ERROR BUDGET

Rev: B

teorico	ERRORE RSS SU AFR =	0,801	(TARGET = 0,1)	ERRORE Worst Case SU AFR =	1,109
	ERRORE RSS SU LAMBDA =	0,054	(TARGET = 0,007)	ERRORE Worst Case SU LAMBDA =	0,075
dopo calibrazione	ERRORE RSS SU AFR =	0,045	(TARGET = 0,1)	ERRORE Worst Case SU AFR =	0,091
OFFSET	ERRORE RSS SU LAMBDA =	0,003	(TARGET = 0,007)	ERRORE Worst Case SU LAMBDA =	0,006
dopo calibrazione	ERRORE RSS SU AFR =	0,021	(TARGET = 0,1)	ERRORE Worst Case SU AFR =	0,036
OFFSET+GAIN	ERRORE RSS SU LAMBDA =	0,001	(TARGET = 0,007)	ERRORE Worst Case SU LAMBDA =	0,002

NOTE

Scenario :worst case errors, max degli errori

1LSB = (V_REF – V_SS)/2^n

digital value =((Analog input voltage)/(reference voltage high- reference voltage low)) * (2^n -1)

Tolleranze e errori espressi in termini assoluti : ± 2 LSB ---> 2LSB ; Lambda sensor resolution at lambda=1 : ± 0.007

ATTENZIONE: VA FATTA LA CALIBRAZIONE IN-CIRCUIT PER AVERE QUESTI VALORI!!!!!!!

Using ADC error parameters

1. The TUE is NOT the sum of all the errors E O , E G , E L , E D occur between ideal and expected digital values. It can be the eff or two errors occuring simultaneously.
2. As ILE is the integral of DLE, it can be considered as indicative add both DLE and ILE together to calculate the maximum error w ital step.
3. Integral Linearity Error is the maximum deviation between any point correlation line. So it represents the linearity of the ADC.
4. ILE and DLE are dependent on the ADC design. It is difficult to
5. The ILE and DLE can be minimized by doing multiple conversi
6. Offset and Gain errors can be easily cancelled / compensated
7. The maximum values for errors specified in datasheet are the in the laboratory test environment for full voltage range.
8. As already mentioned, all the ADCs provide the digital converte erence voltage. To convert analog voltage accurately, the ADC ne V AREF otherwise the digital output received may not be the corr

Temperatura calibrazione =	25	°C	
Min temperatura operativa =	-10	°C	
Max temperatura operativa =	60	°C	
Max delta temperatura =	35	°C	
Massimo tempo accensione =	5	h	

Retta tg a Ipump(Temperatura) in T=750°C (Ri=80 Ohm)		
delta_Ipump =	0,001219	* deltaT
Dati da script MATLAB : RiTemp_Calcs.m		

CIRCUITO

Ri @750°C =	80	Ohm	Dal datasheet
R DC_source =	8400	Ohm	Res per Igen 250uA
Idc_pulse =	250	uA	da: WB02_Lambda_LUT.m
Tolleranza R_DC_source=	1,0%	---	
Rmeasure =	61,9	Ohm	Res misura Ipump
Tolleranza Res 61R9=	0,1%	---	
I_ipgen,max	5,293	mA	da: WB02_Lambda_LUT.m
Gain V/I Howland	255	Ohm	Res gain Howland Current Pump da: WB02_Lambda_LUT.m

Retta tg a LAMBDA(Ipump) in LAMBDA=1 (max variaz)	
Coeff. Angolare m =	0,363131
Termine noto q =	1,009
Dati da script MATLAB : RiTemp_Calcs.m	

Vreg 5V

Zener MMSZ4689T1G

Vout,nominale =	5,1	V	
Line Regulation =	125	mv	Max line regulation error Vout,regolatore
Initial Error =	260	mv	Max initial error on Vout -> +/- 2%

