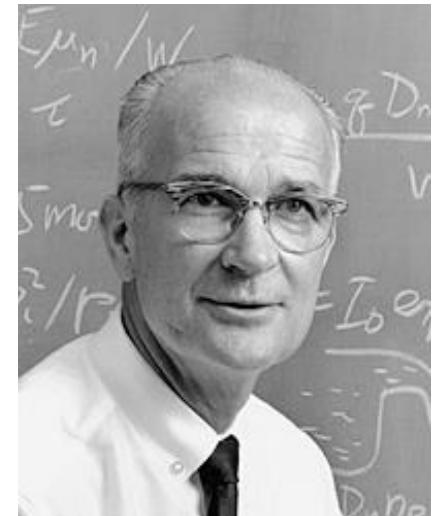
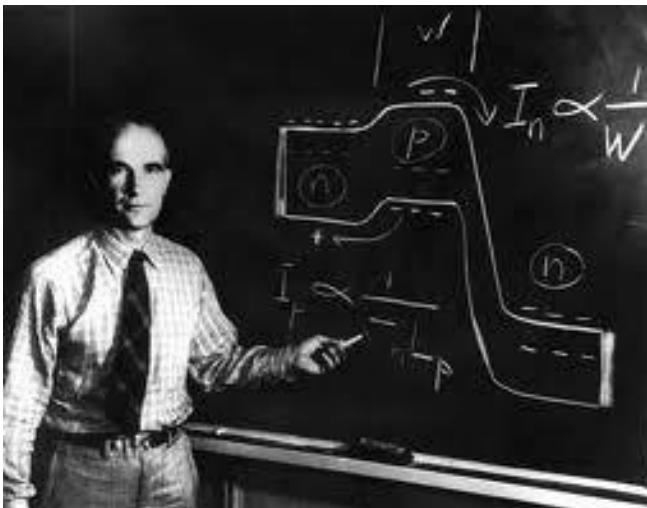


Electronic systems

Samara, 2021

Some historical information



1948

Fathers of modern transistors:

John Bardeen 1908-1991

William Shockley 1910-1989

Walter Brattain 1902-1987



Robert Noyce & John Kilby

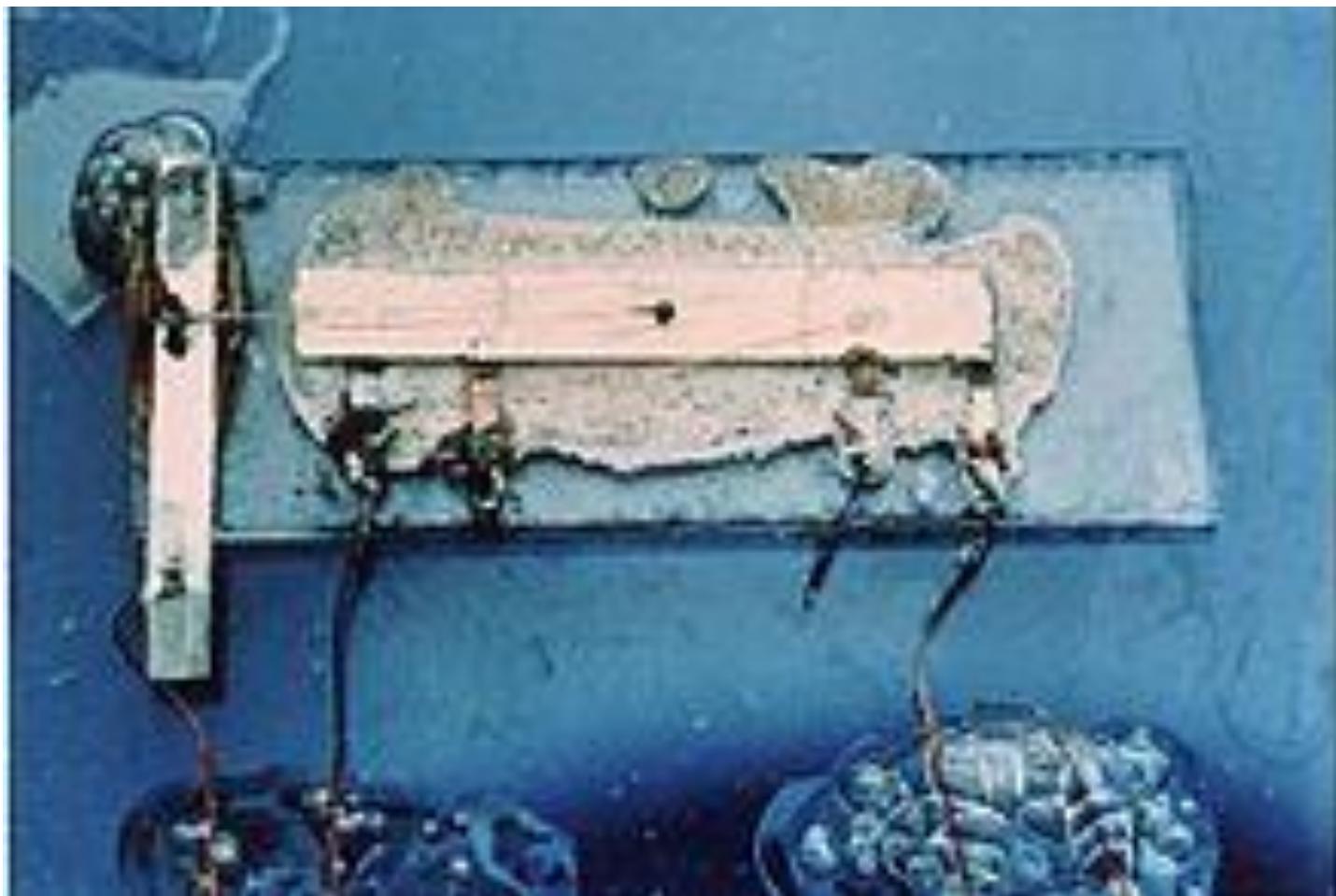


1927-1990



1923-2005

Kilby's first IC



THE IMPROVED μ A702 WIDEBAND DC AMPLIFIER

by R. J. Widlar

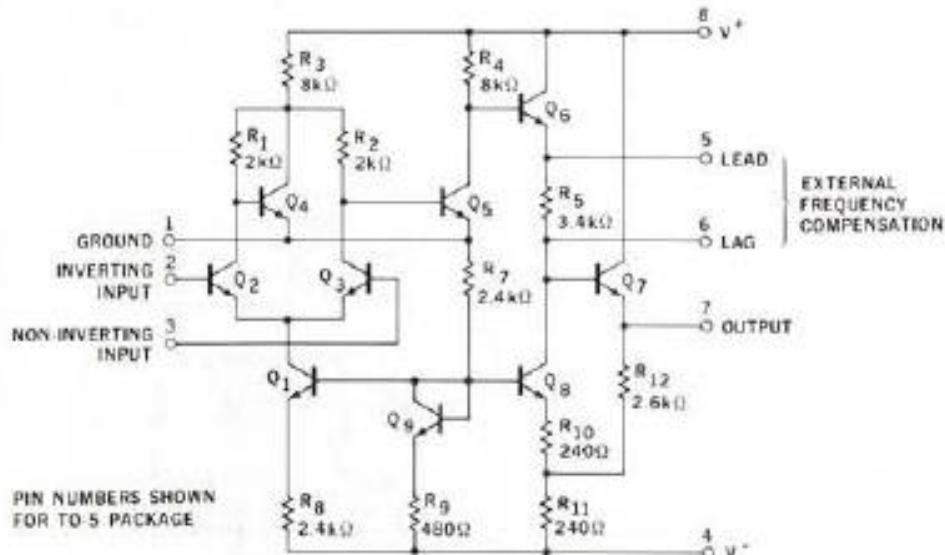
I INTRODUCTION

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

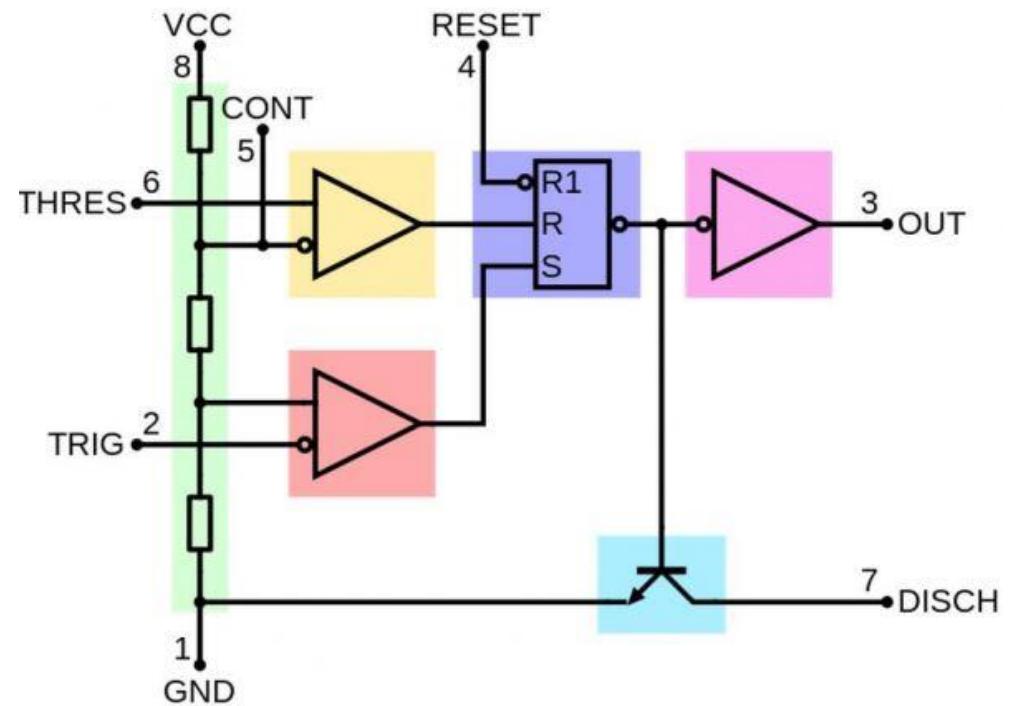
1937-1991





Hans Kamenzind

1934-2012



Electronic systems in microsatellites typically perform:

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

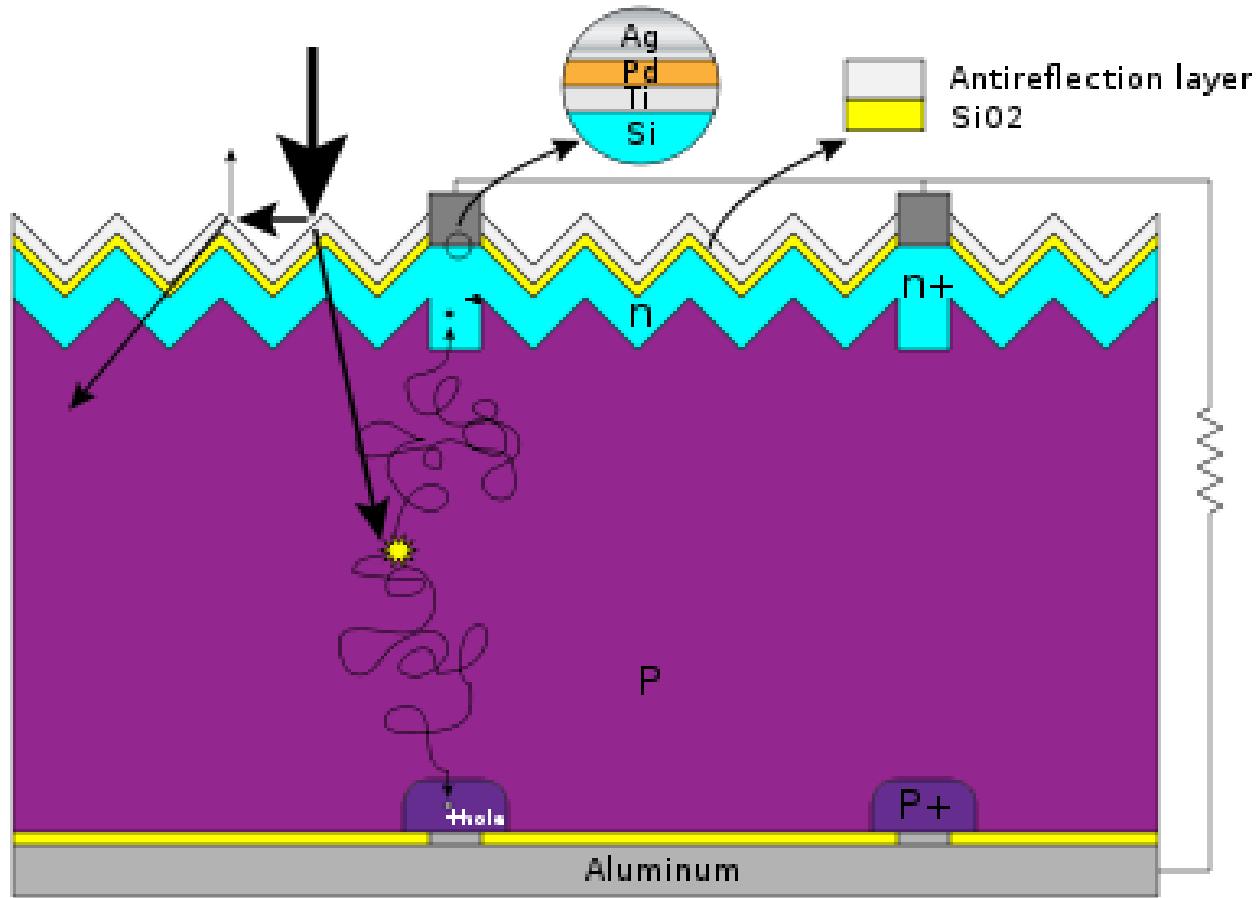
POWER SYSTEMS



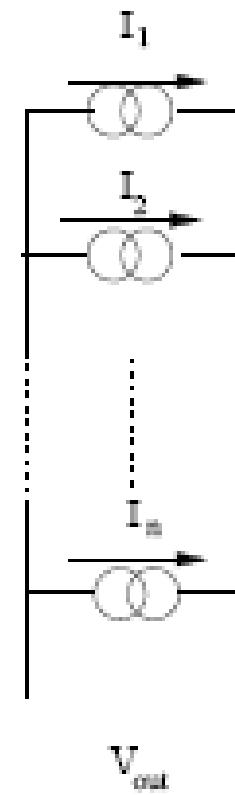
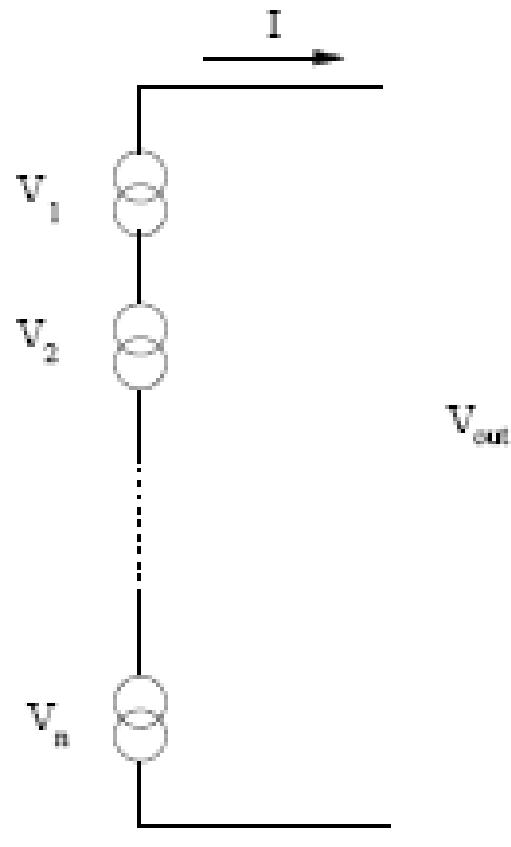
Primary power sources

