Large capacitor drops little voltage



Small capacitor drops significant voltage

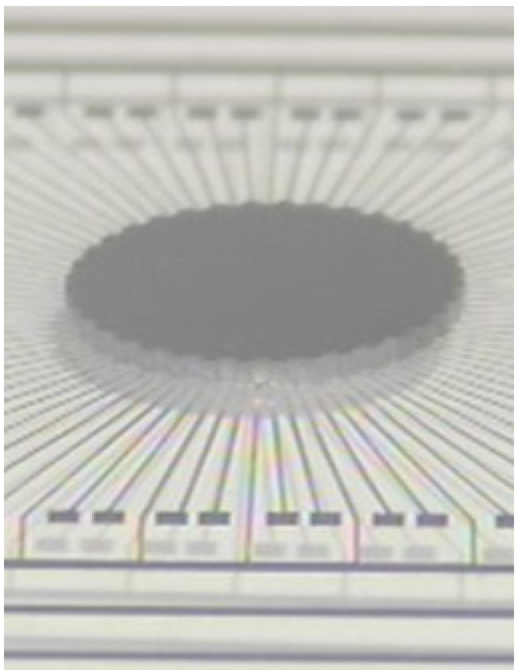


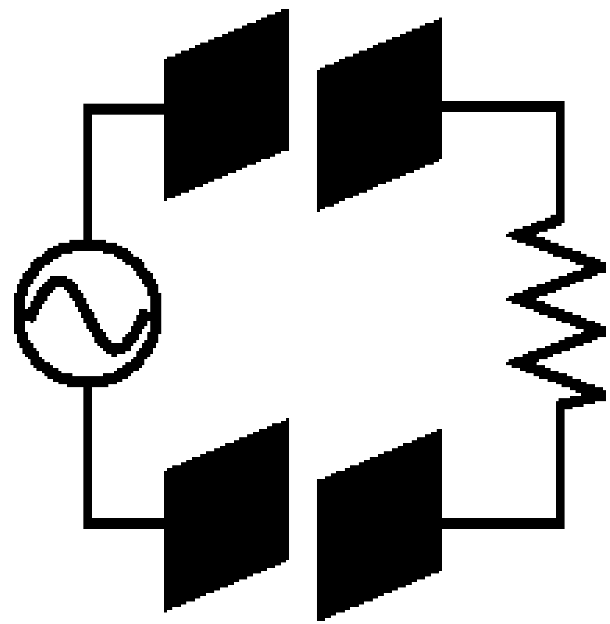
Inductor compensates for voltage drop

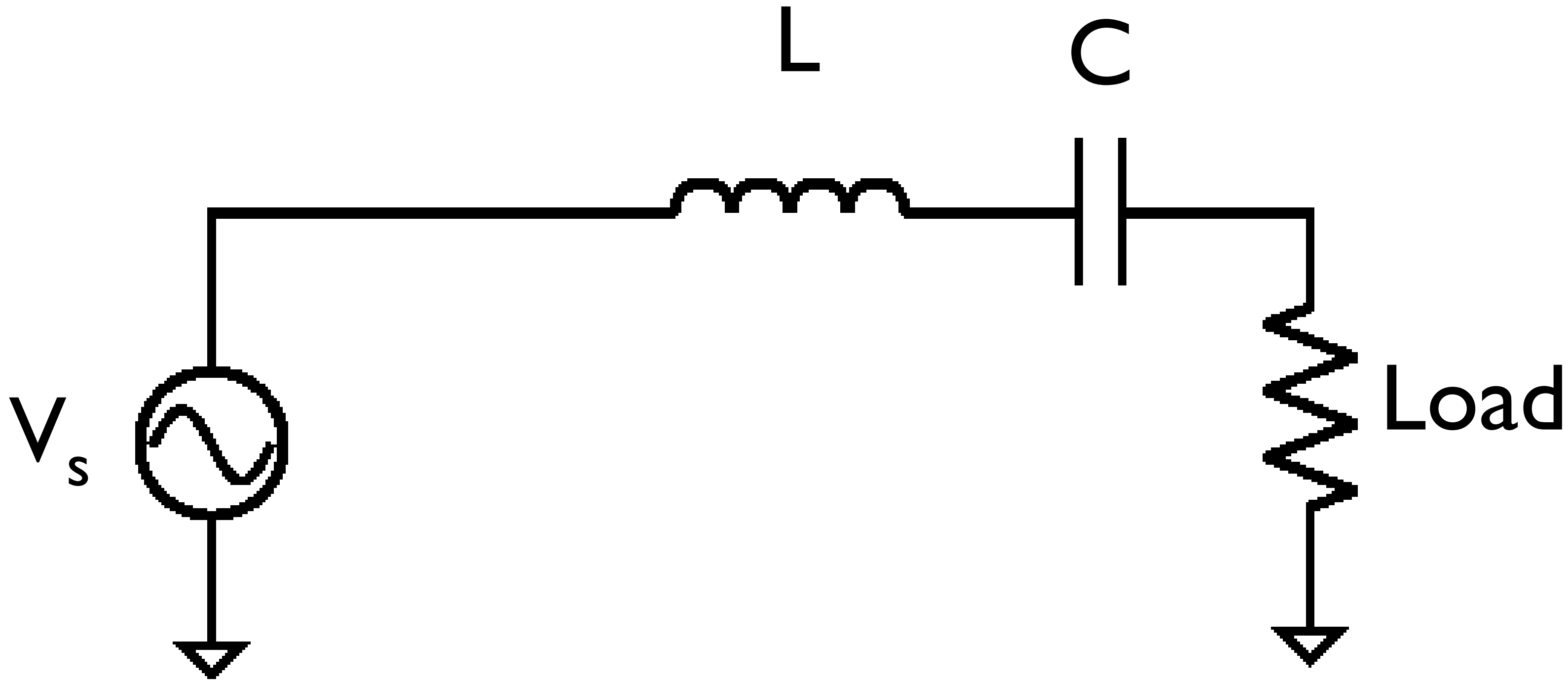
Equivalent circuit at resonance

What we want

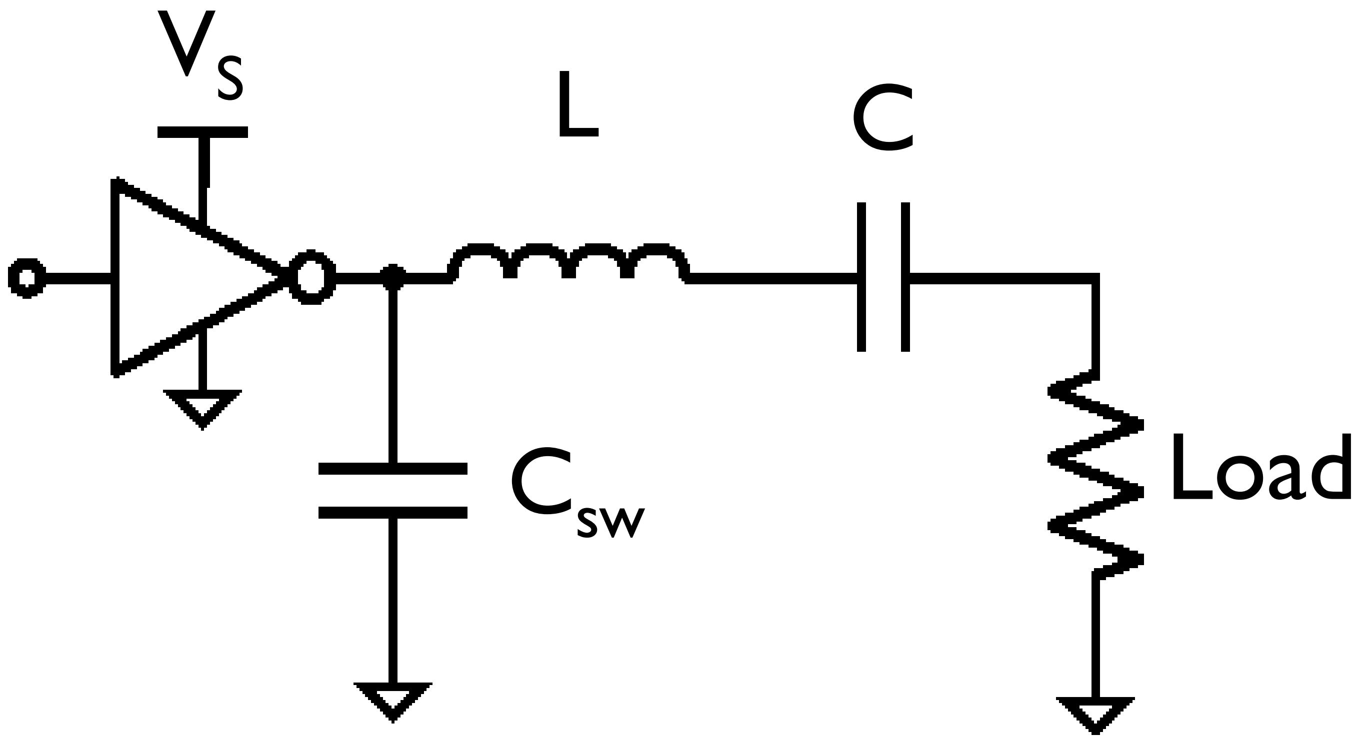
