ESCUELA TECNICA SUPERIOR DE
INGENIEROS INDUSTRIALES Y DE TELECOMUNICACIÓN

UNIVERSIDAD DE CANTABRIA

SOLUCIONES DE EXAMENES
Instrumentación Electrónica de Comunicaciones
(Curso, 2007/2008)

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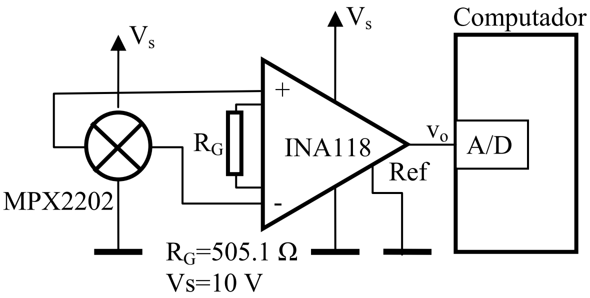
Comentarios:

Los enunciados de los exámenes proponen siempre un caso real de instrumentación que debe analizarse. Las posibles soluciones están abiertas a muchos suposiciones e interpretaciones, y en definitiva decisiones, que deben ser tomadas durante el análisis. La lógica de estas suposiciones de acuerdo con el enunciado del problema, es un aspecto muy relevante de la evaluación del examen. Todo ello lleva a **que la solución de un examen no es única**, y la que aquí se propone es solo una de las posibles que podría realizarse.

Los documentos que se proporcionan son documentos de trabajo para la corrección de los exámenes, y no fueron hechos para ser publicados, por lo **que tienen algunos errores tipográficos en las ecuaciones y en los cálculos numéricos** que llevan a los resultados numéricos. Estúdialos con espíritu crítico.

Instrumentación Electrónica de Comunicaciones Enero, 2008
Ingeniería de Telecomunicaciones

Se necesita medir la presión diferencial en un sistema con gran precisión, en el rango 0 - 100 Kpa (pascal= Newton/m^2), y para ello se utiliza el sensor MPX2202 de Motorola, cuyas hojas características se adjuntan. La presión se mide desde un computador, a través de un convertidor A/D de 12 bits de resolución y un rango dinámico de 0 a 5 voltios.
Como circuito de adaptación se utiliza el amplificador diferencial integrado INA118, de Burr Brown que ha sido diseñado con una ganancia diferencial de 100. También se adjuntan sus hojas características.




```
package body MedidaPresion is
   v0Cal:Float= 0.0;
   v100Cal:Float= 100.0*100.0*0.2E-3;

   function leeAD return Float is ….
      -- Retorna entrada AD en voltios

   function leePresion return float is
   begin
      -- Retorna presión en Kpa
      return 100.0*(readAD-v0cal)/
                        (v100Cal-v0Cal);
   end leePresion;

   procedure calibra0Kpa is begin
      -- Calibración con presión nula
      v0Cal:=leeAD;
   end calibra0Kpa;

   procedure calibra100Kpa is begin
      -- Calibración con presión 100Kpa
      v100Cal:=leeAD;
   end calibra100Kpa;

end MedidaPresion;
```

Para este sistema estudiar:

1) Si se entiende por resolución el mayor cambio de la señal de entrada (en este caso presión) que no es detectable en el resultado de la medida. Cual es la resolución del sistema como consecuencia del error de cuantización del convertidor A/D.
2) Cual es la incertidumbre (para el 95 % de nivel de confianza) de la medida de la presión. Como consecuencia de ruido que se genera en el transductor y en el amplificador. ¿Se consigue disminuir la incertidumbre si se sustituye alguno de estos elementos por otro de menos nivel de ruido?
3) A fin de eliminar los efectos del offset y de las ganancias de los diversos elementos, antes de iniciar las medidas, se realiza un proceso de calibración basado en medir previamente las presiones de 0 Kpa y 100 Kpa, y utilizar sus resultados en la medida de cualquier nueva presión. Acotar el error que se comete en la medida de una presión de 50Kpa, con el sistema de medida si ha sido calibrado por este método.
4) Si en la fuente de alimentación hay un rizado de 1 Vpp y 50 Hz, cual es el máximo error que se comete en la medida como consecuencia de las características del amplificador y de sensor de presión (suponer que el sensor es un puente resistivo).
5) Acotar la precisión y exactitud de la medida de presión si se consideran simultáneamente los cuatro efectos previos (Error de cuantización del convertidor A/D, ruido de los componentes, calibración y ruido de rizado en la fuente de alimentación). Proponer la mejora (sólo una) que tenga un efecto mas relevante sobre la exactitud del proceso de medida.

Order this document
by MPX2202/D

200 kPa On-Chip Temperature Compensated & Calibrated Pressure Sensors

MPX2202
MPXV2202G
SERIES

Motorola Preferred Device

0 to 200 kPa (0 to 29 psi)
40 mV FULL SCALE SPAN
(TYPICAL)

The MPX2202/MPXV2202G device series is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output — directly proportional to the applied pressure. The sensor is a single monolithic silicon diaphragm with the strain gauge and a thin–film resistor network integrated on–chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation. They are designed for use in applications such as pump/motor controllers, robotics, level indicators, medical diagnostics, pressure switching, barometers, altimeters, etc.

Features

- Temperature Compensated Over 0°C to +85°C
- Easy–to–Use Chip Carrier Package Options
- Available in Absolute, Differential and Gauge Configurations

Application Examples

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

Figure 1 illustrates a block diagram of the internal circuitry on the stand–alone pressure sensor chip.

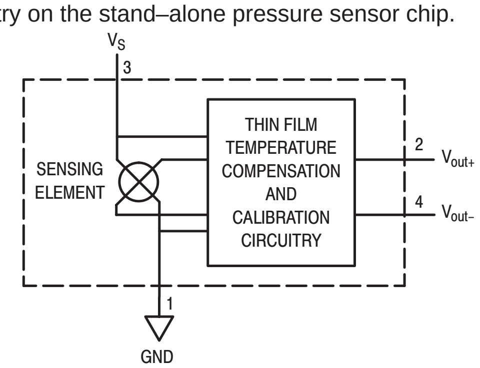


Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The absolute sensor has a built–in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure (P1) side.

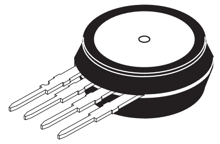
The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure (P1) side relative to the vacuum (P2) side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum (P2) side relative to the pressure (P1) side.

Preferred devices are Motorola recommended choices for future use and best overall value.

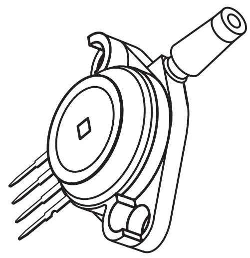
Replaces MPX2200/D

REV 2

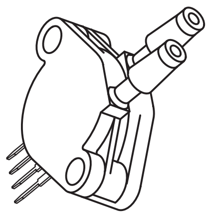
UNIBODY PACKAGE



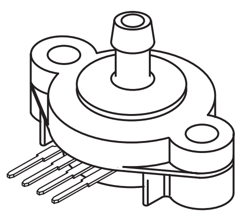
MPX2202A/D
CASE 344



MPX2202AP/GP
CASE 344B



MPX2202DP
CASE 344C

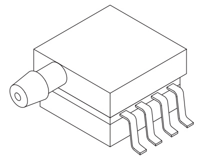


MPX2202ASX/GSX
CASE 344F

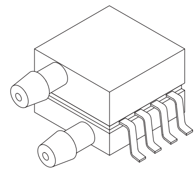
PIN NUMBER			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

NOTE: Pin 1 is noted by the notch in the lead.

SMALL OUTLINE PACKAGE
SURFACE MOUNT



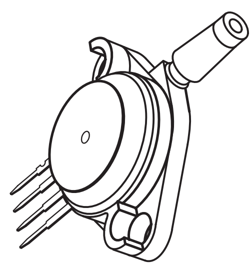
MPXV2202GP
CASE 1369



MPXV2202DP
CASE 1351

PIN NUMBER			
1	Gnd	5	N/C
2	$+V_{out}$	6	N/C
3	V_S	7	N/C
4	$-V_{out}$	8	N/C

NOTE: Pin 1 is noted by the notch in the lead.



MPX2202GVP
CASE 344D

MAXIMUM RATINGS(NOTE)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	800	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

NOTE: Exposure beyond the specified limits may cause permanent damage or degradation to the device.

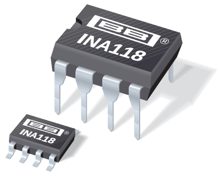
OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristics		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	200	kPa
Supply Voltage		V_S	—	10	16	Vdc
Supply Current		I_o	—	6.0	—	mAdc
Full Scale Span(3)		V_{FSS}	38.5	40	41.5	mV
Offset(4)		V_{off}	–1.0	—	1.0	mV
Sensitivity		ΔV/ΔP	—	0.2	—	mV/kPa
Linearity(5)	MPX2202D Series MPX2202A Series	—	–0.6 –1.0	— —	0.4 1.0	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 200 kPa)		—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)		—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span(5)		TCV_{FSS}	–2.0	—	2.0	$\%V_{FSS}$
Temperature Effect on Offset(5)		TCV_{off}	–1.0	—	1.0	mV
Input Impedance		Z_{in}	1000	—	2500	Ω
Output Impedance		Z_{out}	1400	—	3000	Ω
Response Time(6) (10% to 90%)		t_R	—	1.0	—	ms
Warm–Up		—	—	20	—	ms
Offset Stability(7)		—	—	±0.5	—	$\%V_{FSS}$

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self–heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

BURR - BROWN®



INA118

Precision, Low Power INSTRUMENTATION AMPLIFIER

FEATURES

- LOW OFFSET VOLTAGE: 50µV max
- LOW DRIFT: 0.5µV/°C max
- LOW INPUT BIAS CURRENT: 5nA max
- HIGH CMR: 110dB min
- INPUTS PROTECTED TO ±40V
- WIDE SUPPLY RANGE: ±1.35 to ±18V
- LOW QUIESCENT CURRENT: 350µA
- 8-PIN PLASTIC DIP, SO-8

APPLICATIONS

- BRIDGE AMPLIFIER
- THERMOCOUPLE AMPLIFIER
- RTD SENSOR AMPLIFIER
- MEDICAL INSTRUMENTATION
- DATA ACQUISITION

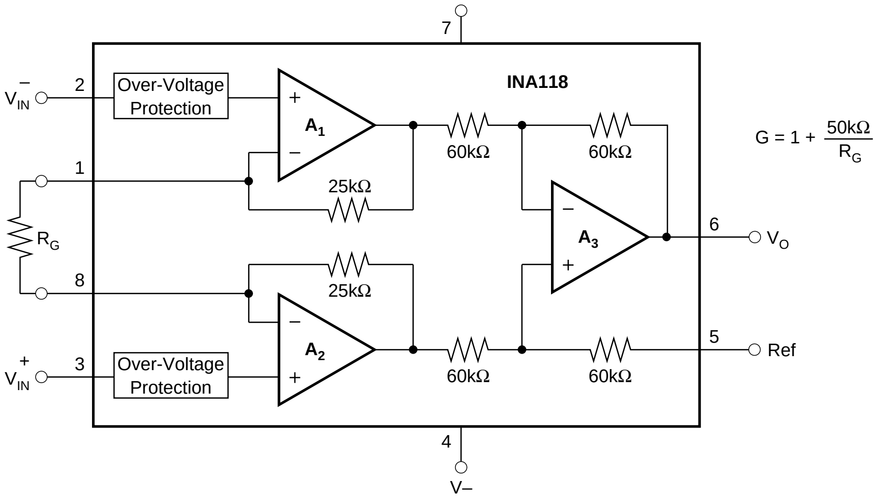
DESCRIPTION

The INA118 is a low power, general purpose instrumentation amplifier offering excellent accuracy. Its versatile 3-op amp design and small size make it ideal for a wide range of applications. Current-feedback input circuitry provides wide bandwidth even at high gain (70kHz at G = 100).

A single external resistor sets any gain from 1 to 10,000. Internal input protection can withstand up to ±40V without damage.