Vreg 3,6V

LM217

Vout,nominale =	3,6	V	
Line Regulation =		mv	Max line regulation error Vout,regolatore
Line Regulation =	0,05%	%	
Line Regulation =	1,8	mV	
Initial Accuracy =	100	mv	Max initial error on Vout -> +/- 2%

AVR

ATXMEGA32E

Vdd =	3,6	V	
Vref =	3	V	Vref ADC I = +-2mA
Vout_HI_min_pin=	3,38	V	Vout,high min pin con Vdd nominale
Vout_HI_min_pin=	3,29	V	Vout_high max pin con Vout,reg< Vnom
Vout_LO_max_pin=	0,17	V	Vout_low max pin con Vdd nominale
NUMERO MISURAZIONI Ipump =	1		

*Retta tg a Temperatura(Rin)= Temp @ 750°C +(DeltaRi * m)*			
Ri	Temp °C	m =	-1,88816
70	768,88		
80	750,00		
90	731,12		
Dati da script MATLAB : RiTemp_Calcs.m			

ADC

ADC STAGE

Bit =	12		
Offset =	1	mv	
Offset residuo dopo correzione=	1	mv	**AFTER calibration value is loaded**
Offset Temperature drift =	0,01	mV/K	
Offset Operating voltage drift =	0,6	mV/V	
Totale Offset error =	*3,32*	lsb	
Totale Offset error dopo CAL=	***3,32***	lsb	**AFTER calibration value is loaded**
Gain error =	-1	mv	ONLY in differential mode, external Vref
Gain error residuo dopo correzione=	1	mv	
Gain Temperature drift =	0,02	mV/K	
Gain Operating voltage drift =	0,5	mV/V	
Totale Gain error =	*-0,41*	lsb	ATTENZIONE: The calibration value is not loaded automatically, and should always be loaded from the production signature row (ADCxCAL0/1) and written to the corresponding ADC calibration registers (CALL/CALH) before enabling the ADC.
Totale Gain error dopo CAL=	***2,32***	lsb	**AFTER calibration value is loaded**

GAIN STAGE

Gain stage Integral non-linearity =			@ 500ksps
Gain tipico usato =	1		Gain tipico del Gain Stage AVR (2, 4, 8, 32, 64 -> uso 2, 4, 8)
Gain stage gain error=		%	
Totale GAIN STAGE Gain error =	*0,00*	lsb	Vmax in ingresso moltiplicata per errore sul guadagno
Gain stage offset error=		mv	input referred (da moltiplicare x gain??)
Totale GAIN STAGE Offset error =	*0,00*	lsb	Vmax in ingresso moltiplicata per errore sul guadagno
Tot GAIN STAGE Gain+Offset err. dopo CAL=		lsb	**AFTER calibration value is loaded**
DNL =		lsb	Vcc -1.0V < Vref < Vcc -0.6V, 500ksps to 2000ksps
INL =	2	lsb	Vcc -1.0V < Vref < Vcc -0.6V, 500ksps to 2000ksps
Quantiz Error =	1	lsb	

DAC

Bit =	12		valid for 5% to 95% output voltage range
Min_Vout =	0,15	V	Linear DAC output se 0.15V < Vout < (Vref-0.15V)
Max_Vout =	2,85	V	Linear DAC output se 0.15V < Vout < (Vref-0.15V)
DNL =		lsb	Vref=Avcc, VCC = 3.6V
INL =	2,5	lsb	Vref=Avcc, VCC = 3.6V
Gain error=	4	lsb	**AFTER calibration value is loaded**
Offset error=	1	lsb	**AFTER calibration value is loaded**
Gain calibration drift =	0,2	mv/k	
Max gain calibration drift over temp range =	7	mv	

OpAmp

LMV358IPT

Vdd =	5,1	V	
V Offset =	9	mV	(dal datasheet)
Vos_temp_drift =	5	uV/°C	Input offset voltage temperature drift (dal datasheet)
Ibias =	500000	pa	Input offset current temperature drift (dal datasheet)
V_time_drift =		uv/h	
Vdrift (Temp) =	175	uV	Drift dovuto al gradiente temperatura (Tmax-Tcalibrazione)
Vdrift (Time) =	0	uV	Drift dovuto al tempo di accensione (3h)
Vout_max,nominale =	5	V	
Vout_headroom,max =	400	mV	(Output Voltage Headroom @ 2kOhm)

