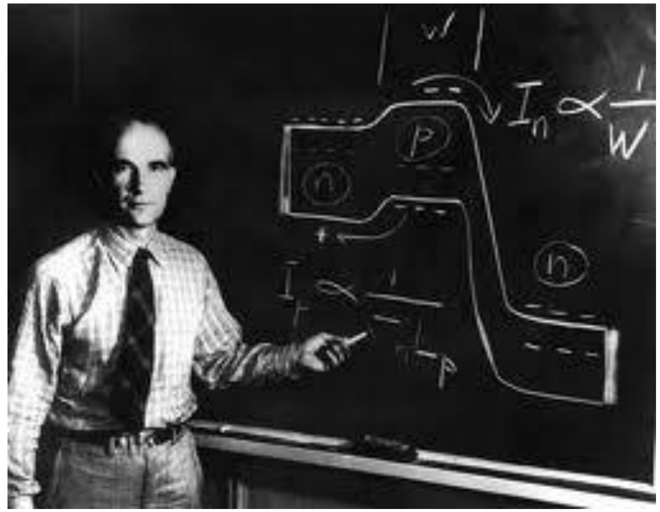
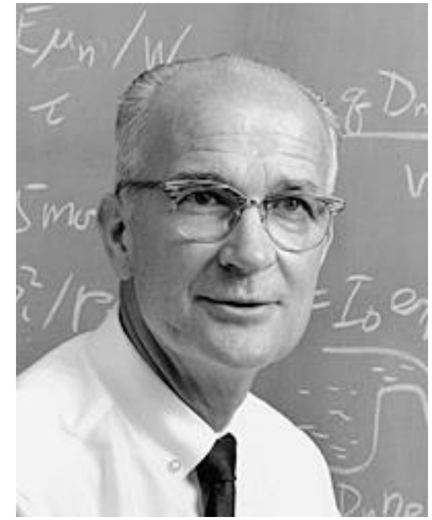
Electronic systems

Samara, 2023

Some historical information





1947

Fathers of modern transistors:

John Bardeen 1908-1991

William Shockley 1910-1989

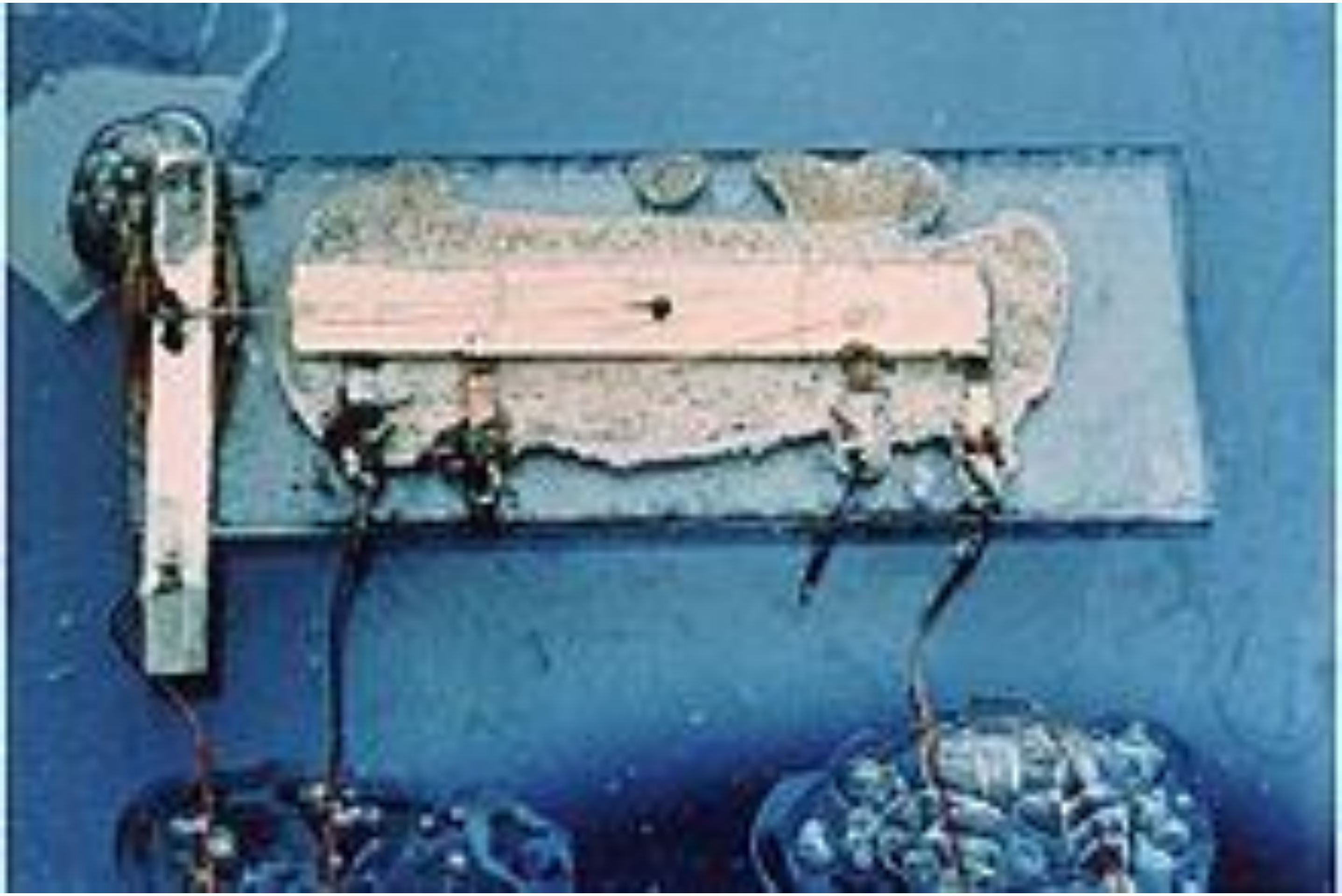
Walter Brattain 1902-1987

Robert Noyce & John Kilby

1927-1990

1923-2005

Kilby’s first IC



THE IMPROVED μA702 WIDEBAND DC AMPLIFIER

by R. J. Widlar

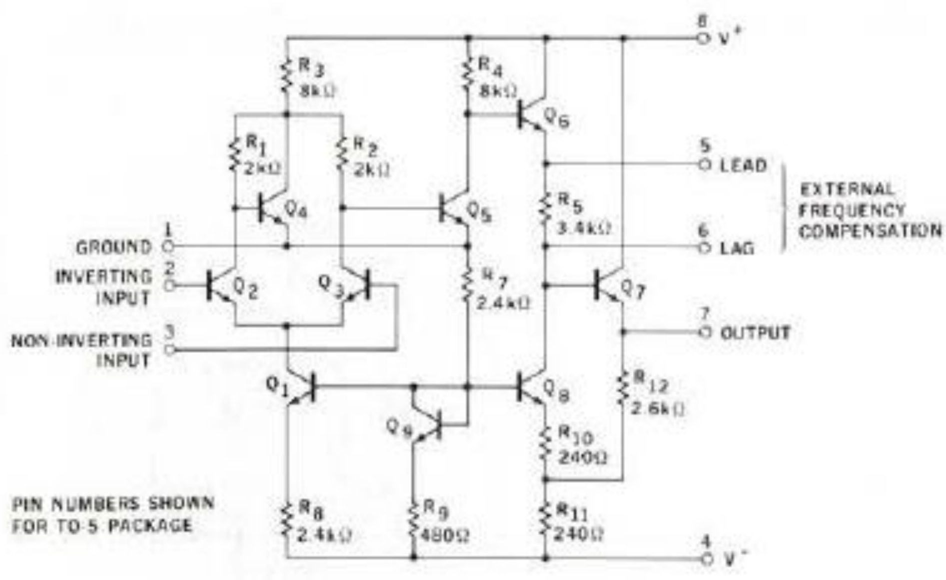
I INTRODUCTION

This paper describes an improved version of the μA702 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 μA702A 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).

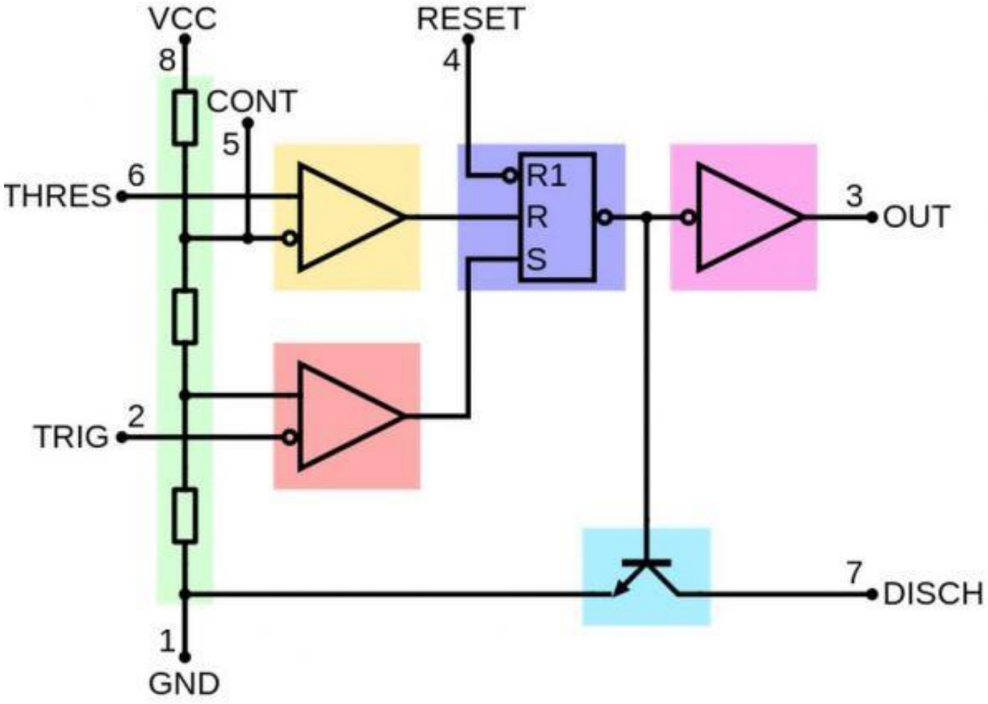
Other changes were more subtle: relocation of components to insure improved matching; lower offsets



Robert Widlar

1937-1991

Hans Kamenzind 1934-2012



Electronic systems in nano/microsatellites typically perform:

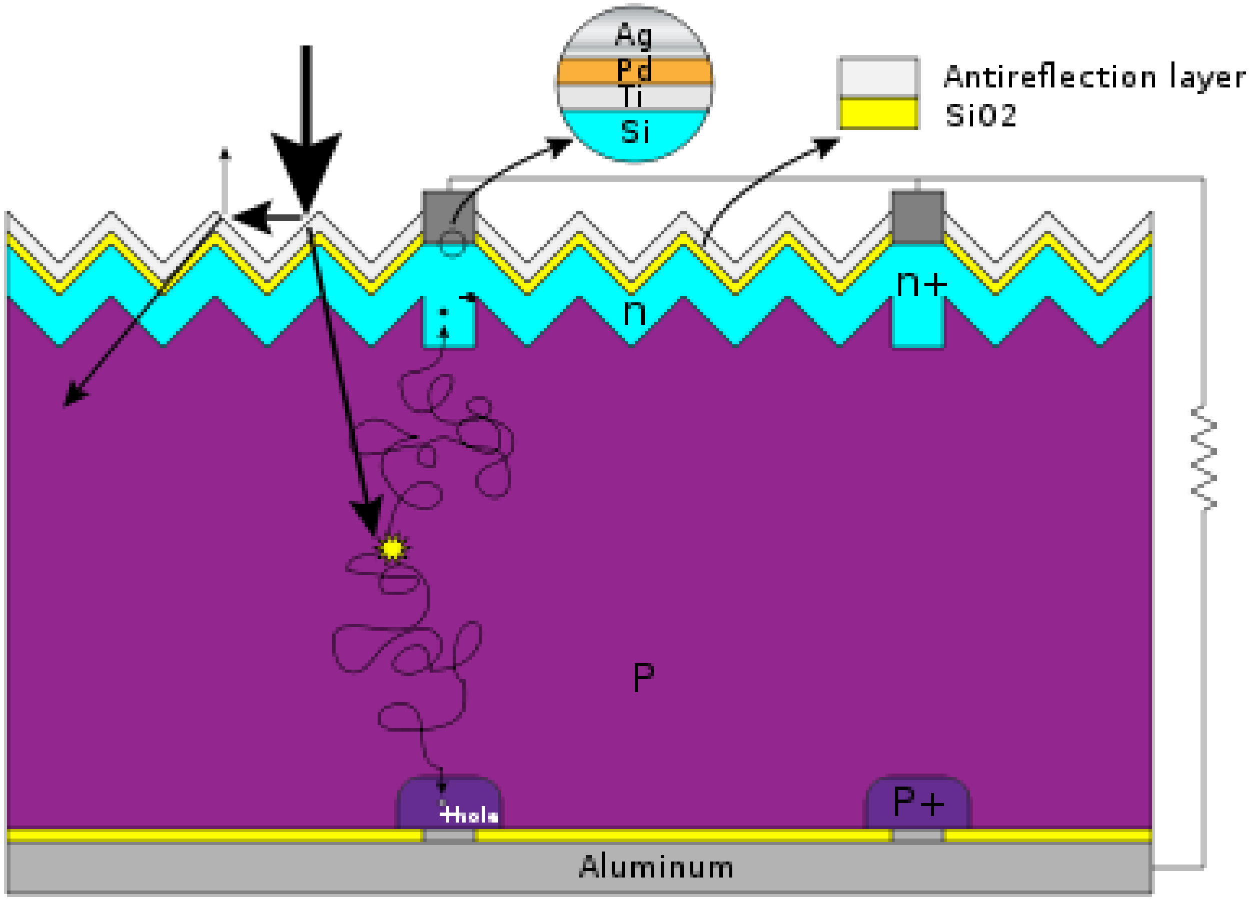
- Power control
- Collection, processing and storing data
- Communication
- Auxiliary functions, providing specific needs

POWER SYSTEMS

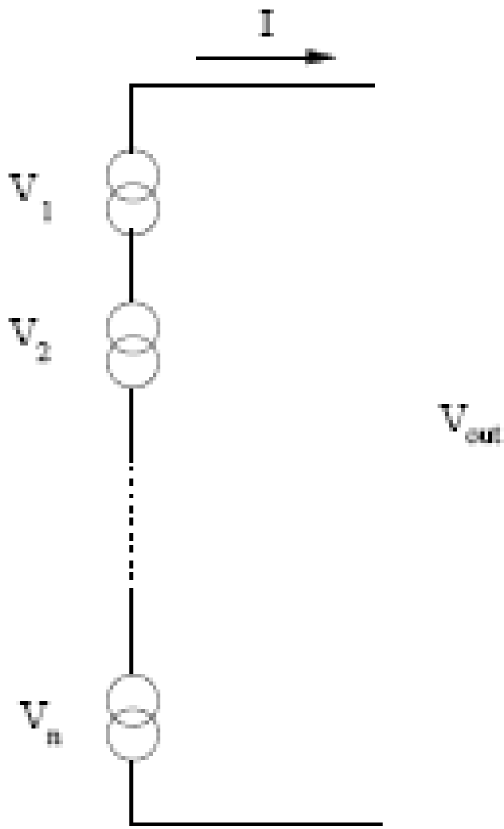
Primary power sources

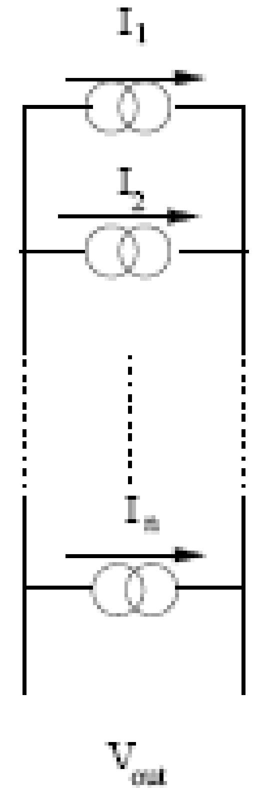
- Solar batteries
- Chemical sources:
  - Batteries;
  - Accumulators;
  - Fuel cells
- Thermo elements

