TAMPERE UNIVERSITY OF TECHNOLOGY

Design and implementation of an FFT Pruning Engine for DSA-Enabled Cognitive Radios

*Manuele Cucchi, Deepak Revanna, **Roberto Airoldi**, Jari Nurmi*

Tampere University of Technology

Department of Electronics and Communications Engineering

P.O. Box 553, FIN-33101, Tampere Finland

Outline

- Motivation
- State of the art
- Objective of work
- Presentation of the architecture
- Implementation of the architecture
- Results

Spectrum Allocation

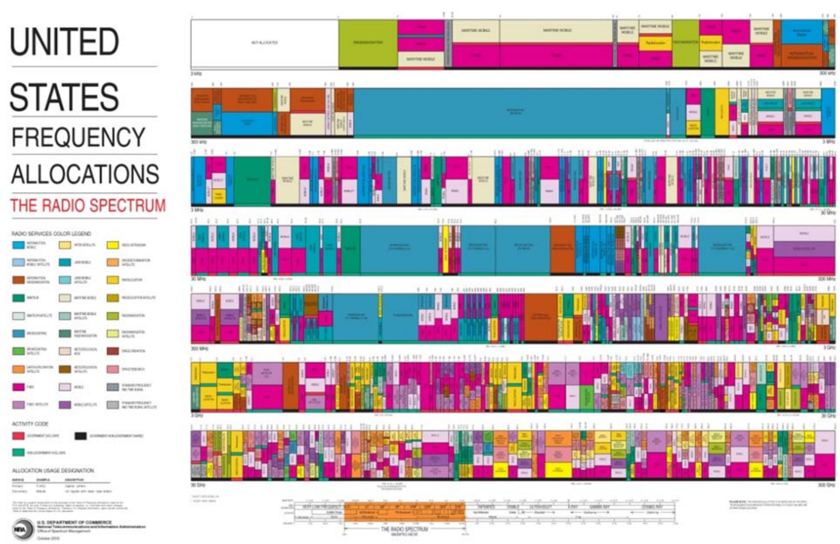
Spectrum
[30 MHz ÷ 10 GHz]

- Television (Digital and Analog)
- Radio (AM e FM)
- Mobile devices(GSM, UMTS …)
- Wireless Network (Bluetooth, Wi-Fi, …)
- Satellite broadcasting

Regulating the use of spectrum by allocating fixed frequencies for all wireless systems
but …

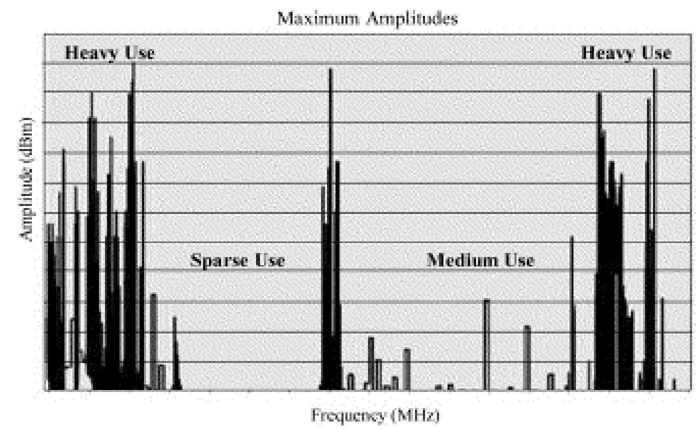
…in recent years, the exponential growth of wireless systems and mobile services, has led to an increasing demand for access to the spectrum in certain bands
paving the way to the

"spectral scarcity "



Dynamic Spectrum Access (DSA)

INEFFICIENT USE OF SPECTRUM



Dynamic Spectrum Access

A DSA technique allows a terminal to scan the spectrum in run-time and allocate bandwidth communications on portions available dynamically , avoiding interference with other users.

DSA-enabled Cognitive Radios (CRs)

DSA /Spectrum Sensing techniques are at the base on Cognitive Radio technology.

ITU (International Telecommunication Union):
A Cognitive Radio device is a radio or system that sense, and is aware of, its operational environment and can dynamically and autonomously adjust its radio operating parameters accordingly

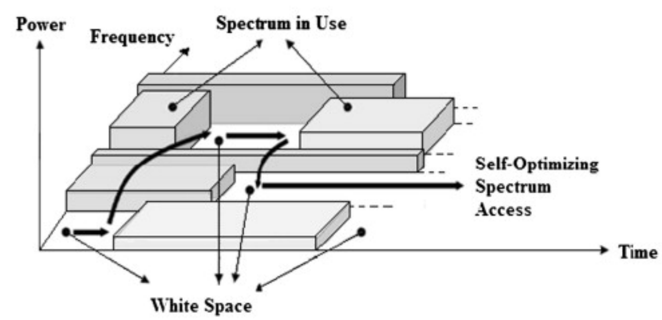
Opportunistic utilization of spectrum

Hierarchical structure of communication

primary users
(with license)

secondary users
(without license)

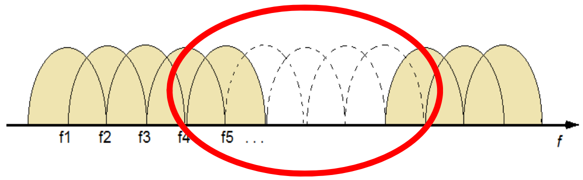
Identification and assignment of
“ White space" or "spectrum hole",
areas of the time-frequency plane
totally or partially not used.



