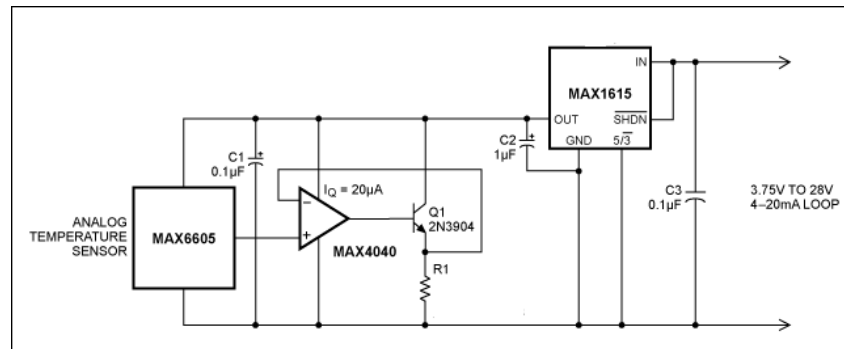


Capteur et chaîne de mesure - TD

Exercice 1 : capteur de température sur boucle de courant 4-20mA

On étudie un schéma d'une chaîne de mesure simple, éprouvé et toujours utilisé dans le domaine industriel pour des capteurs de température déportés et sous fortes contraintes. Le schéma étudié ici est tiré d'une note d'application de *MAXIM* (mais peu très bien être réalisé avec des composants d'autres fondeurs) :



Le principe de la boucle est assez simple, et consiste à coder les valeurs mesurées sur une échelle allant de 4 à 20mA.

1. On s'intéresse au composant MAX1615.
 - (a) Quel est le rôle de ce composant ?
 - (b) Quelle est la consommation de ce composant ?
2. On s'intéresse maintenant au capteur.
 - (a) Quelle est la sensibilité du capteur ?
 - (b) Quelle est l'erreur maximale comise par le capteur ?
 - (c) Que vaut la tension en sortie du capteur en fonction de la température ?
 - (d) A votre avis, quelle est la technologie utilisée dans ce capteur ?
 - (e) Quelle est la consommation du capteur ?
3. On s'intéresse enfin au reste du circuit.
 - (a) Quelle est le rôle du montage basé sur l'AOP, le transistor et $R1$?
 - (b) Cacluler sa grandeur de sortie en fonction de la température.
 - (c) On souhaite avoir une plage de mesure allant de $-25^{\circ}C$ à $125^{\circ}C$. Déterminez la valeur de résistance $R1$ en utilisant une seule résistance de la série $E24$.
 - (d) Quelle est alors l'erreur rajoutée par le circuit de conditionnement ?
 - (e) Quelle est l'incertitude obtenue sur la mesure globale ?

4. Que peut-on dire de la consommation du circuit et de son influence sur la mesure ?
5. Pourquoi à votre avis utilise-t'on une boucle de courant au lieu de transmettre directement la tension issue du capteur ?

Valeur des séries normalisées:

Série E12 (tolérance $\pm 10\%$): 100, 120, 150, 180, 220, 270, 330, 390, 470, 560, 680, 820

Série E24 : (tolérance $\pm 5\%$)100, 110, 120, 130, 150, 160, 180, 200, 220, 240, 270, 300, 330, 360, 390, 430, 470, 510, 560, 620, 680, 750, 820, 910

Extraits de datasheets



Low-Power Analog Temperature Sensor in SC70 Package

MAX6605

General Description

The MAX6605 precision, low-power, analog output temperature sensor is available in a 5-pin SC70 package. The device has a +2.7V to +5.5V supply voltage range and 10µA supply current over the -55°C to +125°C temperature range. For the -40°C to +105°C temperature range, the supply voltage can go as low as +2.4V. Accuracy is ±0.75°C at T_A = +25°C and ±3°C from 0°C to +70°C.

The MAX6605 output voltage is dependent on its die temperature and has a slope of 11.9mV/°C and an offset of 744mV at 0°C. The output typically shows only +0.4°C of nonlinearity over the -20°C to +85°C temperature range.

Applications

- Cellular Phones
- Battery Packs
- GPS Equipment
- Digital Cameras

Features

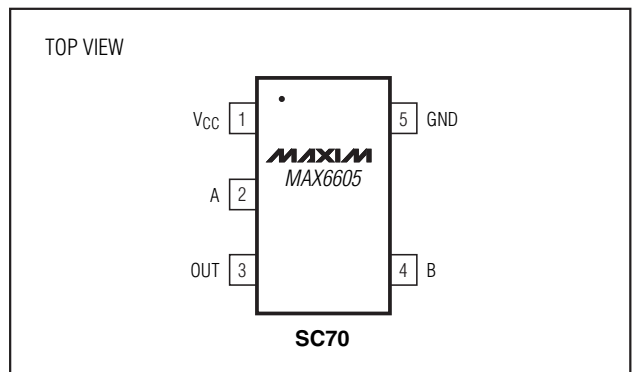
- ◆ Low Current Consumption (10µA max)
- ◆ Small SC70 Package
- ◆ Accurate (±0.75°C at T_A = +25°C)
- ◆ Optimized to Drive Large Capacitive Loads

