# Power Optimization of FIR Filters through the Coefficients Reordering using Anedma Heuristic

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# Contents

# Objective

Verify the reduction in power consumption of FIR filters by the reordering of coefficients using ANEDMA heuristic algorithm.

# Introduction

- Special attention to digital signal processing (DSP) system due to the proliferation of portable battery powered electronic devices;
- FIR filter is one of the most basic operations used in DSP applications;
- By increasing the number of taps of the filter we can improve the definition in transfer function;
- As the summation operation in FIR filter is commutative and associative, thus the coefficient ordering has been used as a technique for low power;
- Techniques proposed by **Mehendale**[1] and **Costa**[2] are limited for small group of coefficients;
- We have used ANEDMA heuristic-based algorithm for the reordering of coefficients in order to observe the impact on reducing power consumption.
- First observation in the impact on reducing power consumption.

[1] M. Mehendale, S. Sherlekar, and G. Venkatesh, *Techniques for low power realization of FIR filters*, in Asia and South Pacific Design Automation Conference, ASPDAC, 1995, pp. 447-450.

[2] E. Costa, S. Monteiro, and S. Bampi, *Gray encoded arithmetic operators applied to FFT and FIR dedicate datapaths*, in 11th IEEE/IFIP International Conference on Very Large Scale Integration, VLSI-SoC, 2003, pp. 307-312.

# Fir Filter Realization

It convolves the input data samples with the desired unit impulses responses.

$$Y[n] = \sum_{i=0}^{N-1} X[n-i]H[i] \tag{1}$$

Y - Output data
X - Input data samples
H - Coefficients of the filter

# Coefficient Manipulation

Coefficient ordering can be used as a technique for low power because in a FIR filter computation:

- The summation operation is both commutative and associative;
- The filter output is independent of the order of computing the coefficient product.

$$Y_n = A_0X_n + A_1X_{n-1} + A_2X_{n-2} + A_3X_{n-3} \tag{2}$$

$$Y_n = A_1X_{n-1} + A_3X_{n-3} + A_0X_n + A_2X_{n-2} \tag{3}$$

# Datapath

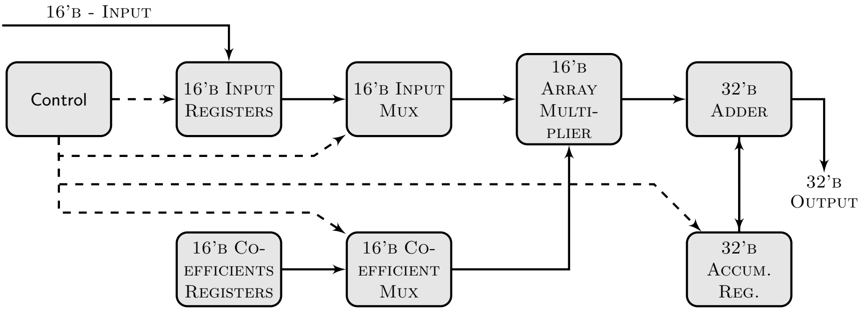


Figure 1 : Schematic for FIR filters datapath.

# ANEDMA Heuristic

- It starts N threads using a random point as initial element;
- Each thread produces an ordering;
- It creates a list with the best candidates for each coefficient, considering the lower Hamming distance;
- Coefficients with just 1 element in its list has this one added to a locked list;
- The locked ones are removed from the other candidates lists;
- A list with more than 1 candidate gets the least significant for the other coefficients;
- At the final all coefficients are placed one beside another.

# Methodology

- Coefficients reordering with ANEDMA heuristic algorithm;
- Description of FIR filters datapath in SystemVerilog;
  - Original[3];
  - ANEDMA[4].
- Functional verification with VCS®;
- Logical sinthesis with DesignCompiler®:
  - XFAB 350nm;
  - XFAB 180nm.
- Power estimation with PrimeTime®:
  - Sinusoidal Vectors;
  - Random Vectors.

[3] V. S. d. Rosa, Uma ferramenta para geração de filtros fir paralelos otimizados com coeficientes constantes, 2005.

[4] A. Luz, E. Costa, and M. Aguiar, Exploring the Use of Heuristic Based Algorithms for the Ordering and Partitioning of Coefficients for Low Power Efficient FIR Filters Realization, in 24$^{rd}$ Symposium on Integrated Circuits and Systems Design, SBCCI, 2011, pp. 91–96.

