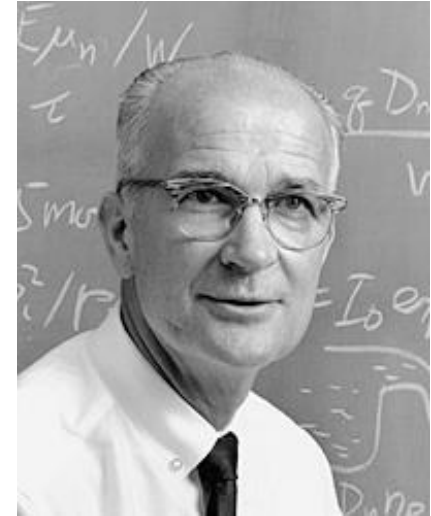
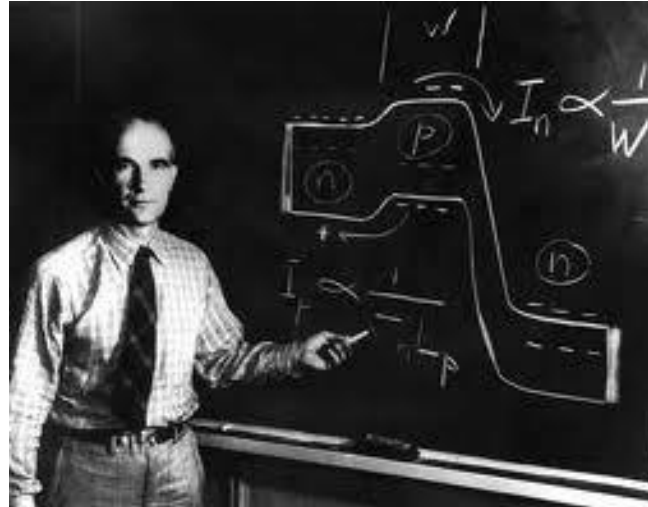


Electronic systems

Samara, 2025

Some historical information



1947

Fathers of modern transistors:

John Bardeen 1908-1991

William Shockley 1910-1989

Walter Brattain 1902-1987



Robert Noyce & John Kilby

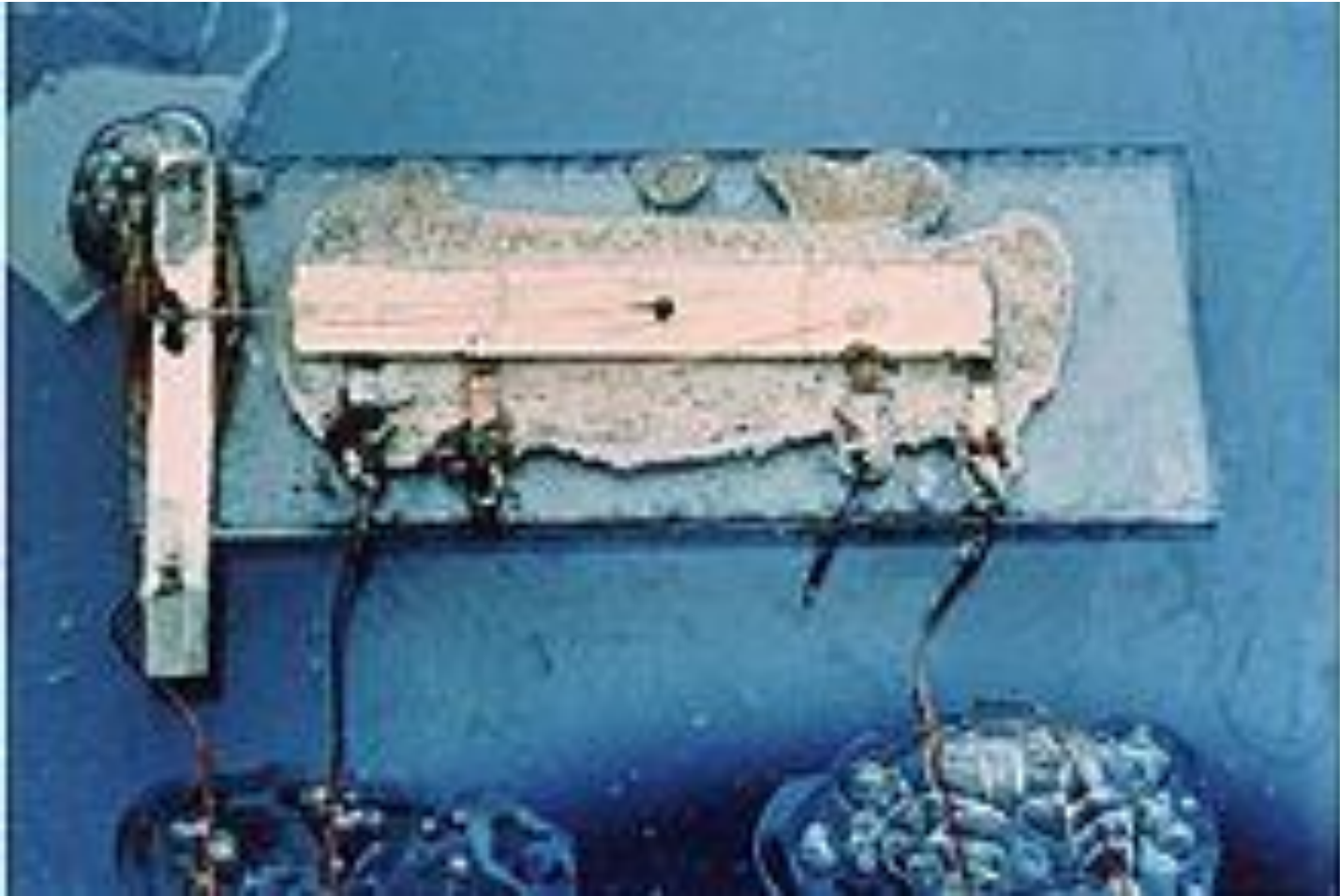


1927-1990



1923-2005

Kilby's first IC



THE IMPROVED μ A702 WIDEBAND DC AMPLIFIER

by R. J. Widlar

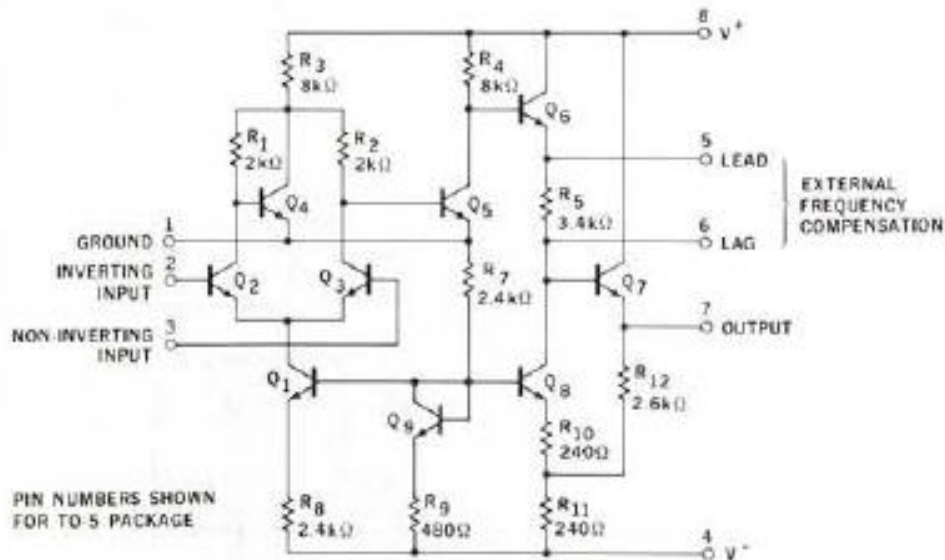
I INTRODUCTION

This paper describes an improved version of the μ A702 and also points out how to protect the amplifier from certain improper operating modes which have been responsible for failures in the past. The original amplifier is described elsewhere.¹

The μ A702A features simplified frequency compensation. It also gives higher gain-bandwidth products—up to 30 MHz. In addition, it has greater thermal

A second change is a larger output transistor which can handle more current without excessive heating; the need for this was not recognized in the original design since the amplifier was intended for low-level applications. The output circuitry has been beefed up to the point where the output may be shorted to the negative supply for a few seconds without damage (although this is neither recommended nor guaranteed).

Other changes were more subtle: relocation of components to insure improved matching; lower offsets



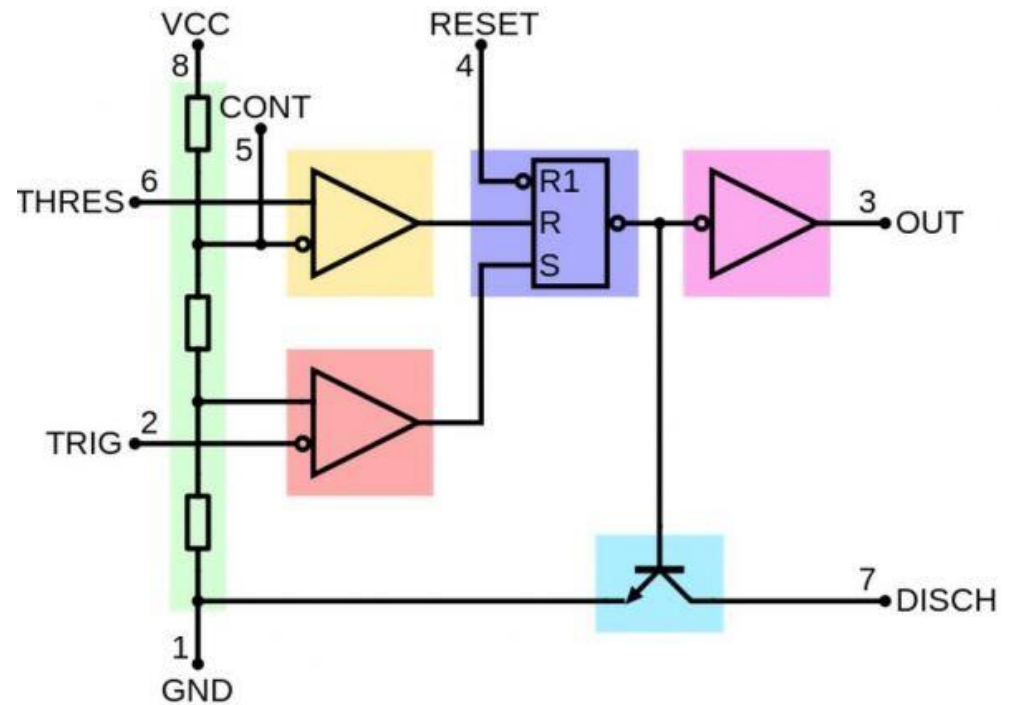
Robert Widlar

1937-1991



Hans Kamenzind

1934-2012



Electronic systems in nano/microsatellites typically perform:

- Power control
- Collection, processing and storing data
- Communication
- Auxiliary functions, providing specific needs

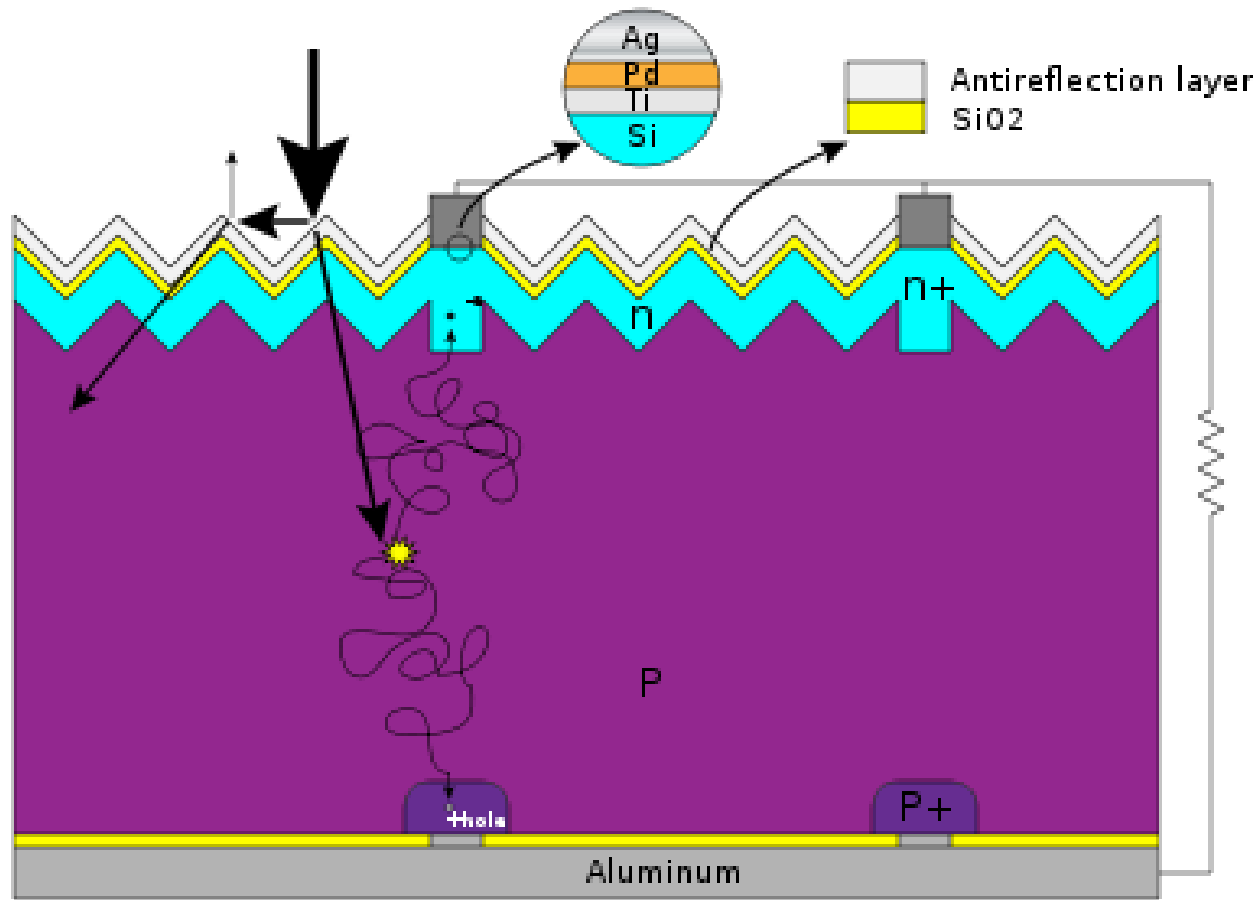
POWER SYSTEMS



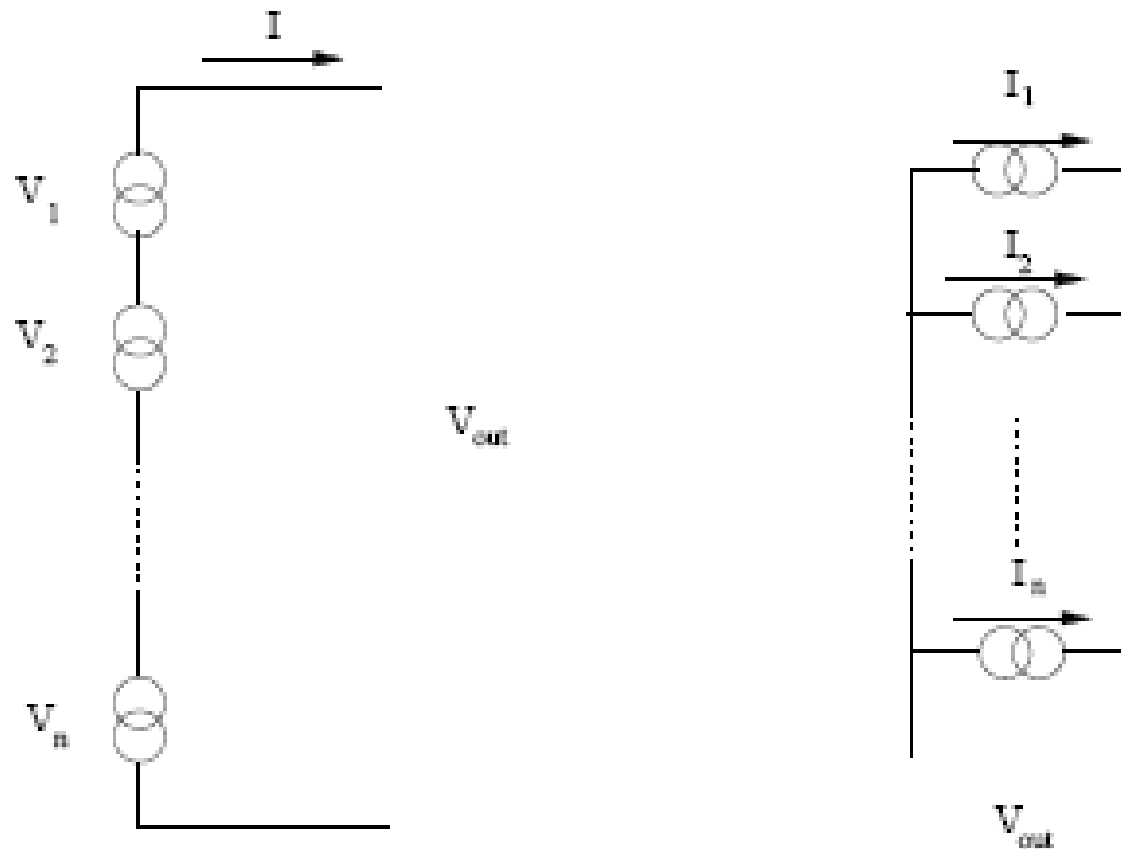
Primary power sources

- Solar batteries
- Chemical sources:
 - Batteries;
 - Accumulators;
 - Fuel cells
- Thermo elements

