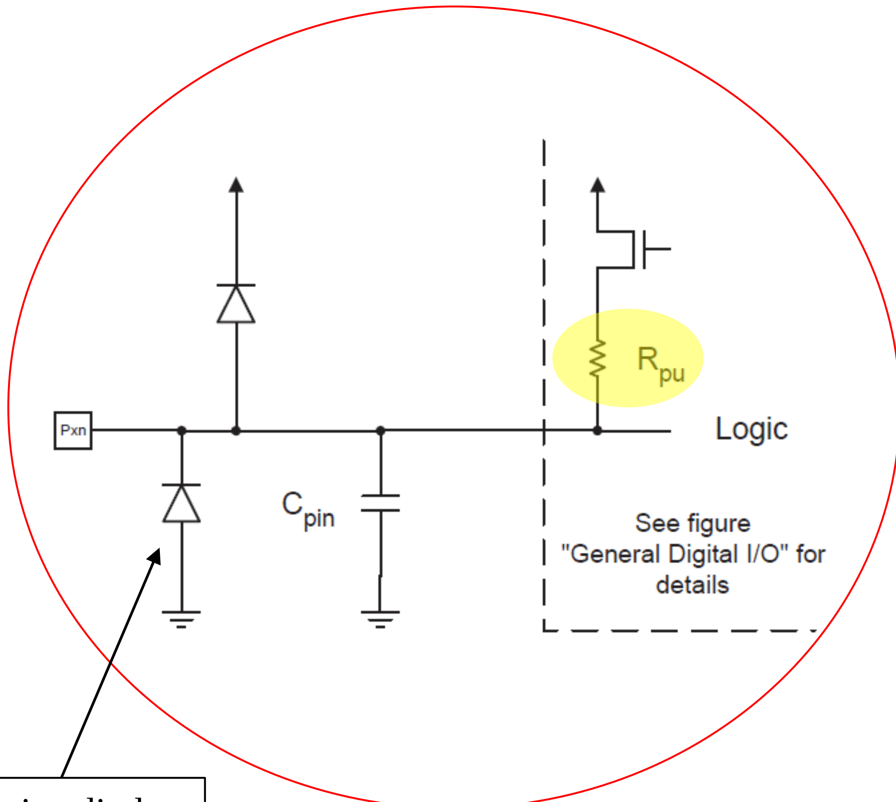
TTK 4155
Industrial and embedded computer systems design

Lecture #4

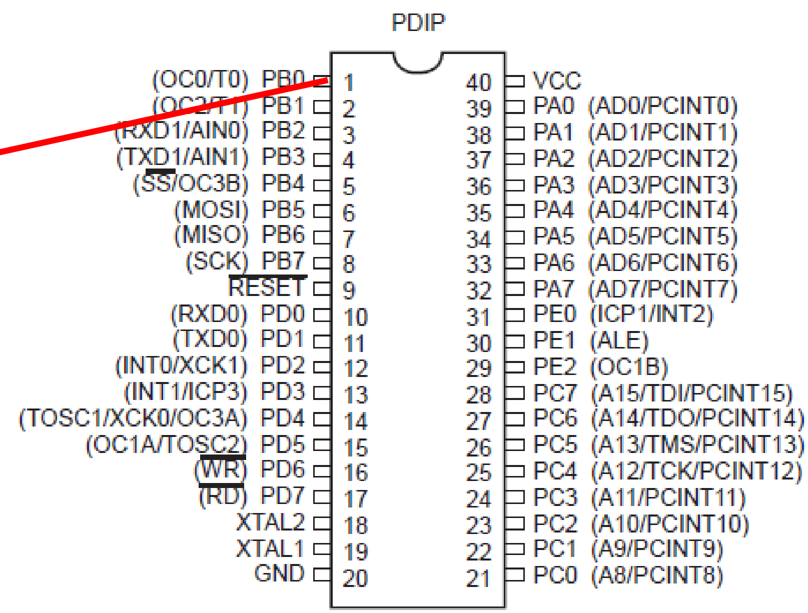
- Some basic topics in circuit design (continued...)
- Power supplies & voltage regulators
  - Shunt regulators
  - Linear regulators
  - Switching regulators
    - Inductor-based
    - Capacitor-based (charge pumps)

NTNU

Pull-up resistors on AVR ATmega microcontroller input ports



Clipping diodes
(protection)



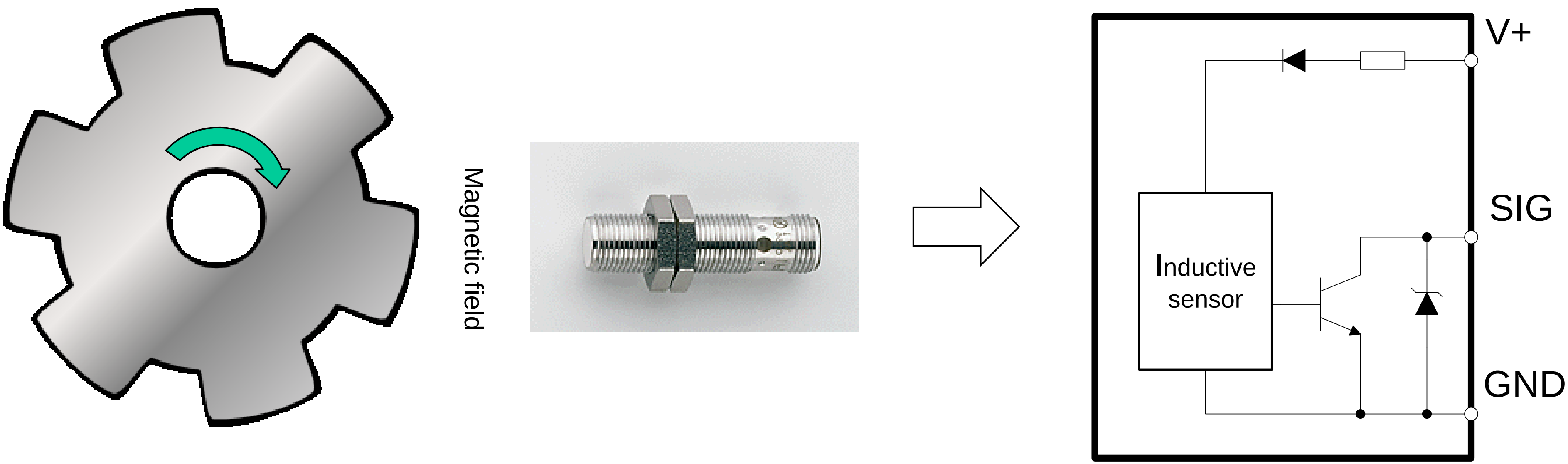
DC Characteristics

T_A = -40°C to 85°C, V_{CC} = 1.8V to 5.5V (unless otherwise noted)

