HY11P13

Application Note

4-20mA Measuring Meter Display

Table of Contents

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1. Brief Introduction

In the industrial applications, it is necessary to gauge generally the non-electric physical quantity signals, such as temperature, pressure, speed, angle and so on. These non-electric physical quantity signals will often be converted to the electric physical quantity signals through the sensors, such as electric current, voltage, power, frequency and so on. But these quantified signals must be converted again to the standard digital communication signals or the analogical electrical signals to transmit to the monitoring centers or the meters that are dozens of meters, or even hundreds of meters away.

The device to transform the physical quantity signals to the analogical electrical signals is called the converter. In the industry, the standard analogical transmitting electrical signals used broadly are 0~5V, 0~10V or 4~20mA. 4~20mA is the most common to be used.

This article will introduce how to use the HY11P13 chip that is designed by HYCON and it can achieve easily the superiority of the simple circuit design, the lower current consumption less than 0.8mA and the loop drop smaller than 2.8V. It is the best solution to use two-wire type 4-20mA current measuring chip and display with control design for the cost competency, the low current consumption and the low loop drop.

2. Theory

2.1. System Construction and Classification

The reason to use 4~20mA transmission signal is that it won't be disturbed easily, the parallel internal resistance of the current source is infinite and the wire series resistance does not affect the precision of the signal in the loop, therefore, it can transmit dozens of meters in ordinary double twists signal wires. The current signal will not be lower than 4mA in the normal operation. This design standard is mainly for testing the broken line condition of the transmission. When the loop is short due to the breakdown, the loop current will drop to 0mA, so it often takes 1.5mA current as the broken warning value. And the largest signal is 20mA for the explosion-proof request in the industrial safety, because the spark energy produced by 20mA current loop broken is insufficient to ignite the gaseous fuel.

Due to the current output converter needs to transform the physical quantity into 4~20mA current signal output, it is necessary to provide the extra external power supply. According to its construction, it can be classified as:

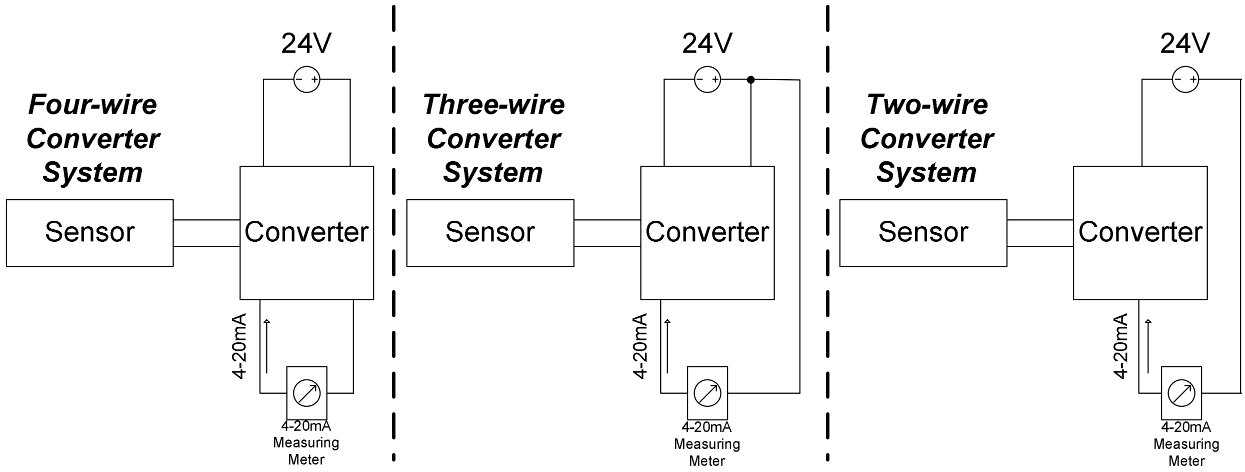

Figure 1 System Construction of Converters

Four-wire Converter:

The ordinary converter design needs to connect externally two power wires and two signal wires.

Three-wire Converter:

The converter is to reduce one wire by the design of one common wire for the signal wire and the power wire.

Two-wire Converter:

By using the design of 4-20mA current loop supplying the converter power, it takes the converter as a special load in the current loop, and its current consumption is controlled between 4~20mA with the change based on the sensor's output size. Therefore, the display meter uses only two series lines in the loop. (The lower limit of the current loop standard in industry is 4mA. So, as long as the converter gets 4mA current supply at least within the measuring range, it is possible for the design to use the two-wire sensor.)

In industrial application domain, the measuring point is generally called on-the-scene which distance is possibly dozens to several hundred meters away from the monitoring centers or the meter controllers. If we can use easily two lines to transmit signals, it must be the competitive advantage in cost. Besides, unlike the four-wire and the three-wire system converters which must often use the expensive mask line for asymmetrical current in the conducting wire, the two-wire system converter uses the very cheap double twisted wire, so it is the first choice inevitably in the application.