# Results

- Large reduction in power consumption from switching activity (5.41 - 26.10%);
- A total power reduction up to 7.63% for 350nm technology and up to 5.18% for 180nm;
- The best optimization, in terms of power consumption, has occurred when using sinusoidal vectors, because the higher correlation between the input data;
- The total area has not presented significant changes between ordered and unordered filters. In fact, it occurs because the reordering of coefficients does not increase the hardware, since only the order of coefficients in the multiplexer is changed;
- The leakage power has not presented significant contribution in the total power, because the used technologies are up to 100nm.

# Sinusoidal Vectors

Table 1 : Power Results - 30c and 50c Filters - Sinusoidal Vectors

| | Filter | 180nm | | | | | | 350nm | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Power (mW) | | | Perc. Reduction (%) | | | Power (mW) | | | Perc. Reduction (%) | | |
| | | Swtg | Int | Total | Swtg | Int | Total | Swtg | Int | Total | Swtg | Int | Total |
| 30c | Band Stop 1 | 0.777 | 5.224 | 6.002 | −9.32 | −1.91 | −2.87 | 8.574 | 46.0 | 54.574 | −10.72 | −2.83 | −4.07 |
| | Band Stop 1 - ANEDMA | 0.705 | 5.124 | 5.829 | | | | 7.655 | 44.7 | 52.355 | | | |
| | High Pass 1 | 0.653 | 5.067 | 5.721 | −16.72 | −3.69 | −5.18 | 7.195 | 43.6 | 50.795 | −18.97 | −4.59 | −6.62 |
| | High Pass 1 - ANEDMA | 0.544 | 4.880 | 5.425 | | | | 5.830 | 41.6 | 47.430 | | | |
| | Low Pass 2 | 0.935 | 5.391 | 6.327 | −11.30 | −2.19 | −3.54 | 10.30 | 48.5 | 58.800 | −12.64 | −3.71 | −5.28 |
| | Low Pass 2 - ANEDMA | 0.829 | 5.273 | 6.103 | | | | 8.998 | 46.7 | 55.698 | | | |
| 50c | Band Pass 1 | 0.884 | 7.506 | 8.390 | −9.97 | −1.53 | −2.42 | 9.699 | 64.1 | 73.799 | −26.10 | −4.84 | −7.63 |
| | Band Pass 1 - ANEDMA | 0.795 | 7.391 | 8.187 | | | | 7.168 | 61.0 | 68.168 | | | |
| | High Pass 2 | 0.901 | 7.520 | 8.422 | −9.45 | −1.36 | −2.22 | 8.372 | 62.7 | 71.072 | −11.81 | −2.07 | −3.22 |
| | High Pass 2 - ANEDMA | 0.816 | 7.418 | 8.235 | | | | 7.383 | 61.4 | 68.783 | | | |
| | Low Pass 1 | 0.709 | 7.285 | 7.995 | −7.75 | −1.25 | −1.83 | 6.324 | 59.6 | 65.924 | −11.34 | −1.85 | −2.76 |
| | Low Pass 1 - ANEDMA | 0.654 | 7.194 | 7.849 | | | | 5.607 | 58.5 | 64.107 | | | |
| | Average Reduction | | | | −10.75 | −1.99 | −3.01 | | | | −15.26 | −3.31 | −4.93 |

