



## Module: Electronics & Telecommunication, 5rd year Hardware Acceleration of Telecommunication Protocols

# Introduction



## Communication with teachers

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<http://www.embedded.agh.edu.pl/fpga-embedded-systems/fpga-dydaktyka/przedmioty/>

Embedded Systems Group

OPERATING SYSTEMS FPGA SYSTEMS DSP SYSTEMS

PRZEDMIOTY

WdE  
LP  
JOS  
JOS z  
HDL  
PSC  
ZZPSC  
PUC  
PLD  
MPiPS

NAJNOWSZE WIĘSY  
Astronarium: CTA  
Narzędzia mroku

PRZEDMIOTY

Przedmioty prowadzone przez pracownię Systemów Wbudowanych FPGA (wybór w lewym menu):

- **WdE**: Wprowadzenie do Elektroniki (E + EIT 1st)
- **LP**: Laboratorium Projektowe (EIT 1st)
- **JOS**: Języki Opisu Sprzętu (EIT 1st)
- **JOS z**: Języki Opisu Sprzętu (EIT zaocznie)
- **HDL**: Hardware Description Languages (EIT 1st)
- **PSC**: Projektowanie Systemów Cyfrowych (E 1st)
- **ZZPSC**: Zastosowane Zagadnienie Projektowania Systemów Cyfrowych (E + EIT 1st)
- **PDC**: Programowalne Układy Cyfrowe (T 2st) teraz pod nazwą **SAPT**: Sprzętowa akceleracja protokołów telekomunikacyjnych
- **PLD**: Programmable Logic Devices (T 2st) now **HAITP**: Hardware Acceleration of Telecommunication Protocols
- **MPiPS**: Metody Projektowania i Modelowania Systemów (E + EIT 2st)



## Hardware Acceleration of Telecommunication Protocols

- Hardware Description Languages - VHDL Verilog
- PLD architectures (SPLD,CPLD,FPGA)
- Design methodology (AHDL/MATLAB/LabView)
- Verification techniques (TB,HES)
- DSP in FPGA
- Embedded systems „softprocesor” – MicroBlaze, Nios
- PLD telecomm applications (NetFPGA)
- High Level Synthesis (Impuls C)



## Lab

<http://www.embedded.agh.edu.pl/fpga-embedded-systems/fpga-dydaktyka/sprzet/>



**DIGILENT**

### Hardware examples

*Nexys™ 3 Spartan-6 FPGA Board*

*Atlys™ Spartan-6 FPGA Development Board*





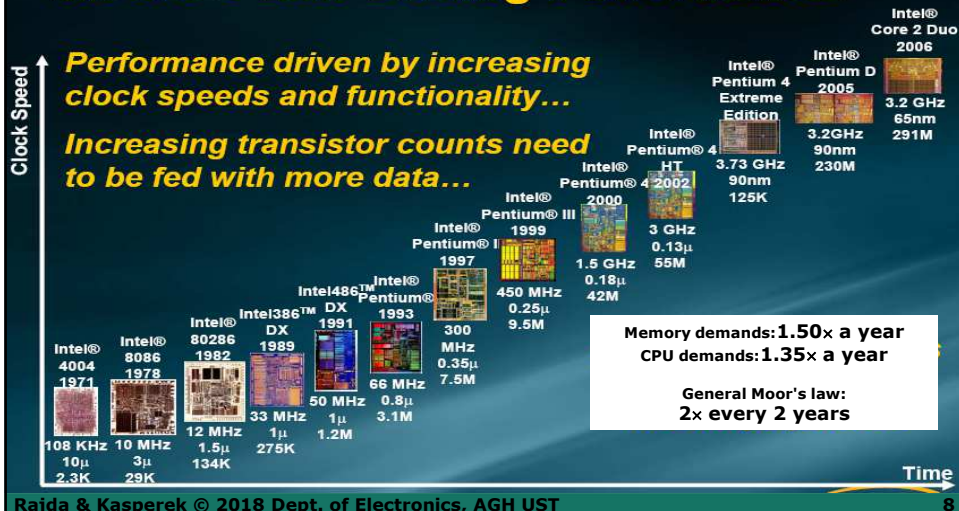
## Today's agenda VHDL a decalogue

1. VHDL – what for?
2. VHDL – what's this?
3. VHDL – how, where, when?
4. VHDL – so what we have?
5. VHDL – yesterday, today, tomorrow
6. VHDL – standards
7. VHDL – literature
8. VHDL – sources
9. VHDL – companies
10. VHDL – Aldec: Active HDL



## VHDL – what for? Design complexity

### Moore's Law Driving Performance





<http://spectrum.ieee.org/static/special-report-50-years-of-moores-law>  
**50 years of Moore's Law**



Fifty years ago this month, Gordon Moore forecast a bright future for electronics. His ideas were later distilled into a single organizing principle—Moore's Law—that has driven technology forward at a staggering clip. We have all benefited from this miraculous development, which has forcefully shaped our modern world.

In this special report, we find that the end won't be sudden and apocalyptic but rather gradual and complicated. Moore's Law truly is the gift that keeps on giving—and surprising, as well.