The INA118 is laser trimmed for very low offset voltage (50µV), drift (0.5µV/°C) and high common-mode rejection (110dB at G = 1000). It operates with power supplies as low as ±1.35V, and quiescent current is only 350µA—ideal for battery operated systems.

The INA118 is available in 8-pin plastic DIP, and SO-8 surface-mount packages, specified for the –40°C to +85°C temperature range.



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Internet: http://www.burr-brown.com/ • FAXLine: (800) 548-6133 (US/Canada Only) • Cable: BBRCORP • Telex: 066-6491 • FAX: (520) 889-1510 • Immediate Product Info: (800) 548-6132

PDS-1199D

Printed in U.S.A. April, 1998

SPECIFICATIONS

ELECTRICAL

At T_A = +25°C, V_S = ±15V, R_L = 10kΩ unless otherwise noted.

PARAMETER	CONDITIONS	INA118PB, UB MIN	INA118PB, UB TYP	INA118PB, UB MAX	INA118P, U MIN	INA118P, U TYP	INA118P, U MAX	UNITS
INPUT								
Offset Voltage, RTI								
Initial	T_A = +25°C		±10 ± 50/G	±50 ± 500/G		±25 ±100/G	±125±1000/G	µV
vs Temperature	T_A = T_{MIN} to T_{MAX}		±0.2 ± 2/G	±0.5 ± 20/G		±0.2 ± 5/G	±1 ± 20/G	µV/°C
vs Power Supply	V_S = ±1.35V to ±18V		±1 ±10/G	±5 ± 100/G		*	±10 ±100/G	µV/V
Long-Term Stability			±0.4 ±5/G			*		µV/mo
Impedance, Differential			10^{10} || 1			*		Ω || pF
Common-Mode			10^{10} || 4			*		Ω || pF
Linear Input Voltage Range		(V+) – 1	(V+) – 0.65		*	*		V
		(V–) + 1.1	(V–) + 0.95		*	*		V
Safe Input Voltage				±40			*	V
Common-Mode Rejection	V_{CM} = ±10V, ΔR_S = 1kΩ							
	G = 1	80	90		73	*		dB
	G = 10	97	110		89	*		dB
	G = 100	107	120		98	*		dB
	G = 1000	110	125		100	*		dB
BIAS CURRENT			±1	±5		*	±10	nA
vs Temperature			±40			*		pA/°C
OFFSET CURRENT			±1	±5		*	±10	nA
vs Temperature			±40			*		pA/°C
NOISE VOLTAGE, RTI	G = 1000, R_S = 0Ω							
f = 10Hz			11			*		nV/√Hz
f = 100Hz			10			*		nV/√Hz
f = 1kHz			10			*		nV/√Hz
f_B = 0.1Hz to 10Hz			0.28			*		µVp-p
Noise Current								
f=10Hz			2.0			*		pA/√Hz
f=1kHz			0.3			*		pA/√Hz
f_B = 0.1Hz to 10Hz			80			*		pAp-p
GAIN								
Gain Equation			1 + (50kΩ/R_G)			*		V/V
Range of Gain		1		10000	*		*	V/V
Gain Error	G = 1		±0.01	±0.024		*	±0.1	%
	G = 10		±0.02	±0.4		*	±0.5	%
	G = 100		±0.05	±0.5		*	±0.7	%
	G = 1000		±0.5	±1		*	±2	%
Gain vs Temperature	G = 1		±1	±10		*	±10	ppm/°C
50kΩ Resistance(1)			±25	±100		*	*	ppm/°C
Nonlinearity	G = 1		±0.0003	±0.001		*	±0.002	% of FSR
	G = 10		±0.0005	±0.002		*	±0.004	% of FSR
	G = 100		±0.0005	±0.002		*	±0.004	% of FSR
	G = 1000		±0.002	±0.01		*	±0.02	% of FSR
OUTPUT								
Voltage: Positive	R_L = 10kΩ	(V+) – 1	(V+) – 0.8		*	*		V
Negative	R_L = 10kΩ	(V–) + 0.35	(V–) + 0.2		*	*		V
Single Supply High	V_S = +2.7V/0V(2), R_L = 10kΩ	1.8	2.0		*	*		V
Single Supply Low	V_S = +2.7V/0V(2), R_L = 10kΩ	60	35		*	*		mV
Load Capacitance Stability			1000			*		pF
Short Circuit Current			+5/–12			*		mA
FREQUENCY RESPONSE								
Bandwidth, –3dB	G = 1		800			*		kHz
	G = 10		500			*		kHz
	G = 100		70			*		kHz
	G = 1000		7			*		kHz
Slew Rate	V_O = ±10V, G = 10		0.9			*		V/µs
Settling Time, 0.01%	G = 1		15			*		µs
	G = 10		15			*		µs
	G = 100		21			*		µs
	G = 1000		210			*		µs
Overload Recovery	50% Overdrive		20			*		µs
POWER SUPPLY								
Voltage Range		±1.35	±15	±18	*	*	*	V
Current	V_{IN} = 0V		±350	±385		*	*	µA
TEMPERATURE RANGE								
Specification		–40		85	*		*	°C
Operating		–40		125	*		*	°C
θ_{JA}			80			*		°C/W

* Specification same as INA118PB, UB.

NOTE: (1) Temperature coefficient of the "50kΩ" term in the gain equation. (2) Common-mode input voltage range is limited. See text for discussion of low power supply and single power supply operation.

Instrumentación Electrónica de Comunicaciones   Enero, 2008
Ingeniería de Telecomunicaciones

Solución de examen

Ecuación directas
De las características del transductor resulta:

$$\frac{\Delta v_s}{\Delta P} = 0.2\frac{mV}{KPa} \quad \Rightarrow \quad v_o = 0.2\frac{mV}{KPa} \times A_d \times P(KPa) = 0.0200\frac{V}{KPa}P(KPa)$$

$$P(KPa) = 50.0\frac{KPa}{V}v_o(V)$$

Presión (KPa)	v_s (mv)	v_o(V)
0	0.0	0.0
50	10.0	1.0
100	20.0	2.0

1º) Resolución debida al error de cuantización del convertidor A/D.
Cambio en v_o sin que cambie el código de salida de A/D

$$\Delta v_o = 5.0 \times 2^{-N} = 5.0 \times 2^{-12} = 0.00122\,V$$

$$\Delta P = 50.0\frac{Kpa}{V}\Delta v_o = 50.0 \times 0.00122 = 0.061\,(KPa)$$

2º) Incertidumbre (95% de nivel de confianza) de la presión medida debida al ruido.

- En las hojas características no existe ningún dato relativo al ruido que se genera en el transductor, por ello no se considera.
- En el amplificador de instrumentación de las hojas características el ruido está caracterizado por:

	10Hz	100Hz	1KHz	Tipo		
e_n (nV/√Hz)	11.0	10.0	10.0	Blanco	e_n=10((nV/√Hz)	
i_n (pA/√Hz)	2.0	-	0.3	Integrado	$i_n(f)=i_{nw}\sqrt{(f_{ic}/f+1)}$	i_{nw}=0.3 pA/√Hz f_{ic}=443Hz

La anchura de banda para G=100 es BW=70KHz y NEF=1.57*BW=110KHz, R_s es la impedancia de salida del transductor R_s=3000 Ω
El ruido que se genera en la salida es

$$v_{onrms} = G\sqrt{e_{nw}^2\,NEF + i_{nw}^2 R_s^2\left(f_{ci}Ln\frac{BW}{f_L} + NEF\right)}$$

$$v_{onrms} = 100\sqrt{\left(10.0\,10^{-9}\right)^2 \times 110.000 + \left(0.3\,10^{-12}\right)^2 3000^2\left(443\,Ln\frac{110000}{10} + 110000\right)} = 0.33mV$$

Esto corresponde en unidades de presión a
U_P=50.0 x U_{vo}= 50.0x0.33 10^{-3}= 0.0165 KPa

La incertidumbre para un nivel de confianza del 95% es I_P=2*U_P=0.033 Kpa

3º) Errores tras eliminar los efectos del offset por calibración,

Al calibrar con dos puntos, se pueden eliminar los errores de offset y ganancia y los errores que resultan son los errores de nolinealidad:

a) Error de linealidad del transductor MPX2202: $\%e_t$ =0.6 %FSSS

$$\Delta v_s = \%e_t \times FS = 0.006 \times 40\ mV = 0.24\ mV \quad => \quad \Delta P = 0.006 \times 800 = 4.8 Kpa$$

b) Error de linealidad del amplificador INA118 para G=100: $\%e_a$ =0.0005% FSR

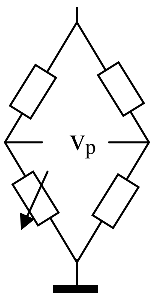
$$\Delta v_o = e_a \times FSR = 0.0005 \times 10 = 0.005 V \quad => \quad \Delta P = \frac{\partial P}{\partial v_o}\Delta v_o = 50\frac{Kpa}{V}0.005V = 0.25Kpa$$

El error total de linealidad:

$$\Delta P_{total} = \left|\Delta P_{transductor}\right| + \left|\Delta P_{amplificador}\right| = 4.8 + 0.25 = 5.3\ Kpa$$

4) Error que se comete si en la fuente hay un rizado de 1Vpp y 50Hz.

No hay información de rechazo al rizado de la fuente de alimentación. El enunciado propone que se considere un modelo de puente resistivo.



Si el transductor fuese de tipo puente, la salida es proporcional a la señal de alimentación.

$$v_p = \alpha(P)\, V_s \quad \Rightarrow \Delta v_p = \alpha(P)\, \Delta V_s \quad \Rightarrow \Delta v_p = v_p \frac{\Delta V_s}{V_s} \quad \Rightarrow \Delta P = P\frac{\Delta V_s}{V_s}$$

$$Para\ P = 50\ Kpa \quad \Rightarrow \quad \Delta P = 50 Kpa \frac{1V}{10V} = 5\ Kpa$$

Es poco probable que el modelo de puente resistivo sea aplicable, ya que en las hojas características no se da información de la dependencia de la sensibilidad de la tensión de alimentación.

5º) La precisión hace referencia a las diferencias entre diferentes medidas realizada por el propio equipo. Le afectan los errores aleatorios: Cuantización del convertidor, ruido de los componentes y ruido de rizado

$$\Delta P_{aleatorio} = \left|\Delta P_{Cuantización}\right| + \left|\Delta P_{Ruido}\right| + \left|\Delta P_{Rizado}\right| = 61 + 13 + 5000\ Pa$$

Soluciones:

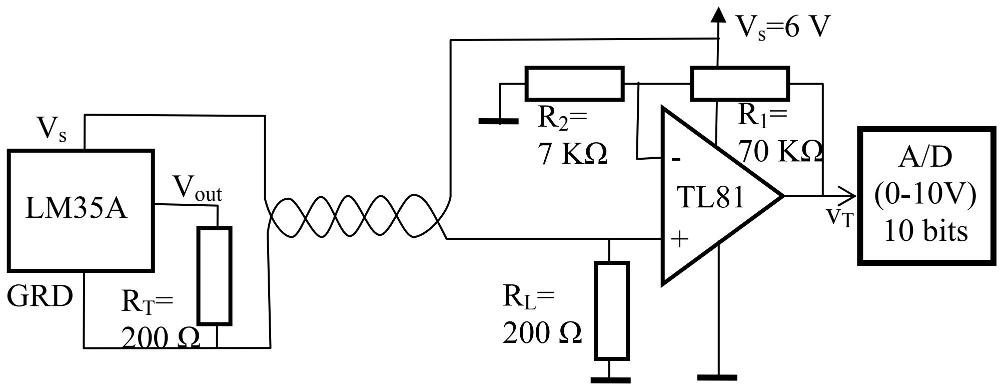
- Para reducir el error de cuantización se puede incrementar la ganancia a 250 que lo admite el rango dinámico del convertidor A/D, y se reduciría el error en el mismo factor. También se puede incrementar la resolución del convertidor.
- Para reducir el ruido, se puede reducir la anchura de banda del amplificador en un factor α compatible con el rango frecuencia de la señal de presión que se mide. El error se reduce en un factor $\sqrt{\alpha}$. También se pueden hacer N medidas y dar como resultado la media y el error se reduce en $\sqrt{N}$

- Para reducir el error debido al rizado. Se puede reducir el rizado introduciendo un circuito de estabilización de la tensión de alimentación. También se puede realizar N medidas distribuidas uniformemente en una ventana de 20 ms (periodo de la red), y dar como resultado su promedio que será independiente del rizado.

