BUFFER ISSUE RESOLUTION DOCUMENT (BIRD)
Rev 15

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ISSUE TITLE: Extending IBIS-AMI for PAM4 analysis
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STATEMENT OF THE ISSUE:

The IBIS 6.0 specification assumes two-level signaling (usually called NRZ or PAM2). Multiple silicon vendors have implemented four-level (PAM4) signaling and are now providing silicon. System designers need to be able to use IBIS-AMI to analyze and implement designs using PAM4 technology.

ANALYSIS PATH/DATA THAT LED TO SPECIFICATION:

IBIS 6.0 assumes NRZ signaling, which affects the way simulators are instructed to prepare an input stimulus for AMI simulation (-0.5V for 0, 0.5V for 1), the way input thresholds are declared in .ibs files (Vinl, Vinh), and the way sampling latch thresholds are declared for AMI post-processing (Rx_Receiver_Sensitivity). To enable PAM4 analysis, the IBIS specification must allow an EDA tool to do the following:

- Prepare the appropriate input stimulus waveform
- Inform algorithmic models of what modulation type is being used
- Set appropriate voltage and timing thresholds for waveform and eye diagram post-processing

The specification should include facilities that allow output eye voltage thresholds and timing offsets to be declared as static values in the model's text files, or output by the algorithmic model at runtime and used by the simulator when post-processing.

Each of the four signal levels in PAM4 signaling represents a different two bit sequence, and the IBIS specification needs a way to define this mapping. Because the mapping may differ from device to device, the mapping needs to be defined at the individual model level.

In this proposal, these facilities are implemented using a combination of parameters in the algorithmic model's .ami file and changes to other parts of the standard (e.g. stimulus waveform voltages) based on the declared modulation type. No changes are proposed for the model's .ibs file.

ANY OTHER BACKGROUND INFORMATION:

Other multi-level signaling technologies (most notably duobinary) are being discussed, but these technologies do not yet have device vendors committed to providing silicon.

Additional editorial changes required.

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bit_time

bit_time is the bit time or unit interval (UI) of the current data, e.g., 100 ps, 200 ps etc. The executable model file may use this information along with the impulse_matrix to initialize the filter coefficients. The unit for bit_time is the second. For PAM4 models bit_time shall be the symbol_time. (red is new)

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Last two paragraphs assume NRZ. Need to add a paragraph or two explaining the contents of **wave** for PAM4.

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"Rx_Clock_Recovery_Mean" is an AMI parameter of Type either Float or UI, Format either Value, List, Range, Corner, Increment, or Steps, and Usage Info which defines a static offset, in seconds or UI, between the recovered clock and the point half way between the PDF medians of consecutive eye zero crossings. (red should be removed?)

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Definition: A static offset between the recovered clock and the point half way between the PDF medians of consecutive eye zero crossings. Entries are assumed to be in units of seconds when declared as Type Float. (red should be removed?)

Should we have a better definition of "eye crossings"

Parameter: **Modulation**

Required: No

Descriptors:

Usage:	Info or In
Type:	String
Format:	Value or List
Default:	<string_literal>
Description:	<string>

Definition: Tells the EDA tool whether NRZ or PAM4 analysis is to be performed.

Usage Rules: This Reserved Parameter tells the EDA tool (and optionally, the algorithmic model) of the modulation scheme to be used for analysis. It is declared as Type String with two pre-defined values of "NRZ" and "PAM4". The value(s) must either be "NRZ" or "PAM4". The default "NRZ" applies if the Modulation parameter is not included in the .ami file.

The Modulation parameter controls how the EDA tool prepares the Stimulus waveform for Getwave-based analysis and post-processes simulation results:

- When Modulation is set to "NRZ", the simulator prepares the input stimulus using -0.5V to represent a logic 0 and 0.5V to represent a logic 1. The Rx Parameter Rx_Receiver_Sensitvity is used to post-process Rx model data.
- When Modulation is set to "PAM4", the simulator prepares the input stimulus using voltage levels of -0.5, -0.166, 0.166 and 0.5 volts to represent PAM4 symbols 0, 1, 2 and 3 respectively. The conversion between binary bits and PAM4 symbols, and the voltage and timing offsets used for simulation waveform processing are specified by the Parameters PAM4_Mapping, PAM4_UpperThreshold, PAM4_CenterThreshold, PAM4_Lower_Threshold, PAM4_UpperEyeOffset and PAM4_LowerEyeOffset.

