Methods to Reduce Effects of DDR5 Rise/Fall Asymmetry in IBIS-AMI Simulations

Walter Katz
The MathWorks, Inc.
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Overview

- DDR5 I/O buffers
  - Equalization methods well suited for IBIS-AMI analysis
- IBIS-AMI Original Intent focused on SerDes
  - Single ended signaling (DDR5) introduces some new issues
    - Rise/Fall asymmetry
    - DC Offset
    - Imbalanced drive impedances
    - Clock Forwarded, Not imbedded Clock
- This presentation focuses on methods that minimize the effects of DDR5 Rise/Fall asymmetry in IBIS-AMI simulations.

DDR5 I/O Buffers & Equalization

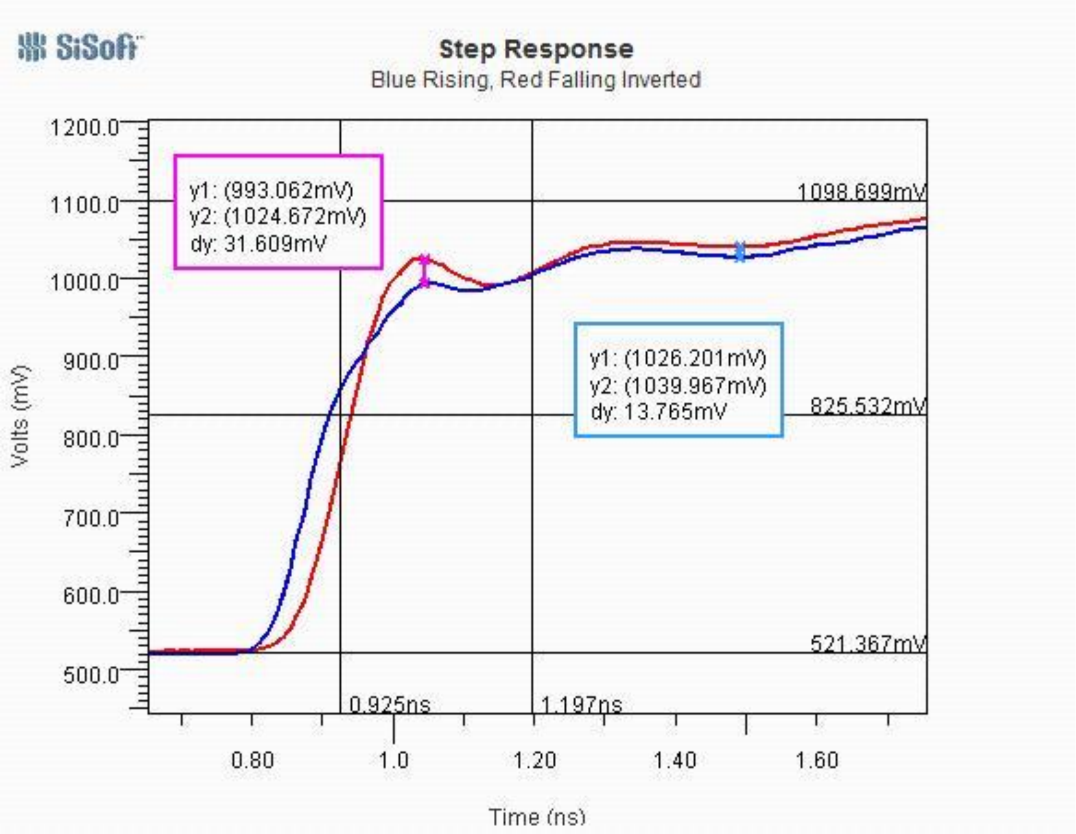
- JEDEC
  - Specifies the Minimum DRAM equalization capabilities
  - Controller equalization is not defined and will be vendor specific.
- Current Expected Capabilities
  - Writes
    - Memory Rx buffers a required to have a multi-tap DFE
    - Controller Tx buffers can have an FFE …
  - Reads
    - Memory Tx buffers have no equalization.
    - Controller Rx buffers may have a CTLE and DFE …