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

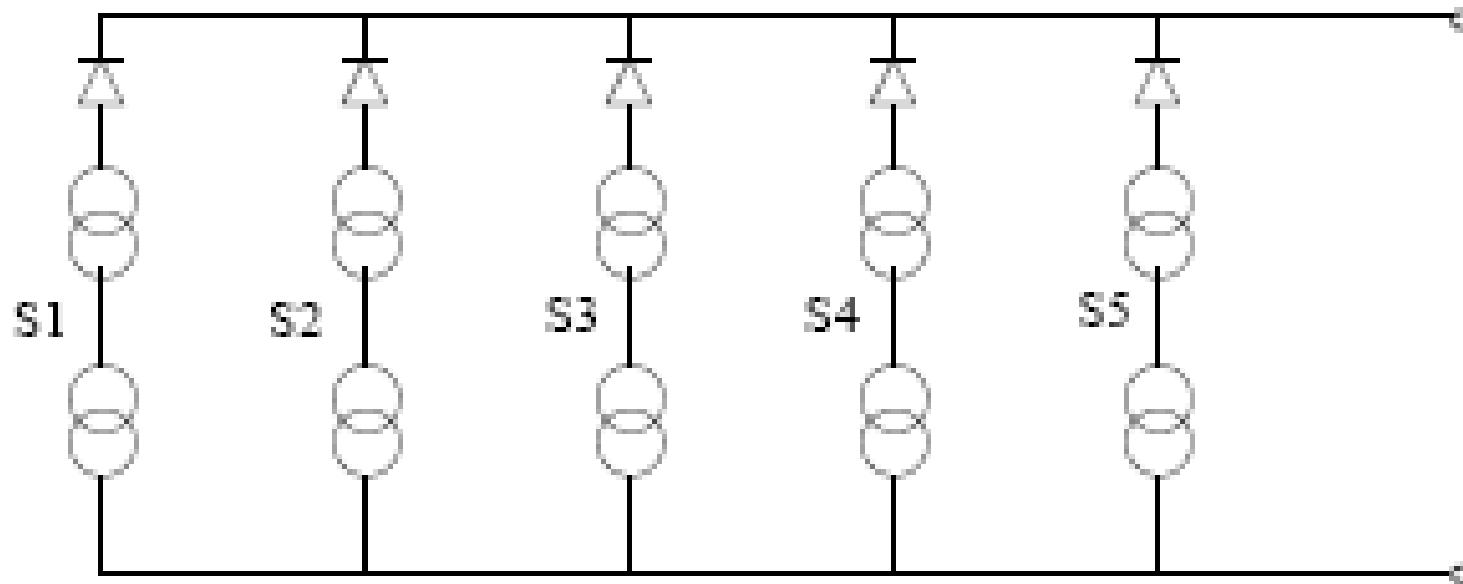
Solar battery structure



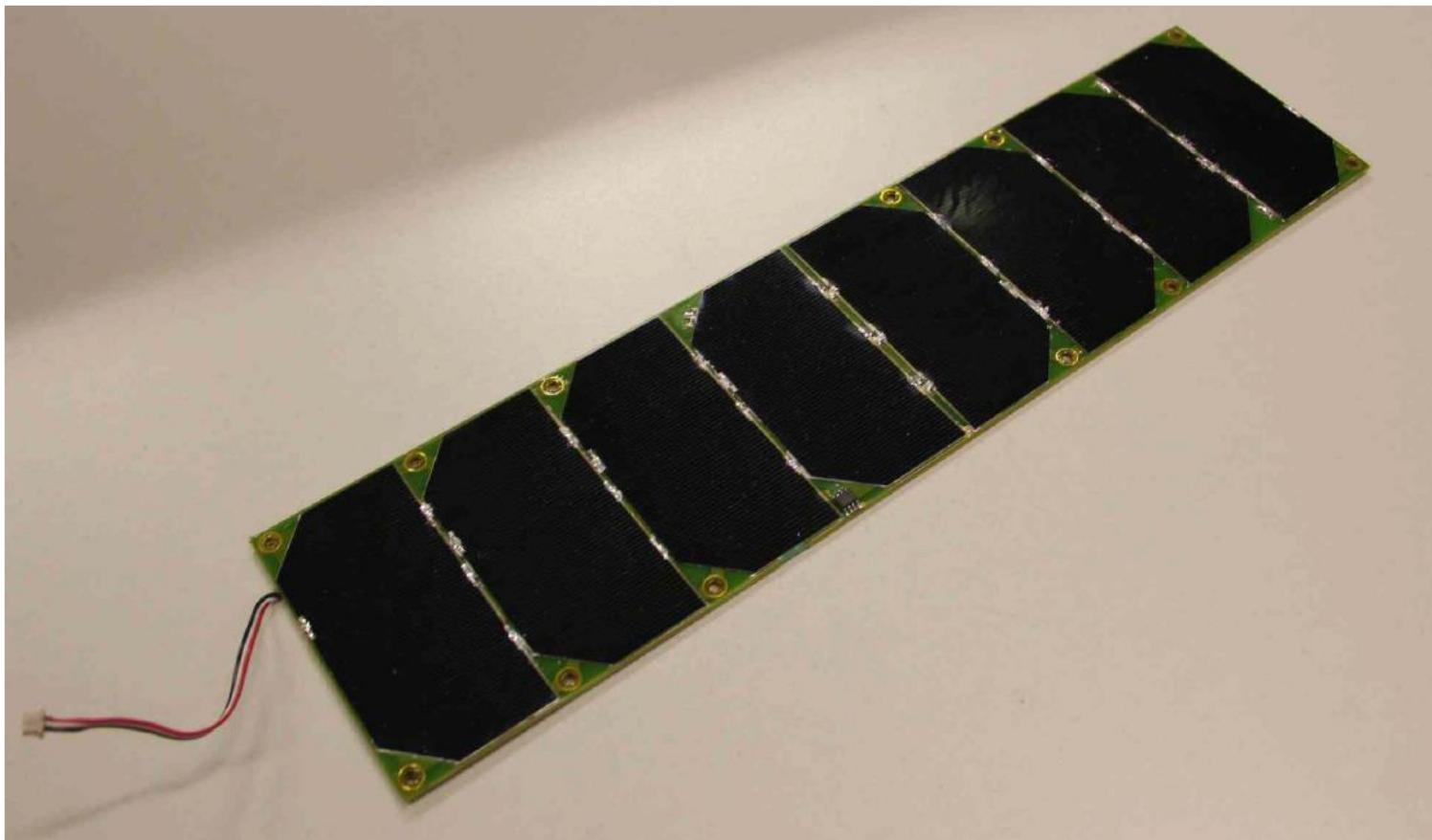
Connection of the batteries



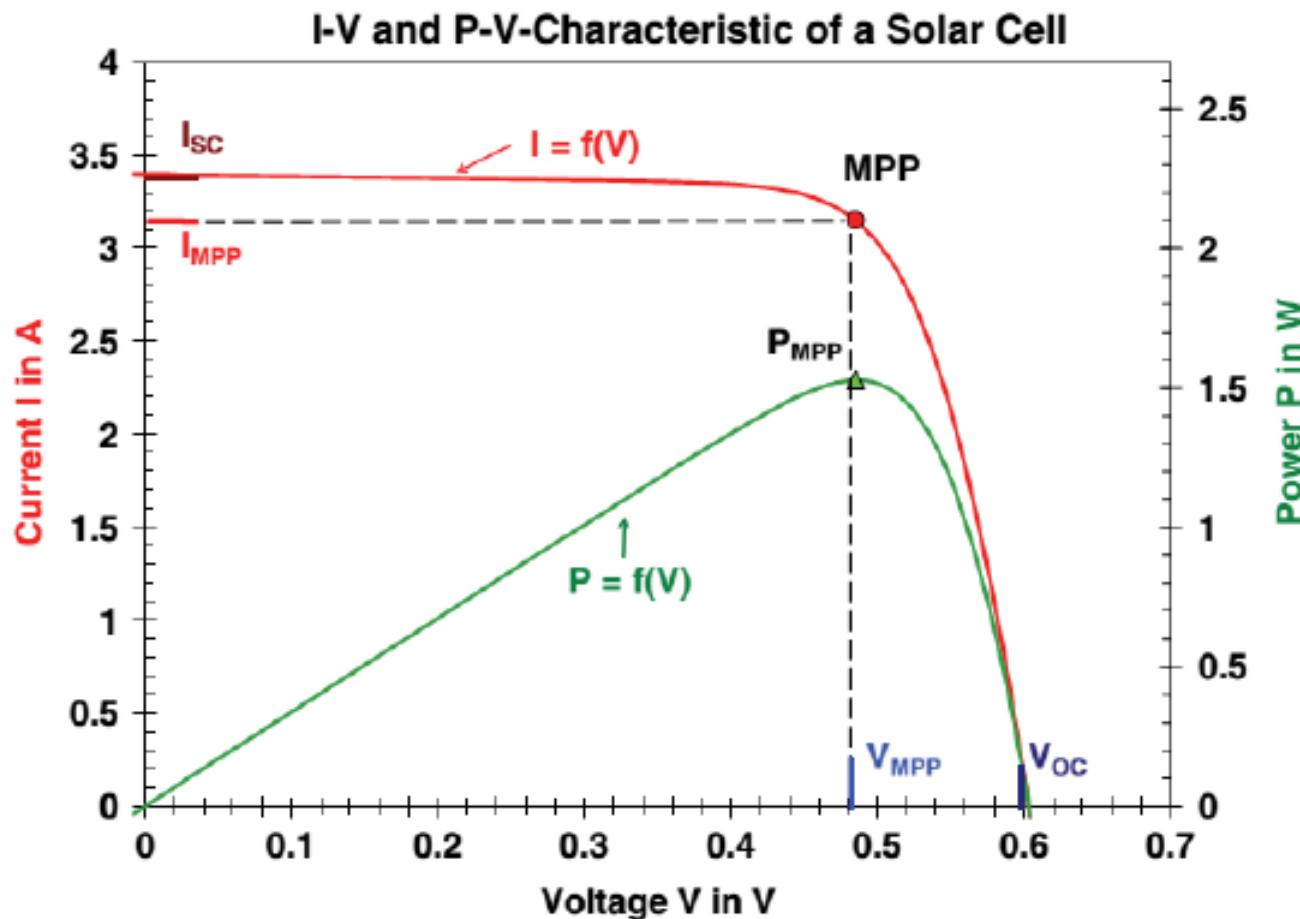
Cubesat circuit



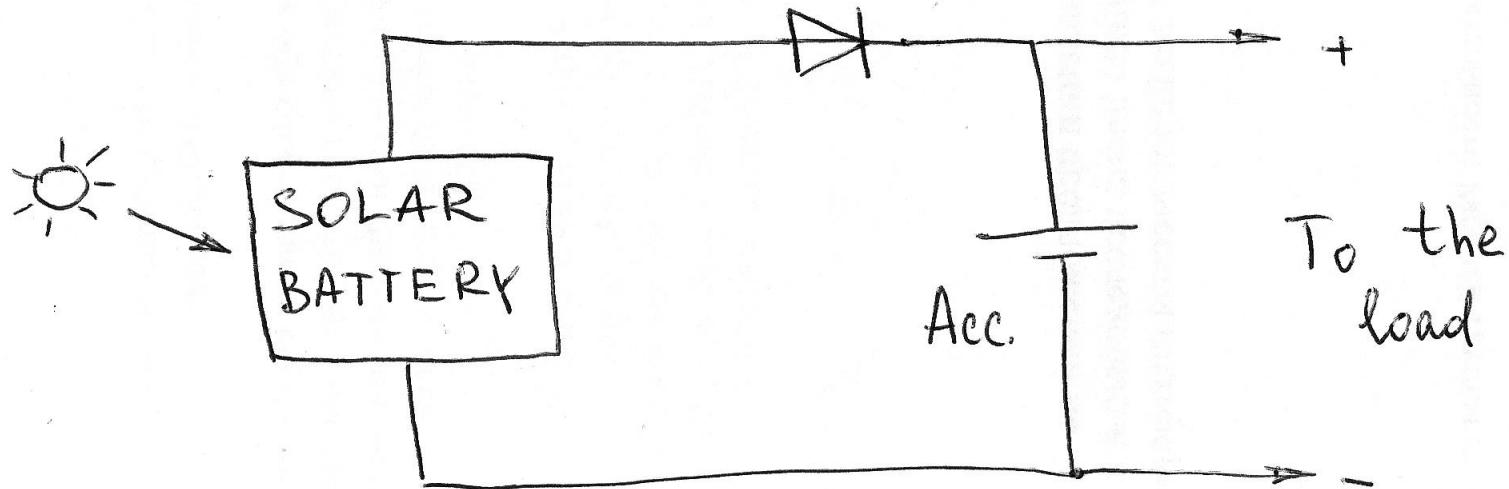
Aalto-1 solar panel



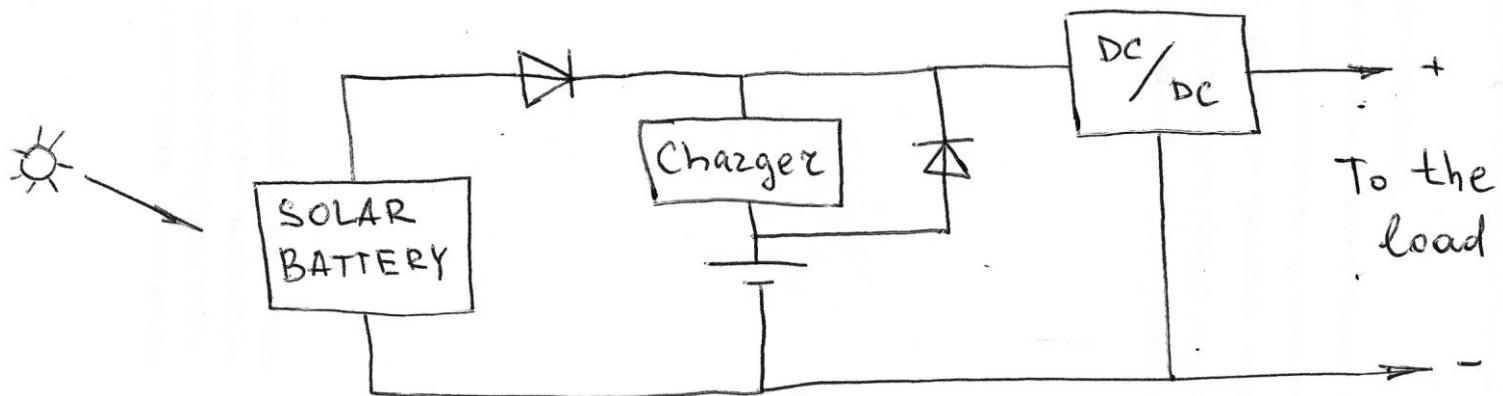
Current-voltage curve of solar battery



Power circuit without voltage control



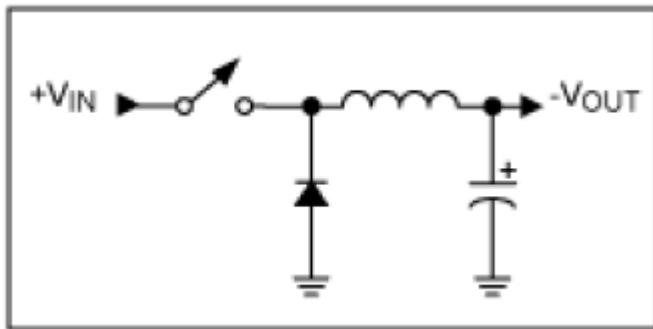
Circuit with voltage regulation



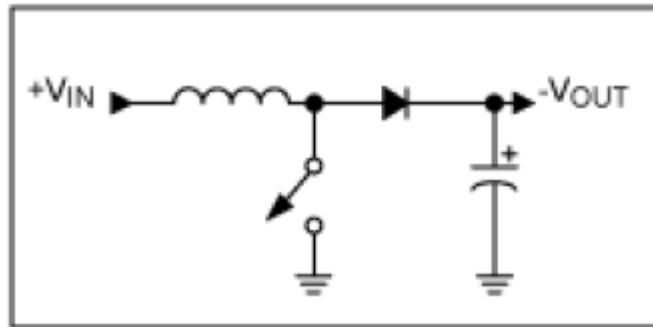
How do you choose?

	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

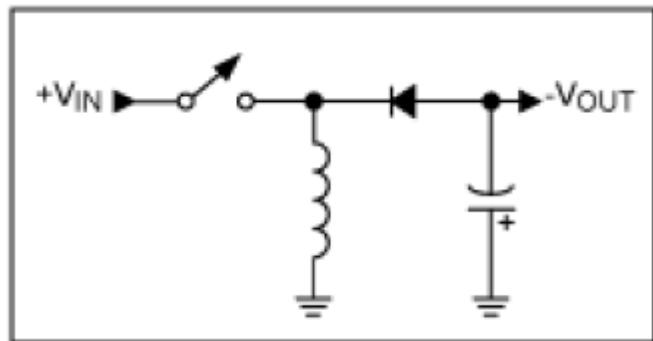
Simple DC/DC Converters



Chopper (buck converter)

