Understanding IBIS-AMI Simulations

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Agenda

- IBIS-AMI Assumptions & Terminology
- IBIS-AMI Model Components
- Analysis Stages & Simulation Types
- Algorithmic Model Types
- Static and Dynamic Equalization
- IBIS-AMI Simulation Cases & Reference Flows
- Interpreting Simulation Results
- Recovered Clock Processing
- Jitter
- Summary

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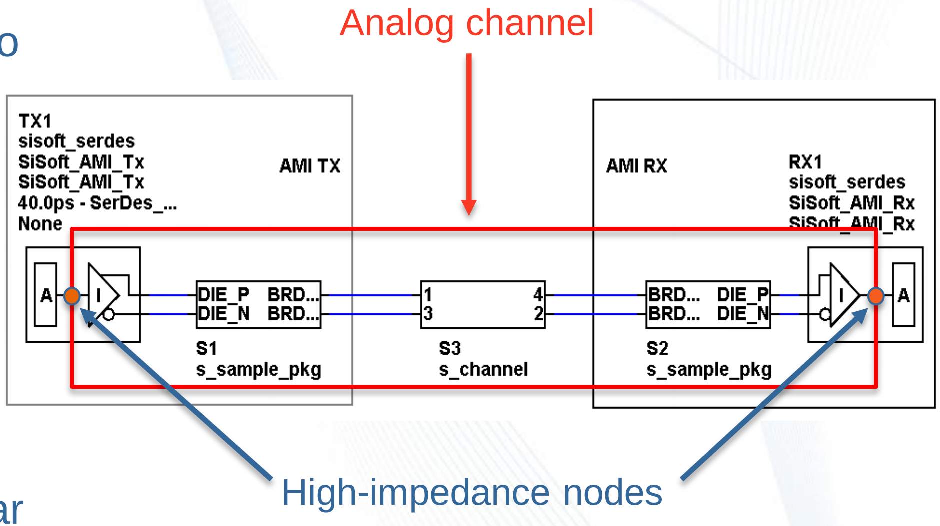
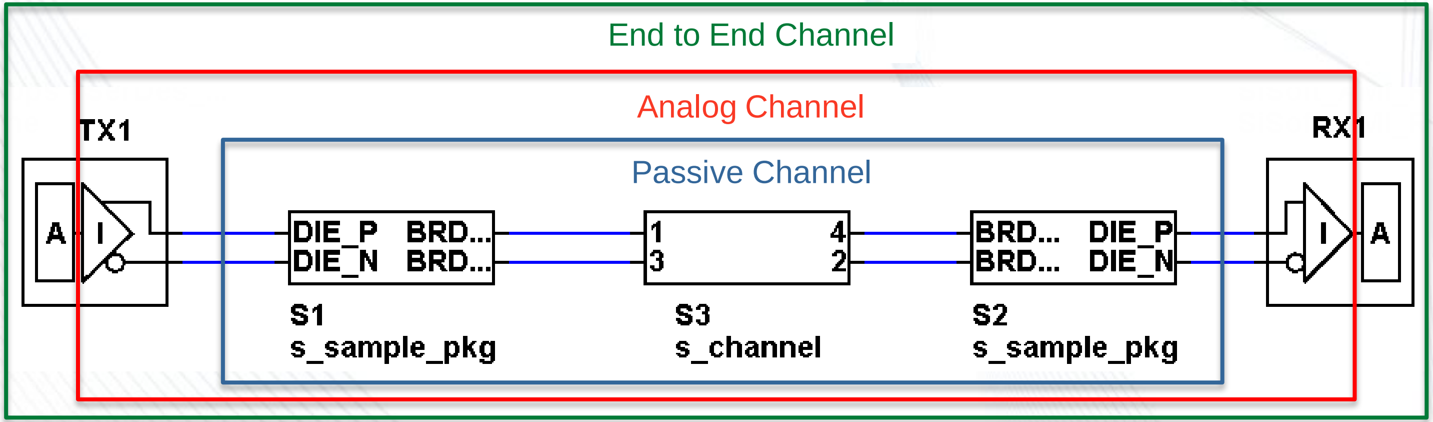
IBIS-AMI Assumptions

- SerDes channels can be broken into two parts for analysis:
  - Analog (electrical) and Algorithmic
- TX analog input & RX analog output have “high-impedance” connection to analog channel
- Analog channel can be considered linear and time-invariant (LTI)



https://ibis.org/ver6.1/ver6_1.pdf, page 170

IBIS-AMI Channel Terminology



- Circuit simulation techniques are used for the analog channel
- Signal processing techniques are used for the end to end channel

