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Spectre® Circuit Simulator Measurement Description Language User Guide and Reference

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will be addressed at a time when the related software can be updated without end-user impact.

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Contents

Preface

Spectre® Circuit Simulator Measurement Description Language (MDL) is a productivity-enhancing tool for simulation and data analysis. This user guide and reference describes MDL and explains how to make the best use of it.

This preface discusses the following:

What MDL Does

MDL is a scripting language that you can use to control the Spectre® circuit simulator and the Virtuoso® Visualization and Analysis tool. With MDL, you can

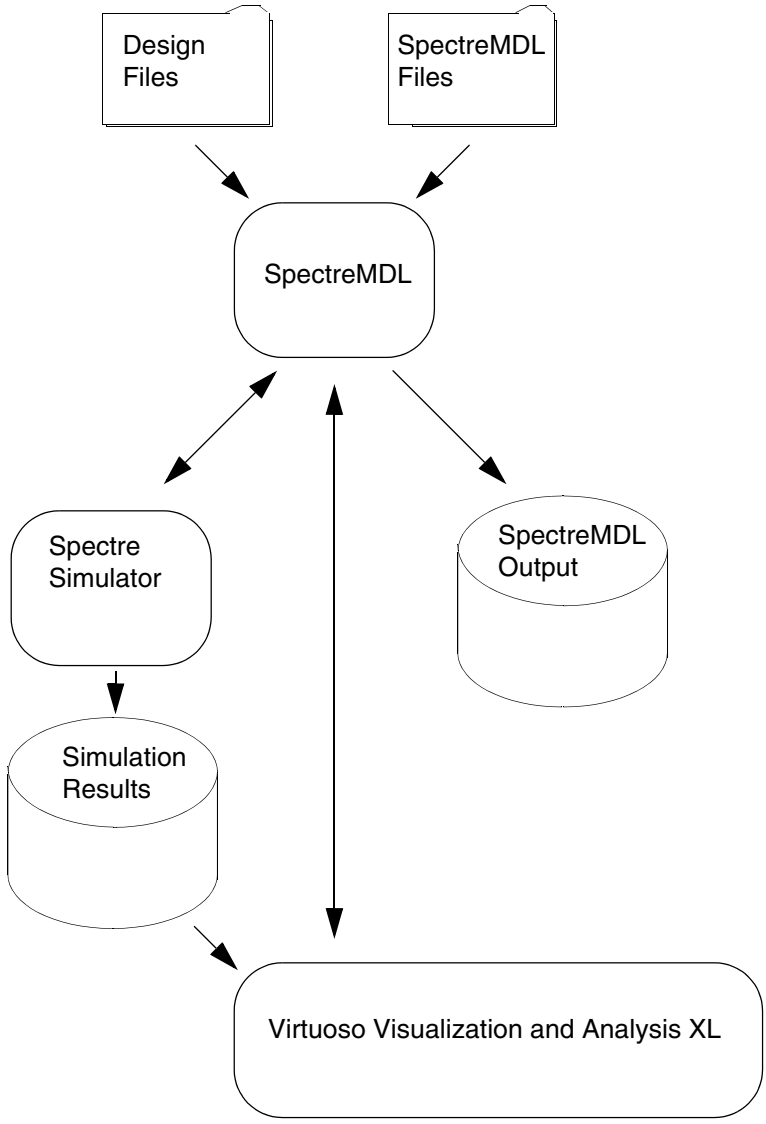
- Create measurement aliases that can be easily reused in different circuits. A measurement alias is a reusable, easily tailored procedure that includes a single analysis statement and a collection of one or more MDL expressions to be evaluated at runtime.
- Efficiently run simulations in batch mode.
- Parameterize measurement aliases, making them reusable over various applications.
- Use the wild card (`\*`) in the MDL control file for all signals mapping.

  Note: The wild card support has been added in the MMSIM 12.1 release.

With these features, MDL allows you to verify circuits easily and with confidence.

The MDL Flow

As illustrated by the following figure, MDL interacts with a variety of inputs, outputs, and tools. Inputs consist of design files and files containing measurement blocks. Outputs include sets of simulation results, the values returned by MDL expressions, and log files. Interacting tools include Spectre, which simulates the design, and Virtuoso® Visualization and Analysis tool, which you can use to plot and post-process the results of the simulation.



The MDL Language

Most of this document is devoted to describing the language used by the MDL tool. That language, like any language, has elements that must be used according to rules. You will find that although MDL is easily learned, the power it gives you to control simulations is great.

Related Documents

For information about related products, consult the sources listed below.

- *Virtuoso® Analog Design Environment User Guide*
- *Cadence Analog Mixed-Signal Simulation Interface Option*
- *Spectre Circuit Simulator Reference*
- *Spectre Classic Simulator, Spectre APS, Spectre X, and Spectre XPS User Guide*

Typographic and Syntax Conventions

Special typographical conventions distinguish certain kinds of text in this document. The formal syntax used in this reference uses the definition operator, `::=`, to define the more complex elements of MDL in terms of less complex elements. However, for simplicity, the syntax for the user-compiled functions omits the definition operator.

- Lowercase words represent syntactic categories. For example,

  ```
  identifier
  ```

- Boldface words represent elements of the syntax that must be used exactly as presented. Such items include keywords, operators, and punctuation marks. For example,

  `real`

- Variables are set in italic font,

  `allowed_errors`

- Vertical bars indicate alternatives. You can choose to use any one of the items separated by the bars. For example,

  ```
  termID ::=
          designID
      |   unsignedInteger
  ```

- Square brackets enclose optional items. For example,

```
parameter_declaration_statement ::=
        [ input ] real parameter [= expression ]
```

- Braces enclose an item that can be repeated zero or more times. For example,

```
unsigned_num ::=
        decimal_digit { decimal_digit }
```

Code examples are set in constant-width font.

```
/* This is an example of the font used for code.*/
```

Keywords and filenames are set in constant-width font, like this: `keyword`, `file_name`.

1

Defining and Using Measurement Aliases

A measurement alias is a Measurement Description Language (MDL) procedure that you can use to run an analysis and extract information about the performance of the circuit. For example, you might use a measurement alias to determine the bandwidth of an amplifier.

Measurement aliases provide a way for you to bind analyses to MDL expressions, creating procedures that can be called multiple times and parameterized for specific applications.

This chapter includes the following sections.

Defining a Measurement Alias

Defining a measurement alias involves combining a call to an analysis with one or more MDL expressions into a reusable procedure. You can define or include an alias measurement only at the top level of an MDL control file. An alias measurement must be defined before it is used in a MDL run statement.

```
alias_measurement_statement ::=
              alias measurement measurement_name {
              {initialization_block}
              run analysis [ as othername]
              {export_block}
              }

analysis :: =
              BuiltInAnalysis | PredefinedAnalysis | AnalysisVariable

BuiltInAnalysis :: =
              dc | ac | tran | noise | info | sp
```

`alias measurement`	Keyword to define a measurement block.The block of MDL statements to be run when the measurement is called. The statements are executed in the defined order. A variable must be defined before it can be used.
`measurement_name`	The name of the measurement alias you are defining. **Note**: You can use special characters like hyphen (-), ampersand (&), caret (^), and so on in the measurement alias names, variable names, and analysis names. However, these special characters must be preceded by an escape symbol (\). For example, `alias measurement transim\-montecarlo`
`initialization_block`	The initialization block. Input variables can be defined only in this block, otherwise MDL ignores them and issues warning messages that they are ignored.
`run` *`analysis`*	The run statement can be used to call a built in Spectre analysis such as dc, ac or tran, to call an analysis defined in the circuit netlist, or to call an analysis variable.
`as` *`othername`*	The results dataset is named *`othername`* if the `as` option is used. If othername is not specified, the results dataset is given the *`measurement_name`*.

export_block	One or more MDL expressions that are evaluated as a result of the analysis. However, you cannot use the search or foreach commands in the *export_block*, nor can the *export_block* include a measurement alias.
PredefinedAnalysis	Name of the analysis defined in the netlist or MDL control file. For information on the analyses supported by MDL, see Supported Spectre Circuit Simulator Analyses on page 46 and SPICE Compatibility for Analyses on page 237.
AnalysisVariable	Name of a pre-defined analysis variable or an element of an array of analyses. For more information, see Analysis on page 62.

For example, consider the following MDL control file.

```
alias measurement showmaxmin { // The measurement alias is defined here.
    run tran1(stop=1u)
    export real maxout=max(V(out))
    export real minout=min(V(out))
}
run showmaxmin // This statement runs the measurement.
```

This control file first defines a measurement alias called showmaxmin. The run statement then runs the measurement alias and writes the maxout and minout values to the dataset.

Using a Measurement Alias

You must define a measurement alias before you can use it. To use a measurement alias, use the run command. If the measurement alias is defined appropriately, you can pass in parameters to the run command in the measurement alias to further specify the behavior. For example, assume you have an MDL control file with the following contents.

```
alias measurement falldelay {
    input real transtop=2u    // This variable is given a default value.
    input real prop_thresh    // This variable has no default value.
    run tran(stop=transtop)   // A run statement is required.
    export real prop_delay_fall=deltax(sig1=V(inp), sig2=V(out),
            dir1='fall, n1=1, start1=0, thresh1=prop_thresh,
            dir2='fall, n2=2, start2=0, thresh2=prop_thresh)
}
run falldelay(transtop=1u, prop_thresh=2)
```

Notice how transtop and prop_thresh are declared as input variables in the measurement alias. The transtop input variable is given a default value of 2u. If you do not

pass a value to `transtop` on the `run` statement, MDL uses the default value. However, the `prop_thresh` input variable does not have a default value, so if you do not pass in a value for it, MDL issues an error. Notice how, in this example, the values to be used for the input variables are passed in on the `run runtran(transtop=1u, prop_thresh=2)` statement.

You can also use netlist variables in the MDL control file without declaring the variables as input parameters. For example, notice the use of `vdd_val` in the `risetime` expression of the following control file.

```
alias measurement runtran {
    input real transtop=2u
    input real prop_thresh
    run tran(stop=transtop)
    export real rise=risetime(trim(sig=V(out),
        from=10n, to=70n), initval=vdd_val/5,  // vdd_val is used here...
        inittype='y, finalval=(vdd_val/5)+2,   // and here.
        finaltype='y, theta1=10, theta2=90)
}
```

The `vdd_val` parameter is a top level variable in the netlist. Notice how in the following netlist fragment, `vdd_val` is defined as a parameter.

```
global 0 vdd! vss!
include "./testmodels.scs" section tt
parameters capval=2.5p vss_val=-5 vdd_val=5  // vdd_val is defined here.
//top level
v2 (vss! 0) vsource dc=vss_val type=dc
v1 (vdd! 0) vsource dc=vdd_val type=dc
```

Statements that require simulation results/computation should follow the analysis statement, as shown in the following example.

```
alias measurement cvmeas {
    run ac1
    export real cv = im(DUT:d) / (6.28319 * 100000)
}
```

There are two ways to define variables in a measurement alias. These are explained using the following example of a measurement alias.

```
alias measurement tranmeas {
export real outcross, maxq
run tran(stop=40n)
outcross=cross(V(q),thresh=2.5)
maxq=max(V(q))
}
```

In the following two lines in the measurement alias definition, the `maxq` variable is declared with the `export` qualifier in a statement that is separate from the statement that uses the variable.

```
export real outcross, maxq
maxq=max(q)
```

Alternatively, you can specify the `maxq` variable in the statement that uses it, as shown below, after the `run` statement.

```
export real outcross
export real maxq=max(q)
```

Defining Measurement Aliases on the Fly

You can define measurement aliases on the fly by adding the `as` keyword to the `run` command.

```
run ac(center=1MHz, span=1kHz) as pb
run ac(start=1_Hz, stop=10MHz) as sb
```

The simulator creates the alias before running the analysis, so in these examples, the default parameter values for the base `ac` analysis are not affected.

The `as` keyword must follow a measurement and applies only to that measurement. The following example

```
temp=50
run dc as dcat50
```

reruns the `dc` analysis with `temp=50`.

You can extend the same concept to analyses. For example, in this pair of statements

```
run tran (stop=10u) as tran1
run tran1
```

the second statement runs `tran` with `stop=10u`. The first command creates an alias to `run tran(stop=10u)` as a new analysis called `tran1`.

Propagating Variables

MDL allows you to propagate variables through your code. For example, in the following measurement alias, notice how `rise_edge` and `fall_edge` are first calculated and then used later to calculate the value `pw`.

```
alias measurement trans {
    run tran(stop=5u)
    real rise_edge=cross(sig=V(out), dir='rise, n=1, thresh=1.5, start=0)
    real fall_edge=cross(sig=V(out), dir='fall, n=1, thresh=1.5, start=0)
    export real pw=fall_edge-rise_edge
}
run trans
```

Defining a Macro

You can define a macro in the MDL control file using the `#define` directive. However, to read and run the macro, you must use must specify `+/=mdle` at the command line. For example, you can define a macro for the export statement in the mdl control file, as follows:

```
#define insat(device) export real insat_/**/device = Idut.device.m0:vdss
alias measurement dcmeas {
    run dc
    insat(M11)
    insat(M22)
    insat(M09)
}

run dcmeas
```

When MDL is run, the above statements expand to the following:

```
run dc
    export real insat_M11=Idut.M11.m0:vdss
    export real insat_M22=Idut.M22.m0:vdss
    export real insat_M09=Idut.M09.m0:vdss
}
```

Accessing Netlist or Model Parameters

MDL allows you to access the parameters in different hierarchical depths of the netlist by specifying the full path to the parameter in a measurement alias.

For example, in a MDL measurement alias,

- A global parameter `v_vdd` can be accessed by:

  ```
  export real par_vdd = v_vdd
  ```

- A subcircuit parameter `mm` can be accessed by:

  ```
  export real par_mm=x1.xmm0:mm
  ```

- An instance parameter `vth` can be accessed by:

  ```
  export real par_vth=i1.mp0:vth
  ```

- A model parameter `vth0` can be accessed by:

  ```
  export real par_vth=i1.mp0.pch1:vth0
  ```

- An `lv`/`lx` parameter of an element can be accessed by:

```
export real mn0_lv1=i0.mn0:lv1
export real mn0_lv1=i0.mn0:lx2
```

You can also change the value of a parameter by specifying the full path to the parameter either in a measurement alias or at the top level of a MDL control file. For example:

- The value of a global parameter `v_vdd` can be changed by:

  ```
  v_vdd = 1.7
  ```

- The value of a subcircuit parameter `mm` can be changed by:

  ```
  x1.xmm0:mm = 3
  ```

- The value of a model parameter `vth0` can be changed by:

  ```
  i1.mp0.pch1:vth0 = 1.5
  ```

Accessing Model Names and Types

MDL allows you to access the model names and model types defined in the netlist.

For example, in a MDL measurement alias:

- A model name, say `mod1`, can be accessed by:

  ```
  export real mdname=mod1:_masterName_
  ```

  If `mod1` is the name of a model, the model name is returned. If `mod1` is the name of a subcircuit, the subcircuit name is returned.

- The model type for the model `mod1` can be accessed by:

  ```
  export real mdtype=mod1:_type_
  ```

  If `mod1` is a model, the primitive name for the model is returned. If `mod1` is a subcircuit, "subckt" is returned.

  Note: Primitive name refers to the built-in device names predefined in Spectre.

Accessing Noise Parameters

MDL allows you to access the noise parameters as follows:

- The noise parameter `rd` can be accessed by:

  ```
  export real rd_noise=mn:rd
  ```

  Note: If a parameter is both a noise parameter and a device parameter, it is treated as a noise parameter.

- Spot noise at given frequency can be accessed by:

```
export real spot_noise=mn:rd @1k
```

- The total noise for a model can be accessed by:

```
export real total_noise=mn:total
```

- The total noise for a circuit can be output by:

```
export total_noise noise:out
```

Using Named and Primitive Analyses

In MDL, you can use both primitive analyses and named analyses. The primitive analyses are those built into Spectre. Named analyses are ones that you define in the netlist. For example, the following measurement alias runs `tran1`, which must be defined in the netlist.

```
alias measurement trans {

    run tran1 // This is an analysis specified in the netlist.

    real rise_edge=cross(sig=V(out), dir='rise, n=1, thresh=1.5, start=0)
    real fall_edge=cross(sig=V(out), dir='fall, n=1, thresh=1.5, start=0)

    export real pw=fall_edge-rise_edge
}
```

In contrast, the following measurement alias runs `tran`, one of the analyses provided by the simulator.

```
alias measurement trans {

    run tran(stop=1u) /* This is a built-in, primitive analysis,
                         which is not defined in the netlist. */

    real rise_edge=cross(sig=V(out), dir='rise, n=1, thresh=1.5, start=0)
    real fall_edge=cross(sig=V(out), dir='fall, n=1, thresh=1.5, start=0)

    export real pw=fall_edge-rise_edge
}
```

Note: The name of the primitive analyses and named analyses must be different. For more information, see Analyses in *Spectre Classic Simulator, Spectre APS, Spectre X, and Spectre XPS User Guide*.

Looping Statements

MDL provides the `foreach` statement to automate repetitive simulations and for sweeps, and provides the `search` statement to identify values that are associated with significant circuit events. With the `mvarsearch` statement, you can set up performance goals for a circuit

along with parameters that may be varied in attempts to reach these goals. Spectre iterates to find the optimal solution.

foreach Statement

The `foreach` statement provides a way for you to run a simulation repeatedly.

```
foreach_statement ::=
         foreach foreach_specifier [ onerror=conditions ]{
             block_of_statements
         }

foreach_specifier ::=
         param_to_vary from alternatives
       | paramset_name

alternatives ::=
         {list}
     |   array
     |   swp (swp_param)

swp_param ::=
         start = strt, stop = stop [, step_def ]
     |   center = cntr, span = spn [, step_def ]

step_def ::=
         step = step
     |   lin = lin_num_steps
     |   dec = steps_per_decade
     |   log = log_num_steps

conditions ::=
    'exit | 'continue
```

param_to_vary	The parameter that the `foreach` statement is to vary. This can be an MDL variable, a netlist parameter, or a device parameter. Valid data types are `real`, `int`, `cplx`, and `analysis`. Each time the `block_of_statements` iterates, the *param_to_vary* is replaced by the next value from the alternatives, except when the *param_to_vary* is `analysis`. When the *param_to_vary* is `analysis`, a `run` statement is required to iterate the next value from the alternatives (see Example 3 for details).
paramset_name	Name of the paramset definition from the netlist.
`block_of_statements`	One or more MDL statements, except variable declarations, measurement alias declarations, and include statements.

{list}	A list of values containing alternative values for *param_to_vary* in the form { *val1*, *val2*,...*valN* }. Valid data types are `real`, `int`, `cplx`, and `analysis`. If an array is present, it must be a de-referenced array element such as `mytran[0]`, `mytran[1]`, etc.
array	An array of sweep values.
strt	The starting value for *param_to_vary*. The *strt* and *stop* parameters are used together to specify sweep limits.
stop	The ending value for *param_to_vary*. The *strt* and *stop* parameters are used together to specify sweep limits. If you do not give a step_def, the sweep is linear when the ratio of stop to strt values is less than 10, and logarithmic when this ratio is 10 or greater.
cntr	Center value of sweep. The *cntr* and *spn* parameters are used together to specify sweep limits.
spn	Span of sweep. The *cntr* and *spn* parameters are used together to specify sweep limits. If you do not give a `step_def`, the sweep is linear when the ratio of the end point of the span to the start point of the span is less than 10, and logarithmic when this ratio is 10 or greater.
step	Step size for linear sweeps.
lin_num_steps	Number of steps for linear sweeps.
steps_per_decade	Number of points per decade for log sweeps.
log_num_steps	Number of steps for logarithmic sweeps.
‘exit	A keyword specifying that the `foreach` loop is to end when the simulation experiences an error, such as a convergence issue. This is the default behavior if the `onerror` option is not specified.
‘continue	A keyword specifying that the `foreach` loop is to continue even when the simulation experiences an error, such as a convergence issue.

Example 1

For example, you might define a measurement and `foreach` statement like the following to determine the maximum output voltage of a circuit. Notice that the `foreach` statement is *not* placed inside the `alias measurement` statement.

```
alias measurement findmax {
    run tran(stop=1u)
    export real maxout=max(V(out))
}
foreach vdd_val from swp(start=5, stop=7, step=0.5) {
    foreach temp from {25, 50, 75, 100} {
        run findmax
    }
}
```

In this example, the outer `foreach` statement varies the value of `vdd_val` and the inner `foreach` varies the value of `temp`. As a result, the `findmax` measurement alias runs with each combination of values, producing a `.measure` file like this.

```
Swept Measurements :
Measurement Name   :  findmax
Analysis Type      :  tran
maxout                vdd_val @ 5         temp @ 25   =  3.07027
maxout                vdd_val @ 5         temp @ 50   =  3.07326
maxout                vdd_val @ 5         temp @ 75   =  3.07565
maxout                vdd_val @ 5         temp @ 100   =  3.08015
maxout                vdd_val @ 5.5         temp @ 25   =  3.06517
maxout                vdd_val @ 5.5         temp @ 50   =  3.06917
maxout                vdd_val @ 5.5         temp @ 75   =  3.07468
maxout                vdd_val @ 5.5         temp @ 100   =  3.07433
maxout                vdd_val @ 6         temp @ 25   =  3.06553
maxout                vdd_val @ 6         temp @ 50   =  3.06703
maxout                vdd_val @ 6         temp @ 75   =  3.06865
maxout                vdd_val @ 6         temp @ 100   =  3.07364
maxout                vdd_val @ 6.5         temp @ 25   =  3.06373
maxout                vdd_val @ 6.5         temp @ 50   =  3.06524
maxout                vdd_val @ 6.5         temp @ 75   =  3.0695
maxout                vdd_val @ 6.5         temp @ 100   =  3.07092
maxout                vdd_val @ 7         temp @ 25   =  3.06274
maxout                vdd_val @ 7         temp @ 50   =  3.06595
maxout                vdd_val @ 7         temp @ 75   =  3.06798
maxout                vdd_val @ 7         temp @ 100   =  3.07035
```

Example 2

As another example, the `paramset` statement is defined as follows in a netlist

```
data_v paramset {
    vhi vlo
    1.9 1.32
    1.8 1.2
    }
data_fet paramset {
    nw nl  pw pl
```

```
    5u 3u 9u 3u
    4u 3u 7u 3u
    }
```

The `alias` and `foreach` statements are defined as follows in the `.mdl` file

```
alias measurement findvth {
    run tran(stop=100n)
    export real outVth = cross(sig=V(out), dir='cross, n=1, thresh=2.5, start=0)
}
foreach temp from {0, 130} {
    foreach data_v {
        foreach data_fet {
            run findvth
            }
    }
}
```

In this example, there are three-level nested sweeps: the inner `foreach` statement varies the value of `nw`, `nl`, `pw` and `pl` from the `data_fet` `paramset` statement defined in the netlist; the middle `foreach` statement varies the value of `vhi` and `vlo` from the `data_v` `paramset` statement defined in the netlist; and the outer `foreach` statement varies the value of `temp`. As a result, the `findvth` measurement alias is run eight times by MDL, producing a `.measure` file like this:

```
Swept Measurements :
     Measurement Name    :    findvth
     Analysis Type       :    tran

outVth                   temp @ 0
                         vhi @ 1.9
                         vlo @ 1.32
                         nw @ 5e-06
                         nl @ 3e-06
                         pw @ 9e-06
                         pl @ 3e-06      =  9.89772e-10

outVth                   temp @ 0
                         vhi @ 1.9
                         vlo @ 1.32
                         nw @ 4e-06
                         nl @ 3e-06
                         pw @ 7e-06
                         pl @ 3e-06     =  1.01348e-09

outVth                   temp @ 0
                         vhi @ 1.8
                         vlo @ 1.2
                         nw @ 5e-06
                         nl @ 3e-06
                         pw @ 9e-06
                         pl @ 3e-06     =  1.37049e-09
```

```
outVth                    temp @ 0
                          vhi @ 1.8
                          vlo @ 1.2
                          nw @ 4e-06
                          nl @ 3e-06
                          pw @ 7e-06
                          pl @ 3e-06      =  1.74369e-09

outVth                    temp @ 130
                          vhi @ 1.9
                          vlo @ 1.32
                          nw @ 5e-06
                          nl @ 3e-06
                          pw @ 9e-06
                          pl @ 3e-06      =  9.56855e-10

outVth                    temp @ 130
                          vhi @ 1.9
                          vlo @ 1.32
                          nw @ 4e-06
                          nl @ 3e-06
                          pw @ 7e-06
                          pl @ 3e-06      =  9.82614e-10

outVth                    temp @ 130
                          vhi @ 1.8
                          vlo @ 1.2
                          nw @ 5e-06
                          nl @ 3e-06
                          pw @ 9e-06
                          pl @ 3e-06      =  1.17573e-09

outVth                    temp @ 130
                          vhi @ 1.8
                          vlo @ 1.2
                          nw @ 4e-06
                          nl @ 3e-06
                          pw @ 7e-06
                          pl @ 3e-06      =  1.22687e-09
```

Example 3

```
alias measurement myrun {
    input analysis tranRun = tran1
    run tranRun
    }

analysis myAltergroups[] = { ag1, ag2, ag3, ag4 }

analysis ag, myAnalysis

foreach ag from myAltergroups {
    run ag    //This is required to activate the next analysis
    foreach myAnalysis from { dc1, dcswp, tran1 } {
    run myrun( tranRun = myAnalysis ) as myAnalysis
```

```
    }
}
```

Specifying the foreach Statement Within the measurement Alias

MDL also supports the `foreach` statement within the measurement alias.

Example

```
alias transient {
    export real v1
    export real temper
    temper=temp
    run tran( stop=7e-08 )
    v1=aa*avg(V(vin))
}
alias measurement top_test {
    export real sum =0;
    export real each_v1[];
    int index=0;
    foreach aa from {10, 20 ,30} {
    run transient as inner;
    sum = sum + inner->v1;
    each_v1[index] = inner->v1;
    index = index+1;
    }
}
```

search Statement

The `search` statement provides a way for you to find the value of a design parameter that corresponds to the circuit meeting or failing a specific performance criterion. The function operates by running the simulation repeatedly, varying the values of interest each time, until a specified condition is met. This capability is typically used to determine values such as setup time and maximum load.

```
search_statement ::=
         search search_specifier [ output=conditions ] {
             block_of_statements
         } method ( condition_statements )

search_specifier ::=
     param_to_vary from binary ( start=strt, stop=stp, tol=tol
     round=['no|'yes])

conditions ::=
     'none | 'last | 'all | 'each
```

```
method::=
        until
    |   while
    |   bisection
```

param_to_vary	The parameter that the search statement is to vary in a binary way.
strt	The starting value for *param_to_vary*. The *strt* and *stp* values should straddle the expected value. If both *strt* and *stp* result in a *condition_statement* that is true or if both result in a *condition_statement* that is false, the search statement fails.
stp	The ending value for *param_to_vary*. The *strt* and *stp* values should straddle the expected value. If both *strt* and *stp* result in a *condition_statement* that is true or if both result in a *condition_statement* that is false, the search statement fails.
tol	The tolerance value, which specifies how precisely the final value is calculated.
round='no|'yes	If set to 'yes, each iteration of the search is an integral value that is rounded of to the nearest middle value.
block_of_statements	One or more run statements.
condition_statements	A statement that determines when the search statement stops. You can use multiple boolean expressions in conditional statements.
'none	A keyword indicating that no analysis output is to be saved to the raw directory irrespective of whether the search succeeds or fails.
'last	A keyword indicating that the analysis output is to be saved only when the last iteration of the search succeeds. No output will be saved to the raw directory if the search fails.
'all	A keyword indicating that the analysis output is to be saved to the raw directory irrespective of whether the search succeeds or fails. This is the default keyword.
'each	A keyword indicating that the analysis output for each iteration of the search is saved to the raw directory irrespective of whether the search succeeds or fails.

until	A keyword indicating that the search statement is to continue looping until the value of *param_to_vary* causes *condition_statements* to become true and then return the first iteration value that meets the tolerance (tol) criteria when *condition_statements* is true. If you use this keyword, *condition_statements* must initially be false.
while	A keyword indicating that the search statement is to continue looping until the value of *param_to_vary* causes *condition_statements* to become false and then return the last iteration value that meets the tolerance (tol) criteria when *condition_statements* is true. If you use this keyword, condition_statements must initially be true.
bisection	A keyword indicating that the search statement is to continue looping till either an until or a while condition is first met.

Example 1

For example, you might define a measurement and search statement like the following to determine the setup time of a flip-flop.

```
alias measurement setup {
    export real vddelay, outcross, Tsetup, vcdelay, setdelay, maxq
    run tran(stop=40n)
    vddelay=cross(sig=V(data), thresh=2.5, dir='rise, n=1)
    vcdelay=cross(sig=V(clock), thresh=2.5, dir='rise, n=1)
    outcross=cross(V(q),thresh=2.5)
    maxq=max(V(q))
    setdelay=vdata:delay
    Tsetup=vcdelay-vddelay
}
search vdata:delay from binary(start=2n, stop=10n, tol=1p) {
    run setup
} until ( setup->maxq < 2.5)
```

In this example, the search statement varies the parameter vdata:delay, which is a parameter named delay on a instance named vdata. The simulation determines when V(q) crosses a threshold value. When V(q) fails to cross the threshold, maxq remains less than 2.5, making the *condition_statements* true. The setup->maxq syntax in the *condition_statement*, refers to the maxq value in the setup block.

Through repeated simulations, the search statement closes in on the value of vdata:delay that marks the change from *condition_statements* being false to *condition_statements* being true.

Example 2

You can also choose whether to save the search results to the raw directory by specifying an output parameter. This feature can be used to prevent creating large size output files that may cause memory issues.

For example, in the following `search` statement, two conditions are specified in the `while` criteria. The simulator will exit and return the last successful value whenever one of the two conditions fails.

```
search vdata:delay from binary(start=2n,stop=10n,tol=1p) output='last {
         run setup
} while (setup->maxq > 1.8 && setup->outcross < 10.3n)
```

As `output='last` is set, the analysis output of the setup measurement will be saved to the raw directory only when the last iteration of the search is successful, otherwise no analysis result is saved.

Note: If the two conditions in the `while` criteria are defined in an `OR` relationship (using the || operator), but not in an AND relationship (using the && operator), the simulator will exit and return the last successful value only when both the conditions fail.

mvarsearch Statement

The `mvarsearch` statement provides a way for you to find the values of design parameters that correspond to the optimal solution of a group of measurements. In essence, this statement provides a multi-parameter, multi-goal search functionality.

This statement works by setting the design parameters to a value, running the defined measurement, evaluating the goal functions, calling an optimizer to determine the next set of design parameter values, and repeating. The statement iterates until an optimal solution is found, or until the maximum number of optimization iterations have been performed.

When the `mvarsearch` is used inside a foreach loop, the `restoreParam` option must be set to `1` to reset the parameters to their initial values after the optimization is complete and avoid any errors in subsequent foreach loops.

```
mvarsearch_statement ::=
     mvarsearch {
         option {
             options_statements
         }
         parameter {
             parameter_statements
         }
         exec {
             exec_statement
```

```
        }
        zero {
            zero_statements
        }
    }
options_statement ::=
    [ method = method ]
    [ accuracy = conv_tol ]
    [ deltax = diff_tol ]
    [ maxiter = maxiter ]
    [ restoreParam = restoreParam ]
parameter_statement ::=
    { param_name, init_val, lower_val, upper_val )
```

method	The method to be used in the algorithm method. Possible values are `'newton` (newton solver) and `'lm` (levenburg marquardt). While `'newton` is faster than `'lm`, `'lm` has more robust convergence properties. You should use `'newton` only when *init_val* values are close to the final solution and you want a faster optimization. `'newton` assumes that the number of *param_statement*=number of *zero_statement*. If this is not true, mvarsearch automatically changes method to `'lm`. Default value: `'lm`
conv_tol	Convergence tolerance. The optimization ends if the relative error in the sum of squares of the calculated objectives in the *zero_statements* is less than *conv_tol*. For example, given objectives `tmp1` and `tmp2`, the optimization ends if: (`tmp1`*`tmp1` + `tmp2`*`tmp2`) < *conv_tol* The smaller the value of *conv_tol*, the more accurate the optimization solution. Default value: 1.0e-04
diff_tol	Step length for the forward-difference approximation to compute the numerical derivatives. For a design parameter of value `x`, the approximation uses *diff_tol*`*x` as the step length. If `x` is very small (less than the machine precision), the step length is taken as *diff_tol*. Default value: `5.0e-03`
maxiter	Maximum number of optimization iterations that should be evaluated before automatically exiting the optimization loop. Default value: `300`

restoreParam	Specifies if the parameters to be optimized should be reset to their initial values after the optimization is complete (restoreParam=1). Default value: 0
param_name	The parameter to be optimized.
init_val	Initial value for the parameter to be optimized. This value provides the optimization algorithm with an initial guess for the parameter to be optimized. Default value: 1.0
lower_val	Lower limit for the parameter to be optimized. The optimization limits parameter to the value of *lower_val* if it becomes less than the specified value. *lower_val* can be used to force a lower limit on physical parameters (such as MOSFET channel width) to ensure that the optimized solution is physically possible.
upper_val	Upper limit for the parameter to be optimized. The optimization limits the parameter to the value of *upper_val* if it exceeds the specified value. *upper_val* can be used to force an upper limit on physical parameters (such as MOSFET channel width) to ensure that the optimized solution is physical possible. Setting *lower_val* and *upper_val* too close to each other can result in discontinuities, making the optimization unsuccessful. Default value: 2.0**init_val*
exec_statement	run statement to compute goal values.
zero_statement	Goal value to be minimized.