Solar battery structure

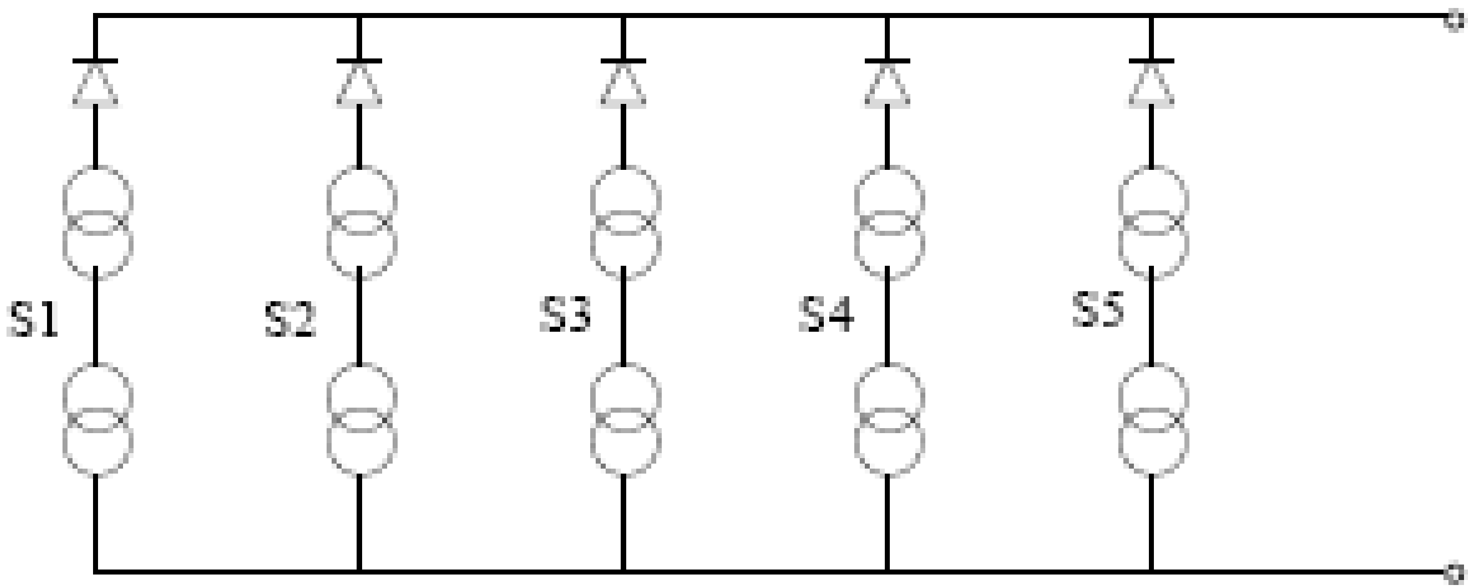


Connection of the batteries

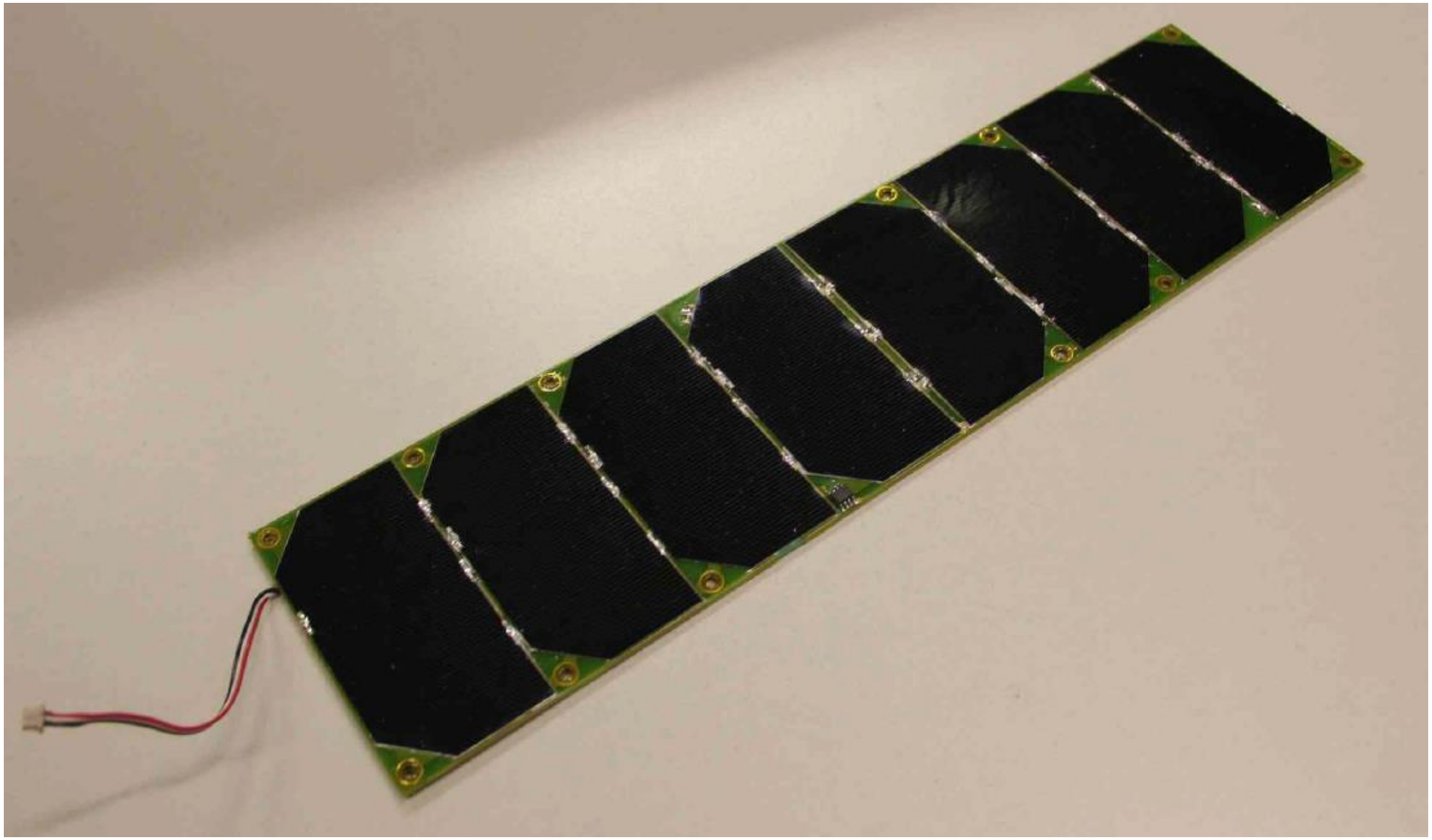




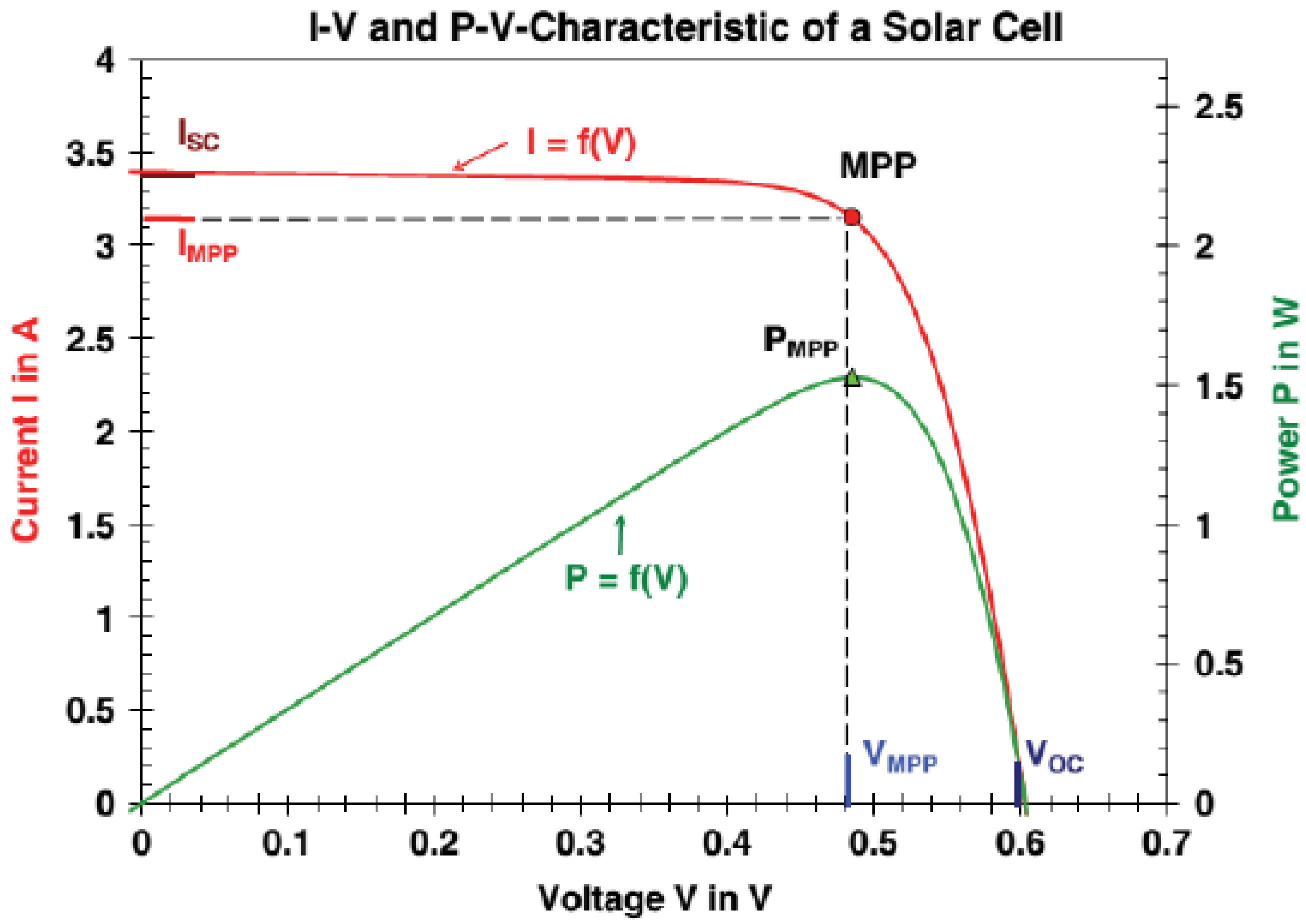
Cubesat circuit



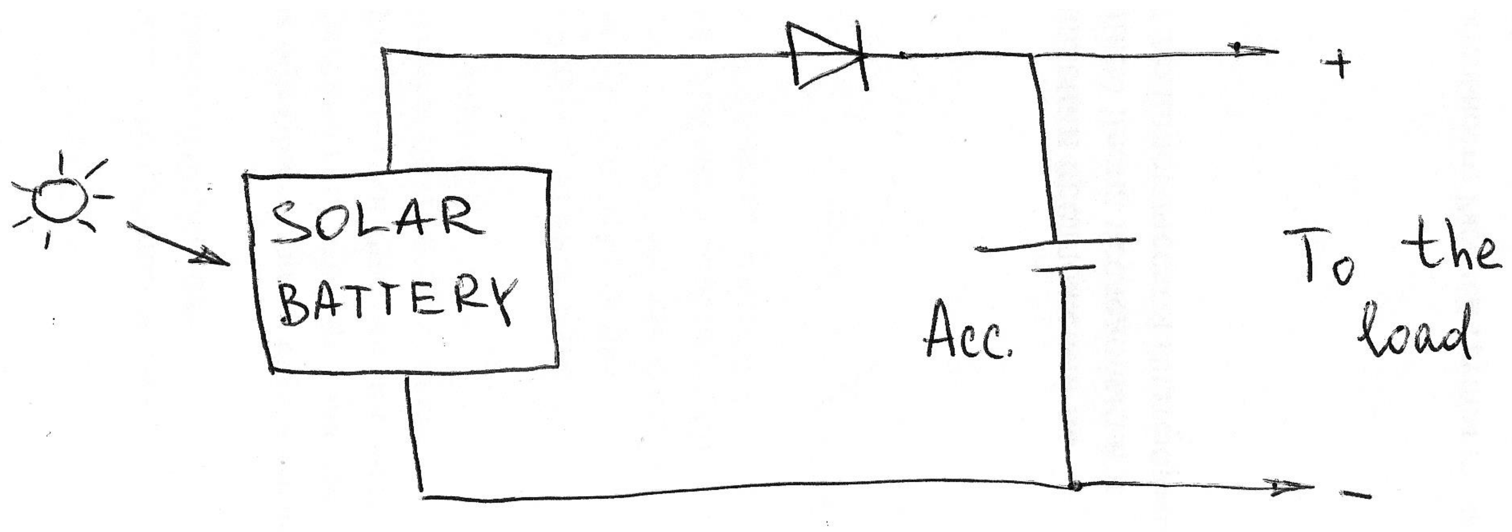
Aalto-1 solar panel



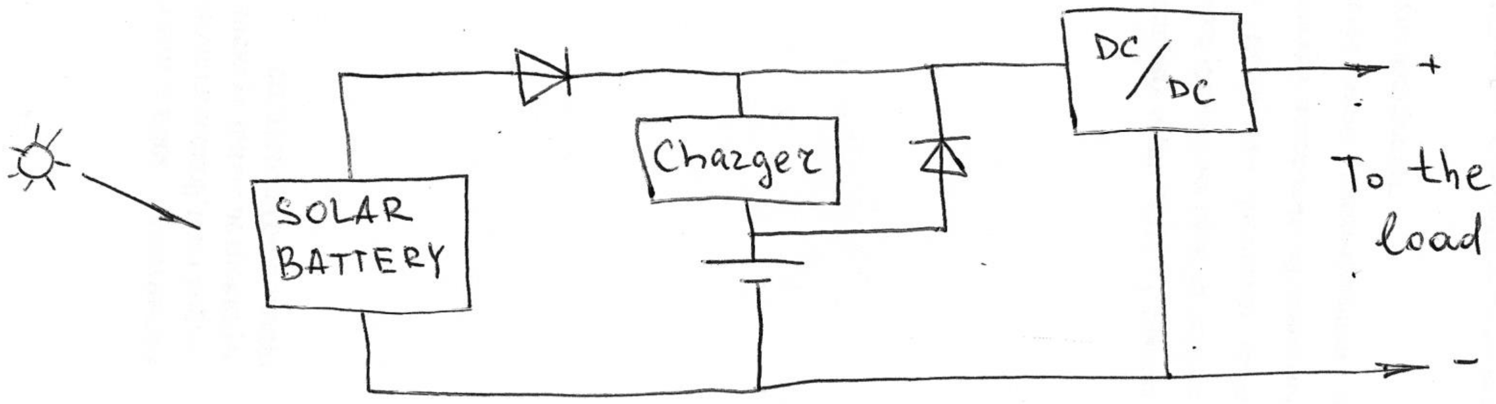
Current-voltage curve of solar battery



Power circuit without voltage control



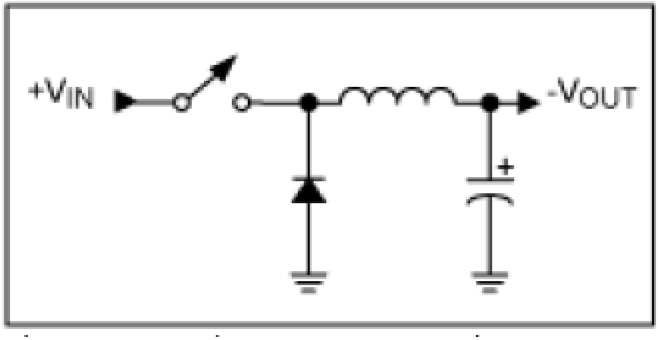
Circuit with voltage regulation



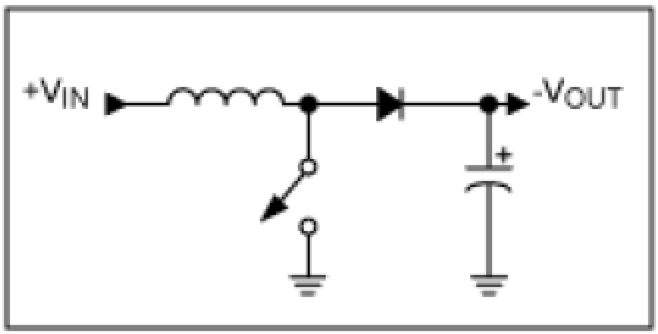
How do you choose?

	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

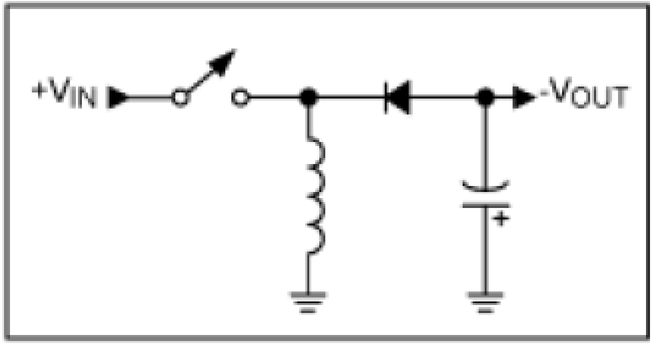
Simple DC/DC Converters



Chopper (buck converter)

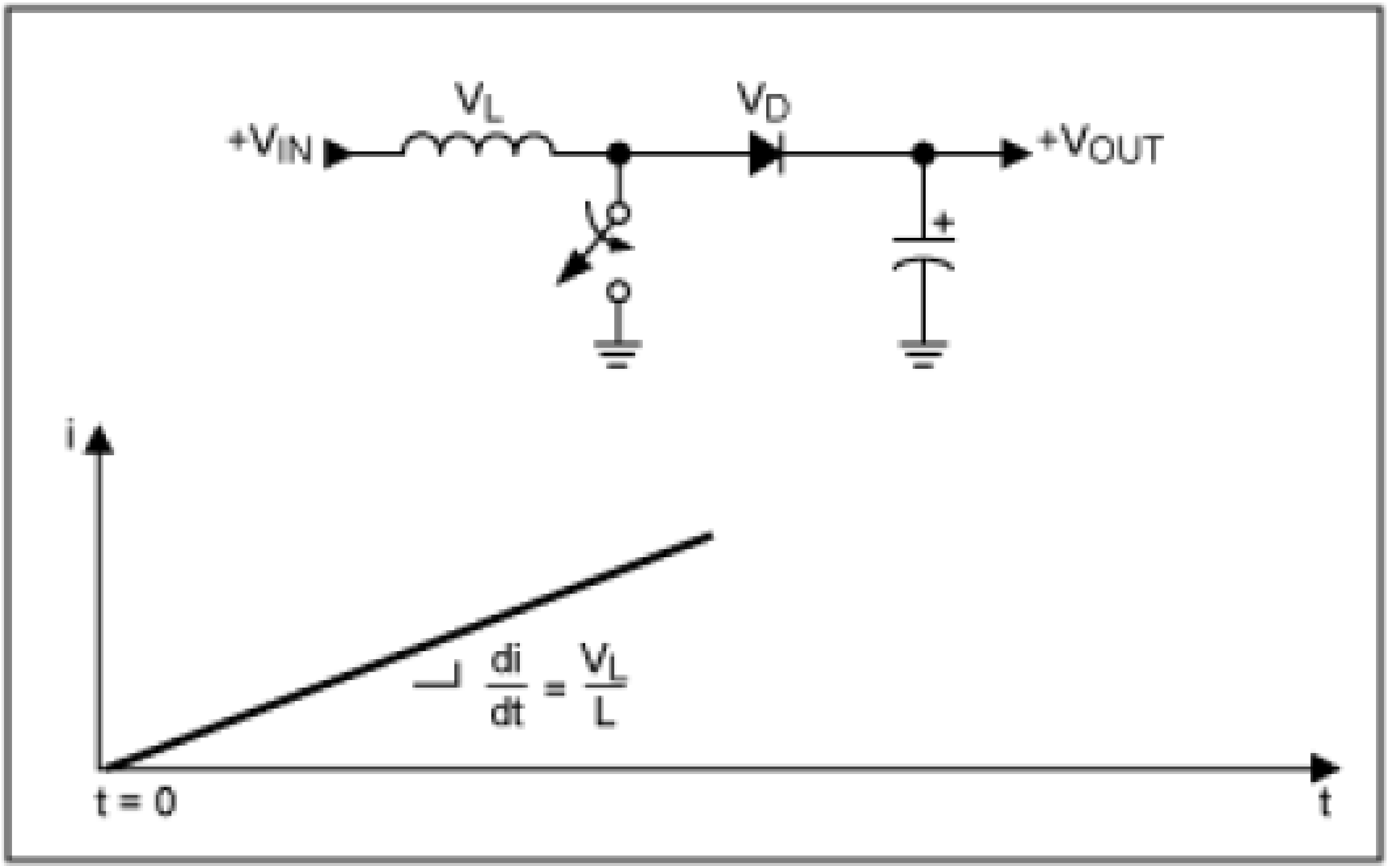


Booster

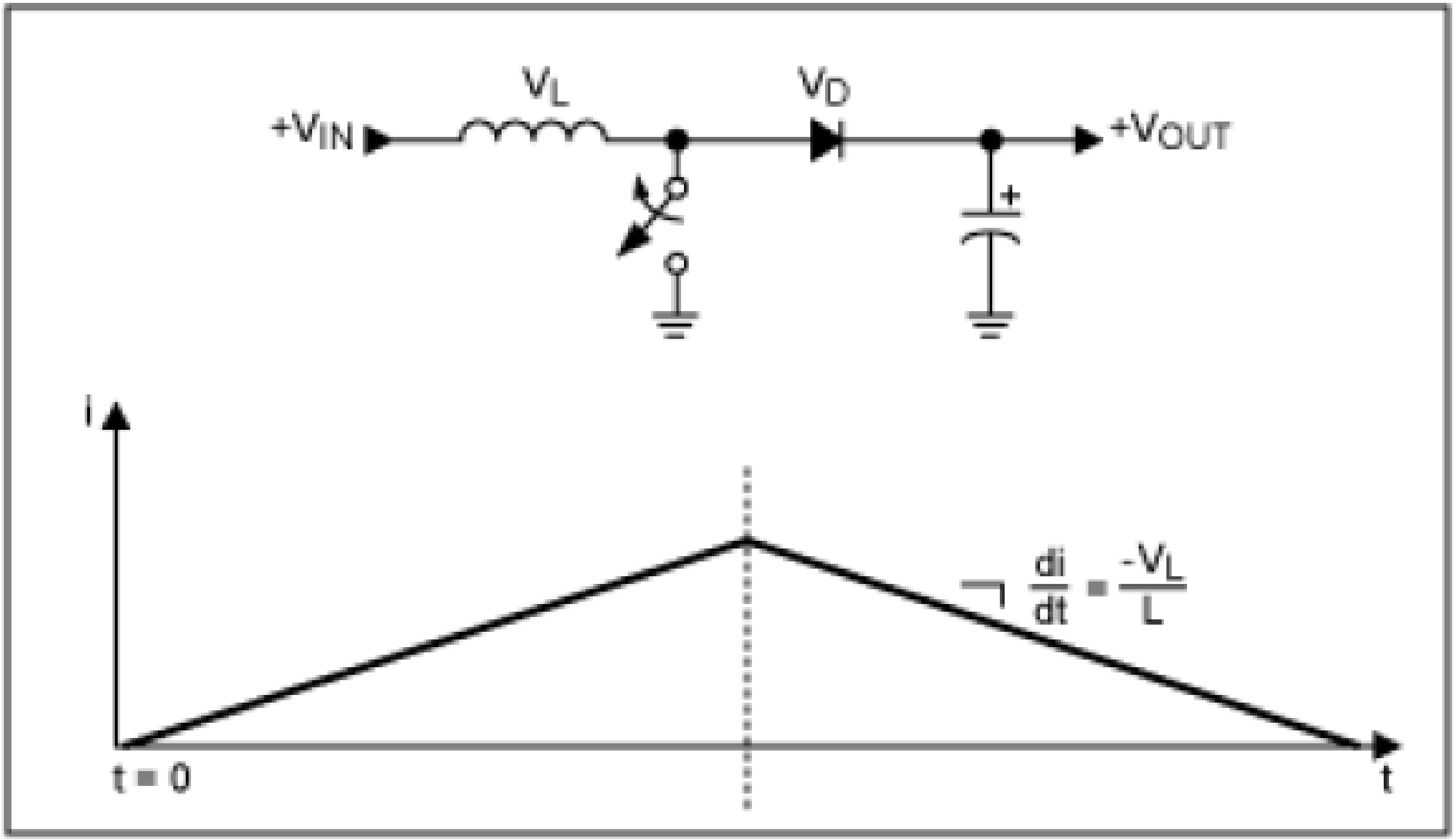


Inverter

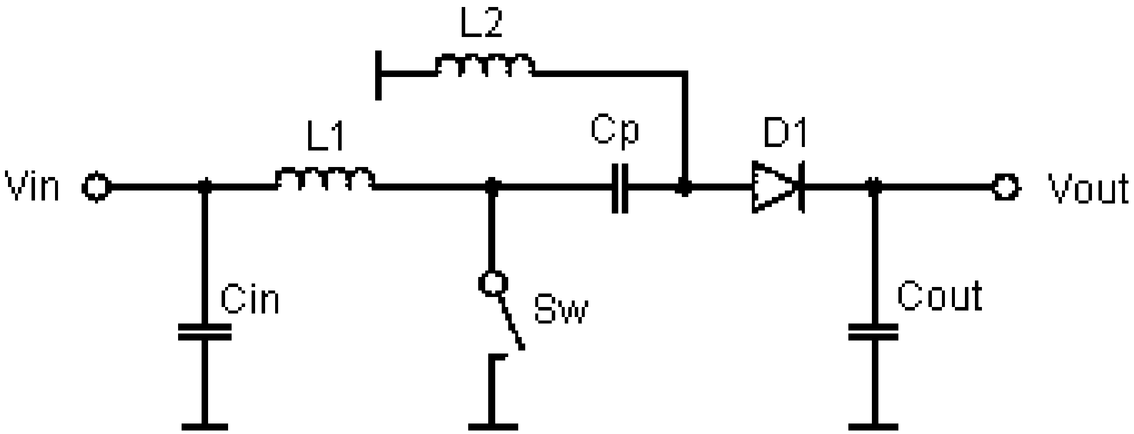
Charge phase

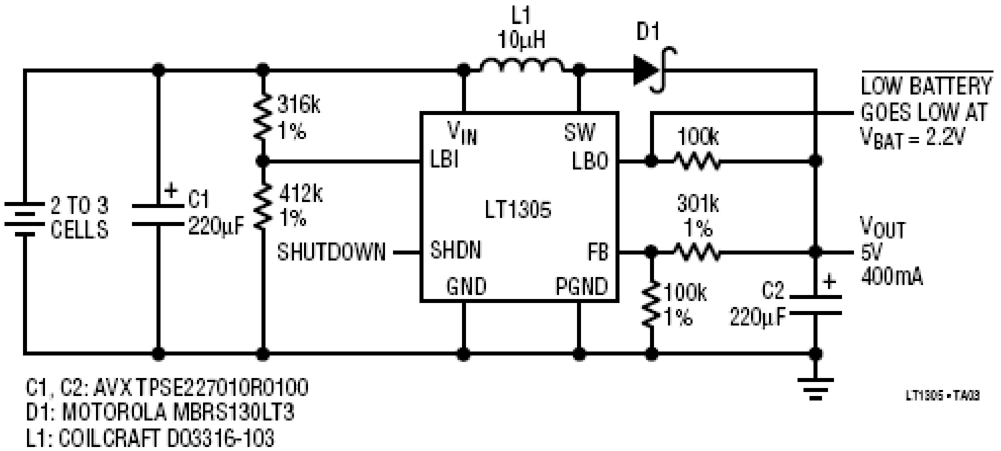


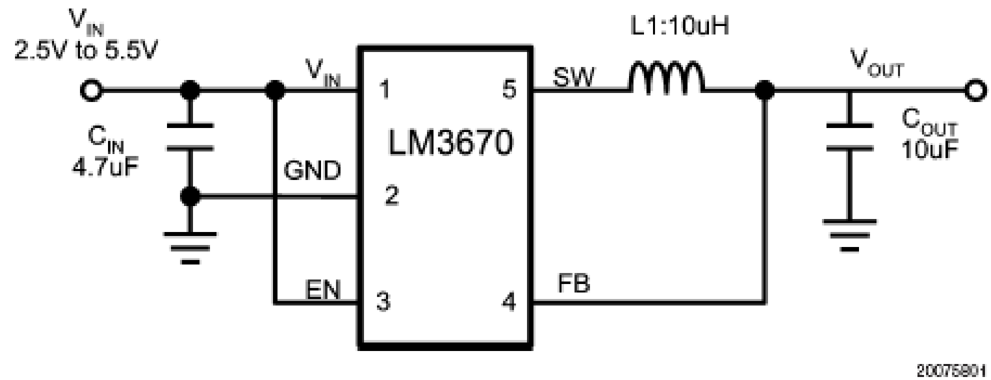
Discharge phase

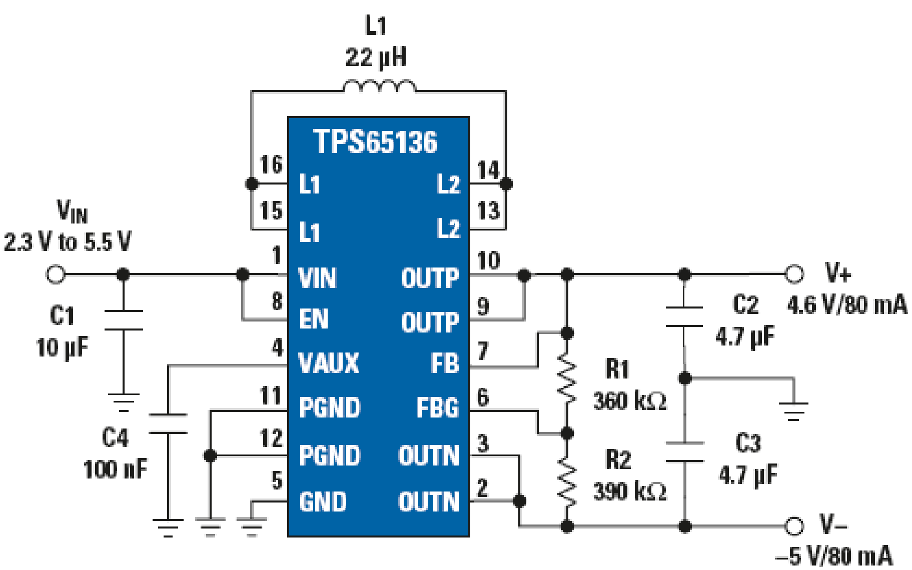


SEPIC Converter



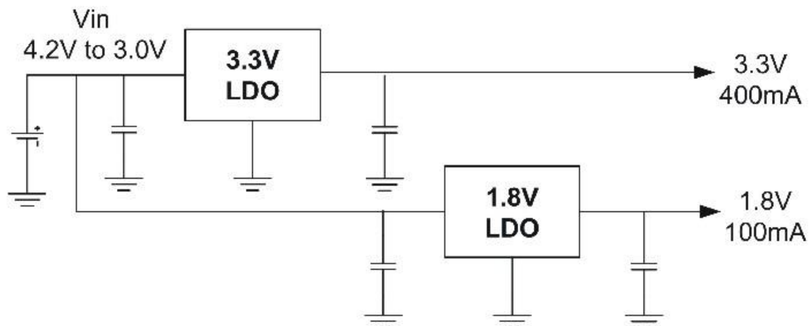

L1
10µH
D1
LOW BATTERY
GOES LOW AT
V_{BAT} = 2.2V
316k
1%
412k
1%
2 TO 3
CELLS
C1
220µF
SHUTDOWN
V_{IN}
LBI
SHDN
GND
SW
LBO
FB
PGND
LT1305
100k
301k
1%
100k
1%
C2
220µF
V_{OUT}
5V
400mA
C1, C2: AVX TPSE227010R0100
D1: MOTOROLA MBRS130LT3
L1: COILCRAFT D03316-103
LT1305 • TA03


V_{IN}
2.5V to 5.5V
C_{IN}
4.7uF
V_{IN}
GND
EN
LM3670
1
2
3
4
5
SW
FB
L1:10uH
V_{OUT}
C_{OUT}
10uF
20075801

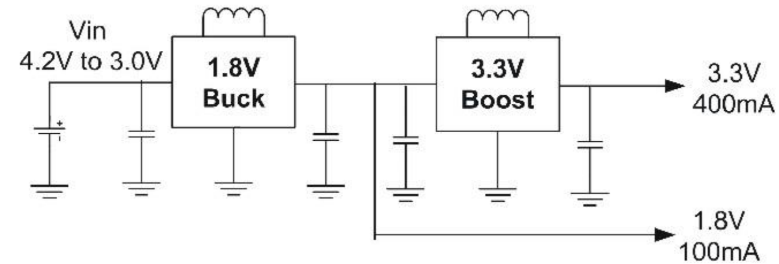

L1
22 µH
TPS65136
V_{IN}
2.3 V to 5.5 V
C1
10 µF
C4
100 nF
L1
L1
VIN
EN
VAUX
PGND
PGND
GND
L2
L2
OUTP
OUTP
FB
FBG
OUTN
OUTN
16
15
1
8
4
11
12
5
14
13
10
9
7
6
3
2
R1
360 kΩ
R2
390 kΩ
C2
4.7 µF
C3
4.7 µF
V+
4.6 V/80 mA
V–
–5 V/80 mA

Combined Solutions

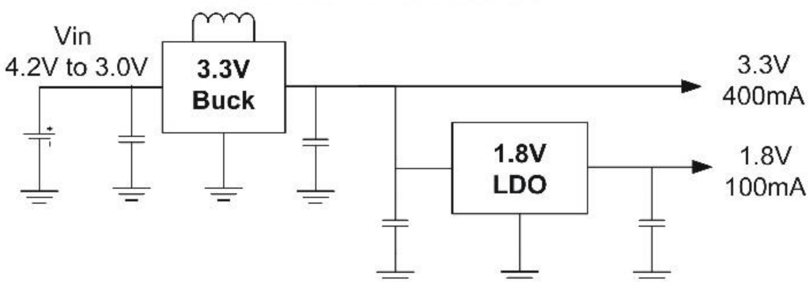
LDO/LDO Solution



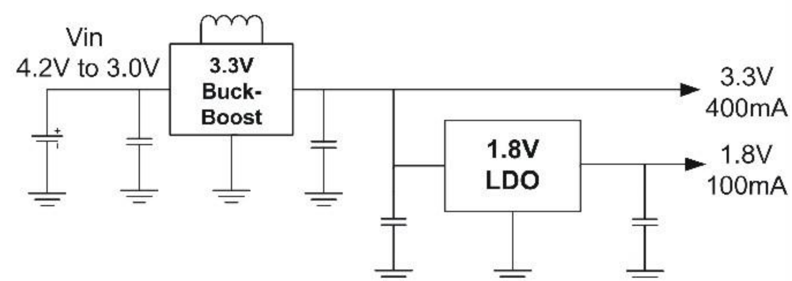
Buck/Boost Solution



Buck/LDO Solution



Buck-Boost/LDO Solution



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		WSON-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)

