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A Resource-efficient FIR Filter Design Based on an RAG Improved Algorithm

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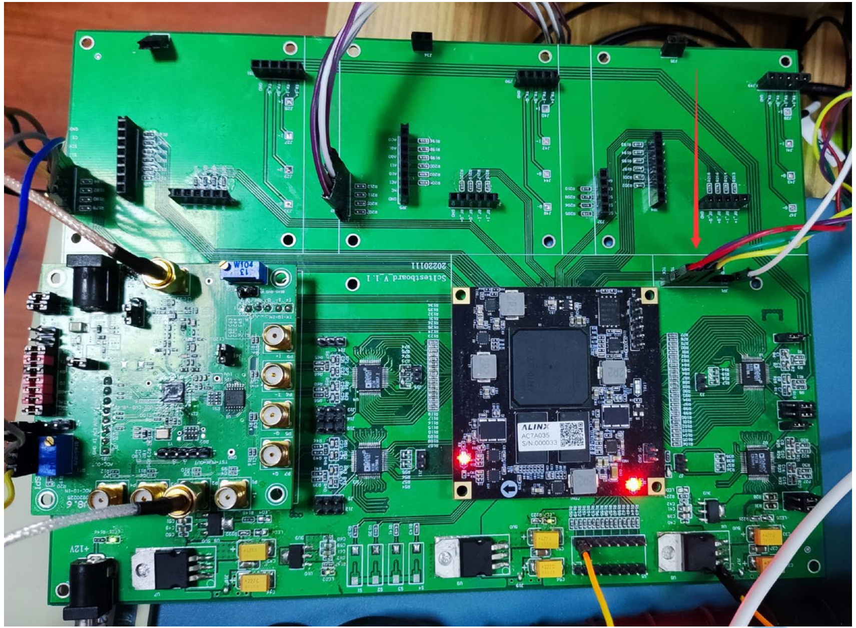
Outline

1. Motivation
2. Methodology
3. Synthesis Results
4. Conclusion

1. Motivation

- Comes from a real-world project about RFIC calibration
- Used to calculate the leak energy



Demands:

- High-speed
- High-performance
- Limited resources

1. Motivation

Basic information about FIR filter:

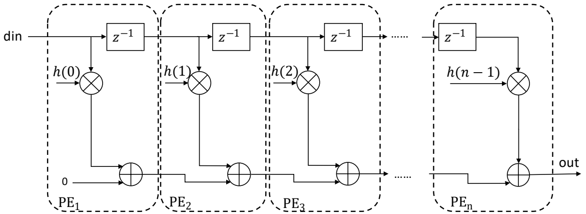
FIR filter's transfer function: $H(z)=\sum_{n=0}^{N-1}h(n)z^{-n}$

FIR filter's differential equation: $y(n)=\sum_{k=0}^{N-1}h(k)x(n-k)$

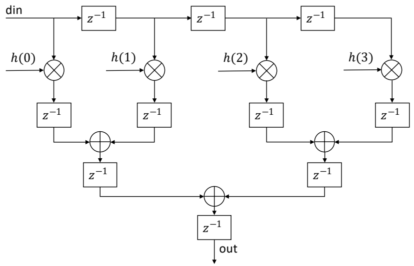
FIR filters' unit impulse response: $h(n)=\sum_{i=0}^{N-1}h(i)\delta(n-i)$