For example, you may define a measurement and mvarsearch statement as follows to obtain the optimal values of p-channel width and n-channel width, and an equivalent rise and fall time of 3ns for an inverter chain.

```
alias measurement trans {
run tran( stop=1u, autostop='yes )
    export real rise=risetime(sig=V(d), initval=0, inittype='y, finalval=3.0,
       finaltype='y, theta1=10, theta2=90) // measured from 10% to 90%
    export real fall=falltime(sig=V(d), initval=3.0, inittype='y, finalval=0.0,
       finaltype='y, theta1=90, theta2=10) // measured from 10% to 90%
}
mvarsearch {
    option {
       accuracy = 1e-3     // convergence tolerance of trans->rise
       deltax = 1e-3       // numerical difference % of design variables
```

```
        maxiter = 100       // limit to 100 iterations
    }
    parameter {
        {para_pw, 1.2u, 0.1u, 10u}
        {para_nw, 1.2u, 0.1u, 10u}
    }
    exec {
        run trans
    }
    zero {
        tmp1 = trans->rise - 3ns
        tmp2 = trans->fall - 3ns
    }
}
```

In the above example, design parameters `para_pw` and `para_nw` are varied by the optimization algorithm starting at an initial value of 1.2 microns with a maximum value of 10 microns and a lower limit of 0.1 microns. At each iteration, the measurement alias `trans` is run after the design parameter value is set. The `zero` values `tmp1` and `tmp2` are then computed using the results from the measurement alias. This iteration continues until one of the following happens:

- `tmp1` and `tmp2` satisfy the *`conv_tool`* criteria determined by the following equation:

  (`tmp1`*`tmp1` + `tmp2`*`tmp2`) < 1.0e-03

- the *`maxiter`* parameter value is exceeded

During this optimization, the parameters `para_pw` and `para_nw` are clamped between the lower limit of 0.1u and the upper limit of 10u. This clamping forces the channel widths of the MOSFETs in this circuit to remain within defined limits while the optimization is performed.

The above example results in the following output:

```
Swept Measurements   :
Measurement Name     :  trans-meas_optimize
Analysis Type         :  tran
fall                   para_pw @ 2.3745e-06
                       para_nw @ 1.16767e-06  =  2.99999997237325e-09
rise                   para_pw @ 2.3745e-06
                        para_nw @ 1.16767e-06  =  3.00129681779706e-09
```

You can define a `mvarsearch` statement inside `foreach` statements as follows:

```
foreach v_vdd from {3, 2.5}
{
    foreach temp from {25, 30}
    {
        mvarsearch {
            option {
            accuracy = 1e-3     // convergence tolerance of trans
            deltax = 1e-3       // step length
            maxiter = 100       // limit to 100 iterations
            restoreParam=1      // a must
        }
```

```
        parameter {
            {pw, 2u, 0.05u, 10u}
            {nw, 2u, 0.05u, 10u}
        }
        exec {
            run trans
        }
        zero {
            tmp1 = trans->rise-25p
            tmp2 = trans->fall-25p
                }
        }
    }
}
```

The above example results in the following output (with `-tab` option in the spectre =mdl command line):

```
Swept Measurements :
Measurement Name   :  trans
Analysis Type      :  tran
v_vdd   temp    pw          nw          fall          rise
3       25      5.58951e-06 4.08718e-06 2.38087e-11         2.62996e-11
3       30      3.6754e-06  3.39895e-06 2.41e-11       2.66064e-11
2.5     25      3.72744e-06 2.05837e-06 2.32133e-11    2.87913e-11
2.5     30      3.35662e-06 1.84146e-06 2.41816e-11 2.96455e-11
```

Include Statement

The `include` statement provides a way for you to insert the contents of an MDL control file into another control file. This feature is useful for creating an MDL control file using other control files as components.

```
include_statement ::=
         include "mdlfile"
```

mdlfile	Path and filename of the MDL file to be inserted.

Remember the following rules when using the `include` statement.

1. The `include` statement is allowed at the top level of the MDL file only.
2. Alias measurement blocks, foreach, search, mvarsearch, and montecarlo statements do not support the `include` statement as a subordinate command.

In the following example,

```
//File main.mdl
include "simple.mdl"
run tr
```

the `main.mdl` and `simple.mdl` files are placed in the current directory.

In the following example,

```
//File simple.mdl
include "meas/mdl2.2"
alias measurement t
run tran(stop=140n)
    export real val1=3*V(11)
    }
run tr3
include "meas/mdl1.2"
run tr2
```

the `mdl1.2` and `mdl1.2` files are placed in the `meas` directory.

Evaluating Expressions Selectively

You can specify the criteria based on which you want MDL to run other statements and evaluate expressions.

If/Else Statement

The `if/else` statement provides a way for MDL to run other statements selectively according to criteria that you specify.

```
if ( CONDITION ) {
    TRUESTATEMENTS
    }
[
(
    else if (ELSEIFCONDITION) {
    ELSEIFSTATEMENTS
    }
)+
]
[
else {
FALSEESTATEMENTS
}
]
```

[...]	Optional block.
(...)+	Indicates that the block can be repeated.
`if`	Indicates that this is an if block of the `if/else` statement.
`else`	Indicates that this is an else block of the `if/else` statement.

CONDITION	Conditional expression which returns 1 if the condition is true and 0 if the condition is false.
ELSEIFCONDITION	Conditional expression which returns 1 if the condition is true and 0 if the condition is false.
TRUESTATEMENTS	Statements that are read only if CONDITION is true.
ELSEIFSTATEMENTS	Statements that are read only if ELSEIFCONDITION is true and CONDITION and all previous ELSEIFCONDITION are false.
FALSESTATEMENTS	Statements that are read only if CONDITION and all previous ELSEIFCONDITION are only.

The `if/else` statement is allowed

- at the top level of an MDL file, and it can include assign, run, mvarsearch, search, foreach, montecarlo, print statements
- inside alias measurement block and executed blocks of mvarsearch, search, montecarlo, foreach statements

Example 1

```
int count=0
foreach count from swp(start=1, stop=3, step=1) {
    if (count==1)
        {
            run tr3
        }
    else if (count == 2)
    {
        if (tr2->val2 == 5)
        {
            run tr2
        }
        run tr1
    }
    else
    {
    run tr2
    }
}
```

Example 2

The following example shows the value of v(11) change from 0 to 5 during the simulation.

```
alias measurement tr1 {
    run tran(stop=160n)
```

```
    export real val2
    export real val1
    export real val3
    export real val4
    export real val5
    export real val6
    export real val7
    export real val8
if ( v(11) > 4)
{
    if  ( v(11) < 4.06 )
    {
        val1=v(11)
    }
    val2 = min(v(11))
}
else if ( v(11) > 3 )
{
    if ( (v(11) > 3.5) && (v(11)<3.7) )
    {
        val3= max( v(11)
        val4= v(11)
    }
    else
    {
        val5=v(11)
        val6=max(v(11))
    }
}
else
{
    val7 = max(v(11))
    val8 = v(11)
    }
}
run tr1
```

In the example above, `val7 = 2.955`, because the max function is a buffered function and assign statement `val7 = max(v(11))` is executed while `v(11)` <= 3.

Ternary Expression Statement

The ternary expression statement provides a way for MDL to evaluate expressions selectively according to criteria that you specify. A ternary expression statement may be used at any location where an expression is supported. Furthermore, as this statement is an expression, its return value may be used as the argument to an assignment statement.

(*CONDITION*) ? *TRUEEXPRESSION* : *FALSEEXPRESSION*

?	MDL keyword indicating that this is a ternary if-operator.
:	MDL keyword separates TRUEEXPRESSION and FALSEEXPRESSION.

CONDITION	Conditional expressions which returns `1` if the condition is true and `0` if the condition is false.
TRUEEXPRESSION	Expression returned if *CONDITION* is true.
FALSEEXPRESSION	Expression returned if *CONDITION* is false.

Remember the following when using a ternary expression statement:

- Add a space before a not-equal-mark (!=). This is to differentiate the not-equal from value assignment to a global signal which is usually suffixed with “!”.
- Add a parenthesis before the colon mark (:) when a letter follows it. This is to differentiate the *TRUEEXPRESSION* from the expression of *instance*:*terminal*

Example

```
val2 = (v(11) == 5)&&(val1 != 'nan) ? v(11) : 2*v(11)
val3 =(val1 != 'nan)?  mag( V(11)==5?max(V(11)):10 )+3 :   2*V(11)
```

Specifying the Output File Format

The print statement provides a way for you to write strings and variables (such as parameters and measurement results) from an MDL control file to the standard output file or an output file defined by you.

You can add a print statement at the following levels:

- at the top level of an MDL control file
- at the level of an alias measurement
- inside a foreach looping statement
- inside an optimization looping statement (such as `search` or `mvarsearch`)
- inside a monte-carlo analysis

```
print _statement::=
     print fmt ( "format", args ) [ to=file | addto=file ]

format::=
     % [ flag ][ width][ .precision ] type [ \n| \t ]

flag::=
     -
```

```
type::=
     d,i | E,e | f | G,g | o | S | s | u | X,x | V
```

Example 1

`flag`	Symbol used to align the text in the output file. `-` left-aligns the text. If `flag` is not specified, the text is right-aligned.
`width`	Minimum field width.
precision	Maximum number of the significant digits to be printed for `g`, `G`, `S`, and `s` types, or the number of decimal digits to be printed for `e,E` and `f` types. Default value: 6
`type`	Defines how the text is to be printed to the output file. The following are supported in MDL: `d,i` – signed decimal integer `E,e` – floating point (in scientific notation) `f` – floating point (in decimal) `G,g` – the shorter of %e, %E and %f (suppresses non-significant zeros) `o` – unsigned octal integer `S` – engineering scale number (e.g. 5m, 5K) `s` – string `u` – unsigned decimal integer `X,x` – unsigned hexadecimal integer. `V` – the value of the args
`\n`	Specifies that a new line is to be inserted.
`\t`	Specifies that a tab space is to be inserted.
`to`	Specifies that the existing results in the output file are to be overwritten by the new results. You should use the `to` option in the first print statement to clean the old results in the specified results file.
`addto`	Specifies that the results are to be appended to the output file.
`file`	File name.

The `enum`, `string`, `net`, `term` and `analysis` type data can be output by print statements. The following example shows output of both numbers and strings.

```
alias measurement printmeas {
    input string out="myfile.out"
    print fmt("Header is %s\n", out) to=out
```

```
    print fmt("%s\t%s\t\t%s\t%s\t%s\n", "maxq", "minq", "REG", \
    "INTREG", "REALREG") addto=out
    run tran1
    export real maxq=max(V(q))
    export real minq=min(V(q))
    enum REG = i0.mp0:region
    export int INTREG = i0.mp0:region
    export real REALREG = real(REG)
    print fmt("%V\t%V\t%V\t%V\t%V\n",maxq, minq, REG, INTREG, \
    REALREG) addto=out
    print fmt("\n%s\t%s\t%s\t%s\t%s\t%s\t%s\n", \
        "%d","%i","%g","%G","%e","%E","%f") addto=out
    print fmt("%d\t%i\t%g\t%G\t%e\t%E\t%f\n\n", \
        10,10,10,10,10,10,10) addto=out
    print fmt("\n%s\t%s\t%s\t%s\n", "%o","%x","%X","%u") addto=out
    print fmt("%o\t%x\t%X\t%u\n",10,10,10,10) addto=out
}
run printmeas (out="test.dat")
```

The simulator writes the following results to the `test.dat` file:

```
Header is test.dat
maxq    minq        REG     intReG  realREG
1.81826 -0.0144086  off     0       0
%d  %i  %g  %G  %e          %E          %f
10  10  10  10  1.000000e+011.000000E+0110.000000
%o      %x      %X      %u
12      a       A       10
```

Example 2

```
print fmt ("\n****Print Results of Foreach Sweep:****\n\n") addto="print.dat"
print fmt ("%-15s%-15s%-15s%-15s\n", "Vdd", "delay", "rise", "fall")
addto="print.dat"
foreach vdd from {1.5, 1.8, 2} {
    run tranmeas
    print fmt("%-15g%-15e%-15S%-15.8S\n", vdd, tranmeas->q_delay, \
        tranmeas->q_rise_time, tranmeas->q_fall_time) addto="print.dat"
}
```

The simulator writes the following results to the `print.dat` file:

```
****Print Results of Foreach Sweep:****
Vdd     delay       rise        fall
1.5     2.016334e-10   106.898p       66.053876p
1.8     1.618669e-10   87.7326p       60.830271p
2       1.460035e-10   79.6162p       58.993397p
```

Example 3

The following example shows how to print the intermediate results of an `mvarsearch` statement.

```
print fmt ("\n****Print Results of Optimization Analysis****\n\n")
to="print_opt.dat"
print fmt ("%-15s%-15s%-15s%-15s\n", "pw","nw","rise","fall")
addto="print_opt.dat"
mvarsearch {
    ...
    exec {
    print fmt("%-15e%-15e", pw, nw) addto="print_opt.dat"
    run trans
    print fmt("%-15e%-15e\n", trans->rise,trans->fall) \
        addto="print_opt.dat"
    }
    ...
}
```

The simulator writes the following results to the `print_opt.dat` file:

```
****Print Results of Optimization Analysis****
pw          nw          rise        fall
2.000000e-062.000000e-062.469632e-112.371606e-11
2.063246e-062.000000e-062.451040e-112.387945e-11
...
...
2.007259e-061.719886e-062.499470e-112.500292e-11
2.007259e-061.719886e-062.499470e-112.500292e-11
```

Autostop

Autostop is a feature that halts simulation as soon as enough data has been collected to evaluate the MDL expressions associated with a transient analysis. Using the autostop feature can save you an enormous amount of simulation time when you characterize circuits. The autostop feature is supported only for transient analysis.

Only functions that determine specific events, such as delay and event measurements, can cause an automatic stop. However, if non-event functions such as `max` and `min` are included in the same measurement alias, the functions are evaluated over the simulation period defined by the event functions.

To use the autostop feature, you turn on the autostop parameter of the `tran` statement. For example, the `tran` statement defined in the design file might look like this.

```
tran1 tran stop=6u method=gear2only autostop=yes
```

Then, in the MDL control file, you specify the information you want to gather. For example, your control file might look like this.

```
alias measurement trans {
run tran1
    export real out_1u=V(out)@1u
    export real prop_delay_fall=deltax(sig1=V(inp), sig2=V(out), dir1='fall,
       n1=1, start1=0, thresh1=1.5, dir2='fall, n2=1, start2=0, thresh2=1.5)
}
run trans
```

This example control file contains two expressions. The first measures the output voltage at 1µs, and the second determines the delay between the input and output falling edges. Because the autostop feature is enabled, the simulation runs only as long as necessary to calculate the two specified values.

If the control file also specifies a third expression such as

```
export real outmax=max(V(out))
```

the simulator finds the maximum value only in the part of the simulation prior to the automatic halt. If there happens to be a greater maximum that occurs after the automatic halt, the simulator does not find it when autostop is enabled.

Monte Carlo

Monte Carlo statements provide a way to run Monte Carlo in MDL for measurement and statistical figures of merit.

```
montecarlo_statement::=
run montecarlo   ( options_statements )
{
block of statements
}
options_statement ::=
    [numruns = <int>, ]
    [seed = <int>, ]
    [variations= <'process |'mismatch |'all >, ]
    [sampling=<'standard |'lds |'lhs>, ]
    [firstrun = <int>, ]
    [ donominal = < 'yes, 'no>, ]
    [ scalarfile  =filename, ]
    [ appendsd  = < 'yes, 'no >, ]
```

For more information on the `block of statements`, see Using a Measurement Alias on page 19.The options in the `options_statement` are consistent with the Monte Carlo analysis in Spectre. For more information on these options, see the *Spectre Classic Simulator, Spectre Accelerated Parallel Simulator (APS), and Spectre Extensive Partitioning Simulator (XPS) User Guide*.

From the MMSIM6.1 release, you can have a Monte Carlo statement inside a foreach loop.

The following information is written to the output file:

- number of iterations
- exported measurement values for each of runs

Statistical figures of merit are also computed and output as part of the termination of the MDL Monte Carlo run:

`max`	The maximum value.
`min`	The minimum value.
`mean`	The mean value.
`var`	The variance from the mean.
`stddev`	The standard deviation.
`avgdev`	The average deviation, mean absolute deviation.
`failedtime`	The number of failed runs.

When the monte carlo analysis is run in MDL for measurement, `max`, `min`, `mean`, `var`, `stddev`, and `avgdev` are computed and written to the output file and NULL values are ignored.

For more information on the functions, see Appendix A, “Built-In Functions,”.

For example, you can define a measurement and Monte Carlo statement like the following for a flip-flop circuit

```
alias measurement tranmeas {
export real rise_out
    run tran(stop=40n, errpreset='conservative)
    rise_out=risetime(V(q), initval=minq, finalval=maxq, inittype='y, \\
    finaltype='y, theta1=10, theta2=90)
}
run montecarlo ( scalarfile="dflip.dat",numruns=50, seed=8, donominal='no,
variations='all, sampling='lds firstrun=1)
{
run tranmeas
}
```

Supported Spectre Circuit Simulator Analyses

MDL supports the following Spectre circuit simulator analyses inside an alias measurement block:

- Transient analysis, including transient noise, transient ac, and transient info (`tran`)
- AC analysis (`ac`)
- DC analysis (`dc`)

- Sweep analysis (`sweep`)
- Noise analysis (`noise`)
- Monte Carlo (`montecarlo`)
- Circuit Information (`info`)
- Alter Group (`altergroup`)
- S-parameter analysis (`sp`)
- Stability Analysis (`stb`)
- Reliability Analysis (`rel`)

The analysis can be defined in the netlist or in the MDL control file.

The following table displays the syntax differences between Spectre and MDL.

Analysis	Spectre Circuit Simulator Syntax	MDL Syntax

transient	`tran1 tran stop=1u errpreset=conservative`	`run tran1 [as tran2]`
		or
		`run tran (stop=1u, errpreset='conservative) [as tran2]`

transient ac	`tran2 tran actimes=[0 20n 40n] acnames=[CaptabInfo ac-2] stop=40n`	`run tran2`
		or
		`run tran ( actimes={0, 20n, 40n}, acnames={CaptabInfo, ac-2}, stop=40n}`

transient info	`tran3 tran infotimes=[10n 30n] infoname=opInfo stop=40n`	`run tran3`
		or
		`run tran ( infotimes={10n, 30n}, infoname=opInfo, stop=40n}`

transient noise	`tran1 tran stop=50n noiseseed=10 noisefmax=30G noisefmin=1M`	`run tran ( stop=50n, noiseseed=10, noisefmax=30G, noisefmin=1M )`

AC	`ac1 ac start=0.1G stop=1G dec=25`	`run ac1 [as ac2]`
		or
		`run ac (start=0.1G, stop=1G, dec=25) [as ac2]`

DC	`dc1 dc oppoint=logfile`	`run dc1 [as dc2]`
		or
		`run dc (oppoint='logfile) [as dc2]`

DC sweep	`dcswp1 dc param=temp start=-40 stop=40 step=10`	`run dcswp1 [as dcswp2]`
		or
		`run dc (param=temp, start=-40, stop=40, step=10) [as dcswp2]`

sweep	`swp1 sweep param=temp values=[25 50] { swp2 sweep param=vdd values=[0.8 3.3] { tran1 tran stop=10n } }`	`run swp1`
		or
		`foreach temp swp from{25, 50} { foreach vdd swp from {0.8, 3.3} { run tran(stop=10n) } }`

noise	`findNoise (out gnd) noise oprobe=out iprobe=v4 start=1 stop=1MHz dec=10`	`run findNoise [as findNoise2]`
		or
		`run noise( oprobe=out, iprobe=v4, start=1, stop=1M dec=10, terminals={"out","gnd"}) [as findNoise2]`

montecarlo	`mc1 montecarlo scalarfile=monte5a.dat numruns=10 variations=all seed=1 sampling=lds{`
	`…`
	`}`
		`run montecarlo (scalarfile="monte4.dat", numruns=10, variations='all, seed=1 sampling='lds) {`
		`…`
		`}`

circuit information	`dcOpInfo info what=oppoint where=rawfile`	`run dcOpInfo [as dcOpInfo2]`
		or
		`run info (what='oppoint where='rawfile) [as dcOpInfo2]`

alter group	`alter1 altergroup { …}`	`run alter1 [as alter2]`

S-parameter	`sp1 sp ports=[PORT_1 PORT_2] dec=20 start=0.1G stop=20G`	`run sp1 [as sp2]`
		or
		`run sp (ports={PORT_1, PORT_2}, dec=20, start=0.1G, stop=20G) [as sp2]`

Stability Analysis	`stb1 stb start=1 stop=1e10 dec=100 probe=Vprobe`	`run stb(start=1, stop=1e10, dec=100, probe=Vprobe)`

Reliability Analysis	`rel reliablity {`
	`age time = [10y]`
	`deltad value = 0.1`
	`……`
	`//run analysis`
	`……`
	`}`
		`run reliability (time_age={10y}, deltad_value = 0.1 ) {`
		`……`
		`//run MDL measurement`
		`……`
		`}`
		Note: For the reliability commands and their equivalent MDL commands, see Appendix D, "Reliability Commands in MDL".

Note that `ac` or `info` analyses used as part of a `tran` statement (`opInfo`, `ac-2`, and `CaptabInfo` in the above table) must be defined in the netlist.

Almost all Spectre netlist pre-defined core analyses are supported by MDL, except for sweep and montecarlo analyses. Therefore almost any predefined analysis can be defined and run outside the alias measurement blocks in an MDL control file, such as at the top level or

anywhere a run statement may be present which includes inside the foreach, montecarlo, search and mvarsearch statements. But the results may not be accessible, nor may measurements be performed on the results as real time data from analyses is accessible only when the analysis is supported inside an alias measurement block.

Supported Spectre Circuit Simulator Formats

The following Spectre circuit simulator formats allow the creation of an MDL `.measure` file:

- PSFBIN
- PSFASCII
- SST2
- FSDB
- WDF
- TR0ASCII

The following Spectre circuit simulator formats are not supported and do not allow the creation of an MDL `.measure` file:

- PSFBINF
- WSFBIN
- WSFASCII
- NUTBIN
- NUTASCII

Optimizations and Tips and Tricks

Data Output Optimizations

1. Use simulator option `save=nooutput` in your design file to disable simulator data save and enhance performance. If you want to save simulator data, use `save=selected` in your design file and specify the signals to be saved.
2. Use the `-rmrawfiles` command line option to delete the `.raw` directory after each MDL run. The `.measure` file is preserved. This minimizes disk space usage between runs.

3. Use `rawfmt=psfbin` (default setting) for best output performance.
4. Only export the variables that you need written to the `.measure` file.

Performance Optimizations

1. Use the paramset in the `foreach` loop if multiple `foreach` runs are desired.
2. Use the `autostop` parameter on the transient analysis runs with the functions `cross()`, `trim()`, `deltax()` to specify termination of the analysis run after values have been computed.
3. Use default accuracy (`moderate`) on the transient analysis, as MDL thresholds and breakpoints ensure accuracy. You do not need to specify small timesteps for equivalent accuracy with MDL.
4. Instead of recomputing multiple identical expressions, use a single expression computation and temporary variables in the measurement aliases.
5. To speed up `mvarsearch` runs, set the nominal value of each varied parameter close to the expected value, if known.
6. Use multiple measurement functions such as `crosses()` and `dutycycles()` instead of using multiple `cross()` or `dutycycle()` measurements.

MDL Reuse

1. Use parameterized alias measurements and `include` statements for MDL alias measurement code reuse.
2. To share data between alias measurement runs, or access data from a run at the top level, use the `->` operator in the top level constructs for accessing previous alias measurement run results.
3. When using the `->` operator to access computed data, remember that re-naming the measurement alias run using the `as` command changes the measurement alias name for the “->” operator. For example,

```
alias measurement maxout
{
      input net mynet;
export real out;
run tran1;
      out = max(V(mynet));
}
run maxout(mynet=out);
// maxout->out = max(V(out))
```

```
run maxout(mynet=dout) as maxdout;
// maxout->out = max(V(out))
```

4. Avoid the use of design file global variables, if possible. Instead, use the input variable functionality of MDL to pass parameter values to the measurement alias.
5. Use `;` at the end of each statement in a measurement alias.
6. Use the `V()` and I() access functions to access voltages and currents instead of just inserting the signal name itself.
7. Define the analysis to be run in the MDL control file and do not rely on the design containing the analysis definition. This is particularly important if you plan to parameterize or reuse the analysis run itself.

Common Pitfalls

1. To avoid search failures, ensure that the start and/or stop values of the search meet the search condition(s) before running the search.
2. Use the search command when the conditions are continuous and monotonically increasing or decreasing. If the conditions are discontinuous or non-monotonic, use `mvarsearch`.
3. Run newly defined alias measurements using default settings prior to inserting them into higher level constructs such as `foreach`, `montecarlo`, `search`, or `mvarsearch` to ensure that the alias measurement does not contain errors.
4. Statements in the alias measurement block before the `run` statement are executed only once before the run statement is executed. Use this functionality to compute constant values, or testbench setup. These expressions are not evaluated at each iteration of the `run` analysis itself.
5. Ensure that variables are not forward referenced by defining them prior to their usage.
6. When specifying enumerated arguments, remember to include the single quotation mark. For example, to set `errpreset` on an MDL defined transient analysis, use `errpreset='moderate`.

Miscellaneous

1. If an MDL run is inadvertently terminated prior to normal termination, or the output *.measure* file is inadvertently removed, use the `processmdl` script located at *`install-path`*`/tools/mdl/bin` to recreate the `.measure` file. The syntax is as follows:
   `processmdl` [options] *`mdlfilename`*

This is also useful for recreating the `.measure` file from the raw directory in tabular format (`-tab`) or for changing the precision of the results (`-prec`). The initial raw directory must remain intact for this to function correctly.

2. To access online help on predefined functions, type `spectre =mdl -h` *`functionname`* in a terminal window (for example, `spectre =mdl -h cross`). For a list of predefined functions, type `spectre =mdl -h functions`.

2

Constructing MDL Expressions

A Measurement Description Language (MDL) expression consists of a series of language elements that conforms to the rules of the language. This chapter defines the Spectre MDL language elements and describes the rules for combining the elements into expressions. As described in the next chapter, expressions can be used, in turn, to make measurements.

The major topics in this chapter include

Basic Language Elements and Scope Rules

The basic language elements include white space, comments, and identifiers.

White Space

The MDL tool ignores blanks, tabs, and pairs consisting of a backslash immediately followed by a new-line character, except when these characters or combinations are in strings or when they separate other language elements.

For example, in MDL, this code fragment,

```
export      real      p2p_rise=pp(trim(sig=V(out),\
    from=0, to=100n))
```

has an effect identical to that of the following fragment.

```
export real p2p_rise=pp(trim(sig=V(out), from=0, to=100n))
```

Comments

In MDL, you can designate a comment in either of two ways.

- An in-line comment starts with the two characters `//` (provided they are not part of a string) and ends with a new-line character. Within an in-line comment, the characters `//`, `/*`, and `*/` have no special meaning. An in-line comment can begin anywhere in the line.

  ```
  // This code fragment contains four in-line comments.
  // Three comments affect whole lines; one is at the end of a line
  run dc // Run the analyses.
  //
  ```

- A block comment starts with the two characters `/*` (provided they are not part of a string) and ends with the two characters `*/`. Within a block comment, the characters `*`, `/*`, and `//` have no special meaning.

  ```
  /*
   * This is an example of a block comment. A block
   * comment can continue over several lines, making it
   * easy to add extended comments to your file.
   */
  ```

Identifiers

You use an identifier to give a unique name to an object such as a variable, a measurement alias, or an analysis name in the `run` or `run as` statement. The unique name allows you to reference the object from other places. Identifiers are case sensitive.

```
identifier ::=
             letter {letter_or_digit}

letter_or_digit ::=
             letter
          |   digit

letter ::=
             a-z
          |   A-Z
          |   _

digit ::=
             0-9
```

For example, the following statements use identifiers that comply with this syntax.

```
real An_Identifier_Name = 15.0
real a_2nd_name = 15.0
real many___underscores = 20.
alias measurement _tran2 {
alias measurement _tran3_ {
```

The following identifier does *not* comply with this syntax.

```
real 2identifier = 15.0      // ILLEGAL! Must begin with a letter.
```

The following two identifiers are different, because their capitalization is different.

```
real rise = 14.0
real RISE = 16.0
```

Scope Rules

The scope of an MDL variable is the measurement alias in which it is defined. For example, assume you have an MDL control file that contains the following statements:

```
alias measurement mytran1 {
    export real out_160n=V(out)@160n
}

alias measurement mytran2 {
    export real out_160n=V(out)@160n
}

run mytran1

run mytran2
```

In this example, there is no conflict between the two `out_160n` values because each is visible only within the measurement alias that defines the variable.

Data Types

Supported data types include: numbers, enumeration names, variables, predefined constants, strings, enum, nets, terminals, arrays, and analyses.

Numbers

MDL supports two data types for arithmetic operations: *integer numbers* and *real numbers*.

Integer Numbers

The syntax for an integer number is

```
integer_number ::=
              [ sign ] unsigned_num

sign ::=
              + | -

unsigned_num ::=
              decimal_digit { decimal_digit }

decimal_digit ::=
              0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9
```

Examples of integer numbers include

```
277195000
-634            // A negative number
0005
```

Real Numbers

The syntax for a real number is

```
real_number ::=
              [ sign ] unsigned_num .unsigned_num
          |   [ sign ] unsigned_num [.unsigned_num] e [ sign ] unsigned_num
          |   [ sign ] unsigned_num [.unsigned_num] E [ sign ] unsigned_num
          |   [ sign ] unsigned_num [.unsigned_num ] scale_letter

sign ::=
              + | -
```

```
unsigned_num ::=
              decimal_digit { decimal_digit }

decimal_digit ::=
              0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

scale_letter ::=
              T | G | M | K | k | _ | m | u | n | p | f | a
```

`scale_letter` A `scale_letter` listed in the following table. If you use `scale_letter`, you must not have any white space between the number and `scale_letter`. Be certain that you use the correct case for `scale_letter`.

scale_letter	Scale Factor
T	10^{12}
G	10^{9}
M	10^{6}
K	10^{3}
k	10^{3}
_	1
m	10^{-3}
u	10^{-6}
n	10^{-9}
p	10^{-12}
f	10^{-15}
a	10^{-18}

Examples of real numbers include

```
2.5K              // 2500
1e-6              // 0.000001
1.3u
5.46M
47p
100m
50
213116.223642
```

Complex Numbers

Complex numbers are numbers that fall on the complex plane. They consist of two real numbers, the first representing the real part and the second the imaginary part. In this release, you can use complex number declaration only to export a number of that type. For example, you can use a statement like the following one.

```
export cplx out_1u=V(out)@1u
```

Assigning a real number to a complex variable sets the real part to the real number and the imaginary part to zero. As a result, the previous statement produces output like the following.

```
out_1u              =  ( 2.99983, 0 )
```

Enumeration Names

Enumeration names consist of a single quote followed by an identifier.

The syntax for a name is

```
name ::=
               'identifier
```

Names can be used to access predefined constants and to select choices in the built-in functions.

Examples of constants include:

```
'pi
'avogadro
```

The following statement illustrates using the name `'fall` in the `cross` function.

```
export real crossOut = cross( arg=V(out), dir='fall, n=1, thresh=1 )
```

Predefined Constants

MDL provides the following predefined constants.

Integer Constants

`'yes`	Boolean true	1
`'no`	Boolean false	0

Real Mathematical Constants

'pi	π	3.14159265
'e	e	2.71828183
'inf	∞	infinity
'nan	Not a number (result of an invalid operation)	NaN
Real Physical Constants		
'q	Charge of an electron	$1.6021918 \cdot 10^{-19}$ C
'c	Speed of light	$2.99792458 \cdot 10^{8}$ m/s
'k	Boltzmann's constant	$1.3806226 \cdot 10^{-23}$ J/K
'h	Planck's constant	$6.6260755 \cdot 10^{-34}$ J-s
'eps0	Permittivity of a vacuum	$8.854187923944200139 68 \cdot 10^{-12}$ F/m
'epsrsi	Relative permittivity of silicon	11.7
'u0	Permeability of a vacuum	$\pi \times 4.0 \cdot 10^{-7}$ H/m
'celsius0	0 celsius	273.15 K
'micron		10^{-6} m
'angstrom		10^{-10} m
'avogadro	Avogadro's number	$6.022169 \cdot 10^{23}$
'logic0	The value of logic 0	0
'logic1	The value of logic 1	5

In the following example, the name 'pi corresponds to the predefined constant π and is automatically converted to the value π for the calculation.

```
export real cos2pi=cos(2*'pi) // Using pi as a parameter.
```

enum

An enum variable can be passed as an input parameter or used as temporary storage for predefined constants or enumerated variables inside an alias measurement as illustrated by the following statements:

```
input enum outdir = 'fall

enum doubleindirection = outdir

enum mypi = 'pi
```

The enum variable contains a reference to a particular enumeration or constant, but does not contain the value represented by that enumeration or constant. For instance:

```
enum mypi = 'pi     //here mypi stores "'pi"
real myrealpi = 'pi   //myrealpi is 3.1415…
real myvarpi = mypi   //myvarpi is 3.1415…
export real cos1 = cos (mypi)
```

You cannot use the enum variable as the argument to an output or an export statement.