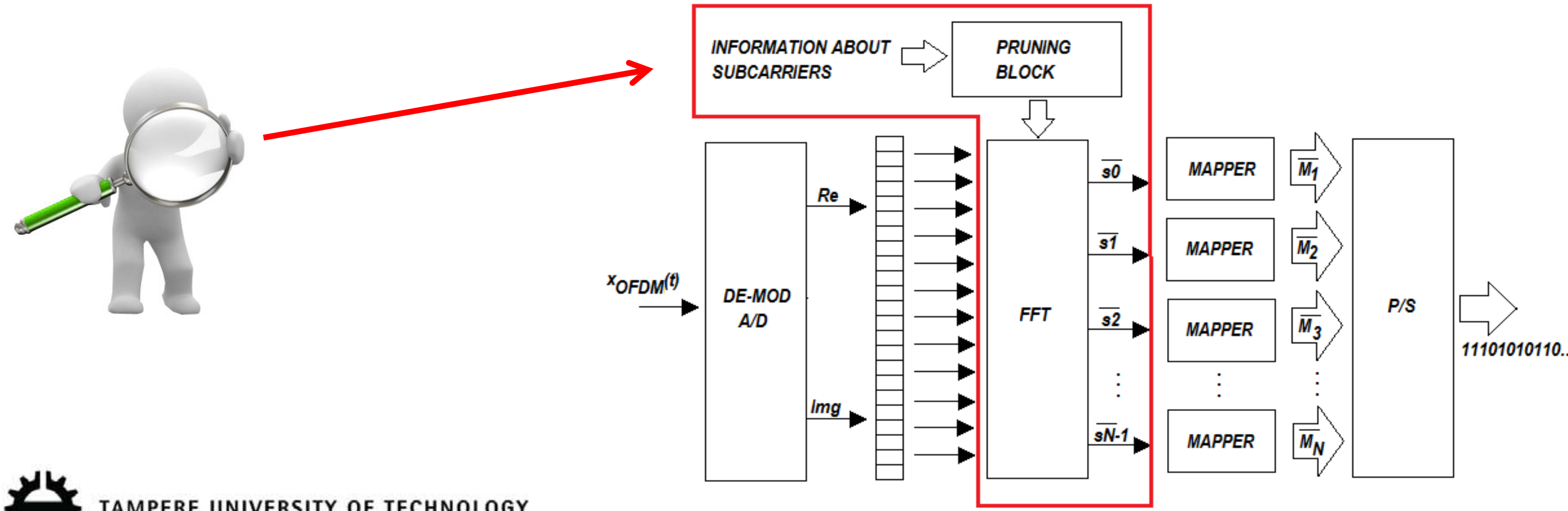
NC-ODFM (Non-Contiguous Orthogonal Frequency Division Multiplexing)

Need of wireless run-time reconfigurable platforms able to select the transmission frequency dynamically (Spectral Agility)

NC-OFDM technique



- Similar of OFDM concepts
- The carriers locates in the vicinity of primary users communications are disabled in order to avoid interference with them.



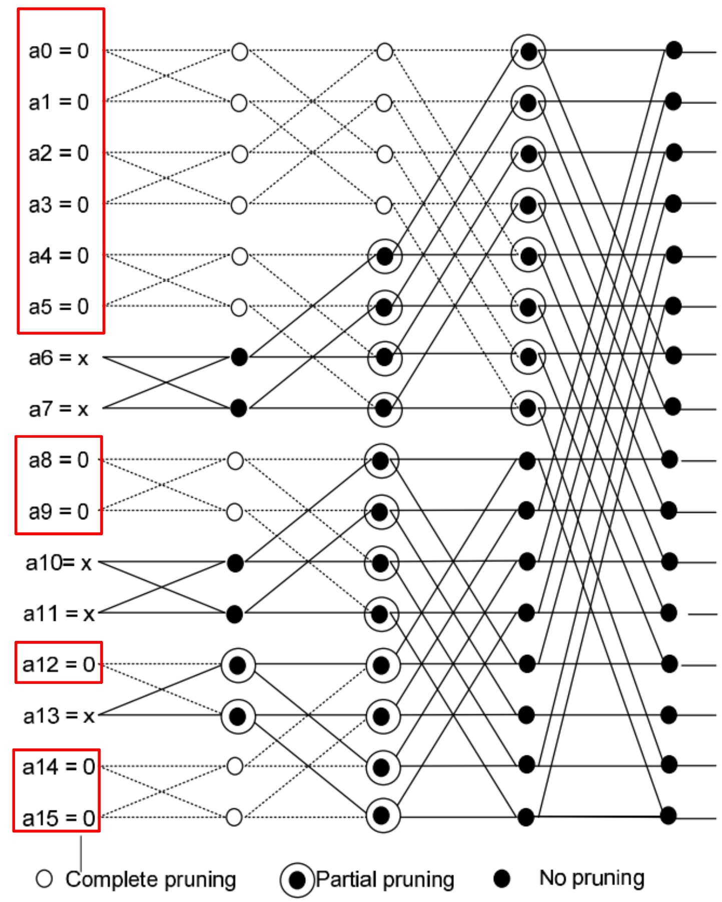
Idea of pruning

Base on FFT RADIX-2 algorithm

Type of FFT algorithm based on the recursive computation of a simple element called butterfly (butterfly), fitted in a symmetrical logic more complex.