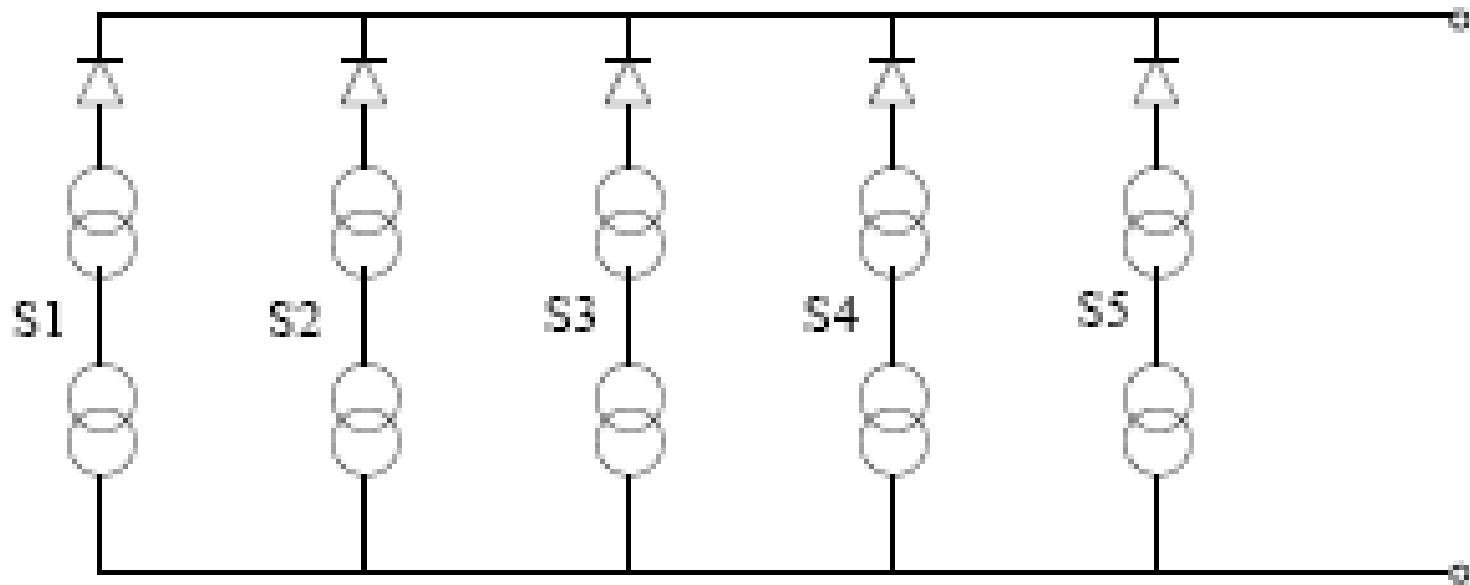
Solar battery structure



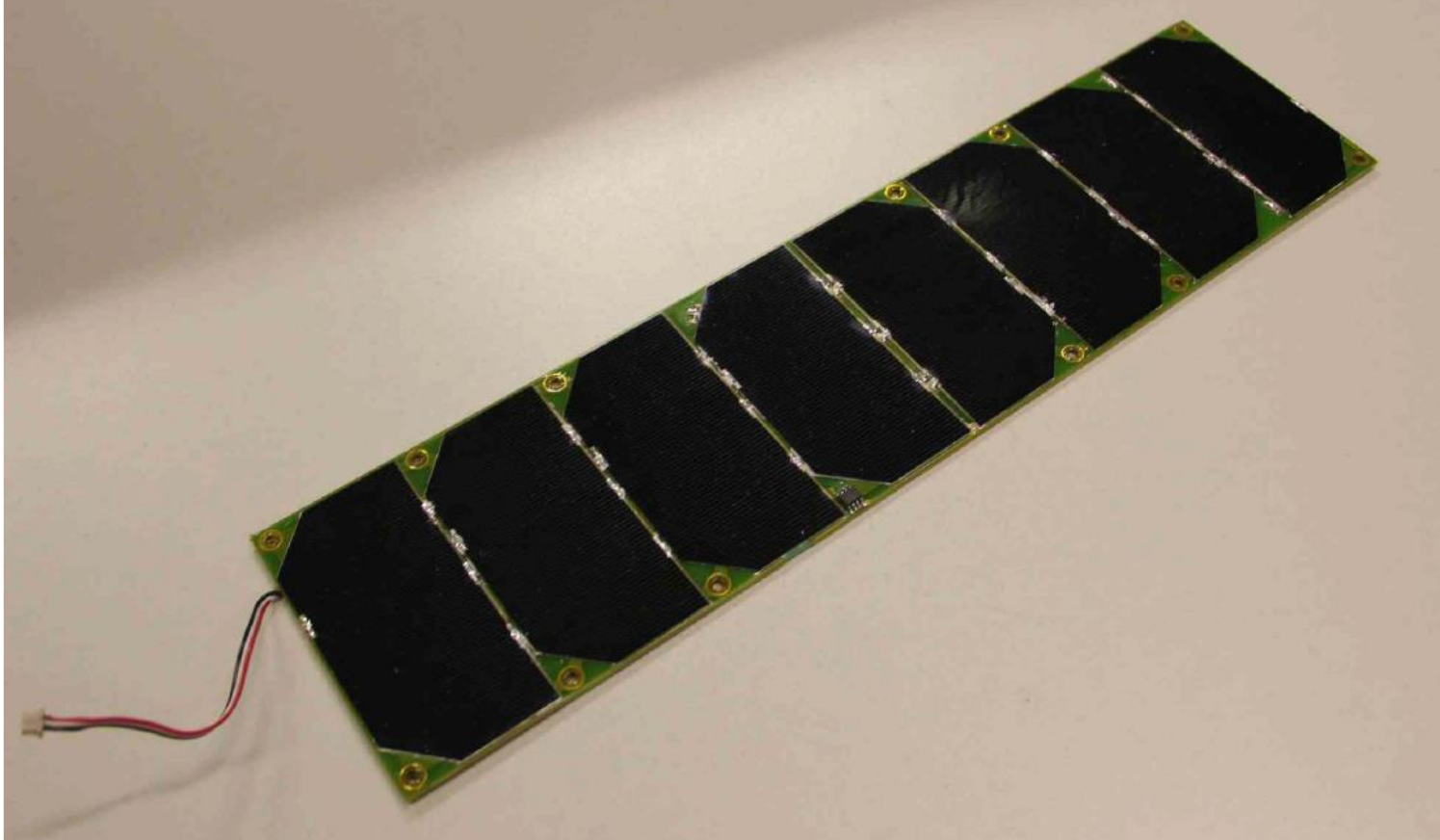
Connection of the batteries



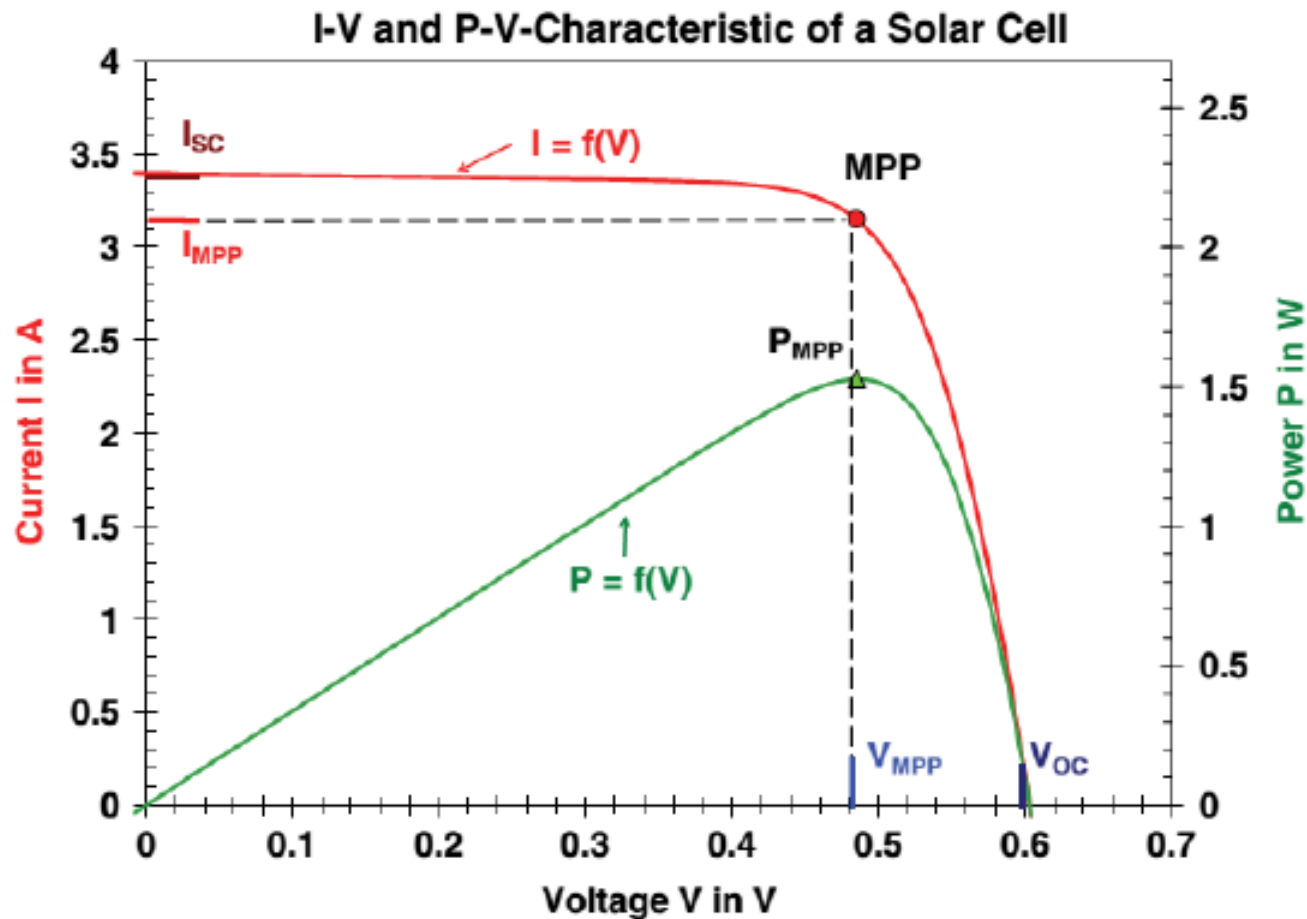
Cubesat circuit



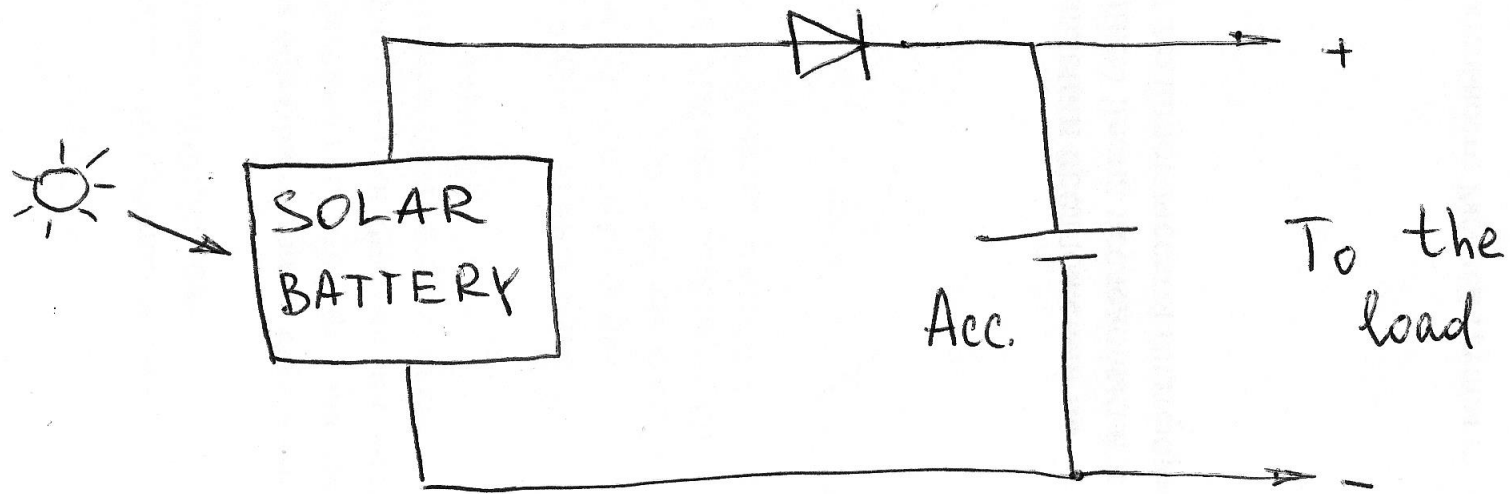
Aalto-1 solar panel



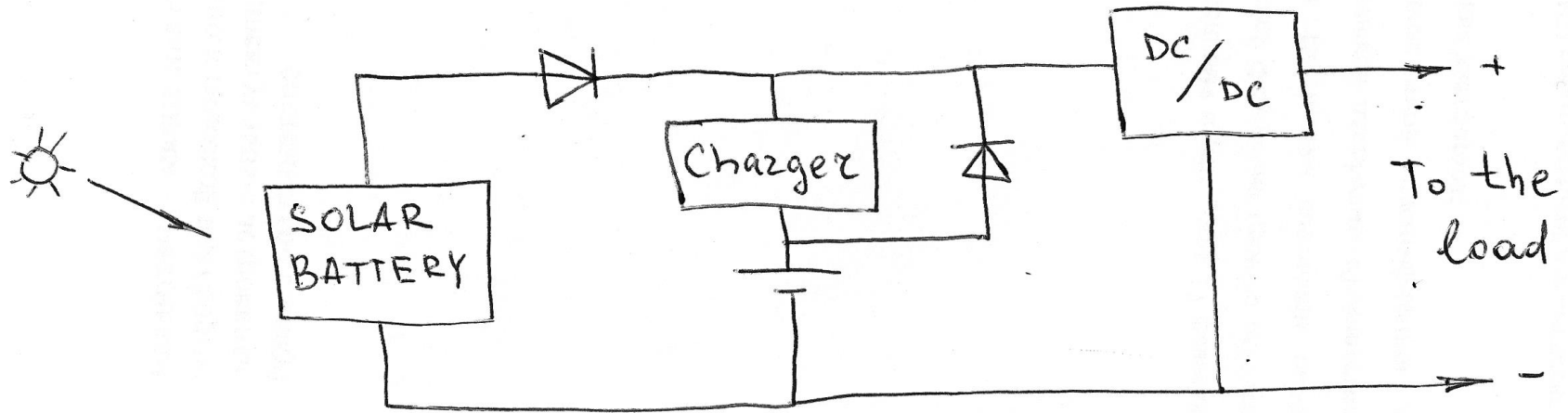
Current-voltage curve of solar battery



Power circuit without voltage control



Circuit with voltage regulation

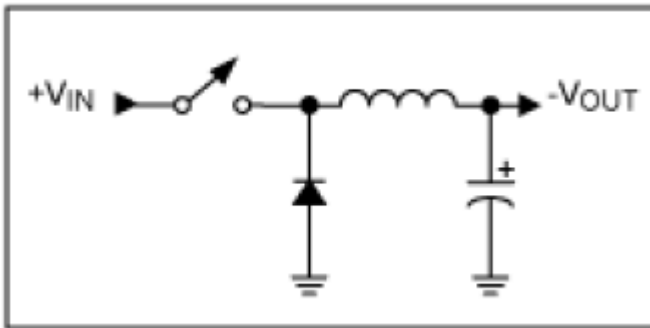


CONVERTERS

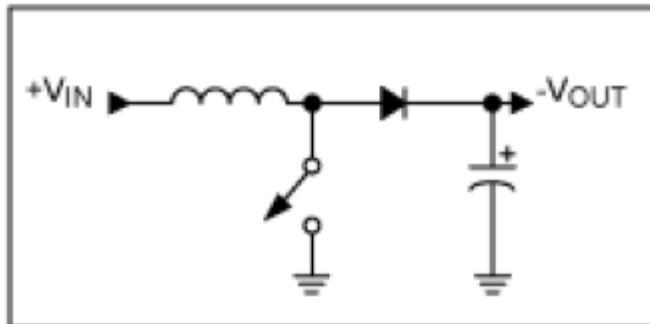
How do you choose?

	Linear Regulator	Switching Regulator
Design Flexibility	Buck	Buck, Boost, Buck-Boost
Efficiency	Normally low to medium-high for low difference between V_{IN} - V_{OUT}	High
Complexity	Low	Medium to high
Size	Small to medium, larger at high power	Smaller at similar higher power (depending on the switching frequency)
Total Cost	Low	Medium to high – external components
Ripple/Noise/EMI	Low	Medium to high
V_{IN} Range	Narrow (depending on power dissipation)	Wide

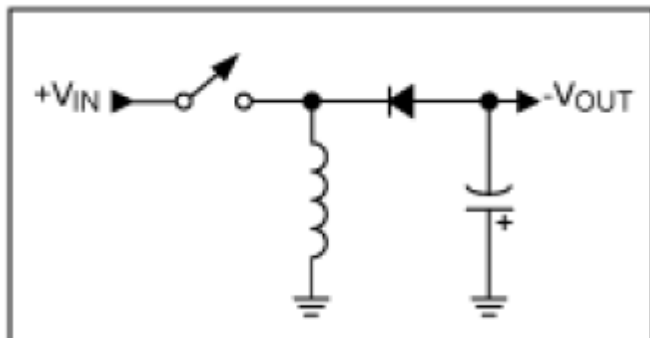
Simple DC/DC Converters



Chopper (buck converter)

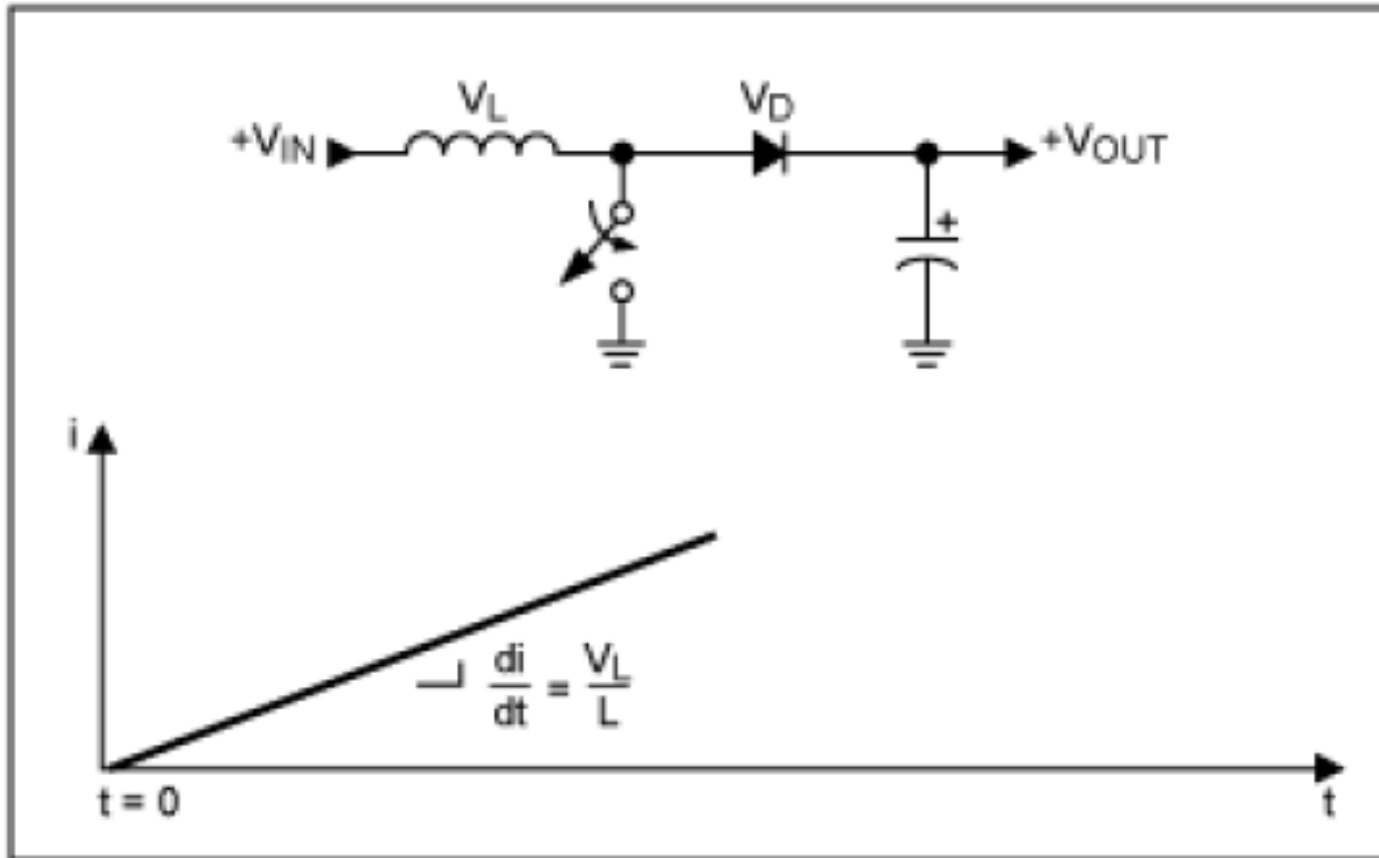


Booster

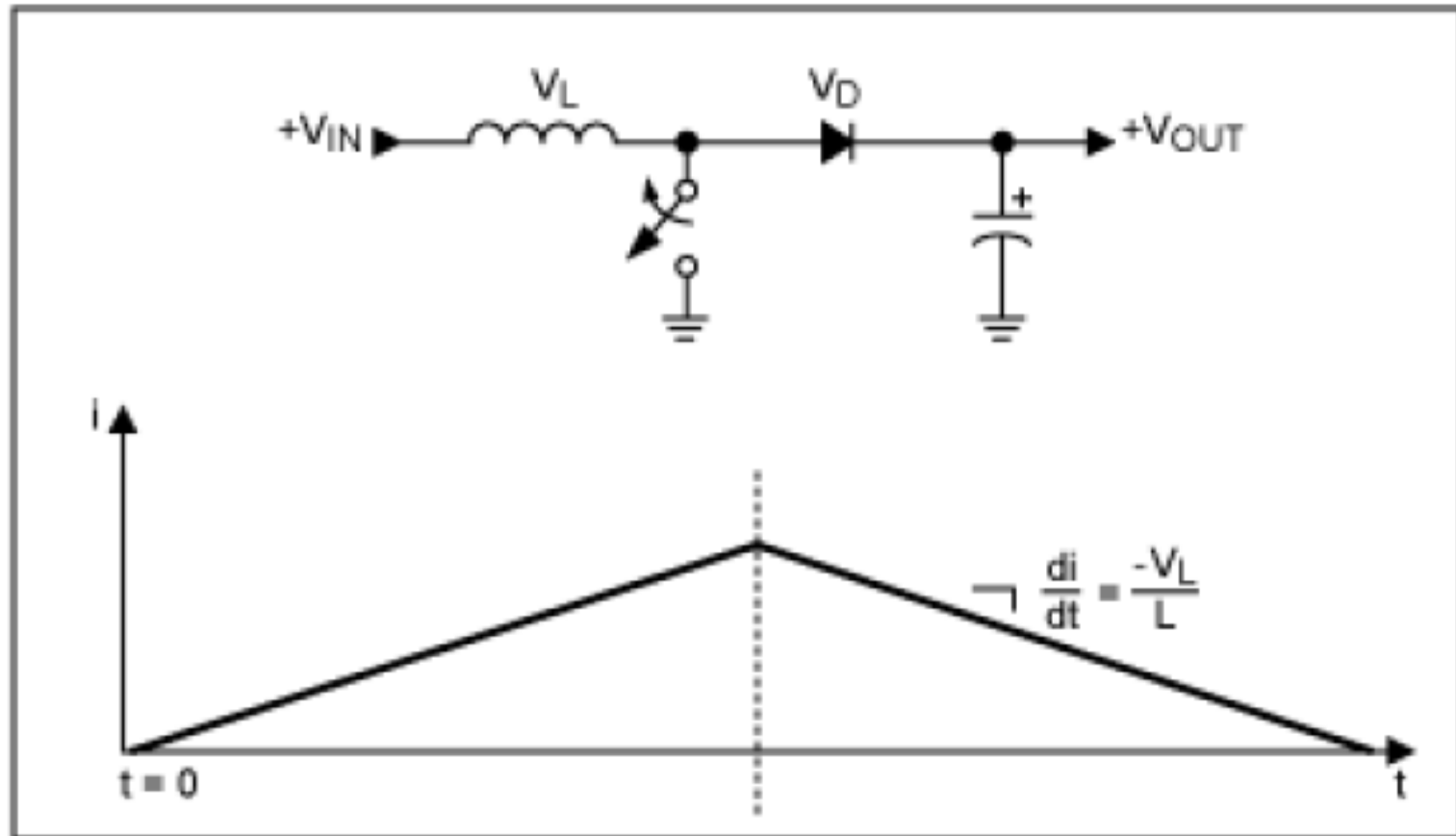


Inverter

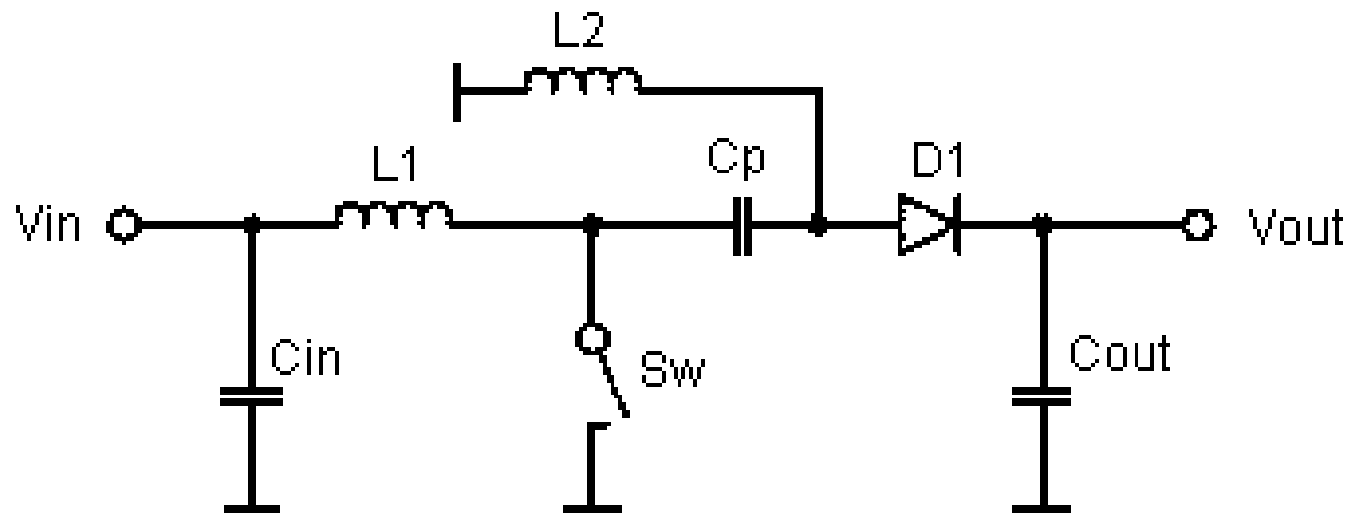
Charge phase

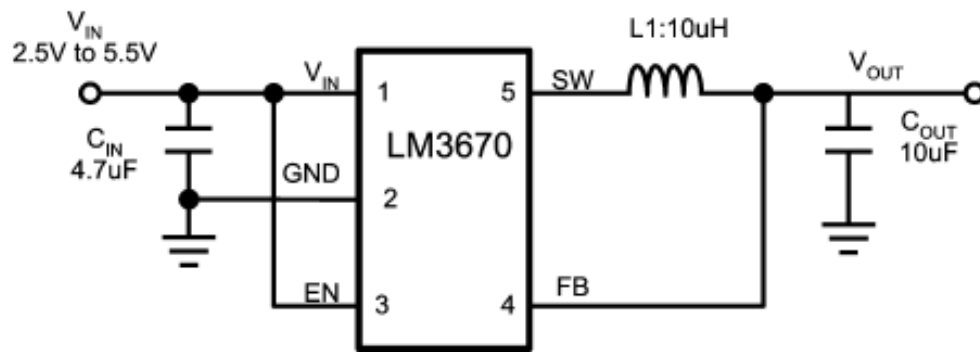
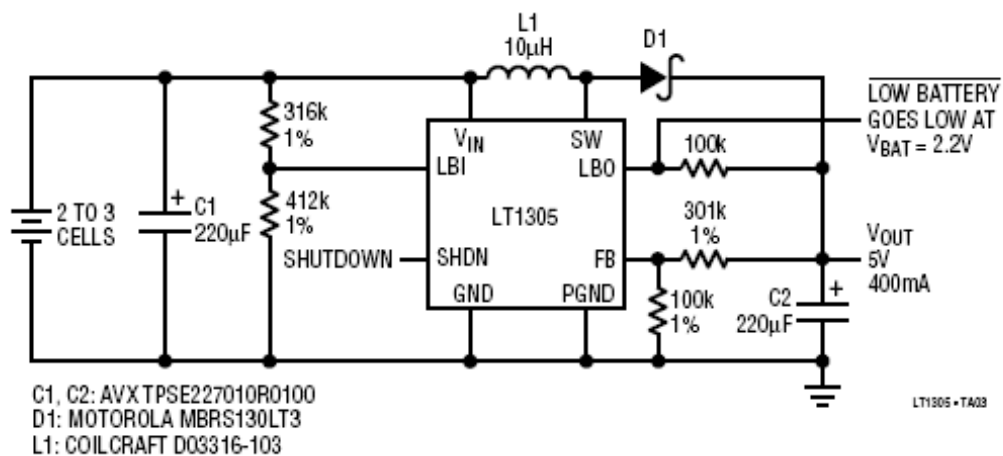


