

DESIGNER'S NOTEBOOK



Initializing the TLC32046 AIC on the TMS320C5x EVM Board

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Design Problem

What is the proper way to initialize the registers of the AIC given certain specifications?

Solution

The main problem encountered involves setting the correct parameters allowing the DSP to run at a fixed rate.

Introduction

The purpose of this Designer's Notebook page is to provide an easy and efficient way to:

- Study the effects of anti-aliasing according to the sample frequency and the low band-pass cut-off frequency.
- Adapt a given prototype defined by its band-pass to the hardware specifications of a development tool based on a TMS320 DSP (C50 EVM board).

The programs enclosed in the appendices consist in sampling an analog input signal issued from a function generator and sending it back to the analog output of the AIC, for visualization on an oscilloscope.

Overview

The initialization of the system can be divided into three distinct parts:

- Initialization of the DSP (software wait states, sign extension mode, global interrupt register, etc.)
- Initialization of the timer and serial port (e.g., Master Clock frequency, receive and transmit registers, etc.)
- Initialization of the AIC (sampling frequency, low pass-band cut-off frequency, and other parameters, etc.)

The initialization of the TMS320C5x DSP status and control registers (for wait-states generation, interrupt flags settings, etc.) as well as the initialization of the timer and serial port are explained in details in the *TMS320C5x User's Guide* (SPRU056), specifically chapters 3 and 5.

The initialization of the AIC is based on three parameters:

- The AIC control register (to set up gain, synchronization, loopback, etc.)
- The Tx counter A register (and Rx counter A if synchronous mode is disabled).
- The Tx counter B register (and Rx counter B if synchronous mode is disabled).

The above parameters, in turn, are based on the two following frequencies specified by the system:

- the sampling frequency, f_s
- the low pass-band cut-off frequency, f_c

In this example, Tx counter A and Tx counter B (also named TA and TB) AIC registers are used in synchronous mode to determine the D/A (and therefore A/D) conversion timing. Both conversion timings are driven by the MSTR CLK supplied by an external quartz oscillator on the EVM board.

The low band-pass cut-off frequency is determined by the approximate formula below:

$$f_c = \frac{f_{MCLK} \text{ (kHz)}}{288 \text{ kHz}} \times \frac{1}{2 \times TA} \times 7.6 \text{ kHz}$$

The high band-pass cut-off frequency is determined by the approximate formula below:

$$f_{cHP} = \frac{f_{MCLK} \text{ (kHz)}}{288 \text{ kHz}} \times \frac{1}{2 \times TA} \times 300 \text{ Hz}$$

Method to Determine TA and TB Values According to the f_s and f_c Inputs

The user can read the TLC32046 analog interface circuit data sheet (literature number SLAS028) for further information concerning the protocol of transmission between the DSP and the AIC.

The TLC32046 AIC integrates a low-pass, switched-capacitor, output-reconstruction filter. As explained in the TLC32046 analog interface circuit data sheet, in order for the switched-capacitor low-pass filter to meet its transfer function specifications, the frequency of the clock inputs of the switched-capacitor filters must be 288 kHz. If the frequencies of the clock inputs are not 288 kHz, the filter transfer function frequencies are scaled by the ratio of the clock frequencies to 288 kHz, as it appears in the two formulas above.

The sampling frequency is given by the following formula: $f_s = \frac{f_{MCLK}}{2 \times TA \times TB}$.

Once f_{MCLK} is fixed, f_s depends on the $TA \times TB$ product and f_c depends only on TA with the following constraints:

1. TA is an integer in the range 4 to 31 (5 unsigned bits).
2. TB is an integer in the range 2 to 63 (6 unsigned bits).
3. f_c as near as possible, but less than $\frac{f_s}{2}$, to satisfy the *Shannon criteria*.

The procedure to determine TA and TB parameters is the following:

Step 1: Calculate $TA \times TB$ related to the desired sampling frequency (note that if the sampling frequency is not a constraint for your application, then it has to be chosen at least $2f_c$ according to the *Shannon criteria* and so that $TA \times TB$ is an integer).

Step 2: Considering that $TA \times TB$ is an integer, within the list of all possible integer values of TA and TB, only some of them satisfy the two first conditions.

Step 3: You must then choose between these results with the one which satisfies the third condition, on calculating f_c .

Example

The quartz oscillator which handles the conversion rate of the AIC on the EVM board provides a master clock frequency of $f_{MCLK} = 10.368$ MHz. For an application requiring a sampling frequency f_s of 9.6 kHz and in order to satisfy the *Shannon criteria*, the bandwidth must be limited to 4.8 kHz. Hence, it is recommended to filter

the input signal by a lowpass filter with a cut-off frequency $f_c = \frac{f_s}{2} = 4.8$ kHz.

