Current IBIS-AMI Support

IBIS Summit, DAC, June 2008

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Current IBIS-AMI Support

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1. Taking care of some unfinished business
   - Updated performance benchmarks
   - Sliding window algorithm in VHDL-AMS
2. Attributes in VHDL-AMS
3. An IBIS-AMI example using the FOREIGN attribute
4. Conclusions – future work
Taking care of some unfinished business

- In my last presentation I promised that the source code of the VHDL-AMS and Matlab models will be posted on the IBIS web site shortly after the summit
  - I apologize for not having this done yet

- The benchmark data of the above presentation (pg. 43) need some correction
  - running the GetWave function with a single call (using the entire waveform) or with multiple calls (using the sliding window technique) has a significant effect on its execution time
  - the benchmarks in the above presentation mixed multi/single calls to GetWave in the comparison, putting the VHDL-AMS and Matlab implementations in an unfavorable light
### Recall – benchmarks from last time

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRBS register length</td>
<td>22</td>
</tr>
<tr>
<td>Sampling time</td>
<td>25 ps</td>
</tr>
<tr>
<td>Bit time</td>
<td>200 ps</td>
</tr>
<tr>
<td>Stop time</td>
<td>20 μs</td>
</tr>
</tbody>
</table>

**Original code in ANSI C:** 10.0 sec

**Matlab (properly coded):** 3.5 sec

**Matlab (C clone):** 14:00.0 sec

**VHDL-AMS (simulator #1):** 23:33.0 sec

**VHDL-AMS (simulator #2):** 1:15:45.0 sec
Updated benchmarks

PRBS register length: 22
Sampling time: 25 ps
Bit time: 200 ps
Stop time: 20 µs

<table>
<thead>
<tr>
<th></th>
<th>Single GW call</th>
<th>Multiple GW call</th>
<th>improvement factor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANSI C code:</strong></td>
<td>0:03:30</td>
<td>0:00:17</td>
<td>12.35</td>
</tr>
<tr>
<td><strong>Matlab C-clone:</strong></td>
<td>0:14:25</td>
<td>not implemented</td>
<td></td>
</tr>
<tr>
<td><strong>Matlab &quot;proper&quot;:</strong></td>
<td>0:00:04</td>
<td>not implemented</td>
<td></td>
</tr>
<tr>
<td><strong>Octave C-clone:</strong></td>
<td>hangs</td>
<td>not implemented</td>
<td></td>
</tr>
<tr>
<td><strong>Octave &quot;proper&quot;:</strong></td>
<td>0:01:47</td>
<td>not implemented</td>
<td></td>
</tr>
<tr>
<td><strong>VHDL-AMS (vendor 1):</strong></td>
<td>0:20:15</td>
<td>0:00:04</td>
<td>303.75</td>
</tr>
<tr>
<td><strong>VHDL-AMS (vendor 2):</strong></td>
<td>1:14:02</td>
<td>0:00:22</td>
<td>201.91</td>
</tr>
</tbody>
</table>

Octave vs. Matlab: 26.75
Notes on new benchmarks

- These benchmarks are still not 100% accurate and fair
  - they were done on two different machines (software to software)
    - 2.33 GHz Dell D820 Latitude laptop with 2 GB memory
    - 3.19 GHz Dell Dimension 8300 desktop with 1 GB memory
  - there are differences in how the tested software load themselves, the models, and the way the models are compiled and executed, making it hard to compare the specific aspects of performance
  - measurements were taken with a clock on the screen

- No far reaching conclusions should be made based on this data, since it is only a crude comparison
  - the tests should be redone under more rigorous control for more precise results
    - run them on the same machine
    - implement timing measurement points in the code

- The performance of the VHDL-AMS IBIS-AMI model is competitive with the C and Matlab implementations
Sliding window algorithm in VHDL-AMS