La exactitud hace referencia a los errores de la medida respecto de una medida exacta. Podría considerarse como tal los errores debidos al offset o las ganancias. Como han sido compensadas mediante calibración. Sólo podría mejorarse utilizando elementos con menor error de linealidad.

Instrumentación electrónica de comunicaciones **Mayo, 2008**
5º curso Ingeniería de Telecomunicaciones

Se utiliza el circuito de la figura para medir la temperatura de un cuerpo desde un computador. Se utiliza el sensor de temperatura LM35, cuyas hojas características se adjuntan.



Para este sistema:
1º) Proponer el código de la función que retorna la temperatura del cuerpo en ºC. Y determinar los rangos de temperatura que se puede medir con esta función.
2º) Cual es el error máximo que se comete en una medida de la temperatura como consecuencia del error de cuantización del convertidor D/A y del offset que introduce el amplificador operacional.
3º) Cual es la incertidumbre en la medida de la temperatura como consecuencia del ruido térmico que se genera en las resistencias y en el amplificador operacional.
4º) Cual es la incertidumbre en la medida de la temperatura que se produce si en la fuente de alimentación existe un ruido de 0.5V rms de 50Hz.
5º) Cual es el error que induce en la medida de la temperatura el autocalentamiento del sensor, si la resistencia térmica Θ_{JA} del sensor de temperatura es de 400 ºC/W.
(Cada cuestión tienen un valor de 2 puntos)

National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

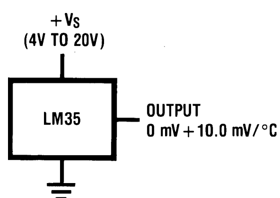
General Description

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ˚ Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼˚C at room temperature and ±¾˚C over a full −55 to +150˚C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1˚C in still air. The LM35 is rated to operate over a −55˚ to +150˚C temperature range, while the LM35C is rated for a −40˚ to +110˚C range (−10˚ with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package.

Features

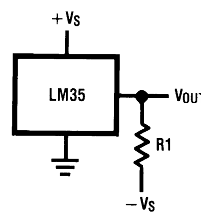
- Calibrated directly in ˚ Celsius (Centigrade)
- Linear + 10.0 mV/˚C scale factor
- 0.5˚C accuracy guaranteeable (at +25˚C)
- Rated for full −55˚ to +150˚C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08˚C in still air
- Nonlinearity only ±¼˚C typical
- Low impedance output, 0.1 Ω for 1 mA load

Typical Applications



DS005516-3

FIGURE 1. Basic Centigrade Temperature Sensor (+2˚C to +150˚C)



DS005516-4

Choose $R_1 = -V_S/50\ \mu A$
V_{OUT}=+1,500 mV at +150˚C
= +250 mV at +25˚C
= −550 mV at −55˚C

FIGURE 2. Full-Range Centigrade Temperature Sensor

Absolute Maximum Ratings (Note 10)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage	+35V to −0.2V
Output Voltage	+6V to −1.0V
Output Current	10 mA
Storage Temp.;	
TO-46 Package,	−60°C to +180°C
TO-92 Package,	−60°C to +150°C
SO-8 Package,	−65°C to +150°C
TO-220 Package,	−65°C to +150°C
Lead Temp.:	
TO-46 Package, (Soldering, 10 seconds)	300°C
TO-92 and TO-220 Package, (Soldering, 10 seconds)	260°C
SO Package (Note 12)	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C
ESD Susceptibility (Note 11)	2500V

Specified Operating Temperature Range: T_{MIN} to T_{MAX} (Note 2)

LM35, LM35A	−55°C to +150°C
LM35C, LM35CA	−40°C to +110°C
LM35D	0°C to +100°C

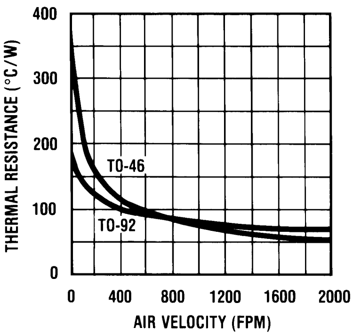
Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35A			LM35CA			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy (Note 7)	T_A=+25°C	±0.2	±0.5		±0.2	±0.5		°C
	T_A=−10°C	±0.3			±0.3		±1.0	°C
	$T_A=T_{MAX}$	±0.4	±1.0		±0.4	±1.0		°C
	$T_A=T_{MIN}$	±0.4	±1.0		±0.4		±1.5	°C
Nonlinearity (Note 8)	$T_{MIN}\leq T_A\leq T_{MAX}$	**±0.18**		**±0.35**	**±0.15**		**±0.3**	°C
Sensor Gain (Average Slope)	$T_{MIN}\leq T_A\leq T_{MAX}$	**+10.0**	**+9.9, +10.1**		**+10.0**		**+9.9, +10.1**	mV/°C
Load Regulation (Note 3) $0\leq I_L\leq1$ mA	T_A=+25°C	±0.4	±1.0		±0.4	±1.0		mV/mA
	$T_{MIN}\leq T_A\leq T_{MAX}$	**±0.5**		**±3.0**	**±0.5**		**±3.0**	mV/mA
Line Regulation (Note 3)	T_A=+25°C	±0.01	±0.05		±0.01	±0.05		mV/V
	$4V\leq V_S\leq30V$	**±0.02**		**±0.1**	**±0.02**		**±0.1**	mV/V
Quiescent Current (Note 9)	V_S=+5V, +25°C	56	67		56	67		µA
	V_S=+5V	**105**		**131**	**91**		**114**	µA
	V_S=+30V, +25°C	56.2	68		56.2	68		µA
	V_S=+30V	**105.5**		**133**	**91.5**		**116**	µA
Change of Quiescent Current (Note 3)	$4V\leq V_S\leq30V$, +25°C	0.2	1.0		0.2	1.0		µA
	$4V\leq V_S\leq30V$	**0.5**		**2.0**	**0.5**		**2.0**	µA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.5**	**+0.39**		**+0.5**	µA/°C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, I_L=0	+1.5		+2.0	+1.5		+2.0	°C
Long Term Stability	$T_J=T_{MAX}$, for 1000 hours	±0.08			±0.08			°C

Typical Performance Characteristics

Thermal Resistance Junction to Air



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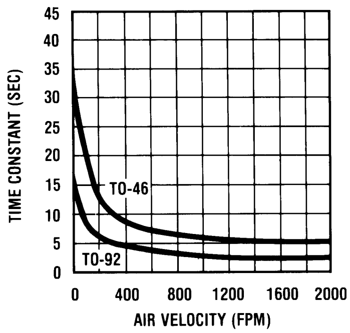
Thermal Time Constant



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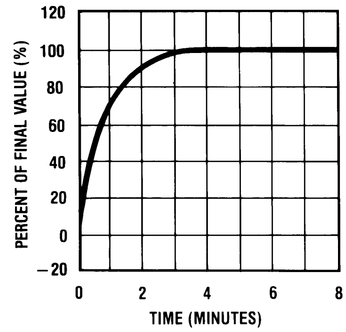
Thermal Response in Still Air



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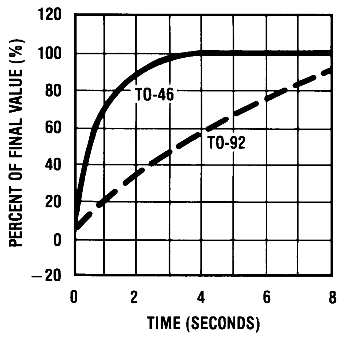
Thermal Response in Stirred Oil Bath



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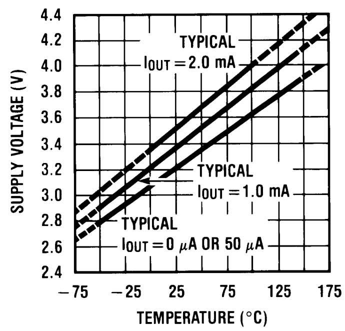
Minimum Supply Voltage vs. Temperature



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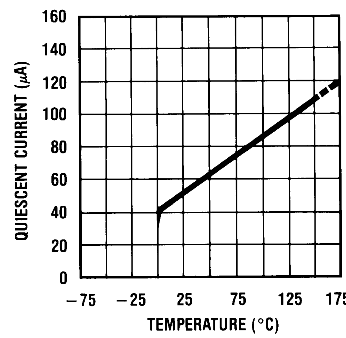
Quiescent Current vs. Temperature (In Circuit of *Figure 1*.)



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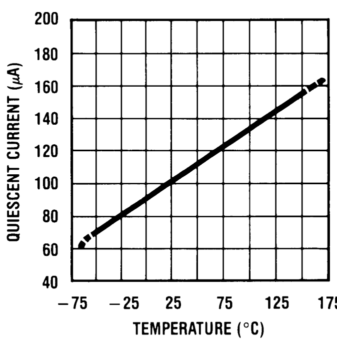
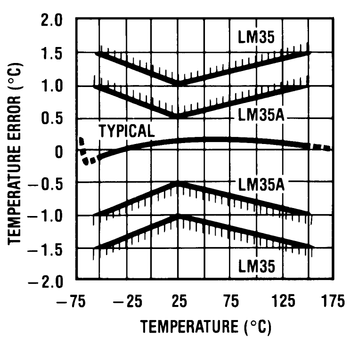
Quiescent Current vs. Temperature (In Circuit of *Figure 2*.)



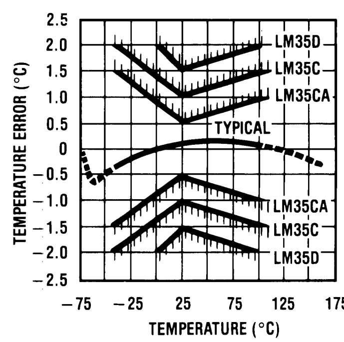
DS005516-31

Accuracy vs. Temperature (Guaranteed)



DS005516-32

Accuracy vs. Temperature (Guaranteed)

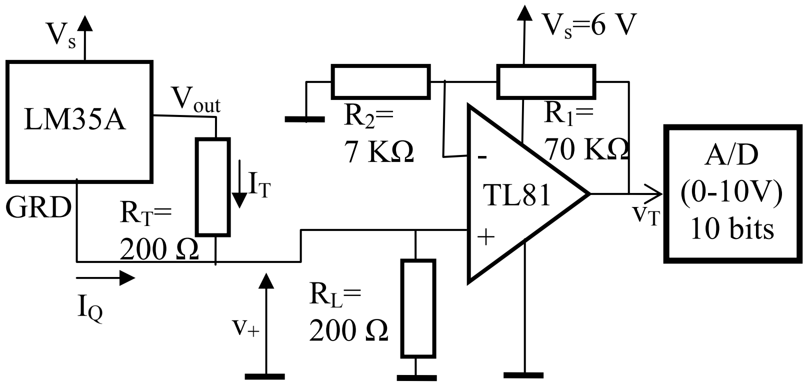


DS005516-33

Instrumentación electrónica de comunicación **Mayo, 2008**

Solución del examen.

1º Código de la función que retorna la temperatura del cuerpo en ºC y rangos de medida.



