# Introduction to Embedded System Design

## Lecture - 4: Elements of Microcontroller Ecosystem, Power Supply for Embedded Systems


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# Elements of Microcontroller Ecosystem

# “Roti, Kapda, Makaan and Internet” for a Microcontroller! (Essential Elements for Survival)

- Clock
- Reset
- Power Supply
- Program Download Capability

# The Clock Subsystem!

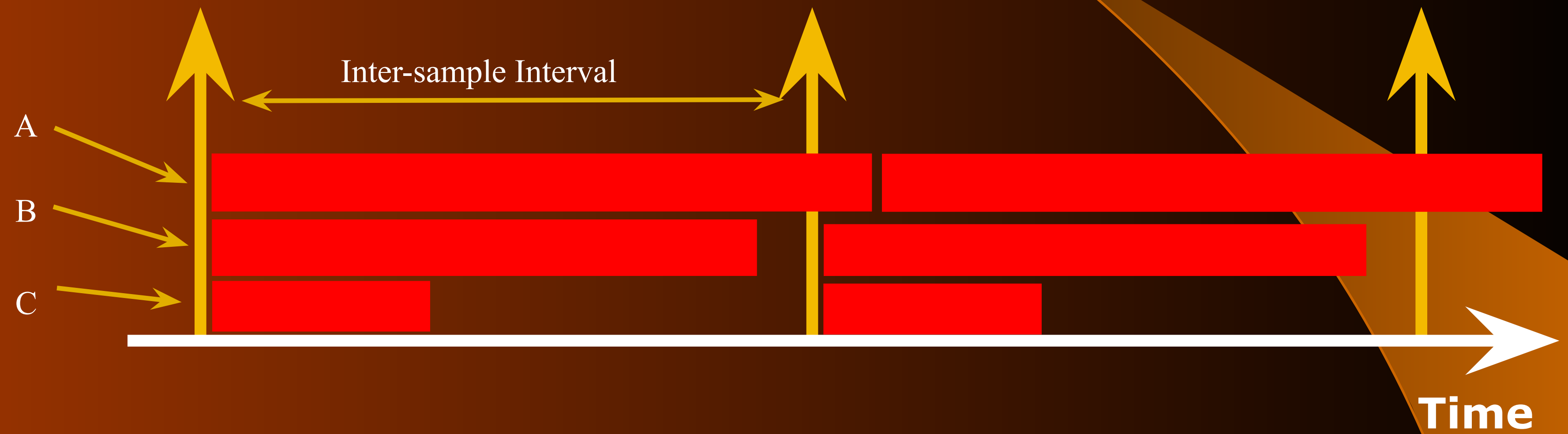
- Why do we need Clock?
- What Should be the Clock Frequency?
- Implications of Clock Frequency Value?
- What Topology for the Clock Generator?
- Desirable Features for the Clock Generator?
- RTC Clock?
- Clock Frequency Stabilization: TCXO, Temperature Sensor + Varactor diode in parallel to Crystal.

# Selecting a Suitable Embedded Controller

- Peripheral Features
- Memory
- Packaging
- Grade (Commercial, Industrial, Automotive, Military)
- Price
- Availability and lead time

But most important!

# Selecting a Suitable Embedded Controller

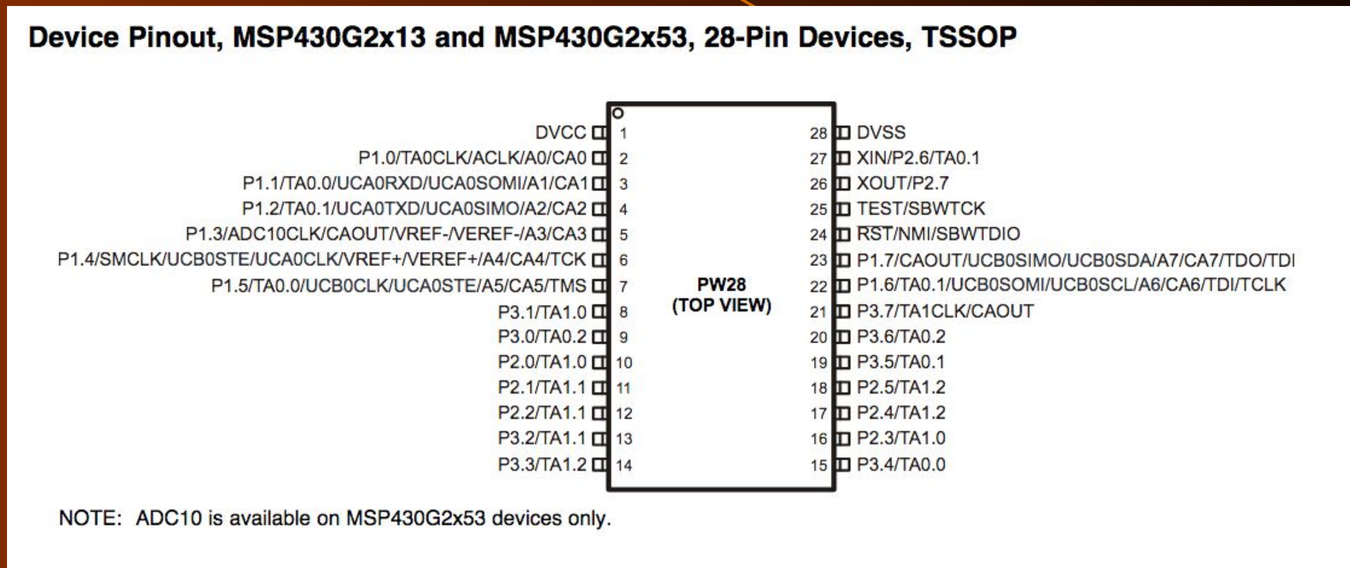


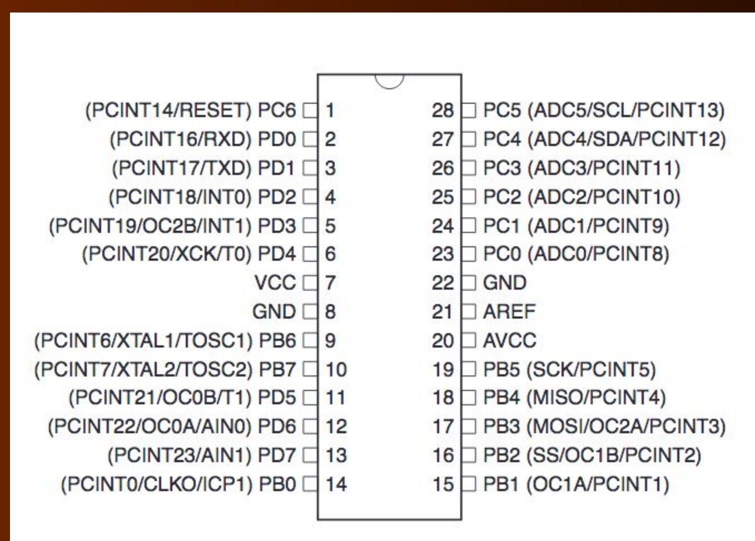

- Algorithm Complexity viz-a-viz Sampling Theorem Constraints
- Controller ‘A’ is unacceptable
- Controller ‘B’ is marginal
- Controller ‘C’ is comfortable!

# The Reset Subsystem!

- Why do we need Reset?
- Sources of Reset?
- Warm and Cold Reset?
- POR, User, BOD and Watchdog.

