



Expanding A/D resolution of the ST6 A/D converter

1 Introduction

Occasionally the analog signal provided by external sensors require an Analog to Digital conversion with a resolution of greater than 8 bits. In order to extract the full information for subsequent data processing within the microcontroller a higher resolution Analog to Digital is thus required.

The solution described in this note enables this higher resolution with the on-chip 8-bit A/D converter of the ST62, using only an additional Operational Amplifier (OpAmp) and a few resistors

Contents

1 Introduction 1

2 Overview 4

3 Principle of operation of an algebraic adder 5

4 Example 7

5 Application example 10

6 Revision history 14



List of figures

Figure 1. Example circuit 4

Figure 2. Generic algebraic adder 5

Figure 3. Conversion routine 8

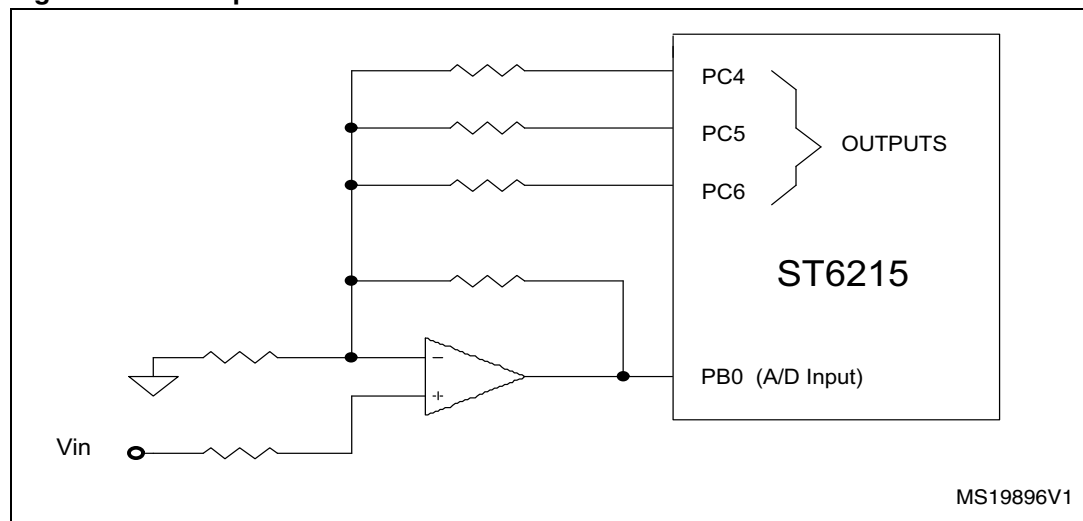
Figure 4. Example circuit 10

2 Overview

The technique implemented is that of the Algebraic Adder, a full discussion of the principle of operation is included in this note.

A practical example of the external components used is shown in the following figure:

Figure 1. Example circuit



The resistances are selected by the ST62 I/O pins depending on the analog input voltage.

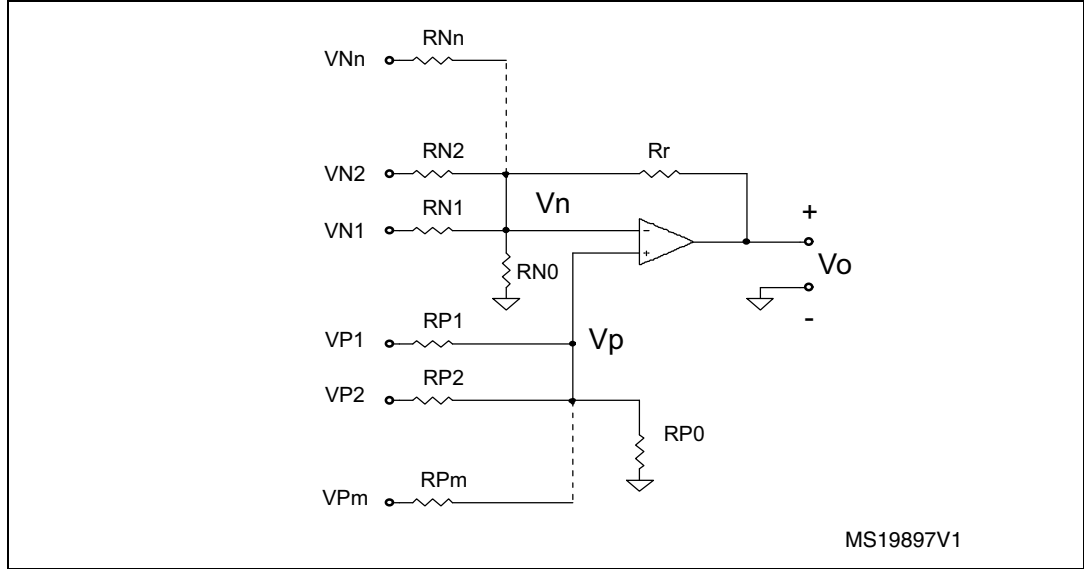
The selection programmed modifies the output voltage of the OpAmp in such a way that the following A/D conversion is always made with the maximum input range of the converter.

