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# DIFID: A COMPUTER PROGRAM FOR EFFICIENT DESIGN OF CASCADE IIR DIGITAL FILTERS

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**Abstract.** A computer program DIFID for cascade IIR digital filter design is presented. The program minimizes quantization effects of the inner date and filter coefficients. Its efficiency is shown on particular examples.

**1. Introduction.** The design of frequency-domain digital filters is connected to the decision of a number of problems such as an approximation of the required attenuation response, choice its initial parameters, search of a filter structure, choice of a type of scaling. Besides for cascade IIR filters it is necessary to define the section structures, variants of pole-zero pairing and section ordering. All these problems need to be decided together with minimization problems of quantization effects of the inner date and filter transfer function coefficients. It permits to expand a range of possible characteristics of developed systems on the basis existing signal processors, and to reduce the chip area, power consume, requirements to speed of operation and cost for systems on custom or semi-custom VLSI.

Currently the complete automation of IIR digital filter design is not possible. Therefore a more simple approach is using, namely for a chosen filter structure a transfer function design problem is deciding. In spite of large number of IIR structures the cascade filters on the basis direct or transposed form sections remain the most attractive for the developers. The deficiencies of the most popular design computer programs for such filters are that the initial parameters are not optimized in them, the quantization of coefficients corresponds to simple rounding and used pairing-ordering procedures are not always effective. In this paper the cascade IIR digital filter design program - DIFID (Radis Ltd.) that is free from these limitations is presented, and its efficiency on particular examples is demonstrated.

**2. DIFID program.** The program permits to calculate cascade IIR lowpass, highpass, bandpass and bandstop digital filters. As prototypes the Chebyshev, Butterworth, Bessel, inverse Chebyshev or Zolotarev-Cauer (elliptic) analog filters are used. The transformation method from a prototype to a digital filter is the bilinear transformation.

The second-order sections are the direct or canonic form or their transposed variants. The scaling with $L_2$-, $L_\infty$- or $l_1$- norm is executed by change of transfer function numerator coefficients or by inserting scaling factors between the sections.

In order to obtain the acceptable solutions with the given or minimum coefficient wordlength a method of variation of initial parameters (VIP) is used [1]. The varied parameter is passband ripple [2]. A mode without application VIP is also allowed.

A heuristic procedure of the pole-zero pairing and section ordering [3] is applied for minimization of the (quantization noise)-to-signal ratio. Besides it is possible for user to set the pairing and ordering.

The noise gain, noise-to-signal ratio, additional number of bit (to compensation of the quantization noise) and zero-input limit cycle upper bound, expressed in bits are calculated for evaluation of quantization effects of fixed point inner date.

The passband ripple, minimum stopband attenuation, passband gain, maximum power spectral density of resulting output quantization noise, ripple and maximum of group delay in passband are evaluated for given quantity of points.

All listed and number of auxiliary parameters together with obtained coefficients give reasonably complete information about the designed filter.

**3. Digital filter design examples.** Let's consider fixed-point cascade IIR digital filter design by the DIFID program in case when the VIP method and pairing-ordering procedure are used. We allow that scaling factors are entered by change of numerator coefficients of the transfer function and for all adding nodes in the filter the norms $L_\infty \cong 1$.

The scaled transfer function with quantized coefficients is

$$H(z) = \prod_{i=1}^{K} \frac{b_{0i} + b_{1i} z^{-1} + b_{2i} z^{-2}}{1 + a_{1i} z^{-1} + a_{2i} z^{-2}} = \prod_{i=1}^{K} \frac{B_i(z)}{A_i(z)} = \prod_{i=1}^{K} H_i(z).$$

The resulting output quantization noise power(in dB) is

$$10\,\mathbf{lg}\Big( \frac{2^{-2b}}{3} \sum_{k=1}^{K} \Big\| \frac{1}{A_k} \prod_{i=k+1}^{K} H_i \Big\|_2^2 \Big),$$

where b - the number of bits (including sign bit) needed to be kept after rounding of date inside the filter, $\prod_{i=K+1}^{K} H_i = 1$.

The edge frequencies are normalized according to a sampling frequency.

Example 1. Lowpass digital filter specifications:

| | |
|---|---|
| Passband ripple,dB | $\leq 0.3$ |
| Minimum stopband attenuation, dB | $\geq 50$ |
| Edge frequencies | 0.0260, 0.0263 |
| Passband gain, dB | $\cong 0$ |
| Date and coefficient wordlength, bit | 16 |
| Analog prototype | Zolotarev-Cauer filter |

