A Framework for Coherent Functional Description and Hardware Abstraction in RF Front Ends

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Goals

- Presentation of the hardware abstraction interest in RF front-ends
- Presentation of the proposed hardware abstraction approach in RF front-ends
- Presentation of a RF design framework based on hardware abstraction concepts
Outline

- Motivations
- Hardware abstraction definition
- Hardware abstraction in RF front-ends
- Existent approaches
- Our hardware abstraction framework
- Conclusion
Motivations

- Tremendous wireless networks evolution
- Multiple communication services
- Software defined radio concept
  - Awareness, reconfigurability, interoperability
- Need for codesign for more optimal performance
- Wireless market growth:
  - Customized products
  - Time-to-market reduction
  - Cost reduction
  - Reliable and low consumption handheld terminals
The Dilemma

Such ambitious objectives need:
- An adaptive design flow
- A fully automatic (or semi-automatic) design and synthesis processes
- A high-level description of systems and subsystems

Then, hardware abstraction becomes interesting and more, essential!
Hardware Abstraction (1/2)

Definition:

Hardware abstraction (HA) is a method of masking physical details of hardware, allowing the designer to focus on the effects rather than the details resulting of manipulating directly the hardware. It is a way to describe the functionality without handling the intrinsic architecture of communication equipments [1, 2, 3].

HA advantages and provision:

- RF front-end (RFFE) HA is based up on a functional description which offers:
  - A compact way to describe the overall system
  - Hiding subsystems and physical details
  - Facilitating high-level simulation
  - Making design process more reliable and almost fully automatic
Existent Approaches (1/6)

- **In baseband side:**
  - HAL (WWRF & SDRF definition) [4]
  - OMG’s UML profile for software radio [5]

- **In RFFE:**
  - OMG’s UML profile for software radio [5]


OMG’s contribution:

- UML profile for software radio aims to enable the development of UML tools to support the development of software radio applications and systems [5]
- OMG has defined a set of UML stereotypes to describe communication equipments
- The UML profile for software radio includes the specification for:
  - Application and device components
  - Communication equipments
  - Infrastructure

Existent Approaches (3/6)

- Application and Device components package [5]:
  - Defines the basic types, application and device components for software radio

- Communication equipment package [5]:
  - Defines basic RF devices’ stereotypes

- Infrastructure package [5]:
  - Defines communication channel, radio services, management and deployment.

Abstraction Hierarchy

Ports are the interfaces that ensure the communication between equipments (either analog or digital)

- Communication Equipment
- IODevice
  - RF component (ampli, frequency converter, filter, antenna)
  - Ports (Input/Output, Analog/Digital)
Critics:
- Attributes were checked regarding some criteria:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Pass</th>
<th>Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sufficiency</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Organization</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Redundancy</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Completeness (¹)</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

(¹) Completeness regarding the number of devices already described (i.e. coupler)
Some devices are not represented by OMG:

**Coupler**

- $P_{in}$
- $I_s$
- $P_D$
- $P_C$

**Four Analog Ports**

**AGC**

- $P_{in}$
- $P_{DC}$
- $G$
- $P_{out}$
- $Ctrl$
Research Methodology

1. Classify OMG attributes by category
2. Prove their completeness

1. Determine the relationships between them
2. Deduce a minimal set of attributes describing each RF component

1. Deduce a minimal set of attributes describing all types of RF component
2. Prove its completeness
Our HA framework (2/13)

Classify:
- OMG attributes can be classified into four planes:
  - Electrical Parameters
  - Temperature and Ageing effects
  - Form Factor
  - Cost and market constraints
Simplify and Generalize:

Regarding the OMG contribution, the idea is to:

1. Figure out a minimal sets of attributes that FULLY describes each RF component (Simplify)
2. Figure out a minimal set of attributes that FULLY describes all RF components (Generalize)

Advantages:
- Description Completeness
- Description Genericalness
- Description Efficiency
Generalize:

A device is a black box characterized by:

- A functionality (transfer function)
- Input / Output / Configuration Parameters

\[ f([x_i]_{1 \leq i \leq m}) \]

CommEquipment

\[ x_1 \rightarrow \ldots \rightarrow x_k \rightarrow f([x_i]_{1 \leq i \leq m}) \rightarrow y_1 \rightarrow \ldots \rightarrow y_n \]

\[ x_{k+1} \leq i \leq m \]: Inputs
\[ x_{k+1} \leq i \leq m \]: Config. Params
\[ y_1 \leq l \leq n \]: Outputs