This selection is made by software, therefore the total conversion time is increased versus a normal 8-Bit conversion, however the precision is increased and the input voltage range can be enlarged.

3 Principle of operation of an algebraic adder

Figure 2 represents the generic algebraic adder.

Figure 2. Generic algebraic adder



The circuit generates an output voltage equal to: i

(1)

$$V_0 = \sum_{i=1}^m K_i \times V_{P_i} - \sum_{i=1}^n K_i \times V_{N_j}$$

To minimize the effects of the input polarizing currents, the total resistances seen from the two inputs of the OpAmp should be the same. Therefore:

(2)

$$\frac{1}{R_r} + \frac{1}{R_{N_0}} + \sum_{j=1}^n \frac{1}{R_{N_j}} = \frac{1}{R_{P_0}} + \sum_{i=1}^m \frac{1}{R_{P_i}} = \frac{1}{R_T}$$

The two resistances RP0 and RN0 are needed to satisfy the above relation. In general, only one of them will be needed.

To analyze the circuit, let us calculate the input voltages:

$$V_P = \frac{\sum_{i=1}^m G_{P_i} \times V_{P_i}}{G_{P_0} + \sum_{i=1}^m G_{P_i}} \quad \text{where} \quad G_x = \frac{1}{R_x} \quad (3)$$

(4)

$$V_n = \frac{V_0 \times G_R + \sum_{j=1}^n G_{N_j}}{G_{N_0}}$$

Relation (2) becomes:

$$G_{N_0} + G_R + \sum_{j=1}^n G_{N_j} = G_{P_0} + \sum_{j=1}^m G_{P_j} = G_T \quad (5)$$

From 3, 4 and 5 we get:

$$V_0 = - \sum_{j=1}^n V_{N_j} \times \frac{R_r}{R_{N_j}} + \sum_{i=1}^m V_{P_i} \times \frac{R_r}{R_{P_i}} \quad (6)$$

Relation (6) is the relevant formula to be used. It also explains the name given to this circuit, since the output voltage is the 'algebraic sum' of the input voltages. To design the actual circuit, you chose one value of R_r (arbitrarily). The other resistances are then determined by the desired coefficients:

$$K_i = \frac{R_r}{R_{P_i}} \quad K_j = \frac{R_r}{R_{N_j}} \quad (7)$$

Finally, the values for R_{N0} and R_{P0} are chosen, based on (2).

4 Example

Let us assume we have a voltage swing of 10 volts (0 to 10) that we want to convert with a 10-bit resolution. And let us assume we have a set of voltage sources V_{Nj} that we can switch between 0 to 5 volts under software control, and each one independently from the other.