DDR5 modeling vs the Original Intent of IBIS-AMI

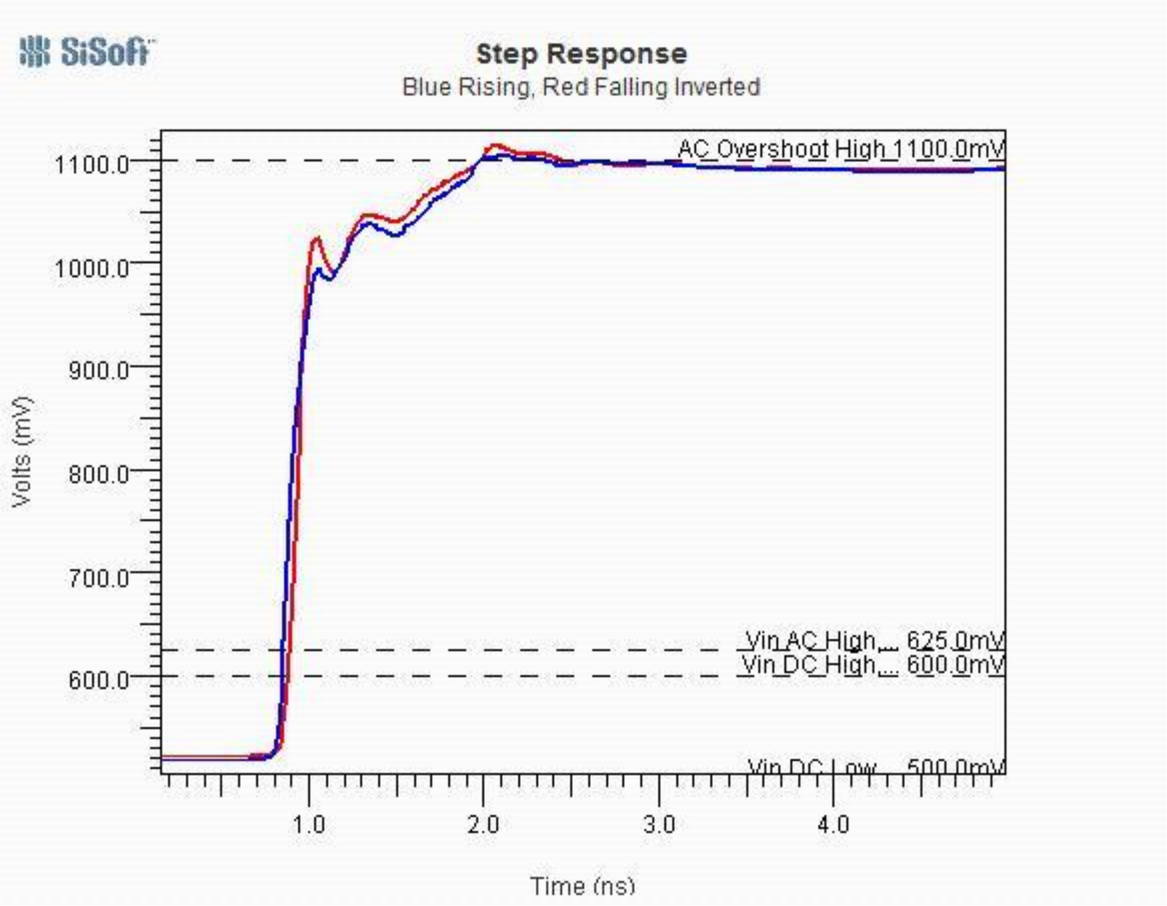
- DDR5 is single ended signaling while IBIS-AMI was originally targeted for differential signaling.
- DDR5 is a parallel clock forwarding interface while IBIS-AMI was originally targeted for interfaces with the clock imbedded in the data.
- IBIS-AMI makes LTI assumptions that are violated when:
  - Tx Rise and Fall times are different
  - Tx High and Low impedances are different
- Simulation results are presented using a preliminary DDR5 IBIS model from DRAM vendor
  - Rise time ~65 ps, Fall time ~45 ps
  - High impedance ~ 40 ohm, low impedance ~30 ohm

LTI Analysis

- Assumes Rising and Falling Edges are Symmetric
  - With DDR, they will be different
  - Faster speed grades may minimize this difference



Impact of Rise/Fall variation & High/Low Impedance variation on Channel Step Response



What To Do?

- There are many different solutions to this problem
  - Each minimize the effects of Rise/Fall variations
  - Impedance variations are more difficult
- This presentation will describe two methods to minimize the error introduced by Rise/Fall variations on DDR5 channels.

Methods That Are Being Compared

- Just Rising Waveform
- Just Falling Waveform
- Using a Melded Impulse Response as input to AMI_GetWave.
- Input to AMI_GetWave is a convolution that applies both the rising and falling impulse response to the output of the Tx AMI_GetWave. The rising impulse response is applied to the waveform sample intervals that are > 0, the falling impulse response is applied to the waveform sample intervals that are < 0.

Issue with Rise/Fall Impedance Variations

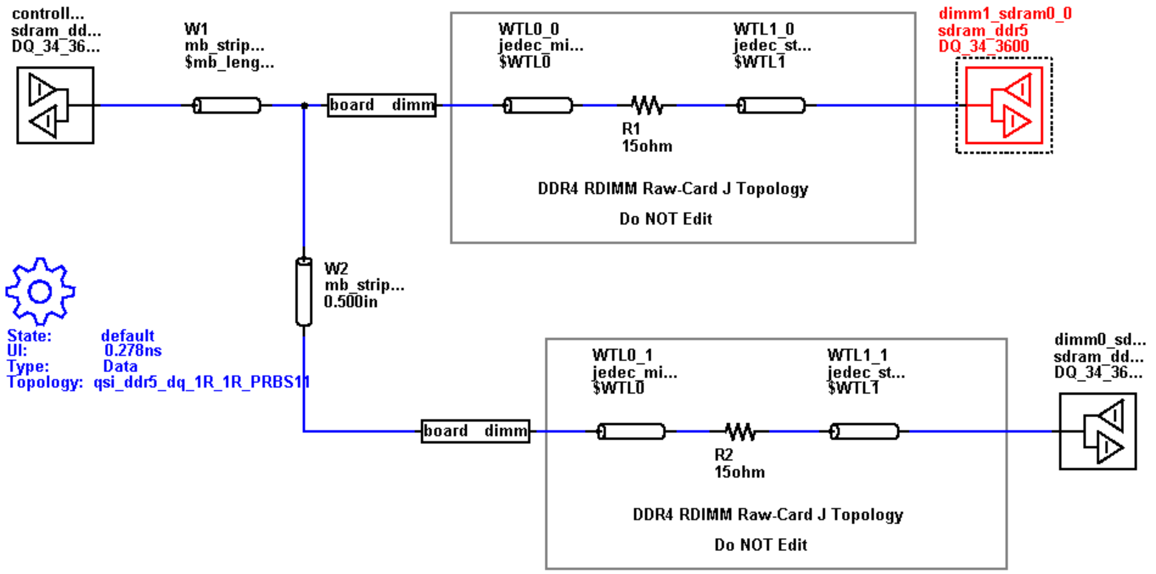
- The simulation
  - Step Responses
    - The rising step response is in the high state when ISI reflects at the driver.
    - The falling step response is in the low state when ISI reflects at the driver.
- The reality
  - The Driver state is unknown when reflected waveforms arrive at the driver.
  - The potentially different driver impedances results in different reflections of these waveforms than in the step response simulations.