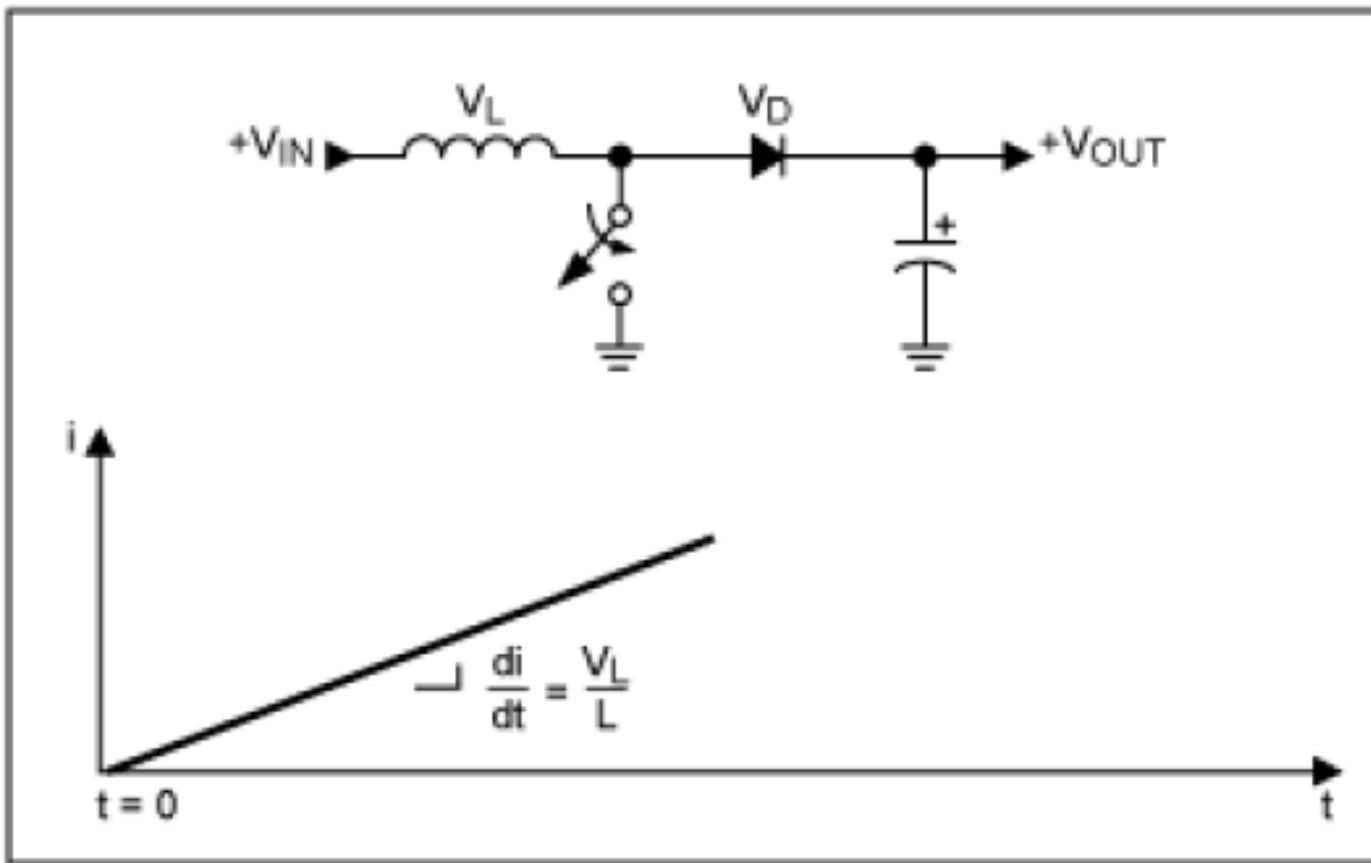


Booster

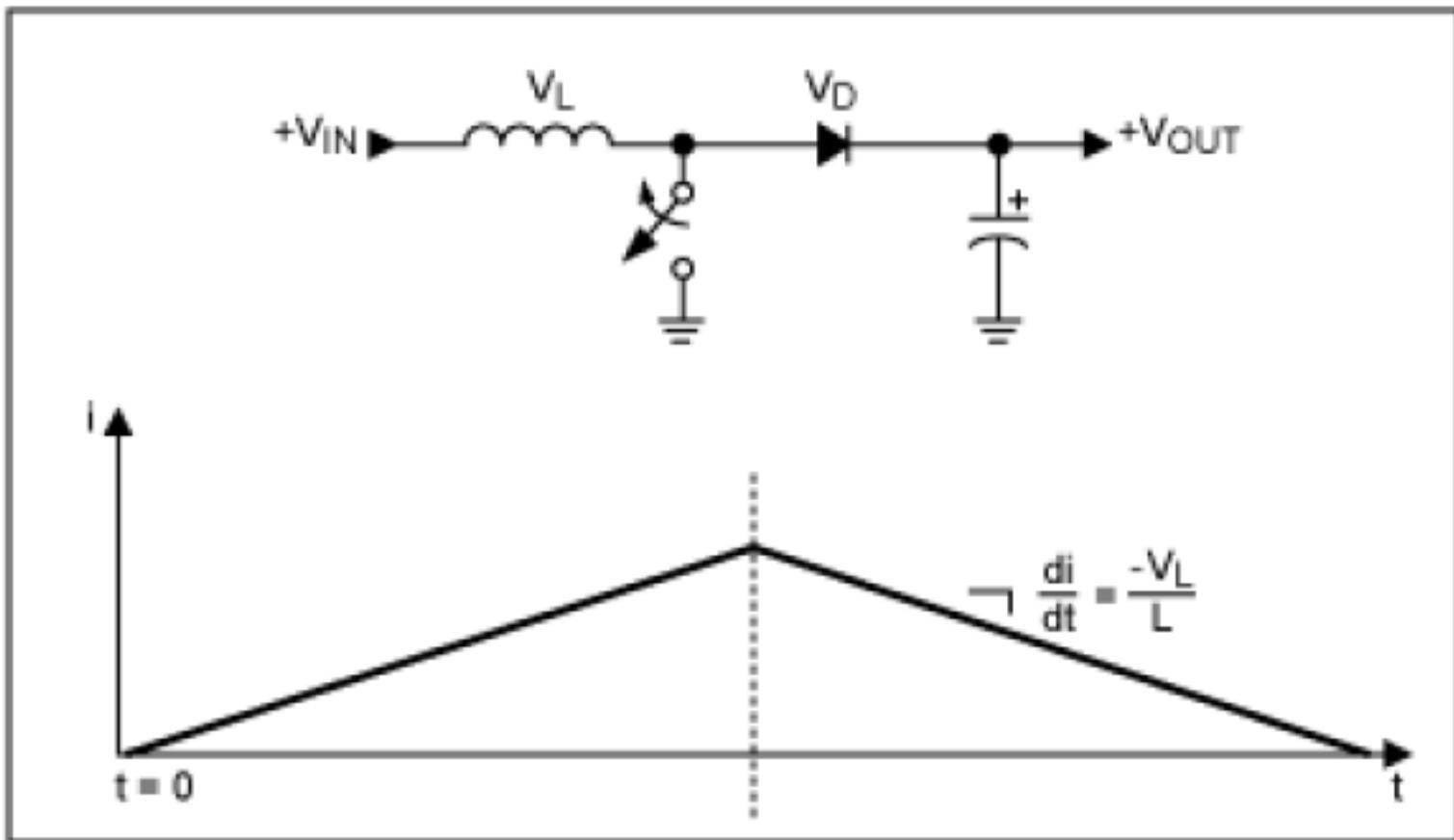


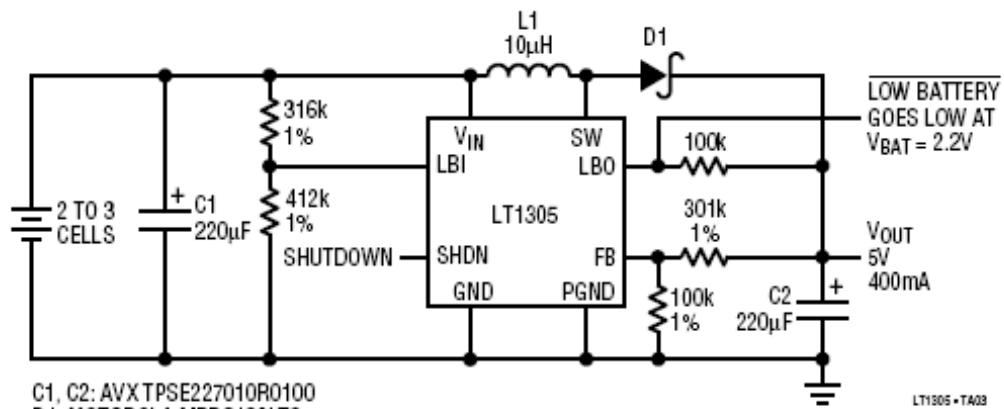
Inverter

Charge phase

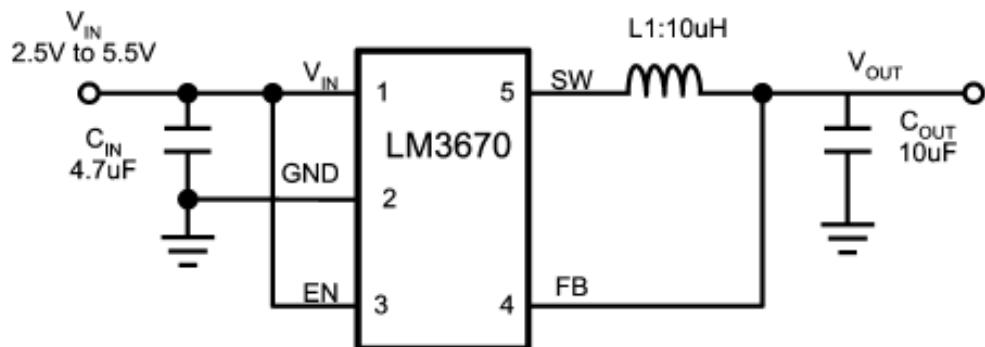


Discharge phase

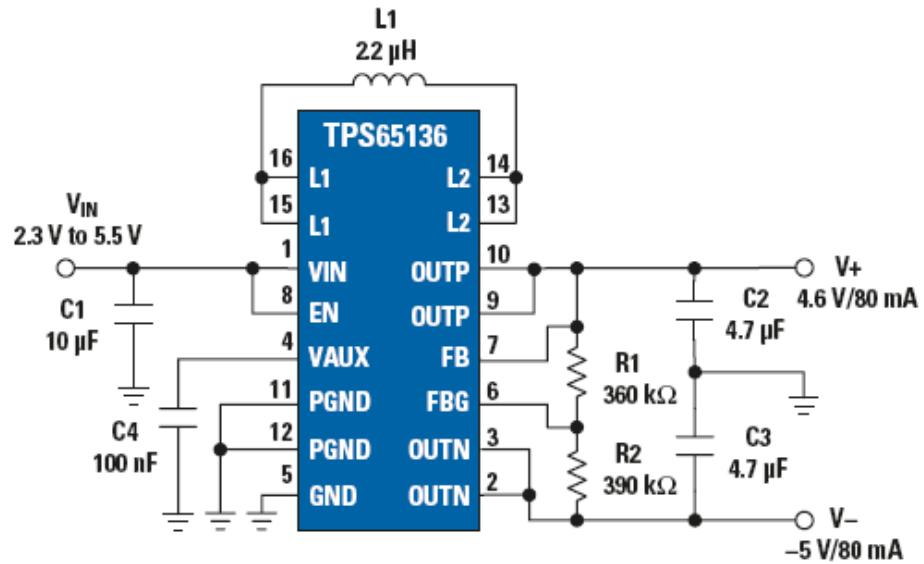




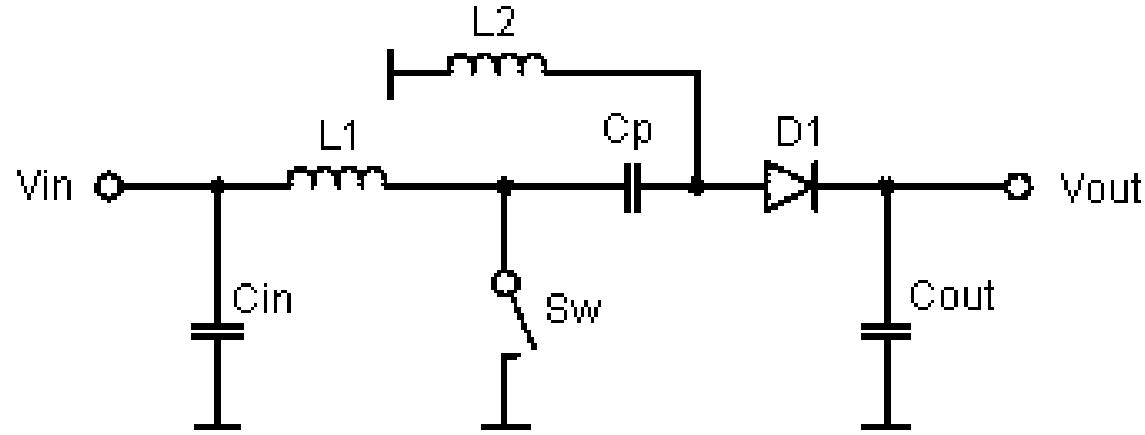
C1, C2: AVX TPSE227010R0100
 D1: MOTOROLA MBR5130LT3
 L1: COILCRAFT D03316-103



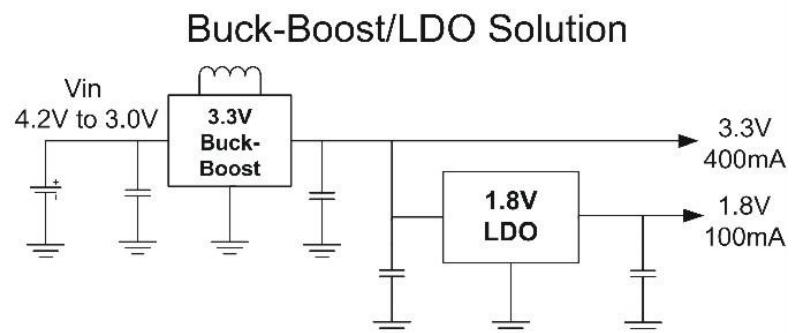
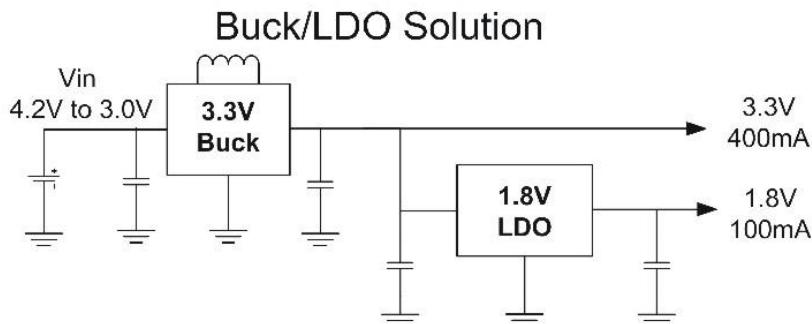
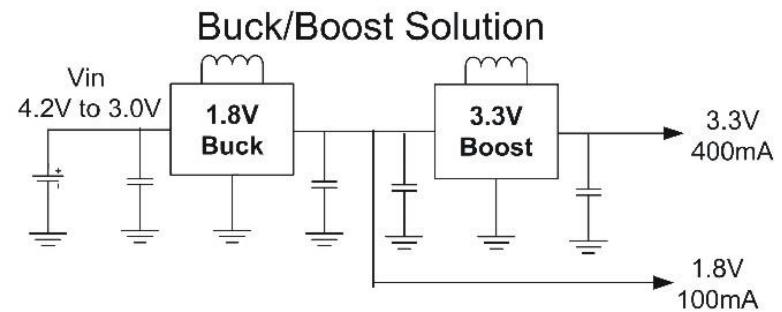
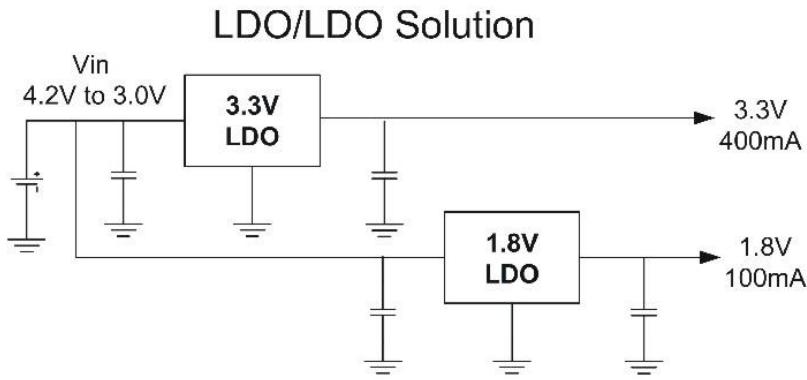
20075001



SEPIC Converter



Combined Solutions



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 SM72442 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

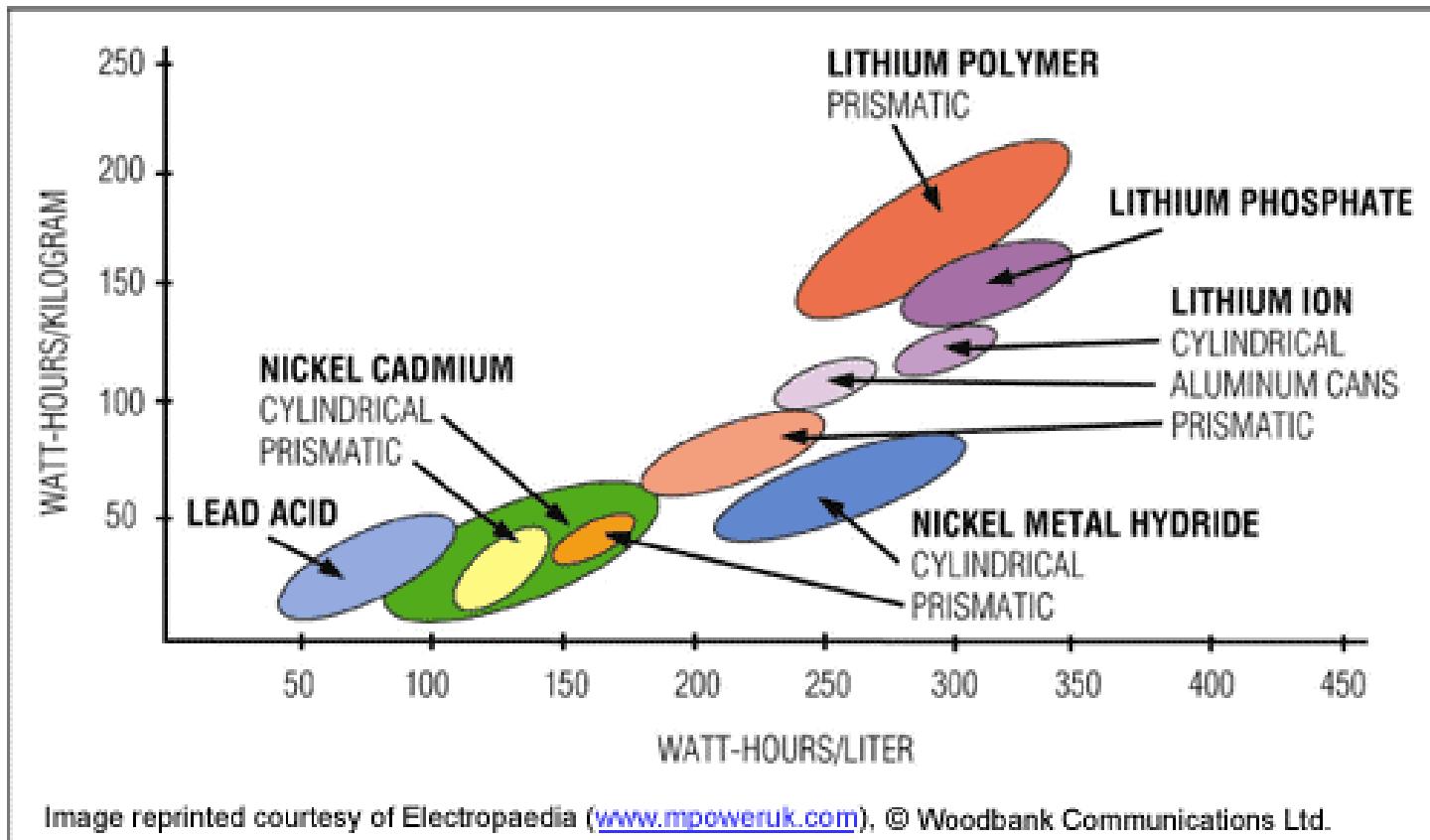
Summary of Common Battery Types

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).

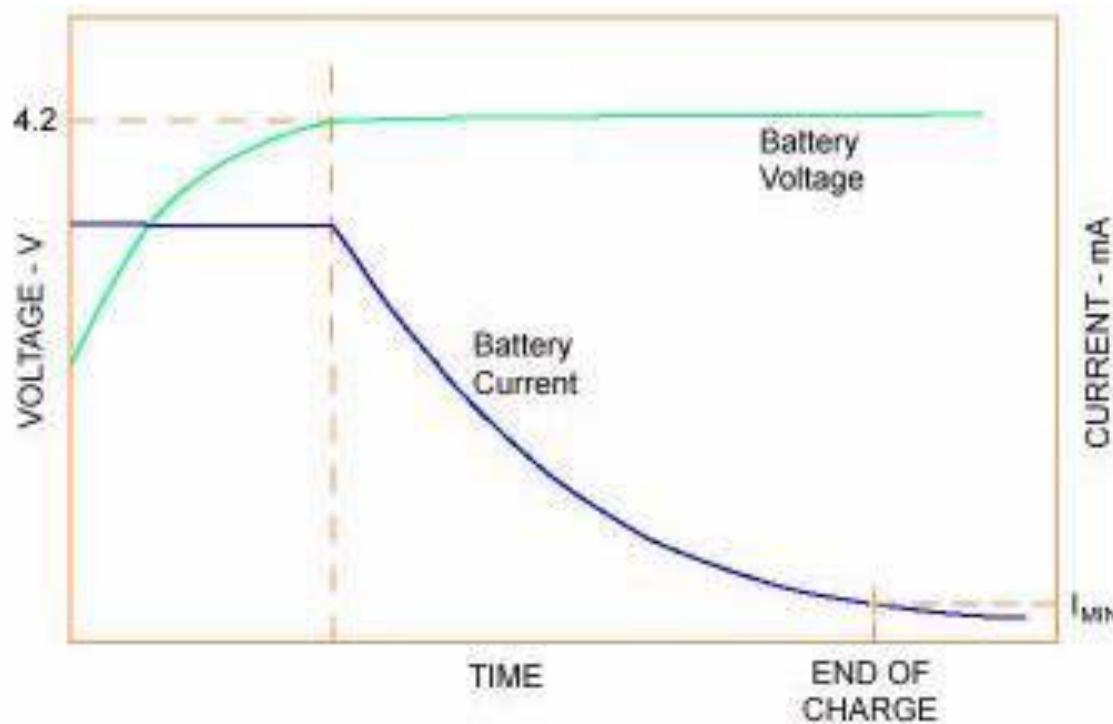
BR –vs- CR: Comparison Table

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
	Coin Type	-30°C~+80°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