According to the explanations above, the results are:

$$\begin{cases} f_c = \frac{f_{MCLK}}{2 \times TA} \times \frac{7.6}{288} = \frac{136.8 \text{ kHz}}{TA} \\ TA \times TB = \frac{f_{MCLK}}{2 \times f_s} = 540 = 2^2 \times 3^3 \times 5 \end{cases}$$

and the constraints are: $\begin{cases} 4 \leq TA \leq 31 \\ 2 \leq TB \leq 63 \end{cases}$

The easiest way to study the different possibilities to obtain the desired sampling frequency and the appropriate cut-off frequency is to fill up a table as shown in Figure 1. The fixed parameter is $f_s = 9.6$ kHz, which involves a product $TA \times TB = 2^2 \times 3^3 \times 5$. First, fill the first column by giving to TB all the possible combinations of the prime factors.

| TB | TA | TA × TB | f _c (kHz) |
|----------|----------|---------|----------------------|
| 2 | 270 > 31 | | |
| 4 | 135 > 31 | | |
| 3 | 180 > 31 | | |
| 6 | 90 > 31 | | |
| 12 | 45 > 31 | | |
| 9 | 60 > 31 | | |
| 18 | 30 | 540 | 4.56 |
| 36 | 15 | 540 | 9.12 |
| 27 | 20 | 540 | 6.84 |
| 54 | 10 | 540 | 13.68 |
| 108 > 63 | | | |
| 5 | 108 > 31 | | |
| 10 | 54 > 31 | | |
| 20 | 27 | 540 | 5.07 |
| 15 | 36 > 31 | | |
| 45 | 12 | 540 | 11.4 |
| 135 > 63 | | | |
| 30 | 18 | 540 | 7.6 |
| 90 > 63 | | | |
| 270 > 63 | | | |
| 60 | 9 | 540 | 15.2 |
| 180 > 63 | | | |
| 540 > 63 | | | |

Figure 1. Possible values of TA and TB according to desired f_c and f_s

Only eight combinations are acceptable:

1. TA=30 and TB=18 giving a cut-off frequency of 4.56 kHz
2. TA=15 and TB=36 giving a cut-off frequency of 9.12 kHz

3. TA=20 and TB=27 giving a cut-off frequency of 6.84 kHz
4. TA=10 and TB=54 giving a cut-off frequency of 13.68 kHz
5. TA=27 and TB=20 giving a cut-off frequency of 5.07 kHz
6. TA=12 and TB=45 giving a cut-off frequency of 11.4 kHz
7. TA=18 and TB=30 giving a cut-off frequency of 7.6 kHz
8. TA=9 and TB=60 giving a cut-off frequency of 15.2 kHz

To select one of these set of values, you have to consider the desired cut-off frequency of your anti-aliasing filter and, then, choose the most appropriate. For the 9.6-kHz sampling frequency, the ideal anti-aliasing filter rejects all frequencies above 4.8 kHz. Hence, you will have to adopt the first combination: TA=30 and TB=18 and to satisfy with a $f_c = 4.56$ kHz.

According to the *Shannon criteria*, the optimized operating conditions are obtained when $f_c \leq \frac{f_s}{2}$. Therefore in most of the cases, we recommend to have f_c as

near as possible, but less than $\frac{f_s}{2}$.

In case of filtering a signal under aliasing conditions, we let the user choose the most appropriate values for TA and TB registers which depend on the non-disturbed pass-band authorized for the application.

For instance, for a sampling frequency of $f_s = 8$ kHz, we preconise you to choose TA=27 and TB=24, in order to obtain: $f_c = 5.07$ kHz and a minimum aliasing.

Besides the three steps of establishing the communications between a DSP and the TLC32046 AIC, interrupt service routines must be defined to set up the action to follow after a data word has been received by the AIC or transmitted to it.

The main program calls the different routines corresponding to the initialization process, enables or disables the interrupt registers when needed, then waits for data to be handled by the receive interrupt service routine.

This program called AICEVM50.ASM can be downloaded from the TI BBS and ftp site mirror. It can be compiled and linked by the tools supplied while purchasing the TMS320C50 EVM. The following procedure tells you how to assemble and link this program to have it run on your board.

```
DSPASM -v50 AICEVM50.ASM
DSKLNK AICEVM50.CMD
EVMRST.EXE
EVMLOAD AICEVM50.OUT
```

Operating Recommendations

Analog Input: - Maximum Absolute Input Voltage: 3V
 - Frequency range: 150 Hz–4560 Hz

Experimental Results

The tests have been done on an EVM board:

| Software | | | | Hardware | |
|----------------|----|----|----------------|---------------------|----------|
| F_s (in kHz) | TA | TB | F_c (in kHz) | Band-Pass (f_c) | Aliasing |
| 8 | 24 | 27 | 5.7 | 100–2200 Hz | Yes |
| 8 | 27 | 24 | 5.07 | 100–2700 Hz | Yes |
| 9.6 | 30 | 18 | 4.56 | 150–4500 Hz | No |
| 16 | 18 | 18 | 7.6 | 140–7600 Hz | No |

The last two results obtained correspond to the case where $F_s > 2F_c$ (see Figure 2).