Discharge phase

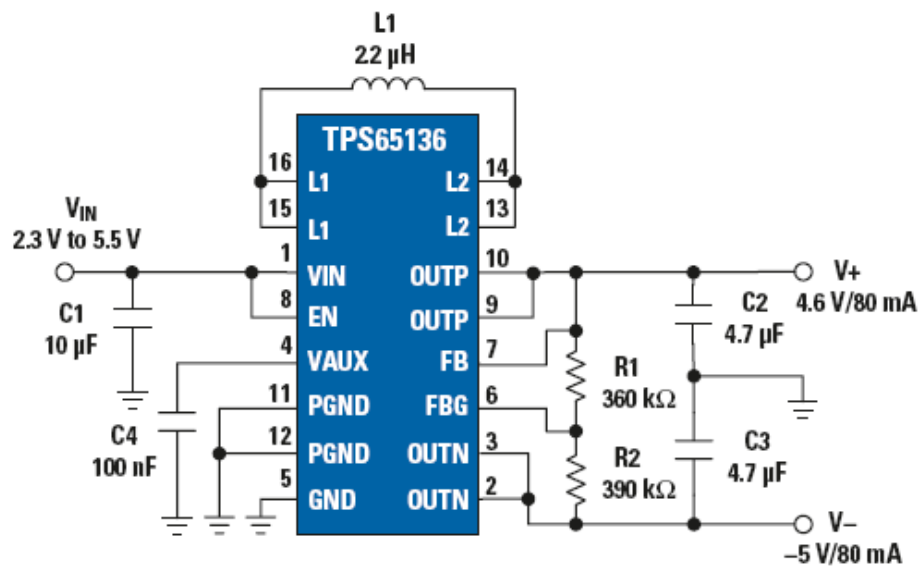


SEPIC Converter



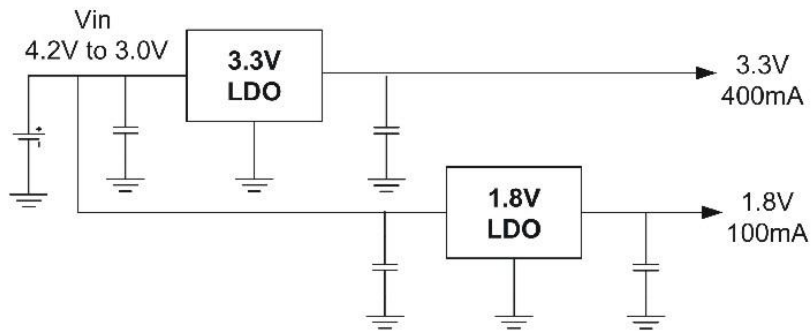


20075801

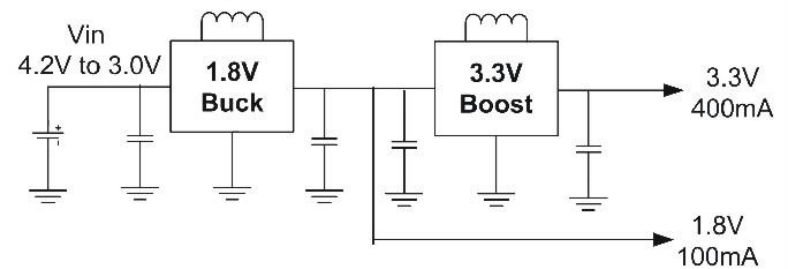


Combined Solutions

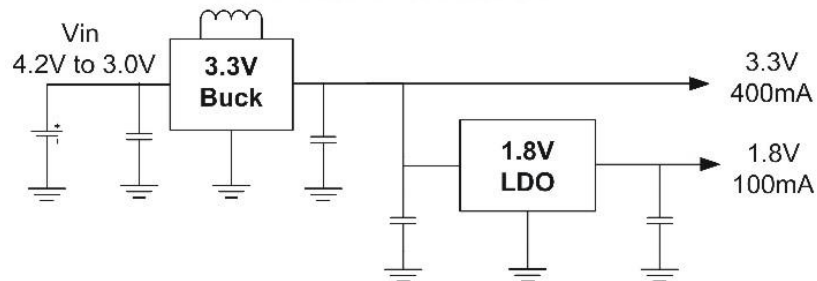
LDO/LDO Solution



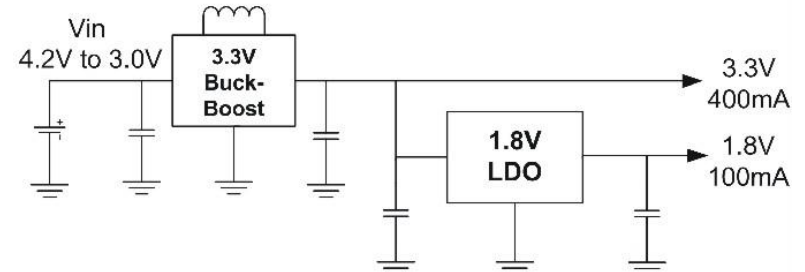
Buck/Boost Solution



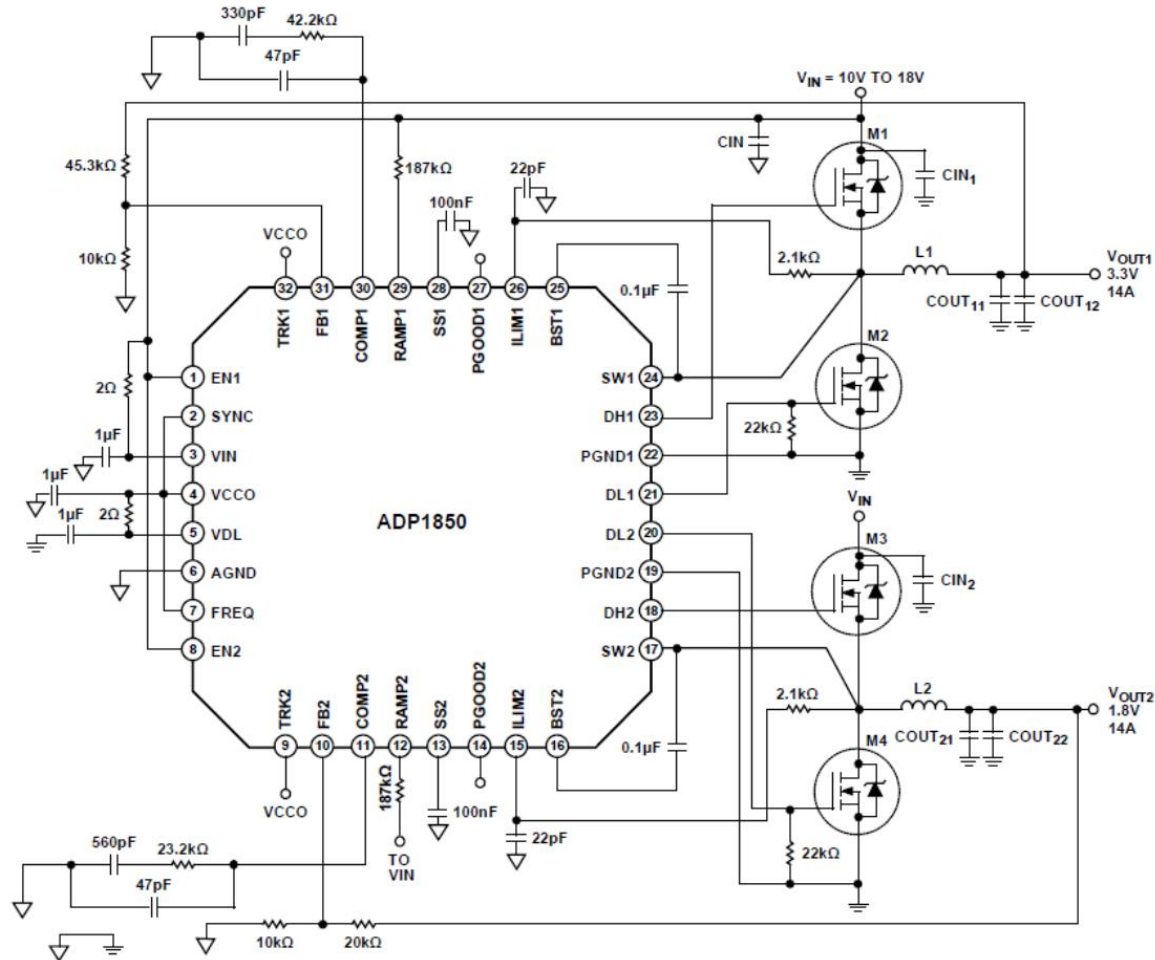
Buck/LDO Solution



Buck-Boost/LDO Solution



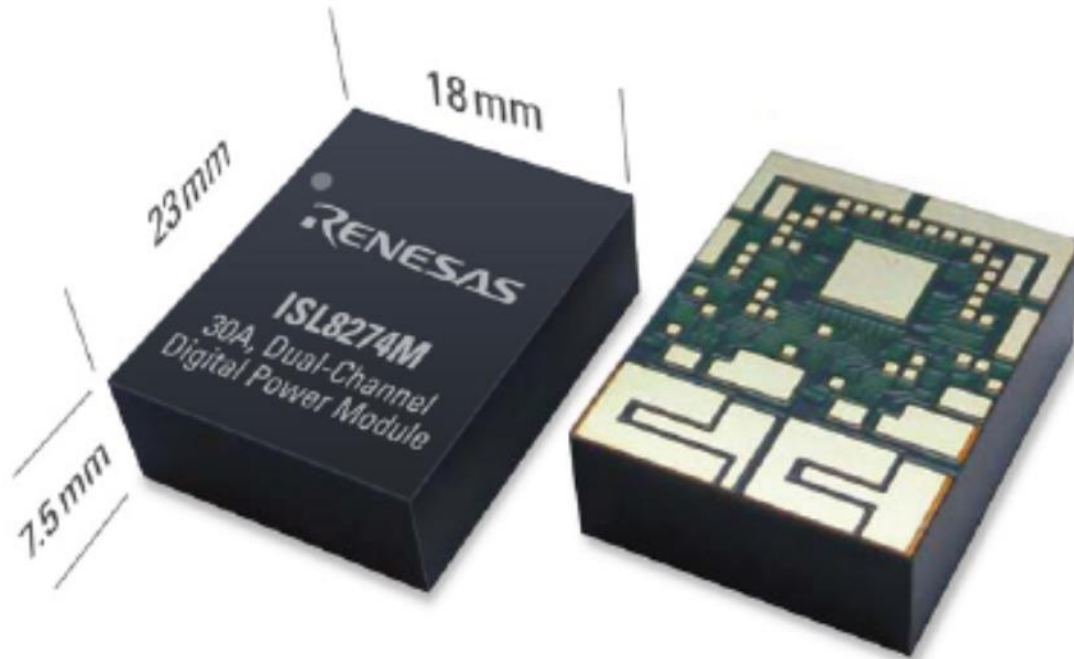
Low voltage & high power



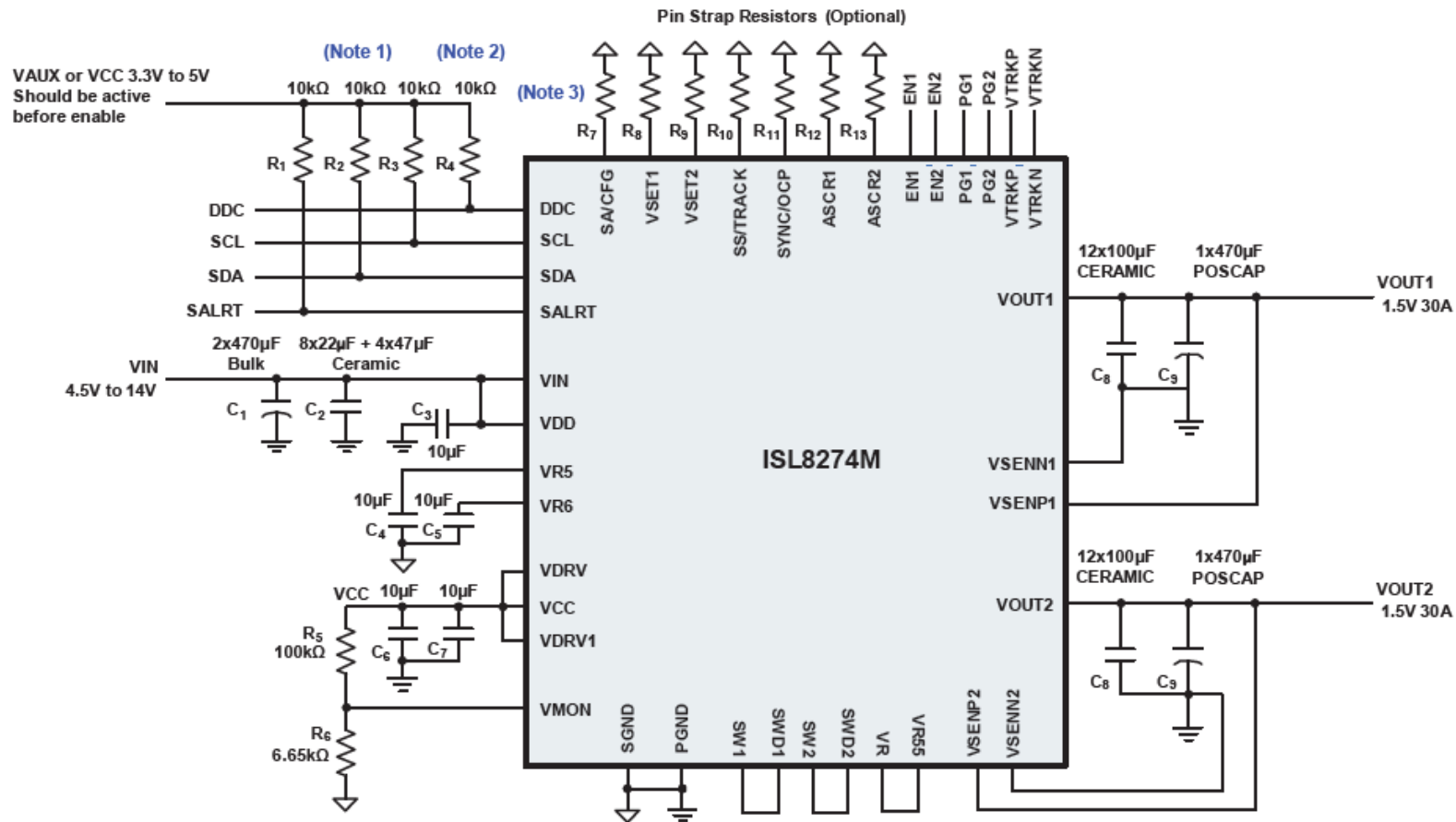
$f_{sw} = 600\text{kHz}$
 CIN: 150 μF /20V, OS-CON, 20SEP150M, SANYO
 L1, L2: 1.2 μH , WURTH ELEKTRONIK, 744325120
 M1, M3: BSC080N03LS
 M2, M4: BSC030N03LS

CIN₁, CIN₂: 10 μF /X7R/25V/1210 $\times$ 2, GRM32DR71E106KA12, MURATA
 COUT₁₁, COUT₂₁: 330 μF /6.3V/POSCAP $\times$ 2, 6TPF330M9L, SANYO
 COUT₁₂, COUT₂₂: 22 μF /X5R/0805/6.3V $\times$ 3, GRM21BR60J226ME39, MURATA

Modules



Modules



Survey of MPPT capable integrated circuits (AVNET, 2011; Linear, 2012; STM, 2012)

Supplier	Part Number	Panel Voltage	Output Voltage	Max Charge Current	Integrated FETs	MPPT Type	Topology	Package	Comments
Texas Instruments	BQ24650	5-28 V	2.6 - 26 V	10 A	No	Temperature compensated fixed point voltage	Buck	QFN-16	
Texas Instruments	BQ24210	3.5 – 7 V		800 mA	Yes	None		WSO-10	
STMicroelectronics	SPV1020	6.5 – 40 V	$V_{in} - 40$ V	9 A	Yes	Perturb & Observe	Boost	PowerSSO-36	
STMicroelectronics	SPV1040	0.3 – 5.5 V	2 – 5.2 V	1 A	Yes	Perturb & Observe	Boost	TSSOP8	
National Solar Magic	SM72442, SM72295	Programmed	9-100 V	Programmed	No	Proprietary algorithm	Buck, Boost	TSSOP-28 SOIC-28	Programmable chipset, Both SM72242 and SM72295 needed
NXP Semiconductors	MPT612	Programmed	5 – 50 V	Programmed	No	Proprietary algorithm	Buck or Boost	LQFP48	MPPT only
Linear Technology	LTM8062 / LTM8062A	4.95 - 32	< 18.8 V	2 A	Yes	Temperature compensated fixed point voltage	Buck	77-Lead LGA	
Linear Technology	LT3652	4.95 – 32 V	< 14.4 V	2 A	Yes	Temperature compensated fixed point voltage	Buck	DFN12, MSOP-12	

CHEMICAL POWER SOURCES

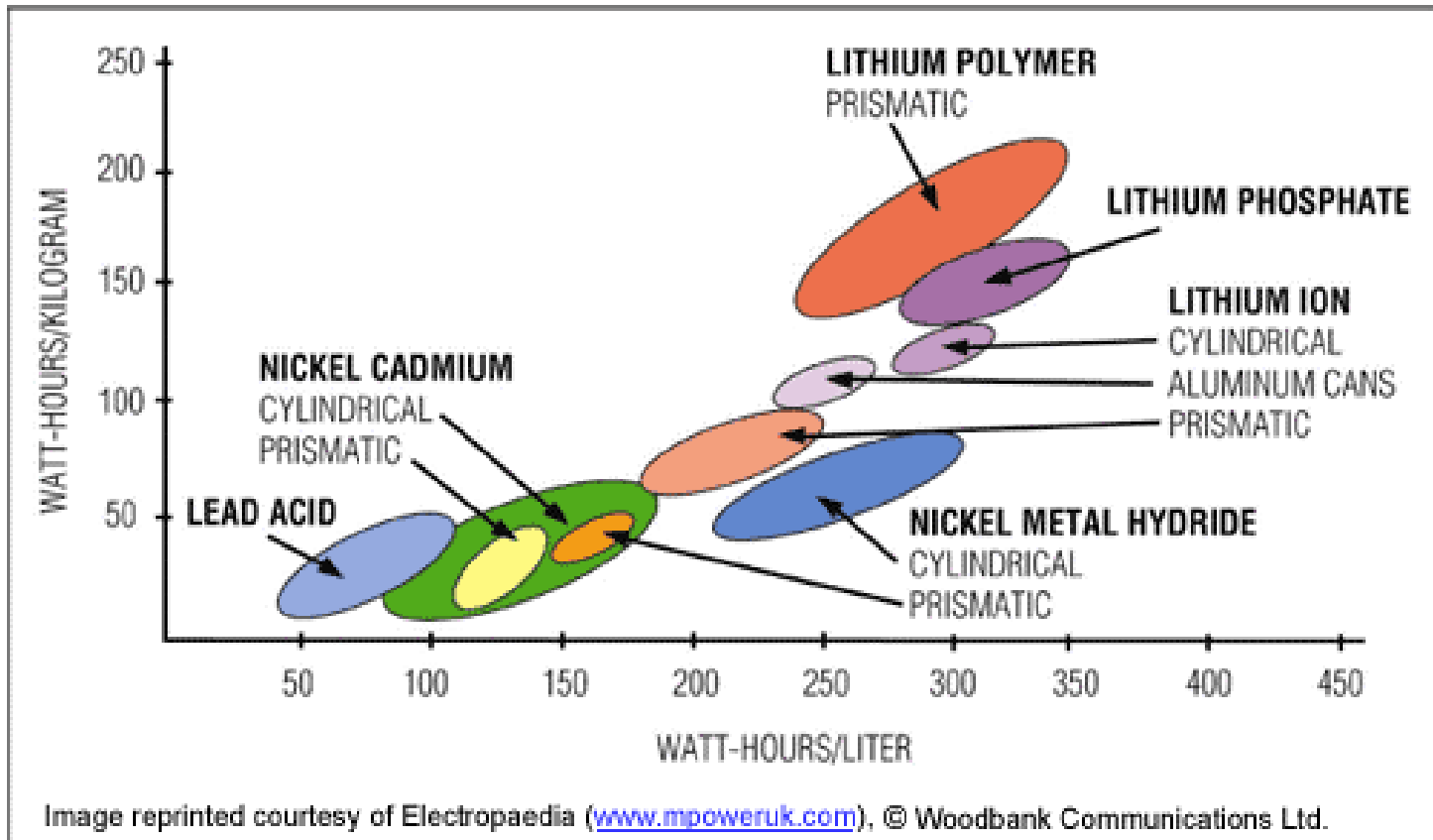
Summary of Common Battery Types

Battery Type	Anode (-)	Cathode (+)	Nominal Voltage	Approximate Energy Density (MJ/kg)	Special Characteristics
Alkaline	Zn	MnO ₂	1.5	0.50	Long shelf life, supports high to medium drain applications
Zinc-Carbon	Zn	MnO ₂	1.5	0.13	Economical in terms of cost per hour for low current consumption
Lithium (BR)	Li	CF _x	3	1.30	Wide temperature operation. High internal impedance (low pulse current).
Lithium (CR)	Li	MnO ₂	3	1.00	Good pulse capability, stable voltage during discharge.
Lithium Thionyl Chloride	Li	SOCl ₂	3.6	1.04	Very low self discharge rate. Can support 20 year battery life.
Zinc-Air	Zn	O ₂	1.4	1.69	High energy density. Relatively short battery life (e.g. weeks to months).

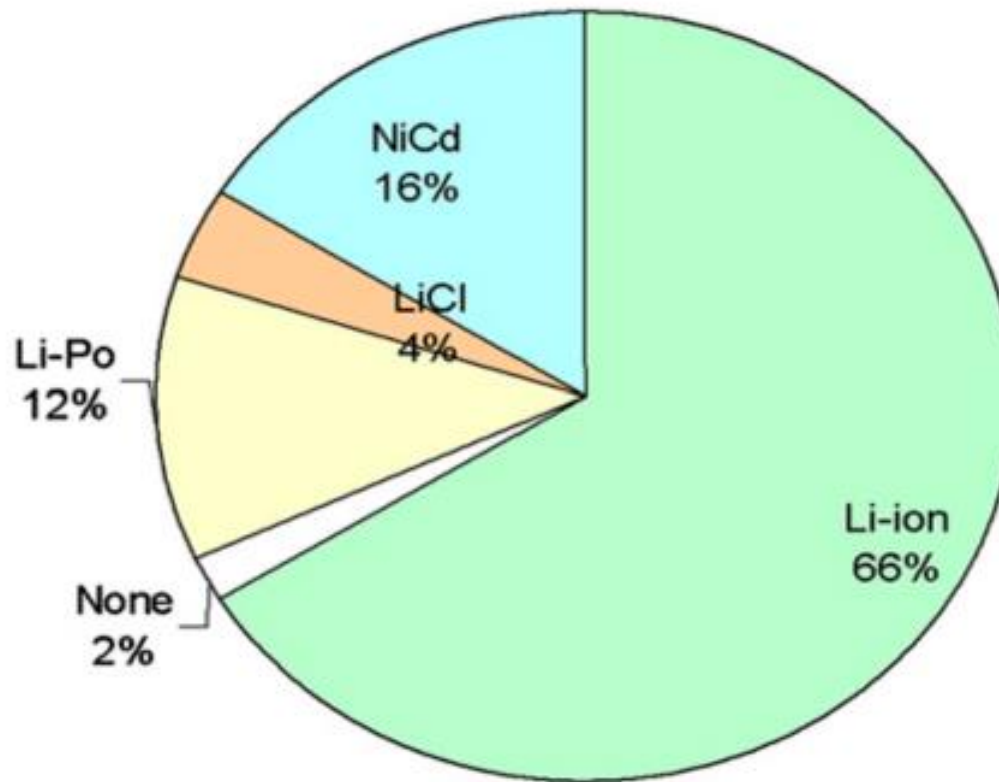
BR –vs- CR: Comparison Table

Item		BR	CR
Negative Material		Lithium (Li)	Lithium (Li)
Positive Material		Poly-Carbonmonofluoride (CF)n	Manganese Dioxide (MnO ₂)
Storage Temperature over 60°C		Good (up to +85°C)	Not recommended
Operating Temperature:	Cylindrical Type	-40°C~+85°C	-40°C~+70°C
	Coin Type	-30°C~+80°C	-30°C~+60°C
	High Temperature Coin Type	-40°C~+125°C	-
	Pin Type	-30°C~+80°C	-
Current Handling Capability		Good	Excellent
Discharge Voltage Characteristics		Stable to end of battery life	Gradually decreases
Discharge Current Characteristics		Better for Low Drain	Better for High Drain
Typical applications		Real Time Clock, Memory B/U	Pulse Discharge, RFID, Keyless Entry, Flashes

Accumulators (rechargeable batteries)

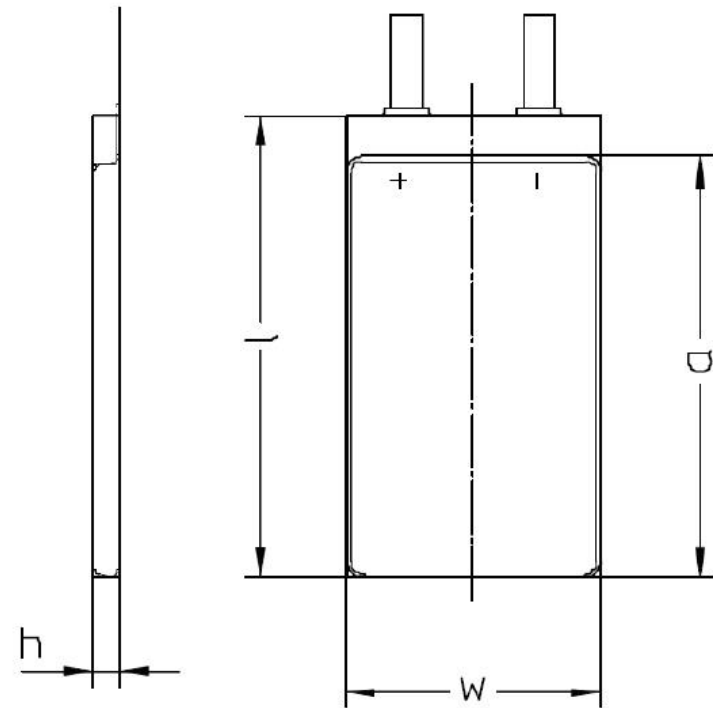


Accumulators (rechargeable batteries)



Acta Astronautica, Vol. 67, J. Bouwmeester, J. Guo, Survey of worldwide pico- and nanosatellite missions, distributions and subsystem technology, pp. 854–862, Copyright (2010)

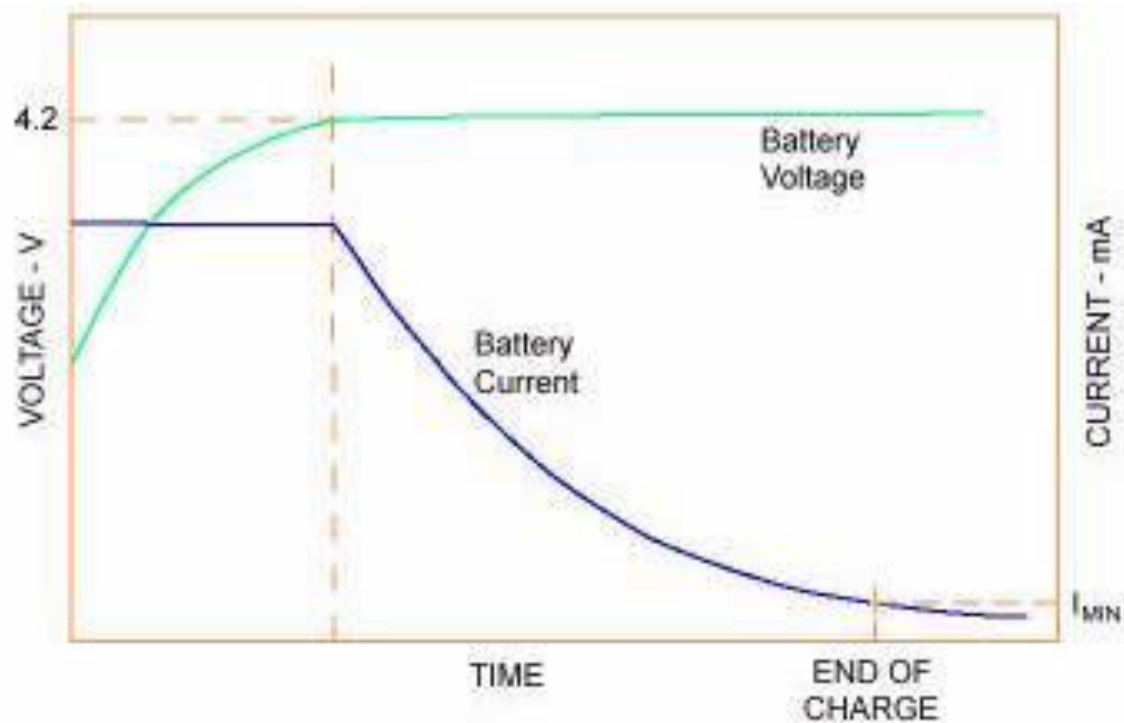
Battery



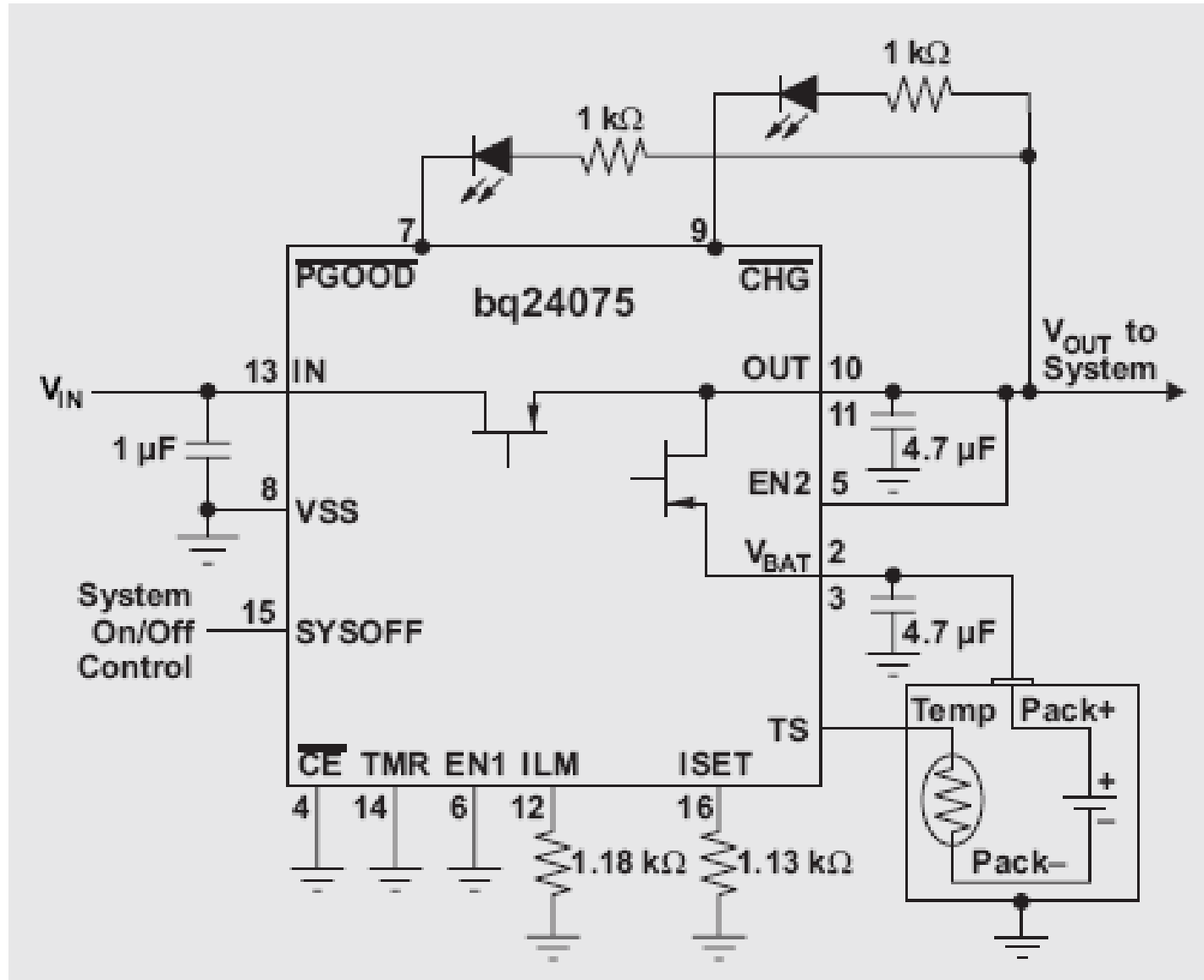
Nominal Voltage : 3.7 V
Typical Capacity : 800 mAh
Minimum Capacity : 770 mAh

Length (l) : 49.2 mm
Width (w) : 34 mm
Height (h) : 4.4 mm
Pouch (a) : 44.2 mm
Weight : 14 g