Since the two-wire system is the best choice, its 4-20mA signal meter shouldn't influence the current size for the signal transmission nor cause large loop drop after adding in the system loop, and it is better to have a simple circuit design. This is a dilemma in choosing the chip. The HY11P13 chip designed by HYCON can achieve easily the simple circuit design, the lower current consumption less than 0.8mA and the loop drop smaller than 2.8V.

2.2. Measuring Modes Comparison

At present the circuit composition of 4-20mA current signal measurement and control meter of the common two-wire types may divide into three parts: The first part is to use TL431 to take out the working voltage in the loop current which is needed by the meter chip. The second part is to use the OPAMP amplifier to transfer the analogy current signal into the analogy voltage signal. The third part is to use the measuring chip with AC converter to transfer the analogy voltage signal into the digital signal and show on the display or proceed other control events according to the signal size.

Figure 2 is the circuit schematic of the ordinary LCD display meter controller. Whether OPAMP is built-in or not, the circuit is hard to avoid the influence of the temperature and the zero displacement, also the loop drop caused by VDD is usually larger than 4.3V and the current consumption is situated between 1.5mA~3mA. For solving above problems, we can only make a complex circuit by increasing the cost and adding more resistors with low temperature shift coefficient, but you will find that it is weak in competency to do so because the cost of the designed product is almost equal to the ones circulating on present market.

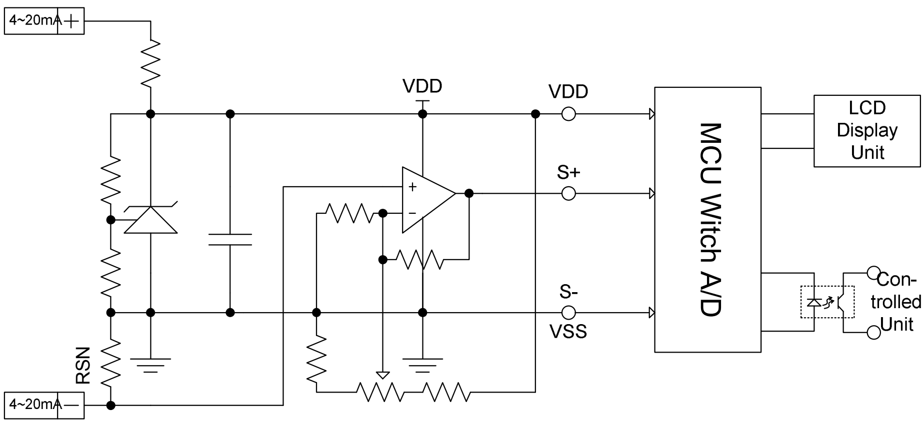

Figure 2 Ordinary LCD Display Meter Controller

Figure 3 is the circuit schematic of LCD display meter controller planned by HYCON designed product. Since the circuit does not use OPAMP to convert current and voltage, it won't be like Figure 2 OPAMP circuit that is influenced by the temperature and the zero displacement. The chip has low working voltage and low power consumption features. The drop caused by VDD to the voltage of the loop is lower than 2.8V, and the current consumption is lower than 0.8mA. To use the products designed with HY11P13 chip, the circuit construction is simple, the loop drop is smaller than 2.8V, and the current consumption is lower than 0.8mA in operation. The whole measuring circuit needs only one low temperature shift resistor RSN that increases greatly the flexibility in use for the system loop and also the product competency.

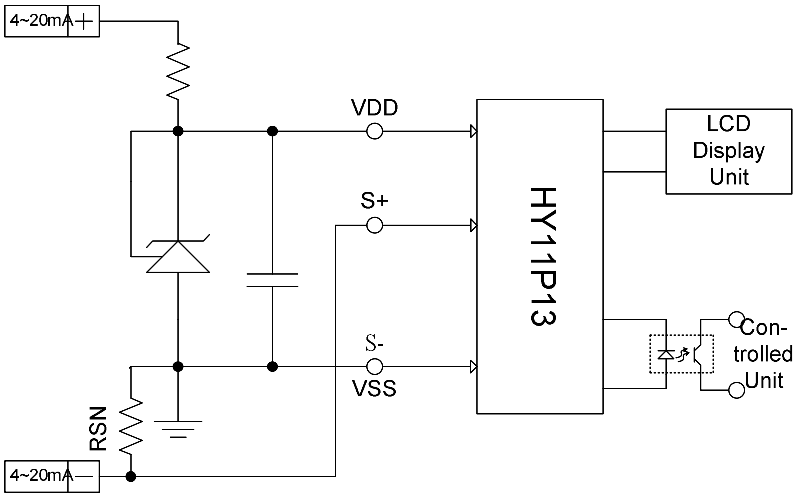

Figure 3 LCD Display Meter Controllers with HY11P13 Chip

2.3. Measuring Specification Analysis

2.3.1. Display Value Analysis

Take the 20000d display meter as the example, the full scale current is 16mA. Each 1d current changes approximately 0.8uA/d, but after flowing through the RSN resistor, each 1d voltage is equivalent approximately 2.4uV/d. Therefore, to suit the measuring specification, the chip should be able to analyze 1uV voltage change at least. If considering the good precision of the product, this chip should be able to analyze the signal below 0.8uV, such as Table 1 Specification Analysis of Meter Display.