Minimizing the Issue with Rise/Fall Impedance Variations

- Use specific Rising/Falling Impulse Response for Main Cursor
- Use the average of the Rising and Falling impedance beyond the main cursor.
- This creates a modified Rising and Falling Impulse Response that is used in the Mixed Method described below.

Reference Channel used for Evaluation

- Maximizes Reflections
- Realistic configuration



Methods Implemented using MATLAB Script

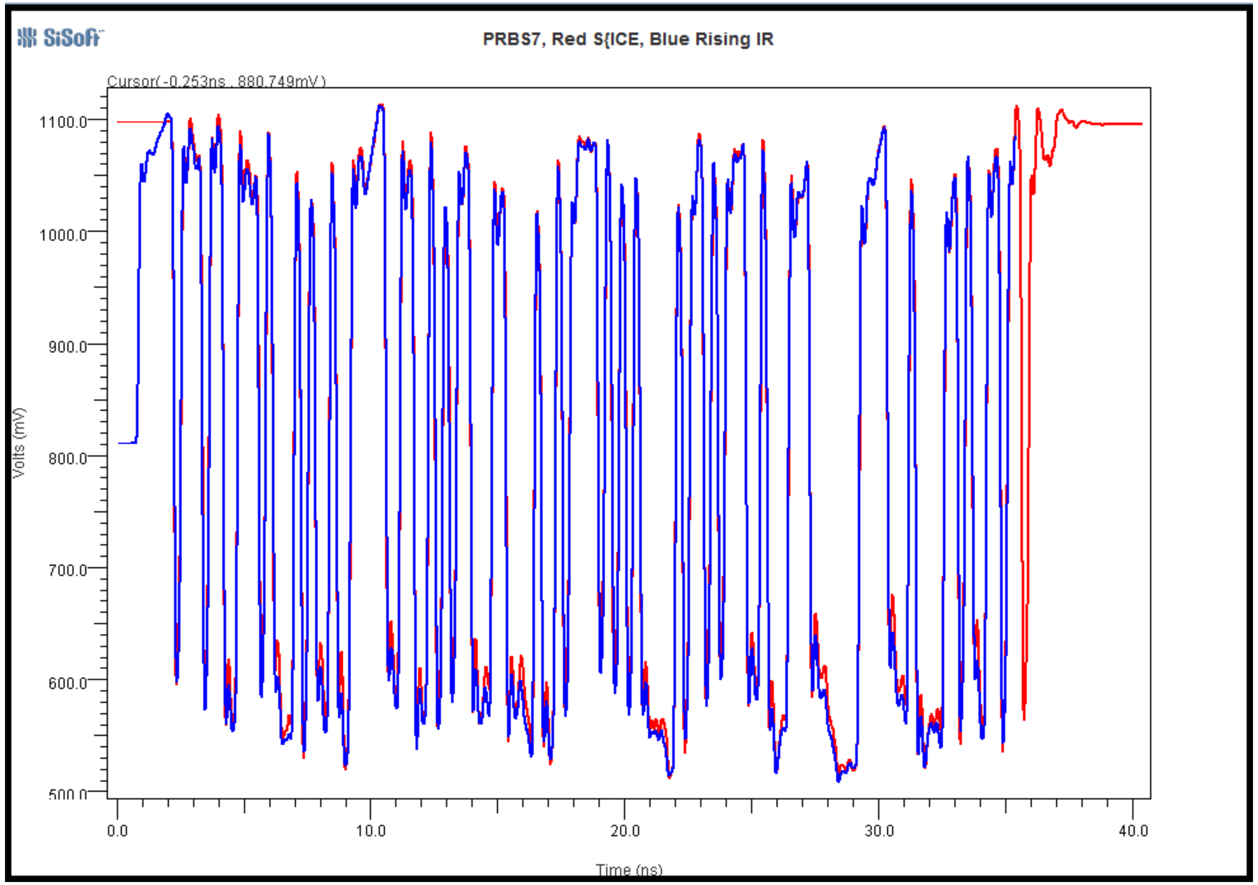
- Rising
  - Uses the rising impulse response
- Falling
  - Uses the inverted falling impulse response
- Melded
  - Uses the melded impulse response (average of the rising and inverted falling impulse response)
- Mixed
  - Uses
    - Rising mixed impulse response when stimulus > 0
    - Inverted Falling mixed impulse response when stimulus < 0
    - Stimulus goes from -0.5 to +0.5

