

# Systems Engineering

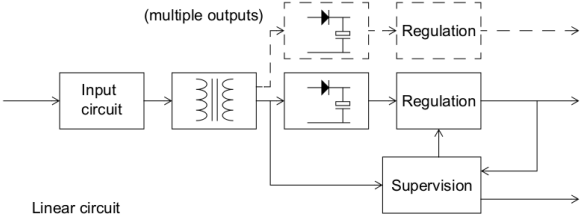
## Power Supplies

Pere Palà

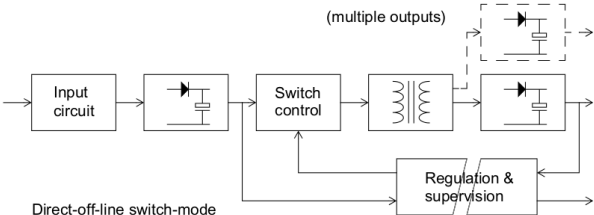
iTIC <http://itic.cat>

v1.0 April 2013

# Block Diagrams



Linear circuit



Direct-off-line switch-mode

Source: The Circuit Designer's Companion

# Linear supply

- ▶ Input circuit
- ▶ Transformer
- ▶ Rectifier
- ▶ Reservoir
- ▶ Regulation
- ▶ Supervision

## Switch-mode supply

- ▶ Rectifier + reservoir
- ▶ Switcher
- ▶ Eliminate 50 Hz mains transformer
- ▶ Substitute by a 100 kHz transformer: less weight and volume
- ▶ Rectifier + small-value reservoir due to high frequency
- ▶ Regulation
- ▶ Supervision

# Specifications

- ▶ Input parameters
  - ▶ Minimum and maximum input voltage
  - ▶ Maximum input current (surge and continuous)
  - ▶ Frequency range
- ▶ Efficiency over range of load and line conditions
- ▶ Output parameters
  - ▶ Output voltage(s)
  - ▶ Load current(s)
  - ▶ Output ripple and noise
  - ▶ Load and line regulation
  - ▶ Transient response
- ▶ Overload
- ▶ Turn-on, turn-off
- ▶ Mechanical parameters
- ▶ Safety approvals

# Commercial power supplies

## Linear Power supplies

- ▶ Fixed / adjustable
- ▶ Output voltage: 5 V..5 kV
- ▶ Number of outputs
- ▶ Output current: 3 mA..50 A
- ▶ Power rating: 0.5 W..500 W

# Linear power supplies



R3 Part No.	Description	L (mm)	W (mm)	H (mm)	Wt (Kg)	EMS Ref	Cover Kit
00-3500	5V 3A	124	102	53	1.0	D500	00-3880
00-3501	5V 6A	143	124	75	1.8	D501	00-3881
00-3502	5V 12A	229	124	81	3.4	D502	00-3882
00-3503	12-15V 1.7A	124	102	53	1.0	D503	00-3880
00-3504	12-15V 3.4A	143	124	75	1.8	D504	00-3881
00-3505	12-15V 6.8A	229	124	81	3.4	D505	00-3882
00-3506	24-28V 1.2A	124	102	53	1.0	D506	00-3880
00-3507	24-28V 2.4A	143	124	75	1.8	D507	00-3881
00-3508	24-28V 3.6A	178	124	81	3.2	D508	00-3883
00-3509	24-28V 4.8A	229	124	81	3.4	D509	00-3882
00-3510	24-28V 7.2A	356	124	86	4.2	D510	00-3885
00-3511	24-28V 10A	356	124	86	4.2	D511	00-3885
00-3512	±12-15V 1.7A	178	124	75	1.0	D512	00-3883
00-3513	±12-15V 3.4A	238	124	81	1.8	D513	00-3884
00-3514	5V 2A ± 9-15V 0.4A	165	102	53	1.0	D514	00-3886
00-3515	5V 3A ± 12-15V 1A	260	102	75	1.8	D515	00-3887
00-3516	5V 6A ± 12-15V 1.7A	279	124	81	3.2	D516	00-3888
00-3517	48V 1.0A	143	124	75	1.0	D517	00-3881
00-3518	120-200V 0.15A	124	102	53	2.3	D518	00-3880
00-3519	± 12-15V 1.0A	165	102	53	3.6	D519	00-3886