- The sliding window algorithm was added to the VHDL-AMS Tx model (for the sake of this test only)
  - normally the EDA tool would chop up the waveform and call GetWave multiple times
  - in this test, the test bench still calls GetWave only once, and the sliding window algorithm is applied to the waveform in the GetWave function
  - in terms of the end result, it really doesn’t matter whether it is the caller of GetWave or GetWave itself that performs the sliding window algorithm
  - this was an easier modification to the existing code
Sliding window code in Tx GetWave

```plaintext
i := 0;
while i < WaveSize loop
  if (ActualWindowSize > WaveSize-i) then
    ActualWindowSize := WaveSize - i;
  end if;

  for indx in 0 to ActualWindowSizel-1 loop -- Save the time of each edge of WaveIn in ClockTimes
    if (WaveIn(indx+i) * LastIn < 0.0) then
      ClockTimes(Clock_index) := GwTime + (real(indx+1)-0.5) * SampleInterval;
      Clock_index := Clock_index + 1;
    end if;
    if (WaveIn(indx+i) /= LastIn) then -- Add step response
      StepSize := WaveIn(indx+i) - LastIn;
      for yndx in 0 to RowSize-1 loop
        tmp_dbl(indx+yndx) := tmp_dbl(indx+yndx) + StepSize * StepResponse(yndx);
      end loop;
      for yndx in indx+RowSize to TempSize-1 loop
        tmp_dbl(yndx) := tmp_dbl(yndx) + StepSize * StepResponse(RowSize-1);
      end loop;
      LastIn := WaveIn(indx+i);
      ReturnVec(indx+i) := tmp_dbl(indx);
    end if;
    LastIn := WaveIn(indx+i);
    ReturnVec(indx+i) := tmp_dbl(indx);
  end loop;

  ClockTimes(Clock_index) := -1.0; -- Terminate the list of clock ticks

  for indx in 0 to RowSize-1 loop -- Save the remaining response for the next block of data
    tmp_dbl(indx) := tmp_dbl(indx+ActualWindowSize);
  end loop;
  for indx in RowSize-1 to tmp_dbl'right loop
    tmp_dbl(indx) := tmp_dbl(RowSize-1);
  end loop;

  GwTime := GwTime + real(ActualWindowSize) * SampleInterval;

  i := i + RequestedWindowSize;
end loop;
```

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A handy language feature of VHDL-AMS

- Attributes
  - there are two kinds: pre-defined and user-defined

- Pre-defined attribute examples:
  - T’left, T’right, T’low, T’high, etc...
  - A’left(n), A’right(n), A’low(n), A’high(n), etc...
  - S’delayed(t), S’stable(t), S’quiet(t), etc...
  - Q’tolerance, Q’dot, Q’integ, Q’above,
    Q’ltf(num, den), Q’ztf(num, den, t, delay), etc...

- For more details, refer to any VHDL-AMS reference
User-defined attributes in VHDL-AMS

- A VHDL-AMS user can declare attributes and write attribute specifications “…nominating items which take on the attribute with particular values”
  - User defined attributes can be given to a wide variety of entity_classes, such as:
    - procedures, functions, packages,
    - architectures, natures, quantities, terminals,
    - constants, variables, signals,
    - etc… (long list)

- Mentor’s VHDL-AMS implementation has a built-in user-defined attribute called “FOREIGN” acting as a C-code interface (which in turn can call practically any compiled code)
  - This capability existed for a long time and can be utilized to execute IBIS-AMI models within VHDL-AMS
Calling IBIS-AMI through VHDL-AMS

- The VHDL-AMS model calls a C-code wrapper through the FOREIGN attribute
  - the C function argument types are mapped to VHDL-AMS types
  - obviously there are some limitations, but the wrapper function can take care of most of the type conversions if necessary
  - the wrapper function can take care of the IBIS requirements of the calling conventions of the Init, GetWave, and Close functions
  - any additional feature and capability can be programmed into the wrapper function(s)

- Once an “IBIS-AMI wrapper” has been developed for VHDL-AMS, any IBIS-AMI model can be executed in any of our tools that has VHDL-AMS capabilities
  - all of this can be user written, no product changes are required
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2. Attributes in VHDL-AMS

3. An IBIS-AMI example using the FOREIGN attribute

4. Conclusions – future work
Block diagram of the following example

This is only one of many possible ways of implementing
IBIS-AMI support via VHDL-AMS
Example with IBIS-AMI Tx and Rx models
Example circuit description