De acuerdo con las hojas características del transductor LM35A:

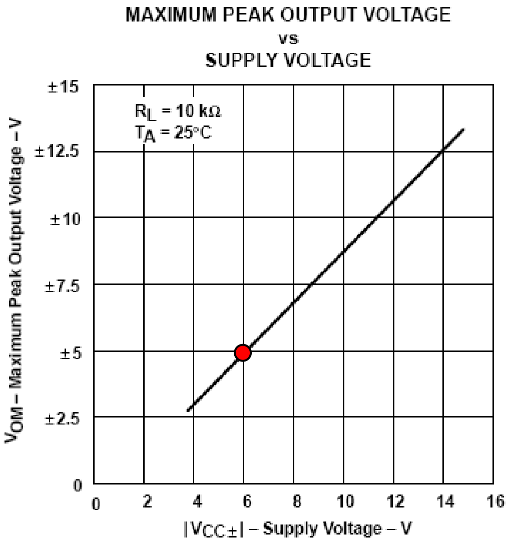
I_Q= 56 µA
V_{out}= 10 mV/ºC x T ºC => I_T=V_{out}/R_T =10 /200 x T = 50 (µA/ºC) x T(ºC)

v_+= (I_Q+I_T) x R_L = (56 + 50 x T) x R_L = 0.112+ 10.0 xT (ºC) (mV)

v_T=A_v x v_+ = (1+ R_1/R_2) x v_+ = (1+10) x (0.012 + 10 x T (ºC)) (mV) (Ec. Directa)

Ec. Inversa : T = [(v_T (V) x 1000/11.0)-0.012] /10.0 (ºC)

De las hojas características del amplificador operacional TL081, el rango de salida del amplificador operacional con alimentación V_s= 6 V es



0V+1.0V< v_T< 6V-1.0V => 1 V < v_T < 5V
Utilizando la ecuación inversa, el rango de temperatura es : 7.97 ºC < T < 44.3 ºC

El programa que puede utilizarse para medir la temperatura en ºC es

```
function Temperatura  return float is
        const float IQ= 56.0E-6; --Corriente de reposo del sensor
        const float m=10.0E-3;   -- Sensibilidad del sensor V/ºC
        const RT= 200.0;         -- RT en ohmios
        const RL=200.0;          -- RL en ohmios
        const Av=11.0            -- Ganancia de amplificador
        function readAD return flota is .. -- Retorna la entrada del AD en voltios
begin
        return  ((readAD / Av/RL)- IQ) * RT/m
end;
```

2º) Error debido a la cuantización del AD y al offset del AO.

Error debido a la cuantización del AD

$\mathbf{\Delta V_T = V_{FE}\ \ 2^{(N+1)} = 10 * 2^{11} = 0.0049\ V}$

$$\Delta T = \frac{\partial T}{\partial v_T}\Delta v_T = \frac{R_T}{R_L\ A_v\ m}\Delta v_T = 0.044^{o}C$$

Error debido al offset del AO

El offset del AO es sólo debido al offset de tensión V_{offset}= 3 mV

El error en v_T a la entrada del A/D es

$$\Delta v_T = A_v V_{offset} = 11 \times 0.003 = 0.033\, V$$

$$\Delta T = \frac{\partial T}{\partial v_T}\Delta v_T = \frac{R_T}{R_L\ A_v\ m}\Delta v_T = 0.3^{o}C$$

3º) Incertidumbre en la medida debida al ruido térmico

La tensión v_T se lee en un único punto, esto es con una ventana muy estrecha, luego sólo considero el ruido blanco.

e_{nv}= 18 nV/√Hz

R_p= 200
R_n=7KΩ//70KΩ=6.35 KΩ

f_T=3 MHz => $f_A=f_T/A_v$= 3 MHz/11=272.7 KHz

$$v_{Trms} = A_v\sqrt{\left(e_{nv}^{\ 2} + 4kT\left(R_p + R_n\right)\right)1.57\ f_A} = 0.75\, mV$$

I_{vT} (95%)= 2 x v_{Trms}= 2 x 0.75=1.5 mV

$$I_T(95\%) = \frac{\partial T}{\partial v_T} I_{v_T}(95\%) = \frac{R_T}{R_L\ A_v\ m} I_{v_T}(95\%) = 9.09\ 0.0015 = 0.014\ ^{o}C$$

4º) Incertidumbre en la medida debido a 0.5 Vrms de 50Hz en la fuente alimentación.

El rizado en la fuente tiene un doble efecto en la salida v_T:

a) Efecto debido a la regulación de línea en el sensor:
Regulación de carga= RL= 0.01 mv/V:

$$v_{Trms} = \frac{RL}{R_T} R_L\ A_v\ \Delta V_{srms} = \frac{0.01\,(mV/V)}{200\Omega} \times 200\Omega \times 11 \times 0.5(V_{rms}) = 0.05\ (mV_{rms})$$

b) Efecto debido a la regulación de carga del AO:
Supply Voltage Rejection Ratio=K_{SVR} = $\Delta V_{IO}/\Delta V_S$=-86 dB= 5.01 10^{-5}

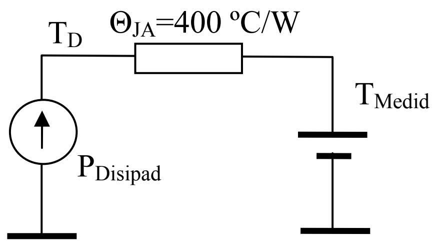
$$v_{Trms} = K_{SVR} \times A_v \times \Delta V_{Srms} = 5.01\ 10^{-5} \times 11 \times 0.5(V_{rms}) = 0.27\ (mV_{rms})$$

Ambas componentes tienen el mismo origen, y por tanto son síncronos. En el peor caso el efecto compuesto es la suma.

I_{vT} (95%)= 2 x v_{Trms}= 2 x (0.05+0.27)= 0.64 mV

$$I_T(95\%) = \frac{\partial T}{\partial v_T} I_{v_T}(95\%) = \frac{R_T}{R_L\ A_v\ m} I_{v_T}(95\%) = 9.09 \times 0.00064 = 0.0058\ ^{o}C$$

5º) Error en la medida debida al autocalentamiento térmico



La máxima potencia se disipan para la máxima temperatura que se mide (T=45ºC).

Vout(45ºC)= 0.01 (V/ºC) 45ºC= 0.45 V
$P_{Disipada}$= V_s * I_Q+ (V_s-V_{out}) V_{out}/200 = 6*59 10^{-6}+ (6-0.45) 0.45/200= 0,013 W

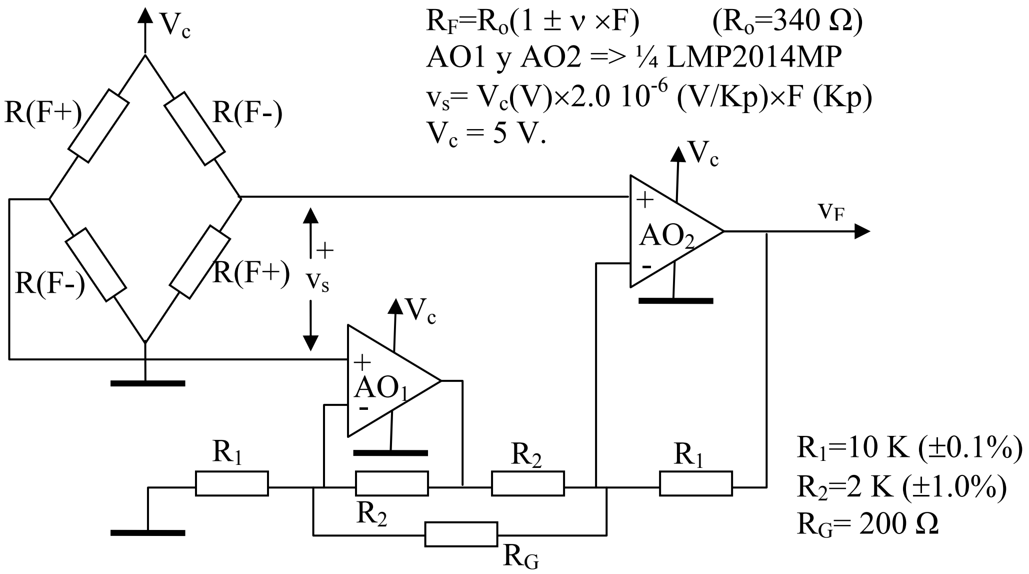
ΔT= T_D-T_{Medida}= $P_{Disipada}$ Θ_{JA}= 0.013(W) *400 (ºC/W)= **5,2 ºC**

INSTRUMENTACIÓN ELECTRÓNICA DE COMUNICACIONES Sept, 2008
5º Curso de ingeniería de Telecomunicación.

Se quiere medir con gran precisión la tensión de un cable de una estructura bajo condiciones cambiantes de carga. La tensión máxima que se desea medir es de 5000 Kp, y las frecuencias significativas de variación de la tensión son inferiores a 20 Hz.

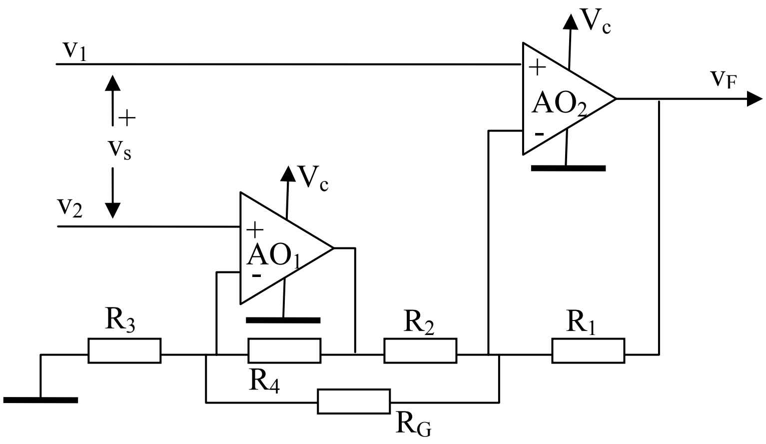
Para ello se utiliza un sensor de fuerza basado en una galga extensiométrica de puente completo. La impedancia de entrada y de salida de la galga es de 340 Ω y la sensibilidad del sensor de fuerza es de $2.0\ 10^{-6} \times V_c$ (V/Kp), siendo V_c la tensión de alimentación de la galga (5 V en la figura).

La tensión diferencial de salida de la galga v_s se amplifica con el amplificador diferencial que se muestra en la figura, y que se ha construido utilizando dos amplificadores Rail to Rail LMP2014MP, cuyas hojas características se adjuntan.



Para este sistema:
1º) Determinar el rango tensiones (fuerzas) que es capaz de medir este sistema.
2º) Determinar el error en la medida de la fuerza que se comete como consecuencia de que la razón de rechazo en modo común que tienen los amplificadores operacionales no es infinita.
3º) Determinar el valor v_{rms} de ruido en la salida del circuito v_F como consecuencia del ruido que introducen los amplificadores operacionales.
4º) Determinar error de no linealidad que introduce el puente de las galgas cuando la entrada es una fuerza de 1000 Kp.
(Cada cuestión puntúa 2.5 puntos)

Análisis del amplificador diferencial



$$v_F = v_1\left(1+\frac{R_1}{R_2 // R_G}\right)+v_1\frac{R_4}{R_G}\frac{R_1}{R_2}-v_2\frac{R_1}{R_G}-v_2\left(1+\frac{R_4}{R_3 // R_G}\right)\frac{R_1}{R_2}$$

Si R_3=R_1 y R_4=R_2

$$v_F = v_1\left(1+\frac{R_1}{R_2 // R_G}\right)+v_1\frac{R_2}{R_G}\frac{R_1}{R_2}-v_2\frac{R_1}{R_G}-v2\left(1+\frac{R_2}{R_1 // R_G}\right)\frac{R_1}{R_2}=v_s\left(1+\frac{R_1}{R_2}+\frac{2R_1}{R_G}\right)$$

July 2005

National Semiconductor

LMP2014MT
Quad High Precision, Rail-to-Rail Output Operational Amplifier

General Description

The LMP2014MT is a member of National's new LMP™ precision amplifier family. The LMP2014MT offers unprecedented accuracy and stability while also being offered at an affordable price. This device utilizes patented techniques to measure and continually correct the input offset error voltage. The result is an amplifier which is ultra stable over time and temperature. It has excellent CMRR and PSRR ratings, and does not exhibit the familiar 1/f voltage and current noise increase that plagues traditional amplifiers. The combination of the LMP2014 characteristics makes it a good choice for transducer amplifiers, high gain configurations, ADC buffer amplifiers, DAC I-V conversion, and any other 2.7V-5V application requiring precision and long term stability.