The presence of zero samples in input of an FFT is a very common situation in a Cognitive Radio context or, in general, in all those systems that want to dynamically adapt to the channel conditions.

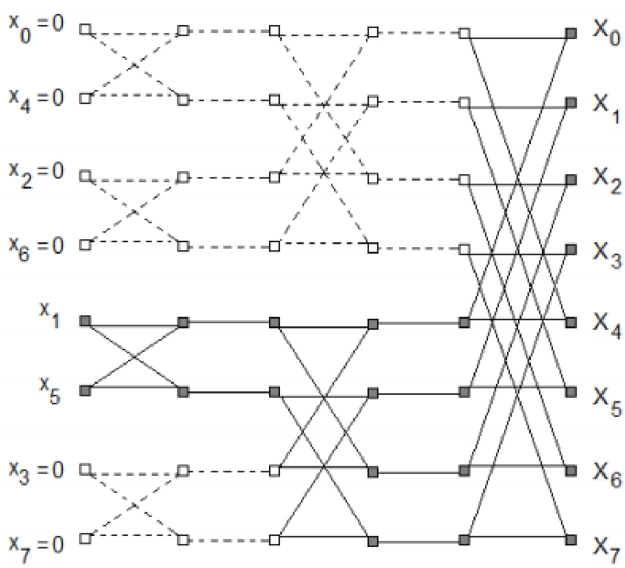
The idea behind FFT pruning is to reduce the computational complexity of the algorithm via the elimination of redundant operations, such as: multiplication or addition of neutral terms as well as multiplications by zero factors



State of the Art

From an implementation point of view, the challenges introduced by FFT pruning reside in how to design and implement efficiently the pruning, without any over complications of the control plane.

*Many **different implementations of the pruning algorithm** have been proposed*



Alves et al.[4]

$$M_{[4]} = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \end{bmatrix}$$

Rajbanshi et al.[5]

$$M_{[5]} = \begin{bmatrix} 2 & 4 & 8 \\ 4 & 4 & 0 \\ 5 & 5 & 1 \\ & 6 & 2 \\ & 7 & 3 \\ & & 4 \\ & & 5 \\ & & 6 \\ & & 7 \end{bmatrix}$$

Airoldi et al.[6]

$$M_{[6]} = \begin{bmatrix} 1 & 2 & 4 \\ 2 & 2 & 0 \\ & 3 & 1 \\ & & 2 \\ & & 3 \end{bmatrix}$$

State of the Art

Different software-hardware solutions have been proposed for the implementation of the FFT pruning algorithm

- ***Venilla et al*****.*****[7]*** *present a 64-point FFT/IFFT with pruning for OFDM-based cognitive radios. The proposed implementation allows the* ***pruning of the input only for contiguous blocks of 16 inputs*** *at the time, limiting by fact the application range of the approach to different types of scenario.*

- ***Xu and Lim [7]*** *propose an FFT pruning design based on a split radix implementation of the FFT kernel. The elements of the pruning matrix identify a multiplication and not a single data input.* ***No power consumption and resources utilization figures are given***

