Voltage and Temperature Measuring

HY11P13

40000/10000 Counts Voltage and Temperature Sensor

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1. Brief Introduction

For the systems that applied in the fields of industries, sound or consumption, the analogical and digital converter (A/D) usually plays a very important role. To meet the needs in many applications, it developed many product types with different A/D constructions in the market. From successive-approximation (SAR) ADC, integral ADC (Dual slope) to Σ-Δ ADC (sigma-delta) that developed in recent years, they all have their own advantages and drawbacks respectively to satisfy different applications. SAR and Dual Slope ADC is mainly applied in data collection and smart instruments in medium or lower speed and medium precision; Σ-Δ ADC is mainly applied in the electronic measuring fields of high accuracy data collection, especially the digital sound system, multimedia, precise measurement and so on. Table 1-1 describes roughly the product resolution and the applied fields in different A/D construction, and Figure 1-2 was the analyzing data of A/D construction in 2005 that may explain the A/D applied fields of different product category.

Construction	Pipelined	SAR	ΣΔ	Dual slope
Converting Rate (Hz)	1M~1G	10K~10M	1~100K	1~1K
Resolution (Bit)	8-16	8-20	12-24	12-22
Applied Fields	Communication Signal Audio Signal	Data Retrieving	Sensor Signal Digital Sound	Sensor Signal

Table 1 The Relationship of Different A/D Construction, Resolution and Converting Rate

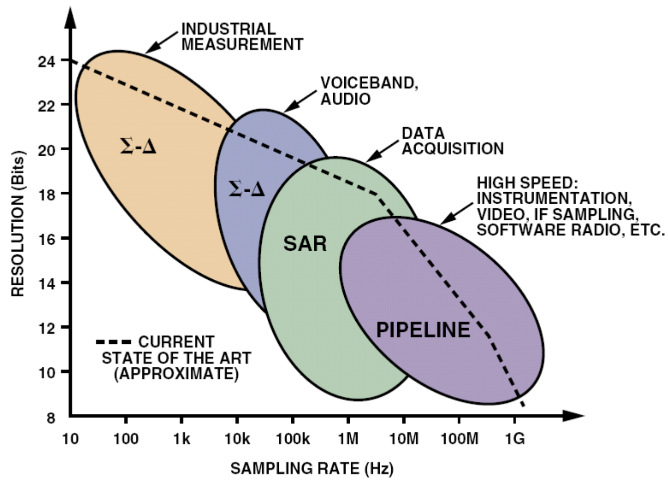


Figure 1 The Relationship of Different A/D Construction, Resolution and Sampling Rate [1]

The following is the brief introduction of SAR, Dual slope and Σ-Δ ADC:

SAR ADC:

This is one of the converting methods being applied widely, and is mainly composed of the comparator, the successive-approximation (SAR) and the logical control unit. For comparing the input signal and the known voltage and converting it to the binary output, its input RMS noise is usually about 1mV and the general resolution is about 12-bit.

Its superiorities lie in that the price is lower when the resolution is lower than 12-bit, its sampling rate may reach 1MSPS (million samples per second), the power loss is lower and the size is small. But its shortcomings are the price is higher when the resolution is higher than 14-bit, and it must process the pre-signal gain amplification and the filter first if use on the sensors so that the cost will increase a lot obviously.

Dual Slope ADC:

It is also called integral ADC and it is mainly constructed by the input switch integrator, the comparator and the counter. Through two times of integrals, it converts the input voltage to the time interval that is proportional to the average, and uses the counter to complete the convert. Its input RMS noise is usually about 10uV and the general resolution is about 16 bits.

Its superiorities lie in the strong suppressive ability to the interference of the alternate noises by using the integrator in the input end. It can suppress the high frequency noise and the fixed low frequency disturbance (such as 50Hz or 60Hz) so that it is suited for using in the noisy industry environment. But its shortcomings are that the converting rate is low. The converting rate in 12-bit is usually only about 100~300SPS.

Σ-Δ ADC:

It is also called the sampling converter that is to process the quantification programming mainly based on the differential size of the value before and after the quantification. It is composed of the analogy Σ-Δ modulator and the digital sampling filter. At first, it samples the signals by the Σ-Δ modulator and increases the quantity to program, then it converts the high resolution signals by the digital sampling filter. Its input RMS noise is usually about 1uV and the general resolution is about 16~20 bit.

Its superiorities lie in that the resolution is higher and may reach as high as 24-bit. The converting rate is higher than the integral ADC. The internal sampling converter has realized the digital filtering function directly and reduced indirectly the request of the sensor signal filtering. But its shortcomings are that the price of high speed Σ-△ ADC is usually much higher. Generally, under the same converting rate, its power consumption is higher than the ones of SAR ADC and Dual slope ADC.

HY11P13, the OP + A/D micro-controller with built-in SPI serial interface, is promoted by HYCON [2] at present. It is a single chip with 18-bit Σ-△ A/D resolution. The chip is with ROM size 4K x 16 and Ram size 256byte, provides 4x20 points LCD display and supports 14 ports at most for the I/O. Its 18-bit high A/D resolution contains 8 groups of network input selections to apply in most of the sensor detections and the network switches. The internal PWM output can reach as high as 10-bit resolution signals for the control driver to use. To match with PFD, it can be used on the sound components to produce the wonderful music.

For the HY11P13 micro-controller, not only its waiting current is lower than 3μA, but also its sleep current is lower than 1μA. To start the A/D application by using the built-in oscillator, the consuming current of the entire chip is only 750μA so that it lengthens the battery life greatly. The built-in groups of voltage detecting points can even monitor the voltage consumption of the battery at the right moment.

This article aims at the eight bit MCU of HYCON HY11P13 for the simplest A/D application by using only few passive components. Its high A/D performance can be applied to many temperature, pressure, gas sensors or weight (fat) scales. By taking only the simple application circuit to meet the application's demands that is a big reduction on the demand of increasing the OPA or the filter circuit to enlarge or stabilize signals generally. In following, we use the 18-bit Σ-△ A/D to make the 40,000 counts big signal voltage measurement, the 10000 counts small signal voltage measurement and the temperature measurement of the built-in temperature sensor. It achieves the maximum temperature error only ±3℃ in - 40℃~85℃ under the single point temperature calibration.

