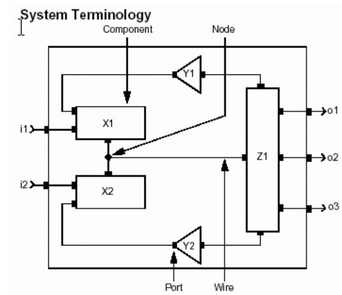
Verilog-AMS

- Verilog-AMS: analog and mixed signal extensions to Verilog
  - On track to become an IEEE Standard
- An earlier language standard was called Verilog-A (Verilog with Analog extensions)
  - Verilog-A is a subset of Verilog-AMS
- Important extensions of *Verilog*-AMS over Verilog-A
  - Both digital and analog signals can be included in same module
  - User-defined conversions modules are automatically inserted in netlist if analog signal connected to digital signal or vice-versa
  - More freedom in accessing digital/analog signals within a module
- These slides will look at some example models and point out important features
  - Http://www.eda.org/verilog-ams
- Much of the same terminology used in VHDL-AMS

Images/Notes from Verilog A reference manual, Cadence, also DAC'99 VHDL-AMS tutorial by Christen, Bakalar, Dewey, Moser.

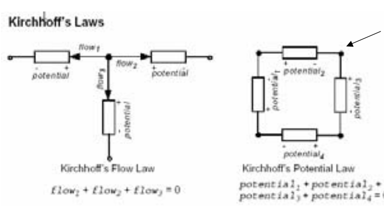
Mixed Signal Terminology



Node: connection point in a system

Port: component's external connection point. A port is also a node.

Simulation: flow vs. potential



A node

Sum of all flows out of a node at any instance of time is 0

Sum of all potentials around a loop at any instance of time is 0

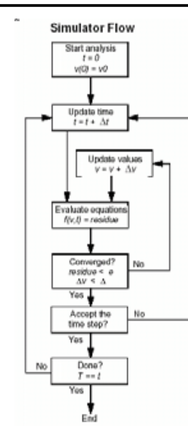
Potential defined with respect to reference node (I.e. gnd). Flow has a direction.

Conservative vs. Signal-Flow

- A *conservative* system obeys Kirchoff's laws
  - Nodes have both potential and flow
- A *signal-flow* system has only flow or potential associated with a node
  - Verilog-A supports modeling of signal-flow systems (sort of, really need 'real' data types for signals to do this right).
  - Verilog-A supports mixing of conservative and signal-flow nodes
- Physical systems are conservative systems
- Abstract systems can use a signal-flow graph model
- View potential as *across* a component (voltage, temperature, velocity)
- View flow as *through* a component (current, force, heat flow rate)

Simulation

- Mathematical descriptions used to relate potentials and flows
  - I.e. I = C dv/dt (flow out of a capacitor related to potential)
- Simulator uses Kirchoff's laws and mathematical descriptions of individual components to develop a system of equations for entire network
  - Equations are differential and non-linear, cannot solve directly
  - Use iterative method that approximates a solution to the equations
  - Tolerances used to control accuracy of simulation



v – vector of all node values
v0 – initial conditions of all node values, may not be close to actual values

ΔT – timestep (transient analysis)

Convergence: is new value close enough to previous value? (within '*reltol*', relative tolerance and under absolute tolerance), and is Kirchoff's flow law satisfied?.

Reltol typically 0.001 of previous difference.

Absolute tolerance (*abstol*, what error can be ignored). Typically 1000 to 1,000,000 smaller than typical value in circuit. Absolute tolerance compared against zero.

Sample Model: Voltage Integrator

```
module V_integrator(in,out);

input in;
output out;
voltage in,out;

// integration coefficient
parameter real ki=1.0 exclude 0;
parameter real dcval = 0;

real k1;
initial k1 = 1/ki;

analog
  V(out) <+ k1*idt(V(in),dcval);

endmodule
```

Port direction (*input,output,inout*)

Port *discipline*

Module parameters, can specify initial values, other limits.