# Linear power supplies

## 1 Watt Encapsulated AC-DC Linear Power Supply



### PRODUCT DESCRIPTION

A comprehensive range of PCB mounting encapsulated power supplies available in either 120Vac or 230Vac input versions, and in single or dual output formats. They are vacuum encapsulated in flame retardant epoxy resin to UL94V0. All units incorporate overcurrent and reverse protection, and will automatically recover upon removal of the fault condition. The input and output pins are on 2.54mm, (0.1") centres for easy PCB mounting. All units also include a 'one shot' thermal fuse to protect against excessive over temperature conditions. The units are fully approved to EN60950 and are compliant to Low Voltage Directive.

Part Number	AC Input Range	Output Voltage	Output Current	Line Reg (Full Input Swing)	Load Reg (0-100%)
EPS 5/200C	207-253V	5V +/-5%	0-200mA	20mV	60mV
EPS 12/100C	207-253V	12V +/-5%	0-100mA	20mV	60mV
EPSP 12/50C	207-253V	+/-12V +/-5%	0-50mA	20mV	60mV
EPSP 15/40C	207-253V	+/-15V +/-5%	0-40mA	20mV	60mV
EPPL 5/200C	108-132V	5V +/-5%	0-200mA	20mV	60mV
EPPL 12/100C	108-132V	12V +/-5%	0-100mA	20mV	60mV
EPSDL 12/50C	108-132V	+/-12V +/-5%	0-50mA	20mV	60mV
EPSDL 15/40C	108-132V	+/-15V +/-5%	0-40mA	20mV	60mV

### PRODUCT SPECIFICATION & DIMENSIONS

Input frequency Range

Isolation test Voltage

Output Ripple

Output Protection

Operating Temperature Range

Weight

47-63Hz

3KV AC RMS Input to Output

10mV Peak to peak (maximum)

All Outputs are short circuit protected

0°C to +40°C

0.155Kg



# Linear power supplies



- 100mA @ +5V d.c. Regulated Output
- Very Compact Design
- Simple Screw-Terminal Connection
- Encapsulated Mains Transformer
- Use with Lascar Panel Meters

Standard Unit				Stock Number
Specification	Min.	Typ.	Max.	PSU 30205
Load regulation			1	%
Line regulation			1	%
Ripple			0.5	mV
Operating temperature	0		70	°C
Output Voltage		5		V d.c.
Output Current		100		mA
Input (50-60Hz)	220	240	250	V a.c.

## Switch-mode power supplies (enclosed)



# Switch-mode power supplies (enclosed)

## Specification

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### Input

Input Voltage	<ul style="list-style-type: none"><li>85-264 VAC (127-370 VDC), see derating curve</li></ul>
Input Frequency	<ul style="list-style-type: none"><li>47-63 Hz</li></ul>
Input Current	<ul style="list-style-type: none"><li>VCS50: 1.1 A, VCS70: 1.4 A, VCS100: 2.0 A typical at 90 VAC</li></ul>
Inrush Current	<ul style="list-style-type: none"><li>60 A max at 230 VAC, cold start at 25 °C</li></ul>
Power Factor	<ul style="list-style-type: none"><li>EN61000-3-2 Class A</li></ul>
Earth Leakage Current	<ul style="list-style-type: none"><li>1.0 mA maximum</li></ul>
Input Protection	<ul style="list-style-type: none"><li>50 &amp; 70 W: T3.15 A/250 V 100 W: T4.0A/250 V, fuse fitted in live line</li></ul>
No Load Input Power	<ul style="list-style-type: none"><li>&lt;0.5 W</li></ul>

