Comparisons of different S parameter DC extrapolation methods and their impacts on equalization

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Objective:

Explore different S parameter DC extrapolation methods and provide the recommendations. Need to determine whether or not S-parameter at or around DC is critical to obtain accurate impulse response

Problem statements:

- **The current ATCA backplane channel S parameter data are measured from 50 MHz to 15 GHz or higher**
- **The S parameter near or around DC may be critical to obtain accurate impulse response but there is no widely-accepted DC extrapolation method with measurement validation**
- **Arbitrary S parameter assignments at DC will introduce error in impulse response calculation and different extrapolation methods will give different results and no detailed comparisons available**

Methodologies

- The line code and equalization performance of the ATCA channel are evaluated using the impulse response by nearest, constant, linear, cubic spline S parameter DC extrapolations
- One general method to calculate the impulse response is to transform the frequency domain S parameters into time domain using the IFFT
- Frequency domain only S parameter measurements can extend to the frequency range close to DC by using two different network analyzers that will cover both low and high frequency bands
- Time-domain combined with frequency domain approach will give the S parameters at DC
- Based on the simulation and measurement results , provide recommendations whether S parameters measurement at DC are needed or only extrapolation is enough

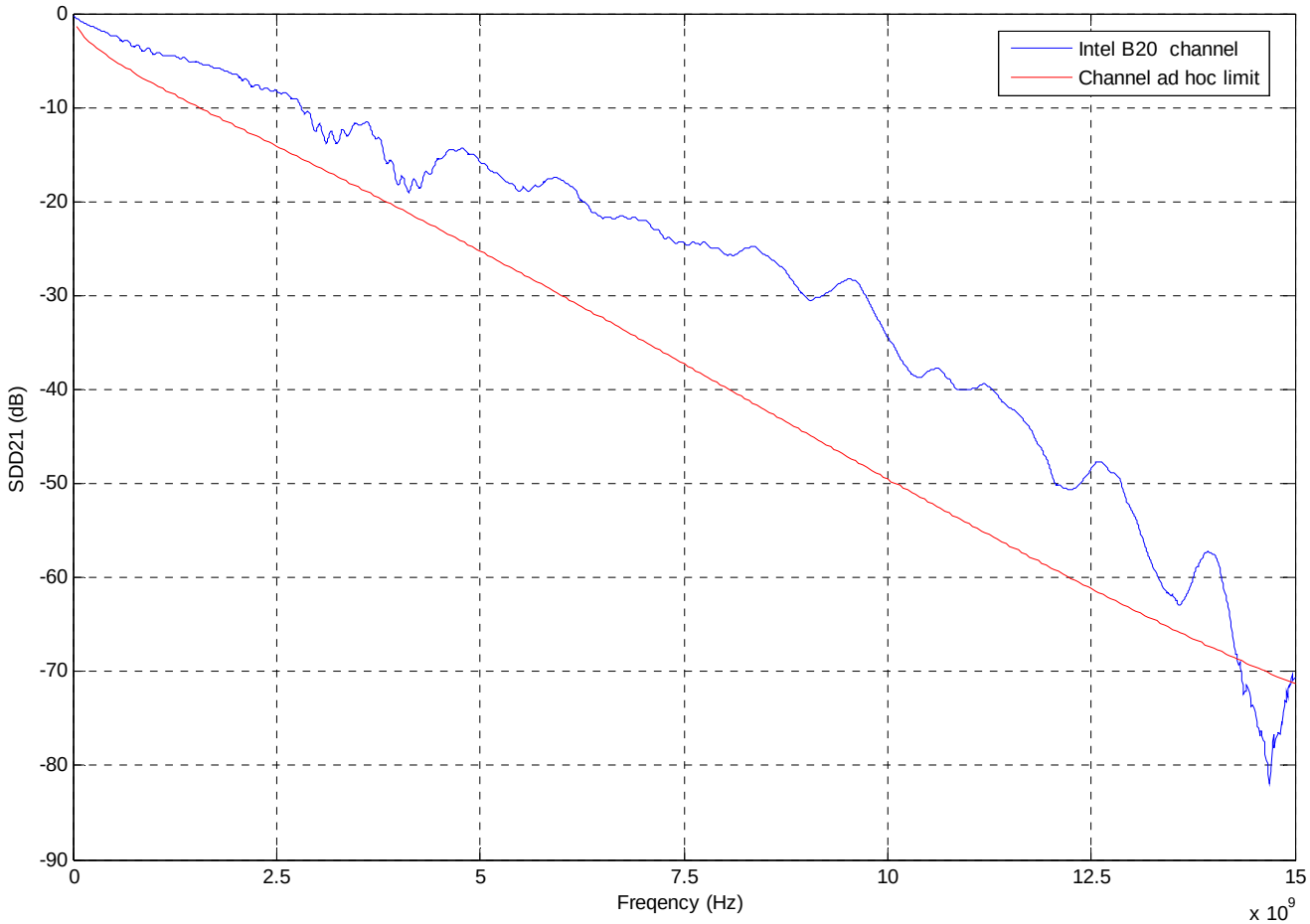
Simulation set up

- PRBS-15 sequence
- NRZ line code at 10.3125 GHz
- Rx DFE equalization with fixed complexity for comparisons in all extrapolation cases
- No Tx pre-emphasis
- Both without and with AC coupling capacitor (4.7 nF)
- Use the eye height to compare the differences of DC extrapolation methods on equalization

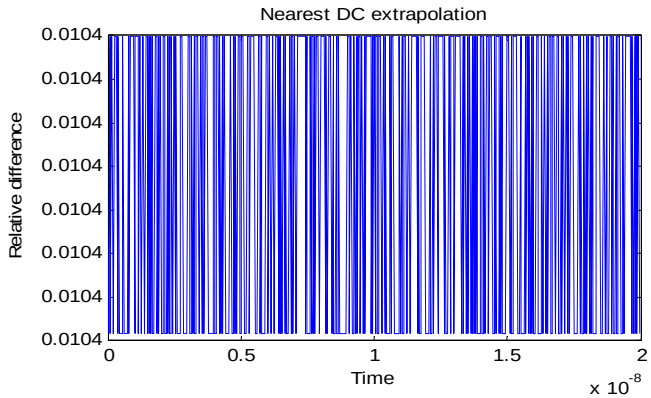
SDD21 parameter DC extrapolation method (no AC capacitor)

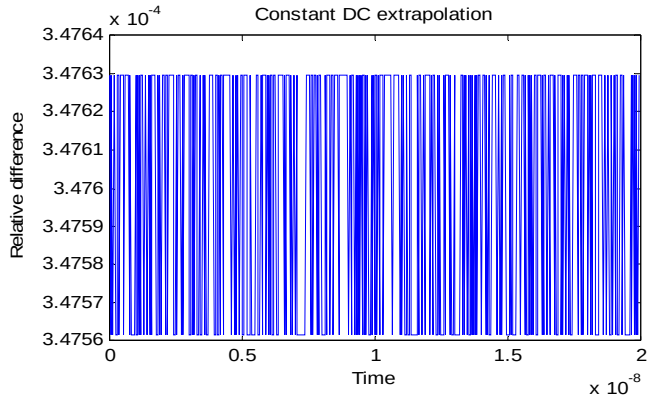
Constant	Nearest	Linear	Cubic	Cubic Spline
1.0 + j0.0	0.0522 - j0.9391	0.9693 - j0.0280	0.9693 - j0.0280	0.9704 - j0.0270

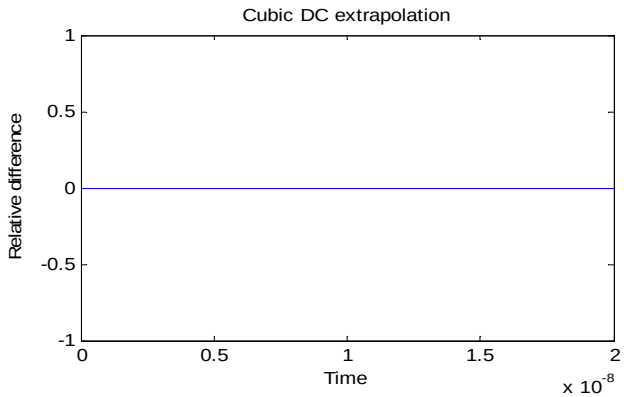
Sample Channel Insertion Loss (no AC capacitor)