**The Multiple Lives of Moore's Law**  
 Why Gordon Moore's grand prediction has endured for 50 years  
22 Mar



**The Death of Moore's Law Will Spur Innovation**  
 As transistors stop shrinking, open-source hardware will have its day  
27 Mar



**Moore's Law, It Seems, Is Slowing Down, But Energy Efficiency Optimization May Be Tough, But There's Still Room to Drive Down Power Consumption in Modern Computers**  
23 Mar



**Gordon Moore: The Man Whose Name Means Progress**  
 The visionary engineer reflects on 50 years of Moore's Law  
22 Mar



**Moore's Curse**  
 There is a dark side to the revolution in electronics: unjustified technological expectations  
18 Mar



**Graphic: Transistor Production Has Reached Astronomical Scales**  
 A look at Moore's Law in action  
2 Apr



**Q&A: Carver Mead**  
 A longtime collaborator recalls the first time he met Gordon Moore  
15 Apr



**Opinion: What Kind of Thing Is Moore's Law?**  
 The trend has more to do with collective behavior than the laws of nature  
17 Apr



**Opinion: Is This Really The Anniversary of Moore's Law?**  
 Gordon Moore's path to his famous prediction  
7 Apr



**VHDL – what for?**  
**Design complexity**

**Strong need for proper tool:**

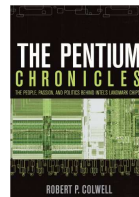
- 1970 - INTEL 4004                      4 engineers                      ~1k transistors
- 1982 - INTEL 80286                    20 engineers                    ~100k transistors
- 1992 - INTEL PENTIUM                100 engineers                   ~3M transistors
- 20?? - ???                                ?00?? engineers ???        ~150M transistors ???

Contemporary requirements:

- hardware-software codesign
- design reuse



**Solution: HDL usage!**  
**(VHDL, Verilog, ...)**





## Hardware Description Languages

AGH

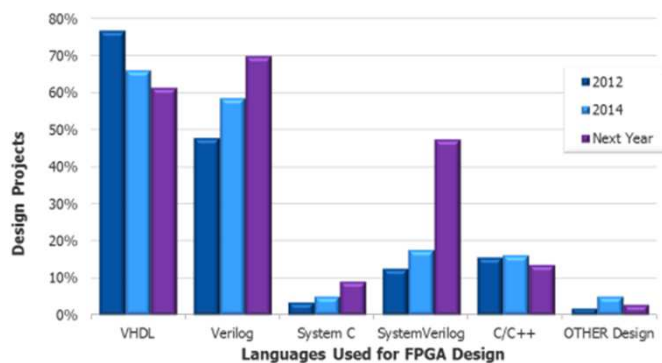
- **PALASM**
- **ABEL**
- **CUPL**
  
- **VHDL**
- **VERILOG, System VERILOG**
- **C, C++, Handel-C, System-C, Impuls -C**
- **others...**



## Hardware Description Languages

AGH

### FPGA Design Language Adoption Trends

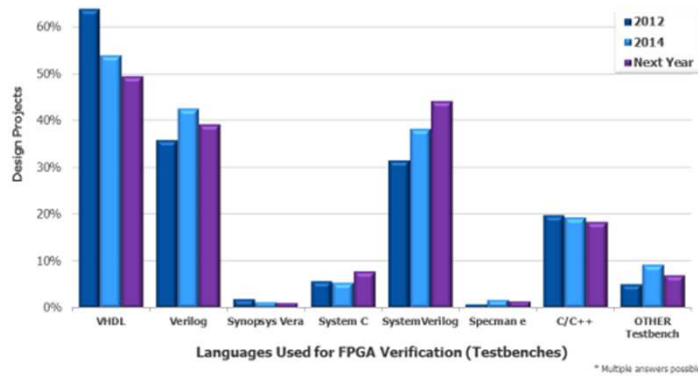


Source: Wilson Research Group and Mentor Graphics, 2014 Functional Verification Study

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www.mentor.com



## FPGA Verification Language Adoption Trends

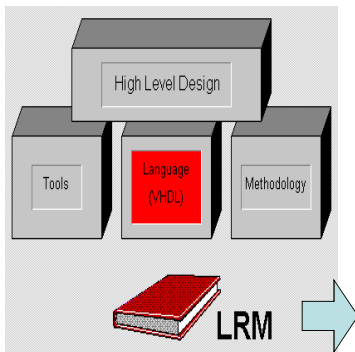


Source: Millen Research Group and Mentor Graphics, 2014 Functional Verification Study

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www.mentor.com

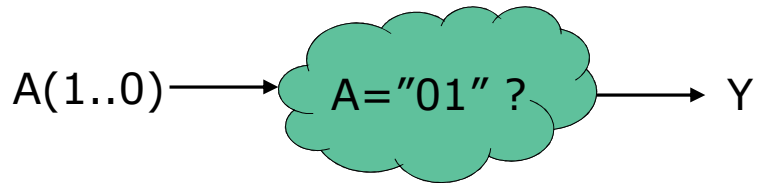


## VHDL - V<sub>H</sub>ASIC H<sub>D</sub>escription L<sub>U</sub>anguage ↳ Very High Speed Integrated Circuit

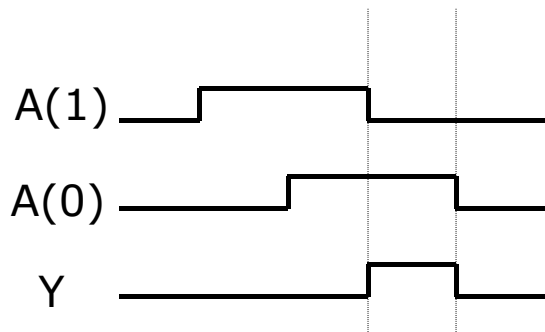


*It is "a formal notation intended for use in all phases of the creation of electronic systems. (...) it supports the development, verification, synthesis, and testing of hardware designs, the communication of hardware design data ..."*