Ordering Information

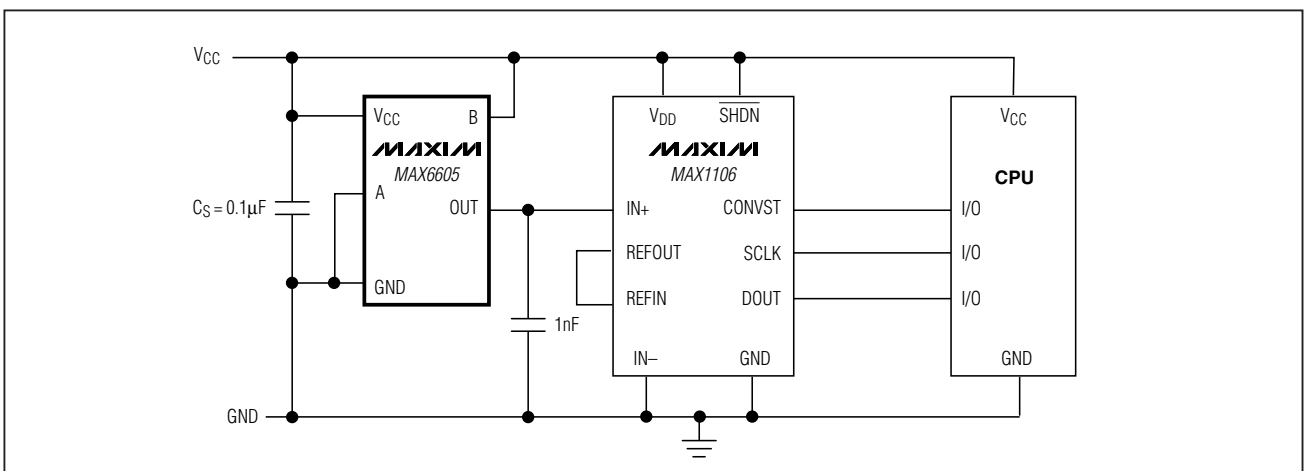
PART	TEMP RANGE	PIN-PACKAGE
MAX6605MXK-T	-55°C to +125°C	5 SC70-5
MAX6605MXK+T	-55°C to +125°C	5 SC70-5
MAX6605MXK/V+T	-40°C to +85°C	5 SC70-5

+ Denotes a lead(Pb)-free/RoHS-compliant package.
 T = Tape and reel.
 /V denotes an automotive qualified part.

Pin Configuration



Typical Application Circuit



Low-Power Analog Temperature Sensor in SC70 Package

ABSOLUTE MAXIMUM RATINGS

V _{CC} to GND	-0.3V to +6V	Continuous Power Dissipation (T _A = +70°C)	
OUT, A, B to GND	-0.3V to (V _{CC} + 0.3V)	5-Pin SC70 (derate 3.1mW/°C above +70°C)	245mW
ESD Protection (Human Body Model)	> 2000V	Operating Temperature Range	-55°C to +125°C
Current into Any Pin	10mA	Junction Temperature	+150°C
Output Short-Circuit Duration	Continuous	Storage Temperature Range	-65°C to +150°C
		Lead Temperature (soldering, 10s)	+300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(V_{CC} = +2.7V to +5.5V, C_L = 1nF, T_A = -55°C to +125°C, unless otherwise noted.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Temperature Error V _{OUT} = 0.744 + (0.0119 × T°C) + (1.604 × 10 ⁻⁶ × T ²)V (Note 2)		V _{CC} = +3.3V	T _A = +25°C	±0.75		°C
			T _A = -0°C to +70°C	-3.0	+3.0	
			T _A = -20°C to +85°C	-3.8	+3.8	
			T _A = -40°C to +100°C	-5.0	+5.0	
			T _A = -55°C to +125°C	-5.8	+5.8	
Supply Voltage	V _{CC}	T _A = -55°C to +125°C	2.7	5.5		V
		T _A = -40°C to +105°C	2.4	5.5		
Supply Current	I _Q	No load	4.5		10	μA
Output Voltage	V _{OUT}	T _A = 0°C	744			mV
Nonlinearity		T _A = -20°C to +85°C	0.4			°C
Sensor Gain (Average Slope)		T _A = -40°C to +100°C	11.1	11.9	12.7	mV/°C
Capacitive Load		Required for stability	1			nF
Load Regulation		T _A = -20°C to +125°C, I _{OUT} = -20μA to +20μA			20	m°C/μA
		T _A = -55°C, I _{OUT} = -10μA to +10μA			20	

Note 1: All parameters are measured at T_A = +25°C. Specifications over temperature range are guaranteed by design.

