**BUFFER ISSUE RESOLUTION DOCUMENT (BIRD)**

**BIRD NUMBER:** 213.1

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

**REQUESTOR:**  Walter Katz, The MathWorks, Inc

**DATE SUBMITTED:** May 5, 2021

**DATE REVISED:** May 31, 2022

**DATE ACCEPTED:** July 22, 2022

**DEFINITION OF THE ISSUE:**

The IBIS 7.1 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=2,3,4,5,6,7,8…

**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 models .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 two new AMI Reserved Parameters PAM\_Thresholds, PAM\_Offsets
* Need to handle 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:

Replace the following paragraph on page 223:

symbol\_time

symbol\_time is the unit interval (UI) of the current data, e.g., 100 ps, 200 ps etc. For NRZ signaling, it is equivalent to bit time. The executable model file may use this information along with the impulse\_matrix to initialize the filter coefficients. The unit for symbol\_time is the second.

With:

symbol\_time

symbol\_time is the unit interval (UI) of the current data, e.g., 100 ps, 200 ps etc. which equals 1/baud rate. For NRZ signaling, it is equivalent to bit time. The executable model file may use this information along with the impulse\_matrix to initialize the filter coefficients. The unit for symbol\_time is the second.

Replace the following four paragraphs on page 228:

For NRZ models, it is assumed that the electrical interface to either the driver or the receiver is differential. Therefore, the sample values are assumed to be differential voltages centered nominally around zero volts. The algorithmic model’s logic threshold may be non-zero, for example to model the differential offset of a receiver. However, that offset will usually be small compared to the input or output differential voltage.

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 data bit is a “1” or a “0”). 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.

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:

The sample values are nominally symmetric around zero volts. The algorithmic model’s logic threshold may contain a residual non-zero offset, however, that offset will usually be small compared to the input or output differential voltage.

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 data bit is a “1” or a “0” for NRZ, or, in the case of PAMn, 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.

Replace the following paragraph on page 229:

**clock\_times**

Vector to return clock times. The clock times are referenced to the start of the simulation (the first AMI\_GetWave call). The clock\_times vector is allocated by the EDA tool and is guaranteed to be greater than the number of clocks expected during the AMI\_GetWave call. The clock times are exactly symbol\_time/2 before the input data signal is sampled. The algorithmic model will return non-negative clock\_times values, and place -1 after the last valid clock tick in the clock\_times vector during each AMI\_GetWave call. If there are no valid clock ticks for the duration of an AMI\_GetWave call, a single entry of -1 will be returned in the clock\_times vector. The units of clock\_times are seconds.

With:

**clock\_times**

Vector to return clock times. The clock times are referenced to the start of the simulation (the first AMI\_GetWave call). The clock\_times vector is allocated by the EDA tool and is guaranteed to be greater than the number of clocks expected during the AMI\_GetWave call. The sample times equal clock\_times + ½ UI + offset, where offset is defined by Reserved Parameters PAM\_Offsets or PAM4\_UpperEyeOffset, PAM4\_CenterEyeOffset and PAM4\_LowerEyeOffset. In the absence of these parameters, offset is assumed to be 0. The algorithmic model will return non-negative clock\_times values, and place -1 after the last valid clock tick in the clock\_times vector during each AMI\_GetWave call. If there are no valid clock ticks for the duration of an AMI\_GetWave call, a single entry of -1 will be returned in the clock\_times vector. The units of clock\_times are seconds.

Replace the following paragraph on page 231:

symbol\_time

symbol\_time is the unit interval (UI) of the current data, e.g., 100 ps, 200 ps etc. For NRZ signaling, it is equivalent to bit time. The unit for symbol\_time is the second.

With:

symbol\_time

symbol\_time is the unit interval (UI) of the current data, e.g., 100 ps, 200 ps etc. which equals 1/baud rate. For NRZ signaling, it is equivalent to bit time. The unit for symbol\_time is the second.

Replace all instances [10] of “*actual\_time*” with “*nominal\_sample\_time*” on pages 266-272.

Replace the following paragraph on page 273:

*Description:* Tells the EDA tool the voltage needed at the receiver data decision point above and below the reference voltage to ensure proper sampling of the equalized signal. The reference voltage is 0 V by default, unless defined by the PAM4\_Lower\_Threshold, PAM4\_Center\_Threshold, or PAM4\_Upper\_Threshold parameters.