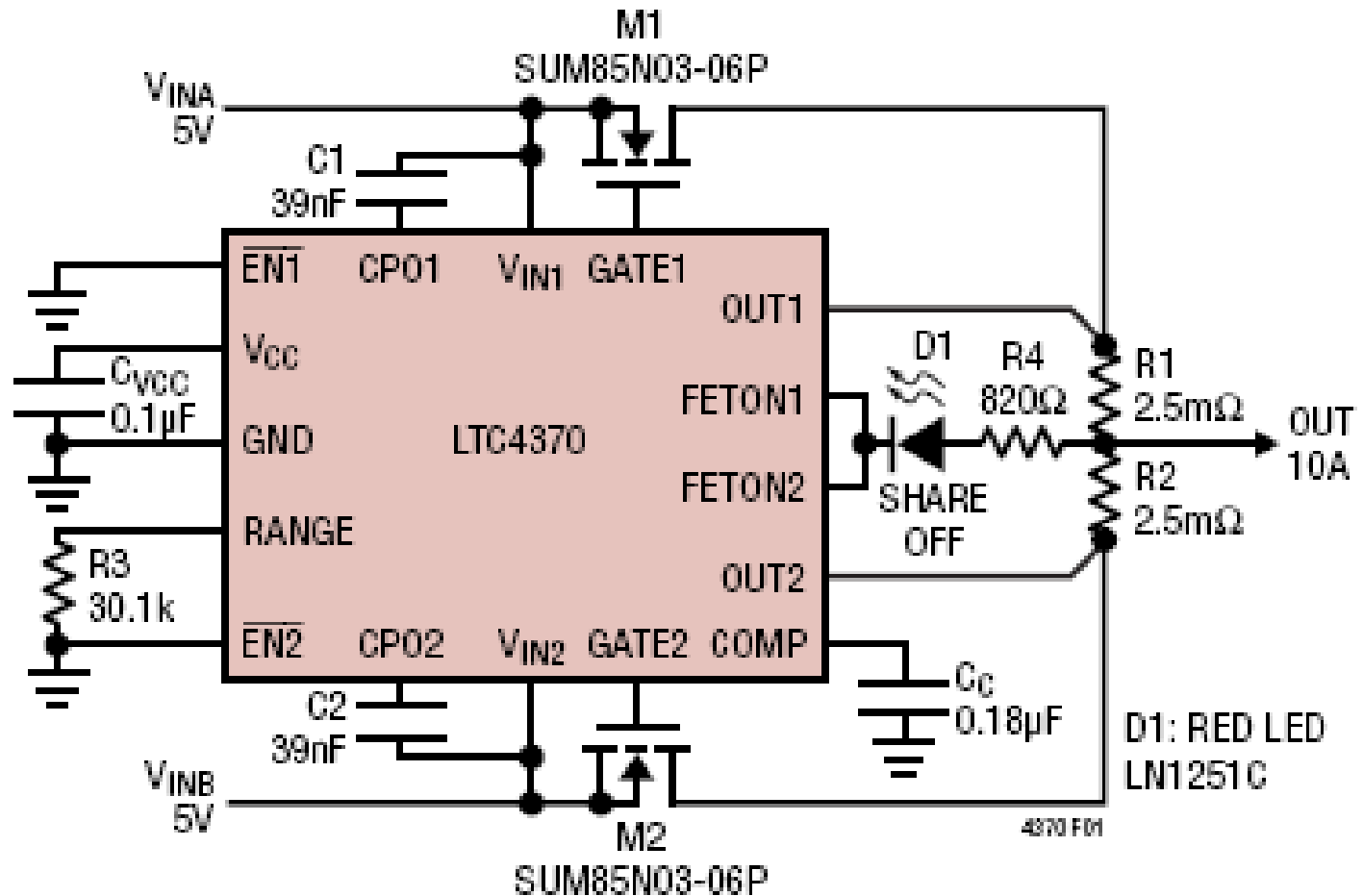
Lithium accumulator charging



Battery charger with power-path control



Sharing of the currents

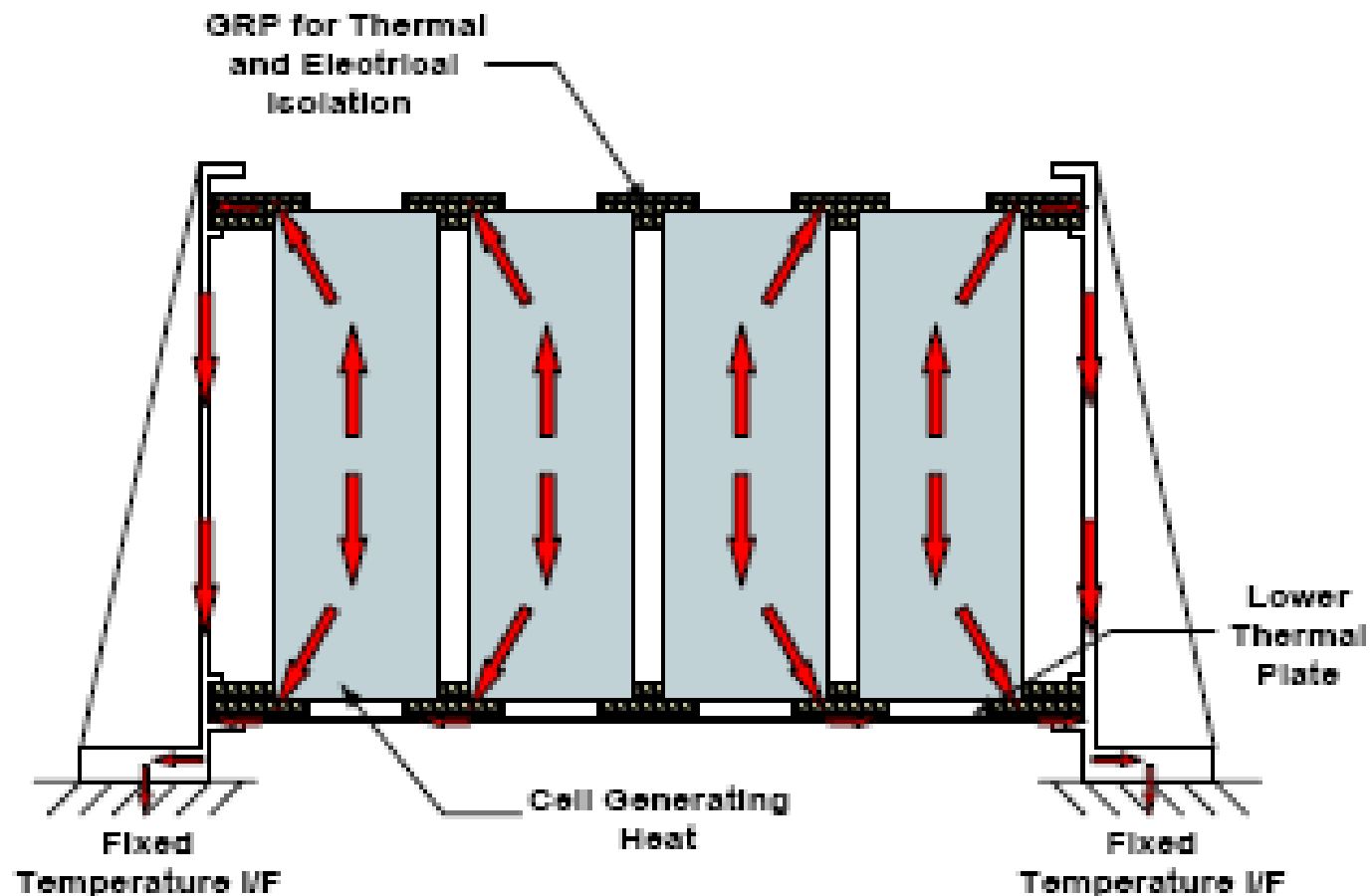


Assemblies



*The RoLand, ST-5 and Nanosat-1
Batteries*

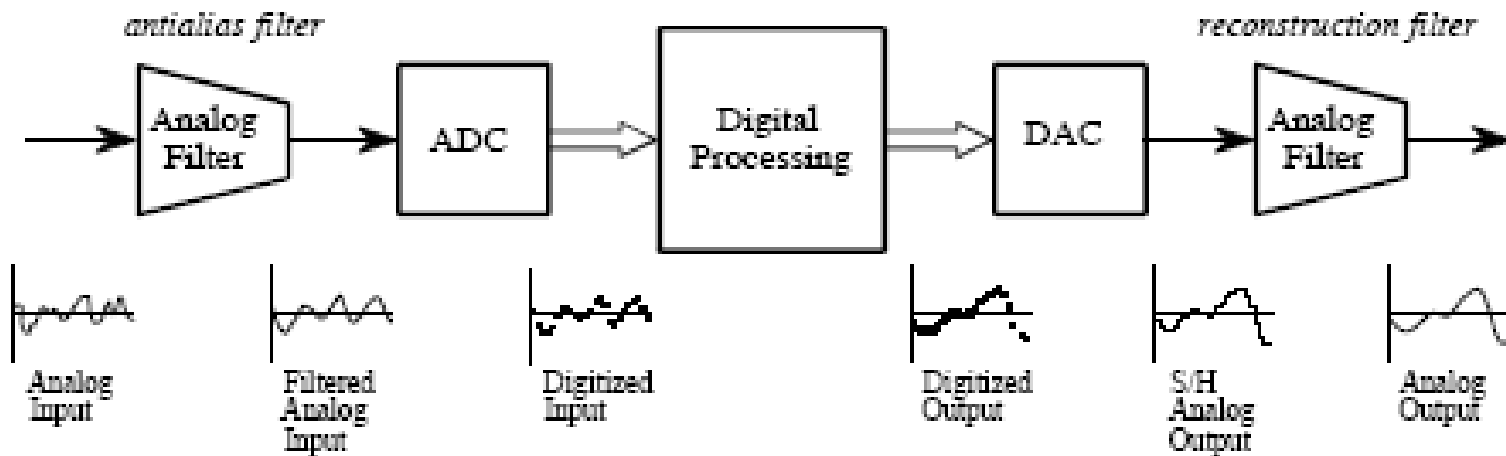
Battery thermal considerations



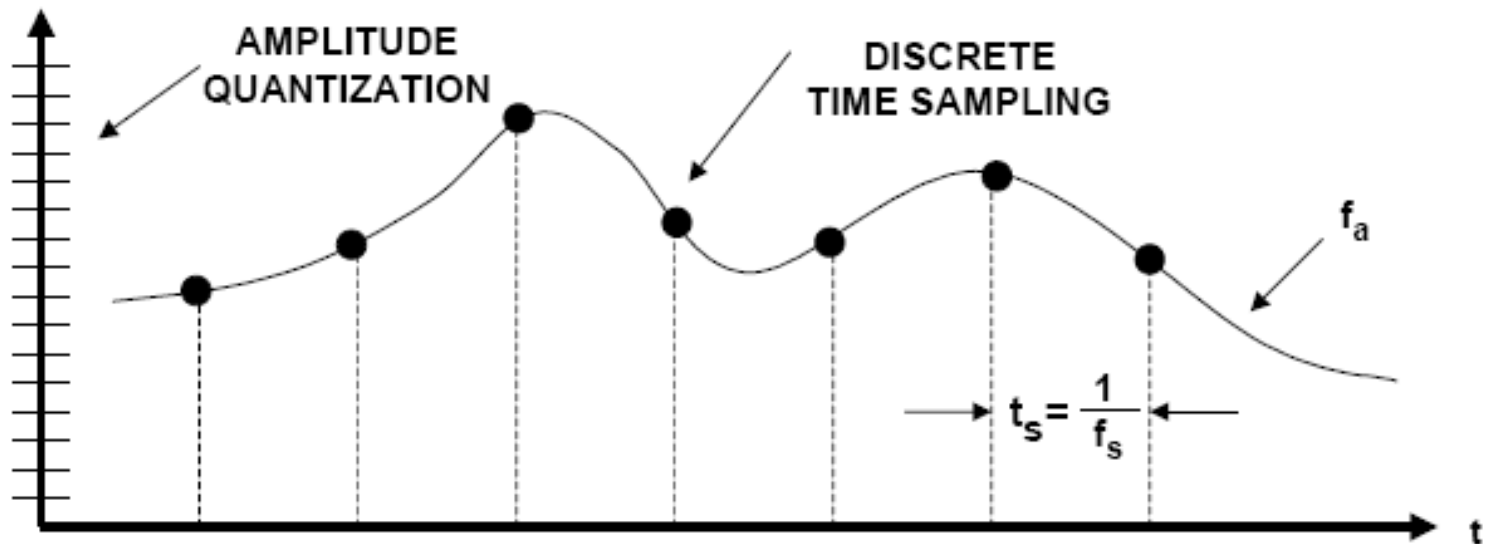
Battery heatflow

Data collecting and processing

Main concept

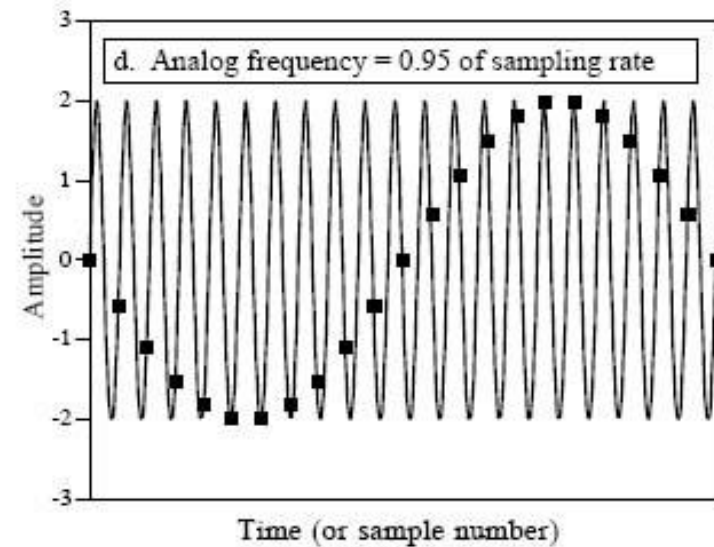
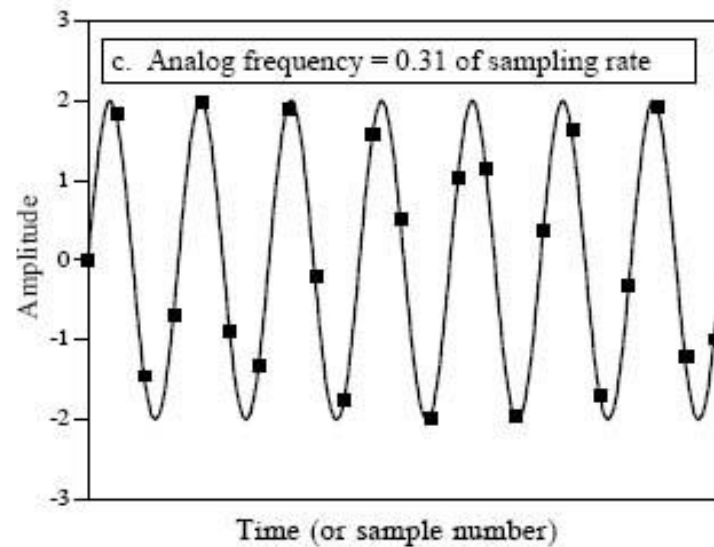
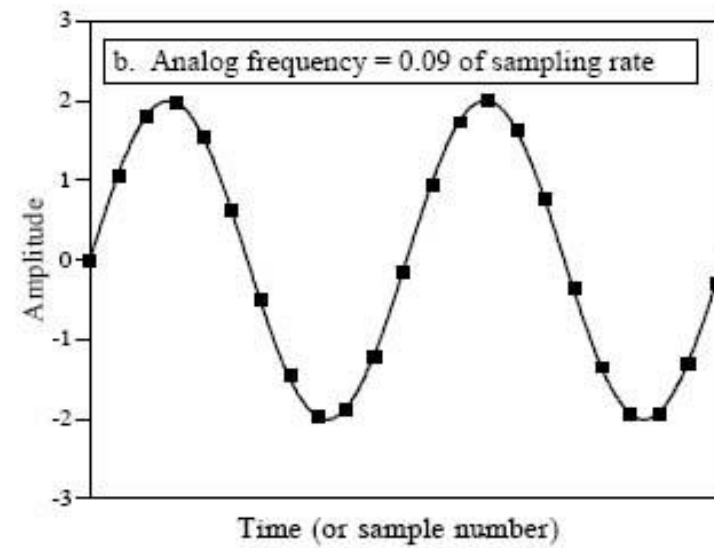
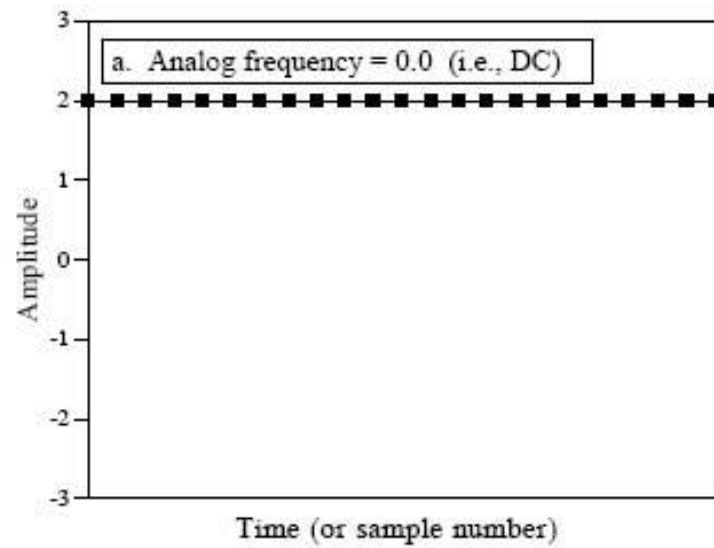


Sampling

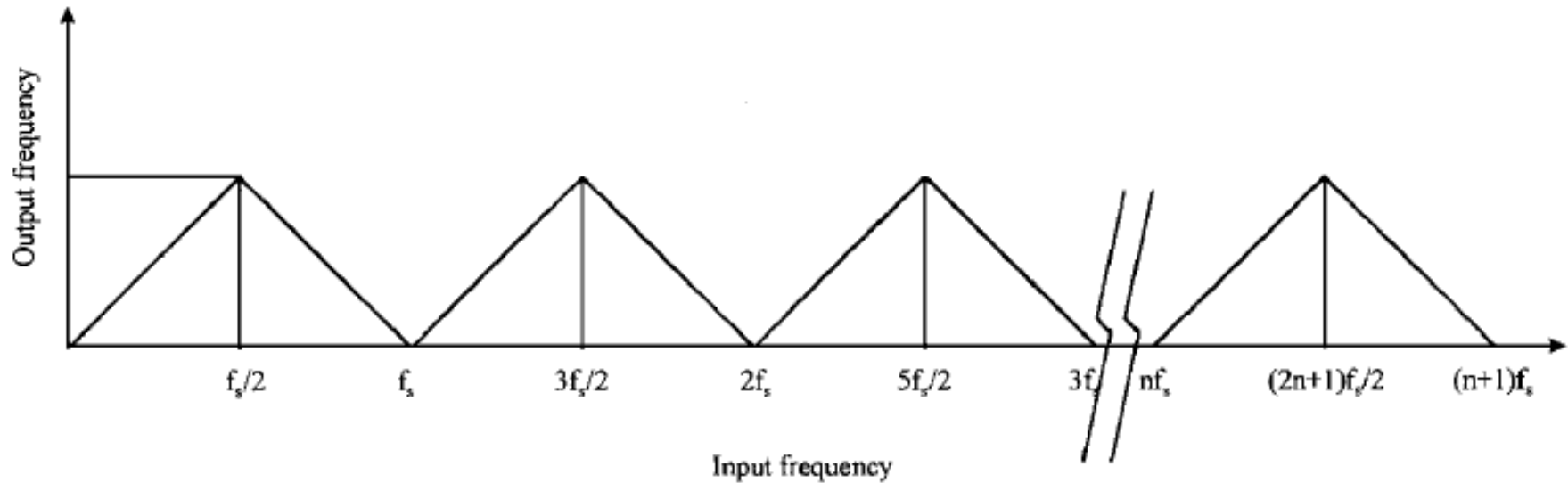


NYQUIST'S CRITERIA

- A signal with a **bandwidth** f_a must be sampled at a rate $f_s > 2f_a$ or information about the signal will be lost.

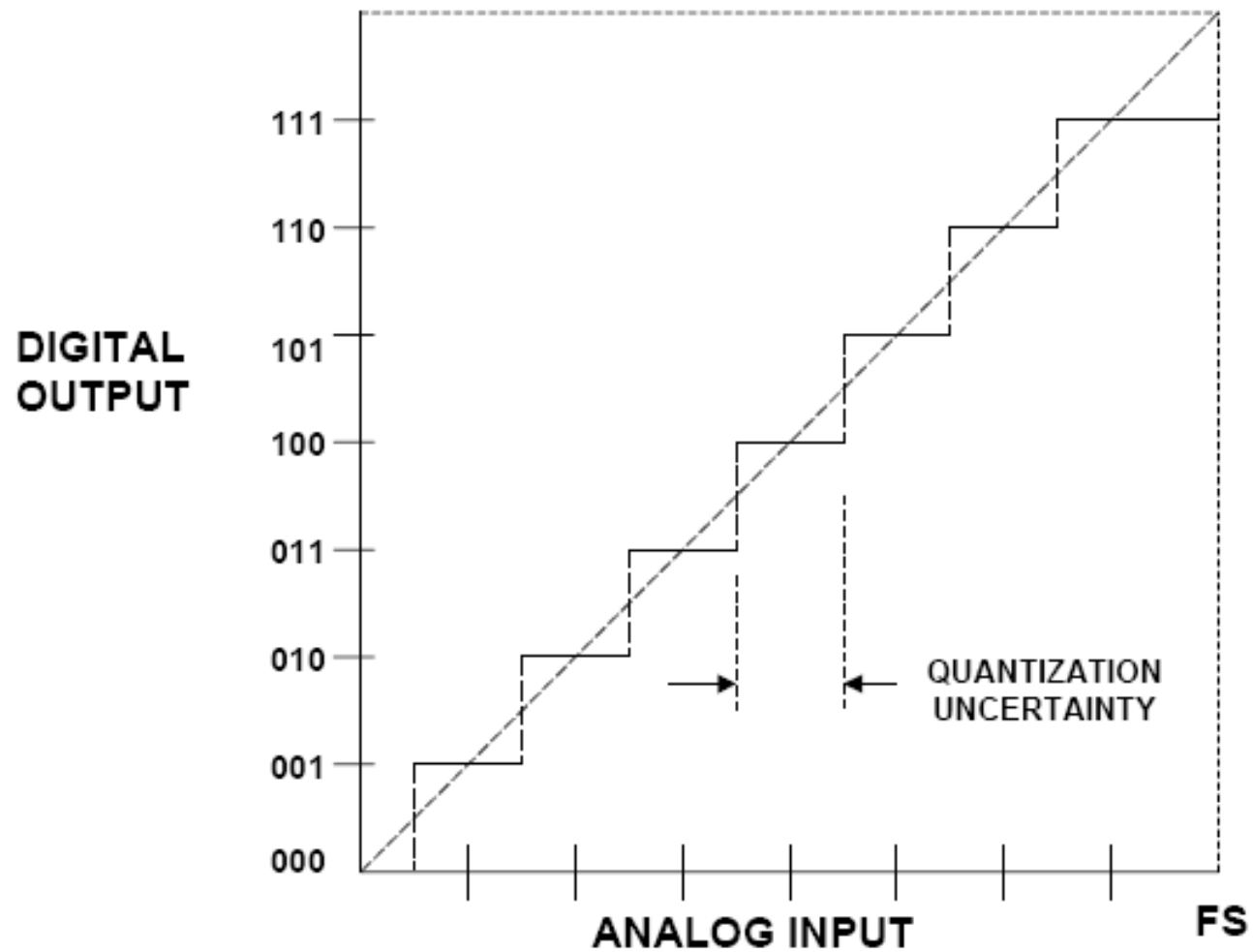


Sampling frequency effect

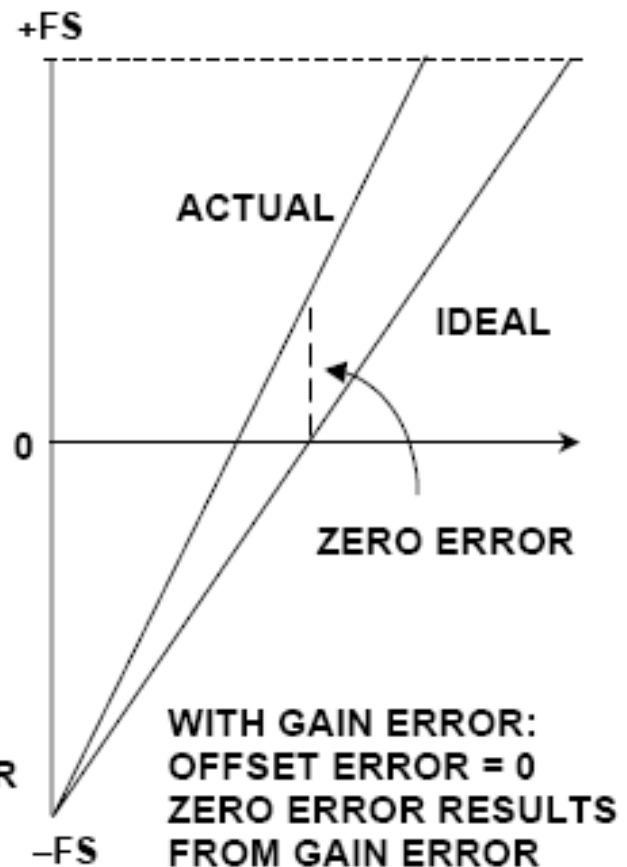
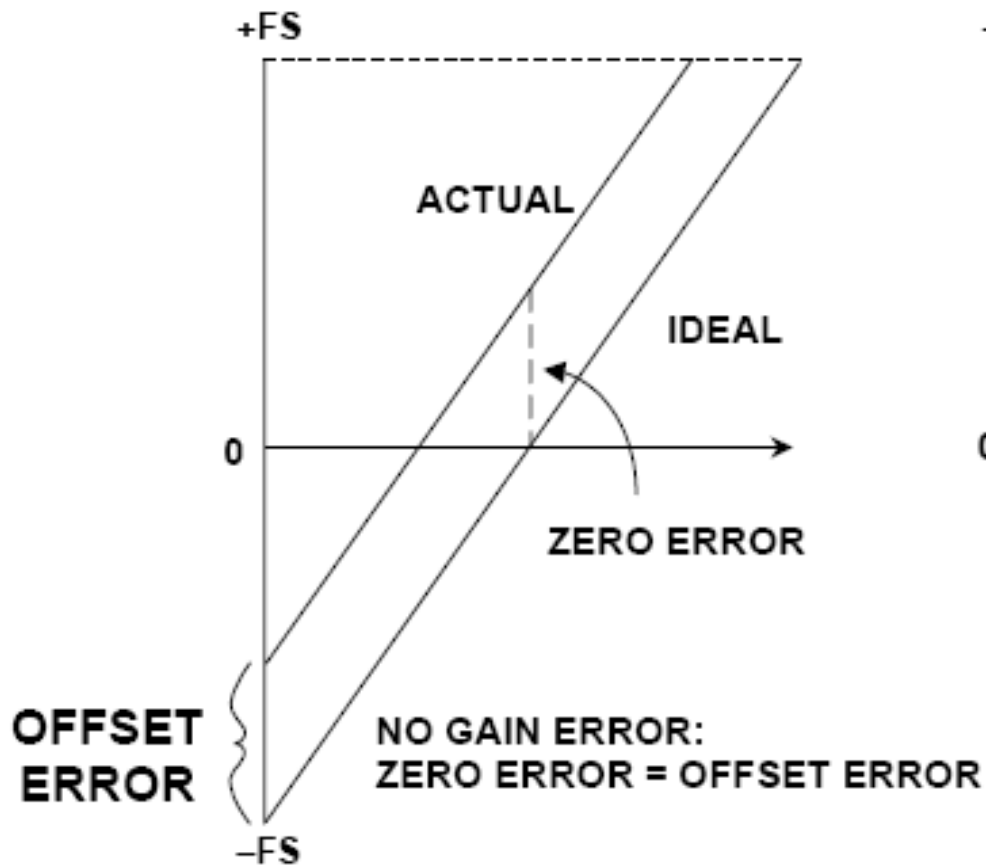


Input versus output frequency of band aliasing.

TRANSFER FUNCTION FOR IDEAL 3-BIT ADC

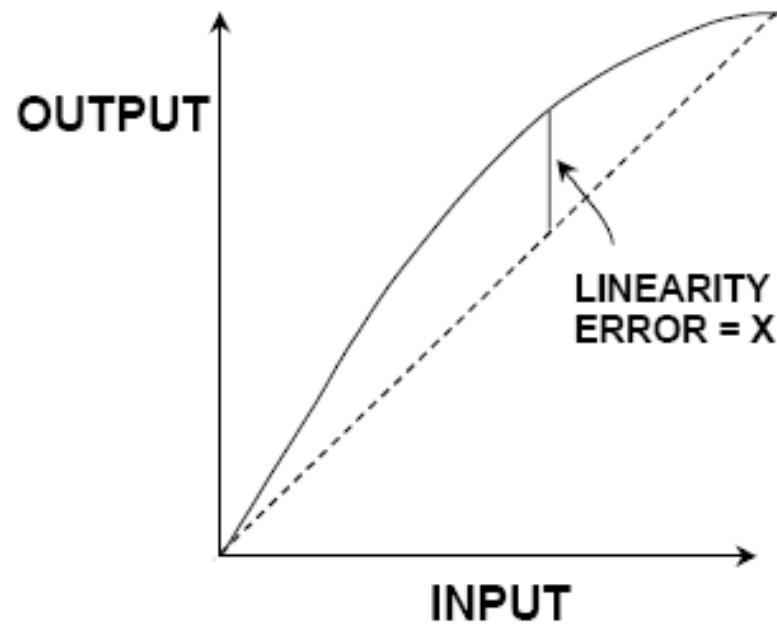


CONVERTER OFFSET AND GAIN ERROR

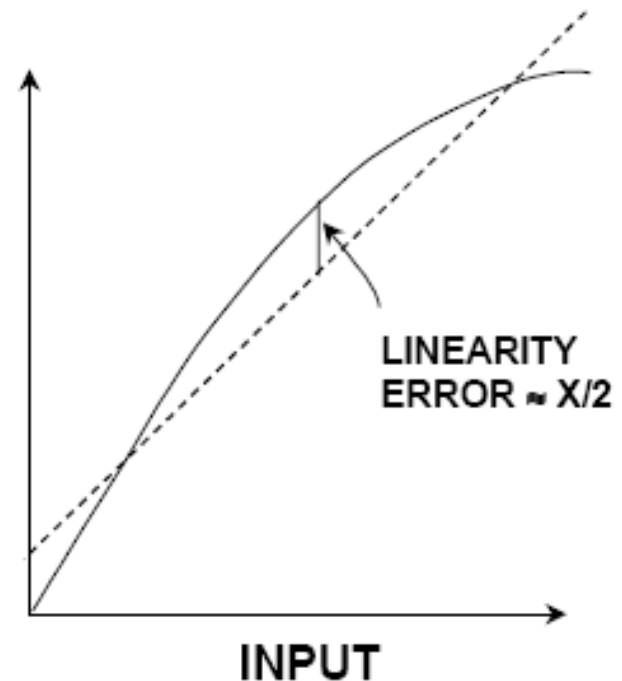


METHOD OF MEASURING INTEGRAL LINEARITY ERRORS (SAME CONVERTER ON BOTH GRAPHS)