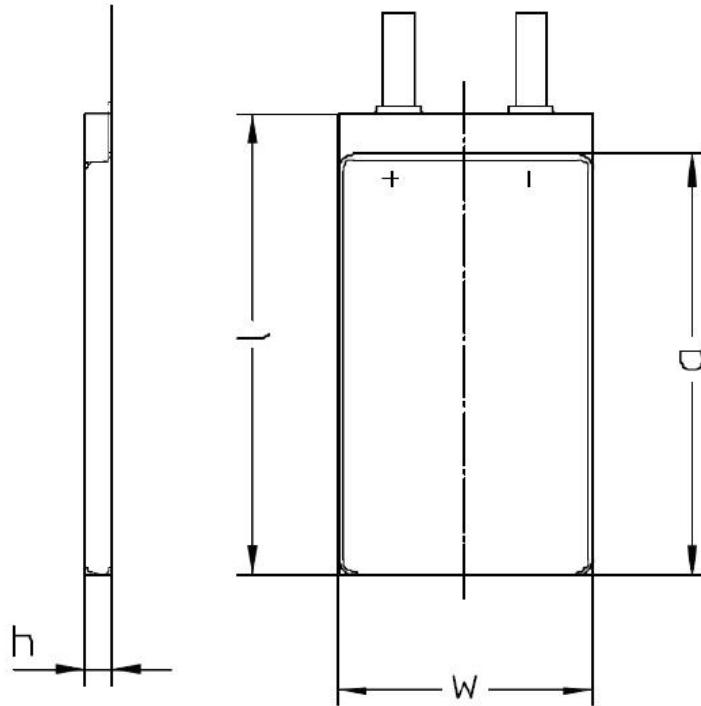
Lithium accumulator charging



Battery

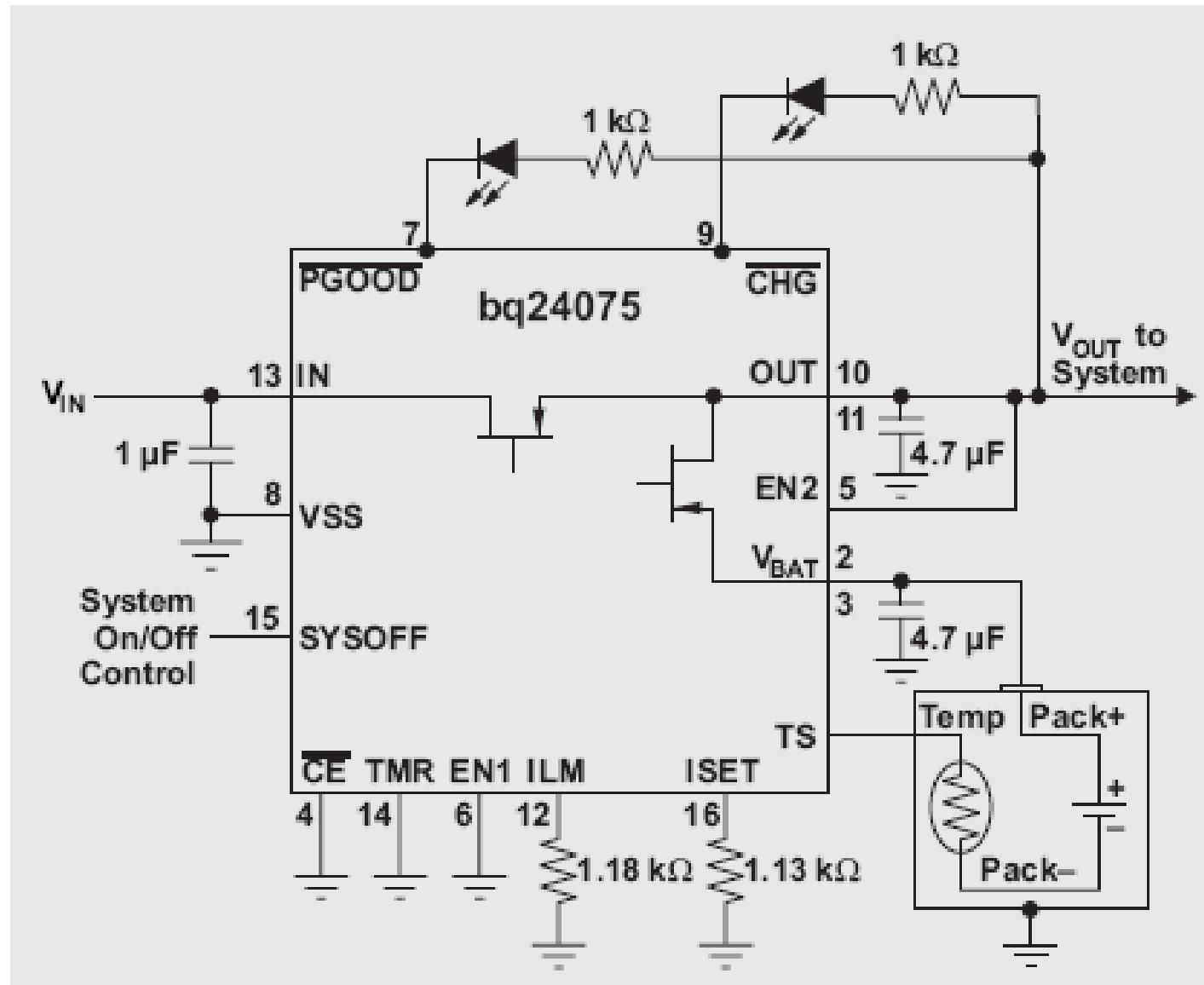


Nominal Voltage : 3.7 V
Typical Capacity : 800 mAh
Minimum Capacity : 770 mAh

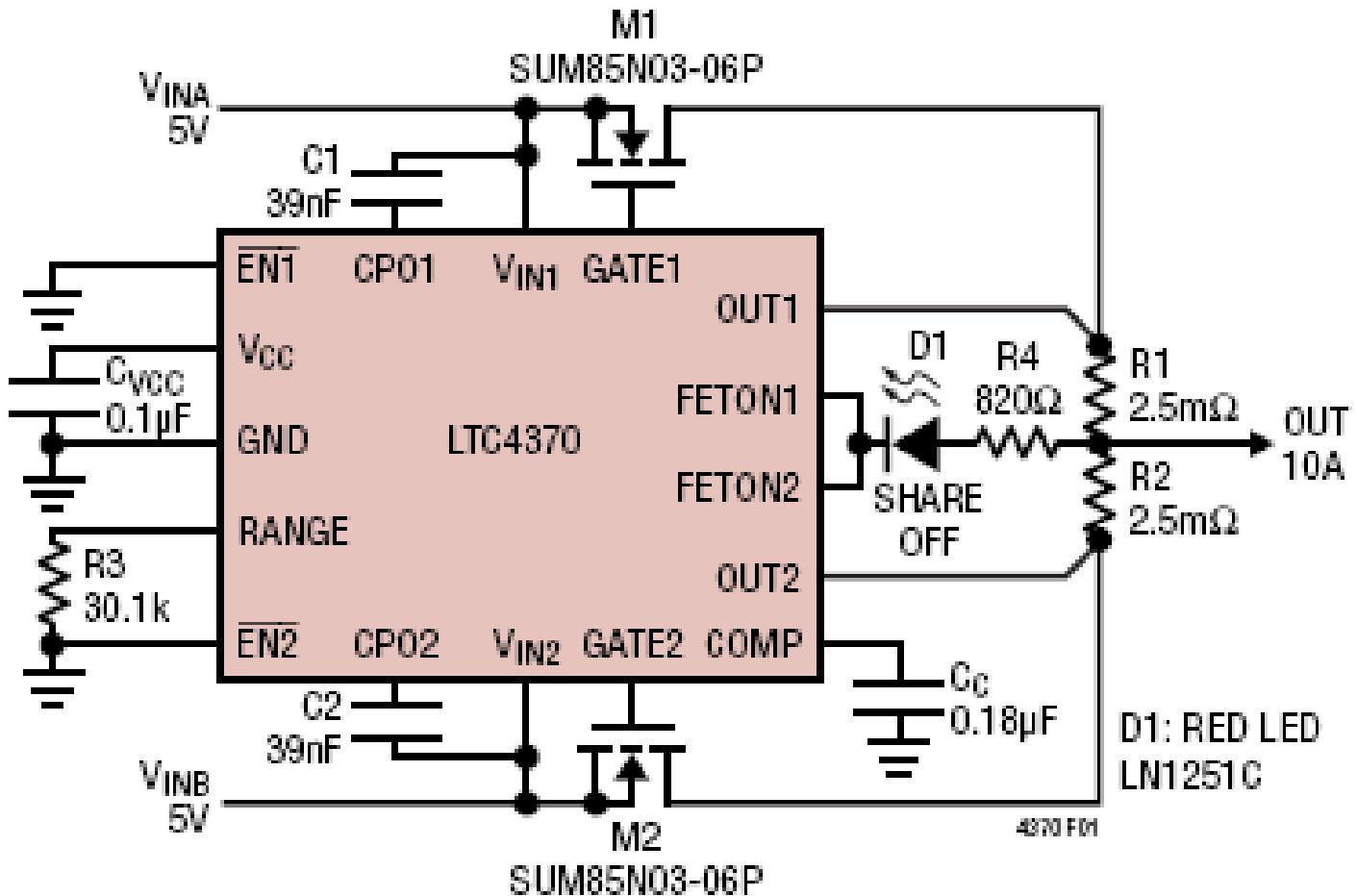


Length (l) : 49.2 mm
Width (w) : 34 mm
Height (h) : 4.4 mm
Pouch (a) : 44.2 mm
Weight : 14 g

Battery charger with power-path control



Sharing of the currents

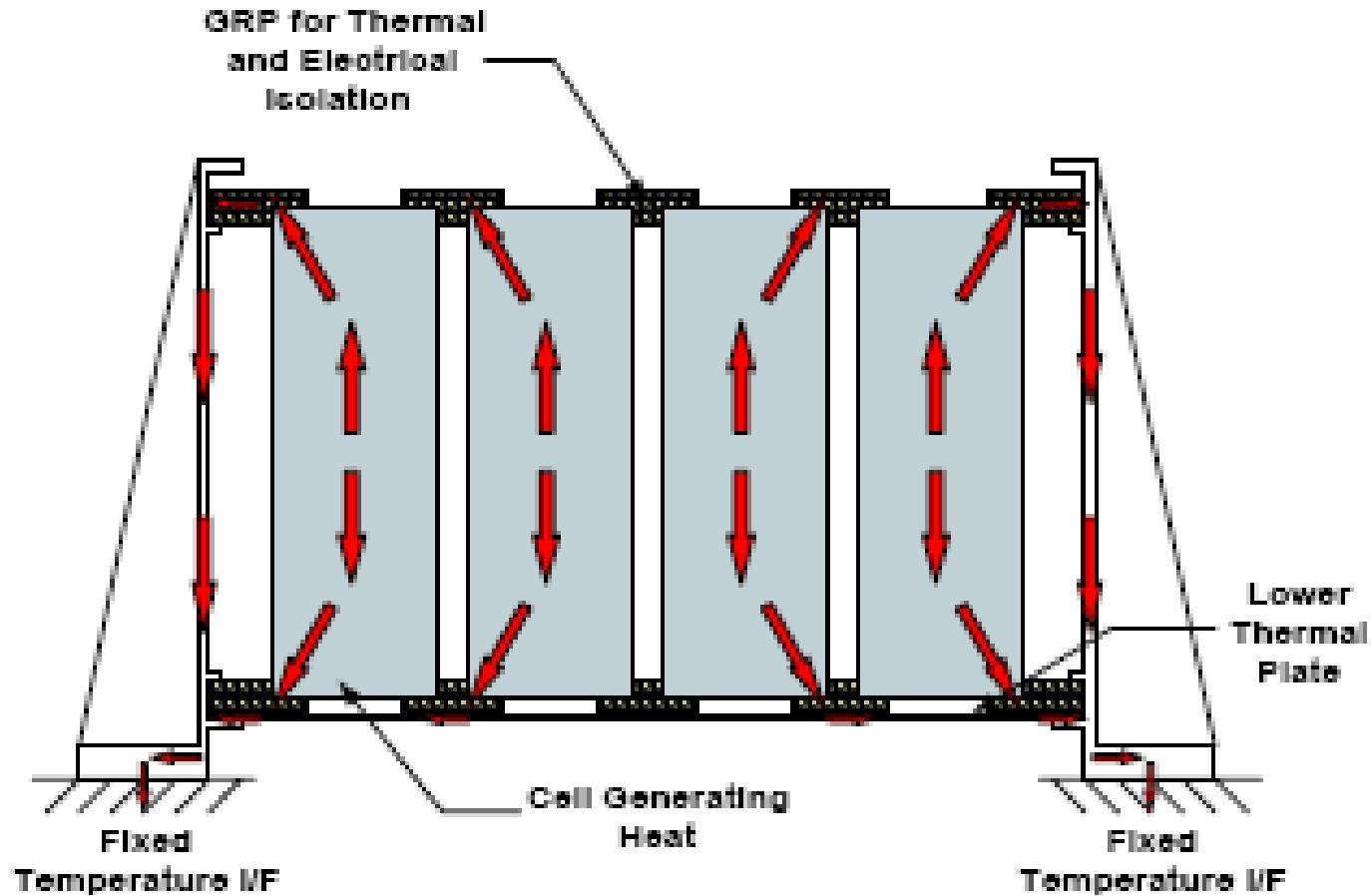


Assemblies



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

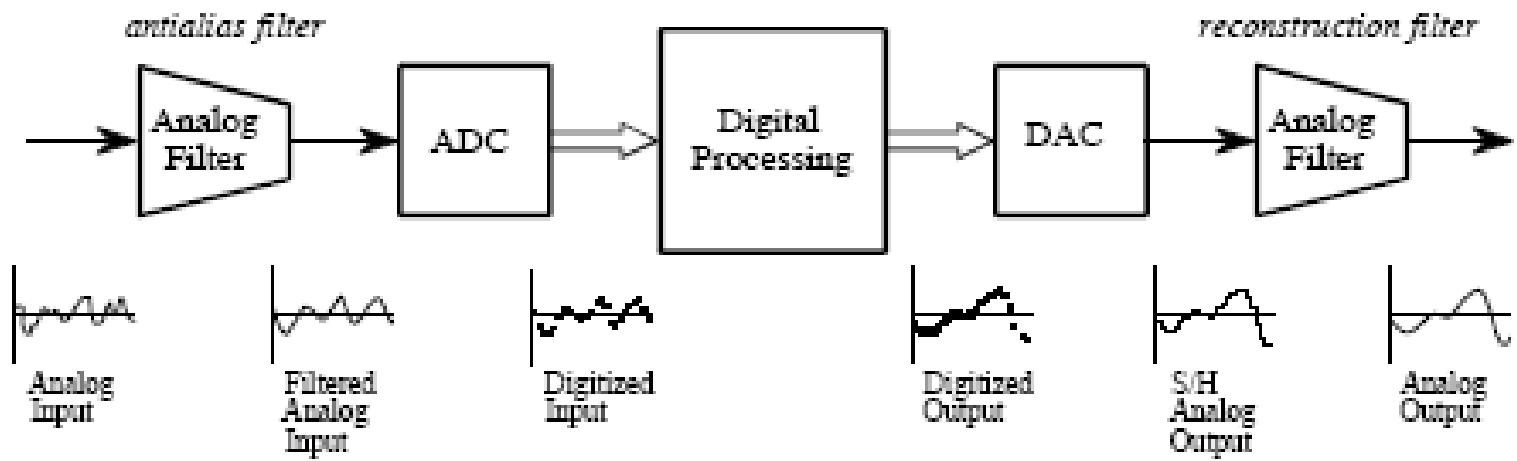
Battery thermal considerations



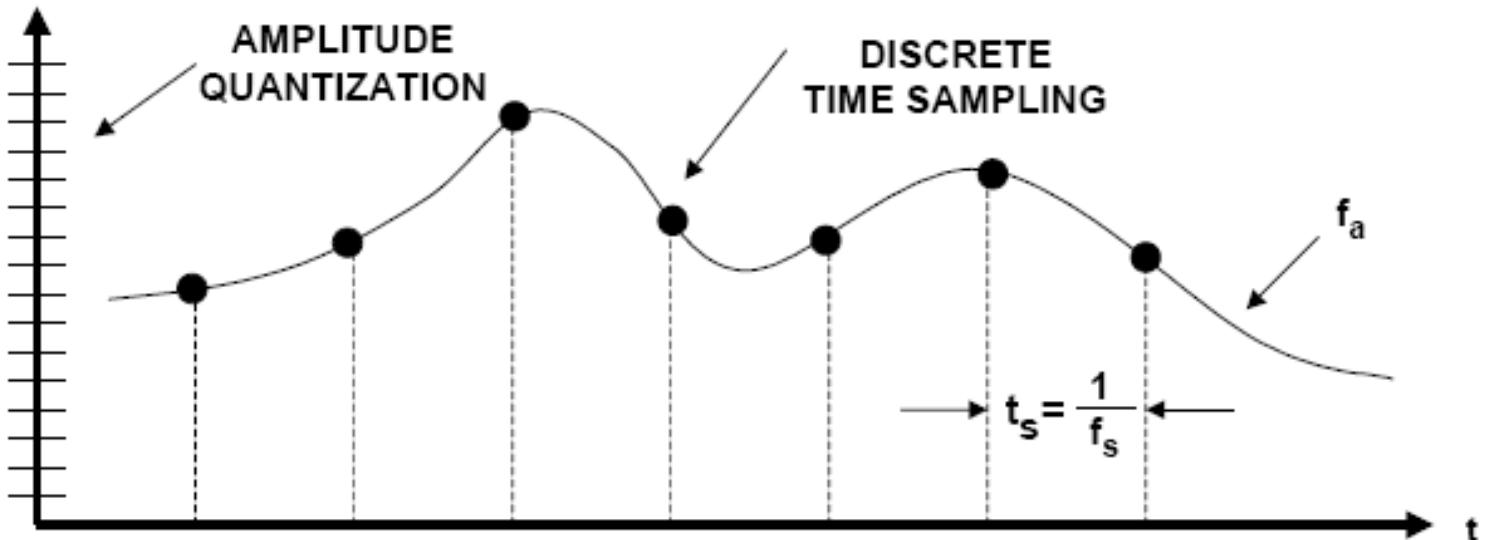
Battery heatflow

Data collecting and processing

Main concept

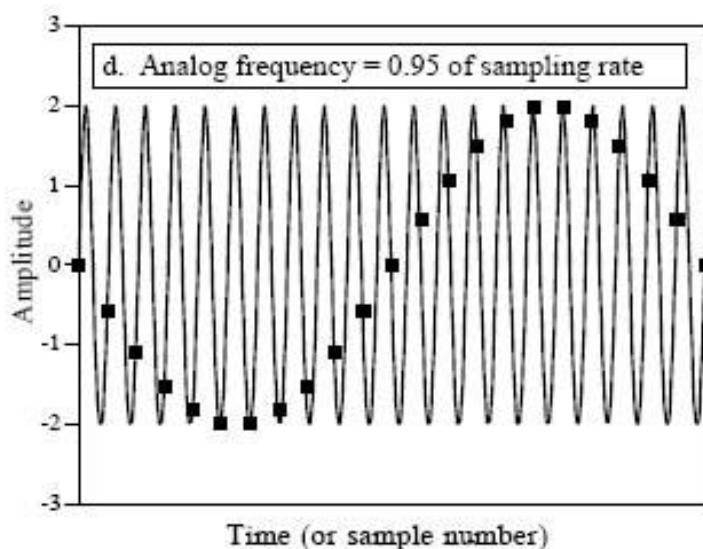
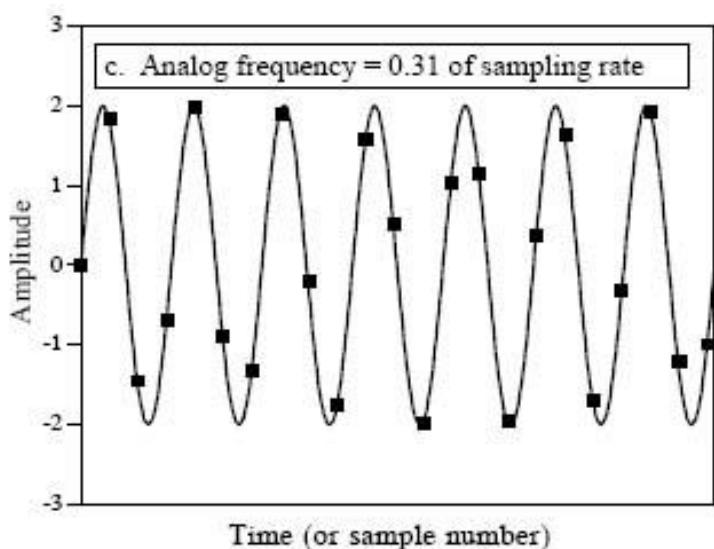
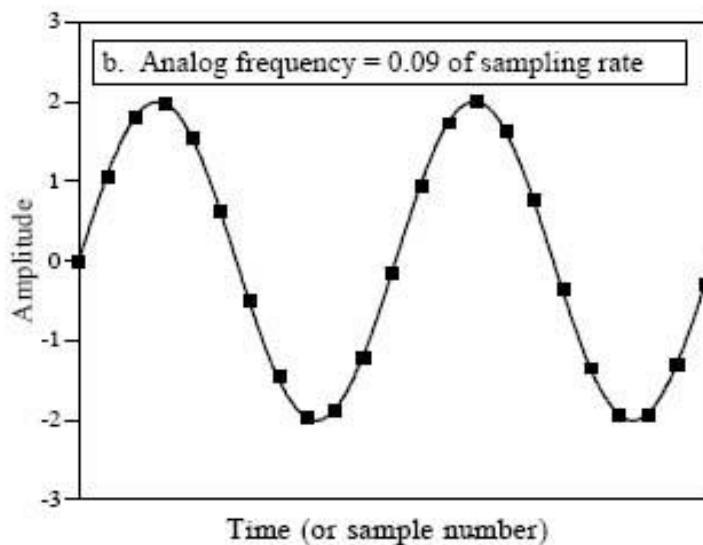
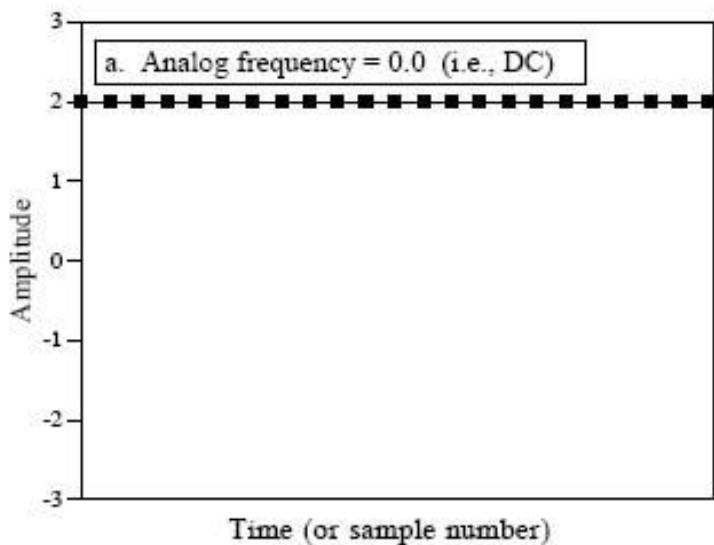


Sampling

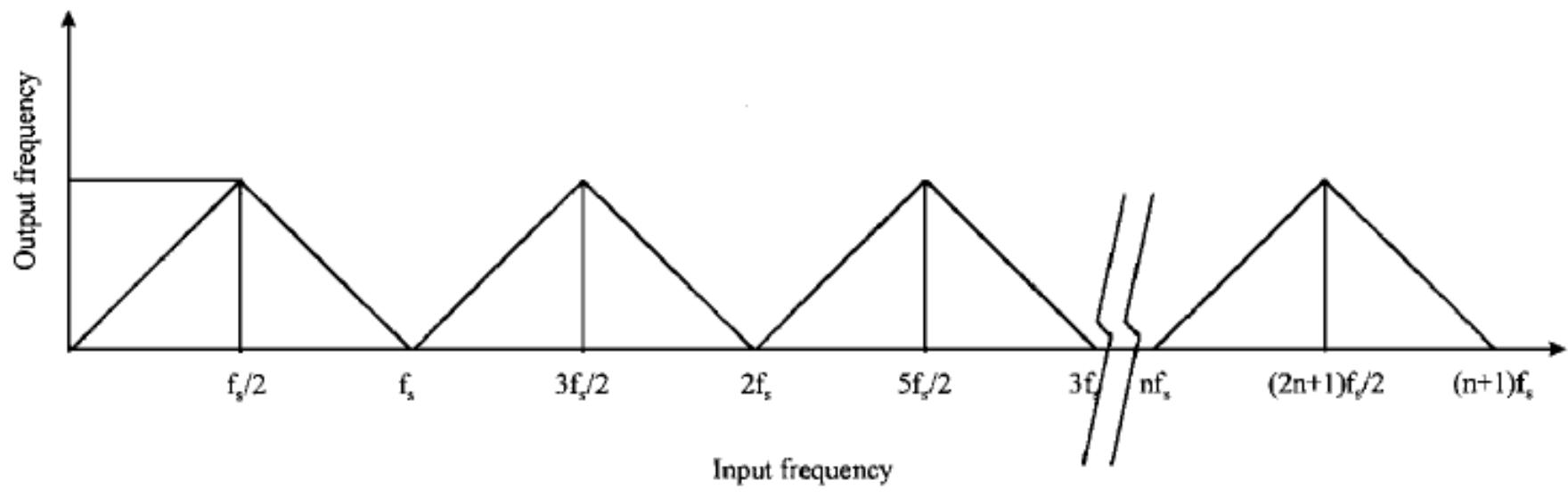


NYQUIST'S CRITERIA

- 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.