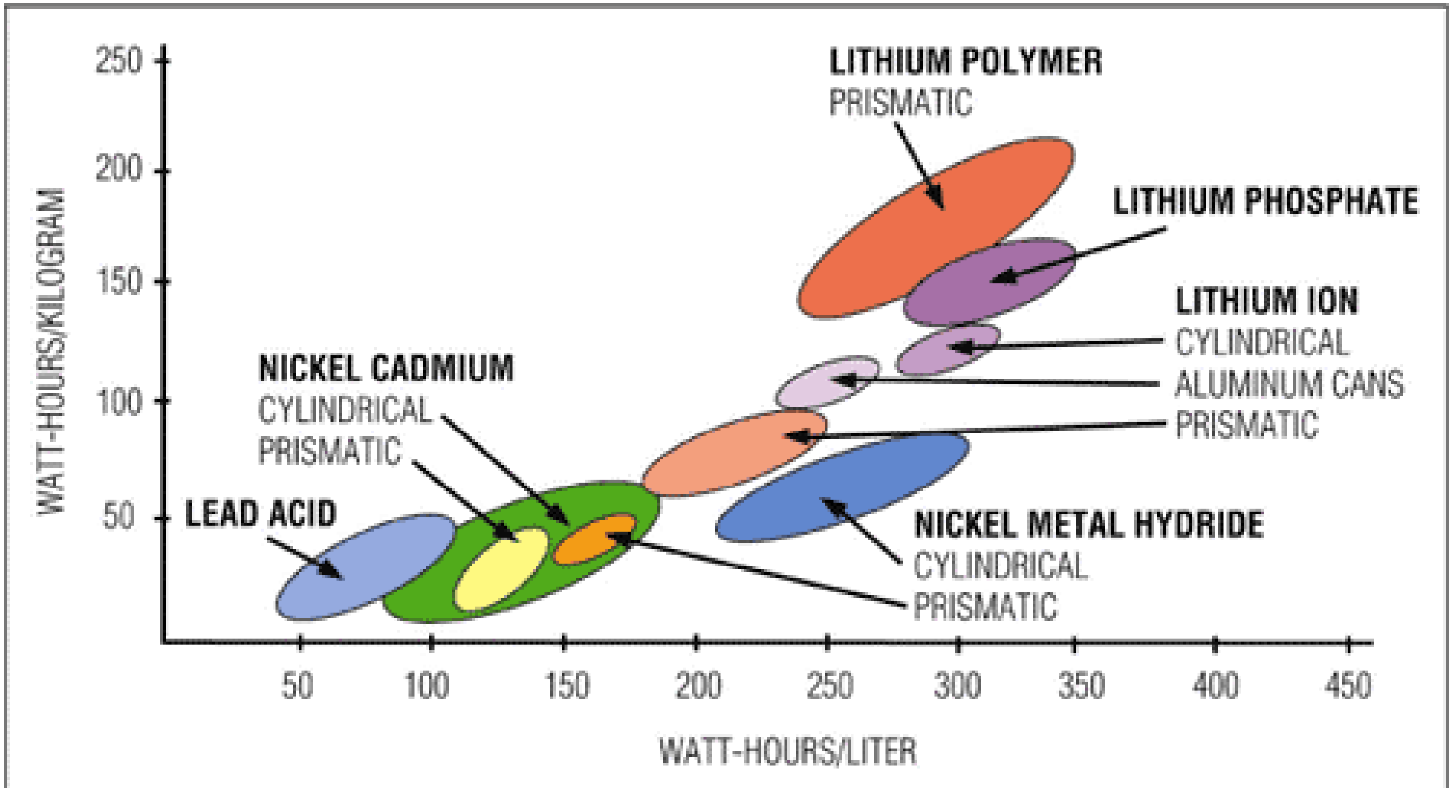
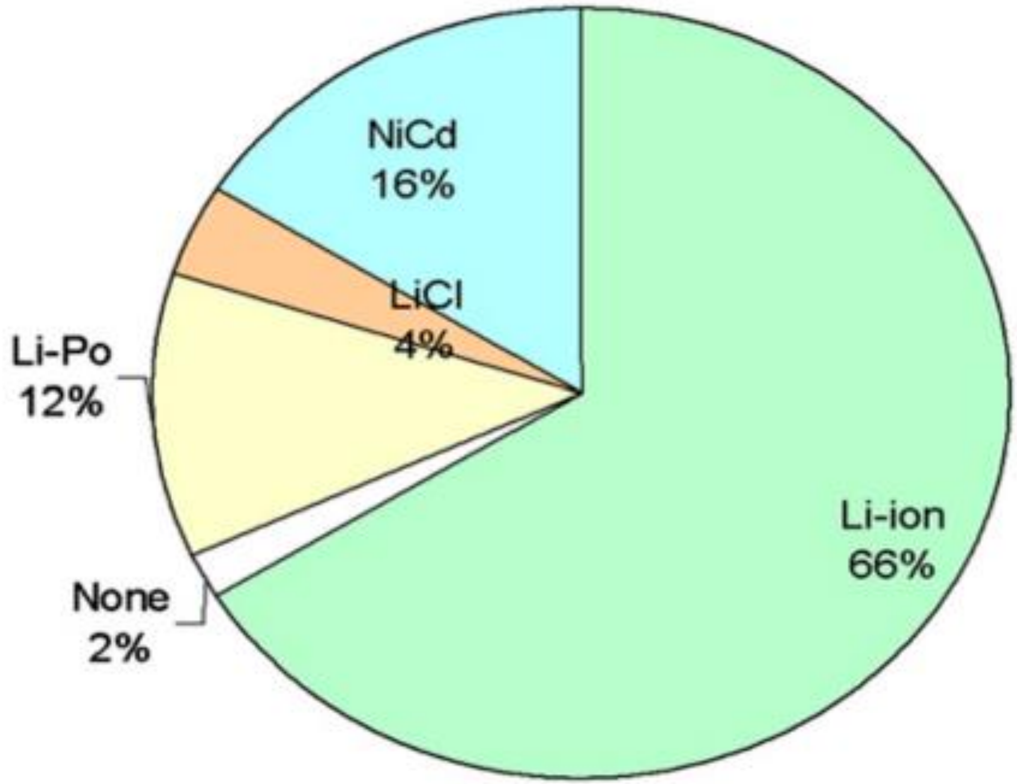


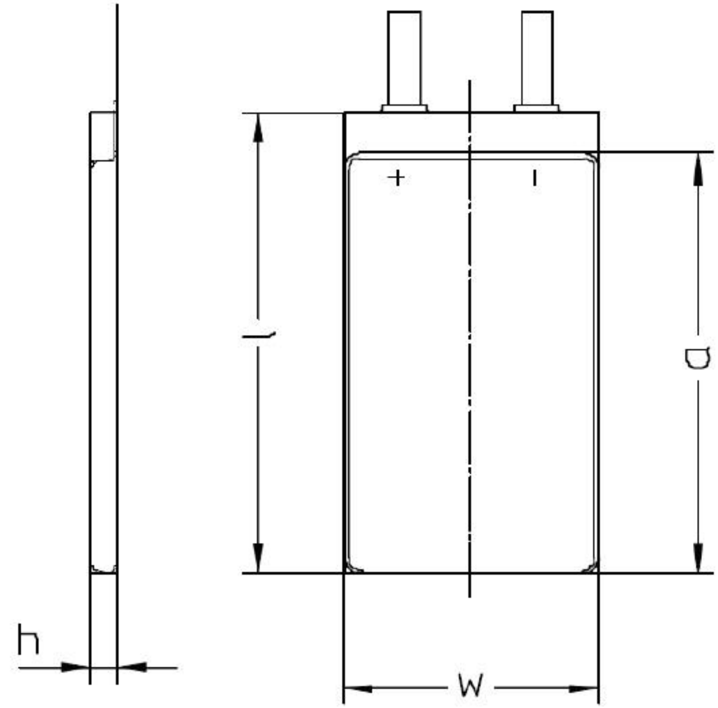
Image reprinted courtesy of Electropaedia (www.mpoweruk.com), © Woodbank Communications Ltd.

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

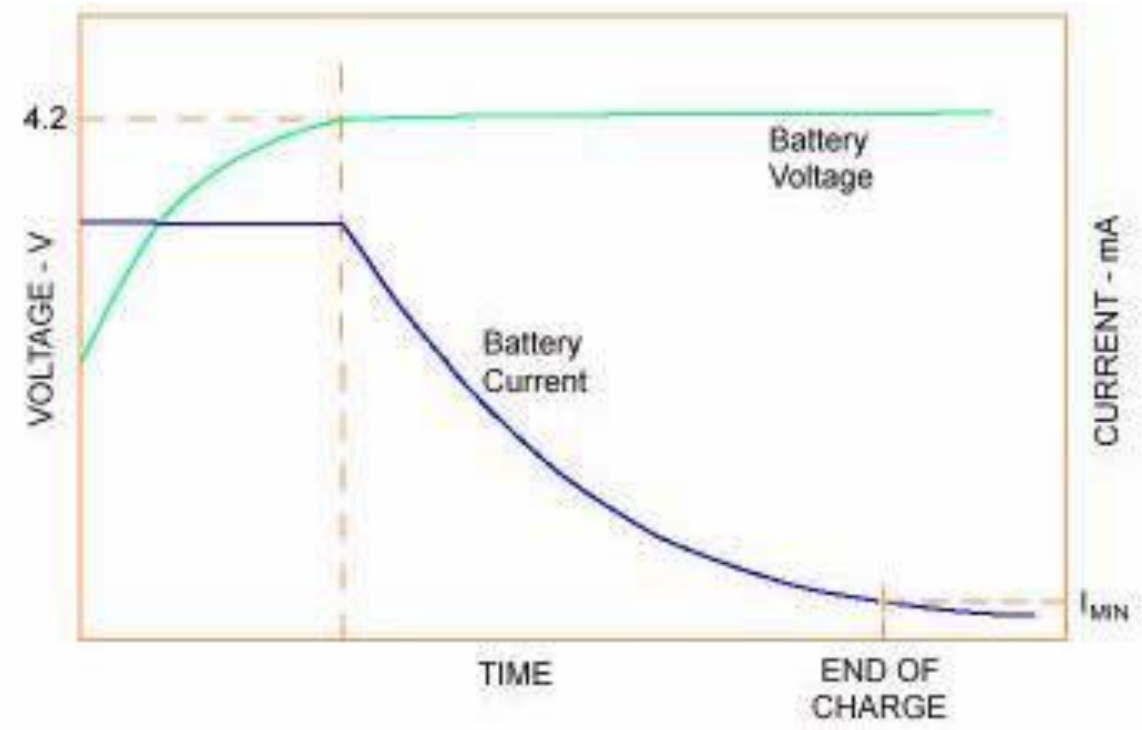


Length (l) :	49.2	mm
Width (w) :	34	mm
Height (h) :	4.4	mm
Pouch (a) :	44.2	mm
Weigth :	14	g

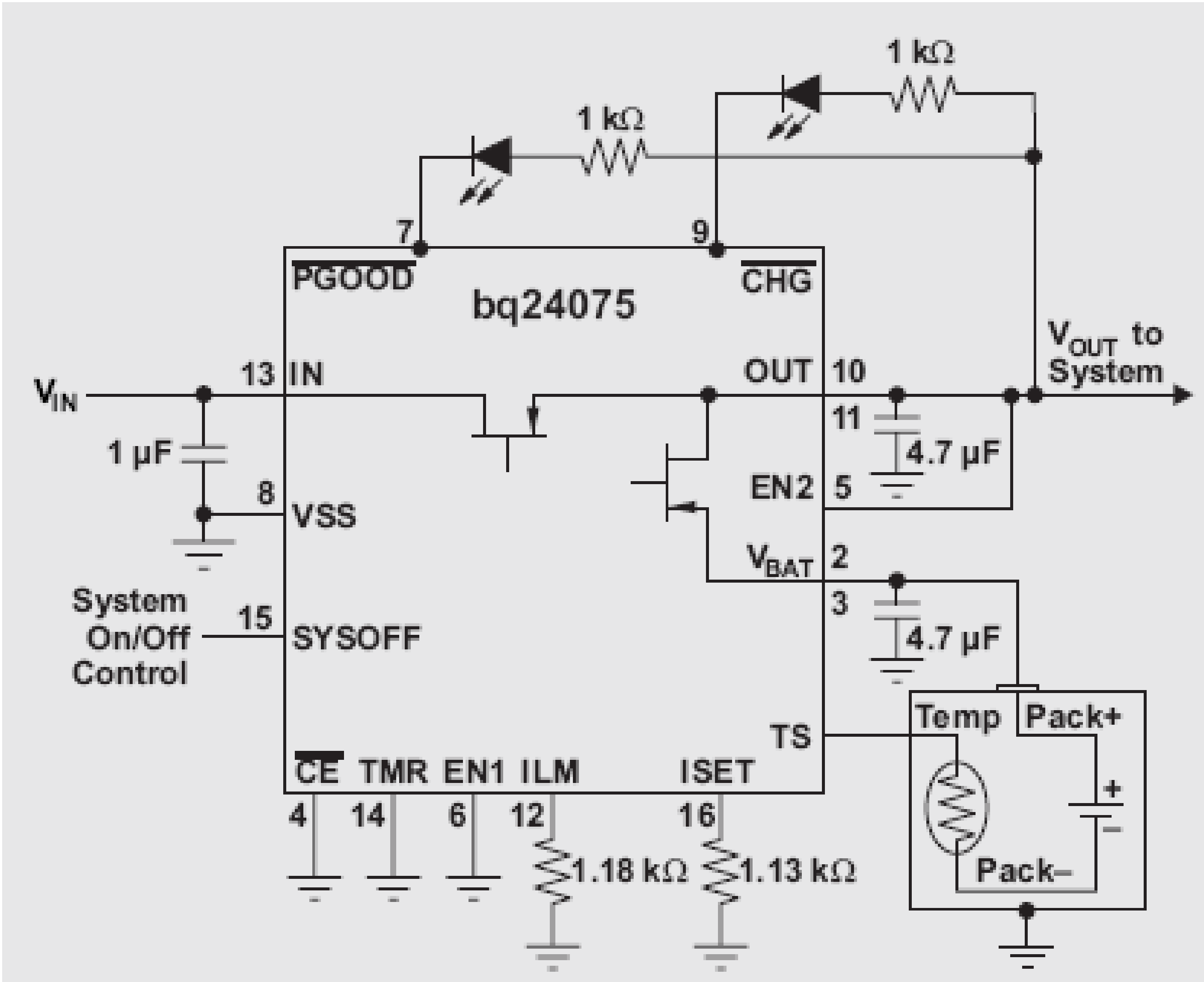
Nominal Voltage :	3.7 V
Typical Capacity :	800 mAh
Minimum Capacity :	770 mAh