[IEEE Standard VHDL Language Reference Manual]



```
Y <= '1' when A = "01" else '0' ;
```



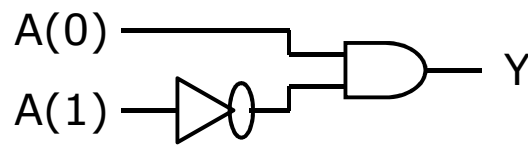
```
Stim <= "10" , "11" after 4 ns ...
```



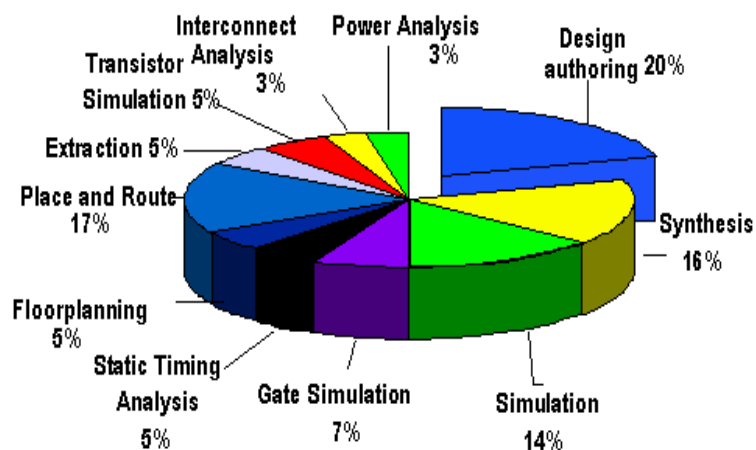


## VHDL – how, where, when? Logic synthesis

**Logic synthesis** – (automatic) translation of textual hardware description into a structure of connections (netlist) between elementary functional blocks of target hardware platform (gates, flip-flops, memories & others...).



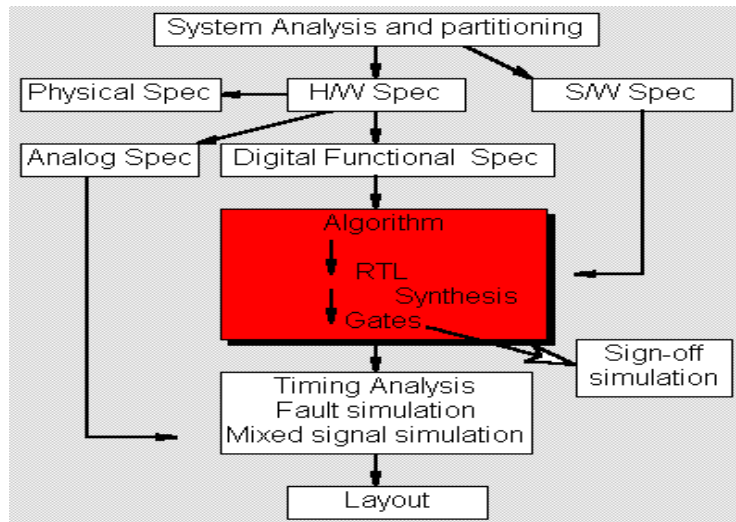
## VHDL – how, where, when? Design phases



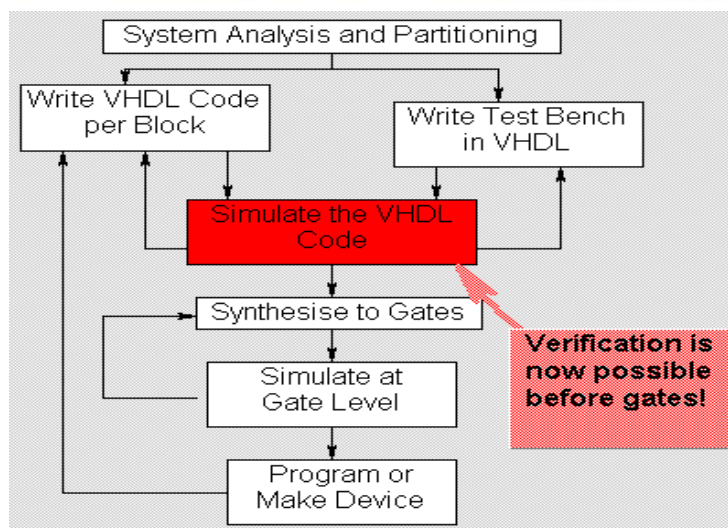
Average iterations between design and layout = 20