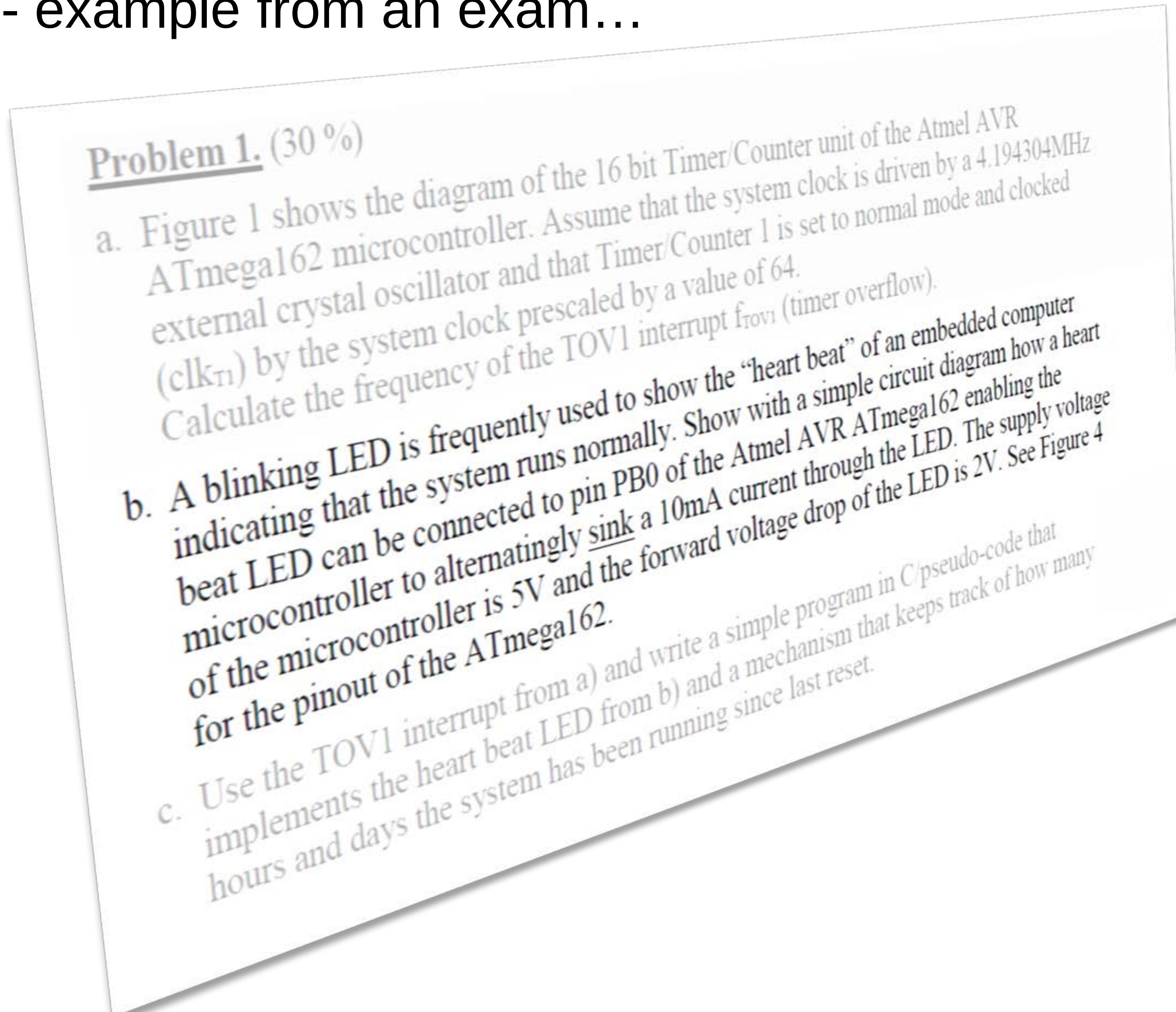
Symbol	Parameter	Condition	Min.	Typ.	Max.	Units
V_{IL}	Input Low Voltage, Except XTAL1 and RESET pin	V_{CC} = 1.8 - 2.4V V_{CC} = 2.4 - 5.5V	-0.5 -0.5		0.2 V_{CC}[1] 0.3 V_{CC}[1]	V
V_{IH}	Input High Voltage, Except XTAL1 and RESET pin	V_{CC} = 1.8 - 2.4V V_{CC} = 2.4 - 5.5V	0.7 V_{CC}[2] 0.6 V_{CC}[2]		V_{CC} + 0.5 V_{CC} + 0.5	V
V_{IL1}	Input Low Voltage, XTAL1 pin	V_{CC} = 1.8 - 5.5V	-0.5		0.1 V_{CC}[1]	V
V_{IH1}	Input High Voltage, XTAL1 pin	V_{CC} = 1.8 - 2.4V V_{CC} = 2.4 - 5.5V	0.8 V_{CC}[2] 0.7 V_{CC}[2]		V_{CC} + 0.5 V_{CC} + 0.5	V
V_{IL2}	Input Low Voltage, $\overline{\text{RESET}}$ pin	V_{CC} = 1.8 - 5.5V	-0.5		0.2 V_{CC}	V
V_{IH2}	Input High Voltage, $\overline{\text{RESET}}$ pin	V_{CC} = 1.8 - 5.5V	0.9 V_{CC}[2]		V_{CC} + 0.5	V
V_{OL}	Output Low Voltage[3], Ports A, B, C, D, and E	I_{OL} = 20 mA, V_{CC} = 5V I_{OL} = 10 mA, V_{CC} = 3V			0.7 0.5	V V
V_{OH}	Output High Voltage[4], Ports A, B, C, D, and E	I_{OL} = -20 mA, V_{CC} = 5V I_{OL} = -10 mA, V_{CC} = 3V	4.2 2.3			V V
I_{IL}	Input Leakage Current I/O Pin	Vcc = 5.5V, pin low (absolute value)			1	µA
I_{IH}	Input Leakage Current I/O Pin	Vcc = 5.5V, pin high (absolute value)			1	µA
R_{RST}	Reset Pull-up Resistor		30		60	kΩ
R_{pu}	I/O Pin Pull-up Resistor		20		50	kΩ

Ex: Sensor (transmitter) with *open collector output*

Inductive proximity sensor
(for ferrous metals)



How to drive a LED from an MCU
- example from an exam…

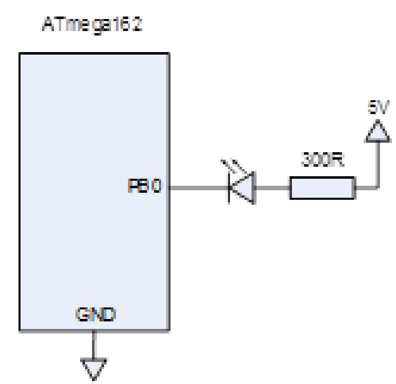


Problem 1. (30 %)

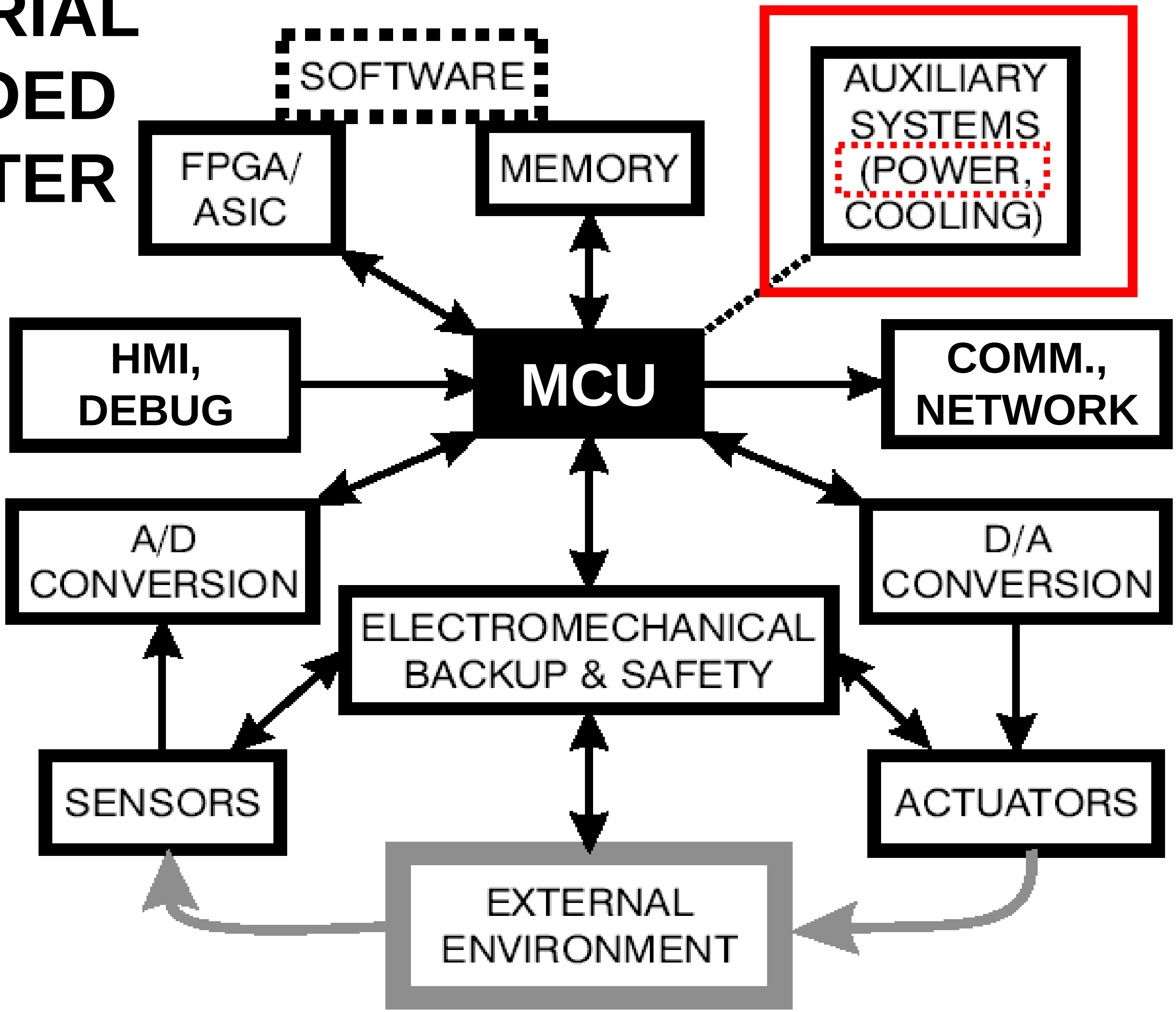
a. Figure 1 shows the diagram of the 16 bit Timer/Counter unit of the Atmel AVR ATmega162 microcontroller. Assume that the system clock is driven by a 4.194304MHz external crystal oscillator and that Timer/Counter 1 is set to normal mode and clocked (clk_{T1}) by the system clock prescaled by a value of 64. Calculate the frequency of the TOV1 interrupt f_{TOV1} (timer overflow).

b. A blinking LED is frequently used to show the "heart beat" of an embedded computer indicating that the system runs normally. Show with a simple circuit diagram how a heart beat LED can be connected to pin PB0 of the Atmel AVR ATmega162 enabling the microcontroller to alternatingly sink a 10mA current through the LED. The supply voltage of the microcontroller is 5V and the forward voltage drop of the LED is 2V. See Figure 4 for the pinout of the ATmega162.

