AN1548
APPLICATION NOTE

HIGH RESOLUTION SINGLE SLOPE CONVERSION WITH THE ANALOG COMPARATOR OF THE ST52X440

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INTRODUCTION

The following application shows the operation of the analog comparator of the ST52x440 microcontroller along with some examples of various resolution measures with varying conversions from 8, 10 and 12 bits.

PRELIMINARY

The ST52_440 includes an Analog Comparator among its peripherals that allows the user to make use of it as a single slope Analog to Digital converter.

In A/D Mode the user may choose either to insert an external capacitor to pin CS or to connect to an external signal to generate ramp. The internal current generator, utilized to charge the capacitor provides 7 possible current values from 0 to 70µA with steps of 10 µA.

The capacitor should have a low voltage coefficient for optimum results. The optimum linearity in conversion can be obtained if the voltage level on the selected input channel does not exceed a maximum of 3V.

A/D CONVERSION THEORY

The A/D slope is formed when a constant current drives a capacitor. According to the basic capacitor theory, the voltage across this capacitor is described by the following equation: [1]

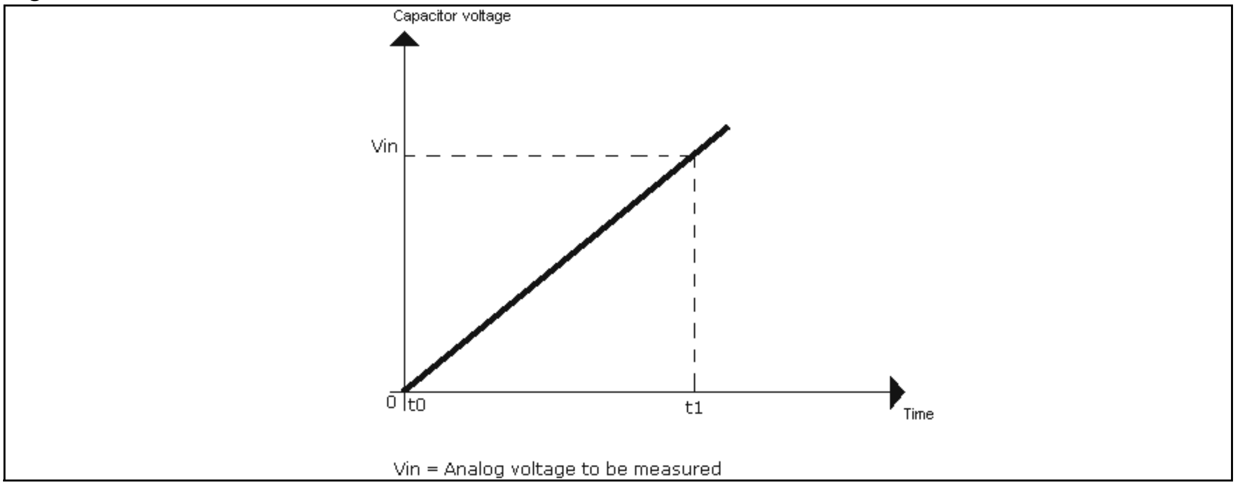
$$V(t) = \frac{1}{C} x \int_{t0}^{t1} i(t)dt$$

Since the current i(t) is constant, the former equation is reduced to the following equation: [2]

$$V(t_1) - V(t_0) = \frac{i}{C} x (t_1 - t_0)$$

This relationship describes a basic linear voltage ramp. The analog to digital conversion is obtained by measuring the time from the beginning of the linear ramp (t0) to time (t1), in which the voltage across the capacitor equals the analog input voltage to be converted. Time is measured by a digital counter circuit. Therefore, the delta time value (t1-t2) represents the magnitude of the analog voltage being converted. In this application note, the delta time value measured will simply be referred to as the “N” for the particular analog voltage being converted.