# User Reset

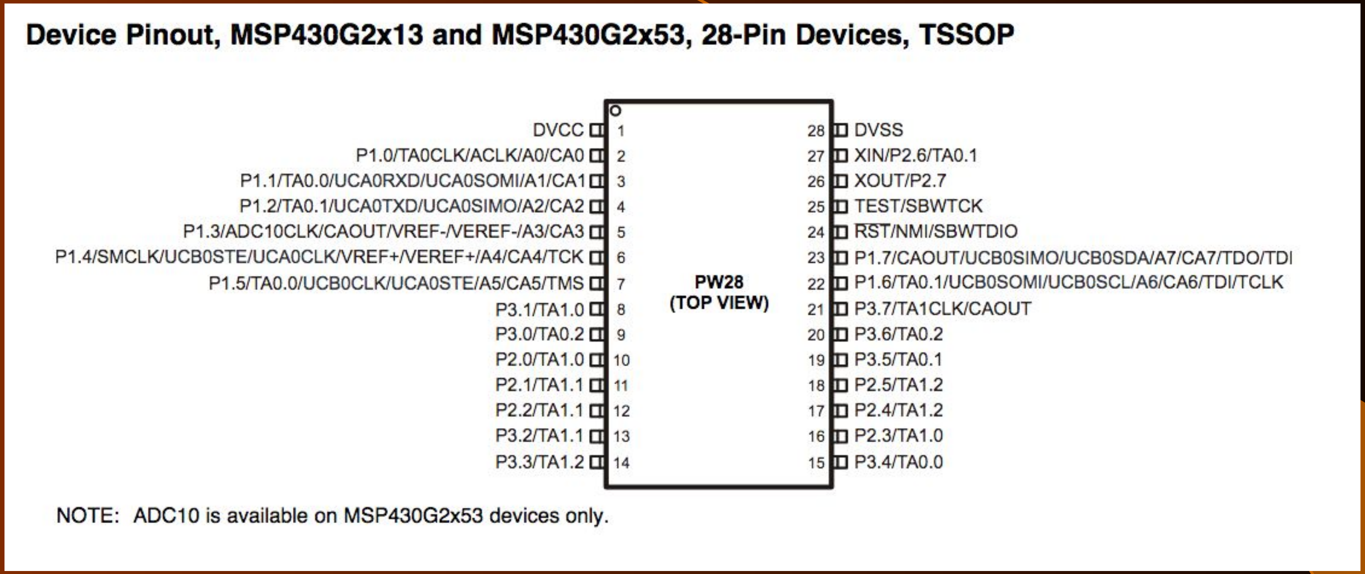

Device Pinout, MSP430G2x13 and MSP430G2x53, 28-Pin Devices, TSSOP
DVCC 1
P1.0/TA0CLK/ACLK/A0/CA0 2
P1.1/TA0.0/UCA0RXD/UCA0SOMI/A1/CA1 3
P1.2/TA0.1/UCA0TXD/UCA0SIMO/A2/CA2 4
P1.3/ADC10CLK/CAOUT/VREF-/VEREF-/A3/CA3 5
P1.4/SMCLK/UCB0STE/UCA0CLK/VREF+/VEREF+/A4/CA4/TCK 6
P1.5/TA0.0/UCB0CLK/UCA0STE/A5/CA5/TMS 7
P3.1/TA1.0 8
P3.0/TA0.2 9
P2.0/TA1.0 10
P2.1/TA1.1 11
P2.2/TA1.1 12
P3.2/TA1.1 13
P3.3/TA1.2 14
28 DVSS
27 XIN/P2.6/TA0.1
26 XOUT/P2.7
25 TEST/SBWTCK
24 RST/NMI/SBWTDIO
23 P1.7/CAOUT/UCB0SIMO/UCB0SDA/A7/CA7/TDO/TDI
22 P1.6/TA0.1/UCB0SOMI/UCB0SCL/A6/CA6/TDI/TCLK
21 P3.7/TA1CLK/CAOUT
20 P3.6/TA0.2
19 P3.5/TA0.1
18 P2.5/TA1.2
17 P2.4/TA1.2
16 P2.3/TA1.0
15 P3.4/TA0.0
PW28
(TOP VIEW)
NOTE: ADC10 is available on MSP430G2x53 devices only.

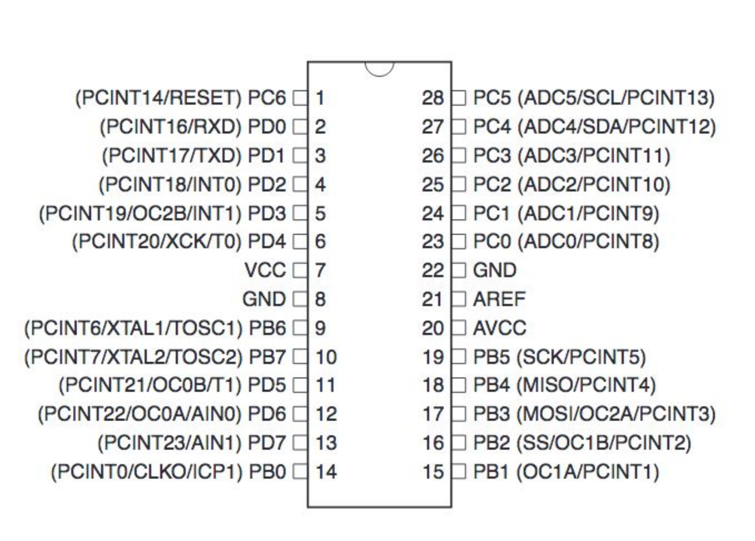

(PCINT14/RESET) PC6 1
(PCINT16/RXD) PD0 2
(PCINT17/TXD) PD1 3
(PCINT18/INT0) PD2 4
(PCINT19/OC2B/INT1) PD3 5
(PCINT20/XCK/T0) PD4 6
VCC 7
GND 8
(PCINT6/XTAL1/TOSC1) PB6 9
(PCINT7/XTAL2/TOSC2) PB7 10
(PCINT21/OC0B/T1) PD5 11
(PCINT22/OC0A/AIN0) PD6 12
(PCINT23/AIN1) PD7 13
(PCINT0/CLKO/ICP1) PB0 14
28 PC5 (ADC5/SCL/PCINT13)
27 PC4 (ADC4/SDA/PCINT12)
26 PC3 (ADC3/PCINT11)
25 PC2 (ADC2/PCINT10)
24 PC1 (ADC1/PCINT9)
23 PC0 (ADC0/PCINT8)
22 GND
21 AREF
20 AVCC
19 PB5 (SCK/PCINT5)
18 PB4 (MISO/PCINT4)
17 PB3 (MOSI/OC2A/PCINT3)
16 PB2 (SS/OC1B/PCINT2)
15 PB1 (OC1A/PCINT1)

# Program Download Capability

- Older Methods (EPROM Eraser + Universal Device Programmer).
- Evolution of Flash Memory $\rightarrow$ ISP.
- Most Popular using SPI.
- JTAG: Dual use. Testing as well as Program Download
- SWD
- IAP using Bootloader.
- UPM + BPM.