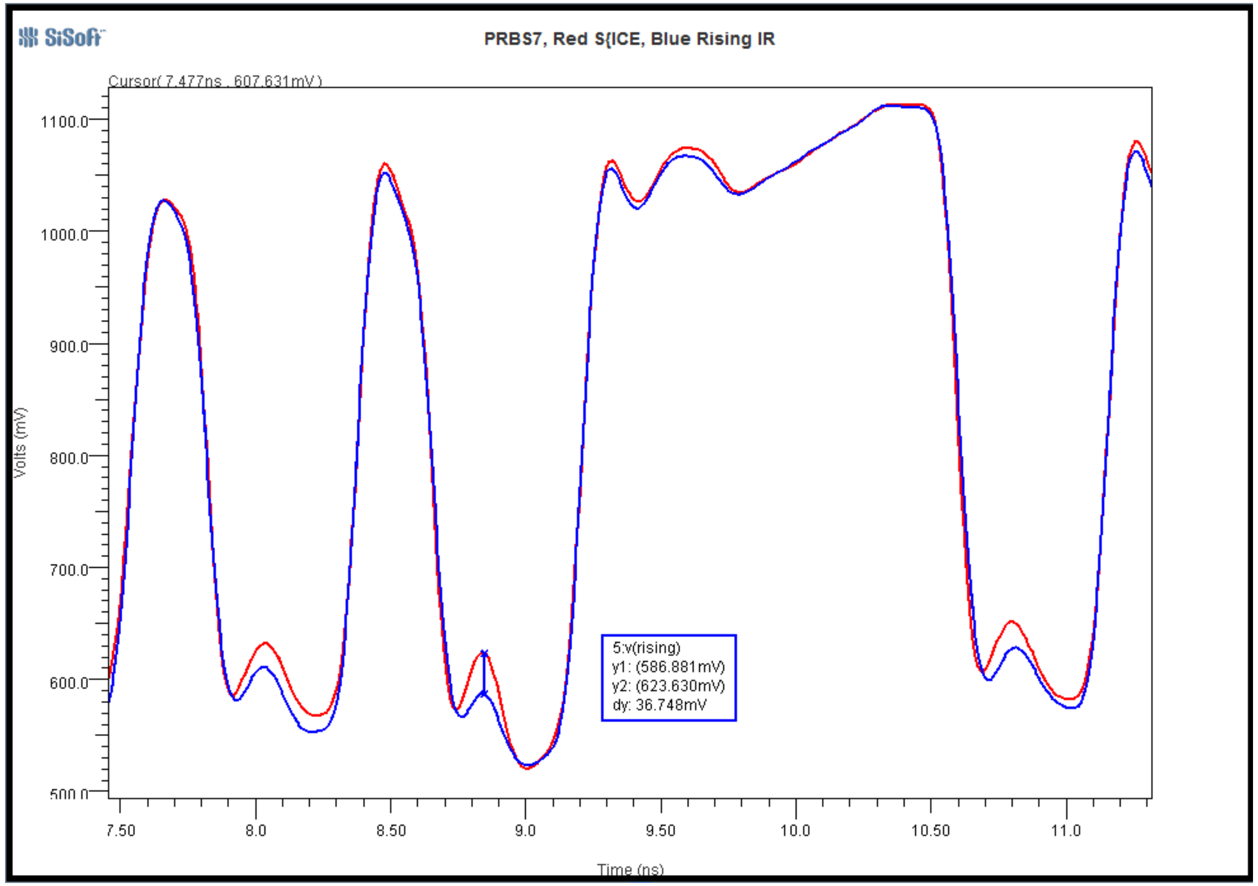
DC_Offset (BIRD 197.2) is added to waveforms to compare to SPICE simulations