Figure 1. LINEAR VOLTAGE RAMP A/D CONVERSION



The magnitude of the analog voltage measured can be determined if the capacitance and the charging current are known. However, these values cannot be determined exactly. Therefore, a reference voltage that is known is used instead. This reference voltage is supplied by a very stable circuit known as a band-gap reference. The analog input voltage is determined ratiometrically by performing two successive A/D conversions: the first on the analog input voltage and the second on the reference voltage. The analog voltage being measured can be calculated by using the equation below: [3]

$$V_{in} = \frac{N_{in}}{N_{BG}} x K_{BG}$$

Where: $\boldsymbol{N_{in}}$= A/D count value for selected input

$\boldsymbol{N_{BG}}$= A/D count value for bandgap reference

$\boldsymbol{K_{BG}}$= Absolute voltage value of the bandgap reference voltage.

Equation (3) assumes that the starting voltage of the linear ramp $V(t_0)$ in both the analog input and the reference voltage conversion is zero. However, the capacitor cannot be discharged completely from the prior conversion and a few millivolts worth of charge (referred to as offset voltage), may remain on the capacitor. This effect is called capacitor dielectric absorption and varies depending on the capacitor's dielectric material, voltage to which it was charged during the last charge cycle and the amount of time the capacitor has had to discharge. While teflon capacitors exhibit the lowest dielectric absorption, polystyrene and polyethylene are also excellent. Ceramic, glass and mica are fair, while tantalum and electrolytic types are poor choices for A/D applications.

Additionally, the comparator (that compares the ramp voltage to the input voltage and stops the timer when the voltage are equal) usually has a few millivolts of offset error in its comparison. This comparator offset voltage adds (or subtracts) to the dielectric absorption offset.

Finally, the counter that times the conversion may have a very small constant turn-on or turn-off delay that affects the measurement in the same manner as offset voltage.

SOFTWARE IMPLEMENTATION

An example of the A/D conversion at a 10 bit resolution is provided below by explaining in detail the configuration mask of the analog comparator of the ST52x440 microcontroller. Further in this application note, the linearity measures performed as the frequency varies will be shown.

Setting Clock Master

First of all, the working frequency of the microchip needs to be established, which in this case is set to 10 Mhz (see Figure 2) afterwards, the Port Pins must be configured (see Figure 3).

Figure 2. CLOCK MASTER CONFIGURATION

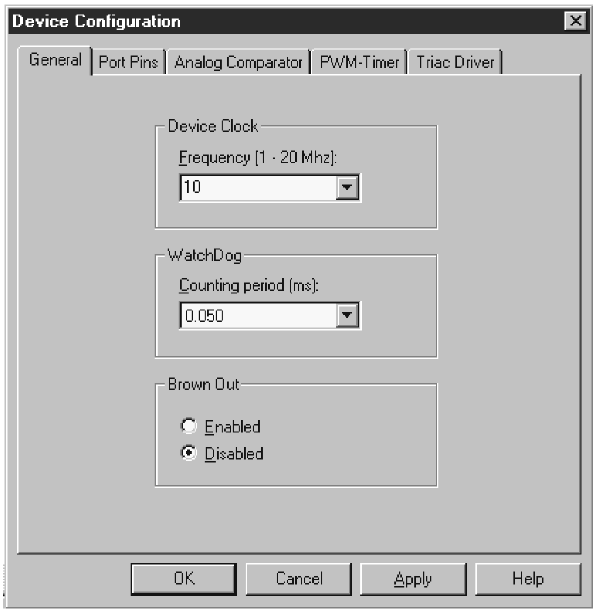
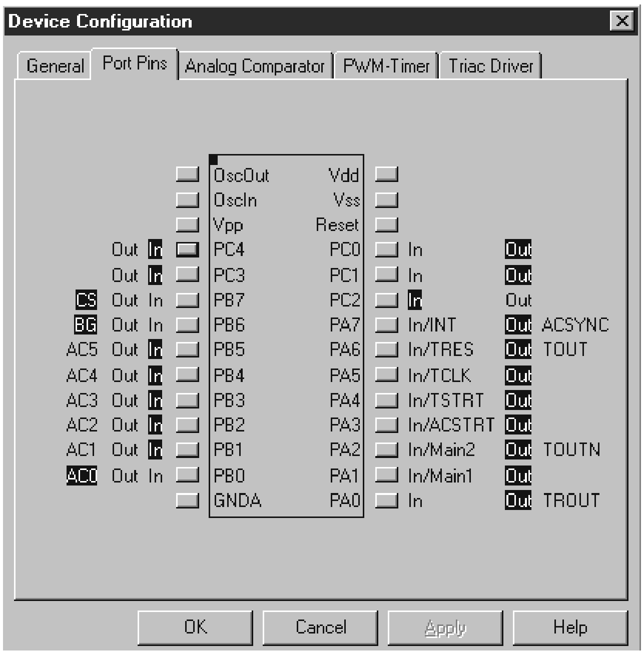