### Output

Output Voltage	<ul style="list-style-type: none"><li>See model table</li></ul>
Output Adjust	<ul style="list-style-type: none"><li>±10.0% (5 V &amp; 12 V versions are -5% to +10%)</li></ul>
Initial Set Tolerance	<ul style="list-style-type: none"><li>±1.0%</li></ul>
Minimum Load	<ul style="list-style-type: none"><li>None required</li></ul>
Start Up Delay	<ul style="list-style-type: none"><li>1 s maximum</li></ul>
Hold Up Time	<ul style="list-style-type: none"><li>10 ms min at 115 VAC and full load</li></ul>
Line Regulation	<ul style="list-style-type: none"><li>±0.5%, 90 VAC to 264 VAC input</li></ul>
Load Regulation	<ul style="list-style-type: none"><li>5 V &amp; 12 V versions: ±1%, Others: ±0.5% 0% to 100% load</li></ul>
Transient Response	<ul style="list-style-type: none"><li>Less than 4% deviation with a 50% to 75% load change at 1 A/μs. Output returns to within 1% in less than 500 μs</li></ul>
Ripple & Noise	<ul style="list-style-type: none"><li>1% maximum pk-pk, 20 MHz bandwidth</li></ul>
Overvoltage Protection	<ul style="list-style-type: none"><li>120-140% of nominal output, auto recovery</li></ul>
Overload Protection	<ul style="list-style-type: none"><li>110-150% of nominal, trip and restart</li></ul>
Short Circuit Protection	<ul style="list-style-type: none"><li>Continuous trip and restart</li></ul>
Temperature Coefficient	<ul style="list-style-type: none"><li>±0.03%/°C after 20 min warm up</li></ul>

### General

Efficiency	<ul style="list-style-type: none"><li>See tables</li></ul>
Isolation	<ul style="list-style-type: none"><li>3000 VAC Input to Output 1500 VAC Input to Ground 500 VAC Output to Ground</li></ul>
Switching Frequency	<ul style="list-style-type: none"><li>65 kHz typical</li></ul>
MTBF	<ul style="list-style-type: none"><li>&gt;500 kHrs to MIL-STD-217F at 25 °C, GB</li></ul>

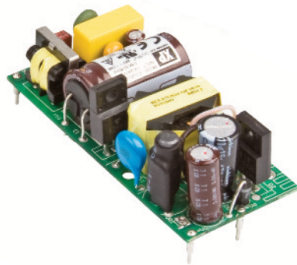
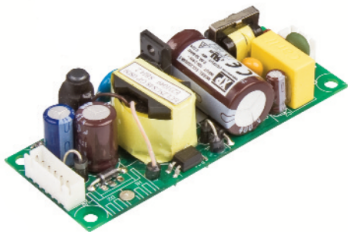
### Environmental

Operating Temperature	<ul style="list-style-type: none"><li>-25 °C to +70 °C, see derating curve</li></ul>
Cooling	<ul style="list-style-type: none"><li>Convection cooled</li></ul>
Operating Humidity	<ul style="list-style-type: none"><li>0-95% R.H, non-condensing</li></ul>
Storage Temperature	<ul style="list-style-type: none"><li>-40 °C to +80 °C</li></ul>
Operating Altitude	<ul style="list-style-type: none"><li>3000 m</li></ul>
Shock	<ul style="list-style-type: none"><li>±3 x 30 g shocks in each plane, 30 g: 11 ms (±0.5 ms), half sine, compliant to EN60068-2-27 &amp; EN60068-2-47</li></ul>
Vibration	<ul style="list-style-type: none"><li>10-500 Hz at 2 g sweep and endurance at resonance in all 3 planes. Conforms to EN60068-2-6</li></ul>

### EMC & Safety

Emissions	<ul style="list-style-type: none"><li>EN55022 Class B conducted &amp; radiated</li></ul>
Harmonic Currents	<ul style="list-style-type: none"><li>EN61000-3-2 class A</li></ul>
Voltage Flicker	<ul style="list-style-type: none"><li>EN61000-3-3</li></ul>
ESD Immunity	<ul style="list-style-type: none"><li>EN61000-4-2, level 3 Perf Criteria A</li></ul>
Radiated Immunity	<ul style="list-style-type: none"><li>EN61000-4-3, level 3 Perf Criteria A</li></ul>
EFT/Burst	<ul style="list-style-type: none"><li>EN61000-4-4, level 3 Perf Criteria A (note 3)</li></ul>
Surge	<ul style="list-style-type: none"><li>EN61000-4-5, installation Class 3, Perf Criteria A</li></ul>
Conducted Immunity	<ul style="list-style-type: none"><li>EN61000-4-6, level 3 Perf Criteria A</li></ul>
Dips & Interruptions	<ul style="list-style-type: none"><li>EN61000-4-11, 30% 10 ms, 60% 100 ms, 100% 5000 ms, Perf Criteria A, B, B</li></ul>
Safety Approvals	<ul style="list-style-type: none"><li>IEC60950-1, CSA C22.2 No.60950-1-03, UL60950-1, TUV EN60950-1</li></ul>