1	2	3
Small	**Efficient**	Robust



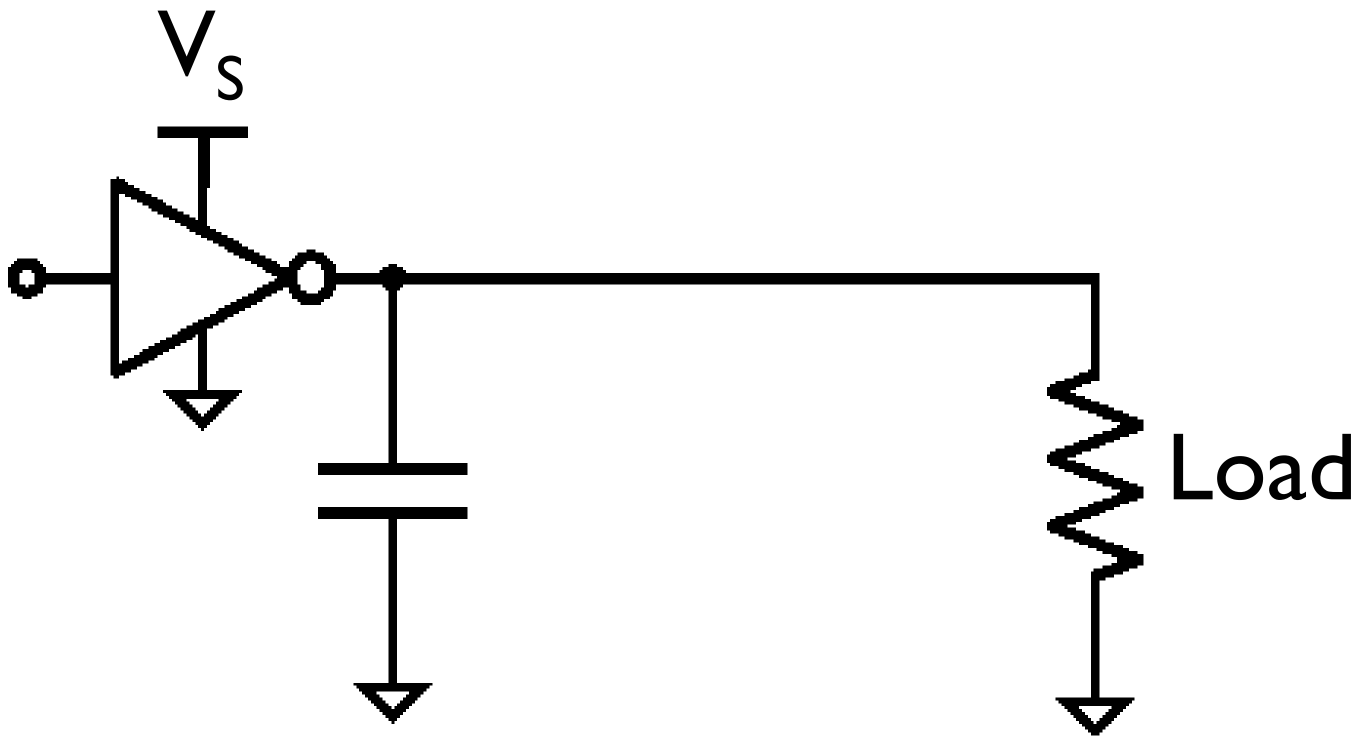




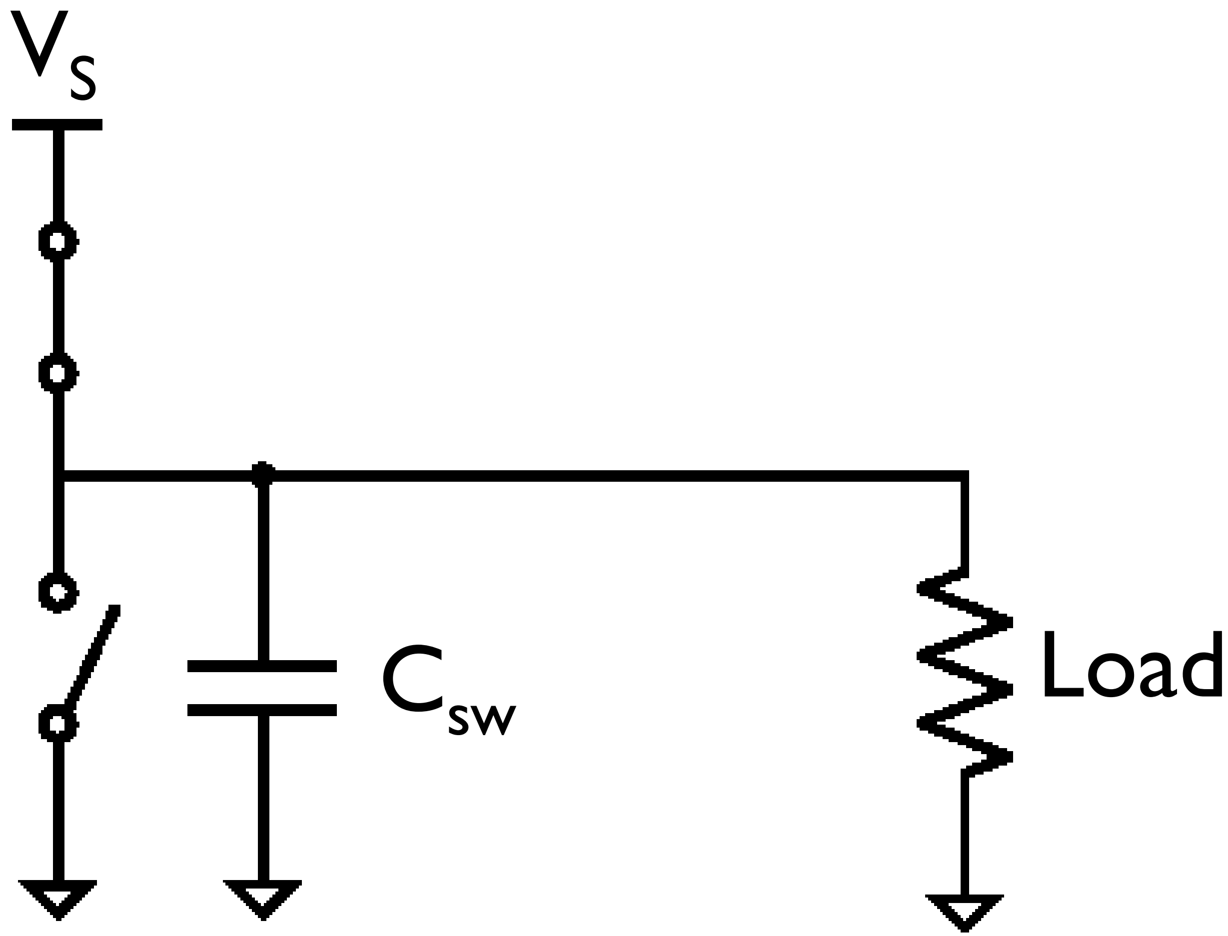
Start with the resonant circuit



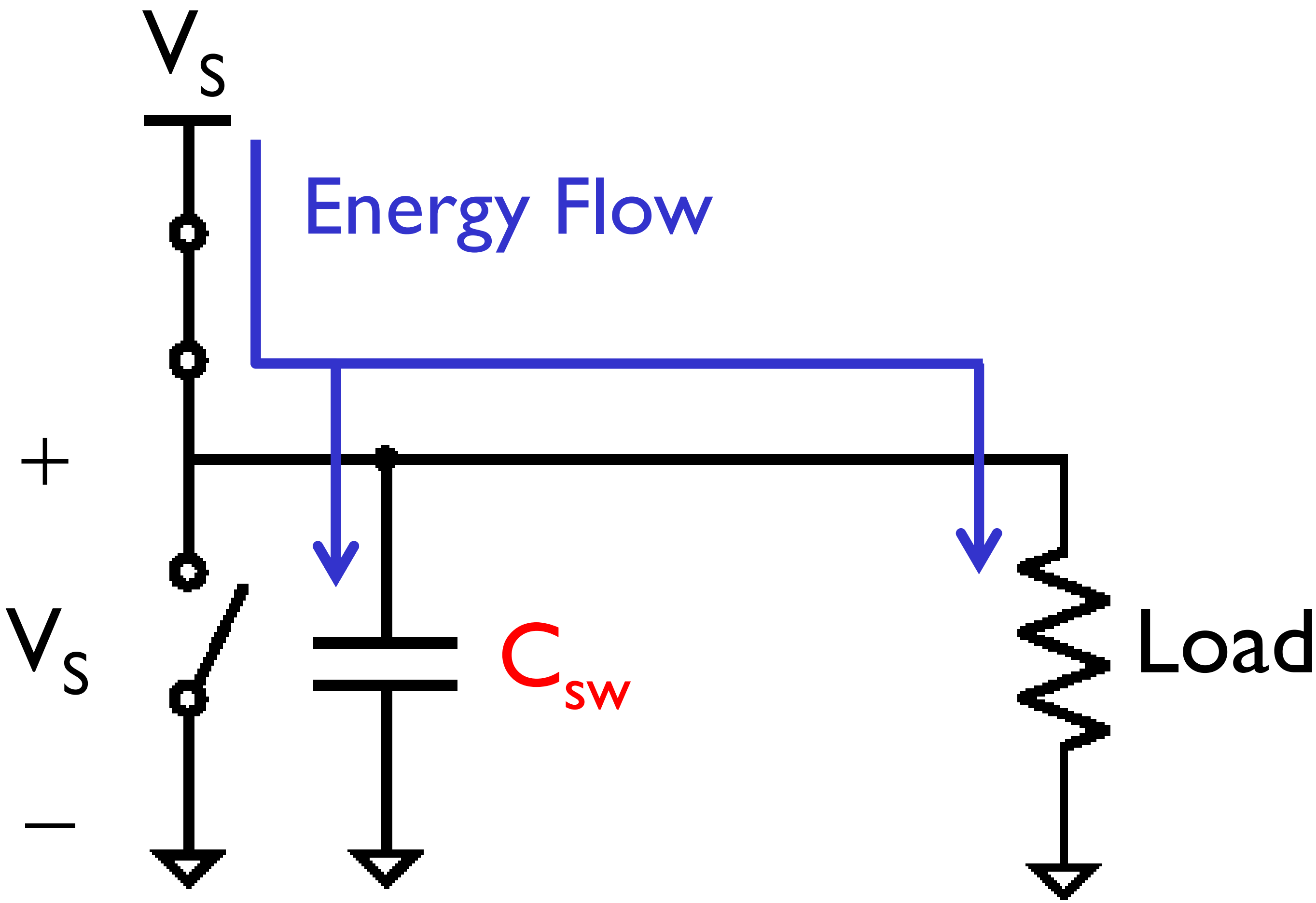
Drive it with an inverter



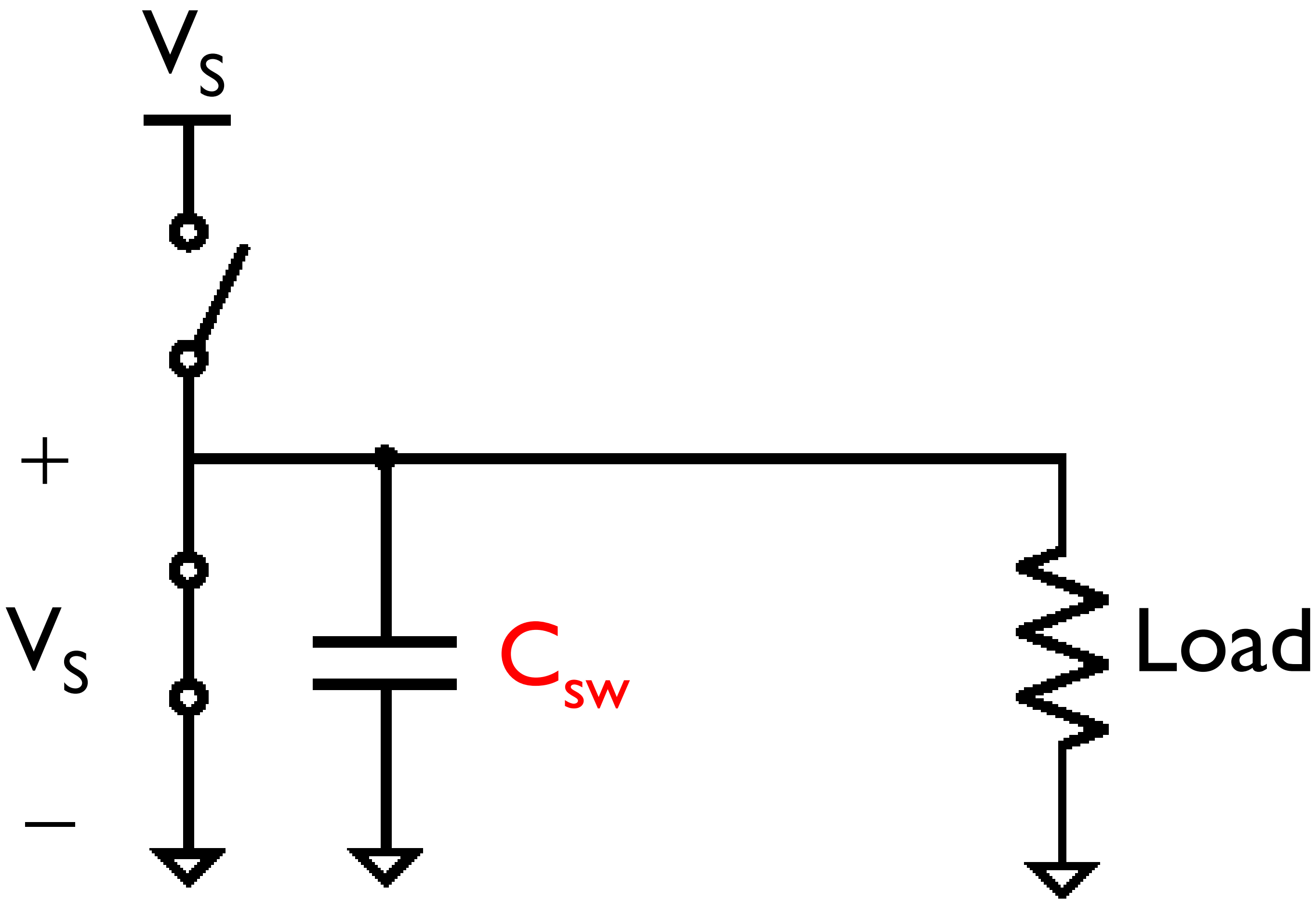
At resonance, the output capacitance remains