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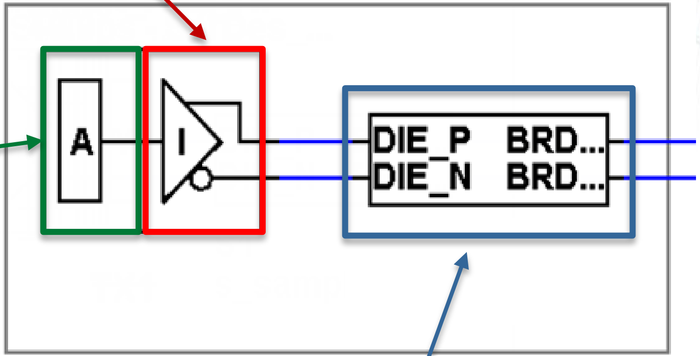
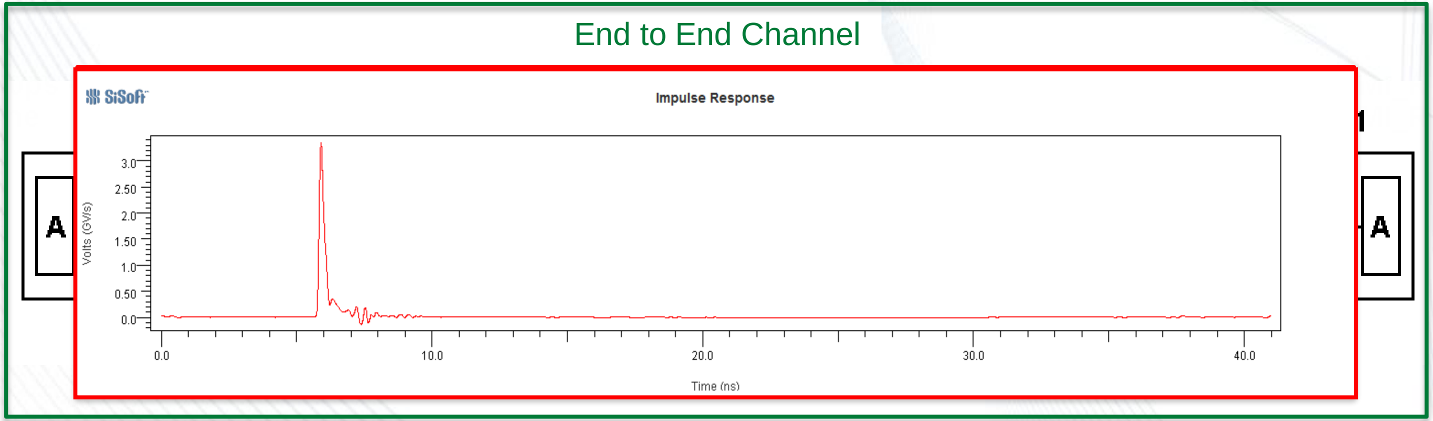
IBIS-AMI Model Components

- Analog model
  - [Model] keyword in .ibs file
  - Tabular V/I & V/T data
  - Assumed to be LTI
- Algorithmic model
  - [Algorithmic Model] keyword in .ibs file
  - .ami file describes capabilities & inputs
- Package model
  - Can be described in .ibs file
  - Often supplied separately as .sNp file



Analysis Stages



- Network Characterization (Circuit Simulation)
- Channel Simulation (Signal Processing)
  - Statistical Simulation
  - Time-Domain Simulation

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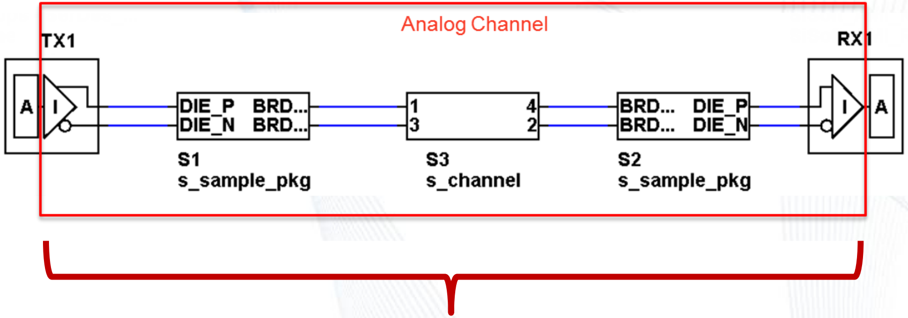
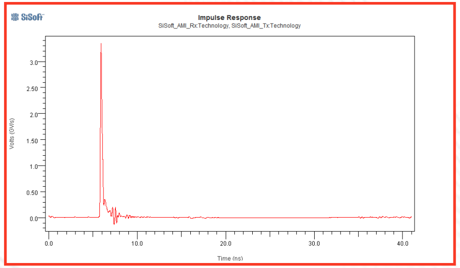
Network Characterization