Let us also assume we can 'cut' the 10 volt swing in 4 'pieces' of 2.5 volts each, and that every 'piece' can be converted with 8-bit resolution. The overall resolution will therefore be:

$$2^8 \text{ (ST6 A/D resolution)} * 2^2 \text{ (# of 'pieces')} = 2^{10}$$

Let us call V_{in} the actual value of the source to be converted. For instance, if $V_{in} \in [10, 7.5]$ volts, we could supply the ST6 A/D with the voltage:

$$(V_{in} - 7.5\text{volt}) \times 2 \Rightarrow \varepsilon[0, 5]\text{volt}$$

or, for (10, 7.5) volts:

$$(V_{in} - 1.5 \times V_{N1}) \times 2 = 2 \times V_{in} - 3 \times V_{N1}$$

where V_{N1} is one of the V_{Nj} sources, either 0 or 5 volts. In similar fashion, for the other intervals, we could obtain:

(7.5, 5) volts

$$(V_{in} - V_{N2}) \times 2 = 2 \times V_{in} - 2 \times V_{N2}$$

(5, 2.5) volts

$$(V_{in} - 0.5 \times V_{N3}) \times 2 = 2 \times V_{in} - V_{N3}$$

(2.5, 0) volts

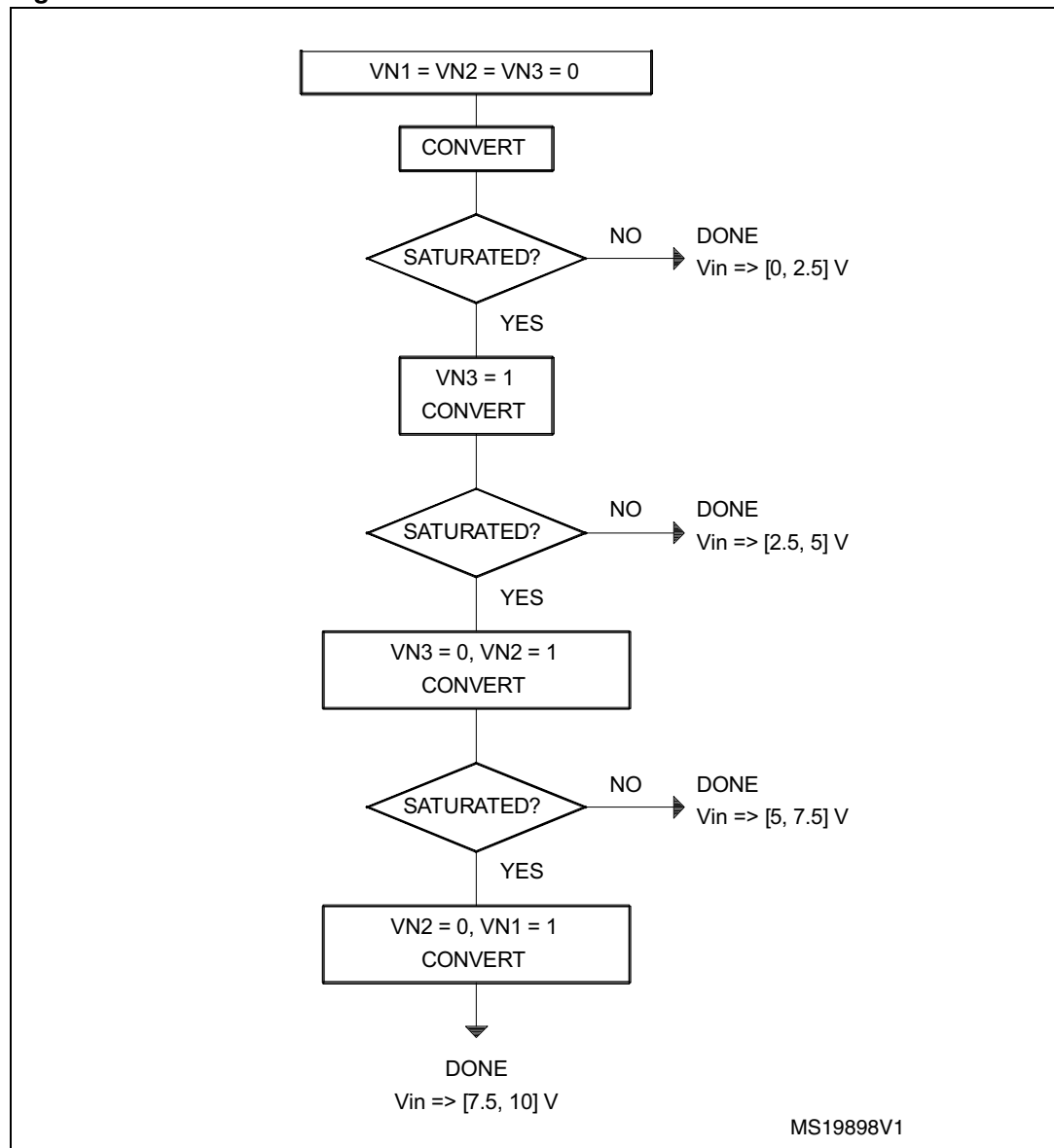
$$(V_{in} - 0 \times V_{N4}) \times 2 = 2 \times V_{in}$$