Display Specification Analysis				
Display Value (d)	Current Change of the Loop (mA)	Resolution (uA/d)	RSN Resistance of the Loop (Ω)	Resolution (uA/d)
1999	16	8.004002	3	24.01
19999	16	0.80004	3	2.4
99999	16	0.160002	3	0.48

Table 1 Specification Analysis of Meter Display

Moreover, it is inevitable that the temperature influences the system. For 100ppm/℃ measuring specification, if regardless the temperature influence to 4-20mA current signal itself, the value shift influenced by the temperature is the most important for the measuring unit (ADC, analogical and digital converter) of the chip in measuring system. So, choosing a low temperature shift coefficient measuring chip can save the time of adjusting the temperature compensation in the system.

Finally, the consideration of the drop caused by the loop is always the problem of the two-wire system meter. In general loop voltage designs, the voltage is 24V and the loop voltage must supply the converter, then provide the series connection separately to the system's meter. This will make the equipments to be many so that it is necessary to consider the low loop drop.

2.4. Measuring Theory

Based on the consideration to achieve above specifications, the HY11P13 chip developed by HYCON can solve the measuring problems easily. The measuring construction is shown as Figure 4. The analogical and digital converter usually has a signal input end (SI+, SI-) and a reference voltage end (VR+, VR-). The measurable range of SD18 (ADC, analogical and digital converter) is VDD+0.2V to VSS-0.2V, and the reference voltage input can be input from the reference potential source ACM with the low temperature shift by itself. With that, it does not only achieve the performance of measuring temperature coefficient approximately at 100ppm/℃ but also get rid of the trouble from choosing low temperature shift resistors. Also, it reduces the interference of the circuit and the increase of the current consumption (It may take the external input method as a consideration for SD18 reference voltage input if the system needs better temperature coefficient specifications.)

Then, use 4-20mA current loop through the RSN resistor (select 5ppm/℃) to produce the negative voltage differential to input SD18 (18-bit, ΣΔADC) so as to proceed the analogical and digital converter. In this way, the entire measuring system including the SD18 temperature drift is approximately below 120ppm/℃.