http://swisscube.epfl.ch/

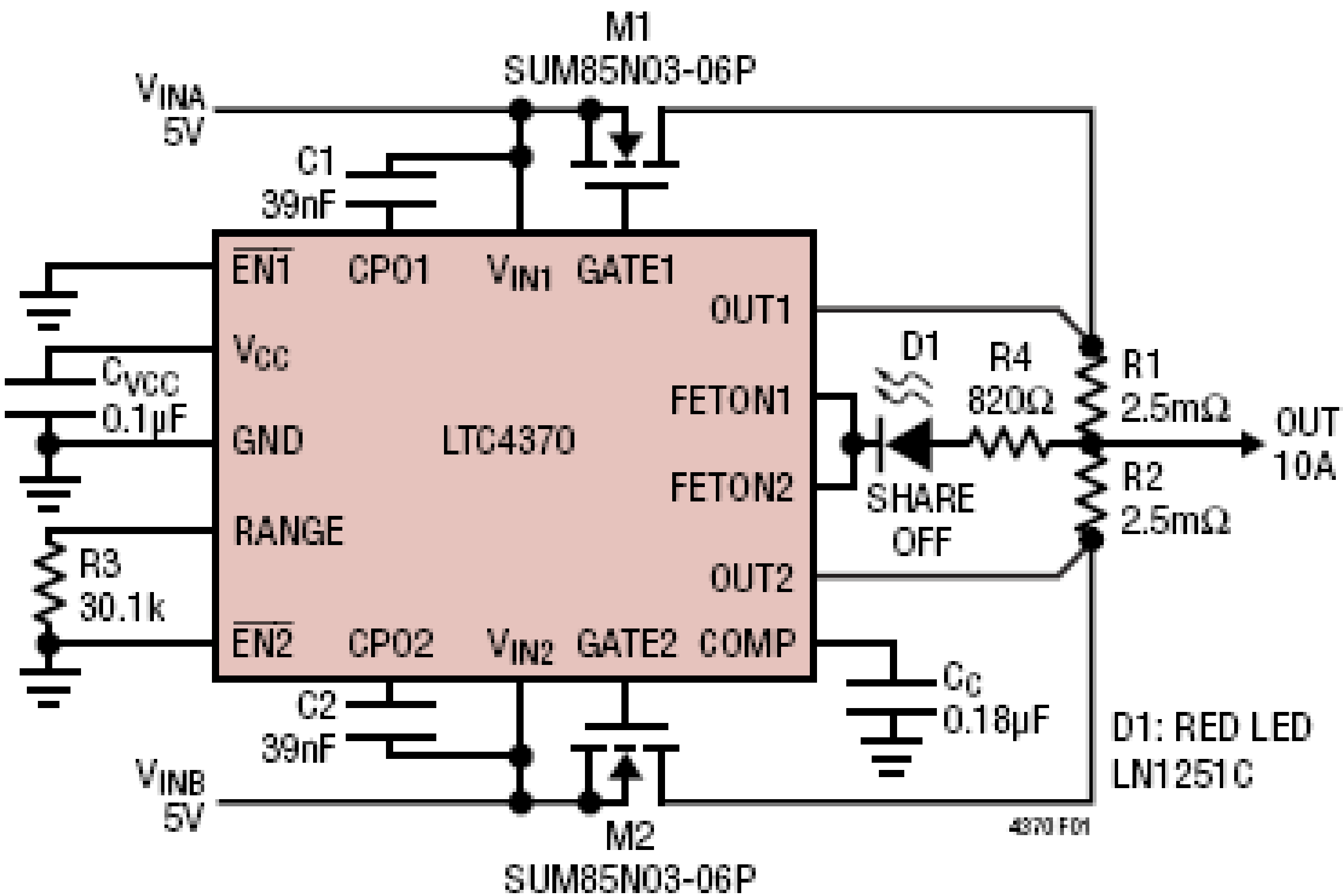
Lithium accumulator charging



Battery charger with power-path control



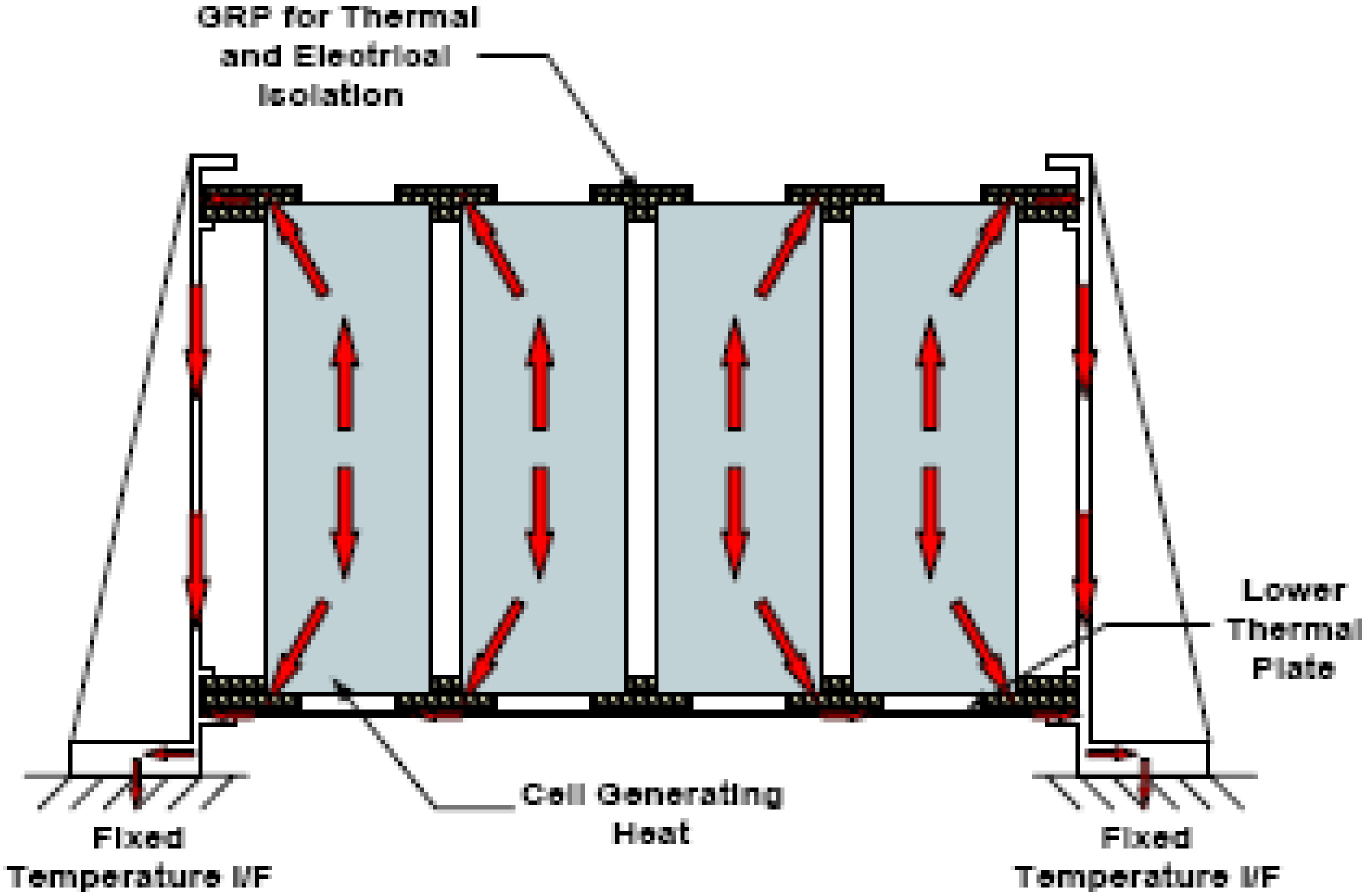
Sharing of the currents



Assemblies

The RoLand, ST-5 and Nanosat-1 Batteries

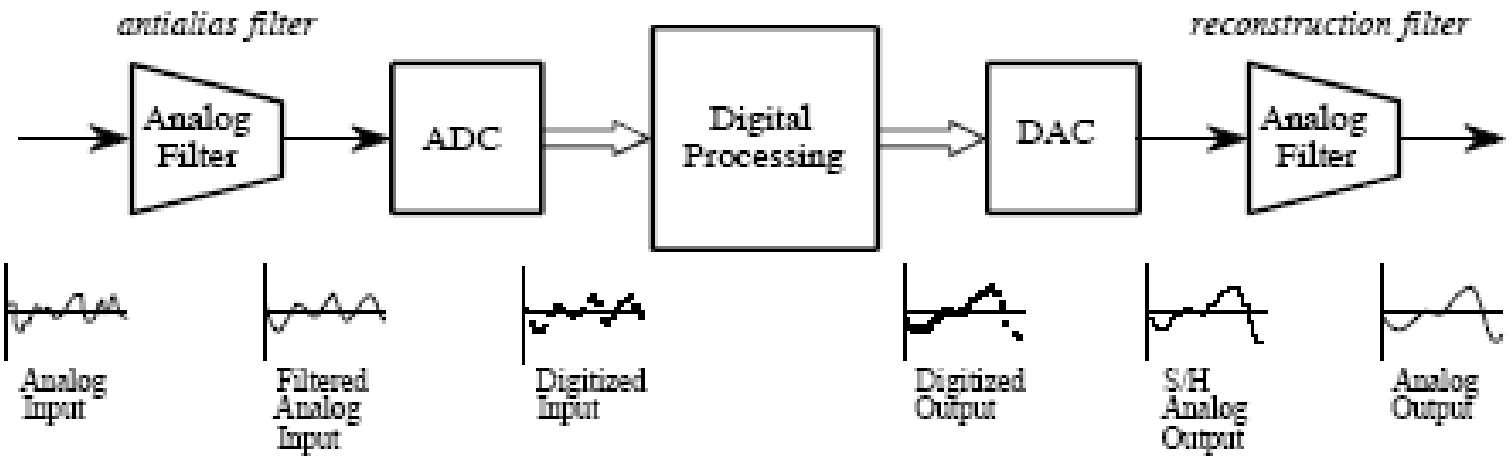
Battery thermal considerations



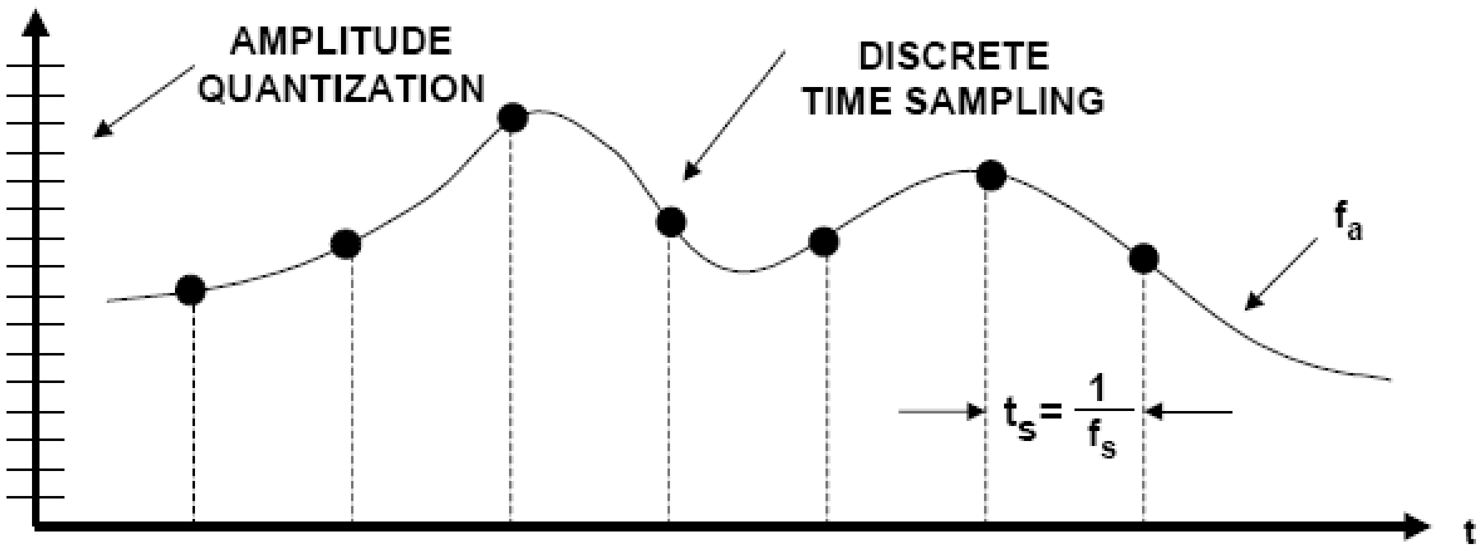
Battery heatflow

Data collecting and processing

Main concept

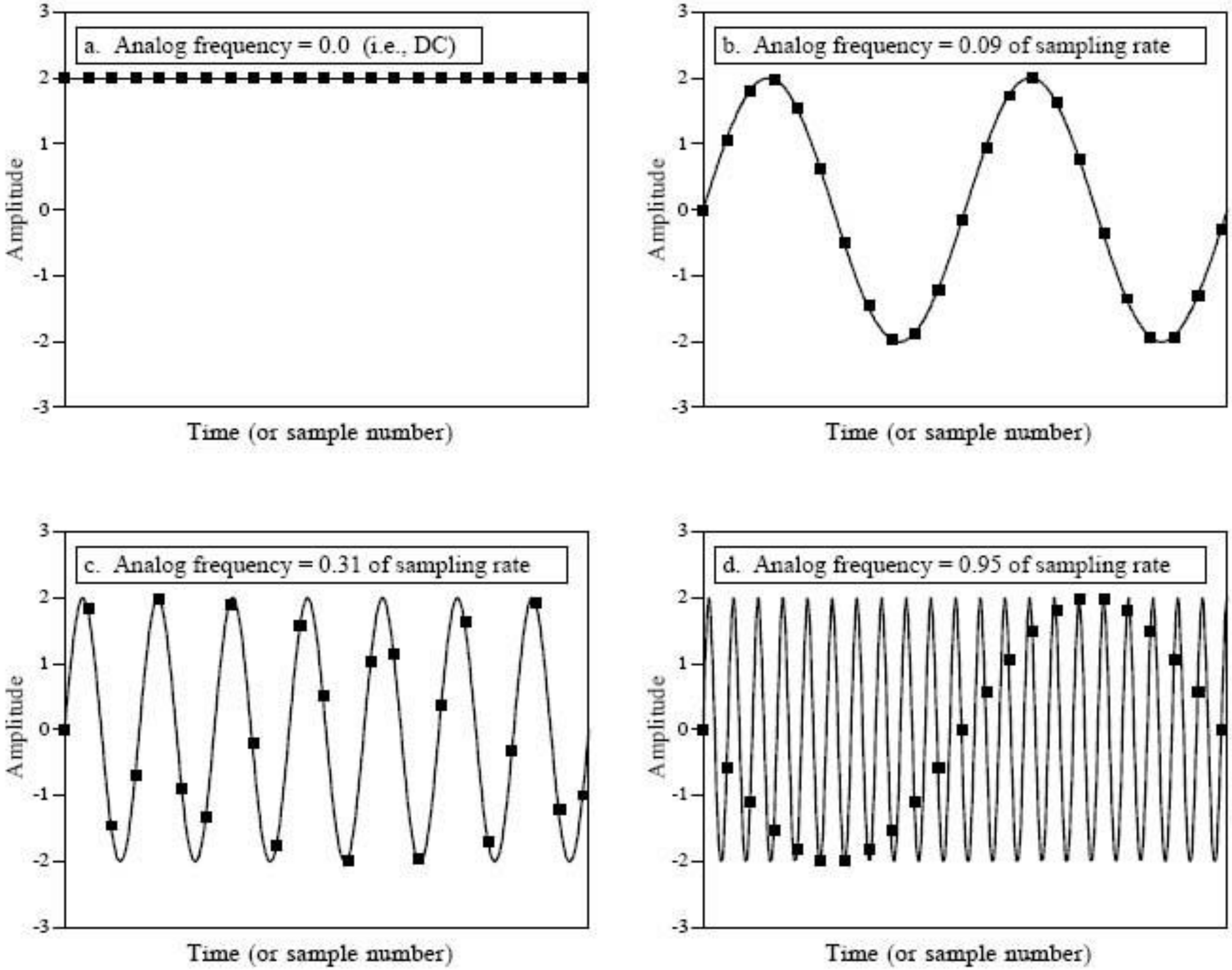


Sampling

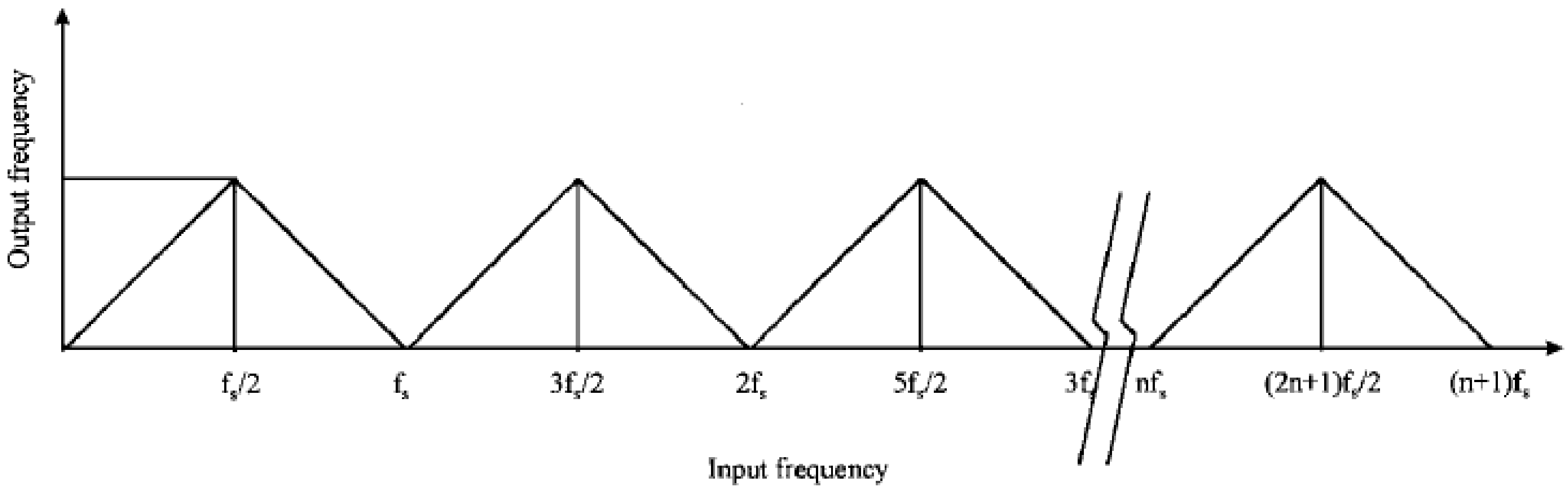


NYQUIST'S CRITERIA

- 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.

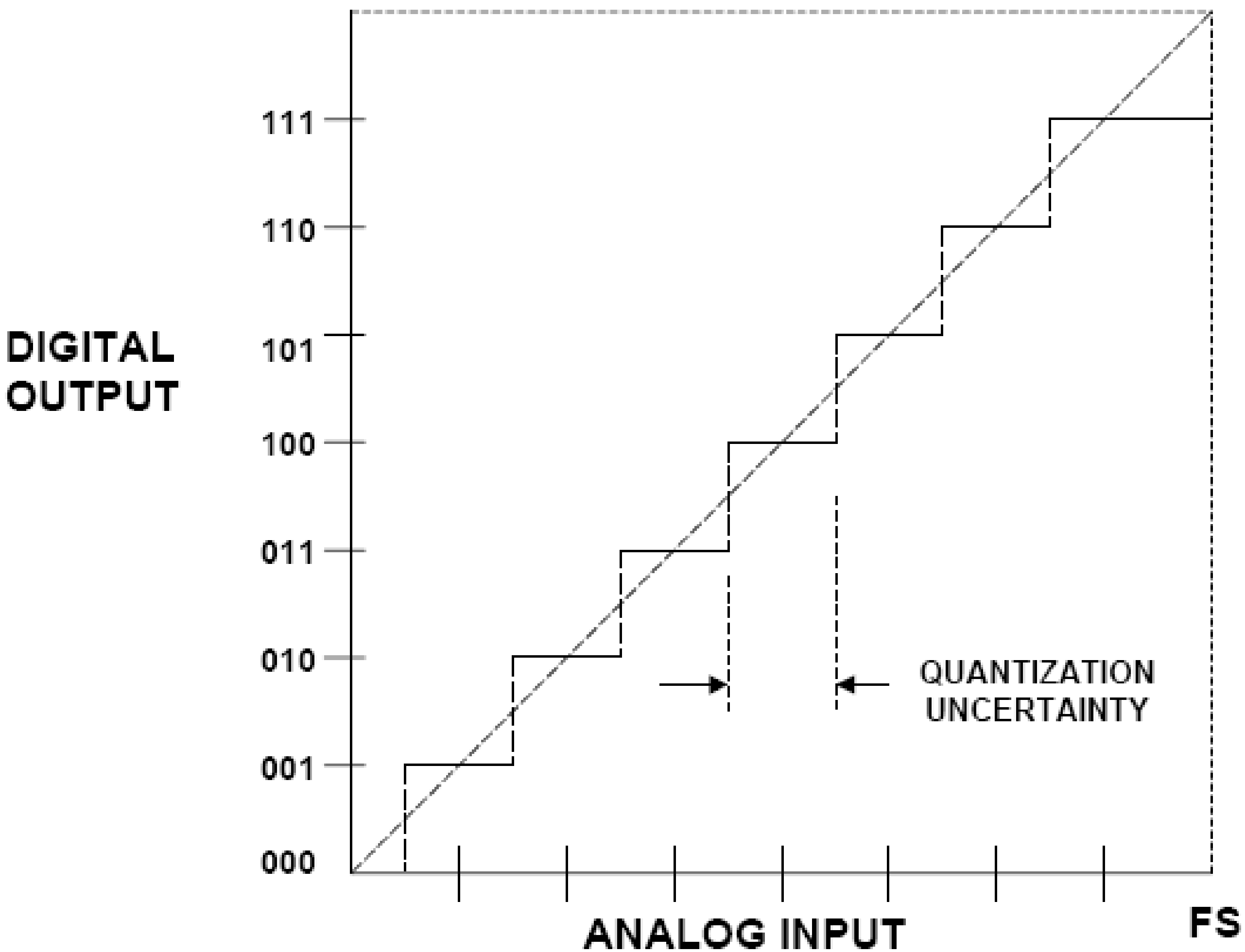

a. Analog frequency = 0.0 (i.e., DC)
b. Analog frequency = 0.09 of sampling rate
c. Analog frequency = 0.31 of sampling rate
d. Analog frequency = 0.95 of sampling rate
Amplitude
Time (or sample number)
3
2
1
0
-1
-2
-3

Sampling frequency effect

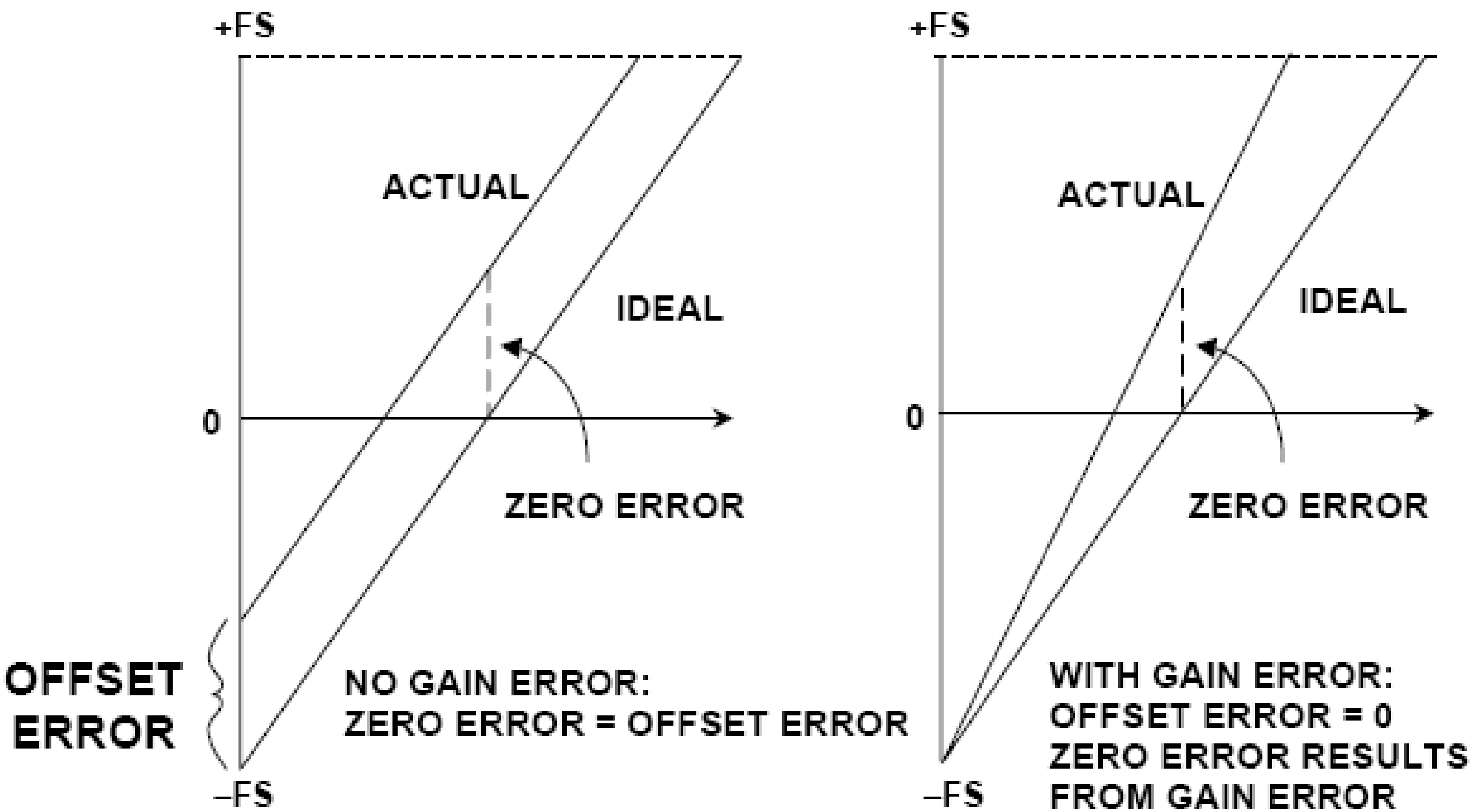


Input versus output frequency of band aliasing.

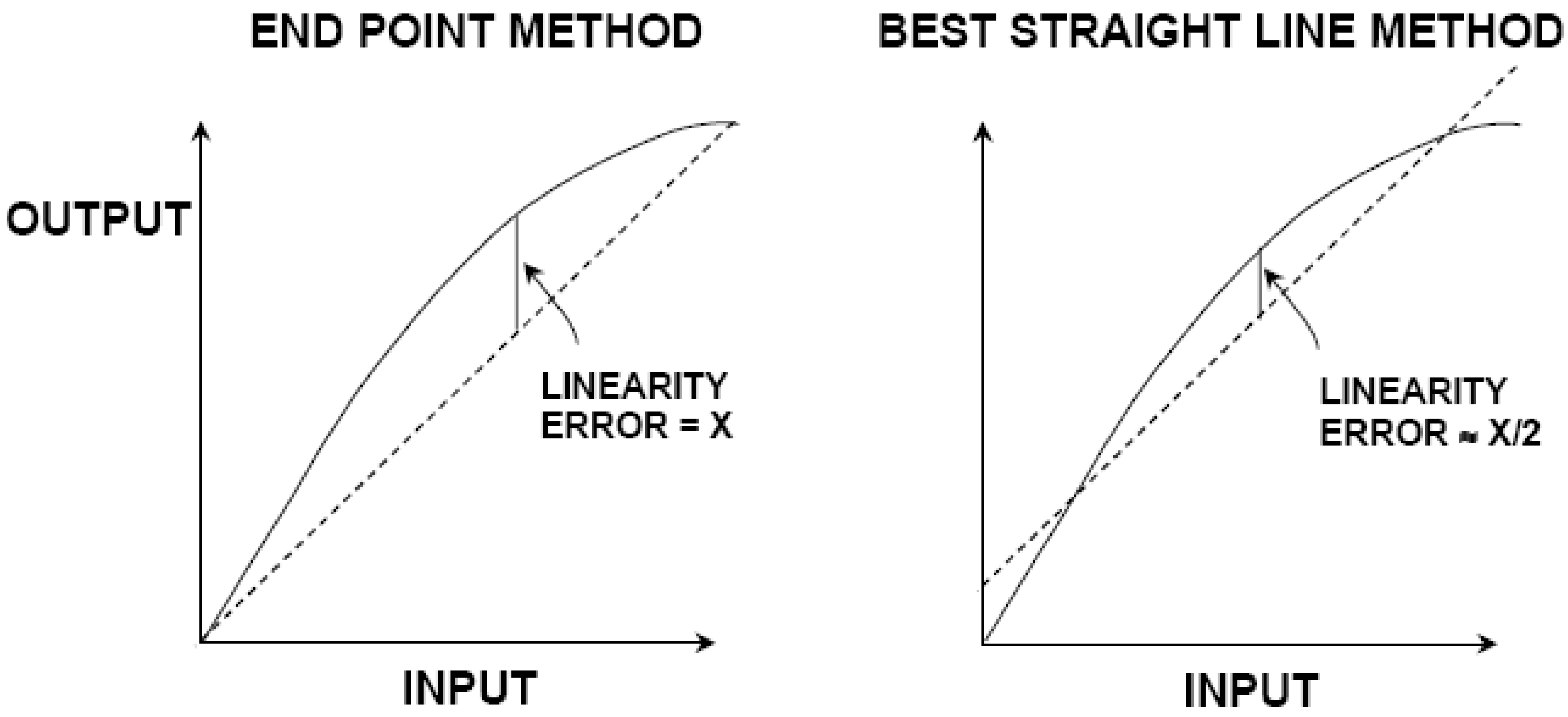
TRANSFER FUNCTION FOR IDEAL 3-BIT ADC



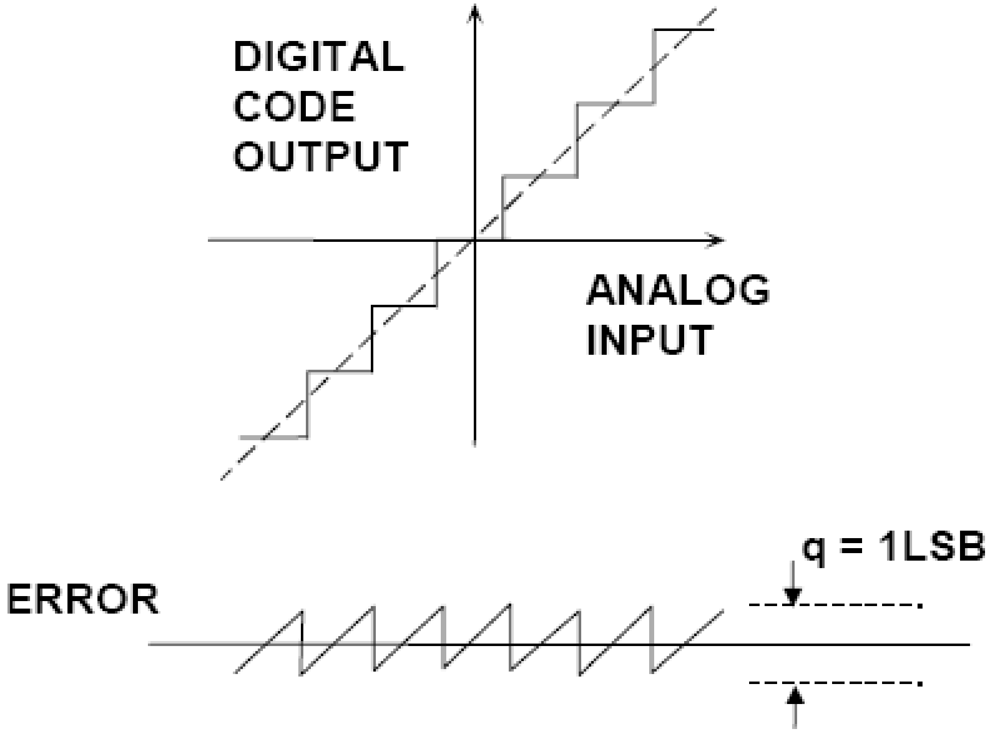
CONVERTER OFFSET AND GAIN ERROR



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



IDEAL N-BIT ADC QUANTIZATION NOISE

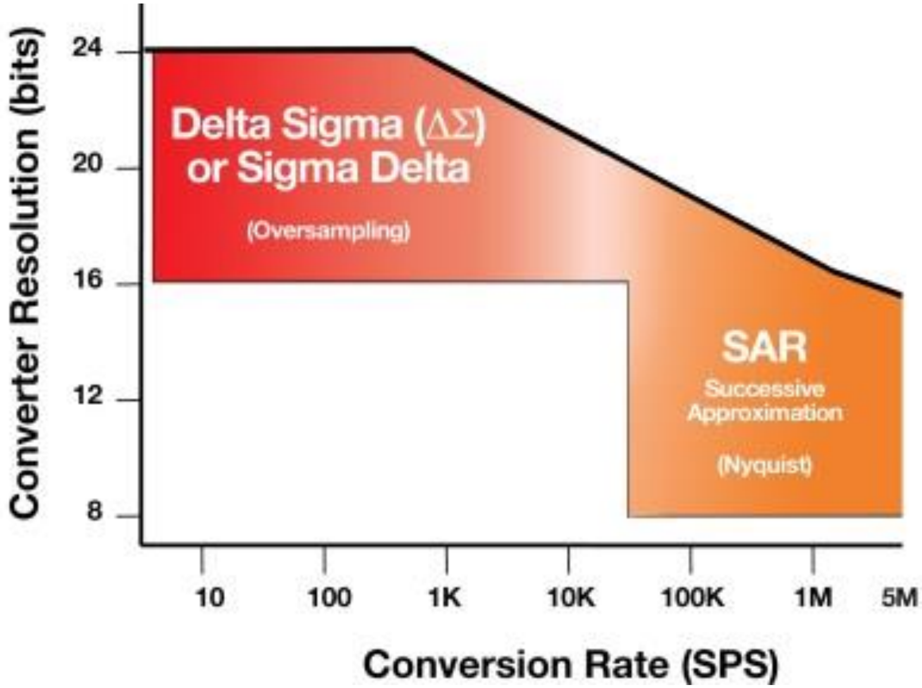


RMS ERROR = $q/\sqrt{12}$

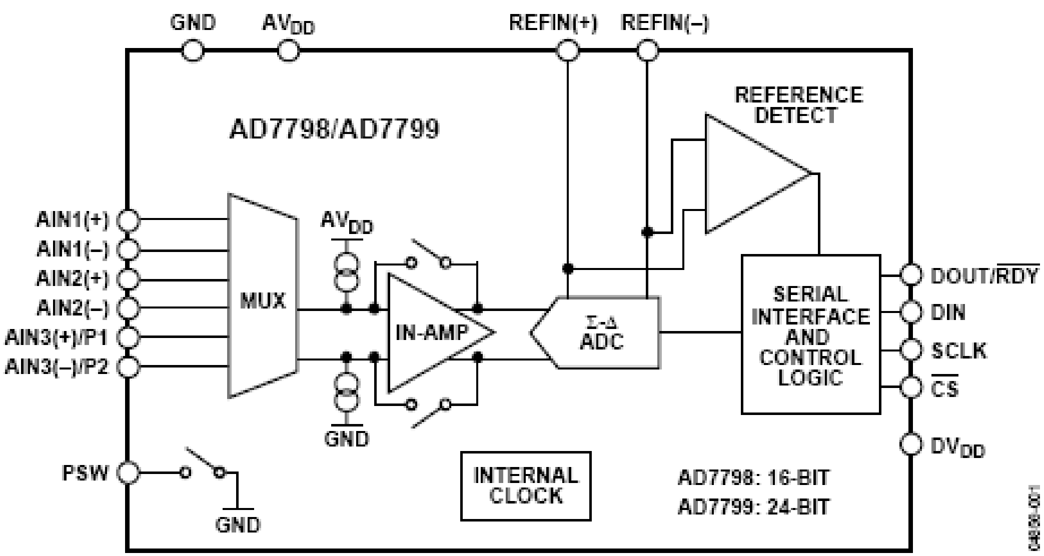
SNR = $6.02N + 1.76dB + 10\log\left[\frac{f_s}{2 \cdot BW}\right]$ FOR FS SINEWAVE

ADC types

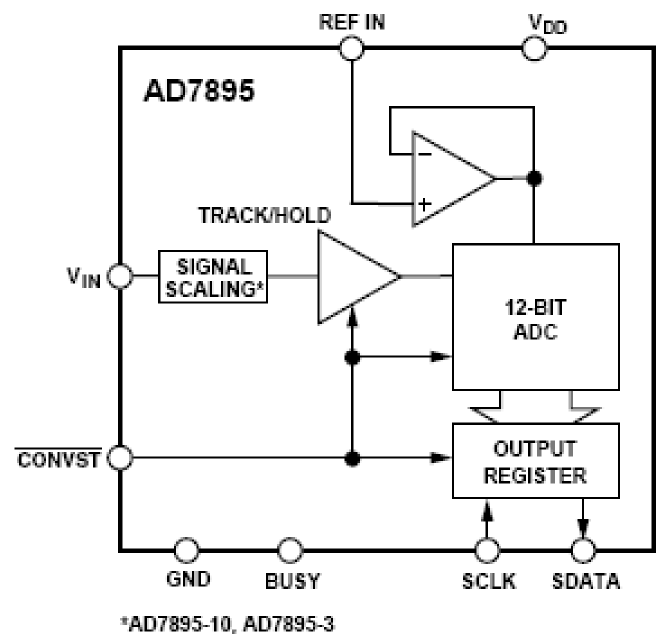
- SAR ADC
- Pipelined ADC
- Sigma-Delta ADC