So, relation (6) becomes:

$$V_0 = 2 \times V_{in} - 3 \times V_{N1} - 2 \times V_{N2} - V_{N3} \text{ where } V_{in} = V_{P1}$$

The software driving the conversion will therefore verify if, given a certain status of the V_{Nj} voltages, the conversion is far from being saturated. If so, another try will be performed with a different status of the V_{Nj} voltages. Figure 3 gives the flow chart of such software.

Figure 3. Conversion routine



The actual circuit values are calculated as follows. With arbitrarily chosen R_r equal to 10 k Ω , the other resistor values are given by:

$$\frac{R_r}{R_{P1}} = 2 \Rightarrow R_{P1} = 5000\Omega$$

$$\frac{R_r}{R_{N1}} = 3 \Rightarrow R_{N1} = 3333\Omega$$

$$\frac{R_r}{R_{N2}} = 2 \Rightarrow R_{N2} = 5000\Omega$$

$$\frac{R_r}{R_{N3}} = 1 \Rightarrow R_{N3} = 10\Omega$$

To satisfy relation (2), we obtain the following values, as indicated in [Figure 4](#).

$$\frac{1}{R_r} + \frac{1}{R_{N0}} + \frac{1}{R_{N1}} + \frac{1}{R_{N2}} + \frac{1}{R_{N3}} + \frac{1}{R_{N0}} + 0.0007$$

$$\frac{1}{R_{P0}} + \frac{1}{R_{P1}} = \frac{1}{R_{P0}} + 0.0002$$

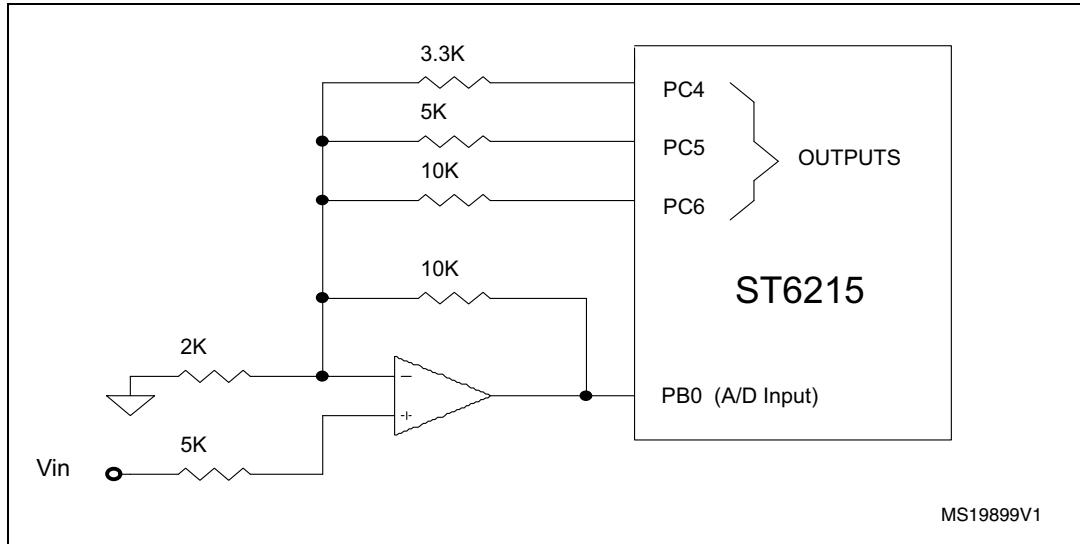
$$\frac{1}{R_{N0}} + 0.0007 = \frac{1}{R_{P0}} + 0.0002$$