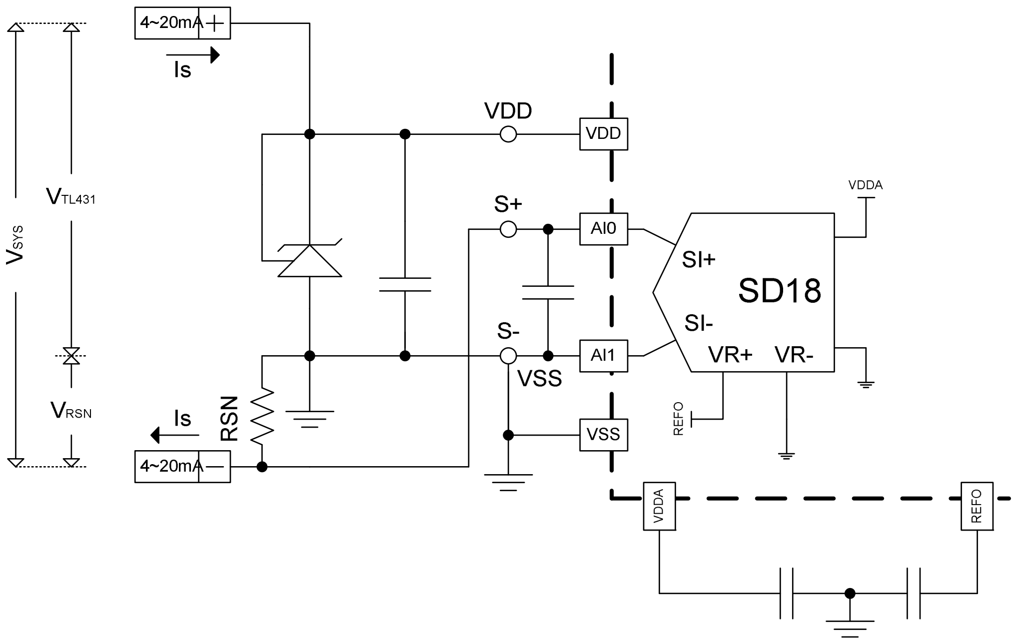

Figure 4 Measuring Construction of HY11P13 Chip

ENOB (Vrms), Reference and Input Buffer off

Gain \ OSR	256	512	1024	2048	4096	8192	16384	32768
1/4 (ENCHP=1)	16.49	17.31	18.23	18.75	19.10	19.71	20.04	20.21
1/2 (ENCHP=1)	16.42	17.23	18.03	18.46	18.80	19.37	19.81	20.03
1 (ENCHP=1)	16.20	17.10	17.84	18.40	18.65	19.14	19.59	19.62
2 (ENCHP=1)	16.16	17.08	17.87	18.30	18.39	18.69	19.13	19.50
4 (ENCHP=1)	15.72	16.21	16.87	17.22	17.67	18.28	18.83	19.16
8 (ENCHP=0)	14.85	15.64	16.13	16.70	17.16	17.70	18.06	18.65
16 (ENCHP=0)	14.81	15.33	16.18	16.67	17.04	17.61	18.09	18.60
32 (ENCHP=0)	14.29	14.85	15.51	15.89	16.33	16.81	17.34	17.88
64 (ENCHP=0)	14.03	14.56	15.17	15.63	15.99	16.53	16.93	17.41
128 (ENCHP=0)	13.69	14.12	14.52	14.91	15.31	15.82	16.21	16.56
256 (ENCHP=0 VR = 1)	12.50	13.11	13.55	14.11	14.61	15.10	15.67	16.12

Table 2 ENOB Values for SD18 Performance Target

Continually we design the drop range of the entire measuring circuit system. The calculating method is as Formula 1. Then refers to the technical data of HY11P13 and TL431 provided by the original factories, and evaluate simultaneously the ENOB performance of the SD18 and the drop to the system's loop to choose the appropriate RSN resistance.

Formula 1 Measuring System Drop

$$V_{SYS} \cong V_{TL431} + V_{RSN}$$

This applicative solution is to use 3Ω RSN resistance and TL431 standard 2.5V stabile voltage circuit design, therefore the overall loop drop is in VSYS=2.5V~2.6V. The voltage change opposite to VSS produced by 4-20mA current signal through the RSN resistance is - 12mV~-66mV, and is input to the SD18 signal measuring end (SI+, SI-).

Is=4mA (Normal)

VSYS=2.5V+3*4mA=2.512V

Is=20mA (Normal)

VSYS=2.5V+3*20mA=2.56V

Is=22mA (Drifting)

VSYS=2.5V+3*22mA=2.566V

To set SD18 reference voltage input to be ACM=1.2V and the input signal (SI+, SI-) amplification to be 16, that is, the largest voltage of the input signal opposite to the reference voltage (VR+, VR-) is approximately 1.056V (the reference voltage value smaller than 0.9 amplification is the best measuring range of SD18). Then, refer to Table 2, we know that the measuring performance ENOB of SD18 is approximately 18.6 bit in resolution, and the resolution is approximately 15.9 bit after converting ADC Noise Free. To filter the wave digitally by software, it increases approximately 1~2bit in resolution. Therefore the actual resolution is 17bit (Noise Free) at least that it is enough to design simply the 0~19999 display meter head, like Table 3 ADC Capability Analysis.

ADC Measuring Capability Analysis								
Maximum Current and Relative Voltage		ADC ΔVR	ADC Resolution		ADC Amplification and Input Signal			
mA	(mV) to VSS	(V)	Noise Free	(uV/LSB)	Gain	(uV/c)	Δ SI*Gain(mV)	
20	-60	1.2	16	18.31	4	9.60048	240	
21	-63	1.2	17	9.16	8	19.20096	504	
22	-66	1.2	18	4.58	16	38.40192	1056	

Table 3 ADC Capability Analysis

Here we calculate the 4-20mA, 20000d display meter for its SD18 internal indexing (c) in each 1d, that is, what the value of the inside and outside ratio.

The voltage signal analysis ability of SD18 internal smallest indexing (1c)

1c=ACM/217=1.2V/217=9.16uV/c

The voltage in each 1d for 4-20mA, 20000d

V1d =(20mA-4mA)*RSN/2x104=48mV/2x104=2.4uV

The voltage in each 1d is amplified through SD18

V1d x16=2.4uV*16=38.4uV

The voltage in each 1d is measured in 17bit resolution through SD18

1d: 1c=38.4uV: 9.16uV ≒1: 4

The inside and outside ratio is 1:4, that is, outside 1d stands for inside 4c.