Converter Resolution (bits)
24
20
16
12
8
Delta Sigma (ΔΣ)
or Sigma Delta
(Oversampling)
SAR
Successive
Approximation
(Nyquist)
10
100
1K
10K
100K
1M
5M
Conversion Rate (SPS)

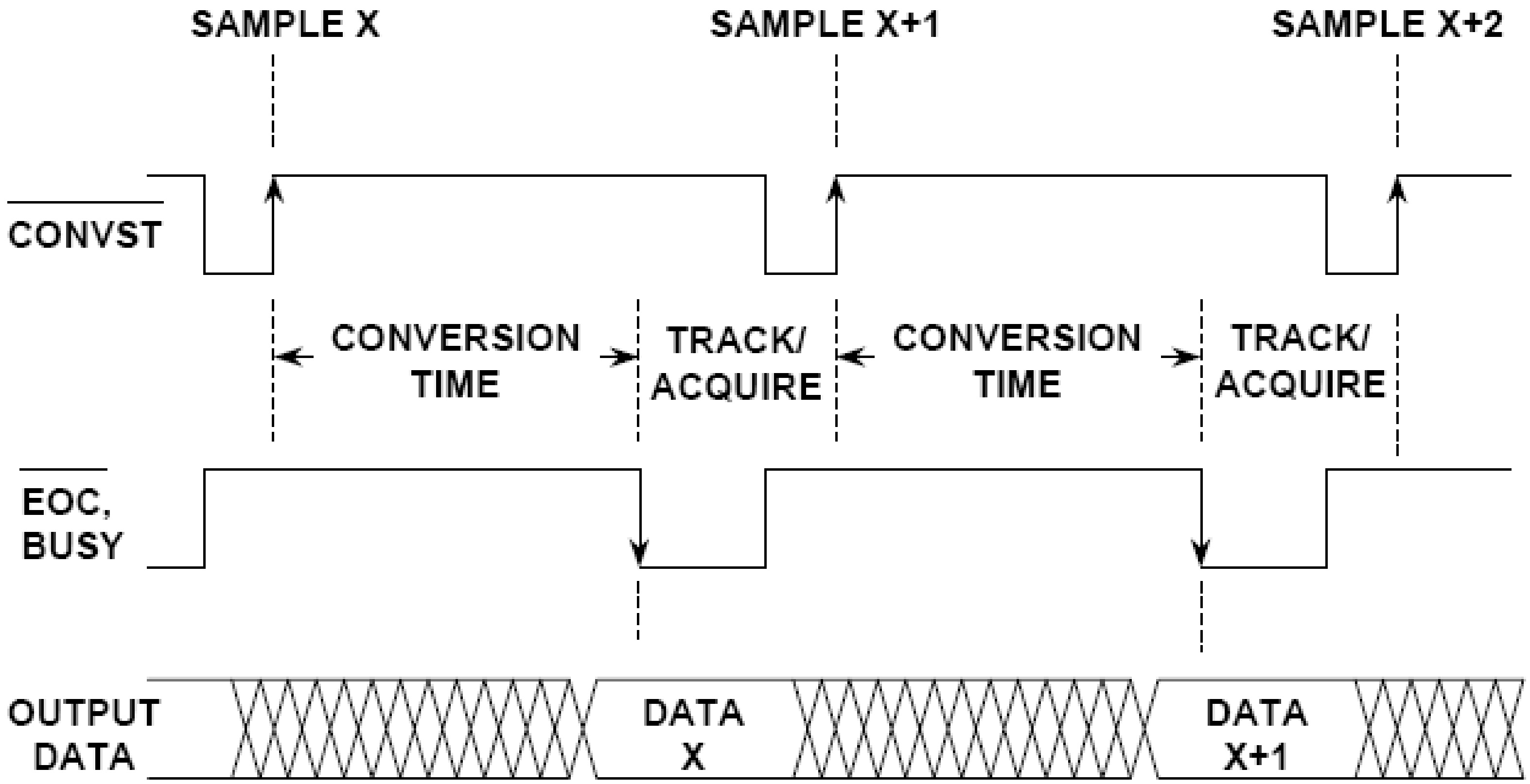


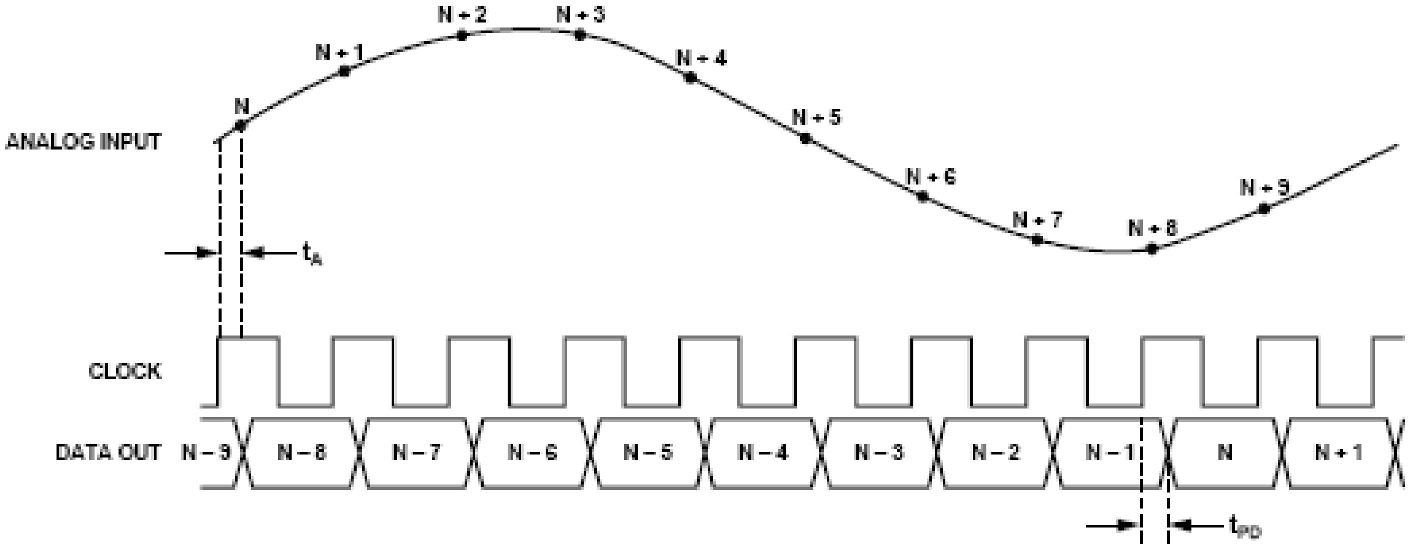
GND
AV_{DD}
REFIN(+)
REFIN(–)
REFERENCE DETECT
AD7798/AD7799
AIN1(+)
AIN1(–)
AIN2(+)
AIN2(–)
AIN3(+)/P1
AIN3(–)/P2
MUX
AV_{DD}
IN-AMP
Σ-Δ ADC
SERIAL INTERFACE AND CONTROL LOGIC
DOUT/$\overline{RDY}$
DIN
SCLK
$\overline{CS}$
DV_{DD}
GND
PSW
GND
INTERNAL CLOCK
AD7798: 16-BIT
AD7799: 24-BIT

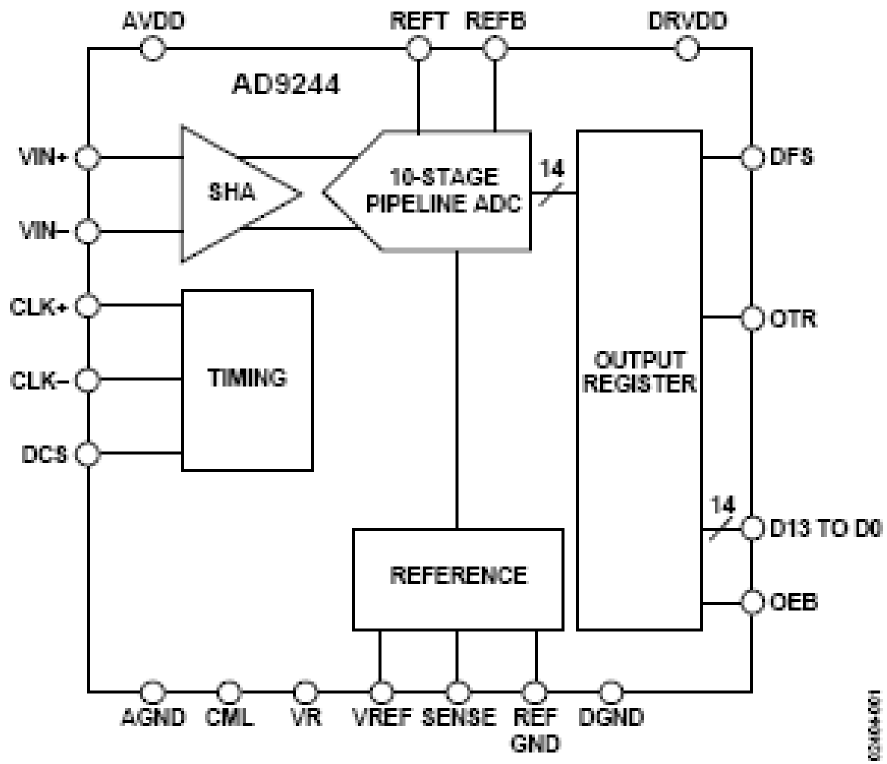


REF IN
V_{DD}
AD7895
TRACK/HOLD
V_{IN}
SIGNAL SCALING*
12-BIT ADC
$\overline{CONVST}$
OUTPUT REGISTER
GND
BUSY
SCLK
SDATA
*AD7895-10, AD7895-3

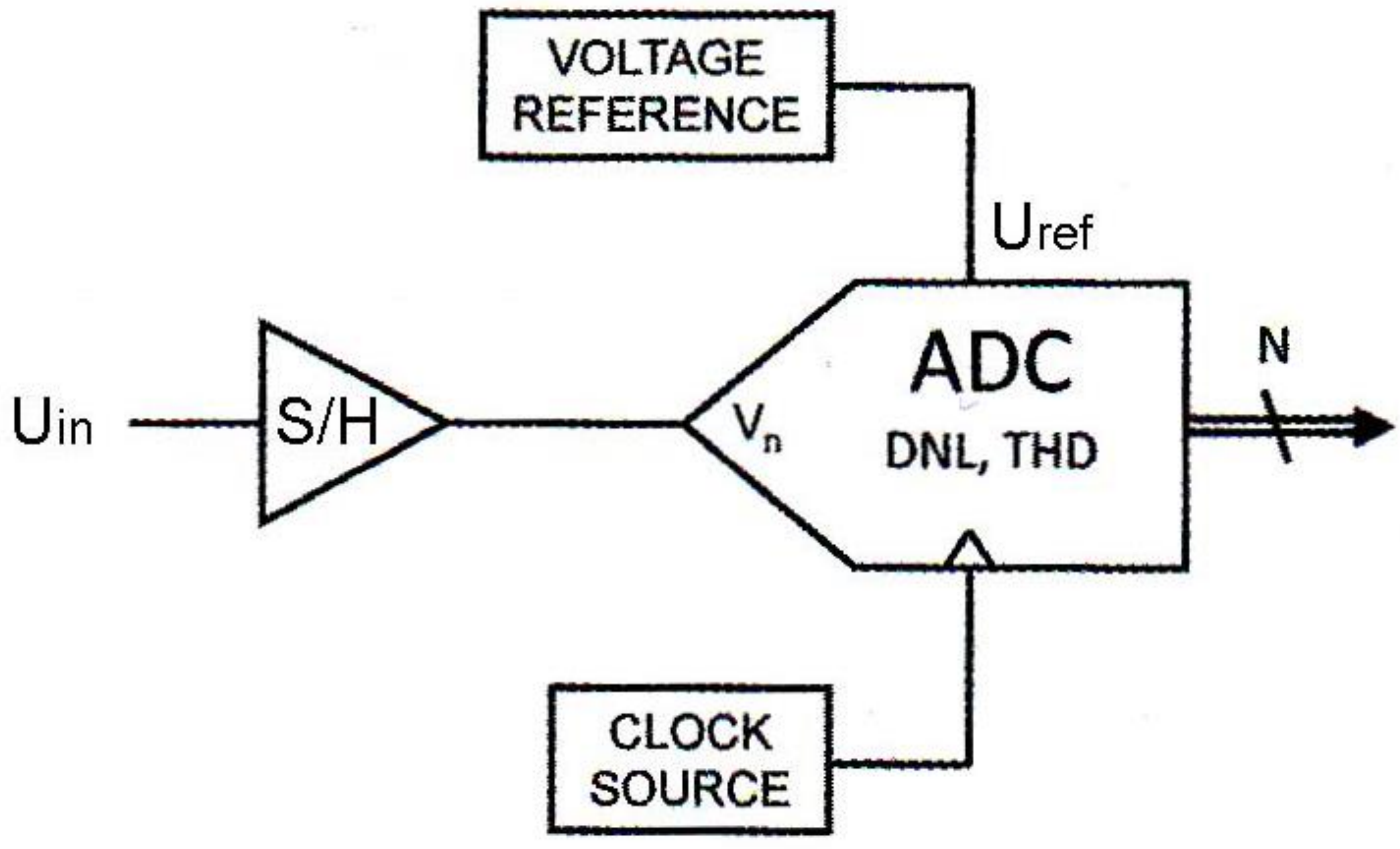
TYPICAL SAR ADC TIMING




ANALOG INPUT
N
N + 1
N + 2
N + 3
N + 4
N + 5
N + 6
N + 7
N + 8
N + 9
t_A
CLOCK
DATA OUT
N – 9
N – 8
N – 7
N – 6
N – 5
N – 4
N – 3
N – 2
N – 1
N
N + 1
t_{PD}

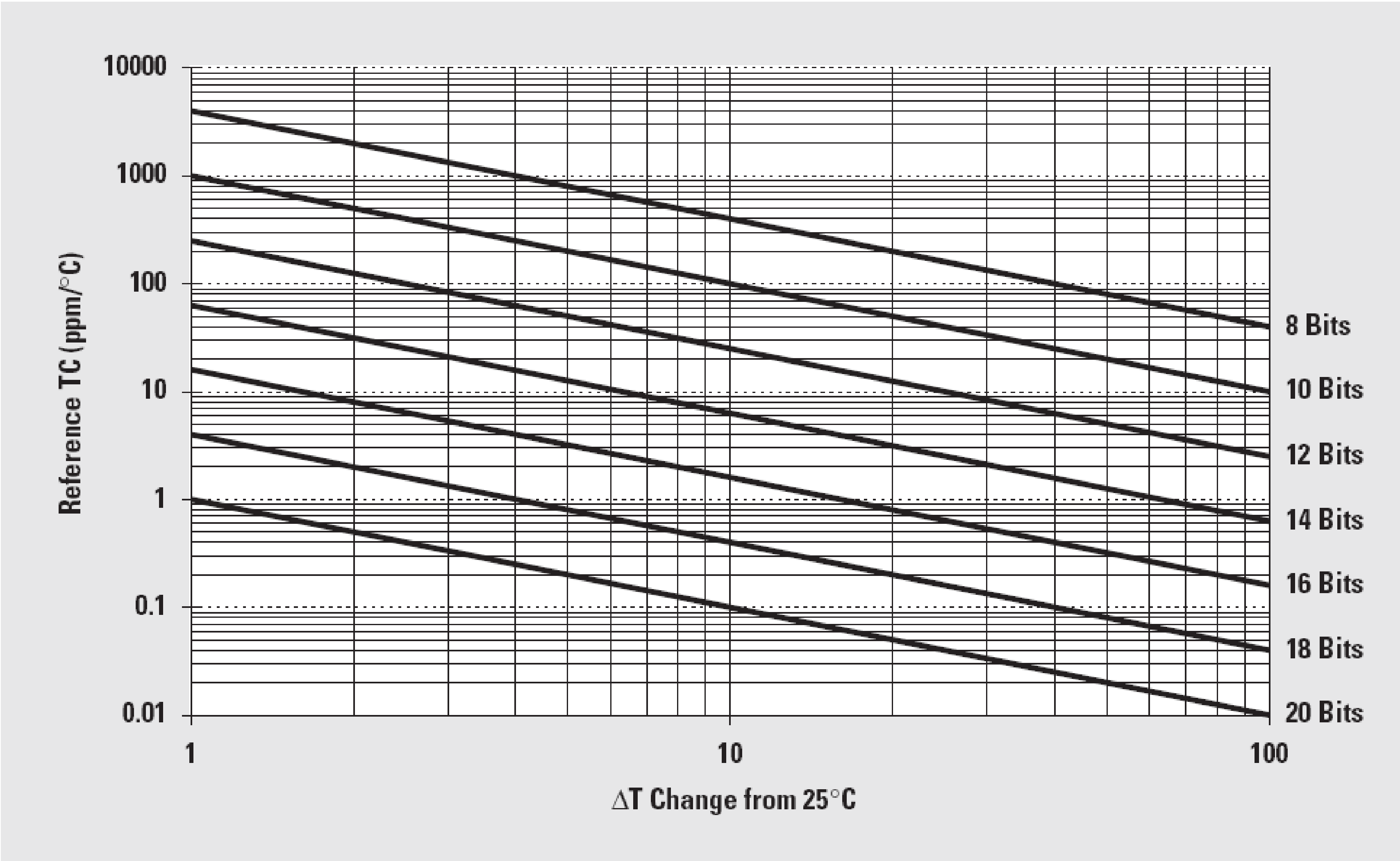

AVDD
REFT
REFB
DRVDD
AD9244
VIN+
VIN–
SHA
10-STAGE
PIPELINE ADC
14
OUTPUT
REGISTER
DFS
OTR
CLK+
CLK–
DCS
TIMING
14
D13 TO D0
REFERENCE
OEB
AGND
CML
VR
VREF
SENSE
REF GND
DGND

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

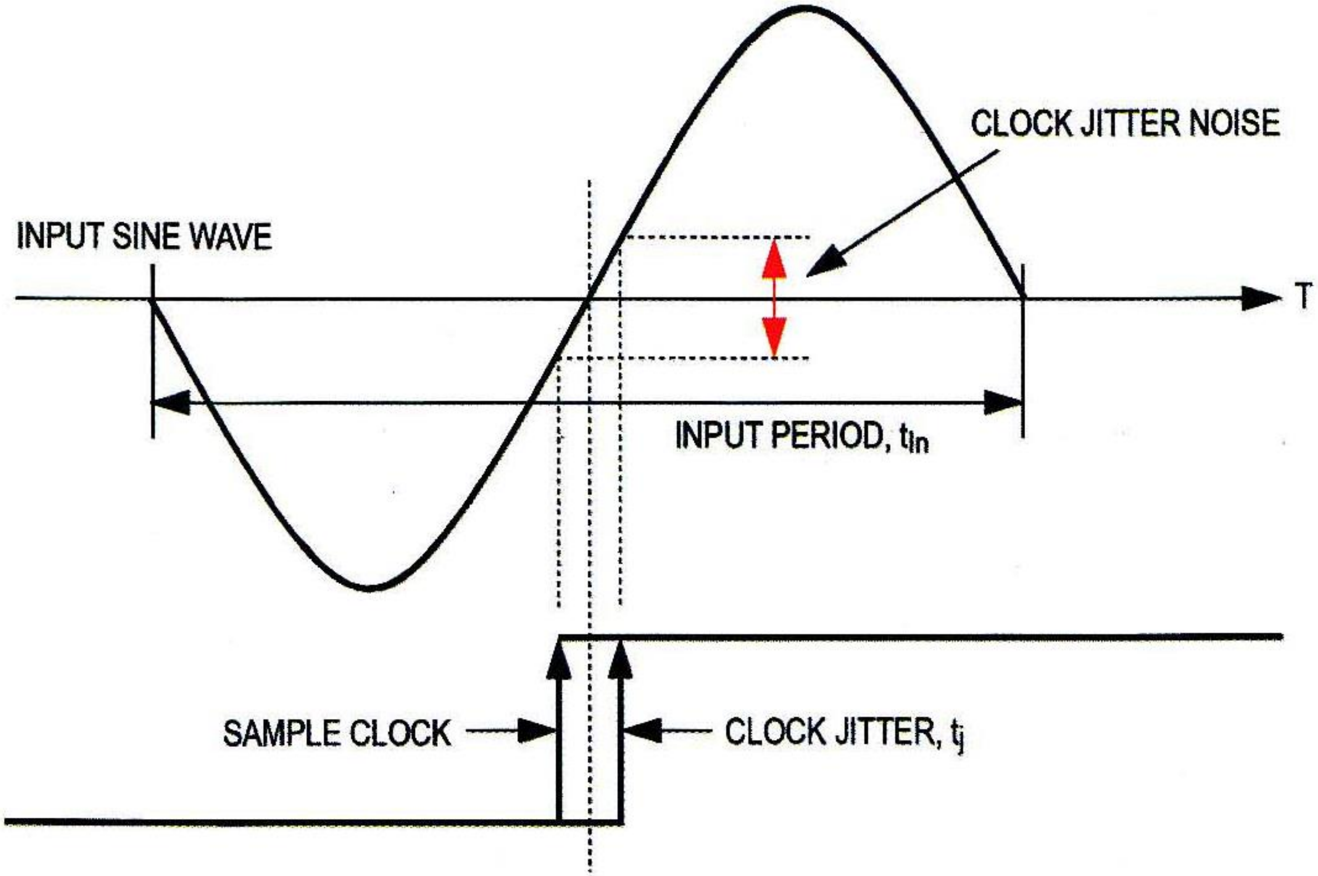
Choose Parameters All | Reset Table | Maximize Filters | Sort by Newest | Save to myAnalog | Download to Excel | Share | Quick Tips | Send Feedback

Compare

615 parts

Part Number	Price (1000+) $ US	Vout typ | V	Initial Accuracy % max | %	Vout Tempco max | ppm/°C	Vref Type	Vnoise typ | V p-p	Temp Range
Filter Parts	0.28 - 546.2	200m - 10	0.02 - 4	0.05 - 170	6 Values Selected	300n - 475u	9 Values Selected
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

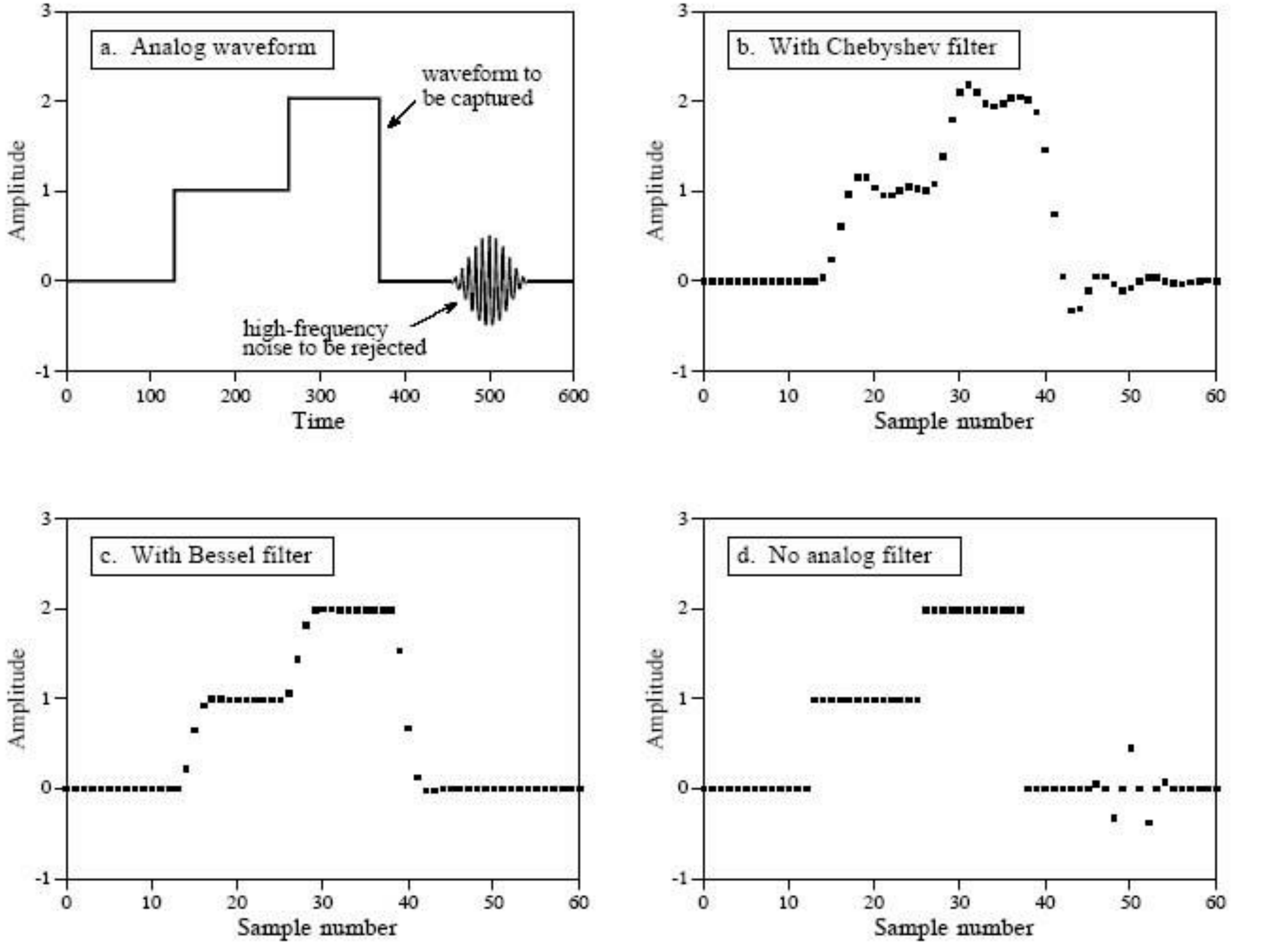
Main purposes:

1. Amplification
2. Impedance matching
3. Filtering

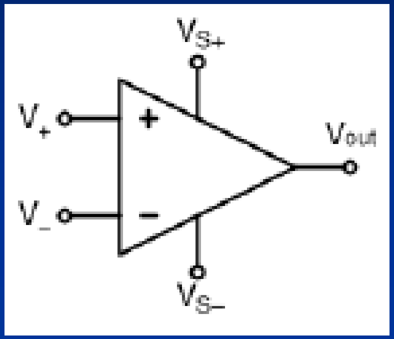
Main requirements:

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- uA702 first solid-state op-amp by Bob Widlar, Fairchild Semiconductors, supply voltages +12 and -6 volts, burn out when temporarily shorted

1965- uA709 by Bob Widlar, high gain, a larger bandwidth, lower input current, supply voltage of approximately +/- 15 Volt DC

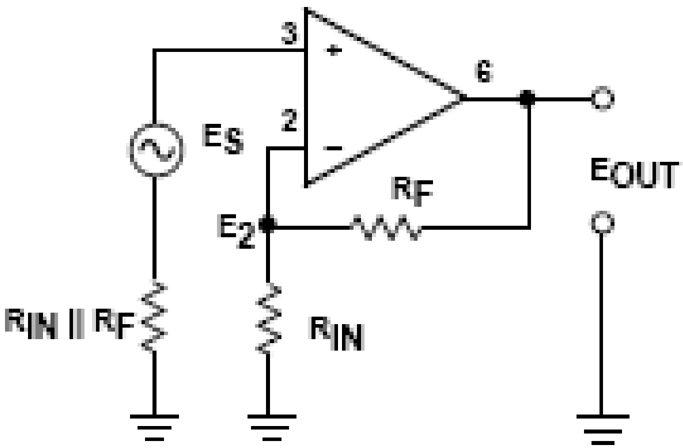
1967- LM101 more versatile op-amp version- gain up to 160K and operation range, 'short-circuit' protection, and simplified frequency compensation.
In 1968 improved version of LM101 was LM101A, National Semiconductor

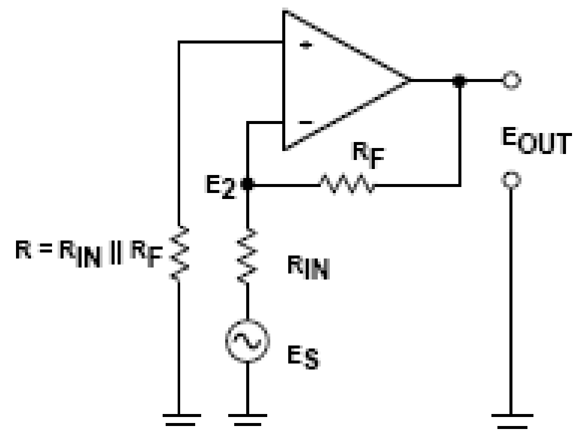
1974- RC4558 first multiple op amp device, which uses NPN input transistors, Raytheon Semiconductor's

In dated sequence, the op-amp developed like this: 1963-uA702, 1965-uA709, 1967-LM101/LH101, 1968-uA741, 1974-RC4558/LM324, 1975-CA3130/LF355, and in 1976 the TL084...