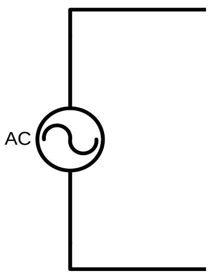
c. Use the TOV1 interrupt from a) and write a simple program in C/pseudo-code that implements the heart beat LED from b) and a mechanism that keeps track of how many hours and days the system has been running since last reset.



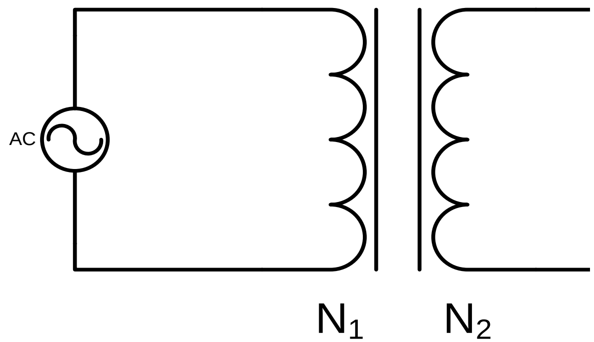
INDUSTRIAL EMBEDDED COMPUTER



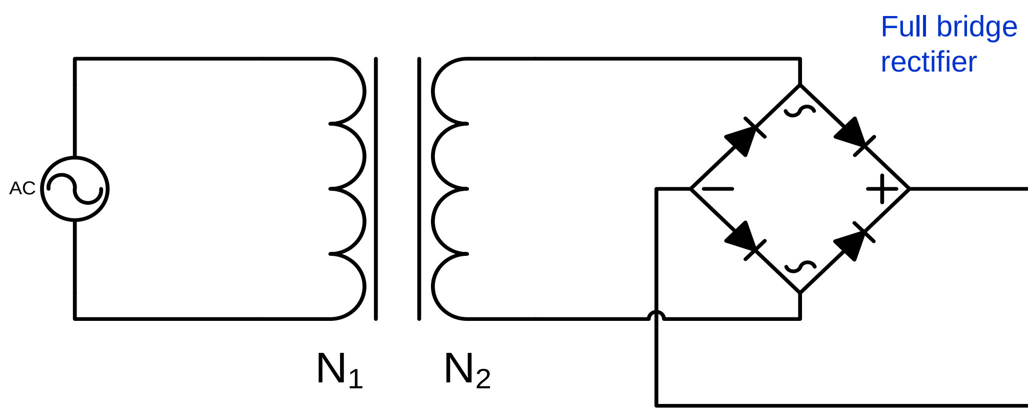
Power supply



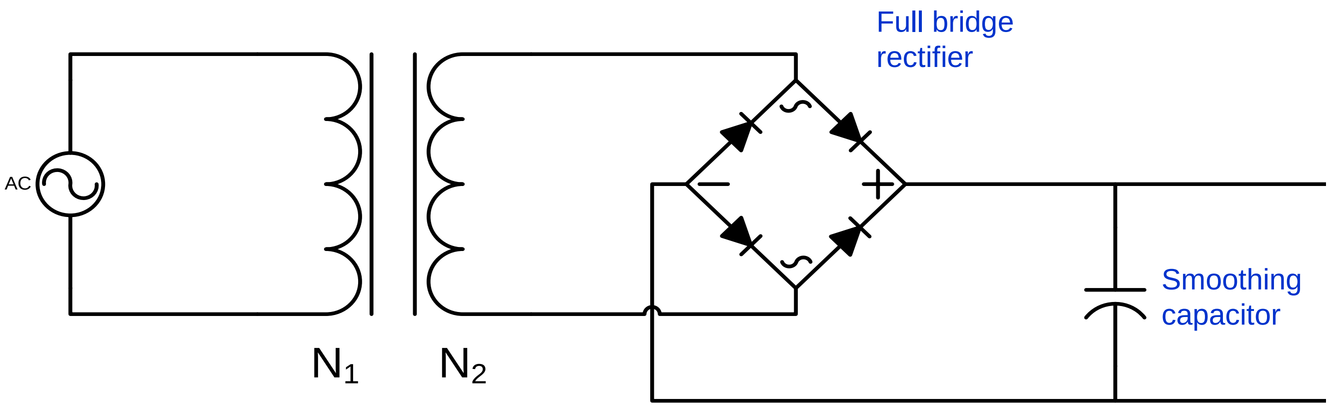
Power supply



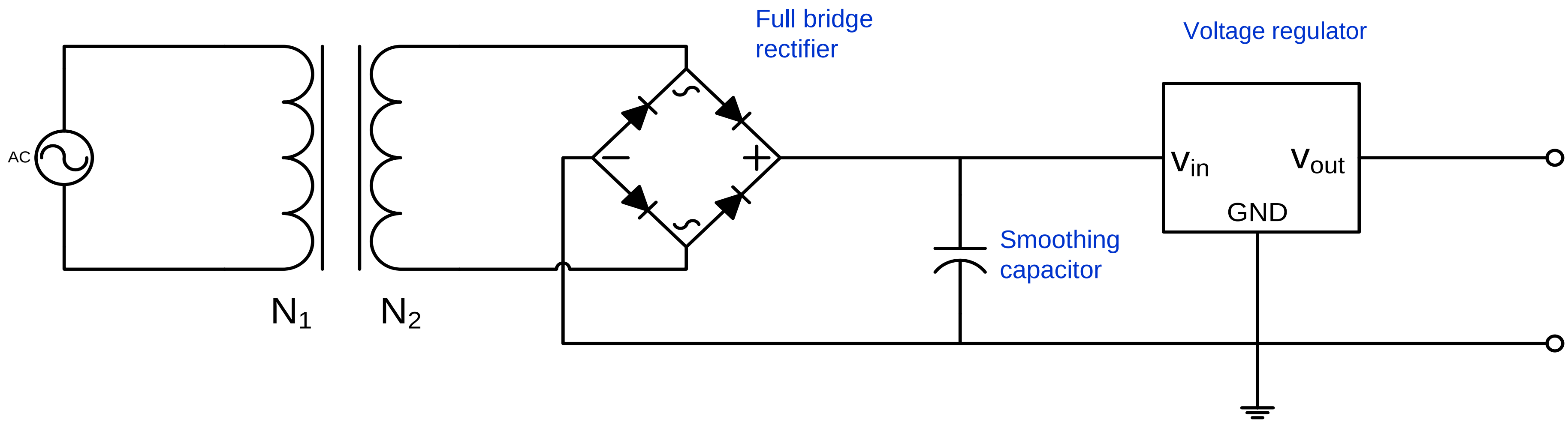
Power supply

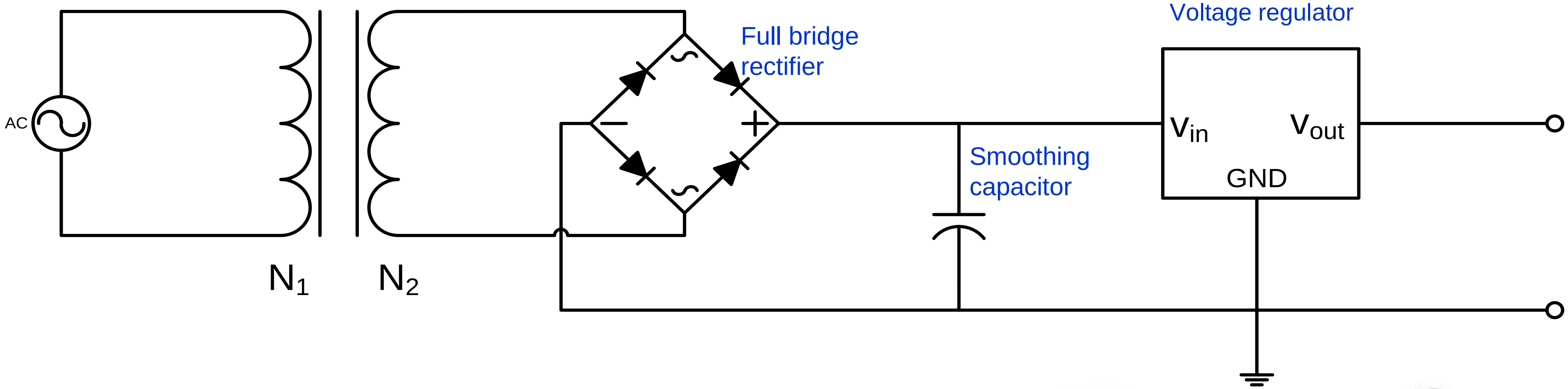