- Inputs:
  - Analog sections of .ibs file
  - Passive topology elements
- Analysis Method:
  - Not specified by IBIS
  - Time-domain (step response)
  - Frequency-domain (transfer function)
- Outputs:
  - Impulse response
  - Fixed time steps
  - Long enough for signal to settle



Time-Domain or Frequency-Domain



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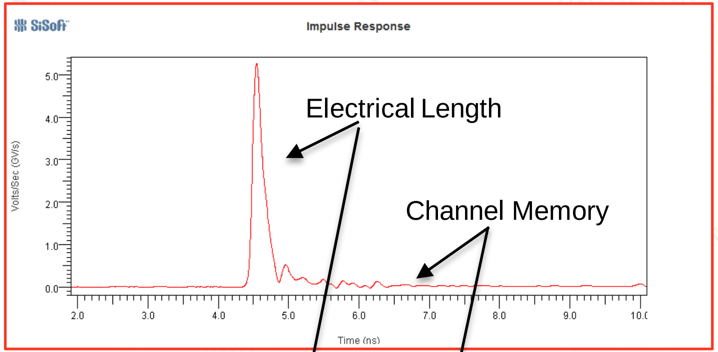
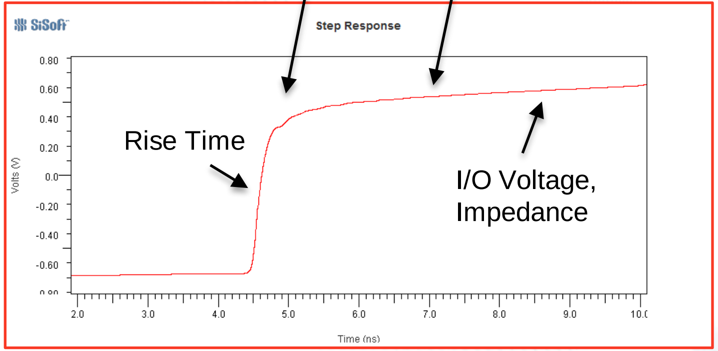
About the Impulse Response …

- Only the impulse response goes forward from Network Characterization …
  - If the impulse response is bad, running Channel Simulation ***is a waste of time***
- Verify impulse response before running channel analysis
- Step response is easier to interpret
  - Voltage levels
  - Rise time
  - Network delay
  - Reflections and settling behavior
- Remember – impulse response does not include TX or RX equalization



Impulse Response



Step Response

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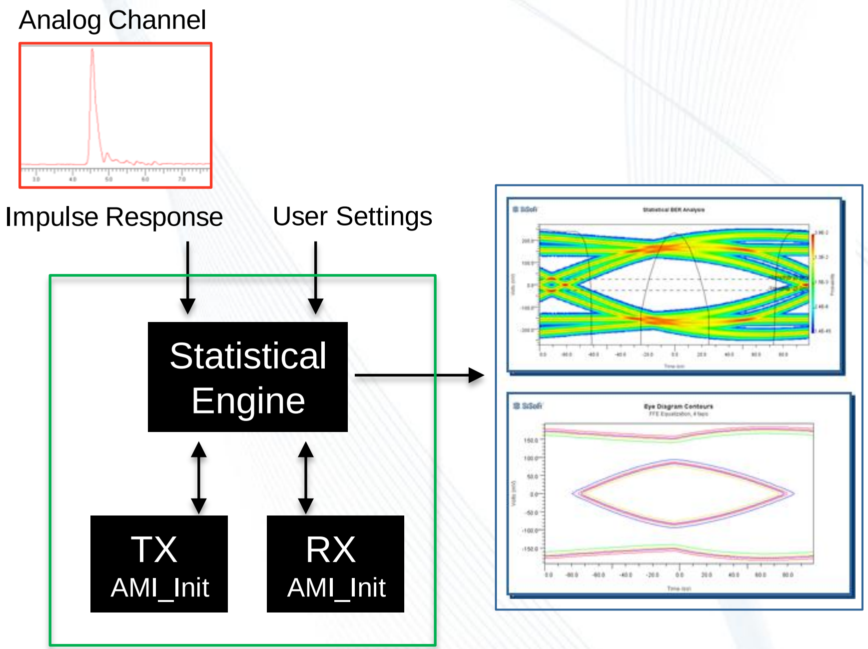
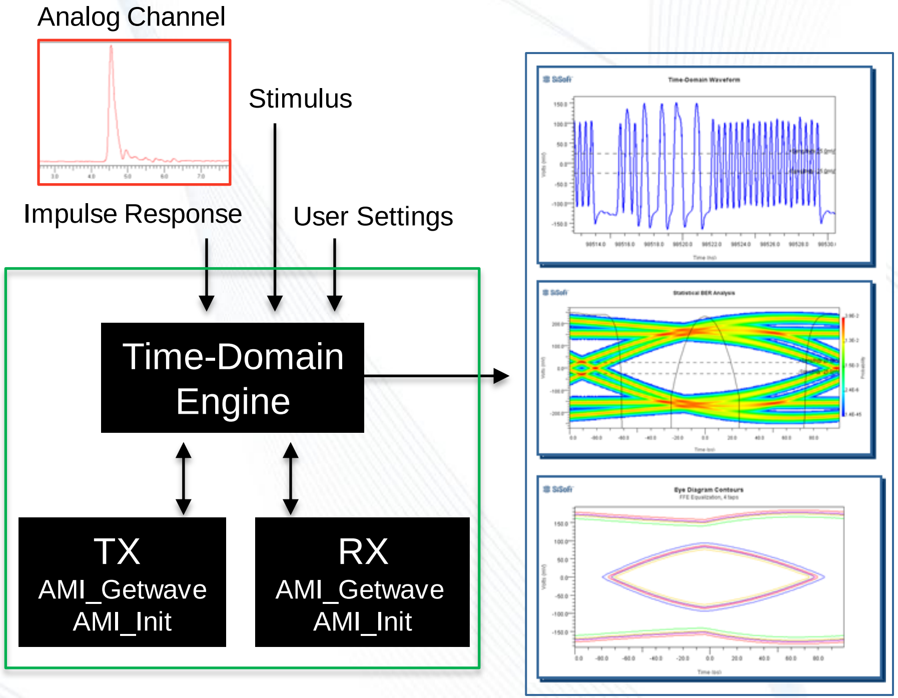
Statistical Simulation