Local variable

Executed at simulator startup

Behavior specified in analog block

Voltage assignment

Branch assignment

Natures and Disciplines

- A nature is a collection of attributes
  - Attributes characterize quantities solved for during simulation

```
nature Mycurrent
  units = "A" ;
  access = I ;
  idt_nature = charge ;
  abstol = 1e-12 ;
  huge = 1e6 ;
endnature
```

Example nature, attributes predefined by Cadence (see Chap4)

Name of the access function for this nature

Nature to apply when idt (time integral) or idt_mod is applied

Maximum allowed change in timestep

Tolerance for convergence

Some predefined Natures

```
nature Current
 units      = "A";
 access     = I;
 idt_nature = Charge;
endnature
```

```
nature Voltage
 units      = "V";
 access     = V;
 idt_nature = Flux;
endnature
```

```
nature Charge
 units      = "coul";
 access     = Q;
 ddt_nature = Current;
endnature"
```

```
nature Flux
 units      = "Wb";
 access     = Phi;
 ddt_nature = Voltage;
endnature"
```

Defined in "discipline.h" include file

(tools/dfII/samples/spectreHDL/include, or Appendix C)

Many others (Maneto_Motive_Force, Temperature, Power, Position, Acceleration)

Disciplines

- Disciplines used to bind natures with potential and flow

```
discipline voltage
  potential Voltage;
enddiscipline

discipline current
 potential  Current;
enddiscipline

discipline electrical
  potential  Voltage;
  flow       Current;
enddiscipline
```

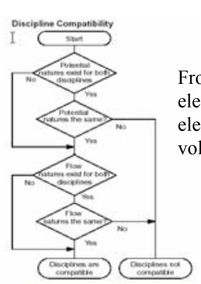
Discipline with single nature called *signal-flow* discipline

Discipline with multiple natures called *conservative* discipline. Nature bound to potential must be different from nature bound to flow.

Can also have an empty discipline (a wire is an empty discipline)

Discipline Compatibilty

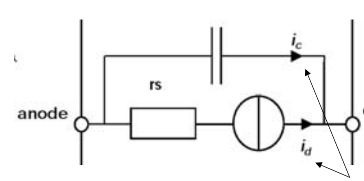
Operations between nodes of different disciplines allowed if potential/flow natures are the same.



From this flowchart, can connect electrical and voltage disciplines, electrical and current disciplines, and voltage and current disciplines.

Branches

- Branch is a path between nodes
- Can only be declared within a module
- Currents summed at branch node



Diode Model

Define two different branch currents

Branches in Diode Model

```
module diode (a, c) ;
electrical a, c ;
branch (a, c) diode, cap ;
branch (a,a) anode;
parameter real rs = 0, is=1e-14, tf=0, cjo=0, imax=1, phi=0.7 ;
analog begin
I(diode) <+ is*($limexp((V(diode)-rs*I(anode)/$vt) – 1) ;
I(cap) <+ ddt(tf*I(diode) - 2 * cjo *
          sqrt(phi * (phi * V(cap)))) ;
if (I(anode) > imax) // Checks current through port
   $strobe( "Warning: diode is melting!" ) ;
end
endmodule
```

Special branch (port branch), used to monitor current through port

Branch currents summed

Thermal voltage, language builtin

Special Variables

Environment Function	Description of Returned Value	Type of Returned Value
`$realtime`	Current simulation time in seconds	Real
`$temperature`	Ambient temperature in degrees Kelvin	Real
`$vt`	Thermal voltage (kT/q) at current simulation temperature	Real
`$vt(temp)`	Thermal voltage at temperature *temp*, specified in degrees Kelvin	Real

Assignments

- Procedural assignments, used to modify integer, reals
  - `sum = a + b`
- Branch contribution statement
  - `V(n1,n2) <+  expr1;`
- Multiple branch assignments can be applied to same node

```
V(n1, n2) <+ expr1;
V(n1, n2) <+ expr2;
```

is equivalent to:

```
V(n1,n2) <+  expr1 + expr2;
```


More on branch assignments

- Simulation of a branch assignment
  - Simulator evaluates right hand expression
  - Simulator adds the value of the right hand expression to any previously retained value for the node (a summation)
  - At end of simulation cycle, summed value assigned to source branch
- If assigning a flow quantity, and previously assigned value was a potential, then potential value is discarded (and vice-versa)
  - When a branch changes between assigned flow and potential quantities, this is known as a switch branch.