2. Theory Description

2.1. 40000 COUNTS

By using Σ-△ A/D, the ratio of the input voltage and the reference voltage becomes the identification of the digital outputs. To set A/D reference voltage (△VR) to be 1.2V, ± 400.00mV to be the input signal (△VIN) and the amplification of the built-in low noise to be 1 (PGA * GAIN), the definition of the ADO output digital code is:

$$ADO = \left(\frac{\Delta VIN}{\Delta VR} \times PGA \times GAIN \times 2^{18} \right)$$

If taking 40000 counts as the display target to display 400.00mV, the smallest display unit would be 10uV. To reach stable 1 standard error in the external display and the ratio of the internal and the external resolutions to be 1:5, the input RMS Noise must be smaller than or be equal to 10uV/5 = 2uV.

Select A/D Output rate to be that the over sampling rate (OSR) mode is 8192, it is equal to the frequency of A/D output:

$$\frac{A/D\,Clock}{OSR} = \left(\frac{250\,KHz}{8192} \right) = 30.5\,Hz$$

For the network setting way, it uses the network cross way provided by the product to get the values so that it may eliminate A/D voltage drift rate (A/D Offset) directly. Make the cancellation by taking the digital output values from the forward network and the reverse network separately. (INH/INL: the external signal input pin; S+/S-: the internal A/D signal input source)

Forward network digital output: ADO1 = +ADO + ADO_{Offset}

Reverse network digital output: ADO2 = -ADO + ADO_{Offset}

The cancelled result of the digital outputs is: (ADO1-ADO2) = 2ADO…Eliminate directly the exist AD Offset.

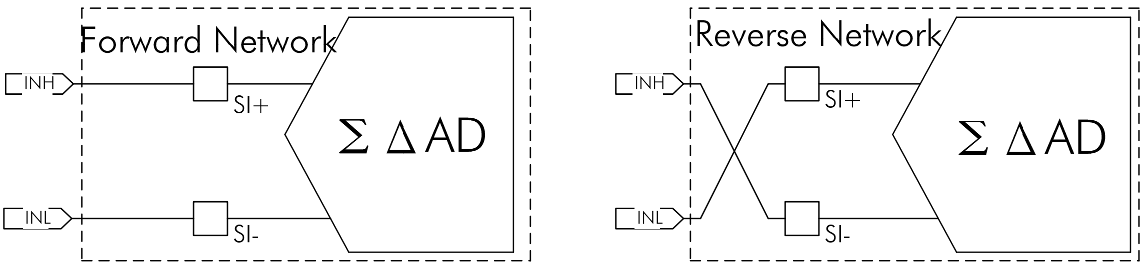


Figure 2 A/D Network Cross Diagram

2.2. 10000 COUNTS

The measuring theory is same as 40000 counts, but because it is to measure 1uV small signal, we have to amplify the input signal. Here we take the low noise amplifier built-in the chip itself so as to save the OPA amplifier components. To set the amplification to be 64 (PGA × GAIN=8×8), and in this amplification, the chip A/D still keep 16Bit resolution. If A/D reference voltage (△VR) is 1.2V and set ±10.000mV to be the input signal (△VIN), then the ADO output digital code is:

$$ADO = \left(\frac{\Delta VIN}{\Delta VR} \times PGA \times GAIN \times 2^{16} \right)$$

If taking 10000 counts as the display target to display 10.000mV, the smallest display unit would be 1uV. To reach stable 1 standard error in the external display and the ratio of the internal and the external resolutions to be 1:3, the input RMS Noise must be smaller than or be equal to 1uV/3 = 0.33uV.

Select A/D Output rate to be that the over sampling rate (OSR) mode is 32768, it is equal to the frequency of A/D output:

$$\frac{A/D\ Clock}{OSR} = \left(\frac{250\ KHz}{32768} \right) = 7.6\ Hz$$

For the network setting way, it still uses the network cross way to get the values so that it may eliminate A/D voltage drift rate (A/D Offset) directly.

2.3. TPS (Temperature Sensor)

The design is composed of internal two groups of diode. It takes the change of the voltage signal to the temperature as the 0V curve of passing 0°K voltage. In the use, it only needs the single point calibration to achieve the accurate temperature value. The two groups of diode +TPS/-TPS have an N time current proportional relationship (I: NI), and the Vbe=V_{TPS} equivalent voltage formula and the equivalent circuit are as follow:

$$V_{TPS} = (n_f) \times \left(\frac{KT}{q} \right) \times \ln(N)$$

K is Boltzmann's constant (1.38×10-23).
q is the charge on the electron (1.6×10-19 Coulombs).
T is the absolute temperature in Kelvins.
N is the ratio of the two currents.
n_f is the ideality factor of the thermal diode.

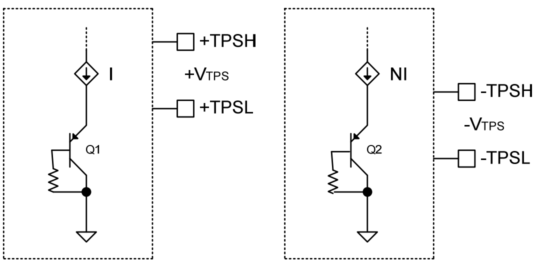


Figure 3 TPS Equivalent Circuit Diagram

Vbe equivalent voltage is:

$Vbe1=V_{+TPS}=V_{ADC1} + V_{ADOffset}$

$Vbe2=V-_{TPS}=V_{ADC2} + V_{ADOffset}$

$\Delta Vbe=(Vbe1-Vbe2)=(V_{+TPS} - V_{-TPS}) = V_{ADC1} -V_{ADC2}$ …To cancel each other can eliminate A/D Offset

Therefore, as long as under the same temperature (TA ℃) and after measuring +TPS and -TPS A/D values, just to cancel the two numbers and to get the averaging value, we can obtain the TPS value corresponding to the temperature, and then through calculating the single point calibration, we can obtain the good temperature curve. Its gain calibration formula is:

$$G_{TPS} = \left(\frac{V_{TPS@TA}}{273 + T_{Offset} + T_A} \right) = \left(\frac{V_{TPS@TA}}{289 + T_A} \right)$$

T_{Offset}: The equivalent series resistance effect caused by the diode itself makes the temperature value be not 0°K when V_{TPS}=0V. The reference value provided by chip designer is T_{Offset}=16°K.