# Power Supply for microcontrollers



# Power Supply: An Important Component

- Source of Power? – Grid, Battery or alternative?
- Stabilization (Voltage Regulation)
- Backup?
- Optimization- modes of operation

# Power Supply: An Important Component

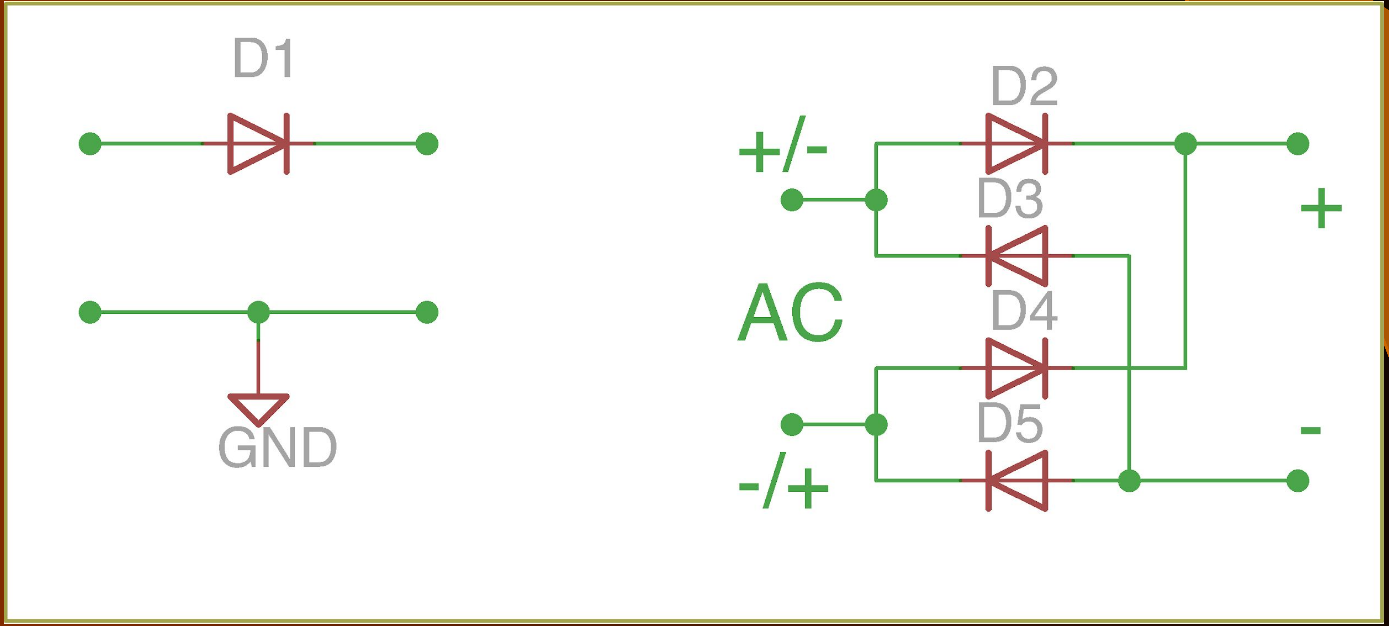
Alternative sources:

- Solar (Photovoltaic, Thermoelectric)
- Hydro
- Vibration/Resonance based on Faraday law
- Ambient RF power conversion.

# Grid Power

- AC Step down → Rectifier.
- Polarity proof input stage.
- Instead of step-down transformer, How about capacitive voltage divider option? Advantages?
- Switching Mode Supply?
- Filtering