Net

A net in the netlist for which the `V()` access function can be used. Hierarchical path of `net` such as `i0.c` is supported. `net` can be used only with the `input` qualifier. For example,

```
net in=data  //data is a node in netlist
input net out=I0.vout  //I0.vout is a node in the netlist
input net arrnets[]={data, q, I0.vout}
```

Terminal

An instance terminal in the netlist for which the `I()` access function can be used. Hierarchical path of `term` such as `i0.m0:d` is supported. `term` can be used only with the `input` qualifier. For example,

```
term t1=vdd:1  //vdd:1 is a terminal in the netlist
input term t2=I0.mp0:1  //I0.mp0:1 is a terminal in the netlist
input term arrterms[]={vdd:1, I0.I1.mp0:1}
```

Analysis

The analysis declaration statement provides a method to store an analysis defined in the netlist or created by as statement in a run statement. The `analysis` statement can be used only with the `input` qualifier.

```
analysis_declaration_statement ::=
     [ qualifier ] analysis identifier [= initvalues ]

qualifier ::=
     input
```

```
initvalues::=
     init_val | { value1, value2, ..., valueN }
```

identifier	Name to be used for the analysis or analysis array variable. For example, analysis1, analysis2[ ].
input	Keyword to declare input data.
analysis	Keyword to represent the analysis type data.
init_val	A single initial analysis name.
{ *value1,value2, …., valueN* }	List of analyses names to initialize an array.

The following MDL control file defines an array of analyses, where at1, tran1, ag1, and tran2 are pre-defined analyses in the netlist.

```
analysis ArrAnalysis[]={at1, tran1, ag1, tran2}
alias measurement myrun {
    input analysis mytran=tran_1     //tran_1 is initial value
    run mytran
    ...
    }
run ArrAnalysis[0]
run myrun (mytran= ArrAnalysis[1]) as meas1
run ArrAnalysis[2]
run myrun (mytran= ArrAnalysis[3]) as meas2
```

Array

An array declaration statement provides a method for defining, using, storing, and outputting a vector of data. You may access this data by a 0-based index, or by passing the entire data using the array name. In addition, you can also output this data to the .measure file.

You can use the array declaration statement to declare a data array and indicate whether the array is used for input, export, or output.

```
array_declaration ::=
     [ MDL_qualifier ] datatype MDL_id [ = initvalues ]

MDL_qualifier ::=
     input | export | output

datatype ::=
     real | int | cplx | string | net | term | analysis

initvalues ::={
     value1, value2,...valueN | init_val_array
```

MDL_id	Name to be used for the array. For example, `arr[ ]`.
input	Keyword to declare an array of input data.
export	Keyword to declare an array of export data.
output	Keyword to declare an array of output data.
real	Keyword indicating that the vector consists of real numbers.
int	Keyword indicating that the vector consists of integer numbers.
cplx	Keyword indicating that the vector consists of complex numbers.
string	Keyword indicating that the vector consists of strings.
net	Keyword indicating that the vector consists of nets.
term	Keyword indicating that the vector consists of instance terminals.
analysis	Keyword indicating that the vector consists of one or more analysis names.
value1, value2,...valueN	List of initial values of the array.
init_val_array	Array used to set initial values.

Example 1

For the following MDL control file,

```
//An example of the array variable syntax.
alias measurement mytran {
    input real varr[ ] = {1.0,2.0,3.0}
    run tran(stop=160n)
    export real outvarr[ ] = varr
}
run mytran as mytran1
int i=0
// Print result
print fmt(" Default values \n") to = "print.txt"
foreach i from swp(start=0, stop=2 , step=1) {
print fmt( "varr[%V]=%V\n" ,i, mytran1->outvarr[i] )  addto="print.txt"
}
//
run mytran(varr={4.0,5.0,6.0}) as mytran2
```

```
//Print result
print fmt(" Pass list \n") addto = "print.txt"
foreach i from swp(start=0, stop=2 , step=1) {
print fmt( "varr[%V]=%V\n" ,i, mytran2->outvarr[i] )  addto="print.txt"
}
real argarr = {7.0,8.0,9.0}
run mytran(varr=argarr) as mytran3
print fmt(" Pass array variable \n") addto = "print.txt"
foreach i from swp(start=0, stop=2 , step=1) {
print fmt( "varr[%V]=%V\n" ,i, mytran3->outvarr[i] )  addto="print.txt"
}
```

The output file, `print.txt`, looks as follows:

```
Default values
varr[0]=1
varr[1]=2
varr[2]=3
Pass list
varr[0]=4
varr[1]=5
varr[2]=6
Pass array variable
varr[0]=7
varr[1]=8
varr[2]=9
```

Example 2

In the following example, multiple cross times of a node voltage are saved to the `.measure` file.

```
alias measurement findqcross {
    run tran (stop=200n, step=40n)
        export real outcross[]= crosses (V(q), n=2, thresh=vdd/2) }
run findqcross.
```

The `.measure` file for the above MDL control file is as follows:

```
Measurmement Name: findqcross
Analysis Type   : tran
outcross[0]     = 4.07e-08
outcross[1]     = 9.017e-08
outcross[2]     = 1.207e-07
outcross[3]     = 1.702e-07
```

Example 3

The following statement:

```
export real xOut = crosses ( sig=V(out), thresh=1 )
```

has the following result:

```
xOut[0]=0.2, xOut[1]=0.3, xOut[2]=0.5
```

You can get the maximum index in the above array by the following statement:

```
real xOutSize = max ( xval (xOut) )
```

Example 4

The following MDL control file measures the delay on bus signals `OUT[0]` and `OUT[1]`.

```
alias measurement delay {
    input net inputnets[] = {a, b}
    run tran(stop=80n)
    export real d1 = cross(V(inputnets[0]), dir='fall, n=1, thresh=vdd/2)
    export real d2 = cross(V(inputnets[1]), dir='fall, n=1, thresh=vdd/2)
}
run delay(inputnets={OUT[0], OUT[1]}) as d1
//Print results
print fmt("d1=%V, d2=%V\n", d1->d1, d1->d2) to="arr.print"
```

The `.measure` file for the above control file is as follows:

```
Measurement Name:  d1
Analysis Type   :  tran
d1              =  5.0075e-08
d2              =  4.2075e-08
```

The output file, `arr.print`, looks as follows:

```
d1=5.0075e-08, d2=4.2075e-08
```

Declarations

```
variable_declaration_statement ::=
     [ qualifier ] datatype variable [= expression ]{, variable [= expression ]}

qualifier ::=
     input | export | output

datatype ::=
     real | int | cplx | string | net | term | array | enum

parameter_declaration_statement ::=
     input real parameter [= expression ]{, parameter [= expression ]}
```

`qualifier` Declares the input variables

- `input` Declares input variables that may be included as an argument to the alias measurement. The input variables must precede the `run` statement in an alias measurement. Although input variables can be initialized with the default value or expression (if present), the value in the parameter list in the `run` statement has higher priority to the default value.
- `output` Declares output variables which are visible outside the alias measurement. They will not be saved to the measurement dataset, nor will they be presented in the `.measure` file. The output variables are defined and evaluated with the default value or expression (if present). If no default value is present, then they have no value (that is, 'nan).
- `export` Declares export variables which are visible outside the alias measurement and are also written to the PSF measurement dataset and the `.measure` file. The `.measure` file name is constructed by adding the `.measure` extension to the base name of the MDL control file. The `.measure` file is placed in the same directory as the results directory. Only the numbers data type is available for export. The export variables are defined and evaluated with the default value or expression (if present). If no default value is present, then they have no value (that is, 'nan).

If you do not specify the `qualifier`, the associated parameters are considered by MDL as local variables whose value is only effective inside the alias measurement. If you calculate values that are used only in later calculations, you can omit the qualifier to minimize the number of expression values written to the `.measure` file.

`datatype` The types to declare the variables. Some types you can use are:

- `real` Indicates a real number.
- `int` Indicates an integer.
- `cplx` Indicates a complex number.
- `string` Indicates a string.

	`net`	Indicates a net in the netlist for which the `V()` access function can be used. `net` can be used only with the input keyword. Hierarchical path of `net` such as `i0.c` is supported.
	`term`	Indicates an instance terminal in the netlist for which the `I()` access function can be used. `term` can be used only with the input keyword. Hierarchical path of `term` such as `i0.m0:d` is supported.
	`array`	Indicates a vector of data. The data type can be integer, real, complex, string, net, term, and analysis. An array of integers, real, and complex numbers can be used with the `input`, `output`, or `export` qualifier, while an array of string, net, term, and analysis can only be used with the `input` qualifier. An array can be accessed by a 0-based index, can be passed by using the array name only, and can be initialized by a list of values with a comma in between or by an existing array.
	`enum`	Indicates an enumerated variable used as a reference to a particular enumeration or constant. It can only be used with the input `qualifier` or without a `qualifier`.
	`analysis`	Indicates an analysis variable.
`variable`		The variables used in the measurement aliases. You must separate multiple variables by commas. You must declare variables before you use them, but you can declare them anywhere and initialize them when they are declared. The variable name must begin with a letter. For more information, see Identifiers on page 57.

Variables with calculated values can be used in subsequent MDL expressions. For example, you might make a complicated expression easier to read by using other expressions to calculate preliminary values.

```
real iq2c=I(i1.q2:c)
real iq2b=I(i1.q2:b)
real iq3b=I(i1.q3:b)
real iq4b=I(i1.q4:b)
export real iref = iq2c + iq2b + iq3b + iq4b
```

Operators

The following sections describe the operators that you can use in MDL and explains how to use them to form expressions. For basic definitions, see

- "Unary Operators" on page 70
- "Binary Operators" on page 70

For information about precedence, see

- "Operator Precedence" on page 71

Overview of Operators

An *expression* is a construct that combines operands with operators to produce a result that is a function of the values of the operands and the semantic meaning of the operators. Any legal operand is also an expression. Expressions can be used only on the right-hand side of an assignment operator.

The operators associate from left to right. That means that when operators have the same precedence, the one farthest to the left is evaluated first. In this example

```
A + B - C
```

the simulator does the addition before it does the subtraction.

When operators have different precedence, the operator with the highest precedence is evaluated first. In this example

```
A + B / C
```

the division (which has a higher precedence than addition) is evaluated before the addition. For information on precedence, see "Operator Precedence" on page 71.

You can change the order of evaluation with parentheses. If you code

```
(A + B) / C
```

the addition is evaluated before the division.

The operators divide into groups, according to the number of operands the operator requires. The groups are the unary operators and the binary operators.

Unary Operators

The unary operators each require a single operand.

Operator	Definition	Type of Argument	Example
+	Unary plus	integer, real, complex	`val = +13 // val=13`
-	Unary minus	integer, real, complex	`val = -(4-5) // val=1`
!	Unary not	integer	`Val =!(V(out)>0)`

Binary Operators

The binary operators each require two operands.

Operator	Definition	Type of Argument	Example
!=	*a* not equal to *b*; evaluates to 0 or1	real, integer	`I = 5.2 != 5.2 // I=0`
*	*a* multiplied by *b*	real, complex, integer	`R = 2.2 * 2 // R=4.4`
+	*a* plus *b*	real, complex, integer	`R = 10.0 + 3.1 // R=13.1`
–	*a* minus *b*	real, complex, integer	`I = 10 - 13 // I= -3`
/	*a* divided by *b*	real, complex, integer	`I = 9/4 // I=2`
<	*a* less than *b*; evaluates to 0 or1	real, integer	`I = 5 < 7 // I=1`
<=	*a* less than or equal to *b*; evaluates to 0 or1	real, integer	`I = 5.0 <= 5.0 // I=1`
==	*a* equal to *b*; evaluates to 0 or1	real, integer	`I = 5.2 == 5.2 // I=1`
>	*a* greater than *b*; evaluates to 0 or1	real, integer	`I = 5 > 7 // I=0`
>=	*a* greater than or equal to *b*; evaluates to 0 or1	real, integer	`I = 5 >= 7 // I=0`

Operator	Definition	Type of Argument	Example

@	Event operator. Interpolates a signal at a particular X-axis value (abscissa).	real, complex	`V(out) @ 1u`
			
			`I(R1) @ cross( sig=V(out), n=1, dir='rise, thresh=1.5 )`

&&	Logical AND; evaluates to 0 or1	integer	`I=(1==1)&&(2==2) // I=1` `I=13&&1 // I=1`
||	Logical OR; evaluates to 0 or1	integer	`I=(1==2)||(2==2) // I=1` `I=13||0 // I=1`

Operator Precedence

The following table summarizes the precedence information for the operators.

Operator	Precedence
+ - (unary)	Highest precedence
@	
* /	
+ - (binary)	
< <= > >=	
== !=	
&&	
||	Lowest precedence

3

Running MDL in Batch Mode

This chapter describes the syntax and options for the `spectre =mdl` commandthat you can use to run the Measurement Description Language (MDL) tool. `You`can use this command for design files written in both Spectre and SPICE languages.

spectre =mdl

Runs MDL on design files written in the Spectre language.

In the following syntax, the vertical bar (|) separates alternatives.

Syntax

```
spectre [spectre_options] =mdl MDL_file
        -netlist netlist_file
       | -h function_name
options :: =
       spectre_options
       | -measure output_file
       | -mt0
       | -nosort
       | -tab
       | -prec 'format'
       | -rmrawfiles
       | -eng numdigits
```

Arguments

options	Spectre command-line options.
=mdl	Enables MDL
MDL_file	The path and filename of the MDL control file to be used. You must specify the control file.
-netlist	Command-line option that specifies the netlist file.
netlist_file	The path and filename of the design file to be simulated. If this option is omitted, MDL looks for a design file with the same basename as the *MDL_file* name, but with an extension of `.scs` or `.ckt`.
-measure	A command-line option used to specify the output file. If you do not use this option, the output of the measurements is placed in a file with the same base name as the *MDL_file* and with the extension `.measure`. For example, if the *MDL_file* is `amp.mdl`, the output file, by default, has the name `amp.measure`. This default file is placed in the directory that holds the *design_file*. So if the design file is `./d2/arith.ckt`, the default measure file is `./d2/amp.measure`.

output_file	The path and file to be used for output data generated by measurements.
-mt0	A command line option used to generate .mt* format data files as well as the default .measure file. When specified, .mt0 is generated by default.
-nosort	Optional argument to specify that variables in the measure file should not be sorted.
-tab	A command line option used to present data in a tabular format in the .measure file. This is useful for swept data.
-nosort	A command line option to specify that variables in the measure file should not be sorted. When this option is specified, the exported variables in the mdl file appear in the .measure file in the order in which they are specified in the netlist. Note that by default, they appear in alphabetically sorted order in .measure file.
-eng *numdigits*	A command line option to specify the engineering format of the signal value output to the measurement file. *numdigits* is the number of significant digits of the signal value. If not specified, 6 significant digits are displayed. If both -prec and -eng arguments are specified, -prec is ignored.
+aps	Run the simulation using APS, as opposed to Spectre by default.

Examples

The following command creates a .measure file called amp.measure in the directory where you run the command,

```
spectre =mdl  amp.mdl -netlist amp.scs
```

You can simplify the above command because the MDL control file and the design file have the same basename. The equivalent simpler command is

```
spectre =mdl amp.mdl
```

You need the options when the MDL control file and the design file have different base names or when the design file has a suffix other than .scs or .ckt.

For example,

```
spectre =mdl  control.mdl -netlist topnetlist.scs
spectre =mdl  control.mdl -netlist netlist.sp
```

The following command creates a measurement result file called `mdlresults` in your home directory.

```
spectre =mdl amp.mdl -measure $HOME/mdlresults
```

The following command presents data in a tabular format.

```
spectremdl   foreach.mdl -design dflip.scs -tab
```

results in the following `.measure` file (called `foreach.measure`)

```
Exported variables from PSF results directory:  dflip.raw

date               :  9:54:01 AM, Tue May 10, 2005
design             :  * DFF
simulator          :  spectre

Swept Measurements :
Measurement Name   :  findqcross
Analysis Type      :  tran
temp            vdd             clk_q_delay
25              1.5             1.91866e-10
25              1.8             1.61376e-10
25              2               1.5053e-10
50              1.5             1.96657e-10
50              1.8             1.66472e-10
50              2               1.55428e-10
75              1.5             2.01521e-10
75              1.8             1.71556e-1
75              2               1.60476e-10
100             1.5             2.0633e-10
100             1.8             1.76775e-10
100             2               1.65437e-10
```

Without the `-tab` option, the same command results in the following .measure file

```
Exported variables from PSF results directory:  dflip.raw

date               :  10:20:35 AM, Tue May 10, 2005
design             :  * DFF
simulator          :  spectre

Swept Measurements :
Measurement Name   :  findqcross
Analysis Type      :  tran
clk_q_delay             temp @ 25
                   vdd @ 1.5          =  1.91866e-10
clk_q_delay             temp @ 25
                   vdd @ 1.8          =  1.61376e-10
clk_q_delay             temp @ 25
                   vdd @ 2            =  1.5053e-10
clk_q_delay             temp @ 50
                   vdd @ 1.5          =  1.96657e-10
clk_q_delay             temp @ 50
                   vdd @ 1.8          =  1.66472e-10
clk_q_delay             temp @ 50
                   vdd @ 2            =  1.55428e-10
clk_q_delay             temp @ 75
                   vdd @ 1.5          =  2.01521e-10
clk_q_delay             temp @ 75
```

```
                    vdd @ 1.8          =  1.71556e-10
clk_q_delay              temp @ 75
                    vdd @ 2            =  1.60476e-10
clk_q_delay              temp @ 100
                    vdd @ 1.5          =  2.0633e-10
clk_q_delay              temp @ 100
                    vdd @ 1.8          =  1.76775e-10
clk_q_delay              temp @ 100
                    vdd @ 2         =  1.65437e-10
```

4

Running MDL in Post-processing Mode

MDL supports the post-processing mode that enables the user to evaluate measurements after the simulation has completed. This is especially helpful if you would like to use the same language (MDL or `.measure` statements) that was used for measurements evaluated during the simulation.

In case the measurements were not set up correctly, or more measurements need to be evaluated, the simulation needs to be run repeatedly to get the desired results. With post-processing capability, you can edit the measurements (in a MDL file, or .measure in the netlist) and then invoke the simulator in a mode, where instead of performing the actual simulation, it reads the simulation results from a specified results directory or file, depending upon the waveform format being used.

The MDL post-processing mode allows you to execute a MDL script on an existing results database. Optionally a netlist can be provided. This allows the MDL script to reference objects in the netlist. For example the parameters in the netlist could be used in the MDL measurements.

mdl

Runs MDL in post-processing mode.

In the following syntax, the vertical bar (|) separates alternatives.

Syntax

```
mdl -batch|-b <file.mdl> [-design|-d netlist] -raw|-r <rawdir> [options]
       mdl -d <netlist containing .measure statement> -raw|-r <rawdir> [options]
```

Arguments

`-batch|-b <file.mdl>`	The filename of the MDL file to be executed.
`-raw|-r <rawdir>`	Location of the results directory.
`-design|-d <netlist>`	The filename of the netlist to be loaded by MDL. This can also be a netlist containing `.measure` statemtents.
`-measure|-m <file.measure>`	The default output filename is taken from the basename of the design argument, and appended with the `.measure` extension. This option creates an output file with the specified name. If an absolute path is not specified, the output file is created in the directory of the design argument.
`+log|+l <logfile>`	Copies all messages to logfile.
`=log|=l <logfile>`	Sends all messages to logfile.
`-prec|-p '<format>'`	Optional argument to specify the precision of of the measured value output in the measurement file. **Example:** `%.15g` will output the measured values to 15 significant digits. The argument is ignored if `-engineering` argument is used.
`-eng|-e <numdigits>`	Optional argument to specify the engineering format of the signal value output to the measurement file. `<numdig>` is a number of significant digits of the signal value. `<numdig>` is optional. If `<numdig>` is omitted than value of the `<numdig>` is 6. `-prec` argument is ignored.
`-tab|-t`	Optional argument to specify that the measure file should be displayed in tabular format.

`-append|-a`	Optional argument to specify that the measure file should be opened in append mode.
`-nosort|-n`	Optional argument to specify that variables in the measure file should not be sorted.
`-outdir|-o`	Optional argument to specify an alternate output directory location for all output files. This does not change the location of the raw directory if explicitly specified with the `-raw` option.
`-warn|-w`	Optional argument to issue warning for ignoring unsupported constructs. Default is to issue an error.
`-faults`	Applies the MDL file to a fault dataset. You can use `-ft` as an abbreviation of `-faults`.

Most of the options are consistent with previous versions of `spectremdl` executable. However, the `-warn` option allows unsupported constructs (`search`, `mvarsearch`) to be ignored and evaluation to proceed.

Examples

Assume that an MDL script, `test.mdl` was used to generate a raw directory, `input.raw` using Spectre.

```
$ spectremdl -batch test.mdl -design input.scs -raw input.raw
```

To rerun the script on the results, the following command will be used:

```
$ mdl -b test.mdl -r input.raw
```

In this case, the measurement results are written out to the `test.measure` file. The `-m` command-line option can override the name of the output file.

```
$ mdl -b test.mdl -r input.raw -m input.measure
```

If the netlist `input.scs` was used to generate the results, it is possible that the MDL file references parameters from the netlist. Without the netlist, the MDL measurements cannot be evaluated, hence the netlist must be provided on the command-line so that those parameters and their values can be found.

```
$ mdl -b test.mdl -d input.scs -r input.raw
```

Another usage is for users who do not have MDL script, but instead use `.MEASURE` statements in the netlist (or in a file included in the netlist). Here `test.sp` may either contain the complete design or may have just `.measure` statements.

```
$ mdl -d test.sp -r test.raw
```

```
.include "param.sp"  // optional parameter definiton
.include "design.sp" //optional design
.include "test.msr"  // contains measurements

$ mdl -d test.msr -r test.raw
```

Here `test.msr` may contains some parameter definition of the parameters referenced in the `.measure` statement. There is no need for complete design.

```
.param VDD=1.8
.meas tran  tfr trig v(a) val='0.5*VDD'  fall=1 targ v(y) val='0.5*VDD' rise=1
.measure tran tranmaxout1 max v(out)
.measure tran tranavg avg v(out)
```

Some waveform formats do not use the result directory concept. Cadence formats (such as PSF or SST), when generated from Spectre and Spectre APS, place a logFile in the results directory that is used to associate datasets with the physical files containing the simulation data. For formats that do not support this, it is necessary to explicitly specify the file contains the data rather than the results directory itself.

An example using the FSDB format is:

```
$ mdl -d tran.msr -r input.raw/tran.fsdb
```

In this example, `tran.msr` contains the measurements for the specified transient analysis results file, `input.raw/tran.fsdb`. The content of `tran.msr` could be

```
.measure tran tranmaxout1 max v(out)
.measure tran tranavg avg v(out)
```

In another example, the some measurements are evaluated using a DC analysis results file.

```
$ mdl -d dc.msr -r input.raw/dc.fsdb
```

Here, `dc.msr` contains the measurements to be evaluated, as in

```
.measure dc dcnmaxout1 max v(out)
.measure dc dcavg avg v(out)
```

Limitations

There are limitations when using this mdl tool to execute an MDL script.

The primary limitation that exists with the post-processing flow is a result of the nature of this flow. It can only work with the data that is in the netlist, MDL file and results database. Hence, if a signal that is used in an MDL expression is not saved in the database, then the expression will fail to evaluate.

For example, when the netlist is used, device input parameters can be used in expressions; however oppoint parameters cannot be used, unless they were already saved.

Other restrictions are:

- Other consequences of being only able to use information that is readily available in the MDL script, netlist (if supplied) and results database are the following;
  - The `mvarsearch` and `search` statements are not currently supported. When these are seen, mdl prints an error message and ignores these statements.
  - For montecarlo, the parameter `savefamilyplots=yes` must be set during the simulation run. Else, the waveform data for each iteration of the montecarlo run will not be saved.
    - Re-elaboration is not supported. Hence, if the measurement references the process or mismatch parameters, mdl will only see the nominal parameter values.
  - Foreach and montecarlo are only supported for PSF format.
  - Result dataset generated from `alter`/`sweep` specified in the netlist have different naming convention. Hence, if a netlist contains `alter`/`sweep` then dataset will not be located. It is recommended to use MDL scripts for `alter`/`sweep` so that corresponding dataset can be found.
- The MDL post-processing flow works on waveforms rather than on each individual point of a signal as occurs in the SpectreMDL flow. There are following consequences to this:
  - An `if` statement in a measurement alias can behave differently if the condition depends upon a signal value. In SpectreMDL, this could result in the true or false block being executed multiple times for each datapoint on the signal. In the post-processing flow, the condition is evaluated only once for the complete waveform.

If there is a sweep contained in the netlist, the dataset generated by Spectre is different from the dataset generated by MDL. Hence, MDL will not be able to locate the correct dataset. This is why currently, the `.measure` flow is supported for a netlist that does not contain sweep in the netlist.

A

Built-In Functions

The built-in functions support two syntaxes:

- Positional syntax

  Requires each optional parameter up to and including the last optional parameter entered, but beyond that everything can be omitted.

  cross(*sig*[, *dir*[, *n*[, *thresh*[, *start*[, *xtol*[, *ytol*[, *accuracy*]]]]]]] **)**

- Named syntax

  Allows any optional parameter to be specified — the preceding optional parameters need not be specified.

  cross(sig=*sig* [, **dir=***dir*] [, **n=***n*] [, **thresh=***thresh*]
  [, **start=***start*] [, **xtol=***xtol*] [, **ytol=***ytol*]
  [, **accuracy=***accuracy*] **)**

For example, the following statements are equivalent.

```
export real crossOut = cross(V(out), 'fall, 1, 1 )
export real crossOut = cross( sig=V(out), dir='fall, n=1, thresh=1 )
```

abs

Returns the absolute value of a signal.

Syntax

abs(*arg***)**

abs(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real myabs = abs( -5 )
```

returns

```
myabs = 5
```

```
export real outabs = abs(arg=V(out))@1m
```

returns the value of the signal `V(out)` at 1ms.

acos

Returns the arc cosine of a signal.

Syntax

acos(*arg* **)**

acos(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real myacos = acos( 1)
```

returns

```
myacos = 0
```

acosh

Returns the hyperbolic arc cosine of a signal.

Syntax

acosh(*arg* **)**

acosh(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real myacosh = acosh( 1)
```

returns

```
myacosh = 0
```

analstop

Returns the simulation stop value.

Syntax

analstop( )

Arguments

None

Example

Used in MDL File

```
alias measurement transient {
    run tran( step=1e-12, pstep=1e-12, stop=2e-08 )
    export real anal_stop= analstop()
}
run  transient
```

returns

```
anal_stop = 2e-08
```

angle

Returns the angle of a real or complex number, or a waveform in degrees.

Syntax

angle(*arg***)**

angle(arg=*arg* **)**

Arguments

arg	The real or complex number, or a waveform.

Example 1

```
export real myangle = angle( cplx(1,2) )
```

returns

```
myangle = 63.43
```

Example 2

```
export real phasemargin = angle( s(2,1) ) @ ft
```

returns

```
phasemargin= 15.0369
```

argmax

Returns the X value corresponding to the maximum Y value of a signal. If multiple X values are returned, the first one is used.

Syntax

argmax(*sig* **)**

argmax(sig=*sig* **)**

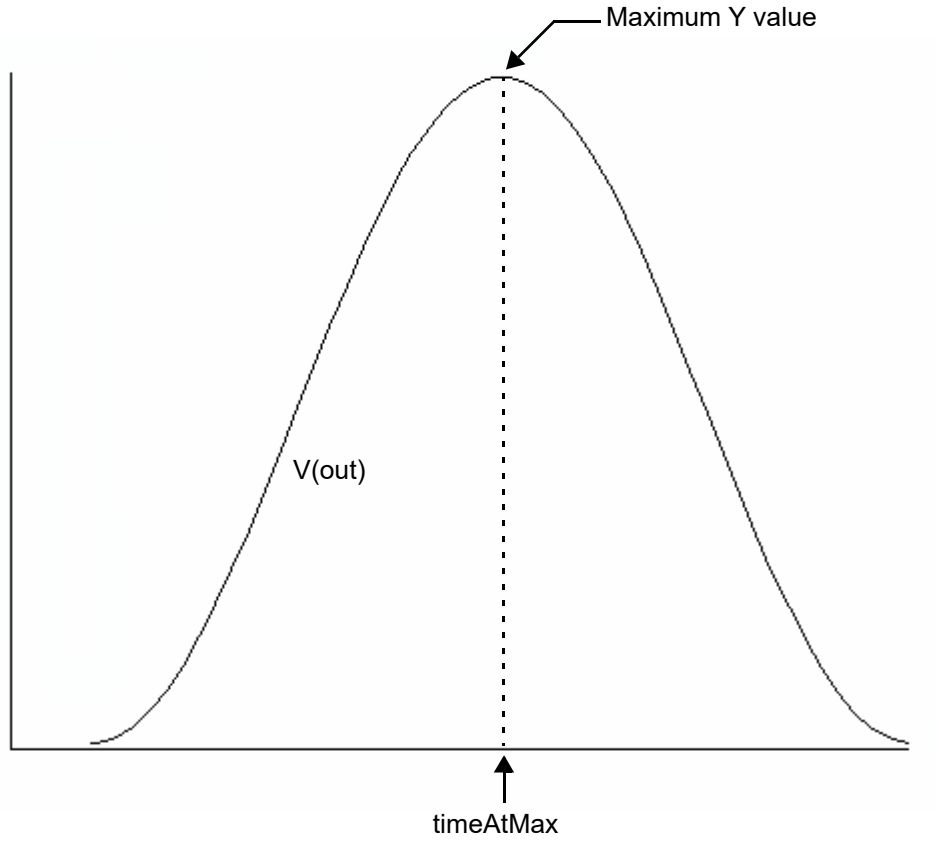
Arguments

sig	The signal.

Example

```
export real timeAtMax = argmax( V(out) )
```

The following diagram illustrates how the result is determined.



argmin

Returns the X value corresponding to the minimum Y value of a signal. If multiple X values are returned, the first one is used.

Syntax

argmin(*arg* **)**

argmin(arg=*arg* **)**

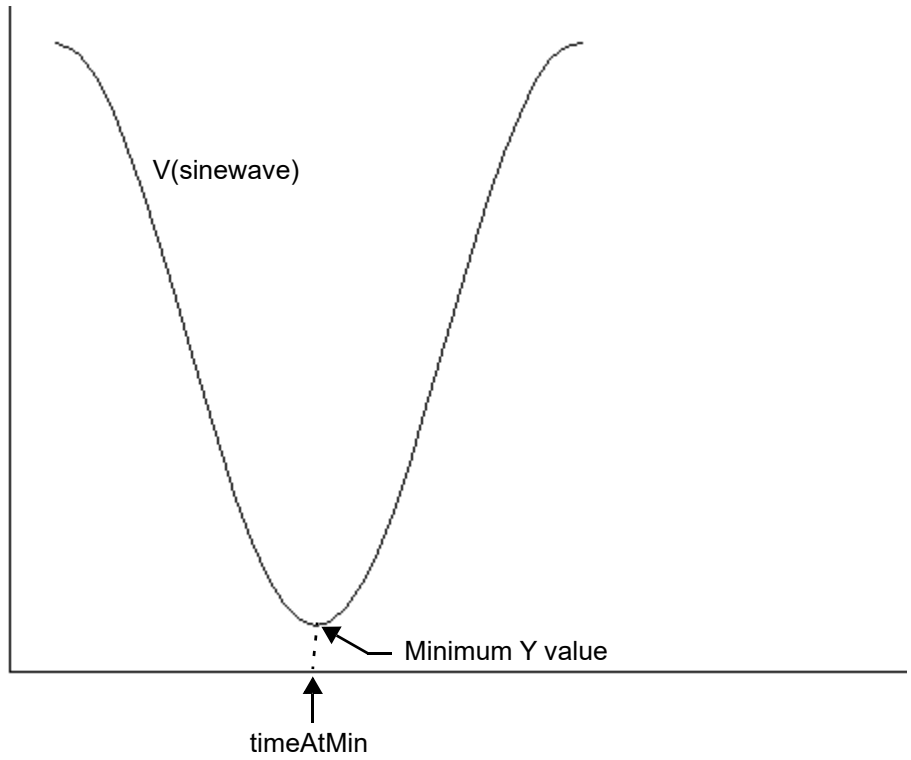
Arguments

arg	The signal.

Example

```
export real timeAtMin = argmin( V(sinewave) )
```

The following diagram illustrates how the result is determined.



asin

Returns the arc sine of a signal.

Syntax

asin(*arg* **)**

asin(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real myasin = asin( 1 )
```

returns

```
myasin = 1.57
```

asinh

Returns the hyperbolic arc sine of a signal.

Syntax

asinh(*arg* **)**

aSinh(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real myasinh = asinh( 1 )
```

returns

```
myasinh = 0.88
```

atan

Returns the arc tangent of a signal.

Syntax

atan(*arg* **)**

atan(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real myatan = atan( 1 )
```

returns

```
myatan = 1.56
```

atanh

Returns the hyperbolic arc tangent of a signal.