When measuring the temperature, we still set the A/D reference voltage (△VR) to be 1.2V, the input signal to be the internal TPS signal switch, the built-in low noise amplification to be 1 (PGA * GAIN), and the chip specification V_{TPS} temperature drift coefficient to be 17.8uV/0.1℃. If take 0.1℃ as the smallest unit to display, it must reach stable 1 standard error for the external display, and the ratio of the internal and external resolutions is set to 1:6, therefore, the Input RMS Noise must be smaller than or be equal to 17.8uV/6 = 2.97uV.

Select A/D Output rate to be that the over sampling rate (OSR) mode is 8192, it is equal to the frequency of A/D output:

$$\frac{A/D\,Clock}{OSR} = \left(\frac{250\,KHz}{8192} \right) = 30.5\,Hz$$

2.4. Control Chip

For above simple A/D application, it can be completed by using the HY11P13 microprocessor. HY11P13 microprocessor needs only 8 passive components to complete the A/D signal measurement, and if match the OSR setting, it can achieve GAIN=1, 8Hz/18bits stable output, even if measuring the small signal (built-in amplifier to enlarge 128 times), it can still achieve 16Bit resolution.

In CPU instructions, it provides 66 sets of instructions that enable users to program easier, even if it is merely the assembly program construction at present. For LCD display points, it provides 80 points (4 COM*20 SEG) to supply the general handhold application products, and it also provides 3 groups of Timer. No matter the clock setup or even the PWM control driver switch, the complete functions let users may dispose according to their applications. The SPI transmission interface can provide users to make A/D analysis and communication record.

3. Design Plan

3.1. Hardware Description

The simple passive components in the chip itself include the POWER which is with 4 regulated voltage capacitors (VDD /VLCD /VDDA /ACM), the Pull high resistor of RST pin itself and the ground capacitor. To match them with the A/D signal input end and the filter capacitor of the reference voltage end can construct the simple A/D measuring system. The peripheral circuit EEPROM 24C02 matched for them is mainly for saving the calibrating parameters in voltage and temperature measurement. The additional layout of voltage demo circuit is composed of the changeable resistance to be the DC voltage signal input source for demo.

This product provides many groups of A/D input channels. So, in this article, we take AI0/AI1 as the voltage signal input pin and AI2/AI3 as the reference voltage input pin. The application is completed by the simplest circuit. The reference voltage source uses the VDDA differential voltage to input the reference voltage source through AI2/AI3 and uses the internal VREGN amplifier to process the reference voltage 1/2 signal reduction so as to achieve ΔVR=(2.4V-0V)/2=1.2V.

The reference point of the voltage input signal source is to take the power ACM (1.2V) as the reference source and connect it to AI1 pin so as to supply the AI0 pin input to measure the +/- signal, just like 4000 counts which its voltage measuring scope can reach ±400mV input signal.

The joint of R9/R8/R10 resistance is mainly for stable signal source input provided for A/D voltage signal test.

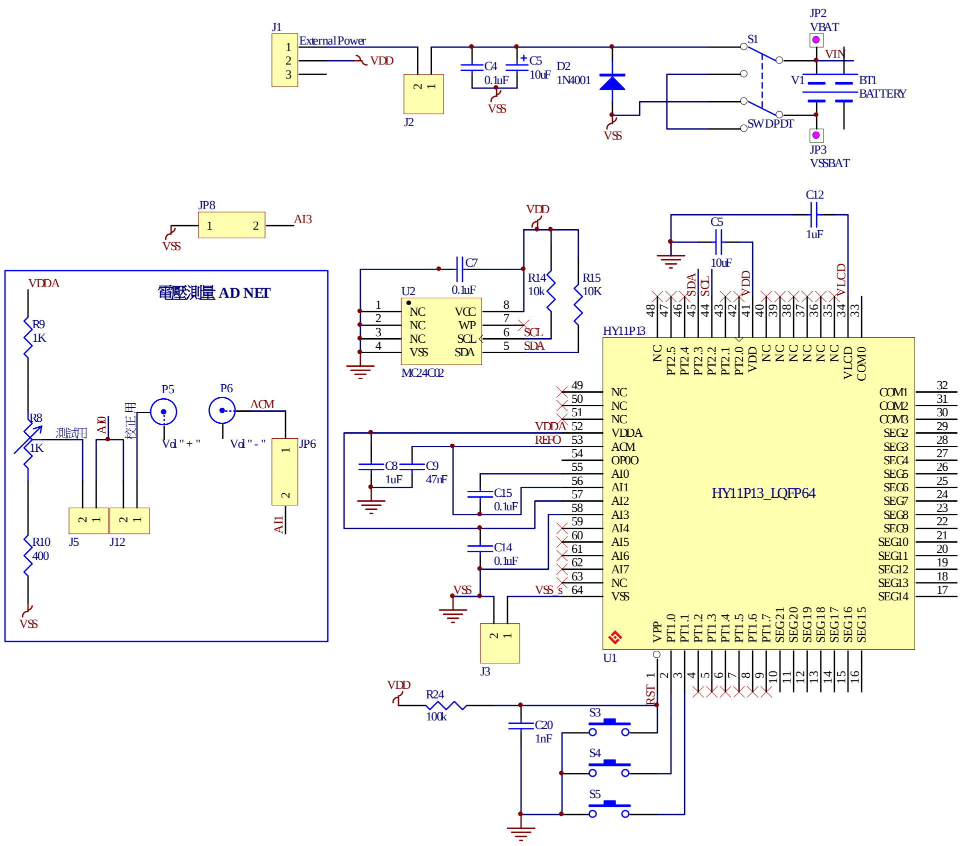


Figure 4 Circuit Diagram

3.2. Chip Circuit Description

This application board is suitable for HY11P13 PKG_LQFP64 (10mm*10mm) / DICE and HY11P12 DICE. The user must define different chip PAD according to different chip models. For the actual output pins, it may refer to the U1 pin definition in Figure 3-1 Circuit Diagram.

