Application Note
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Using the TMS470R1x ADC Self-Test to Identify Shorted and Open ADC Inputs

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ABSTRACT

This document describes how to configure the ADC self-test mode and perform a conversion to identify shorted and open ADC inputs and how the self-test mode works. It also describes how to determine the status of the respective input from the converted values.

Contents

List of Tables

1 Introduction

With the self-test mode, you can detect shorted and open ADC inputs. To identify these faults, the inputs can be individually pulled up or pulled down to AD_{REFHI} or AD_{REFLO}, respectively. You can test any number of channels, and you can perform any conversion type, including continuous or single conversion, freeze enabled or non-freeze enabled, interrupts enabled or disabled.

2 Configuration

The self-test mode uses the complete initialization of the ADC module. It requires the following settings at a minimum:

- Activation and deactivation of the self-test mode. Achieve this by setting and resetting Bit 9 (SELF TST) in the ADCR1. If you are using the Software Peripheral Drivers (SPDs), then use the ADC_FSTest_V function. See the example in Appendix A.
- Using AD_{REFHI} or AD_{REFLO} as the test voltage. Set or reset Bit 10 (HILO) in the ADCR1, or if using the SPDs, then use the ADC_FSTest_V function. See the example in Appendix A.

The example below uses the SPDs for the ADC module.

NOTE: Setting the module in self-test mode while a conversion sequence is ongoing in the normal operation mode can corrupt the current channel conversion result. The purpose of the self-test mode is to ensure that the value is out of the fail detection limits; it is not intended to provide accurate results.

3 How to Perform a Conversion

You need to perform a normal conversion In the self-test mode. This conversion includes selecting the required channels, giving the channels the adequate group ID, and invoking a conversion. You could use the same conversion sequence as for a normal conversion, except that you need to enable the self-test mode first. The converted values are also read out of the respective registers with the same routines as in a normal conversion. See example below.

4 How It Works

In the self-test mode, reference voltages (high or low potential) are combined with the input signal of the respective channel. The connected reference voltage charges or discharges (depending on whether high or low potential is selected) the internal capacitors. The internal capacitors are the sample capacitor and the parasitic capacitor of the input combined.

The self-test mode requires double the normal sampling time. During the first half of the extended sampling period, the ADC input is driven by both the reference voltage (AD_{REFHI} or AD_{REFLO}, depending on the HILO bit), and the selected channel input voltage. The reference voltage is combined through two resistors connected parallel to each other with the respective input voltage. It is during this period that the internal capacitors are charged or discharged.

During the second half of the extended sampling period, the reference voltage stops driving the ADC input, with only the selected channel input voltage driving the input. This is when the conversion takes place.

Three conversions, one in self-test mode with input pulled up to AD_{REFHI}, another in self-test mode with input pulled down to AD_{REFLO}, and the third in normal mode, need to be made. With the results of the three conversions, the status of the AD input pin can be determined with the help of Table 1.

Table 1. Conversion Factors

Normal Conversion V_n	Self-Test, Pull-Up Conversion, V_u	Self-Test, Pull-Down Conversion, V_d	Status
V_n	$V_n<V_u<V_{REFHI}$†	$V_{REFLO}<V_d<V_n$†	Good
V_{REFHI}	V_{REFHI}	approx V_{REFHI}‡	Shorted to V_{REFHI}§
V_{REFLO}	approx V_{REFLO}‡	V_{REFLO}	Shorted to V_{REFLO}§
Unknown	V_{REFHI}	V_{REFLO}	Open

† The self-test value obtained when the pin is good can be estimated if the input resistance is known, given that the self-test resistor is approximately 3K Ω.
‡ The self-test value obtained when the pin is shorted can be estimated to be within approximately 95% of the reference value to which it is shorted due to the input multiplexer’s internal resistance of typically 250 Ω.
§ $V_{REFHI} \leftarrow AD_{REFHI}$ and $V_{REFLO} \leftarrow AD_{REFLO}$

4.1 Interpreting the Results

The following describes how each status can be interpreted using the conversion results shown in Table 1.

If the input is good:

- The normal conversion would produce a result (V_n) that is in range.
- Self-test with pull-up would produce a result (V_u) that is above the normal conversion (V_n) but below V_{REFHI}, because the internal capacitors would start to discharge to V_n level ($V_n<V_u<V_{REFHI}$).
- Self-test with pull-down would produce a result (V_d) that is below the normal conversion (V_n) but above V_{REFLO}, because the internal capacitors would start to charge to the V_n level ($V_{REFLO}<V_d<V_n$).

If the input is shorted to V_{REFHI}:

- The normal conversion would produce a result (V_n) which is close to V_{REFHI}.
- A self-test with pull-up would produce a result (V_u) which is also close to V_{REFHI}.
- A self-test with pull-down would produce a result (V_d) that is above V_{REFLO}, because the short would have prevented the internal capacitors from reaching absolute V_{REFLO} levels.

If the input is shorted to V_{REFLO}:

- The normal conversion would produce a result (V_n) that is close to V_{REFLO}
- The self-test with pull-up would produce a result (V_u) that is below V_{REFHI}, because the short would have prevented the internal capacitors from reaching absolute V_{REFHI} levels.
- The self-test with pull-down would produce a result (V_d) that is also close to V_{REFLO}.

If the input is open:

- The normal conversion would produce a result (V_n) that is undefined. Since the input doesn’t have any internal pull-up or pull-down resistor, the input is floating.
- The self-test with pull-up would produce a result (V_u) that is nearly equal to V_{REFHI}.