Other Notes: When Usage is declared as In, this Parameter is also passed to the algorithmic model. The EDA tool continues to behave as described above. The use of a single Parameter to control both EDA tool and model behavior is intended to streamline the experience for the end-user.

Examples:

```
(Modulation (Usage Info)(Value "PAM4")(Type String)
      (Description "This is a PAM4 model.")
)

(Modulation (Usage In)(List "NRZ" "PAM4")(Type String)
      (Description "This model can be used either for NRZ or PAM4 analysis.")
)
```

Parameter: **PAM4_Mapping**
Required: No
Descriptors:

Usage:	Info
Type:	String
Format:	Value (List? If List stay Info?)
Default:	<string_literal>
Description:	<string>

Definition: Tells EDA tool how to map voltage levels to two-bit PAM4 symbols

Usage Rules: Different devices may translate between voltage levels and two-bit symbols differently, and this parameter defines the mapping to be used for a specific model. There are two different pieces of information to be mapped:

- The four voltage levels in the signal (for example -0.5V, -0.166V, 0.166V, 0.5V in the transmitter's waveform stimulus)
- The four two-bit PAM4 symbols (00, 01, 10, 11)

The PAM4_Mapping parameter declares a four character string that declares how the EDA tool should map between voltage levels and bit sequences. The *positions* in the string (1^{st}, 2^{nd}, 3^{rd}, 4^{th}) correspond to signal voltage *levels*, beginning with the most negative voltage and becoming incrementally more positive. The *values* of the characters in the string correspond to two-bit binary sequences, with "0" = binary 00, "1" = binary 01, "2" = binary 10, and "3" = binary 11. Thus, a string of "0132" tells the simulator:

- The most negative signal (level 0) should be considered as binary 00
- The next higher voltage (level 1) should be considered as binary 01
- The next higher voltage (level 2) should be considered as binary 11
- The most positive voltage (level 3) should be considered as binary 10

If the Reserved AMI Parameter Modulation is set to "PAM4" and PAM4_Mapping is *not* declared, the EDA tool should assume a default value of "0132" for PAM4_Mapping. The PAM4_Mapping parameter is ignored when the Reserved AMI Parameter Modulation is not declared or set to "NRZ". The PAM4_Mapping parameter must contain four characters and each of the four characters "0", "1", "2" and "3" must occur once.

Other Notes: There are two reasons why a mapping is required:

1. The EDA tool needs to convert a symbol error rate into a bit error rate. For PAM4, each symbol carries two bits of information. So when an incorrect symbol is received, there can be either one or two bit errors involved. The EDA tool needs to know how many bits were received in error to accurately calculate a BER.
2. SerDes designers may choose other mappings for reasons of their own. The choice of a mapping may affect the bit error rate, but, for example, might produce error patterns that fall more often into the correctable space of a particular choice of Forward Error Correction (FEC) code. The mapping enables SerDes designers to communicate these choices, and for system developers to evaluate these choices.

Examples:

```
(PAM4_Mapping (Usage Info)(Value “0123”)(Type String)
      (Description "Simple mapping from voltages to symbols.")
)

(PAM4_Mapping (Usage Info)(Value “0132”)(Type String)
      (Description "Gray code is being used.")
)
```

Parameters: **PAM4_UpperThreshold, PAM4_CenterThreshold, PAM4_LowerThreshold**

Required: No

Descriptors:

Usage:	Info, InOut, Out, or Dep
Type:	Float
Format:	Value
Defaults:	<numerical_literal> …
Description:	<string>

Definition: Voltages used by EDA tools for PAM4 waveform and eye processing

Usage Rules: The EDA tool uses these voltages in conjunction with Rx clock information to detect which of the four PAM4 symbols a waveform represents when the signal is sampled:

- Voltages *lower* than **PAM4_Lower_Threshold - Rx_Receiver_Sensivity** are detected as voltage level 0
- Voltages *lower* than **PAM4_Center_Threshold – Rx_Receiver_Sensitivity** and *greater* than **PAM4_Lower_Threshold + Rx_Receiver_Sensitivity** are detected as voltage level 1
- Voltages *lower* than **PAM4_Upper_Threshold – Rx_Receiver_Sensitivity** and *greater* than **PAM4_Center_Threshold + Rx_Receiver_Sensitivity** are detected as voltage level 2
- Voltages *greater* than **PAM4_Upper_Threshold + Rx_Receiver_Sensivity** are detected as voltage level 3

Voltages that do *not* fall into one of these regions are considered a symbol error.

If these parameters are declared as Usage InOut or Out, the algorithmic model is expected to output values from the AMI_Init and AMI_GetWave call for the EDA tool to use during waveform and eye processing.

- If the Reserved AMI Parameter Modulation is set to “PAM4” and these threshold values are *not* declared, the model maker shall assume that the EDA tool may choose a value for each of these three parameters.

The PAM4_UpperThreshold, PAM4_CenterThreshold and PAM4_LowerThreshold parameters are ignored when the Reserved AMI Parameter Modulation is declared or set to “NRZ”.

Other Notes:

Examples:

```
(PAM4_LowerThreshold (Usage Info)(Value -0.333)(Type Float)
      (Description "Lower eye voltage threshold for waveform and eye processing.")
)
 (PAM4_CenterThreshold (Usage Info)(Value 0.0)(Type Float)
      (Description "Center eye voltage threshold for waveform and eye processing.")
)
 (PAM4_UpperThreshold (Usage Info)(Value 0.333)(Type Float)
      (Description "Upper eye voltage threshold for waveform and eye processing.")
)

(PAM4_LowerThreshold (Usage Out) (Type Float)
      (Description "Lower eye voltage threshold returned by AMI_Init.")
)
 (PAM4_CenterThreshold (Usage Out) (Type Float)
      (Description "Center eye voltage threshold returned by AMI_Init.")
)
 (PAM4_UpperThreshold (Usage Out) (Type Float)
      (Description "Upper eye voltage threshold returned by AMI_Init.")
)
```

Parameters: **PAM4_UpperEyeOffset, PAM4_LowerEyeOffset**

Required: No

Descriptors:

Usage:	Info, InOut, Out or Dep
Type:	Float
Format:	Value
Default:	<numeric_literal>
Description:	<string>

Definition: Sampling clock offsets for Upper and Lower PAM4 eyes

Usage Rules: Rx models provide a single set of sampling information returned that pertains to the center eye during PAM4 analysis. When the PAM4 Upper and Lower eyes have a time shift with respect to the Center eye, these parameters are used to define a sampling offset from the Center eye.

When a positive value is declared, the latch in question will sample the waveform *after* the sample time for the center eye. When a negative value is declared, the latch in question will sample the waveform *before* the sample time for the center eye.

If these parameters are declared as Usage InOut or Out, the algorithmic model is expected to output values from the AMI_Init and AMI_GetWave call for the EDA tool to use during waveform and eye processing.

If the Reserved AMI Parameter Modulation is set to “PAM4” and these offset values are *not* declared, the EDA tool is expected to use a default value of 0.0 for both parameters. The PAM4_UpperEyeOffset and PAM4_LowerEyeOffset parameters are ignored when the Reserved AMI Parameter Modulation is not declared or set to “NRZ”.

Other Notes:

Examples:

```
(PAM4_UpperEyeOffset (Usage Info)(Value 2.5e-12)(Type Float)
      (Description "The Upper eye is sampled 2.5ps after the Center eye.")
)

(PAM4_UpperEyeOffset (Usage Out)(Default 2.5e-12)(Type Float)
      (Description "The Upper eye sampling offset returned by AMI_Init.")
)
```