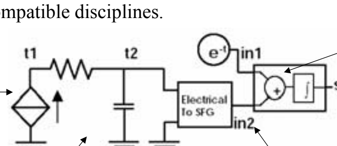
Control Structures

- Begin/end blocks
- If /else
- Case
- Repeat Loop (loop fixed number of times)
- While/Loop (conditional loop)
- For/Loop
- Generate (similar to generate capability in VHDL but not quite as powerful)

Details of these constructs in Verilog-A ref manual, chapter 5.

Conservative/Signal-Flow Interface

To model a mixed conservative/signal-flow system, must have an interface model between the two since terminals of the two have incompatible disciplines.



Abstract system

Physical system

Conservative (electrical discipline)

Signal flow. VHDL-AMS, Verilog-AMS supports ‘real’ type here. Verilog-A must use single-nature discipline – do not need interface if potential/flow natures are same as physical system.

constants.h

Many constants defined in constants.h (appendix C in verilog reference manual).

```
`define M_E          2.7182818284590452354
`define M_LOG2E      1.4426950408889634074
`define M_LOG10E     0.43429448190325182765
`define M_LN2        0.69314718055994530942
`define M_LN10       2.30258509299404568402
`define M_PI         3.14159265358979323846
`define M_TWO_PI     6.28318530717958647652
`define M_PI_2       1.57079632679489661923
```

etc… Refer to them in code via:

`M_LN2

Note the backquote in front of the constant name.

Model Example: Capacitor

```
module cap(p,n);
 inout p,n;
 electrical p,n;

 parameter real c=0 from [0:inf);
 analog

   I(p,n) <+ c*ddt(V(p,n));
endmodule;
```

Electrical discipline, bidirectional terminals.

Specifies range on parameter

Time derivative operator, implements dv/dt

Predefined as part of the language.

Model Example: Sine Wave Generator

```
module V_sine_generator(out);

 output out;
 voltage out;

 parameter real freq   = 1K from (0:inf),
                ampl   = 1,
                offset = 0;

 analog
 begin
   V(out) <+ ampl * sin(`M_TWO_PI * freq * $realtime)
                + offset;
  bound_step(0.05/freq);
 end
endmodule
```

constant

Simulator time

Specifies maximum time between allowed between adjacent points in simulation. Forces simulation tracking of signals to accuracy required by model for correct operation.

Analog Operators

- Built-in functions that operate on more than just the current value of their arguments – they maintain internal state
  - Limited Exponential function ($limexp)
  - Time derivative operator (ddt)
  - Time Integral operator (idt)
  - Circular integrator operator (idtmod)
  - Delay operator (delay)
  - Transition filter (transition)
  - Slew filter (slew)
  - Laplace transform filters (laplace_zp, laplace_zd, laplace_np, laplace_nd)
  - Z-transform filters (zi_zp, zi_zd, zi_np, zi_nd)

Miscellaneous Functions

- $strobe (aka $display) – formatted output statement
- $pwr – specify model power consumption
- File IO
  - $fopen
  - $fstrobe, $fdisplay
  - $fclose
- $finish – simulator exit
- $stop – simulator exit
- Can also have user-defined local functions within a module

Mechanical Model: Friction

```
module damper1d(n1,n2);
module spring1d(n1,n2);

 inout n1,n2;
 kinematic n1,n2;

 parameter real k = 10 from (0:inf);
// spring constant given in n/m
 parameter real l = 0.1 from (0:inf);
// length of spring in m
 analog
   F(n1,n2) <+ k*(Pos(n1,n2) - l);
endmodule
```

Kinematic discipline has position (potential), force (flow) natures.

Newtons/meter

Recall that a mechanical spring is akin to a resistor in the electrical world. Spring constant is equivalent to conductance.