InAmp

INA2232

Vdd =	5	V	
V Offset =	9	mV	(dal datasheet)
Vos_temp_drift =	5	uV/°C	Input offset voltage temperature drift (dal datasheet)
Ibias =	10	pa	Input offset current temperature drift (dal datasheet)
V_time_drift =	0,4	uv/month	
Vdrift (Temp) =	175	uV	Drift dovuto al gradiente temperatura (Tmax-Tcalibrazione)
Vdrift (Time) =	0	uV	Drift dovuto al tempo di accensione (3h)
Gain error =	0,4	%	Gain >5 ---> G=5*(1+R2/R1)
Output Voltage Swing from Rail =	50	mV	Output does not swing to positive rail if gain is less than 10.
Vout_max,nominale =	4,95	V	
Vout_A2_max =	3,8	V	For ensured operation, Vo_A2 should be less than Vdd – 1.2V.
Vout_headroom,max =		mV	(Output Voltage Headroom vs. Output Resistance @ xx kOhm)

Vref

LM4128BMF-3.0

Vref =	3	V	
Tempco [0-70°C] =	75	ppm/°C	Temperature coefficient is measured by the "Box" method; i.e., the maximum ΔV REF is divided by the maximum ΔT.
Initial Accuracy =		mV	se specificata in mv
Initial Accuracy =	0,2	%	se specificata in %
Initial Accuracy =	*6*	mV	
Line Regulation =	85	Ppm / 1Vin	
Load Regulation =	120	Ppm / 1mA	
Long Term Stability =	50	Ppm / 1000Hrs	Long term stability is V REF @ 25°C measured during 1000 hrs.
Thermal hysteresis =	75	ppm	Thermal hysteresis is defined as the change in +25°C output voltage before and after cycling the device from (-40°C to 125°C).
Total errors =	0,99	mV	Max variaz Vref dovuta al carico per Vref

	Temperature error =	2,625	**mV**	Max variaz Vref dovuta alla temperatura
	Errore totale Vref =	**9,62**	**mV**	

Diodo protez.
Input Opamp
BAT54

Ireverse =	1,00	**uA**	Reverse current @ 5Vrev, 50°C
Rprot_Opamp =	100	**Ohm**	

ERRORE SU VNERNST

				TEORICO	MISURATO	CALIBR. OFFSET	CALIBR. OFFSET+GAIN		
Parte ANALOGICA									
Diodo protez.									
Input Opamp	Irev @ Vrev=5V , 50°C	1,00	**uA**						
BAT54	Verror =	100	**uV**	0,10		0,1	0,1	**mV**	Errore dovuto a V = I_reverese,diodo* Rinput
InAmp	GAIN=	5							*Da:WB02_Lambda_LUT.m - GAIN = 5 + 5* (R2/R1)*
INA2232	Errore non linearità =	---	**mV**					**mV**	
	Offset =	9	**mV**	9		*calibrato*	*calibrato*	**mV**	
	Drift (Temp + Time) =	175	**uV**	0,175		0,175	0,175	**mV**	
Parte DIGITALE				DA QUI IN POI GLI ERRORI VENGONO DIVISI PER IL GUADAGNO SEZIONE ANALOGICA					
Vref	Errore Vref =	1,923	**mV**	1,923				**mV**	
LM4128BMF-3.0									
ADC	Offset =	3,32	**lsb**	0,486		*calibrato*	*calibrato*	**mV**	deviation between the first actual transition and the first ideal transition.
ATXMEGA32E	DNL =	---	**lsb**					**mV**	Differential non-linearity (uso solo INL)
	INL =	2	**lsb**	0,293		0,293	*calibrato*	**mV**	Integral non-linearity
	Gain error =	2,32	**lsb**	0,340		0,340	*calibrato*	**mV**	deviation between the last actual transition and the last ideal transition (Vin=Vref-1LSB).
	Quantiz Error =	1	**lsb**	0,147		0,147	0,147	**mV**	(da usare per segnali che arrivano a Vref)
	TOTALE Worst Case			**12,464**	0	**1,055**	**0,422**	**mV**	
	TOTALE RSS ERRORS			**9,23**	**0,00**	**0,51**	**0,25**	**mV**	The design will probably never have an error of this magnitude, because the error specification assumes worst-case conditions for most parameters. The Root Sum Square approach is valid if the errors are uncorrelated.
	ERRORE SU LAMBDA								Errore su lambda praticamente 0 per Vnernst 'vicino' a 450mV!
	ERRORE SU AFR			**0,000**					Variaz Lambda=???
	ERRORE SU LAMBDA Worst Case								