- **U1** contains a VHDL-AMS model
  - it generates a step function to excite the “channel”
- **R1** represents a simple resistive driver impedance
- **TL1, L1, C1** represents a T-line, package and input
  - the “channel” can be an arbitrary circuit, including S-parameter models, but it must include the Tx and Rx impedances
- The first part of the TD simulation generates a channel response
  - the length of this is a parameter in the VHDL-AMS model
- When the channel response is done, the AMI Tx and Rx models are executed using that channel response
  - the VHDL-AMS model includes a PRBS pattern generator
- After that, the results are returned to the simulator through the VHDL-AMS model for plotting
## VHDL-AMS code segment for U1

```vhdl
begin

    -- StepGen process
    StepGen : process is
    begin
        wait for StepTime;
        sStep <= 1.0;
        wait;
    end process StepGen;

    -- Run_AMI process
    Run_AMI : process is
    begin
        wait for StepTime;
        if (RowSize <= ChRespSize) then
            TxMatrixInOut(RowSize) <= VwfmIn'dot; RowSize <= RowSize + 1;
        else
            TxImpulseMatrix := TxMatrixInOut;
            RxImpulseMatrix := RxMatrixInOut;
            WaveIn := AMIwaveInOut;
            computing : VHDL_IBIS_AMI(TxImpulseMatrix, RowSize,
                                      Aggressors, StepTime,
                                      BitTime, UseTxInitOutput,
                                      TxParameters, TxDLLfileName,
                                      WaveIn, WaveSize,
                                      RxImpulseMatrix, UseRxInitOutput,
                                      RxParameters, RxDLLfileName);
            TxMatrixInOut(TxImpulseMatrix'range) <= TxImpulseMatrix;
            RxMatrixInOut(RxImpulseMatrix'range) <= RxImpulseMatrix;
            AMIwaveInOut(WaveIn'range)        <= WaveIn;
            wait;
        end if;
    end process Run_AMI;
end
```

---

**IBIS-AMI wrapper call (C-code)**

---

**Current IBIS-AMI Support**
VHDL-AMS code segment for U1 (cont’d)

---

Ticker : process is
begin
  wait for StepTime;
  if (CountInit < ChRespSize) and (Now > ChRespDuration) then
    CountInit <= CountInit + 1;
  end if;
  if (CountGW < AMIwaveInOut'right) and (Now > ChRespDuration) then
    CountGW <= CountGW + 1;
  end if;
end process Ticker;
---

break on sStep, CountInit, CountGW;

VwfmStep == sStep;
if (CountInit > 0) use
  VwfmTxInit == TxMatrixInOut(CountInit);
  VwfmRxInit == RxMatrixInOut(CountInit);
else
  VwfmTxInit == 0.0;
  VwfmRxInit == 0.0;
end use;

if (CountGW > 0) use
  VwfmGW == AMIwaveInOut(CountGW);
else
  VwfmGW == 0.0;
end use;

end architecture Call_TxRx;
---
IBIS-AMI wrapper C-code sample (load DLLs)

// Load DLL files and get the addresses of the AMI functions

hTxDLLfile = LoadLibrary(Tx_DLL_file_name);
if (hTxDLLfile == NULL)
    printf("WARNING: Tx DLL file [%s] not found.\n", Tx_DLL_file_name);
else {
    printf("INFO: Tx DLL file [%s] loaded successfully.\n", Tx_DLL_file_name);

    AMI_Tx_Init = (pAMI)GetProcAddress(hTxDLLfile, "AMI_Init");
    AMI_Tx_GetWave = (pAMI)GetProcAddress(hTxDLLfile, "AMI_GetWave");
    AMI_Tx_Close = (pAMI)GetProcAddress(hTxDLLfile, "AMI_Close");

    if ((&AMI_Tx_Init == NULL) && (&AMI_Tx_GetWave == NULL) && (&AMI_Tx_Close == NULL))
        printf("WARNING: Tx DLL file [%s] contains no AMI functions.\n", Tx_DLL_file_name);
    else {
        printf("INFO: Tx DLL file [%s] contains:\n", Tx_DLL_file_name);
        if (AMI_Tx_Init != NULL)
            printf("AMI_Init\n");
        if (AMI_Tx_GetWave != NULL)
            printf("AMI_GetWave\n");
        if (AMI_Tx_Close != NULL)
            printf("AMI_Close\n");
    }
}
...
...
...
IBIS-AMI wrapper C-code sample (Tx Init)