# Low Voltage AC Input: Polarity Safe or Polarity Proof Input Stage



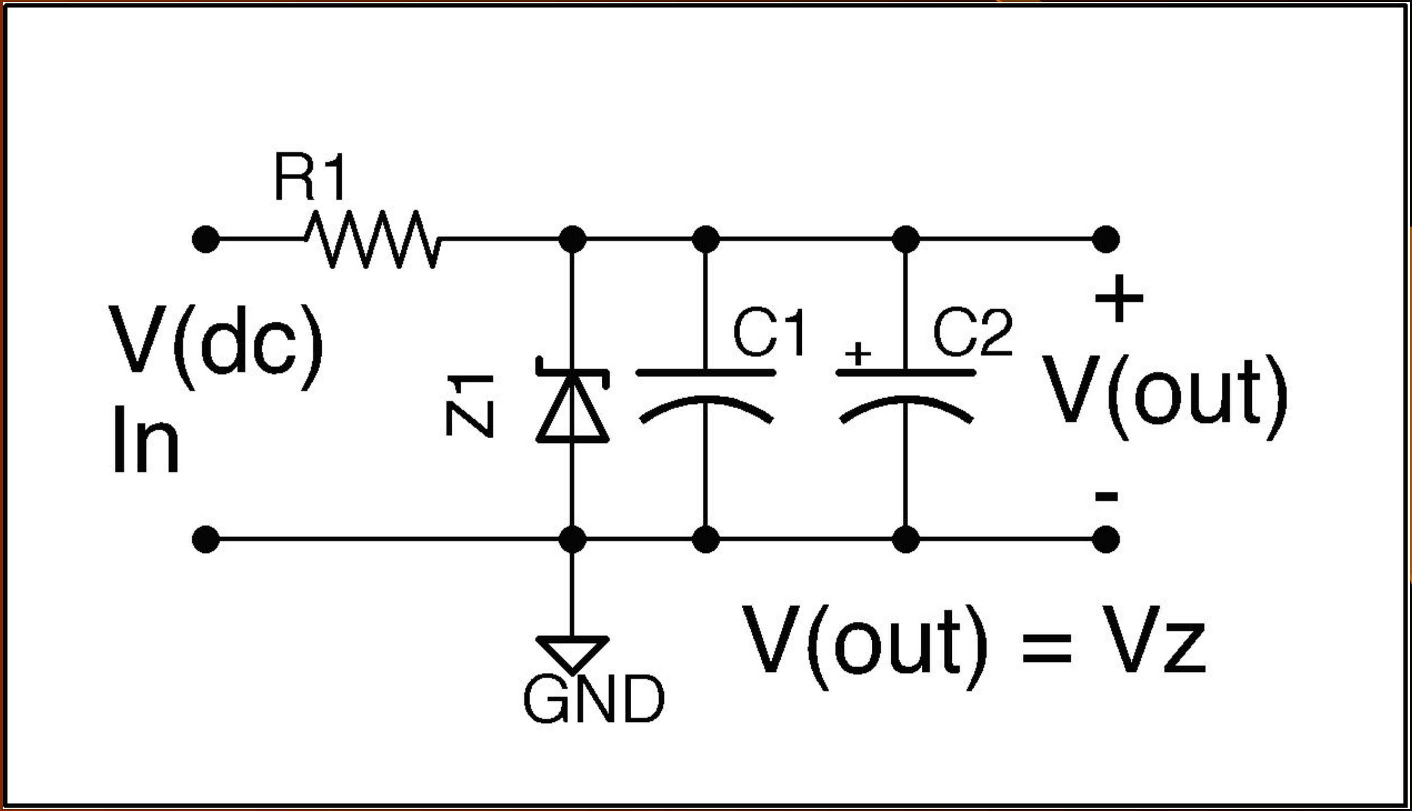
# Voltage Regulators

- Linear Regulator
- Switching Regulator

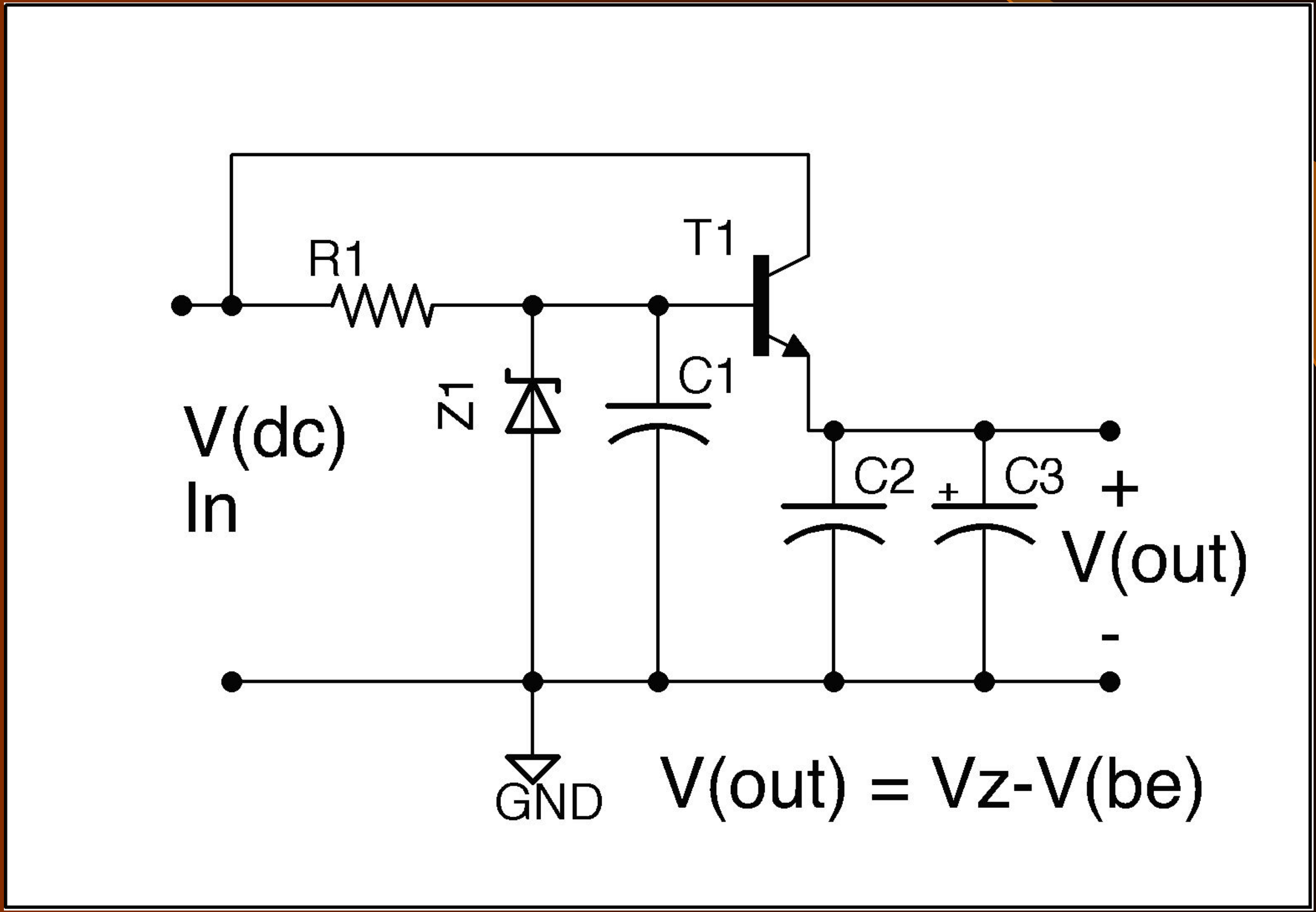
# Voltage Stabilization

- Linear Regulators- Ease of use, cheap, low component count. The classic 78xxx series. Issues? Large Dropout voltage, Large quiescent current I(q).
- Use Low Drop Out (LDO) linear regulators.
- Low Quiescent Current too.