Power supply

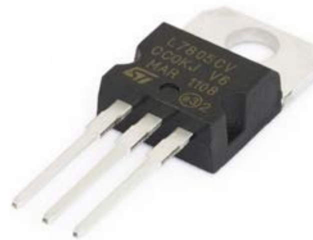


Power supply



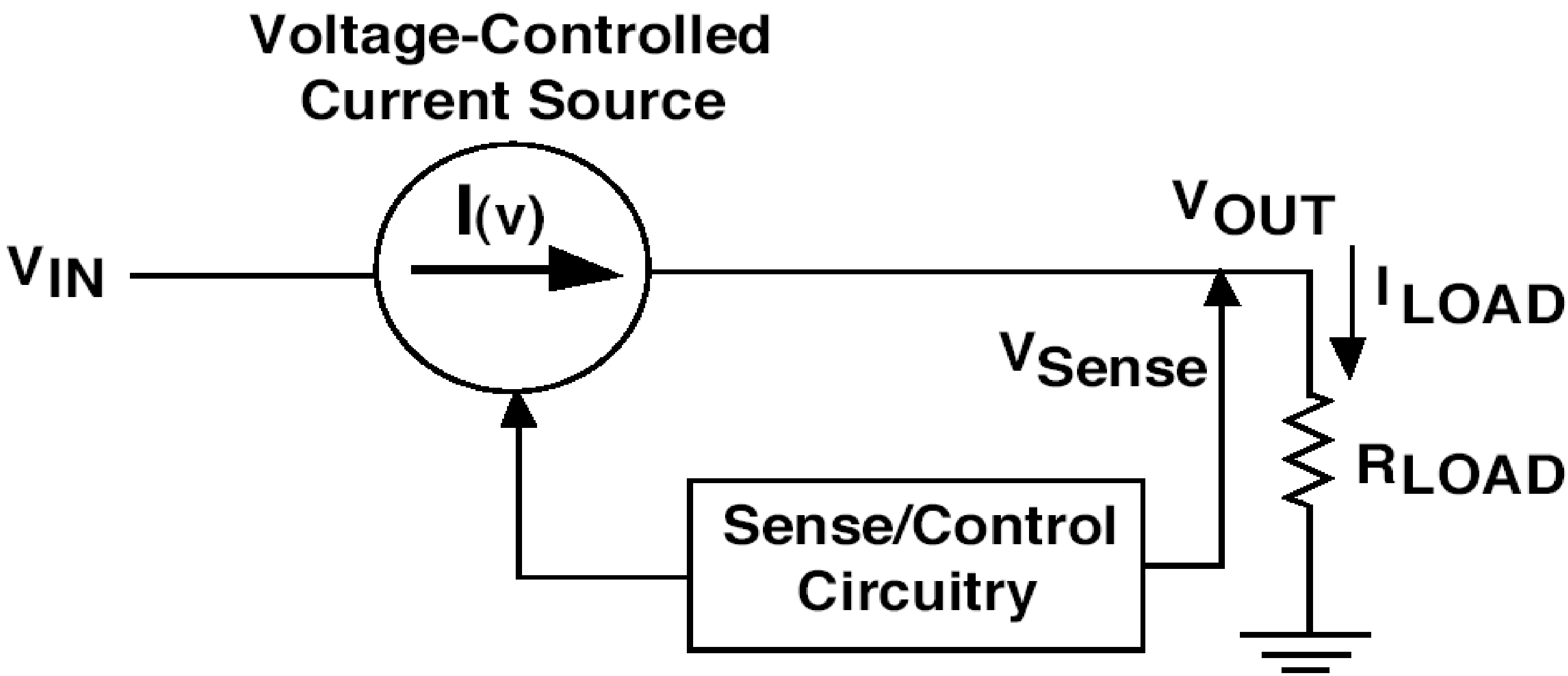


Voltage regulator




- provides a *stable, noise-free supply voltage…*
- at the *desired level…*
- and with *sufficient power capacity…*
- independent of variations in input voltage and load current:
  - Line regulation (= 100 * $\Delta V_{out}/\Delta V_{in}$ [%])
  - Load regulation (= 100 * $(V_{out\text{-}maxload} - V_{out\text{-}minload})/V_{out\text{-}nomload}$ [%])

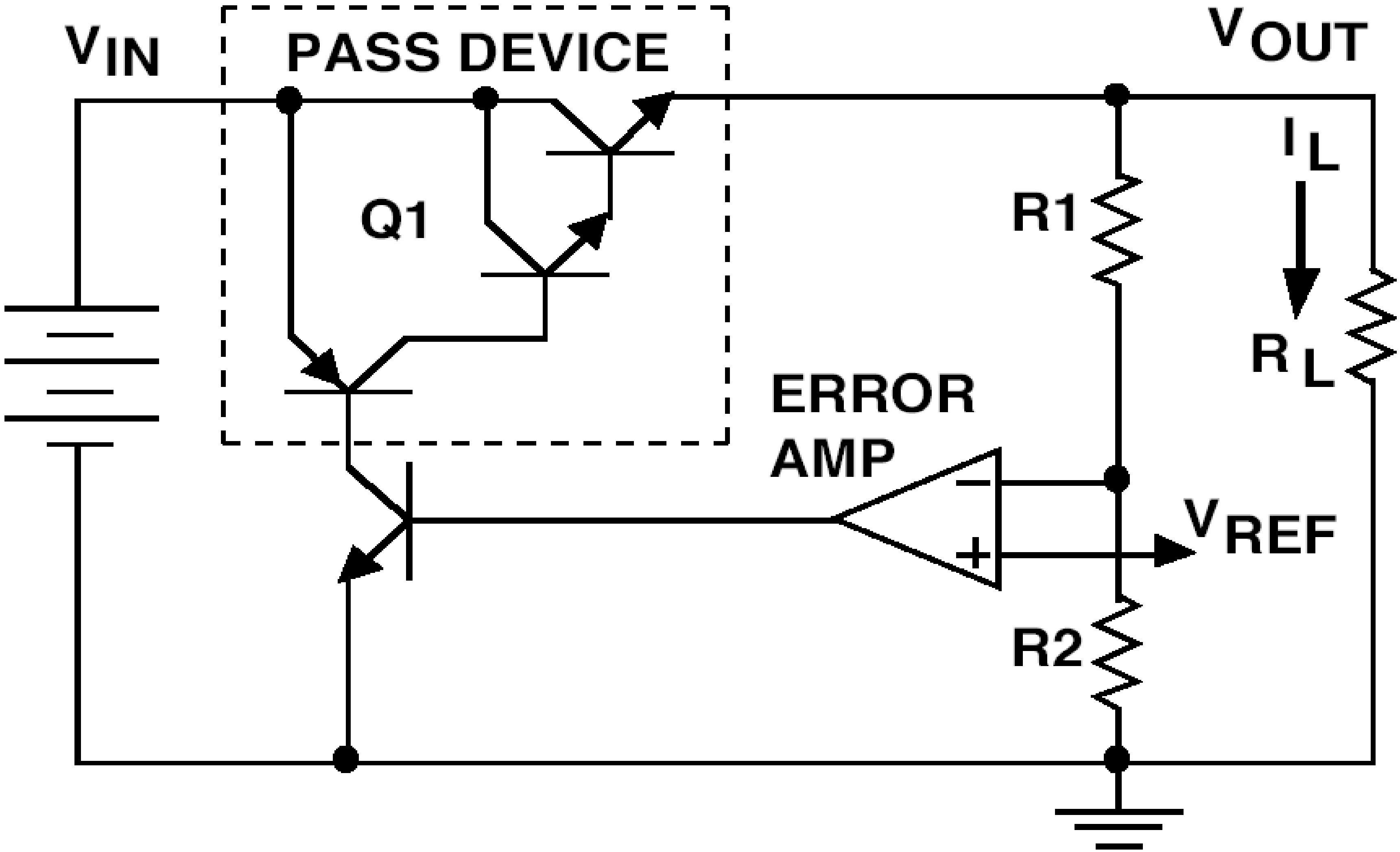
Linear regulator (principle)