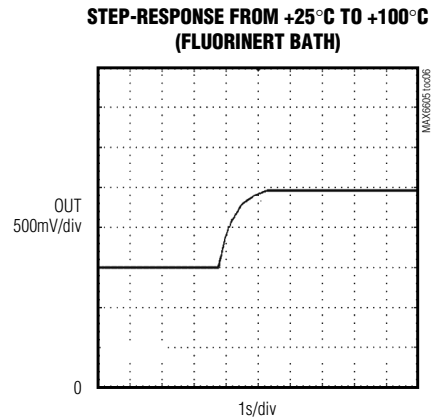
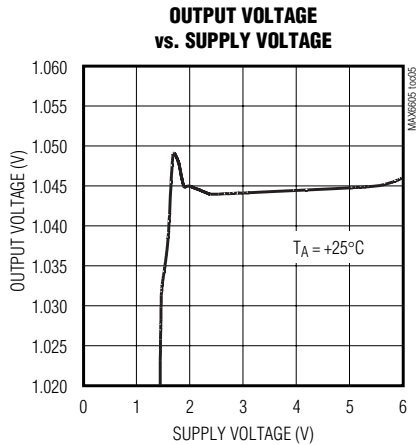
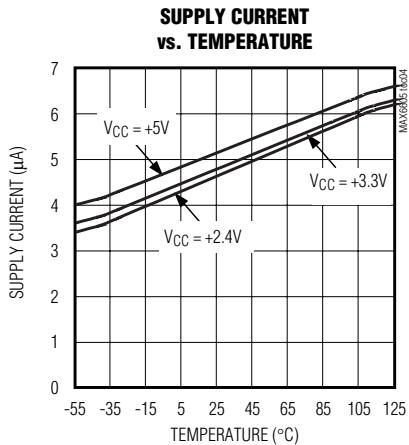
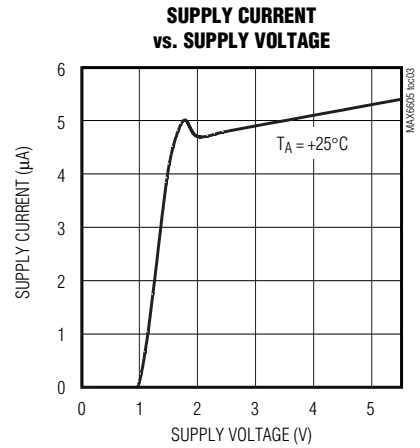
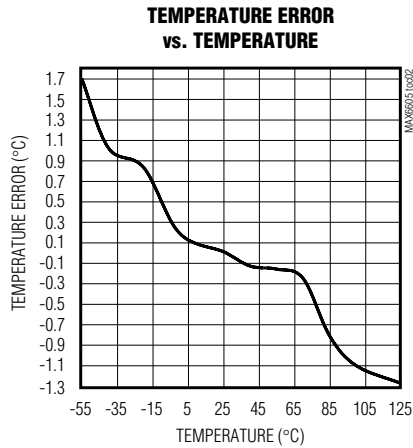
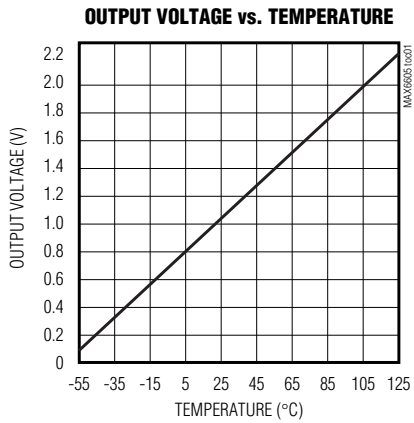
Note 2: Error (expressed in °C) is defined as the difference between the calculated and measured values of output voltage. Guaranteed by design to 5 sigma.

Low-Power Analog Temperature Sensor in SC70 Package

Typical Operating Characteristics

($V_{CC} = +3.3V$, $C_S = 0.1\mu F$, $C_L = 1nF$, unless otherwise noted.)

MAX6605



Low-Power Analog Temperature Sensor in SC70 Package

Pin Description

PIN	NAME	FUNCTION
1	VCC	Supply Input. Decouple with a 0.1µF capacitor to GND.
2	A	Must be connected to GND.
3	OUT	Temperature Sensor Output, $C_L \geq 1nF$
4	B	Must be connected to VCC.
5	GND	Ground

Detailed Description

The MAX6605 analog output temperature sensor's output voltage is a linear function of its die temperature. The slope of the output voltage is 11.9mV/°C, and there is a 744mV offset at 0°C to allow measurement of negative temperatures. The MAX6605 has three terminals: VCC, GND, and OUT. The maximum supply current is 10µA, and the supply voltage range is from +2.4V to +5.5V for the -40°C to +105°C temperature range and +2.7V to +5.5V for the -55°C to +125°C temperature range. The temperature error is <1°C at $T_A = +25^\circ\text{C}$, <3.8°C from $T_A = -20^\circ\text{C}$ to +85°C, and <5.8°C from $T_A = -55^\circ\text{C}$ to +125°C.

Nonlinearity

The benefit of silicon analog temperature sensors over thermistors is linearity over extended temperatures. The nonlinearity of the MAX6605 is typically 0.4°C over the -20°C to +85°C temperature range.

Transfer Function

The temperature-to-voltage transfer function has an approximately linear positive slope and can be described by the equation:

$$V_{OUT} = 744\text{mV} + (T \times 11.9\text{mV}/^\circ\text{C})$$

where T is the MAX6605's die temperature in °C.