3.3. BOM List

符號	元件	描述
BT	CR2032	CR2032電池
C12	1u	0805
C14	0.1u	0805
C15	0.1u	0805
C20	1n	0805
C5	10u	0805
C7	0.1u	0805
C8	1u	0805
C9	47n	0805
D2	1N4001	SMD
J1	1-2 short	DIP
J12	short	DIP
J2	short	DIP
J3	short	DIP
J4	LCD	4*17
J5	short	DIP
JP6	short	DIP
JP7	short	DIP
JP8	short	DIP
P5	Voltage Positive Input	
P6	Voltage Negative input	
R10	400	0805
R14	10k	0805
R15	10k	0805
R24	100k	0805
R8	1k	0805
R9	1k	0805
S1	Switch	Switch
U1	HY11P13	HYCON IC
U2	24C02	EEPROM
S3	Button	Button
S4	Button	Button
S5	Button	Button

3.4. Software Description

Flow chart: There are Power-On Calibration and Measuring Modes. For the program procedure flow, please refer to Figure 3-3 below. For the calibration procedure flow, please refer to the description of Figure 3-4.

For the software computing flow in measuring mode, please refer to the description of Figure3-5 that is narrated as follow:

Switch to the positive network, discard 2 records of ADO, and take 4 records of ADO to average. (Average1)

Switch to the negative network, discards 2 records of ADO, and take 4 records of ADO to average. (Average2)

(Display DATA) = (ADO3 * (to calibrate external count)) / (EEPROM calibrated value)

If the calibration is under 300mV, the display value =(ADO3 * 30000) / ($ADO3_{300mV}$)

To operate Hexadecimal to Decimal and to round up.

Judge if do LCD display —OL—.

LCD displays the measured value and then repeat the measurement.