## VHDL – how, where, when? System design flow



## VHDL – how, where, when? Design process of digital hardware





## VHDL – how, where, when? Basic design units

**entity  
name**

```
entity COMPARE is
  port (A,B: in bit;
        C: out bit);
end COMPARE;
```

**architecture  
style of name**

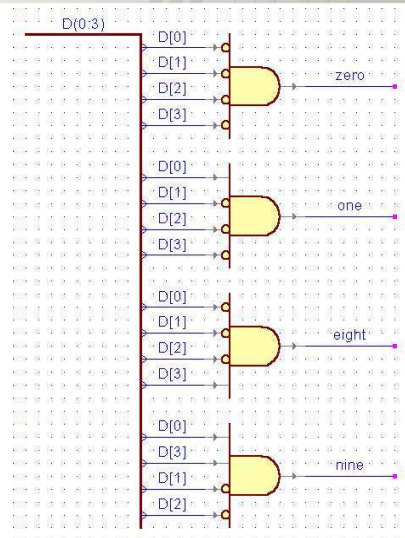
```
architecture BEHAVIORAL of COMPARE is
begin
  process (A,B)
  begin
    if (A=B) then
      C <= '1';
    else
      C <= '0';
    end if;
  end process;
end BEHAVIORAL;
```



## VHDL – examples Decoder

```
entity DECODER is
  port (D: in bit_vector (0 to 3);
        ZERO: out boolean;
        ONE: out boolean;
        EIGHT: out boolean;
        NINE: out boolean);
end DECODER;

architecture FIRST of DECODER is
begin
  ZERO <= (D="0000");
  ONE <= (D="0001");
  EIGHT <= (D="1000");
  NINE <= (D="1001");
end FIRST;
```



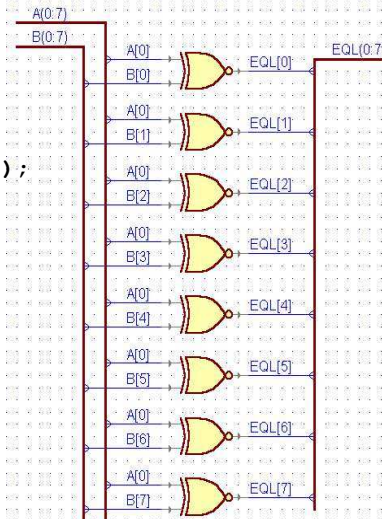


## VHDL – examples Comparator

```
entity COMPARE is
  port(A,B: in bit_vector (0 to 7));
       EQL: out bit_vector (0 to 7));
end COMPARE;

architecture SECOND of COMPARE is
begin
  EQL <= not (A xor B);
end SECOND;
```

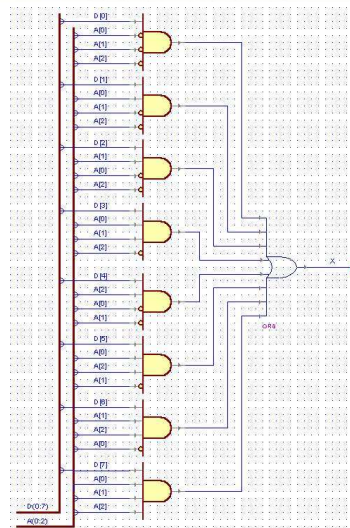
**Fault !**



## VHDL – examples Multiplexer

```
entity MPLEXER is
  port(D: in bit_vector (0 to 7);
       A: in integer range 0 to 7;
       X: out bit);
end MPLEXER;

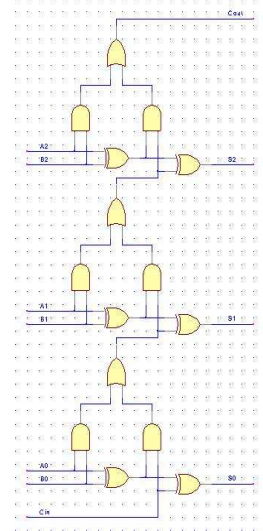
architecture THIRD of MPLEXER is
begin
  X <= D(A);
end THIRD;
```





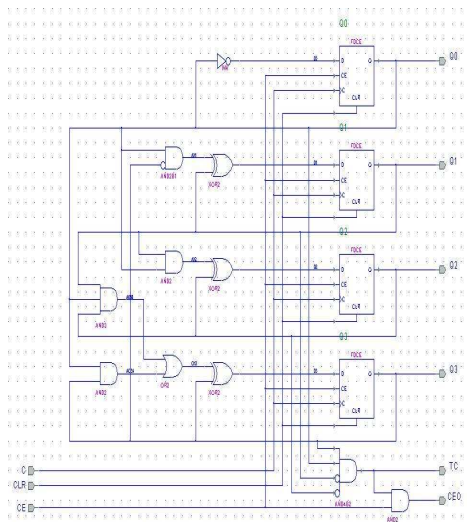
## VHDL – examples Adder

```
use IEEE.STD_LOGIC_UNSIGNED.all;  
  
entity SUM is  
  port(A,B: in std_logic_vector (0 to 2);  
       Cin: in std_logic;  
       S: out std_logic_vector (0 to 2);  
       Cout: out std_logic);  
end SUM;  
  
architecture FOURTH of SUM is  
  signal V: std_logic_vector (0 to 3);  
begin  
  V <= A + B + Cin;  
  S <= V(0 to 2);  
  Cout <= V(3);  
end FOURTH;
```



## VHDL – examples Counter

```
architecture FIFTH of COUNT is  
begin  
  process (C, CLR)  
  begin  
    if CLR='1' then  
      Q := 0;  
    elsif C='1' and C'event then  
      if CE='1' then  
        if Q = 9 then  
          Q := 0;  
        else  
          Q := Q + 1;  
        end if;  
      end if;  
    end process;  
  end FIFTH;
```