2.5. Control Chip

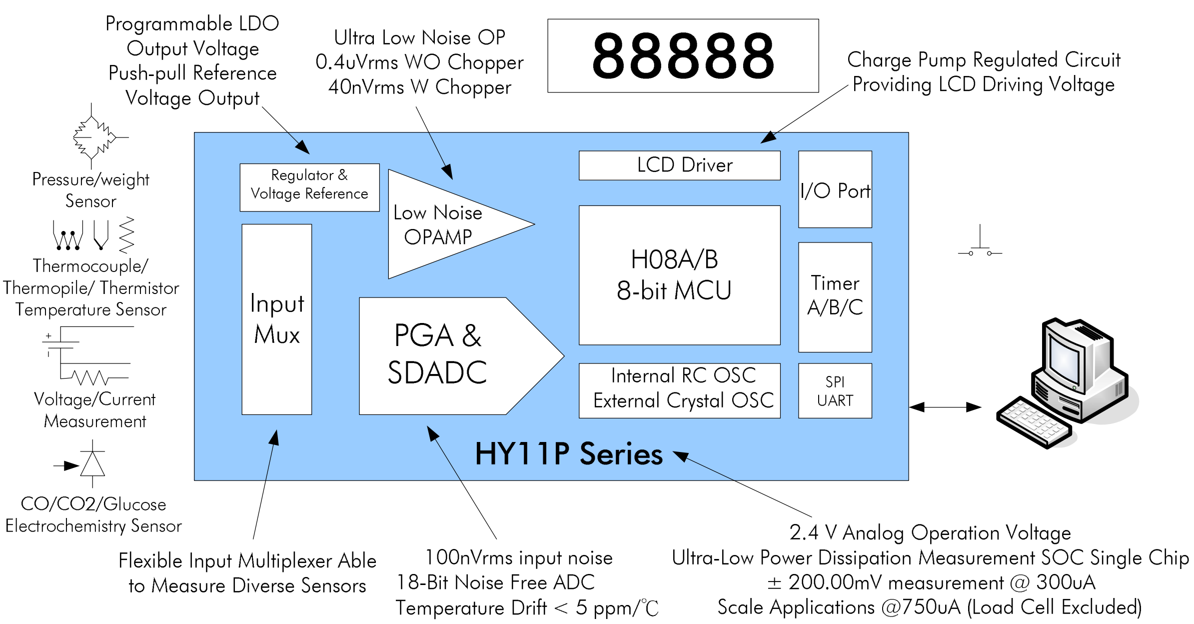

Figure 5 HY11P13 High Performance 8bit OTP Single Chip System

- 8 bit enhanced RISC (Reduced Instruction Set Computing) has totally 68 instructions including the hardware multiplying instructions and the look-up instructions.
- 2.2V to 3.6V working voltage range, -40℃~85℃ working temperature range.
- External quartz oscillator and internal high accuracy RC oscillator, 6 kinds of CPU clock rate switches, the best save power plan for users.
  a. Operation mode 300uA@2MHz
  b. Idle mode 3uA@32KHz
  c. Sleep mode 1uA
- 4KWord OTP (One Time Programmable) Type program memory, 256 Byte data memory
- Brownout and Watch dog Timer, to avoid CPU down
- 18-bit fully differential input ΣΔADC
  a. Built-in PGA (Programmable Gain Amplifier) and 10 input signal selections by 1/4, 1/2, 1～128 amplification.
  b. Built-in zero input adjustment, measuring range increasable for various applications.
  c. Built-in high resistance input buffer (not suitable for the input amplification above 32)
  d. Built-in absolute temperature sensor.
- Super low input noise (<1uVpp) operating amplifier, offering the amplification for the small signal of the high output resistance and the voltage convert of the small current.
- 1.2V low temperature shift coefficient reference voltage source output with Push-Pull drive capability, offering the drive voltage to the sensor.
- 10mA low voltage differential voltage-stabilized source output, 4 selections for different output voltages.
- 4x20 LCD driver
  a. Static, 1/2, 1/3 and 1/4 Duty; 1/2 and 1/3 Bias software selection
  b. Built-in Charge Pump voltage stabilizing, offering 4 kinds of LCD bias voltage
- 8 -bit Timer A
- 16-bit Timer B module with Capture/Compare function
- 16-bit Timer C module with PWM/PFD wave producing function
- Series communication SPI module