Syntax

atanh(*arg* **)**

atanh(arg=*arg* **)**

Arguments

arg	The scalar or signal.

avg

Returns the average value of a signal.

Syntax

avg(*arg* **)**

avg(arg=*arg* **)**

Arguments

arg	The signal.

Example

```
export real myavg = avg( V(out) )
```

avgdev

Returns the mean absolute deviation of a scalar argument or waveform. The mean absolute deviation is defined as follows:

```
1/N * ( |X1-mean| + |X2-mean| +..... |XN-mean| )
```

where | is the absolute value of the difference and *N* is the total number of Samples.

Syntax

avgdev(*arg* **)**

avgdev(arg=*arg* **)**

Arguments

arg	The scalar argument or waveform.

bw (bandwidth)

Calculates the bandwidth of a waveform.

Syntax

bw(*sig*, *response*, *db*, *max* **)**

bw(sig=*sig*, **response=***response*, **db=***db*, **max=***max* **)**

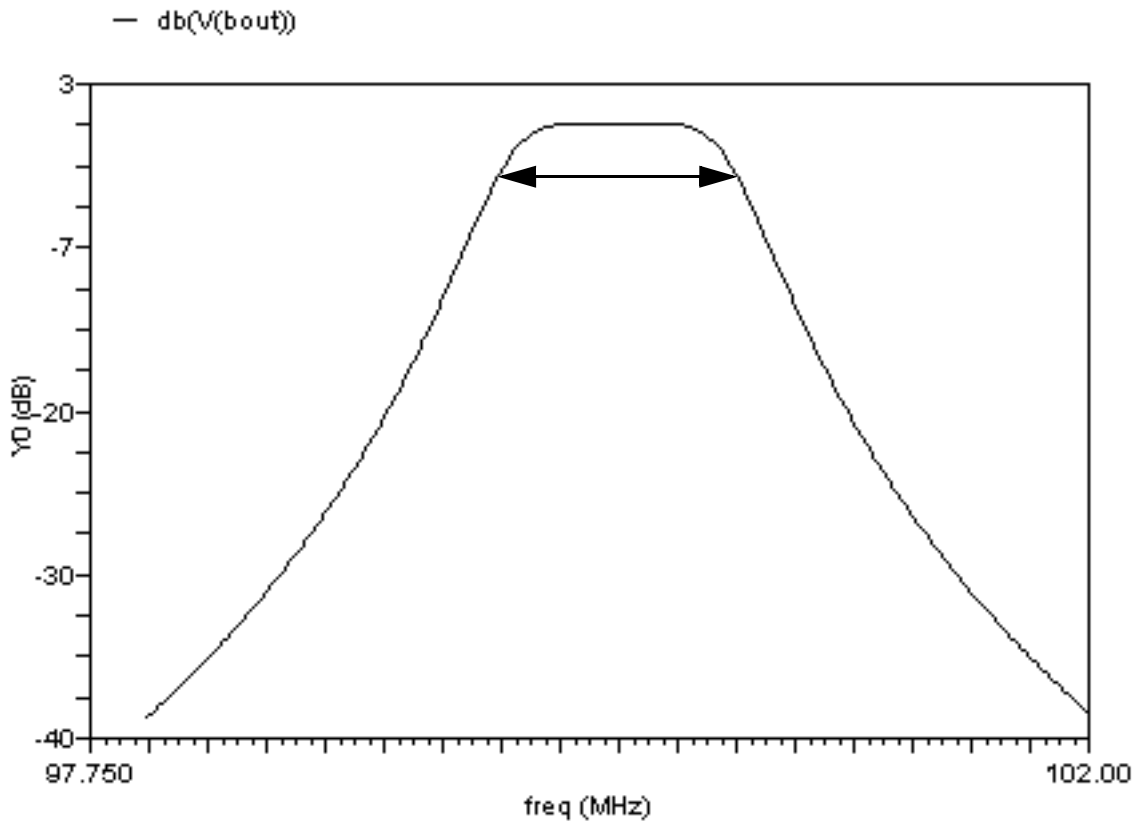
Arguments

sig	The signal. In the SKILL mode, Virtuoso Visualization and Analysis XL wraps the signal with the `mag` function. In the MDL mode, you need to wrap the signal name with the `mag` function, otherwise Virtuoso Visualization and Analysis XL returns an error.
response	The response type: When `'low`, computes the low-pass bandwidth by determining the smallest frequency at which the magnitude of the input waveform drops *db* decibels below the DC gain. When `'high`, computes the high-pass bandwidth by determining the largest frequency at which the magnitude of the input waveform drops *db* decibels below the gain at the highest frequency in the response waveform. When `'band`, computes the band-pass bandwidth by: 1. Determining the lowest frequency (f_{max}) at which the magnitude of the input waveform is maximized; 2. Determining the highest frequency less than f_{max} at which the input waveform magnitude drops *db* decibels below the maximum; 3. Determining the lowest frequency greater than f_{max} at which the input waveform magnitude drops *db* decibels below the maximum; 4. Subtracting the value returned by step 2 from the value returned by step 3. The value returned by step 2 or step 3 must exist. Valid values: `'low`, `'high`, `'band` Default: `'low`

db	The decibels down from the peak. In the SKILL mode, *db* is a number equal to or greater than zero. In the MDL mode, *db* is a number less than zero. Default: -3.01029995664
max	The maximum amplitude of the waveform. You only need to specify this if you want to set the maximum amplitude lower than the waveform's maximum value. If the *max* is specified, Measurement Description Language (MDL) uses this value instead of computing a value.

Example

Assume you have the following signal.



Then the following statement

```
export real bwOut = bw(mag(V(bout)), response='band)
```

generates, at the default *db* value of -3, the bw value

```
1000004.1627941281Hz
```

Note that the output in MDL includes the unit (Hz in the above example), whereas in SKILL it does not.

This value (approximately 1MHz) is illustrated on the graph by the double-ended arrow.

ceil

Rounds a real number up to the closest integer value.

Syntax

ceil(*arg* **)**

ceil(arg=*arg* **)**

Arguments

arg	The real number.

Example

```
export real myceil = ceil( 1.6 )
```

returns

```
myceil = 2
```

cfft

Performs a Fast Fourier Transform on a complex time domain waveform and returns its frequency spectrum. The `cfft` function takes two time signals that in combination form a complex input signal.

Syntax

cfft(*sig_re*, *sig_im*, *from*, *to*, *numPoints*[, *window*]**)**

cfft(sig_re=*sig_re*, **sig_im=***sig_im*, **from=***from*, **to=***to*, **numPoints=***numPoints*
[, **window=***window*]**)**

Arguments

sig_re	The real part of the signal.
sig_im	The imaginary part of the signal.
from	The starting X value.
to	The ending Y value.
numPoints	The number of data points to be used for calculating the cfft. If this number is not a power of 2, it is automatically raised to the next higher power of 2.
window	The algorithm used for calculating the cfft. In this release only one algorithm is supported. Valid value: `'rectangular` Default: `'rectangular`

clip

Returns the portion of a signal between two points along the Y-axis.

Syntax

clip(*sig*, *from*, *to* **)**

clip(sig=*sig*, **from=***from*, **to=***to* **)**

Arguments

sig	The signal.
from	The starting point on the Y-axis.
to	The ending point on the Y-axis.

Example 1

The following example works in an MDL control file.

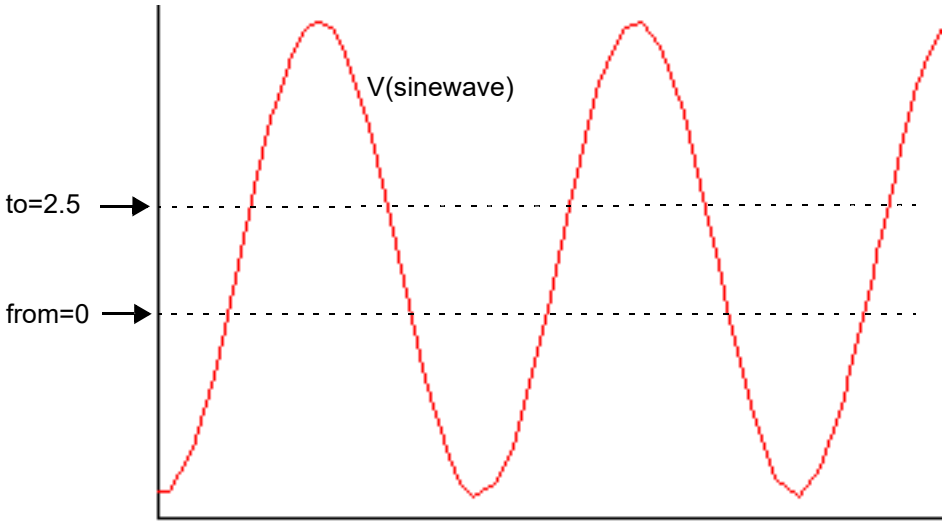
```
export real clipOut = avg ( clip (sig=V(sinewave), from=0, to=2.5) )
```

Example 2

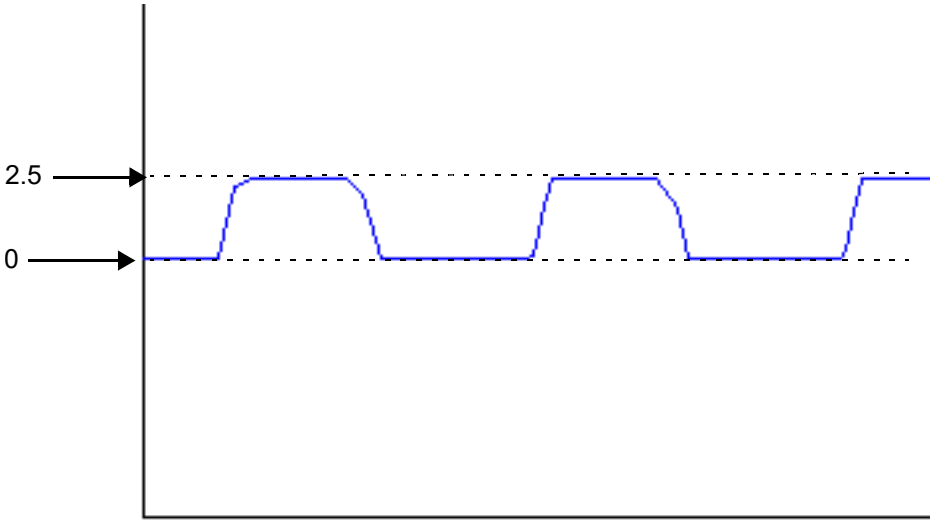
In Virtuoso Visualization and Analysis XL,

```
clip (sig=V(sinewave), from=0, to=2.5)
```

transforms the following input signal



into the following output signal.



conj

Returns the conjugate of a complex number.

Syntax

conj(*arg* **)**

conj(arg=*arg* **)**

Arguments

arg	The complex number.

Example

```
export cplx mycplx = cplx ( 1,2 )
export cplx conj_mycplx = conj ( mycplx )
```

returns

```
mycplx = (1,2)
conj_mycplx = (1,-2)
```

convolve

Returns a waveform consisting of the time domain convolution of two signals. This function is available in Virtuoso Visualization and Analysis XL only.

Syntax

convolve(*sig1*, *sig2*[, *n_interp_steps*]**)**

clip(sig1=*sig1*, **sig2=***sig2*[, **n_interp_steps=***n_interp_steps*]**)**

Arguments

sig1	The first signal.
sig2	The second signal.
n_interp_steps	Number of steps for interpolating waveforms.

Equation

Convolution is defined by the following equation:

$$\int_{from}^{to} f1(s)\,f2(t-s)\,ds$$

Example

```
real vcdelay[]=crosses(sig=V(clock), thresh=0.9, dir='rise, n=1)
real outcross[]=crosses(V(q),n=6,thresh=vdd/2)
export real myconv[] = convolve(vcdelay,outcross,5)
```

returns

```
myconv[00]          =  2.57108e-13
myconv[01]          =  2.02971e-13
myconv[02]          =  1.74678e-13
myconv[03]          =  1.81539e-13
myconv[04]          =  2.03094e-13
myconv[05]          =  2.3083e-13
myconv[06]          =  2.65196e-13
myconv[07]          =  3.06643e-13
myconv[08]          =  3.55544e-13
myconv[09]          =  3.84546e-13
```

```
myconv[10]          =  3.94928e-13
myconv[11]          =  3.96003e-13
myconv[12]          =  3.88035e-13
myconv[13]          =  3.70677e-13
myconv[14]          =  3.43269e-13
myconv[15]          =  3.05072e-13
```

cos

Returns the cosine of a signal.

Syntax

cos(*arg* **)**

cos(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real mycos = cos( 1 )
```

returns

```
mycos = 0.54
```

cosh

Returns the hyperbolic cosine of a signal.

Syntax

cosh(*arg* **)**

cosh(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real mycosh = cosh( 1 )
```

returns

```
mycosh = 1.54
```

cplx

Returns a complex number created from two real arguments.

Syntax

cplx(*R*[, *I*] **)**

cplx(R=*R* [, **I=***I*] **)**

Arguments

R	The value representing the real part.
I	The value representing the imaginary part.

Example

```
export cplx mycplx = cplx( 1,2 )
```

returns

```
mycplx = (1,2)
```

cross

Returns the X value where a signal crosses the threshold Y value.

Syntax

```
cross( sig[, dir[, n[, thresh[, start[, xtol[, ytol[, accuracy]]]]]]] )

cross( sig=sig[, dir=dir] [, n=n] [, thresh=thresh] [, start=start] [,
     xtol=xtol] [, ytol=ytol] [, accuracy=accuracy] )
```

Arguments

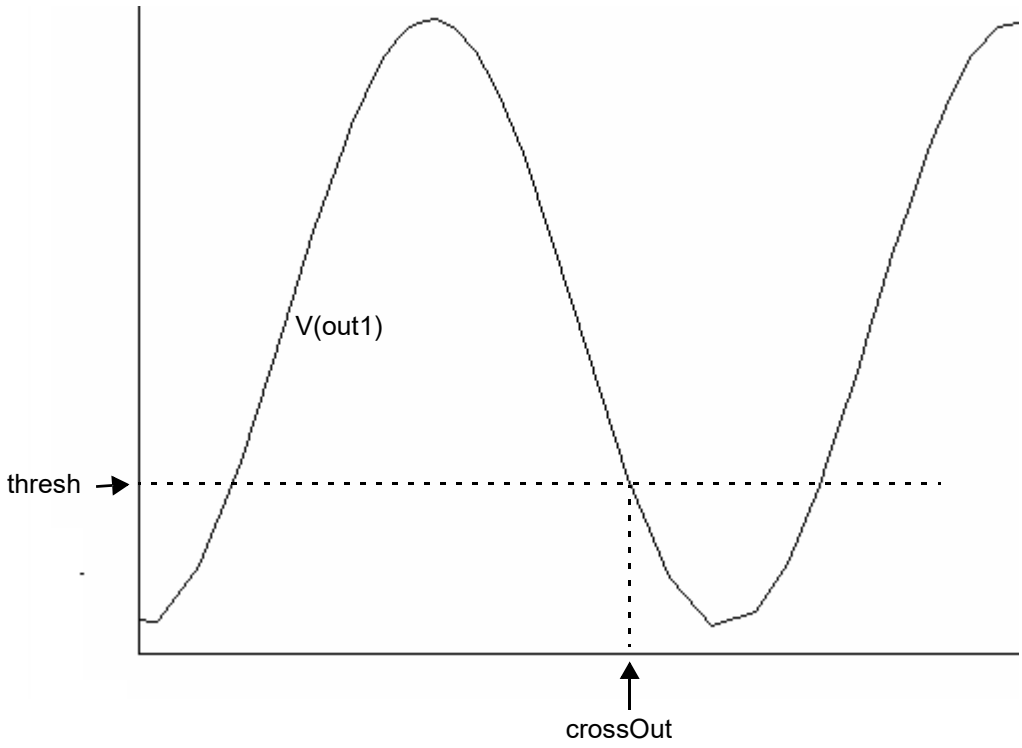
sig	The signal.
dir	The direction of the crossing event. `'rise` directs the function to look for crossings where the Y value is increasing, `'fall` for crossings where the Y value is decreasing, and `'cross` for crossings in either direction. Valid values: `'cross`, `'rise`, `'fall` Default: `'cross`
n	The occurrence of the crossing. The first crossing is n=1, the second crossing is n=2, and so on. The value of `n` can be negative numbers: n=-1 for the last occurrence before the end of the waveform, n=-2 for the second-last occurrence before the end of the waveform, and so on. Default: `1`
thresh	The threshold to be crossed. Default: `0`
start	The time at which the function is enabled. Default: `0`
xtol	The relative tolerance in percentage value in the X direction. Default: `1`
ytol	The relative tolerance in percentage value in the Y direction. Default: `1`

accuracy	Specifies whether the function should use interpolation, or use iteration controlled by the absolute tolerances to calculate the value. `'interp` directs the function to use interpolation, and `'exact` directs the function to consider the xtol and yval values. Data types: name for scalar Valid values: `'interp`, `'exact` Default: `'exact`

Example

```
export real crossOut = cross( sig=V(out), dir='fall, n=1, thresh=1 )
```

The following diagram illustrates how the result is determined.



crosscorr

Returns the cross correlation of the specified signals. This function is available only in Virtuoso Visualization and Analysis XL.

When the input signals are double waveforms,

crosscorr (*sig1*, *sig2*) = convolve (*sig1*, flip(*sig2*))

When one of the input signals is a complex waveform (*sig2* in the following case),

crosscorr (*sig1*, *sig2*) = convolve (*sig1*, flip(conj(*sig2*)))

Syntax

crosscorr(*sig1*, *sig2*[, *n_interp_steps*]**)**

crosscorr(sig1=*sig1*, **sig2=***sig2*[, **n_interp_steps=***n_interp_steps*]**)**

Arguments

sig1	The first signal.
sig2	The second signal.
n_interp_steps	Number of steps for interpolating waveforms.

crosses

Returns the X values where a signal crosses the threshold Y value.

Syntax

```
crosses( sig[, dir[, n[, thresh[, start[, xtol[, ytol[, accuracy]]]]]]] )

crosses( sig=sig [, dir=dir] [, n=n] [, thresh=thresh] [, start=start] [,
     xtol=xtol] [, ytol=ytol] [, accuracy=accuracy] )
```

Arguments

sig	The signal.
dir	The direction of the crossing event. `'rise` directs the function to look for crossings where the Y value is increasing, `'fall` for crossings where the Y value is decreasing, and `'cross` for crossings in either direction. Valid values: `'cross`, `'rise`, `'fall` Default: `'cross`
n	The occurrence of the crossing. If n=1, the function returns the first crossing and all subsequent crossings. If n=3, the function returns the third crossing and all subsequent crossings. The value of n can be negative numbers: if n=-2, only the last two crossings are returned. Default: `1`
thresh	The threshold to be crossed. Default: `0`
start	The time at which the function is enabled. Default: `0`
xtol	The relative tolerance in percentage value in the X direction. Default: `1`
ytol	The relative tolerance in percentage value in the Y direction. Default: `1`

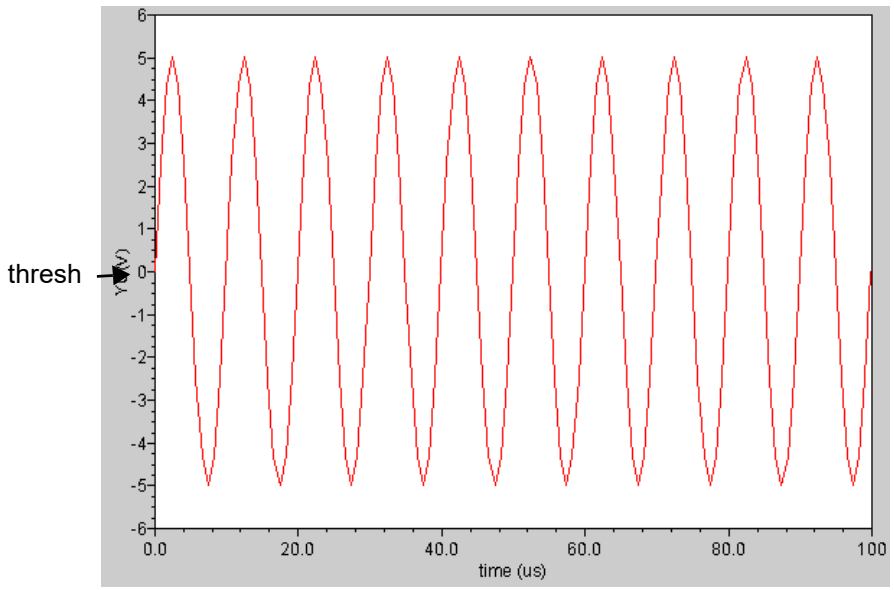
accuracy	Specifies whether the function should use interpolation, or use iteration controlled by the absolute tolerances to calculate the value. `'interp` directs the function to use interpolation, and `'exact` directs the function to consider the xtol and yval values. Data types: name for scalar Valid values: `'interp`, `'exact` Default: `'exact`

Example

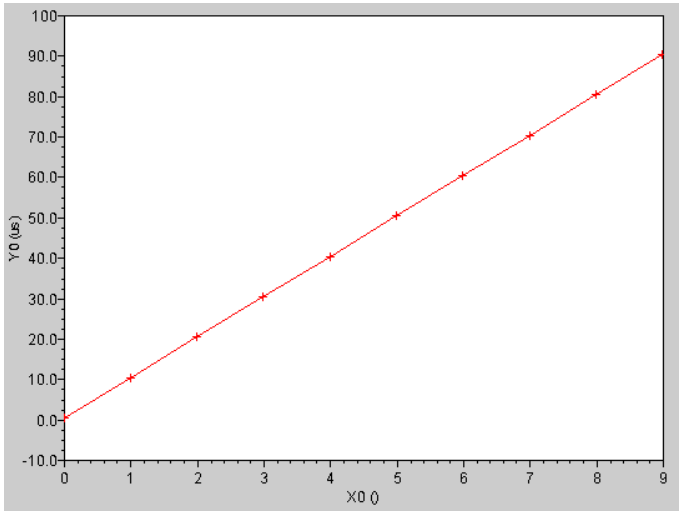
```
export real crossesOut[] = crosses( sig=V(out), dir='rise, thresh=0.0 )
```

returns

```
crossesOut[0] = 1e-05
crossesOut[1] = 2e-05
crossesOut[2] = 3e-05
crossesOut[3] = 4e-05
crossesOut[4] = 5e-05
crossesOut[5] = 6e-05
crossesOut[6] = 7e-05
crossesOut[7] = 8e-05
crossesOut[8] = 9e-05
```



The output waveform looks as shown below:



d2r (degrees-to-radians)

Converts a waveform from degrees to radians.

Syntax

d2r(*arg* **)**

d2r(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real myd2r = d2r( 180 )
```

db

Converts a signal to db where db=20*log(x). This function usually applies to voltage or current signals in volts or amperes.

Syntax

db(*arg* **)**

db(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real dcgain = db( V(out) / V(in)) @1MHz
```

The above example assumes that `out` and `in` are signals from an ac dataset.

db10

Converts a signal to db where db=10*log(x). This function usually applies to power signals in watts.

Syntax

db10(*arg* **)**

db10(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real mydb10= db10( v0:pwr )
```

dbm

Converts a signal to dbm where dbm=10*log(x)+30. This function usually applies to power signals in milliwatts (mW).

Syntax

dbm(*arg* **)**

dbm(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real mydbm= dbm ( v0:pwr )
```

deltax

Returns the difference in the abscissas of two cross events.

Syntax

```
deltax( sig1[, sig2 [, dir1[, n1[, thresh1[, start1[, dir2[, n2[, thresh2[,
     start2], xtol[, ytol[, accuracy]]]]]]]]]] )

deltax( sig1=sig1, sig2=sig2 [, dir1=dir1] [, n1=n1] [, thresh1=thresh1] [,
     start1=start1] [, dir2=dir2] [, n2=n2] [, thresh2=thresh2] [,
     start2=start2] [, xtol=xtol][, ytol=ytol][, accuracy=accuracy])
```

Arguments

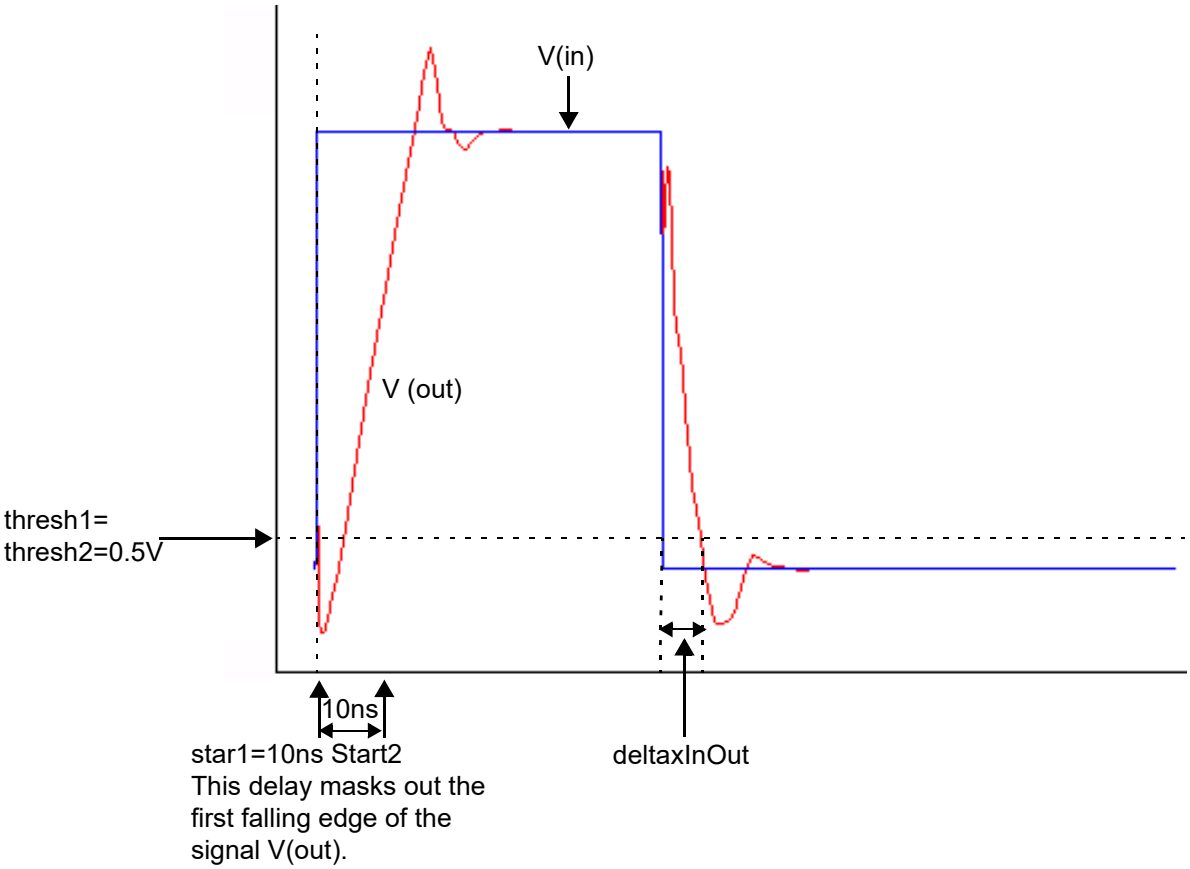
sig1	The signal whose cross event begins the measurement interval.
sig2	The signal whose cross event ends the measurement interval.
dir1	The direction of the cross at the beginning of the measurement interval. `'rise` directs the function to look for crossings where the Y value is increasing, `'fall` for crossings where the Y value is decreasing, and `'cross` for crossings in either direction. Valid values : `'cross 'rise, 'fall` Default: `'cross`
n1	The occurrence of the crossing for the beginning of the measurement interval. The first crossing is n=1, the second crossing is n=2, and so on. Default: `1`
thresh1	The Y value whose crossing begins the measurement interval. Default: 0
start1	The time at which the function is enabled. Default: 0

dir2	The direction of the cross at the end of the measurement interval. `'rise` directs the function to look for crossings where the Y value is increasing, `'fall` for crossings where the Y value is decreasing, and `'cross` for crossings in either direction. Valid values: `'cross, 'rise, 'fall` Default: `'cross`
n2	The occurrence of the crossing for the end of the measurement interval. The first crossing is n=1, the second crossing is n=2, and so on. Default: 1
thresh2	The Y value whose crossing ends the measurement interval. Default: 0
start2	The offset from `start1` where the function begins looking for the cross that ends the delay measurement. Default: 0
absstart2	The absolute offset from the beginning of the signal where the function begins looking for the cross that ends the delay measurement. Default: 0
xtol	The relative tolerance in percentage value in the X direction. Default: 1
ytol	The relative tolerance in percentage value in the Y direction. Default: 1
accuracy	Specifies whether the function should use interpolation, or use iteration controlled by the absolute tolerances to calculate the value. `'interp` directs the function to use interpolation, and `'exact` directs the function to consider the xtol and yval values. Data types: name for scalar Valid values: `'interp,` Default value: `'exact`

Example 1

```
export real deltaxInOut = deltax( sig1=V(in), sig2=V(out), dir1='fall, \
thresh1 = 0.5, dir2='fall, thresh2=0.5, start1=10n, start2=10n )
```

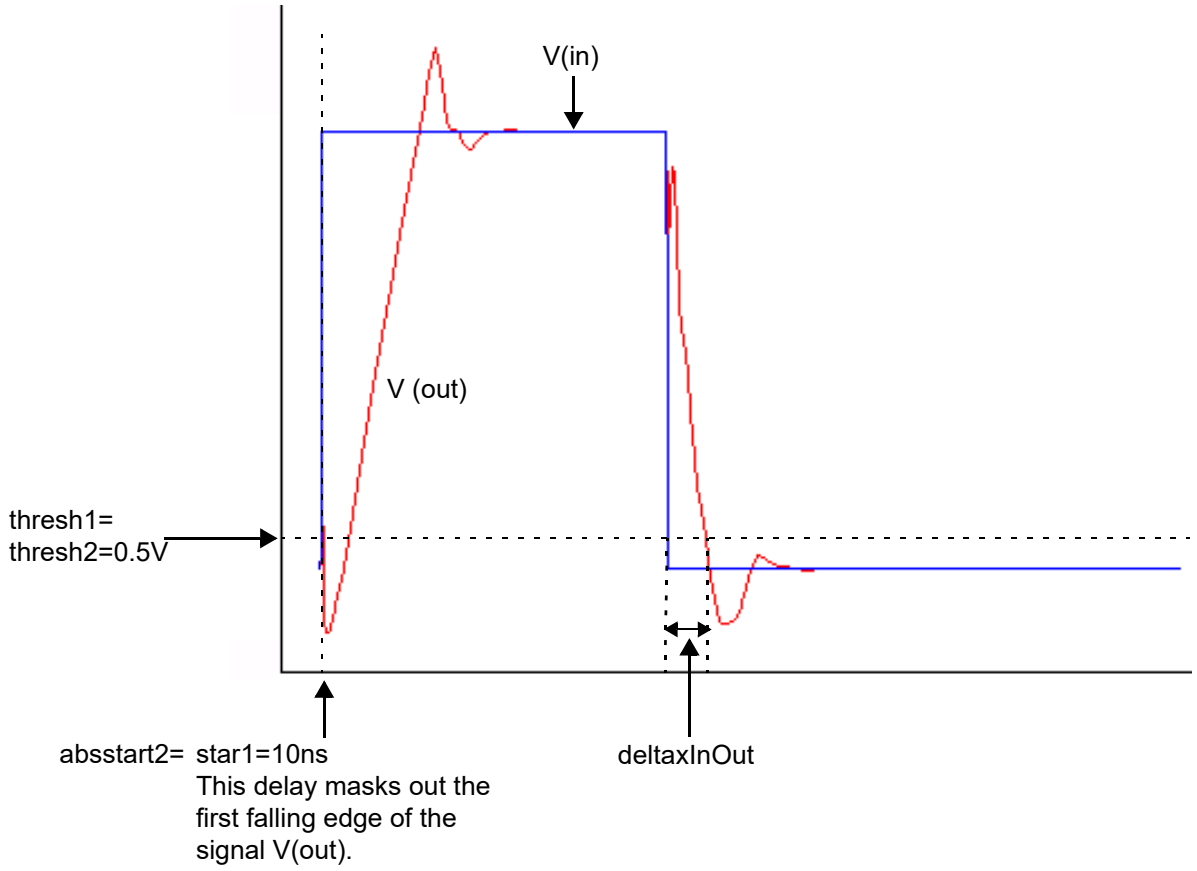
The following diagram illustrates how the result from the above example is determined.



Example 2

```
export real delay2 = deltax( sig1=V(in), sig2=V(out), dir1='fall, \
thresh1 = 0.5, dir2='fall, thresh2=0.5, start1=10n, absstart2=10n )
```

The following diagram illustrates how the result from the above example is determined.



deltaxes

The deltaxes function is similar to the deltax function. However, it returns the differences in the abscissas of two cross events in the form of an array.

Note: For syntax and arguments, please see deltax.

deriv

Returns the derivative of a signal.

Syntax

deriv(*sig* **)**

deriv(sig=*sig* **)**

Arguments

sig	The signal.