1. Motivation

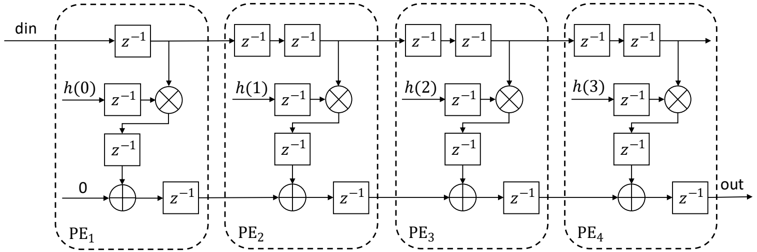
Some existing FIR filters' architecture



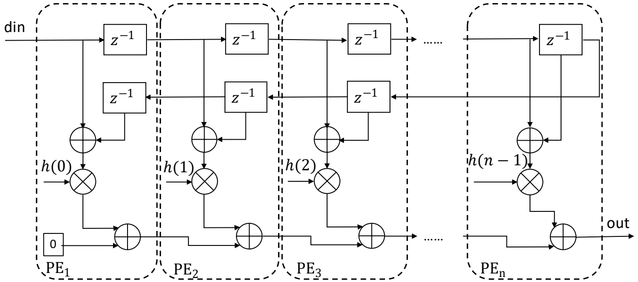
Basic



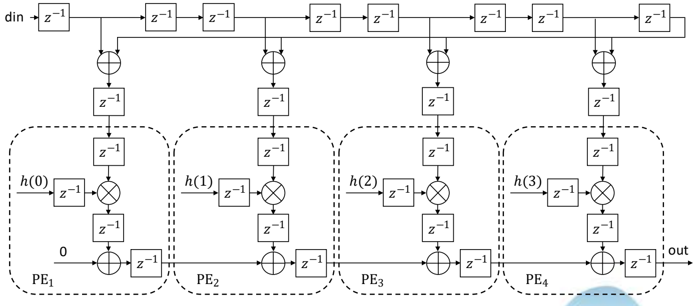
Wallace Tree



Systolic



Even Symmetry



Systolic+Even symmetric

1. Motivation

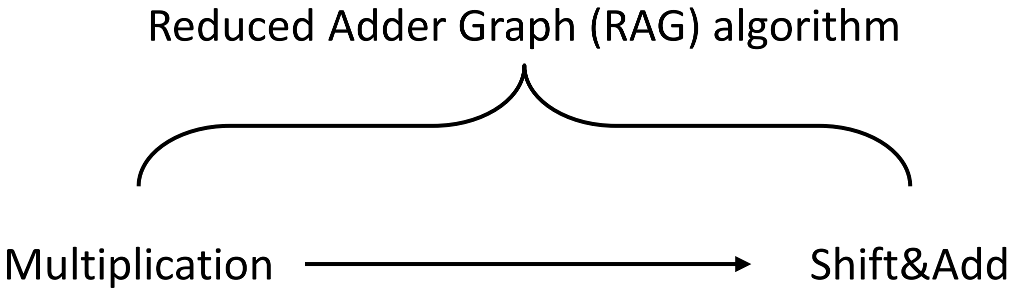
Demand 1: High-speed →
- Full parallel
- Short critical path
- Pre-add (Wallace tree)

Demand 2: Resources-efficient ✕ A lot of resources required

2. Methodology

Most of the resources are used to calculate addition and multiplication.

The highest clock frequency is restricted by critical path.



2. Methodology

Steps 0: Separate the coefficients into different sets.

Set $coeff$ → All filter's coefficients

Set $coeff_r$ → smaller coefficients

Set $coeff_s$ → larger coefficients

Set $cost_n$ → adder depth for (1, 2, 3, 4)

Set $cost_o$ → other adder depth

2. Methodology

Step 1: Take the absolute values of all coefficients and store them in $coeff$ set;

Step 2: Remove the duplicate coefficients and coefficients with value 2^n, and the number of remaining coefficients is denoted as N;

Step 3: The smaller coefficients are deposited into set $coeff_r$, and the number of coefficients deposited is $\frac{N}{2}$ or $\frac{N-1}{2}$;

Step 4: Deposit the remaining larger coefficients into set $coeff_s$;

2. Methodology

Step 5: Divide the even numbers in set $coeff_r$ by 2^n to obtain the base;

Step 6: Look up the table to get the depth of adder corresponding to each base number, store these coefficients in set $cost_n$, and store the coefficients which cannot be categorized by the table in set $cost_o$;

Step 7: Realize coefficients in set $cost_1$;

2. Methodology

Step 8: Check the sum/difference of coefficients in all realized cost sets, realize the coefficients in higher cost sets by the sum/difference of coefficients and the realized coefficients, and finally realize the coefficients in set $cost_o$;

Step 9: Realize the coefficients in set $coeffs_s$ according to the hardware structure of systolic FIR filter with symmetric coefficients.