Therefore:

$$T (^\circ\text{C}) = (V_{OUT} - 744\text{mV}) / 11.9\text{mV}/^\circ\text{C}$$

To account for the small amount of curvature in the transfer function, use the equation below to obtain a more accurate temperature reading:

$$V_{OUT} = 0.744\text{V} + 0.0119\text{V}/^\circ\text{C} \times T(^\circ\text{C}) + 1.604 \times 10^{-6} \text{ V}/^\circ\text{C}^2 \times (T(^\circ\text{C}))^2$$

Applications Information

Sensing Circuit Board and Ambient Temperatures

Temperature sensor ICs like the MAX6605 that sense their own die temperatures must be mounted on, or close to, the object whose temperature they are intended to measure. Because there is a good thermal path between the SC70 package's metal leads and the IC die, the MAX6605 can accurately measure the temperature of the circuit board to which it is soldered. If the sensor is intended to measure the temperature of a heat-generating component on the circuit board, it should be mounted as close as possible to that component and should share supply and ground traces (if they are not noisy) with that component where possible. This will maximize the heat transfer from the component to the sensor.

The thermal path between the plastic package and the die is not as good as the path through the leads, so the MAX6605, like all temperature sensors in plastic packages, is less sensitive to the temperature of the surrounding air than it is to the temperature of its leads. It can be successfully used to sense ambient temperature if the circuit board is designed to track the ambient temperature.

As with any IC, the wiring and circuits must be kept insulated and dry to avoid leakage and corrosion, especially if the part will be operated at cold temperatures where condensation can occur.

The thermal resistance junction to ambient (θ_{JA}) is the parameter used to calculate the rise of a device junction temperature (T_J) due to its power dissipation. For the MAX6605, use the following equation to calculate the rise in die temperature:

$$T_J = T_A + \theta_{JA} ((V_{CC} \times I_Q) + (V_{CC} - V_{OUT}) I_{OUT})$$

The MAX6605 is a very-low-power temperature sensor and is intended to drive very light loads. As a result, the temperature rise due to power dissipation on the die is insignificant under normal conditions. For example, assume that the MAX6605 is operating from a +3V supply at +21.6°C ($V_{OUT} = 1\text{V}$) and is driving a 100kΩ load ($I_{OUT} = 10\mu\text{A}$). In the 5-pin SC70 package, the die temperature will increase above the ambient by:

$$T_J - T_A = \theta_{JA} ((V_{CC} \times I_Q) + (V_{CC} - V_{OUT}) I_{OUT}) = 324^\circ\text{C}/\text{W} \times ((3\text{V} \times 10\mu\text{A}) + (3\text{V} - 1\text{V}) \times 10\mu\text{A}) = 0.0162^\circ\text{C}$$

Therefore, the error caused by power dissipation will be negligible.



High-Voltage, Low-Power Linear Regulators for Notebook Computers

MAX1615/MAX1616

General Description

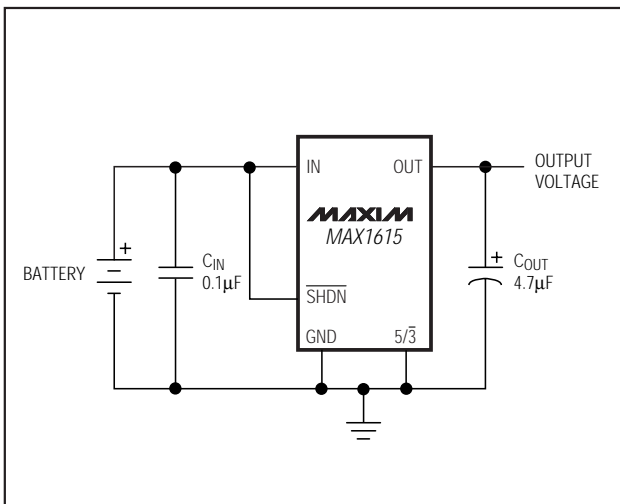
The MAX1615/MAX1616 are micropower, SOT23-5 linear regulators that supply always-on, keep-alive power to CMOS RAM and microcontrollers (μ Cs) in systems with high-voltage batteries. Key features include wide input voltage range, low dropout voltage, and low quiescent supply current.

Despite a miserly $8\mu\text{A}$ (max) no-load supply current, the MAX1615/MAX1616 have excellent line-transient response and AC power-supply rejection ratio. They provide a clean, fixed 5V or 3.3V output (MAX1615) or an adjustable 1.24V to 28V output (MAX1616), even when subjected to fast supply-voltage changes that occur during the switchover from battery to AC adapter input power. The space-saving SOT23-5 package has excellent thermal characteristics and tolerates up to 571mW of power dissipation. Fault protection is provided by internal foldback current limiting and thermal-shutdown circuitry. The MAX1615/MAX1616 are now available in lead-free packages.