Example1

```
export real out_4n= deriv( V(out) )@4n
```

The derivative is calculated for signal `V(out)` at `t=4ns`.

Example 2

```
export real out_dvdt_fall=deriv(out)@cross(out, dir='fall, n=1, thresh=1.5)
```

The derivative is calculated for signal `V(out)` at its first crossing point at `1.5V` in the `fall` direction.

dutycycle

Calculates the ratio of the time for which the signal remains high to the period of the signal. You should use this function on periodic signals only.

Syntax

dutycycle(*sig*, *theta*, *mode***)**

dutycycle(sig=*sig*, **theta=***theta*, **[mode***='integrate* | *'percentage* | *'threshold* **])**

Arguments

sig	The signal.
theta	Percentage that defines the logic high of the signal. A threshold value is calculated as follows: yThresh=((Ymax - Ymin) * theta * 0.01) + Ymin The portion of the signal above yThresh is taken as high. Default value: `50.0`
mode='integrate	If `mode` is set to `integrate`, `theta` is ignored and the threshold value is calculated as in the SKILL mode.
mode='percentage	If `mode` is set to `percentage`, `theta` will be a percentage value. This is the default value.
mode='threshold	If `mode` is set to `threshold`, the value of `theta` is taken as the threshold value.

Note: If `mode` is not specified, it will automatically be set to *`percentage`*.

Example

```
export real dutycycleOut = dutycycle ( sig=V(out), theta=40 )
```

returns

```
dutycycleOut = 0.25436626860397216
```

dutycycles

Returns the dutycycle of a nearly-periodic signal as a function of time.

Syntax

dutycycles(*sig*, *theta* **)**

dutycycles(**sig=***sig*, **theta=***theta* **)**

Arguments

sig	The signal.
theta	Percentage that defines the logic high of the signal. A threshold value is calculated as follows: `yThresh=((Ymax - Ymin) * theta * 0.01) + Ymin` The portion of the signal above yThresh is taken as high. Default value: `50.0`

Example 1

In Virtuoso Visualization and Analysis XL,

```
export real dutycyclesOut = dutycycles ( sig=V(out), theta=40 )
```

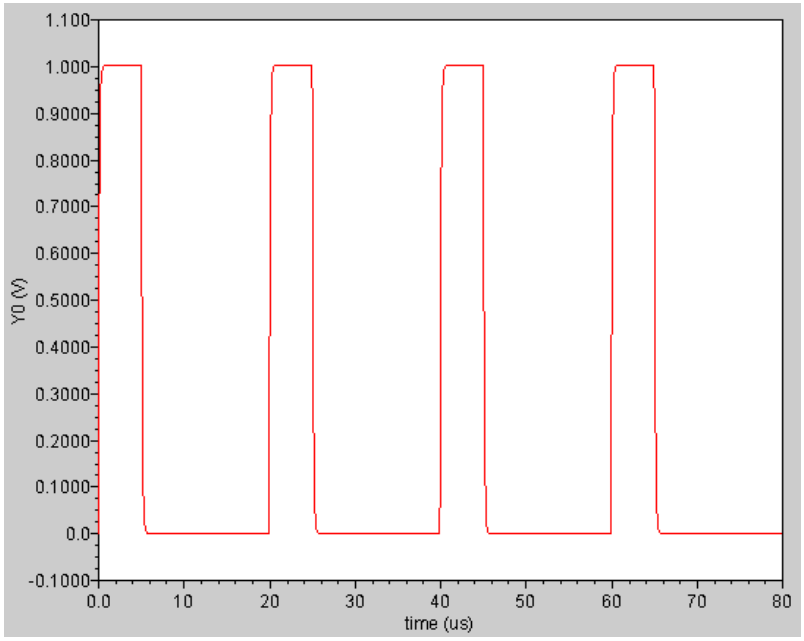
Example 2

```
export real dutycycles_q[] = dutycycles ( sig=V(q), theta=40 )
```

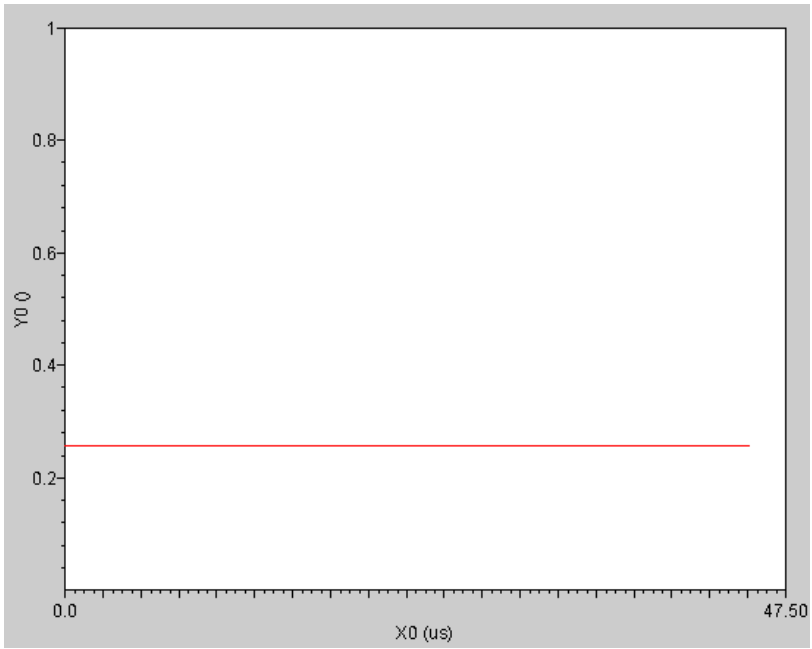
returns

```
dutycycles_q[0] = 0.3877
dutycycles_q[1] = 0.6897
dutycycles_q[2] = 0.685696
```

transforms the following input signal



into the following output signal



exp

Returns the e^x value of a signal.

Syntax

exp(*arg* **)**

exp(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real myexp = exp( 2 )
```

returns

```
myexp = 7.389
```

falltime

Returns the fall time for a signal measured between percent high and percent low of the difference between the initial and final values. The measurement is always done with ordinate (Y-axis) values.

Note: You can use the `falltimes` function to obtain the fall time for all edges instead of a single edge that is returned by the `falltime` function.

Syntax

```
falltime( sig[, initval[, finalval[, inittype[, finaltype[, theta1[, theta2[,
     xtol[, ytol[, accuracy]]]]]]]] )

falltime( sig=sig, initval=initval, finalval=finalval [, inittype=inittype] [,
     finaltype=finaltype] [, theta1=theta1] [, theta2=theta2] [, xtol=xtol] [,
     ytol=ytol] [, accuracy=accuracy] )
```

Arguments

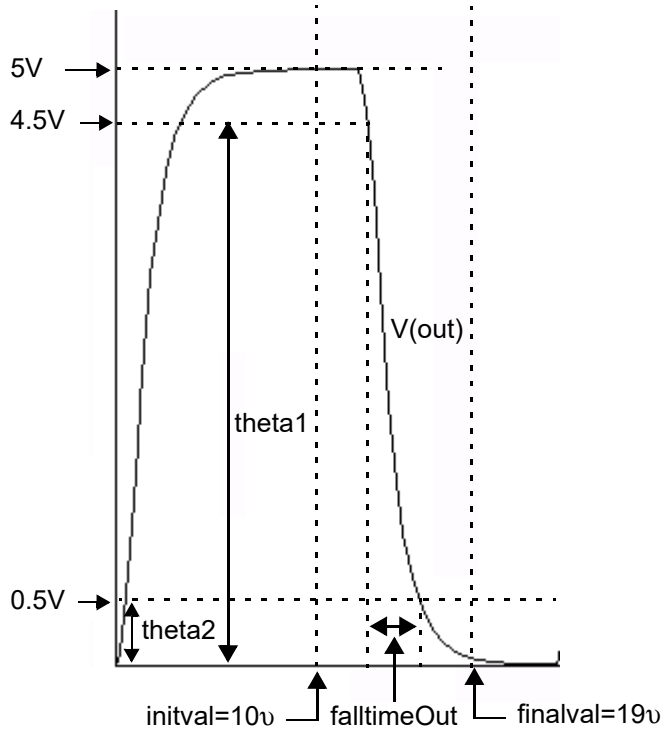
sig	The signal.
initval	The Y-axis value (if inittype is 'y) or X-axis value at the specified X-axis point (if inittype is 'x) that starts the falltime interval.
finalval	The Y-axis value (if inittype is 'y) or X-axis value at the specified X-axis point (if inittype is 'x) that ends the falltime interval.
inittype	When 'x, the initial value is an X value. When 'y, the initial value is a Y value. Valid values: 'x, 'y Default: 'y
finaltype	When 'x, the final value is an X value. When 'y, the final value is a Y value. Valid values: 'x, 'y Default: 'y
theta1	The threshold high expressed as a percentage of the difference between the initial and final values. Default: 90
theta2	The threshold low expressed as a percentage of the difference between the initial and final values. Default: 10
xtol	The relative tolerance in percentage value in the X direction. Default: 1
ytol	The relative tolerance in percentage value in the Y direction. Default: 1

accuracy	Specifies whether the function should use interpolation, or use iteration controlled by the absolute tolerances to calculate the value. `'interp` directs the function to use interpolation, and `'exact` directs the function to consider the xtol and yval values. Data types: name for scalar Valid values: `'interp`, `'exact` Default: `'exact`

Example

```
export real falltimeOut = falltime ( arg=V(out), initval=10u, inittype='x,
finalval=19u, finaltype='x, theta1=90, theta2=10)
```

The following diagram illustrates how the result from the above example is determined.



fft

Performs a Fast Fourier Transform on the signal and returns its frequency spectrum.

Syntax

fft(*sig*, *from*, *to*, *numPoints*, *window* **)**

fft(sig=*sig*, **from=***from*, **to=***to*, **numPoints=***numPoints*, **window=***window* **)**

Arguments

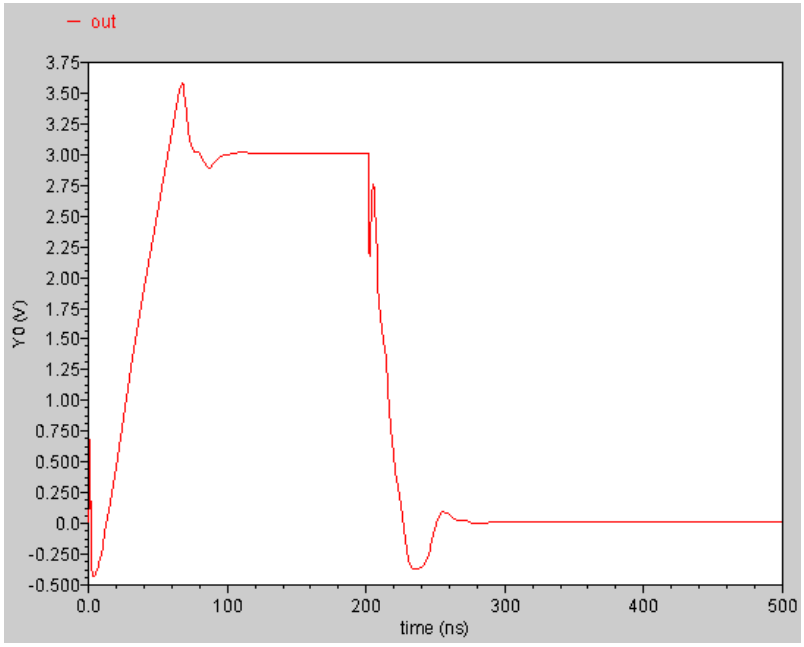
sig	The signal.
from	The starting X value.
to	The ending X value.
numPoints	The number of data points to be used for calculating the fft. If this number is not a power of 2, it is automatically raised to the next higher power of 2.
window	The algorithm used for calculating the fft. For more information, see window. Valid values: 'rectangular, 'bartlett, 'bartletthann, 'blackman, 'blackmanharris,'cosine2, 'cosine4, 'extcosbell, 'flattop, 'halfcyclesine, 'half3cyclesine, 'halfcyclesine3, 'half6cyclesine, 'halfcyclesine6, 'hamming, 'hanning, 'nuttall, 'parzen, 'triangular Default: 'rectangular

Example

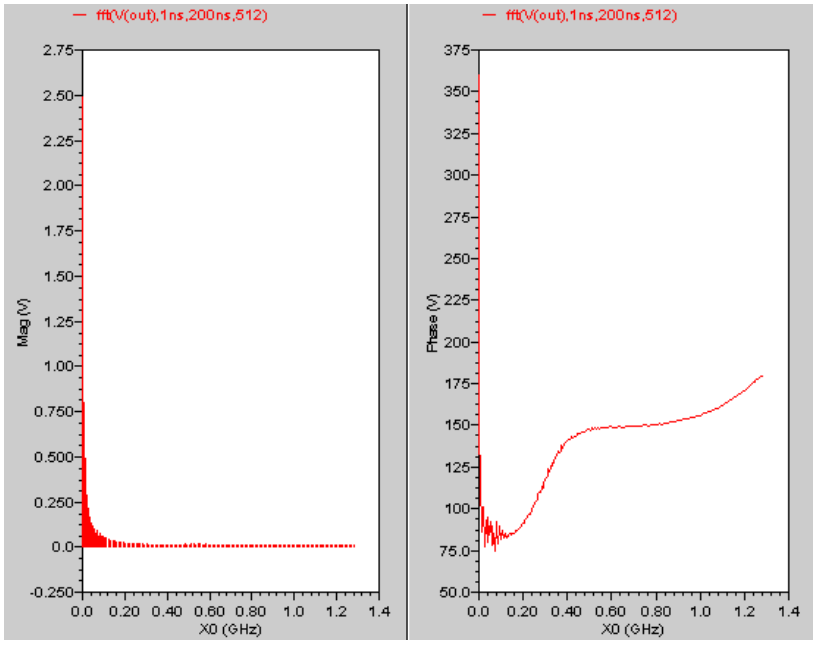
In Virtuoso Visualization and Analysis XL,

```
fft( sig=(V(out), from=1ns, to=200ns, numPoints=512, window='bartlett)
```

transforms the following input signal



into the following output signal. The left subwindow shows the magnitude part of the spectrum and the right subwindow shows the phase part.



flip

Returns a reversed version of a signal (rotates the signal along the Y-axis).

Syntax

flip (*sig* **)**

flip (sig=*sig* **)**

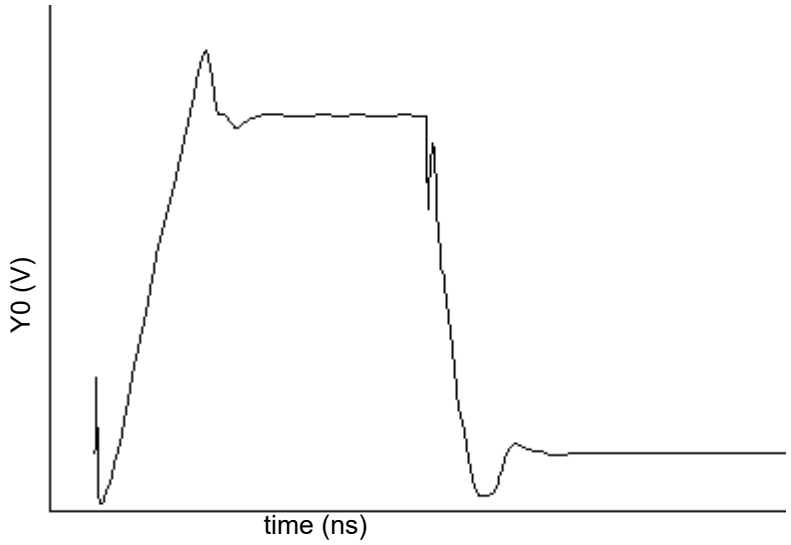
Arguments

sig	The signal.

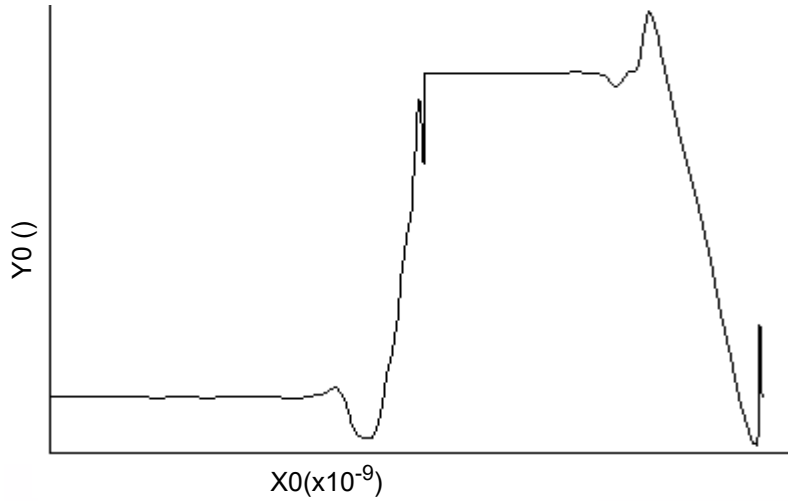
Example

```
export real flipOut = flip( V(out) )
```

transforms the following input signal



into the following output signal.



floor

Rounds a real number down to the closest integer value.

Syntax

floor(*arg* **)**

floor(arg=*arg* **)**

Arguments

arg	The real number.

Example

```
export real myfloor = floor( 1.6 )
```

returns

```
myfloor = 1
```

fmt

Provides formatting capability to turn MDL datatypes into a string representation.

Syntax

fmt(*"format", varargs* **)**

fmt(format=*"format"*, **varargs=***varargs* **)**

Arguments

"format"	The percent code format string. In addition to the standard percent codes in C (%s, %S, %g, %G, %e, %E, %f, %d, %i, %u, %o, %x, %X), the following percent codes are also available: %V - the value of the *varargs* argument. The following "\" qualifiers (constant escape sequences) are also supported: \n - newline \t - tab In addition to these, full precision qualifier support exists for all supported percent codes.
varargs	Arguments to the `fmt` function used to fill in the percent code values in the *format* string.

Example

```
alias measurement printmeas {
    input string out="myfile.out"
    print fmt("Header is %s\n", out) to=out
    print fmt("%s\t%s\t\t%s\t%s\t%s\t%s\n",
     "%d","%f","%o","%x","%X","%u") addto=out
    print fmt("%d\t%f\t%o\t%x\t%X\t%u\n",10,10,10,10,10,10) addto=out
}
run printmeas (out="test.dat")
```

The simulator writes the following results to the `test.dat` file:

```
Header is test.dat
%d      %f              %o      %x      %X      %u
10      10.000000       12      a       A       10
```

freq

Returns an array of frequencies defined by the given threshold crossing and direction for a signal.

Syntax

freq(*sig*, *thresh*, *dir* **)**

freq(sig=*sig*, **thresh=***thresh*, **dir=***direction* **)**

Arguments

sig	The signal.
thresh	The threshold Y-axis value to be crossed.
dir	The direction of the crossing event. Valid values: `'rise`, `'fall`

Example

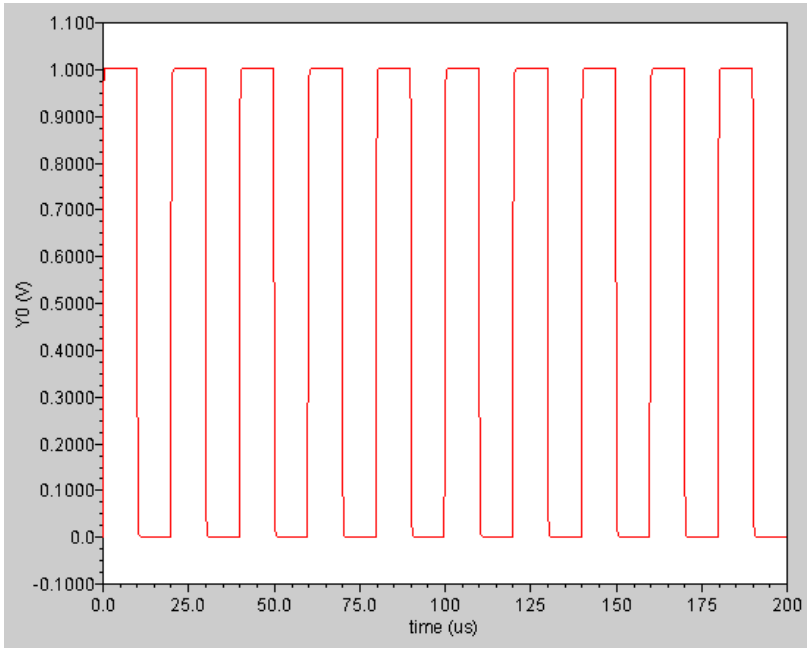
In Virtuoso Visualization and Analysis XL,

```
export real freqOut = freq ( sig=V(out), thresh=0.5, dir='rise )
```

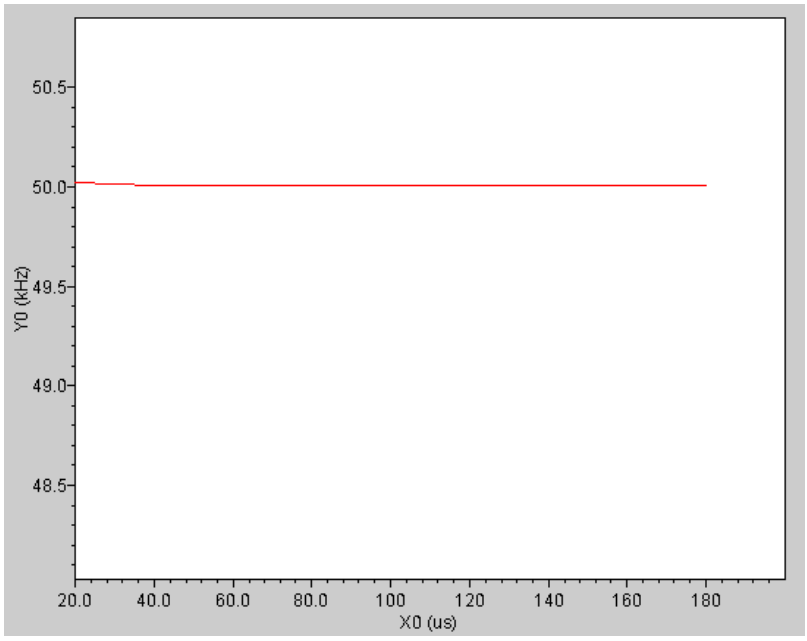
returns

```
freqOut[0] = 5.0001e+04
freqOut[1] = 5e+04
```

the following input signal



is converted to the following output signal



freq_jitter

Returns a waveform representing the deviation from the average frequency.

Syntax

freq_jitter(*sig*, *thresh*, *dir*, *binsize* **)**

freq_jitter(**sig=***sig*, **thresh=***thresh*, **dir=***direction*, **binsize=***binsize* **)**

Arguments

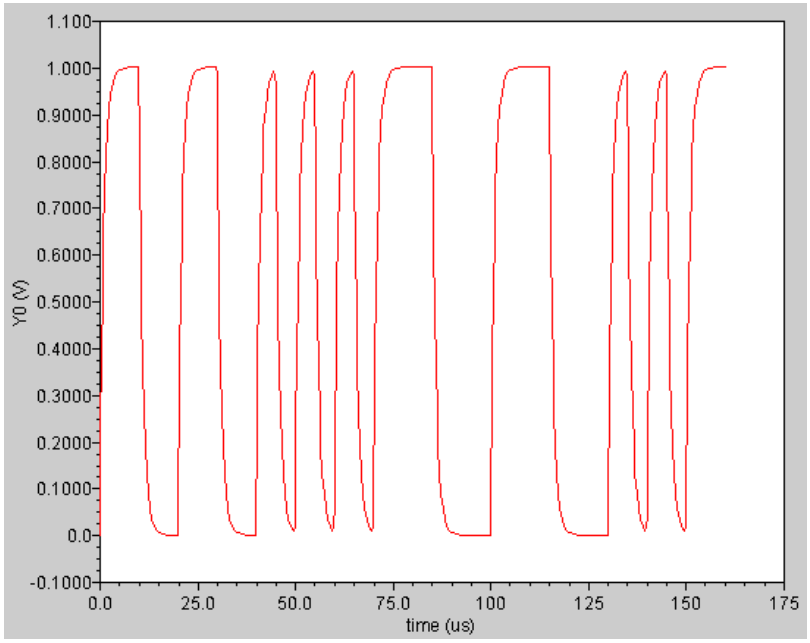
sig	The signal.
thresh	The threshold Y-axis value to be crossed.
dir	The direction of the crossing event. Valid values: `'rise`, `'fall`
binsize	Integer used to calculate the average frequency of the signal. If binsize=0, all frequencies are used to calculate the average. If binsize=*N*, the last *N* frequencies are used to calculate the average. Default value=`0`

Example

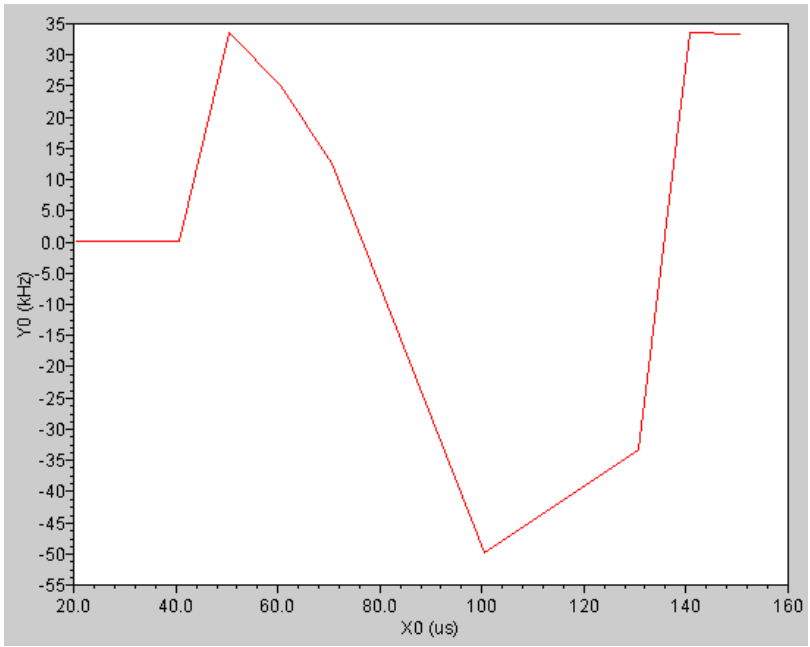
In Virtuoso Visualization and Analysis XL,

```
export real freq_jitterOut = freq_jitter ( sig=V(out), thresh=0.5, dir='rise,
binsize=4 )
```

the following input signal



is converted to the following output signal



gainBwProd

Returns the product of DC gain and upper cutoff frequency for a low-pass type filter or amplifier.

Syntax

gainBwProd(*sig* **)**

gainBwProd(sig=*sig* **)**

Arguments

sig	The signal. It can represent the magnitude of the gain or a frequency response.

Example

```
export real gainBwProdOut = gainBwProd ( sig=mag(out) )
```

returns

```
gainBwProdOut = 1804641.158689868
```

gainmargin

Computes the gain margin of the loop gain of an amplifier.

The gain margin is calculated as the magnitude (in dB) of the gain at f0. The frequency f0 is the smallest frequency in which the phase of the gain provided is -180 degrees. For stability, the gain margin must be positive.

Syntax

gainmargin(*sig* **)**

gainmargin(sig=*sig* **)**

Arguments

sig	The loop gain of interest over a sufficiently large frequency range.

Example

```
export real gainmar=gainmargin(vout)
```

getinfo

Returns information related to the simulator, such as version, subversion, and command information.

Syntax

getinfo(*type* **)**

getinfo(type=*type* **)**

Arguments

type	Type of information to be displayed. Valid values are 'simulator, 'version, 'subversion, and 'cmd.

Example

```
string simulator=getinfo('simulator)
string version=getinfo('version)
string subversion=getinfo('subversion)
string cmdline=getinfo('cmd)
```

groupdelay

Calculates the rate of change of phase with respect to frequency in a frequency response measurement.

```
groupdelay=d(phase)/dw
```

where w=angular frequency in rad/s=2*PI*f

Syntax

groupdelay (*sig* **)**

groupdelay (**sig=***sig* **)**

Arguments

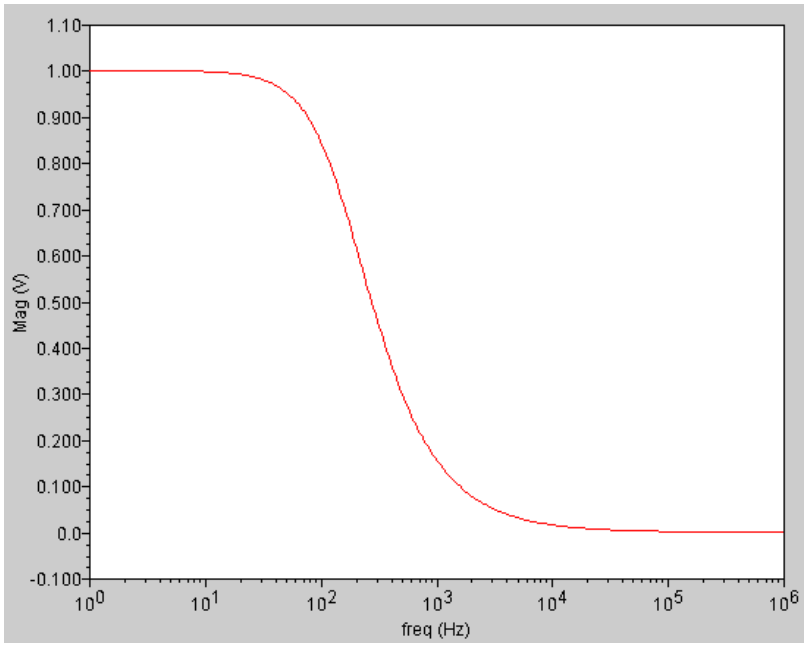
sig	The signal. It should represent frequency response.

Example

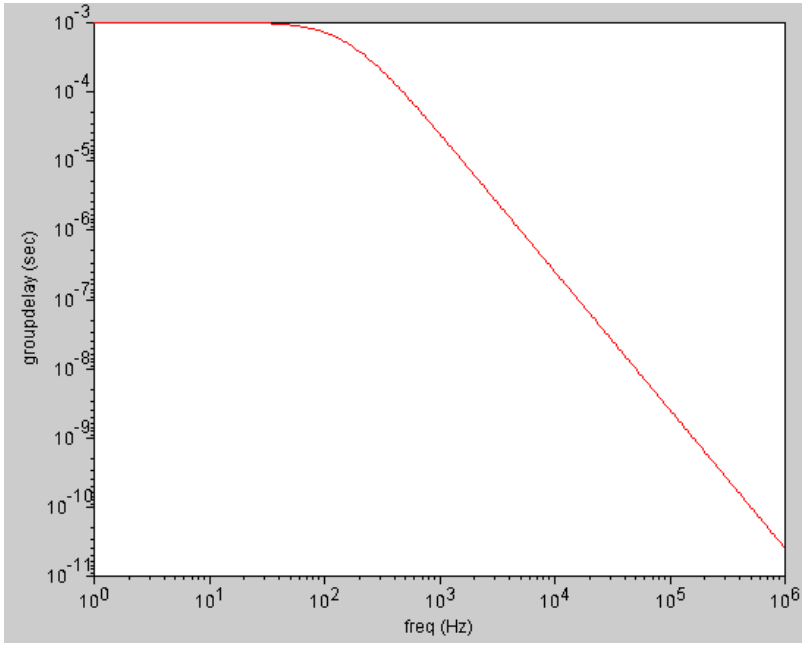
In Virtuoso Visualization and Analysis XL,

```
export real groupdelayOut = groupdelay ( sig=out )
```

the following input signal



is converted to the following output signal



histo

Creates a histogram from a signal.

The histo function is available from the calculator. It is not supported within a Spectre MDL control file since it returns a scalar and not a waveform.

Syntax

histo(*sig*, *nbins*, *min*, *max* **)**

histo(sig=*sig*, **nbins=***nbins*, **min=***min*, **max=***max* **)**

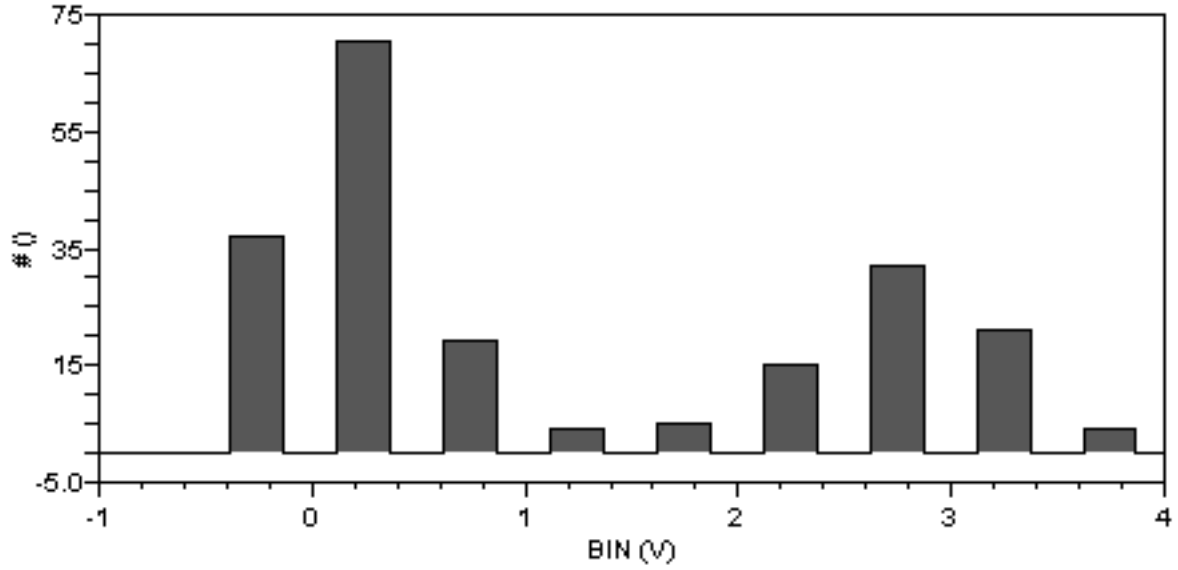
Arguments

sig	The waveform.
nbins	The number of bins to be created.
min	The value that specifies the smaller end point of the range of values included in the histogram.
max	The value that specifies the larger end point of the range of values of values included in the histogram.

Example