//---------------------------------------------------------------
// Run Tx AMI_init
//---------------------------------------------------------------
// Make the input of Tx_Init the input of Rx_Init
if (Use_Tx_Init_Output == 0)
    memcpy(Rx_impulse_matrix, Tx_impulse_matrix, row_size*(aggressors+1)*sizeof(double));

if (AMI_Tx_Init != NULL) {
    AMI_ReturnVal = 0;
    AMI_ReturnVal = AMI_Tx_Init(Tx_impulse_matrix,
                                row_size, aggressors,
                                sample_interval,
                                bit_time,
                                Tx_parameters_in,
                                &Tx_parameters_out,
                                &Tx_memory_handle,
                                &Tx_msg);
}
else
    printf("WARNING: The AMI_Init function doesn't exist in the Tx DLL file:  [%s]\n\n", Tx_DLL_file_name);

// Make the output of Tx_Init the input of Rx_Init
if (Use_Tx_Init_Output != 0)
    memcpy(Rx_impulse_matrix, Tx_impulse_matrix, row_size*(aggressors+1)*sizeof(double));
//---------------------------------------------------------------
IBIS-AMI wrapper C-code sample (Rx Init)

```c
// Run Rx AMI_init
if (AMI_Rx_Init != NULL) {
    AMI_ReturnVal = 0;
    AMI_ReturnVal = AMI_Rx_Init(Rx_impulse_matrix,
                                row_size,
                                aggressors,
                                sample_interval,
                                bit_time,
                                Rx_parameters_in,
                                &Rx_parameters_out,
                                &Rx_memory_handle,
                                &Rx_msg);
}
else
    printf("WARNING: The AMI_Init function doesn't exist in the Rx DLL file: [%s]\n", Rx_DLL_file_name);

// Convolve stimulus with (modified or unmodified) impulse response
// Scale impulse response by sample_interval
if (Use_Rx_Init_Output == 0) {
    // Use output of Tx_Init
    for(i = 0; i < row_size; i++) {
        tmp_imp_resp[i] = sample_interval * Tx_impulse_matrix[i];
    }
}
else {
    // Use output of Rx_Init
    for(i = 0; i < row_size; i++) {
        tmp_imp_resp[i] = sample_interval * Rx_impulse_matrix[i];
    }
}
```
// Do the rest of the convolution using the sliding window technique
ActualWindowSize = RequestedWindowSize;
for(i = 0; i < wave_size; i = i + RequestedWindowSize) {
    if (ActualWindowSize > wave_size - i) {
        ActualWindowSize = wave_size - i;
        printf("Last window size(%d) = %d\n", i/RequestedWindowSize+1, ActualWindowSize);
    }

    for(indx = 0; indx < ActualWindowSize; indx++) {
        for(yndx = 0; yndx < row_size; yndx++) {
            tmp_wave[indx+yndx] += wave_in[i+indx] * tmp_imp_resp[yndx];
        }
        last_in = wave_in[i+indx];
        wave_in[i+indx] = tmp_wave[indx]; //Save the output
    }
}

//Save the remaining response for the next block of data
for(indx = 0; indx < row_size; indx++) {
    tmp_wave[indx] = tmp_wave[indx+RequestedWindowSize];
}
for( ; indx < tmp_size; indx++) {
    tmp_wave[indx] = 0;
}
} // End of FOR loop
IBIS-AMI wrapper C-code sample (Tx GetWave)

