**BUFFER ISSUE RESOLUTION DOCUMENT (BIRD)**

**BIRD NUMBER:** 213

**ISSUE TITLE:** Extending IBIS-AMI for PAMn Analysis

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**DATE ACCEPTED:**

**DEFINITION OF THE ISSUE:**

The IBIS 7.0 specification assumes two-level and four-level signaling (usually called NRZ or PAM2 and PAM4). Multiple silicon vendors have implemented three-level (PAM3) signaling and are now providing silicon. Silicon vendors are evaluating five and more than five-level signaling. System designers need to be able to use IBIS-AMI to analyze and implement designs using PAMn technology, where n=3,5,6,7,8…

**SOLUTION REQUIREMENTS:**

To enable PAMn 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
* Determine appropriate voltage and timing thresholds for waveform and eye diagram post-processing

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.

* Need to do an editorial scrub of all occurrences of PAM4
* Need to replace the section Parameter: Modulation with the new section in the BIRD
* Need to add four new AMI Reserved Parameters PAM\_Thresholds, PAM\_Offsets, PAM\_Mapping\_Name, PAM\_Mapping\_Table
* Need to handle legacy PAM4 keywords (Backward compatibility)

**PROPOSED CHANGES:**

In general, need to do an editorial scrub for all occurrences of PAM4 and adjust to PAMn as appropriate:

Insert after the first paragraph on page 253:

For PAMn clock\_times are defined as ½ UI before the times that the Rx latch is sampled.

Replace the following paragraph on page 203:

**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.

With:

**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 PAMn models, bit\_time shall be the symbol time.

Replace the following paragraph on pages 207/208:

For PAM4 models, it is assumed that the electrical interface to either the driver or the receiver is differential and will have four logic levels.

The output waveform is expected to be the waveform at the decision point of the receiver (that is, the point in the receiver where the choice is made as to whether the symbol is a “0”, “1”, “2” or a “3”). It is understood that for some receiver architectures, there is no one circuit node which is the decision point for the receiver. In such a case, the output waveform is expected to be the equivalent waveform that would exist at such a node were it to exist.

With:

For PAMn models, it is assumed that the electrical interface to either the driver or the receiver is differential and will have n logic levels.

The output waveform is expected to be the waveform at the decision point of the receiver (that is, the point in the receiver where the choice is made as to whether the symbol is a “0”, “1”, … or “n-1”). It is understood that for some receiver architectures, there is no one circuit node which is the decision point for the receiver. In such a case, the output waveform is expected to be the equivalent waveform that would exist at such a node were it to exist.

On Page 208 make the following changes (underlined):

Each valid value in the clock\_times vector shall be used to sample the output waveform by adding to it bit\_time/2 (symbol\_time/2 for PAMn), regardless of whether that waveform sample occurs in the waveform segment being returned by the current call to AMI\_GetWave, or in the waveform segment to be returned by the next AMI\_GetWave call. Care should be taken in implementation of clock\_times to ensure that the calculations used always maintain full double-precision floating point accuracy across multi-million bit simulations.

Add the following new parameters:

Parameter: **Modulation\_Levels**

*Required:* No, and illegal before AMI\_Version 7.1

*Direction*: Rx, Tx

*Descriptors*:

Usage: Info or In

Type: Integer

Format: Value or List

Default: <numeric\_literal>

Description: <string>

*Definition:* Tells the EDA tool (and optionally, the algorithmic model) whether NRZ or PAMn modulation is to be used for analysis.

*Usage Rules:* It is declared as Type Integer. Modulation and Modulation\_Levels cannot both be present. If The format is Value, then the value must be greater than 2. If the format is List then the list shall contain only two values, one of which must be “2” and the other greater than 2. If neither Modulation nor Modulation\_Levels are defined, then the Modulation shall be NRZ. The following table maps typical Modulation\_Levels to common modulation names.

Modulation\_Levels Common Name

2 NRZ, PAM2

3 PAM3, Duobinary

4 PAM4

5 PAM5

….