MATLAB Script For These Four Methods

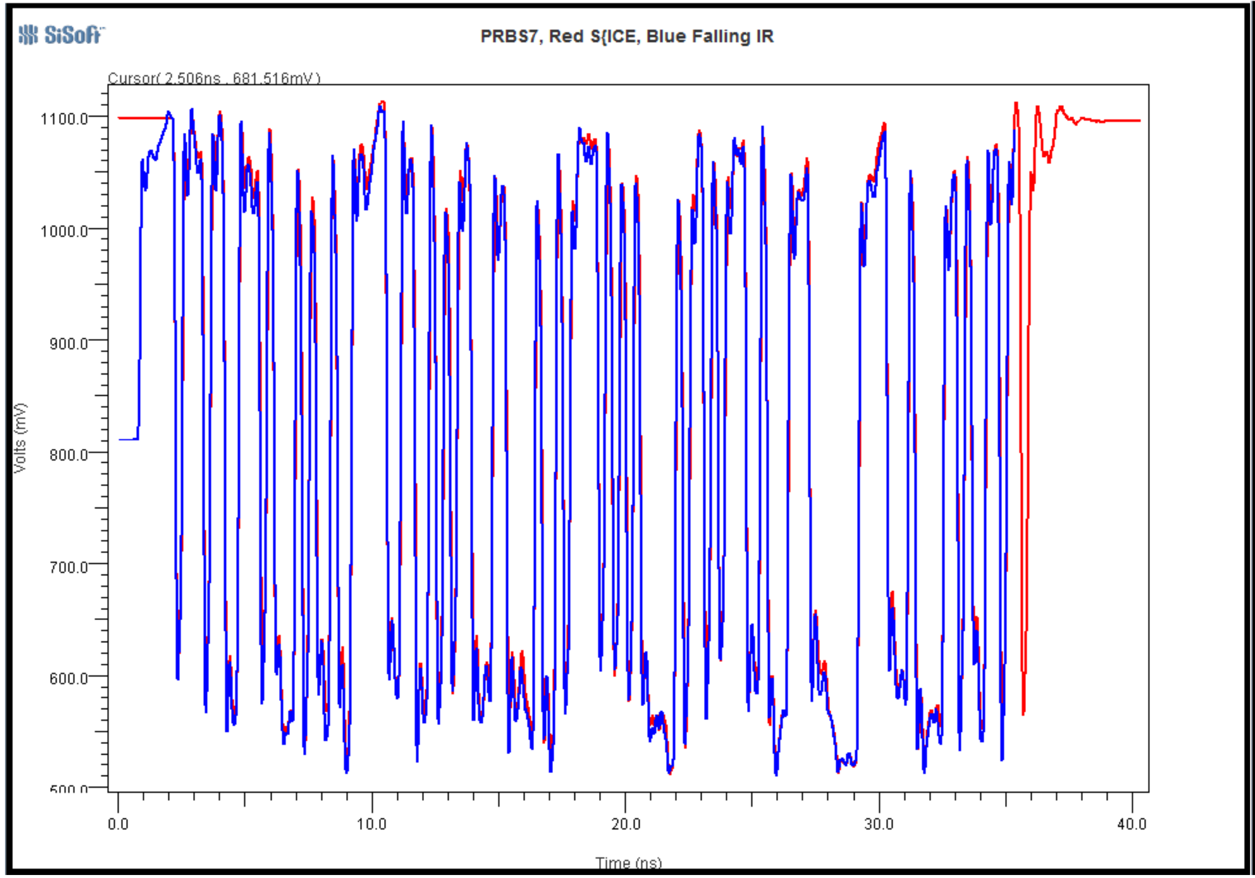
```
%  waveIn(1:sizeWave)          is input Waveform
%  risingIR(1:sizeIR)          is Rising Impulse Response
%  fallingIR(1:sizeIR)         is Falling Impulse Response
%  meldedIR(1:sizeIR)          is Melded Impulse Response
%  risingMixedIR(1:sizeIR)     is Rising/Mixed Impulse Response
%  fallingMixedIR(1:sizeIR)    is Falling/Mixed Impulse Response

waveOut=zeros(sizeWave,5);    % allocate Matrix, column 1 is time, columns 2:5 are 4 results for 4 methods
for itime = 1:sizeWave-sizeIR
    txOut=waveIn(itime)*sampleInterval;
    waveOut(itime,1)=(itime-1)*sampleInterval;    % first column of waveOut is time
    endOfWave=itime-1+sizeIR;
    % do the four convolutions for rising, falling, melding and mixed IR
    waveOut(itime:endOfWave,3)=waveOut(itime:endOfWave,3)+txOut*risingIR(1:sizeIR);  % convolution using rising IR