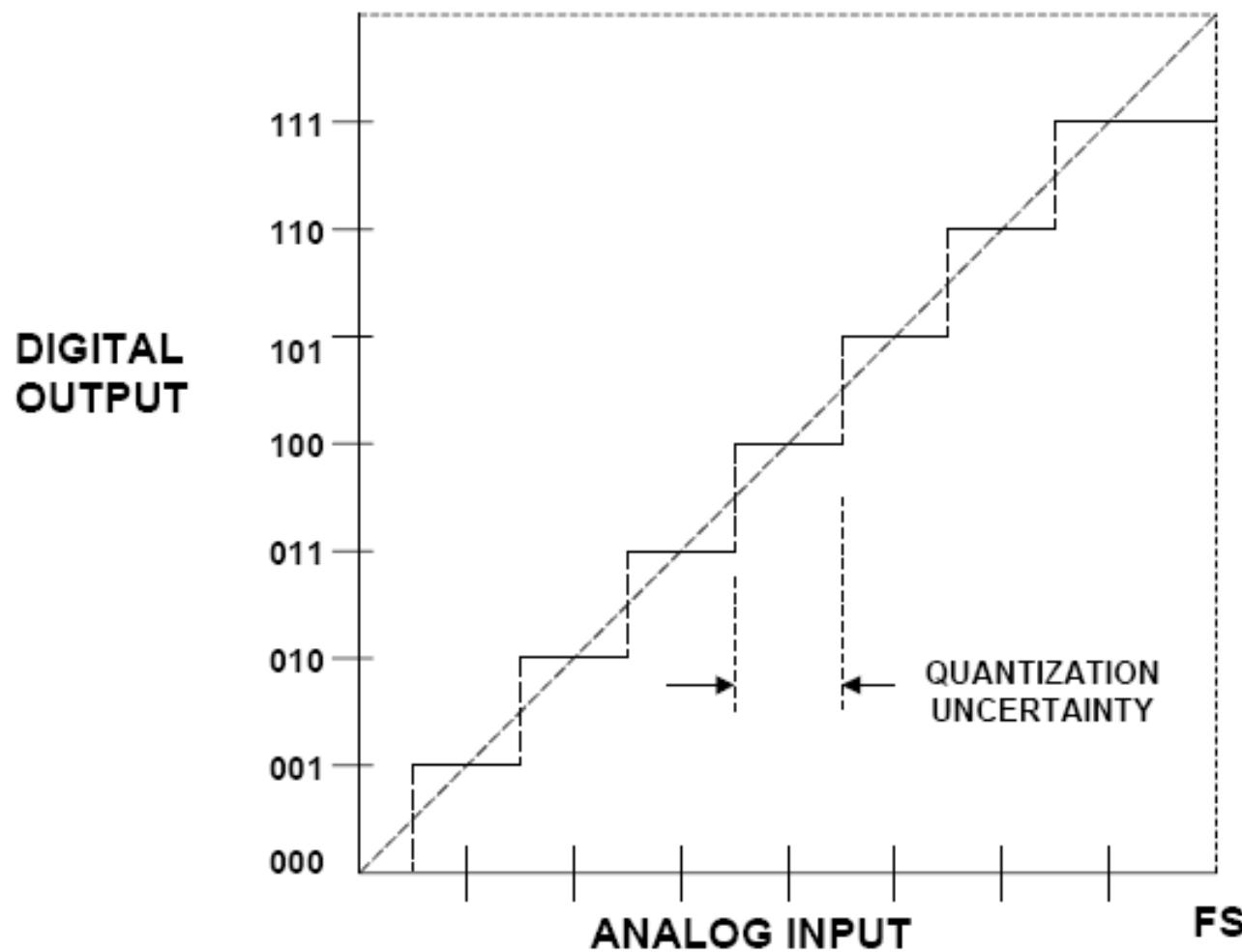


Sampling frequency effect

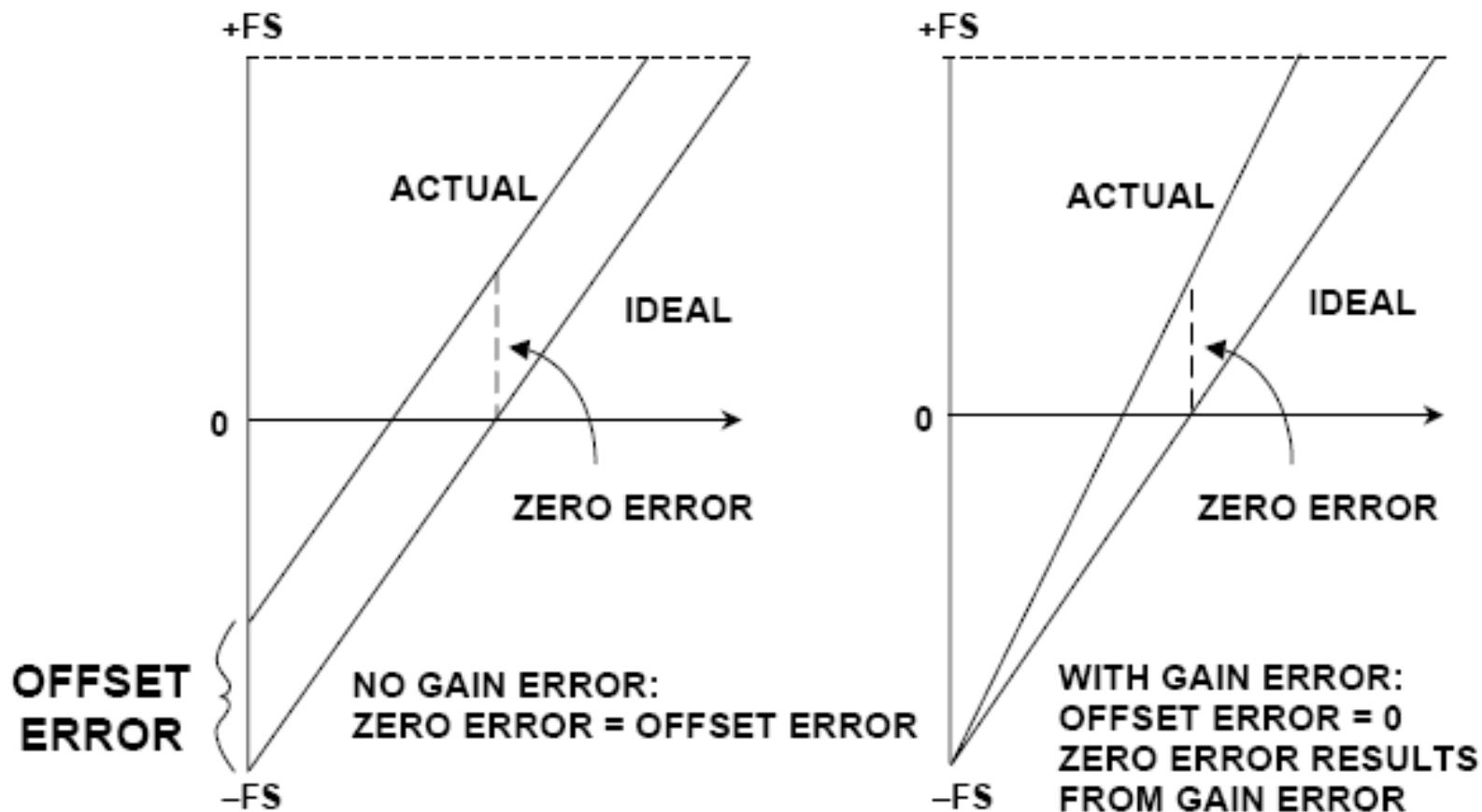


Input versus output frequency of band aliasing.

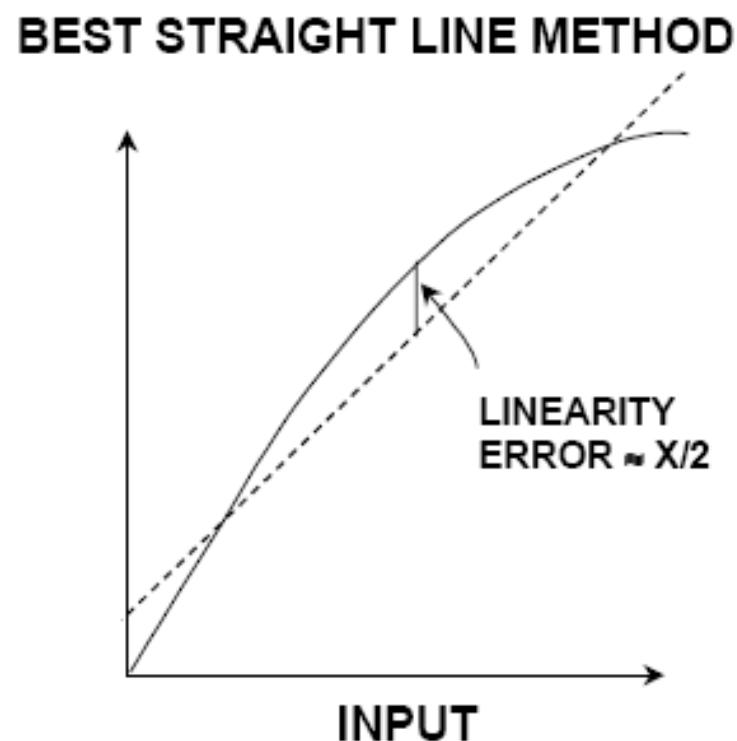
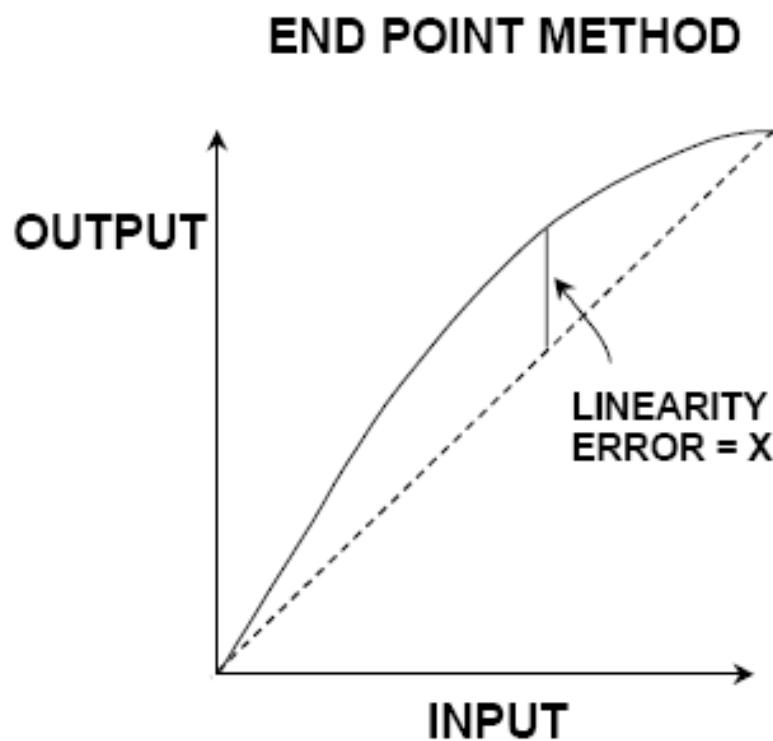
TRANSFER FUNCTION FOR IDEAL 3-BIT ADC



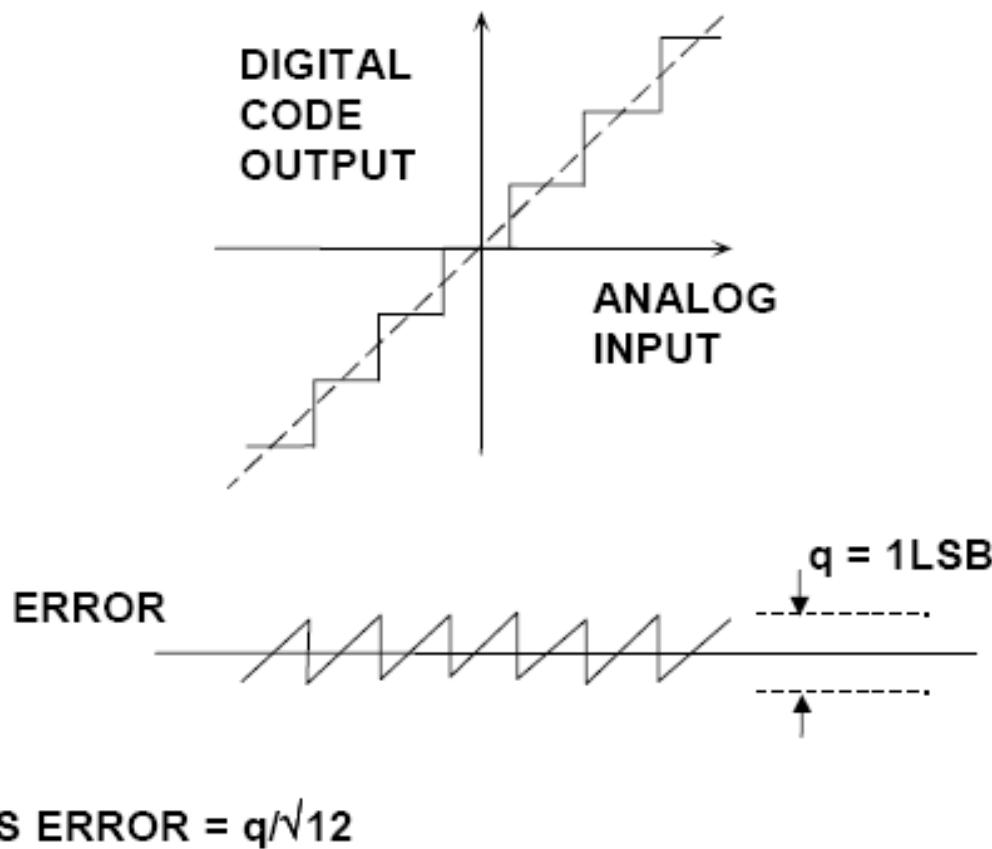
CONVERTER OFFSET AND GAIN ERROR



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



IDEAL N-BIT ADC QUANTIZATION NOISE

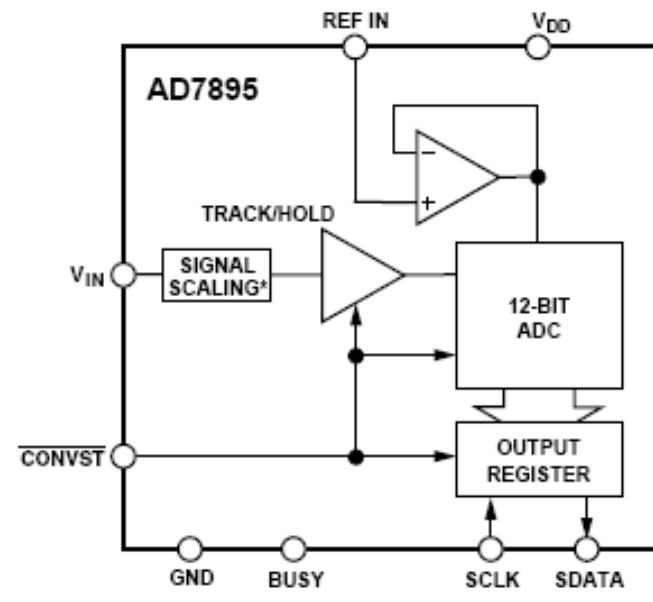
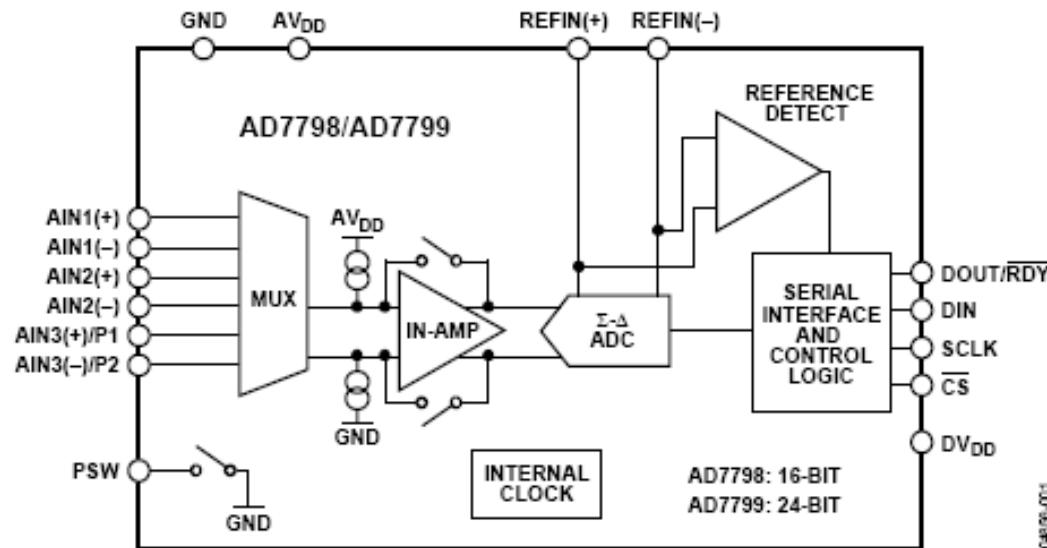
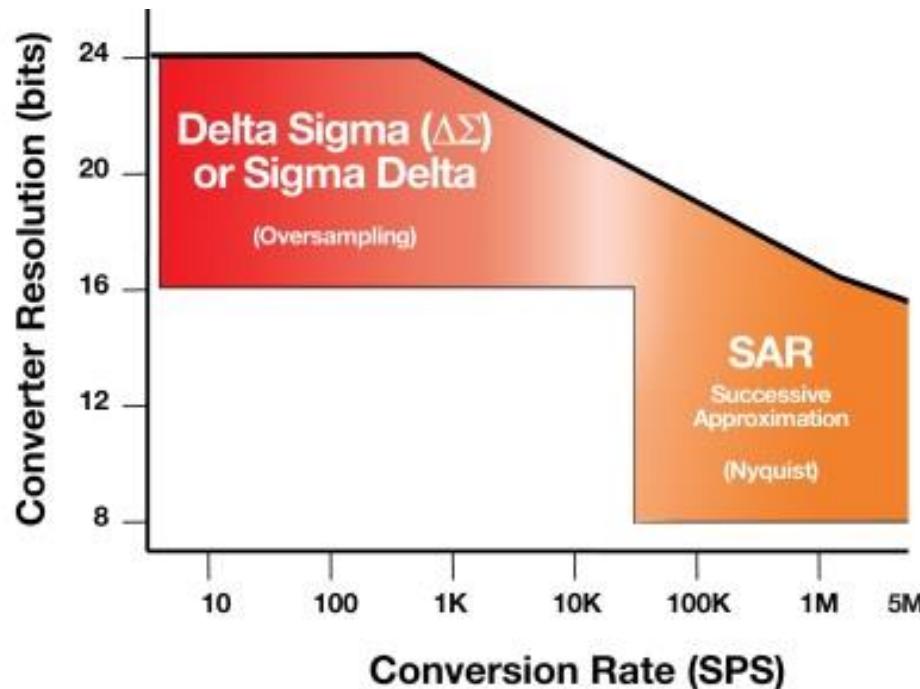