Since 1976 the types of op amps have increased almost daily

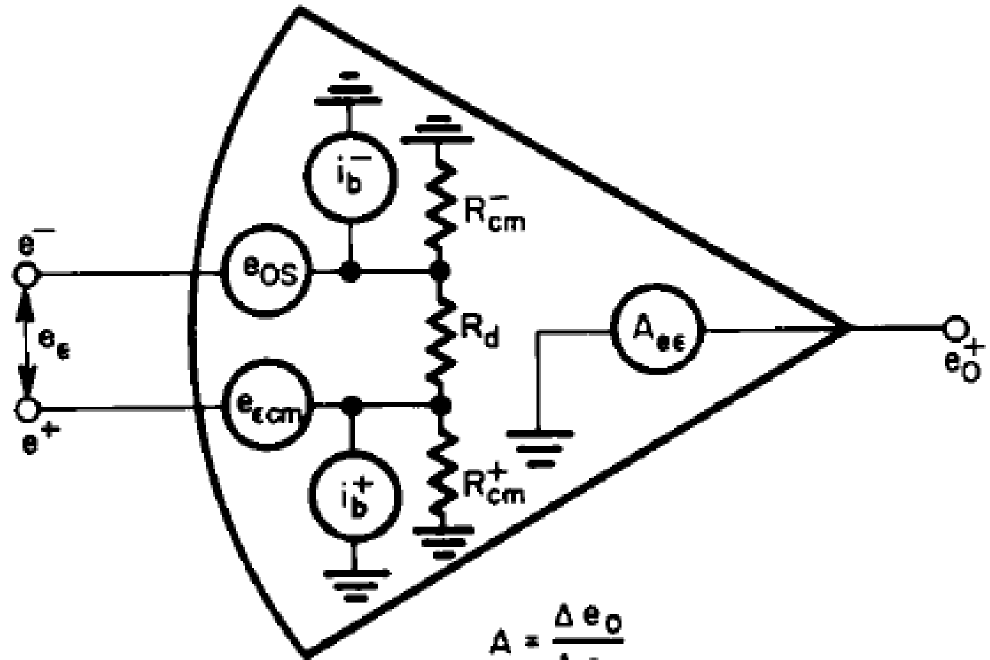
Operational amplifiers





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

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



$$A = \frac{\Delta e_O}{\Delta e_\epsilon}$$

$$e_{\epsilon cm} = e^+/CMR$$

$$e_\epsilon = e^- - e^+$$

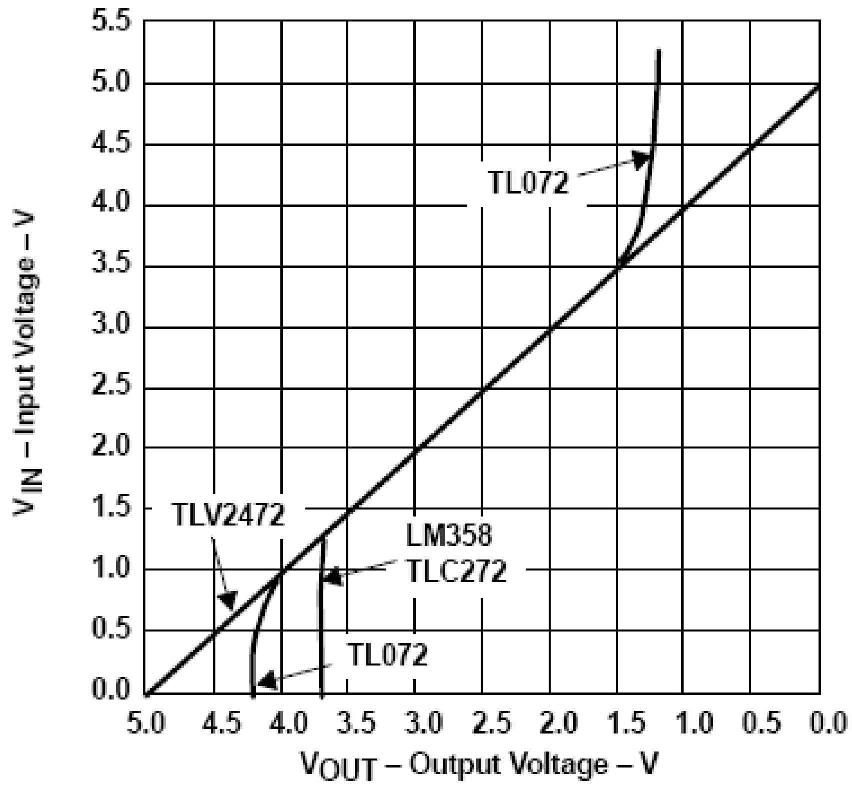
$$e_{os} = E_{os} + \left(\frac{\Delta e_{os}}{\Delta T}\right)\Delta T + \left(\frac{\Delta e_{os}}{\Delta V_s}\right)\Delta V_s + \left(\frac{\Delta e_{os}}{\Delta t}\right)\Delta t$$

↓ μV @ 25°C ↓ μV/°C ↓ μV/% ↓ μV/DAY

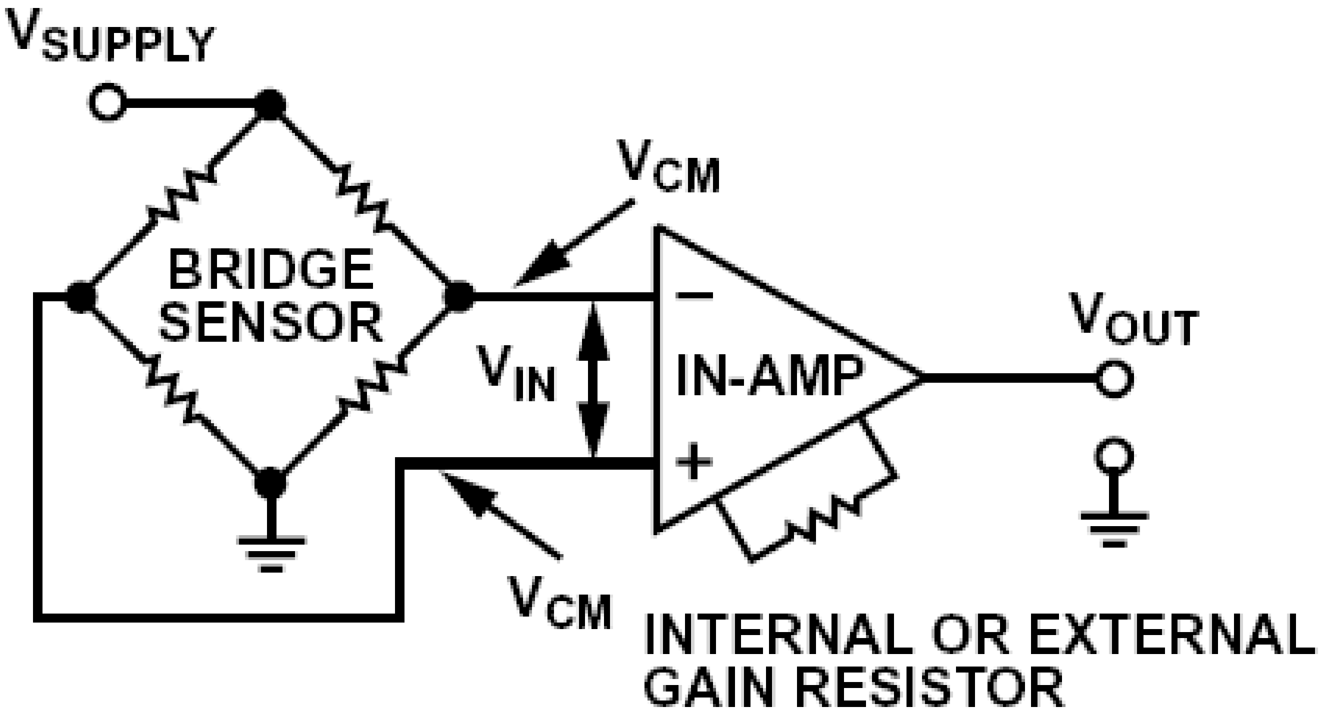
$$i_b = I_b + \left(\frac{\Delta i_b}{\Delta T}\right)\Delta T + \left(\frac{\Delta i_b}{\Delta V_s}\right)\Delta V_s + \left(\frac{\Delta i_b}{\Delta t}\right)\Delta t$$

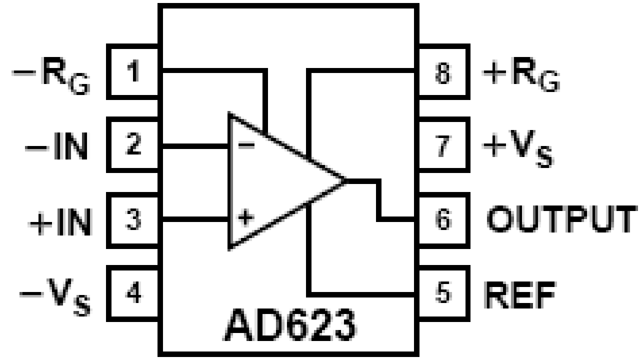
↓ nA @ 25°C ↓ nA/°C ↓ nA/% ↓ nA/DAY

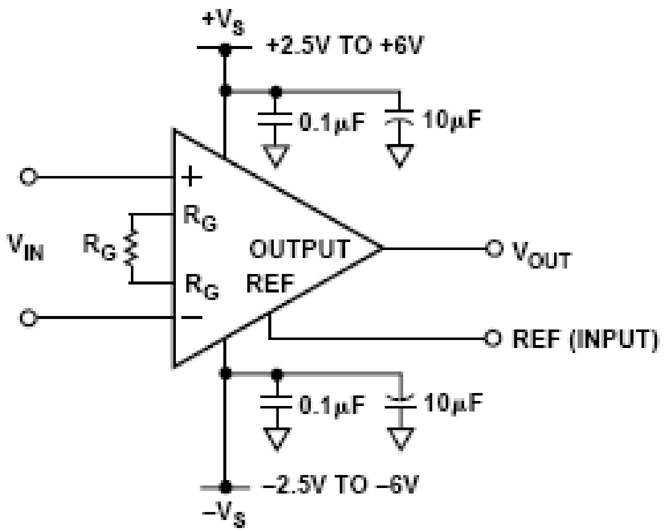
Rail-to-rail amplifier's basics



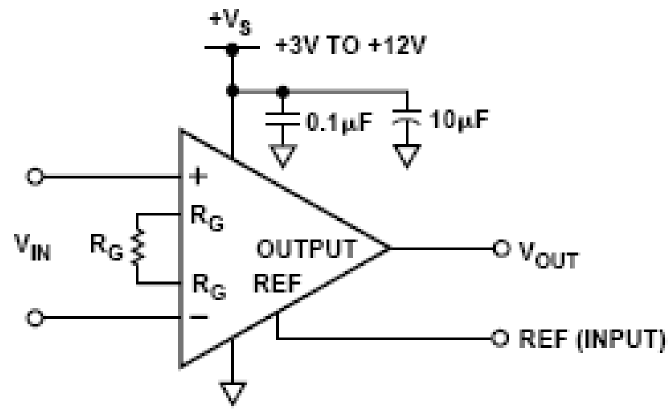
Instrumentation amplifiers





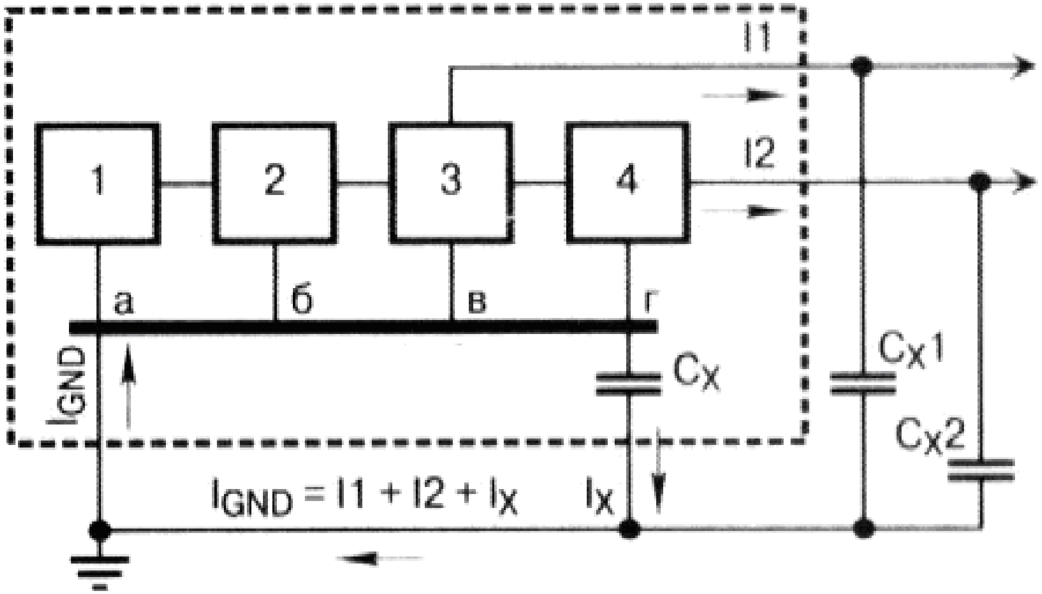


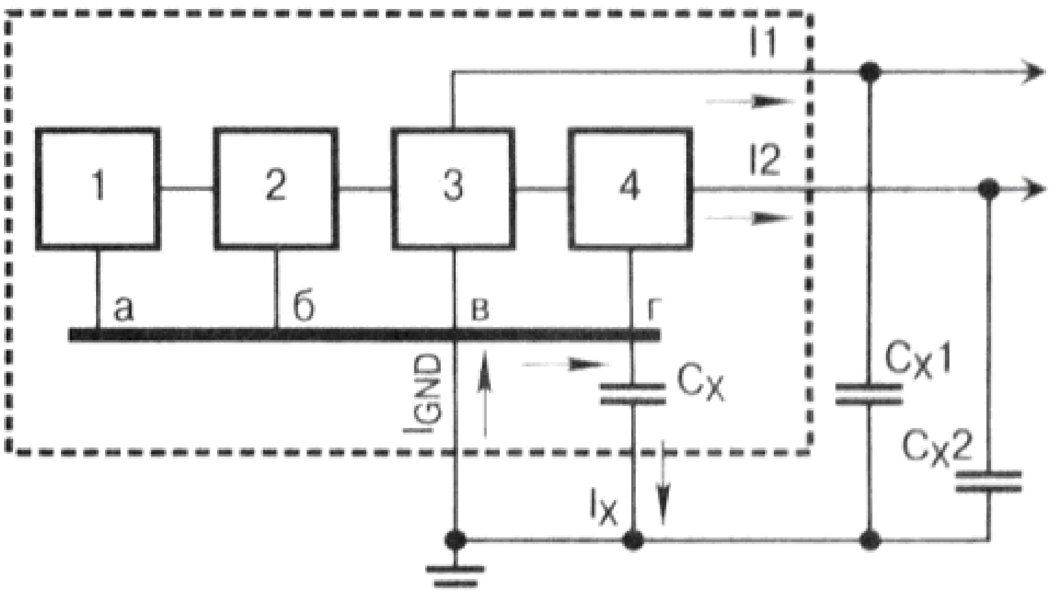
a. Dual Supply

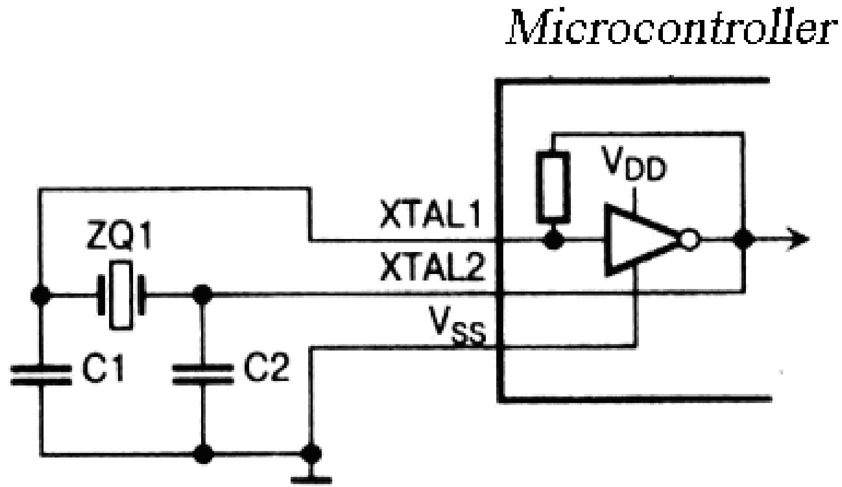


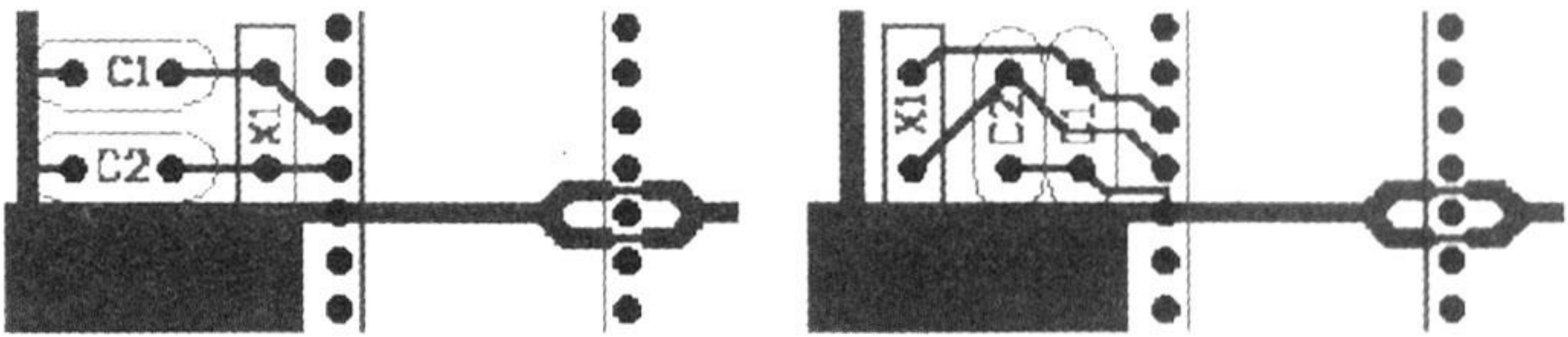
b. Single Supply

Interference

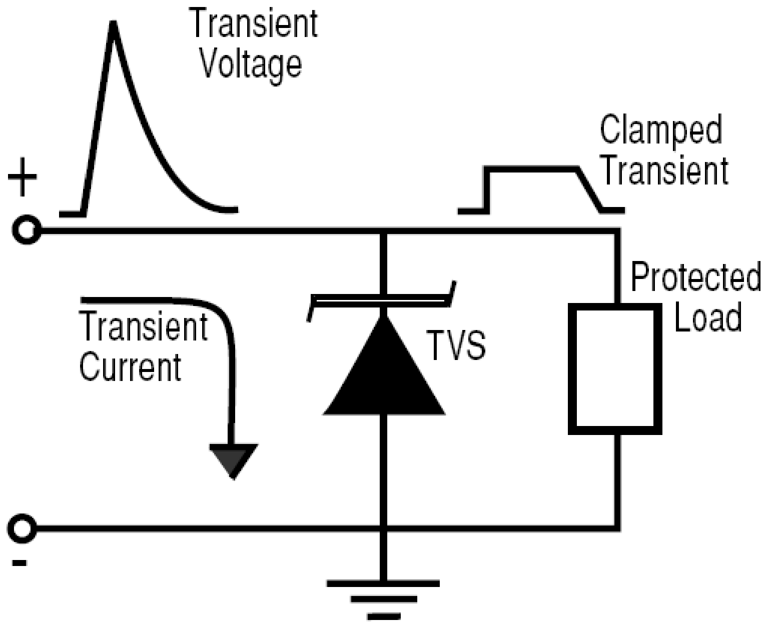

I1
I2
1
2
3
4
а
б
в
г
IGND
Cx
Cx1
Cx2
IGND = I1 + I2 + IX
IX

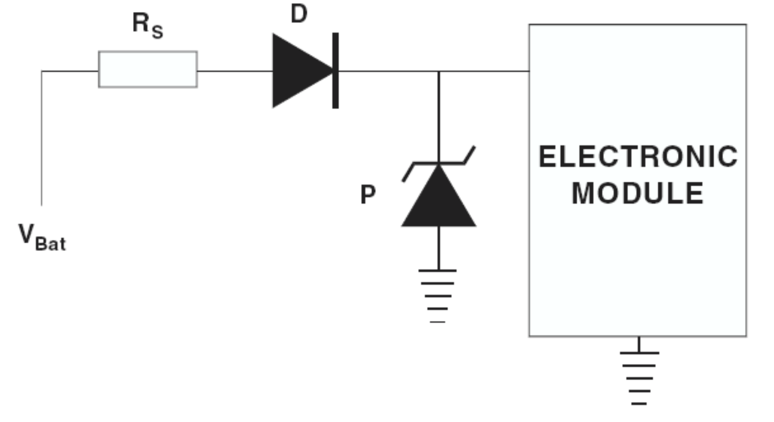

I1
I2
1
2
3
4
а
б
в
г
IGND
Cx
Cx1
Cx2
IX


Microcontroller
V_{DD}
XTAL1
ZQ1
XTAL2
V_{SS}
C1
C2

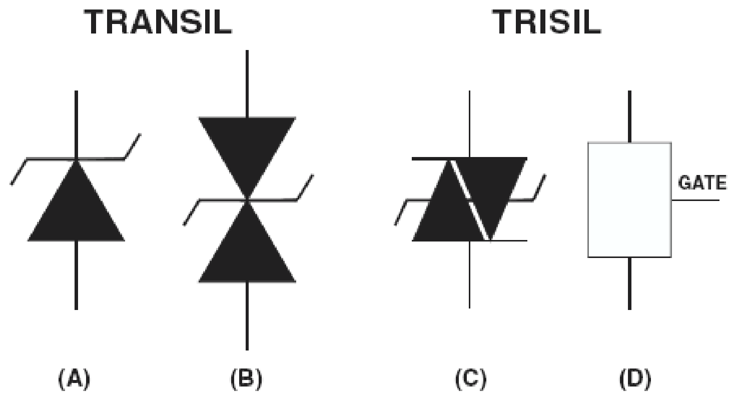

C1
C2
X1

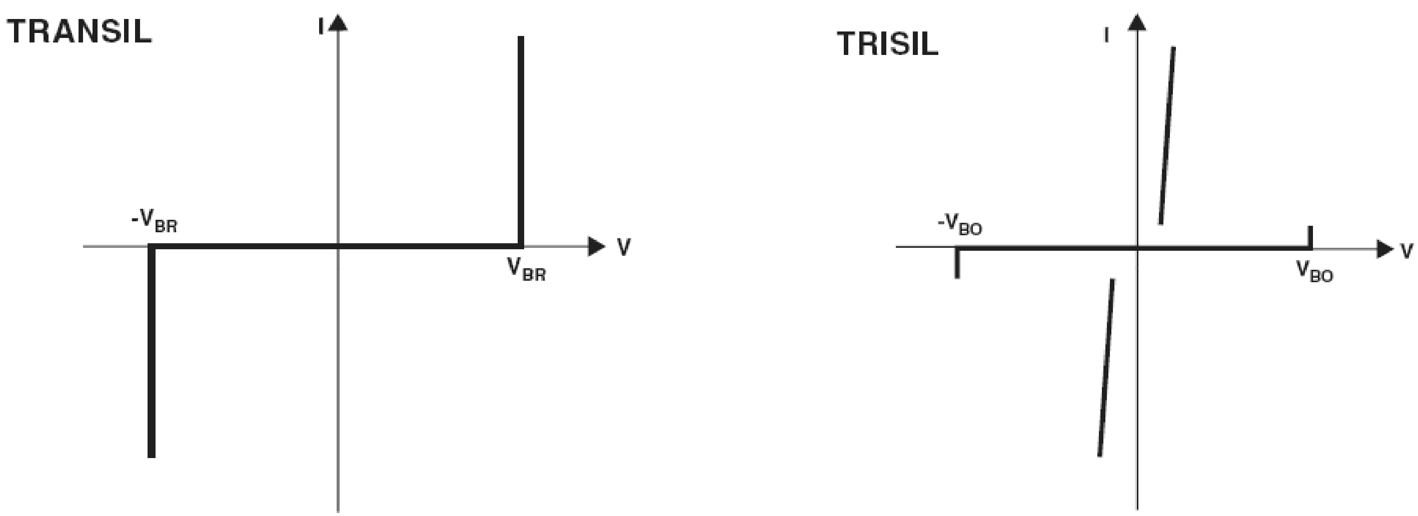
Surge protection

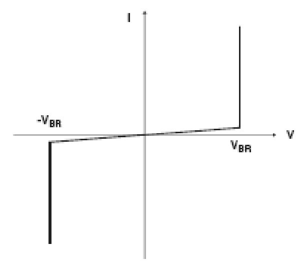
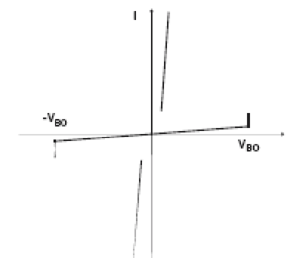
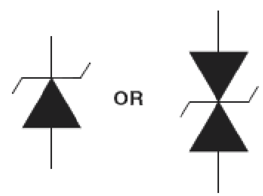
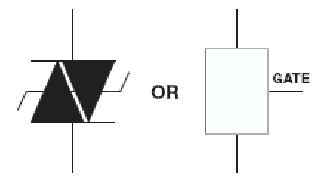