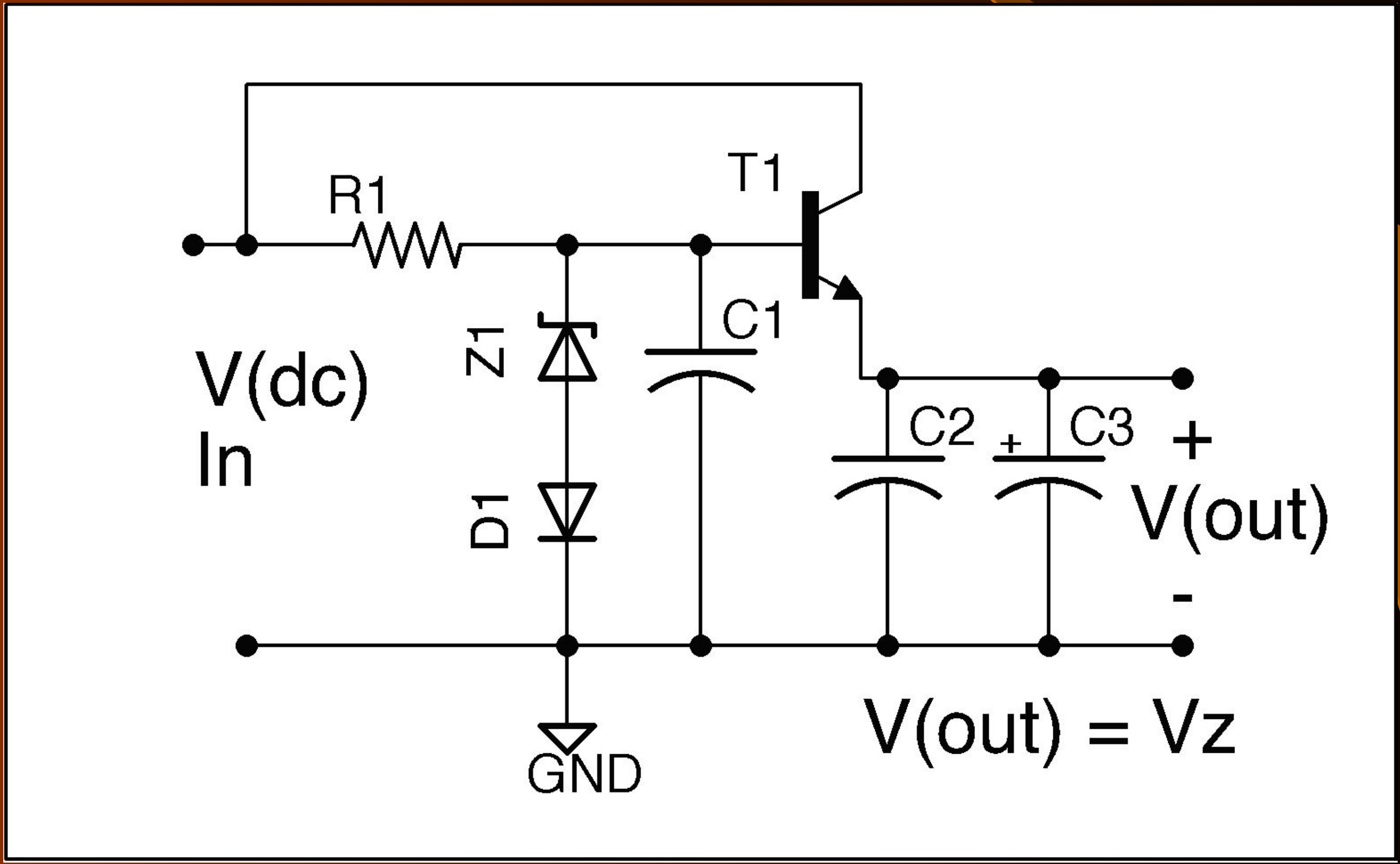
# Linear Regulator Topologies



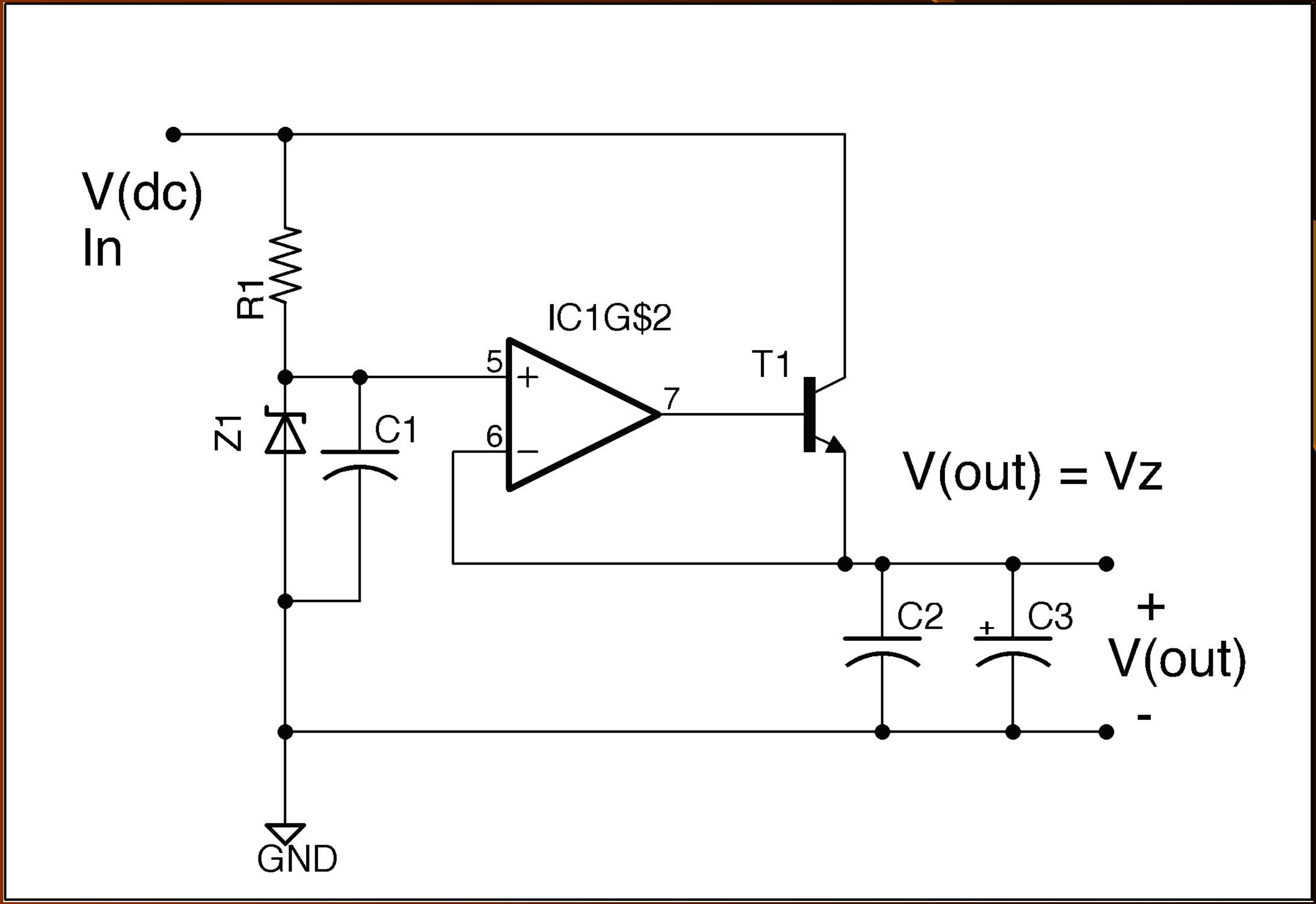
# Linear Regulator Topologies



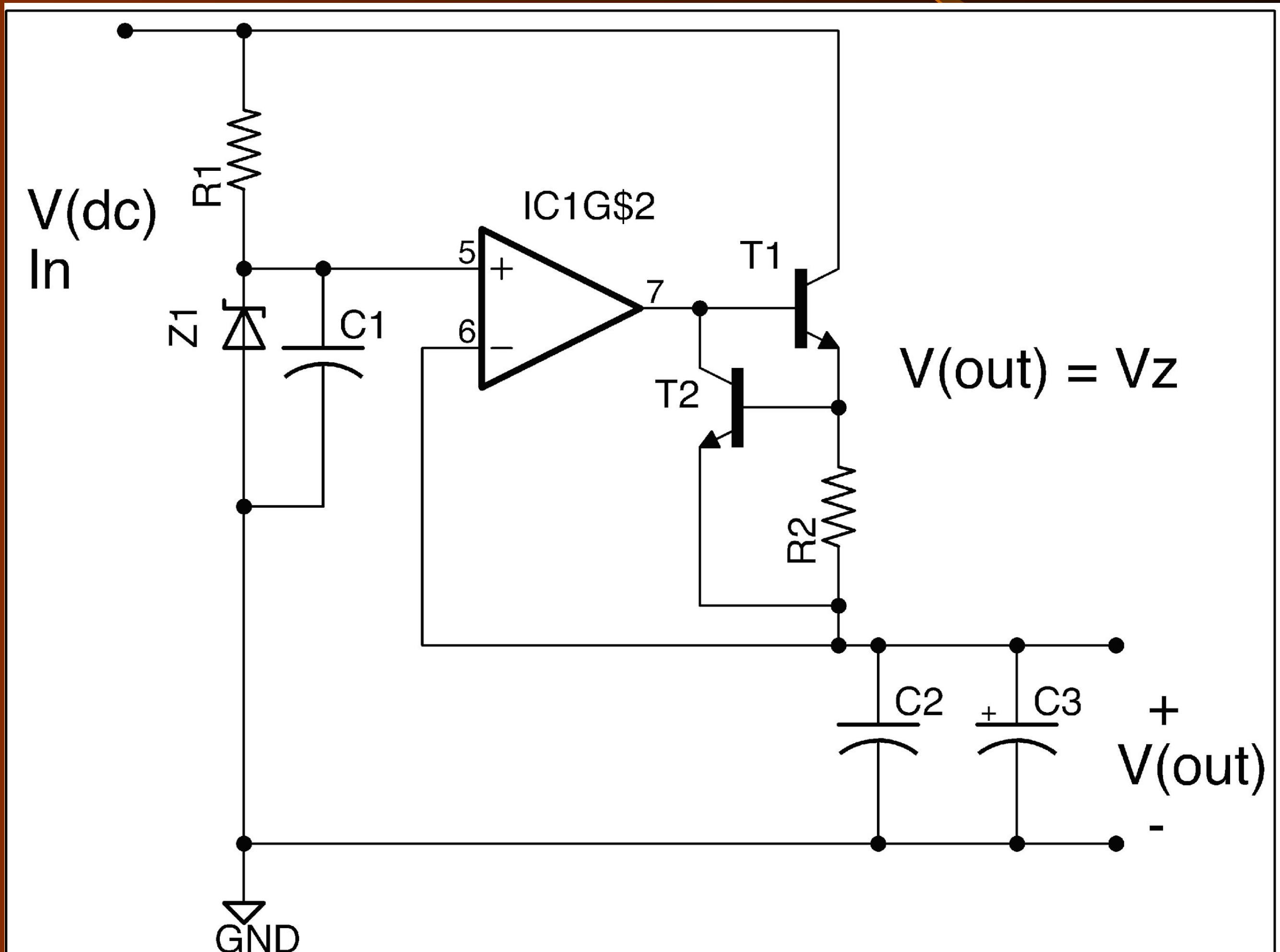
# Linear Regulator Topologies



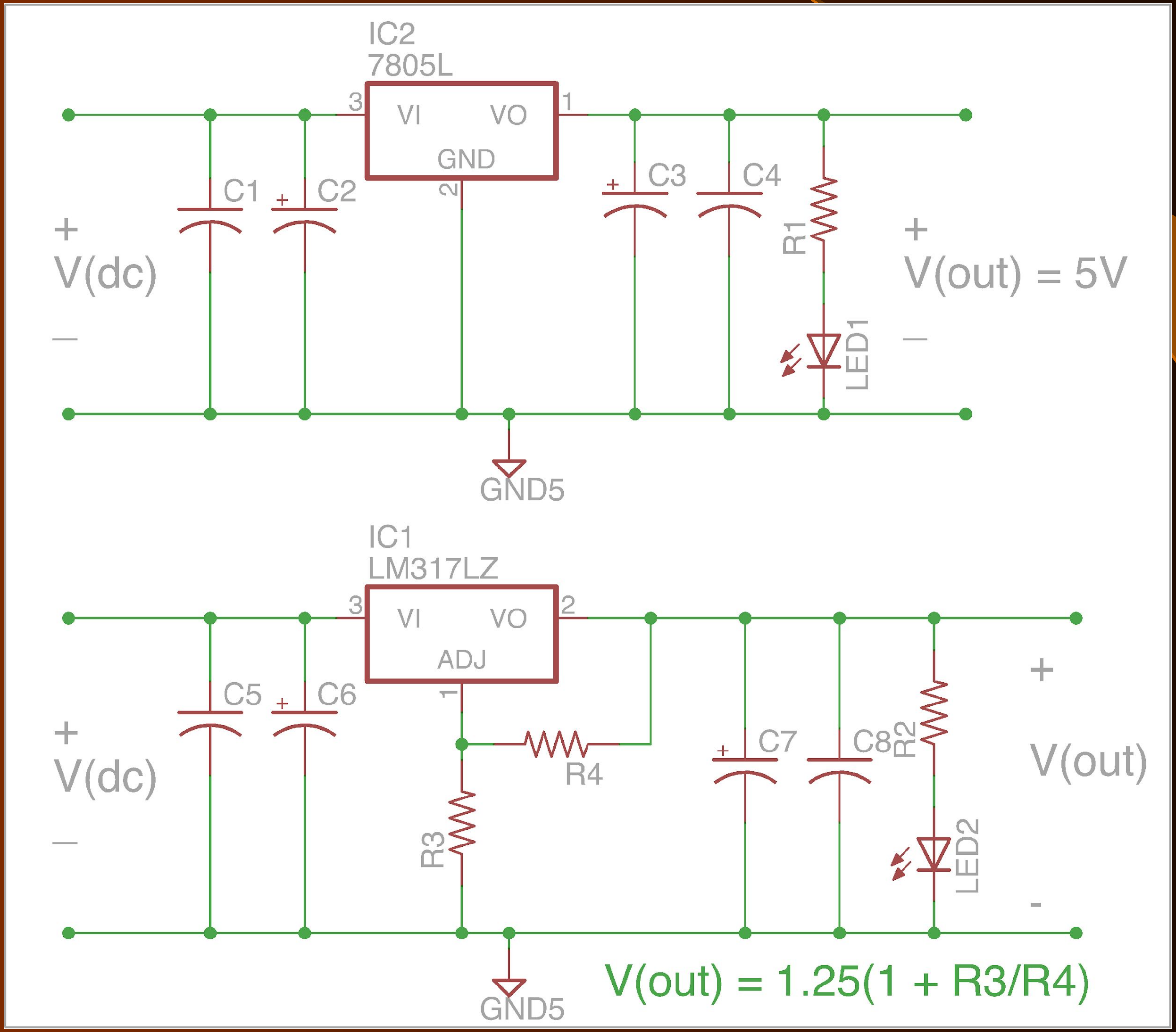
# Linear Regulator Topologies



# Linear Regulator Topologies



# 3-Terminal Linear Regulator



# Linear Regulators

- The classic 7805 is history.
- Why? 5V no longer voltage of choice.
- Large Drop out voltage (3V or more)