Applications

- CMOS/RTC Backup Power
- Microcontroller Power
- Notebook Computers
- Smart-Battery Packs
- PDA's and Handy-Terminals
- Battery-Powered Systems

Typical Operating Circuit



Features

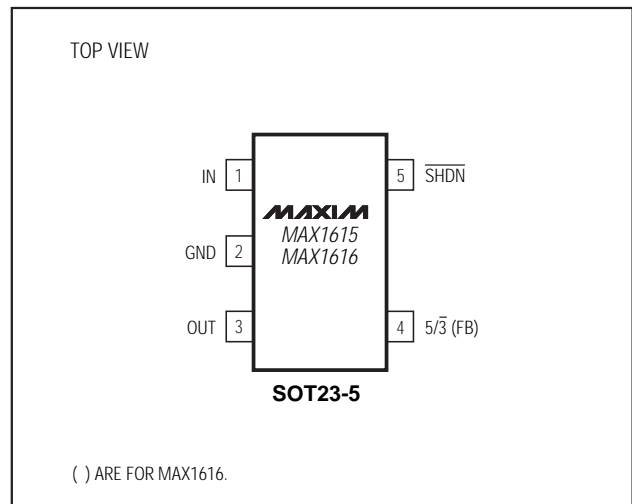
- ◆ 4V to 28V Input Range
- ◆ 8 μA (max) Quiescent Supply Current
- ◆ $1\mu\text{A}$ Shutdown Supply Current
- ◆ 3.3V or 5V, Pin-Selectable Output (MAX1615)
Adjustable 1.24V to 28V Output (MAX1616)
- ◆ 30mA Output Current
- ◆ $\pm 2\%$ Initial Output Accuracy
- ◆ Thermal-Overload Protection
- ◆ 5-Pin SOT23 Package
- ◆ Low Cost

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE	SOT TOP MARK
MAX1615EUK-T	-40°C to +85°C	5 SOT23-5	ABZD
MAX1615EUK+T	-40°C to +85°C	5 SOT23-5	ABZD
MAX1616EUK-T	-40°C to +85°C	5 SOT23-5	ABZE
MAX1616EUK+T	-40°C to +85°C	5 SOT23-5	ABZE

+ Denotes lead-free package.

Pin Configuration



For pricing, delivery, and ordering information, please contact Maxim/Dallas Direct! at 1-888-629-4642, or visit Maxim's website at www.maxim-ic.com.

High-Voltage, Low-Power Linear Regulators for Notebook Computers

ABSOLUTE MAXIMUM RATINGS

IN to GND	-0.3V to 30V	Continuous OUT Current	40mA
Terminal Voltages to GND		Continuous Power Dissipation ($T_A = +70^\circ\text{C}$) (Note 1)	
SHDN to GND	-0.3V to ($V_{IN} + 0.3\text{V}$)	SOT23-5 (derate 7.1mW/°C above $+70^\circ\text{C}$)	571mW
5/3 to GND	-0.3V to ($V_{OUT} + 0.3\text{V}$)	Operating Temperature Range	
FB (MAX1616) to GND	-0.3V to ($V_{OUT} + 0.3\text{V}$)	MAX161_EUK-T	-40°C to +85°C
OUT to GND	-0.3V to 30V	Storage Temperature Range	-65°C to +160°C
OUT Short-Circuit to GND	30sec	Lead Temperature (soldering, 10s)	+300°C

Note 1: See *Operating Region and Power Dissipation* section.