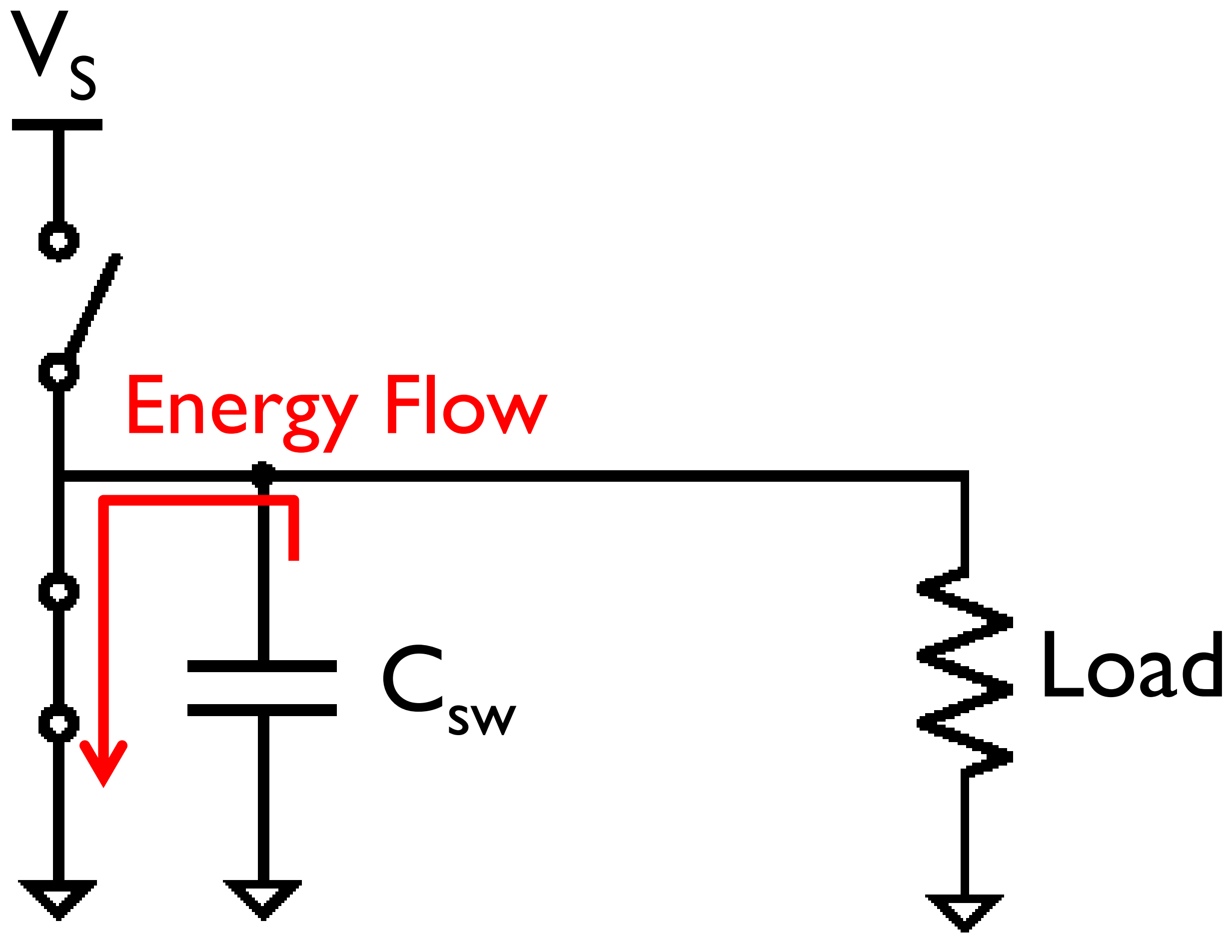
Turn on the top switch



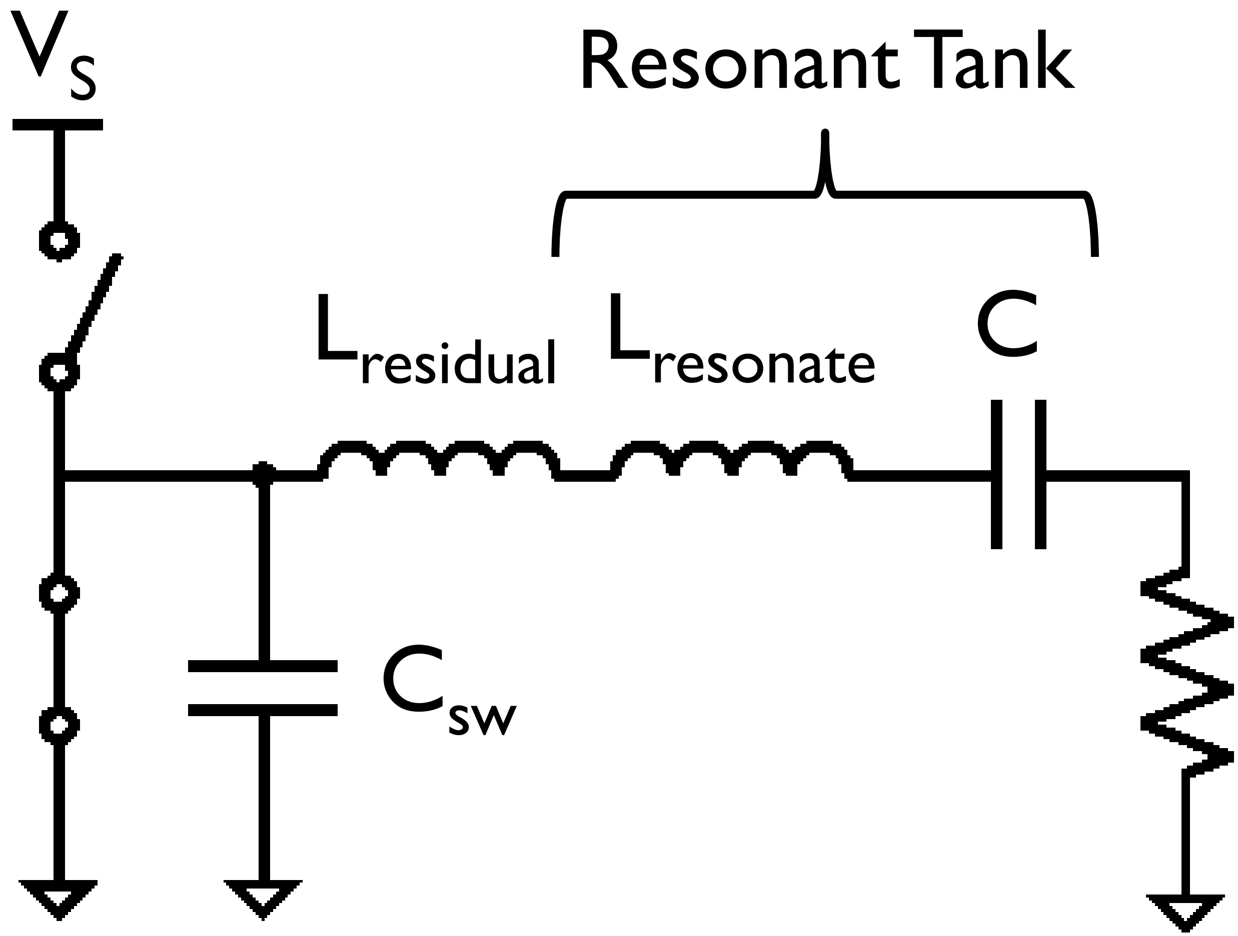
Output capacitor charged to V_S



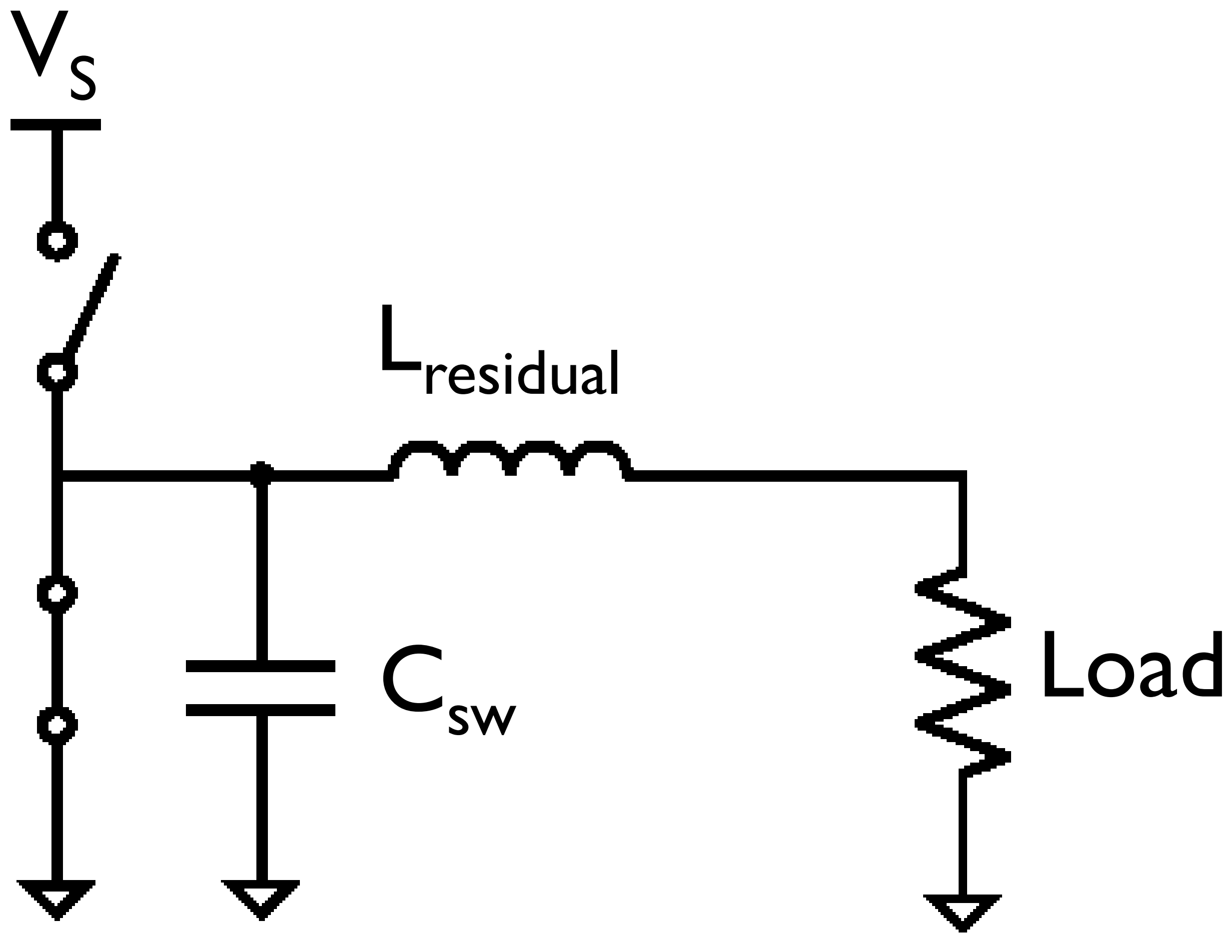
Turn on the bottom switch



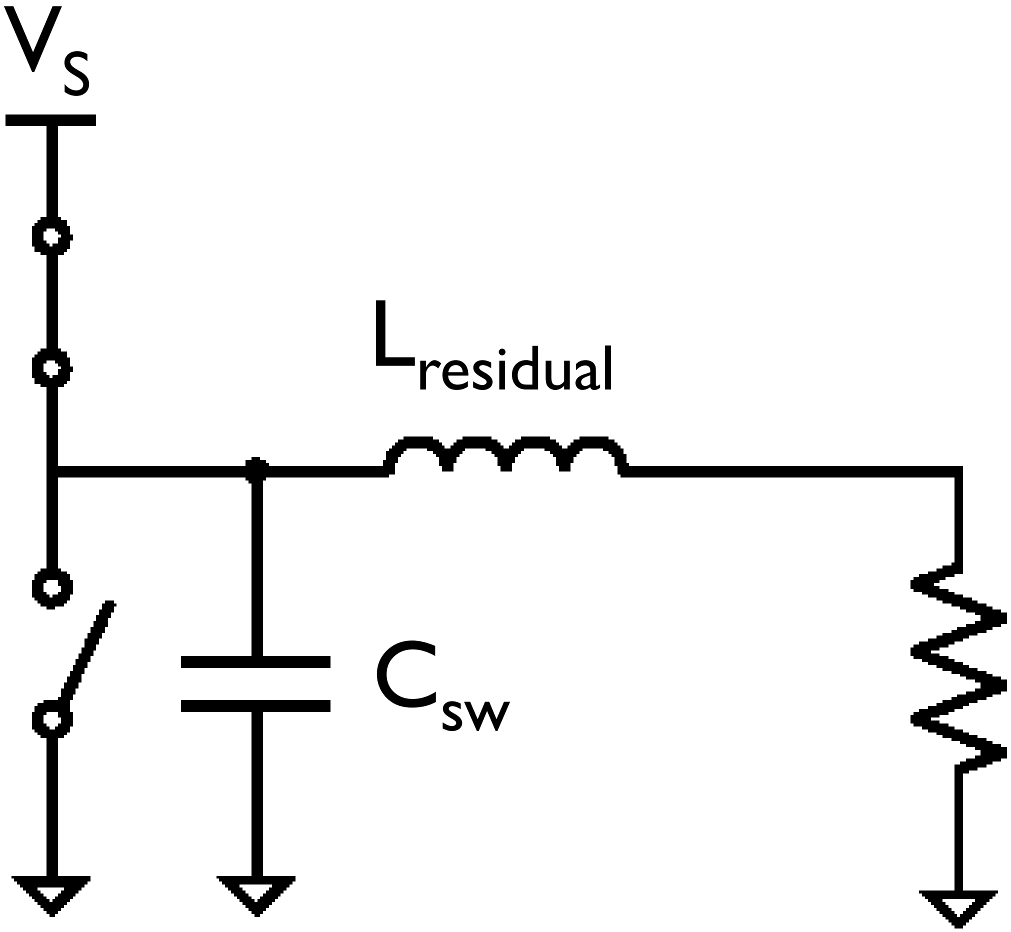
Energy stored on capacitor is wasted



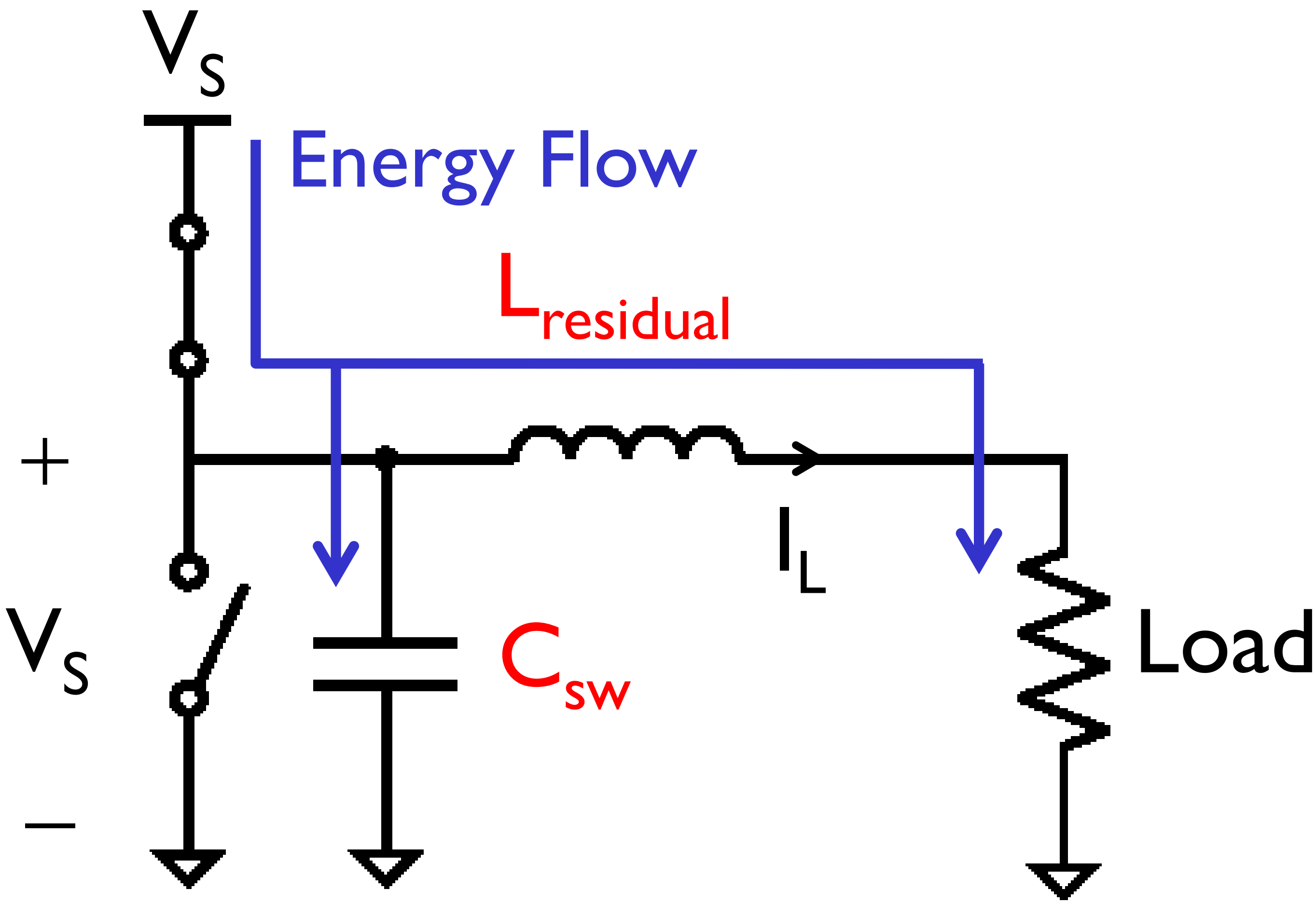
Operate above resonance



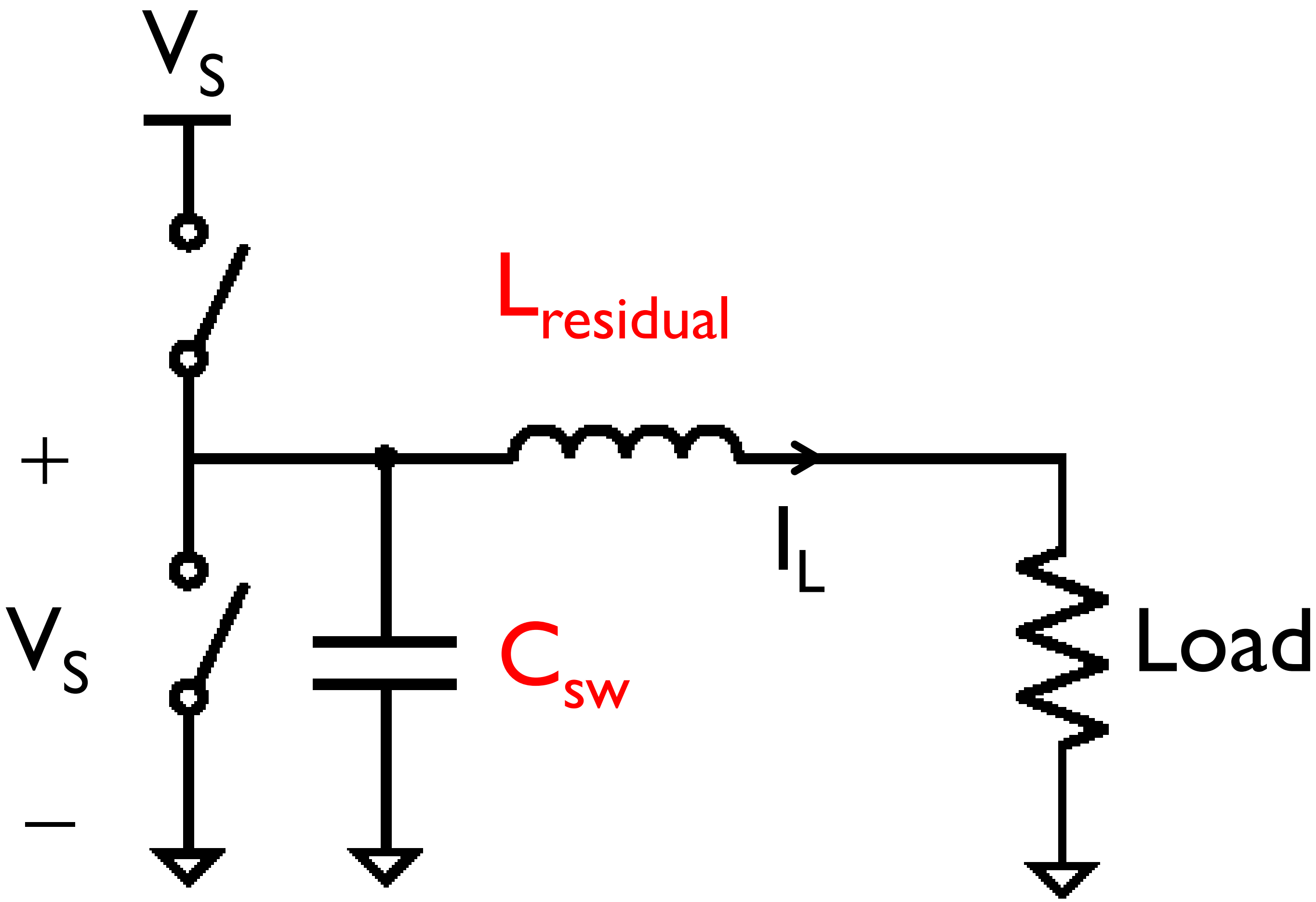
Equivalent circuit above resonance