- Large Quiescent Current – 10 mA.
- Alternatives?

LDO! 0.1V drop out, 10-100uA Quiescent Current

Examples: LP2950 (2.7, 3, 3.3V etc)

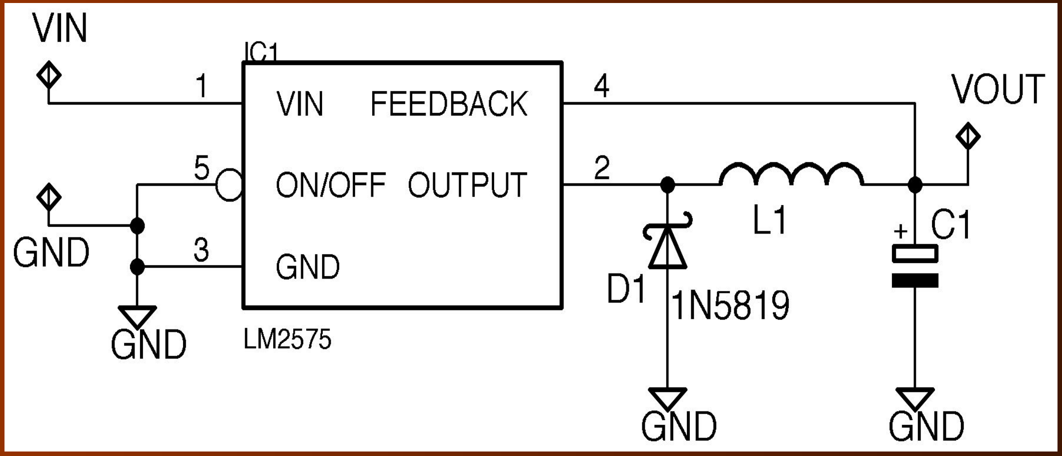
LP38500-ADJ 0.6V dropout.

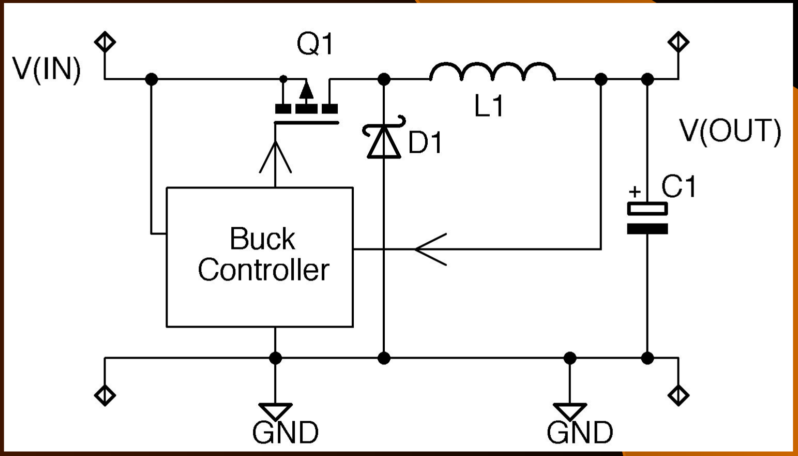
# Switching Regulators

- Advantages: 90%+ efficiency
- Pitfalls: Inductor, switching diode, high current switch.
- Lower ESR output capacitor
- Relatively large output noise.
- Type depends on input voltage availability and output voltage requirements.