ERRORE SU Vri

				TEORICO	MISURATO	CALIBR. OFFSET	CALIBR. OFFSET+GAIN		
Parte ANALOGICA									
InAmp	GAIN=	5							*Da:WB02_Lambda_LUT.m - GAIN = 5 + 5* (R2/R1)*
INA2232	Errore non linearità =	---	**mV**						Opamp usato come buffer per Vnernst e Vri
	Offset =	9	**mV**	9,000		*calibrato*	*calibrato*	**mV**	
	Drift (Temp + Time) =	175	**uV**	0,175		0,175	0,175	**mV**	
Diodo protez.									
Input Opamp	Irev @ Vrev=5V , 50°C	1,00	**uA**						
	Verror =	100	**uV**	0,100		0,100	0,100	**mV**	Errore dovuto a V = I_reverese,diodo* Rinput
Vpulse									
ATXMEGA32E	Errore quantizz. ADC =	1	**LSB**						
	Errore quantizz. ADC =	0,732422	**mV**	0,732		0,732	0,732	**mv**	Errore dovuto a quantiz err. ADC per lettura Vout,pulse
	Errore quantizz. ADC su Ipulse =	0,087193	**uA**						
	Errore Rdcpulse =	0,346	**mV**	0,346		*calibrato*	*calibrato*	**mV**	1% tolleranza su R (caso peggiore: Ri@750°C=80 Ohm)
Parte DIGITALE				DA QUI IN POI GLI ERRORI VENGONO DIVISI PER IL GUADAGNO SEZIONE ANALOGICA					
Vref	Errore Vref =	1,923	**mV**	1,923		*calibrato*	*calibrato*	**mV**	
LM4128BMF-3.0									
ADC	Offset =	3,32	**lsb**	0,486		*calibrato*	*calibrato*	**mV**	deviation between the first actual transition and the first ideal transition.
ATXMEGA32E	DNL =	---	**lsb**					**mV**	Differential non-linearity (uso solo INL)
	INL =	2	**lsb**	0,293		0,293	*calibrato*	**mV**	Integral non-linearity
	Gain error =	2,32	**lsb**	0,340		0,340	*calibrato*	**mV**	deviation between the last actual transition and the last ideal transition (Vin=Vref-1LSB).
	Quantiz Error =	1	**lsb**	0,147		0,147	0,147	**mV**	HP sfrutto l intera dinamica possibile
	TOTALE Worst Case			**13,543**	0	1,787	1,154	**mV**	
	TOTALE RSS ERRORS			**9,266**	**0,000**	**0,895**	**0,774**	**mV**	The design will probably never have an error of this magnitude, because the error specification assumes worst-case conditions for most parameters. The Root Sum Square approach is valid if the errors are uncorrelated.
	ERRORE SU Ri			0,350		0,034	0,029	**Ohm**	Ri,nominale=80 Ohm e Ri_misurata=Vdc/Idc
	ERRORE SU Temp			0,660		0,064	0,055	**°C**	coefficienti da: RiTemp_Calcs.m
	ERRORE SU LAMBDA			0,0003		0,0000	0,0000		Errore su lambda dovuto alla temperatura (con Ipump a max pendenza)
	ERRORE SU AFR			**0,0043**		**0,0004**	**0,0004**		Variaz Lambda= (delta_Ipump(T) * delta_T) * (delta_Lambda(Ipump)/delta_Ipump)
	ERRORE SU Ri Worst Case			0,511		0,067	0,044	**Ohm**	
	ERRORE SU Temp Worst Case			0,965		0,082	0,082	**°C**	
	ERRORE SU LAMBDA Worst Case			0,00043		0,00004	0,00004		