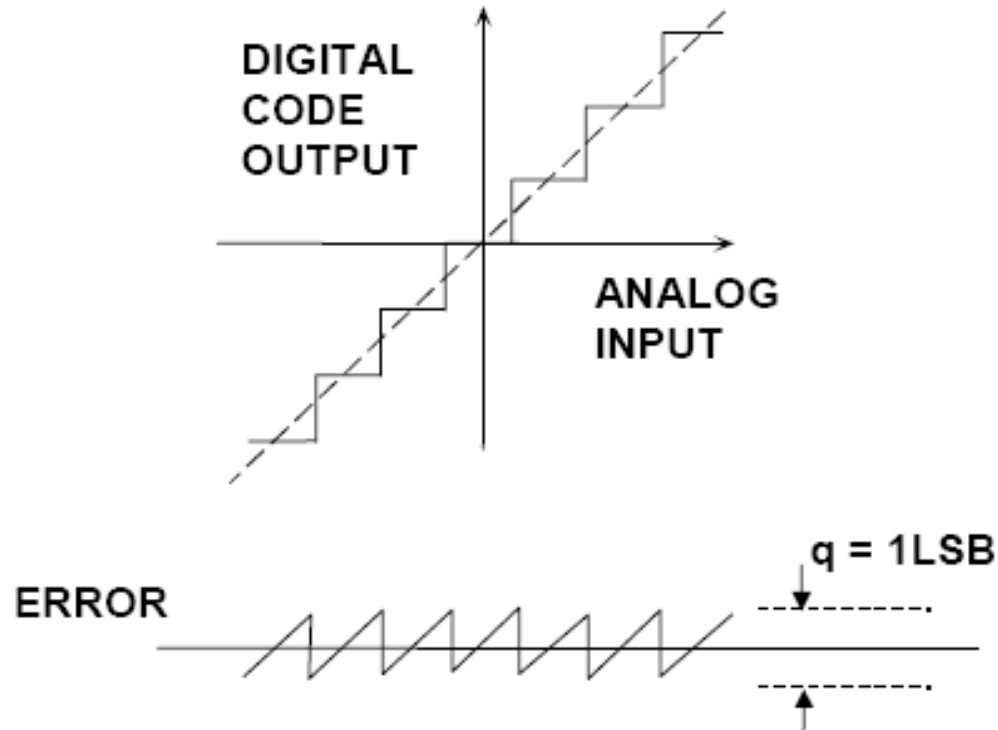
END POINT METHOD



BEST STRAIGHT LINE METHOD



IDEAL N-BIT ADC QUANTIZATION NOISE

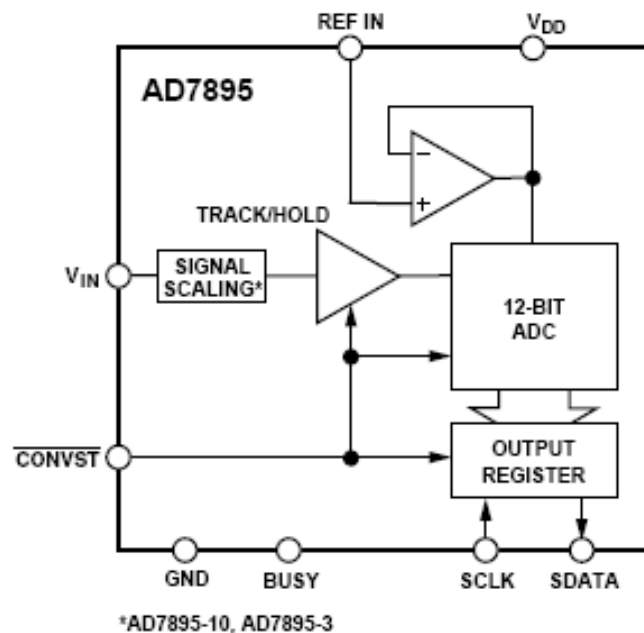
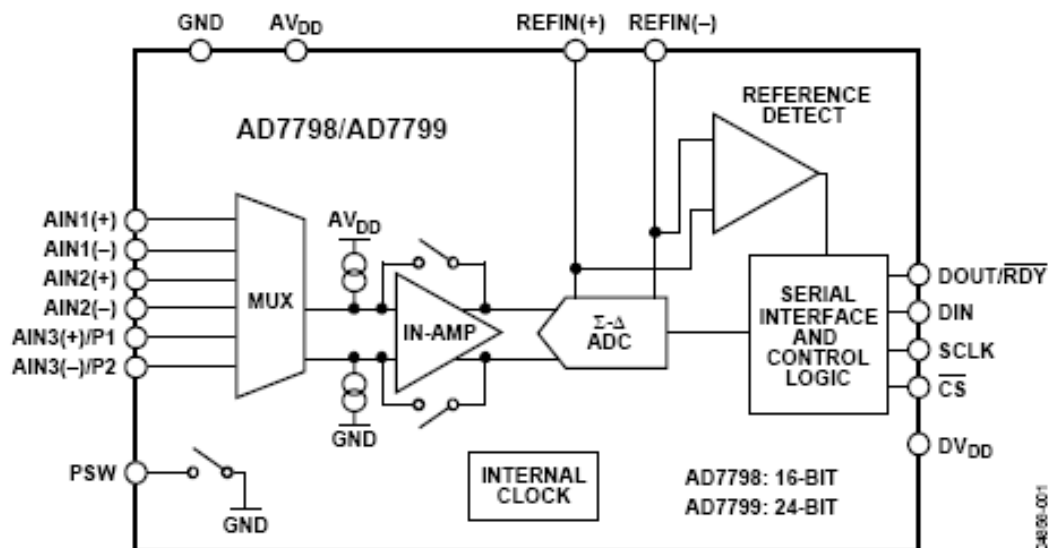
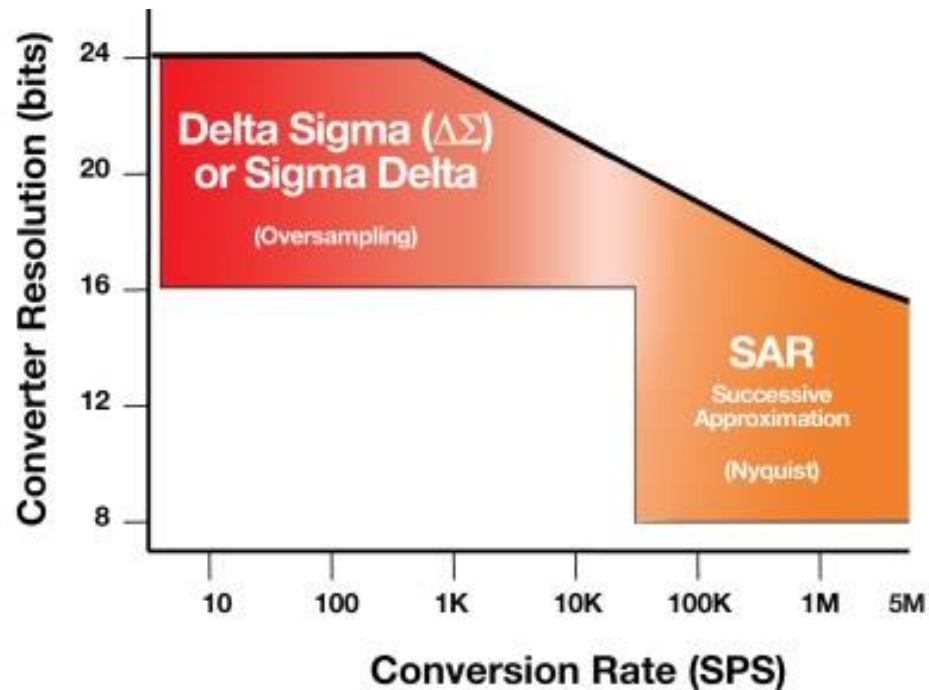


$$\text{RMS ERROR} = q/\sqrt{12}$$

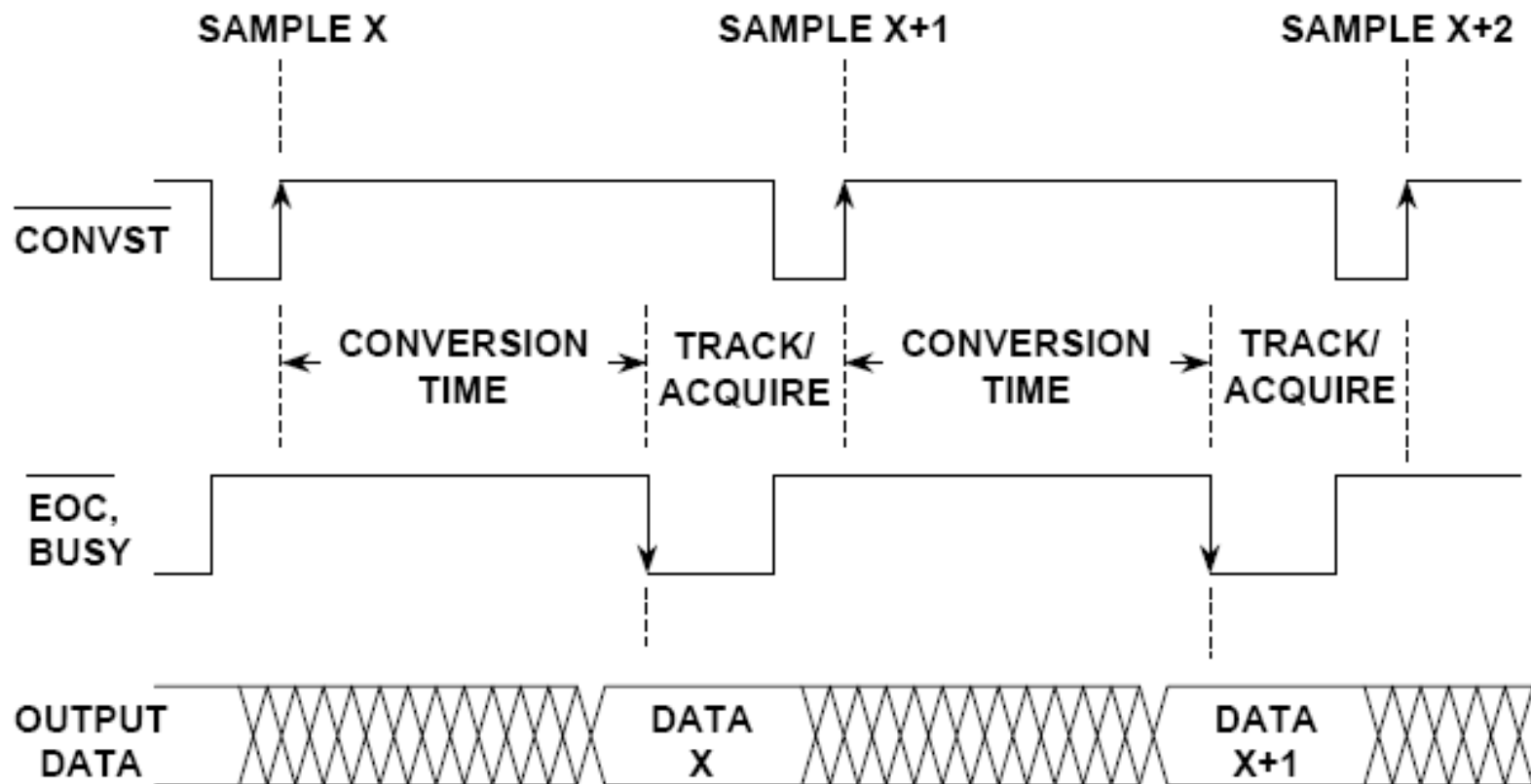
$$\text{SNR} = 6.02N + 1.76\text{dB} + 10\log\left[\frac{f_s}{2 \cdot \text{BW}}\right] \text{ FOR FS SINEWAVE}$$

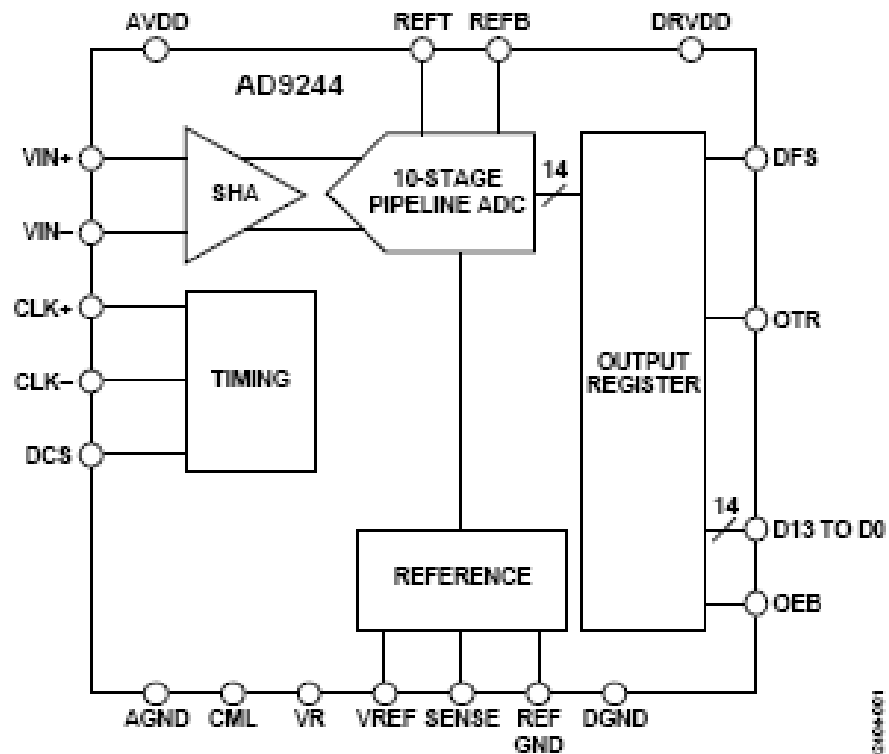
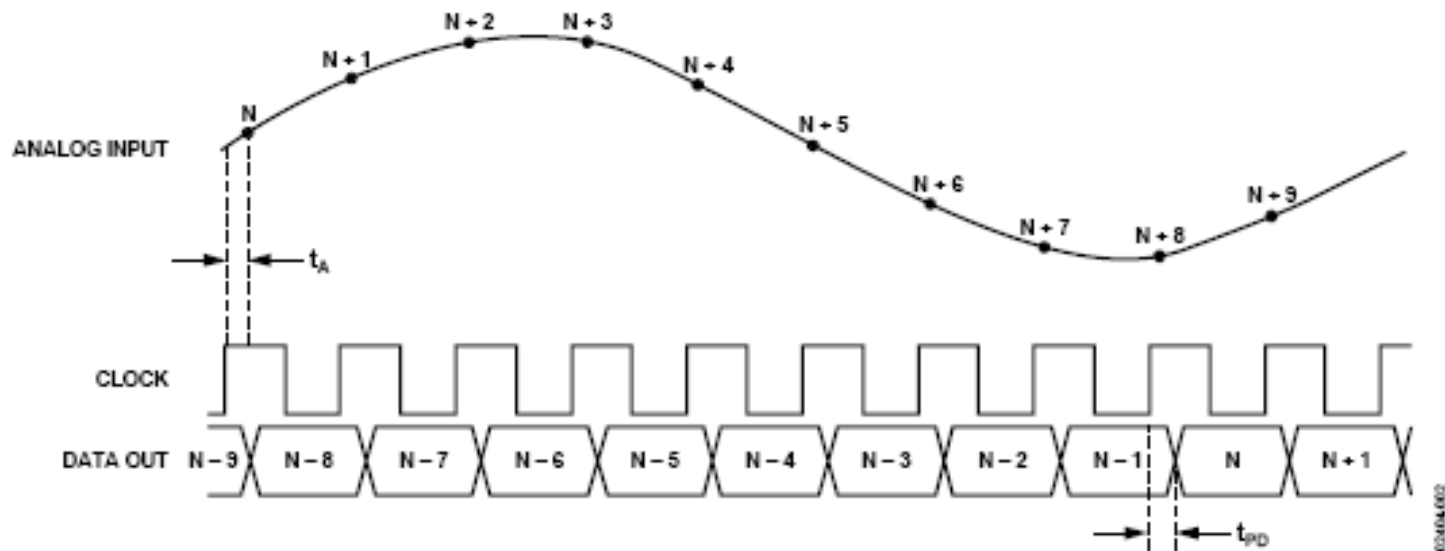
ADC types

- SAR ADC
- Pipelined ADC
- Sigma-Delta ADC

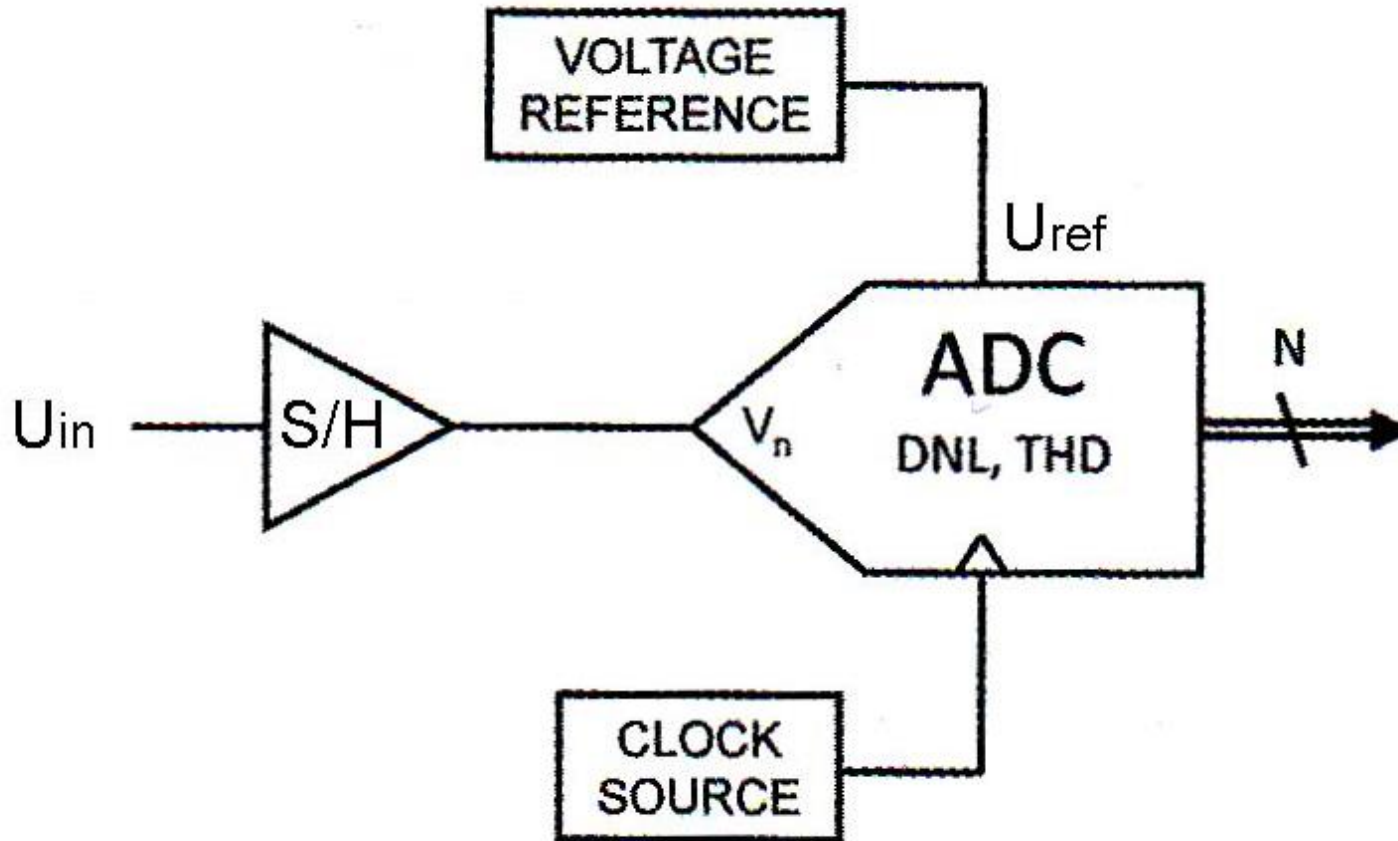


TYPICAL SAR ADC TIMING



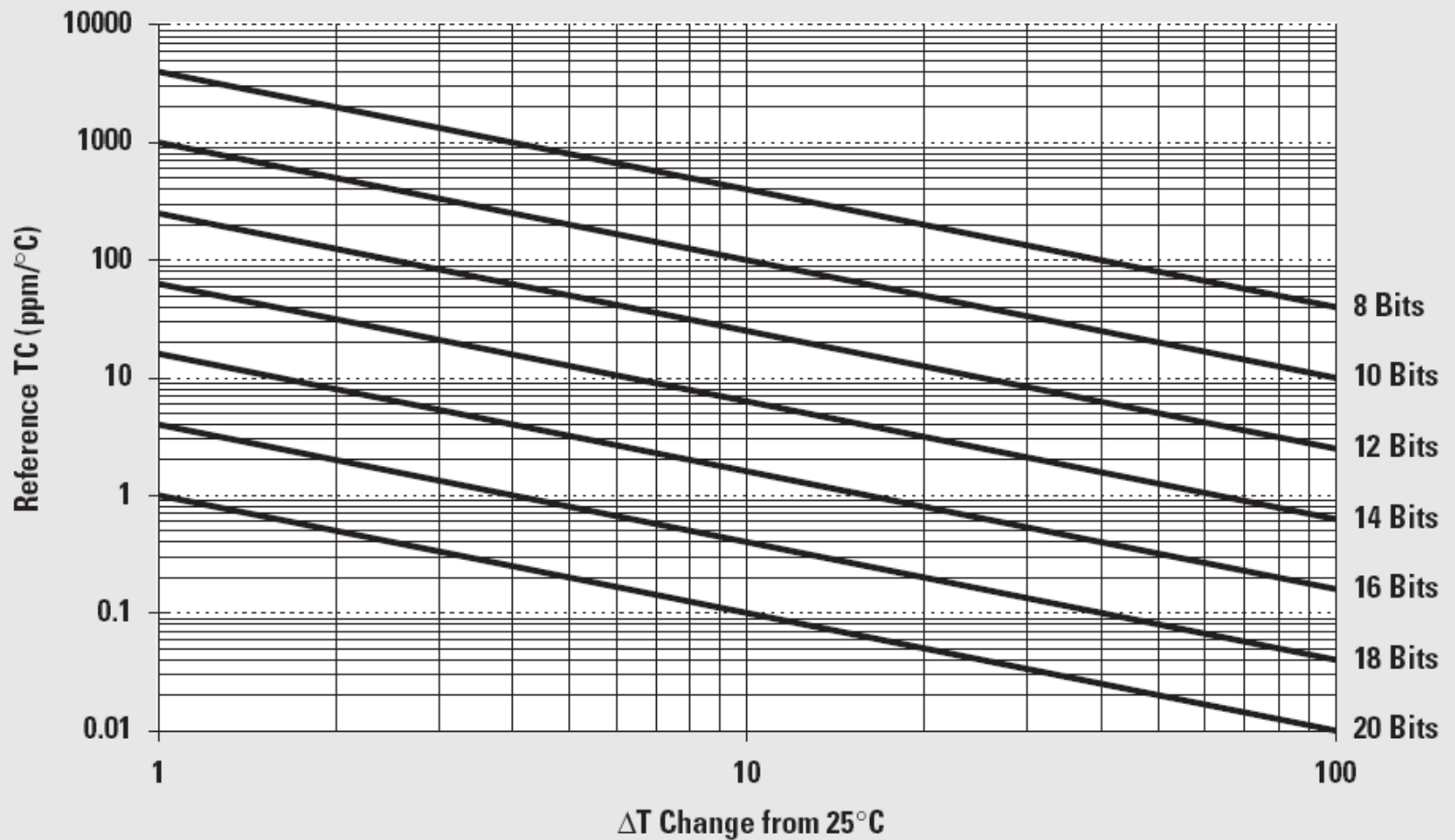


Typical structure



Voltage reference

BANDGAP	BURIED ZENER	XFET®
< 5V Supplies	> 5V Supplies	< 5V Supplies
High Noise @ High Power	Low Noise @ High Power	Low Noise @ Low Power
Fair Drift and Long Term Stability	Good Drift and Long Term Stability	Excellent Drift and Long Term Stability
Fair Hysteresis	Fair Hysteresis	Low Hysteresis

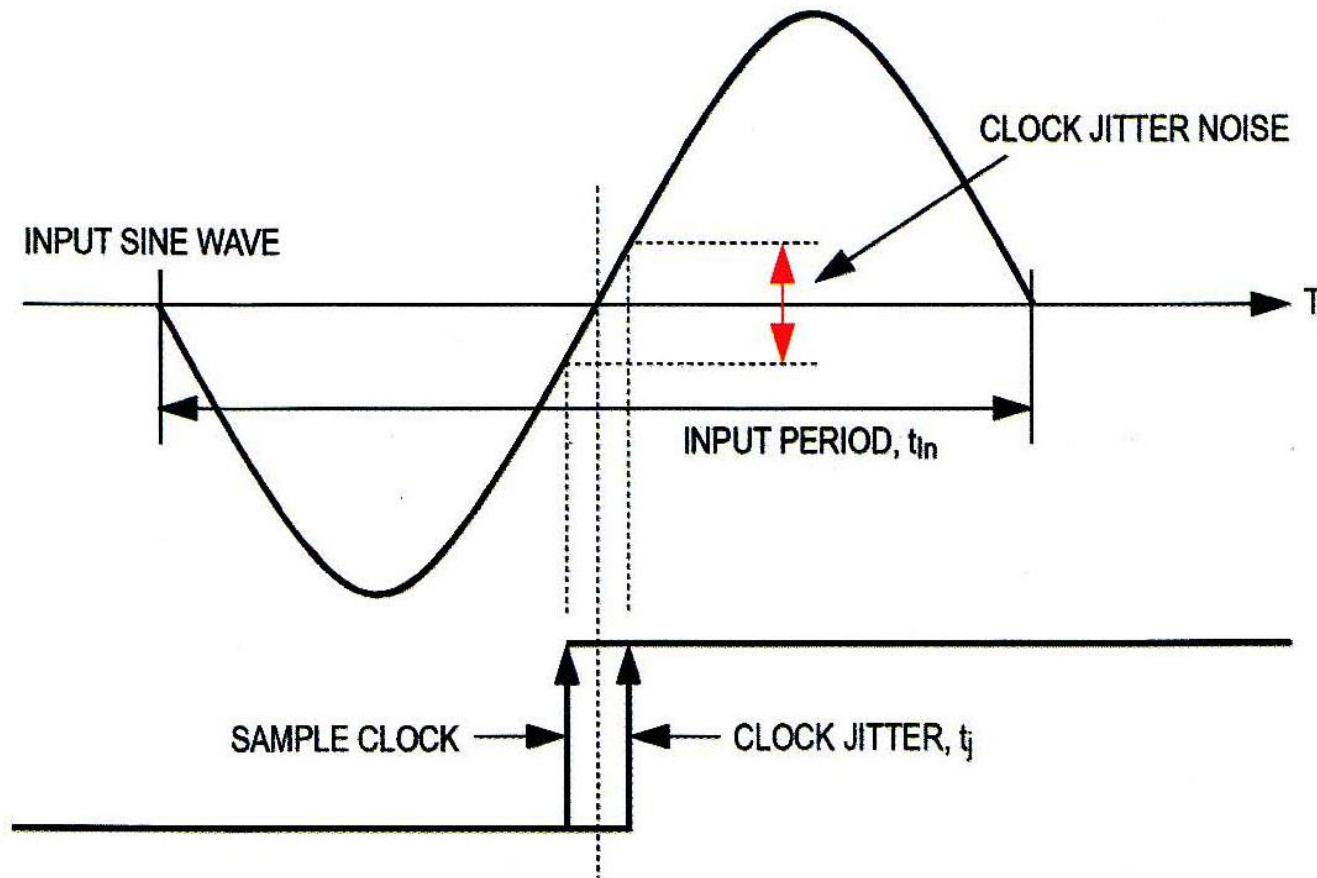


Reference TC vs. ΔT change from 25°C for 1 LSB change

Selection example

Choose Parameters		All	Reset Table	Maximize Filters	Sort by Newest	Save to myAnalog	Download to Excel	Share	Quick Tips	Send Feedback
	Part Number Filter Parts 615 parts Compare	Price (1000+) \$ US 0.28 - 546.24 HIDE	Vout typ V 200m - 10 HIDE	Initial Accuracy % max % 0.02 - 4 HIDE	Vout Tempco max ppm/°C 0.05 - 170 HIDE	Vref Type 6 Values Selected HIDE	Vnoise typ V p-p 300n - 475u HIDE	Temp Range 9 Values Selected HIDE		
☐	LT1004IZ-2.5	\$2.75 (LT1004IZ-2.5#PBF)	2.5	0.8	-	Shunt	-	-40 to 85°C		
☐	AD584S	-	10	-	-	Series	-	-55 to 125°C		
☐	LTZ1000ACH	\$56.00 (LTZ1000ACH#PBF)	7.2	4	0.05	Super Zener	1.2μ	-55 to 125°C		
☐	LTZ1000CH	\$44.00 (LTZ1000CH#PBF)	7.2	4	0.05	Super Zener	1.2μ	-55 to 125°C		
☐	LM399AH	\$8.20 (LM399AH#PBF)	6.95	-	0.5	Shunt	-	0 to 70°C		
☐	ADR4525D	\$9.97 (ADR4525DEZ)	2.5	0.02	0.8	Series (Low Dropout)	1.25μ	0 to 70°C		
☐	ADR4540D	\$9.97 (ADR4540DEZ)	4.096	0.02	0.8	Series (Low Dropout)	2.7μ	0 to 70°C		
☐	ADR4550D	\$9.97 (ADR4550DEZ)	5	0.02	0.8	Series (Low Dropout)	2.8μ	0 to 70°C		
☐	ADR4525C	\$7.97 (ADR4525CRZ)	2.5	0.02	1	Series (Low Dropout)	1.25μ	0 to 70°C		
☐	ADR4540C	\$7.97 (ADR4540CRZ)	4.096	0.02	1	Series (Low Dropout)	2.7μ	0 to 70°C		
☐	ADR4550C	\$7.97 (ADR4550CRZ)	5	0.02	1	Series (Low Dropout)	2.8μ	0 to 70°C		
☐	LM399H	\$5.81 (LM399H#PBF)	6.95	-	1	Shunt	-	0 to 70°C		
☐	LT6657AHMS8-1.25	\$5.49 (LT6657AHMS8-1.25#PBF)	1.25	0.1	1.5	Series, Shunt	1.25μ	-40 to 125°C		
☐	LT6657AHMS8-2.5	\$5.49 (LT6657AHMS8-2.5#PBF)	2.5	0.1	1.5	Series, Shunt	1.25μ	-40 to 125°C		
☐	LT6657AHMS8-3	\$5.49 (LT6657AHMS8-3#PBF)	3	0.1	1.5	Series, Shunt	1.25μ	-40 to 125°C		
☐	LT6657AHMS8-4.096	\$5.49 (LT6657AHMS8-4.096#PBF)	4.096	0.1	1.5	Series, Shunt	1.25μ	-40 to 125°C		