# Switching Regulators - II

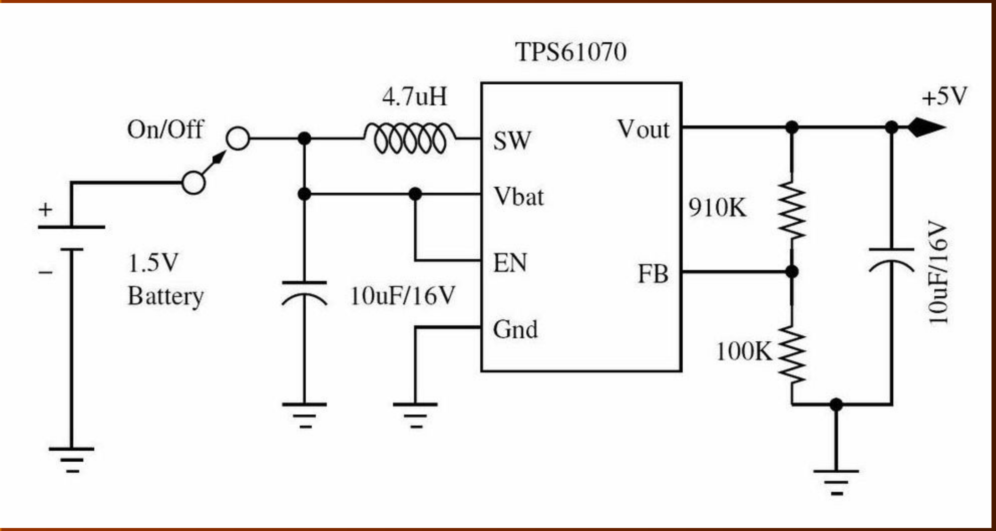
- Broadly 3 categories: Buck, Boost, Buck-boost.
- Buck: V(out) < V(in); I(out) > I(in)
- Buck example: LM2575 (1A max); LM2576 (3A max.)

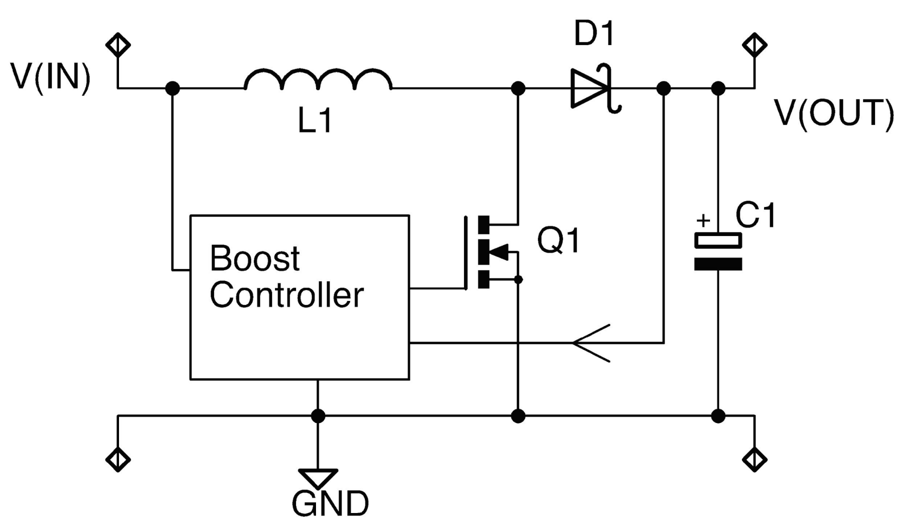


# Switching Regulators - III

- Boost: V(out) >= V(in); I(out) < I(in)
- TPS61070; V(in) 0.9V to 5.5V; V(out) <5.5V (adjustable); Switch Current: 600mA
- LT1308: V(in): 1V to 10V; Vout < 34V. Switch Current: 3A.

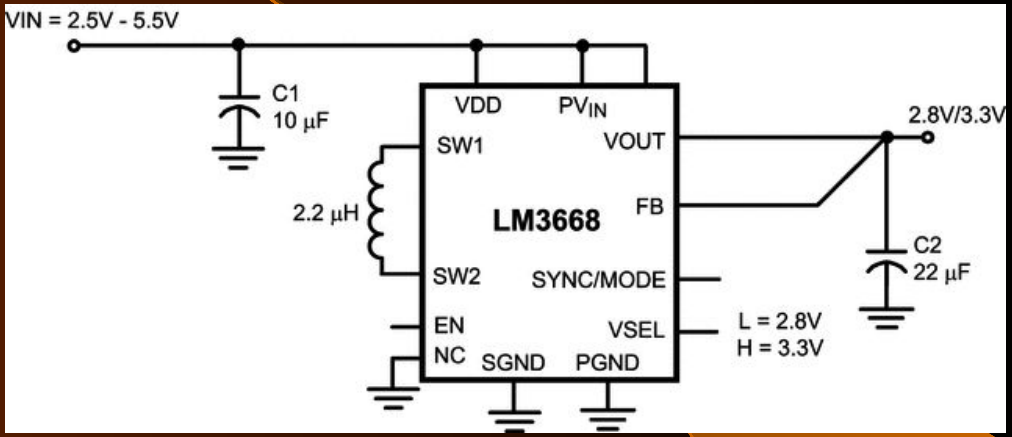


# Switching Regulators - IV

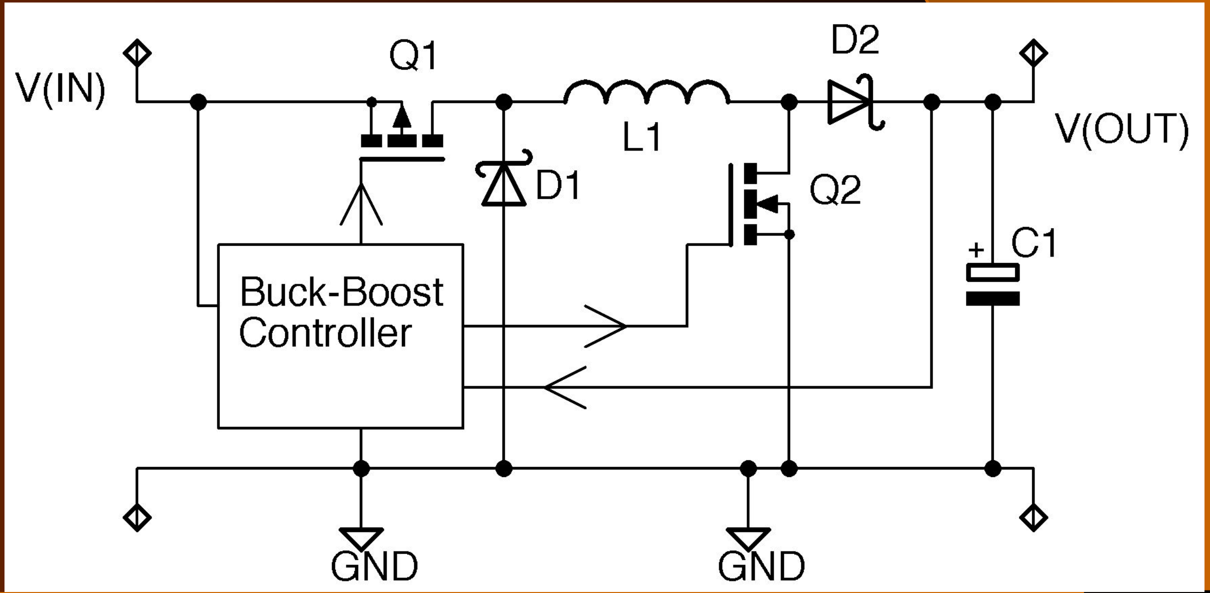
- Buck-Boost:

Vin(min) < V(out) < Vin(max)