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

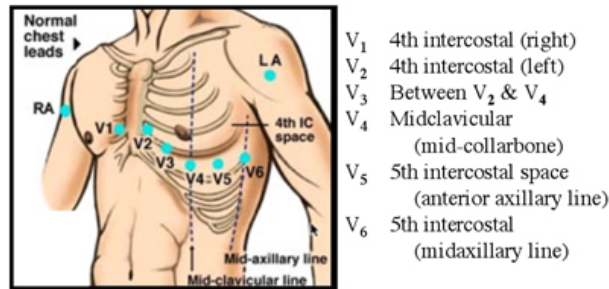
($V_{IN} = 15\text{V}$, $\overline{\text{SHDN}} = V_{IN}$, $I_{LOAD} = 5\mu\text{A}$, $T_A = T_{MIN}$ to T_{MAX} , unless otherwise noted. Typical values are at $T_A = +25^\circ\text{C}$.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS	
Input Voltage Range	V_{IN}			4		28	V	
Supply Current	I_{IN}	$\overline{\text{SHDN}} = \text{IN}$, $T_A = +25^\circ\text{C}$			6.2	8	μA	
		$\overline{\text{SHDN}} = \text{IN}$, $V_{IN} = 6\text{V}$ to 28V , $T_A = T_{MIN}$ to T_{MAX}				15		
Minimum Load Current						5	μA	
Shutdown Supply Current	I_{IN}	$\overline{\text{SHDN}} = \text{GND}$ (shutdown mode)	$T_A = +25^\circ\text{C}$			1.5	μA	
			$T_{MIN} = T_{MIN}$ to T_{MAX}			3		
Dropout Supply Current		Output set to 5V, $V_{IN} = 4\text{V}$	$T_A = +25^\circ\text{C}$		70		μA	
Output Voltage (MAX1615) (Note 3)		$I_{LOAD} = 1\text{mA}$, $T_A = +25^\circ\text{C}$, $V_{IN} = 6\text{V}$ to 28V	$5/\overline{3} = \text{GND}$	3.26	3.33	3.40	V	
			$5/\overline{3} = \text{OUT}$	4.95	5.05	5.15		
			$I_{LOAD} = 5\mu\text{A}$ to 30mA , $T_A = T_{MIN}$ to T_{MAX} , $V_{IN} = 6\text{V}$ to 28V	$5/\overline{3} = \text{GND}$	3.15			3.48
				$5/\overline{3} = \text{OUT}$	4.75			5.25
FB Threshold (MAX1616) (Note 3)	V_{FBT}	FB = OUT, $V_{IN} = 6\text{V}$ to 28V	$T_A = +25^\circ\text{C}$, $I_{LOAD} = 1\text{mA}$	1.215	1.240	1.265	V	
			$T_A = T_{MIN}$ to T_{MAX} , $I_{LOAD} = 5\mu\text{A}$ to 30mA	1.18		1.28		
FB Input Current (MAX1616)	I_{FB}	$V_{FB} = 1.3\text{V}$		-10	12	30	nA	
Dropout Voltage	ΔV_{DO}	$I_{LOAD} = 30\text{mA}$ (Note 4)				350	mV	
Output Current Limit		$V_{IN} = 6\text{V}$			100		mA	
OUT Reverse Leakage Current		IN = unconnected, V_{OUT} forced to 5V			70		μA	
Capacitive Load Requirements (Note 5)		MAX1615		0.16			$\mu\text{F}/\text{mA}$	
		MAX1616		0.23				
Start-Up Time Response		Rising edge of IN or $\overline{\text{SHDN}}$ to OUT within specification limits, $R_L = 500\Omega$, $C_{OUT} = 6.8\mu\text{F}$, V_{OUT} set to 5V				1	ms	
Start-Up Overshoot	V_{OSH}	$R_L = 500\Omega$, $C_{OUT} = 10\mu\text{F}$ within 90% of nominal output voltage			0.5		% V_{OUT}	

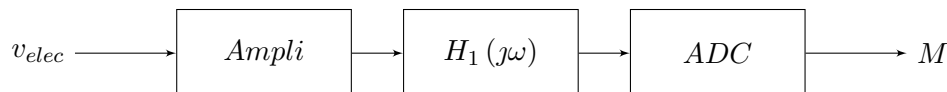
Exercice 2 : Aquisition ECG

l'aquisition d'ECG embarqué repose sur l'utilisation de 6 électrodes précordiales permettant l'enregistrement des biopotentiels associés aux contractions/relaxation des oreillettes et ventricules du coeur. La disposition des électrodes est donnée dans la figure ci-dessous, deux électrodes supplémentaires (RA et LA, *right and left arms*) sont utilisées pour rendre la mesure immune au bruit et perturbations.

Precordial or Chest Leads



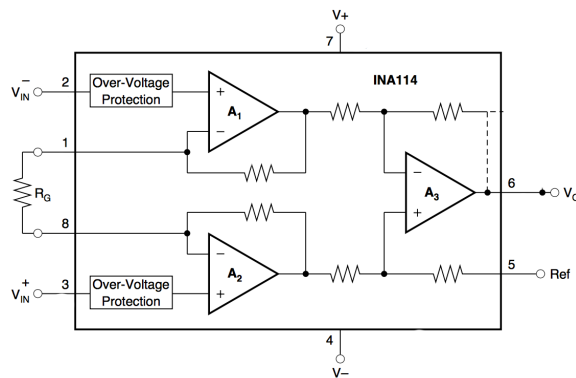
Pour une électrode enregistrée par rapport à l'une des électrodes enregistrée par rapport à RA ou LA, une chaîne de traitement et de conversion analogique numérique simple, représentée dans le schéma bloc ci-dessous, est mise en place. Les 6 électrodes nécessitent donc 6 canaux mis en parallèles.