Other useful benefits of the LMP2014 are rail-to-rail output, a low supply current of 3.7 mA, and wide gain-bandwidth product of 3 MHz. These extremely versatile features found in the LMP2014 provide high performance and ease of use.

Features

(For V_S = 5V, Typical unless otherwise noted)

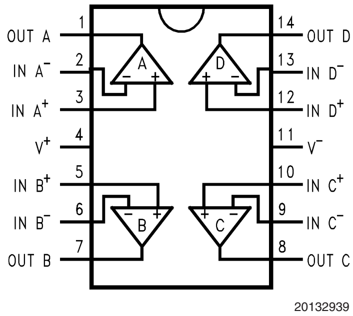
- Low guaranteed V_{OS} over temperature 60 µV
- Low noise with no 1/f 35nV/ $\sqrt{Hz}$
- High CMRR 130 dB
- High PSRR 120 dB
- High A_{VOL} 130 dB
- Wide gain-bandwidth product 3 MHz
- High slew rate 4 V/µs
- Low supply current 3.7 mA
- Rail-to-rail output 30 mV
- No external capacitors required

Applications

- Precision instrumentation amplifiers
- Thermocouple amplifiers
- Strain gauge bridge amplifier

Connection Diagram

14-Pin TSSOP



Top View

Ordering Information

Package	Part Number	Temperature Range	Package Marking	Transport Media	NSC Drawing
14-Pin TSSOP	LMP2014MT	0˚C to 70˚C	LMP2014MT	94 Units/Rail	MTC14
	LMP2014MTX			2.5k Units Tape and Reel	

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

ESD Tolerance	
Human Body Model	2000V
Machine Model	200V
Supply Voltage	5.8V
Common-Mode Input Voltage	$-0.3 \leq V_{CM} \leq V_{CC}$ +0.3V
Lead Temperature (soldering 10 sec.)	+300˚C
Differential Input Voltage	±Supply Voltage
Current at Input Pin	30 mA
Current at Output Pin	30 mA
Current at Power Supply Pin	50 mA

Operating Ratings (Note 1)

Supply Voltage	2.7V to 5.25V
Storage Temperature Range	−65˚C to 150˚C
Operating Temperature Range	
LMP2014MT, LMP2014MTX	0˚C to 70˚C

2.7V DC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for $T_J = 25$˚C, $V^+ = 2.7V$, $V^- = 0V$, $V_{CM} = 1.35V$, $V_O = 1.35V$ and $R_L > 1$ MΩ. **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Min (Note 3)	Typ (Note 2)	Max (Note 3)	Units
V_{OS}	Input Offset Voltage			0.8	30 **60**	μV
	Offset Calibration Time			0.5	10 **12**	ms
TCV_{OS}	Input Offset Voltage			0.015		μV/˚C
	Long-Term Offset Drift			0.006		μV/month
	Lifetime V_{OS} Drift			2.5		μV
I_{IN}	Input Current			-3		pA
I_{OS}	Input Offset Current			6		pA
R_{IND}	Input Differential Resistance			9		MΩ
CMRR	Common Mode Rejection Ratio	$-0.3 \leq V_{CM} \leq 0.9V$ $0 \leq V_{CM} \leq 0.9V$	95 **90**	130		dB
PSRR	Power Supply Rejection Ratio		95 **90**	120		dB
A_{VOL}	Open Loop Voltage Gain	R_L = 10 kΩ	95 **90**	130		dB
		R_L = 2 kΩ	90 **85**	124		dB
V_O	Output Swing	R_L = 10 kΩ to 1.35V V_{IN}(diff) = ±0.5V	2.63 **2.655**	2.68		V
				0.033	0.070 **0.075**	V
		R_L = 2 kΩ to 1.35V V_{IN}(diff) = ±0.5V	2.615 **2.615**	2.65		V
				0.061	0.085 **0.105**	V
I_O	Output Current	Sourcing, V_O = 0V V_{IN}(diff) = ±0.5V	5 **3**	12		mA
		Sinking, V_O = 5V V_{IN}(diff) = ±0.5V	5 **3**	18		mA
I_S	Supply Current per Channel			0.919	1.20 **1.50**	mA

2.7V AC Electrical Characteristics

T_J = 25˚C, V^+ = 2.7V, V^- = 0V, V_{CM} = 1.35V, V_O = 1.35V, and R_L > 1 MΩ. **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Min (Note 3)	Typ (Note 2)	Max (Note 3)	Units
GBW	Gain-Bandwidth Product			3		MHz
SR	Slew Rate			4		V/μs
θ_m	Phase Margin			60		Deg
G_m	Gain Margin			−14		dB
e_n	Input-Referred Voltage Noise			35		$nV/\sqrt{Hz}$
i_n	Input-Referred Current Noise					$pA/\sqrt{Hz}$
e_np-p	Input-Referred Voltage Noise	R_S = 100Ω, DC to 10 Hz		850		nV_{pp}
t_{rec}	Input Overload Recovery Time			50		ms

5V DC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for T_J = 25˚C, V^+ = 5V, V^- = 0V, V_{CM} = 2.5V, V_O = 2.5V and R_L > 1MΩ. **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Min (Note 3)	Typ (Note 2)	Max (Note 3)	Units
V_{OS}	Input Offset Voltage			0.12	30 **60**	μV
	Offset Calibration Time			0.5	10 **12**	ms
TCV_{OS}	Input Offset Voltage			0.015		μV/˚C
	Long-Term Offset Drift			0.006		μV/month
	Lifetime V_{OS} Drift			2.5		μV
I_{IN}	Input Current			-3		pA
I_{OS}	Input Offset Current			6		pA
R_{IND}	Input Differential Resistance			9		MΩ
CMRR	Common Mode Rejection Ratio	$-0.3 \le V_{CM} \le 3.2$ $0 \le V_{CM} \le 3.2$	100 **90**	130		dB
PSRR	Power Supply Rejection Ratio		95 **90**	120		dB
A_{VOL}	Open Loop Voltage Gain	R_L = 10 kΩ	105 **100**	130		dB
		R_L = 2 kΩ	95 **90**	132		dB
V_O	Output Swing	R_L = 10 kΩ to 2.5V V_{IN}(diff) = ±0.5V	4.92 **4.95**	4.978		V
				0.040	0.080 **0.085**	V
		R_L = 2 kΩ to 2.5V V_{IN}(diff) = ±0.5V	4.875 **4.875**	4.919		V
				0.091	0.125 **0.140**	V
I_O	Output Current	Sourcing, V_O = 0V V_{IN}(diff) = ±0.5V	8 **6**	15		mA
		Sinking, V_O = 5V V_{IN}(diff) = ±0.5V	8 **6**	17		mA
I_S	Supply Current per Channel			0.930	1.20 **1.50**	mA

5V AC Electrical Characteristics

T_J = 25˚C, V^+ = 5V, V^- = 0V, V_{CM} = 2.5V, V_O = 2.5V, and R_L > 1MΩ. **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Min (Note 3)	Typ (Note 2)	Max (Note 3)	Units
GBW	Gain-Bandwidth Product			3		MHz
SR	Slew Rate			4		V/μs
θ_m	Phase Margin			60		deg
G_m	Gain Margin			–15		dB
e_n	Input-Referred Voltage Noise			35		$nV/\sqrt{Hz}$
i_n	Input-Referred Current Noise					$pA/\sqrt{Hz}$
e_np-p	Input-Referred Voltage Noise	R_S = 100Ω, DC to 10 Hz		850		nV_{PP}
t_{rec}	Input Overload Recovery Time			50		ms

Note 1: Absolute Maximum Ratings indicate limits beyond which damage may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not guaranteed. For guaranteed specifications and test conditions, see the Electrical Characteristics.

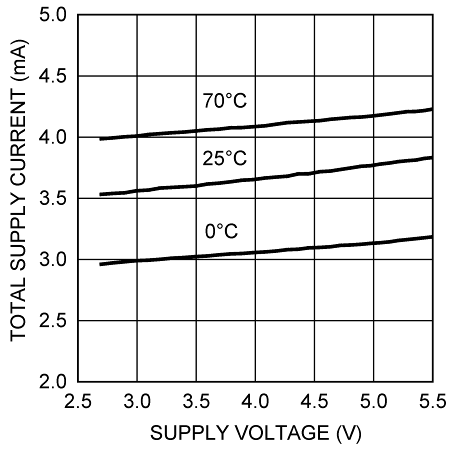
Note 2: Typical values represent the most likely parametric norm.

Note 3: Limits are 100% production tested at 25˚C. Limits over the operating temperature range are guaranteed through correlations using statistical quality control (SQC) method.

Typical Performance Characteristics

T_A=25C, V_S= 5V unless otherwise specified.

Supply Current vs. Supply Voltage



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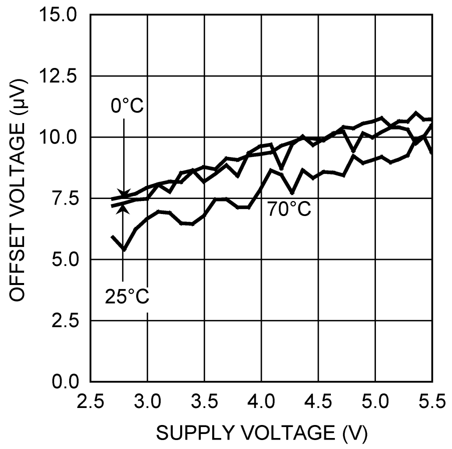
Offset Voltage vs. Supply Voltage



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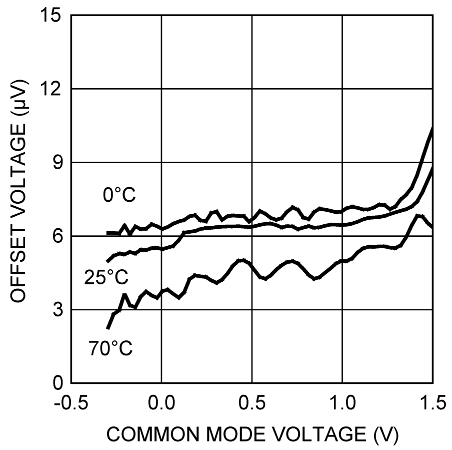
Offset Voltage vs. Common Mode



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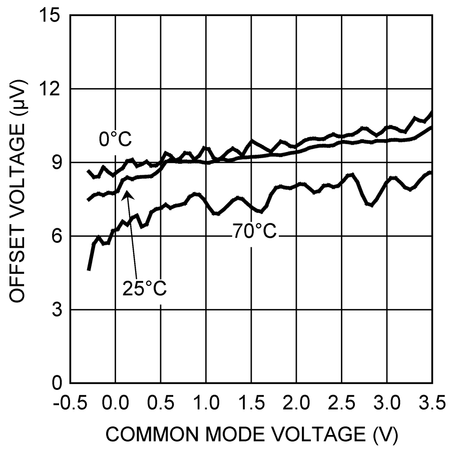
Offset Voltage vs. Common Mode



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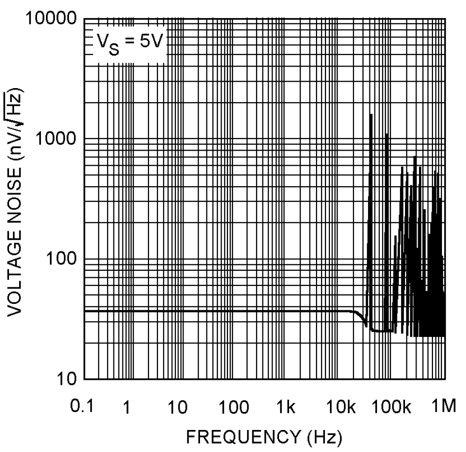
Voltage Noise vs. Frequency



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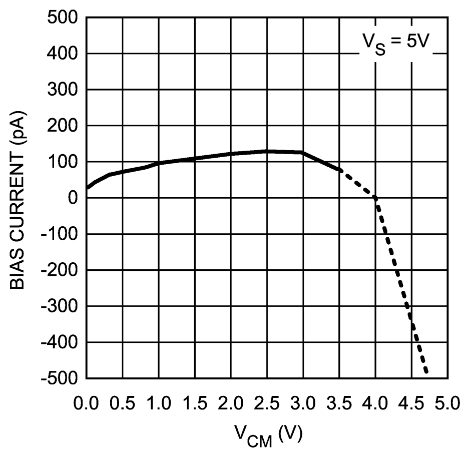
Input Bias Current vs. Common Mode