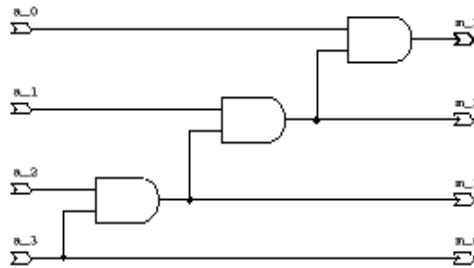




## VHDL – examples Logic replication

```
entity REPLICATOR is
port (a: bit_vector (0 to 3);
      m: out bit_vector (0 to 3));
end REPLICATOR;

architecture SIXTH of REPLICATOR is
begin
process (a)
variable b: bit;
begin
b := '1';
for i in 0 to 3 loop
b := a(3-i) and b;
m(i) <= b;
end loop;
end process;
end REPLICATOR;
```



## VHDL – so what we have? Benefits

- **Specification of the project independent of the technology**
  - possibility of cooperation with many manufacturers
  - avoiding problems with technologies withdrawn
  - easy upgrades and improvements
- **Low-level design automation**
  - shorter development time
  - cost reduction
  - elimination of low-level errors
- **Improvement of design quality**
  - easy testing of optional technologies
  - verification of operation at high abstraction level
  - easy verification of implementations
  - modularity – easy design reuse



## VHDL – yesterday

AGH

- 1980 DoD USA – start of the VHSIC technology program (Very High Speed Integrated Circuits)
- 1981 Woods Hole, Massachusetts – conference on the proposition of the future HDL standard
- 1983 DoD sets VHDL foundations: – Intermetrics, TI & IBM consortium gathers contract
- 1984 version 6.0 ready
- 1985 exemption from ITAR restrictions (US International Traffic and Arm Regulation), VHDL 7.2 with references submitted to IEEE to the standardization and further development
- 1987 IEEE Std 1076 released
- 1993 IEEE Std 1076-1993 amendment released
- 2000 IEEE Std 1076a-1993 erratum released
- 2003 IEEE Std 1076-2003 amendment released
- 2005 taking the initiative by Accellera
- 2006 IEEE Std 1076-2006 amendment released
- 2008 IEEE Std 1076-2008 amendment released



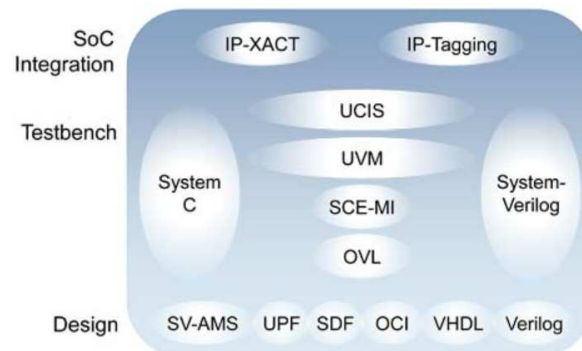
## VHDL – today

AGH



[http://www.eda.org/images/about/Accellera\\_Overview\\_2018.pdf](http://www.eda.org/images/about/Accellera_Overview_2018.pdf)

Accellera Systems Initiative  
EDA and IP Design Standards and Initiatives





## VHDL – standards

AGH

- IEEE Std 1076/INT-1991, IEEE Standards Interpretations: IEEE Std 1076-1987 IEEE Standard VHDL Language Reference Manual
- IEEE Std 1076-1993, IEEE Standard VHDL Language Reference Manual
- IEEE Std 1076a-2000, Amendment to IEEE Std 1076-1993
- IEEE Std 1029.1-1998, IEEE Standard for VHDL Waveform and Vector Exchange (WAVES) to Support Design and Test Verification
- IEEE Std 1076.1-1999, IEEE Standard VHDL Analog and Mixed-Signal Extensions (VHDL-AMS)
- IEEE Std 1076.2-1996, IEEE Standard VHDL Mathematical Packages
- IEEE Std 1076.3-1997, IEEE Standard VHDL Synthesis Packages
- IEEE Std 1076.4-1995, IEEE Standard for VITAL Application-Specific Integrated Circuit (ASIC) Modeling Specification
- Approved draft of IEEE Std 1076.6-1999, IEEE Standard for VHDL Register Transfer Level Synthesis
- IEEE Std 1149.1-1990, IEEE Standard Test Access Port and Boundary-Scan Architecture
- IEEE Std 1149.1b-1994, Supplement to IEEE Std 1149.1-1990, IEEE Standard Test Access Port and Boundary-Scan Architecture
- IEEE Std 1164-1993, IEEE Standard Multivalued Logic System for VHDL Model Interoperability (Std\_logic\_1164)



## VHDL – literature

AGH

- „A Guide to VHDL”, S. Mazor, P. Langstraat
- „VHDL Analysis and Modelling of Digital Systems”, Z. Navabi
- „VHDL Hardware Description and Design”,  
R. Lipsett, C. Schaefer, C. Ussery
- „The VHDL Cookbook”, P. J. Ashenden
- „VHDL programming: with advanced topics”, L. Baker
- „VHDL starter's guide”, S. Yalamanchili
- „VHDL for designers”, S. Sjöholm, L. Lindh
- „VHDL made easy!”, D. Pellerin, D. Taylor
- „VHDL answers to frequently asked questions”, B. Cohen
- „VHDL and AHDL digital systems implementation”, F. A. Scarpino
- „Active-VHDL Series BOOK#2 – *EVITA* Interactive Tutorial”,  
J. Mirkowski, M. Kapustka, Z. Skowroński, A. Biniszkiwicz
- „VHDL: a logic synthesis approach”, D. Naylor, S. Jones