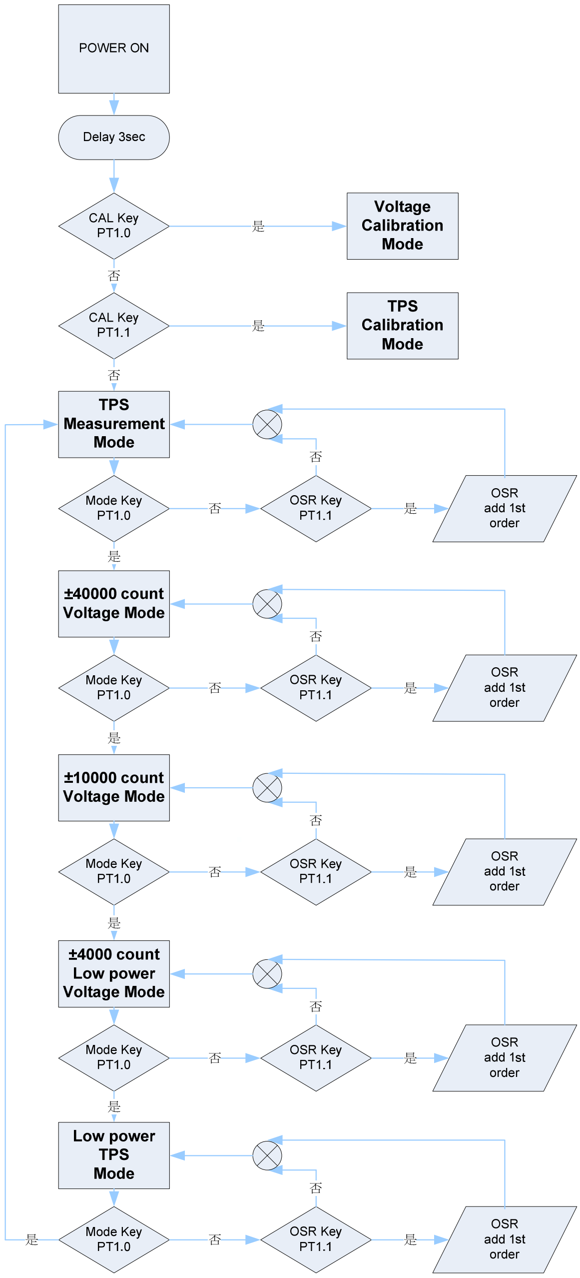


Figure 6 Flow Diagram

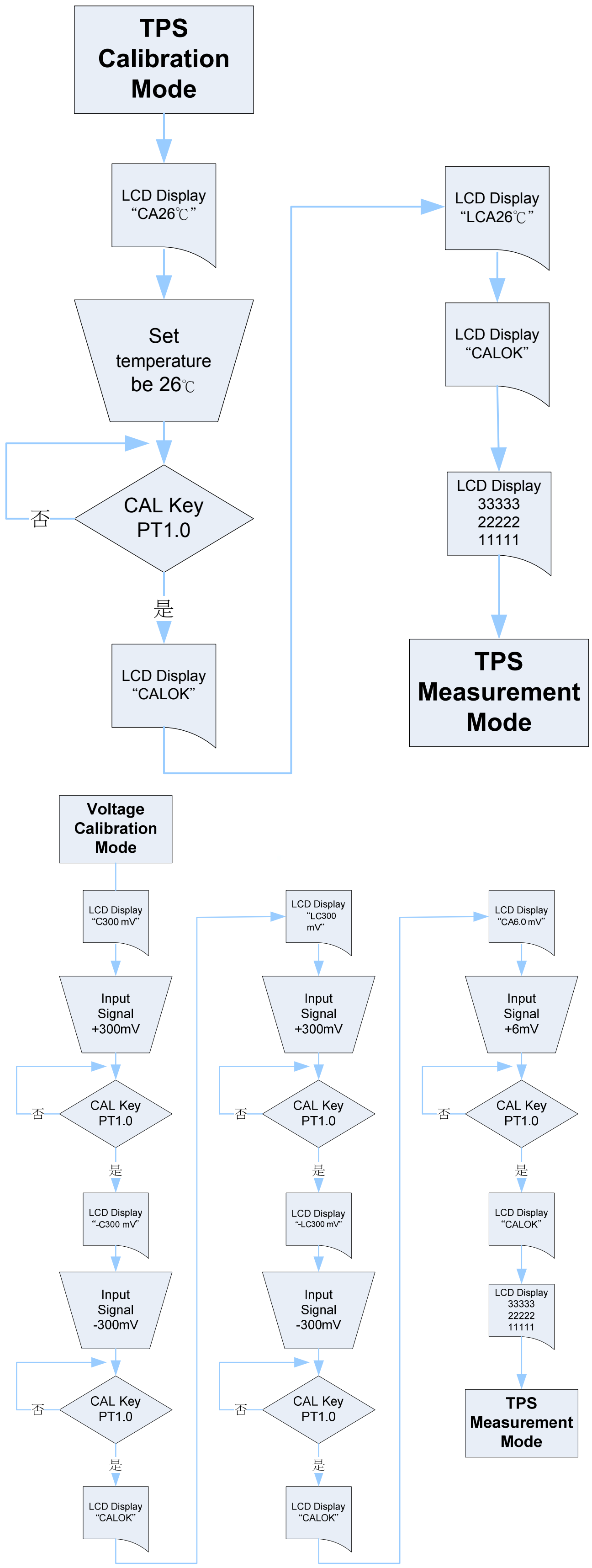


Figure 7 Calibration Mode Flow Diagram

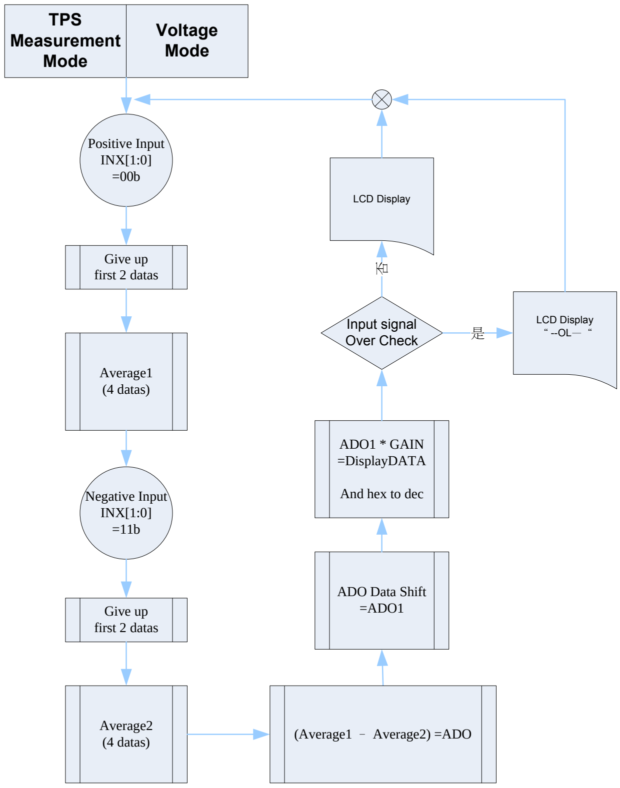


Figure 8 Measuring Flow

4. Technical Specification

4.1. Technical Specification

Operating Voltage : 2.4V~3.6V.
Power Consuming : 0.2mA ~ 0.75mA.
Resolution : Voltage: 1uV ~ 10uV; Temperature: 0.1℃.
Display Speed (Hz) : Depends on the OSR settings of different modes.
Display Value : ±400.00mV, ±10.000mV, ±400.0mV, ±150.0℃.

4.2. Experiment Method

Experiment Instruments: Power Supply - Agilent E3630A
Calibrator- Fluke 5500A
USB/SPI Communication Board - PIC18LFxx Base

In this article, it takes A/D network collocation method as Figure 4-1 for HY11P13 chip and inputs the DC voltage value to make the static INL (integral misalignment) error test, and then analyzes under the condition of ΔVR=1V, ΔVIN being the voltage input signal source of the calibrator Fluke5500A and the input signal being ±450mV and 1mV/Step.