## Switch-mode power supplies (open frame)



# Switch-mode power supplies (PCB mount)

UL 60950-1

## Features

- ◆ AC/DC power modules for PCB mounting
- ◆ Highest power density
- ◆ Fully encapsulated plastic case
- ◆ Universal input 90–264 VAC, 47–440 Hz
- ◆ High efficiency
- ◆ EMI meets EN 55022, class B and FCC, level B
- ◆ Low ripple and noise
- ◆ Short circuit and overload protection
- ◆ 3-year product warranty



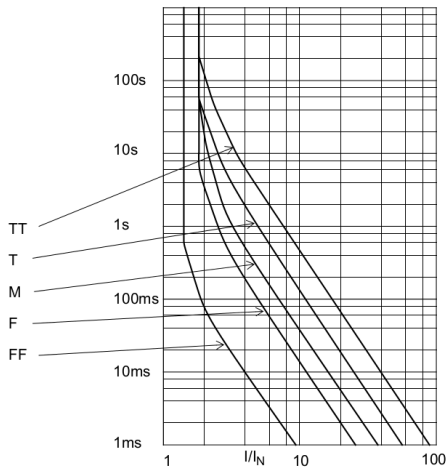
The TMLM Series switching power supplies, offer highest power density in a fully encapsulated module which can be soldered directly on to PCBs. This feature makes these modules an ideal solution for all space critical applications in commercial and industrial electronic equipment. International safety approvals qualify the product for worldwide markets. SMD-technology and high efficiency guarantees a high reliability of these Power Supplies.

## Models

Order Code	Output Power max.	Output 1	Output 2	Efficiency
TMLM 04103	4.0 Watt	3.3 VDC / 1200 mA		68 %
TMLM 04105	4.0 Watt	5.0 VDC / 800 mA		72 %
TMLM 04109	4.0 Watt	9.0 VDC / 444 mA		75 %
TMLM 04112	4.0 Watt	12 VDC / 333 mA		76 %
TMLM 04115	4.0 Watt	15 VDC / 267 mA		76 %
TMLM 04124	4.0 Watt	24 VDC / 167 mA		77 %
TMLM 04253	3.5 Watt	+5.0 VDC / 600 mA	+3.3 VDC / 150 mA	72 %
TMLM 04225	3.6 Watt	+12 VDC / 250 mA	+5.0 VDC / 120 mA	75 %

# Fuses

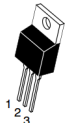
## Typical time-current curves



## 1.0 A Positive Voltage Regulators

These voltage regulators are monolithic integrated circuits designed as fixed-voltage regulators for a wide variety of applications including local, on-card regulation. These regulators employ internal current limiting, thermal shutdown, and safe-area compensation. With adequate heatsinking they can deliver output currents in excess of 1.0 A. Although designed primarily as a fixed voltage regulator, these devices can be used with external components to obtain adjustable voltages and currents.

- Output Current in Excess of 1.0 A
- No External Components Required
- Internal Thermal Overload Protection
- Internal Short Circuit Current Limiting
- Output Transistor Safe-Area Compensation
- Output Voltage Offered in 1.5%, 2% and 4% Tolerance
- Available in Surface Mount D<sup>2</sup>PAK-3, DPAK-3 and Standard 3-Lead Transistor Packages



**TO-220-3  
T SUFFIX  
CASE 221AB**

Heatsink surface  
connected to Pin 2.