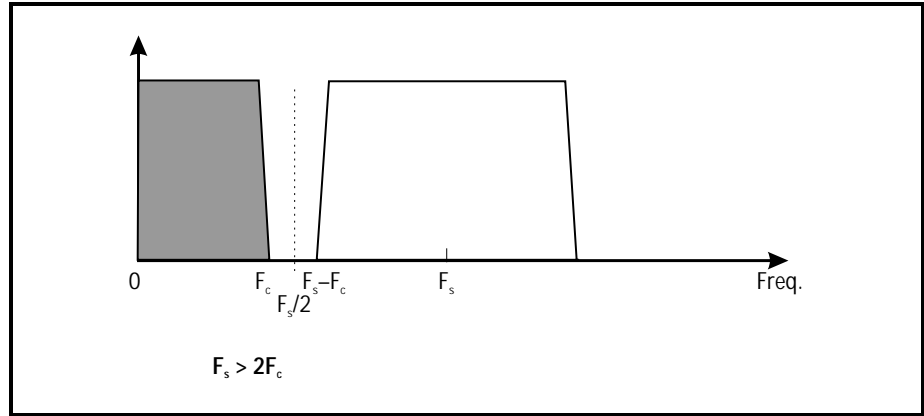


Figure 2. Shannon criteria satisfied

The *Shannon criteria* is satisfied. The band-pass obtained matches with the values of the cut-off frequencies calculated by the formulas above.

The first two results correspond to the case where $F_s < 2F_c$.

The results obtained for these values of TA and TB confirm the presence of aliasing in the output signal respectively in the range [2.7; 5.7 kHz] and [2.2; 5.07 kHz]. The output signal is not stable on the screen of the oscilloscope, when synchronized by the input signal.

Interpretation

Theoretically, let us consider a low-pass filter instead of a band-pass filter to simplify the reasoning (see Figure 3). Then, all the frequencies between 0 and $F_s/2$ are sampled according to the Shannon rule, but the frequencies in $[F_s/2, F_c]$ are under aliasing. Because of the resulting superposition in the spectrum, the resulting non-disturbed bandwidth is actually $[0, F_s - F_c]$ (as represented in the shaded portion on Figure 3).

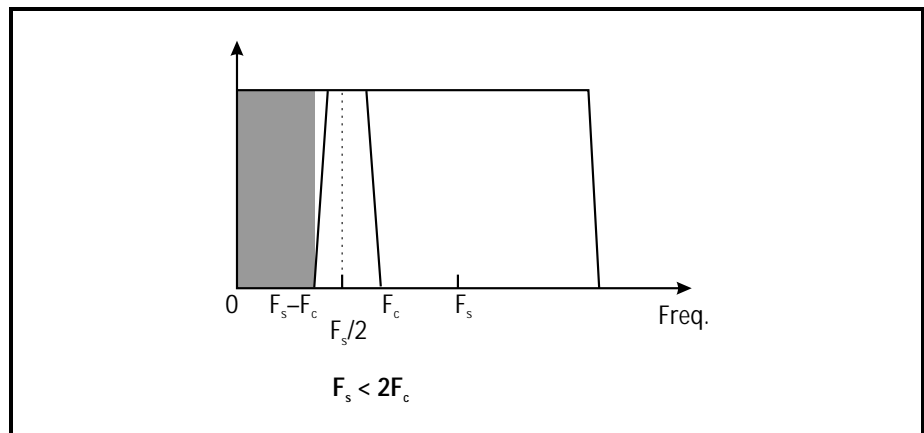


Figure 3. Shannon criteria unsatisfied: presence of aliasing

In the last example, $f_c > \frac{f_s}{2}$, the results confirm the presence of aliasing in the output signal. The signal is not stable on the screen of the oscilloscope. All the

frequencies between 0 and $\frac{f_s}{2}$ are sampled according to the Shannon rule, but the frequencies in $\left[\frac{f_s}{2}; f_c\right]$ are under aliasing in the spectrum $[f_c; f_s - f_c]$:

For the first case, the bandwidth [100–2200 Hz] is not at all modified by aliasing. Theoretically, according to the *Shannon criteria*, the signal is not altered in the range [100–2300 Hz].

For the second case, the bandwidth [100–2700 Hz] is not at all modified by aliasing. Theoretically, according to the *Shannon criteria*, the signal is not altered in the range [100–2930 Hz].

This Designer's Notebook page should be used in conjunction with Designer's Notebook page #25, TMS320C2x/'C5x EVM AIC Initialization and Configuration, for more information concerning the way to initialize the AIC.