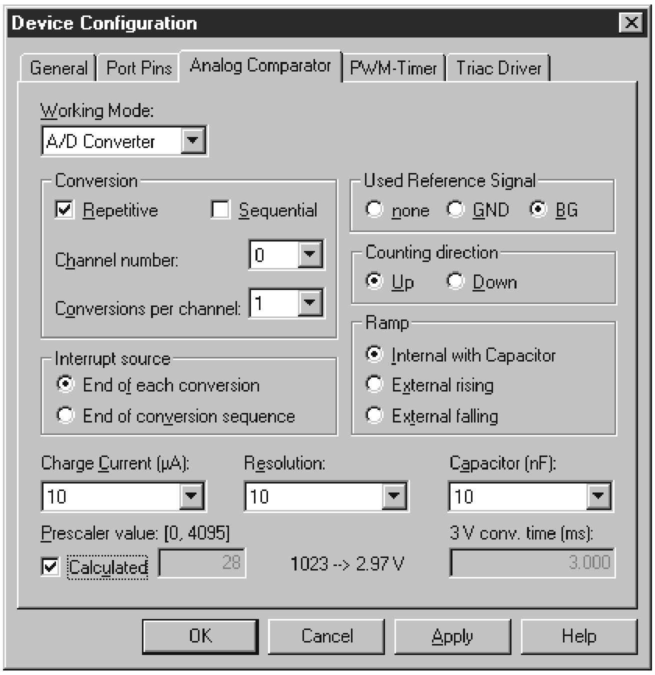
Figure 3. PORT PIN CONFIGURATION



Setting Device Configuration

In this application, the digital outputs are represented by all of Port A (PA0-PA7) and the two pins of Port C (PC0 and PC1). The analog input to which we will apply a variable tension from 0V to 3V is pin PB0, configured in the Alternate Function AC0, one of the possible analogic inputs. Pin PB7 is set as CS to apply the capacitor (10nF to 1000nF are recommended) for the ramp generation. Lastly, by setting pin PB6 as BG, the bandgap is mode available. Once the value of the capacitor to be inserted is established, the Analog Comparator mask can be configured (see Figure 4).

Figure 4. ANALOG COMPARATOR CONFIGURATION



Setting Analog Comparator

The first thing that has to be set in the analog comparator of the ST52x440 is the **Working Mode**. Afterwards, the type of conversion to be performed may be selected. **Repetitive** mode offers a cyclic A/D conversion, while **Sequential** mode only provides a sequential A/D conversion for all the analog channels that are configured. Obviously, if only one channel is configured **Sequential** mode wont be available.

The user may also set the number of times for which a conversion can be performed for the same channel, from 1 to 3. This number represents the group of conversions, which the **Interrupt Source** check boxes refers to. For example, let's suppose we have two analog channels, ACO and AC1 and we set the **"Conversion per channel"** for each one of these on 3. By selecting the option **"End of each Conversion"** an interrupt will occcur at the end of each single Analog-Digital conversion. Instead, by selecting the option **"End of each Conversion Sequence"** an interrupt will occur at the end of the last analog channel, AC1. The options contained in the **Used reference Signal** offer the possibility of being able to insert a channel of reference that can be either mass or bandgap in the A/D conversion. For example, by setting the option **BG**, the conversion of the signal applied in input will occur alternatively with the conversion of the bandgap. By setting **none**, only the analog conversion signal in input will be performed. The options of the **Counting direction** section represent the way in which the calculation will begin the ramp conversion. For example, by setting the resolution to 8 bits with the **Counting direction** on **Down** the following result will be obtained:

$$N = 255 \to 0\text{Volt}$$

and

$$N = 0 \to 3\text{Volt}$$

viceversa, if the option **Up** is selected the counter will begin from zero and the following result will be obtained:

$$N = 0 \to 0\text{Volt}$$

and

$$N = 255 \to 3\text{Volt}$$

Another possibility that is offered with the ST52x440 microcontroller is the application of a ramp of voltage as a replacement of the external capacitor. This work modality can be set in the **Ramp** section, in which the user can choose the positive or negative slope of the input ramp. If this working mode is chosen instead of the external capacitor, we have to keep in mind that pin PA3 in **Alternate Function ACSTRT** must be used as a timer start, in order to syncronize itself with the beginning of the ramp.

Particular attention needs to be given to the three list boxes which configure the following:

Charge current (uA) = the current generator used to charge the capacitor

Resolution = the resolution with which to perform the A/D conversions

Capacitor (nF) = the value of the capacitor to be connected to the micro

Prescaler value: [0,4095] shows the range of the prescaler values to set in the edit field, in accordance to the following equation: [4]

$$P = \left[\frac{C(nF)xCKM(Mhz)xFullScale(V)x10^3}{\text{Charge Current}(\mu A)x2^{\text{Resolution}}}\right] - 1$$

where : **C** = value of the capacitor expressed in nF;

CKM = value fo the frequency of the clock master expressed in MHz;

FullScale = value of the maximum range expressed in Volts;

Charge_Current = value of the generator of the current expressed in uA.

The prescaler value can be set manually, according to the necessities of the maximum range of the user, or it can be calculated automatically by the Visual FIVE program by clicking on the box **"calculated".**

The Visual FIVE program will calculate the prescaler in such a manner that it has maximum resolution to the maximum voltage range, which is equal to 3V.

The last box, **3V Conv.Time (ms)** provides an indication of the time duration of the charge of the capacitor in order to reach 3 Volts.

Main Program

The following figures show the various blocks that compose the program through which the measures of the A/D conversions can be performed. Figure 5 shows the main program.