8 PAM8

…

The Modulation\_Levels parameter controls how the EDA tool prepares the stimulus waveform for AMI\_GetWave-based analysis and post-processes simulation results:

* When Modulation\_Levels is set to 2, 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\_Sensitivity is used to post-process Rx model data.
* When Modulation\_Levels is set to “n”, the simulator prepares the input stimulus using voltage levels between -0.5 and 0.5 volts in uniform increments of 1.0/(n-1) volts. There are n voltage levels corresponding to n symbol values between 0 and n-1. The voltage and timing offsets used for simulation waveform processing are specified by new Out Parameters PAM\_Thresholds and PAM\_Offsets.

*Example:*

(Modulation\_Levels (Usage In)(List 2 3)Type Integer)

(Description "This model can be used either for NRZ or PAM3 analysis.")

)

*Parameter:* **PAM\_Thresholds**

*Required:* No if Modulation\_Levels is not defined, yes if Modulation\_Levels is defined, and illegal before AMI\_Version 7.1

*Direction*: Rx

*Descriptors*:

Usage: Info, In, Inout, Out, Dep

Type: Integer Float

Format: Table

Defaults: <numeric\_literal>

Description: <string>

*Definition:* Voltages used by EDA tools for PAM<n> waveform and eye processing. The one (and only) column of the table shall be Threshold (volts). The number of rows in the table shall be n-1.

*Usage Rules:* The EDA tool uses the voltages in column 1 in conjunction with Rx clock information to detect which of the n PAM<n> symbols a waveform represents when the signal is sampled.

A PAM<n> eye has n-1 “eyes” and n symbol values. The eye with the lowest voltage is eye “1”, the eye with the next highest voltage is eye “2” and so on until the eye with the highest voltage is eye “n-1”. The threshold for each eye is typically at the “vertical center” of that eye.

* Voltages *lower* than **Row 1 PAM\_Thresholds - Rx\_Receiver\_Sensitivity** are detected as symbol value **0**
* Voltages *lower* than **Row 2 PAM\_Thresholds – Rx\_Receiver\_Sensitivity** and *greater* than **Row 1 PAM\_Thresholds + Rx\_Receiver\_Sensitivity** are detected as symbol value **1**
* **…**
* Voltages *lower* than **Row n-1 PAM\_Thresholds – Rx\_Receiver\_Sensitivity** and *greater* than **Row n-2 PAM\_Thresholds + Rx\_Receiver\_Sensitivity** are detected as symbol value **n-2**
* Voltages *greater* than **Row n-1** **PAM\_Thresholds + Rx\_Receiver\_Sensitivity** are detected as symbol value **n-1**

*Other Notes:* Modulation\_Levels=4 may use either PAM\_Thresholds or PAM4\_UpperThreshold, PAM4\_CenterThreshold and PAM4\_LowerThreshold, but not both.

*Example:*

(PAM\_Thresholds (Usage Out)(Type Float)

(Description "Thresholds for waveform and eye processing.")

(Table

(Labels “Threshold”)

(0.0)

)

)

*Parameters:* **PAM\_Offsets**

*Required:* No if Modulation\_Levels is not defined, yes if Modulation\_Levels is defined, and illegal before AMI\_Version 7.1

*Direction*: Rx

*Descriptors*:

Usage: Out

Type: Integer Float or Integer UI

Format: Table

Defaults: <numeric\_literal> …

Description: <string>

*Definition:* Sampling clock offsets for PAMn eyes

*Usage Rules:* Rx models provide a single set of sampling information returned that pertains to a nominal eye centered between consecutive edge transition times during PAMn analysis. When the PAMn eyes have a time shift with respect to the nominal eye, this parameter is used to define a sampling offset for each eye from the clock time of the reference row.

If the AMI Reserved Parameter Modulation is set to a “PAM<n>” and these offset values are *not* declared, the EDA tool is expected to use a default value of 0.0 for each offset parameter. The PAM\_Offsets parameter are ignored when the AMI Reserved Parameter Modulation is not declared or is declared and set to “NRZ” (or PAM2).

If PAM\_Offsets is defined, then the clock time for each eye can be independently adjusted.

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

A PAM<n> eye has n-1 “eyes” and n symbol values. The eye with the lowest voltage is eye “1”, the eye with the next highest voltage is eye “2” and so on until the eye with the highest voltage is eye “n-1”. The reference row is determined by the value of “n”.