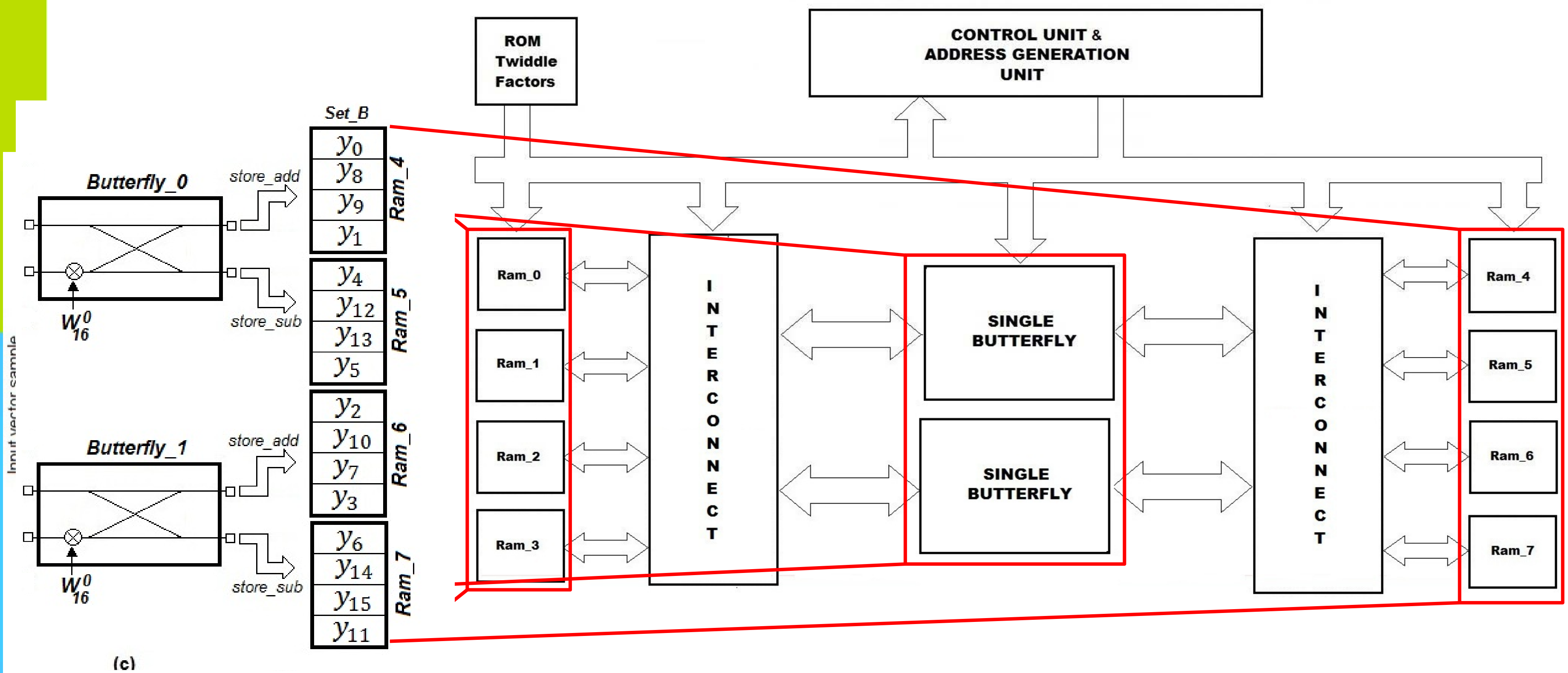
- ***Chen et al*****.** ***[9]*** *introduce an FFT processor for OFDMA communication systems.* ***The pruning algorithm*** *introduced relies on OFDMA specifications and therefore* ***might not be agile enough to follow*** *the dynamics of the inputs that could be more variegates*

The objective of work

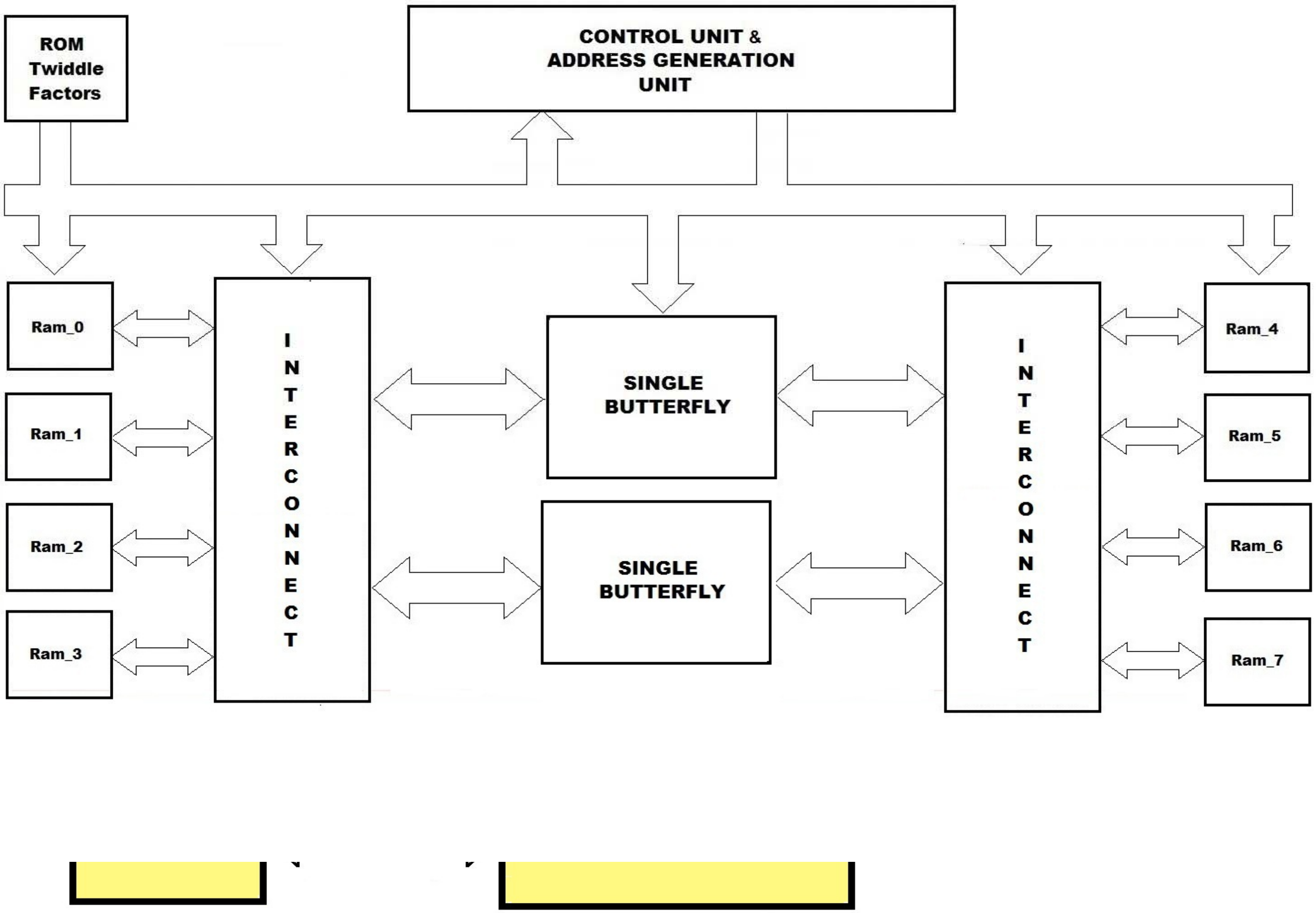
Definition of an **FFT algorithm pruning** able to lighten the work of computational FFT block, allowing a more effective implementation of the latter