Figure 5. MAIN PROGRAM

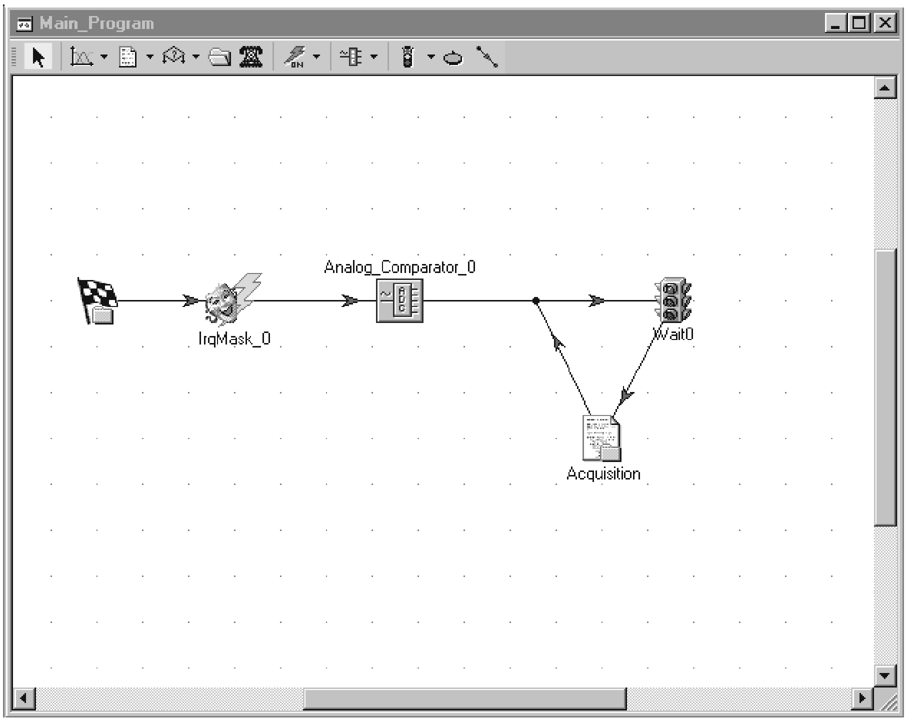
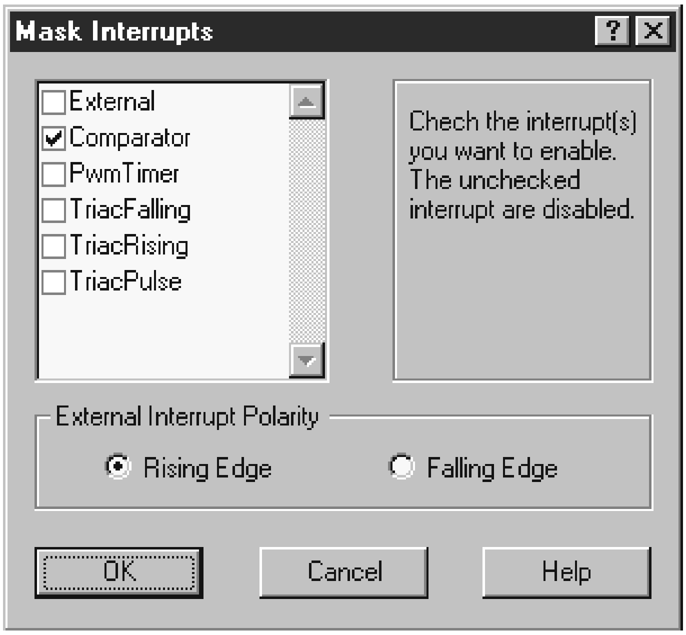


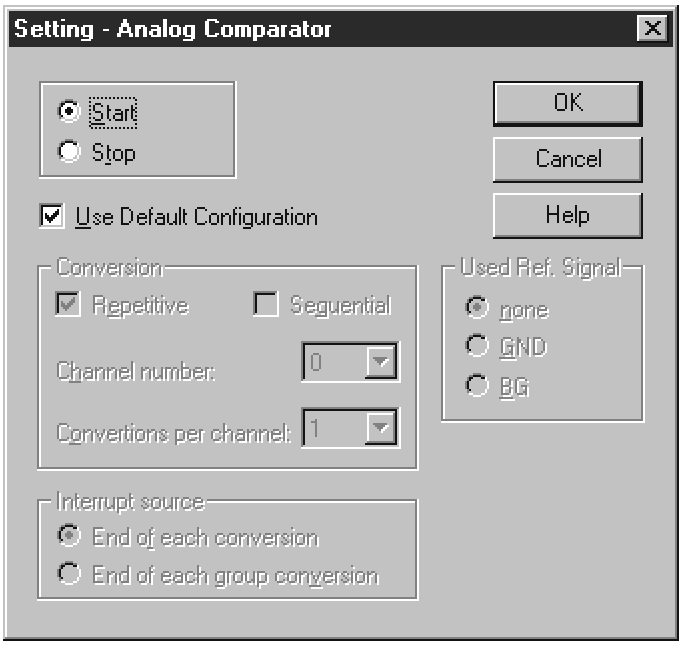
Figure 6 shows the block of the Irq_Mask_0, which enables the interrupts of the comparator.

Figure 6. COMPARATOR INTERRUPT ENABLE



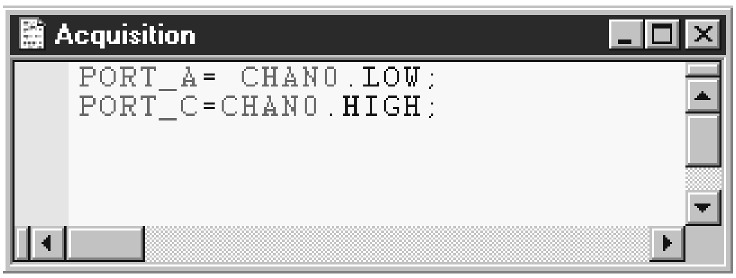
The second block in the main program is represented by figure 7 and simply indicates the start of the Analog Comparator and takes into account the configuration set during the Setting Device Configuration (figure 4).