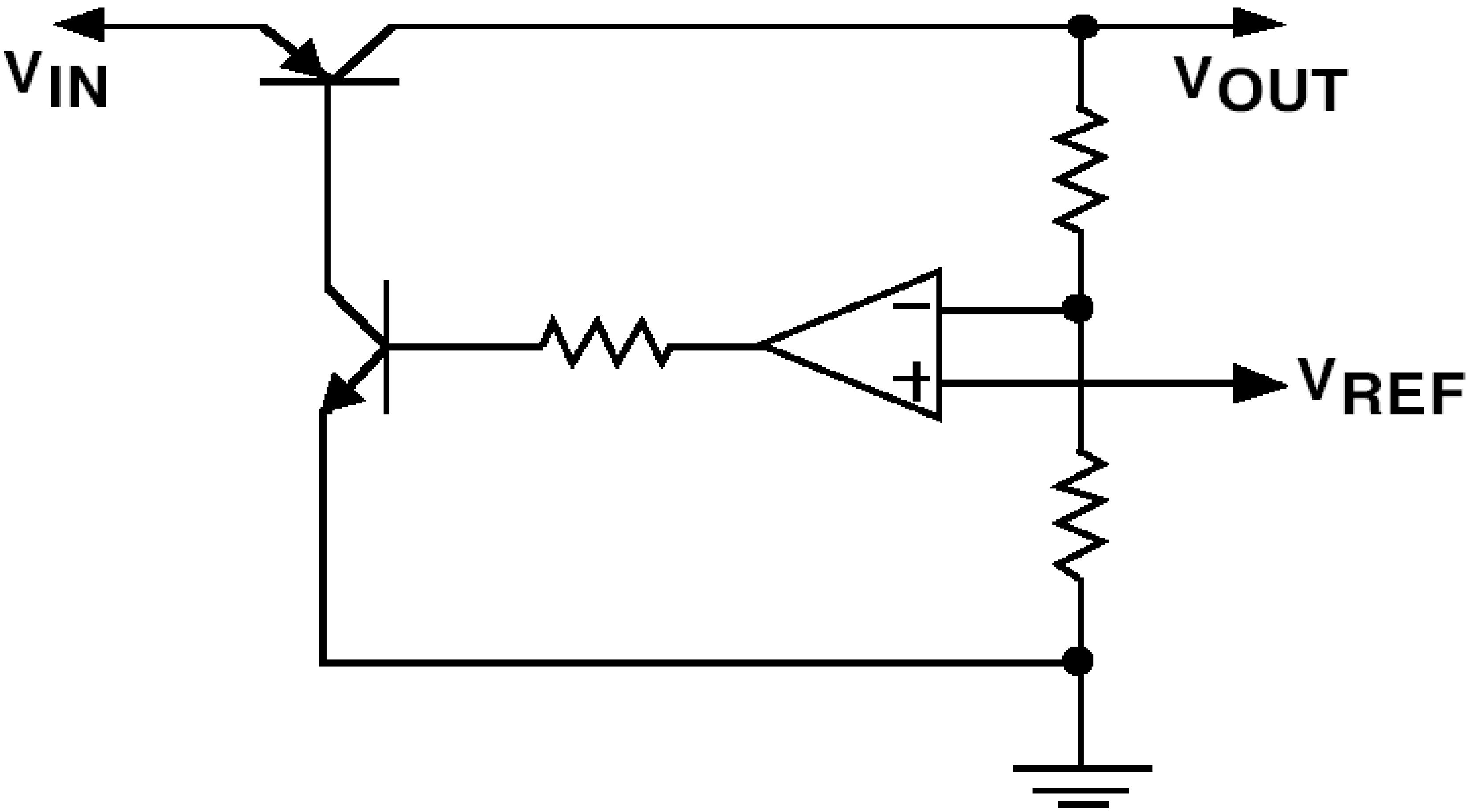
Three main types:

- Standard
- LDO (Low DropOut)
- Quasi LDO

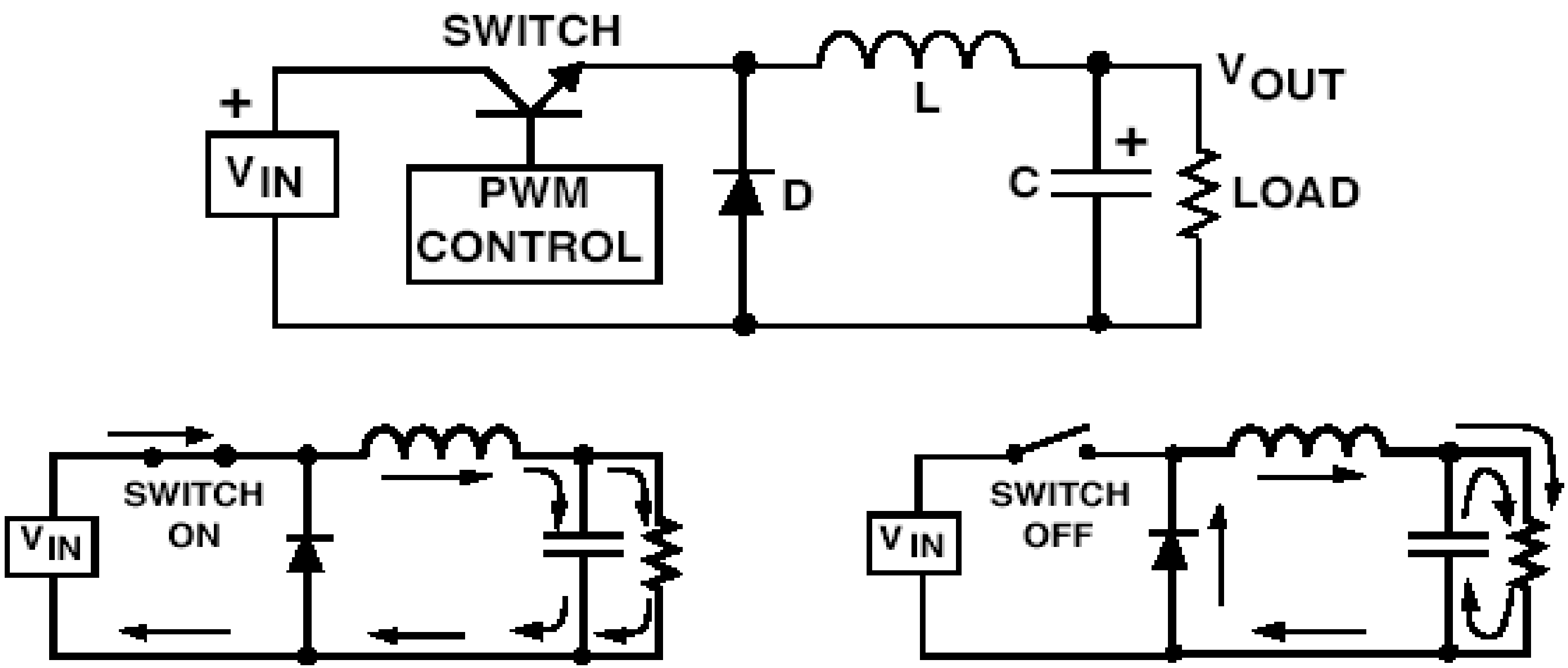
Linear regulator, standard type



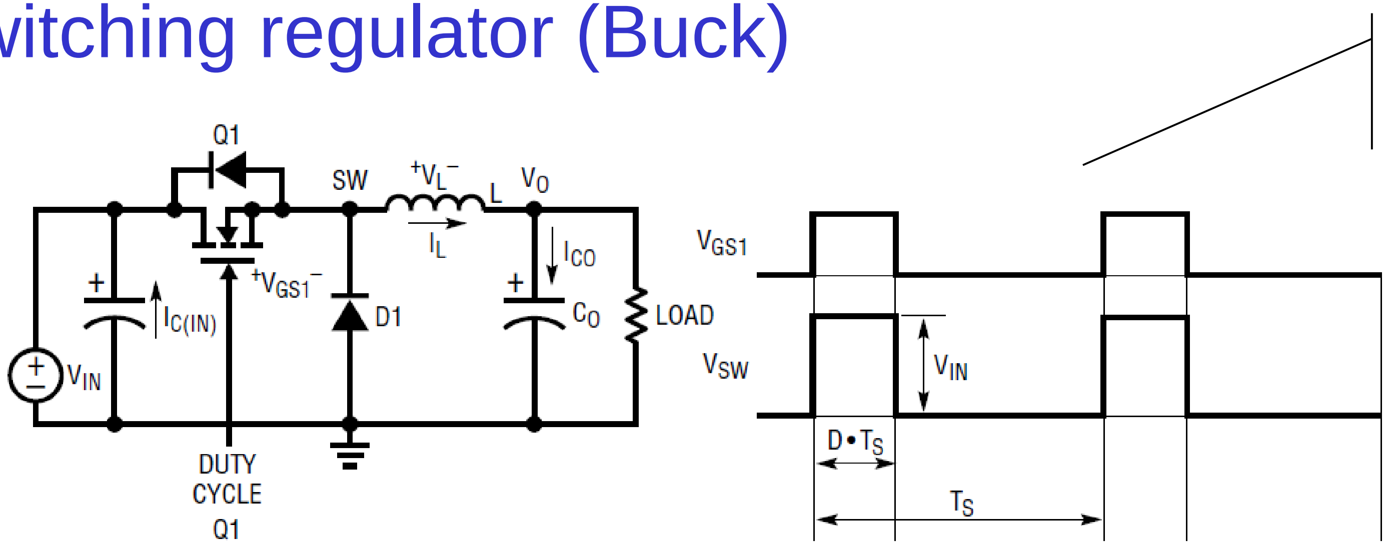
LDO regulator



Switching regulator (Buck)