With:

*Description:* Tells the EDA tool the voltage needed at the receiver data decision point above and below the reference voltage to ensure proper sampling of the equalized signal. The reference voltage is 0 V by default, unless defined by the PAM4\_Lower\_Threshold, PAM4\_Center\_Threshold, PAM4\_Upper\_Threshold parameters, or the PAM\_Thresholds parameter.

Replace the following paragraph on page 278:

Prior to AMI\_Version 6.1, AMI modeling supported only NRZ SerDes signaling. AMI\_Version 6.1 introduces support for PAM4 SerDes signaling. A SerDes waveform is periodically sampled to determine the value of the waveform between transitions. The time interval between these samples is the Unit Interval (UI), also referred to as symbol\_time (the value passed into the AMI\_Init function), and symbol\_time. Symbol\_time is a generic name since a single symbol (or UI) can either represent a bit in NRZ or two bits in PAM4 signaling. The clock\_times returned by AMI\_GetWave are edge threshold crossing times, and are ½ UI before the nominal sample times. For PAM4, the edge threshold crossing time is only meaningful for transitions between symbols 0 and 3 and between symbols 1 and 2.

With:

Prior to AMI\_Version 6.1, AMI modeling only supported NRZ SerDes signaling. AMI\_Version 6.1 introduced a set of parameters to support four-level Pulse Amplitude Modulation (PAM4) SerDes signaling. In addition, AMI\_Version 7.2 introduced Modulation\_Levels, PAM\_Thresholds, and PAM\_Offsets to support PAMn SerDes signaling. Since the PAMn parameters are a superset of the PAM4 parameters (which also include the PAM4 signaling levels), it is highly recommended to use the PAMn parameters for PAM4 signaling instead of the older PAM4 equivalents.

Replace the following paragraph on page 278:

*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”. Valid entries for this parameter are “NRZ” and “PAM4”. The default “NRZ” applies if the Modulation parameter is not included in the .ami file.

With:

*Usage Rules:* Modulation and Modulation\_Levels shall not both be present. 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”. Valid entries for this parameter are “NRZ” and “PAM4”. The default “NRZ” applies if the Modulation parameter is not included in the .ami file.

Replace the following section on page 280:

If the AMI Reserved Parameter Modulation is set to “PAM4” and PAM4\_Mapping is *not* declared, the EDA tool should assume a default “Gray code” value of “0132” for PAM4\_Mapping. The PAM4\_Mapping parameter is ignored when the AMI Reserved Parameter Modulation is not declared or is declared and 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.

There are two reasons why a mapping is required:

With:

If the AMI Reserved Parameter Modulation is set to “PAM4” and PAM4\_Mapping is *not* declared, the EDA tool should assume a default “Gray code” value of “0132” for PAM4\_Mapping. The PAM4\_Mapping parameter is ignored when the AMI Reserved Parameter Modulation is not declared or is declared and set to “NRZ”. The PAM4\_Mapping parameter is illegal when the AMI Reserved Parameter Modulation\_Levels is present. The PAM4\_Mapping parameter must contain four characters and each of the four characters “0”, “1”, “2” and “3” must occur once.

There are two reasons why PAM4\_Mapping might be used:

Replace the following paragraph on page 281:

The PAM4\_UpperThreshold, PAM4\_CenterThreshold and PAM4\_LowerThreshold parameters are ignored when the AMI Reserved Parameter Modulation is not declared or is declared and set to “NRZ”.

With:

The PAM4\_UpperThreshold, PAM4\_CenterThreshold and PAM4\_LowerThreshold parameters are ignored when the AMI Reserved Parameter Modulation is not declared or is declared and set to “NRZ”, or when AMI Reserved Parameter Modulation\_Levels is declared.

Replace the following paragraph on page 282:

If the AMI Reserved 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 each offset parameter not declared. The PAM4\_UpperEyeOffset, PAM4\_CenterEyeOffset and PAM4\_LowerEyeOffset parameters are ignored when the AMI Reserved Parameter Modulation is not declared or is declared and set to “NRZ”.