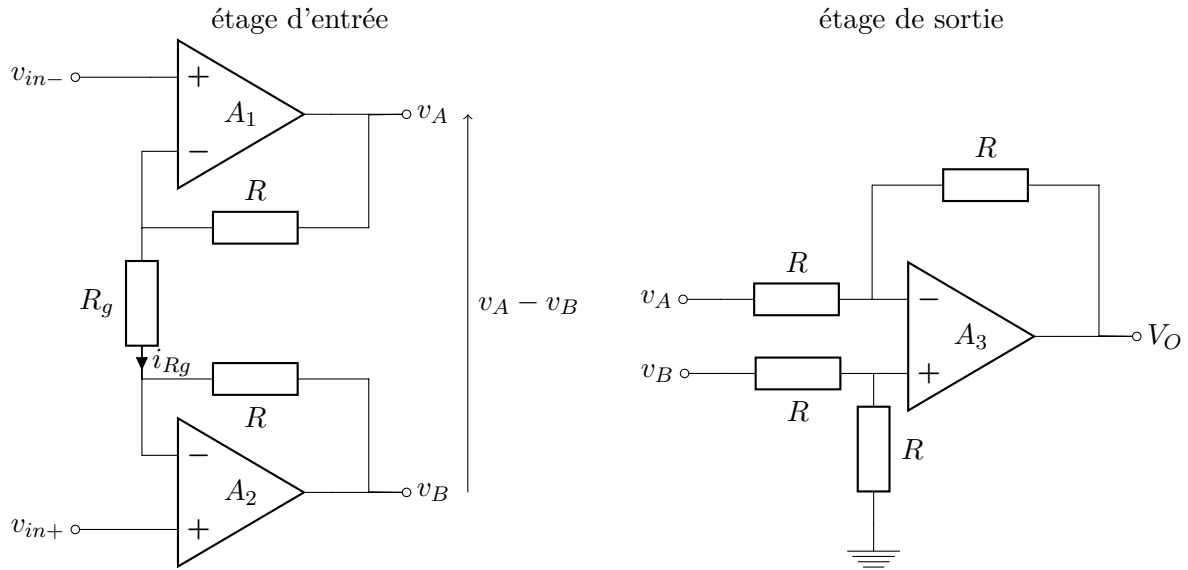
Le signal est amplifié à travers un amplificateur d'instrumentation, puis filtré et converti. Le signal d'entrée est au maximum de $5mV$, la fréquence cardiaque maximale selon les individus peut atteindre environ 240 battements par minute lors d'efforts intense. Pour permettre une analyse fine on considèrera la fréquence maximale du signal de $200Hz$. Le circuit électronique est alimenté en $0 - 3.3V$.

Etage d'amplification d'instrumentation

L'amplification du signal est assurée par un amplificateur d'instrumentation. Ce type d'amplificateur est extrêmement fréquent lors de l'utilisation de capteurs de manière générale. Le schéma interne, ici du composant INA 114 est présenté dans la figure ci dessous :



Cet amplificateur est composé de deux étages séparés représentés avec des notations dans les schémas ci dessous :



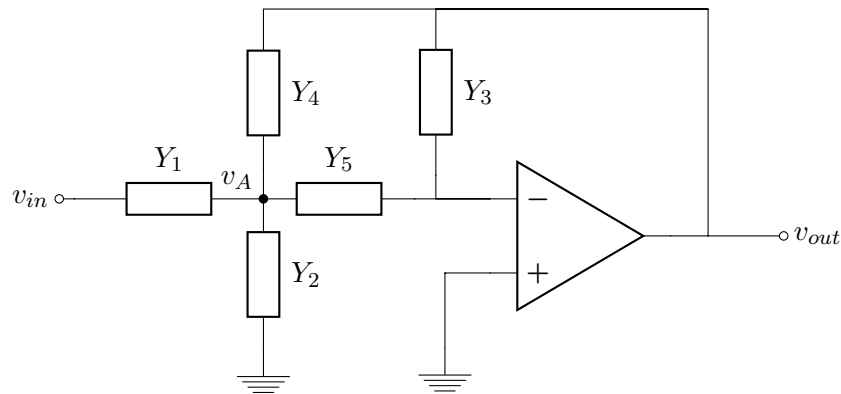
1. On s'intéresse à l'étage d'entrée.
 - (a) Exprimer le courant i_{R_g} en fonction de la tension d'entrée.
 - (b) En déduire la tension de sortie en fonction de la tension d'entrée.
2. L'étage de sortie est assez simple, exprimer le potentiel de sortie en fonction de la tension d'entrée.
3. On s'intéresse au montage global.
 - (a) Déduire des questions précédentes le gain différentiel du montage.
 - (b) A votre avis, que ce passe t'il si les résistances notées R ne sont pas égales (variation des process de fabrication, mismatch géométrique...)?
 - (c) Quels sont les rôles de chacun des étages? En particulier, pourquoi selon vous le gain est il mis sur le premier étage?
 - (d) On cherche à avoir un signal pleine échelle, on sait que pour l'INA 114, $R = 25k\Omega$. Calculer R_g .
 - (e) A $R_g = +\infty$, la bande passante est de $1MHz$. Quelle est la bande passante avec notre cahier des charges?

Filtrage Anti-repliement et conversion/conditionnement

La conversion, puis le traitement, sont réalisés par un micro-contrôleur de type MS430F, très utilisé dans les systèmes embarqués pour la santé, en particulier pour des raisons de faible consommation.

1. A partir de la datasheet, en combien de bits sont convertis les signaux? Que valent les quantas avant et après amplification?
2. Quelle est la fréquence de Nyquist?
3. En pratique on échantillonne à 10 fois la fréquence maximale du signal. On ne souhaite pas atténuer le signal réel de plus de $1dB$. Dresser le gabarit du filtre anti-repliement.
4. Par un raisonnement simple, de quel ordre de filtre a-t-on besoin?