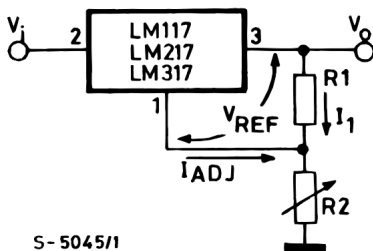


Pin 1. Input  
2. Ground  
3. Output

**D<sup>2</sup>PAK-3  
D2T SUFFIX  
CASE 936**

Heatsink surface (shown as terminal 4 in  
case outline drawing) is connected to Pin 2.

## LM317 adjustable regulator



- ▶  $V_O = V_{REF}(1 + R2/R1) + I_{ADJ}R2$
- ▶  $I_{ADJ} \approx 100 \mu A$

LM317 Datasheet



## LP38691

### LP38693 500mA Low Dropout CMOS Linear Regulators

#### *Stable with Ceramic Output Capacitors*

Check for Samples: [LP38691](#), [LP38693](#)

#### FEATURES

- All WSON Options are Available as AEC-Q100 Grade 1
- 2.0% Output Accuracy (25°C)
- Low Dropout Voltage: 250 mV @ 500mA (typ, 5V out)
- Wide Input Voltage Range (2.7V to 10V)
- Precision (Trimmed) Bandgap Reference
- Ensured Specs for -40°C to +125°C
- 1µA Off-State Quiescent Current
- Thermal Overload Protection
- Foldback Current Limiting
- PFM, SOT-223 and 6-Lead WSON Packages
- Enable Pin (LP38693)

#### APPLICATIONS

- Hard Disk Drives
- Notebook Computers
- Battery Powered Devices
- Portable Instrumentation

#### DESCRIPTION

The LP38691/3 low dropout CMOS linear regulators provide tight output tolerance (2.0% typical), extremely low dropout voltage (250 mV @ 500mA load current,  $V_{OUT} = 5V$ ), and excellent AC performance utilizing ultra low ESR ceramic output capacitors.

The low thermal resistance of the WSON, SOT-223 and PFM packages allow the full operating current to be used even in high ambient temperature environments.

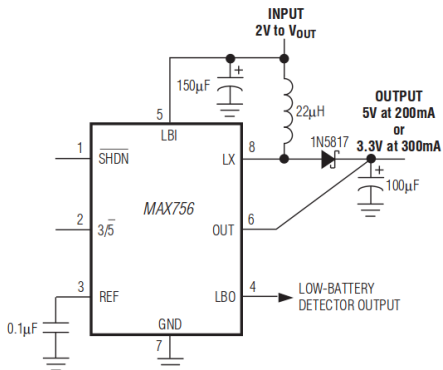
The use of a PMOS power transistor means that no DC base drive current is required to bias it allowing ground pin current to remain below 100 µA regardless of load current, input voltage, or operating temperature.

**Dropout Voltage:** 250 mV (typ) @ 500mA (typ. 5V out).

**Ground Pin Current:** 55 µA (typ) at full load.

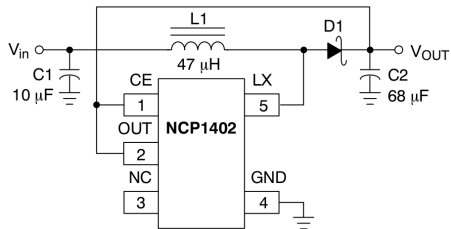
**Precision Output Voltage:** 2.0% (25°C) accuracy.

# MAX756 Step-Up DC-DC converter



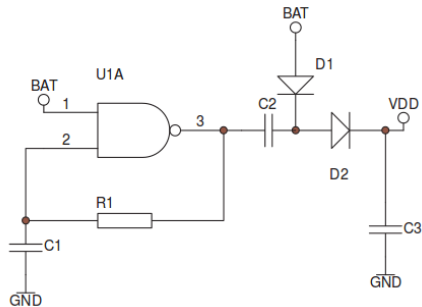
MAX756 Datasheet

# NCP1402 Step-Up DC-DC converter



NCP1402 Datasheet

# Voltage Doubler



Single cell power supply

# Batteries

- ▶ Electro-chemical reaction
- ▶ Anode (negative) and cathode (positive) terminals...
- ▶ ...separated by an electrolyte
- ▶ Voltage (time, temperature, history ...)
- ▶ Primary cells (non-rechargeable)
- ▶ Secondary cells (rechargeable)