- Inputs:
  - Analog channel impulse response
  - User selections for model parameters
  - Algorithmic models
    (AMI_Init / impulse response processing)
- Analysis Method:
  - Convolution engine (pulse response)
- Outputs:
  - Not specified by IBIS
  - Statistical eye diagrams
  - Eye height / width measurements
  - Eye contours @ probabilities
  - Equalized / unequalized responses



Time-Domain Simulation

- Inputs:
  - Impulse responses from prior steps
  - User-defined input stimulus
  - Algorithmic models (AMI_Getwave / waveform processing)
- Analysis Method:
  - Waveform processing & convolution
- Outputs:
  - Not specified by IBIS
  - Persistent eye diagrams
  - Eye height / width measurements
  - Eye contours @ probabilities
  - Equalized / unequalized responses



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Algorithmic Model Types

3 types of algorithmic models exist:

1. Impulse response (Init) only
   - Init_Returns_Impulse = TRUE
   - Getwave_Exists = FALSE
2. Waveform (Getwave) only
   - Init_Returns_Impulse = FALSE
   - Getwave_Exists = TRUE
3. Dual
   - Init_Returns_Impulse = TRUE
   - Getwave_Exists = TRUE

```
(IBIS_AMI_Tx
   (Description "Generic transmitter model published by SiSoft")

   (Reserved_Parameters
      (Ignore_Bits (Usage Info) (Type Integer) (Default 4)
         (Description "Ignore four bits to fill up tapped delay line."))
      (Max_Init_Aggressors (Usage Info) (Type Integer) (Default 25)
         (Description "Number of aggressors is actually unlimited."))
      (Init_Returns_Impulse (Usage Info) (Type Boolean) (Default True)
         (Description "Both impulse and parameters_out returned."))
      (GetWave_Exists (Usage Info) (Type Boolean) (Default True)
         (Description "GetWave is well and truly provided in the module."))
) | End Reserved_Parameters

   (Model_Specific
      (tap_filter (Description "Array of transmit de-emphasis tap weights")
         (-1 (Usage InOut)(Format Range 0.0 -1.0 1.0)(Type Tap)(Default 0)
               (Description "Pre-cursor tap weight"))
         (0  (Usage InOut)(Format Range 1.0 -1.0 1.0)(Type Tap)(Default 1)
               (Description "Main tap weight"))
         (1  (Usage InOut)(Format Range 0.0 -1.0 1.0)(Type Tap)(Default 0)
               (Description "First post-cursor tap weight"))
         (2  (Usage InOut)(Format Range 0.0 -1.0 1.0)(Type Tap)(Default 0)
               (Description "Second post-cursor tap weight"))
      ) | End tap_filter
      (tx_swing (Usage In)(Format Range 0.8 0.3 1.0)(Type Float)(Default 0.8)
               (Description "Peak differential output voltage"))
   ) | End Model_Specific

) | End IBIS_AMI_Tx
```

Reserved_Parameters
Provide information on model function and control analysis flow
[Info for the simulator]

Model_Specific
Parameters used by this specific model, legal and default values
[Info for providing inputs to the model]