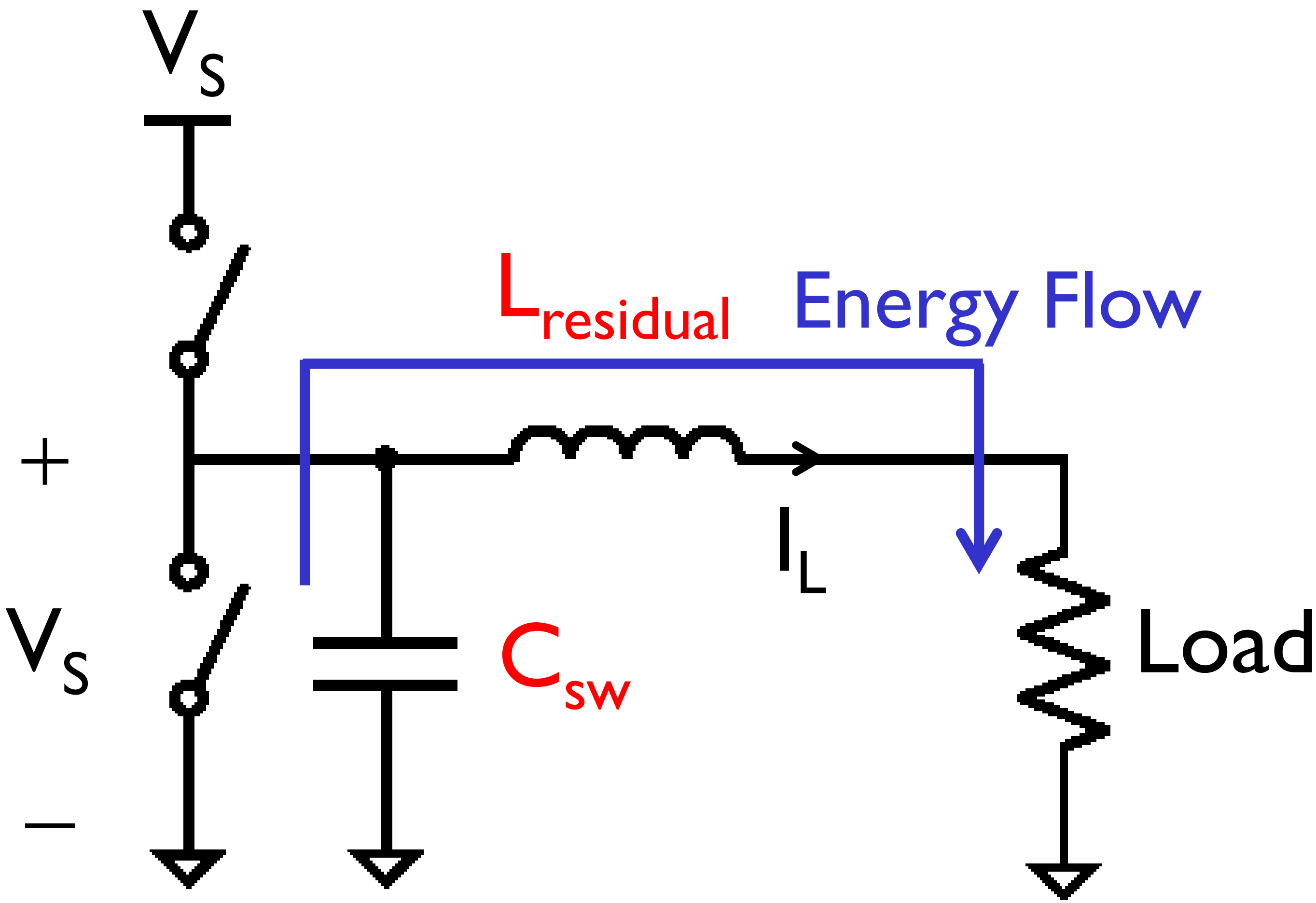
Turn on the top switch



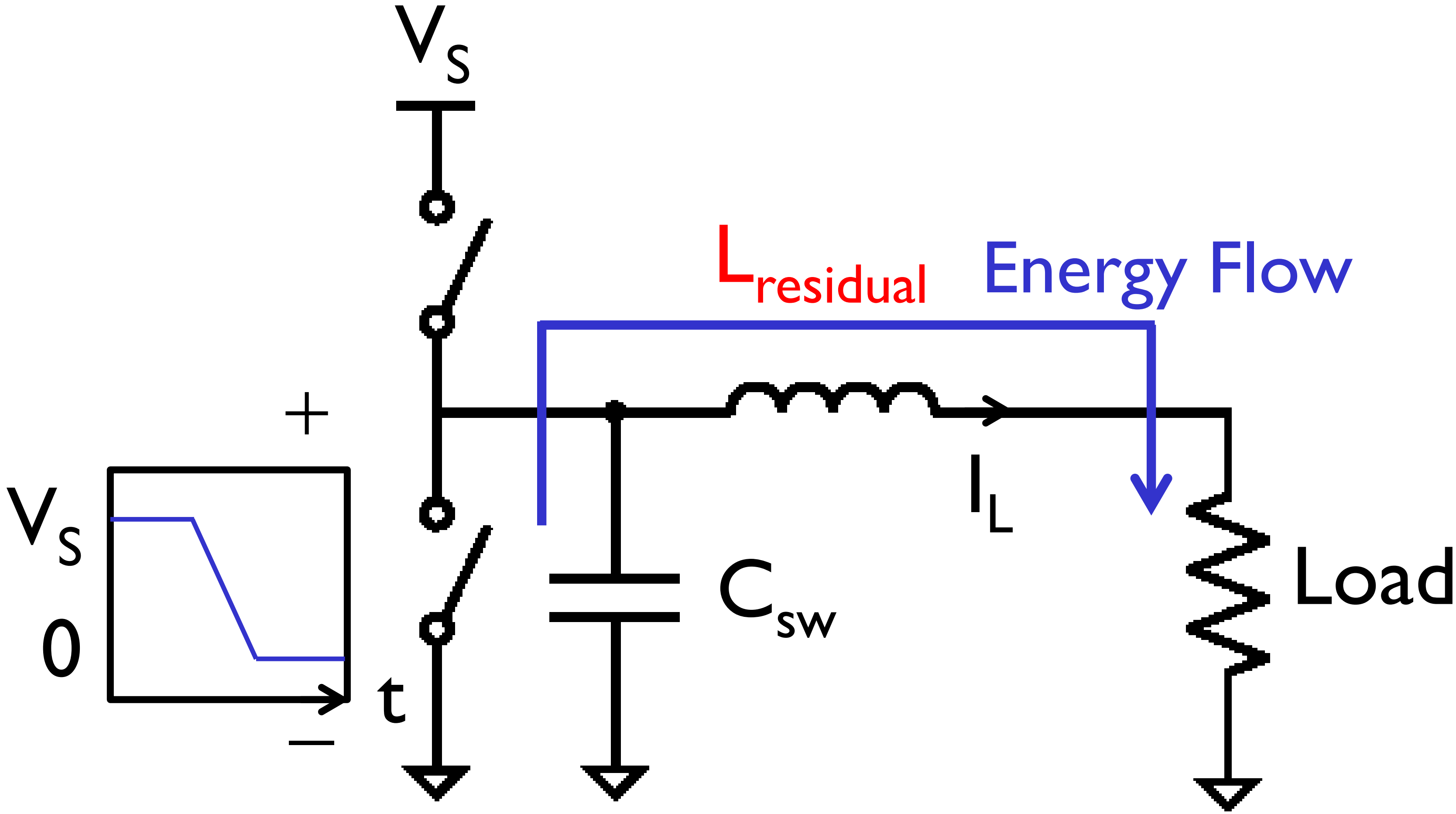
Energy Stored: ½ $C_{sw} V_S^2$ & ½ $L_{residual}\ I_L^2$



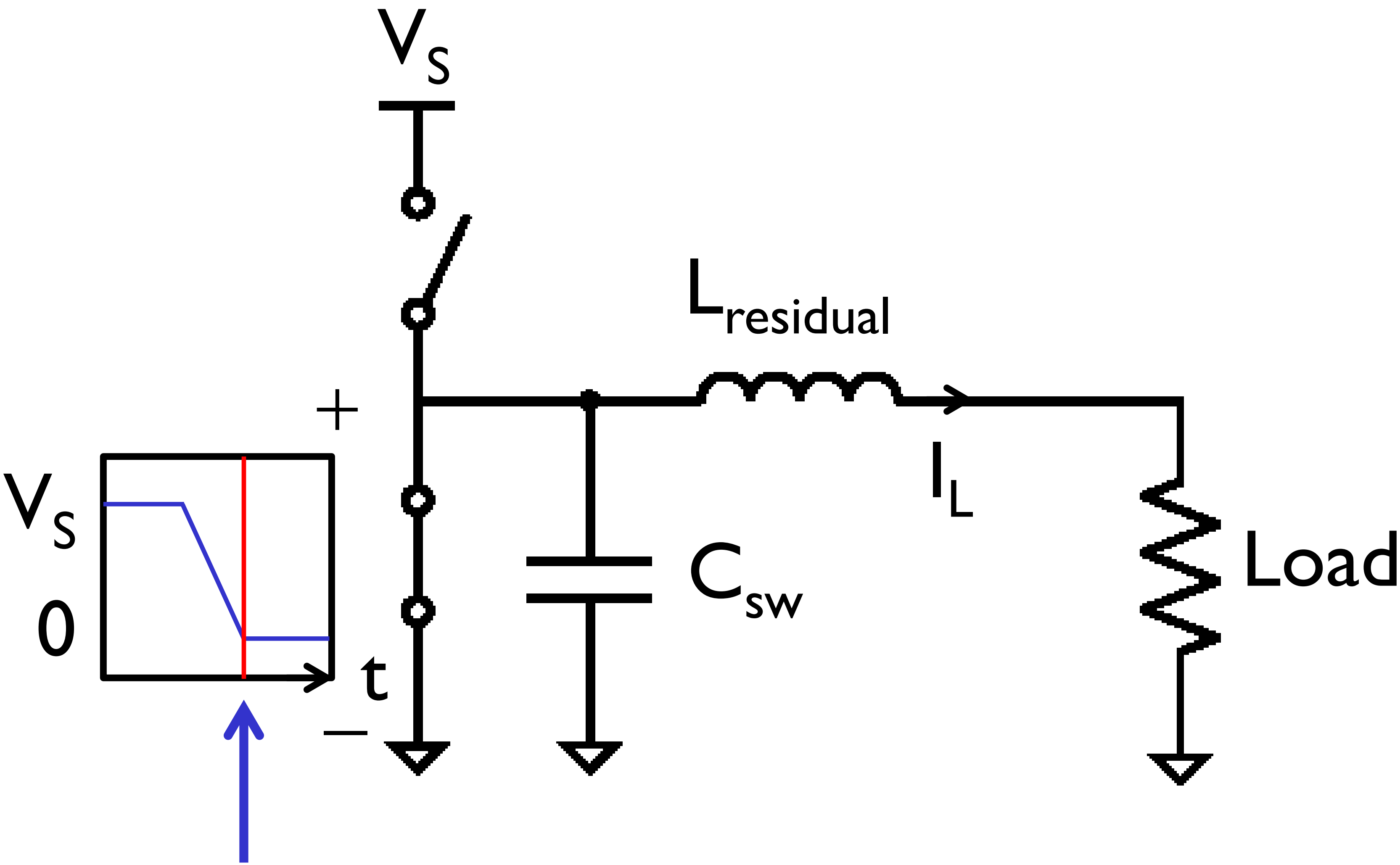
Open **both** switches



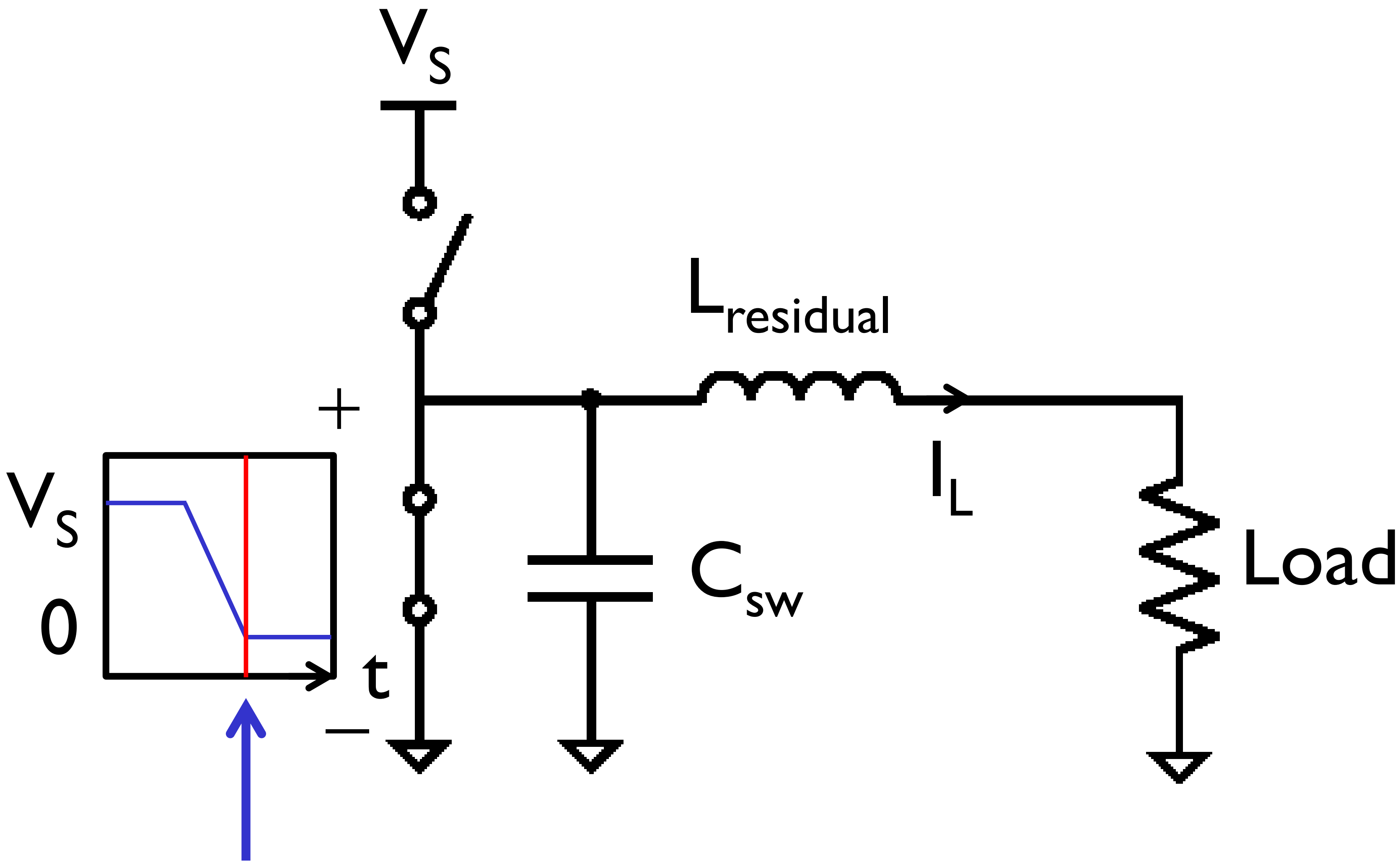
Inductor transfers capacitor energy to load



Output voltage pulled to zero



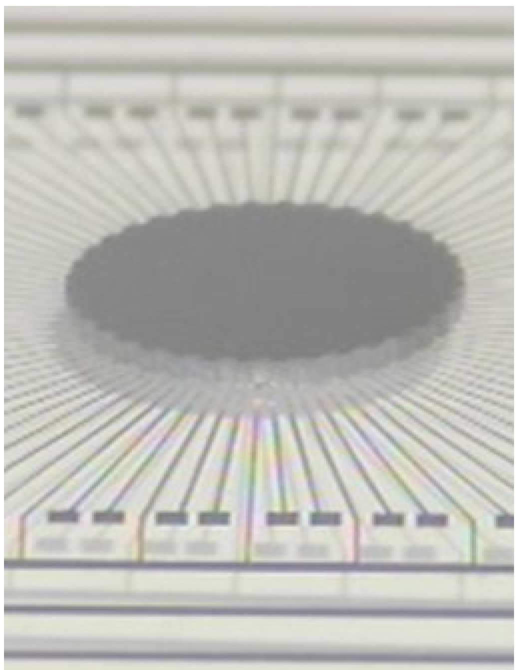
Close the switch when the voltage reaches zero