Batteries and Accumulators Directive (91/157/EEC)

# Design considerations

- ▶ Use standard types
- ▶ Voltage and capacity ratings
  - ▶ Nominal open circuit voltage
  - ▶ Real voltage falls as deployed
  - ▶ Capacity  $C$  (Ah, mAh)
- ▶ Discharge
  - ▶ Discharge rate: fraction of  $C$
  - ▶ 1000 mAh battery discharged with constant 20 mA will last 50 hours
  - ▶ Discharge modes:
    - ▶ Constant  $R$
    - ▶ Constant  $I$
    - ▶ Constant  $P = VI$

# Series and parallel connections

- ▶ Series connection
  - ▶ Boost voltage
  - ▶ Less reliability
- ▶ Parallel connection
  - ▶ Increase capacity
  - ▶ More reliability (with series diodes)

## Mechanical considerations

- ▶ Contact material: nickel-plated steel, stainless
- ▶ Springy contacts
- ▶ Multiple-point contacts
- ▶ Venting of gases



# Some typical batteries

## Alkaline manganese dioxide

Designation			Voltage	Dimensions (mm)		
IEC	ANSI	Size		Dia or (LxW)	Height	mAh*
LR03	24A	AAA	1.5	10.5	44.5	1150
LR6	15A	AA	1.5	14.5	50.5	2850
LR14	14A	C	1.5	26.2	50	7800
LR20	13A	D	1.5	34.2	61.5	15000
6LR61	1604A	PP3	9	26.5 x 17.5	48.5	580

Source: Duracell

# Some typical batteries

## Lithium manganese dioxide - coin cell

Designation		Size	Voltage	Dimensions (mm)		
IEC	ANSI			Dia or (LxW)	Height	mAh
CR2016	5000LC		3	20	1.6	90
CR2025	5003LC		3	20	2.5	165
CR2032	5004LC		3	20	3.2	230
CR2430	5011LC		3	24.5	3	280
CR2450	5029LC		3	24.5	5	560



CR 2016



CR 2025



CR 2032



CR 2450

## Some typical batteries

### Silver oxide button cells

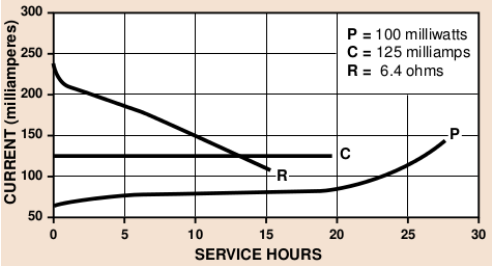
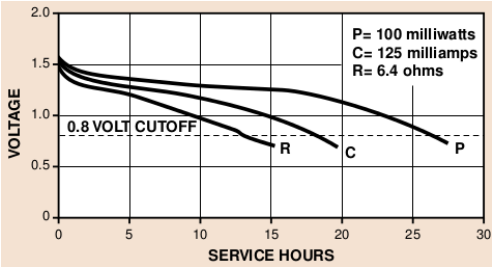
Designation		Size	Voltage	Dimensions (mm)		
IEC	ANSI			Dia or (LxW)	Height	mAh
SR41	1135S0		1.55	7.87	3.6	42
SR43	1133S0		1.55	11.56	4.19	120
SR44	1131S0		1.55	11.56	5.58	165
SR48	1137S0		1.55	7.87	5.38	70
SR54	1138S0		1.55	11.56	3.05	70
SR55	1160S0		1.55	11.56	2.21	40

## Energy density

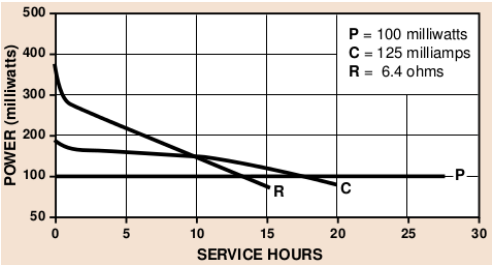
Size	V	mAh	weight (g)	volume (ml)	Wh/kg	Wh/l
AAA	1.5	1150	11	4	126	345
AA	1.5	2850	24	8	143	428
C	1.5	7800	65	27	144	347
D	1.5	15000	138	56	130	322
PP3	9	580	46	23	91	182