5. On décide d'utiliser pour le filtre une structure de type cellule de Rauch :



- (a) Exprimer v_A en fonction de v_{in} et v_{out} , puis v_- en fonction de v_A et v_{out} .
 - (b) En déduire la fonction de transfert à l'aide des conductances des composants.
 - (c) Afin de réaliser un passe bas on utilise la combinaison on utilise $Y_1 = Y_4 = Y_5 = \frac{1}{R}$ et $Y_2 = jC_1\omega$ et $Y_3 = jC_2\omega$. Mettre la fonction de transfert sous la forme canonique d'un second ordre.
 - (d) On pose $C_1 = 30nF$, et $f_0 = 400Hz$. En déduire les valeurs de R et C_2 pour un amortissement de 1.
 - (e) Combien d'AOP sont nécessaires pour une chaîne d'amplification/filtrage au global ?
6. Calculer le débit théorique du flux de données entrant dans le micro-contrôleur pour les 6 canaux.
 7. A votre avis, quel sera le débit réel ?
 8. On souhaite mettre en place un filtre numérique de type FIR coupe-bande de $50Hz$ pour réduire les perturbations par effet d'antenne. On choisit le *MSP430FR2111*. Quel est l'ordre maximal du filtre pour les 6 canaux pour remplir la mémoire RAM. Dans ce cas, quelle est la contrainte sur la période d'horloge pour respecter un traitement temps réel des données captées ?

Extraits de datasheets

MSP430FR21xx, MSP430FR2000 Mixed-Signal Microcontrollers

1 Device Overview

1.1 Features

- Embedded Microcontroller
 - 16-Bit RISC Architecture up to 16 MHz
 - Wide Supply Voltage Range From 3.6 V Down to 1.8 V (Minimum Supply Voltage is Restricted by SVS Levels, See the [SVS Specifications](#))
- Optimized Low-Power Modes (at 3 V)
 - Active Mode: 120 μ A/MHz
 - Standby
 - LPM3.5 With VLO: 1 μ A
 - Real-Time Clock (RTC) Counter (LPM3.5 With 32768-Hz Crystal): 1 μ A
 - Shutdown (LPM4.5): 34 nA Without SVS
- High-Performance Analog
 - 8-Channel 10-Bit Analog-to-Digital Converter (ADC)
 - Integrated Temperature Sensor
 - Internal 1.5-V Reference
 - Sample-and-Hold 200 ksp/s
 - Enhanced Comparator (eCOMP)
 - Integrated 6-Bit DAC as Reference Voltage
 - Programmable Hysteresis
 - Configurable High-Power and Low-Power Modes
- Low-Power Ferroelectric RAM (FRAM)
 - Up to 3.75KB of Nonvolatile Memory
 - Built-In Error Correction Code (ECC)
 - Configurable Write Protection
 - Unified Memory of Program, Constants, and Storage
 - 10^{15} Write Cycle Endurance
 - Radiation Resistant and Nonmagnetic
- Intelligent Digital Peripherals
 - One 16-Bit Timer With Three Capture/Compare Registers (Timer_B3)
 - One 16-Bit Counter-Only RTC Counter
 - 16-Bit Cyclic Redundancy Checker (CRC)
- Enhanced Serial Communications
 - Enhanced USCI A (eUSCI_A) Supports UART, IrDA, and SPI
- Clock System (CS)
 - On-Chip 32-kHz RC Oscillator (REFO)
 - On-Chip 16-MHz Digitally Controlled Oscillator (DCO) With Frequency-Locked Loop (FLL)
 - $\pm 1\%$ Accuracy With On-Chip Reference at Room Temperature
 - On-Chip Very-Low-Frequency 10-kHz Oscillator (VLO)
 - On-Chip High-Frequency Modulation Oscillator (MODOSC)
 - External 32-kHz Crystal Oscillator (LFXT)
 - Programmable MCLK Prescaler of 1 to 128
 - SMCLK Derived From MCLK With Programmable Prescaler of 1, 2, 4, or 8
- General Input/Output and Pin Functionality
 - 12 I/Os on 16-Pin Package
 - 8 Interrupt Pins (4 Pins of P1 and 4 Pins of P2) Can Wake MCU From LPMs
 - All I/Os are Capacitive Touch I/Os
- Development Tools and Software (Also See [Tools and Software](#))
 - Free Professional Development Environments
 - Development Kits ([MSP-TS430PW20](#), [MSP-FET430U20](#), [MSP-EXP430FR2311](#), and [MSP-EXP430FR4133](#))
- Family Members (Also See [Device Comparison](#))
 - MSP430FR2111: 3.75KB of Program FRAM + 1KB of RAM
 - MSP430FR2110: 2KB of Program FRAM + 1KB of RAM
 - MSP430FR2100: 1KB of Program FRAM + 512 Bytes of RAM
 - MSP430FR2000: 0.5KB of Program FRAM + 512 Bytes of RAM
- Package Options
 - 16-Pin: TSSOP (PW16)
 - 24-Pin: VQFN (RLL)
- For Complete Module Descriptions, See the [MSP430FR4xx and MSP430FR2xx Family User's Guide](#)

1.2 Applications

- Appliance Battery Packs
- Smoke and Heat Detectors
- Door and Window Sensors
- Lighting Sensors
- Power Monitoring
- Personal Care Electronics Portable
- Health and Fitness Devices