Jitter effect



Analog signal conditioning

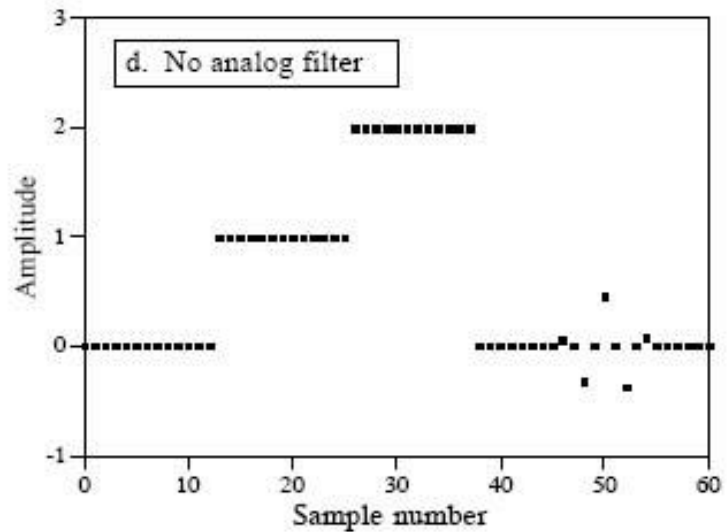
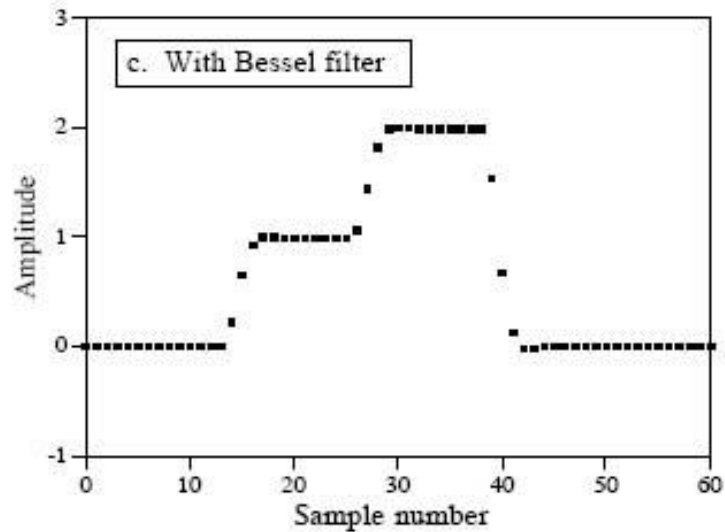
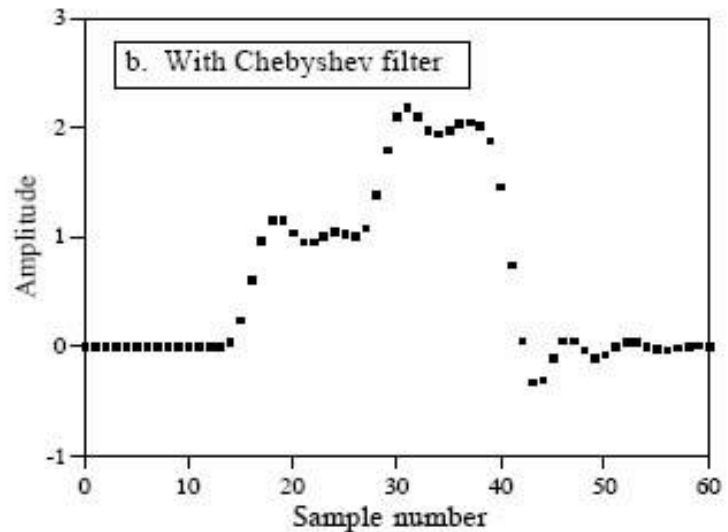
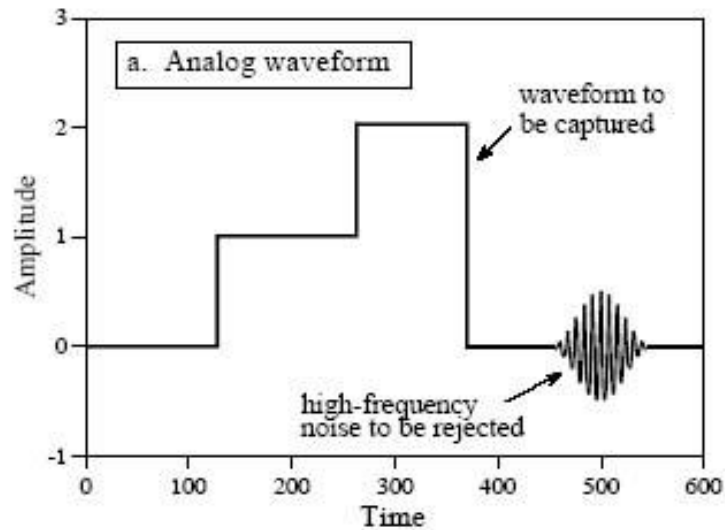
Main purposes:

1. Amplification
2. Impedance matching
3. Filtering

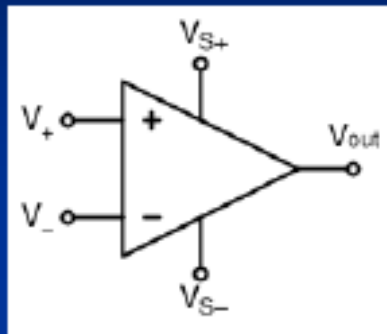
Main requirements:

1. Low noise
2. Good linearity
3. High accuracy

Antialiasing filter



Operational amplifier (op-amp)



V_+ , V_- positive and negative inputs

V_{out} output

V_{S+} , V_{S-} positive and negative power supply (12-18 Volts)

Note: V_{S+} same as V_{DD} , V_{CC} , V_{CC+}

V_{S-} same as V_{SS} , V_{EE} , V_{CC-}

Op-amp is a high-gain voltage differential amplifier;
typical gain G is in the range 100,000-200,000;

it amplifies the difference in the voltage applied to the pair of inputs

Historical facts: 1952- K2-W first op-amp, G.A. Philbrick lab

1963- μ A702 first solid-state op-amp by Bob Widlar, Fairchild Semiconductors, supply voltages +12 and -6 volts, burn out when temporarily shorted

1965- μ A709 by Bob Widlar, high gain, a larger bandwidth, lower input current, supply voltage of approximately ± 15 Volt DC

1967- LM101 more versatile op-amp version- gain up to 160K and operation range, 'short-circuit' protection, and simplified frequency compensation.

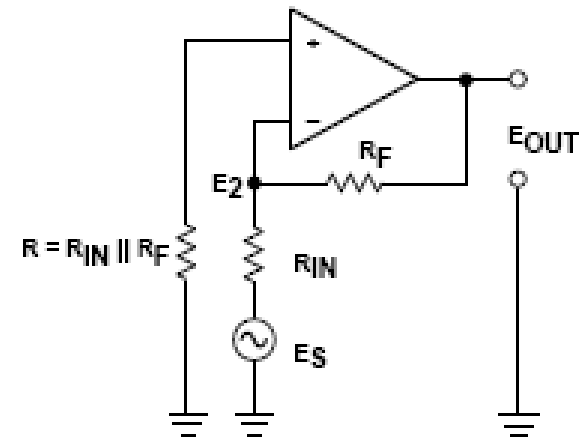
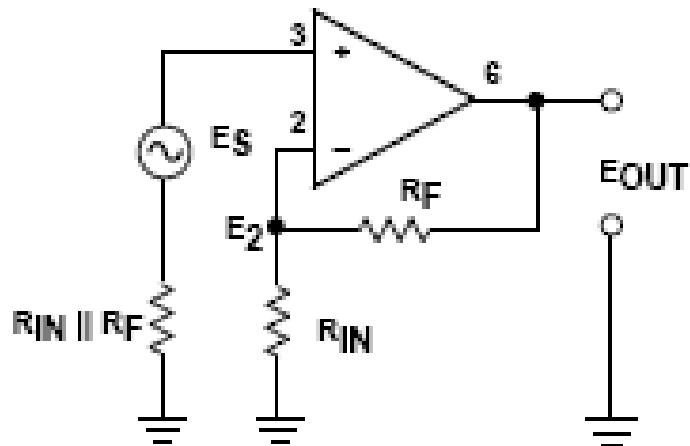
In 1968 improved version of LM101 was LM101A, National Semiconductor

1974- RC4558 first multiple op amp device, which uses NPN input transistors, Raytheon Semiconductor's

In dated sequence, the op-amp developed like this: 1963- μ A702, 1965- μ A709, 1967-LM101/LH101, 1968- μ A741, 1974-RC4558/LM324, 1975-CA3130/LF355, and in 1976 the TL084...

Since 1976 the types of op amps have increased almost daily

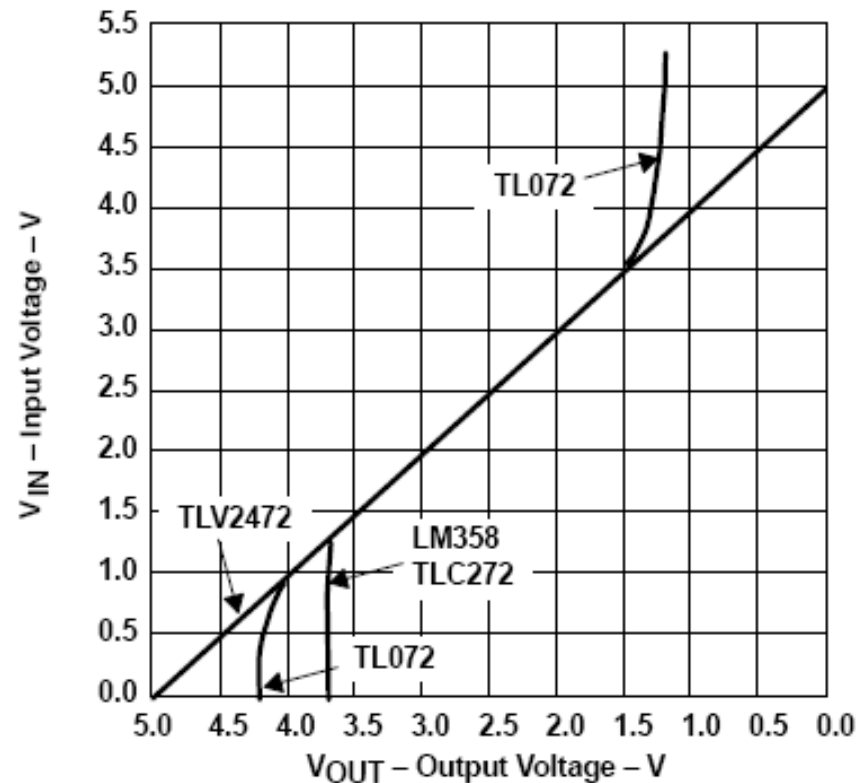
Operational amplifiers



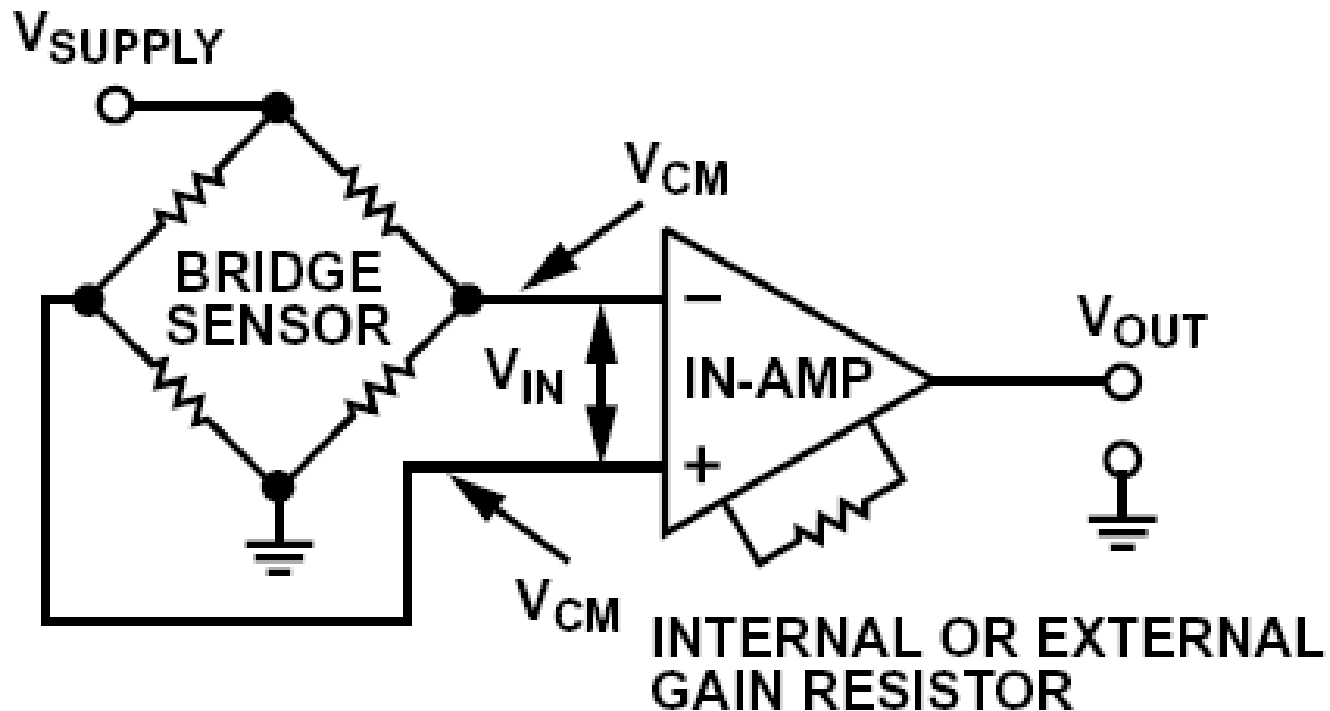
$$E_{OUT} = E_S \left(1 + \frac{R_F}{R_{IN}} \right)$$

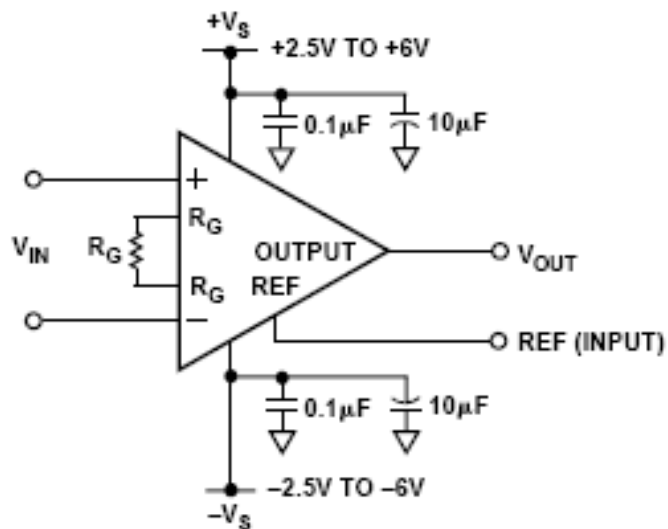
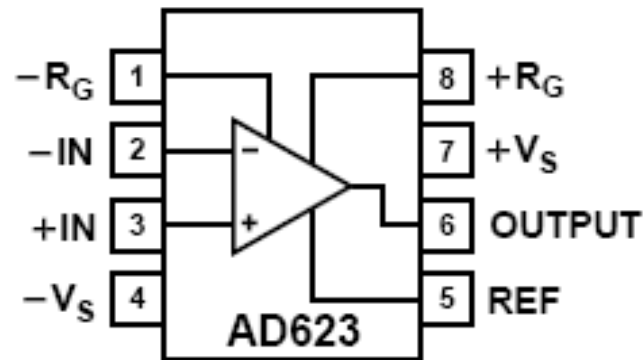
$$E_O = E_S \frac{R_F}{R_{IN}}$$

Rail-to-rail amplifier's basics

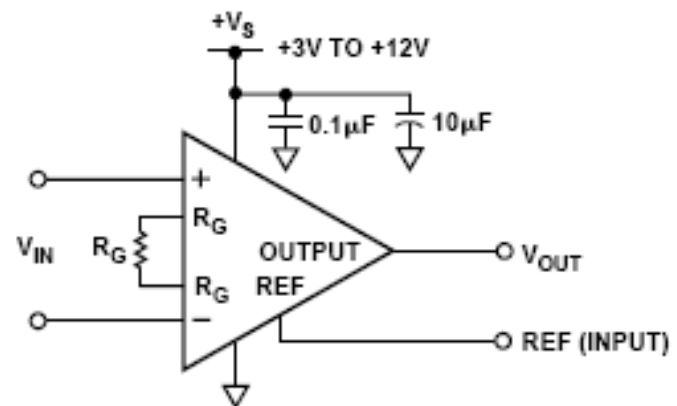


Instrumentation amplifiers





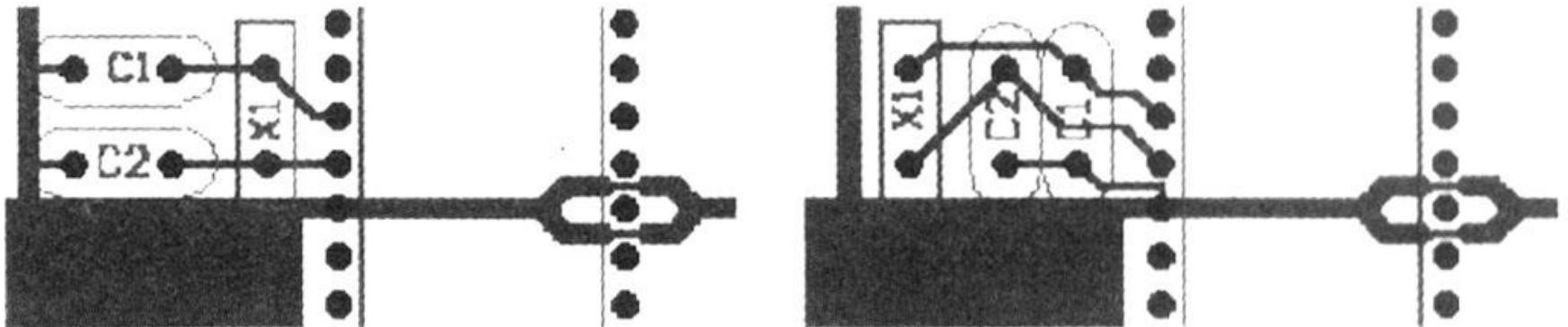
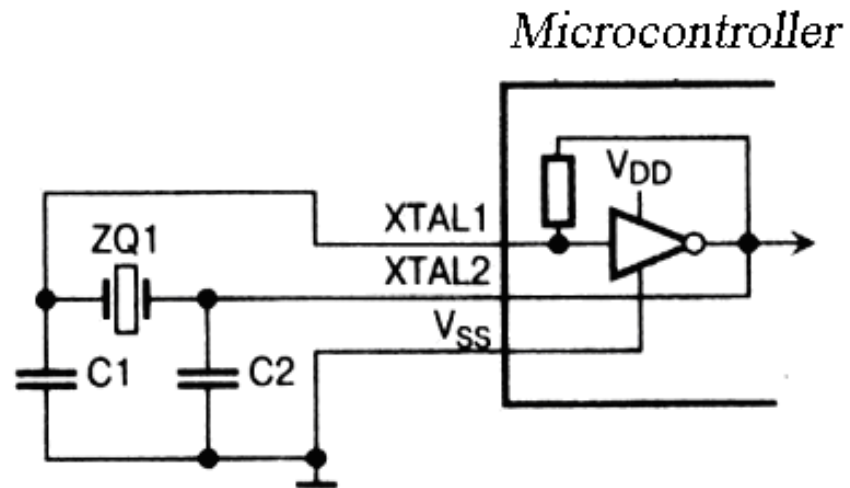
a. Dual Supply



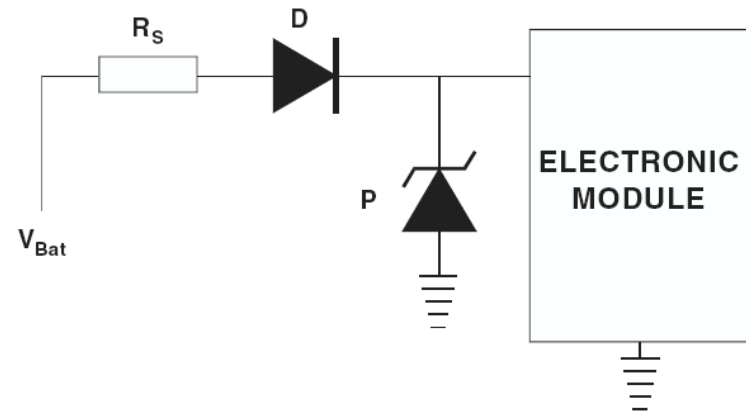
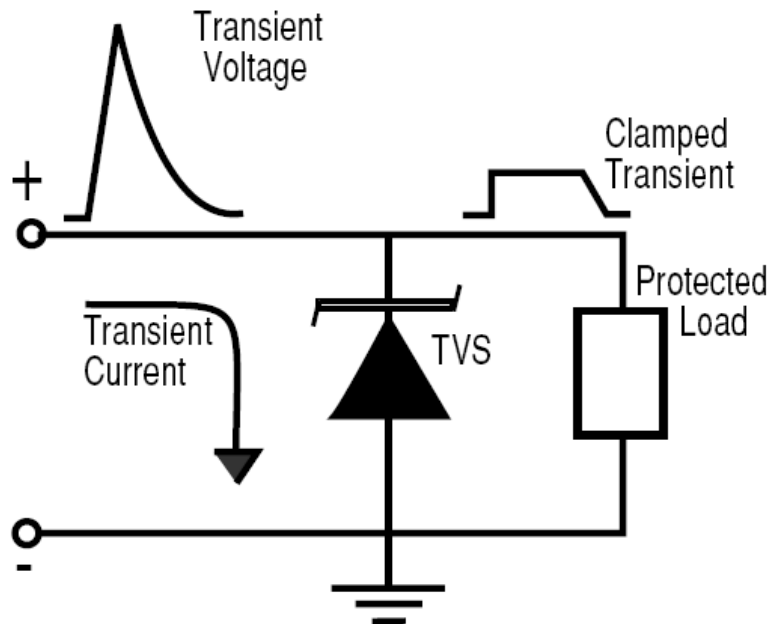
b. Single Supply

Interference

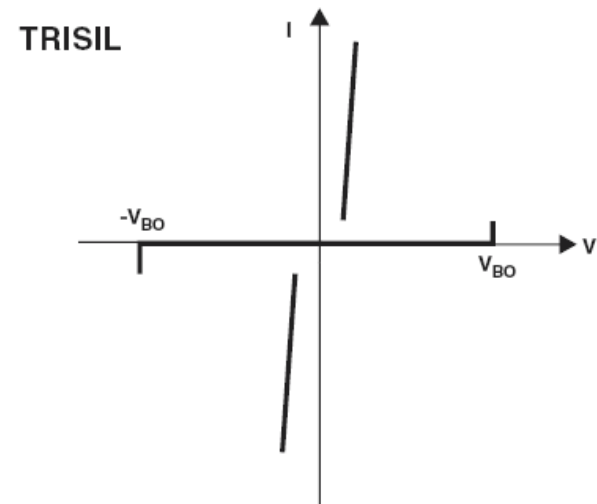
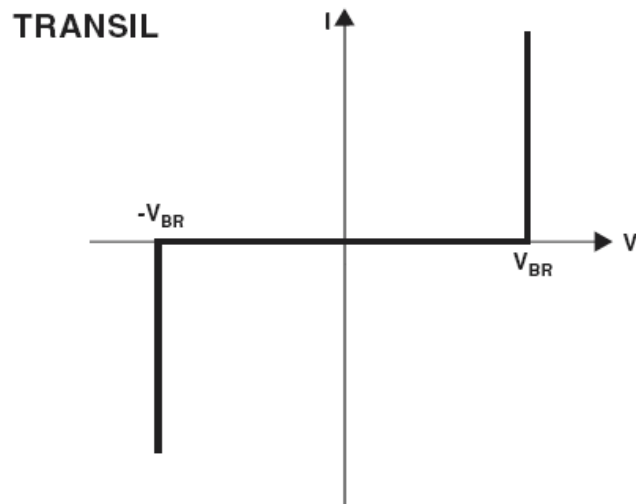
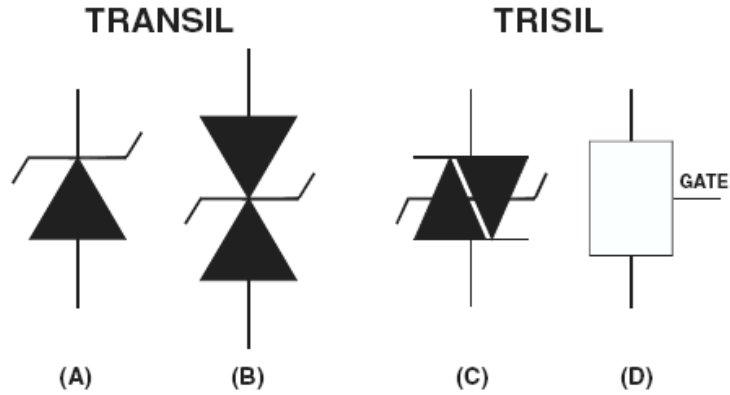


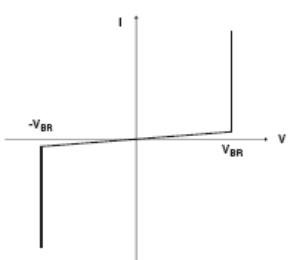
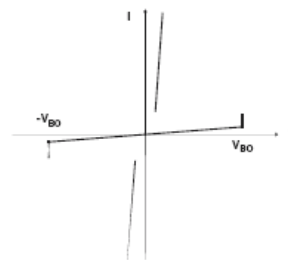
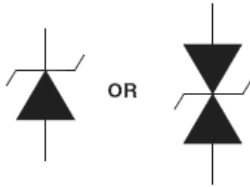
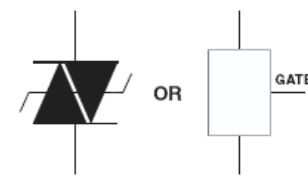