\( f() \): functionality (transfer function)
Mathematically speaking,
- The device functionality can be modeled by a multi-dimensional transfer function $f$
- Inputs / Outputs / Config. parameters can be modeled by one-dimensional scalar matrices designated resp. $[x_i]$ and $[y_j]$

$$
\begin{bmatrix}
  y_1 \\
  M \\
  y_n
\end{bmatrix} = f
\begin{bmatrix}
  x_1 \\
  M \\
  x_m
\end{bmatrix}
$$
Hardware Framework Main Objective:

- MAINLY, fully (or at least semi-) automated process of topology choice of any RF system from *Functional Description* to *Synthesis*.
- However, currently no functional description nor synthesis steps exist in design cycle!
- Then, How to do?
  - We must adapt the RF design flow by integrating these two steps.
Our HA framework (7/13)

Our Proposal:

Specifications
Analysis
Synthesis
Implementation
Validation

UML Diagrams
XML Description
Functional Description
Our HA framework (7/13)

Our Proposal:

- Specifications
- Analysis
- Synthesis
- Implementation
- Validation

- Coherence Verification
- System-level Simulation
Our HA framework (7/13)

Our Proposal:

- Specifications
- Analysis
- Synthesis
- Implementation
- Validation

- Granularity Refine
- Technology Mapping
- Performance Simulation
Our HA framework (7/13)

Our Proposal:

- Specifications
- Analysis
- Synthesis
- Implementation
- Validation

Standard Processes
However, the following issues must be addressed:

A. The reuse of existent simulation and design tools
B. The communication between the different design stages: design data flow – transit between steps

Solutions:

A. **Issue A**: language and tool-neutral interfaces between the different design stages
B. **Issue B**: a proposed Q-matrix
Newer design scheme [3]:

- Specifications
- Functional Description
  - XML Description
  - UML Diagrams
- Validation
  - Tests & Measurements
- Implementation
  - Manufacturing
  - Coherence Verification
  - System Simulation
- Analysis
  - Granularity Refine
  - Technology Mapping
  - Performance Simulation
- Synthesis
  - VHDL-AMS, ADS, …
- Legend:
  - Interface
  - Design Step
  - Design Data Exchange

Now, let’s us focusing on the electrical plane!

Minimal set of electrical parameters

We need a generic representation of electrical parameters $\Rightarrow$ \textit{Q-matrix}
Mathematical definition of Q-matrix [6]

\[ Q_{ij} = \frac{b_j}{a_i} \text{ at } f = f_j \]

Where:

- \( b_j \): the reflected wave at the \( j^{th} \) port
- \( a_i \): the incident wave at the \( i^{th} \) port
- \( f_i \): frequency of the signal entering the \( i^{th} \) port
- \( f_j \): frequency of the signal leaving the \( j^{th} \) port
Then [6], \( Q \equiv Q[T, t, P, F]_{N \times N \times N_T \times N_t \times N_P \times N_f} \)

**Where:**
- \( T \): temperature
- \( t \): time (aging)
- \( P \): power
- \( F \): frequency
- \( N \): total number of ports
- \( N_t \): number of time steps
- \( N_T \): number of temperature points
- \( N_P \): number of power points
- \( N_f \): number of frequency points

Q-matrix:
- A multidimensional matrix which captures the electrical parameters of a RF component.
- Generalize and extend the port definition of the OMG specification
- Corresponds to a Input/Output and DC/RF port

Advantages:
- Generic (an extended [S] in function of temperature, time, frequency, power, device ports)
- Compact
- Complete
Conclusion (1/3)

- Communications trends issues:
  - Design schemes
  - Abstraction methodologies

- Hardware abstraction:
  - Definition and provision

- Existent approaches:
  - **Baseband**: various elaborated studies
  - **RF**: scarce contributions (OMG’s one is the most complete)
Conclusion (2/3)

● Our hardware abstraction framework:
  ● Based on the OMG’s one
  ● Proposes a novel design scheme
  ● Resolves the corresponding issues

● New design scheme
  ● High-level functional description (Specifications)
  ● Coherence verification (Analysis)
  ● Granularity refine and Technology mapping (Synthesis)
Conclusion (1/3)

- Issues:
  - Existent simulation and design tools reuse: (sol.: interfaces between design stages)
  - Communication between design stages (sol.: Q-matrix)

- However a lot of efforts are still needed:
  - Definition of synthesis building blocks
  - Extension of the HA mathematical formalism
  - …
Thank you!

Any Questions, please?