$$\text{Assuming } \frac{R}{P0} = \infty \Rightarrow R_{N0} = 2K\Omega$$

5 Application example

An example ST62 software program follows on the next pages. It executes the program flow of [Figure 3](#) in the application circuit of [Figure 4](#).

Figure 4. Example circuit



The ST6215 pin allocation is arbitrary. The three outputs can drive other identical circuits, when more the one 10-bit A/D channel is needed. Also, a different number of 'pieces' can be used to achieve a different resolution.

```

;*****
;* File name: HIRES_AD.ASM
;*
;* ALGEBRAIC ADDER AND ST6 A/D CONVERTERS - Application note software
;* This software is an example on how to increase the ST6 converter
;* resolution. Please refer to the application note for further
;* explanations.
;*
;* Allocation of pins: PC4, PC5 and PC6 are, respectively, voltage sources
;* VN1, VN2 and VN3. PB0 is an A/D input
;*
;*****

        .input "6215_reg.asm" ;ST6215 standard definitions file
VN1 .equ 4                ;PC4 bit select
VN2 .equ 5                ;PC5 bit select
VN3 .equ 6                ;PC6 bit select
drccs .def 0bfh,0ffh,0ffh ;shadow register for Data Register C

```

```

Hres .def 0bdh,0ffh,0ffh ;MS 2 bits of conversion result, and
                           ;conversion flag

conv_f .equ 7;the MSB of Hres is the high resolution
                           ;end of conversion flag

c1 .equ 6 ;conversion step flags
c2 .equ 5
c3 .equ 4
c4 .equ 3 ;using Hres
Lres .def 0beh,0ffh,0ffh ;LSB of conversion result
,***** N O T E *****
;register W is used to save the accumulator contents
;in standard interrupt routines
,*****

.org 880h ;one module only. Do not use this
          ;assembly directive if you organize
          ;your software in linkable modules

init ldi drb,1
      ldi orb,1 ;PB0 is analog input
      ldi ddrc,070h ;PC4..6 are open drain outputs
      ldi orc,070h ;PC4..6 are push-pull outputs now
      ldi drcs,0 ;assume PC7 is input with pull-up,
                  ;no interrupt
      ldi ior,10h ;enable interrupts
      ldi Hres,0
      reti ;initialize interrupt machine

conv ;this is an endless loop converting
      ;PB0 input with 10-bit resolution
      ;the first time here after reset,
      ;VN1=VN2=VN3=0

      set conv_f,Hres
      set c1,Hres
      set 5,adcr ;start high resolution conversion
      jrs conv_f,Hres,$
      nop ;here the high resolution result is
          ;available in Hres-Lres

      jp conv

adcint
      ld w,a ;save accumulator
      ld a,adr ;in accumulator conversion result
      jrs c1,Hres,c1conv

```

```

        jrs c2,Hres,c2conv
        jrs c3,Hres,c3conv
c4conv  ldi Hres,3
        ld Lres,a
        ld a,drcs
        res VN1,a
        ld drcs,a
        ld drc,a          ;VN1=VN2=VN3=0
        jp convout
c1conv  pi a,0ffh
                                   jrnz c1c1
lr Hres
        ld Lres,a
convout d a,w
        reti
c1c1    ld a,drcs
        set VN3,a
        ld drcs,a
        ld drc,a          ;VN1=VN2=0, VN3=1
        set 5,adcr         ;start conversion
        res c1,Hres
        set c2,Hres
        jp convout         ;exit interrupt
c2conv  cpi a,0ffh
        jrnz c2c1
        ldi Hres,1
        ld Lres,a
        jp convout
c2c1    ld a,drcs
        res VN3,a
        set VN2,a
        ld drcs,a
        ld drc,a          ;VN1=VN3=0, VN2=1
        set 5,adcr         ;start conversion
        res c2,Hres
        set c3,Hres
        jp convout         ;exit interrupt
c3conv  cpi a,0ffh
        jrnz c3c1