Prototyping of entire architecture on *FPGA board Altera Stratix V* and evaluation of the performance of the pruning block.

Arch. of the FFT Core

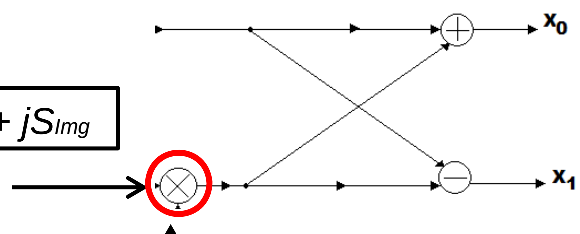


FFT pruning architecture



Butterflies blocks

$S = S_{Re} + jS_{Img}$

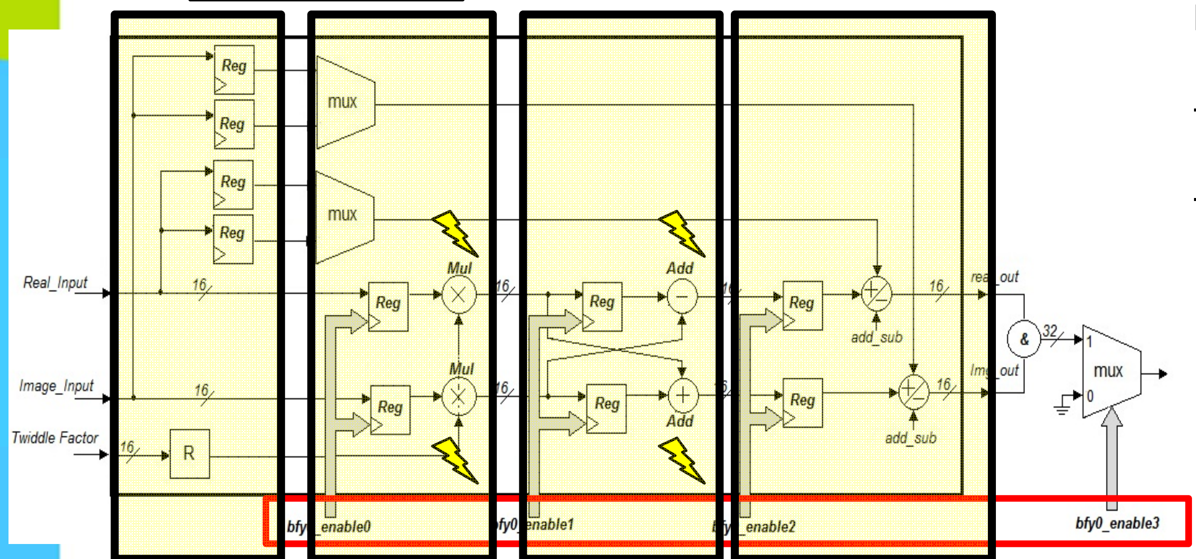


$W = W_{Re} + jW_{Img}$

$A = W_{RE} S_{RE}$; $B = W_{Re} S_{Img}$; ***(First cycle of clock)***

$C = W_{Img} S_{RE}$; $D = W_{Img} S_{Img}$ ***(Second cycle of clock)***

$SW = A - D + j(C+B)$ ***(Third cycle of clock)***



PIPELINE: 4 cycle of clock

For each butterfly, there are:

- 4 multiplications
- 4 additions

Clock Gating Technique

Pruning Matrix

The presence of invalid inputs in the first stage will be propagated along the structure of our Radix-2 algorithm. The calculation of various butterfly can be eliminated, because of it is the result of operations between zeros.