3. Design Scheme

3.1. Hardware Description

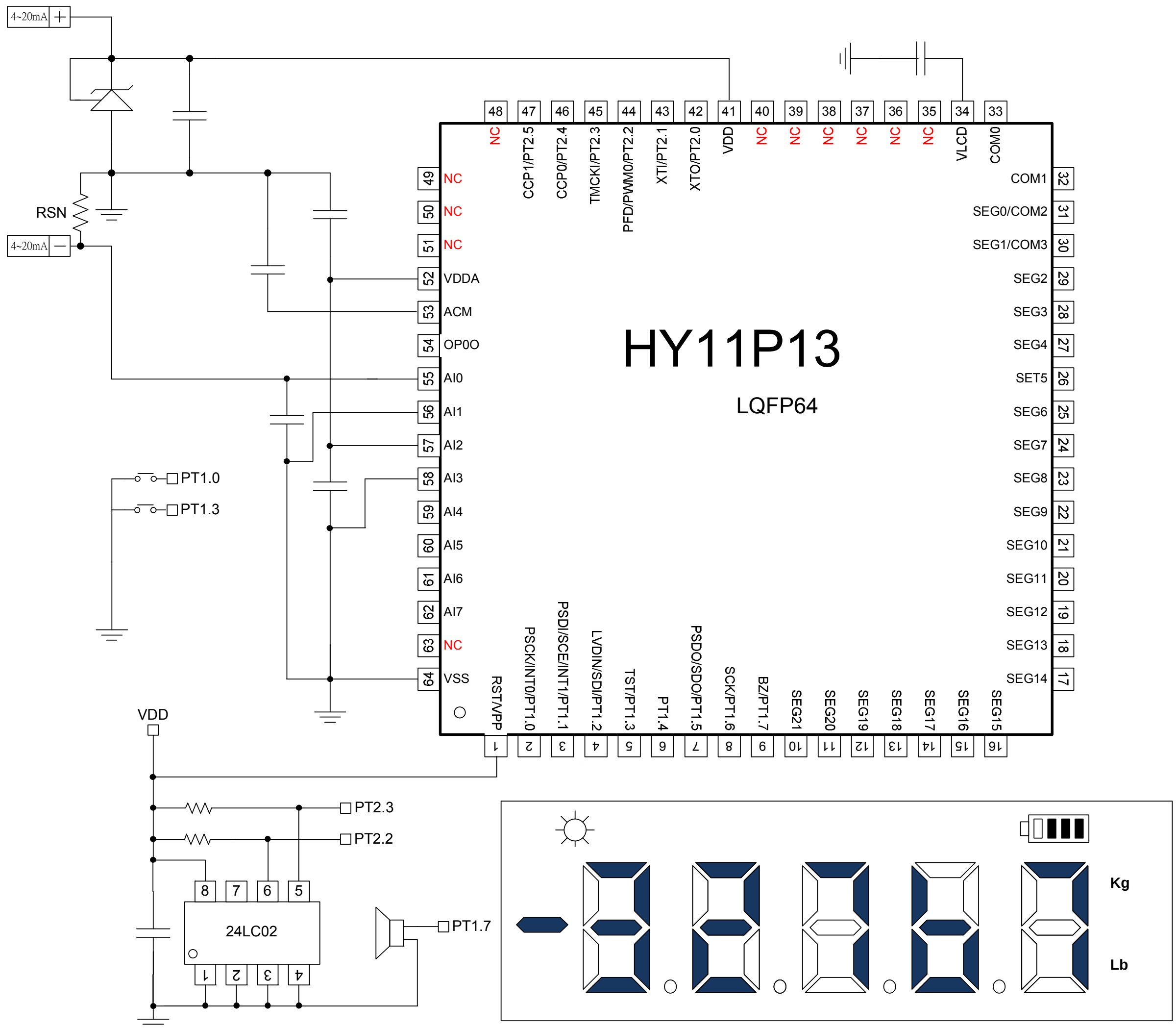

Figure 6 HY11P13 Application Circuit

3.2. Circuit Description

The working voltage of HY11P13 chip is gotten by using the characteristic that the measuring signal source is a current change loop. In the loop, it can stabilize 2.5V potential difference to HY11P13 through the voltage stabilizing chip TA431.

To measure the 4-20mA current change is to use the voltage change by measuring the RSN resistance that is series connected in current loop. The voltage change opposite to the chip is a negative potential change so that we cannot use the internal input buffer of HY11P13 when doing the measurement.

24LC02 is the memory chip used in storing the calibrated parameters, default values and so on data. PT1.0 and PT1.1 have calibration, setup, zero reset and inner code display functions.

3.3. Software Description

3.3.1. Easy Digital Filter and Theory

As the signal is amplified to 16, SD18 output Bit can only achieve ±15bit (Noise Free). The SD18 resolution can be promoted 1~2 bit again if using the digital filter. The working theory of this simple digital filter is to take the average of eight records of SD18 outputs, that is, to plus the new SD18 output and the former 7 values value each time and then divide them into 8, and output the result to ADC OUT buffer, like Figure 7 "SD18 Output Data and Digital Wave Filter".

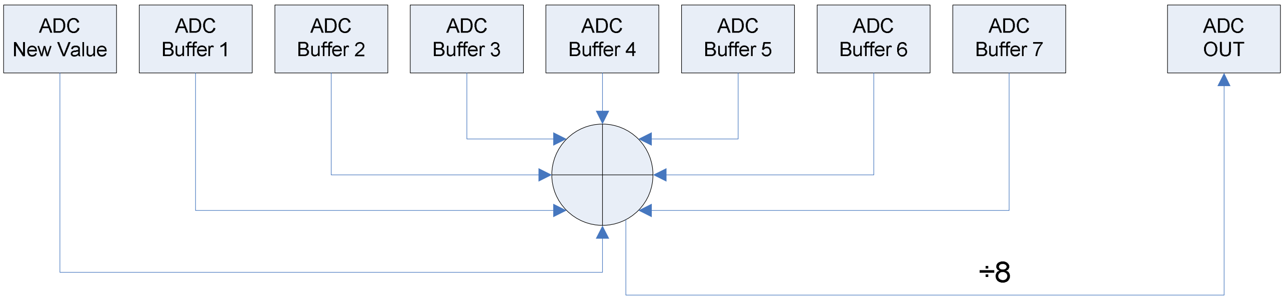

Figure 7 SD18 Output Data and Digital Wave Filter

After the SD18 average being output to ADC OUT, take it as the new value and put it to Buffer 1, and move the data in Buffer1 to Buffer2…and such like until moving Buffer 6 to Buffer 7, then discard the original Buffer 7 data, like Figure 8 "Digital Wave Filter Data Algorithm".