- The self-test with pull-down would produce a result (V_d) that is nearly equal to V_{REFLO}.

You may find it helpful to use an upper and lower range for comparing the values with the reference voltages. See the example in Appendix A.

5 Factors Affecting Conversion Results

The conversion results depend on different factors:

- Acquisition time or sampling time
- Impedance of circuit connected to the respective input incase of normal connection
- Temperature
- Stability of the reference voltages

5.1 Acquisition Time

The acquisition time is a major factor. The result can vary considerably depending on the time set. A long sampling time is good for a normal conversion, but if the sampling time is too long for a self-test, the internal capacitors have enough time to charge or discharge between the two periods. The results correspondingly drift away from the real value because of leakage currents. Too short an acquisition time is also not ideal, since the voltage on the input is not stable. Depending on the peripheral clock (ICLK) frequency, you may need to adjust the sampling time.

5.2 Impedence of External Circuit

The impedance of the external circuit is another major factor. Depending on the external resistance and capacitance, you may need to adjust the acquisition time, since the capacitors may need longer to get charged and to have a stable voltage. It is also important because with the help of the external resistance, the comparison values expected can be approximately calculated (refer to the application note *ADC Source Impedance,* literature number SPNA061, for more information).

5.3 Operating Temperature

The operating temperature also affects the conversions, since the leakage currents increase exponentially with increasing temperatures. Here again, you may need to adjust the acquisition time.

5.4 Stability of Reference Voltages

The stability of the reference voltages affects the accuracy of the conversions just as it affects a normal conversion.

Appendix A Programming Example

```
/**********************************************************************************/
/*                                                                                */
/*  PROJECT:    ADC Self-Test                                                     */
/*                                                                                */
/**********************************************************************************/
#include "adc470.h"
typedef enum
{
    Open,
    ShortToVREFHI,
    ShortToVREFLO,
    Good,
    Undetermined
} SELFTESTRES;
void Init()
{
    ADCOPMODSET cop_mode = (ADCOPMODSET)(AdcPs1 | AdcAcq32 | AdcBridgeDis);
    /*Clock prescaler value to 1, Prescaler value for the sampling time to 32,
     Bridge connection disabled   */
    /* values of the clock prescale and the sampling time need to be adjusted
     according to the application */

    ADCCONVMODSET conv_mode = (ADCCONVMODSET)(AdcGp1Single | AdcGp1NoFreeze);
    /*Set SWGroup1 in single conversion Mode, the SWGroup1 conversion flow is not
      freezable */
    ADC_Init_V(cop_mode, conv_mode, Adc0);
}
void Conv_Start()
{
    ADCCHNSEL chn_sel = (ADCCHNSEL)(AdcChn1);
    /* Channel 1 selected */

    ADCGRPID grp_id = AdcSWGp1;
    /*Software Group1 Identifier */
    //while(Adc0->ADSR_UN.ADSR_ST.CONVGP1BUSY_B1==1);
     /* Test the conversion status */

    ADC_ConvStart_N(chn_sel, grp_id, NULL, Adc0);
}
SELFTESTRES Self_Test()
{
```

```
volatile UWORD ResultHi[1]; // Result buffer for conversion in self-test mode
with ADREFHI
volatile UWORD ResultLo[1]; // Result buffer for conversion in self-test mode
with ADREFLO
volatile UWORD ResultNo[1]; // Result buffer for conversion in normal mode
SELFTESTRES status = Undetermined;  // initial status
unsigned int upper_limit = ;        // Value depends on application
unsigned int lower_limit = ;        // Value depends on application



ADC_FSTest_V(AdcFSTestREFHI,Adc0);   // Self-test mode enabled with low ref voltage
Conv_Start();                        // invoking of conversion
ADC_GroupResult_V((UWORD*)ResultHi,AdcSWGp1,Adc0); // Converted values stored in buffer

ADC_FSTest_V(AdcFSTestREFLO,Adc0);   // Self-test mode enabled with high ref voltage
Conv_Start();                        // invoking of conversion
ADC_GroupResult_V((UWORD*)ResultLo,AdcSWGp1,Adc0); // Converted values stored in buffer

ADC_FSTest_V(AdcFSTestDisable,Adc0);             // Self-test mode disabled
Conv_Start();                                    // invoking of conversion
ADC_GroupResult_V((UWORD*)ResultNo,AdcSWGp1,Adc0); // Converted values stored in buffer


   if ((lower_limit>ResultLo[0]) && (upper_limit<ResultHi[0]))
   /*  VREFLO>Vd    &  VREFHI<Vu */
   {
   status = Open;
   }

   else if ((lower_limit<ResultLo[0]) && (upper_limit<ResultHi[0]) &&
(upper_limit<ResultNo[0]))
   /*  VREFLO<Vd        &    VREFHI<Vu &  VREFHI<Vn  */
   {
   status = ShortToVREFHI;
   }

   else if ((lower_limit>ResultLo[0]) && (upper_limit>ResultHi[0]) &&
(lower_limit>ResultNo[0]))
   /*  VREFLO>Vd            &   VREFHI>Vu   &  VREFLO>Vn     */
   {
   status = ShortToVREFLO;
   }

   else if ((lower_limit<ResultLo[0]<ResultNo[0]) && (upper_limit<ResultHi[0]<ResultNo[0]))
   /*  VREFLO<Vd<Vn     &    VREFHI<Vu<Vn        */
```

```
    {
    status = Good;
    }

    return status;
}
main()
{
     Init();
     Self_Test();
     for(;;);
}
```

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

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