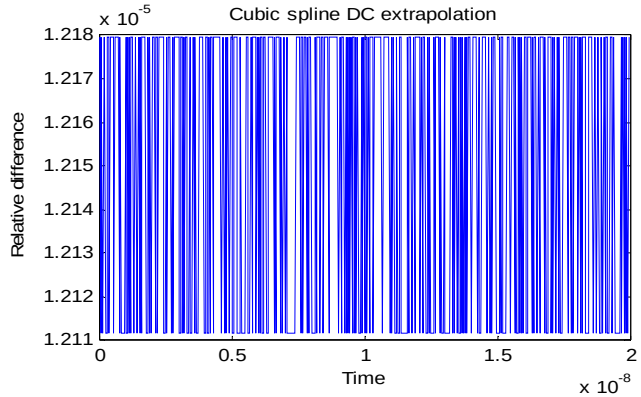


Relative impulse response differences between extrapolation methods







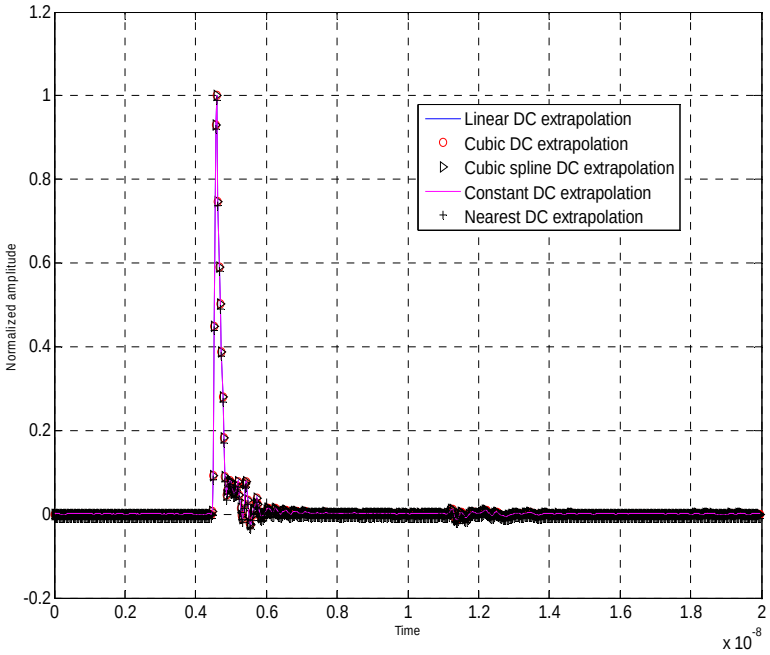


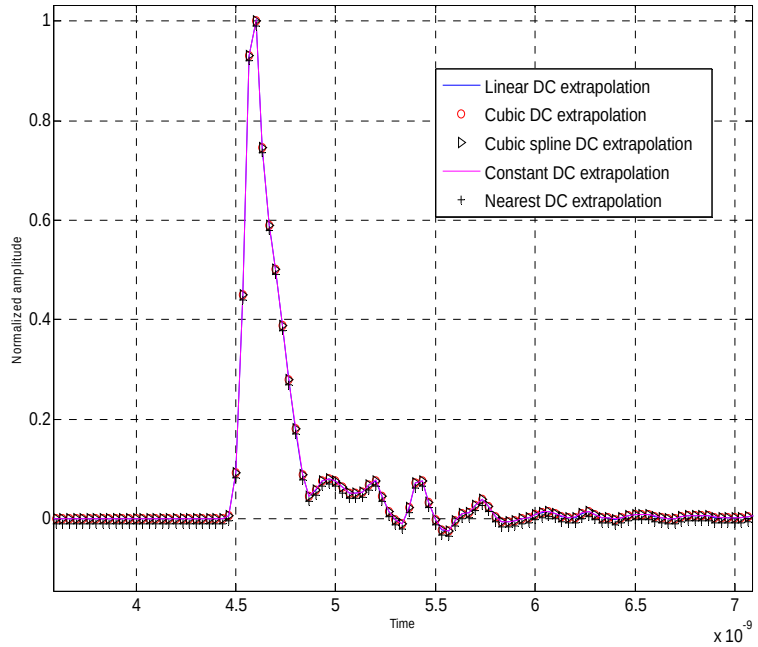
$$\text{Relative difference} = \frac{\text{abs}(h_{extrap\_method} - h_{extrap\_linear})}{\max(\text{abs}(h_{extrap\_linear}))}$$