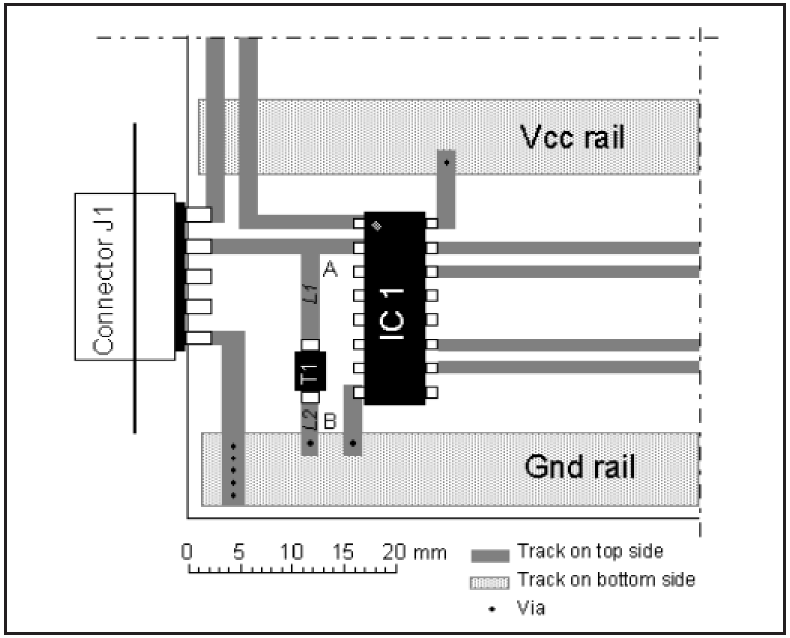
Surge protection

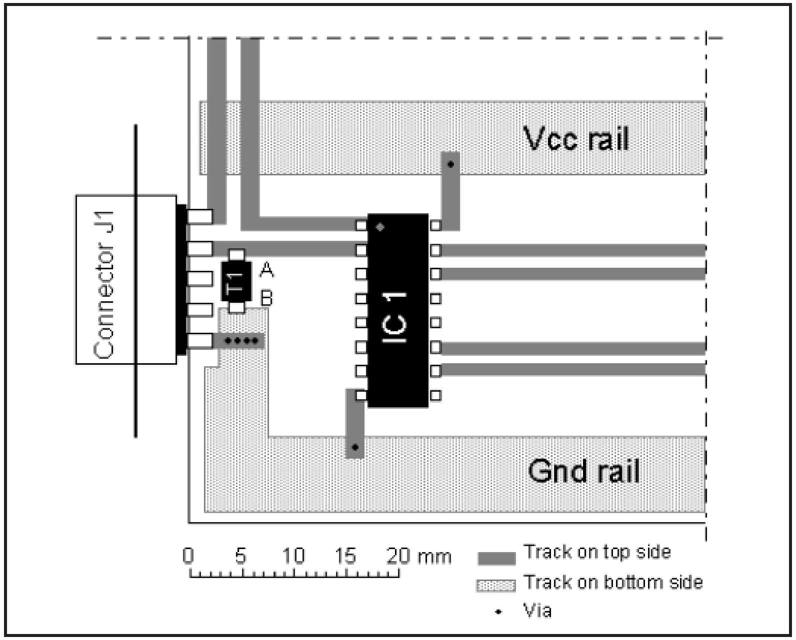




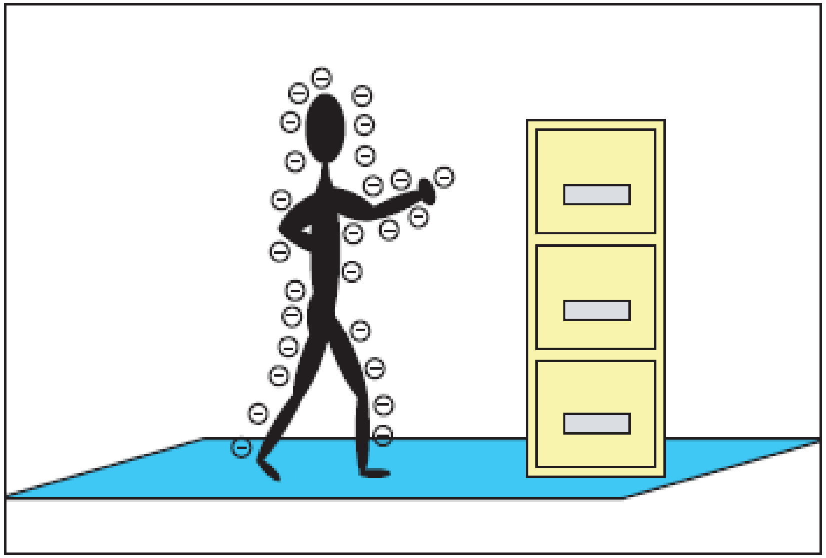
	TRANSIL	TRISIL
TYPE OF ACTION	**CLAMPING**	**CROWBAR**
ELECTRICAL CHARACTERISTICS		
SCHEMATICS		
ELECTRICAL BEHAVIOUR		
ACTION START	Vsurge > V_{BR}	Vsurge > V_{BO}
ACTION STOP	Vsurge < V_{BR}	I < Holding Current

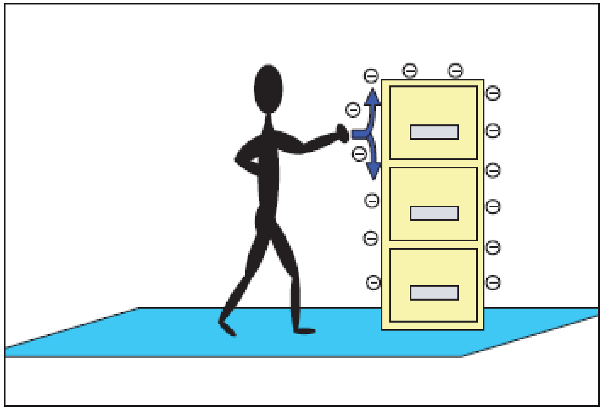
PCB topology effect



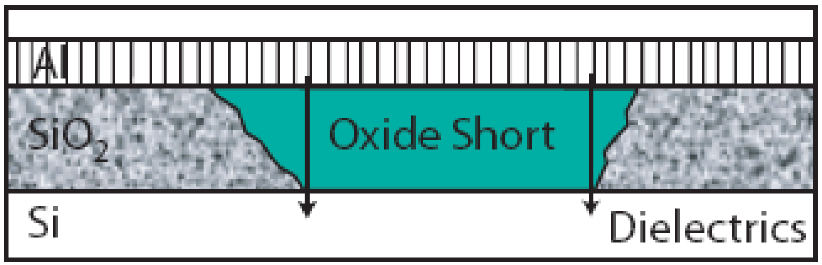


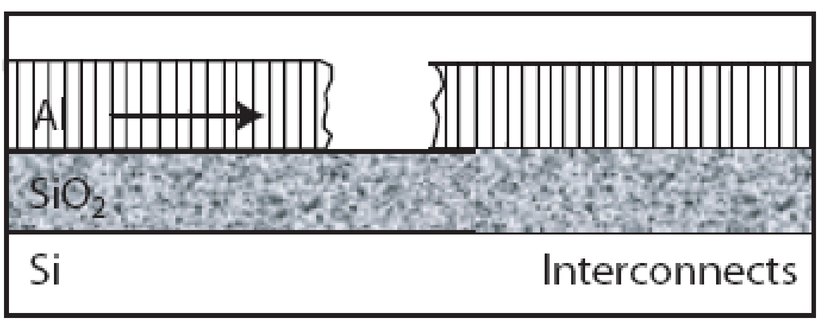
Electrostatic Discharge (ESD)

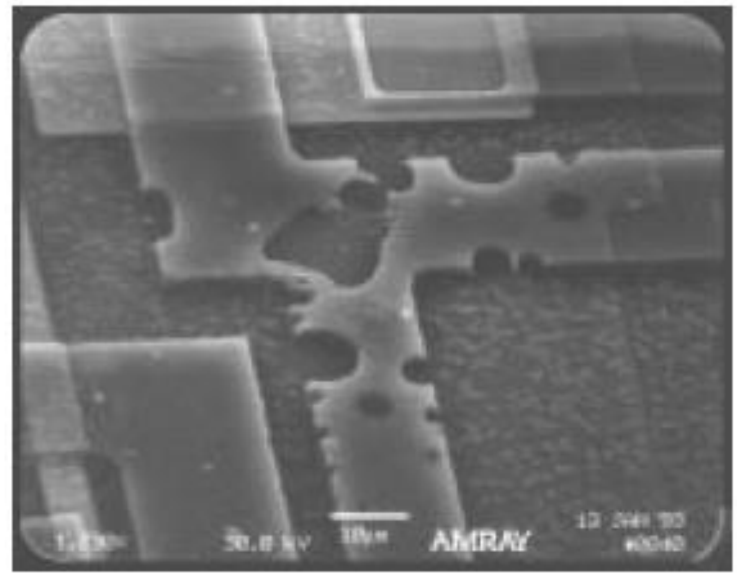




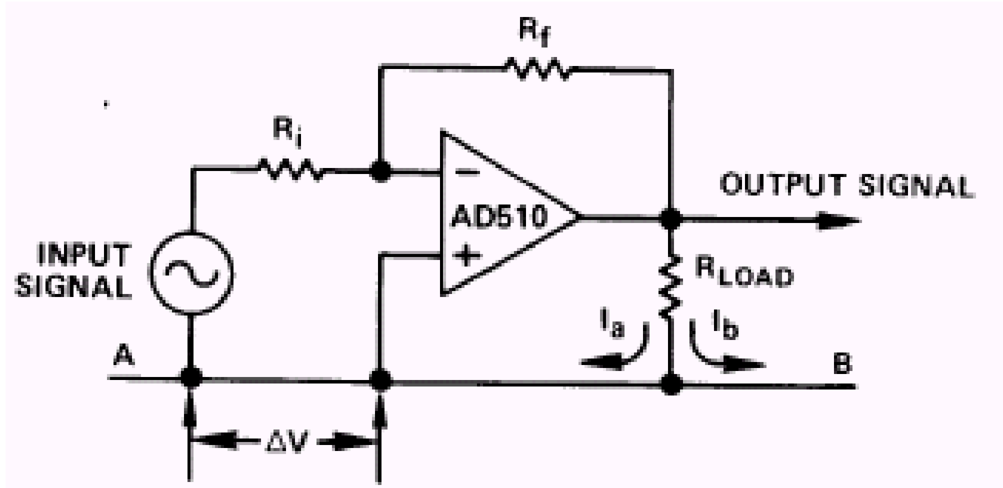
ESD impact


Al
SiO2
Oxide Short
Si
Dielectrics

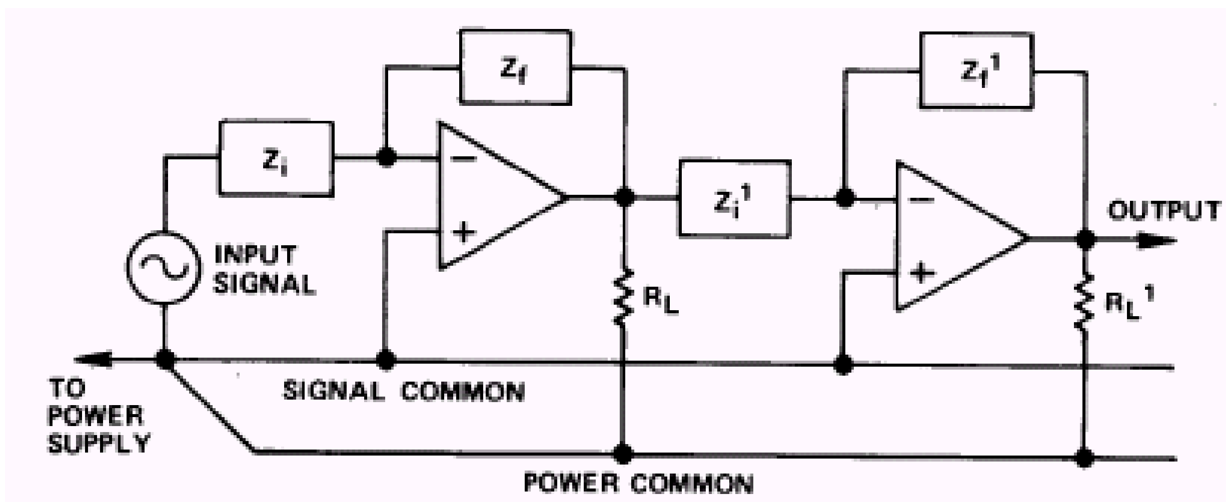

Al
SiO2
Si
Interconnects


AMRAY

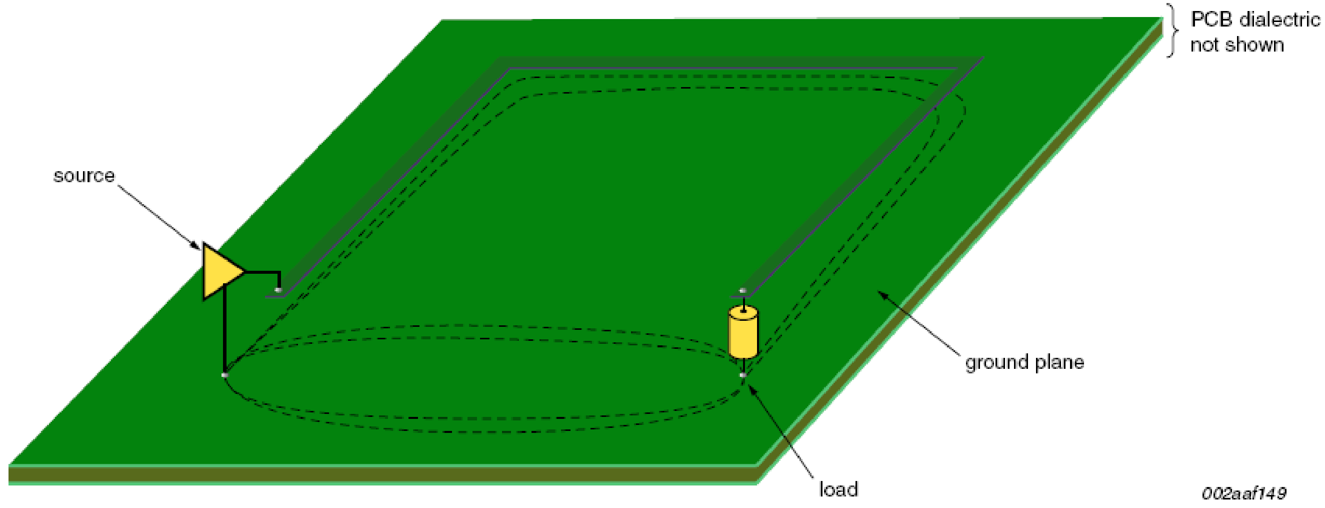
Common wire



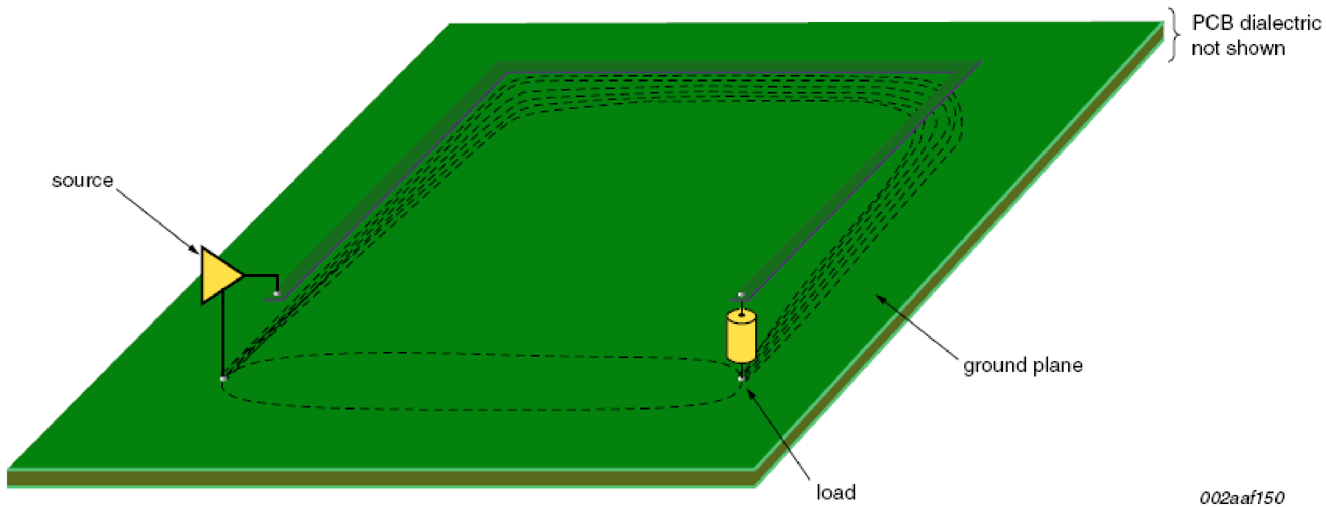
R_f
R_i
AD510
OUTPUT SIGNAL
INPUT SIGNAL
R_{LOAD}
I_a
I_b
A
B
ΔV



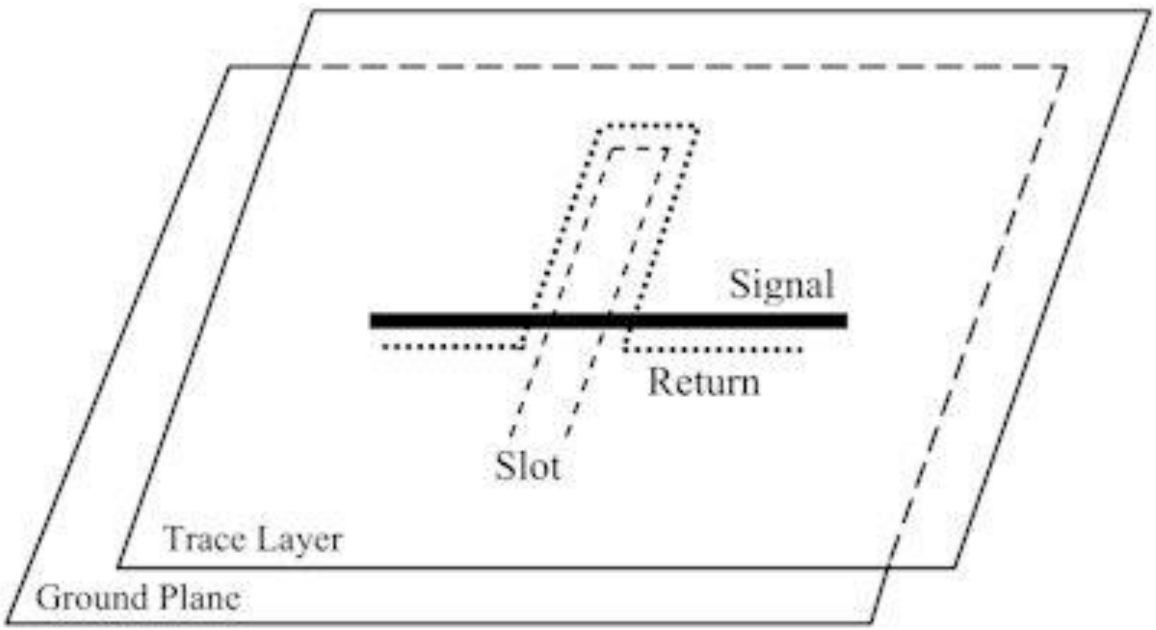
Z_f
Z_i
Z_f^1
Z_i^1
INPUT SIGNAL
OUTPUT
R_L
R_L^1
TO POWER SUPPLY
SIGNAL COMMON
POWER COMMON