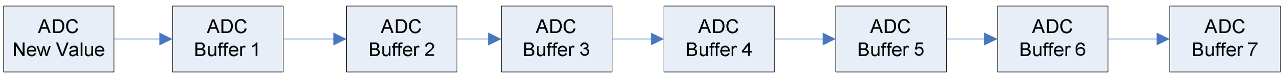

Figure 8 Digital Wave Filter Data Algorithm

Because the reaction time of the average output is quite slow, it needs to jump over this average program when encountering a large change on ADC value. When the SD18 output new value is bigger than the average over 0x200, record this new SD18 value first and not join the average operation. If the next SD18 output value is still bigger than the average over 0x200, then take new value to replace all SD18 buffers and output it to ADC OUT; but if the SD18 value is not over 0x200, discard the former records, and return to the original average flow. The digital wave filter processing flow is as shown in Figure 9.

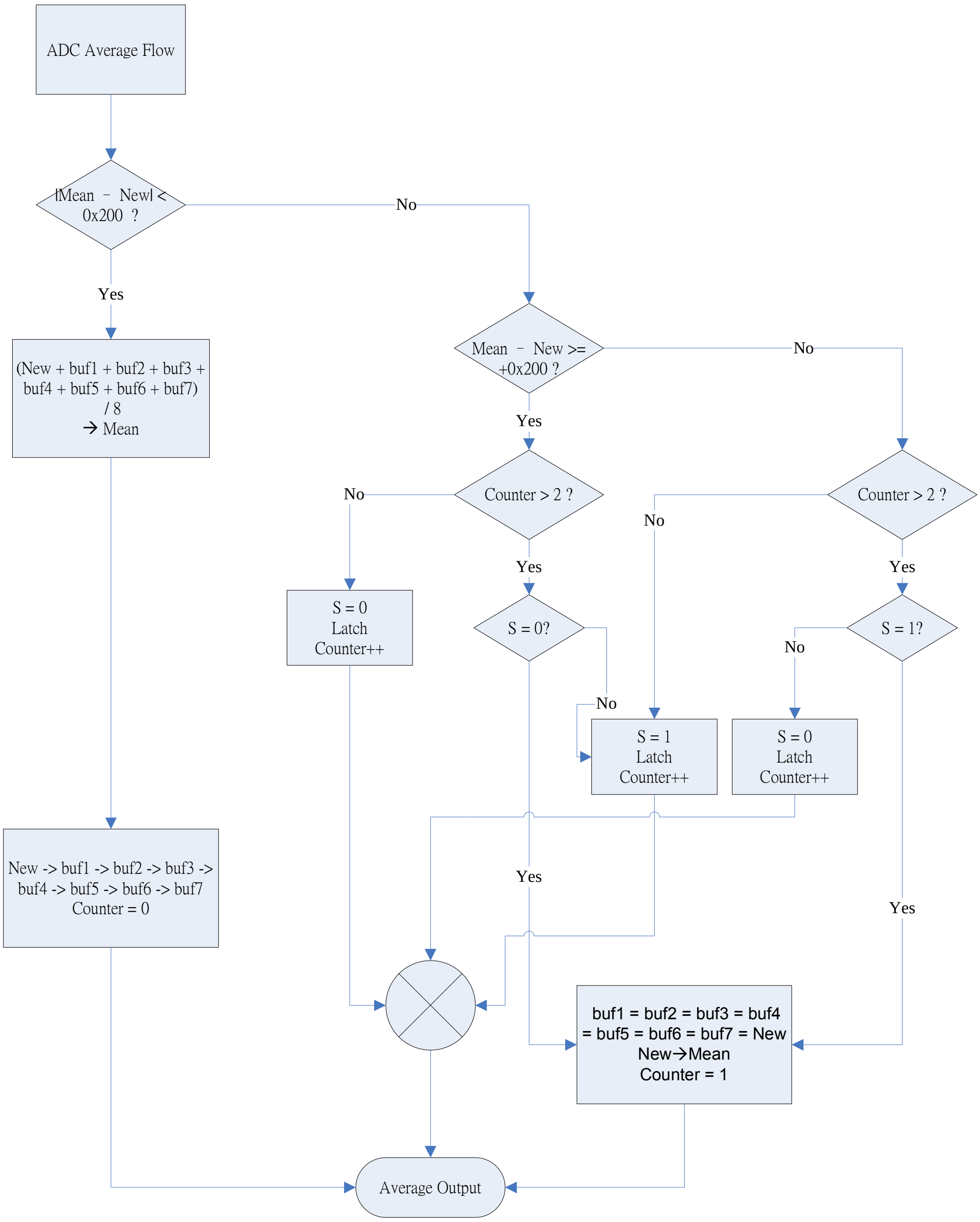

Figure 9 Digital Wave Filter Data Process

4. Technical Specification

Power Connection : two-wire current loop (4-20mA current input)
Loop Drop : < 2.8V
Power Consumption : < 0.8mA
Temperature Shift : < 120ppm/℃
Data Display : 5 bit LCD display
Data Update : 1/sec
Resolution : 0.001mA
Display Value : 0～19999