Source: Duracell

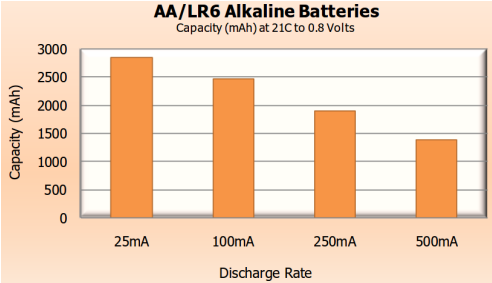
# Discharge profiles



# Discharge profiles /2



Source: Duracell



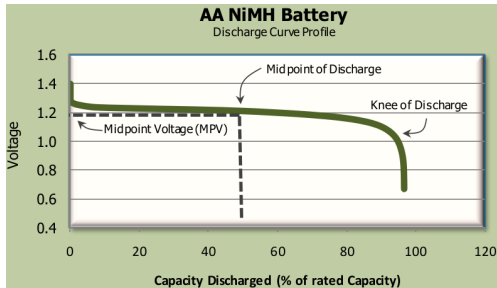
Source: Energizer

## Secondary cells

- ▶ Lead-acid
  - ▶ Capacity 1–100 Ah
  - ▶ Nominal 2 V
  - ▶ Open circuit 2.15 V
  - ▶ End-of-cycle 1.75 V
  - ▶ Standard case sizes in 6 V or 12 V
- ▶ Nickel-cadmium
  - ▶ Capacity 150–7000 mAh
  - ▶ Nominal 1.2 V
  - ▶ Open circuit 1.35–1.4 V
  - ▶ End-of-cycle 1 V
  - ▶ Case sizes same as standard cells
  - ▶ Memory effect: better to fully discharge them
- ▶ Nickel-Metal-Hydride (NiMH)
- ▶ Lithium Ion

# NiMH

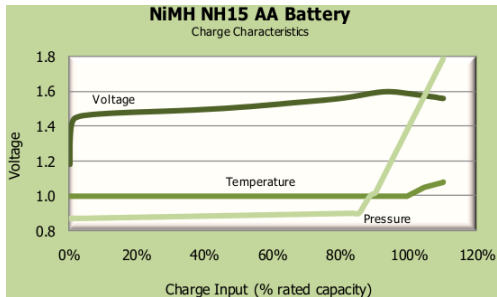
- ▶ Capacity ( $\times 1.4$  NiCd). 1800 mAh (AA)
- ▶ Nominal 1.2 V, open circuit 1.35–1.4 V, end-of-cycle 1 V
- ▶ Case sizes same as standard cells
- ▶ No memory effects
- ▶ Low internal resistance
- ▶ PP3 (9V) batteries: 8.4 V (or 9.6 V), 200 mAh





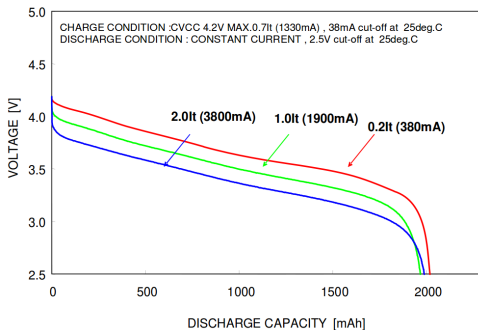
# Charging NiMH

- ▶ Continuous charging up to 0.1 C is permissible. 16 hours.
- ▶ Timer-controlled at 0.3 C.
- ▶ Smart charging
  - ▶ Delta voltage. Drop of voltage during charge (15 mV)
  - ▶ Monitoring temperature
  - ▶ C/2 (2 to 3 hours) optimum
  - ▶ C only if really necessary
- ▶ Trickle charging ( $< C/40$ ) to top off or maintain
- ▶ Self discharge: 50% in 6 months