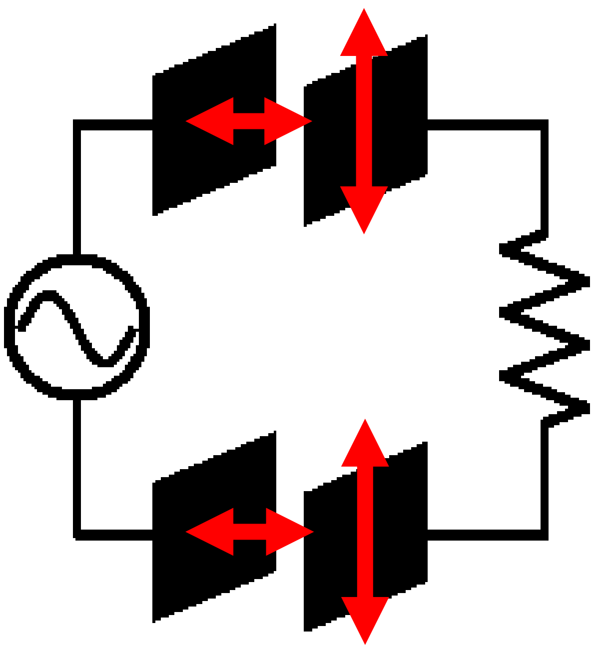


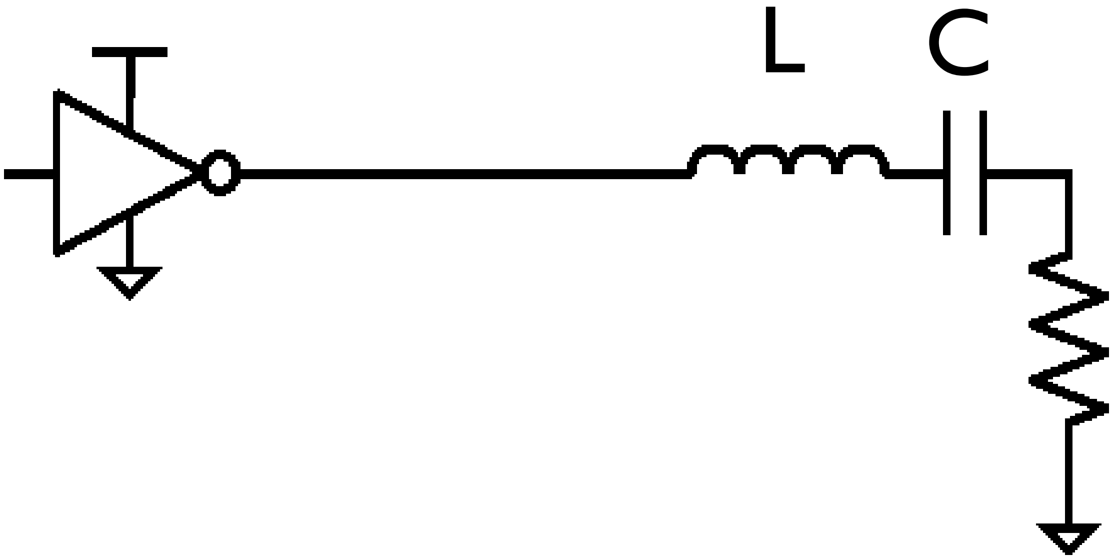
Known as Zero Voltage Switching (ZVS)

What We Want

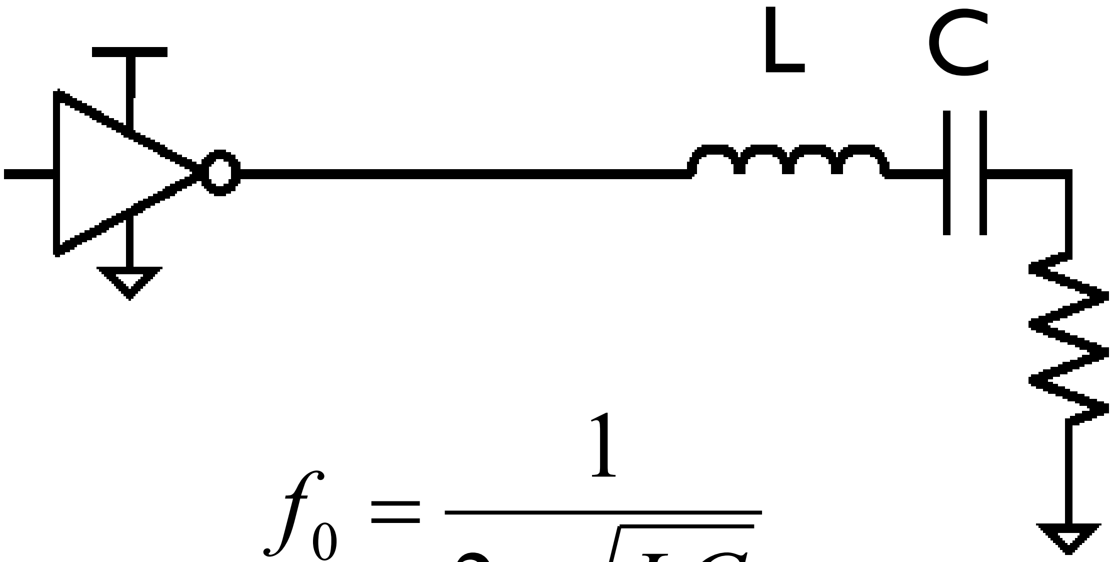
1	2	3
Small	Efficient	Robust





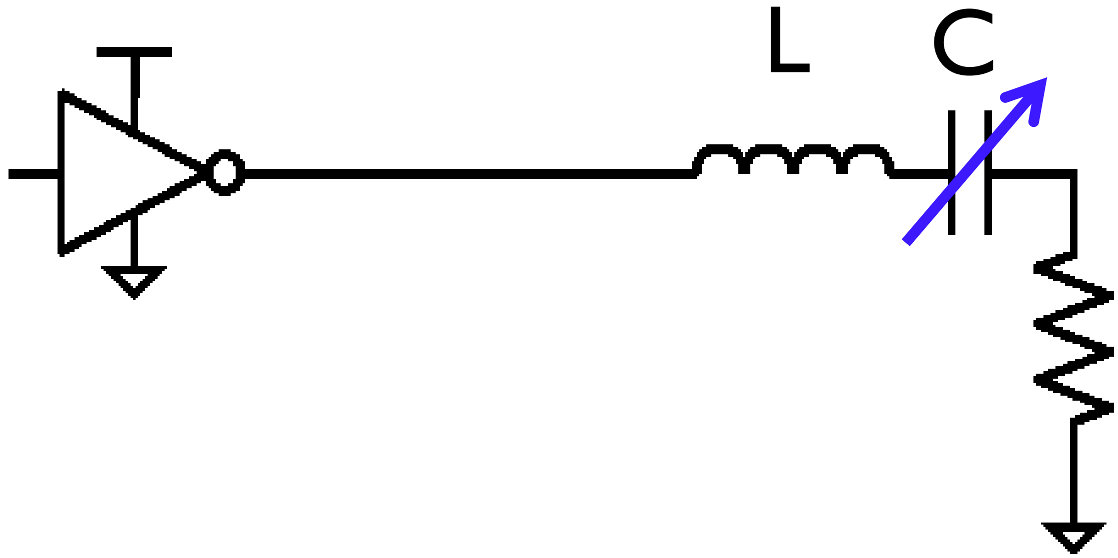


Start with the resonant circuit (again)

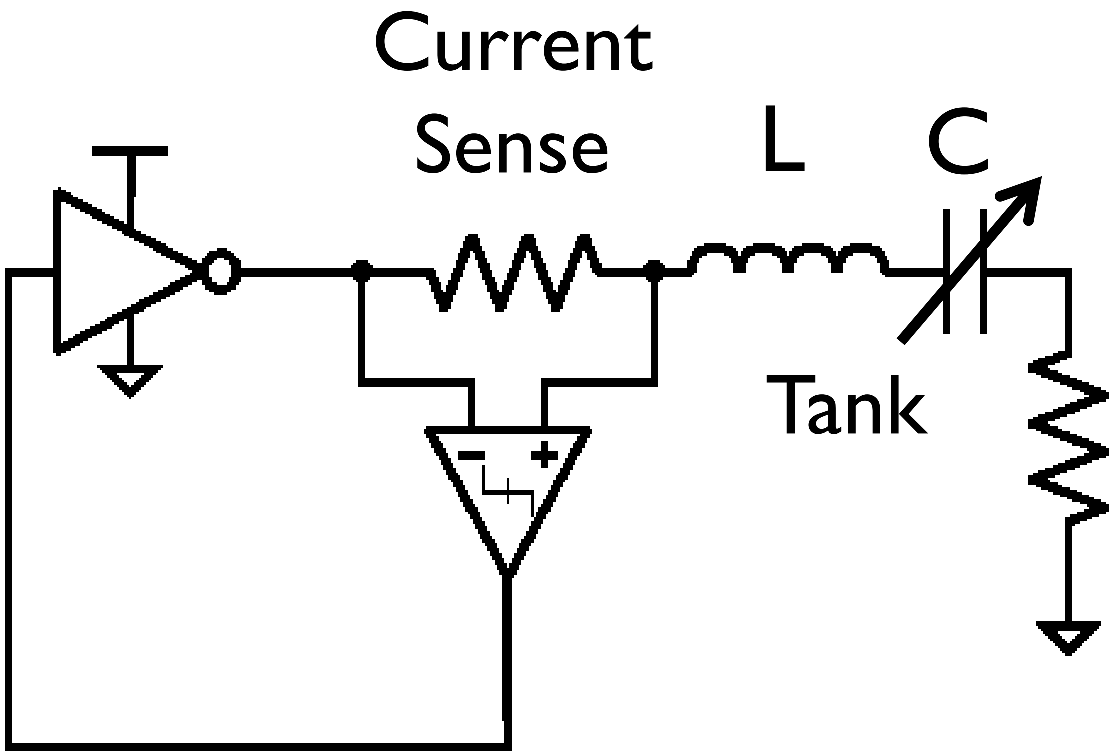


$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

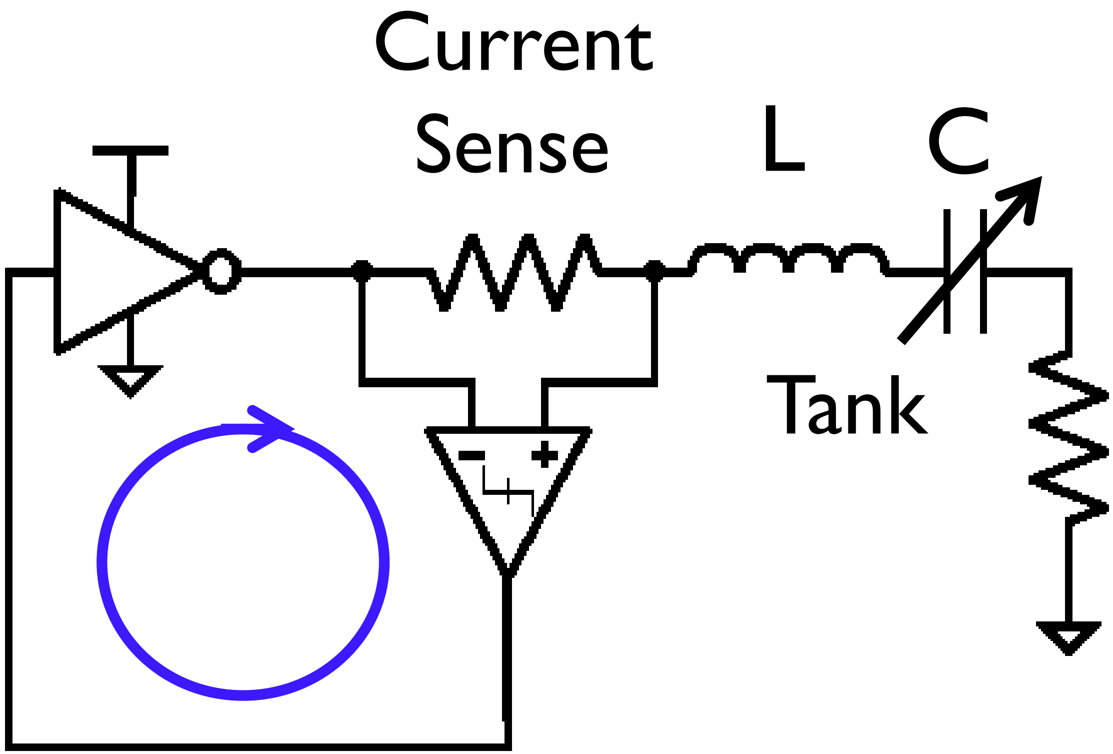
Would like to operate at (or near) resonance