ERRORE SU Vipump

				TEORICO	MISURATO	CALIBR. OFFSET	CALIBR. OFFSET+GAIN		
Parte DIGITALE									
DAC	DNL =	---	**lsb**					**mV**	
ATXMEGA32E	INL =	2,5	**lsb**					**mV**	
	Gain error=	1	**lsb**					**mV**	
	Offset error=	1	**lsb**					**mV**	
	Totale decimale =	0,5	**lsb**	0,09		0,089	0,089	**mV**	Tiene conto del fatto che un errore su Ipump,out si cancella scalando l' output del DAC di un numero intero di LSB
Parte ANALOGICA									
Current Pump									
	Errore var Rmeasure 61.9 =	0,33	**mV**	0,33		*calibrato*	*calibrato*	**mV**	Errore dovuto a % tolleranza su Rmeasure con Ipgen massima
	(con tolleranza Res 61R9=	0,1%	)						
InAmp	GAIN=	5,0							*Da:WB02_Lambda_LUT.m - GAIN = 5 + 5* (R2/R1)*
INA2232	Errore non linearità =	---	**mV**					**mV**	Opamp
	Offset =	9	**mV**	9,00		*calibrato*	*calibrato*	**mV**	"
	Drift (Temp + Time) =	175	**uV**	0,18		0,175	0,175	**mV**	Drift dovuto al gradiente temperatura (Tmax-Tcalibrazione) e al tempo (3h)
Parte DIGITALE				DA QUI IN POI GLI ERRORI VENGONO DIVISI PER IL GUADAGNO SEZIONE ANALOGICA					
Vref	Errore Vref =	1,923	**mV**	1,92				**mV**	
LM4128BMF-3.0									
									Guadagno del ADC
ADC	Offset =	3,32	**lsb**	0,49		*calibrato*	*calibrato*	**mV**	deviation between the first actual transition and the first ideal transition.
ATXMEGA32E	DNL =	---	**lsb**					**mV**	Differential non-linearity (uso solo INL)
	INL =	2	**lsb**	0,29		0,293	*calibrato*	**mV**	Integral non-linearity
	Gain error =	2,32	**lsb**	0,34		0,340	*calibrato*	**mV**	
	Quantiz Error =	1	**lsb**	0,15		0,147	0,147	**mV**	
	TOTALE Worst Case			**12,78**	0	**1,04**	**0,41**	**mV**	
	TOTALE RSS ERRORS			**9,24**	**0,00**	**0,51**	**0,24**	**mV**	The design will probably never have an error of this magnitude, because the error specification assumes worst-case conditions for most parameters. The Root Sum Square approach is valid if the errors are uncorrelated.
	ERRORE SU Ipump			149,208		8,264	3,957	**uA**	Vout = Ipump * Rmeasure * Guadagno
	ERRORE SU LAMBDA			0,054		0,003	0,001		Errore sulla parte RICH della curva (coef.f ang. Maggiore -> errore massimo)
	ERRORE SU AFR			**0,796**		**0,044**	**0,021**		dove Ipump,teorica = -1,85mA dovuto alla extratensione in G64
	ERRORE SU Ipump Worst Case			206,559		16,950	6,719	**uA**	
	ERRORE SU LAMBDA Worst Case			0,075		0,006	0,002		