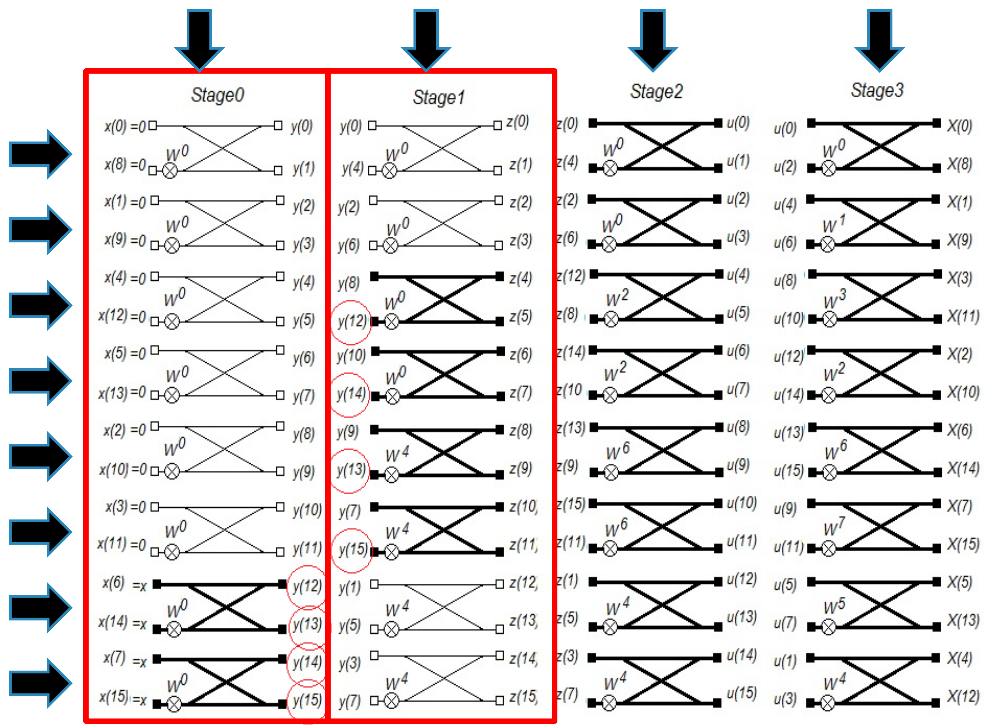
Pruning Matrix is a binary matrix that maps each butterfly of algorithm

Each bit of each column refers to a specific butterfly of each stage: only if both inputs are zero, the corresponding bit of the matrix will be set to zero

log₂(N)

$$M = \begin{bmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 \end{bmatrix}$$

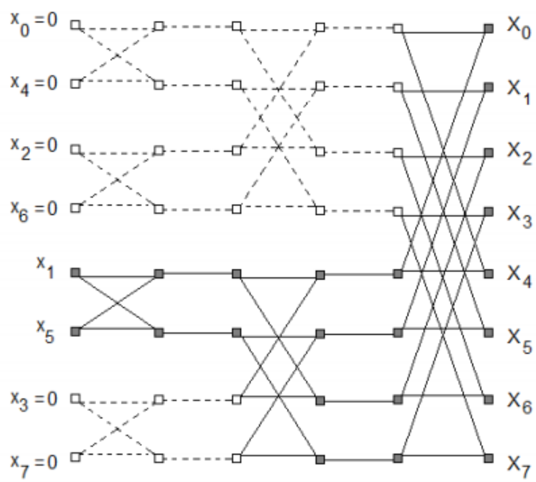
N/2



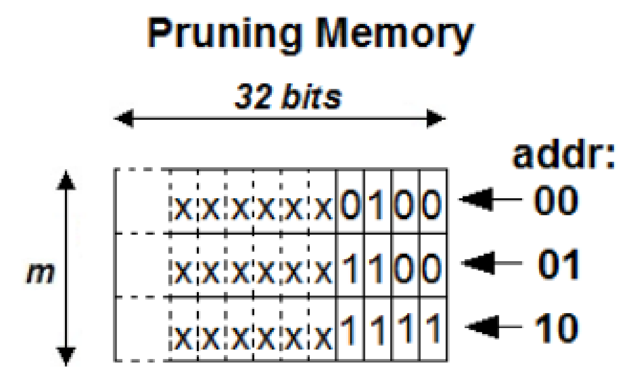
Pruning Matrix

The pruning matrix is stored into a RAM memory. A single memory word stores the configuration for up to 32 consecutive butterflies.