Surge protection

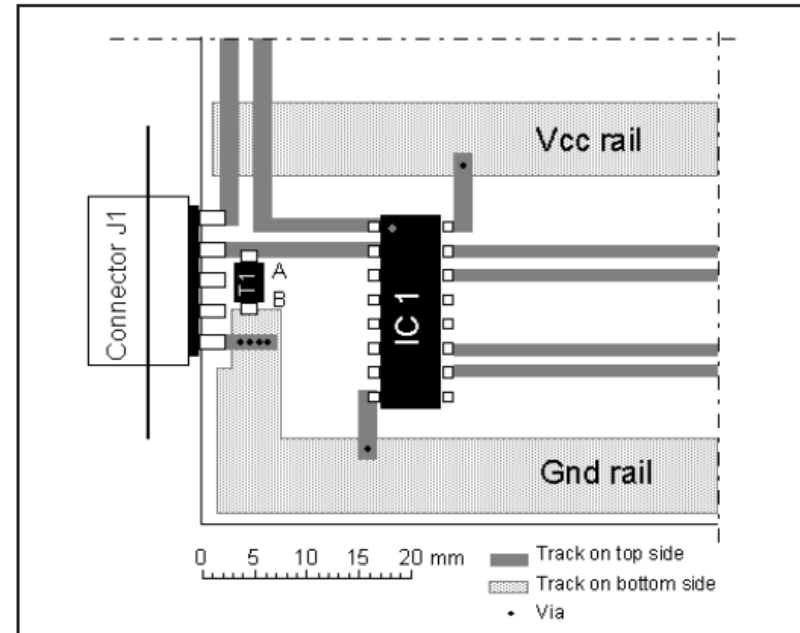
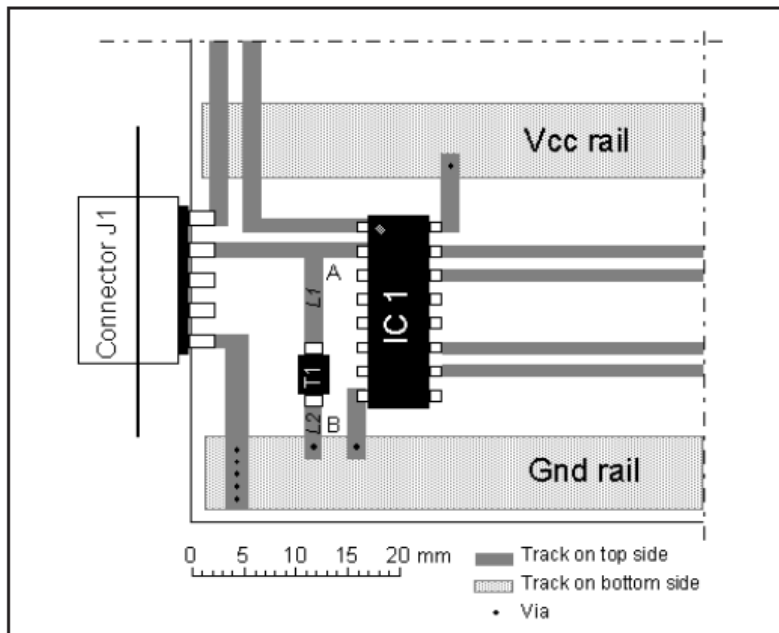


Surge protection

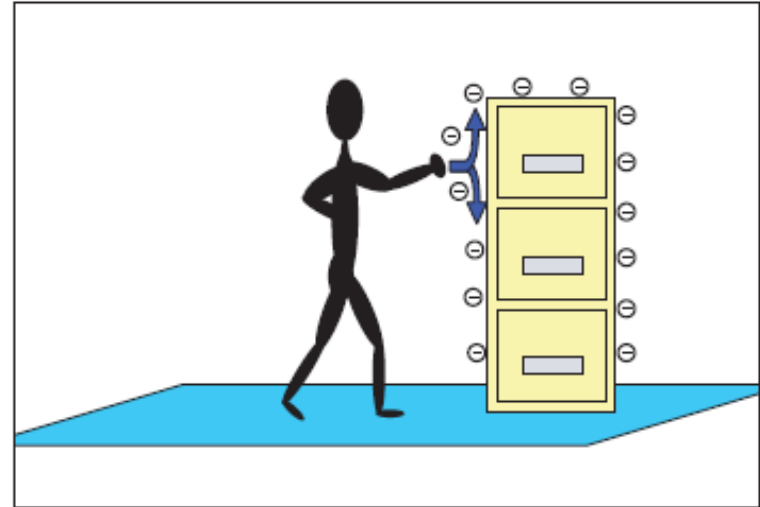
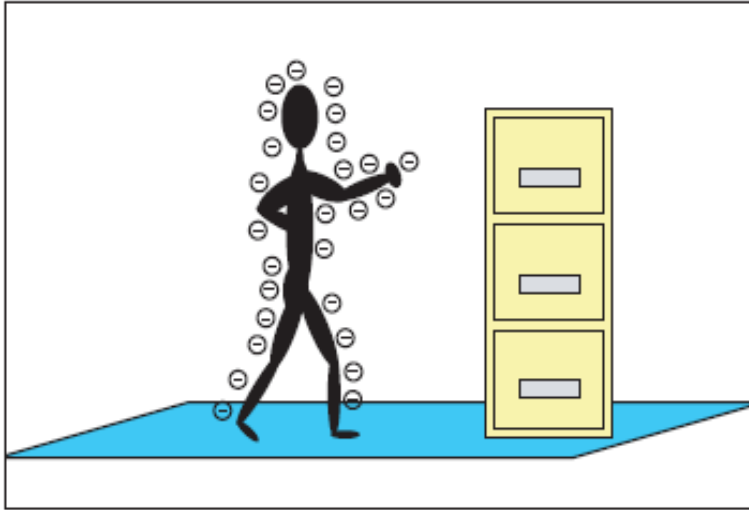


	TRANSIL	TRISIL
TYPE OF ACTION	CLAMPING	CROWBAR
ELECTRICAL CHARACTERISTICS		
SCHEMATICS		
ELECTRICAL BEHAVIOUR		
ACTION START	$V_{\text{surge}} > V_{BR}$	$V_{\text{surge}} > V_{BO}$
ACTION STOP	$V_{\text{surge}} < V_{BR}$	$I < \text{Holding Current}$

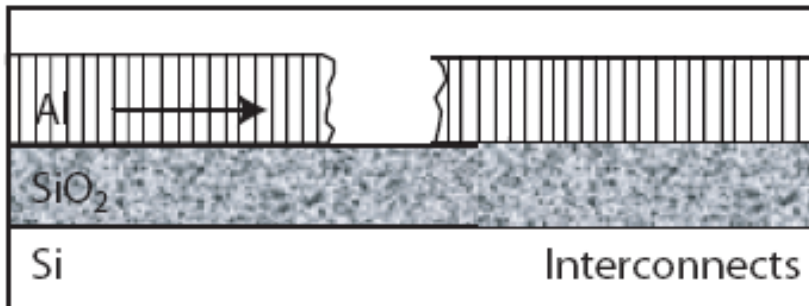
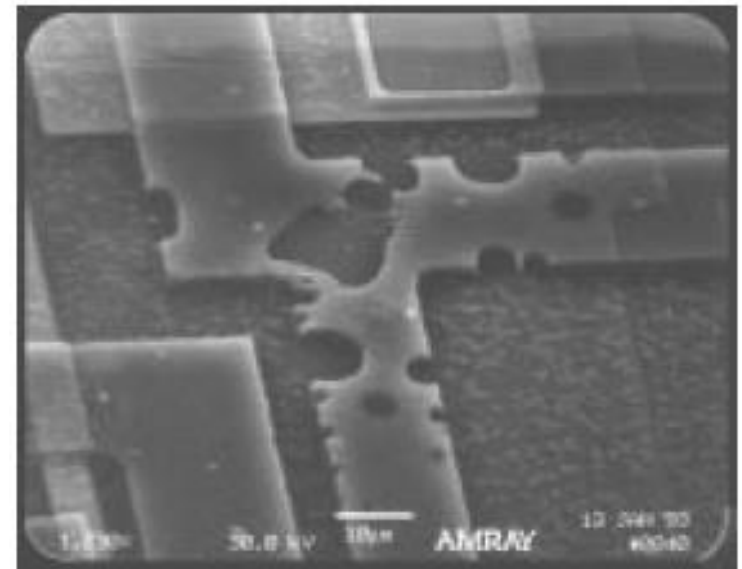
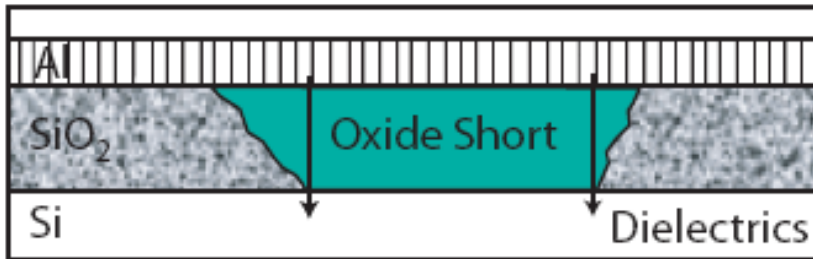
PCB topology effect



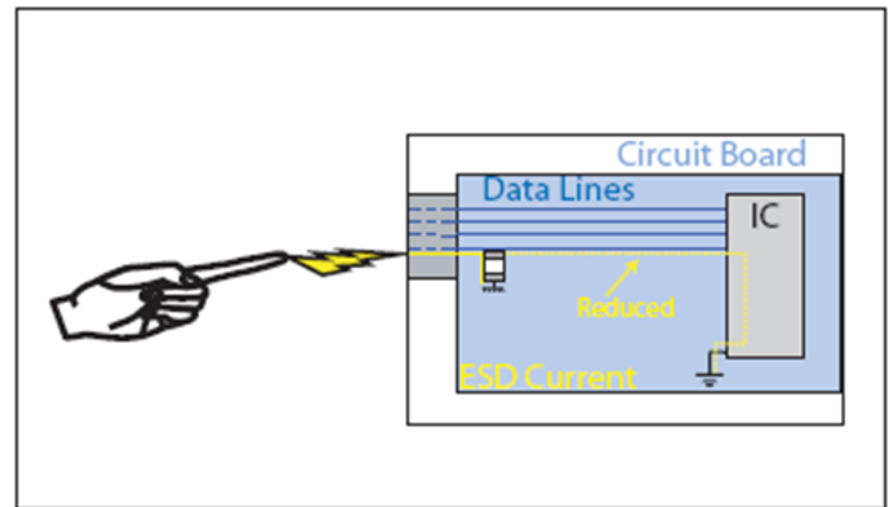
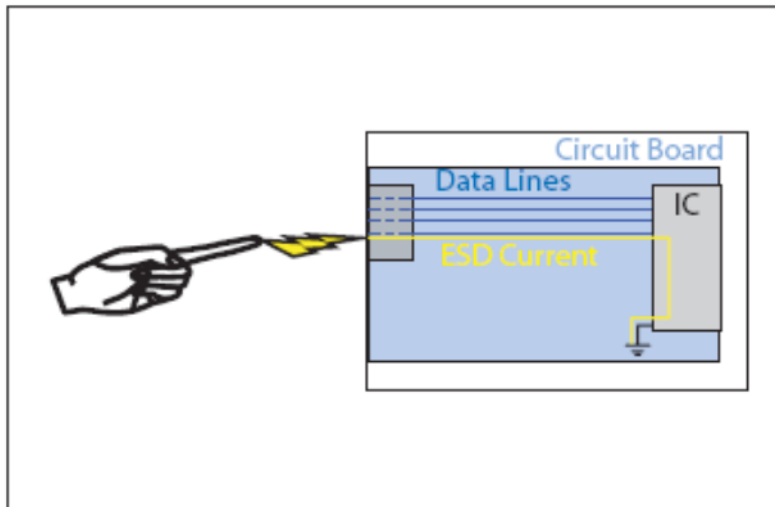
Electrostatic Discharge (ESD)



ESD impact



ESD impact





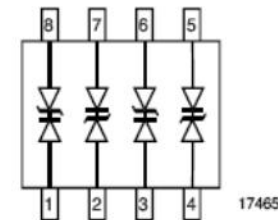
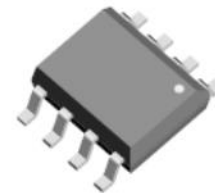
GCDA05

Vishay Semiconductors

Low Capacitance ESD Protection Diode Array for High-Speed Data Interfaces

Features

- Transient protection for data lines as per IEC 61000-4-2 (ESD) 15 kV (air) 8 kV (contact) IEC 61000-4-5 (Lightning) 12 A ($t_p = 8/20 \mu s$)
- Small package for use in portable electronics
- Protects two I/O lines
- Low capacitance for high-speed data lines
- Low leakage current



Mechanical Data

Case: SO-8 molded Plastic body

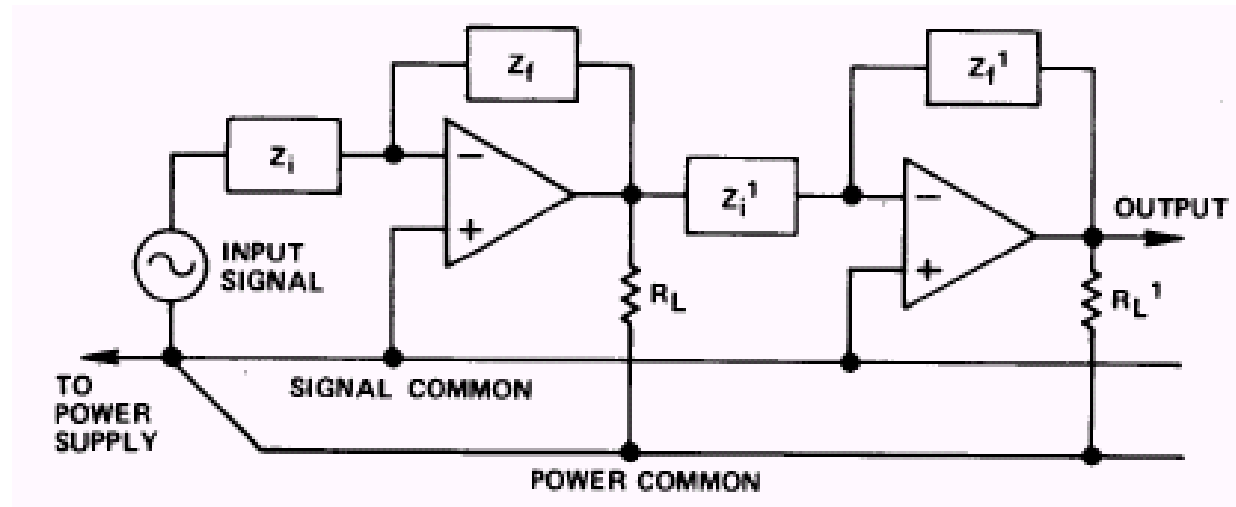
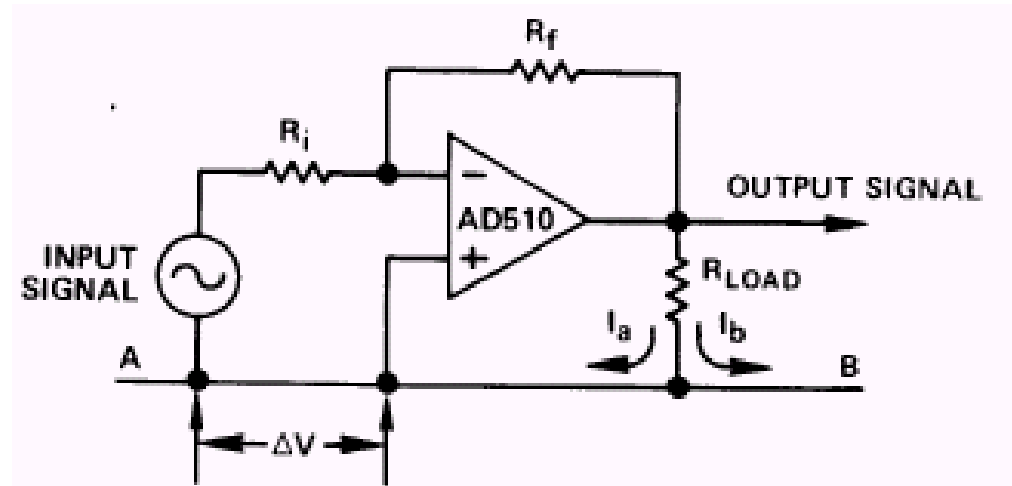
Molding Compound Flammability Rating:

UL 94 V-0

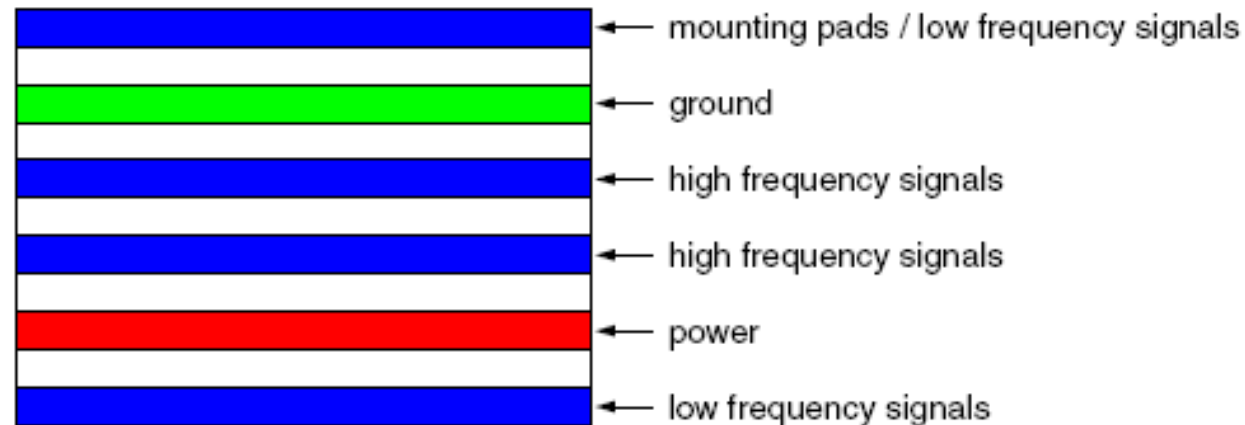
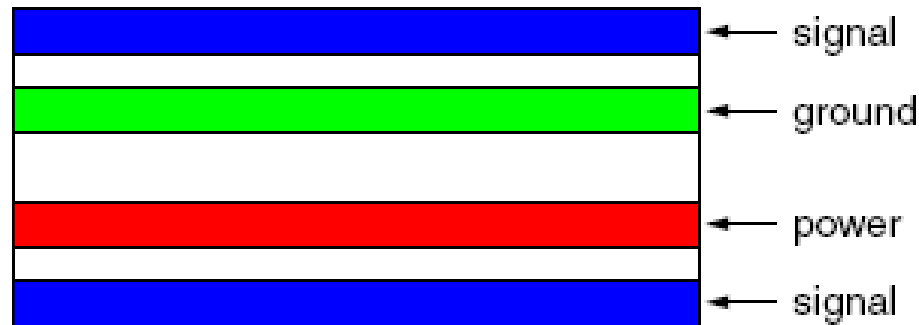
Terminals: High temperature soldering guaranteed:
260 °C/10 sec. at terminals

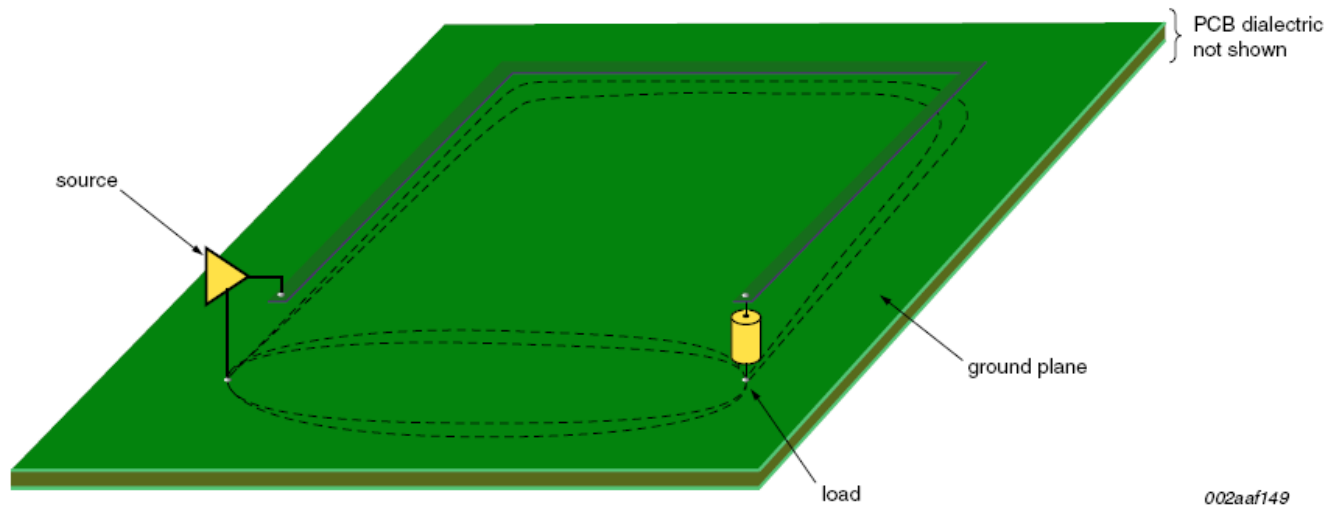
Weight: 0.5 g

Common wire

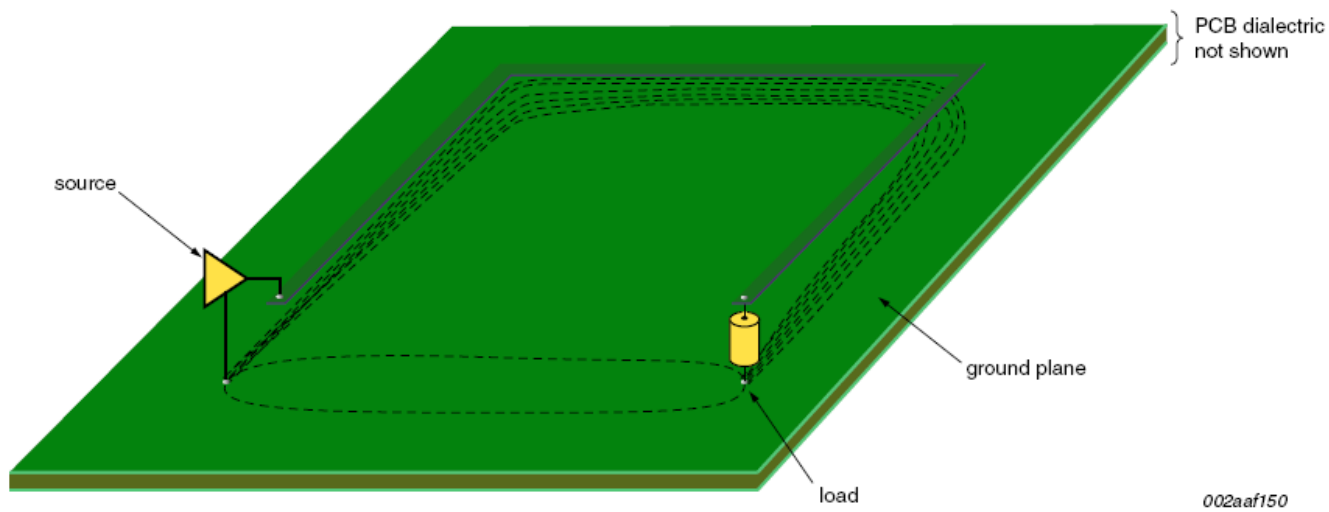


Printed circuit boards

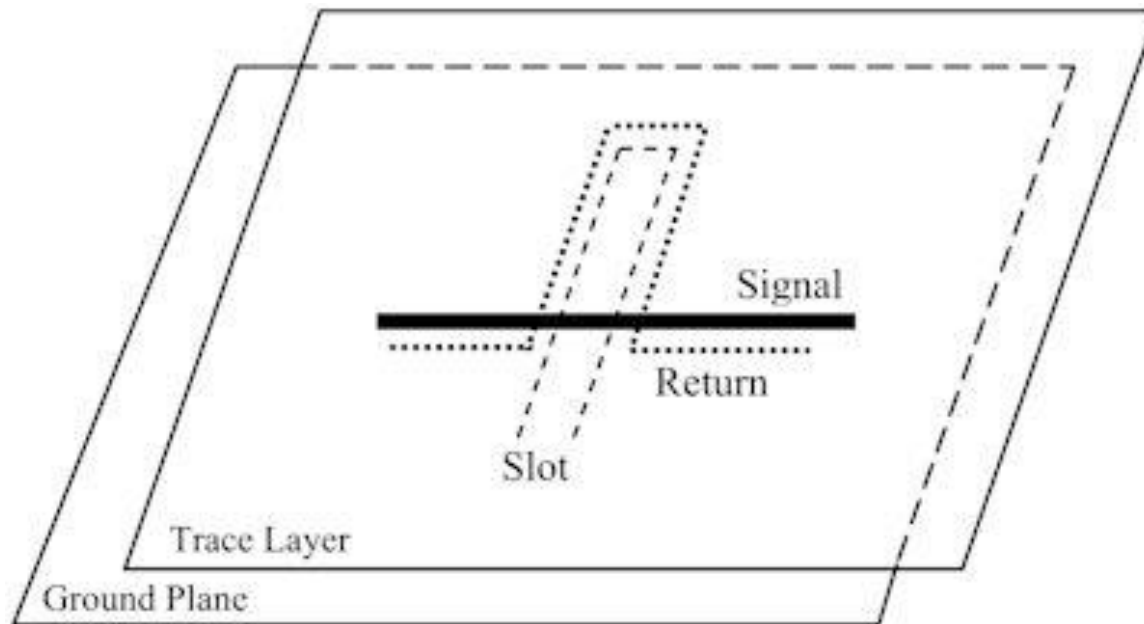




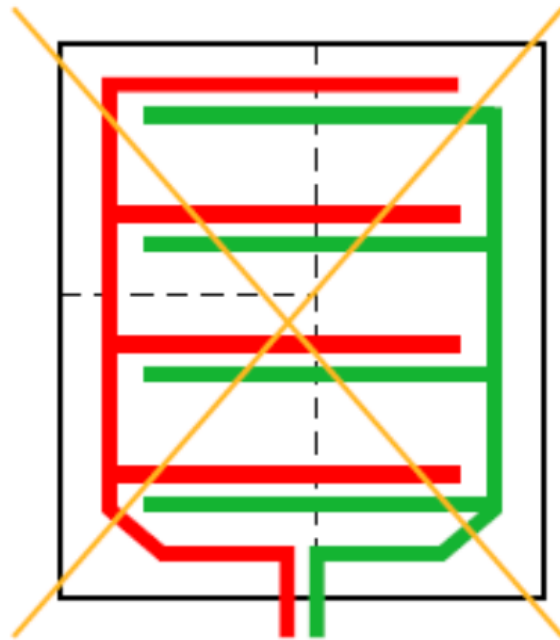
a. Low frequency



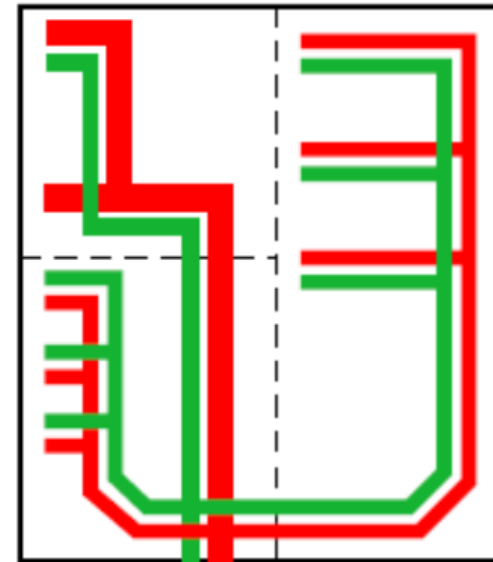
Return current



Which topology is better ?