Figure 7. START ANALOG COMPARATOR



The last block in the main program is a small code that transfers the digital value N into Port_A and Port_C. The “Wait” block sincronizes the digital value at the end of every conversion. If using an 8 bit resolution, the second code instruction in figure 8 can be omitted.

Figure 8. CODE FOR ACQUISITION

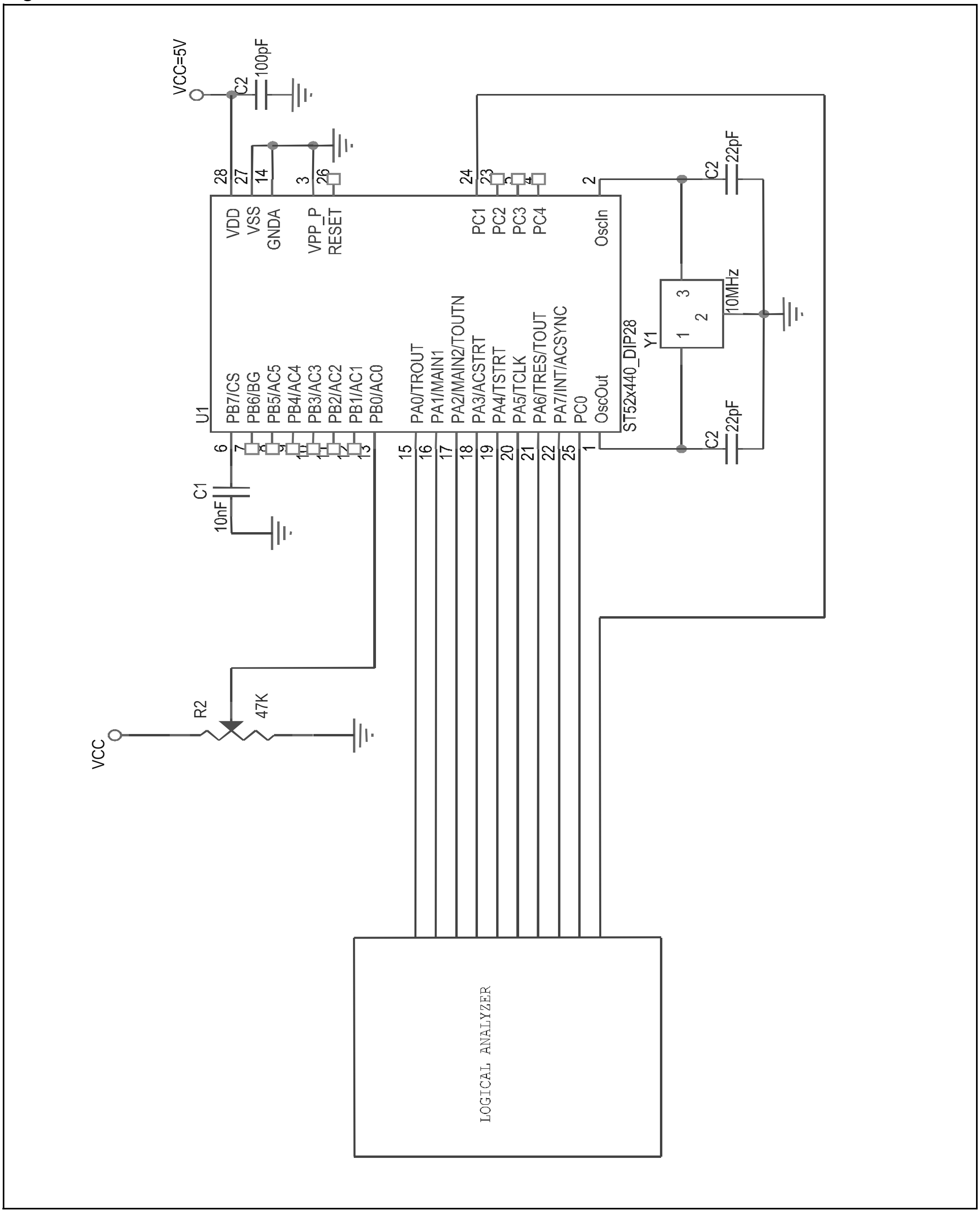


HARDWARE IMPLEMENTATION

Schematic

The schematic used to convert an analog signal in input to PB0 pin of the ST52x440 micro into a digital signal that can be taken from the pins of Port_A and Port_C , which is shown in Figure 9 below.

Figure 9. SCHEMATIC



MEASURES

The following section shows the measures of the analog comparator of the ST52x440 microcontroller. The measures were performed at 8,10 and 12 bits changing the dimensions of the capacitors by 10,100,1000nF, internal current generators by 10,40,70uA and the frequency by 5,10,20MHz for each one of these resolutions. In order to provide an example, we will take into consideration only a few of these tests.

The tests were performed at constant temperatures of around 25°Celsius.

Figure 10. A/D CONVERSION-8 BIT

input Volt.	measure	theoretic value
3	253	249.2
2.85	240	236.7
2.52	211	209.3
2.25	188	186.9
2	166	166.1
1.87	155	155.3
1.5	124	124.6
1.24	100	103.0
1	82	83.1
0.5	39	41.5
0.3	23	24.9
0.2	15	16.6
	Note:	
	BG = 2.51V	
	Presc.= 58	
	Freq.=5Mhz	
	I=10uA	
	C=10nF	

Figure 11. A/D CONVERSION-10 BIT

input Volt.	measure	theoretic value
2.95	1022	996.9
2.85	980	963.1
2.4	826	811.0
2	715	675.9
1.82	624	615.0
1.51	515	510.3
1.2	407	405.5
1	339	337.9
0.7	228	236.6
0.29	90	98.0
	Note:	
	BG = 2.58V	
	Presc.= 28	