h_{extrap_method} : *Impulse response*

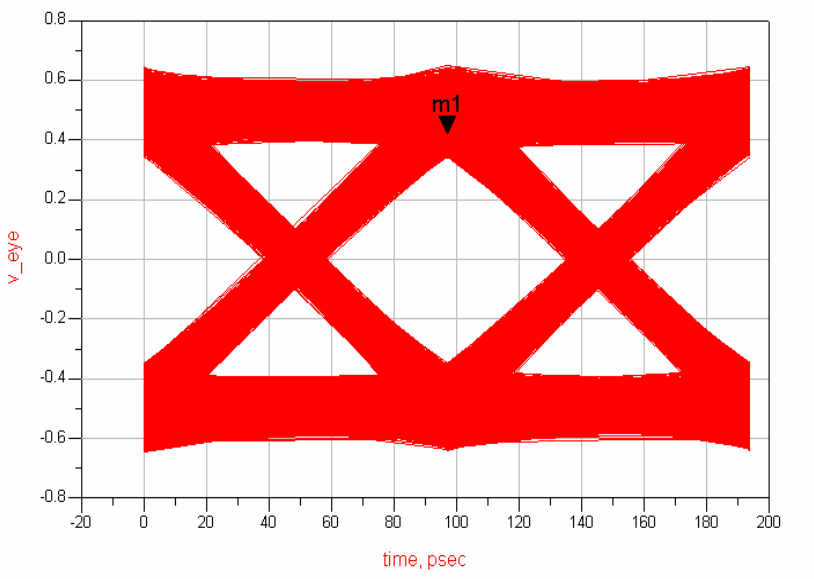
$extrap\_method$: *Cubic, Cubic Spline, Constant, Nearest*

Impulse responses of different DC extrapolation methods





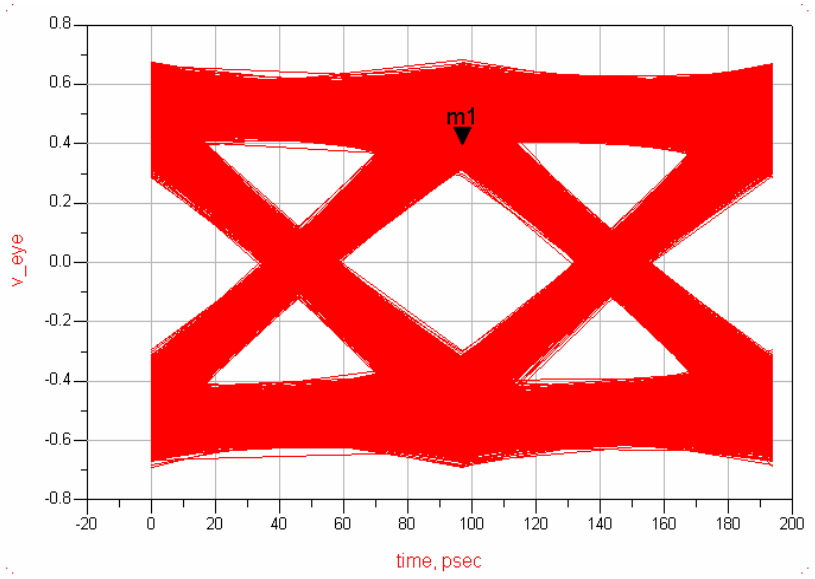
Equalized eye diagrams using DC extrapolations without AC capacitor