.AMI file

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Static and Dynamic Equalization

- Static equalization
  - Impulse response processing (Init)
  - Happens once - does not vary from bit to bit
  - Treated as LTI by simulation engine
  - Can be used to generate Statistical and Time-Domain results
- Dynamic equalization
  - Waveform processing (Getwave)
  - Based on user stimulus and can vary from bit to bit
  - Includes equalization and clock recovery behavior
  - Only used to generate Time-Domain results

Model Type	Equalization
Init-Only	Static
Getwave-Only	Dynamic
Dual	Static & Dynamic

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The 9 AMI Simulation Cases

- The method an AMI simulator uses to create Time-Domain results is based on the types of TX and RX algorithmic models involved.

$$\left\{\begin{array}{l}\text{Init-Only}\\ \text{Getwave-Only}\\ \text{Dual}\end{array}\right\} \times \left\{\begin{array}{l}\text{Init-Only}\\ \text{Getwave-Only}\\ \text{Dual}\end{array}\right\} = \text{9 Cases}$$

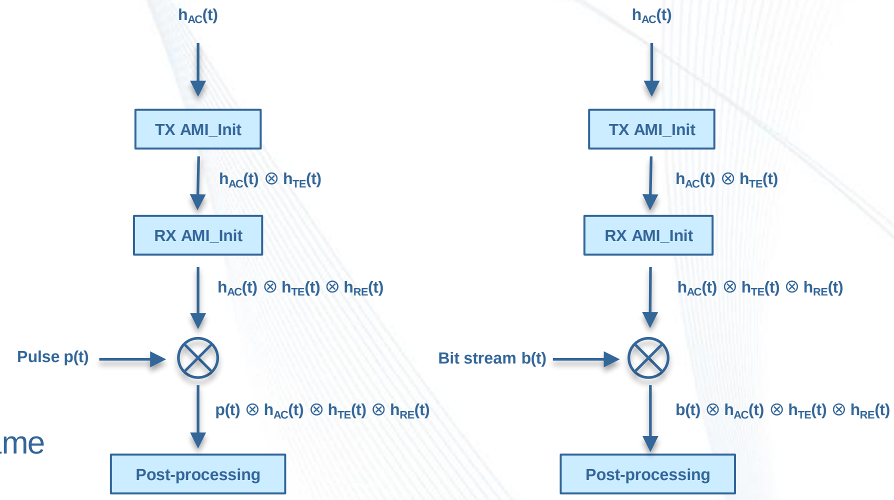
Case #	TX			RX		
	Getwave Exists	**Init_Returns_Impulse**	**Meaning**	**Getwave Exists**	**Init_Returns_Impulse**	**Meaning**
1	FALSE	TRUE	Init Model Only	FALSE	TRUE	Init Model Only
2	FALSE	TRUE	Init Model Only	TRUE	FALSE	Getwave Model Only
3	FALSE	TRUE	Init Model Only	TRUE	TRUE	Dual Model
4	TRUE	FALSE	Getwave Model Only	FALSE	TRUE	Init Model Only
5	TRUE	FALSE	Getwave Model Only	TRUE	FALSE	Getwave Model Only
6	TRUE	FALSE	Getwave Model Only	TRUE	TRUE	Dual Model
7	TRUE	TRUE	Dual Model	FALSE	TRUE	Init Model Only
8	TRUE	TRUE	Dual Model	TRUE	FALSE	Getwave Model Only
9	TRUE	TRUE	Dual Model	TRUE	TRUE	Dual Model

IBIS-AMI Simulation Terminology …

- $h_{AC}(t)$ – Analog channel impulse response
- $p(t)$ – Unit pulse at target data rate
- $b(t)$ – Data bit stream suitable for convolution processing
- $h_{TE}(t)$ – Impulse response of TX AMI_Init equalization
- $h_{RE}(t)$ – Impulse response of RX AMI_Init equalization
- $g_{TE}[x(t)]$ – Waveform output of TX Getwave processing
- $g_{RE}[x(t)]$ – Waveform output of RX Getwave processing

Case 1: TX: Init-only ➔ RX: Init-only

- Statistical Simulation
  - Includes TX & RX equalization
- Time-Domain simulation
  - Neither model supports waveform processing
  - Static TX & static RX equalization
  - Any clock recovery is performed by simulator
- Implications
  - Statistical and Time-Domain equalization is the same
  - Little benefit in running Time-Domain simulation, unless
    - Low density encoding (e.g. 8b10b) is used
    - Need to isolate specific stimulus pattern
  - Time-Domain simulations (if run) can be fairly short, as there are no RX control loops to settle