1. If n=2, then there is only one reference row. In this case PAM\_Offsets must have only one row, and its offset value shall be 0.0.
2. If n is even, the reference row is n/2, and its offset value shall be 0.0.
3. If n is odd, the reference row is (n-1)/2, and its offset value shall be 0.0.

*Other Notes:* In statistical analysis, offset from the center of the nominal eye shall include Rx\_Clock\_Recovery\_Mean and the PAM\_Offsets. In time-domain analysis, PAM\_Offsets shall be n-1 independent corrections to the clock times.

*Example:*

(PAM\_Offsets (Usage Out)(Type Integer Float)

(Description "Clock timing offsets for waveform and eye processing.")

(Table

(Labels “Row” “Offset”)

(0.0)

)

)

Parameter: **PAM\_Mapping\_Name**

*Required:* No if Modulation\_Levels is not defined, yes if Modulation\_Levels is defined, and illegal before AMI\_Version 7.1

*Direction*: Rx, Tx

*Descriptors*:

Usage: Info or In

Type: String

Format: Value

Default: <string\_literal>

Description: <string>

*Definition:* Tells the EDA tool how many binary bits get mapped into how many PAMn symbol levels.

*Usage Rules:* The string shall contain two numbers separated by a “/”. The first number is the number of binary bits that get mapped into the second number, which is the number of PAMn symbol levels. When Modulation\_Levels=4 (PAM4), this string shall be “4/2”. For PAM3, this string may be “11/7”. The EDA tool can use this string to create its own mapping or can use the data in the parameter PAM\_Mapping\_Table.

*Example:*

(PAM\_Mapping\_Name (Usage Info)(Type String)(Value “11/7”)

(Description "11 binary bits get mapped into 7 symbols.")

)

Parameter: **PAM\_Mapping\_Table**

*Required:* No if Modulation\_Levels is not defined, yes if Modulation\_Levels and PAM\_Mapping\_Name are defined, and illegal before AMI\_Version 7.1

*Direction*: Rx, Tx

*Descriptors*:

Usage: Info

Type: String

Format: Table

Default: <string\_literal>

Description: <string>

*Definition:* Tells the EDA tool how to map binary data into PAMn symbol levels.

*Usage Rules:* The Table shall contain two columns, “Binary” and “PAM”. The number of rows in this table shall be 2^(number of binary bits defined in PAM\_Mapping\_Name). Length of strings in the first column shall be number of binary bits defined in PAM\_Mapping\_Name and shall contain only the characters “0” and “1”. Length of strings in the second column shall be number of PAM symbols defined in PAM\_Mapping\_Name and shall contain integer numbers or alphabetic characters as follows.

Character Symbol Level

“0” 0

“1” 1

“2” 2

…

“9” 9

“A” 10

“B” 11

“C” 12

“D” 13

“E” 14

“F” 15

“G” 16

“H” 17

…

*Other Notes:* The following is an algorithm for a simple mapping.

Given PAM\_Mapping\_Name=”11/7” and Modulation\_Number=3:

n=3;

Bits=11;

Symbols=7;

Binary=2^Bits-1; % any number between 0 and 2^Bits-1;

PAM=zeros(1,Symbols);

for i=1:Symbols

PAM(Symbols+1-i)=mod(Binary,n);

Binary=(Binary- PAM(Symbols+1-i))/n;

end

*Examples:*

Example for Modulation\_Levels=3:

(PAM\_Mapping\_Table (Usage Info)(Type String)

(Description "11 binary bits get mapped into 7 symbols.")

(Table

(Labels “Binary” “PAM”)

(“00000000000” “0000000”)

(“00000000001” “0000001”)

(“00000000010” “0000002”)

(“00000000011” “0000010”)

…

(“11111111111” “2210211”)

)

)

Example for Modulation\_Levels=16:

(PAM\_Mapping\_Table (Usage Info)(Type String)

(Description "4 binary bits get mapped into 1 symbol.")

(Table

(Labels “Binary” “PAM”)

(“0000” “0”)

(“0001” “1”)

(“0010” “2”)

(“0011” “3”)

…

(“1111” “F”)

)

)

**BACKGROUND INFORMATION/HISTORY:**