Constant S parameter DC extrapolation

Forward taps: 3 Backward taps:5

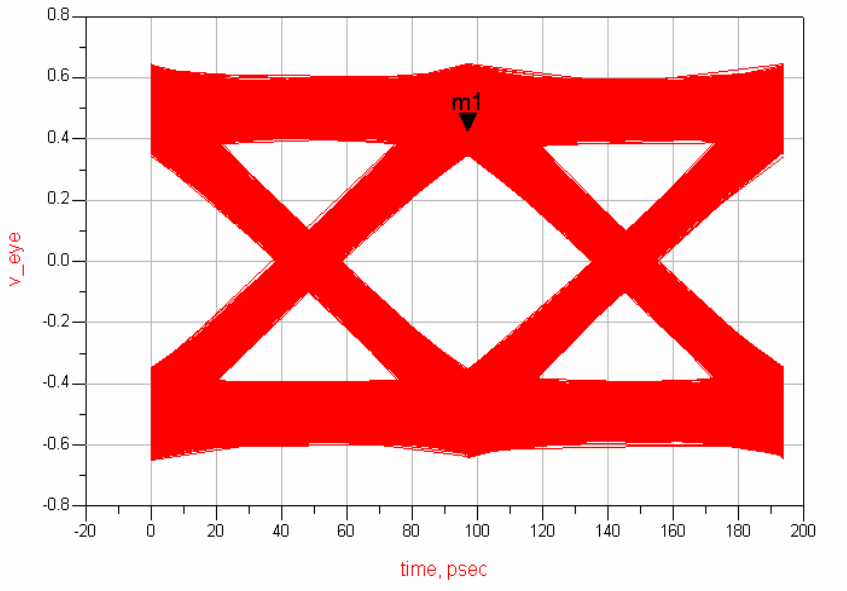
Eye height: 0.674



Nearest S parameter DC extrapolation

Forward taps: 3 Backward taps:5
Eye height: 0.563

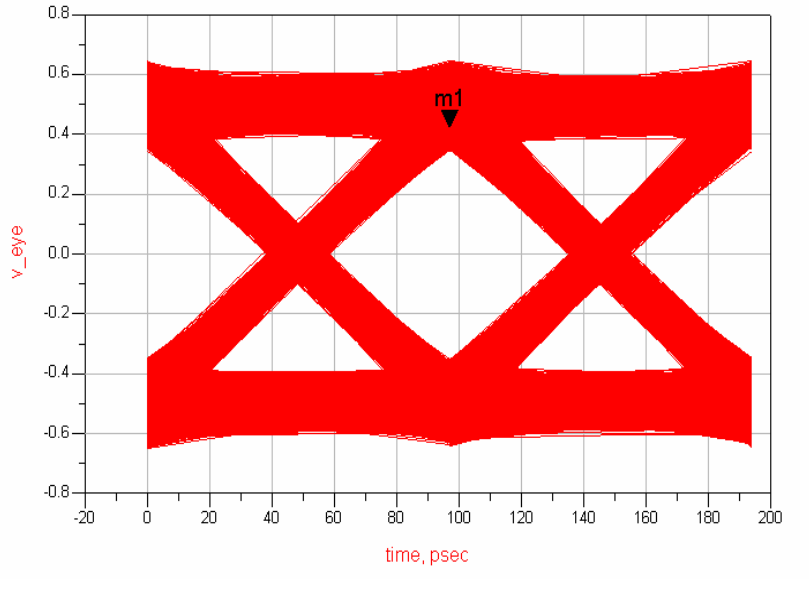
Equalized eye diagrams using DC extrapolations without AC capacitor



Linear S parameter DC extrapolation

Forward taps: 3 Backward taps:5

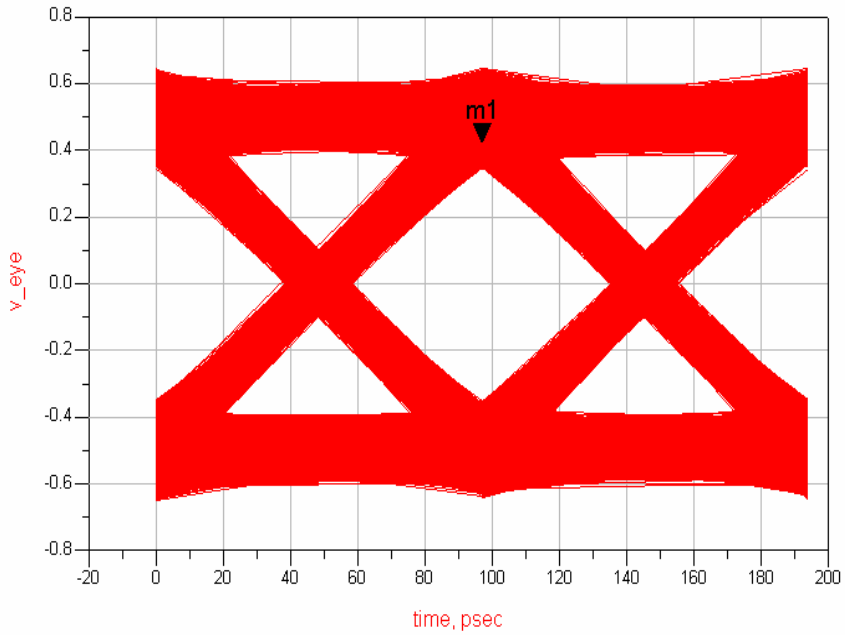
Eye height: 0.673



Cubic S parameter DC extrapolation

Forward taps: 3 Backward taps:5
Eye height: 0.673

Equalized eye diagrams using DC extrapolations without AC capacitor



Extrapolation Methods	Constant	Nearest	Linear	Cubic	Cubic spline
Eye Diagram height	0.674	0.563	0.673	0.673	0.673