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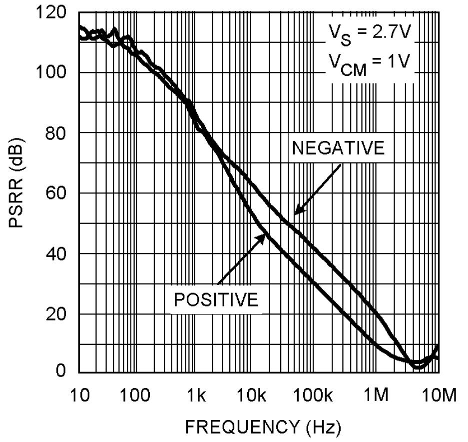
Typical Performance Characteristics (Continued)

PSRR vs. Frequency



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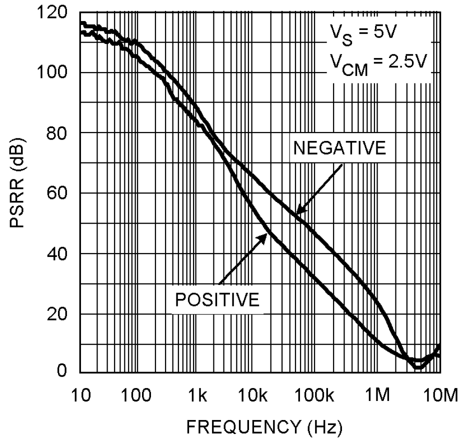
PSRR vs. Frequency



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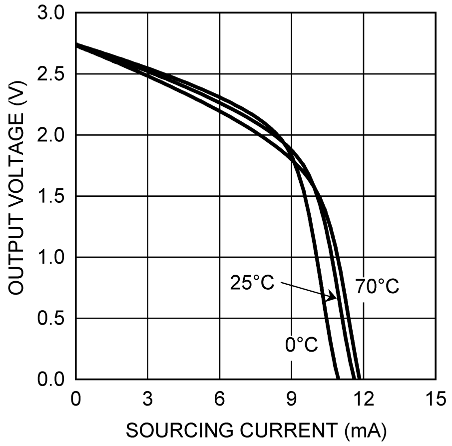
Output Sourcing @ 2.7V



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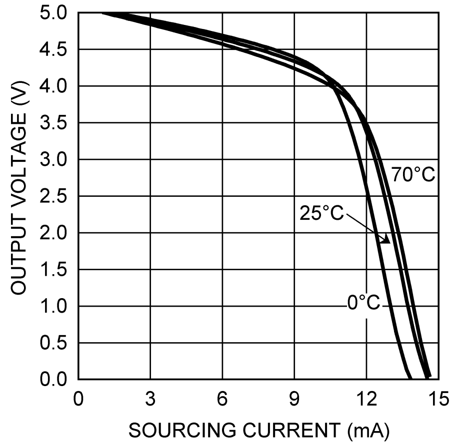
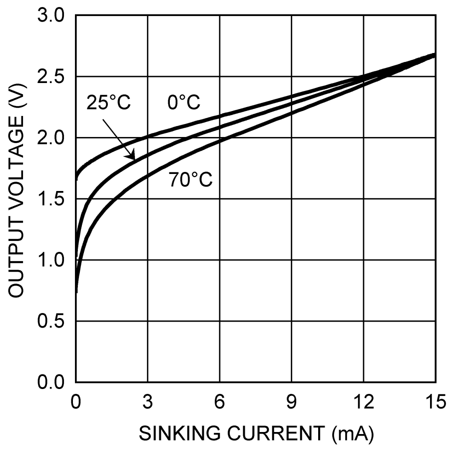
Output Sourcing @ 5V



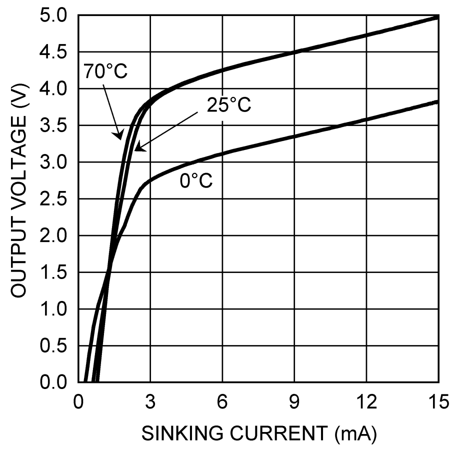
20132948

Output Sinking @ 2.7V



20132949

Output Sinking @ 5V



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INSTRUMENTACIÓN ELECTRÓNICA DE COMUNICACIONES   Sept, 2008
5º Curso de ingeniería de Telecomunicación.

Solución del examen.

1º) Rango de fuerzas que puede medir

Puente de galgas:

$v_s = 2{,}0\,10^{-6} \times 5.0 \times F$

Amplificador diferencial

$v_F = v_s \times A_d = v_s \times \left(1 + \frac{R_1}{R_2} + \frac{2R_1}{R_G}\right) = 106.0\; v_s$

Ec. Directa: $v_F = 106.0 \times 2.0\,10^{-6} \times 5.0 \times F = 0.00106\,10^{-3}\left(\frac{V}{Kp}\right) \times F(Kp)$

Ec. Inversa: $F(Kp) = 943.40\left(\frac{Kp}{V}\right) \times v_F(V)$

La máxima tensión de salida de AO es 4.978 V

$v_F < 4.978 \quad => \quad 2.0\,10^{-6} \times 5.0 \times 106.0 \times F < 4.978 \quad => \quad F < 4696.22\; Kp$

2º)El efectos debido al CRM se puede describir como una seña en la entrada del amplificador de valor v_c/CMRR :

CMRR= 130 dB= $10^{(130/20)}$= 3.16 10^6

$V_c = V_s/2 = 2.5$ V

$$\Delta v_{oCMRR} = |\Delta v_{oCMRR1}| + |\Delta v_{oCMRR2}| = 2 \times \frac{2.5}{3.16\,10^6} \times 106 = 167.7\,\mu V$$

$$\Delta F_{CMRR} = 1.785.71 \times \Delta v_{oCMRR} = 0.158\; Kp$$

3º) El ruido que introducen los amplificadores operacionales es blanco, luego su valor será

$$v_{oNoise} = \sqrt{v_{oNoise\,AO1}{}^2 + v_{oNoise\,AO2}{}^2} = \sqrt{2} \times v_{oNoise\,AO} = \sqrt{2} \times A_d \times e_{nW}\sqrt{1.57 \times BW}$$

$e_{nW} = 35.0\; nV/\sqrt{Hz}$

f_T=3 MHz

$$BW = \alpha\; fT = \left(\frac{R2//(RG/2)}{R2//(RG/2) + R1}\right) = \frac{1}{105} \times 3 = 28{,}57\; KHz$$

v_{oNoise}=0.061 mV_{rms}

4º) En un puente completo, el sistema es lineal, luego el error de linealidad es nulo.

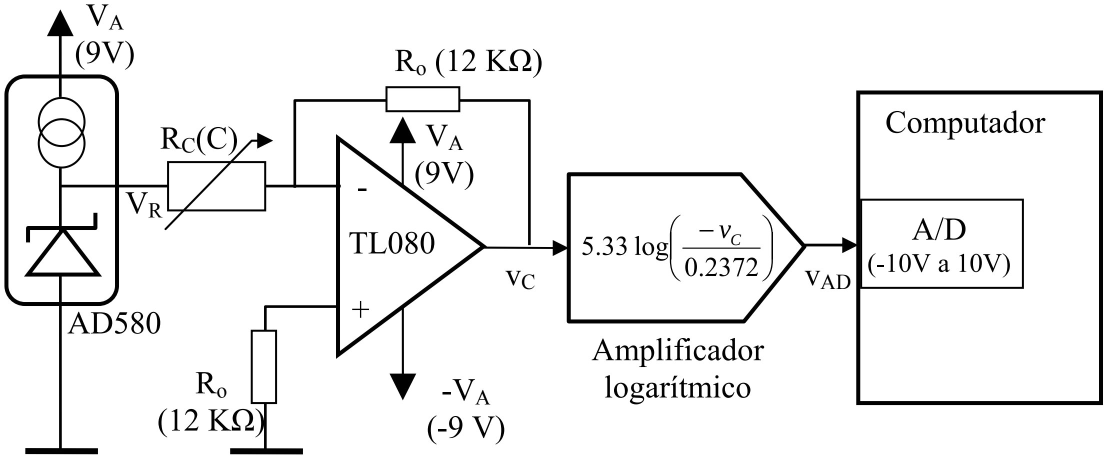
$$v_s = V_c\left(\frac{R(F+)}{R(F+) + R(F-)} - \frac{R(F-)}{R(F+) + R(F-)}\right) = V_c\left(\frac{Ro(1 + \nu\; F)}{2Ro} - \frac{Ro(1 - \nu\; F)}{2Ro}\right) = \frac{V_c}{Ro}F$$

Instrumentación Electrónica de Comunicaciones **Diciembre, 2008**
5º curso de Ingeniería de Telecomunicación

Se desea medir la concentración de un ión químico en un rango que varía entre 10 y 10000 ppm. Para ello se utiliza un sensor que se comporta como una resistencia cuyo valor varía inversamente lineal con la concentración de acuerdo con la ecuación,

$$\frac{1}{R_C(C)} = 2.5\,10^{-8}\left(\frac{\Omega^{-1}}{ppm}\right)\times C(ppm)$$

A tal fin se utiliza el montaje experimental que se muestra en la figura. El circuito de referencia de tensión AD580, el transductor y el amplificador operacional generan una tensión v_C que es proporcional a la concentración del ión que se mide. Un adaptador logarítmico transforma la señal de medida a un rango compatible con el rango -10 a 10 voltios del conversor A/D.



Analizar el método de medida en los siguientes aspectos:

1. Proponer el código de una función

   function LeeConcentraciónEnPPM() return Float

   que mida desde el computador la concentración del ión. Para ello, suponer que se dispone de una función *LeeAD() return Float*, que retorna el valor en voltios que hay en la entrada del conversor A/D.
2. Si se desea medir la concentración con un error relativo inferior al 1%, determinar la resolución que debe tener el conversor A/D.
3. ¿Cual es el umbral de medida de la concentración?, si se considera que la fuente de referencia de tensión AD580 introduce ruido.
4. Si la fuente de alimentación tiene un rizado de 50 Hz y 1 Vpp, ¿cual es la incertidumbre de la medida de la concentración de 1000 ppm?.
5. ¿Cual es el máximo error sistemático que se introduce en la medida de la concentración de 1000 ppm? si se consideran los efectos de los offset en los amplificadores operacionales.

Nota: cada cuestión puntúa sobre 2.

High Precision 2.5 V IC Reference

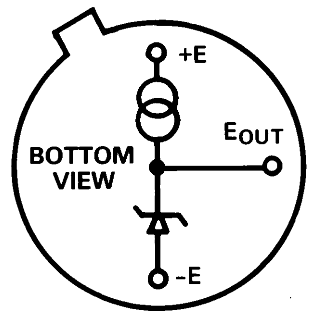
AD580*

FEATURES

Laser Trimmed to High Accuracy: 2.500 V ± 0.4%
3-Terminal Device: Voltage In/Voltage Out
Excellent Temperature Stability: 10 ppm/°C (AD580M, U)
Excellent Long-Term Stability: 250 µV (25 µV/Month)
Low Quiescent Current: 1.5 mA max
Small, Hermetic IC Package: TO-52 Can
MIL-STD-883 Compliant Versions Available

FUNCTIONAL BLOCK DIAGRAM

TO–52



PRODUCT DESCRIPTION

The AD580 is a three-terminal, low cost, temperature compensated, bandgap voltage reference which provides a fixed 2.5 V output for inputs between 4.5 V and 30 V. A unique combination of advanced circuit design and laser-wafer trimmed thin-film resistors provide the AD580 with an initial tolerance of ±0.4%, a temperature stability of better than 10 ppm/°C and long-term stability of better than 250 µV. In addition, the low quiescent current drain of 1.5 mA max offers a clear advantage over classical Zener techniques.