```

```

        ldi Hres,2
        ld Lres,a
        jp convout
c3c1    ld a,drcs
        res VN2,a
        set VN1,a
        ld drcs,a
        ld drc,a          ;VN2=VN3=0, VN1=1
        set 5,adcr        ;start conversion
        res c3,Hres
        set c4,Hres
        jp convout        ;exit interrupt
        .org 0ff0h
        jp adcint         ;A/D interrupt vector
        .org 0ffeh
        jp init ;reset vector
        .end
```

6 Revision history

Table 1. Document revision history

Date	Revision	Changes
21-Dec-1992	1	Initial release.
02-Nov-2011	2	Updated format and company logo.

Please Read Carefully:

Information in this document is provided solely in connection with ST products. STMicroelectronics NV and its subsidiaries ("ST") reserve the right to make changes, corrections, modifications or improvements, to this document, and the products and services described herein at any time, without notice.

All ST products are sold pursuant to ST's terms and conditions of sale.

Purchasers are solely responsible for the choice, selection and use of the ST products and services described herein, and ST assumes no liability whatsoever relating to the choice, selection or use of the ST products and services described herein.

No license, express or implied, by estoppel or otherwise, to any intellectual property rights is granted under this document. If any part of this document refers to any third party products or services it shall not be deemed a license grant by ST for the use of such third party products or services, or any intellectual property contained therein or considered as a warranty covering the use in any manner whatsoever of such third party products or services or any intellectual property contained therein.

UNLESS OTHERWISE SET FORTH IN ST'S TERMS AND CONDITIONS OF SALE ST DISCLAIMS ANY EXPRESS OR IMPLIED WARRANTY WITH RESPECT TO THE USE AND/OR SALE OF ST PRODUCTS INCLUDING WITHOUT LIMITATION IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE (AND THEIR EQUIVALENTS UNDER THE LAWS OF ANY JURISDICTION), OR INFRINGEMENT OF ANY PATENT, COPYRIGHT OR OTHER INTELLECTUAL PROPERTY RIGHT.

UNLESS EXPRESSLY APPROVED IN WRITING BY TWO AUTHORIZED ST REPRESENTATIVES, ST PRODUCTS ARE NOT RECOMMENDED, AUTHORIZED OR WARRANTED FOR USE IN MILITARY, AIR CRAFT, SPACE, LIFE SAVING, OR LIFE SUSTAINING APPLICATIONS, NOR IN PRODUCTS OR SYSTEMS WHERE FAILURE OR MALFUNCTION MAY RESULT IN PERSONAL INJURY, DEATH, OR SEVERE PROPERTY OR ENVIRONMENTAL DAMAGE. ST PRODUCTS WHICH ARE NOT SPECIFIED AS "AUTOMOTIVE GRADE" MAY ONLY BE USED IN AUTOMOTIVE APPLICATIONS AT USER'S OWN RISK.

Resale of ST products with provisions different from the statements and/or technical features set forth in this document shall immediately void any warranty granted by ST for the ST product or service described herein and shall not create or extend in any manner whatsoever, any liability of ST.

ST and the ST logo are trademarks or registered trademarks of ST in various countries.

Information in this document supersedes and replaces all information previously supplied.

The ST logo is a registered trademark of STMicroelectronics. All other names are the property of their respective owners.

© 2011 STMicroelectronics - All rights reserved

STMicroelectronics group of companies

Australia - Belgium - Brazil - Canada - China - Czech Republic - Finland - France - Germany - Hong Kong - India - Israel - Italy - Japan - Malaysia - Malta - Morocco - Philippines - Singapore - Spain - Sweden - Switzerland - United Kingdom - United States of America

www.st.com

