Abstract

In the paper the problem of digital filter sensitivity analysis due to the finite word length representation of their coefficients is considered. To illustrate the presented problem the simulation of a FIR and 5-th order low pass elliptic IIR filters has been done in the Ptolemy Software Environment. The practical aim of this paper is showing the possibility of application the TMS320C50 DSP Starter Kit DSK to digital filter sensitivity analysis. Moreover, building the complete laboratory measurement stand of digital filters with the minimal number of instrumentation by another application of the digital signal processor as a wobbulator - in rapid verification of digital filters is introduced.

Introduction

Although the cost of memory chips has been significantly decreased in some applications it is very important to reduce the word’s length of digital filters, so the minimal and sufficient word length ought to be found. The influence of the finite word length effect of digital filters on the range of stable work and the magnitude and the phase characteristics are observed. Moreover, minimal and sufficient word's lengths of digital filters results in power reduction without decreasing their performances.

The sufficient minimal word length depends on the type of digital filter applied (Finite Impulse Response - FIR or Infinite Impulse Response - IIR). Moreover, for IIR filters this influence strongly depends on the structure of the filter [2]. In the paper, the sensitivities of the magnitude and the phase characteristics of FIR and four structures of the IIR filters, (namely: the accurate realisation, a direct form, a lattice structure, and a cascade connections of biquadrat sections - in our case of 5-th order filter there are a bilinear section and two biquadrat ones) due to finite word length have been considered.

In this project the MATLAB Signal Processing Toolbox [3] has been applied to find the coefficients of the direct, cascade, and lattice (k-set of coefficients) filters. The v-set of coefficients for the lattice filter has been calculated by the own program elaborated on the base of the algorithm from literature.

Computer Simulation of Influence of FIR Filter Coefficients Truncation Effect on its Magnitude and Phase Characteristics

Figure 1a shows the diagram of the circuit for simulation of the FIR filters. It consists of the following blocks (stars in the Ptolemy [1] terminology):

- **Impulse** - the star generating Cronecker’s impulses,
- **FIR** - accurate FIR filter,
- **FIR** - FIR filter with the truncated coefficients,
- **galaxy** - performing the measurement of the magnitude (log. and lin.) and phase characteristics,
- **XMGraph** - block generating frequency response characteristic of the simulated circuit.

The circuit (galaxy) in Fig. 1b has been created for testing the designed projects and it consists of the following blocks

- **Block FFT** - Fourier discrete transformation calculation block,
- **Cx to Rect (C->R)** - block converting complex type samples into the real type pair,
- **Rect to Polar** - block converting rectangular co-ordinates into polar ones (conversion imaginary and real values into the module and phase),
- **dB** - block converting linear scale into the logarithmic one.
Results of Computer Simulation of FIR Filters and their Practical Verification on the TMS320C5x DSP Starter Kit

The galaxy has three outputs, namely: logarithmic and linear for magnitude and phase of the frequency response.

The simulation results from this galaxy are displayed by XMGraph star. It is the block generating frequency response characteristic of the simulated circuit (digital filter). The characteristics obtained in the simulation process (Synchronous Data Flow domain) for the designed FIR filter ($N = 44$, $R_s = 45\text{dB}$, $f_{\text{cutoff}} = 0.05f_s$) are presented in Fig. 2 (a) and (b).

In the next stage of the design, the code for the TMS302C50 DSK is generated for the project of the filters (with and without truncation of the coefficients). It is done in the C50 domain [1].

After compilation of the code obtained from the C50 domain it is loaded to the TMS320C50 DSK which performs the filtering process. The characteristics of the real FIR digital filter working on TMS320C50 DSK are measured by the second laboratory stand working as a wobbulator on another digital signal processor [5]. Taking into account the band-width of this measurement stand it is important to choose such a starter kit, which has sufficiently high value of sampling frequency of an analog to digital converter. The amplitude and phase characteristics obtained by this computer stand are displayed on the screen. Figure 3 shows them for the verified FIR digital filters with and without the truncation of the filter coefficients.
Fig. 2. The simulation results of (a) the magnitude and (b) the phase characteristics of the FIR filters: without (Set1), and with truncation of filter coefficients to five decimal digits (Set0).

Fig. 3. The magnitude and phase characteristics of the measured FIR digital filters working on the TMS320C50 DSK for different truncation of filter coefficients, (a), (b) to 8 decimal digits, (c), (d) to 5 decimal digits.
Influence of IIR Filter Coefficients Truncation Effect on its Magnitude and Phase Characteristics

The quantization effect is more important in IIR digital filters. Due to the recursive structure of IIR filters the rounding or truncation of filter coefficients can lead to their instability. To illustrate this problem the simulation has been done in the Ptolemy Software environment for the narrow band 5-th order low pass elliptic filters $R_p = 1$dB, $R_s = 40$dB, $f_{cutoff} = 0.05f_s$ [4]. Its poles are located in the nearest neighborhood of the unit circle (Fig. 4a) and its co-ordinates are as follows: $p_{1,2} = 0.9366 \pm j0.3037$, $p_{3,4} = 0.9083 \pm j0.2169$, $p_5 = 0.8849$.

![Elliptic filter poles location for (a) the accurate representation and (b) coefficient quantization](image)

Fig. 4. Elliptic filter poles location for (a) the accurate representation and (b) coefficient quantization ($\bullet$ - accurate representation; $\mathcal{D}$ - 3 decimal digits quantization; $\mathcal{E}$ - 2 decimal digits quantization).

![The diagrams of the circuit for simulation of designed IIR filters and its galaxies: (1) of the direct structure, (2) of the cascade filter realization, (3) of the lattice structure, and (4) for performing the measurement of the magnitude (log. and lin.) and phase characteristics. The star (5) is the IIR digital filter with the structure from the Ptolemy library.](image)

Fig. 5. The diagrams of the circuit for simulation of designed IIR filters and its galaxies: (1) of the direct structure, (2) of the cascade filter realization, (3) of the lattice structure, and (4) for performing the measurement of the magnitude (log. and lin.) and phase characteristics. The star (5) is the IIR digital filter with the structure from the Ptolemy library.

In the diagrams of the circuit for simulation of IIR filters (Fig.5) the galaxy (6) for performing the measurement of the magnitude (log. and lin.) and phase characteristics is presented in Fig. 1b.

The obtained results of simulations (Fig.6) and the verifications of the designed digital filters show the correctness of the method applied.
Fig 6. The simulation results of (a) the magnitude and (b) the phase characteristics of the IIR filters for their different structures, where: A stands for Accurate realisation; D - Direct form; C - Cascade connection of biquadrat sections (in this case of the 5-th order filter there are bilinear section and two biquadrat ones); L - Lattice structure.

Conclusions

Presented approach has been applied in the students’ laboratory for practical verification of individual projects not only concerning the analysis of the finite word effects but also in the general case design and applications of DSP circuits/algorithms. The elaborated measurement stand enables shortening the time required for verification of the new projects designed. Moreover, possibility of fast and convenient saving the magnitude and phase characteristics into files is very useful during the design process of DSP (sub)systems.

References