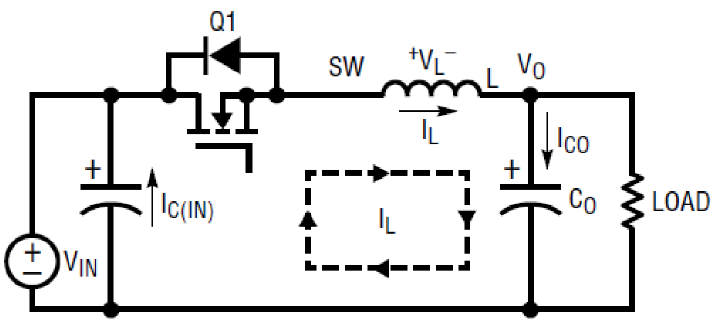
Switching regulator (Buck)



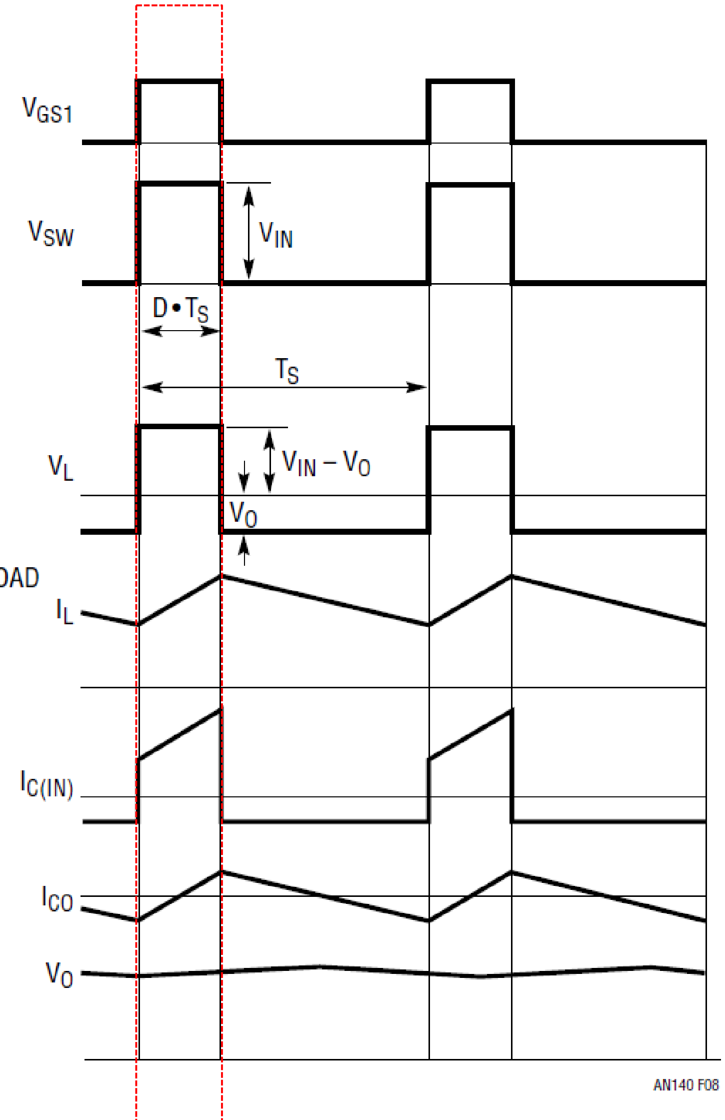
PWM:

$0 < D < 1$

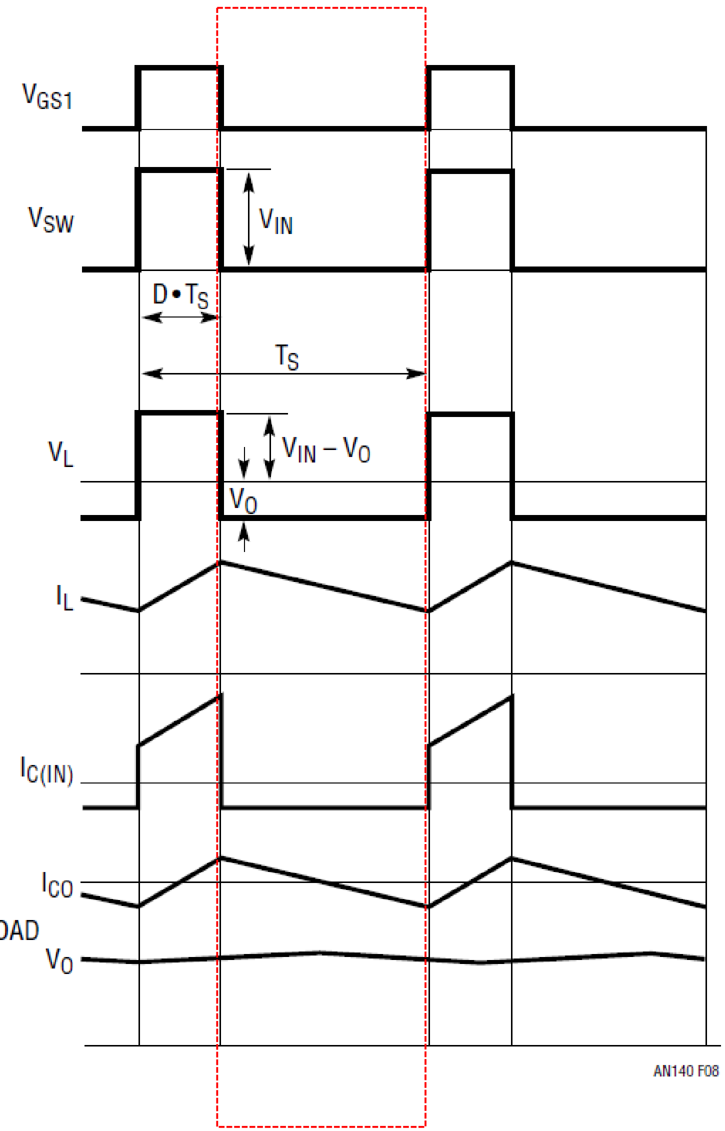
Switching regulator (Buck)