```
histo(V(out),nbins=10, min=-1.0, max=4.0)
```

creates a display with 10 bins that might look like this when the leftmost bin is empty.



I

Current probe function.

Syntax

```
I(devname)                    //equivalent to devname:0
I(devname:term)               //term can be either terminal name or terminal index
I(Instname:term)              //term can be either terminal name or terminal index
```

The `I` probe function does not support current access by node name, nor does it support current difference between two `devname:term`(s). In other words, it is illegal to apply the `I` probe to a node or a pair of nodes.

Arguments

devname	The N-terminal device instance name.
Instname	The N-terminal subcircuit instance name.
term	The terminal name or terminal index of a device or a subcircuit.

Examples

```
I(Rload:1)     // Returns the current through terminal Rload:1
I(I0.mp1:d)    // Returns the current through device terminal name d
I(I0:vdd1)     // Returns the current through subcircuit terminal name vdd1
```

ifft

Performs an inverse Fast Fourier Transform on a frequency spectrum and returns the time domain representation of the spectrum.

Syntax

ifft (*sig* **)**

ifft (**sig=***sig***)**

Arguments

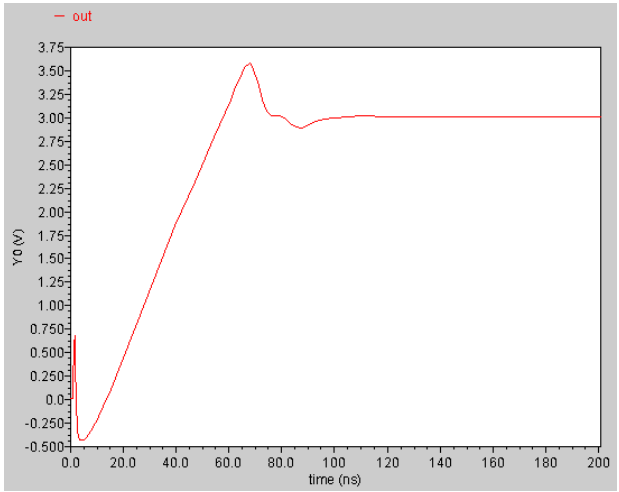
sig	The frequency spectrum.

Example

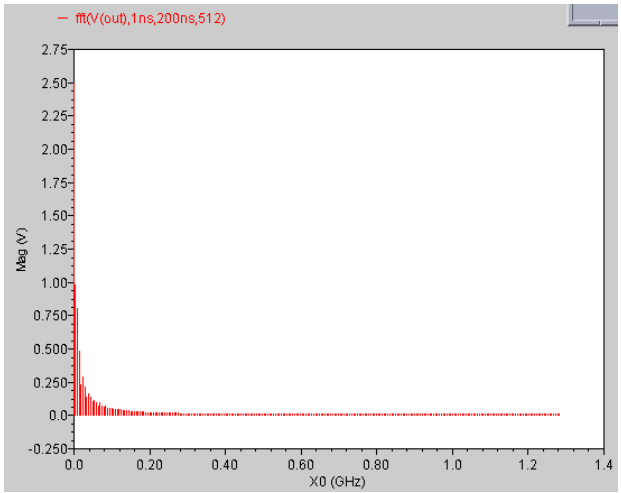
```
fft( sig=V(out), from=1ns, to=200ns, npoints=512)
```

results in the graph on the right side.

The signal `out`



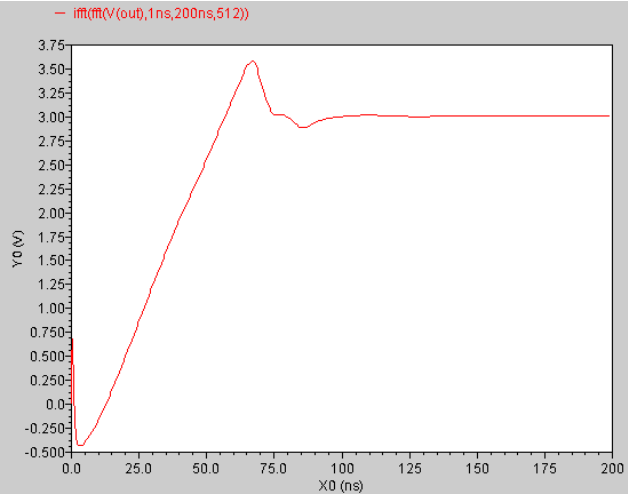
Fast fourier transform of the signal `out`



Now if I perform an `ifft` on the above expression,

```
ifft( fft( sig=V(out), from=1ns, to=200ns, npoints=512) )
```

The result is the same as the original signal (`out`) – from 1ns to 200ns.



iinteg

Returns the incremental area under the waveform.

Syntax

iinteg(*sig* **)**

iinteg(sig=*sig* **)**

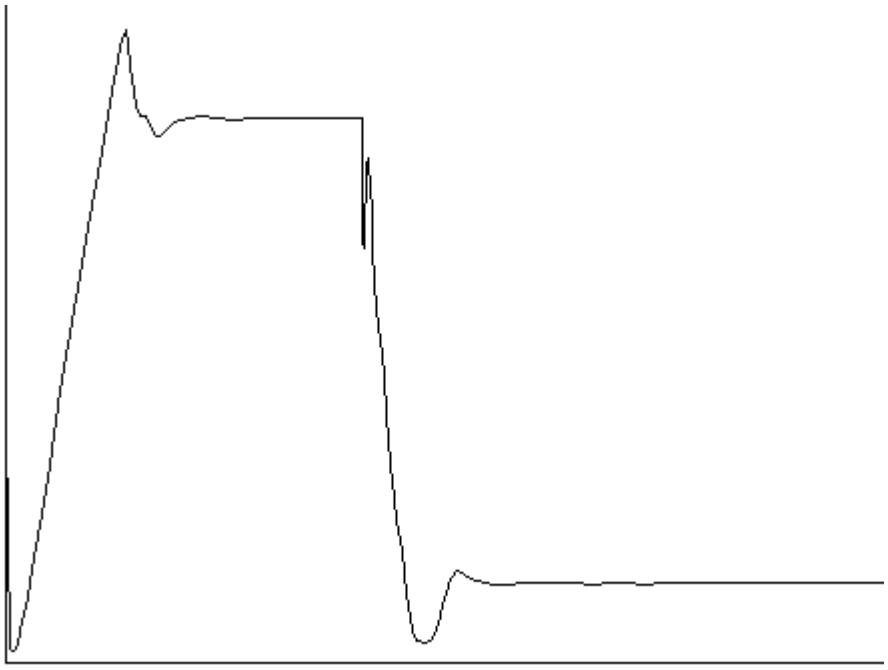
Arguments

sig	The signal.

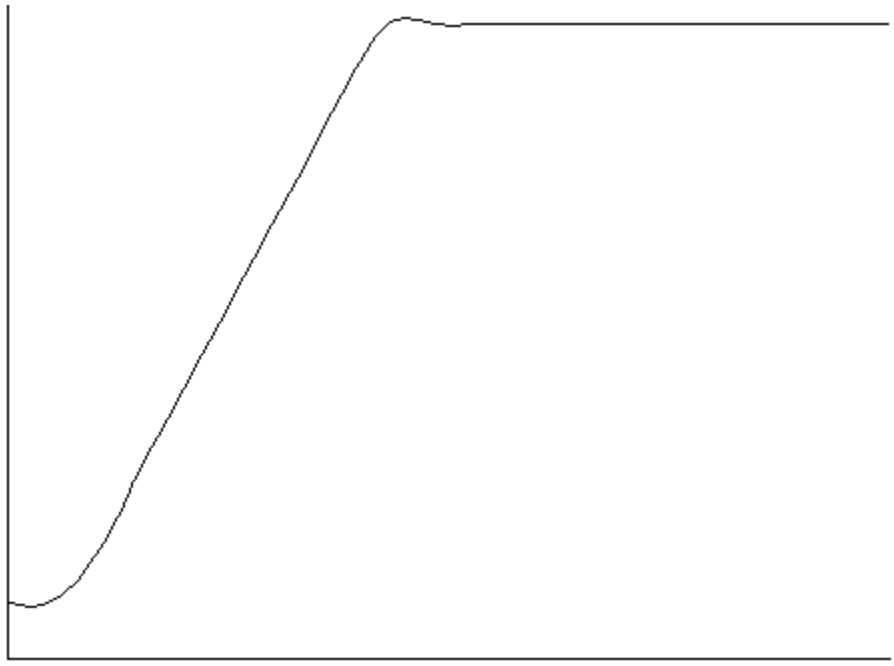
Example 1

```
export real iintegOut = iinteg( V(out) )
```

transforms the following input signal



into the following output signal



Each X value on the output trace is equal to the area under the input trace from start till that particular X-value.

im

Returns the imaginary part of a complex number.

Syntax

im(*arg* **)**

im(arg=*arg* **)**

Arguments

arg	The complex number.

Examples

```
export real myim = im( cplx(1,2) )
```

returns

```
myim = 2
```

```
export real im_sll = im( s(1,1) )
```

returns

```
im_sll = 0.670029
```

int

Returns the integer portion of a real value.

Syntax

int(*arg* **)**

int(arg=*arg* **)**

Arguments

arg	The real number whose integer portion is to be returned.

Example

```
int(4.998)
```

returns the value

```
4
```

integ

Returns the area bounded under the curve.

Syntax

integ(*sig* **)**

integ(sig=*sig* **)**

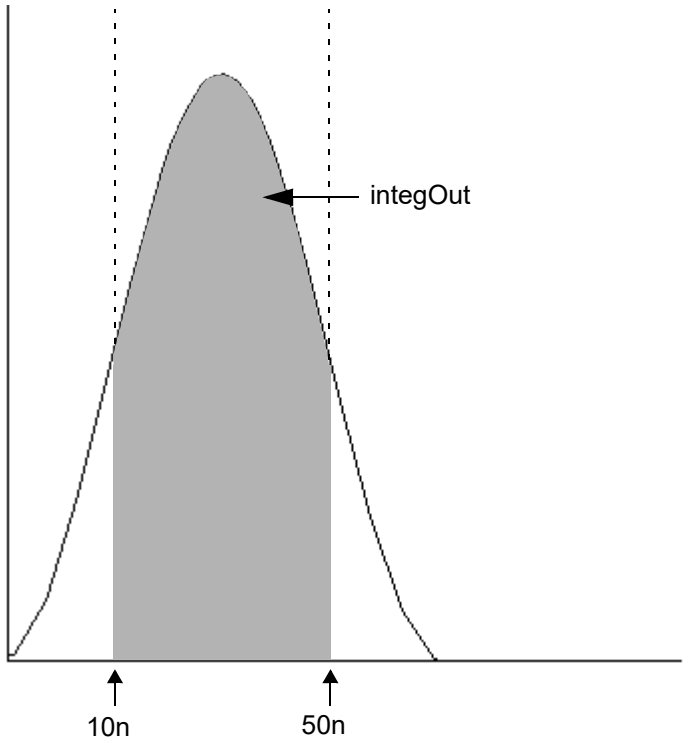
Arguments

sig	The signal.

Example 1

```
export real integOut = integ( trim( sig=V(sinewave), from=10n, to=50n ) )
```

The following diagram illustrates how the result from the above example is determined. The result is equal to the shaded area in the graph.



ln

Returns the natural logarithm of a signal or a number. If no specific point of a signal is specified, MDL returns value for the last simulation point of the signal.

Syntax

ln(*arg* **)**

ln(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Examples

```
export real mylog = ln ( 10 )
```

returns

```
mylog = 2.3
```

```
export real myln = ln ( v(q))
export real myln_ons = ln ( v(q) @0 )
```

returns

```
myln = -0.223144
myln_ons   = -21.9773
```

log10

Returns the base 10 logarithm of a signal or a number. If no specific point of a signal is specified, MDL returns value for the last simulation point of the signal.

Syntax

log10(*arg* **)**

log10(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real mylog10 = log10( 10 )
```

returns

```
mylog10 = 1
```

mag

Returns the magnitude of a signal or complex number.

Syntax

mag(*arg* **)**

mag(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real mymag = mag( cplx(1,2) )
```

returns

```
mymag = 2.236
```

max

Returns the maximum value of a signal, maximum value of two real values, or the maximum value or a signal and a real value

Syntax

max(*arg* **)**

max(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example 1

```
export real maxOut1 = max ( V(out ) )
```

Example 2

```
export real maxOut2 = max ( V(out)@100n, V(out)@200n )
```

This returns the value of `out` at 100n or 200n – whichever is greater.

Example 3

```
export real maxq=max(trim(q, from=0, to=100n))
```

This returns the maximum value of `out` over the range of `t=0ns` to `t=100ns`.

Example 4

```
export real maxOut4 = max( I(IP1)@ 1.0 , 1e-15 );
```

min

Returns the minimum value of a signal or the minimum value of two real values.

Syntax

min(*arg* **)**

min(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real minOut1 = min( V(out) )
```

Example 2

```
export real minOut2 = min ( V(out)@100n, V(out)@200n )
```

This returns the value of `out` at 100n or 200n – whichever is smaller.

mod

Returns the floating point remainder of the dividend divided by the divisor. The divisor cannot be zero.

Syntax

mod(*dividend*, *divisor* **)**

mod(dividend=*dividend*, **divisor=***divisor* **)**

Arguments

dividend	The scalar dividend.
divisor	The scalar divisor.

Example

```
export real mymod = mod( 546, 324 )
```

returns

```
mymod = 222
```

movingavg

Calculates the moving average for the specified signal.

Syntax

movingavg(*sig*[, *n*]**)**

movingavg(sig=*sig*[, **n=***n*] **)**

Arguments

sig	The signal.
n	Number of points specifying the bin size. Default: 1

overshoot

Returns the overshoot/undershoot of a signal as a percentage of the difference between initial and final values.

Syntax

overshoot(*sig*[, *initval*[, *finalval*[, *inittype*[, *finaltype*]]]] **)**

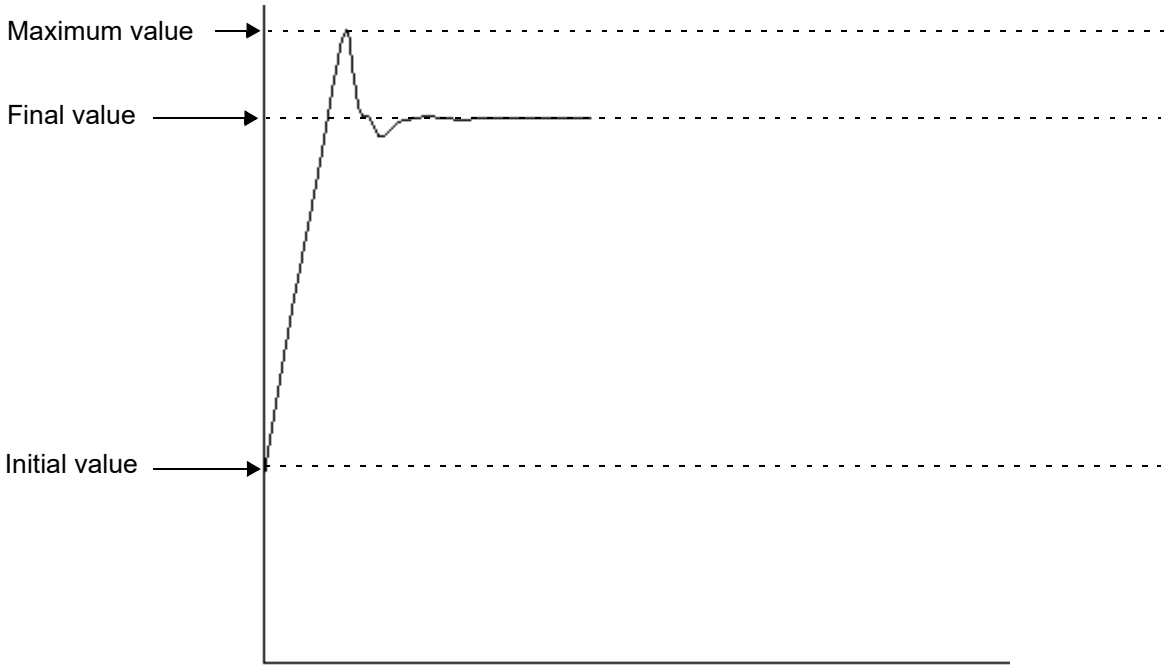
overshoot(sig=*sig*, **initval=***initval*, **finalval=***finalval* [, **inittype=***inittype*]
[, **finaltype=***finaltype*] **)**

Arguments

sig	The signal.
initval	The initial value. To calculate the undershoot of a signal, the initval should be higher than finalval.
finalval	The final value.
inittype	When 'x, the initial value is a time value. When 'y, the initial value is a current or voltage value. Valid values: 'x, 'y Default: 'y
finaltype	When 'x, the final value is a time value. When 'y, the final value is a current or voltage value. Valid values: 'x, 'y Default: 'y

Example

```
export real overshootOut = overshoot ( sig=V(out), initval=1, finalval=3,
inittype='y, finaltype='y) )
```



OvershooutOut is given by the following formula:

$$OvershooutOut = \frac{MaximumValue - FinalValue}{FinalValue - InitialValue}$$

period_jitter

Returns a waveform representing the deviation from the average period.

Syntax

period_jitter (*sig*, *thresh*, *dir*, *binsize* **)**

period_jitter (**sig=***sig*, **thresh=***thresh*, **dir=***direction*, **binsize=***binsize* **)**

Arguments

sig	The signal.
thresh	The threshold Y-axis value defining the period/frequency of the signal.
dir	The direction of the crossing event. Valid values: `'rise`, `'fall` Default value: `'rise`
binsize	Integer used to calculate the average frequency of the signal. If binsize=0, all periods are used to calculate the average. If binsize=*N*, the last *N* periods are used to calculate the average. Default value=`0`

Example

```
export real period_jitterOut = period_jitter ( sig=V(out), thresh=0.5, dir='rise,
binsize=4 )
```

ph

Returns the phase of a signal in radians.

Syntax

ph(*arg*[, **wrap**=<*value*>]**)**

ph(arg=*arg*, **wrap**=*value* **)**

Arguments

arg	The signal.
value	Wraps the phase. The phase is wrapped around +/- PI. Possible values are yes (default) and no. The value can be scalar.

Example

```
ph( v(out), wrap='no )
```

phasemargin

Computes the phase margin of the loop gain of an amplifier. The phase margin is calculated as the difference between the phase of the gain in degrees at f0 and at -180 degrees. The frequency f0 is the smallest frequency where the gain is 1. For stability, the phase margin must be positive. The value is returned in degrees.

Syntax

phasemargin(*sig* **)**

phasemargin(sig=*sig* **)**

Arguments

sig	The loop gain of interest over a sufficiently large frequency range. *sig* can be `v(nodeName)` or `I(deviceName)`.

Example

```
export real phasemar=phasemargin(vout)
```

pow

Returns the value of base raised to the power of exponent ($base^{exponent}$).

Syntax

pow(*base*, *exponent* **)**

pow(base=*base*, **exponent=***exponent* **)**

Arguments

base	The base argument.
exponent	The exponent argument.

Example

```
export real mypow = pow( 2,2 )
```

returns

```
mypow = 4
```

pp (peak-to-peak)

Returns the difference between the highest and lowest values of a signal.

Syntax

pp(*sig***)**

pp(sig=*sig* **)**

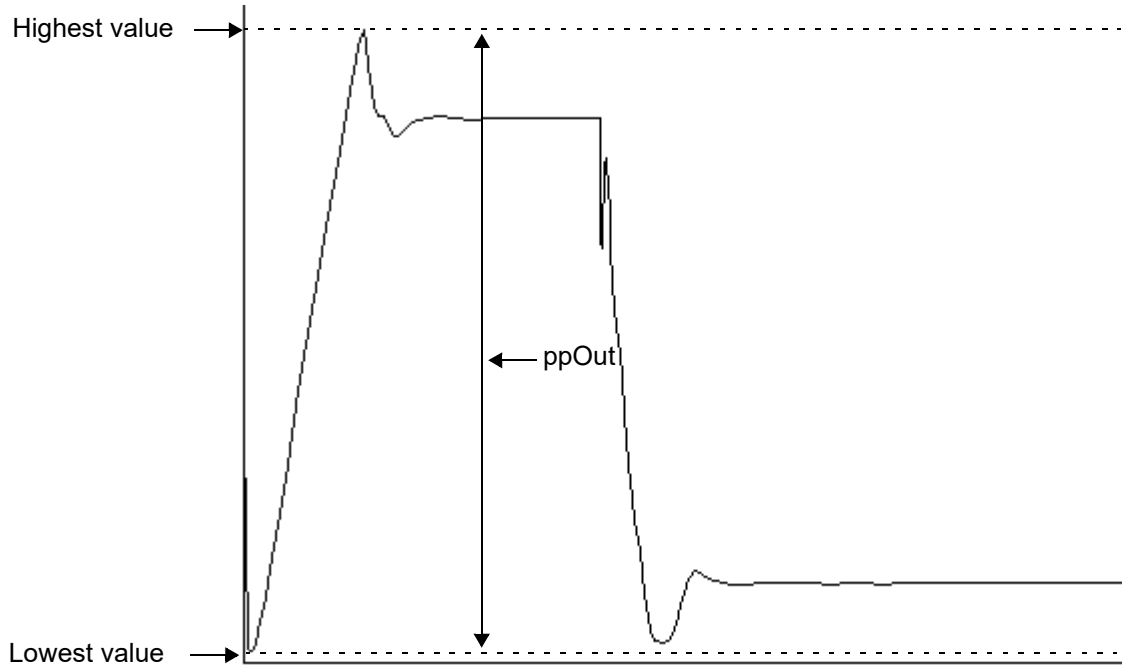
Arguments

sig	The signal.

Example 1

```
export real ppOut = pp( V(out) )
```

The following diagram illustrates how the result from the above example is determined.



pzbode

Calculates and plots the transfer function for a circuit from pole zero simulation data. This function is available only in the MDL mode.

Syntax

pzbode(*poles*, *zeroes*, *c*, *minfreq*, *maxfreq*, *npoints***)**

pzbode(poles=*poles* **, zeroes=***zeroes* **, c=***c* **, minfreq=***minfreq* **, maxfreq=***maxfreq* **, npoints=***npoints* **)**

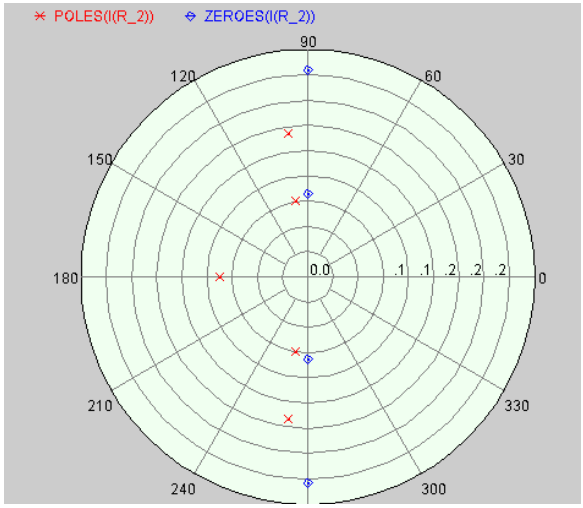
Arguments

poles	The poles.
zeroes	The zeroes.
c	The transfer gain constant.
minfreq	The minimum frequency for the bode plot.
maxfreq	The maximum frequency for the bode plot.
npoints	The frequency interval for the bode plot, in points per decade.

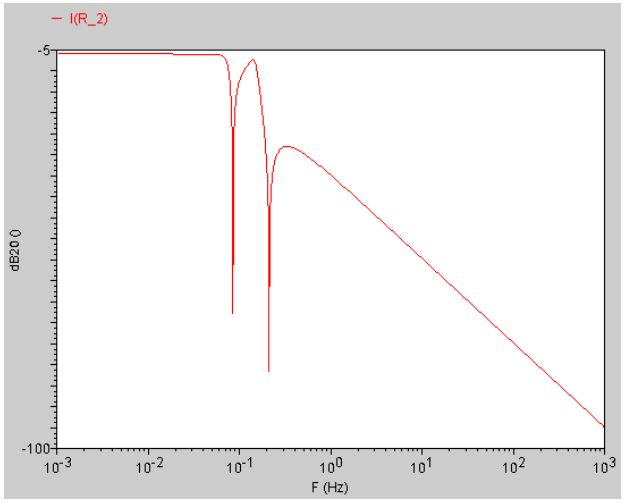
Example

The following diagram illustrates how the result with the values *poles*=`POLES<I<R_1>>`, *zeroes*=`ZEROES<I<R_1>>`, *c*=`I<R_1>\[K\]`, *minfreq*=`1e-3`, *maxfreq*=`1e3`, and *npoints*=`1000` is determined.

Polar Plot



Corresponding bode plot



pzfilter

Filters the poles and zeroes according to the specified criteria. The `pzfilter` function works only on pole zero simulation data. This function is available only in the MDL mode.

Syntax

```
pzfilter( poles, zeroes, maxfreq, reldist, absdist, minq)

pzfilter( poles=poles , zeroes=zeroes , maxfreq=maxfreq , reldist=reldist ,
     absdist=absdist , minq=minq )
```

Arguments

poles	The poles.
zeroes	The zeroes.
maxfreq	The frequency up to which the poles and zeroes are plotted.
reldist	The relative distance between the pole and zero. Pole-zero pairs with a relative distance lower than the specified value are not plotted.
absdist	The absolute distance between the pole and zero. Pole-zero pairs with an absolute distance lower than the specified value are not plotted.
minq	The minimum Q-factor. Pole-zero pairs with a Q-factor less than the specified value are not cancelled. The equations that define the Q-factor of a complex pole or zero are described in the section below.

Note: If you do not specify *maxfreq*, *reldist*, *absdist*, or *minq*, `pzfilter` filters out the poles and zeroes with a frequency higher than 10 GHz (default value of *maxfreq*).

Equations Defining the Q-Factor of a Complex Pole or Zero

$$Re(X) < 0.0 \qquad Q = 0.5 \times \sqrt{[Im(X)/Re(X)]^2 + 1}$$

$$Re(X) = 0 \qquad UNDEFINED$$

$$Re(X) > 0.0 \qquad Q = -0.5 \times \sqrt{[Im(X)/Re(X)]^2 + 1}$$

Filtration Rules

- Real poles can be cancelled only by real zeroes. A real pole `P` is cancelled by a real zero `Z` if the following equation is satisfied:

$$|P - Z| < absdist + \frac{|P + Z|}{2} \times reldis$$

- Complex poles and zeroes always occur in conjugated pairs. A pair of conjugated poles can only be canceled by a pair of conjugated zeroes. A pole pair `P1=a+jb`, `P2=a-jb` is cancelled by a zero pair `Z1=c+jd`, `Z2=c-jd`, if the following equation is satisfied:

$$|P1 - Z1| = |P2 - Z2| = \sqrt{(a-c)^2 + (b-d)^2} < absdist + \frac{|a+c|}{2} \times reldis$$

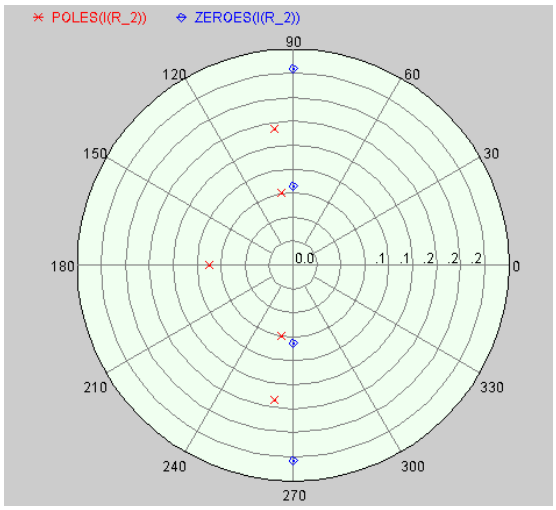
- Poles in the right-half plane are never cancelled because they show the instability of the circuit.

Example

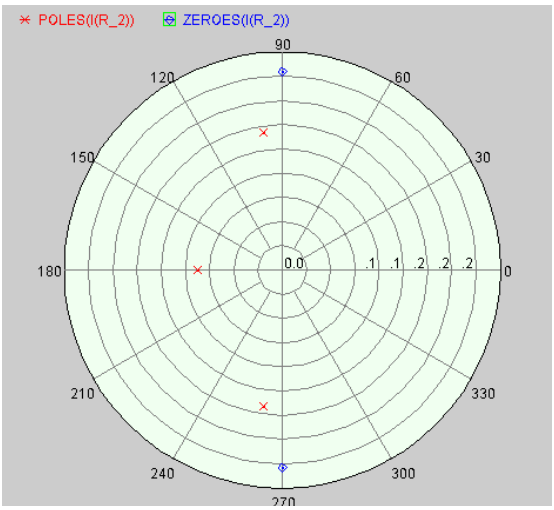
The values *poles*=`POLES<I<R_2>>`, *zeroes*=`ZEROES<I<R_2>>`, *absdist*=`0.05`, and *minq*=`10000` filters pole-zero pairs with a relative distance of less than 0.05 Hz from the plot

on the left side. In the filtered plot shown on the right side, two pole-zero pairs have been filtered out.

Original polar Plot



Filtered polar plot



r2d (radians-to-degrees)

Converts a scalar or waveform expressed in radians to degrees.

Syntax

r2d(*arg* **)**

r2d(arg=*arg* **)**

Arguments

arg	The signal.

Example

```
export real myr2d = r2d( 3.14 )
```

returns

```
myr2d = 179.909
```

re

Returns the real portion of a complex number.

Syntax

re(*arg* **)**

re(arg=*arg* **)7**

Arguments

arg	The complex number.

Examples

```
export real myre = re( cplx(1,2) )
```

returns

```
myre = 1
```

```
export real real_sll = re( s(1,1) )
```

returns

```
real_sll = 0.682203
```

real

Creates a real number from an integer number.

Syntax

real(*arg* **)**

real(arg=*arg* **)**

Arguments

arg	The integer.

risetime

Returns the rise time for a signal measured between percent low and percent high of the difference between the initial and final value.

Note: You can use the `risetimes` function to obtain the rise time for all edges instead of a single edge returned by the `risetime` function.