2. Methodology

Concise summary:

For those smaller one, shift and add.

For those bigger one, multiply.

Aim:

Keep the balance of DSP consumption and LUT consumption to achieve resource-efficient.

3. Synthesis Results

Resources/ Performance	Algorithm Architecture		
	Pulsed Fully Parallel	RAG Algorithm	RAG Improved Algorithm
LUT	574	4956	934
FF	1286	528	904
DSP	4	0	2
Power(W)	32.8	234.7	38.6
Temp(℃)	70.8	125.0	79

Table 1: 64^{th} order FIR filter

3. Synthesis Results

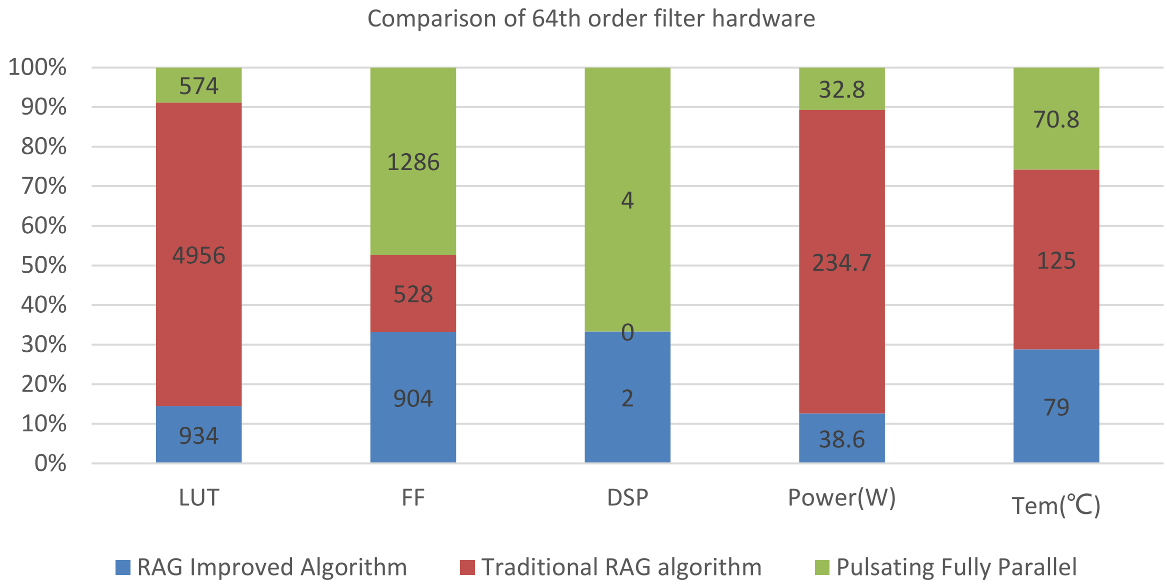
Resources / Performance	Algorithm Architecture		
	Pulsed Fully Parallel	RAG Algorithm	RAG Improved Algorithm
LUT	358	695	555
FF	679	287	538
DSP	4	0	2
Power(W)	21.34	24.52	19.75
Temp(℃)	54.8	59.3	52.6

Table 2: 32th order FIR filter

Resources/ Performance	Algorithm Architecture		
	Pulsed Fully Parallel	RAG Algorithm	RAG Improved Algorithm
LUT	141	212	185
FF	203	120	222
DSP	4	0	2
Power(W)	41.762	33.673	36.75
Temp(℃)	83.4	72.1	76.4

Table 3: 8th order FIR filter

4. Conclusion



Thank you!

If you have any question,
feel free to ask!