But the capacitance depends on alignment and gap

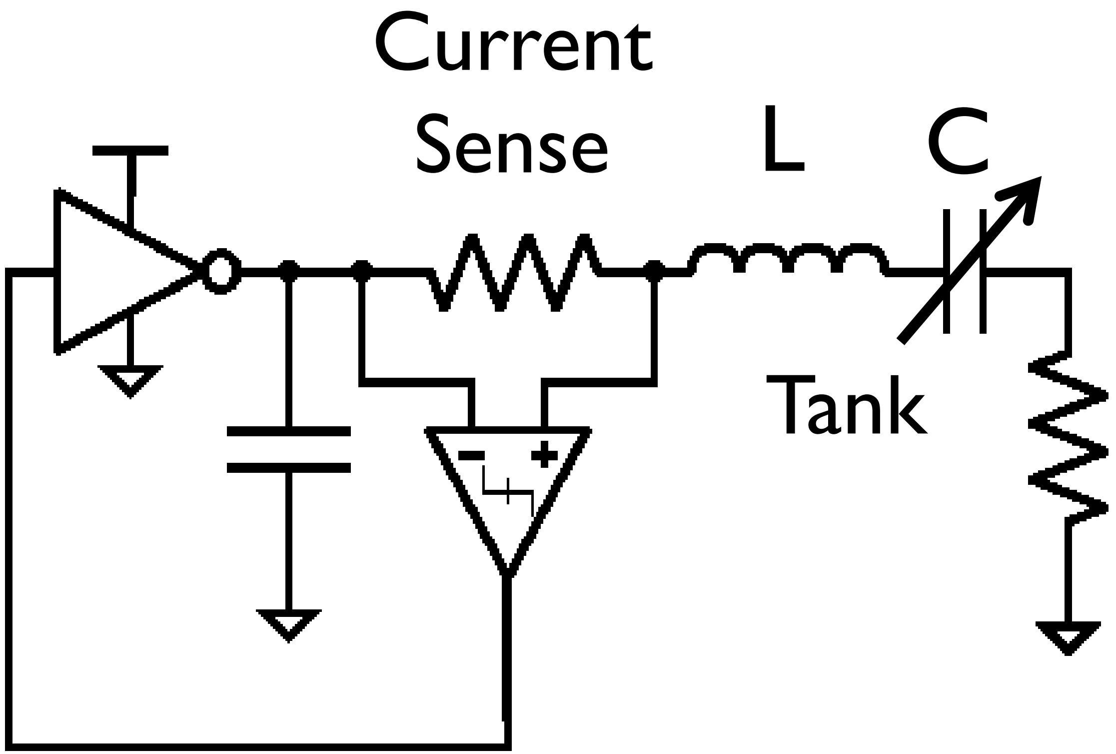


Build an oscillator with L and C forming the tank

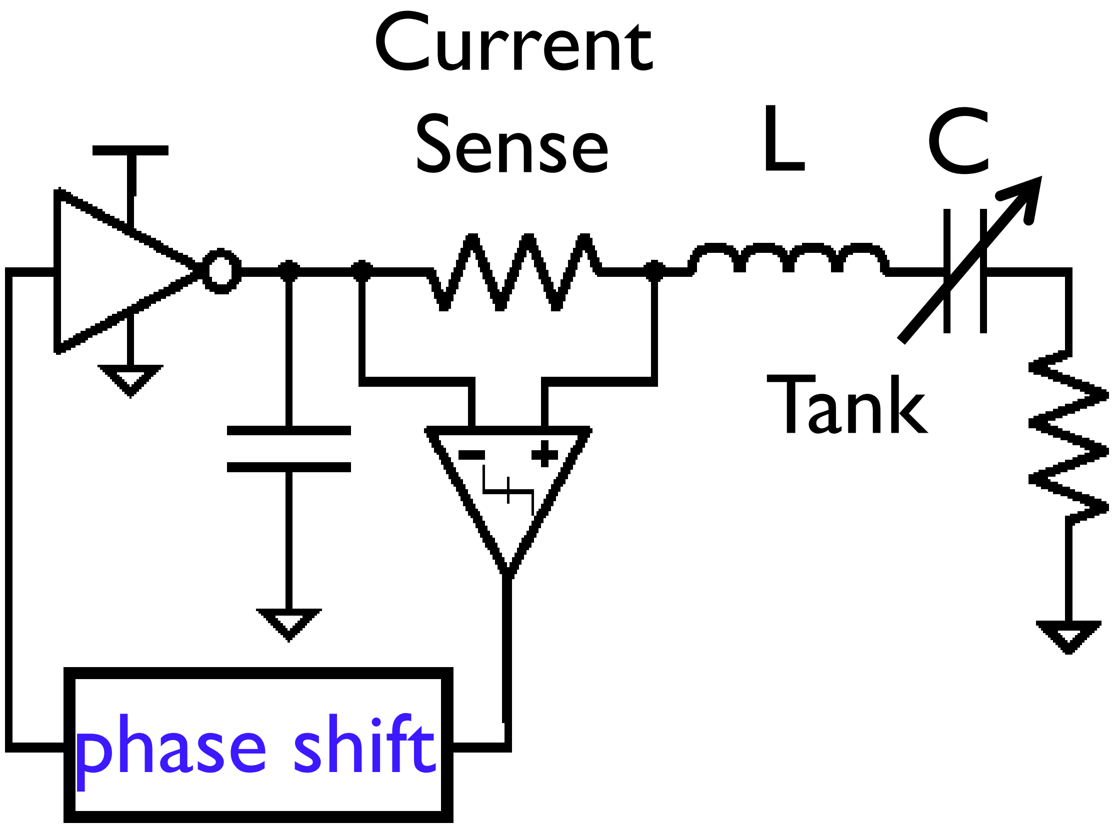


Phase shift around the loop = 0°

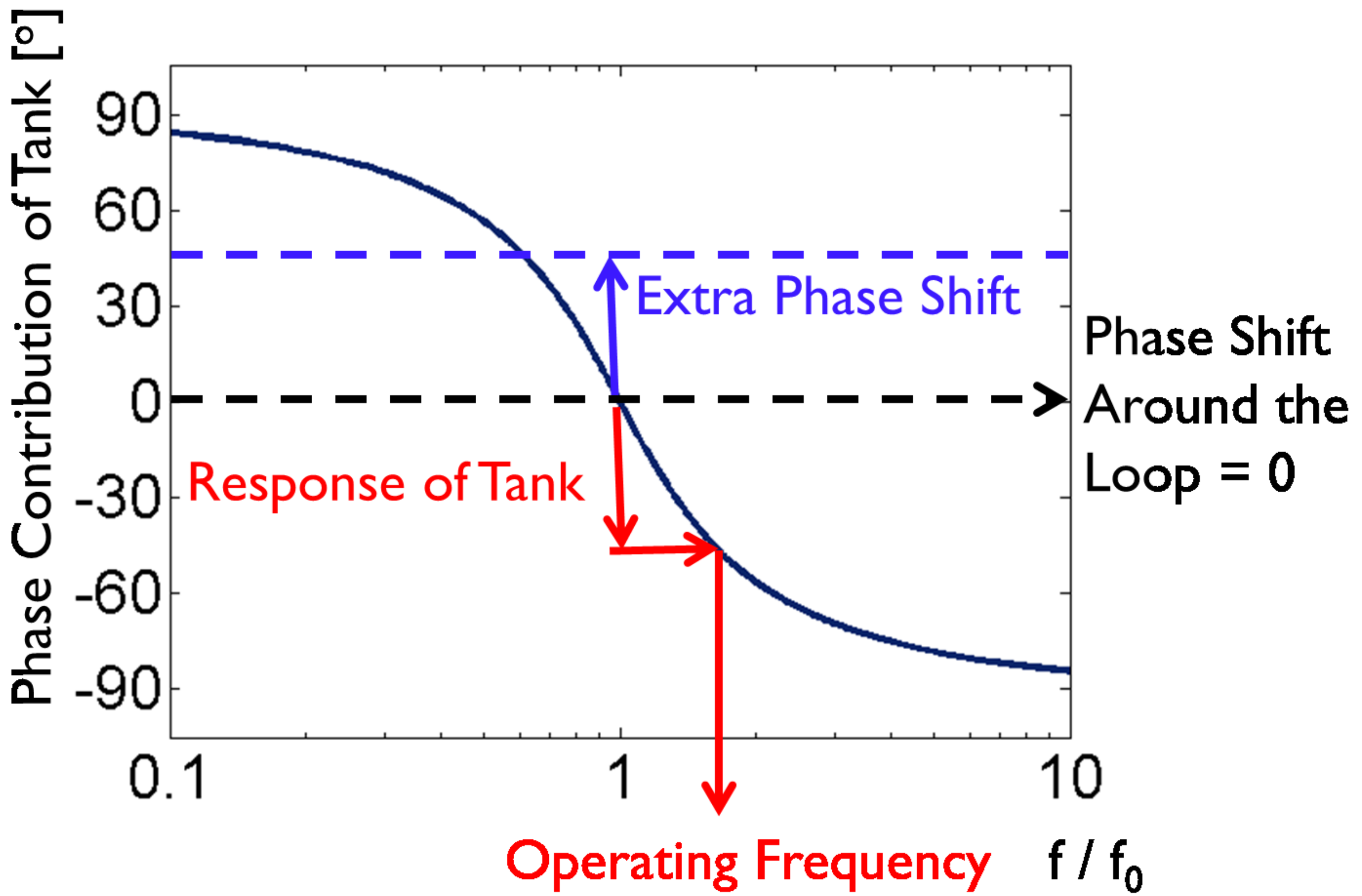
Current in tank forced in phase with drive voltage



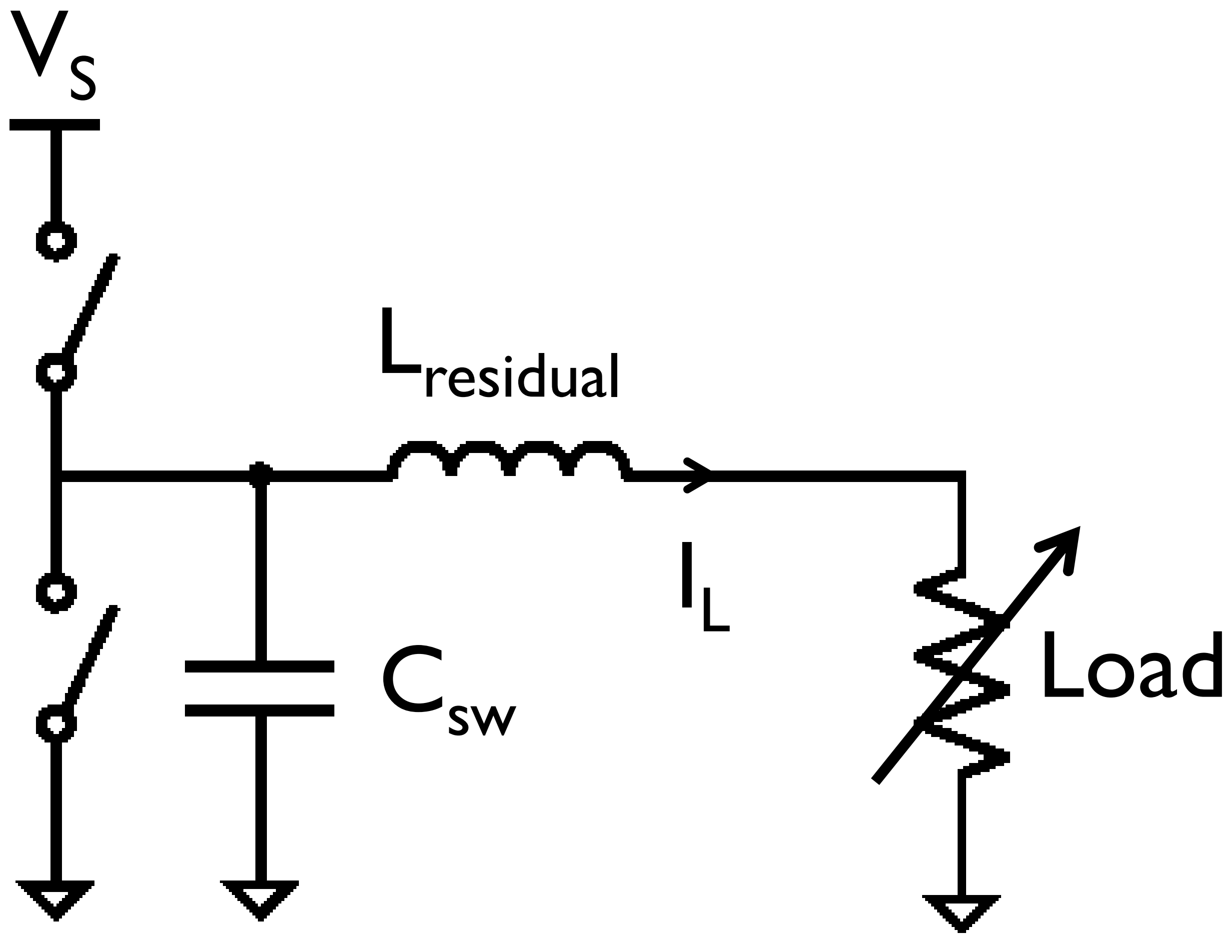
But we need to operate above resonance



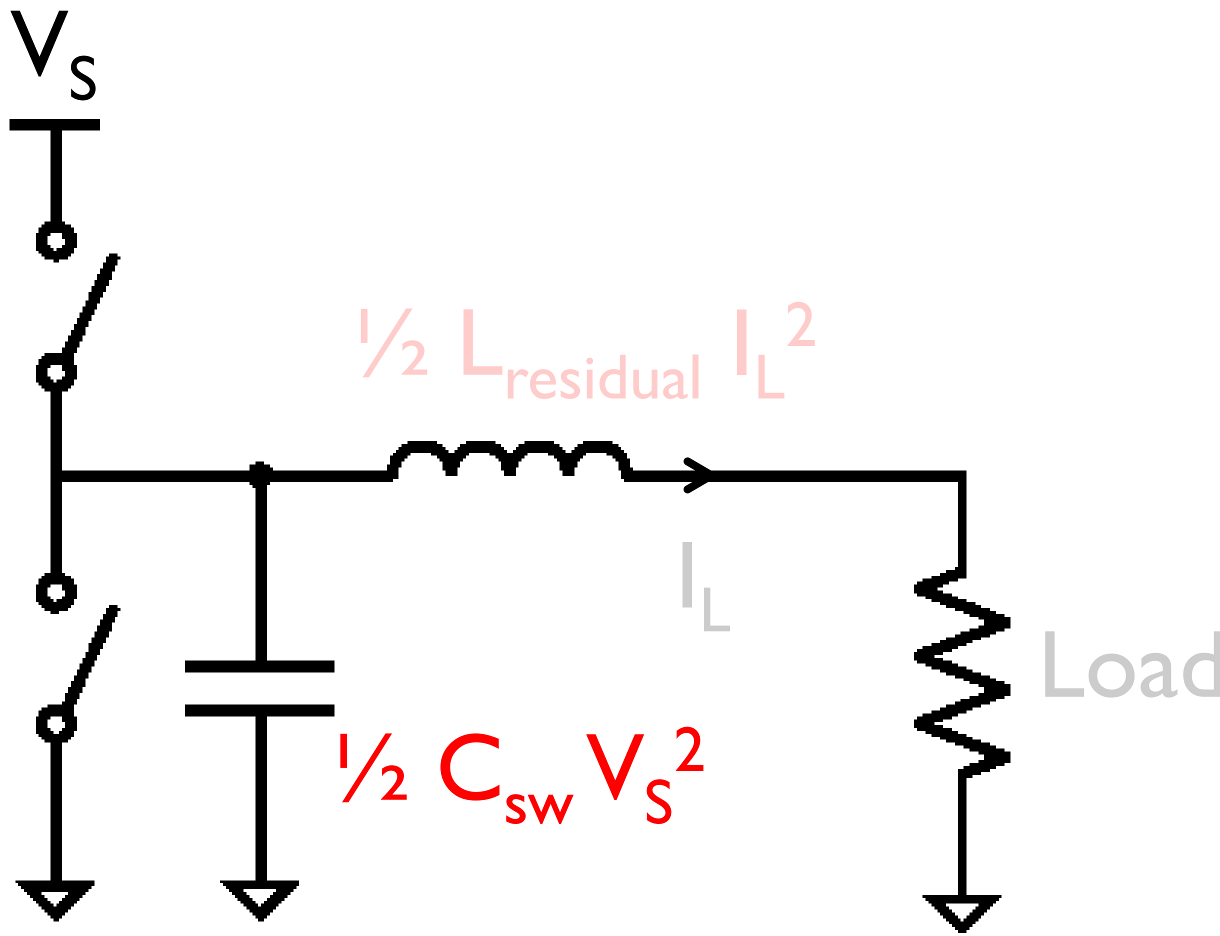
Introduce extra phase shift



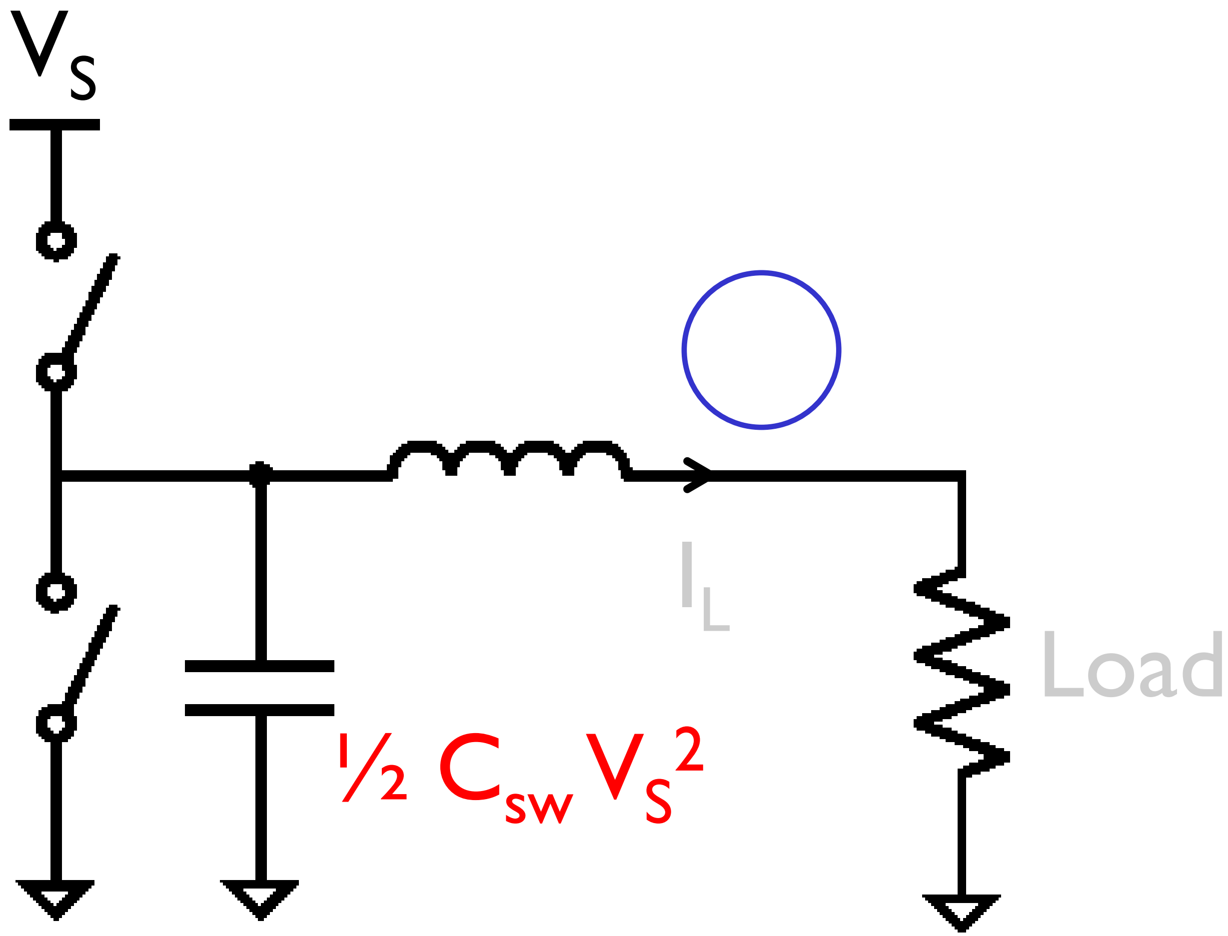
Adding phase shift changes the frequency