$$\text{RMS ERROR} = q/\sqrt{12}$$

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

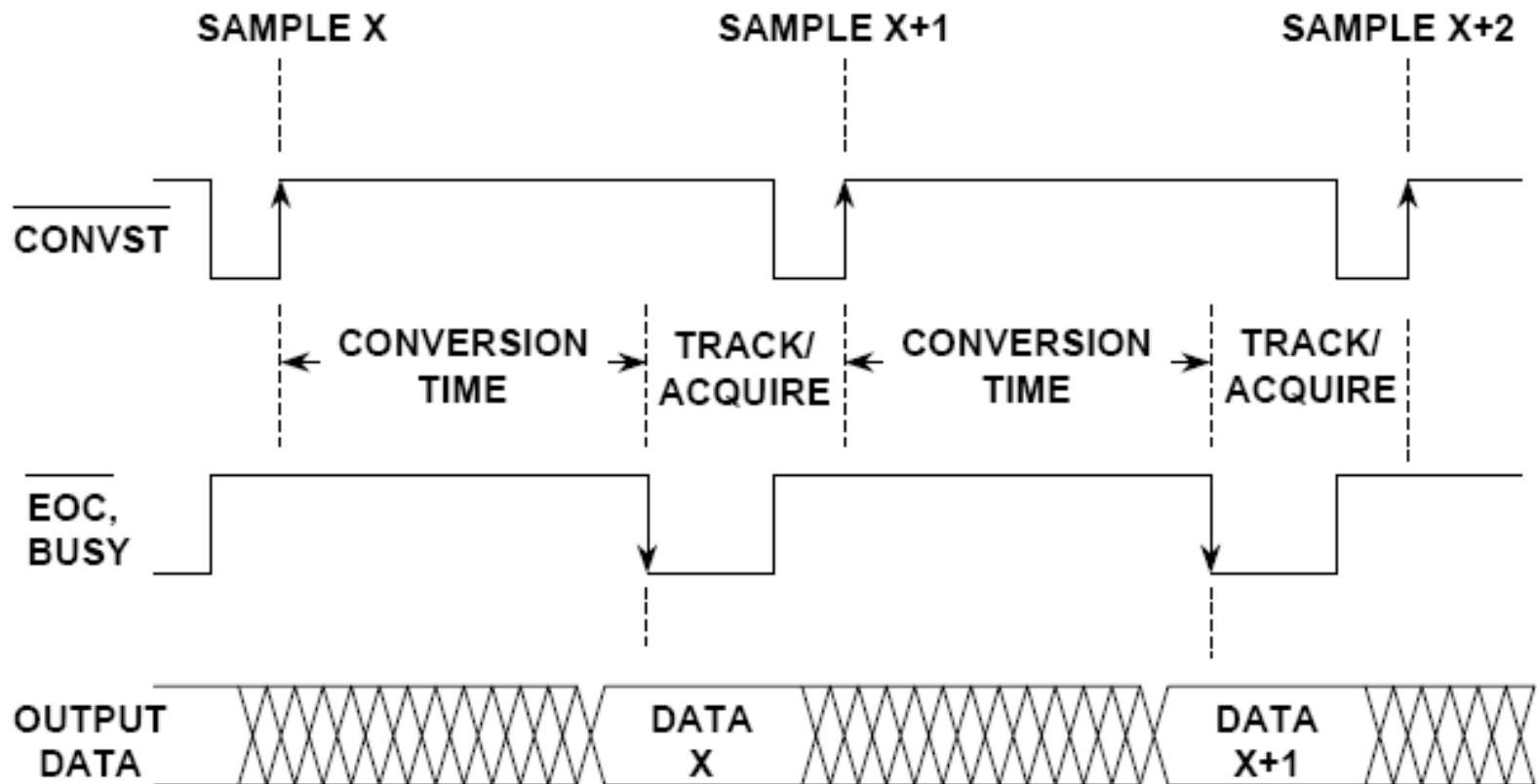
ADC types

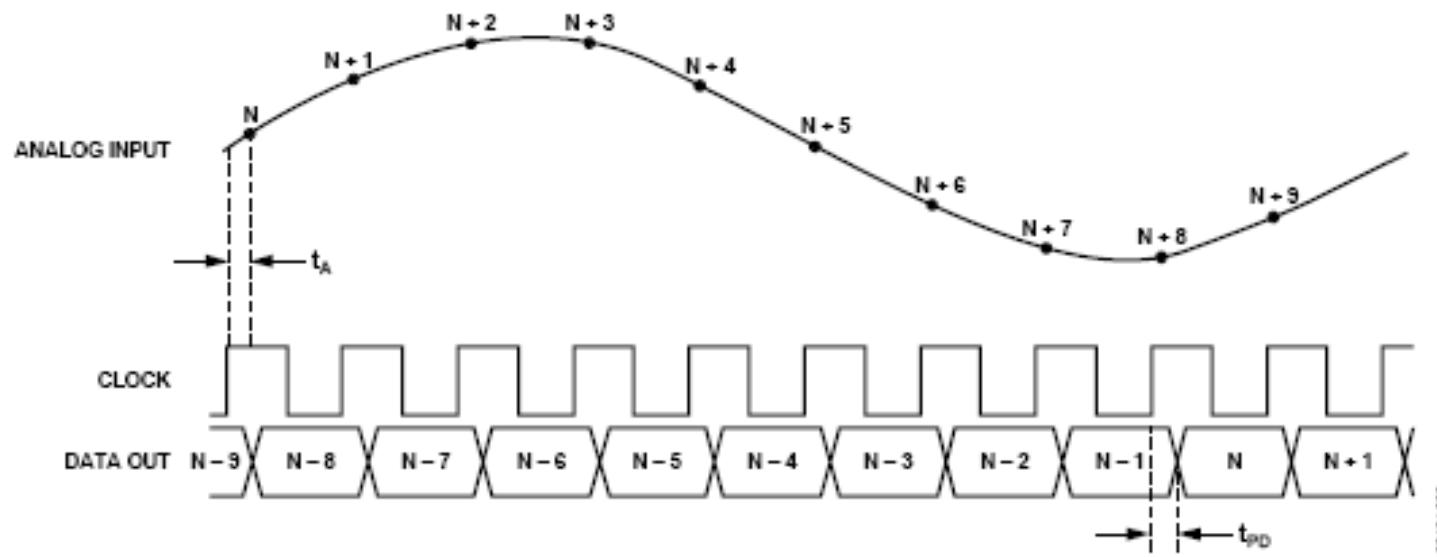
- SAR ADC
- Pipelined ADC
- Sigma-Delta ADC



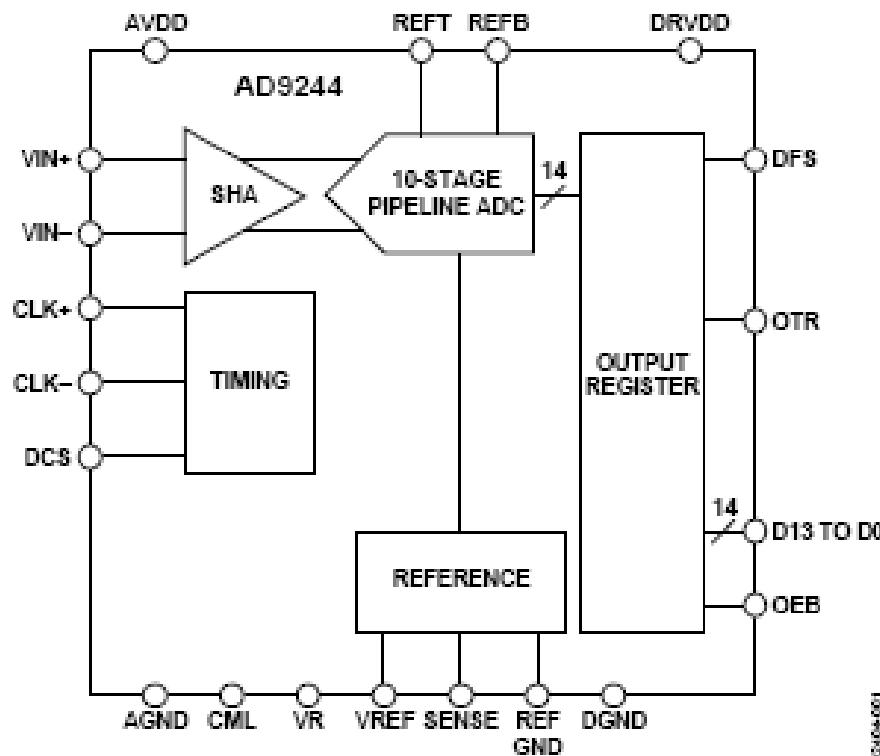
*AD7895-10, AD7895-3

TYPICAL SAR ADC TIMING



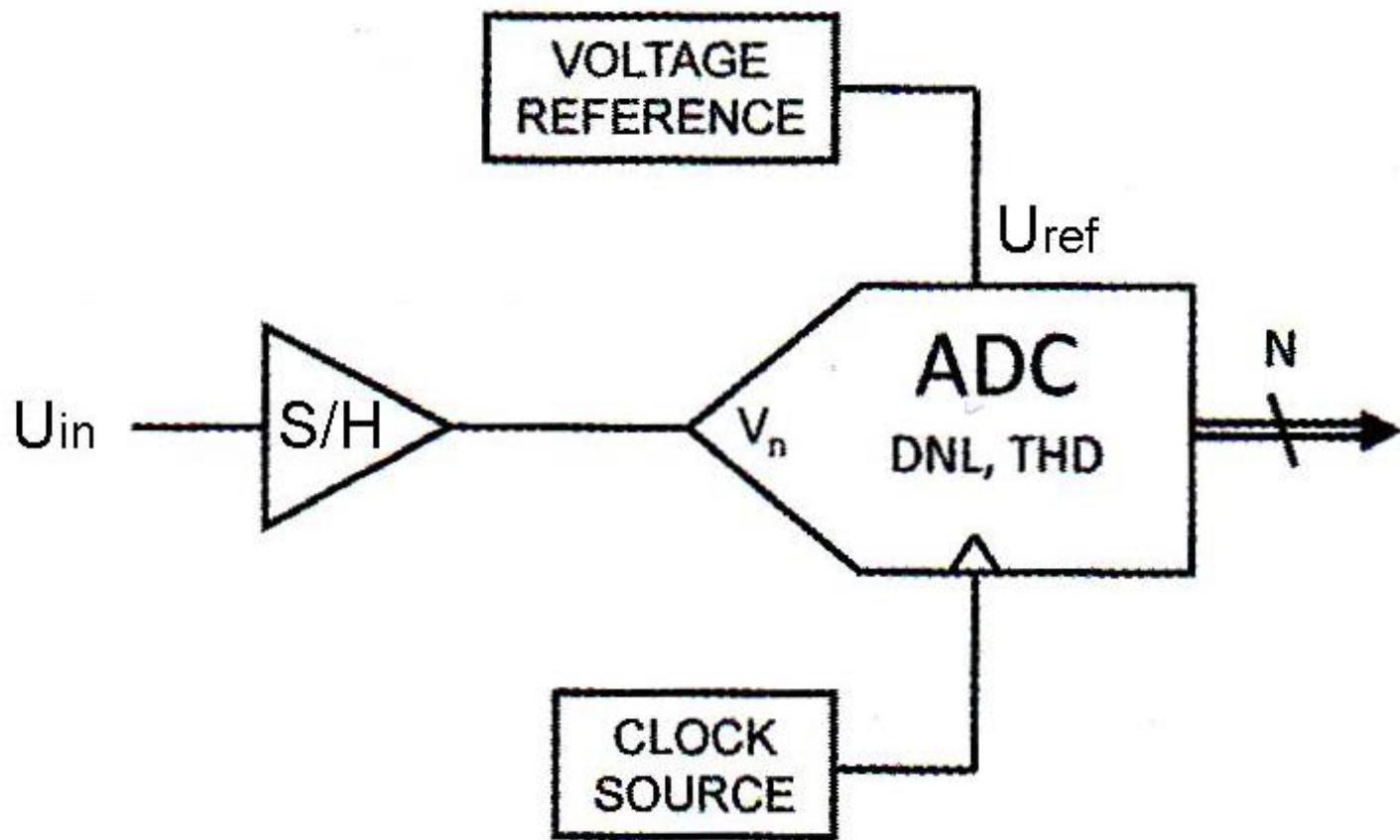


0204002



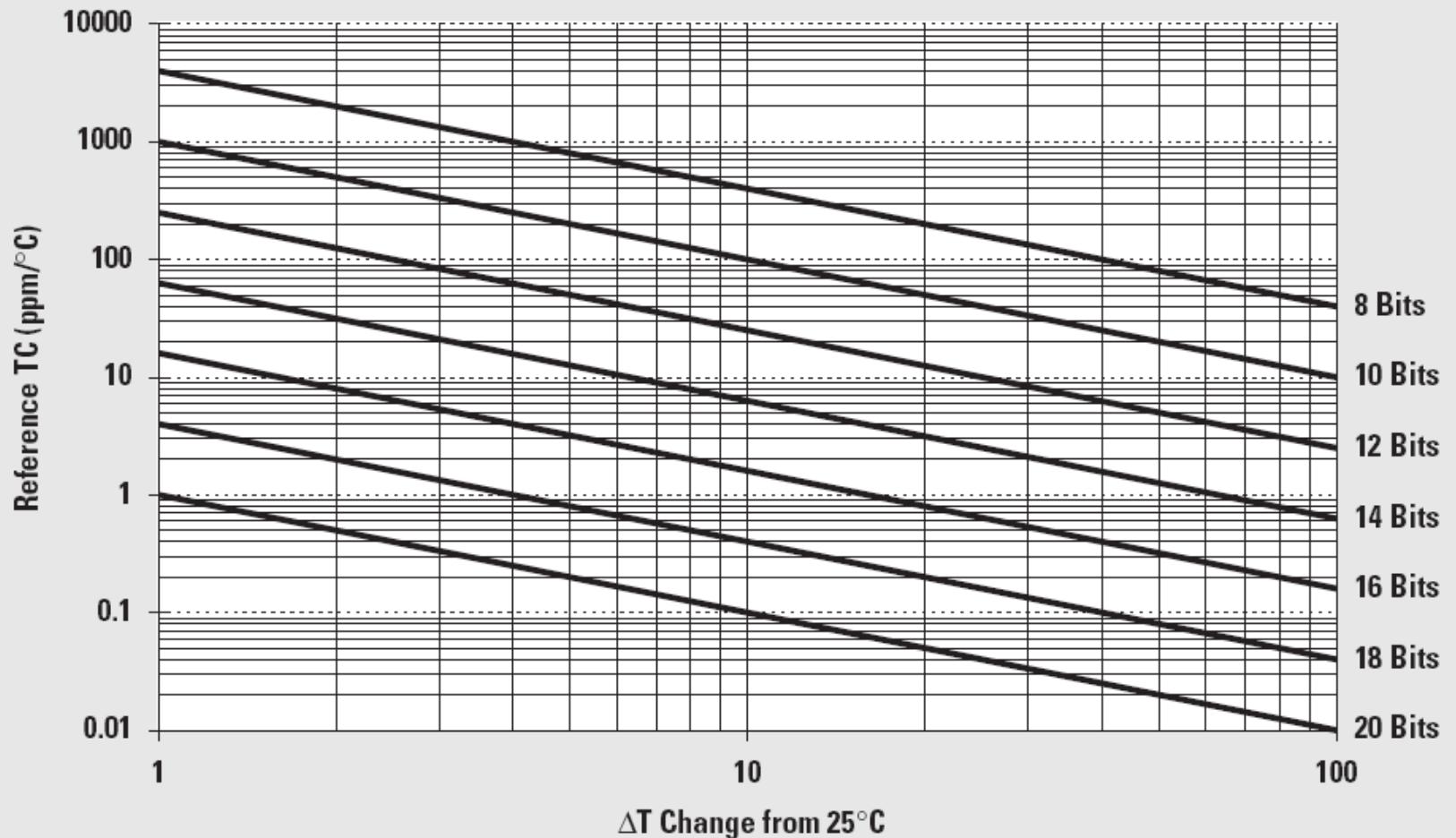
0204001

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

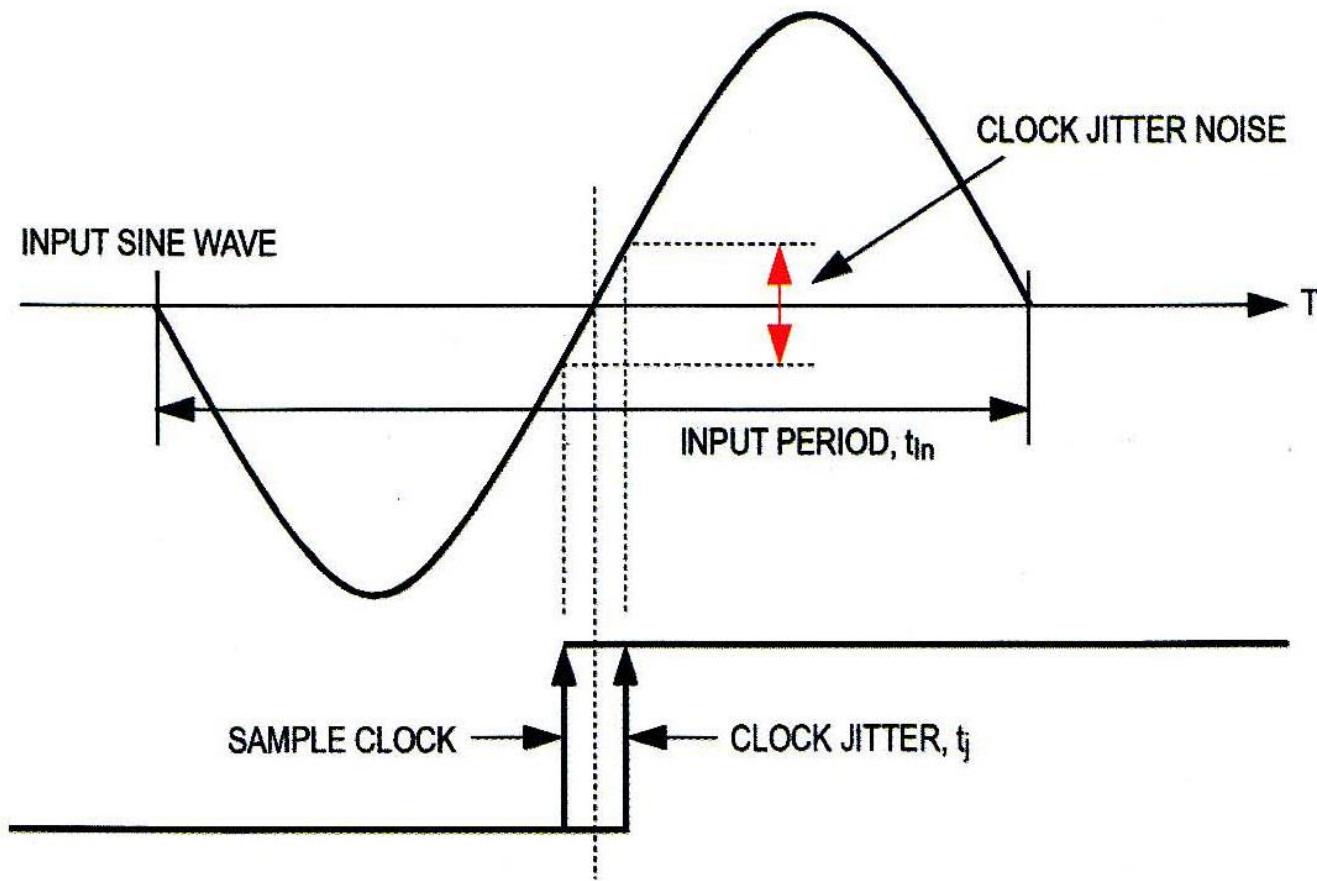


Reference TC vs. ΔT change from 25°C for 1 LSB change

Selection example

Choose Parameters		All	Reset Table	Maximize Filters	Sort by Newest	Save to myAnalog	Download to Excel	Share	Quick Tips	Send Feedback
<input type="checkbox"/>	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		
<input type="checkbox"/>	Filter Parts	0.28 - 546.25	200m - 10	0.02 - 4	0.05 - 170	6 Values Selected	300n - 475u	9 Values Selected		
Compare	615 parts LT1004IZ-2.5	\$2.75 (LT1004IZ-2.5#PBF)	2.5	0.8	-	Shunt	-	-40 to 85°C		
<input type="checkbox"/>	AD584S	-	10	-	-	Series	-	-55 to 125°C		
<input type="checkbox"/>	LTZ1000ACH	\$56.00 (LTZ1000ACH#PBF)	7.2	4	0.05	Super Zener	1.2μ	-55 to 125°C		
<input type="checkbox"/>	LTZ1000CH	\$44.00 (LTZ1000CH#PBF)	7.2	4	0.05	Super Zener	1.2μ	-55 to 125°C		
<input type="checkbox"/>	LM399AH	\$8.20 (LM399AH#PBF)	6.95	-	0.5	Shunt	-	0 to 70°C		
<input type="checkbox"/>	ADR4525D	\$9.97 (ADR4525DEZ)	2.5	0.02	0.8	Series (Low Dropout)	1.25μ	0 to 70°C		
<input type="checkbox"/>	ADR4540D	\$9.97 (ADR4540DEZ)	4.096	0.02	0.8	Series (Low Dropout)	2.7μ	0 to 70°C		
<input type="checkbox"/>	ADR4550D	\$9.97 (ADR4550DEZ)	5	0.02	0.8	Series (Low Dropout)	2.8μ	0 to 70°C		
<input type="checkbox"/>	ADR4525C	\$7.97 (ADR4525CRZ)	2.5	0.02	1	Series (Low Dropout)	1.25μ	0 to 70°C		
<input type="checkbox"/>	ADR4540C	\$7.97 (ADR4540CRZ)	4.096	0.02	1	Series (Low Dropout)	2.7μ	0 to 70°C		
<input type="checkbox"/>	ADR4550C	\$7.97 (ADR4550CRZ)	5	0.02	1	Series (Low Dropout)	2.8μ	0 to 70°C		
<input type="checkbox"/>	LM399H	\$5.81 (LM399H#PBF)	6.95	-	1	Shunt	-	0 to 70°C		
<input type="checkbox"/>	LT6657AHMS8-1.25	\$5.49 (LT6657AHMS8-1.25#PBF)	1.25	0.1	1.5	Series, Shunt	1.25μ	-40 to 125°C		
<input type="checkbox"/>	LT6657AHMS8-2.5	\$5.49 (LT6657AHMS8-2.5#PBF)	2.5	0.1	1.5	Series, Shunt	1.25μ	-40 to 125°C		
<input type="checkbox"/>	LT6657AHMS8-3	\$5.49 (LT6657AHMS8-3#PBF)	3	0.1	1.5	Series, Shunt	1.25μ	-40 to 125°C		
<input type="checkbox"/>	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