Cubic Spline S parameter DC extrapolation

Forward taps: 3 Backward taps:5

Eye height: 0.673

DC extrapolation impacts on equalization performance comparisons (without AC capacitor)

Comparison of the DC extrapolation methods with AC capacitor (4.7 nF)

- **Simulation methodology**
- **The S parameter extrapolations are implemented in the Agilent ADS simulator using the S parameter sweep. The extrapolations in S domain are chosen as Constant, Cubic, Cubic spline and linear**
- **Use the ATCA channel measurement data as a four port network with AC capacitor**
- **The S parameter sweep simulations start from DC and end at 15 GHz with step size of 10 MHz**
- **The DC extrapolated channel S parameters are used to extract the channel impulse response and to evaluate DFE equalization performance**

S parameter DC extrapolation with AC capacitor (4.7 nF)

Constant DC extrapolation S21 parameters

freq	S(2,1)
0.0000 Hz	0.000 + j0.000
10.00 MHz	0.081 - j0.933
20.00 MHz	0.066 - j0.935
30.00 MHz	0.061 - j0.936
40.00 MHz	0.059 - j0.936
50.00 MHz	0.057 - j0.936

Cubic DC extrapolation S21 parameters

freq	S(2,1)
0.0000 Hz	0.000 + j0.000
10.00 MHz	0.920 - j0.278
20.00 MHz	0.784 - j0.545
30.00 MHz	0.582 - j0.749
40.00 MHz	0.333 - j0.883
50.00 MHz	0.057 - j0.936

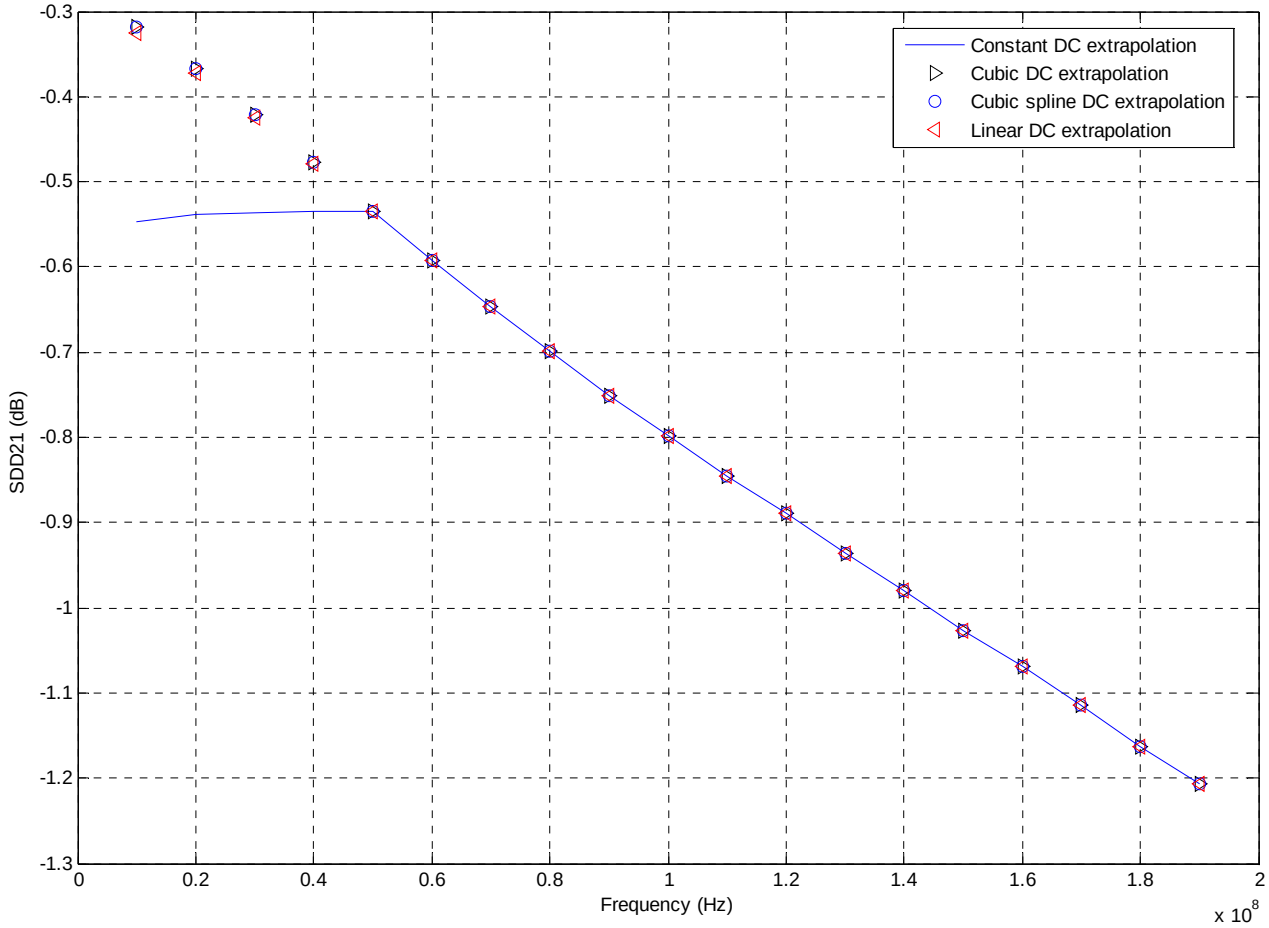
Cubic spline DC extrapolation S21 parameters