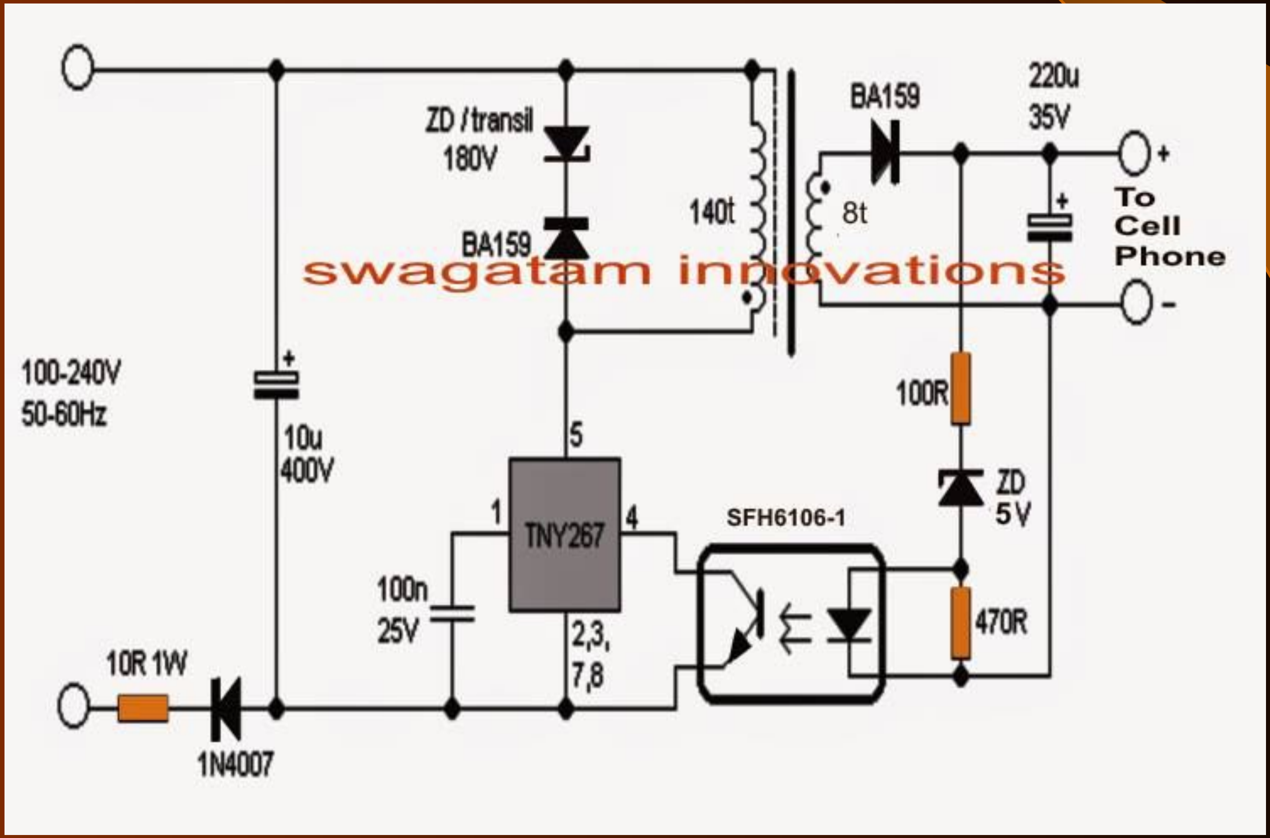

- Buck-Boost example: LM3668.

V(in) 2.5V to 5.5V. Vout: 2.8V or 3.3V (fixed). I(max): 1A.



# Switching Cell Phone Charger

- E(avg)= 4*f*N*a*B



# Various Power Supply Topologies

- Line Frequency Transformer + Linear (fixed or variable) regulator
- Line Frequency Transformer + switching (buck or boost) regulator
- Switching Power Supply
- Capacitive attenuator + Zener
- Alkaline + Boost/Buck

# Various Power Supply Topologies - II

- Lithium + Boost (for 5V)
- Lithium + Buck-Boost (3.3V)
- Lithium + Boost for 5V and Buck/LDO for 3.3V
- Radio Frequency based Ultra low power
- Faraday based
- Solar + Battery + Regulator
- Vibration resonance (http://www.perpetuum.com/)
- Thermoelectric (TEG) based

# Modern ICs

- Partitioned Design
- Speed Versus Noise Margin trade off
- Analog Subsystem
- All the above leads to multiple power supply rails.

# Linear Power Supply for Embedded Processors

| Rail | Rail Volts (V) | Est IOUT (A) | POUT (W) | Cnrvtr VIN (V) | Converter Type | Linear Eff = Vo/Vin (%) | PIN= POUT/Eff (W) | PIN/VIN= IIN Req'd (A) | Cnvrtr Power Dsptd (W) |
|---|---|---|---|---|---|---|---|---|---|
| Vcc1 | 1.1 | 0.6 | 0.66 | 3.7 | Linear | 30 | 2.22 | 0.60 | 1.56 |
| Vcc2/Io2 | 1.8 | 0.3 | 0.54 | 3.7 | Linear | 49 | 1.11 | 0.30 | 0.57 |
| Io2 | 3.3 | 0.2 | 0.66 | 3.7 | Linear | 89 | 0.74 | 0.20 | 0.08 |
| TOTAL | | | 0.66 | | | | 4.07 | 1.10 | |

# Linear + Switched Power Supply for Embedded Processors

| Rail | Rail Volts (V) | Est IOUT (A) | POUT (W) | Cnrvtr VIN (V) | Converter Type | Est. Eff (%) | PIN= POUT/Eff (W) | PIN/VIN= IIN Req'd (A) | Cnvrtr Power Dsptd (W) |
|---|---|---|---|---|---|---|---|---|---|
| Vcc1 | 1.1 | 0.6 | 0.66 | 3.7 | Switch | 92 | 0.72 | 0.19 | 0.06 |
| Vcc2/Io2 | 1.8 | 0.3 | 0.54 | 3.7 | Switch | 93 | 0.58 | 0.16 | 0.04 |
| Io2 | 3.3 | 0.2 | 0.66 | 3.7 | Linear | 89 | 0.74 | 0.20 | 0.08 |
| TOTAL | | | 0.66 | | | | 2.04 | 0.55 | |

# Power Optimization

Broadly 3 Levels of power consumption

- Active mode – full power and performance
- Sleep mode – Oscillator On, synchronous components off. Asynchronous On. Interrupts, RTC etc On. System Restart fairly quickly. Power consumption about half of active mode.
- Power Down mode – 1/1000 of active power. All components power down; Only asynchronous components – interrupts On. Restart is slow and requires oscillator startup ~ several 100s of ms.

# Power Backup Sources

Sporadic availability of power. Need to smoothen out the availability.

- Batteries – Lead-acid, NiCd, NiMH, Li, Li-poly
- Supercapacitors?

# Battery Characteristics

| Type | Voltage (V) | Power(W/Kg) | Eff. | Cycles | Life (yr) |
|---|---|---|---|---|---|
| Lead-Acid | 2.1 | 180 | 70-90 | 500-800 | 3-20 |
| NiCd | 1.2 | 150 | 70-90 | 1500 | - |
| NiMH | 1.2 | 250-1000 | 66% | 1000 | - |
| Li ion | 3.6 | 1800 | 99.9 | 1200 | 2-3 |
| Li-poly | 3.6 | 3000+ | 99.8 | 500-1000 | 2-3 |

# Lecture - 4 Summary

Thank you!