## VHDL –Internet resources

AGH

- Discussion group: **comp.lang.vhdl** (little outdated ☹)
- EDA Industry Working Groups homepage: <http://www.eda.org/>  
<http://www.edac.org/>
- Accellera: <http://www.accellera.org/>
- Design Automation Cafe: <http://www.dacafe.com/>
- SOC Central <http://www.soccentral.com/>
- Doulos High Level Design Web site: <http://www.doulos.com/>
- RASSP WWW site: <http://www.eda.org/rassp/>
- The Hamburg VHDL Archive:  
<http://tams-www.informatik.uni-hamburg.de/research/vlsi/vhdl/>



## VHDL – tutorials

AGH

- An Introductory VHDL Tutorial, Green Mountain Computing Systems: <http://www.gmvhdl.com/VHDL.html>
- Doulos High Level Design Web site; A Hardware Engineers Guide to VHDL: <http://www.doulos.com/hegv/index.htm>
- Interactive VHDL Tutorial from Aldec, Inc.:  
<http://www.aldec.com/products/tutorials/>
- VHDL Verification Course by Stefan Doll:  
<https://pl.scribd.com/document/48441518/Stefan-Doll-VHDL-Verification-Course-UPDATED>



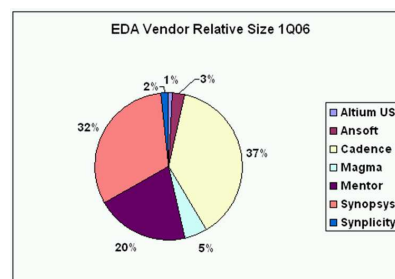
## VHDL – free IP cores

- OpenIP home page: <http://www.opencores.org/>
- The Hamburg VHDL archive:  
<http://tams-www.informatik.uni-hamburg.de/vhdl/index.php?content=06-models>
- Micron Technology, Inc. (memories): <http://www.micron.com/>
- VHDL Library of Arithmetic Units developed by R. Zimmermann:  
[http://www.iis.ee.ethz.ch/~zimmi/arith\\_lib.html](http://www.iis.ee.ethz.ch/~zimmi/arith_lib.html)



## VHDL – EDA companies (products)

- Aldec (*Active-HDL, Riviera*)
- Altium (*Altium Designer*)
- Cadence Design Systems
- Mentor Graphics (Model Technology: *ModelSim*)
- Synopsys (Synplicity: *SynplifyPro*)
  
- Xilinx (*XST*)
- Altera (*Quartus*)
  
- Green Mountain Computing Systems (*Direct VHDL*)





## VHDL – Aldec Inc.



- **Products**
  - Software (ActiveCAD, ActiveHDL)
  - Hardware-based Simulation Accelerators
  - IP Cores
- **Donation to the laboratory:**
  - Computers – 11×PC (former)
  - Software (ActiveHDL)
    - 20 sites license (*Professional Edition*)
    - *Student Edition*
  - HES accelerators
- **Department in Kraków!**



## VHDL – Aldec Inc.

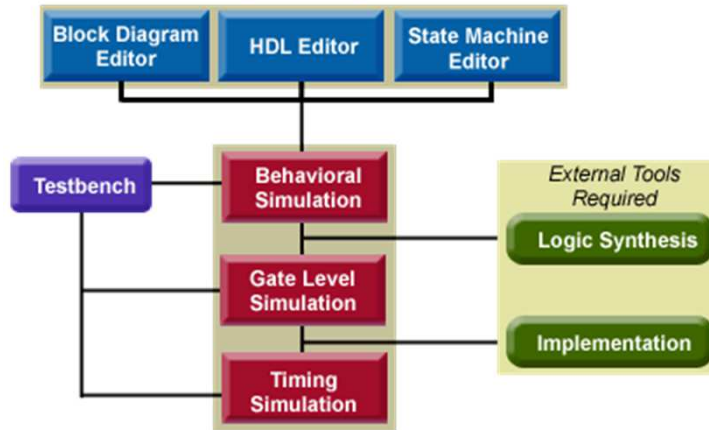


- **Student traineeships**
- **Diploma theses (IP Cores)**
  - $\mu$ P/ $\mu$ C: PIC17C4x, PIC16C5x, 8051-SoC
  - peripheral: 8251-SIO, 8255-PIO, 8257-DMA, 8259-INT
  - interfaces: CAN, UART/IrDA, USB, I2S, PS/2, VGA, I2C, SD, ...
  - telecom: Reed-Solomon, Viterbi, Utopia, DTMF, MP3, ADPCM, LDPC, Kasumi, ...
- **Professional career**