Syntax

```
risetime( sig[, initval[, finalval [, inittype[, finaltype[, theta1[,
     theta2[, xtol[, ytol[, accuracy]]]]]]]] )

risetime( sig=sig, initval=initval, finalval=finalval [, inittype=inittype] [,
     finaltype=finaltype] [, theta1=theta1] [, theta2=theta2] [, xtol=xtol] [,
     ytol=ytol] [, accuracy=accuracy] )
```

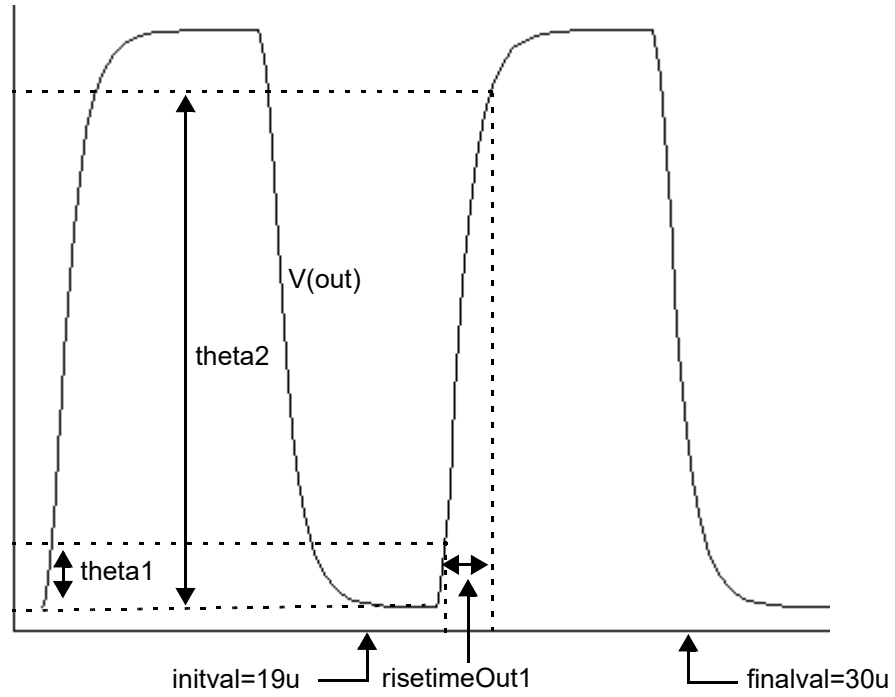
Arguments

sig	The signal.
initval	The X value (if inittype is `'x`) or Y value (if inittype is `'y`) that starts the rise time interval. The measurement is always done in ordinate values.
finalval	The X value (if inittype is `'x`) or Y value (if inittype is `'y`) that ends the rise time interval.
inittype	When `'x`, the initial value is an X value. When `'y`, the initial value is a Y value. Valid values: `'x, 'y` Default: `'y`
finaltype	When `'x`, the final value is an X value. When `'y`, the final value is a Y value. Valid values: `'x, 'y` Default: `'y`
theta1	The percent low. Default: `10`
theta2	The percent high. Default: `90`
xtol	The relative tolerance in percentage value in the X direction. Default: `1`
ytol	The relative tolerance in percentage value in the Y direction. Default: `1`
accuracy	Specifies whether the function should use interpolation, or use iteration controlled by the absolute tolerances to calculate the value. `'interp` directs the function to use interpolation, and `'exact` directs the function to consider the xtol and yval values. Data types: name for scalar Valid values: `'interp`, `'exact` Default: `'exact`

Example 1

```
export real risetimeOut1 = risetime( sig=V(out), initval=19u, finalval=30u,
inittype='x, finaltype='x, theta1=10, theta2=90)
```

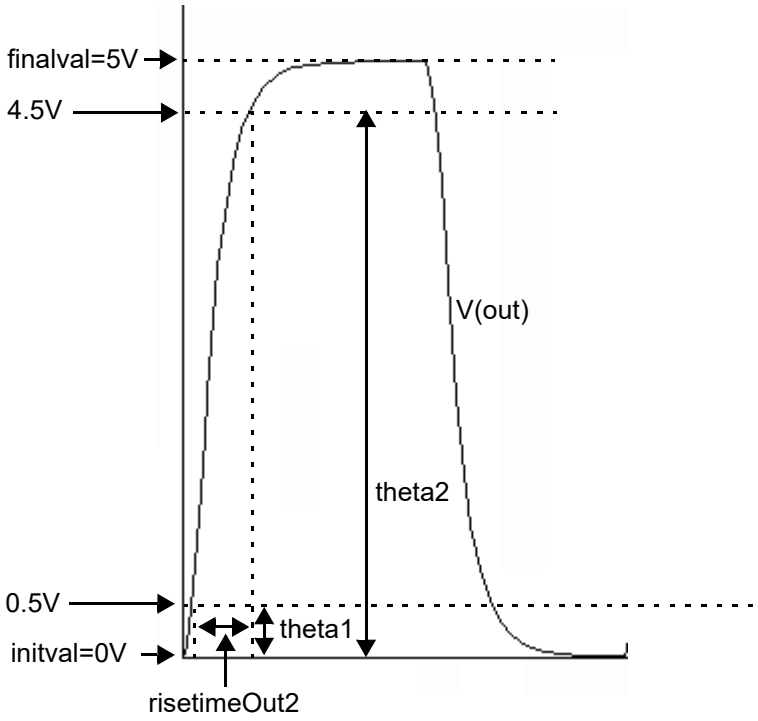
The following diagram illustrates how the result from the above example is determined.



Example 2

```
export real risetimeOut2 = risetime( sig=V(out), initval=0V, finalval=5V,
inittype='y, finaltype='y, theta1=10, theta2=90)
```

The following diagram illustrates how the result from the above example is determined.



rmsnoise

Returns the root mean square noise of a signal. The root mean square is defined as:

```
rmsnoise=sqrt{ integral[Sig(t) * Sig(t)] }
```

Syntax

rmsnoise(*sig:param* **)**

rmsnoise(sig=*sig*:*param* **)**

Arguments

sig	The signal.
param	The parameter that refers to the noise to be provided. Possible values are `out` (output noise), `in` (input noise), `F` (noise factor), `NF` (noise figure) and `gain` (circuit gain).

Example

```
export real total_noise = rmsnoise ( myNoise:out )
```

SpectreMDL returns the total output referred noise from the pre-defined noise analysis `myNoise`.

rms (root-mean-square)

Returns the root mean square of a signal.

Syntax

rms(*sig* **)**

rms(sig=*sig* **)**

Arguments

sig	The signal.

Example

```
export real rmsOut = rms( V(out))
```

round

Rounds a number to the closest integer value.

Syntax

round(*arg* **)**

round(arg=*arg* **)**

Arguments

arg	The number.

Example

```
export real myround = round( 1.234 )
```

returns

```
myround = 1
```

S

Returns the complex value of Scattering (S) parameter of a network. Only available from sp analysis results.

Syntax

s(*rowindex*, *colindex*)

s(**rowIndex=***rowIndex*, **colIndex=***colIndex*)

Arguments

rowindex	The scattering matrix row index.
colindex	The scattering matrix column index.

In general, the 2-port network S-parameter definitions are:

s(1,1) input port voltage reflection coefficient

s(1,2) reverse voltage gain

s(2,1) forward voltage gain

s(2,2) output port voltage reflection coefficient

If used with the functions like db, angle, re or im, the real number value is returned:

db(s(1,1)) returns the db of s(1,1)

angle(s(1,1)) returns the phase of s(1,1) in degrees

ph(s(1,1)) returns the phase of s(1,1) in radians

re(s(1,1)) returns the real part of s(1,1)

im(s(1,1)) returns the image part of s(1,1)

Example

```
export real ft = cross( sig = ( db(s(2,1) ) ), dir = ’cross, n=1 )
```

returns

ft = 3.68369e+09

sample

Returns a waveform or an array representing a sample of the signal based on step size or points per decade.

Syntax

sample(*sig*, *from*, *to*, *by*, *type* **)**

sample(**sig=***sig*, **from=***from*, **to=***to*, **by=***by*, **type=***type* **)**

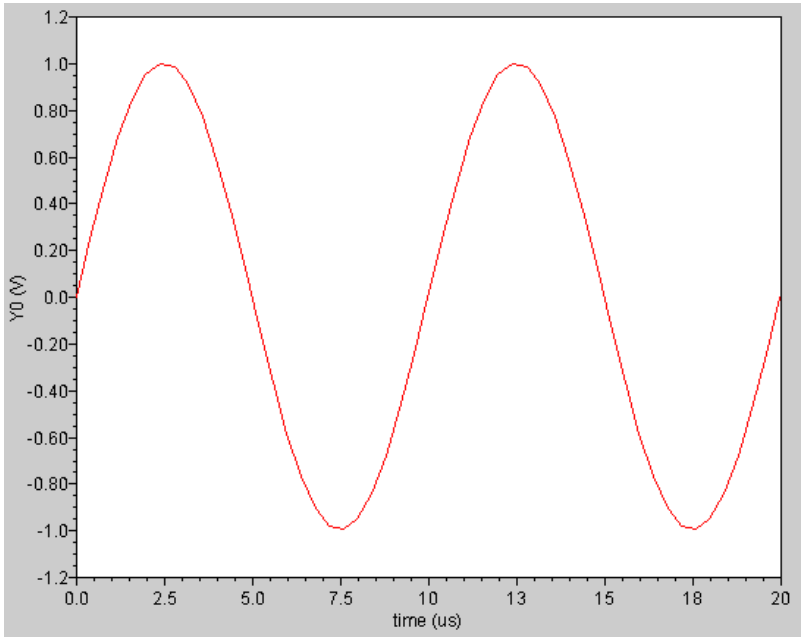
Arguments

sig	The signal.
from	The X-axis value at which the sampling begins.
to	The X-axis value at which the sampling stops.
type	Specifies whether the sample should be linear or logarithmic. Valid values: `'linear`, `'log`
	Default value: `'linear`
by	If type is `'linear`, specifies the step size for the sample. If type is `'log`, specifies the points per decade.

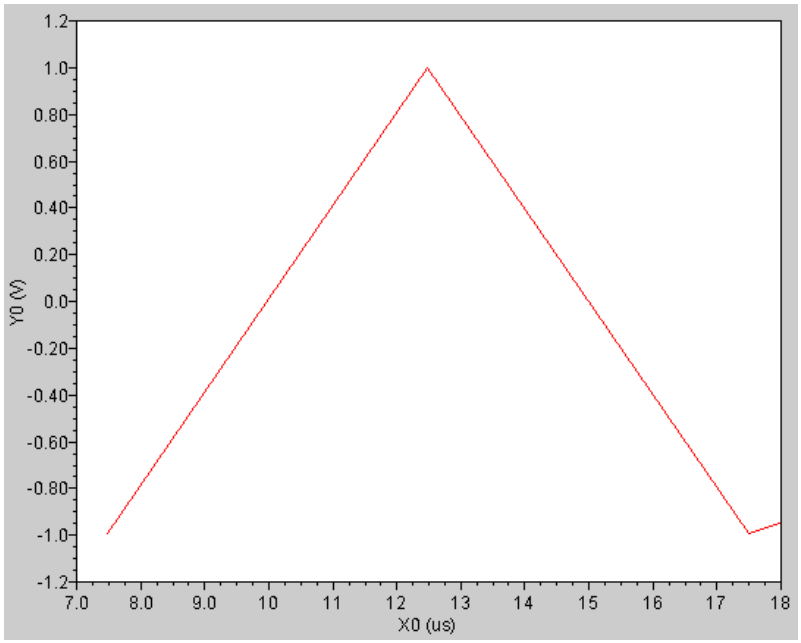
Example 1

```
export real sampleOut = sample(sig=V(2), from=7.5us, to=18us, by=5us, type='linear)
```

transforms the following input signal



into the following output signal



Example 2

```
export real v2smpl[] = sample(sig=V(2), from=10n, to=40n, by=0.1n)
```

The above example samples signal `V(2)` into an array as shown below:

```
v2smp1[0] = 1.08957e-10
v2smp1[1] = 1.21644e-08
v2smp1[2] = 1.8
v2smp1[3] = 2.39729e-07
v2smp1[4] = 1.8
...
```

settlingtime

Calculates the time required by a signal to settle at a final value within a specified limit.

Syntax

settlingtime(*sig*, *initval*, *finalval*, *inittype*, *finaltype*, *theta***)**

settlingtime(sig=*sig*, **initval=***initval*, **finalval=***finalval*, **inittype=***inittype*, **finaltype=***finaltype*, **theta=***theta* **)**

Arguments

sig	The signal.
initval	The starting value for the measurement.
finalval	The final value for the measurement.
inittype	Specifies whether *initval* is an X-axis or Y-axis value. If it is 'x, *initval* is the X-axis value. If it is 'y, *initval* is the Y-axis value.
finaltype	Specifies whether *finalval* is an X-axis or Y-axis value. If it is 'x, *finalval* is the X-axis value. If it is 'y, *finalval* is the Y-axis value and the signal settles at *finalval* until the end.
theta	Percentage of (*finalval*-*initval*) within which the signal has to settle.

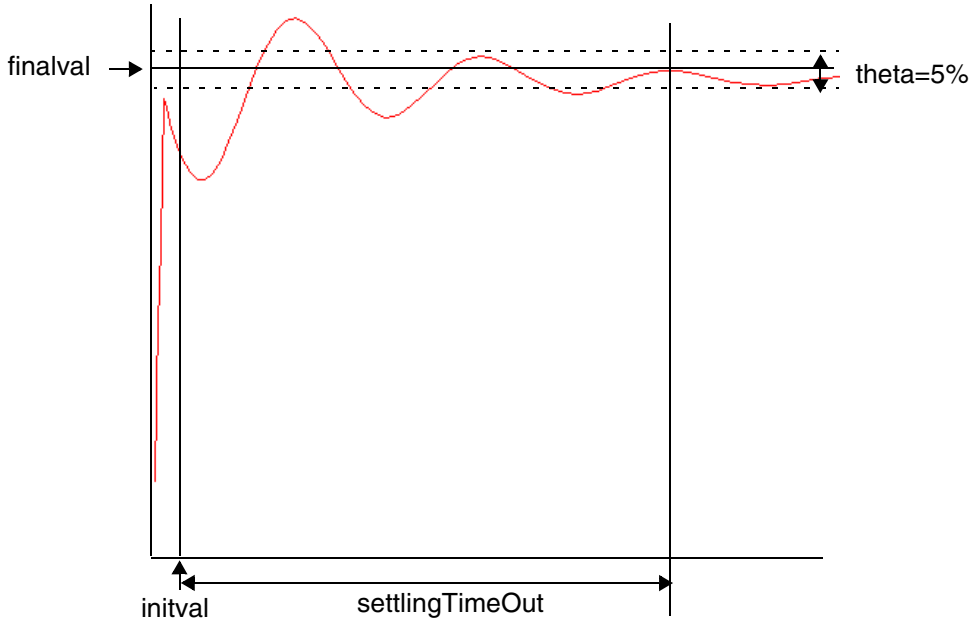
Example

```
export real settlingTimeOut = settlingtime( sig=V(out), initval=0, finalval=1.0,
inittype='y, finaltype='x, theta=5 )
```

returns

```
settlingTimeOut = 3.7185180980334184E-5sec
```

The following diagram illustrates how the result from the above example is determined.



sign

Returns a value that corresponds to the sign of a number.

Syntax

sign(*arg* **)**

sign(arg=*arg* **)**

Arguments

arg	The number whose sign is to be returned. If the number is greater than zero, the `sign` function returns 1.0; if the number is equal to zero, the `sign` function returns 0.0; if the number is less than zero, the `sign` function returns -1.0.

Example

```
sign( -17.3)
```

returns

```
-1.0
```

sin

Returns the sine of a signal.

Syntax

sin(*arg* **)**

sin(arg=*arg* **)**

Arguments

arg	The signal.

Example

```
export real mysin = sin( 1 )
```

returns

```
mysin = 0.84
```

sinh

Returns the hyperbolic sine of a signal.

Syntax

sinh(*arg* **)**

sinh(arg=*arg* **)**

Arguments

arg	The signal.

Example

```
export real mysinh = sinh( 1 )
```

returns

```
mysinh = 1.18
```

size

Returns the size of an array or the number of points in a waveform.

Syntax

size(*arg,* [, from [, to]]**)**

size(arg=*arg* [, **from=***from*] [, **to=***to*]**)**

Arguments

arg	The signal or the array.
from	The starting abscissa.
to	The ending abscissa

Example 1

```
run tran(  step=1e-09, pstep=1e-09, stop=9e-02 )
export real signalNum = size( V(R1), 8.9e-022, 9e-02)
```

returns

```
signalNum = 108018
```

Example 2

```
export real cro = crosses(sig=(V(R1))-(1/ 2),dir='cross,n=int(1))
export real num = size(cro)
```

returns

```
cro[0]          =  8.33333e-07
cro[1]          =  4.16583e-06
cro[2]          =  1.08334e-05
cro[3]          =  1.41666e-05
num             = 4
```

Example 3

```
export real arr [] = {1.1, 2.2}
export real num = size(arr)
```

returns

```
arr[0]    = 1.1
arr[1]    = 2.2
num      = 2
```

slewrate

Computes the average rate at which the buffer expression changes from percent low to percent high of the difference between the initial value and the final value.

Syntax

```
slewrate( sig[, initval[, finalval [, inittype[, finaltype[, theta1[,
     theta2[, xtol[, ytol[, accuracy]]]]]]]] )

slewrate( sig=sig, initval=initval, finalval=finalval [, inittype=inittype] [,
     finaltype=finaltype] [, theta1=theta1] [, theta2=theta2] [, xtol=xtol] [,
     ytol=ytol] [, accuracy=accuracy] )
```

Arguments

sig	The signal.
initval	The X value (if inittype is 'x) or Y value (if inittype is 'y) that starts the rise time interval.
finalval	The X value (if inittype is 'x) or Y value (if inittype is 'y) that ends the rise time interval.
inittype	When 'x, the initial value is an X value When 'y, the initial value is a Y value. Valid values: 'x, 'y Default: 'y
finaltype	When 'x, the final value is an X value. When 'y, the final value is a Y value. Default: 'y
theta1	The percent low. Default: 10
theta2	The percent high. Default: 90
xtol	The relative tolerance in percentage value in the X direction. Default: 1
ytol	The relative tolerance in percentage value in the Y direction. Default: 1

accuracy	Specifies whether the function should use interpolation, or use iteration controlled by the absolute tolerances to calculate the value. `'interp` directs the function to use interpolation, and `'exact` directs the function to consider the xtol and yval values. Data types: name for scalar Valid values: `'interp`, `'exact` Default: `'exact`

Example

A statement like

```
export real slewrate1 = slewrate( V(out), 20ns, 60ns )
```

produces a result similar to

```
6.337662406448401E7V/s
```

slice

Returns the slice of an array.

Syntax

slice(arg, from, to, step)

slice(**arg**=*arg*, **from**= *from*, **to** = *to*, **step** =*step*)

Arguments

array	A user-defined array, or an array that comes from the built-in function.
from	Array starting subscript.
to	Array ending subscript.
step	Array step.

Example

```
real arr[]={1.0,2.0,3.0,4.0,5.0,6.0,7.0}
export real myslice1=slice(arr,from=2,to=5,step=1)
export real myslice2=slice(arr,from=2,to=5,step=2)
```

returns

```
myslice1[0]   =  2
myslice1[1]   =  3
myslice1[2]   =  4
myslice1[3]   =  5

myslice2[0]   =  2
myslice2[1]   =  4
```

snr

Calculates the signal to noise ratio from a complex frequency based signal.

Syntax

snr(*sig*, *sig_from*, *sig_to*, *noise_from*, *noise_to* **)**

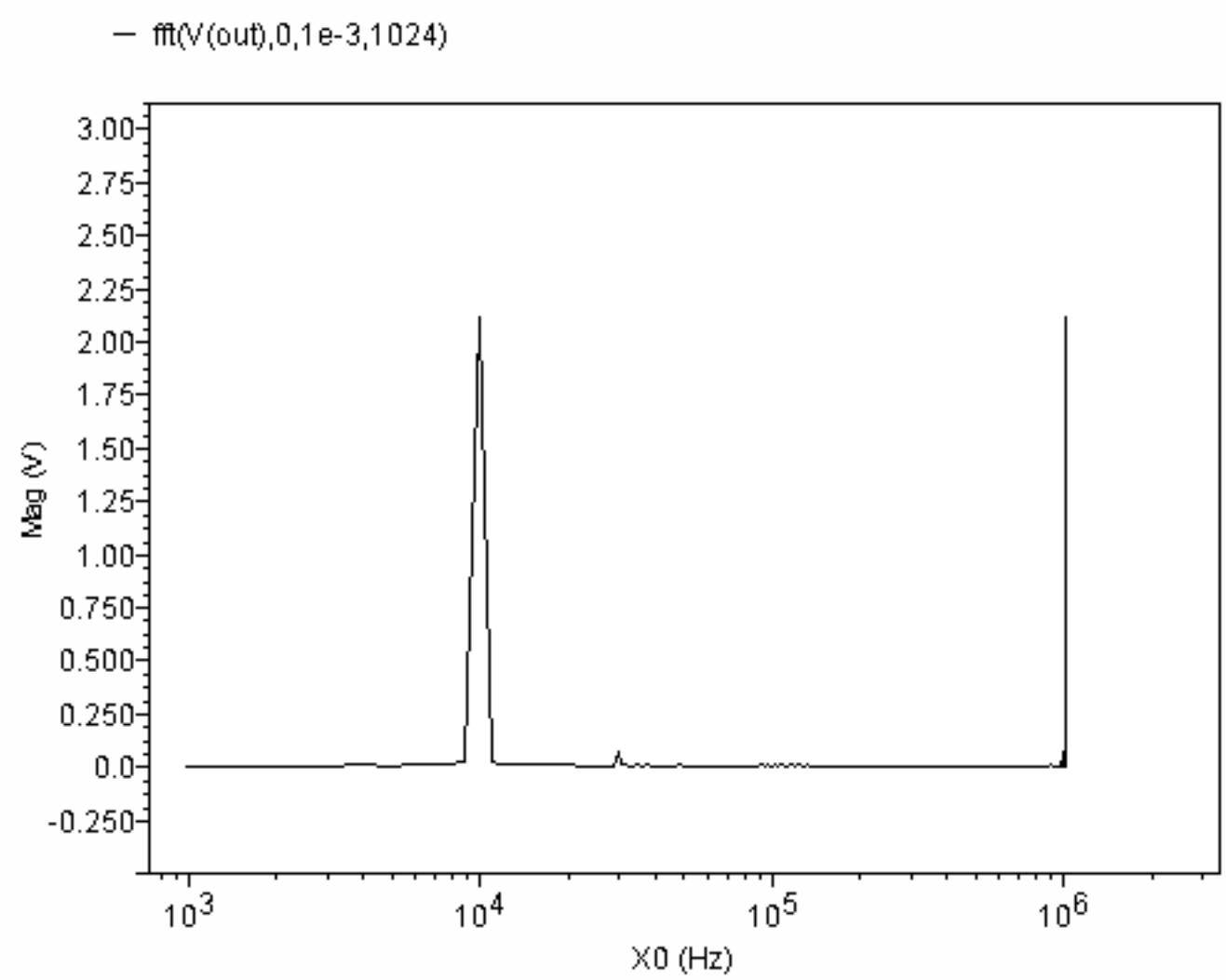
snr(sig=*sig*, **sig_from=***sig_from*, **sig_to=***sig_to*, **noise_from=***noise_from*, **noise_to=***noise_to* **)**

Arguments

sig	The signal.
sig_from	The left window border of the signal. The *sig_from* value must be greater than or equal to *noise_from*.
sig_to	The right window border of the signal. The *sig_to* value must be less than or equal to *noise_to*.
noise_from	The left window border of the noise.
noise_to	The right window border of the noise.

Example

You have the following frequency plot.



To determine the signal-to-noise ratio, you use the statement

```
export real snr(fft(V(out),0,1e-3,1024),9e3,11e3,1,500e3)
```

which, in this case, returns

```
29.268026738835342dB
```

spectrumMeas

Calculates Signal-to-Noise-and-Distortion Ratio (SINAD), Spurious Free Dynamic Range (SFDR), Effective Number of Bits (ENOB), and Signal-to-Noise Ratio (without distortion) by using discrete Fourier transform of the clipped portion of any given input signal.

The spectrum measure is used for characterizing A-to-D converters and is typically supported for transient simulation data.

Syntax

```
spectrumMeas( signal, startTime, endTime, numberofSamples, numberofNoisebins,
     startFrequency, endFrequency, windowType )

spectrumMeas( signal=signal, startTime=startTime, endTime=endTime,
     numberofSamples=numberofSamples, numberofNoisebins=numberofNoisebins,
     startFrequency=startFrequency, endFrequency=endFrequency,
     windowType=windowType adcspan=adcspan measureType=measureType )
```

Arguments

signal	The signal to be measured.
startTime	The time to start clipping the signal in the time domain.
numberofSamples	Number of noise bins where the size of one bin is the reciprocal of the data window width. For example, 1 ms of transient data creates a bin size of 1 kHz. Valid values: Any integer power of two greater than or equal to zero. Default value: 0, which implies that no signal is spilling into the bins. A frequency band of bin-size times the number of bins is calculated and adjusted as a function of the selected window. Frequency components in each band to the left and right of the fundamental or the harmonics are set to zero and do not contribute to any output result.
startFrequency	Lower limit of frequency range for the spectrum measures. Default value: First frequency point of the FFT.
endFrequency	Upper limit of frequency range for the spectrum measures. Default value: Last frequency point of the FFT.

windowType	Windowing function applied to the input waveform. Valid values: 0: Rectangular, 1: Blackman, 2: BlackmanHarris, 3: Cosine2, 4: Cosine4, 5: ExtCosBell, 6: HalfCycleSine, 7: HalfCycleSine3, 8: HalfCycleSine6, 9: Hanning, 10: Hamming, 11: Parzen, and 12: Triangular. Default value: 0: Rectangular.
adcSpan	Full-scale span ignoring any DC offsets. This is used in ENOB calculation. Valid values: Any floating point value. Default value: If ADC Span is not specified or is nil, it is assumed to be 0 and is taken to be the peak-to-peak value of the fundamental.
measureType	Result specifier. Valid values: 0:sinad, 1:snhr, 2:sfdr(db), and 3:enob. Default value: 0:sinad."

Example (netlist)

```
.tran 1n 1000n
.measure tran sinad param=spectrumMeas(V(1), 10ns, 110ns, 200, 0, 0, 0, 0, 0, 0)
.measure tran snhr param=spectrumMeas(V(1), 10ns, 110ns, 200, 0, 0, 0, 0, 0, 1)
.measure tran sfdr param=spectrumMeas(V(1), 10ns, 110ns, 200, 0, 0, 0, 0, 0, 2)
.measure tran enob param=spectrumMeas(V(1), 10ns, 110ns, 200, 0, 0, 0, 0, 0, 3)
```

Example (MDL file)

```
alias measurement transient {
    export real sinad, snhr, sfdr, enob
    export real temper
    temper=temp
    run tran( step=1.0000000000000001e-09, pstep=1e-09, stop=1.0000000000000002e-
06 )
    sinad=spectrumMeas( V(1),1e-08 ,1.1e-07 ,200 ,0 ,0 ,0 ,0 ,0 ,0 )
    snhr=spectrumMeas( V(1),1e-08 ,1.1e-07 ,200 ,0 ,0 ,0 ,0 ,0 ,1 )
    sfdr=spectrumMeas( V(1) ,1e-08 ,1.1e-07 ,200 ,0 ,0 ,0 ,0 ,0 ,2 )
    enob=spectrumMeas( V(1),1e-08 ,1.1e-07 ,200 ,0 ,0 ,0 ,0 ,0 ,3 )
}
 run transient as transient1
```

sqrt

Returns the square root of a signal.

Syntax

sqrt(*arg* **)**

sqrt(arg=*arg* **)**

Arguments

arg	The signal.

Example

```
export real mysqrt = sqrt( 4 )
```

returns

```
mysqrt = 2
```

stathisto

Creates a histogram from a signal.

The stathisto function is available from the calculator. It is not supported within a Spectre MDL control file since it returns a scalar and not a waveform.

Syntax

```
stathisto( sig [, nbins][, min][, max][, innerswpval] )
stathisto(sig=sig [, nbins=nbins] [, min=min] [, max=max]
     [, innerswpval=inner swpval])
```

Arguments

sig	The waveform.
nbins	The number of bins to be created.
min	The value that specifies the smaller end point of the range of values included in the histogram.
max	The value that specifies the larger end point of the range of values included in the histogram.
innerswpval	The inner-most sweep parameter in the dataset. You use this parameter to slice through parametric waveforms to extract the data for the histogram. Default: The first available value of time in the dataset.

Example

Assume that you have the results of running a Monte Carlo analysis on top of a transient analysis, so that the inner-most swept variable is time. Now, for the particular value of time specified by the *innerswpval* argument specification, the `stathisto` function creates a histogram by analyzing all the Monte Carlo iterations and extracting from each one the value of the signal at the specified time.

For example, to create a histogram for the time 100ns, you might use the following statement.

```
stathisto(I(V10\:p),innerswpval=100e-9)
```

To create a histogram for the time 650ps, you might use the following statement.

```
stathisto(I(V10\:p),innerswpval=.65e-9)
```

stddev

Returns the standard deviation of a signal. Standard deviation is defined as follows:

`sqrt( variance(`*N*`) )`

Syntax

stddev(*arg* **)**

stddev(arg=*arg* **)**

Arguments

arg	The signal.

sum

Returns the sum value of an array.

Syntax

sum(*arg* **)**

sum(arg=*arg* **)**

Arguments

arg	A user-defined array, or an array that comes from the built-in function.

Example

```
real arr[ ] = {1.0, 2.0, 3.0}
export real mysum=sum(arr)
```

returns

```
mysum=6.0
```

system

Returns a string, which is the output of *command* executed by shell.

Syntax

system (*command* **)**

system (**command=***command* **)**

Arguments

command	A user-specified shell command.

Example

```
string d1=system( "date +\"%y%m%d%H%M\"" );
print fmt("%s", d1) addto="aa.data"
```

returns

```
1302130702
```

Note: The function should only be used at the top-level MDL file, or before the `run` command in an alias measurement, and not during analysis.

tan

Returns the tangent of a signal.

Syntax

tan(*X* **)**

tan(X=*X* **)**

Arguments

X	The scalar or signal.

Example

```
export real mytan = tan( 1 )
```

returns

```
mytan = 1.56
```

tanh

Returns the hyperbolic tangent of a signal.

Syntax

tanh(*arg***)**

tanh(arg=*arg* **)**

Arguments

arg	The scalar or signal.

Example

```
export real mytanh = tanh( 1 )
```

returns

```
mytanh = 0.76
```

thd

Computes the percentage of the total harmonic distortion (THD) of a signal with respect to the fundamental frequency and is expressed as a voltage percentage.

Syntax

```
thd( signal, from, to, numberofSamples, fundamental )
```

```
thd( signal=signal, from=from, to=to, numberofSamples=numberofSamples,
     fundamental=fundamental )
```

Arguments

signal	Signal to be measured
from	Start time of the signal frequency
to	Stop time of the signal frequency
numberofSamples	Number of time domain points to be used
fundamental	Fundamental frequency of the signal

Example (netlist)

```
.tran 1n 1000n
.measure tran thd param='thd(V(1), 10ns, 110ns, 200, 1G)'
```

Example (MDL file)

```
alias measurement transient {
    export real thd
    export real temper
    temper=temp
    run tran( step=1.0000000000000001e-09, pstep=1e-09, stop=1.0000000000000002e-
06 )
    thd=thd( V(1) ,1e-08 ,1.1e-07 ,200 ,1000000000 )
}
```

trim

Returns the portion of a signal between two points along the abscissa.

Syntax

trim(*sig*[, *from*[, *to*]] **)**

trim(sig=*sig* [, **from=***from*] [, **to=***to*] **)**

Arguments

sig	The signal. Data types: real for scalar
from	The starting abscissa. Data types: real for scalar
to	The ending abscissa. Data types: real for scalar

Example 1

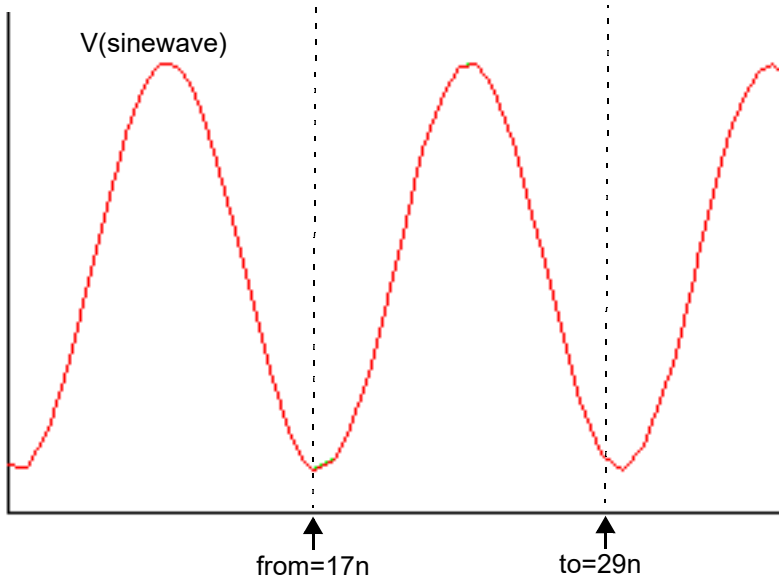
The following example works in an MDL control file.

```
export real trimOut = max ( trim( sig=V(sinewave), from=17n, to=29n ))
```

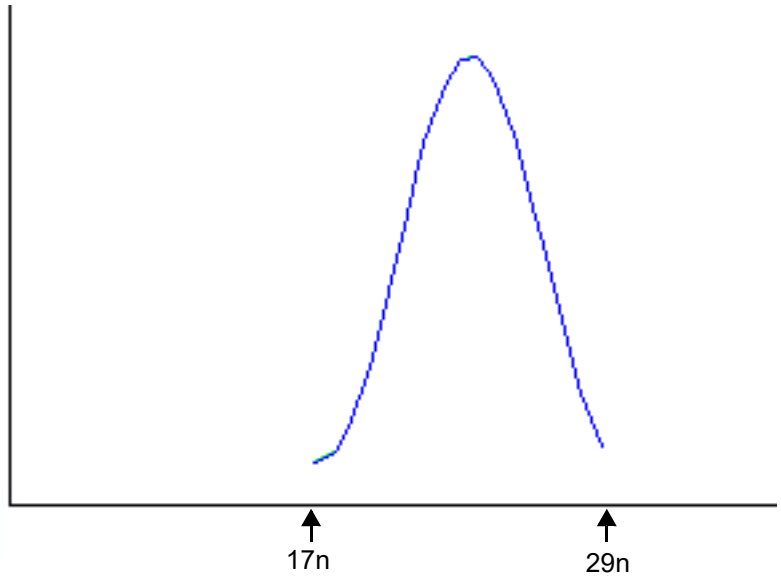
In Virtuoso Visualization and Analysis XL,

```
trim ( sig=V(sinewave), from=17n, to=29n )
```

transforms the following input signal



into the following output signal



V

Returns the voltage of a net.