freq	S(2,1)
0.0000 Hz	0.000 + j0.000
10.00 MHz	0.920 - j0.278
20.00 MHz	0.784 - j0.545
30.00 MHz	0.582 - j0.749
40.00 MHz	0.333 - j0.883
50.00 MHz	0.057 - j0.936

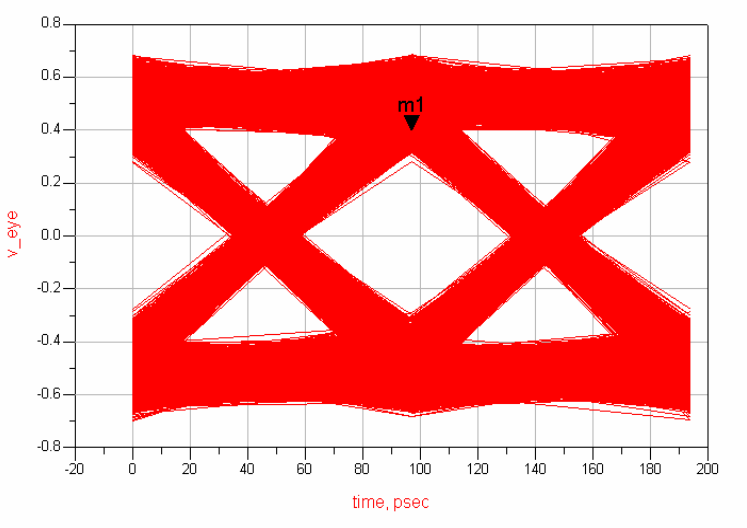
Linear DC extrapolation S21 parameters

freq	S(2,1)
0.0000 Hz	0.000 + j0.000
10.00 MHz	0.920 - j0.278
20.00 MHz	0.784 - j0.545
30.00 MHz	0.582 - j0.749
40.00 MHz	0.333 - j0.883
50.00 MHz	0.057 - j0.936

S parameter DC extrapolations with AC capacitor (4.7 nF)



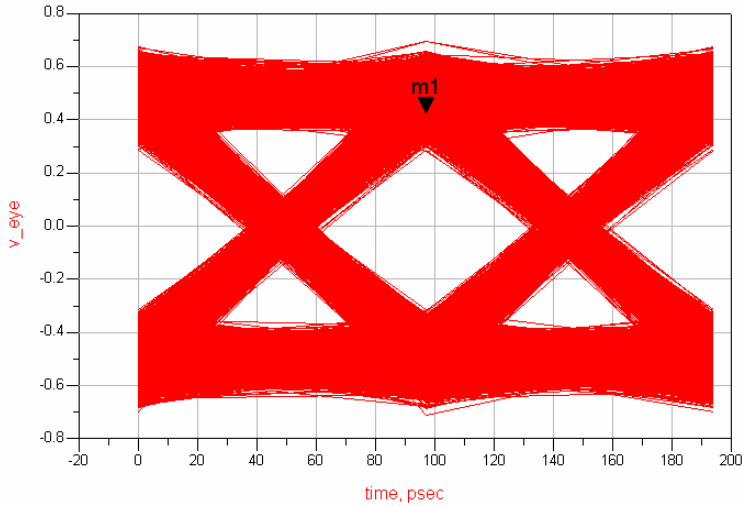
Equalized eye diagrams using DC extrapolations with AC capacitor