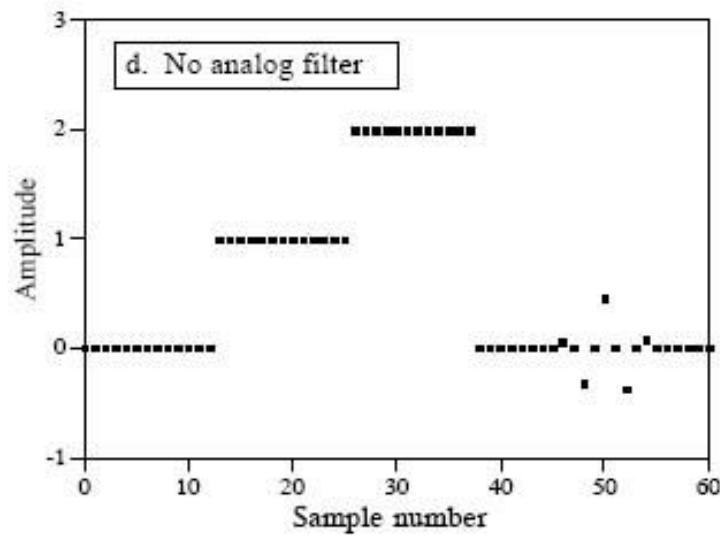
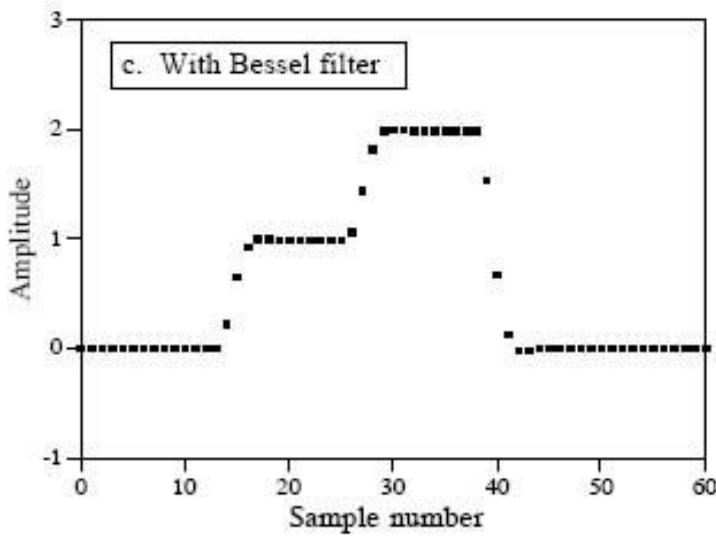
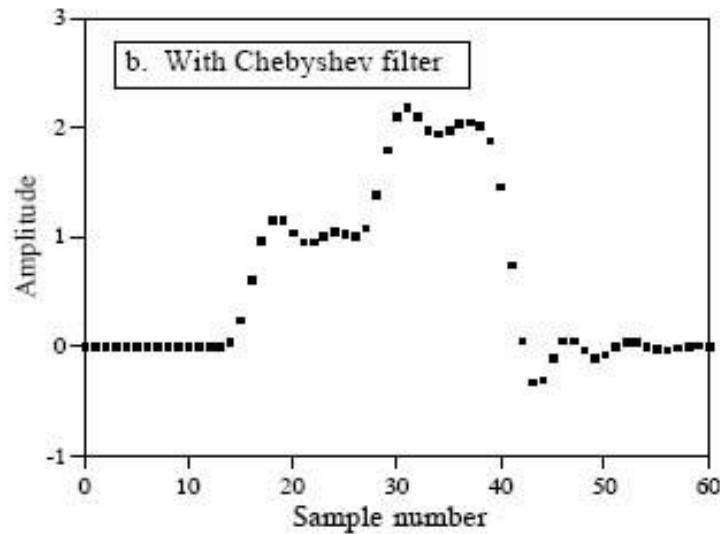
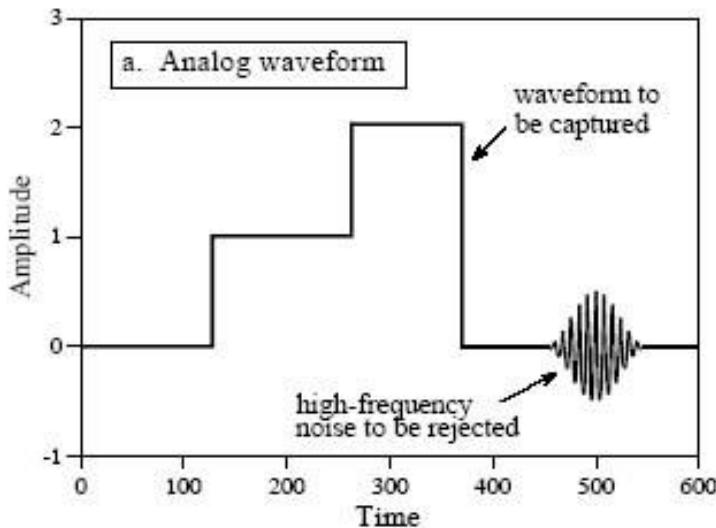
Main purposes:

1. Amplification
2. Impedance matching
3. Filtering

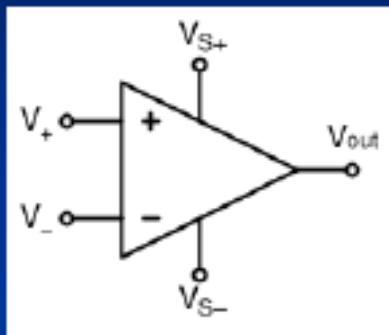
Main requirements:

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.

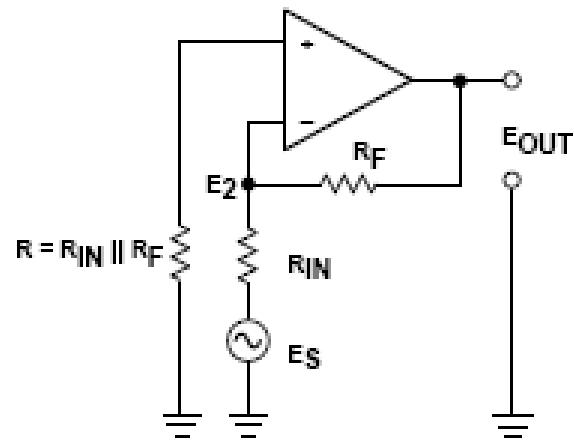
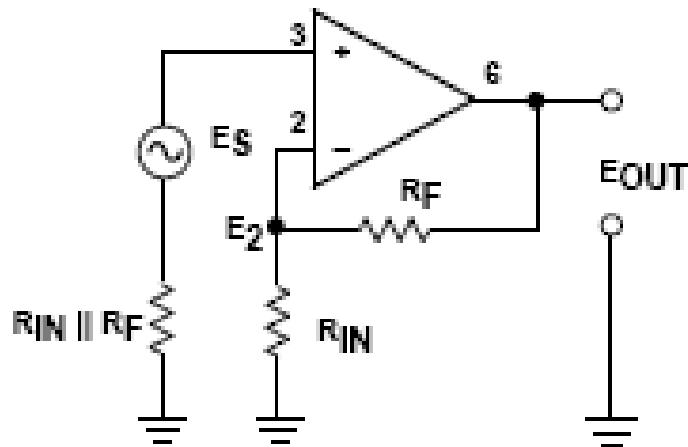
In 1968 improved version of LM101 was LM101A, National Semiconductor

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...

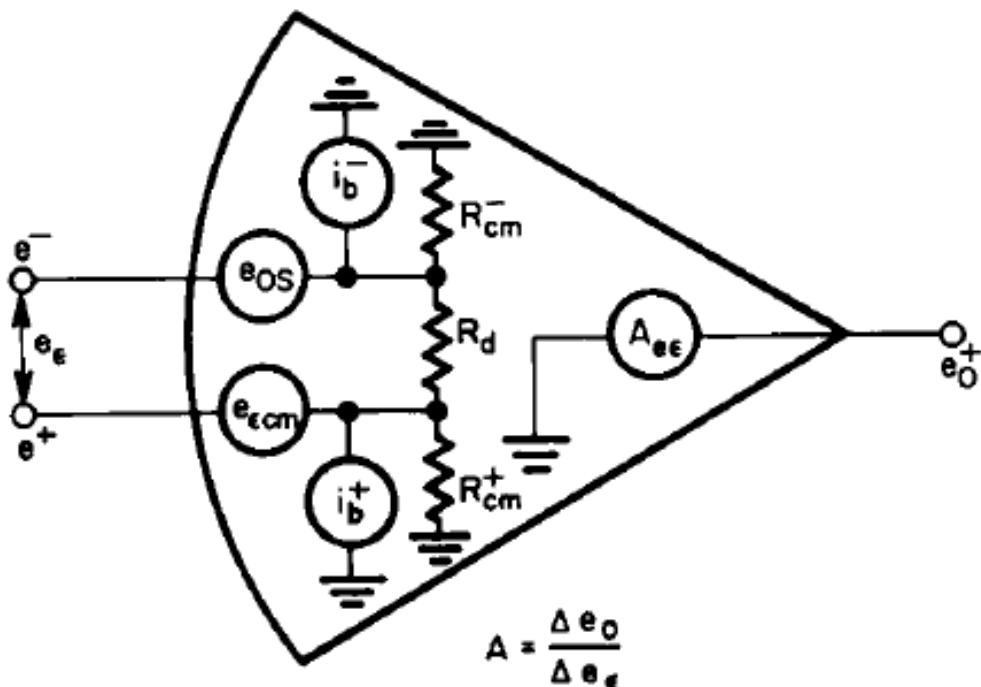
Since 1976 the types of op amps have increased almost daily

Operational amplifiers



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

$$E_{OUT} = E_S \frac{R_F}{R_{IN}}$$



$$A = \frac{\Delta e_0}{\Delta e_\epsilon}$$

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

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

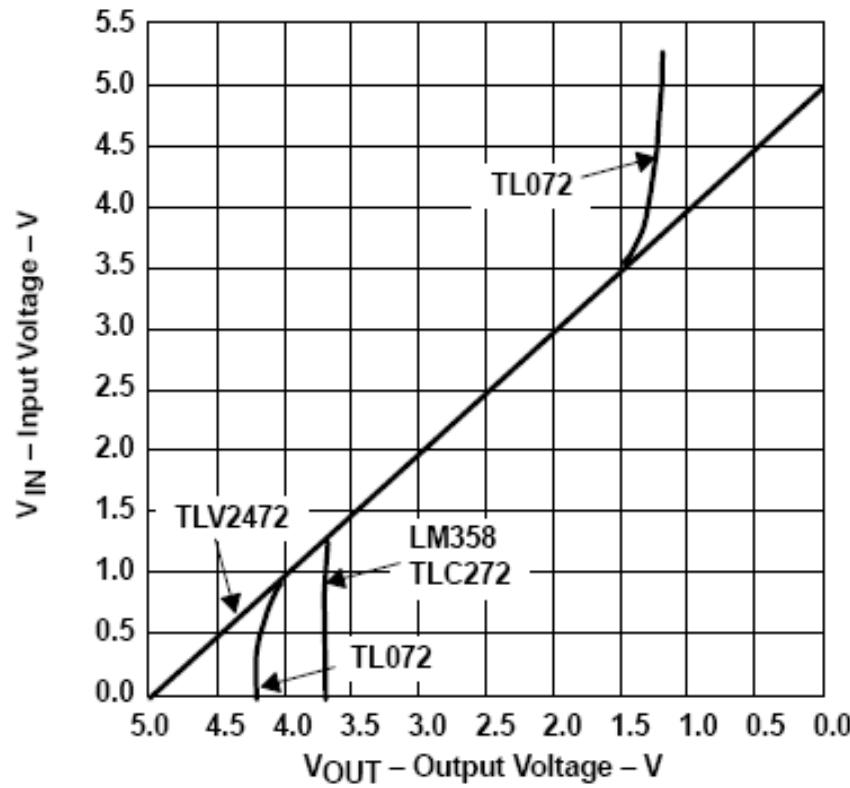
$$e_{OS} = E_{OS} + \left(\frac{\Delta e_{OS}}{\Delta T}\right) \Delta T + \left(\frac{\Delta e_{OS}}{\Delta V_S}\right) \Delta V_S + \left(\frac{\Delta e_{OS}}{\Delta t}\right) \Delta t$$

\downarrow \downarrow \downarrow \downarrow
 $\mu V @ 25^\circ C$ $\mu V / ^\circ C$ $\mu V / %$ $\mu V / DAY$

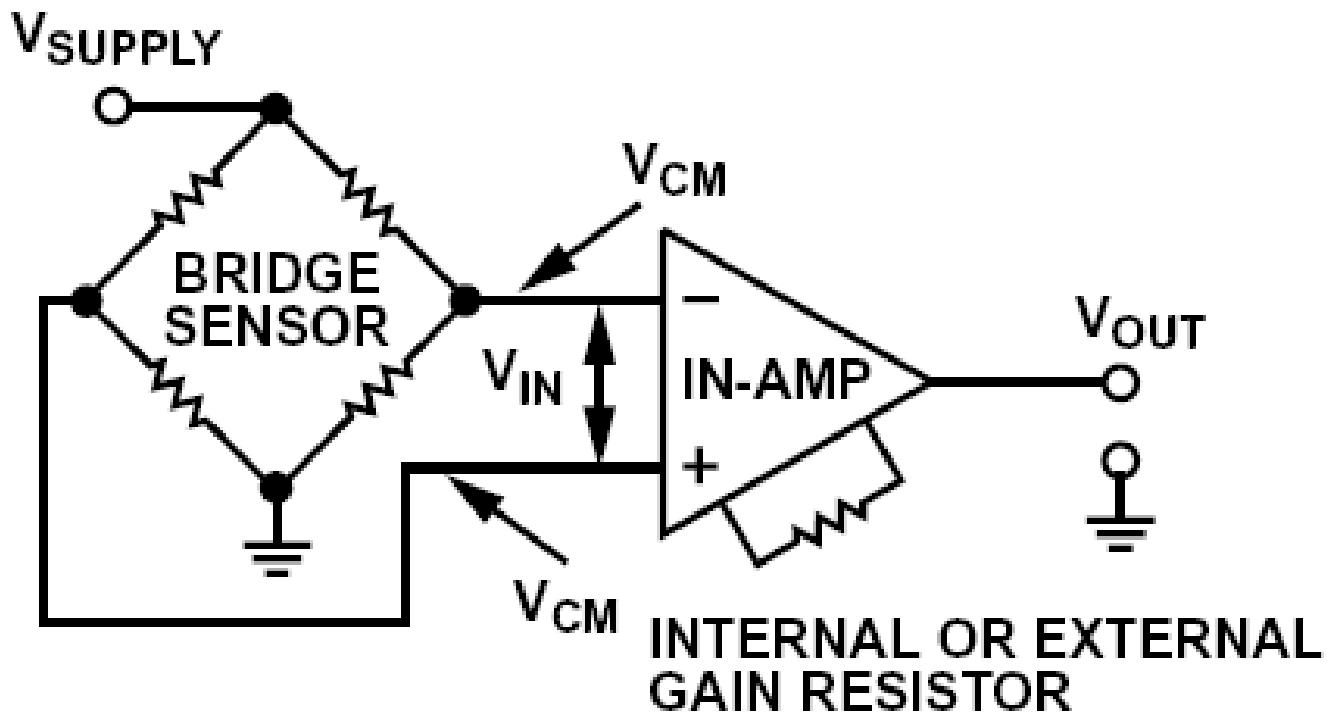
$$i_b = I_b + \left(\frac{\Delta i_b}{\Delta T}\right) \Delta T + \left(\frac{\Delta i_b}{\Delta V_S}\right) \Delta V_S + \left(\frac{\Delta i_b}{\Delta t}\right) \Delta t$$

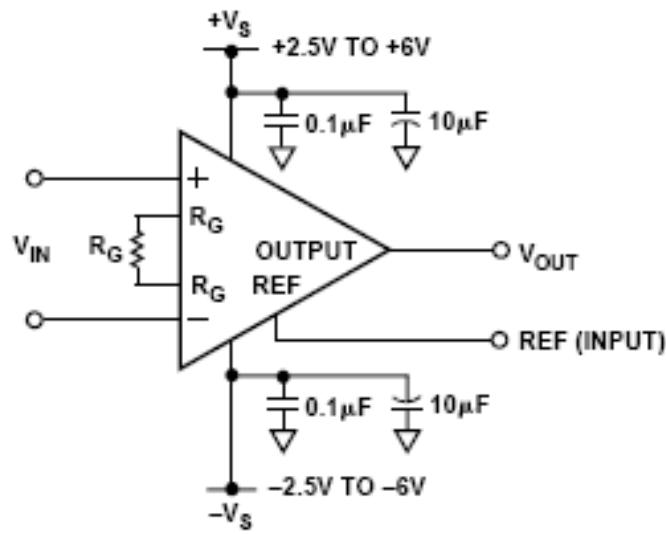
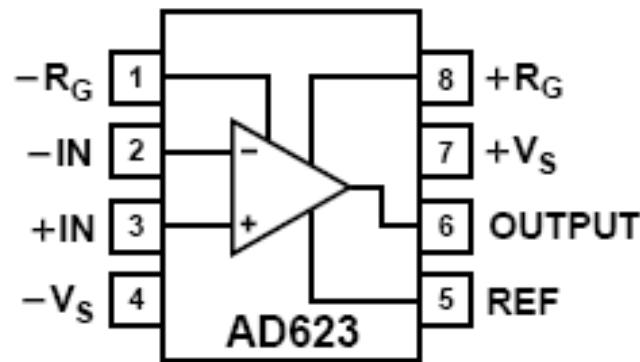
\downarrow \downarrow \downarrow \downarrow
 $nA @ 25^\circ C$ $nA / ^\circ C$ $nA / %$ nA / DAY