    waveOut(itime:endOfWave,4)=waveOut(itime:endOfWave,4)+txOut*fallingIR(1:sizeIR); % convolution using falling IR
    waveOut(itime:endOfWave,5)=waveOut(itime:endOfWave,5)+txOut*meldIR(1:sizeIR);    % convolution using melded IR
    if(txOut > 0)
        % waveform > 0 use rising mixed IR
        waveOut(itime:endOfWave,2)=waveOut(itime:endOfWave,2)+txOut*risingMixedIR(1:sizeIR);
    elseif(txOut < 0)
        % waveform < 0 use falling mixed IR
        waveOut(itime:endOfWave,2)=waveOut(itime:endOfWave,2)+txOut*fallingMixedIR(1:sizeIR);
    end
end
waveOut(1:end,2:5)=waveOut(1:end,2:5)+DC_Offset;   % Add DC_Offset to 4 waveforms
plot(waveOut(1:end,1),waveOut(1:end,2:5))          % Plot the four waveforms vs time
```

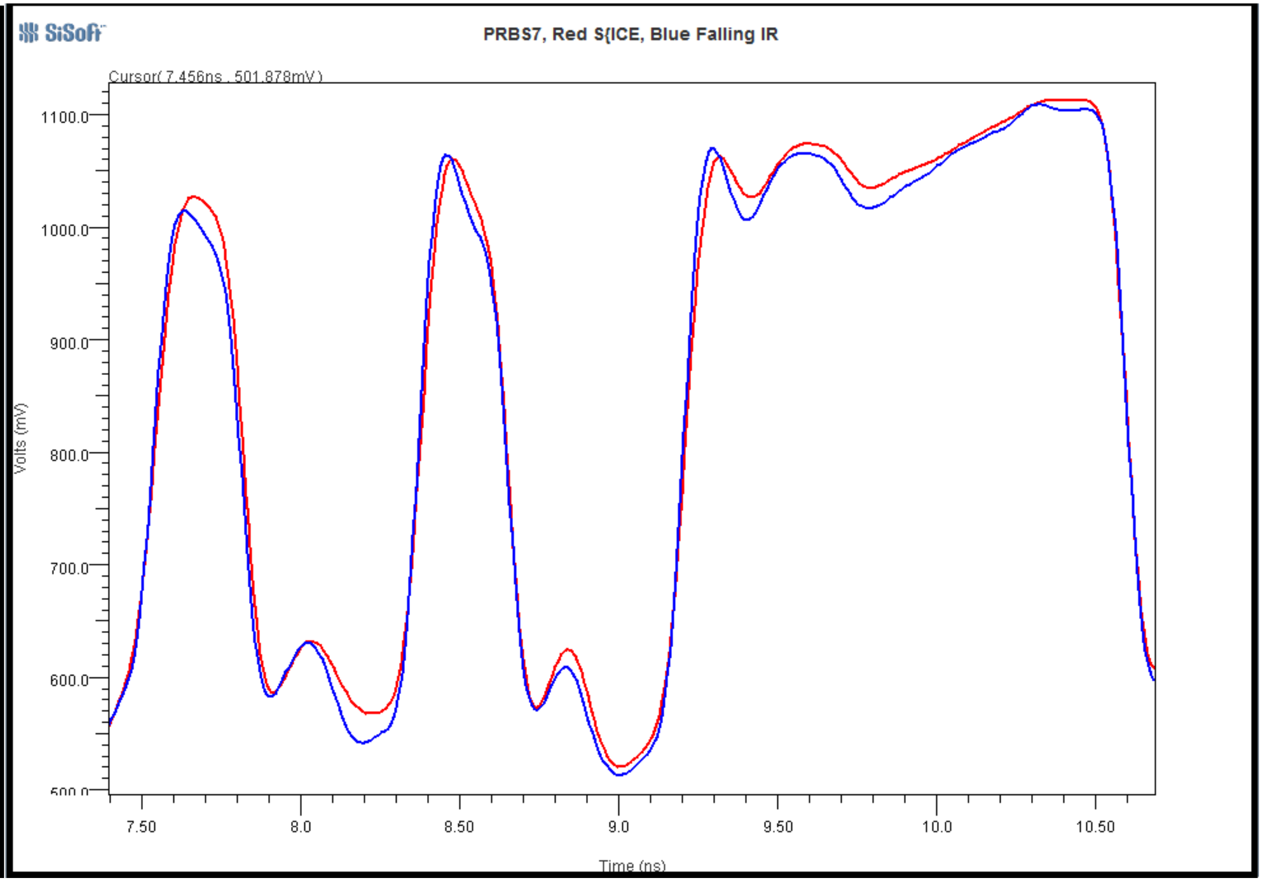
Rising Impulse Response, Red SPICE, Blue Convolution