// Run Tx AMI_GetWave
if ((AMI_Tx_Init != NULL) && (AMI_Tx_GetWave != NULL)) {
    ActualWindowSize = RequestedWindowSize;
    AMI_ReturnVal = 0;
    for(i = 0; i < wave_size; i = i + RequestedWindowSize) {
        if (ActualWindowSize > wave_size - i) {
            ActualWindowSize = wave_size - i;
            printf("AMI_Tx_GetWave last window size(%d) = %d\n", i/RequestedWindowSize+1, ActualWindowSize);
        }
        AMI_ReturnVal = AMI_Tx_GetWave(&wave_in[i],
                                      ActualWindowSize,
                                      clock_times,
                                      &Tx_parameters_out,
                                      Tx_memory_handle);
        }
        if (AMI_ReturnVal != 1) {
            printf("WARNING: AMI_Tx_GetWave execution ended prematurely.\n\n");
            break;
        }
    } // End of FOR loop
} else {
    if (AMI_Tx_GetWave == NULL)
        printf("WARNING: The AMI_GetWave function doesn't exist in the Tx DLL file: [%s]\n\n", Tx_DLL_file_name);
    else
        printf("WARNING: The AMI_GetWave function couldn't be executed because the AMI_Init function doesn't exist in the Tx DLL file: [%s]\n\n", Tx_DLL_file_name);
}
IBIS-AMI wrapper C-code sample (Rx GetWave)

```
// Run Rx AMI_GetWave

if ((AMI_Rx_Init != NULL) && (AMI_Rx_GetWave != NULL)) {
    ActualWindowSize = RequestedWindowSize;
    AMI_ReturnVal = 0;

    // This IF statement is here for debugging purposes, because this Rx model's
    // GetWave function cannot be called with the sliding window algorithm.
    if (0)
        {
            for( i = 0;  i < wave_size;  i = i + RequestedWindowSize ) {
                if (ActualWindowSize > wave_size - i) {
                    ActualWindowSize = wave_size - i;
                    printf("AMI_Rx_GetWave last window size(%d) = %d\n", i/RequestedWindowSize+1, ActualWindowSize);
                }
                AMI_ReturnVal = AMI_Rx_GetWave(&wave_in[i],
                                                ActualWindowSize,
                                                clock_times,
                                                &Rx_parameters_out,
                                                Rx_memory_handle);

                if (AMI_ReturnVal != 1) {
                    printf("WARNING: AMI_Rx_GetWave execution ended prematurely.\n");
                    break;
                }
            } // End of FOR loop
        }
    else
        {
            AMI_ReturnVal = AMI_Rx_GetWave(wave_in,
                                            RxWaveSize,
                                            clock_times,
                                            &Rx_parameters_out,
                                            Rx_memory_handle);
        }
} // End of FOR loop
```

IBIS-AMI wrapper C-code sample (Close)

```c
else {
    if (AMI_Tx_GetWave == NULL)
        printf("WARNING: The AMI_GetWave function doesn't exist in the Rx DLL file: [%s]\n\n", Rx_DLL_file_name);
    else
        printf("WARNING: The AMI_GetWave function couldn't be executed because the AMI_Init function doesn't exist in the Rx DLL file: [%s]\n\n", Rx_DLL_file_name);

    // Run Rx AMI_Close
    //----------------------------------------------------------------------------------------
    if ((AMI_Rx_Init != NULL) && (AMI_Rx_Close != NULL)) {
        AMI_ReturnVal = 0;
        AMI_ReturnVal = AMI_Rx_Close(Rx_memory_handle);
    }
    else {
        if (AMI_Tx_Close == NULL)
            printf("WARNING: The AMI_Close function doesn't exist in the Tx DLL file: [%s]\n\n", Tx_DLL_file_name);
        else
            printf("WARNING: The AMI_Close function couldn't be executed because the AMI_Init function doesn't exist in the Tx DLL file: [%s]\n\n", Tx_DLL_file_name);

        // Run Tx AMI_Close
        //----------------------------------------------------------------------------------------
        if ((AMI_Tx_Init != NULL) && (AMI_Tx_Close != NULL)) {
            AMI_ReturnVal = 0;
            AMI_ReturnVal = AMI_Tx_Close(Tx_memory_handle);
        }
        else {
            if (AMI_Tx_GetWave == NULL)
                printf("WARNING: The AMI_GetWave function doesn't exist in the Tx DLL file: [%s]\n\n", Tx_DLL_file_name);
            else
                printf("WARNING: The AMI_GetWave function couldn't be executed because the AMI_Init function doesn't exist in the Tx DLL file: [%s]\n\n", Tx_DLL_file_name);
        }
    }
    else {
```

Current IBIS-AMI Support
Waveform results of the example
100k bits of PRBS 22 over 20 µs – no EQ
100k bits of PRBS 22 over 20 µs – Tx EQ

-100 mV
100k bits of PRBS 22 over 20 µs – Tx & Rx
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Conclusions – future work

- **VHDL-AMS** is a viable option for algorithmic modeling
  - its performance is fast, and the language is flexible
- **IBIS-AMI models (DLLs)** are fully supported in any Mentor tool that has VHDL-AMS capabilities
  - direct execution of the compiled IBIS-AMI models
- Any programming language, capable of producing executables can be supported through VHDL-AMS
  - Matlab, Visual Basic, Perl, you name it
  - execution speed of the compiled code does not suffer any degradation through VHDL-AMS since it is executed externally
- An IBIS (v5.0) parser will be needed to automate the IBIS parameter extraction for the IBIS-AMI models
  - this will happen most likely after the IBIS v5.0 spec has been ratified