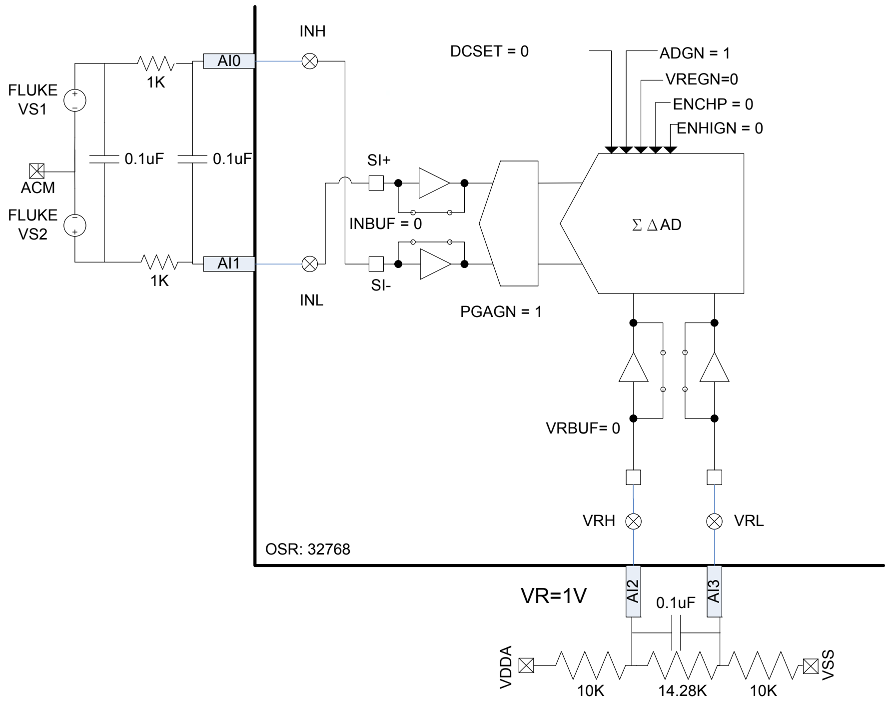


Figure 9 A/D INL Testing Circuit

In this article, it takes the digital output value at the place of the ±300mV input signal as the check point after completing all input signals measurement to get a linear value (ADOCAL), and then calculates the INL error by the actual digital output value of each spot and the linear value (ADOCAL):

$$INL = \frac{(\text{Actual ADO} - ADO_{CAL})}{\text{Full scale range}} \quad (\%/FSR)$$

Table 4-2 is to analyze the static INL error of DC input signal source and the result is shown in the input range. The overall integral misalignment error ｜ INL error ｜ ≦ 10PPM.

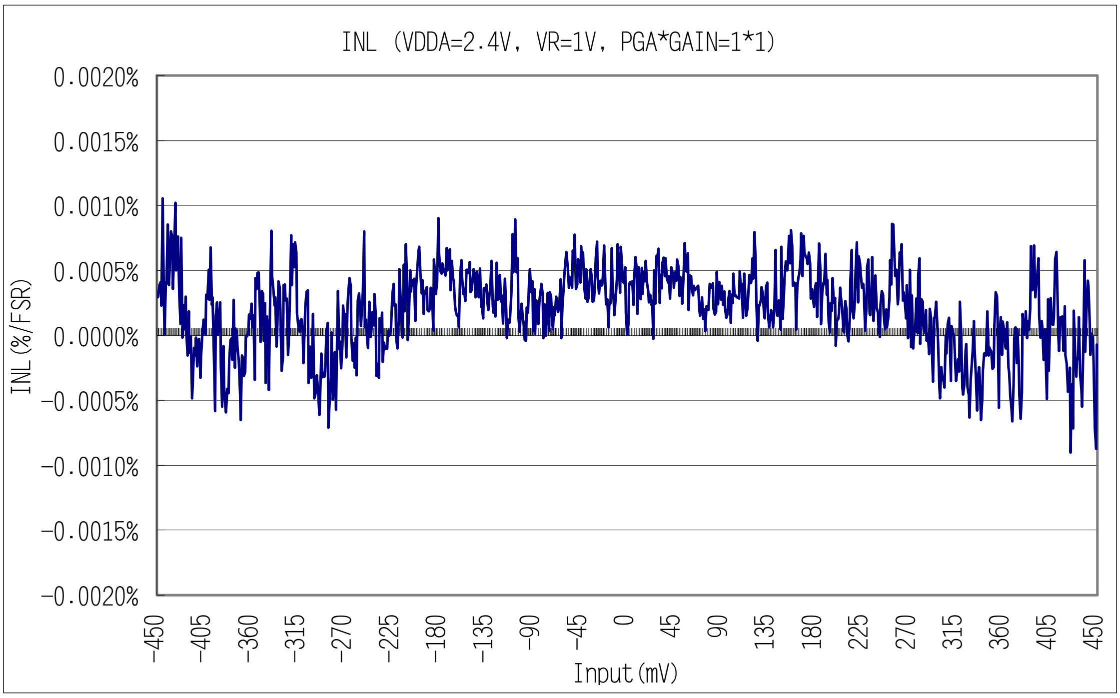


Table 2 A/D INL Test Analysis

Under the following settings, sampling 8192 records A/D output data to analyze: (VDDA=2.4V, VR+=VDDA, VR-=VSS, INH=AI0, INL=AI1, INIS ON (inner short-circuit), OSR=8192, PGA=1, GAIN=1, the internal gain is amplified to 1*1*2=2 times).

The 8192 analyzed data display RMS Noise = 10.92 LSB. For Time Domain, please refer to Table 4-3. But based on the software program processing method, which is to calculate by taking the average of 4 records each time, the total valid records are 8192/4=2048 records. To recalculate, its RMS Noise =6.26 LSB.

Then Input RMS Noise(uV) = 6.26*2.4/(1*1*2*2^22) = 1.791uV

Therefore, the actual Input RMS Noise=1.791uV. It is no problem to achieve 40000 counts, 400.00mV display, to set the ratio of the internal and external RMS Noise to be 1:5 (Input RMS Noise must be smaller than 2uV) and 1 standard stable display externally.

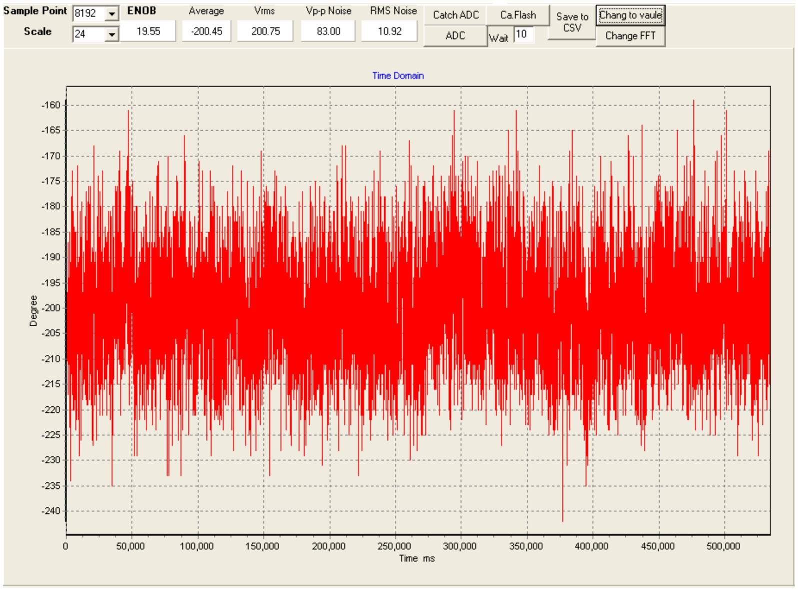


Table 3 Time domain (at PGA*GAIN=1*1)

Under the following settings, sampling 8192 records A/D output data to analyze: (VDDA=2.4V, VR+=VDDA, VR-=VSS, INH=AI0, INL=AI1, INIS ON (inner short-circuit), OSR=32768, PGA=8, GAIN=8, the internal gain is amplified to 8*8*2=128 times).