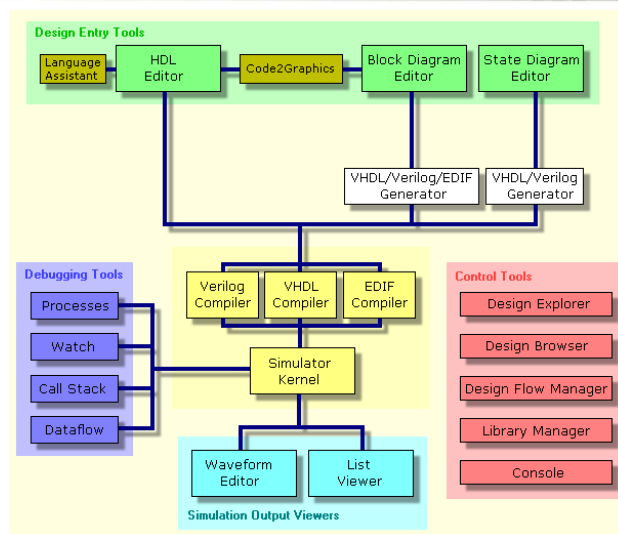


## ActiveHDL – modules

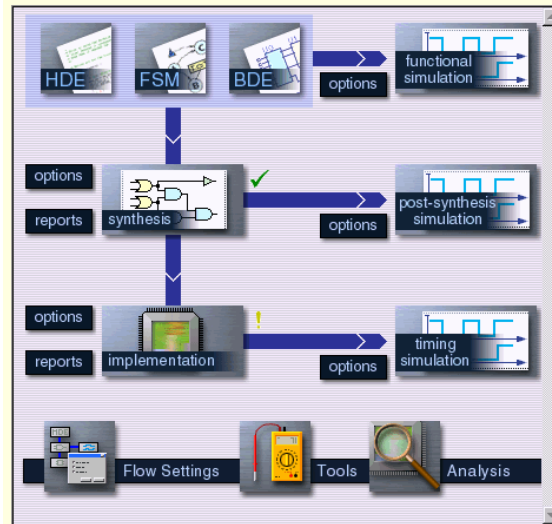
**Active-HDL™**  
Complete FPGA Verification Environment



## ActiveHDL – modules



## ActiveHDL – Design Flow



## ActiveHDL – HDL editor

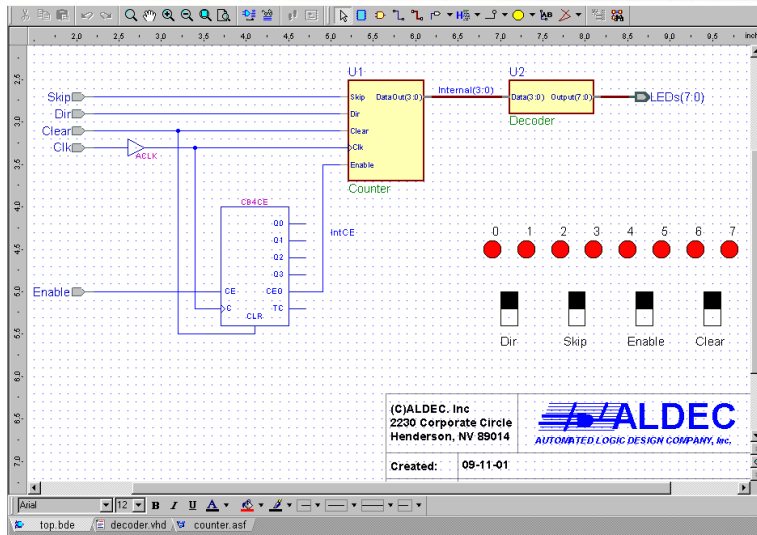
```

1  library IEEE;
2  use IEEE.std_logic_1164.all;
3
4  entity Decoder is
5      port (
6          Data: in STD_LOGIC_VECTOR (3 downto 0);
7          Output: out STD_LOGIC_VECTOR (7 downto 0)
8      );
9  end Decoder;
10
11
12  architecture Decoder of Decoder is
13  begin
14      with Data select
15          Output <= "00000000" when "0000",
16                  "10000000" when "0001",
17                  "01000000" when "0010",
18                  "00100000" when "0011",
19                  "00010000" when "0100",
20                  "00001000" when "0101",
21                  "00000100" when "0110",
22                  "00000010" when "0111",
23                  "00000001" when "1000",
24                  "11111111" when others;
25  end Decoder;
26
27
28
29
30
31
32
33
34
35

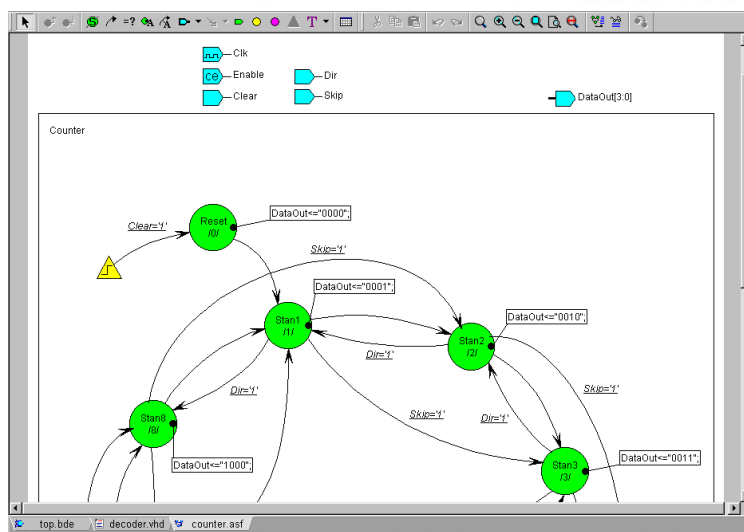
```