Design results: $b_{2i} = b_{0i}$, $i = 1,\ldots,6$,

| i | $a_{1i}$ | $a_{2i}$ | $b_{0i}$ | $b_{1i}$ |
|---|---|---|---|---|
| 1 | -1.91833496093750 | 0.93347167968750 | 0.17266845703125 | -0.33520507812500 |
| 2 | -1.97045898437500 | 0.99676513671875 | 0.90466308593750 | -1.78424072265625 |
| 3 | -1.95062255859375 | 0.97277832031250 | 0.41809082031250 | -0.82153320312500 |
| 4 | -1.96502685546875 | 0.99023437500000 | 0.55767822265625 | -1.09899902343750 |
| 5 | -1.87628173828125 | 0.88238525390625 | 0.06250000000000 | -0.10308837890625 |
| 6 | -1.97259521484375 | 0.99926757812500 | 0.97259521484375 | -1.91864013671875 |

| | | |
|---|---|---|
| Passband ripple,dB | 0.271 | (1.535) |
| Minimum stopband attenuation, dB | 52.4 | (54.6) |
| Passband gain, dB | 0.002 | (-0.050) |
| Output noise power, dB | -55.2 | (-47.70) |

Example 2. Lowpass digital filter specifications:

| | |
|---|---|
| Passband ripple,dB | $\leq 0.15$ |
| Minimum stopband attenuation, dB | $\geq 55$ |
| Edge frequencies | 0.04, 0.045 |
| Passband gain, dB | $\cong 0$ |

| | |
|---|---|
| Date and coefficient wordlength, bit | 16 |
| Analog prototype | Chebyshev filter |

Design results: $b_{2i} = b_{0i}$, $i = 1,\ldots,9$,

| i | $a_{1i}$ | $a_{2i}$ | $b_{0i}$ | $b_{1i}$ |
|---|---|---|---|---|
| 1 | -1.92584228515625 | 0.93127441406250 | 0.00115966796875 | 0.00225830078125 |
| 2 | -1.92193603515625 | 0.98138427734375 | 0.01391601562500 | 0.02789306640625 |
| 3 | -1.92004394531250 | 0.94165039062500 | 0.00451660156250 | 0.00903320312500 |
| 4 | -1.91619873046875 | 0.95898437500000 | 0.00750732421875 | 0.01501464843750 |
| 5 | -1.91735839843750 | 0.94952392578125 | 0.00256347656250 | 0.00512695312500 |
| 6 | -1.92315673828125 | 0.93548583984375 | 0.00415039062500 | 0.00830078125000 |
| 7 | -1.91741943359375 | 0.96966552734375 | 0.00720214843750 | 0.01434326171875 |
| 8 | -1.92736816406250 | 0.92913818359375 | 0.00402832031250 | 0.00805664062500 |
| 9 | -1.93023681640625 | 0.99371337890625 | 0.01580810546875 | 0.03155517578125 |

| | |
|---|---|
| Passband ripple,dB | 0.147 (0.434) |
| Minimum stopband attenuation, dB | 55.2 (57.5) |
| Passband gain, dB | 0.005 (-0.682) |
| Output noise power, dB | -57.9 (-18.7) |

Example 3. Bandpass digital filter specifications:

| | |
|---|---|
| Passband ripple,dB | $\leq 3$ |
| Minimum stopband attenuation, dB | $\geq 35$ |
| Edge frequencies | 0.004, 0.01, 0.4, 0.45 |
| Passband gain, dB | $\cong 0$ |
| Date wordlength, bit | 16 |
| Coefficient wordlength, bit | 11 |
| Analog prototype | Butterworth filter |

Design results: $b_{1i} = 0$; $b_{2i} = -b_{0i}$, $i=1,\ldots,6$,

| i | $a_{1i}$ | $a_{2i}$ | $b_{0i}$ |
|---|---|---|---|
| 1 | 1.05859375 | 0.28906250 | 0.35546875 |
| 2 | -1.91406250 | 0.91796875 | 1.57421875 |
| 3 | 1.44531250 | 0.75000000 | 0.23828125 |
| 4 | -1.96484375 | 0.96875000 | 2.00000000 |
| 5 | 1.17968750 | 0.43359375 | 0.41406250 |
| 6 | -1.88671875 | 0.89062500 | 2.26171875 |

| | |
|---|---|
| Passband ripple,dB | 2.838 (4.220) |
| Minimum stopband attenuation, dB | 35.8 (37.9) |
| Passband gain, dB | 0.004 (- 0.05) |
| Output noise power, dB | - 65.1 (+ 1.7) |

For the comparison in brackets the parameters of the filters designing with the use of the QEDsign-2000/demo software package (Momentum Data Systems) are indicated. As it can be seen, for all examples the solutions found by DIFID completely satisfy to the given specifications unlike the solutions received by QEDeisgn. Besides for two last examples DIFID results in considerably smaller output noise powers.

**4. Conclusion.** The presented examples of the filter design confirm the efficiency of DIFID program. Wider researches show that in comparison to the QEDesign software package the DIFID program can give similar or best results. It depends on the particular filter requirements. The DIFID can be successfully used for design of cascade IIR digital filters on the basis of DSP and PLD.

## References

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