The AD580 is recommended as a stable reference for all 8-, 10- and 12-bit D-to-A converters that require an external reference. In addition, the wide input range of the AD580 allows operation with 5 volt logic supplies making the AD580 ideal for digital panel meter applications or whenever only a single logic power supply is available.

The AD580J, K, L and M are specified for operation over the 0°C to +70°C temperature range; the AD580S, T and U are specified for operation over the extended temperature range of –55°C to +125°C.

PRODUCT HIGHLIGHTS

1. Laser-trimming of the thin-film resistors minimizes the AD580 output error. For example, the AD580L output tolerance is ±10 mV.
2. The three-terminal voltage in/voltage out operation of the AD580 provides regulated output voltage without any external components.
3. The AD580 provides a stable 2.5 V output voltage for input voltages between 4.5 V and 30 V. The capability to provide a stable output voltage using a 5-volt input makes the AD580 an ideal choice for systems that contain a single logic power supply.
4. Thin-film resistor technology and tightly controlled bipolar processing provide the AD580 with temperature stabilities to 10 ppm/°C and long-term stability better than 250 µV.
5. The low quiescent current drain of the AD580 makes it ideal for CMOS and other low power applications.
6. The AD580 is available in versions compliant with MIL-STD-883. Refer to the Analog Devices Military Products Databook or current AD580/883B data sheet for detailed specifications.

***Protected by Patent Nos. 3,887,863; RE30,586.**

REV. A

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 617/329-4700 Fax: 617/326-8703

AD580–SPECIFICATIONS (@ E_{IN} = +15 V and +25°C)

Model	AD580J Min	AD580J Typ	AD580J Max	AD580K Min	AD580K Typ	AD580K Max	AD580L Min	AD580L Typ	AD580L Max	AD580M Min	AD580M Typ	AD580M Max	Units
OUTPUT VOLTAGE TOLERANCE													
(Error from Nominal 2.500 Volt Output)			**±75**			**±25**			**±10**			**±10**	mV
OUTPUT VOLTAGE CHANGE													
T_{MIN} to T_{MAX}			**15**			**7**			**4.3**			**1.75**	mV
			85			40			25			10	ppm/°C
LINE REGULATION													
7 V ≤ V_{IN} ≤ 30 V		1.5	**6**		1.5	**4**			**2**			**2**	mV
4.5 V ≤ V_{IN} ≤ 7 V		0.3	**3**		0.3	**2**			**1**			**1**	mV
LOAD REGULATION													
ΔI = 10 mA			**10**			**10**			**10**			**10**	mV
QUIESCENT CURRENT		1.0	**1.5**		1.0	**1.5**		1.0	**1.5**		1.0	**1.5**	mA
NOISE (0.1 Hz to 10 Hz)		8			8			8			8		µV (p-p)
STABILITY													
Long Term		250			250			250			250		µV
Per Month		25			25			25			25		µV
TEMPERATURE PERFORMANCE													
Specified	0		+70	0		+70	0		+70	0		+70	°C
Operating	–55		+125	–55		+125	–55		+125	–55		+125	°C
Storage	–65		+175	–65		+175	–65		+175	–65		+175	°C
PACKAGE OPTION*													
TO-52 (H-03A)		AD580JH			AD580KH			AD580LH			AD580MH		

Model	AD580S Min	AD580S Typ	AD580S Max	AD580T Min	AD580T Typ	AD580T Max	AD580U Min	AD580U Typ	AD580U Max	Units
OUTPUT VOLTAGE TOLERANCE										
(Error from Nominal 2.500 Volt Output)			**±25**			**±10**			**±10**	mV
OUTPUT VOLTAGE CHANGE										
T_{MIN} to T_{MAX}			**25**			**11**			**4.5**	mV
			55			25			10	ppm/°C
LINE REGULATION										
7 V ≤ V_{IN} ≤ 30 V		1.5	**6**			**2**			**2**	mV
4.5 V ≤ V_{IN} ≤ 7 V		0.3	**3**			**1**			**1**	mV
LOAD REGULATION										
ΔI = 10 mA			**10**			**10**			**10**	mV
QUIESCENT CURRENT		1.0	**1.5**		1.0	**1.5**		1.0	**1.5**	mA
NOISE (0.1 Hz to 10 Hz)		8			8			8		µV (p-p)
STABILITY										
Long Term		250			250			250		µV
Per Month		25			25			25		µV
TEMPERATURE PERFORMANCE										
Specified	–55		+125	–55		+125	–55		+125	°C
Operating	–55		+150	–55		+150	–55		+150	°C
Storage	–65		+175	–65		+175	–65		+175	°C
PACKAGE OPTION*										
TO-52 (H-03A)		AD580SH			AD580TH			AD580UH		

NOTES
*H = Metal Can.

Specifications subject to change without notice.

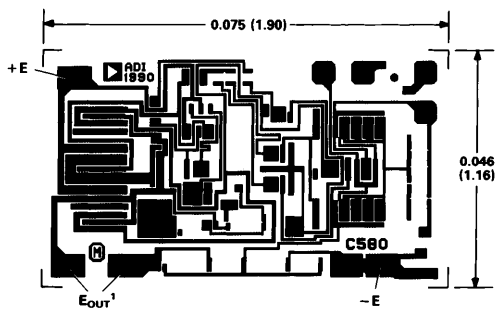
Specifications shown in **boldface** are tested on all production units at final electrical test. Results from those tests are used to calculate outgoing quality levels. All min and max specifications are guaranteed, although only those shown in **boldface** are tested on all production units.

ABSOLUTE MAXIMUM RATINGS

Input Voltage . . . . 40 V
Power Dissipation @ +25°C
  Ambient Temperature . . . . 350 mW
Derate above +25°C . . . . 2.8 mW/°C
Lead Temperature (Soldering 10 sec) . . . . +300°C
Thermal Resistance
  Junction-to-Case . . . . 100°C
  Junction-to-Ambient . . . . 360°C/W

AD580 CHIP DIMENSIONS AND PAD LAYOUT

Dimensions shown in inches and (mm).



NOTE
[1]BOTH E_{OUT} PADS MUST BE CONNECTED TO THE OUTPUT.

The AD580 is also available in chip form. Consult the factory for specifications and applications information.

THEORY OF OPERATION

The AD580 family (AD580, AD581, AD584, AD589) uses the "bandgap" concept to produce a stable, low temperature coefficient voltage reference suitable for high accuracy data acquisition components and systems. The device makes use of the underlying physical nature of a silicon transistor base-emitter voltage in the forward-biased operating region. All such transistors have approximately a –2 mV/°C temperature coefficient, unsuitable for use directly as a low TC reference; however, extrapolation of the temperature characteristic of any one of these devices to absolute zero (with emitter current proportional to absolute temperature) reveals that it will go to a V_{BE} of 1.205 volts at 0K, as shown in Figure 1. Thus, if a voltage could be developed with an opposing temperature coefficient to sum with V_{BE} to total 1.205 volts, a zero-TC reference would result and operation from a single, low voltage supply would be possible. The AD580 circuit provides such a compensating voltage, V_1 in Figure 2, by driving two transistors at different current densities and amplifying the resulting V_{BE} difference (ΔV_{BE}—which now has a positive TC); the sum (V_Z) is then buffered and amplified up to 2.5 volts to provide a usable reference-voltage output. Figure 3 is the schematic diagram of the AD580.

The AD580 operates as a three-terminal reference, which means that no additional components are required for biasing or current setting. The connection diagram, Figure 4 is quite simple.

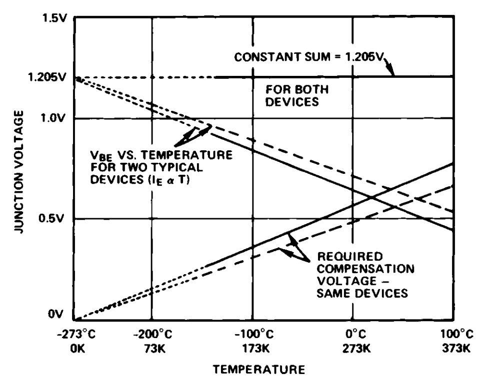


Figure 1. Extrapolated Variation of Base-Emitter Voltage with Temperature ($I_E \alpha T$), and Required Compensation, Shown for Two Different Devices

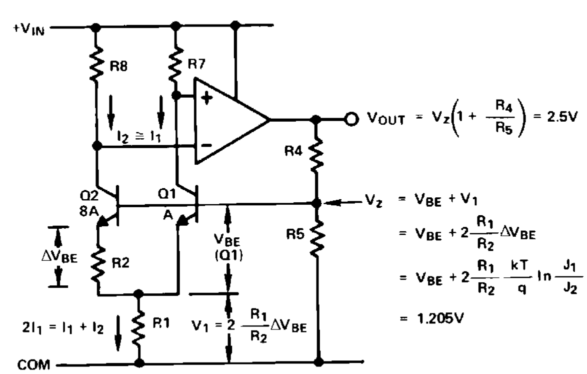


Figure 2. Basic Bandgap-Reference Regulator Circuit

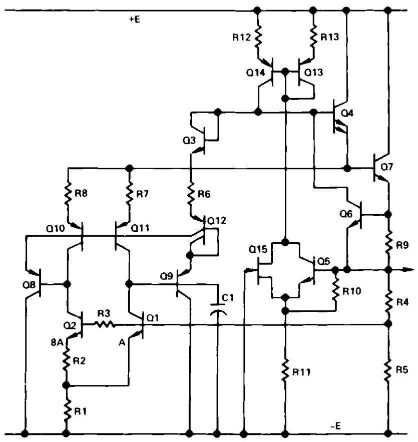


Figure 3. AD580 Schematic Diagram

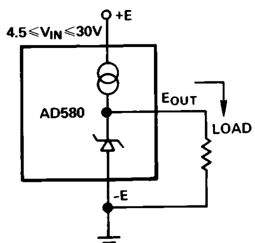


Figure 4. AD580 Connection Diagram

VOLTAGE VARIATION VS. TEMPERATURE

Some confusion exists in the area of defining and specifying reference voltage error over temperature. Historically, references are characterized using a maximum deviation per degree Centigrade; i.e., 10 ppm/°C. However, because of the inconsistent nonlinearities in Zener references (butterfly or "S" type characteristics), most manufacturers use a maximum limit error band approach to characterize their references. This technique measures the output voltage at 3 to 5 different temperatures and guarantees that the output voltage deviation will fall within the guaranteed error band at these discrete temperatures. This approach, of course, makes no mention or guarantee of performance at any other temperature within the operating temperature range of the device.

The consistent Voltage vs. Temperature performance of a typical AD580 is shown in Figure 5. Note that the characteristic is quasi-parabolic, not the possible "S" type characteristics of classical Zener references. This parabolic characteristic permits a maximum output deviation specification over the device's full operating temperature range, rather than just at 3 to 5 discrete temperatures.

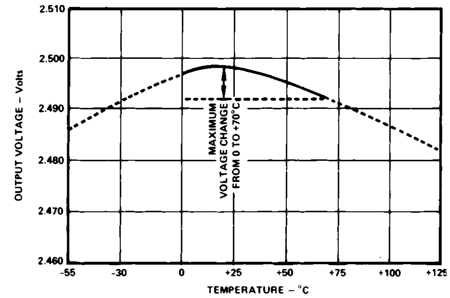


Figure 5. Typical AD580K Output Voltage vs. Temperature

The AD580M guarantees a maximum deviation of 1.75 mV over the 0°C to +70°C temperature range. This can be shown to be equivalent to 10 ppm/°C average maximum; i.e.,

$$\frac{1.75\,mV\ \text{max}}{70°C}\times\frac{1}{2.5\,V}=10\ ppm/°C\ \text{max}\ average$$

The AD580 typically exhibits a variation of 1.5 mV over the power supply range of 7 volts to 30 volts. Figure 6 is a plot of AD580 line rejection versus frequency.