Apply Field : Various converters for Pressure, Temperature, Flow and PH meters
Working Temperature : -40℃ ～ +85℃
Save Temperature : -55℃ ～ +125℃
Relative humidity : ＜95% (20±5℃ condition) no dew
Anti-inverse Protection, 24V over-voltage and over-current protection

5. Conclusion

This applicative solution is to use HY11P13 chip to achieve 4-20mA two-wire measuring meters without power supply by the simple circuit construction. The features of the solution are as follow:

- Simple circuit with high measuring resolution and low temperature ship coefficient.
- Low loop drop and low current consumption.
- I/O has ±10mA loading ability. High expansibility to the control demand and easy to design.
- Signal sampling rate is up to 250KHz and data updating rate is adjustable according to the actual needs.

HY11P13 is a very suitable measuring chip to apply in current or voltage signals and high ratio of the performance to the price.

6. Operation Description

6.1. Operating Process

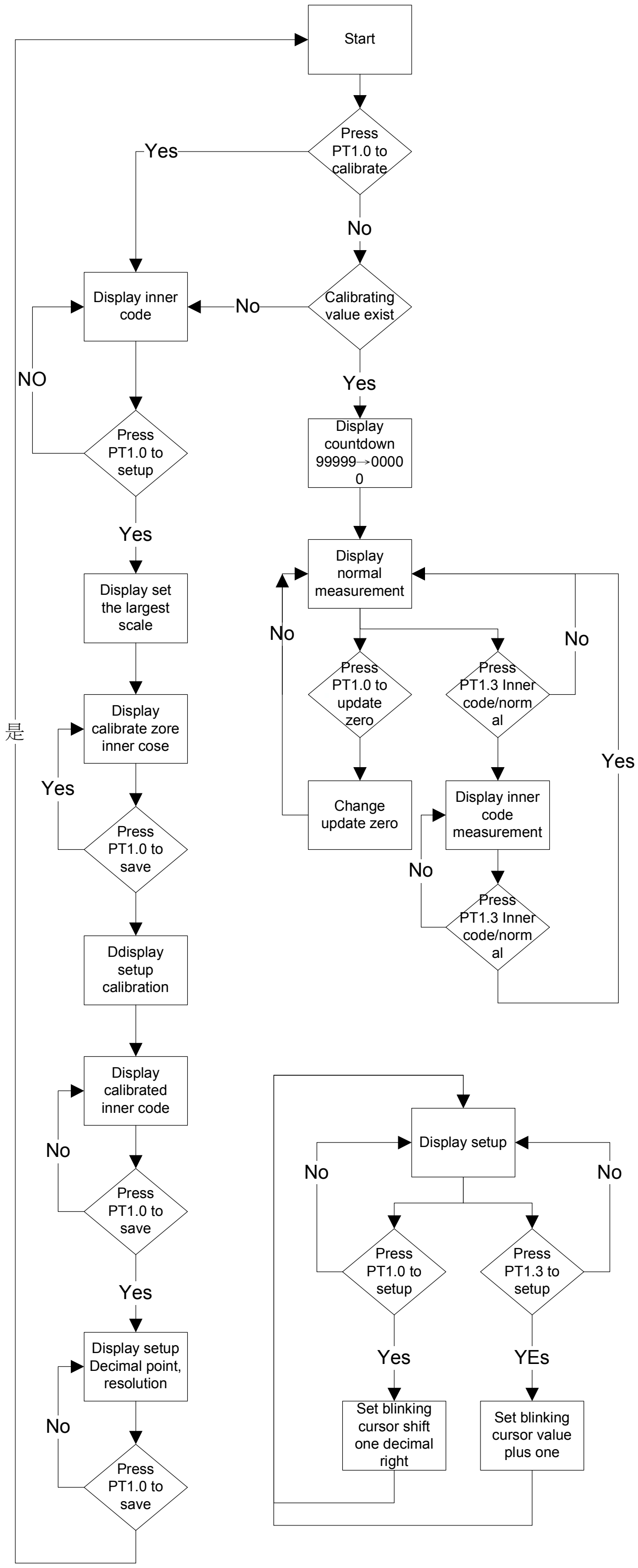

Figure 10 Operating Process