NO



GND V_{CC}

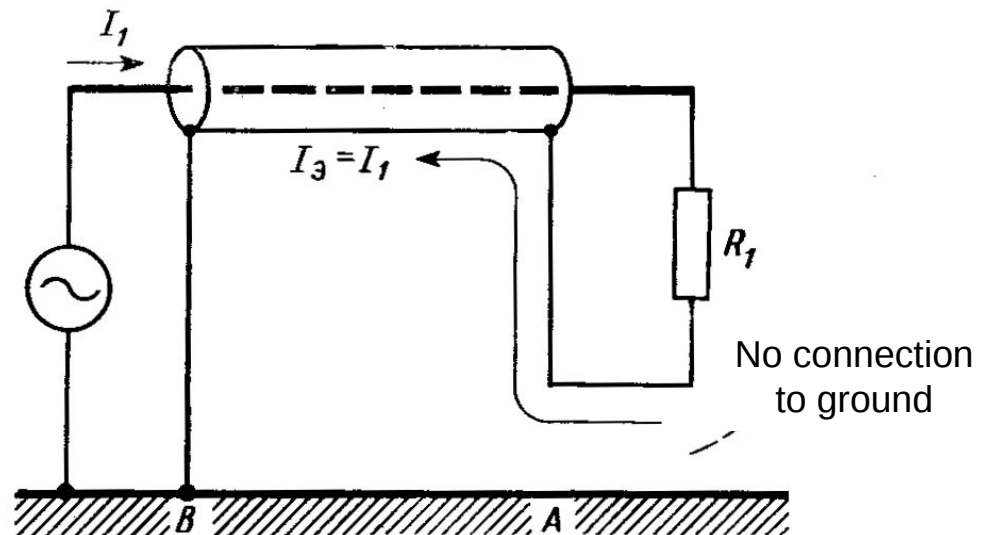
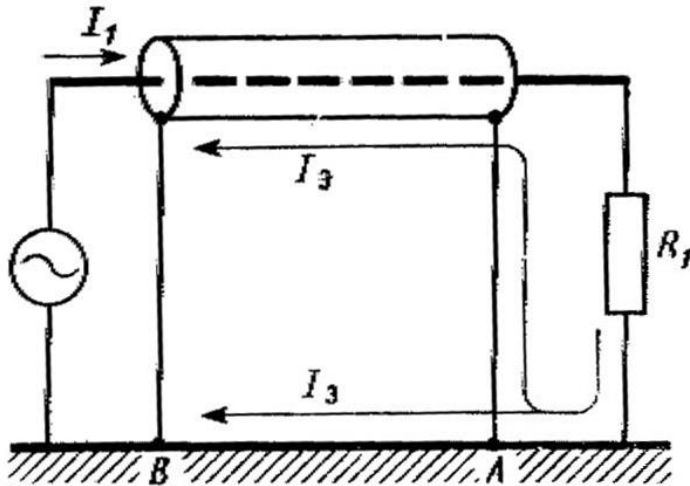
YES

002aae903

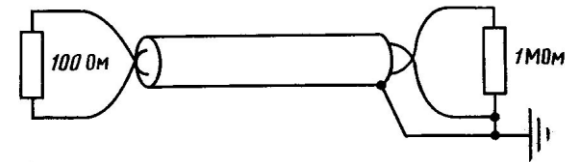
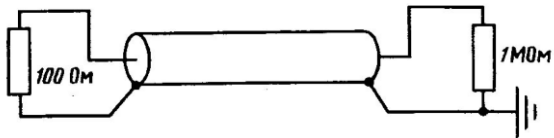
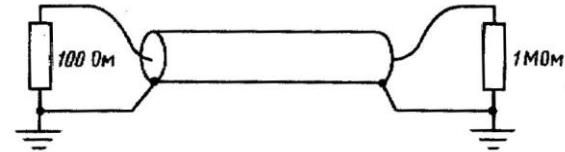
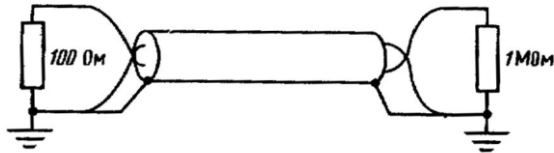
Power and ground routing

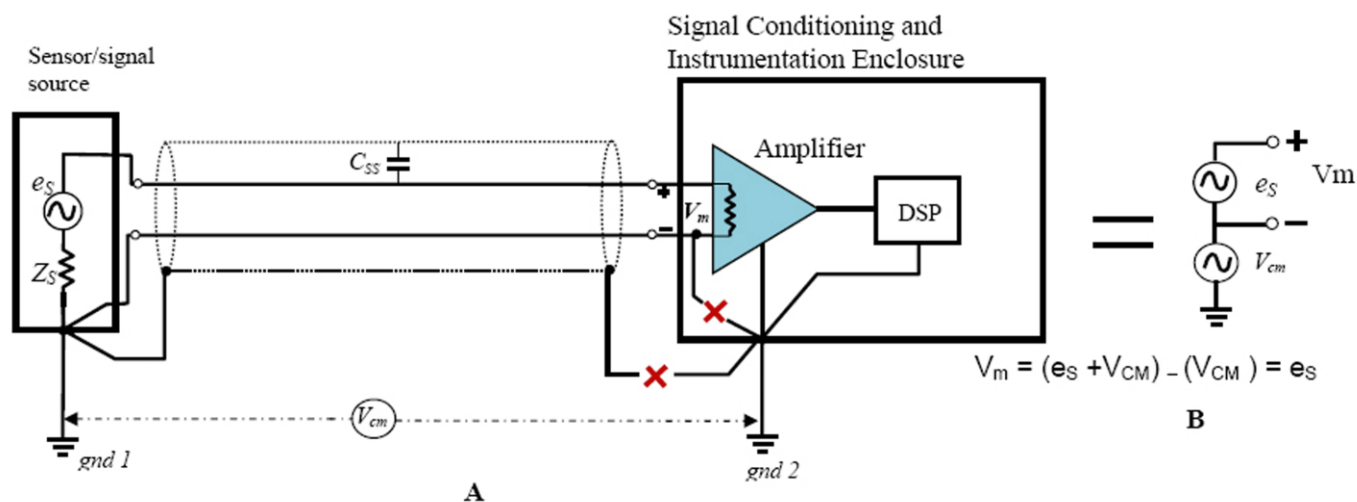
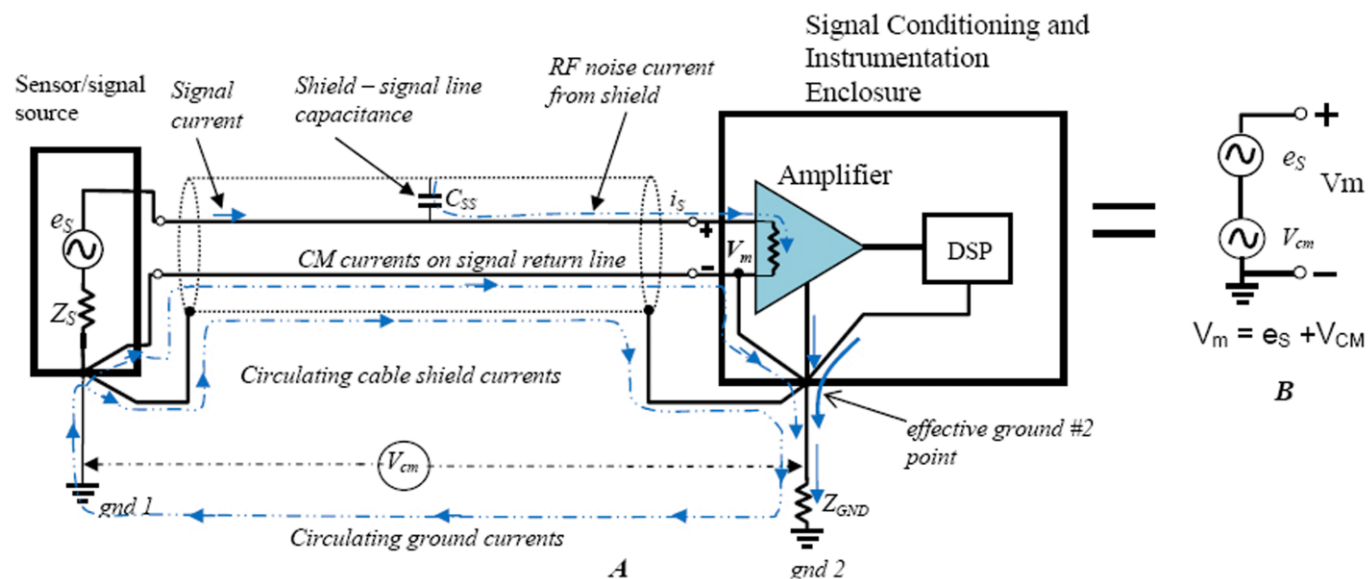
SHIELDING

Shield currents



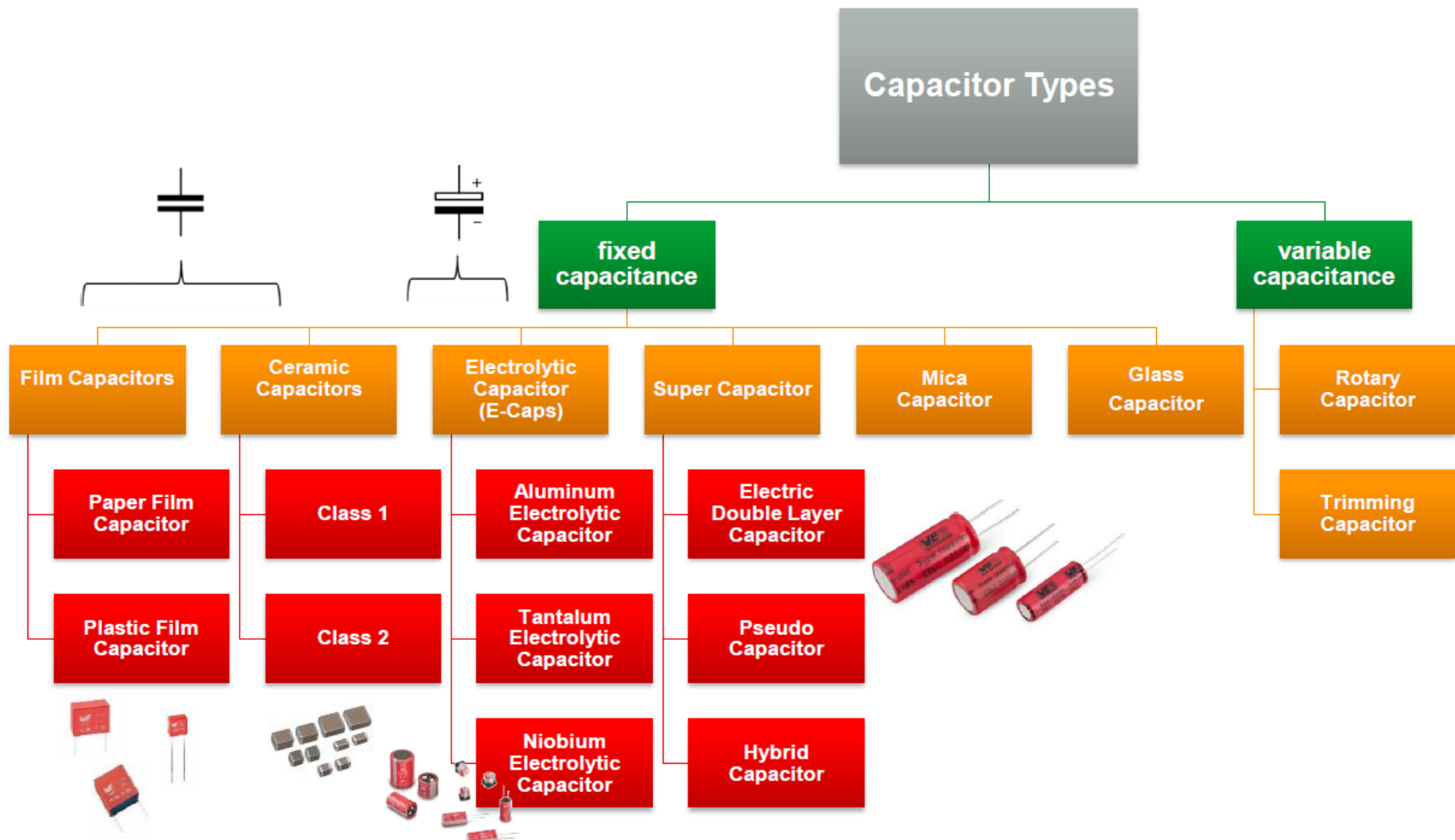
Shielding options



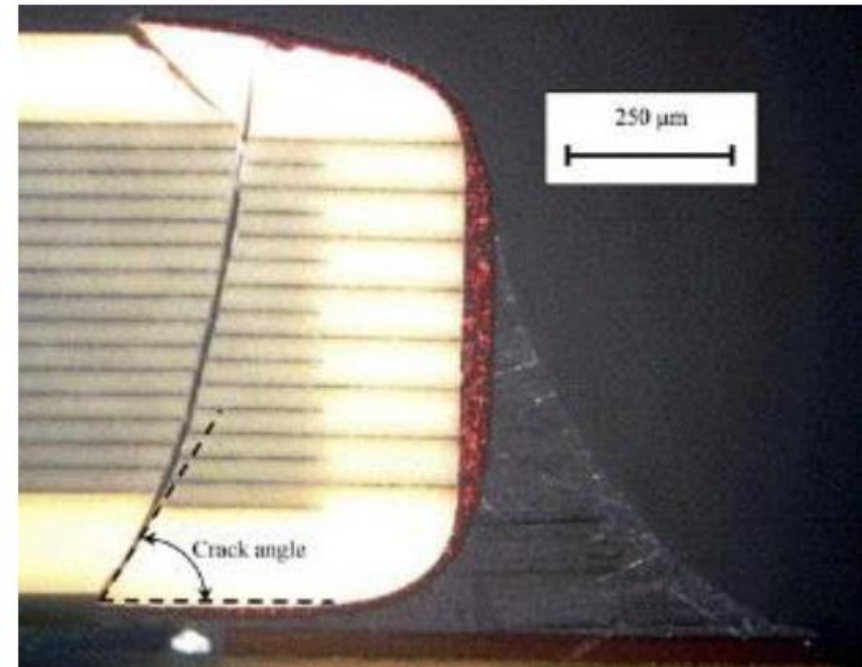
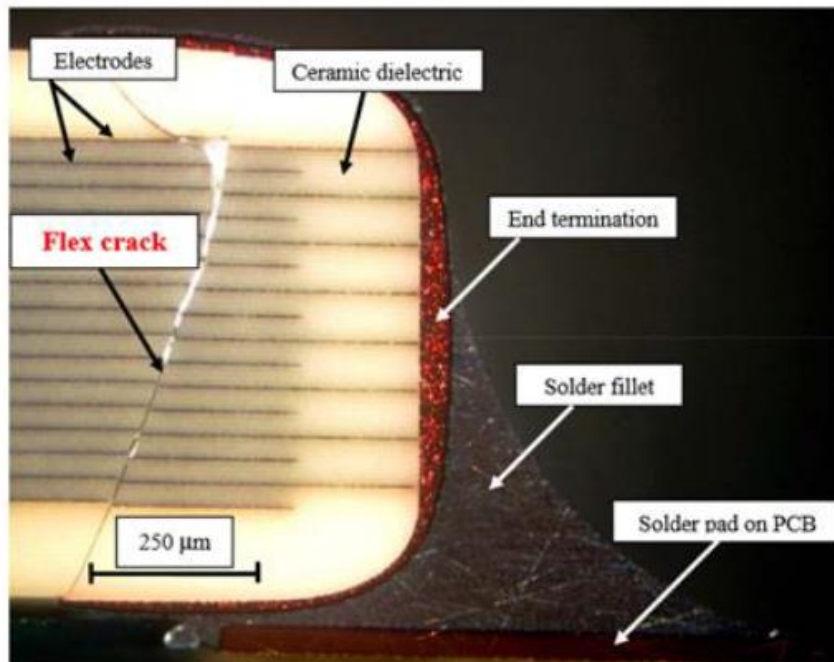


PASSIVE COMPONENTS

Capacitor Types



MLCC underwater rocks Cracking



Differences Class 1 and Class 2 Ceramic

	Class 1	Class 2
Material:	Titanium Dioxide (TiO_2)	Barium Titanate ($BaTiO_3$)
Permittivity:	>10 ... 500	>500 ... > 10000
Capacity range:	1pF - 33nF	100pF - 100μF
Voltage range:	10V - 50V	6,3V - 100V
Size:	0402 - 1812	0402 - 1812
Voltage dependency:	No	Yes
Frequency dependency:	Yes	Yes
Temperature dependency:	No	Yes
Aging:	No	Yes

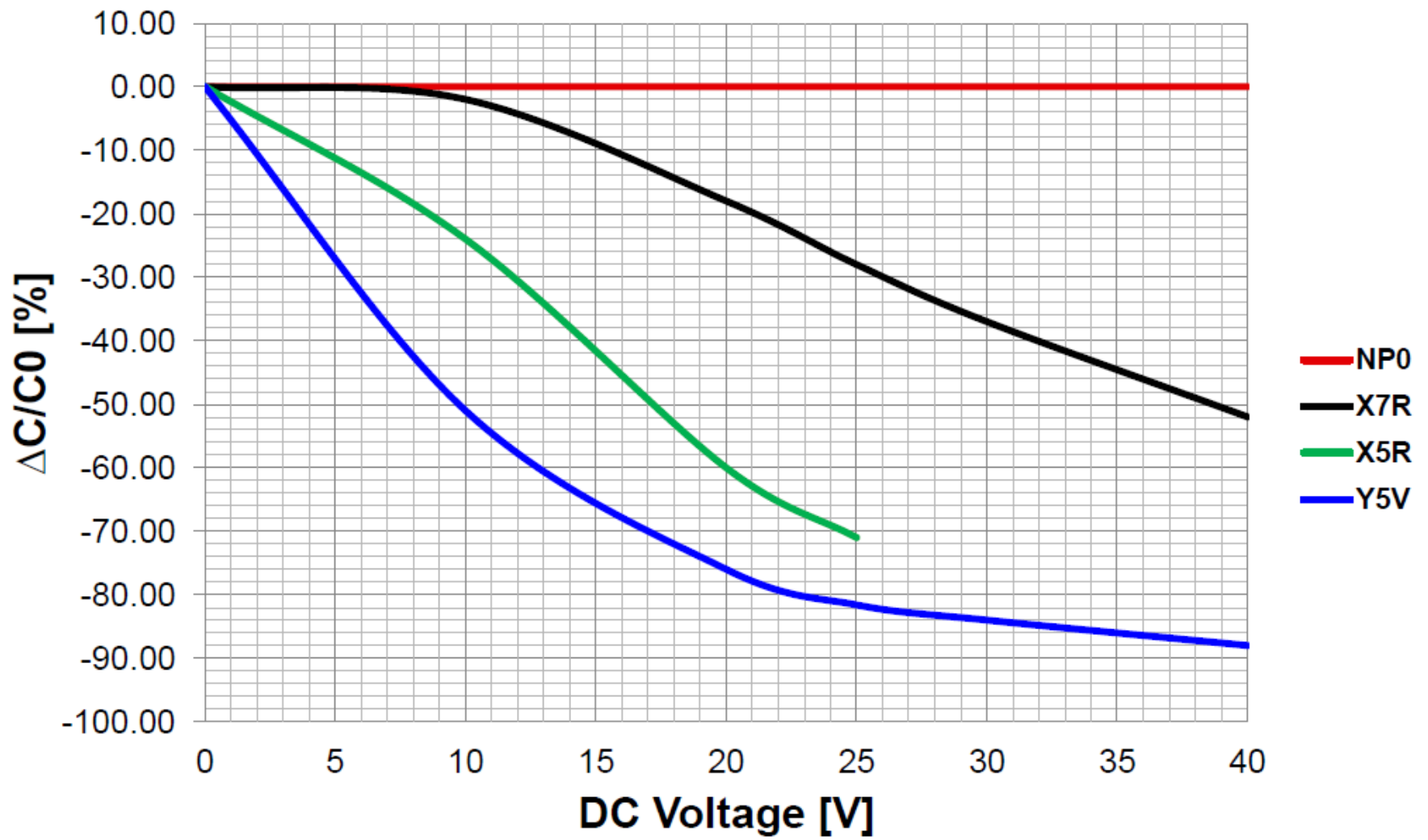
Coding of Class 1 Ceramics

IEC 60384-21 coding for class 1 ceramics			
Coding			
Identifier	Temperature coefficient TC [ppm/°C]	Tolerance of the temperature coefficient TC [ppm/°C]	Equivalent EIA-RS-198 coding
P100	100	±30	M7G
NP0	0	±30	C0G
N33	-33	±30	S2G
N75	-75	±30	U1G
N150	-150	±60	P2H
N220	-220	±60	R2H
N330	-330	±60	S2H
N470	-470	±60	T2H
N750	-750	±120	U2J
N1000	-1000	±250	M3K
N1500	-1500	±250	P3K

Coding of Class 2 Ceramics

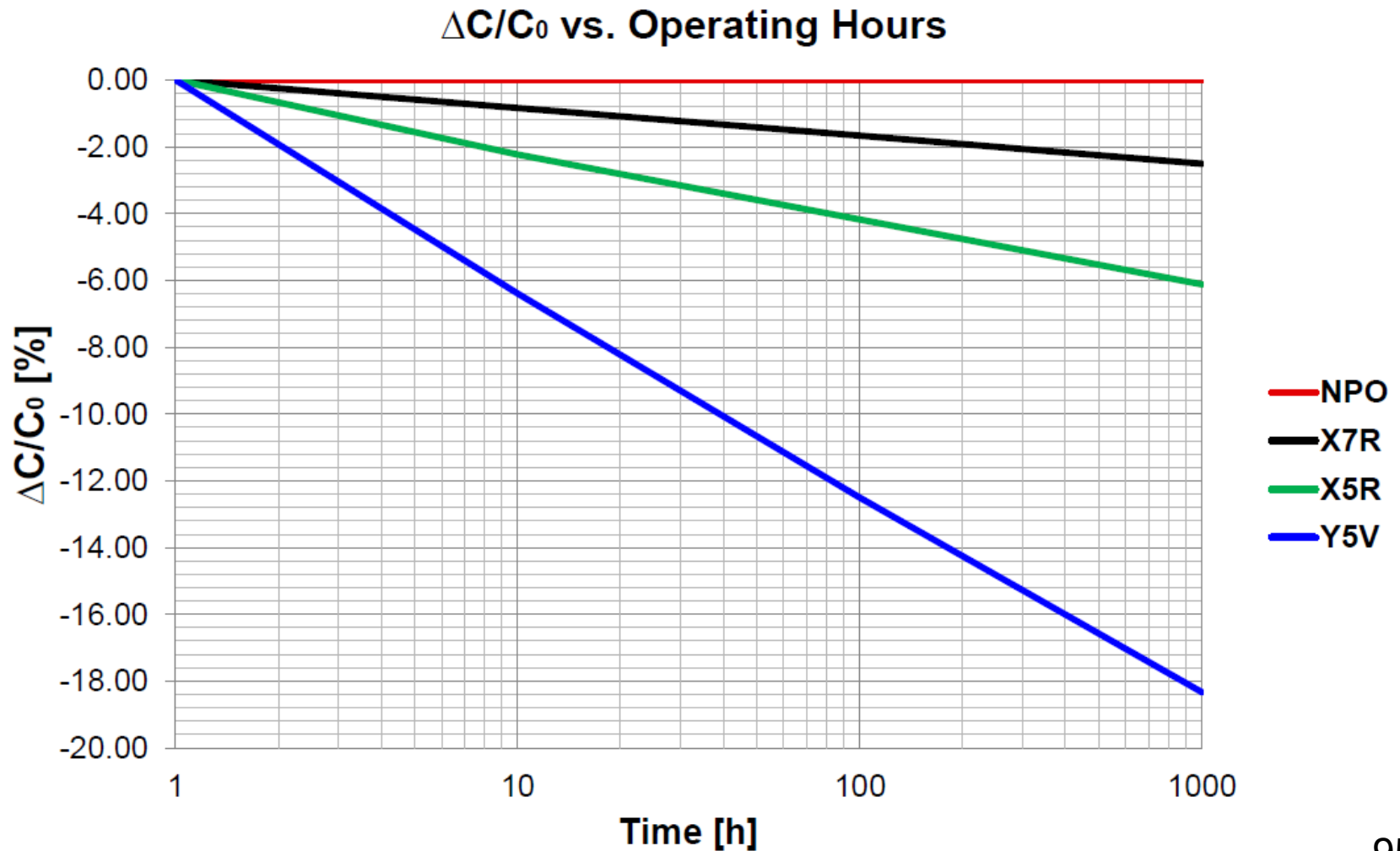
EIA-RS-198 coding for class 2 ceramic capacitors					
1st character		2nd character		3rd character	
Letter	Lower temperature limit	Number	Upper temperature limit	Letter	Capacitance change over the permissible temperature range
X	−55 °C	2	+45 °C	A	±1.0%
Y	−30 °C	4	+65 °C	B	±1.5%
Z	+10 °C	5	+85 °C	C	±2.2%
		6	+105 °C	D	+3.3%
		7	+125 °C	E	+4.7%
		8	+150 °C	F	+7.5%
		9	+200 °C	P	±10%
				R	±15%
				S	±22%
				T	+22/−33%
				U	+22/−56%
				V	+22/−82%

$\Delta C/C_0$ vs. DC Voltage

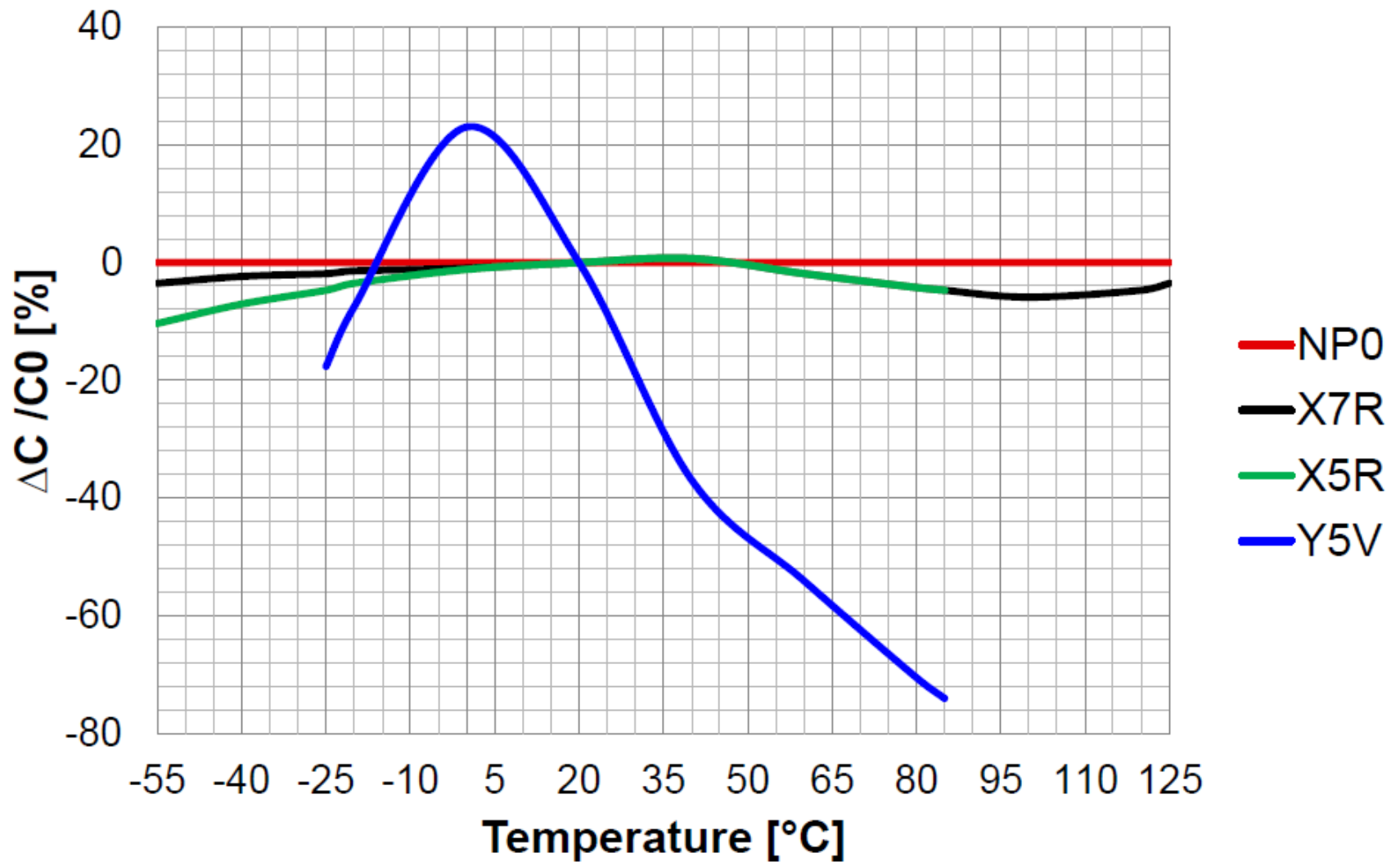


MLCC underwater rocks

Aging



$\Delta C/C_0$ vs. Temperature



Thank you for your attention !



Relax...