NOISE PERFORMANCE

Figure 7 represents the peak-to-peak noise of the AD580 from 1 Hz (3 dB point) to a 3 dB high end shown on the horizontal axis. Peak-to-peak noise from 1 Hz to 1 MHz is approximately 600 µV.

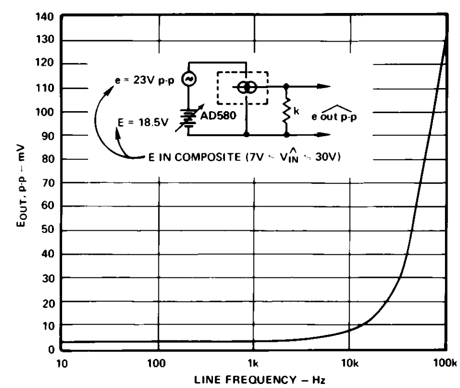


Figure 6. AD580 Line Rejection Plot

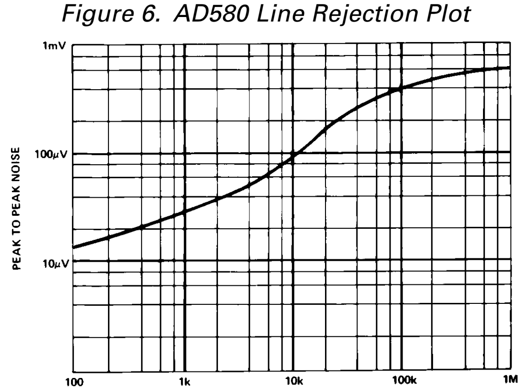
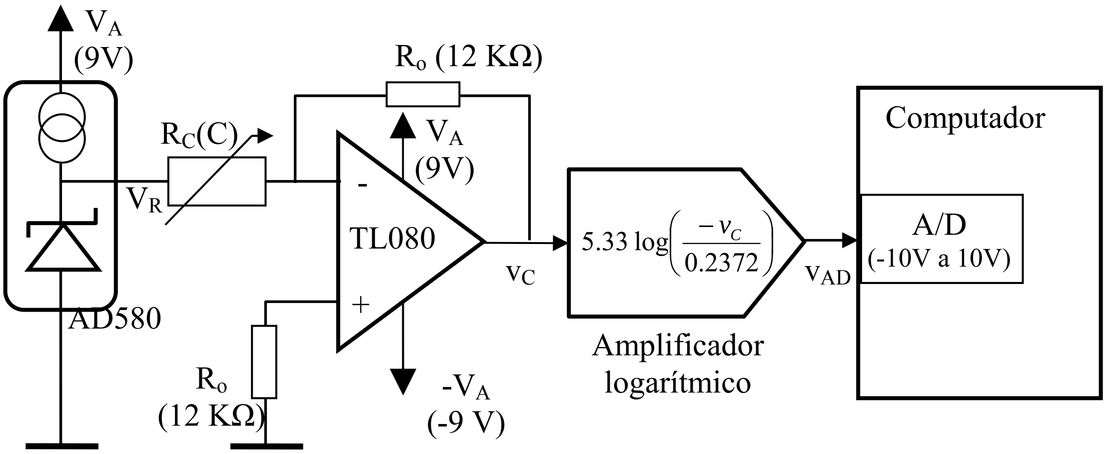


Figure 7. Peak-to-Peak Output Noise vs. Frequency

Instrumentación Electrónica de Comunicaciones **Diciembre, 2008**
5º curso de Ingeniería de Telecomunicación

Solución del examen

1º Análisis del sistema



Ecuaciones directas:

$$v_C = \frac{V_r\ R_o}{R_C(C)} = V_r(Volt)R_o(\Omega)\ 2.5\,10^{-8}\left(\frac{\Omega^{-1}}{ppm}\right)C(ppm)$$

$$v_{AD} = 5.33\log\left(\frac{-v_C}{0.2372}\right) = 5.33\log\left(\frac{-V_r\ \ R_o\ 2.510^{-8}}{0.2372}C\right)$$

Verificación de valores típico:

Concentración (ppm)	v_C(Volt)	v_{AD}(Volt)
0	-7.5oE-3	-7.995
100	-7.50E-2	-2.655
1000	-7,50E-1	2.655
10000	-7.5E00	7.995

Los valores que resultan son compatibles con el rango (-10 V a +10 V) del A/D.
La ecuación inversa es:

$$C = \frac{0.2372}{-V_r R_o 2.510^{-8}} 10^{\frac{v_{AD}}{5.33}}$$

El programa que permite medir la concentración desde el computador es:

```
funtion LeeConcentracionEnPPM() return Float is
   K: constant Float= 5.33;
   Vref: constant Float= 0.2372;
   Vr: constant Float=2.5;
   Ro: constant Float=12000;
   a: constant Float= 2.5E-8;
   vAD:Float;
begin
     vAD= leeAD;
    return Vref/Vr/Ro/a*10^(-vAD/K);
end LeeConcentracionEnPPM;
```

2º) Resolución del A/D si se desea medir la concentración con un error relativo inferior al 1%

Un error del 1 % en la entrada del convertidor logarítmico equivale a un error absoluto en la salida de

$$\Delta v_{AD} = K\ \log(1+\frac{e_{rel}}{100}) = 5.33\ \log(1.01) = 0.023\,Volt$$

El número de bits de resolución del A/D debe ser

$$rango \times 2^{-(N+1)} = 20\times 2^{-(N+1)} = \Delta v_{AD} = 0.023\,V \quad => \quad N = \frac{\log(2)}{\log\left(\frac{0.023}{20}\right)} - 1 = 8.76 = 9 bits$$

3º) Umbral en la medida de la concentración, por el ruido introducido en el transductor. Interpreto umbral como la resolución para la concentración mas baja que se puede medir (10 ppm).

Para esta concentración (10 ppm) la resistencia R_C(10 ppm)= 4 M, luego la anchura de banda de la etapa amplificadora será:

$$BW = ft \times \alpha = 4\ MHz \times \frac{4000000}{4000000+12000} = 4\ MHz$$

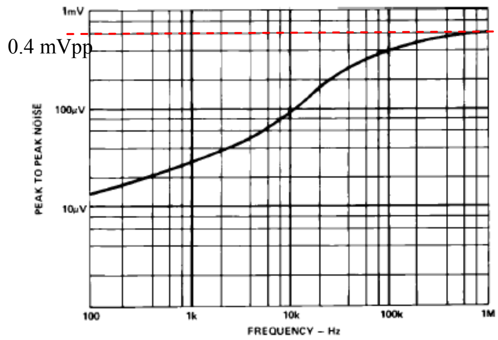


Figure 7. Peak-to-Peak Output Noise vs. Frequency

De acuerdo con la grafica del circuito de referencia de tensión, el ruido en el transductor es,

$$v_{RNpp} = 0.4\,V_{pp}$$

este ruido en la salida v_C del amplificador es función de la concentración C, ya que la lo es la ganancia R_o/R_C entre V_R y v_C,

$$v_{CNpp} = v_{RNpp} \times 12000 \times 2.5\,10^{-8} \times 10 = 1.2\mu V$$

La resolución para C=10ppm es,

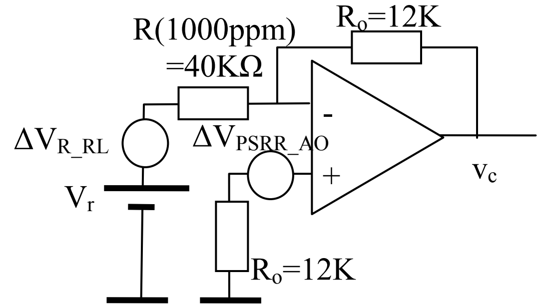
$$U_C = 3\times C_{Nrms} = 3\times v_{CNrms} \times \left.\frac{\partial C}{\partial v_C}\right|_{C=10\,ppt} = 3\times \frac{v_{CNpp}}{6} \times \left.\frac{\partial C}{\partial v_C}\right|_{C=10\,ppt} =$$

$$= 3\times \frac{1.2\,10^{-6}}{6} \times 1.33\,10^{3} = 0{,}53\,10^{-3}\ ppm$$

la cual es completamente despreciable.

4º) Incertidumbre de la medida de la concentración por un rizado de 1 Vpp en la red. Se evalua para una C=1000 ppm.

Hay dos fuente de influencias:



a) <u>ΔV_{RRL} debido a regulación de línea de la referencia de tensión.</u>

En las hojas características del AD580 hay una acotación:

Model	AD580S Min	Typ	Max	Units
LINE REGULATION				
7 V ≤ V_{IN} ≤ 30 V		1.5	6	mV
4.5 V ≤ V_{IN} ≤ 7 V		0.3	3	mV

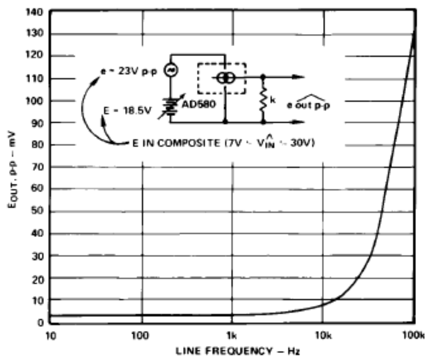


Figure 6. AD580 Line Rejection Plot

Una acotación razonable es $\Delta V_{RRL} < 0.3$ mV

Su efecto sobre la salida v_c:

$$\Delta v_c = \frac{Ro}{R(C)} \Delta V_{RRL} = \frac{12}{40} 0.3 = 0.09\ mVpp$$

b) <u>ΔV_{PSRRAO} debido al PSRR del amplificador operacional.</u>

La información disponible en el amplificador operacional TL080 es

PARAMETER		TEST CONDITIONS†	TL081M, TL082M MIN	TYP	MAX	UNIT
k_{SVR}	Supply voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$)	V_{CC} = ±15 V to ±9 V, V_O = 0, R_S = 50 Ω, T_A = 25°C	80	86		dB

Esto significa que

$$\frac{\Delta V_{cc}}{\Delta v_{PSRRAO}} = 86dB = 10^{\frac{86}{20}} = 20000 \qquad => \quad \Delta v_{PSRRAO} = \frac{1\,Vpp}{20000} = 0.05\ mVpp$$

Su efecto sobre la salida es $\Delta v_c = \Delta v_{PSRRAO}\left(1 + \frac{Ro}{R(C)}\right) = 0.05 \times 1.3 = 0.065 mVpp$

Como son efectos correlacionados, en el peor caso el efecto combinado de ambos es la suma de sus valores absolutos,

$$\Delta v_{c\,total} = |0.09| + |0.065| = 0.155\,Vpp$$

El error máximo en la medida de la concentración es:

$$\Delta C = \Delta v_c \left.\frac{\partial C}{\partial v_c}\right|_{C=1000\,ppm} = 0.155\,10^{-3} \times 1333.33 = 0.087\ ppm \quad => \quad I_C = 2 \times \frac{\Delta C}{2\sqrt{2}} = 0{,}061\ ppm$$

5º) Máximo error sistemático debidos al offset de tensión del amplificador operacional para C=1000 ppm

La información disponible en las hojas características del TL081 sobre su offset es la siguiente:

PARAMETER		TEST CONDITIONS†		TL081I TL082I TL084I MIN	TYP	MAX	UNIT
V_{IO}	Input offset voltage	$V_O = 0$, $R_S = 50\ \Omega$	$T_A = 25°C$		3	6	mV
			T_A = full range			9	
I_{IO}	Input offset current‡	$V_O = 0$	$T_A = 25°C$		5	100	pA
			T_A = full range			10	nA
I_{IB}	Input bias current‡	$V_O = 0$	$T_A = 25°C$		30	200	pA
			T_A = full range			20	nA

Con resistencias de 12 KΩ las intensidades de offset son despreciables. El efecto sobre v_c debido al offset de tensión es

$$\Delta v_c = \left(1 + \frac{Ro}{R(C)}\right) \times 3mV = 1.33 \times 3mV = 4.0mV \quad =>$$

$$\Delta C = \left.\frac{\partial C}{\partial v_c}\right|_{C=1000\,ppm} \Delta v_c = 1333.3 \times 4.0\,10^{-3} = 5.332\ ppm$$