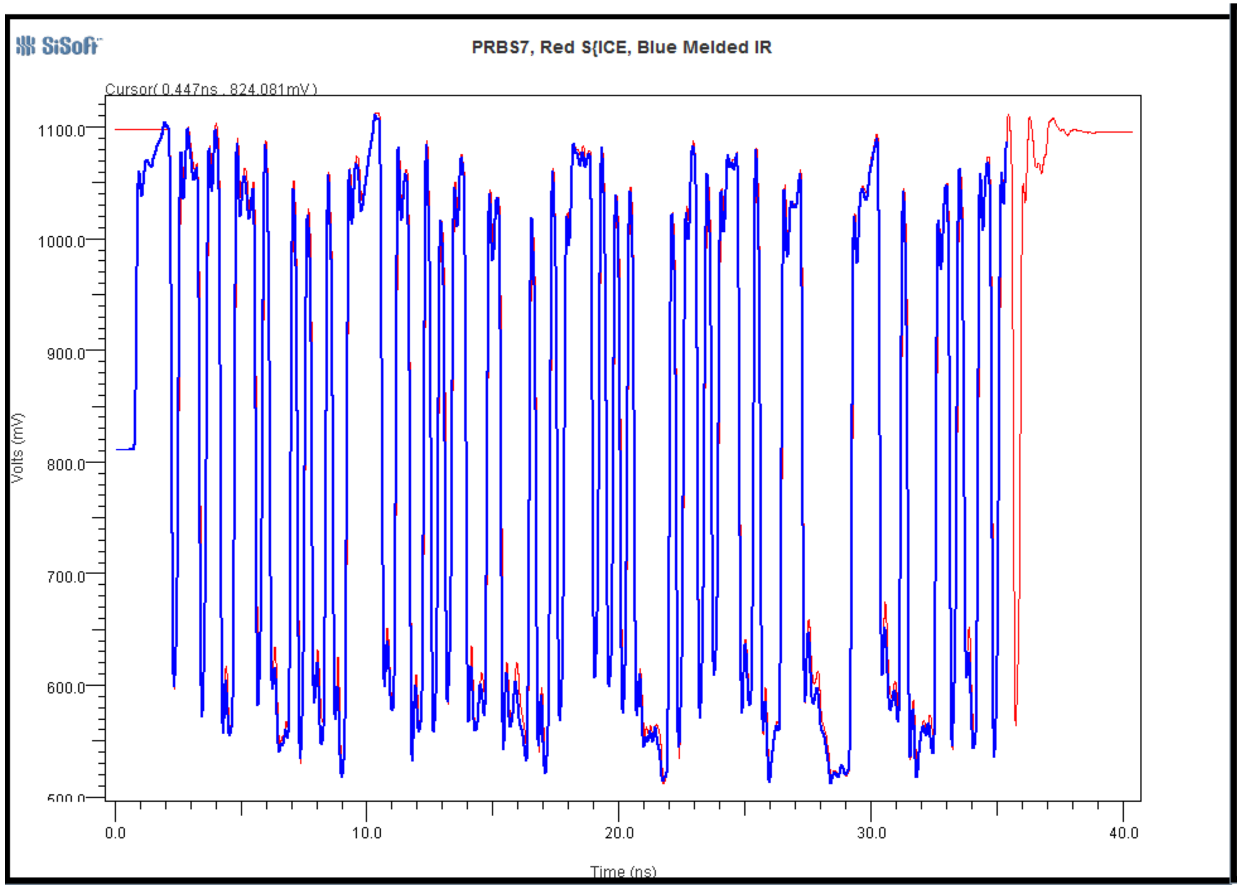


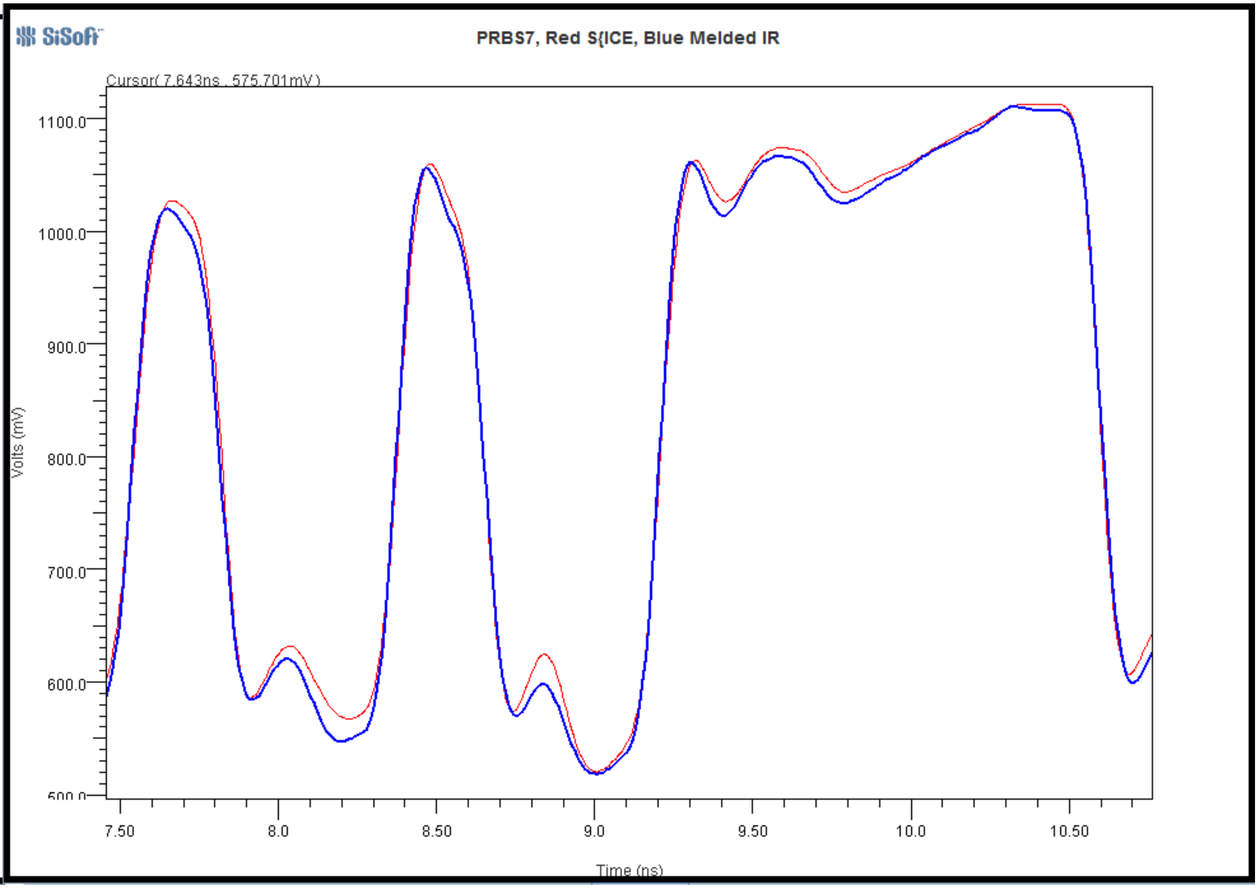
Falling Impulse Response, Red SPICE, Blue Convolution