The 8192 analyzed data display RMS Noise = 75.53 LSB. For Time Domain, please refer to Table 4-4. But based on the software program processing method, which is to calculate by taking the average of 4 records each time, the total valid records are 8192/4=2048 records. To recalculate, its RMS Noise =68.21 LSB.

Then Input RMS Noise(uV) = 68.21*2.4/(8*8*2*2^22) = 0.305uV

Therefore, the actual Input RMS Noise=0.305uV. It is no problem to achieve 10000 counts, 10.000mV display, to set the ratio of the internal and external RMS Noise to be 1:3 (Input RMS Noise must be smaller than 0.33uV) and 1 standard stable display externally.

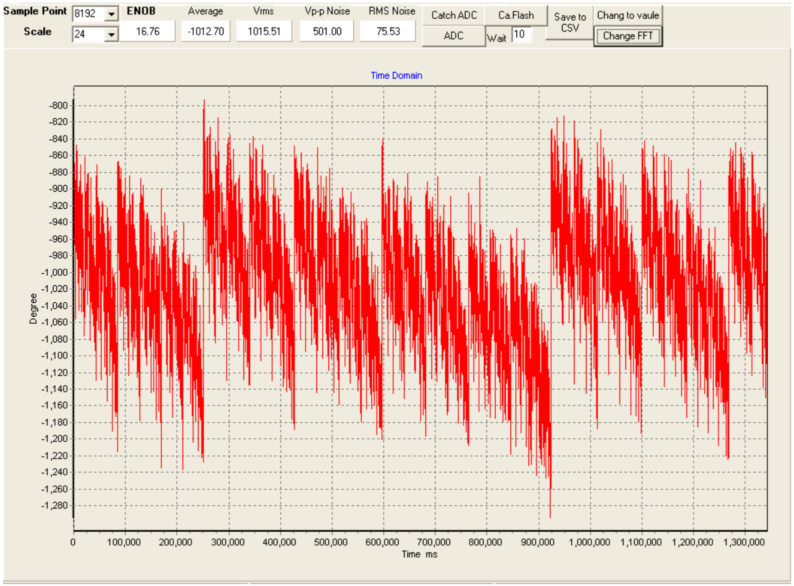


Table 4 Time domain (at PGA*GAIN=8*8)

In this article, we takes the CR2032 button battery as the power supply to proceed the current consumption tests of the chip according to different measuring modes, and found that its consuming current is about 0.16mA~0.73mA (different modes) and its sleeping current is lower than 1uA. For details, please see the data description in Table 4-5:

Measuring Mode @ VDD=3V	IDD(uA)	Powr Consumption (mW)
40000 counts Mode	370	1.11
10000 counts Mode	733	2.20
Low power 4000 counts Mode	166	0.50
TPS Mode	463	1.39
Low power TPS mode	254	0.76
SLEEP Mode	0.66	0.002

Table 5 Chip Power Consumption Measuring Data

5. Conclusion

To proceed the 10uV/1uV input signal measuring, except the external connection by many lines, it has to amplify the signal by using the general Σ-△ A/D serial products on the market and the external OPAMP, and it has to match the RC filter circuit to achieve the small signal stable movement. But, by this way, not only the cost of the components increases and the prepared materials of the production are complex, but also it causes the noise disturbance questions. To amplify the signal by using the external OPAMP, the signal will be very easy to be influenced by the noise and to distort or to lose the stability.

From the analysis, we know that to achieve 40000 counts and 400.00mV display, the smallest unit is 10uV. To set the ratio of the internal and external resolutions to be 1:5, then the Input RMS Noise must be smaller than 2uV (10uV/2). For the actual test, the internal gain is 1 (PGA*GAIN=1*1), display Input RMS Noise=1.791uV that the value is smaller than 2uV, therefore, it can achieve the ratio of the internal and external resolutions to be 1:5 and 1 standard stable display externally.

However, the smallest unit for TPS measuring display is 0.1℃, to set the internal and external resolutions to be 1:6, the Input RMS Noise must be smaller than 2.97uV. For the actual test, the internal gain is the same as 1 so that it can achieve the temperature display to set the ratio of the internal and external resolutions to be 1:6, and 1 standard stable display externally.

To achieve 10000 counts and 10.000mV display, the smallest unit is 1uV. To set the ratio of the internal and external resolutions to be 1:3, then the Input RMS Noise must be smaller than 0.33uV. For the actual test, the internal gain is 64 (PGA*GAIN=8*8) and display Input RMS Noise=0.305uV, therefore, it can achieve the ratio of the internal and external resolutions to be 1:3 and 1 standard stable display externally.

To take the actual test on the HY11P13 chip of HYCON, we found that it can achieve the measuring purpose only by the combination of few passive components for the chip. Even to amplify 1uV small signal, it needs only the built-in low noise amplifier in the chip A/D so that it can not only save the cost of the OPAMP components, but also can reduce greatly the signal distortion caused by the external noise disturbance. The author actually tested the dialing and receiving by Nokia7610 handset (the GSM 900/1800 system) and found that the signal amplifying system of the external connection OPAMP line is very easy to be disturbed by the handset signal and the measuring results are unusual by using other chips. However, HY11P13 chip is hardly affected in its testing result. The actual result of it on the external display is ±1 count inaccuracy at most. In this article, we used HY11P13 chip only to proceed with the A/D application measurement that it is mainly for the demonstration of its performance, stability and low power consumption. On the high performance of the chip A/D, we believe that it can be applied to other related sensor measuring fields.