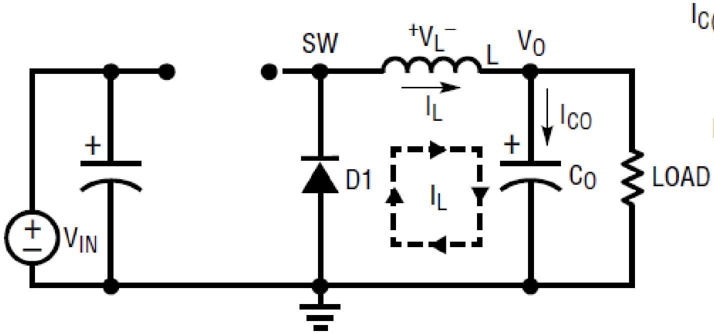


A. INDUCTOR CHARGING MODE



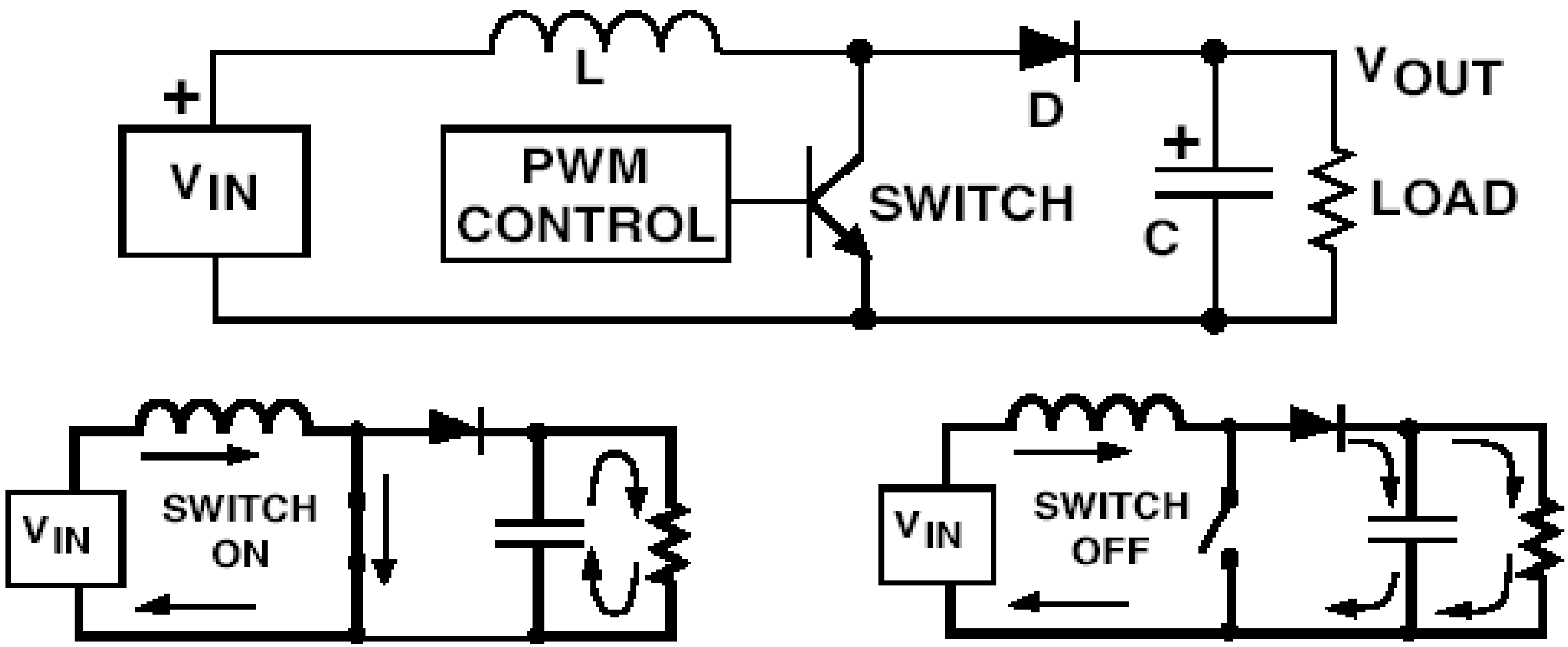
Switching regulator (Buck)





B. INDUCTOR DISCHARGING MODE

Switching regulator (Boost)

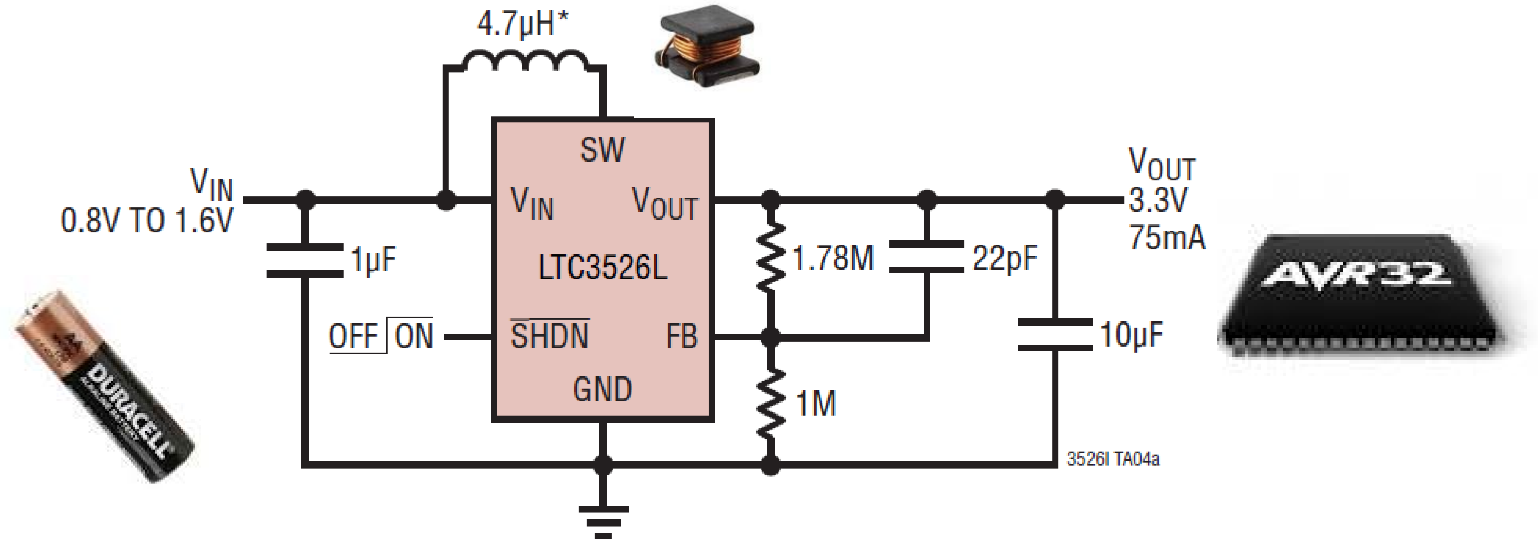


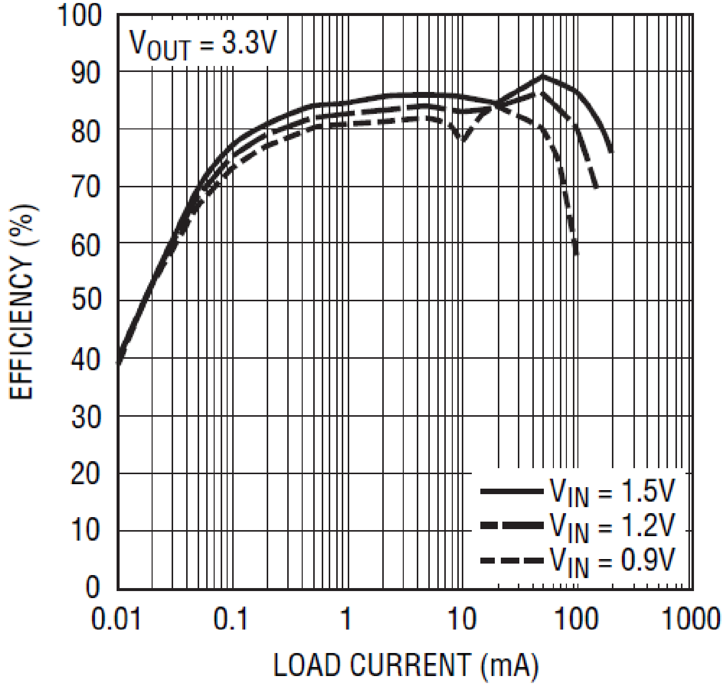
Design considerations switching regs.

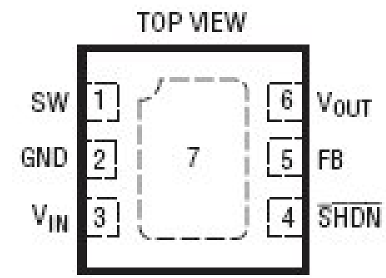
Remember that switching regulators are relatively noisy:

- Output ripple (10 - 100 mV typical, f_{PWM})
- Supply ripple (f_{PWM})
- Switching current in inductor causes radiation of el. noise

Circuits operating with low-level signals (<100 µV typ.) must take special care to avoid problems!