Rail-to-rail amplifier's basics

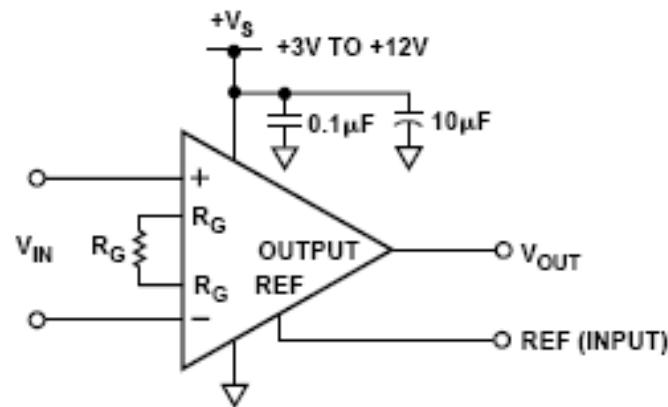


Instrumentation amplifiers





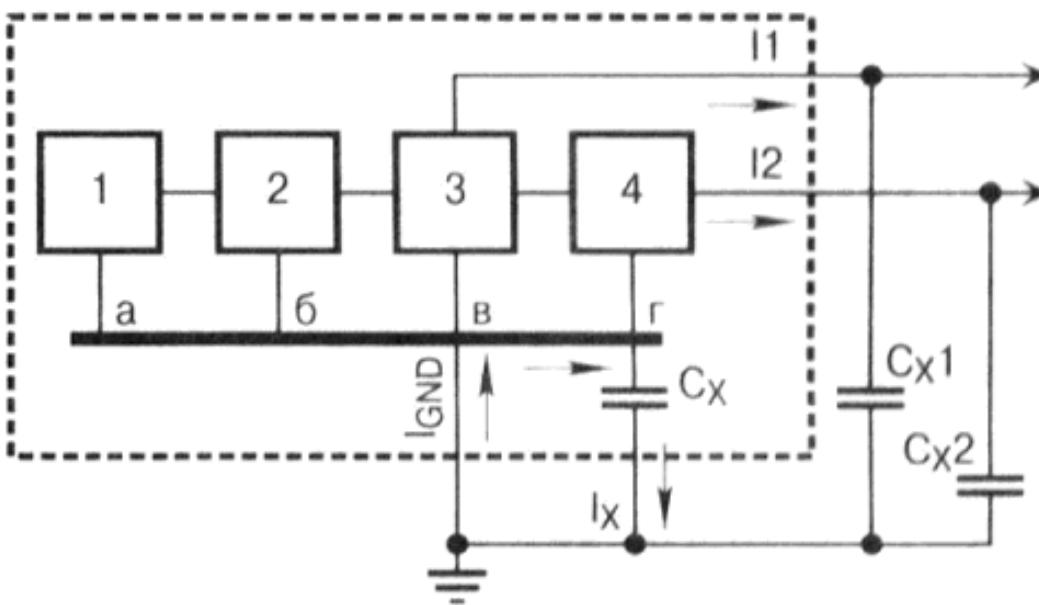
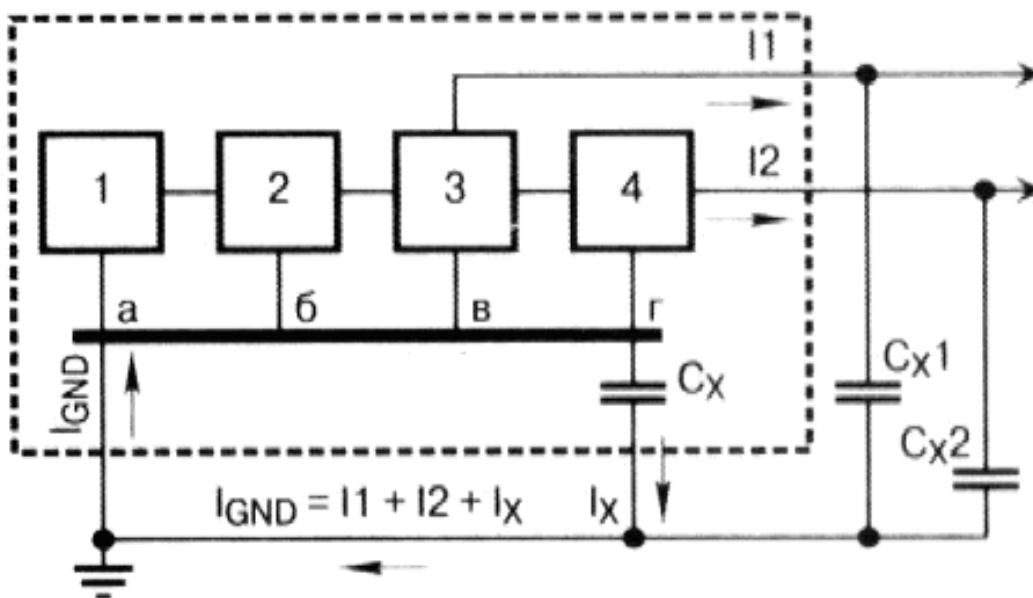
a. Dual Supply



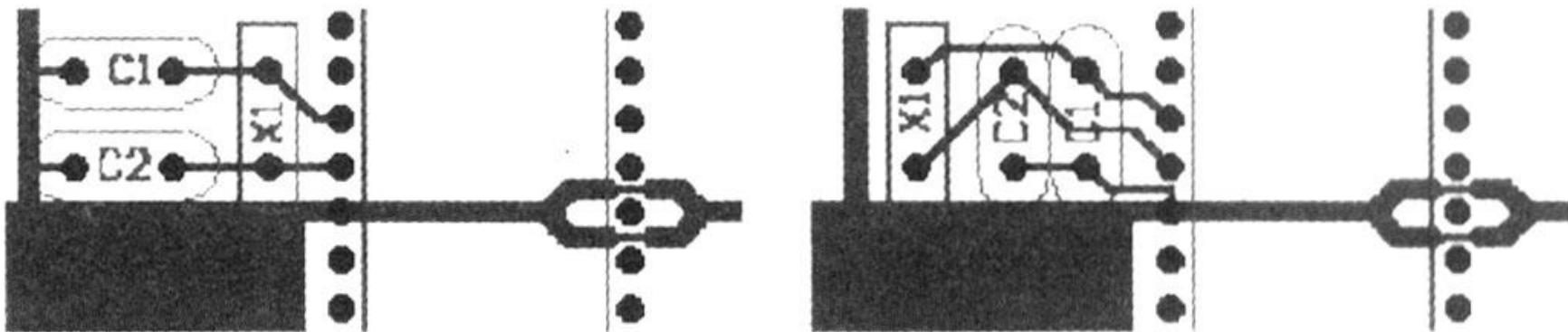
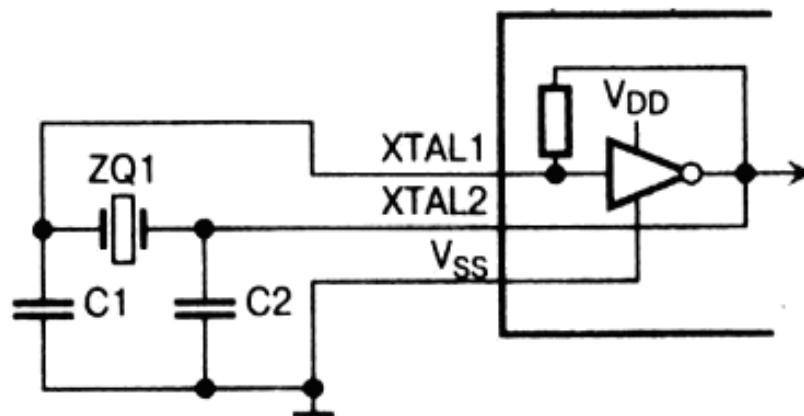
b. Single Supply

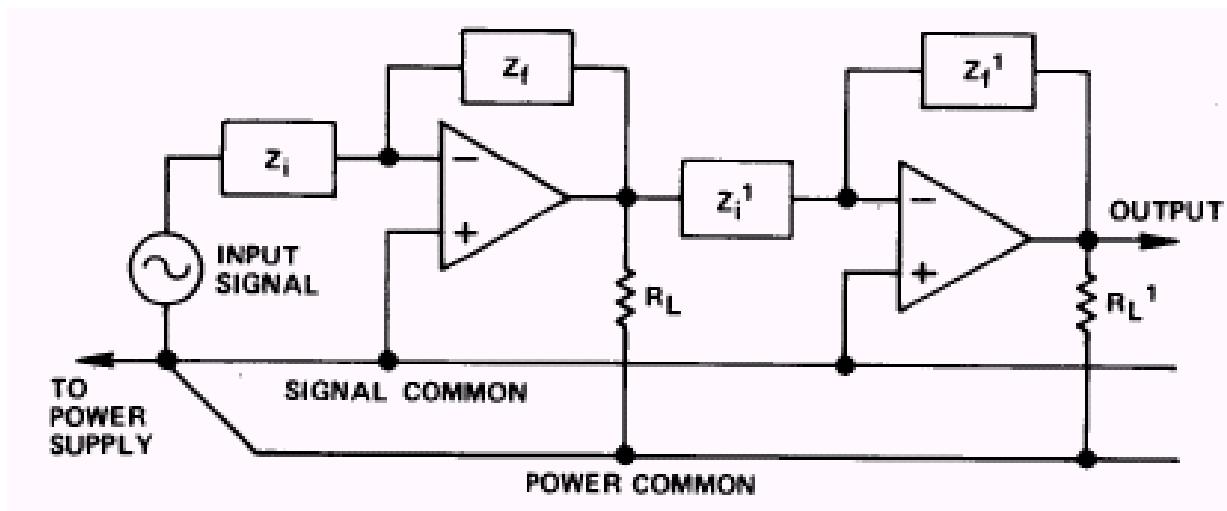
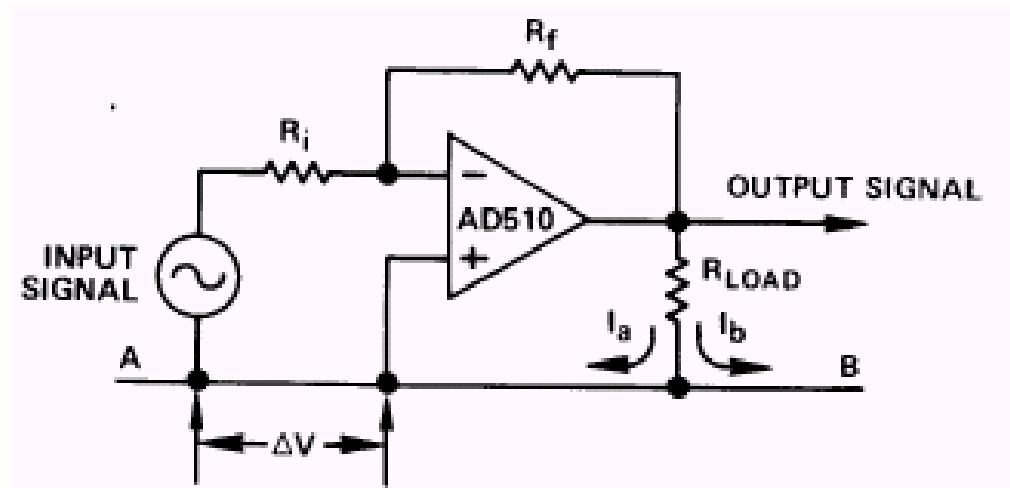
Interference



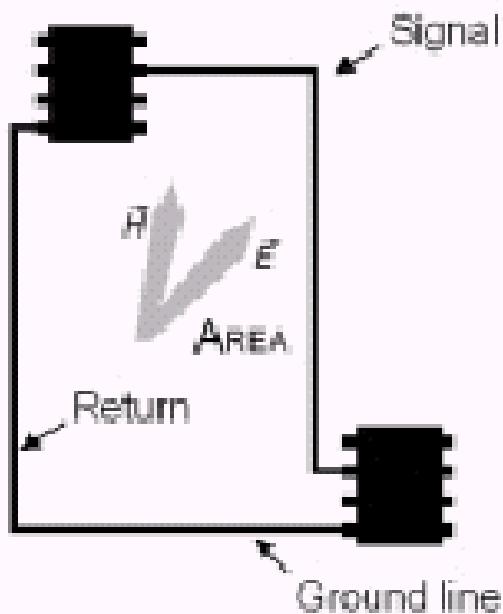


Microcontroller

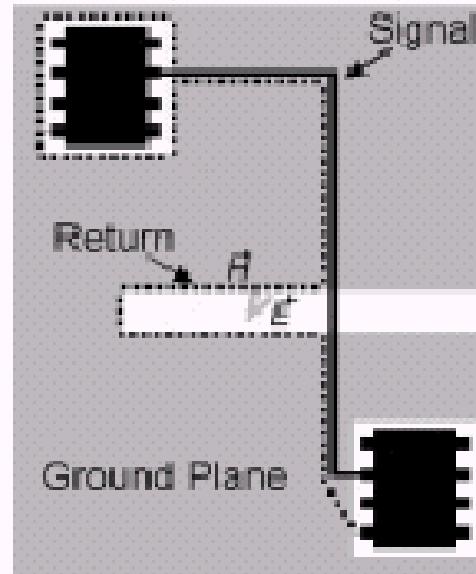




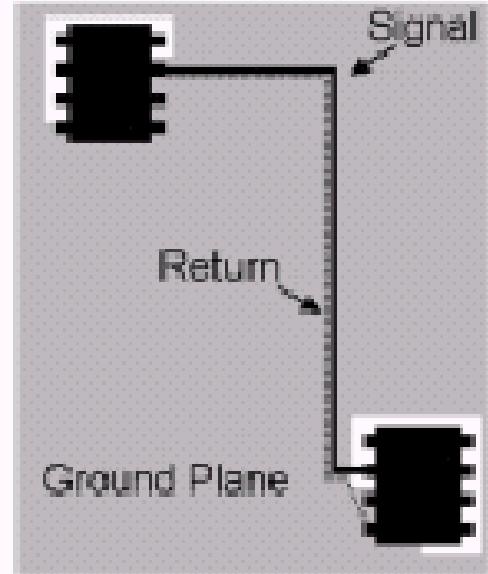
Version A



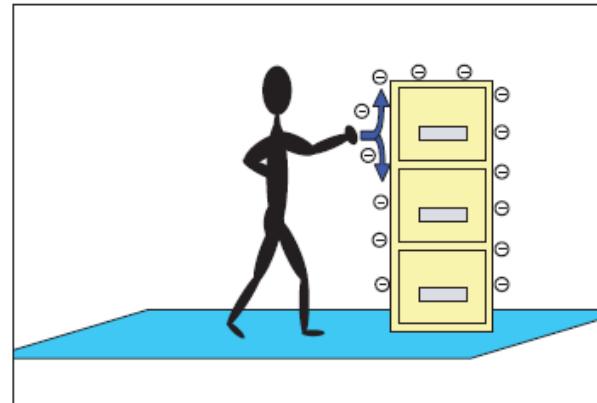
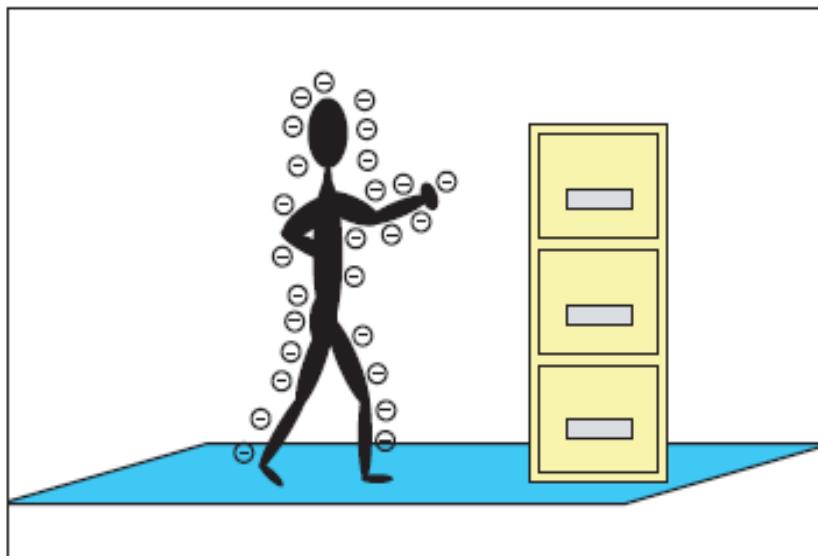
Version B



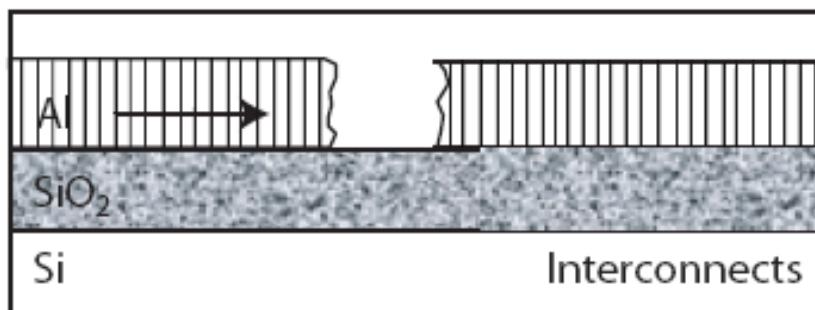
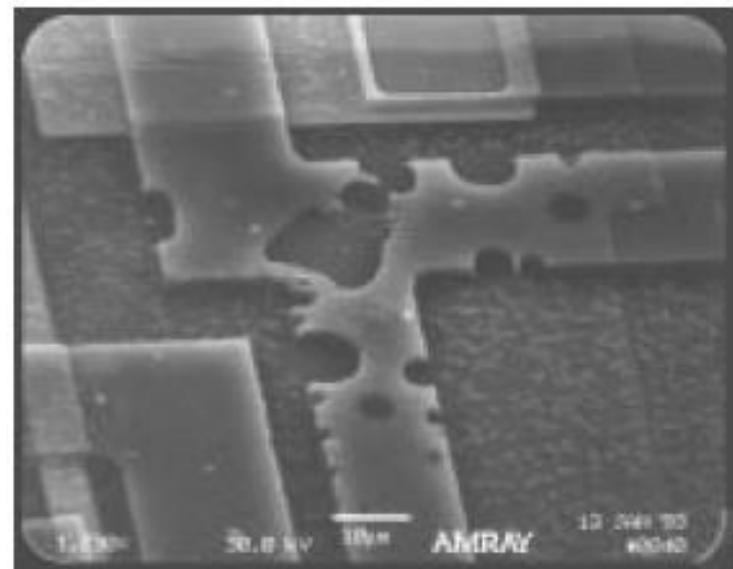
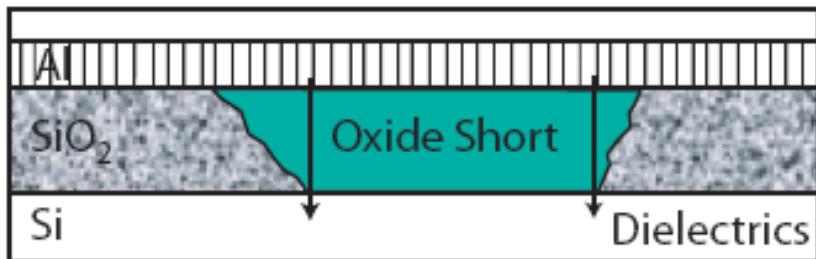
Version C



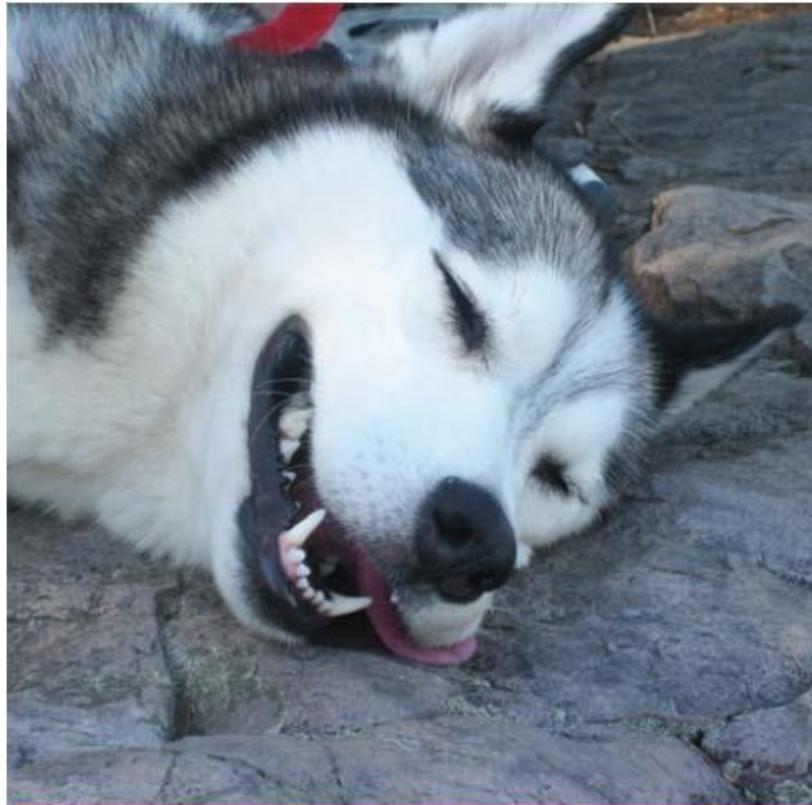
Electrostatic Discharge (ESD)



ESD impact



Thank you for your attention !



Relax...