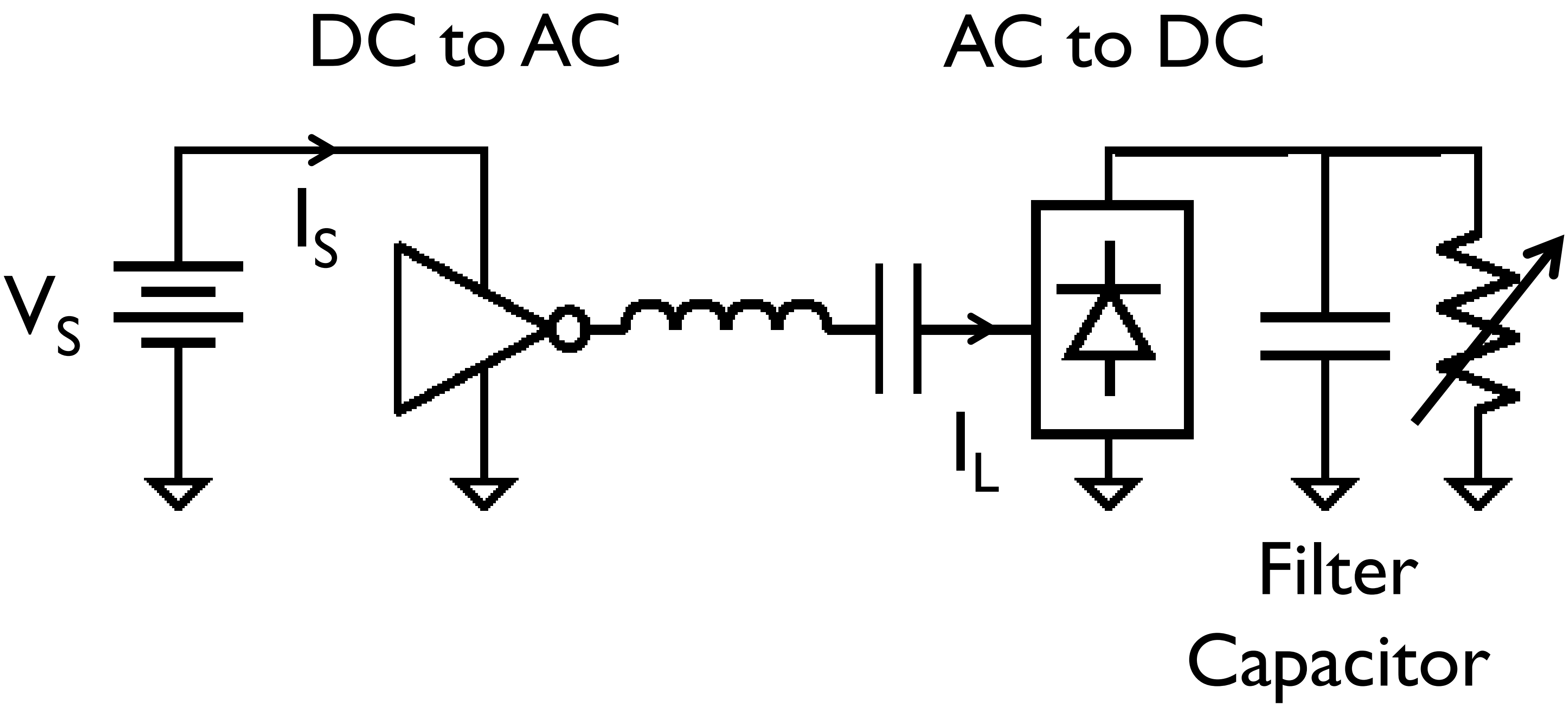
The equivalent circuit above resonance (again)



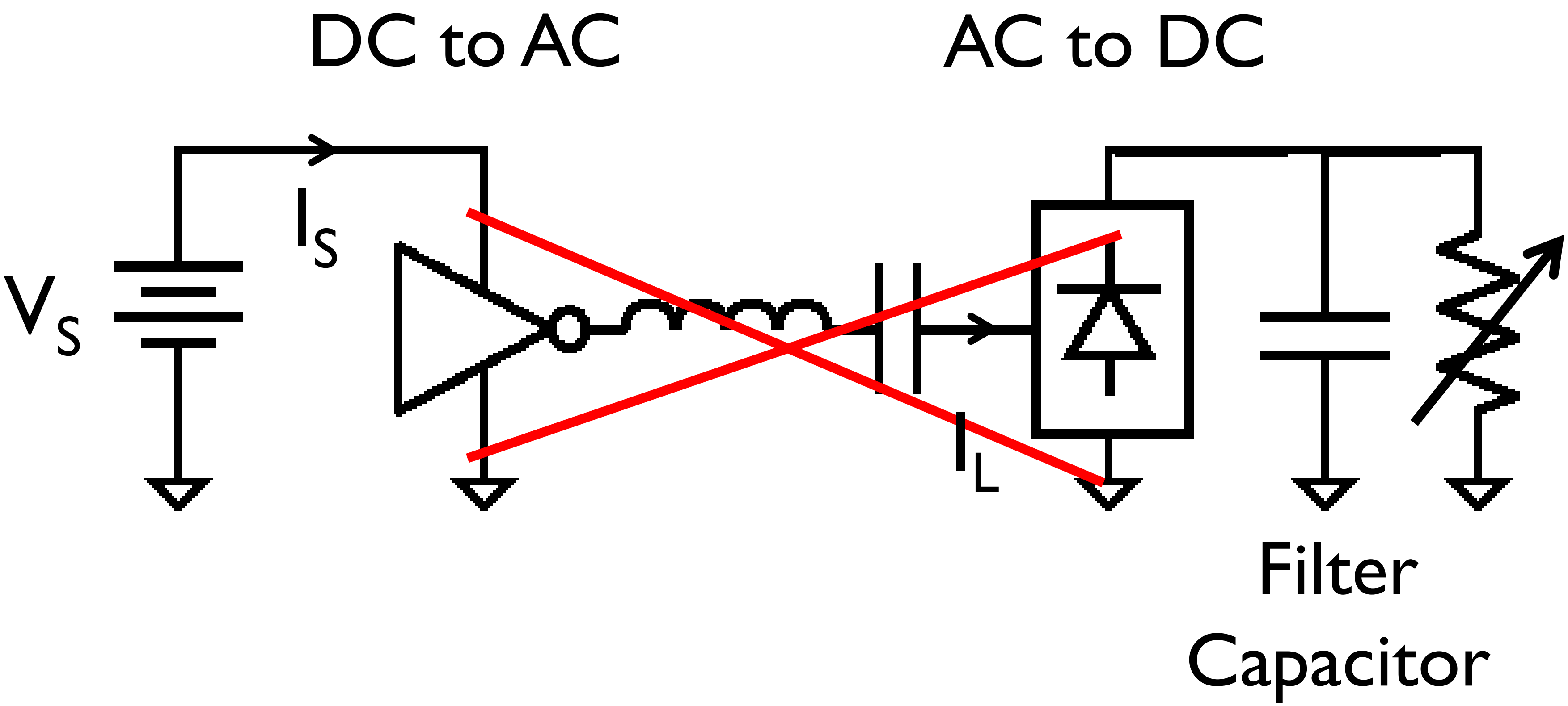
Light-load condition: not enough current in tank to get Zero Voltage Switching (ZVS)



Require a minimum I_L for ZVS

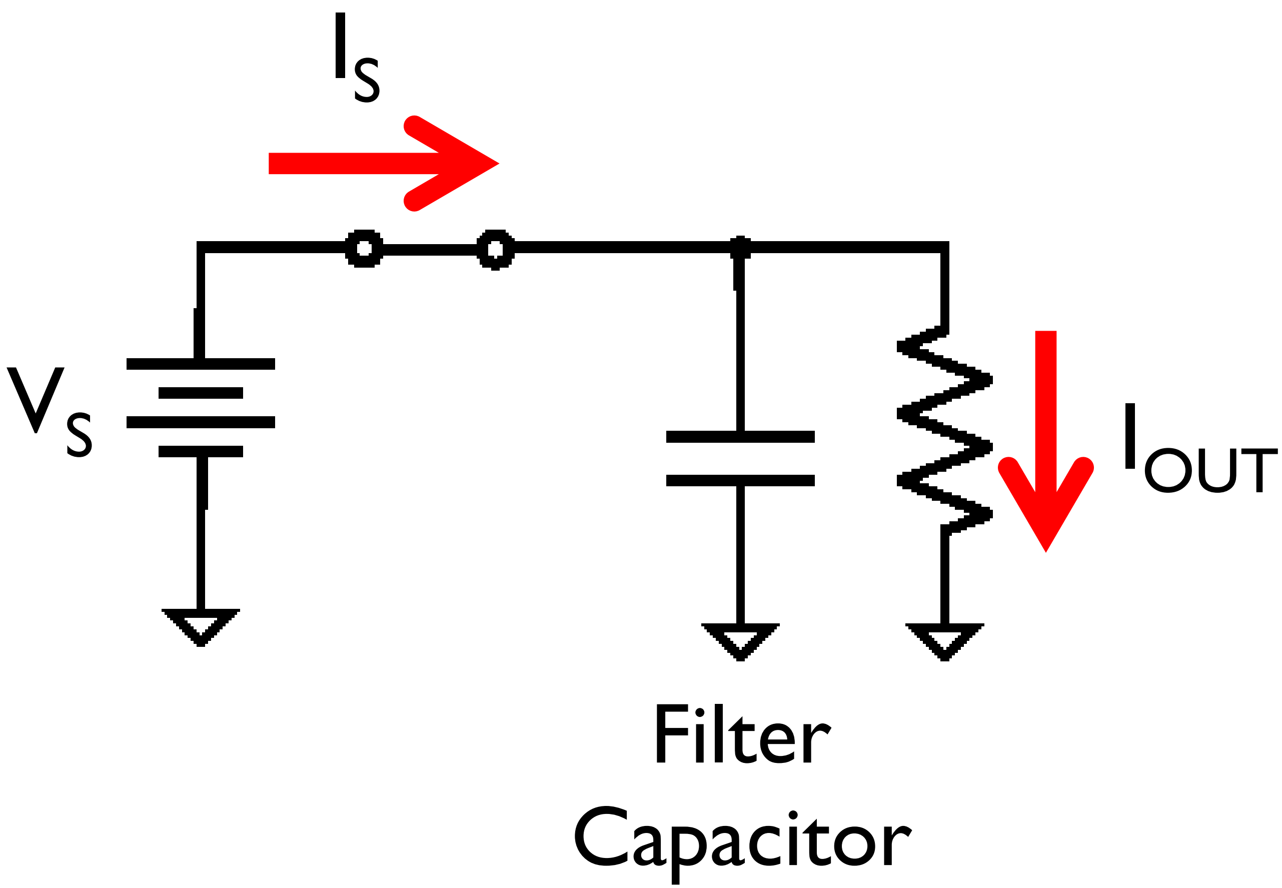


$I_S \approx I_L \Rightarrow$ Require a minimum I_S for ZVS



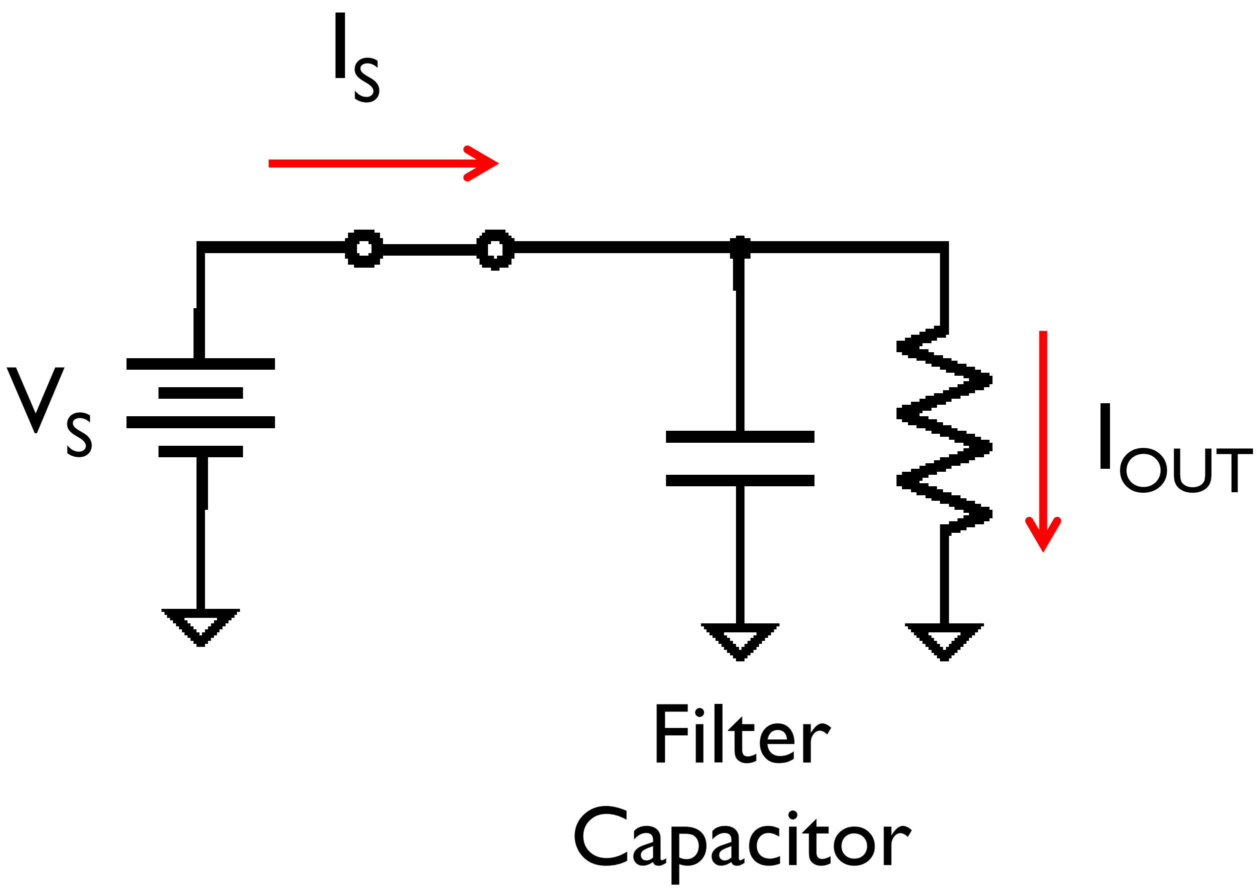
Can analyze this with a simple DC circuit