Statistical Flow
Static TX EQ, Static RX EQ

Time-Domain Flow
Static TX EQ, Static RX EQ

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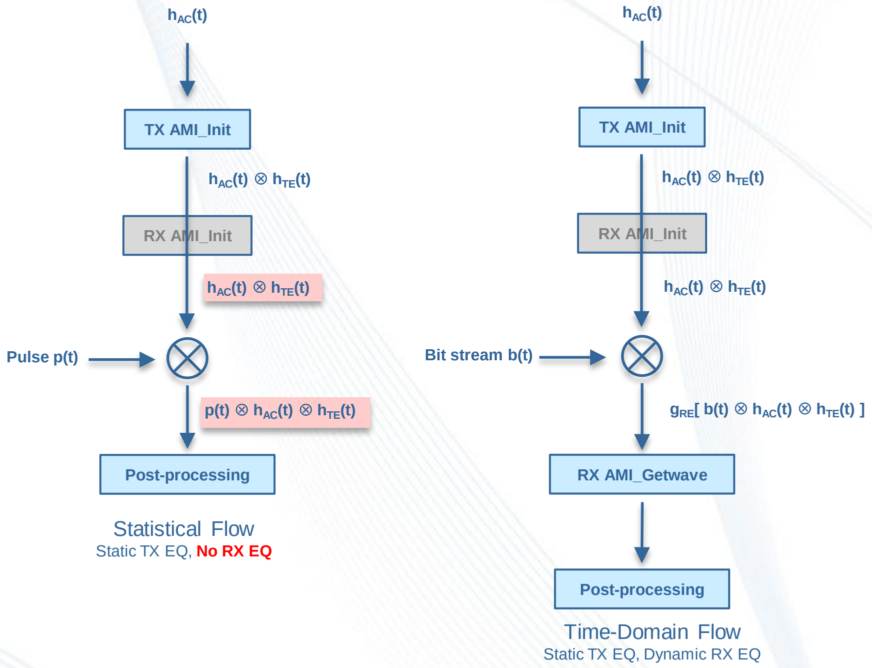
Case 2: TX: Init-only ➔ RX: Getwave-only

- Statistical Simulation
  - Includes TX equalization only
- Time-Domain simulation
  - Static TX & Dynamic RX equalization
  - Clock recovery (usually) performed by RX model
- Implications
  - Statistical results are missing RX equalization
    - Consider results as “signal at RX die pad”
  - Statistical and Time-Domain TX behavior is the same
  - Time-domain simulations must allow RX feedback loops to settle before data accumulation begins



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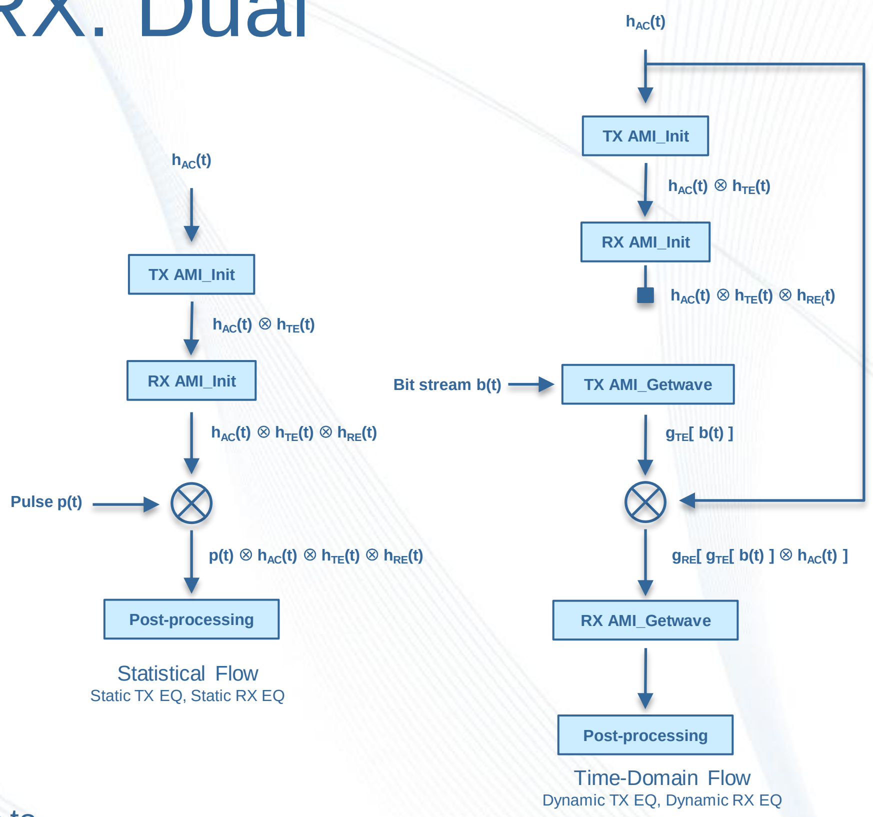
Case 9: TX: Dual ➔ RX: Dual