	Freq.=10Mhz	
	I=10uA	
	C=10nF	

Figure 12. A/D CONVERSION - 12 BIT

input Volt.	measure	theoretic value
3	3780	3675.0
2.76	3498	3381.0
2.52	3212	3087.0
2.17	2750	2658.3
1.96	2493	2401.0
1.67	2113	2045.8
1.25	1606	1531.3
1.02	1292	1249.5
0.77	964	943.3
0.54	667	661.5
0.3	355	367.5
	Note:	
	BG = 2.51V	
	Presc.= 3	
	Freq.=5Mhz	
	I=10uA	
	C=10nF	

Notes:

input VOLT = Value of the analogic voltage applied at the input of the microcontroller;

measure = measure of conversion taken from a Logical analyzer on exit of the microcontroller;

theoretic value = theoretical conversion of the input voltage, calculated by the following equation: [5]

$$N = \frac{V(t) \times C}{I \times (P+1) \times T_{CLK}}$$

where:

V(t) = tension applied in a certain instant in (0;3) Volts;

C = value of the capacitor connected to the microcontroller;

P =Prescaler

T_{CLK}=Period of the Clock Master

I=value of the generator of current configured;

N=theoretical conversion that should be released by the A/D converter

CONCLUSIONS

In this application note we have presented the operation of the analog comparator of the ST52x440 microcontroller, a simple program to perform simple A/D conversion measures at variable resolution. The accuracy of the tests strongly depend on the measurement conditions. Notable improvements can be obtained using particular precautions such as: bord low noise, operating range between 1 and 3 volts (maximum linearity), digital filtering of conversions, etc.

REFERENCES

[1] ST52T440/E440 Datasheet

[2] Visual FIVE 5.0, STMicroelectronics, 2002

Full Product Information at http://www.st.com/five

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