Constant DC extrapolation with AC capacitor

Forward taps: 3 Backward taps:5

Eye height: 0.540

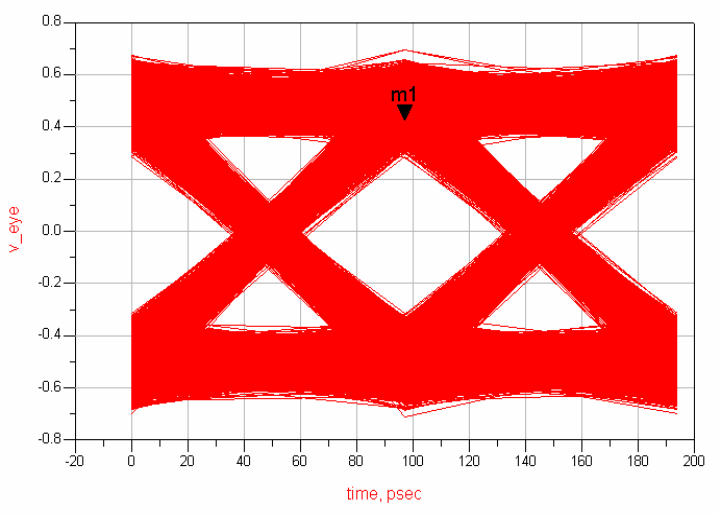


Cubic DC extrapolation with AC capacitor

Forward taps: 3 Backward taps:5

Eye height: 0.577

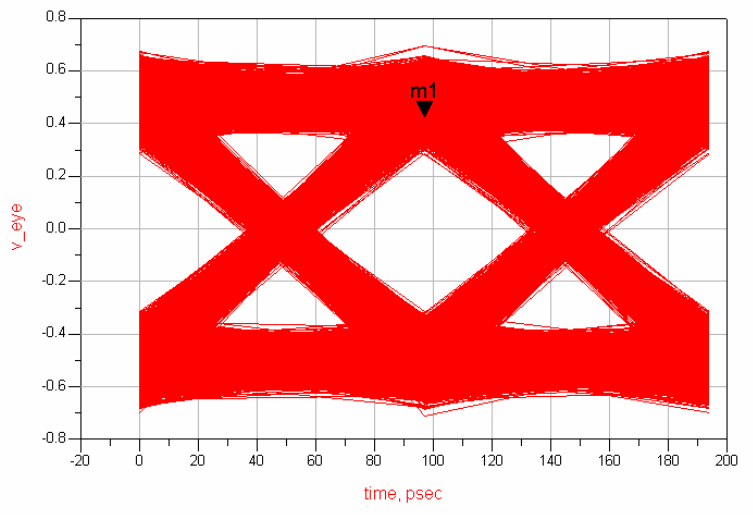
Equalized eye diagrams using DC extrapolations with AC capacitor



Cubic spline DC extrapolation with AC capacitor

Forward taps: 3 Backward taps:5

Eye height: 0.577



Linear DC extrapolation with AC capacitor

Forward taps: 3 Backward taps:5

Eye height: 0.577

DC extrapolation impacts on equalization performance comparisons (with AC capacitor)

Extrapolation methods	Constant	Cubic	Cubic spline	Linear
Eye Diagram height	0.540	0.577	0.577	0.577

Conclusion

- The differences between different S parameter DC extrapolation methods are small
- Linear, cubic, and cubic spline extrapolations do not make much differences
- Based on existing simulation results, the constant DC extrapolation gives maximum eye opening without AC capacitor while performs worst with the capacitor. The linear, cubic, and cubic spline methods are consistent and all gives the same eye opening with and without AC capacitor
- The simulations of the selected channel model show that impacts on the equalization performance of all extrapolation methods are not significant to affect the bit decisions

Future plan

- More channel models will be evaluated using the same methodology
- Optional measurement result validation is recommended