- Statistical Simulation
  - Includes TX & RX equalization
- Time-Domain simulation
  - Dynamic TX & Dynamic RX equalization
  - Clock recovery (usually) performed by RX model
- Implications
  - Best possible case: fully supports Statistical & Time-Domain simulation
  - Time-domain simulations must allow RX feedback loops to settle before data accumulation begins
  - Statistical simulations can be used for exploration, Time-Domain simulations for validation
  - Should compare Statistical & Time-Domain results to determine how well Statistical results predict their Time-Domain counterparts



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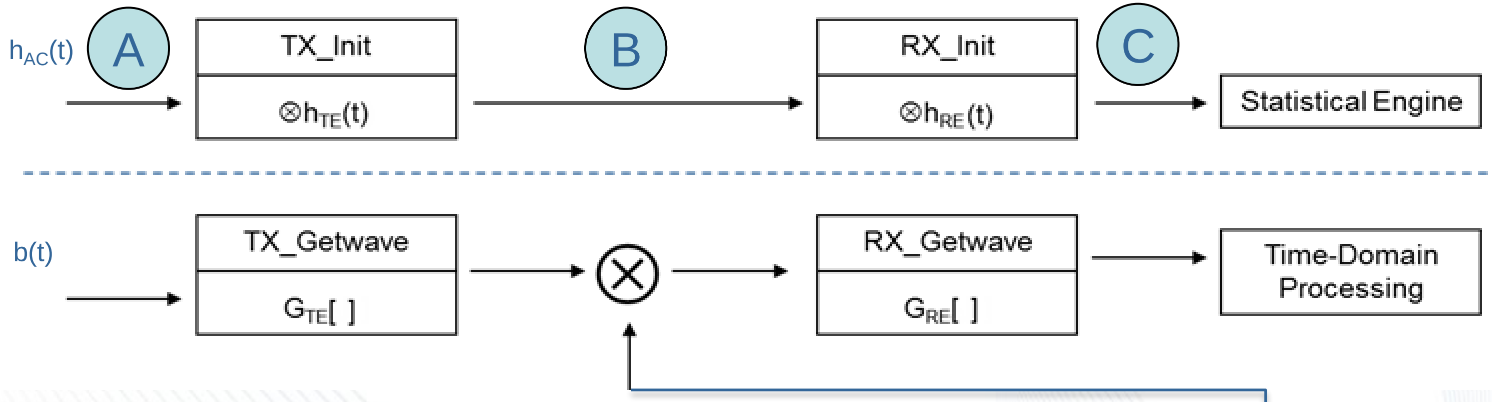
IBIS-AMI Reference Flow



Case #	TX			RX			Convolution Input
	Getwave Exists	**Init Returns Impulse**	**Meaning**	**Getwave Exists**	**Init Returns Impulse**	**Meaning**	
1	FALSE	TRUE	Init-Only	FALSE	TRUE	Init-Only	C
2	FALSE	TRUE	Init-Only	TRUE	FALSE	Getwave-Only	A or B
3	FALSE	TRUE	Init-Only	TRUE	TRUE	Dual	B
4	TRUE	FALSE	Getwave-Only	FALSE	TRUE	Init-Only	C
5	TRUE	FALSE	Getwave-Only	TRUE	FALSE	Getwave-Only	A, B, or C
6	TRUE	FALSE	Getwave-Only	TRUE	TRUE	Dual	A
7	TRUE	TRUE	Dual	FALSE	TRUE	Init-Only	iFFT(FFT(C)/FFT(B))
8	TRUE	TRUE	Dual	TRUE	FALSE	Getwave-Only	A
9	TRUE	TRUE	Dual	TRUE	TRUE	Dual	A

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Interpreting Simulation Results

Case #	TX			RX			Statistical	Time Domain
	Getwave Exists	**Init_Returns_Impulse**	**Meaning**	**Getwave Exists**	**Init_Returns_Impulse**	**Meaning**		
1	FALSE	TRUE	Init-Only	FALSE	TRUE	Init-Only	OK	Static TX EQ, Static RX Eq
2	FALSE	TRUE	Init-Only	TRUE	FALSE	Getwave-Only	No RX EQ	Static TX EQ, Dynamic RX Eq
3	FALSE	TRUE	Init-Only	TRUE	TRUE	Dual	OK	Static TX EQ, Dynamic RX Eq
4	TRUE	FALSE	Getwave-Only	FALSE	TRUE	Init-Only	No TX EQ	Dynamic TX EQ, Static RX EQ
5	TRUE	FALSE	Getwave-Only	TRUE	FALSE	Getwave-Only	No TX or RX EQ	Dynamic TX EQ, Dynamic RX EQ
6	TRUE	FALSE	Getwave-Only	TRUE	TRUE	Dual	No TX EQ	Dynamic TX EQ, Dynamic RX EQ
7	TRUE	TRUE	Dual	FALSE	TRUE	Init-Only	OK	Dynamic TX EQ, Static RX EQ
8	TRUE	TRUE	Dual	TRUE	FALSE	Getwave-Only	No RX EQ	Dynamic TX EQ, Dynamic RX EQ
9	TRUE	TRUE	Dual	TRUE	TRUE	Dual	OK	Dynamic TX EQ, Dynamic RX EQ