With:

If the AMI Reserved 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 each offset parameter not declared. The PAM4\_UpperEyeOffset, PAM4\_CenterEyeOffset and PAM4\_LowerEyeOffset parameters are ignored when the AMI Reserved Parameter Modulation is not declared or is declared and set to “NRZ”, or when AMI Reserved Parameter Modulation\_Levels is declared.

Add the following new parameters:

Parameter: **Modulation\_Levels**

*Required:* No, and illegal before AMI\_Version 7.2

*Direction*: Rx, Tx

*Descriptors*:

Usage: 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:* Modulation and Modulation\_Levels shall not both be present. If the format is Value, then the value shall be greater than 1. If the format is List then all values shall be greater than 1. If neither Modulation nor Modulation\_Levels are defined, then the modulation scheme used by the EDA tool must 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 levels between 0 and n-1. The voltage and timing offsets used for simulation waveform processing are specified by the 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:* Yes, illegal if Modulation\_Levels is not specified.

*Direction*: Rx

*Descriptors*:

Usage: Out

Type: String

Format: Value

Defaults: <string\_literal>

Description: <string>

*Definition*: Voltages used by EDA tools for PAMn waveform and eye processing. The string returned must contain n-1 float values of the threshold (volts) separated by white spaces.

*Usage Rules:* The EDA tool uses the voltages passed in through this parameter in conjunction with Rx clock information to detect which of the n PAMn symbols a waveform represents when the signal is sampled.

A PAMn eye has n-1 “eyes” and n symbol levels. The first float value in the string (**Value 1**) returned for PAM\_Thresholds is the voltage threshold of eye number 1, the second value (**Value 2**) is the voltage threshold of eye number 2 and so on. The threshold for each eye is typically at the “vertical center” of that eye.

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

*Example:*

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

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

(Value “0.00 0.00 0.00”)

)

*Parameters:* **PAM\_Offsets**

*Required:* No, and illegal if Modulation\_Levels is not specified.

*Direction*: Rx

*Descriptors*:

Usage: Out

Type: String

Format: Value

Defaults: <string\_literal>

Description: <string>

*Definition:* Sampling clock offsets for PAMn eyes. The string returned must contain n-1 float values of the clock offsets separated by white spaces.

*Usage Rules:* A PAMn receiver has n-1 latches. PAM\_Offsets is used to allow different sampling times at each latch (eye). There are existing ways to determine the nominal\_sample\_time that the latches are sampled. The values of PAM\_Offsets are added to the nominal\_sample\_time. The sampling time of the kth eye = nominal\_sample\_time + kth value of PAM\_Offsets, where nominal\_sample\_time is defined as follows.

Case 1: Statistical simulation, Rx\_Decision\_Time is present

*nominal\_sample\_time = Rx\_Decision\_Time*

Case 2: Statistical simulation, Rx\_Clock\_Recovery\_Mean is present, Rx\_Decision\_Time is not present

*nominal\_sample\_time = ideal\_time + Rx\_Clock\_Recovery\_Mean*

Case 3: Statistical simulation, Rx\_Clock\_Recovery\_Mean and Rx\_Decision\_Time are not present

*nominal\_sample\_time = ideal\_time*

Case 4: Time domain simulation, Rx AMI\_GetWave outputs clock\_times

*nominal\_sample\_time = clock\_times*

Case 5: Time domain simulation, Rx AMI\_GetWave does not output clock\_times

*nominal\_sample\_time = ideal\_time + Rx\_Clock\_Recovery\_Mean*

where ideal\_time is halfway between the median of the threshold crossing times on both sides of the eye. If the AMI Reserved Parameter Modulation\_Levels is defined and these offset values are *not* declared, the EDA tool is expected to use a default value of 0.0 for each offset parameter.

*Other Notes:*

*Example:*

 (PAM\_Offsets (Usage Out) (Type String)

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

(Value “0.0e-12 0.0e-12 0.0e-12 0.0e-12”)

)

**BACKGROUND INFORMATION/HISTORY:**

BIRD213.1 removes Mapping\_Name and Mapping\_Table parameters. Edits capture changes for IBIS 7.1. It also makes many editorial and clarification changes captured in the minutes of weekly IBIS ATM task group discussions beginning on February 8, 2022.