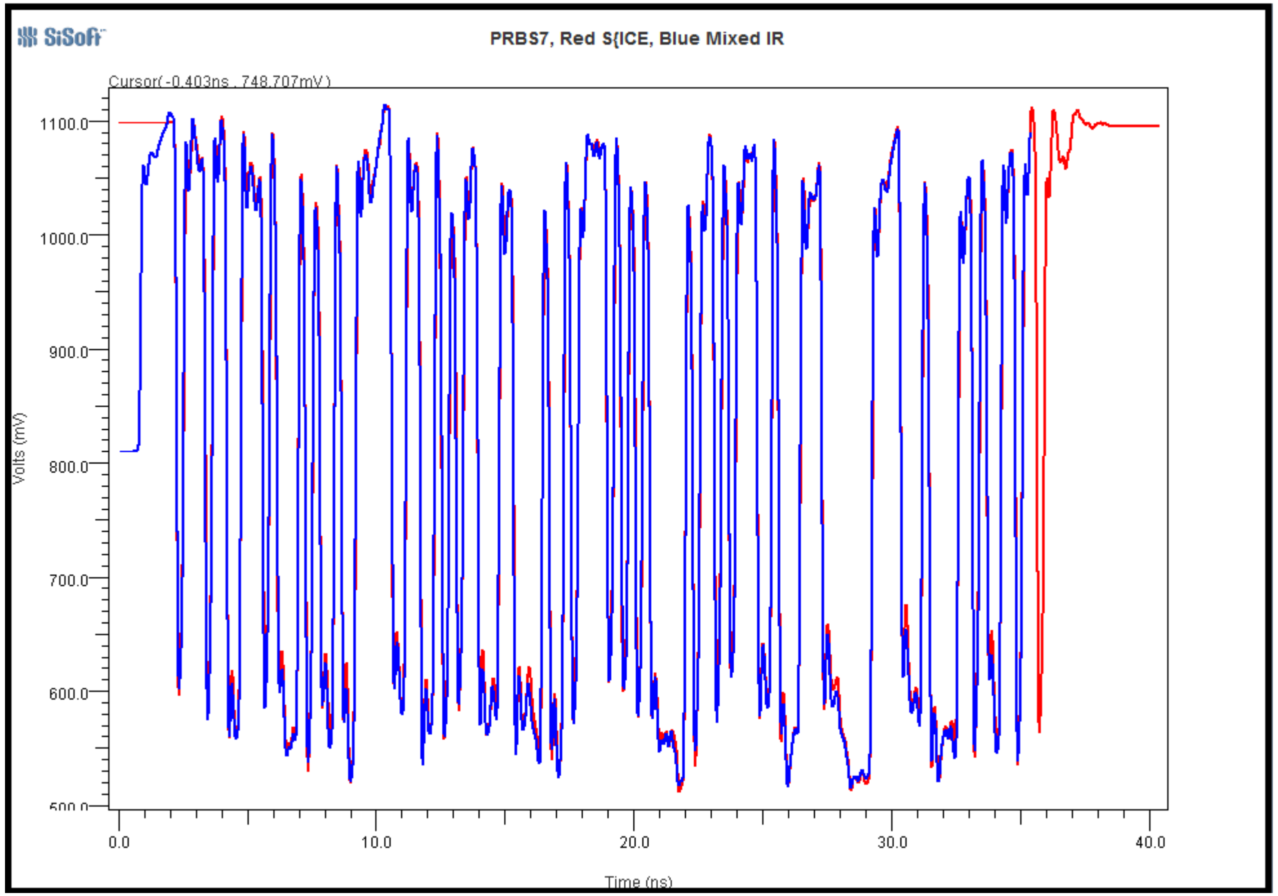


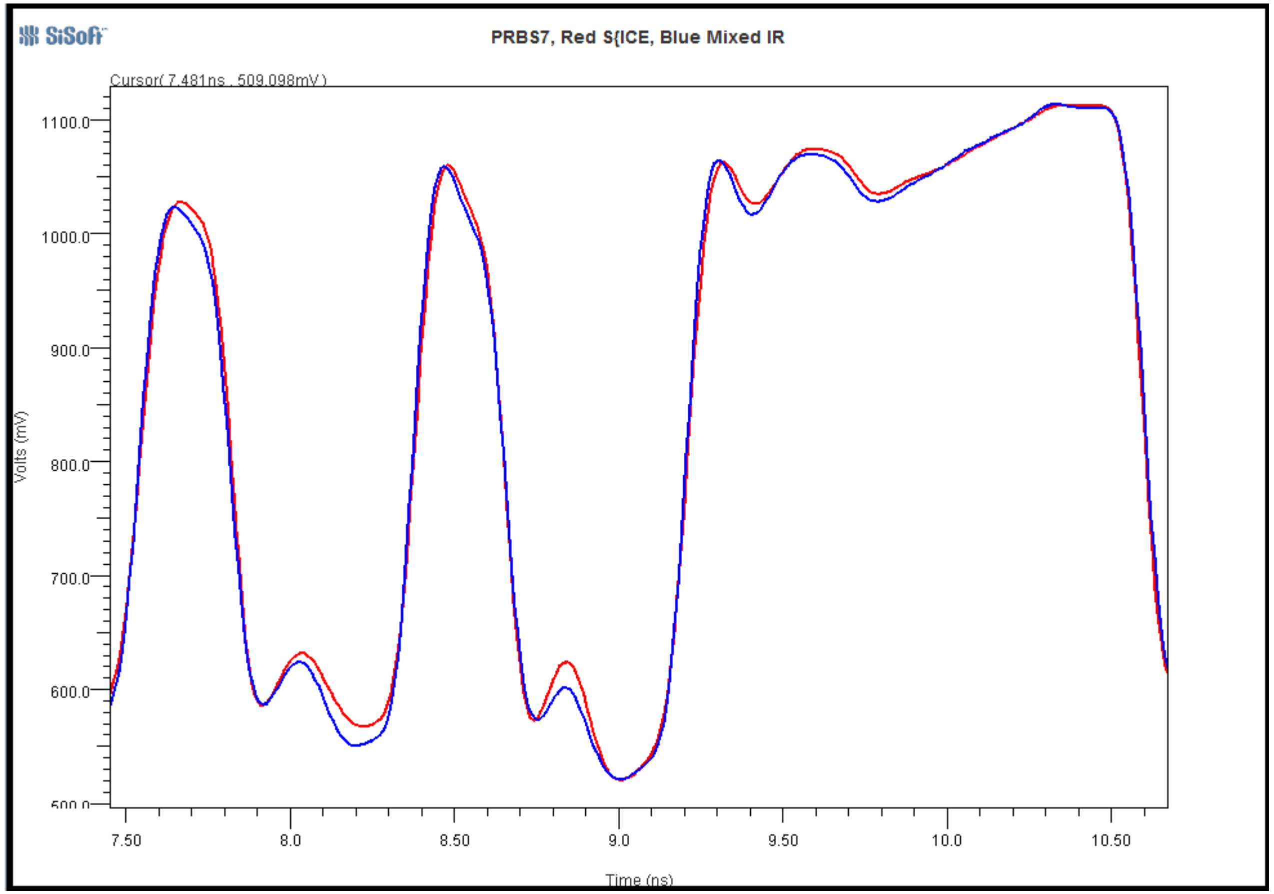
Melded Impulse Response, Red SPICE, Blue Convolution





Mixed Impulse Response, Red SPICE, Blue Convolution





Conclusion

- Methods have been presented that minimize the affect of asymmetric Rising and Falling edges on IBIS-AMI simulations.
- A Melded Impulse Response can be used for AMI Statistical Analysis.
- A Melded or Mixed Impulse Response can be used by the EDA tool to generate a waveform input to the Rx AMI_GetWave.

Differences between SPICE Simulation and convolution methods can be reduced to less than 15 mV.