(dark green)	Correct equalization of TX and RX modeled
(light green)	Correct equalization of TX and RX modeled :Assuming no adaptation in TX
(light orange)	Assumes Static RX EQ is a good representation of the RX: No Adaptation
(yellow)	Assumes Static RX EQ is a good representation of the RX: No Adaptation, advanced simulator required
(pink)	Equalization data is missing

- Statistical simulations can be missing TX and/or RX equalization, depending on case
  - Some partial statistical results are useful, others are not
- Time-Domain simulations ALWAYS include TX & RX equalization
  - Equalization can be either static or dynamic, depending on the case
- Case 9 fully supports both Statistical & Time-Domain simulation

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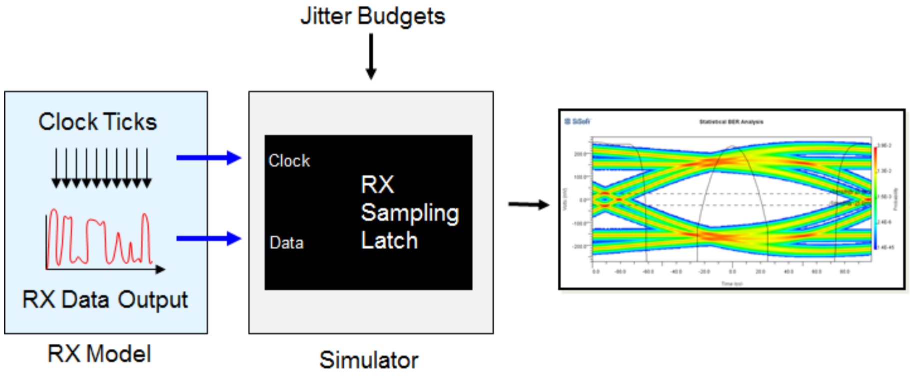
Recovered Clock Processing

- AMI models can return both equalized signal and recovered clock behavior
- Understanding where an eye is sampled is critical to analyzing system margin
- RX models are not required to return clock behavior
  - Simulators must handle these situations appropriately
- RX jitter budgets are combined with clock behavior returned from the algorithmic model



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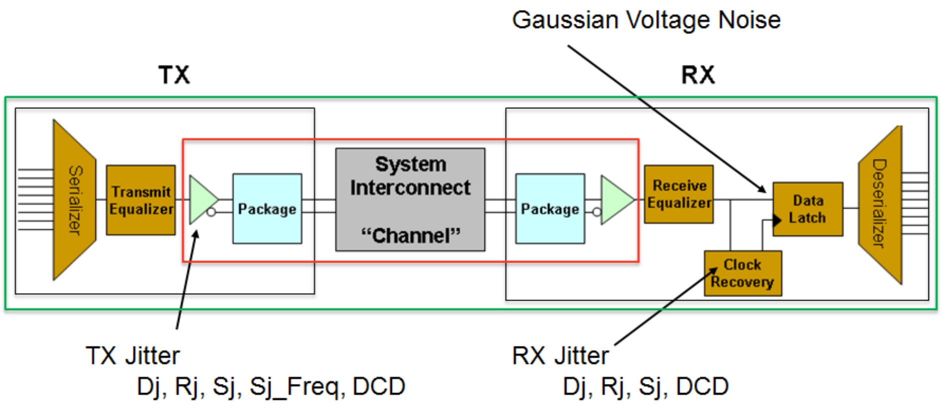
Jitter and Noise

- IBIS 6.1 provides multiple TX & RX impairments

- TX jitter directly modulates the TX output
  - There is no jitter transfer function; transfer is 100%

- RX jitter affects recovered clock behavior
  - Simulators combine jitter data with clock information returned by the model

- RX noise affects sampling latch data input



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Summary

- IBIS-AMI simulation is a multi-stage process that includes pre- and post-processing steps
- IBIS-AMI simulations combine Circuit Simulation & Signal Processing
- Each Algorithmic model can be 1 of 3 types
- Simulators must support 9 different simulation flows
  - The significance of Statistical results varies by flow
  - Time-Domain results have differing TX & RX equalization by flow
- Understanding simulators work and how to isolate issues is key

Thank You