a. Low frequency

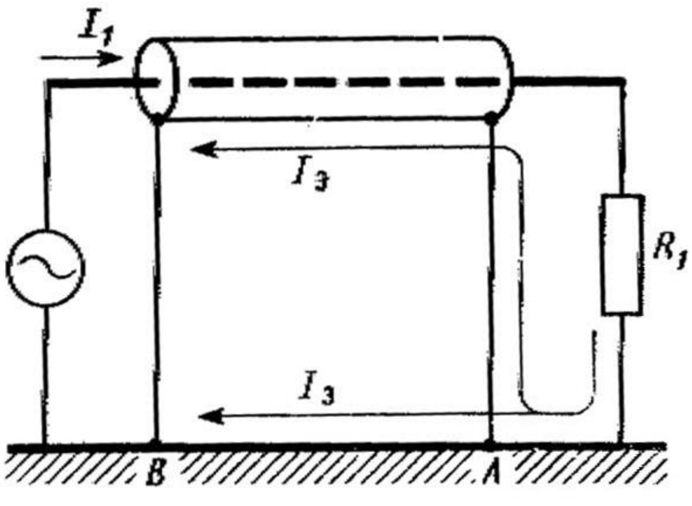


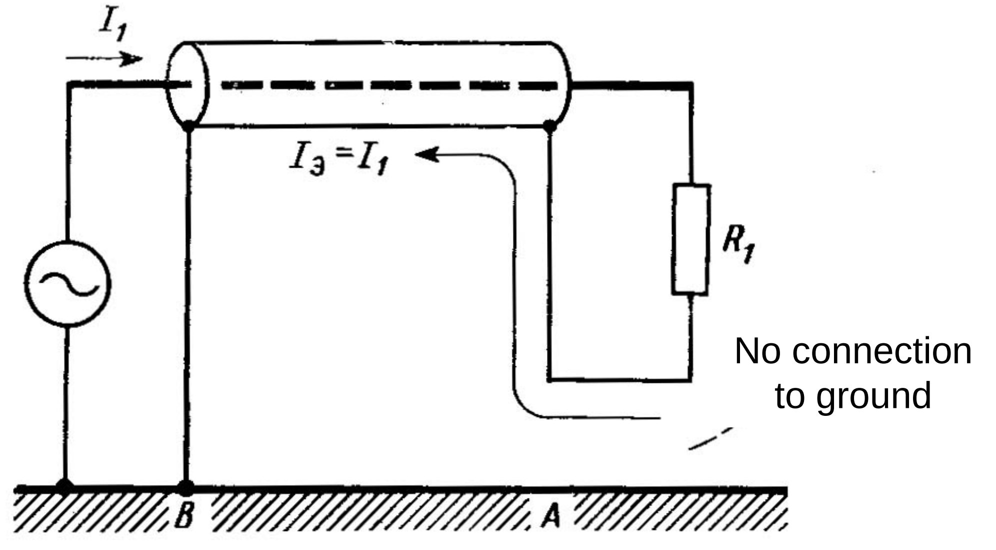
Return current



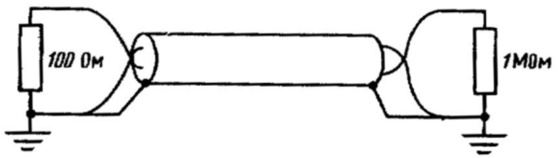
SHIELDING

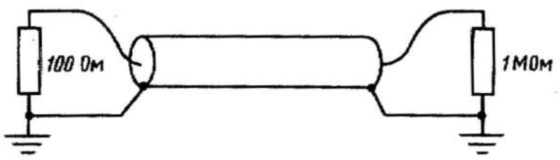
Shield currents

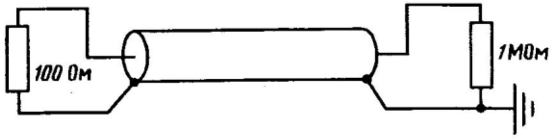


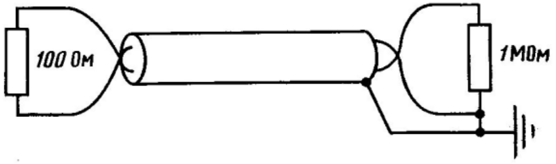


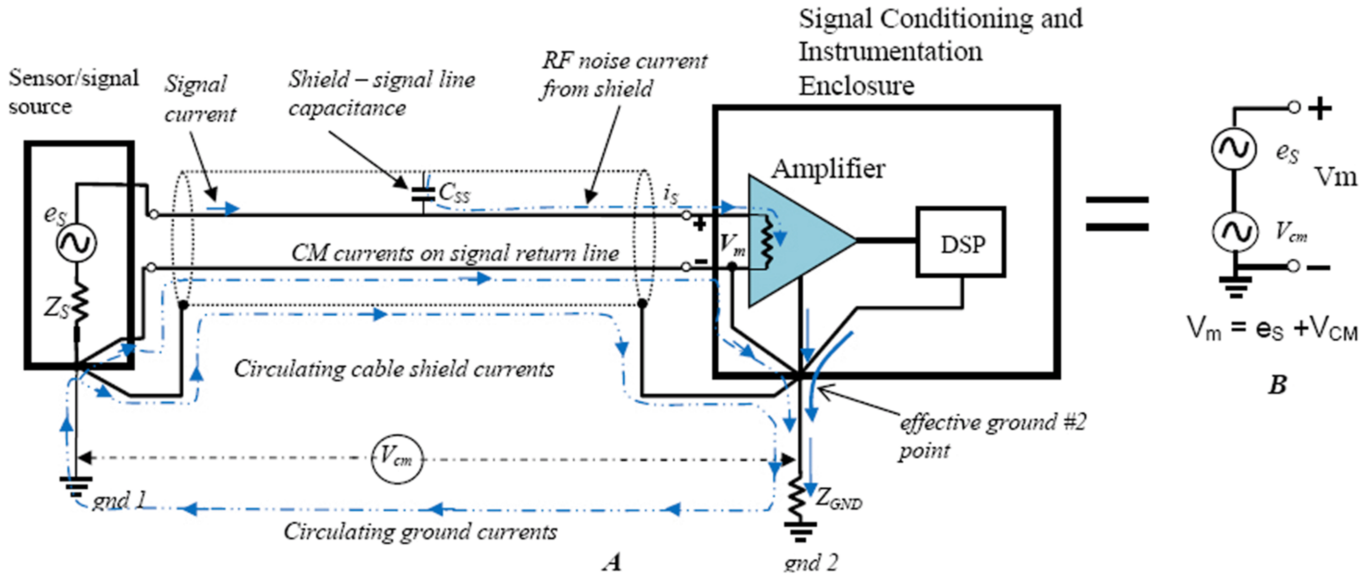
Shielding options

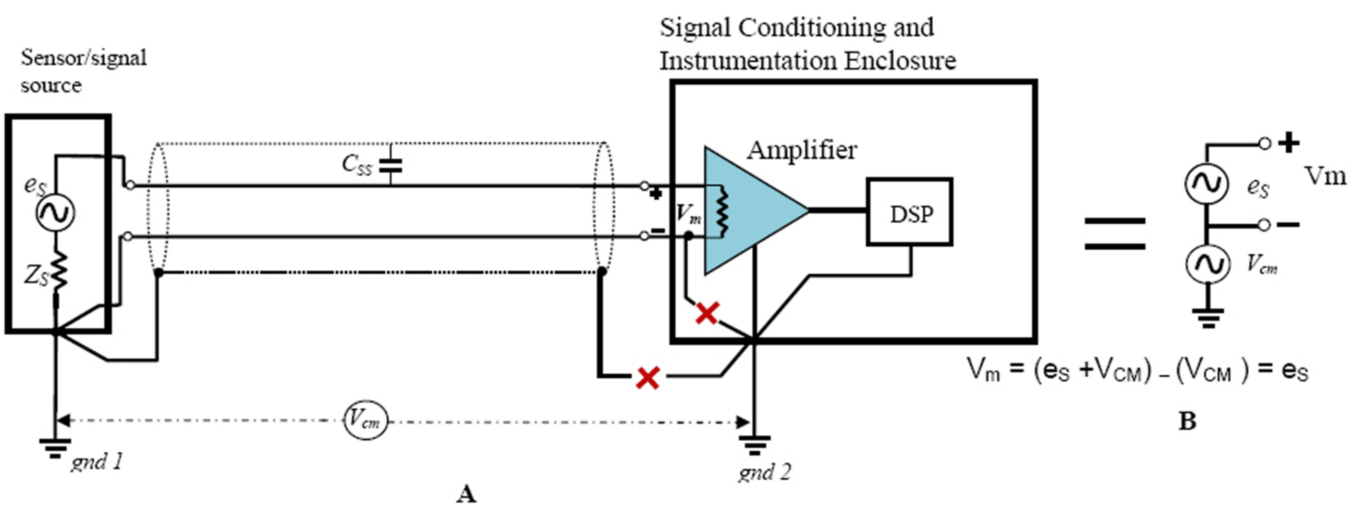




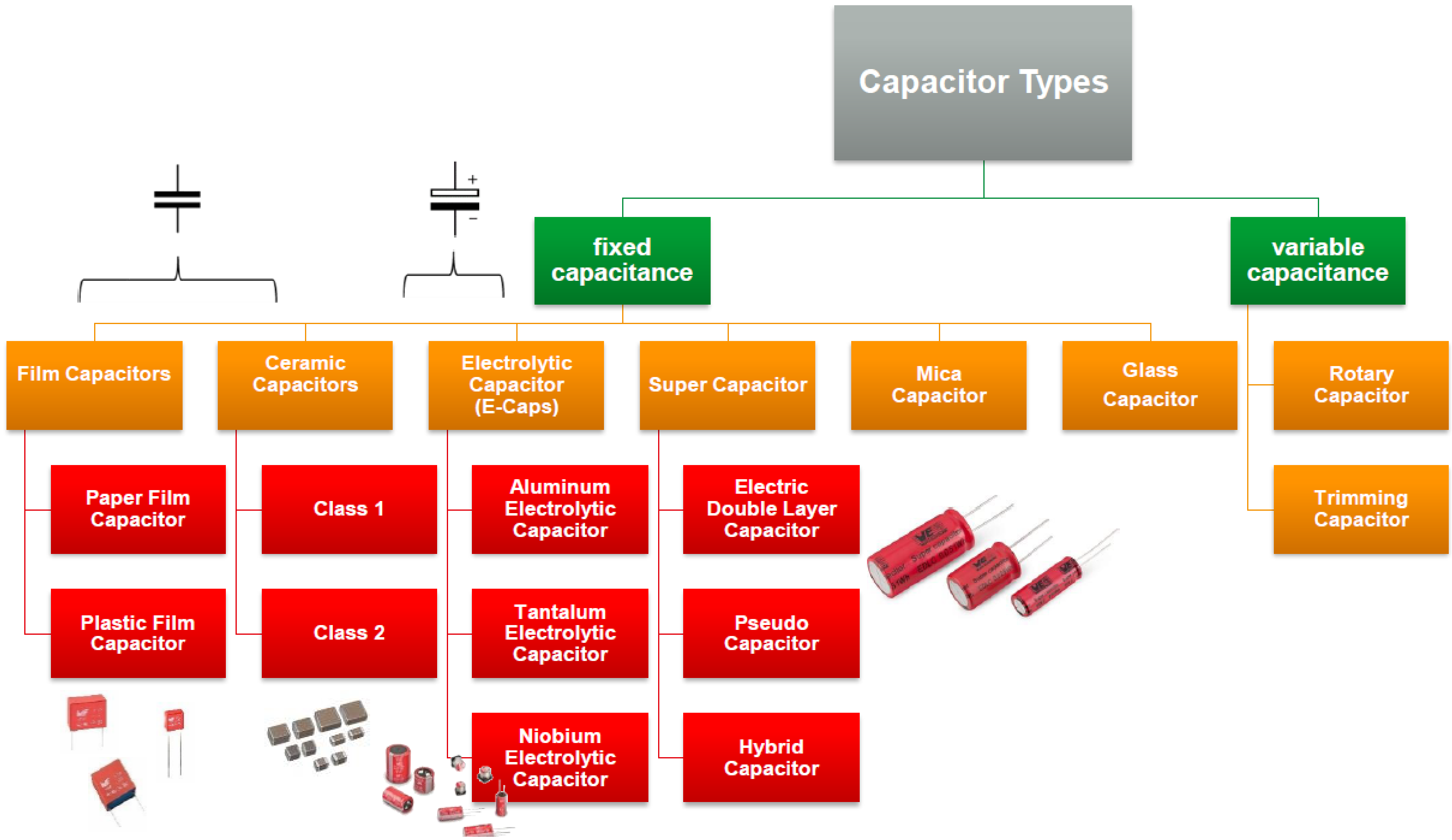




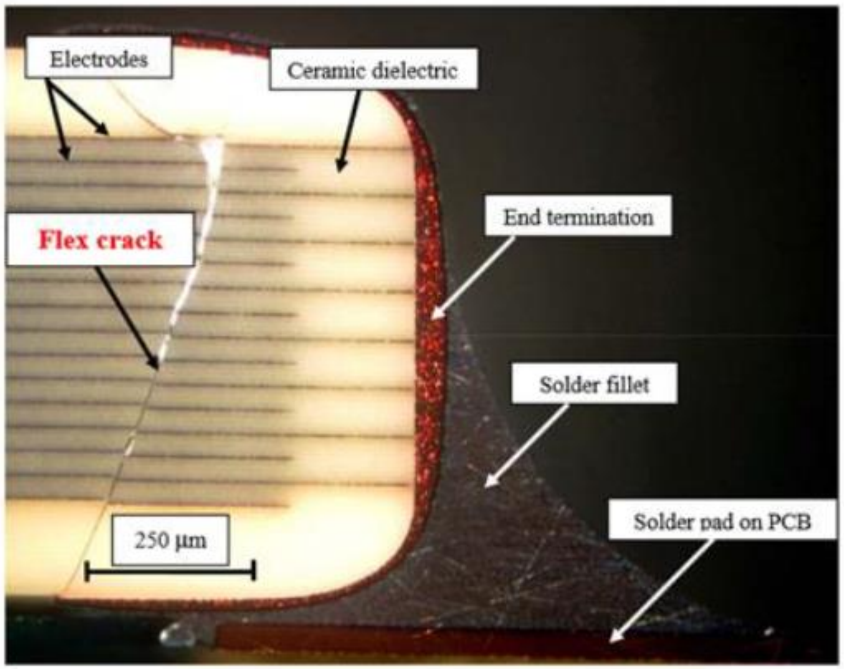

Signal Conditioning and Instrumentation Enclosure
Sensor/signal source
Signal current
Shield – signal line capacitance
RF noise current from shield
C_{SS}
i_S
Amplifier
DSP
e_S
Z_S
V_m
CM currents on signal return line
Circulating cable shield currents
effective ground #2 point
V_{cm}
gnd 1
Z_{GND}
Circulating ground currents
gnd 2
A
e_S
Vm
V_{cm}
$V_m = e_S + V_{CM}$
B

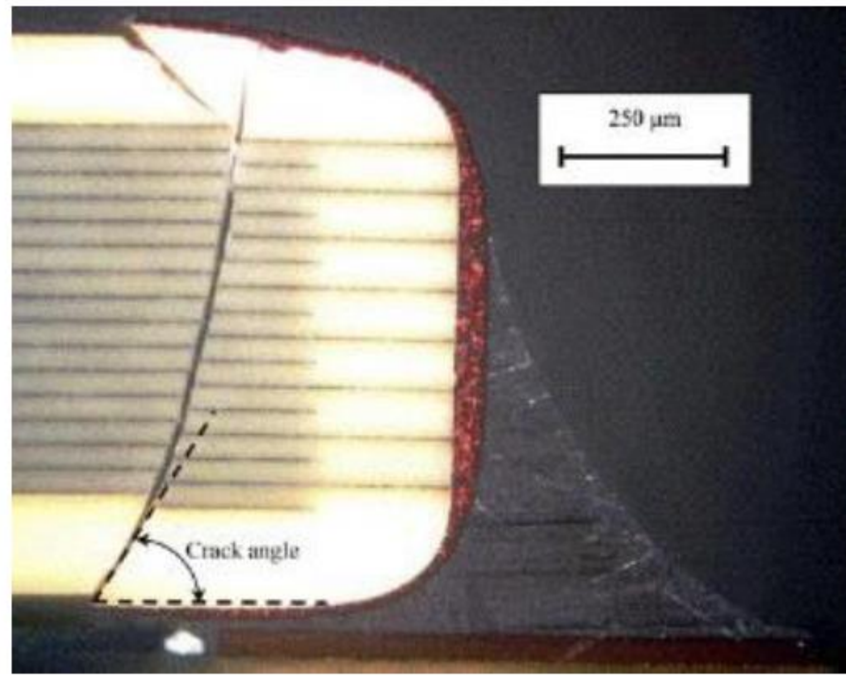

Signal Conditioning and Instrumentation Enclosure
Sensor/signal source
C_{SS}
Amplifier
DSP
e_S
Z_S
V_m
V_{cm}
gnd 1
gnd 2
A
e_S
Vm
V_{cm}
$V_m = (e_S + V_{CM}) - (V_{CM}) = e_S$
B

Capacitor Types



MLCC underwater rocks
Cracking





Differences Class 1 and Class 2 Ceramic

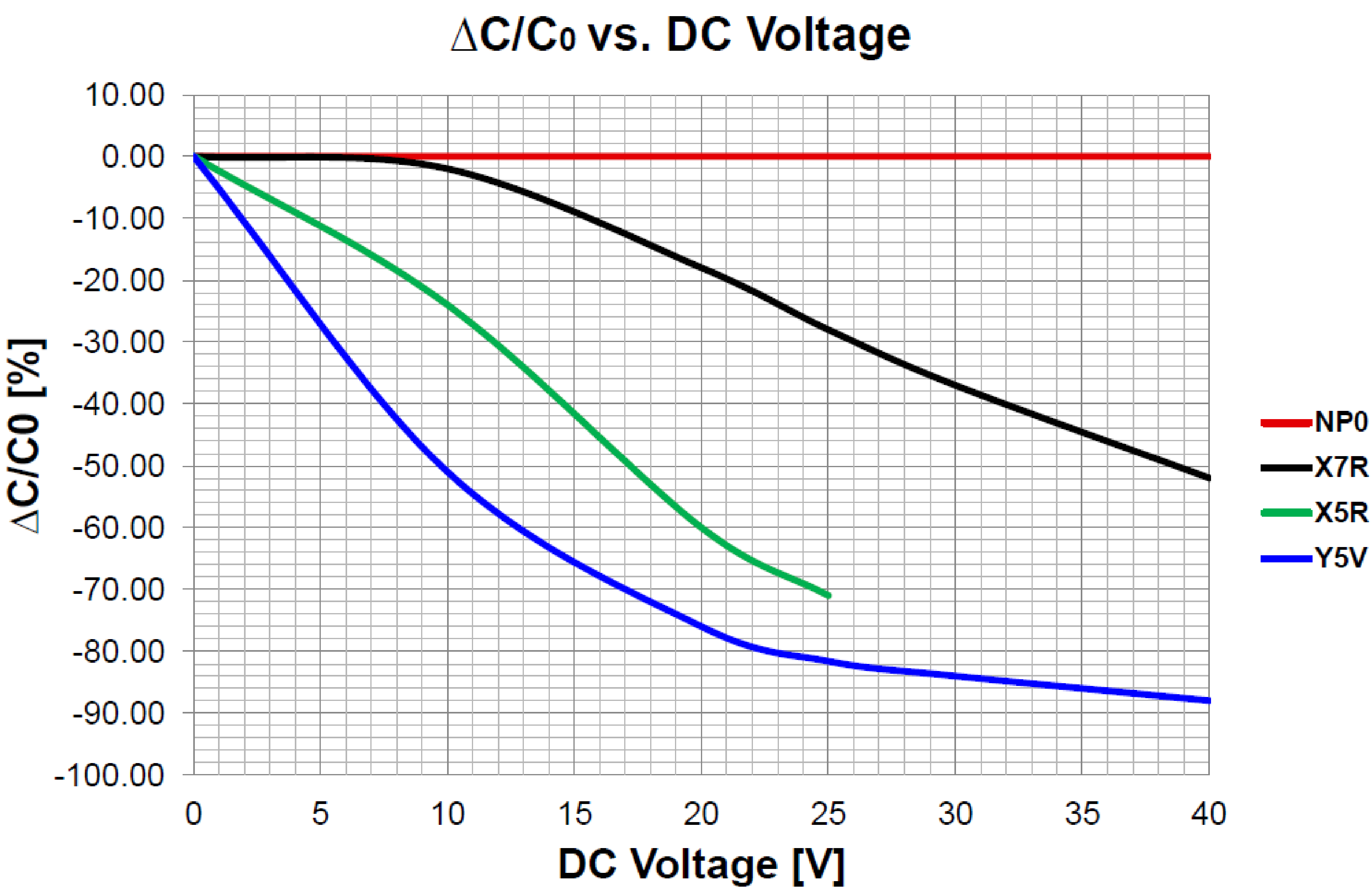
	Class 1	Class 2
Material:	Titanium Dioxide (*TiO_2*)	Barium Titanate ($BaTiO_3$)
Permittivity:	>10 … 500	>500 …> 10000
Capacity range:	1pF - 33nF	100pF - 100µF
Voltage range:	10V - 50V	6,3V - 100V
Size:	0402 - 1812	0402 - 1812
Voltage dependency:	No	Yes
Frequency dependency:	Yes	Yes
Temperature dependency: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

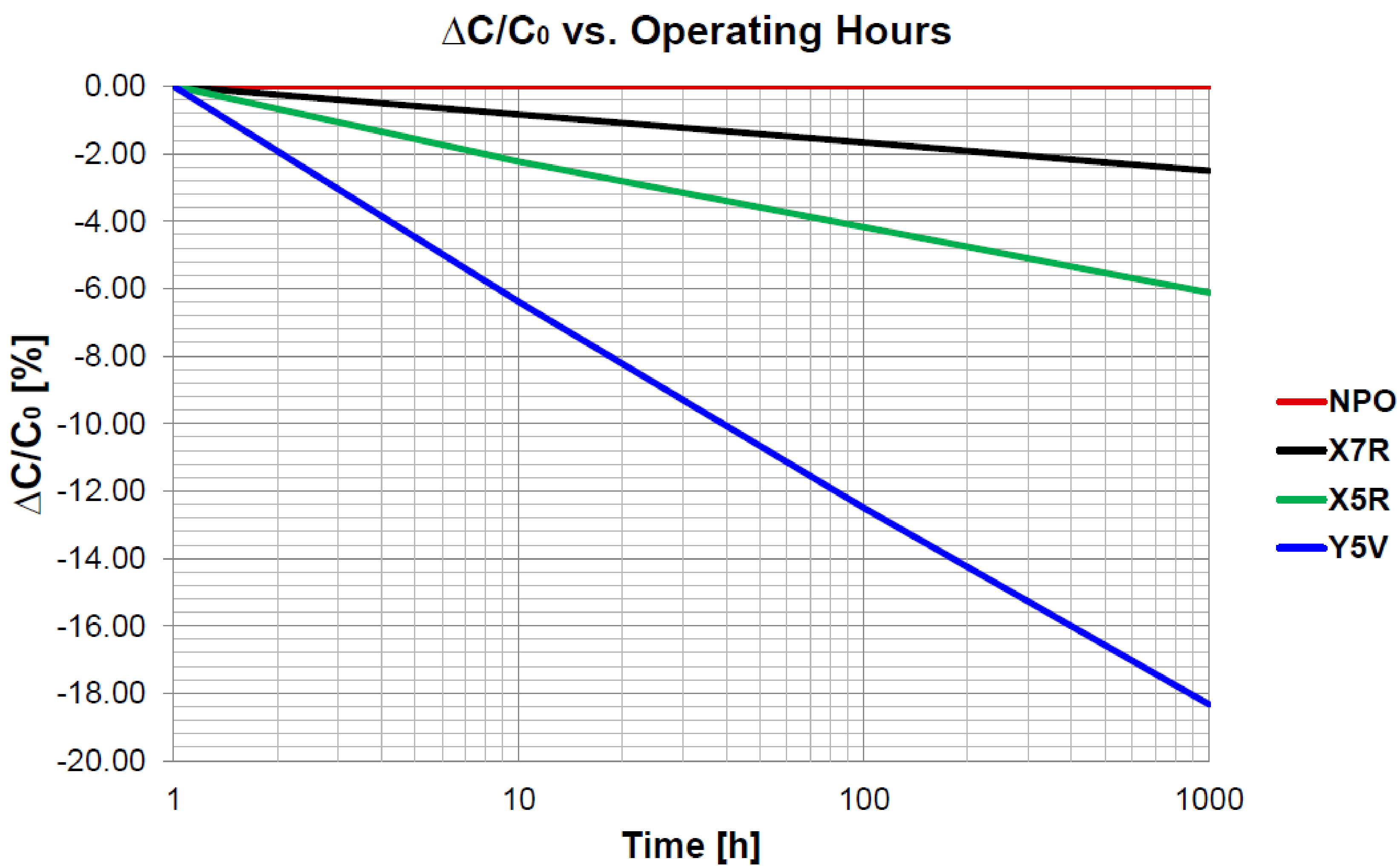
Coding of Class 2 Ceramics

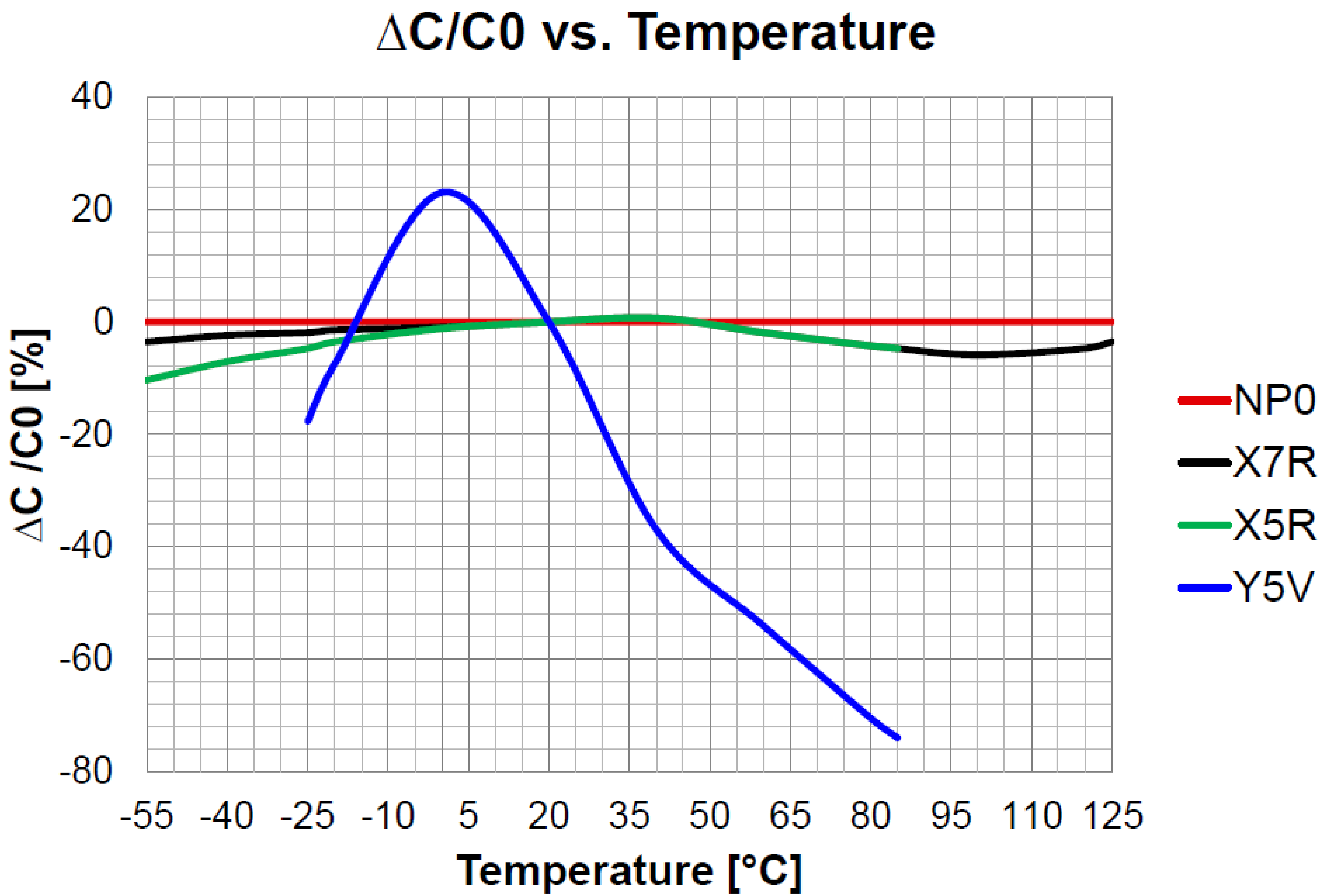
EIA-RS-198 coding for class 2 ceramic capacitors					
1st character		2nd character		3rd character	
Letter	Lower temperature limit	Number	Upper temperature limit	Letter	Capacitance change over the permissible temperature range
X	–55 °C	**2**	+45 °C	**A**	±1.0%
Y	–30 °C	**4**	+65 °C	**B**	±1.5%
Z	+10 °C	**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%



ΔC/C0 vs. DC Voltage
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
-80.00
-90.00
-100.00
ΔC/C0 [%]
0
5
10
15
20
25
30
35
40
DC Voltage [V]
NP0
X7R
X5R
Y5V

MLCC underwater rocks
Aging




ΔC/C0 vs. Temperature
40
20
0
-20
-40
-60
-80
ΔC /C0 [%]
-55
-40
-25
-10
5
20
35
50
65
80
95
110
125
Temperature [°C]
NP0
X7R
X5R
Y5V

Thank you for your attention !