6. Operating Description

6.1. Panel Layout

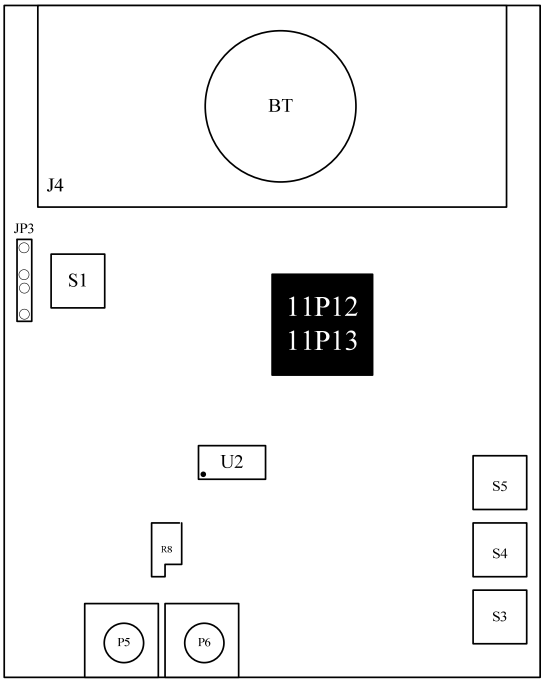


Figure10 Demo Board TOP View

For the meanings what the symbols stand for, please refer to the following description:

BT: CR2032 Battery
S1: Power Switch
S3: Button, RST PIN
S4: Button, PT1.0 Interrupt
S5: Button, PT1.1 Interrupt
11P12/11P13: Suited for HY11P13 Package, HY11P13 Dice, HY11P12 Dice
U2: 24C02, EEPROM (SCL:PT2.2, SDA:PT2.3)
P5: Positive Signal
P6: Negative Signal
J4: LCD Panel
R8:1K Adjustable Resistance

6.2. Using Method

It provides one Power ON switch (S1) and three activating switches (S3, S4, and S5).

S1: Chip Power ON/OFF Switch.
S3: Chip Reset Switch.
S4: Measuring Mode Switch.
S5: OSR / Sleep Mode Switch.

Operating Procedure:

Measuring Mode:

After starting, LCD will display the countdown digit and enter 40000 counts voltage measuring mode directly after completing the display.

S4 switch (PT1.0) provides the function to switch different kinds of modes. The switch order is as follow:

TPS Temperature Measurement:

The allowed measuring rage of the temperature is -150℃~150℃.

40000 counts Voltage Measurement:

The allowed input rage of the voltage is ±450mV; it displays —OL— if exceed.

10000 counts Voltage Measurement:

The allowed input rage of the voltage is ±9.5mV; it displays —OL— if exceed.

Low power 4000 counts Voltage Measurement:

The allowed input rage of the voltage is ±450mV; it displays —OL— if exceed.

Low power TPS Temperature Measurement:

The allowed measuring rage of the temperature is -150℃~150℃.

TPS Temperature Measurement: (Back to TPS measurement)

S5 switch (PT1.1) provides OSR Mode/Sleep Mode Switch:

OSR Mode:

By different measuring mode, press OSR each time to upgrade one class directly.

Sleep Mode:

S5 Switch (PT1.1): to press the switch over 2 seconds, then hold it and press S4 Switch (PT1.0), LCD will display SLEEP that it can make the chip enter sleep mode directly. To activate S4/S5 Switch can wake up the chip. After the chip is awaken, return to the TPS measurement..

Calibration Mode:

After starting, press S4/S5 before LCD digit completing countdown to enter the Calibration Mode.

Press S4 to enter the voltage calibration mode:

Input calibrating voltage 300.00mV, then press S4 to start 40000/4000 count voltage calibration.

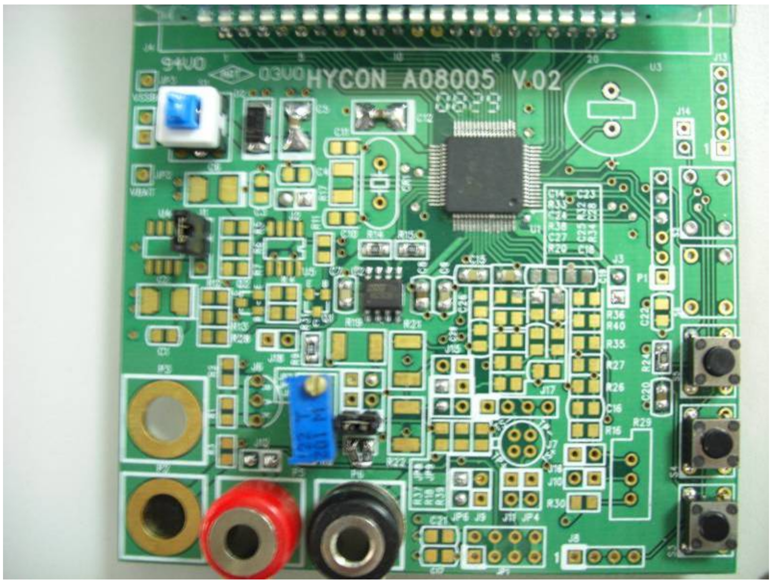
When finish, input 6.000mV, then press S4 to continue 10000 count voltage calibration.

Press S5 to enter the Temperature Calibration Mode:

To control the temperature is at 26℃, and then press S4 to continue temperature mode calibration.

When the calibration is finished, return to TPS mode to start the measurement.

6.3. The Actual Welds Board



7. Attachment

Example Program:

11P13- Voltage and temperature V04.rar

8. References

[1] Analog Dialogue 39-06, June (2005)- http://www.analog.com/analogdialogue

[2] HYCON's Product Datasheet: HY11P13- http://www.hycontek.com/