Example for 16-point FFT

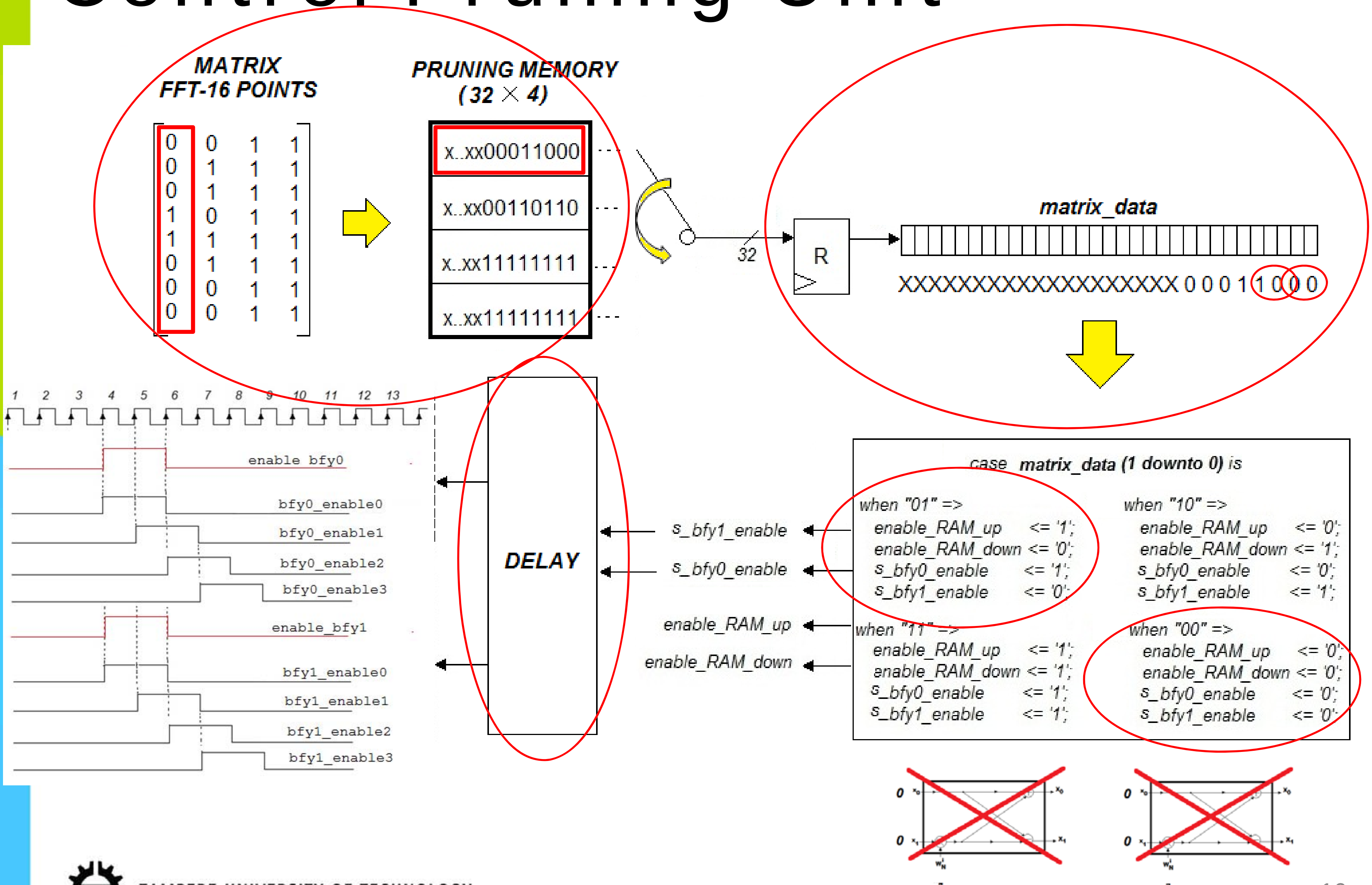


$$P = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \\ 1 & 1 & 1 \\ 0 & 1 & 1 \end{bmatrix}$$