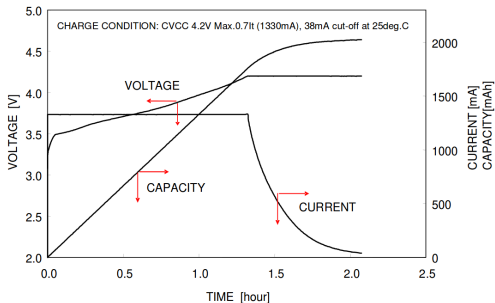
# Lithium ion

- ▶ Nominal 3.6 V or 3.7 V, open circuit 4.2 V or 4.3 V, end-of-cycle 2.5 V
- ▶ A variety of case sizes
- ▶ No memory effects
- ▶ High internal resistance



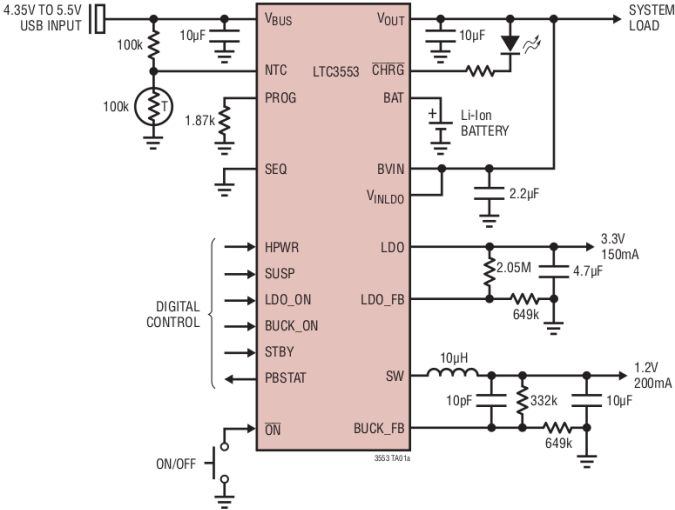
# Charging Lithium ion

- ▶ Panasonic NCR18500 (2000 mAh)
- ▶ Constant current charging at 0.7 C until  $v = 4.2$  V
- ▶ Constant voltage charging at 4.2 V until  $i < 38$  mA
- ▶ Use 4.3 V for other cells. Current threshold as in datasheet!



# Lithium ion charge controller

## LTC3553



# Lithium Ion Standard Cells

18650



# Lithium Ion Standard Cells

## Panasonic Lithium Ion NCR18650

### Features & Benefits

- High energy density
- Long stable power and long run time
- Ideal for notebook PCs, boosters, portable devices, etc.

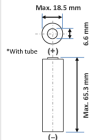
\* At temperatures below 10°C, charge at a 0.35C rate.

### Specifications

Rated capacity <sup>(1)</sup>	Min. 2700mAh
Capacity <sup>(2)</sup>	Min. 2750mAh Typ. 2900mAh
Nominal voltage	3.6V
Charging	CC-CV, Std. 1925mA, 4.20V, 3.0 hrs
Weight (max.)	46.5 g
Temperature	Charge*: 0 to +45°C Discharge: -20 to +60°C Storage: -20 to +50°C
Energy density <sup>(3)</sup>	Volumetric: 577 Wh/l Gravimetric: 214 Wh/kg

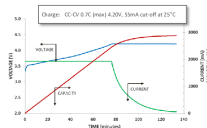
<sup>(1)</sup> At 20°C <sup>(2)</sup> At 25°C <sup>(3)</sup> Energy density based on bare cell dimensions

### Dimensions

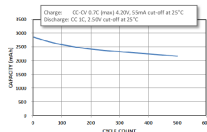


For Reference Only

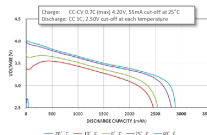
### Charge Characteristics



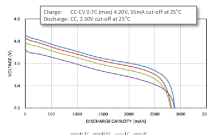
### Cycle Life Characteristics



### Discharge Characteristics (by temperature)



### Discharge Characteristics (by rate of discharge)



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