Variable Load



At full load, I_S is large

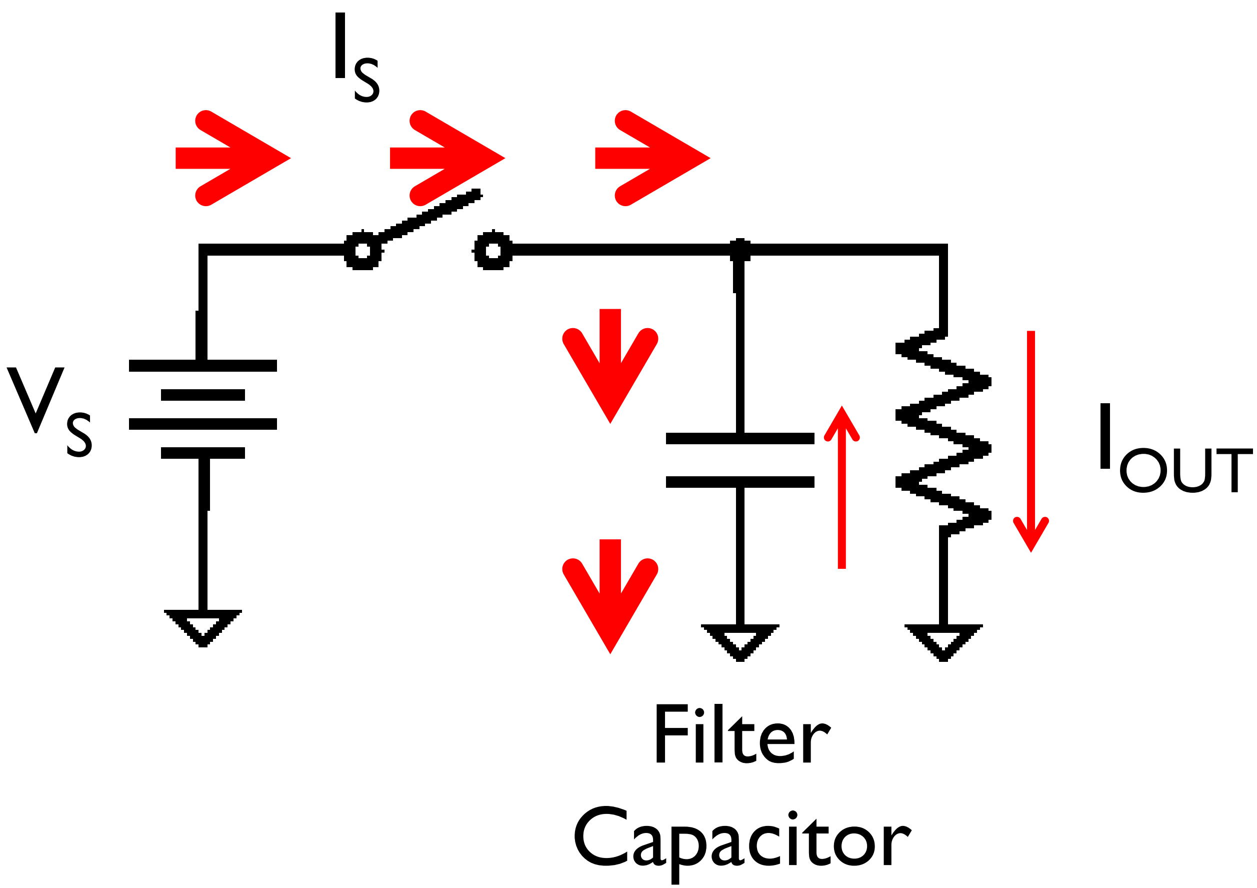
Variable Load



At light load, I_S is too small

Zero Voltage Switching is lost

Variable Load

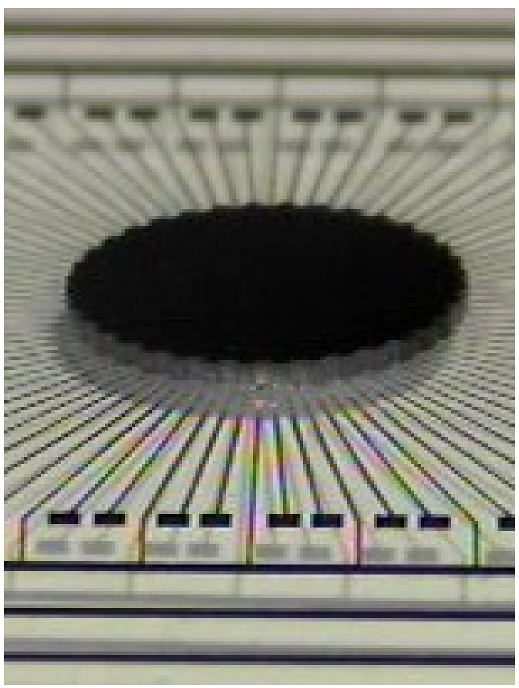


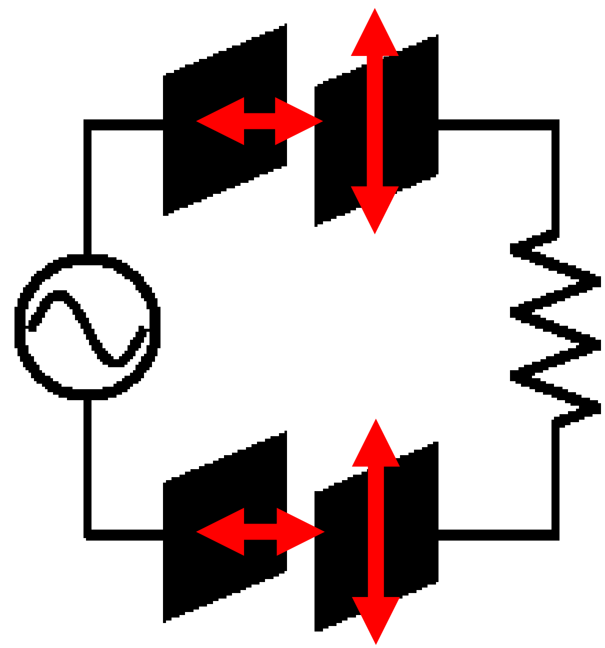
On/off modulation causes I_S to increase when driver is on: Zero Voltage Switching restored

What We Want

1 + 2 + 3

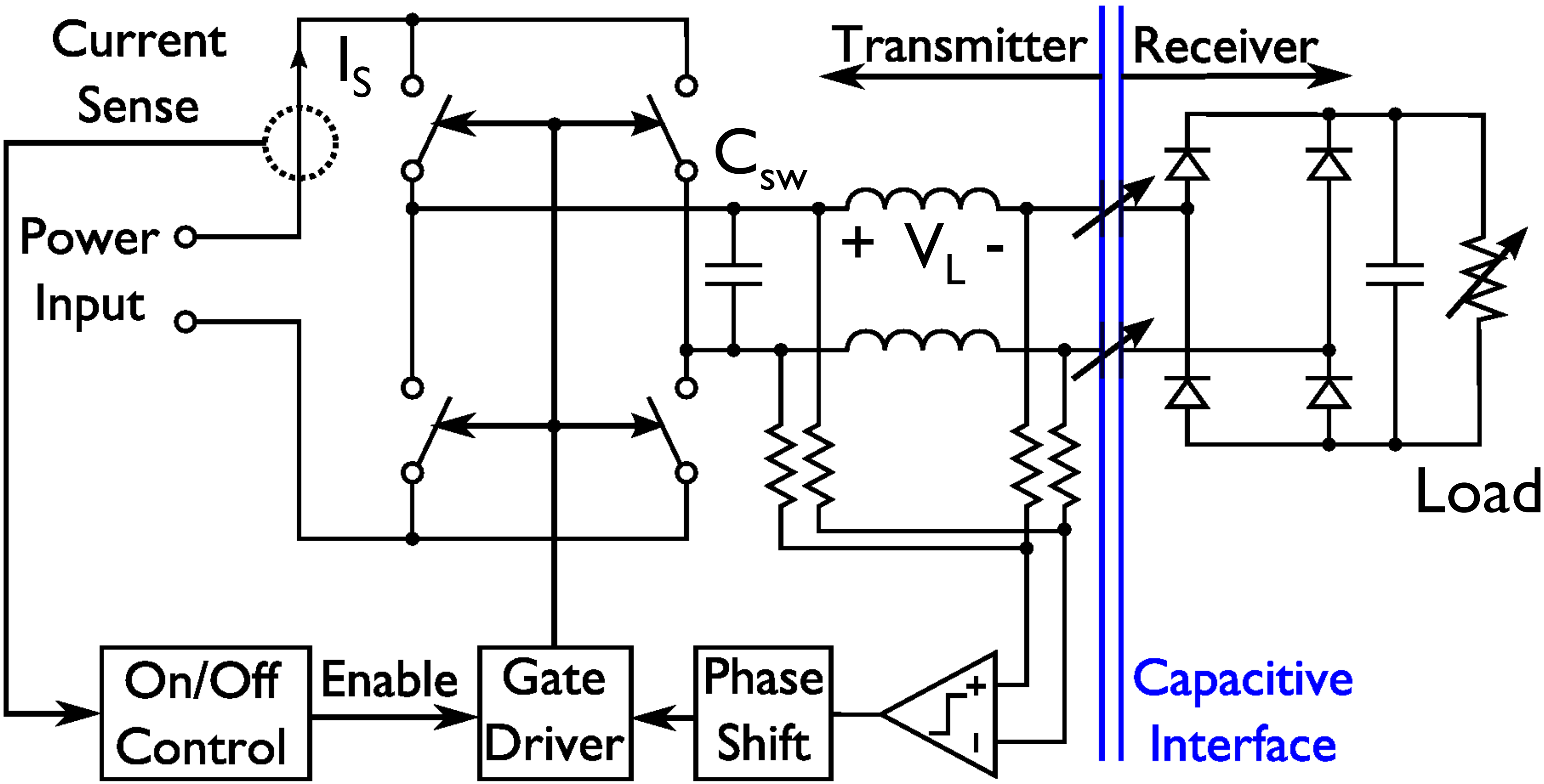
Small Efficient Robust



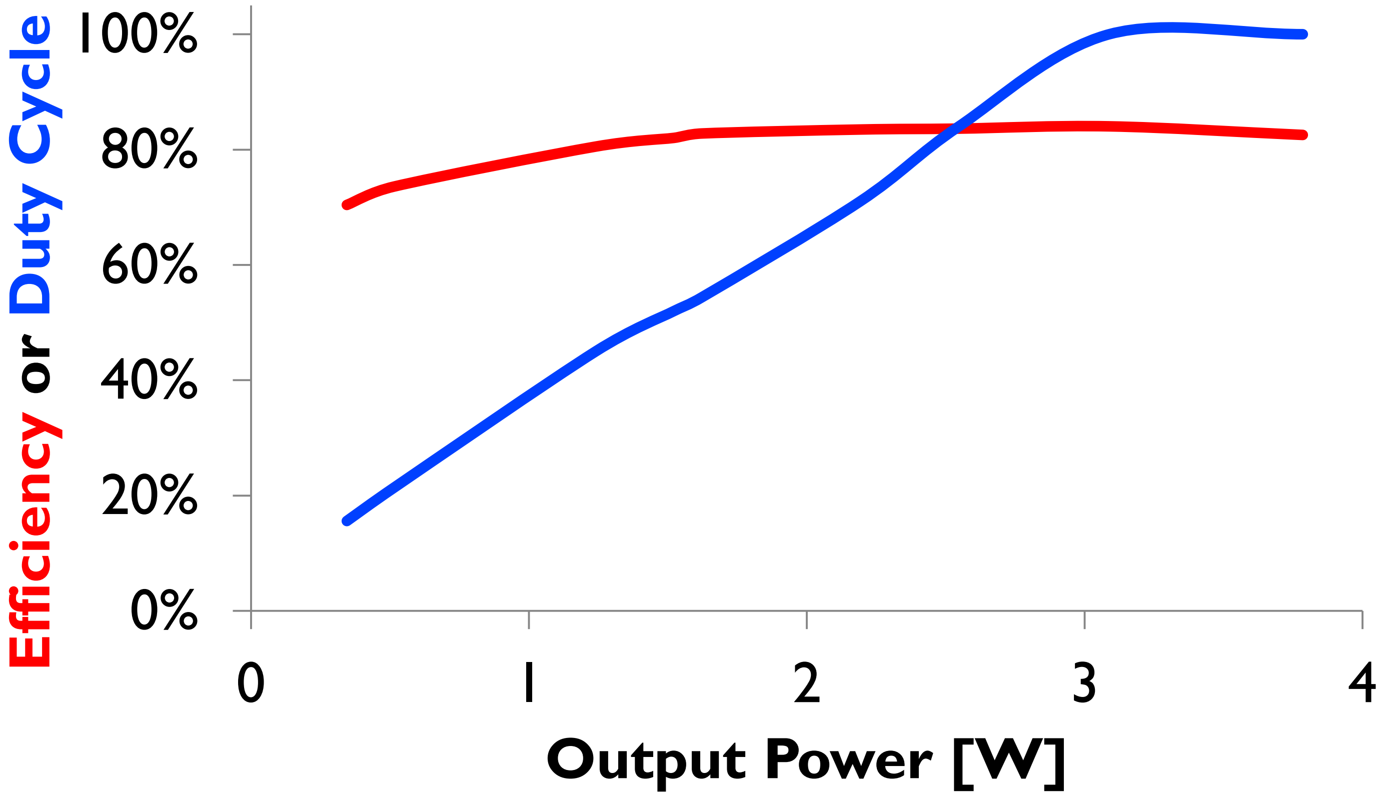


BSAC

Capacitive Power Transfer System



With 6 by 10 cm^2, we transfer 3.8 W at 83% efficiency over a 0.5 mm air gap.



How?

1. Resonant operation

   Compensate for **small** coupling capacitance

2. Zero Voltage Switching

   Improve the **efficiency**

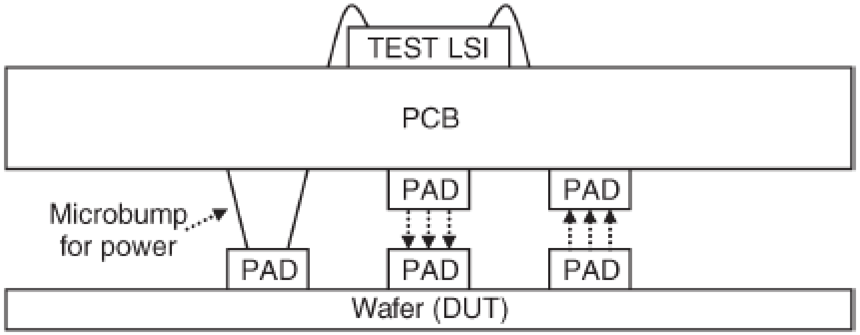
3. Automatic Tuning

   Robust to changes in coupling capacitance

4. Duty cycle adjustment without feedback from RX

   Preserve efficiency at light loads

Capacitive Data Transfer



- 2 Gb/s data rate
- < 2 mW

Technology		0.18 μm CMOS
Supply voltage		1.8 V
Max. data rate		2 Gb/s
Sensitivity		25 mV
Input cap. (RX)		>600 fF
BER		$<10^{-10}$
Core power @2 Gb/s	TX	4.87 μW
	RX	1.63 mW
Core area	TX	60 μm^2
	RX	2900 μm^2

G.-S. Kim, M. Takamiya, and T. Sakurai "A 25-mV-Sensitivity 2-Gb/s Optimum-Logic-Threshold Capacitive-Coupling Receiver for Wireless Wafer Probing Systems," TCAS II, Vol. 56, No. 9, Sept. 2009

Thank You!

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