FFT Radix-2 ***Matrix 4x3*** ***(3x32) bits***

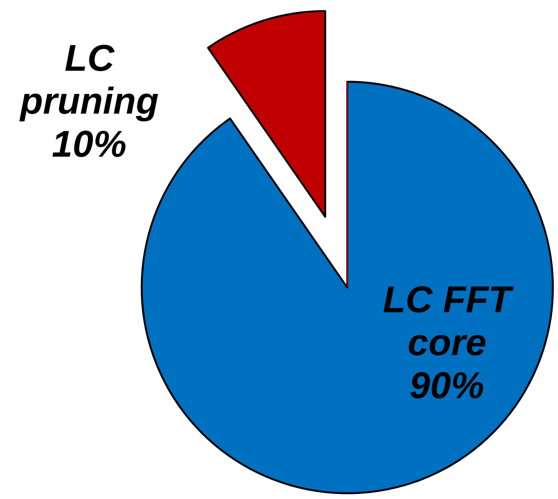
Control Pruning Unit



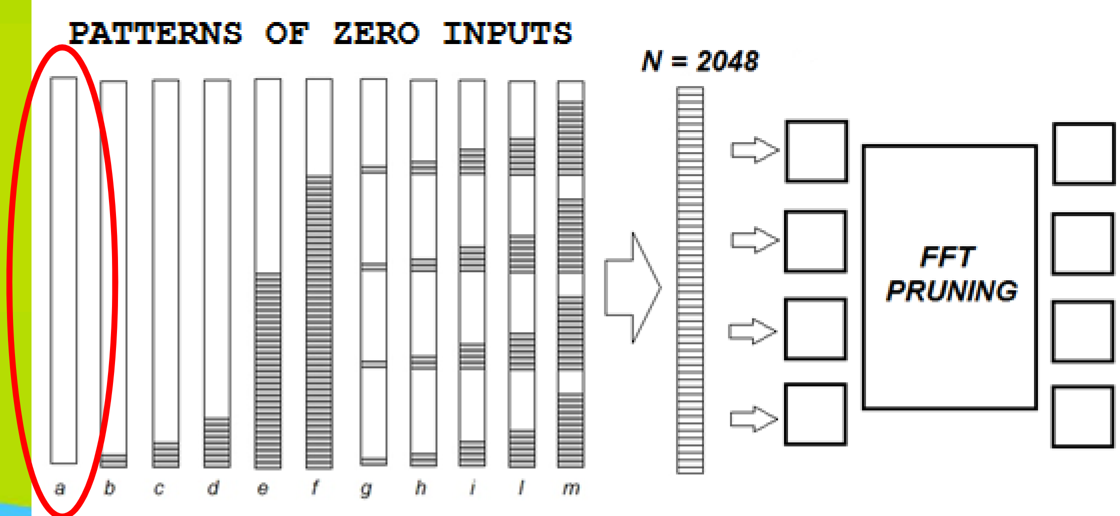
Results (1)

FPGA resources utilization

Device-Family	**Stratix V GS 5SGSMD5K2F40C2N**
Vcc	0.90 [V]
Frequency	100 [MHz]
Time of Simulation	120 [us]
Total Pins	680/864
DSP blocks	4
Logic Utilization (in ALMs)	1056/172600
Total LC Combinational	1170
LC Combinational by FFT core	1057
LC Combinational by pruning	113



Results (2)



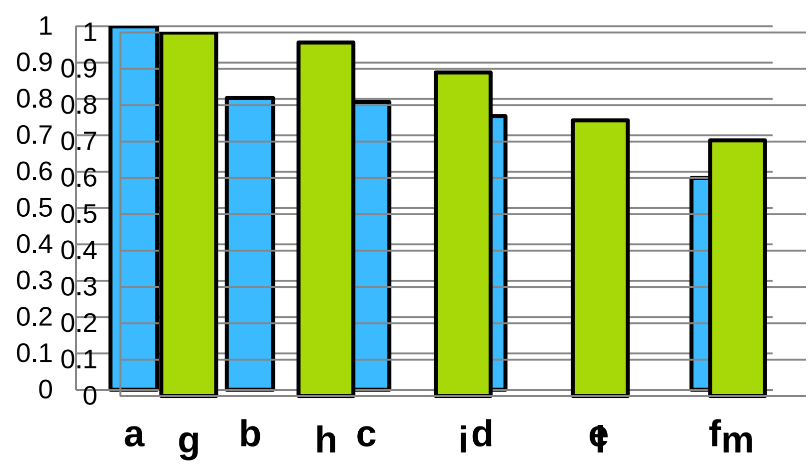
Power Consumption

Power Play Altera Analyzer

Maximum savings achieved :
40%

Table 1. Power Consumption with different pattern of Zero Input

Pattern Zero	Total Power by Hierarchy	Percentage of Power Saved
Pattern a	182 [mW]	–
Pattern b	146 [mW]	19.8 %
Pattern c	144 [mW]	20.9 %
Pattern d	137 [mW]	24.7 %
Pattern e	116 [mW]	36.3 %
Pattern f	106 [mW]	41.8 %
Pattern g	183 [mW]	
Pattern h	177 [mW]	2.7 %
Pattern i	162 [mW]	11.0 %
Pattern l	138 [mW]	24.2 %
Pattern m	128 [mW]	29.7 %



THANK YOU

References

[4] R. G. Alves, P. L. Osorio, and M. N. S. Swamy, “General FFT pruning algorithm,” in Proceedings of the 43rd IEEEMidwest Symposium on Circuits and Systems, vol. 3, 2000, pp. 1192–1195.

[5] R. Rajbanshi, A. M. Wyglinski, and G. J. Minden, “An Efficient Implementation of NC-OFDM Transceivers for Cognitive Radios,” in Proceedings of the 1st International Cognitive Radio Oriented Wireless Networks and Communications Conference, 2006, pp. 1–5.

[6] R. Airoldi, F. Garzia and J. Nurmi, "Efficient FFT Pruning

Algorithm for Non-Contiguous OFDM Systems," in Proceedings of the 2011 Conference on Design and Architectures for Signal and Image Processing (DASIP), 2011, pp.144-149.

[7] Vennila et al., ”Dynamic paertial reconfigurable FFT/IFFT pruning for OFDM based Cognitive Radio”, in Proceedings of IEEE International Symposium on Cyrcuits and Systems (ISCAS), 2012, pp. 33-36.

[8] Xu et al., ”An Efficient Design of Split-Radix FFT Pruning for OFDM based Cognitive Radio System”, in Proceedings of the 2011 International SoC Design Conference (ISOCC), 2011, pp. 368-372.

[9] Chen at al., ”An Energy Efficient Partial FFT Processor for the OFDMA Communication System”, IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 57, no. 2, pp. 136-140, 2010