Syntax

V(*node***)**

V(*node, node***)**

V(*Instname*:*term***)**

V(*Instname*:*term, Instname*:*term***)**

```
V(devname)      //which outputs voltage value between positive and negative
     terminals of a 2-terminal device.
```

`V(node)` takes precedence over `V(devname)`. It is illegal to apply the `V` probe function to a devname and a node, or a pair of devnames. `V` can be uppercase or lowercase.

Arguments

node	The net name with or without the hierarchical path.
Instname	The instance name. It can be a N-terminal device instance or a N-terminal subcircuit instance.
devname	The 2-terminal device name (not including the 2-terminal subcircuit instance).
term	The terminal name or terminal index of a device or a subcircuit instance.

Examples

```
V(p,n)         // Returns the voltage between nodes p and n.
V(Rload:1)     // Returns the voltage from terminal Rload:1 to ground.
V(I0:q)        // Returns the voltage from terminal I0:q to ground.
V(I0:q,I1:y)   //Returns the voltage between terminal I0:q and terminal I1:y.
```

variance

Returns the statistical variance of a signal. The variance is defined as follows:

`1/(`*N*`-1) * ( (X1 - mean)^2 + (X2-mean)^2 + .... (XN-mean)^2) ,`

where *N* is the total number of samples.

Syntax

variance(*arg***)**

variance(arg=*arg* **)**

Arguments

arg	The scalar or signal.

window

Applies the specified window to a signal.

Syntax

window(*arg*[, *window*] **)**

fft(arg=*arg*[, **window=***window*] **)**

Arguments

arg	The signal.
window	The window to be applied. Valid values: 'rectangular, 'bartlett, 'bartletthann, 'blackman, 'blackmanharris,'cosine2, 'cosine4, 'extcosbell, 'flattop, 'halfcyclesine, 'half3cyclesine, 'halfcyclesine3, 'half6cyclesine, 'halfcyclesine6, 'hamming, 'hanning, 'nuttall, 'parzen, 'triangular Default: 'rectangular

Equations and Examples

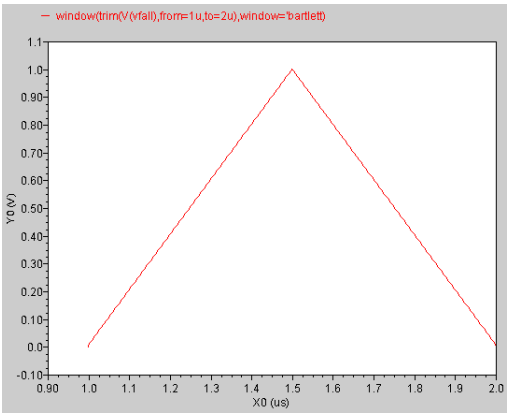
This section describes the equations used by each type of window and then shows an example. In the equations:

N = total number of waveform points

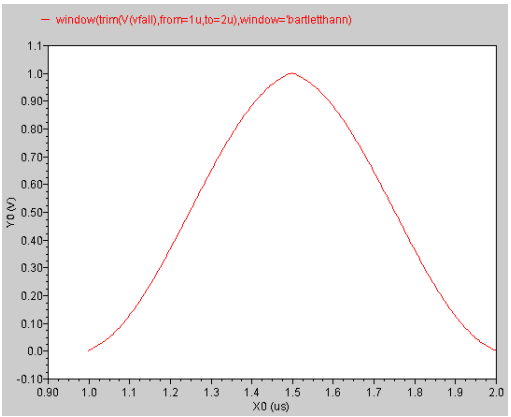
n = current waveform point

Window	Equation and Example	Where
'rectangular	$w(n) = 1$	

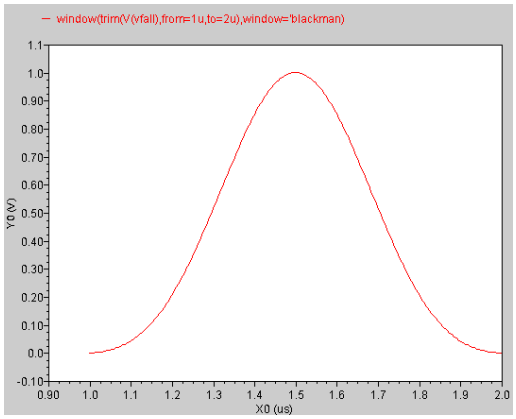
Window	Equation and Example	Where
'bartlett	$w(n) = 1 - abs\left(2 \times \frac{n}{N} - 1\right)$	0≤n≤N
	$w(n) = 0$	otherwise



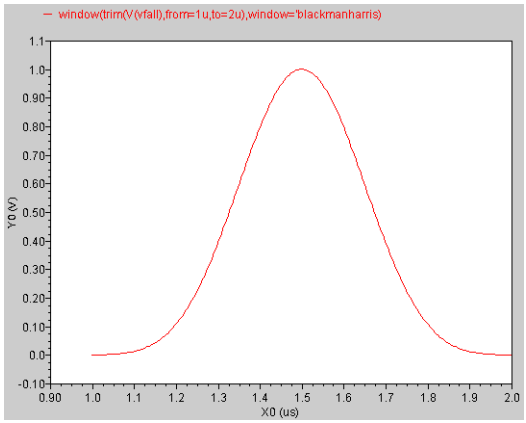
'bartletthann	$w(n) = 0.62 - 0.48 \times abs\left(\frac{n}{N} - 0.5\right) + 0.38 \times \cos\left(2 \times 'pi \times \left(\frac{n}{N} - 0.5\right)\right)$	0≤n≤N
	$w(n) = 0$	otherwise



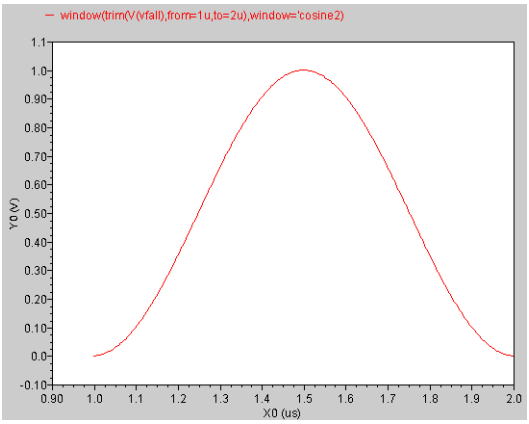
Window	Equation and Example	Where
'blackman	$w(n) = 0.42 - 0.50 \times \cos\left(2 \times 'pi \times \frac{n}{N}\right) + 0.08 \times \cos\left(4 \times 'pi \times \frac{n}{N}\right)$	0≤n≤N
	$w(n) = 0$	otherwise



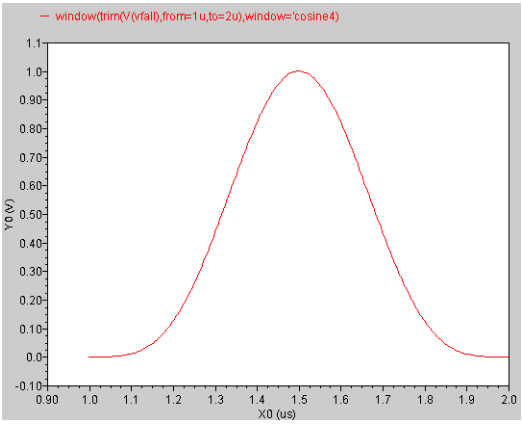
'blackmanharris	$w(n) = 0.35875 - 0.48829 \times \cos\left(2 \times 'pi \times \frac{n}{N}\right) + 0.14128 \times \cos\left(4 \times 'pi \times \frac{n}{N}\right) + -0.01168 \times \cos\left(6 \times 'pi \times \frac{n}{N}\right)$	0≤n≤N
	$w(n) = 0$	otherwise



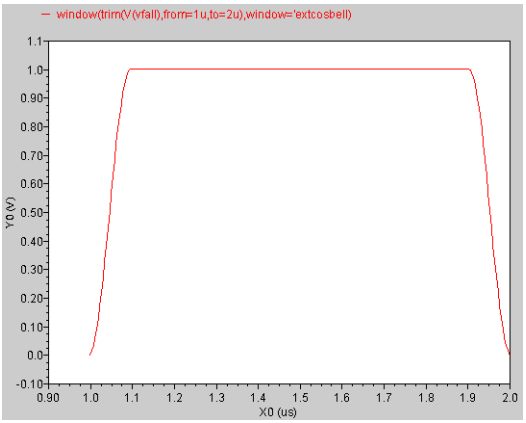
Window	Equation and Example	Where
'cosine2	$w(n) = 0.5 - 0.5 \times \cos\left(2 \times 'pi \times \frac{n}{N}\right)$	0≤n≤N
	$w(n) = 0$	otherwise



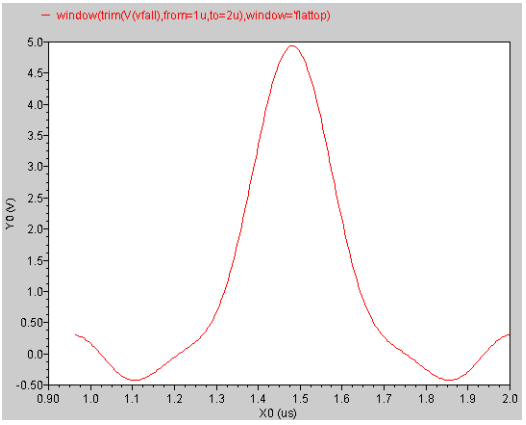
'cosine4	$w(n) = \left(0.5 - 0.5 \times \cos\left(2 \times 'pi \times \frac{n}{N}\right)\right)^2$	0≤n≤N
	$w(n) = 0$	otherwise



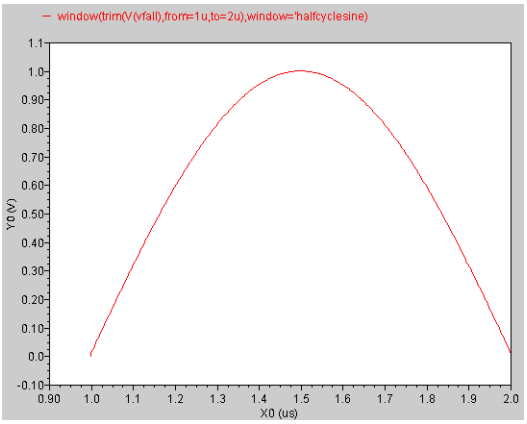
Window	Equation and Example	Where
'extcosbell	$w(n) = 0.5 - 0.5 \times \cos\left(10 \times 'pi \times \frac{n}{N}\right)$	abs(n/N - 0.5) > 0.4
	$w(n) = 1$	otherwise



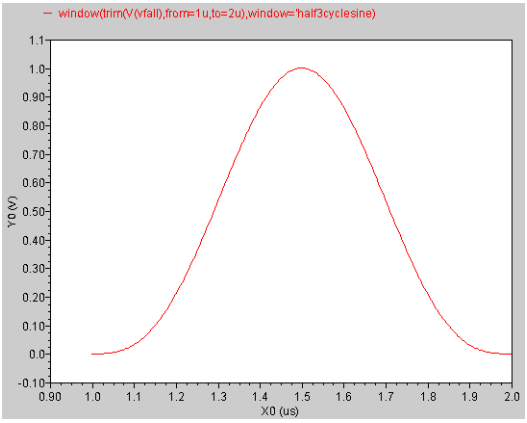
'flattop	$w(n) = 1 - 1.93 \times \cos\left(2 \times 'pi \times \frac{n}{N}\right) + 1.29 \times \cos\left(4 \times 'pi \times \frac{n}{N}\right) - 0.388 \times \cos\left(6 \times 'pi \times \frac{n}{N}\right) + 0.322 \times \cos\left(8 \times 'pi \times \frac{n}{N}\right)$	0≤n≤N
	$w(n) = 0$	otherwise



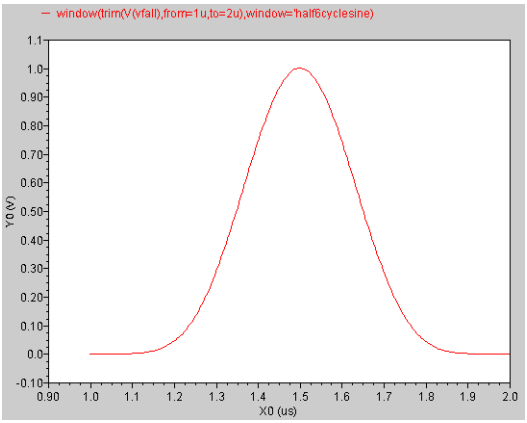
Window	Equation and Example	Where
'halfcyclesine	$w(n) = \sin\left('pi \times \frac{n}{N}\right)$	0≤n≤N
	$w(n) = 0$	otherwise



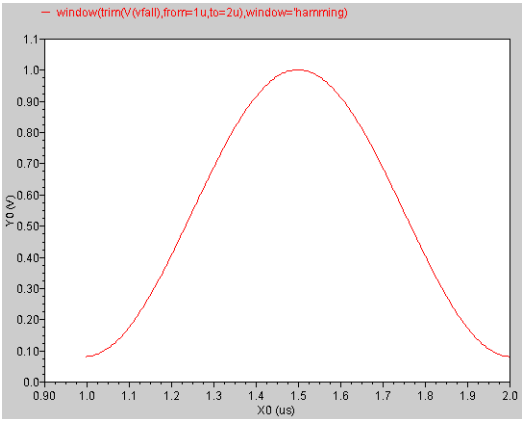
'half3cyclesine and 'halfcyclesine3	$w(n) = \left(\sin\left('pi \times \frac{n}{N}\right)\right)^3$	0≤n≤N
	$w(n) = 0$	otherwise



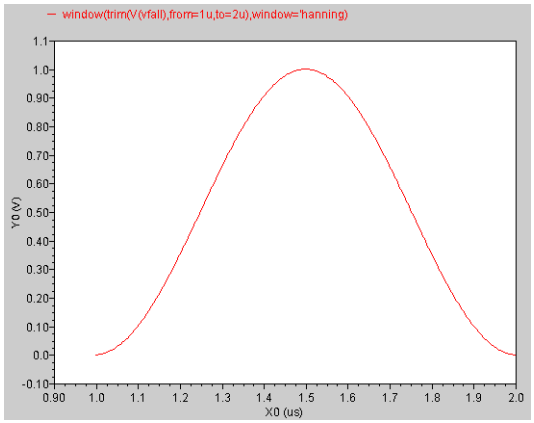
Window	Equation and Example	Where
'half6cyclesine and 'halfcyclesine6	$w(n) = \left(\sin\left('pi \times \frac{n}{N}\right)\right)^6$	0≤n≤N
	$w(n) = 0$	otherwise



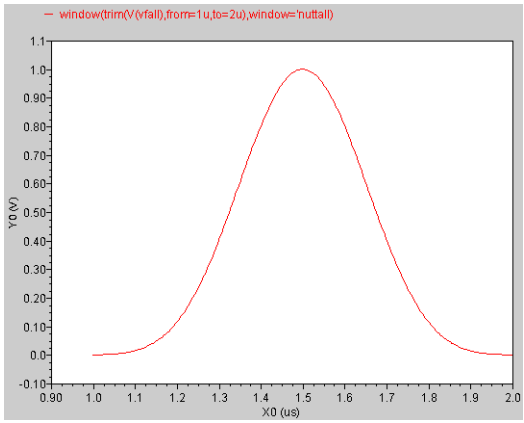
'hamming	$w(n) = 0.54 - 0.46 \times \cos\left(2 \times 'pi \times \frac{n}{N}\right)$	0≤n≤N
	$w(n) = 0$	otherwise

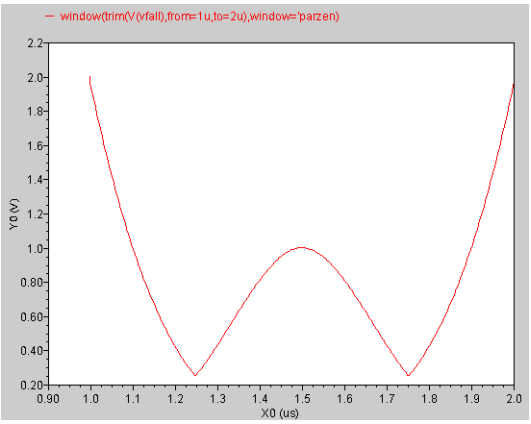


Window	Equation and Example	Where
'hanning	$w(n) = 0.5 - 0.5 \times \cos\left(2 \times 'pi \times \frac{n}{N}\right)$	0≤n≤N
	$w(n) = 0$	otherwise



'nuttall	$w(n) = 0.3635819 - 0.4891775 \times \cos\left(2 \times 'pi \times \frac{n}{N}\right) + 0.1365995 \times \cos\left(4 \times 'pi \times \frac{n}{N}\right) - 0.0106411 \times \cos\left(6 \times 'pi \times \frac{n}{N}\right)$	0≤n≤N
	$w(n) = 0$	otherwise



Window	Equation and Example	Where
'parzen	$w(n) = 1 - 6 \times abs\left(2 \times \frac{n}{N} - 1\right) + 6 \times abs\left(2 \times \frac{n}{N} - 1\right)$ $w(n) = 2 \times abs\left(2 \times \frac{n}{N} - 1\right)$ 	abs(2*n/N-1)≤0.5 otherwise
'triangular	Same as bartlett. For more information, see 'bartlett on page 223.	

xval

Returns the vector consisting of the abscissas of the points in the signal.

Syntax

xval(*arg* **)**

xval(arg=*arg* **)**

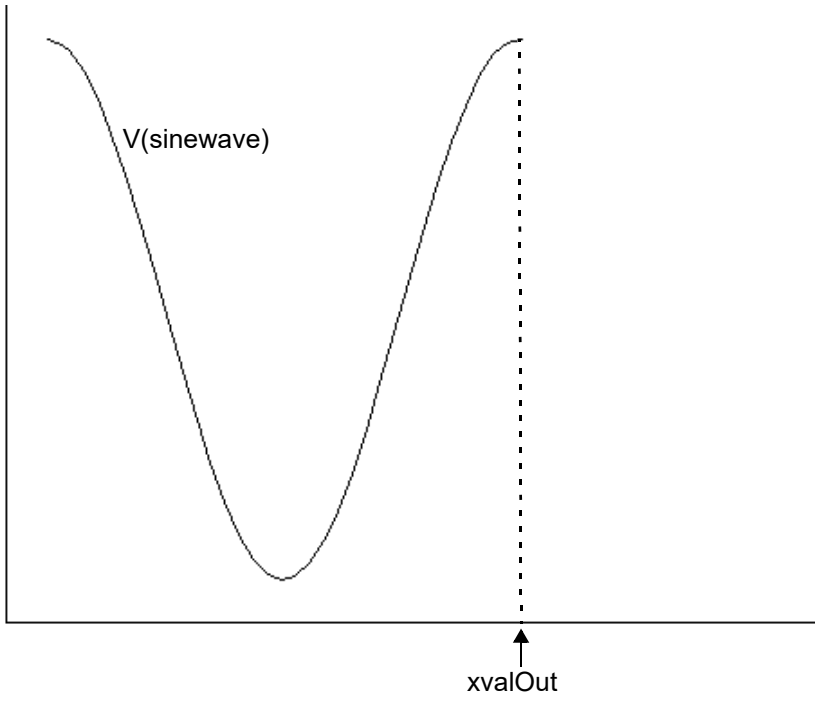
Arguments

arg	The signal.

Example 1

```
export real xvalOut = max ( xval( V(out) ) )
```

Returns the maximum X-axis value for `V(out)`.



Example 2

```
export real xvalMax=xval(max(V(out)))
```

Returns the X-axis value of the point where `V(out)` is at its maximum voltage value.

Y

Returns the complex value of the Admittance (Y) parameter of a network.

Syntax

y(*rowindex*, *colindex*)

y(**rowIndex=***rowIndex*, **colIndex=***colIndex*)

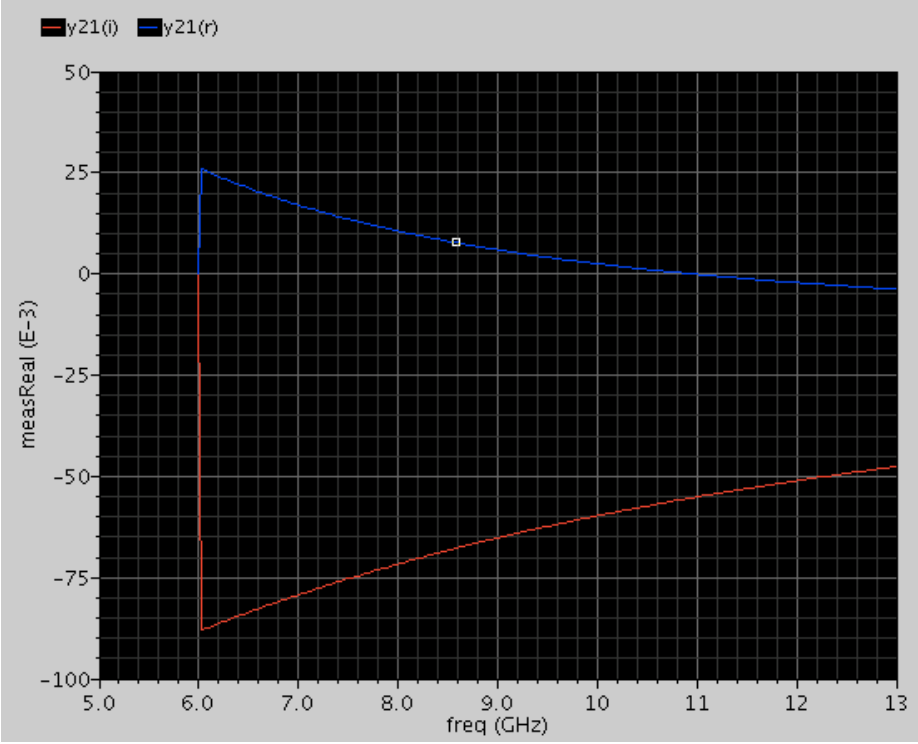
Arguments

rowindex	The admittance matrix row index. The value can be scalar.
colindex	The admittance matrix column index. The value can be scalar.

Example

```
real __mdlvar_13=_hprobe( "y21(r)", re(y(2,1)) )
real __mdlvar_14=_hprobe( "y21(i)", im(y(2,1)) )
```

The output looks like below.



yval

Returns a vector consisting of the ordinates of the points in the signal. This function can also calculate the ordinate value at a specified abscissa value.

Syntax

yval(*arg* **)**

yval(arg=*arg* **)**

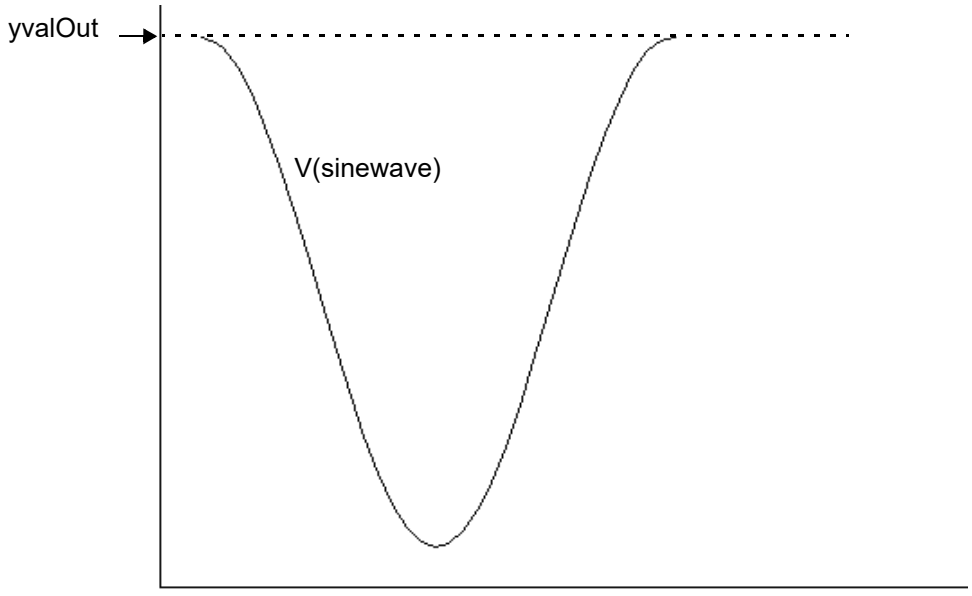
Arguments

arg	The signal.

Example 1

```
export real yvalOut = max ( yval( V(out) ) )
```

Returns the maximum Y-axis value for `V(out)`.



Example 2

```
export real yvalOut1 = yval ( V(out)@ 100ns )
```

returns

```
3.467928474540306
```

Z

Returns the complex value of Impedance (Z) parameter of a network.

Syntax

z(*rowindex*, *colindex*)

z(**rowIndex=***rowIndex*, **colIndex=***colIndex*)

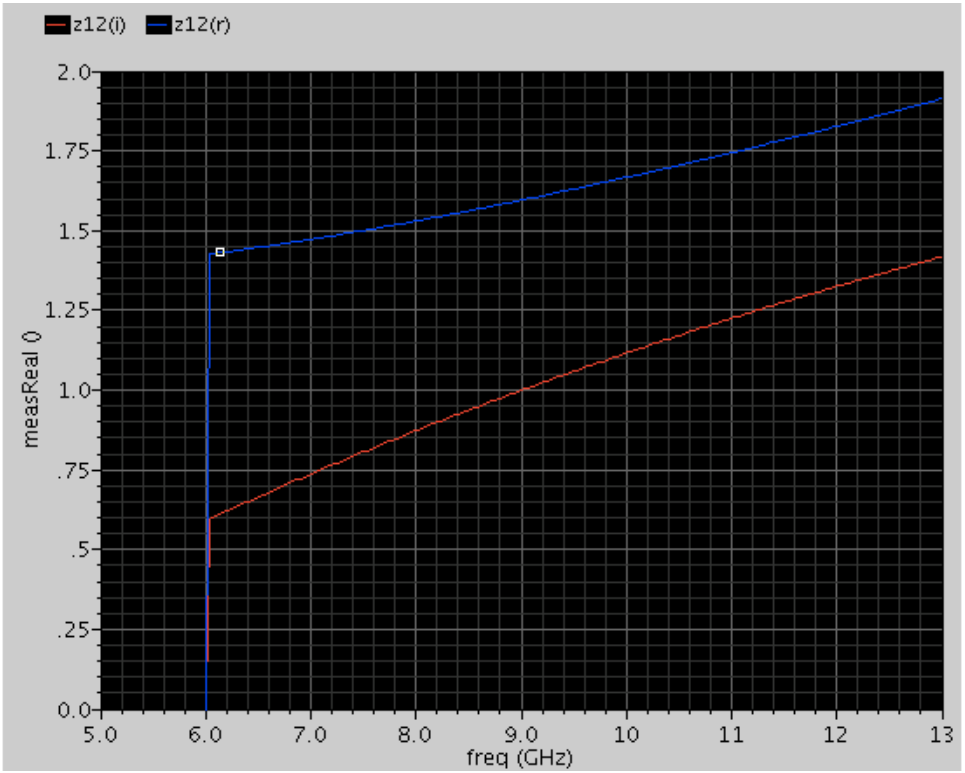
Arguments

rowindex	The impedance matrix row index. The value can be scalar.
colindex	The impedance matrix column index. The value can be scalar.

Example

```
real __mdlvar_7=_hprobe( "z22(r)", re(z(2,2)) )
real __mdlvar_8=_hprobe( "z22(i)", im(z(2,2)) )
```

The output looks like below.



B

SPICE Compatibility for Analyses

MDL supports the SPICE `.tran`, `.ac`, `.dc`, and `.op` analyses as described below.

1. MDL supports SPICE `.tran`, `.ac`, `.dc`, and `.op` analyses defined in the netlist.
2. Each `.tran`, `.ac`, `.dc`, or `.op` is mapped to a Spectre `tran`, `ac`, `dc`, or `op` analysis. Multiple SPICE analyses per analysis type are supported as well. Here is a list of Spectre mapped names:

	Spectre Mapped Name	
SPICE Analysis Type	**First Run Name**	**Subsequent Run Names**
.TRAN	timeSweep	tran2, tran3, …,tran*n*
.AC	frequencySweep	ac2, ac3, …, ac*n*
.DC	srcSweep	dc2, dc3, …, dc*n*
.OP	opBegin	op2, op3, …, op*n*

Therefore, the following statements are necessary in an MDL control file when running MDL on a netlist in SPICE format:

```
run opBegin          // runs first defined .OP analysis
run op2              // runs second defined .OP analysis

run srcSweep         // runs first defined .DC sweep analysis
run dc2              // runs second defined .DC sweep analysis

run frequencySweep   // runs first defined .AC analysis
run ac2              // runs second defined .AC analysis

run timeSweep        // runs first defined .TRAN analysis
run tran2            // runs second defined .TRAN analysis
```

3. When running MDL, the SPICE `.measure`/`.probe`/`.print` statements defined in the netlist are ignored. In other words, the MDL control file supersedes the SPICE `.measure`/`.probe`/`.print` statements defined in the netlist.
However, if running Spectre but not MDL (for instance, using command line `spectre`

spice.ckt), the .measure/.probe/.print statements defined in the netlist supersede the spice .mdl control file.

4. The analyses can be parameterized in the MDL control file without modifying the netlist (see Example 2 on page 238).
5. Mixed syntax netlists (containing both Spice and Spectre syntax analyses statements) are also supported in MDL (see Example 3 on page 239).
6. Multi-level sweeps of .tran/.dc/.ac are not supported in MDL. For example, the following SPICE .ac statement is not supported.

   ```
   .ac dec 20 1k 100k SWEEP V1 1 3 2
   ```

   You can use MDL foreach statement to sweep V1:mag and run AC analysis inside the alias measurement (see Example 4 on page 239). If you want to do a DC sweep, you need to sweep V1:dc and run a DC analysis.

Example 1

For the SPICE analyses below:

*in Netlist

```
.TRAN 1ns 5us
.TRAN 1ns 10us START=8us
.ac dec 10 1 10M
.ac dec 10 100M 1G
```

The equivalent MDL statements are:

//in MDL control file

```
run timeSweep                 // runs first .tran with stop time of 5us
run tran2 (start=8us)         // runs second .tran with stop time of 10us
run frequencySweep            // runs first .ac sweeping from 1Hz to 10MHz
run ac2                       // runs second .ac sweeping from 100MHz to 1GMHz
```

Example 2

The following example shows how to set a new value for the parameters of built-in analyses without modifying the netlist:

For the following SPICE analysis:

*in Netlist

```
.TRAN 1ns 5us
```

The following statement tells the simulator to run transient analysis with the new stop time 100us:

//----in MDL control file -----

```
run timeSweep(stop=100u)                // set stop time to new value 100us
```

Example 3

For mixed syntax statements like the following:

*in Netlist

```
.op
.dc V1 0 1 0.1
simulator lang=spectre
mytran tran stop=1ms
```

The equivalent MDL statements are:

//in MDL control file

```
run opBegin       // runs .op pre-defined in SPICE syntax
run srcSweep      // runs .dc pre-defined in SPICE syntax
run mytran        // runs tran analysis pre-defined in SPECTRE syntax
```

Example 4

To implement the following SPICE-like sweeps:

```
.ac dec 20 1k 100k SWEEP V1 1 3 2
```

You can use the following statements:

*in Netlist

```
.ac dec 20 1k 100k
```

//in MDL control file

```
alias measurement acmeas {
     run freqencySweep
     <export variable block>
     }

foreach V1:dc from swp (start=1, stop=3, step=2) {
     run acmeas
     }
```

C

SPICE Compatibility for options supported by MDL

Support the SPICE option .option co=<number>

Spectre supports the SPICE option ".option co=<number>" as described below.

1. Spectre supports the SPICE option co to control the number of columns in the .print file by mapping it to the Spectre option colslog.
2. When <number> is defined between (n*15) and ((n+1)*15), then the (n+1) columns with 15 bit per column are printed to the .print file, where n columns is for defined variables and 1 column is for independent variable such as time for transient, frequency for AC analysis and swept parameter for DC analysis.
3. The default value is 80, printing 6 column data.
4. The minimum value is 31, printing 2 column data. If it is less than 31, Spectre uses the default value (80) and prints 6 column data.
5. The co option is not supported in .alter block.

Example 1

```
.option co=132
```

Spectre outputs 9 columns on a single line in .print file.

Example 2

```
Simulator lang=spectre
Opt1 options colslog=60
```

Spectre outputs 5columns on a single line in .print file.

Support equal interval output for `.print`

1. Spectre can print transient results to `.print` file in equal step (that are defined in `.tran` statement) by taking advantage of the spectre option `printstep`.
2. The value of `printstep` can be 1 | 0, true | false or yes | no. When `printstep=1/true/yes`, Spectre prints transient results in equal step as specified in `.tran` statement. When `printstep=0/false/no` (default), Spectre prints transient results in non-equal solver time.
3. The printstep option is not supported in `.alter` block.

Example 1

```
.option printstep=1
.tran 1ns 20ns
.print tran v(1)
```

Spectre prints transient results in an equal interval of `1ns` in `.print` file.

Example 2

```
Simulator lang=spectre
Opt1 options printstep=yes
Simulator lang=spice
.tran 1u 5m
.print tran v(1)
```

Spectre prints transient results in an equal interval of `1us` in `.print` file.