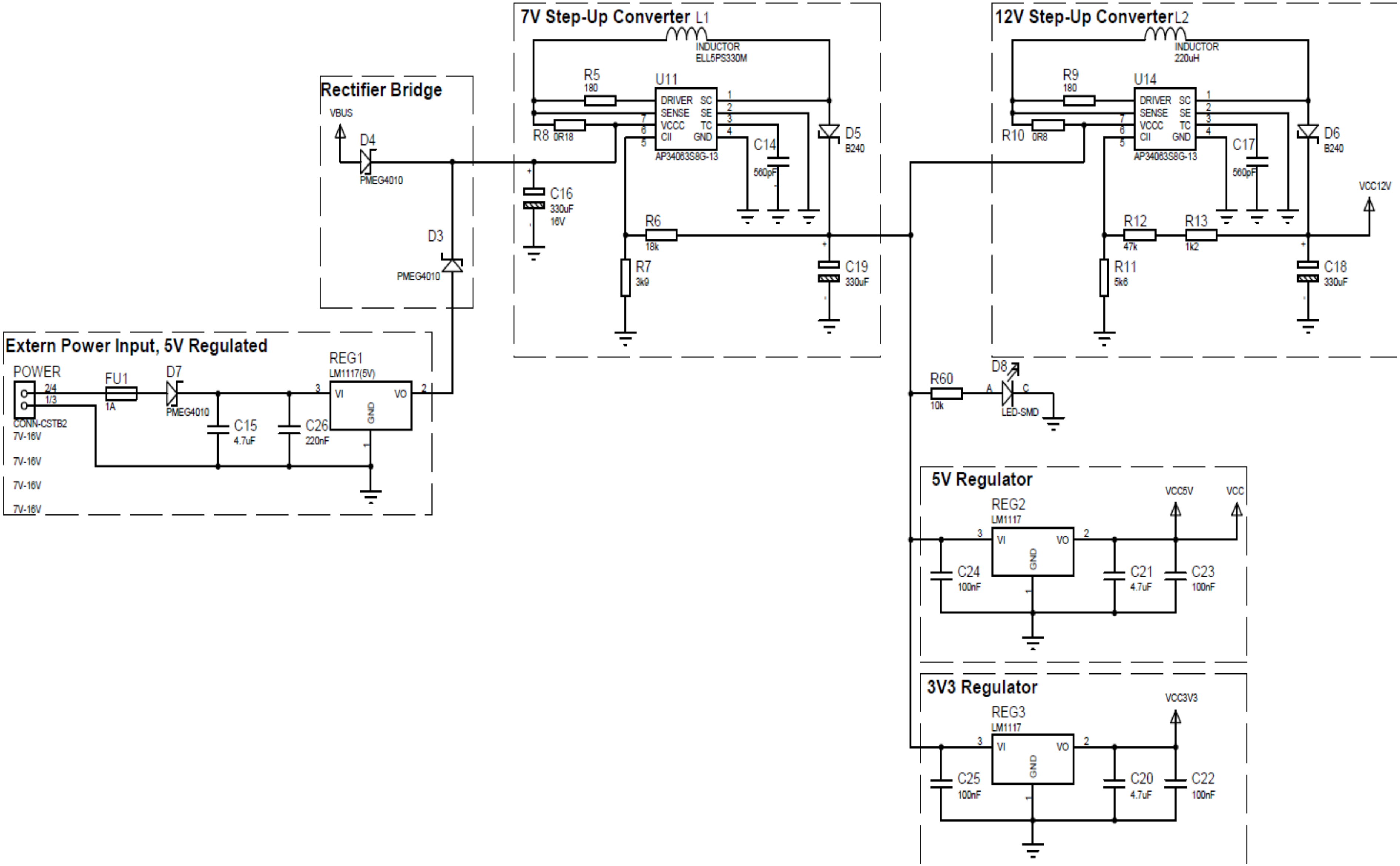






DC PACKAGE
6-LEAD (2mm × 2mm) PLASTIC DFN
$T_{JMAX} = 125°C$, $\theta_{JA} = 60°C/W$ (NOTE 6)
EXPOSED PAD (PIN 7) IS GND, MUST BE SOLDERED TO PC BOARD

Example: Voltage regulation on USB multifunction node



Charge pump ("Flying capacitor")

- Inductorless DC/DC converters
  - Buck, boost, inverting
  - Low current

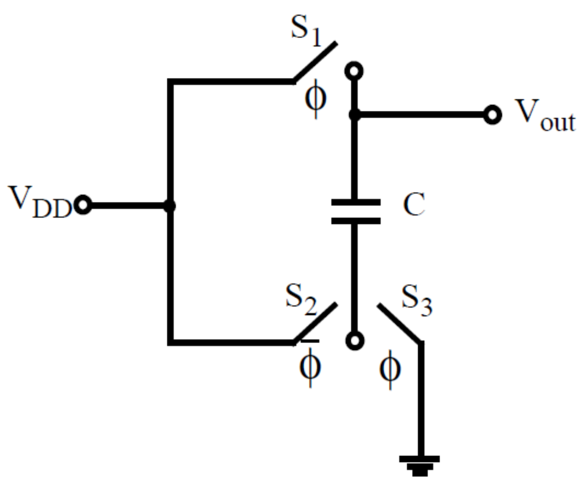
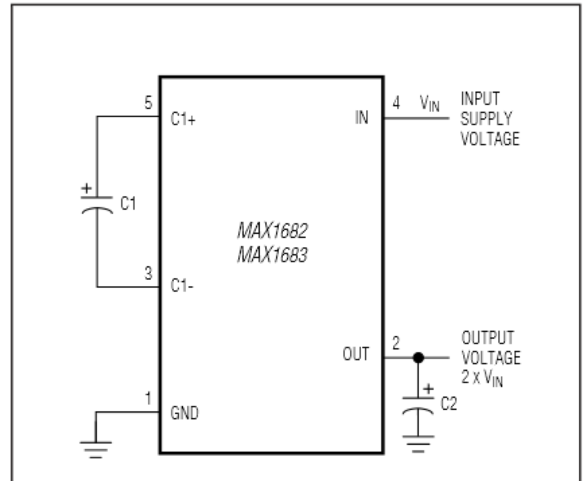


Fig. 1. Simple voltage doubler

$$(V_{out} - V_{DD}) \cdot C = V_{DD} \cdot C$$

$$V_{out} = 2 \cdot V_{DD}$$

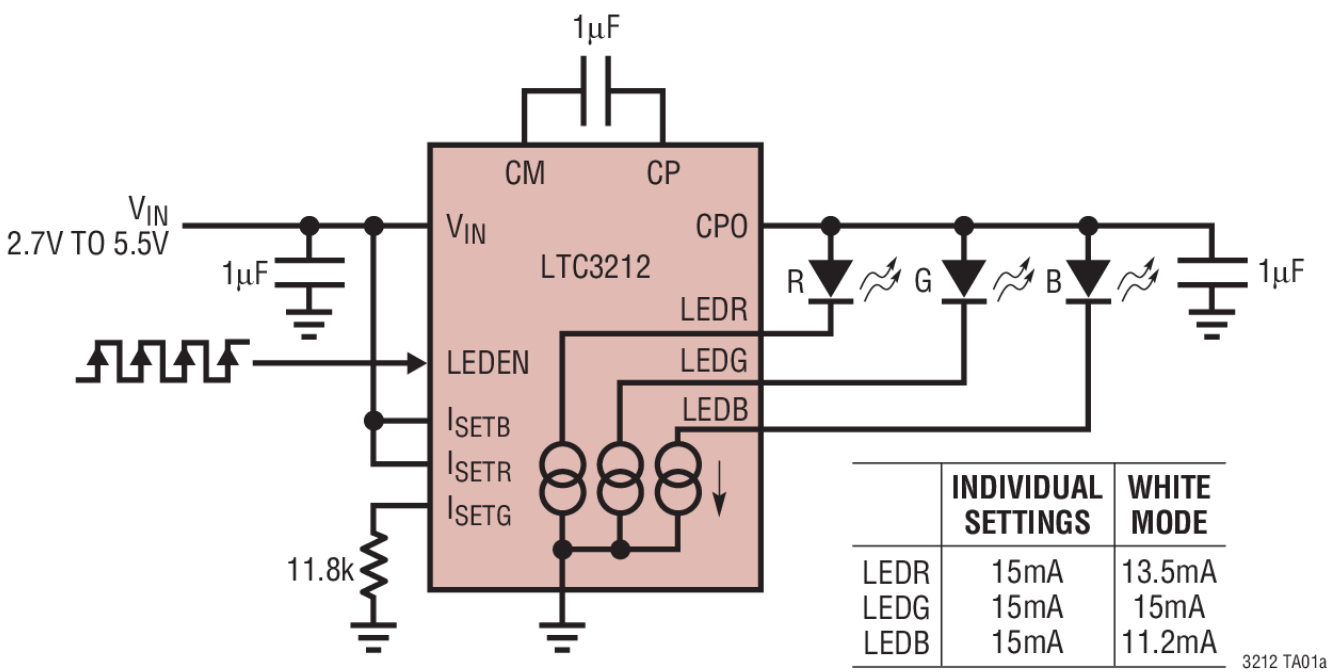


VOLTAGE DOUBLER

- Vin: +2.0V to +5.5V
- Iout: < 45mA
- Efficiency: 98%

Example: RGB LED driver

RGB Power Supply and Current Control



	INDIVIDUAL SETTINGS	WHITE MODE
LEDR	15mA	13.5mA
LEDG	15mA	15mA
LEDB	15mA	11.2mA