# Random Vectors

Table 2 : Power Results - 30c and 50c Filters - Random Vectors

| | Filter | 180nm | | | | | | 350nm | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Power ($mW$) | | | Perc. Reduction (%) | | | Power ($mW$) | | | Perc. Reduction (%) | | |
| | | Swtg | Int | Total | Swtg | Int | Total | Swtg | Int | Total | Swtg | Int | Total |
| 30c | Band Stop 1 | 0.994 | 5.546 | 6.540 | −6.88 | −1.19 | −2.06 | 10.700 | 49.8 | 60.500 | −7.44 | −2.21 | −3.13 |
| | Band Stop 1 - ANEDMA | 0.925 | 5.480 | 6.406 | | | | 9.904 | 48.7 | 58.604 | | | |
| | High Pass 1 | 0.862 | 5.382 | 6.244 | −9.29 | −2.40 | −3.35 | 9.221 | 47.2 | 56.421 | −10.41 | −3.18 | −4.36 |
| | High Pass 1 - ANEDMA | 0.782 | 5.253 | 6.035 | | | | 8.261 | 45.7 | 53.961 | | | |
| | Low Pass 2 | 1.163 | 5.717 | 6.880 | −8.60 | −1.42 | −2.63 | 12.600 | 52.4 | 65.000 | −9.52 | −2.67 | −4.00 |
| | Low Pass 2 - ANEDMA | 1.063 | 5.636 | 6.699 | | | | 11.400 | 51.0 | 62.400 | | | |
| 50c | Band Pass 1 | 1.099 | 7.823 | 8.922 | −8.37 | −1.09 | −1.98 | 11.800 | 67.9 | 79.700 | −20.71 | −4.71 | −7.08 |
| | Band Pass 1 - ANEDMA | 1.007 | 7.738 | 8.745 | | | | 9.356 | 64.7 | 74.056 | | | |
| | High Pass 2 | 1.162 | 7.903 | 9.065 | −7.57 | −0.97 | −1.82 | 11.000 | 66.7 | 77.700 | −8.18 | −4.71 | −7.08 |
| | High Pass 2 - ANEDMA | 1.074 | 7.826 | 8.900 | | | | 10.100 | 65.8 | 75.900 | | | |
| | Low Pass 1 | 0.976 | 7.692 | 8.668 | −5.41 | −0.87 | −1.38 | 9.036 | 63.8 | 72.836 | −6.50 | −1.41 | −2.04 |
| | Low Pass 1 - ANEDMA | 0.923 | 7.625 | 8.548 | | | | 8.449 | 62.9 | 71.349 | | | |
| | Average Reduction | | | | −7.69 | −1.32 | −2.20 | | | | −10.46 | −2.59 | −3.82 |

# Conclusions

- The efficiency of the Anedma algorithm could be proved, because the power consumption of different set of filters was reduced, after using the reordering of coefficients based on the guidance given by the Anedma algorithm;
- As expected the switching power presented the largest power percentage reduction for the used technologies;
- The total power reduction was not too large, because the amount of internal cell power, that is responsible for most part of it, is not so much afected by the reordering of coefficients.

# Future Works

Verify the power optimization in FFT and DCT architectures.

# Acknowledgment

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Thank You!

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# ANEDMA Heusitic Alagorithm Example[5]

E1C = ([E3],[E6],[E7],[E10])
E2C = ([E6],[E8],[E9])
E3C = ([E9])
E4C = ([E7])
E5C = ([E4],[E6],[E9])
E6C = ([E2],[E5],[E8])
E7C = ([E4])
E8C = ([E9])
E9C = ([E8])
E10C = ([E4])
EBloq = ([E1])

- Set E1 as initial point;
- Organize the candidate list for each coefficient.

[5] A. Luz, E. Costa and M. Aguiar, *Heurísticas para Ordenação e Particionamento de Coeficientes em Arquiteturas de Filtros FIR*. Catholic University of Pelotas, 2011, pp. 38-40.

# ANEDMA Heusitic Alagorithm Example[5]

E1C = ([E3],[E6],[E10])
E2C = ([E6])
E3C = ([E9])
E4C = ([E7])
E5C = ([E6])
E6C = ([E2],[E5])
E7C = ()
E8C = ()
E9C = ([E8])
E10C = ([E4])
EBloq = ([E1],[E9],[E7],[E4],[E8])

- The lists with one candidate have this one added to de blocked list (EBloq);
- The blocked ones are removed from the other candidates lists;
- E6 turns the unique candidate for E2C and E5C.

# ANEDMA Heusitic Alagorithm Example[5]

E1C = ([E3],[E10])
E2C = ([E6])
E3C = ([E9])
E4C = ([E7])
E5C = ()
E6C = ([E2],[E5])
E7C = ()
E8C = ()
E9C = ([E8])
E10C = ([E4])
EBloq = ([E1],[E9],[E7],[E4],[E8],[E6])

- E6 is choosen by E2C considering that is the best choise in function of the next options for each list;
- It is added to Ebloq, though.

# ANEDMA Heusitic Alagorithm Example[5]

E1C = ([E3])
E2C = ([E6])
E3C = ([E9])
E4C = ([E7])
E5C = ([E10])
E6C = ([E5])
E7C = ([E1])
E8C = ([E2])
E9C = ([E8])
E10C = ([E4])
EBloq = ([E1],[E9],[E7],[E4],[E8],[E6],[E3],[E10],[E5],[E2])
Result = ([E1],[E3],[E9],[E8],[E2],[E6],[E5],[E10],[E4],[E7])

- E1C and E6C have your ones select at random, and those ones are automatically added to EBloq;
- E5C and E8C get the restant coefficients that have the lower Hamming distance;
- All the elements were added to the EBloq list and the resulting order is made puting all the coefficient one beside another starting by the initial point E1.