## ActiveHDL – BDEditor



## ActiveHDL – FSM editor





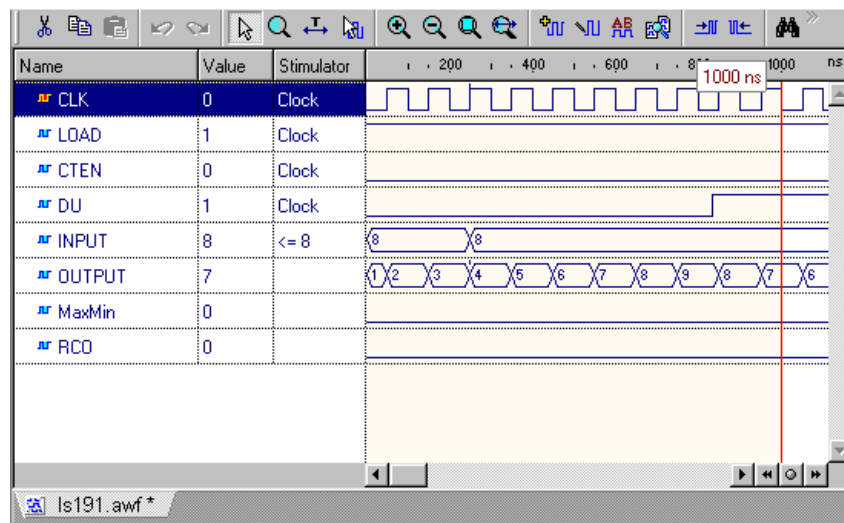
## ActiveHDL – Design Browser

The left screenshot shows the Design Browser for the project 'freq\_top (freq\_top)'. It displays a tree structure under 'Unsorted' containing files like 'hex2led.vhd', 'CONTROL.asf', 'cnt\_4b.vhd', 'freq\_top.bde', 'freq\_top.vhd', and 'TestBench'. Below this is the 'freq\_meter library' containing 'CNT\_48 (CNT\_48)', 'CNT\_BCD', and 'freq\_top (freq\_top)'. Annotations include 'top-level selection list box' pointing to the project name and 'resource files' pointing to the file list.

The right screenshot shows the Design Browser for the component 'FQMETER (FQMETER)'. It displays a hierarchy tree starting with 'Root : FQMETER' and listing components like 'U25: CONTROL', 'U26: CNT', 'U27: CNT', 'U1: ILD4V', 'U2: ILD4V', 'U28: BCD2LED', 'U29: BCD2LED', and 'U21: AND2V'. Below the tree is a table with columns 'Name', 'Type', 'Value', 'Last Value', and 'Last Event Time'. Annotations include 'top-level selection list box' pointing to the component name, 'hierarchy tree' pointing to the component list, 'filter box' pointing to the table header, and 'object list' pointing to the table rows.



## ActiveHDL – Waveform Viewer





## ActiveHDL – List Viewer

simulation time    simulation cycle    signals/nets

toolbar    Add Signals...

Time	DELTA	LATCH	LTC	RESET	F10KHZ	FX	A	B
9.885 ms	0	0	68	0	1	0	00	02
9.885 ms	1	0	68	0	1	0	00	02
9.885 ms	2	0	68	0	1	0	00	02
9.890 ms	0	0	68	0	1	1	00	02
9.890 ms	1	0	68	0	1	1	00	02
9.900 ms	0	0	68	0	0	0	00	02
9.900 ms	1	0	68	0	0	0	00	02
9.900 ms	2	0	68	0	0	0	00	02
9.900 ms	3	0	68	0	0	0	00	02
9.905 ms	0	0	68	0	0	1	00	02
9.905 ms	1	0	68	0	0	1	00	02

list1



## ActiveHDL – Library Manager

Library Manager

File Edit Search View Design Simulation Tools Library Help

Library	Mode	Comment	Unit Name	Secondary Unit Name	Source Type	Target Language	Sy
ovi_uni3000	B	Xilinx Verilog library	E xor5	xor5_v	Source Code	VHDL	\
ovi_uni5200	B	Xilinx Verilog library	D xor6	xor6	Block diagram	EDIF	\
ovi_unisim	B	Xilinx Verilog library	D xor7	xor7	Block diagram	EDIF	\
ovi_xilinxco...	B	Xilinx Verilog library for Co	D xor8	xor8	Block diagram	EDIF	\
synopsys	B	Library containing packa	D xor9	xor9	Block diagram	EDIF	\
simprim_1_4	B	Post P&R timing simulatio	P global	global	Source Code	VHDL	\
simprim	B	Post P&R timing simulatio	P vcomponents		Source Code	VHDL	\
std	B	Standard VHDL library	P vpkg	vpkg	Source Code	VHDL	\
simprim_edif	B	Post P&R timing simulatio					
vl	B	Standard Verilog library					
synplify	B	Primitive library for post sy					
unisim	B	Functional components li					
xc4000e	B	Xilinx schematic library					
xabelsim	B	Functional components li					
xilinxcorelib	B	Functional simulation libr					

Package Contents

XDR9	XNDR6	X74_352	X74_174
XDR8	X74_L85	X74_298	X74_168
XDR7	X74_521	X74_283	X74_165S
XDR6	X74_518	X74_280	X74_164
XNDR9	X74_42	X74_273	X74_163
XNDR8	X74_390	X74_195	X74_162
XNDR7	X74_377	X74_194	X74_161

Ready



To be continued...

