True Differential IBIS model for SerDes Analog Buffer

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Agenda

- Overview of Differential IBIS
- Description of test-case
- Flow used to create differential IBIS model
- Comparison: Pseudo-differential vs. True-Differential IBIS Serial-Link
- Conclusion

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Overview of Differential IBIS
- Current approaches

- Traditionally, differential buffer have been modeled as
  - Pseudo Differential buffer using two Single-ended IBIS models
    - Accuracy can suffer if there is substantial differential current which is the case with Serial Link analog buffers that has series elements between PADP and PADN
  - External Model approach: Call to buffer netlist
    - Netlist (IP) needs to be revealed
  - External Model approach: Call to S-parameter model
    - Rx buffer needs to be characterized as S-parameters

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Overview of Differential IBIS
- Alternate approach

- While S-parameter approach is best suited for analog buffers in serial links, we provide an alternate way to model it through standard IBIS tabular format with use of series elements to model differential current.
- This extends the approach suggested in IBIS cookbook that suggests modeling of differential current using series Resistance.
  - Here we propose use of reactive elements (R/L/C) to model differential current.

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Description of test-case - IBIS modeling of Serial Link RX IO

- 10Gbps Serial link
- 28nm technology node
- Typical process node
- Rx analog buffer had additional blocks for equalization that were modeled as AMI code
  - Frontend attenuation
  - VGA
  - CTLE
  - DFE
  - CDR

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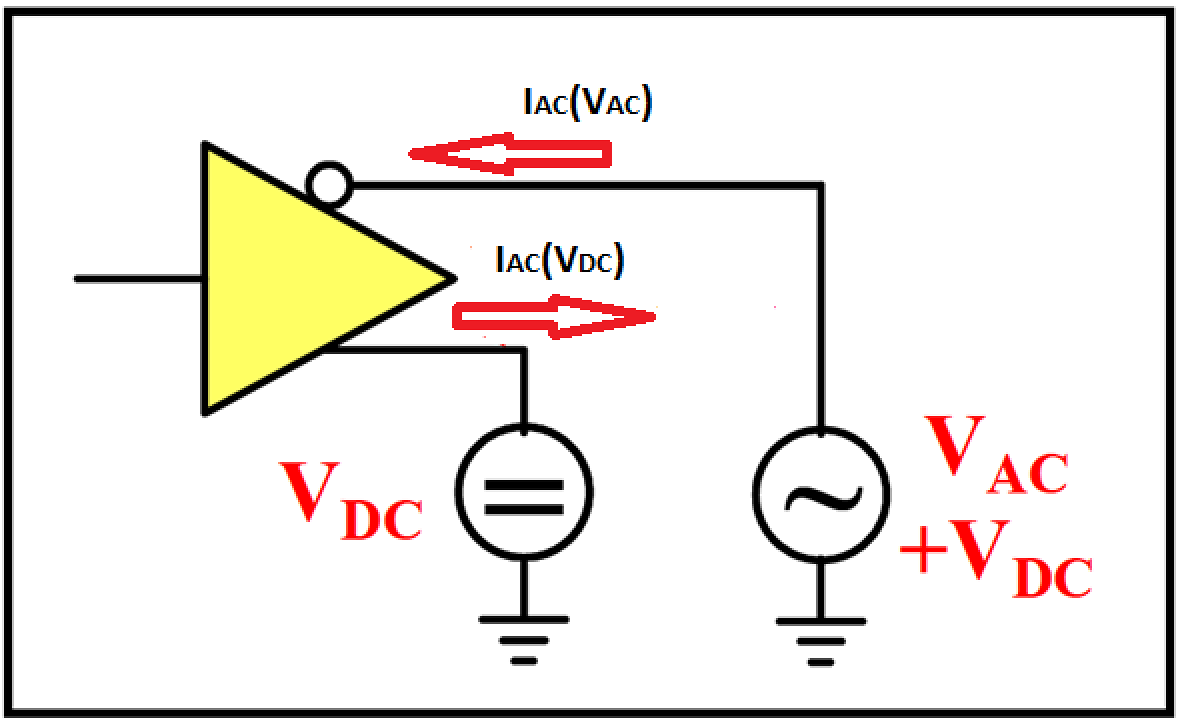
Flow used to create differential IBIS model - True differential

- Setup for common mode and differential mode impedance extraction



Flow used to create differential IBIS model - True differential

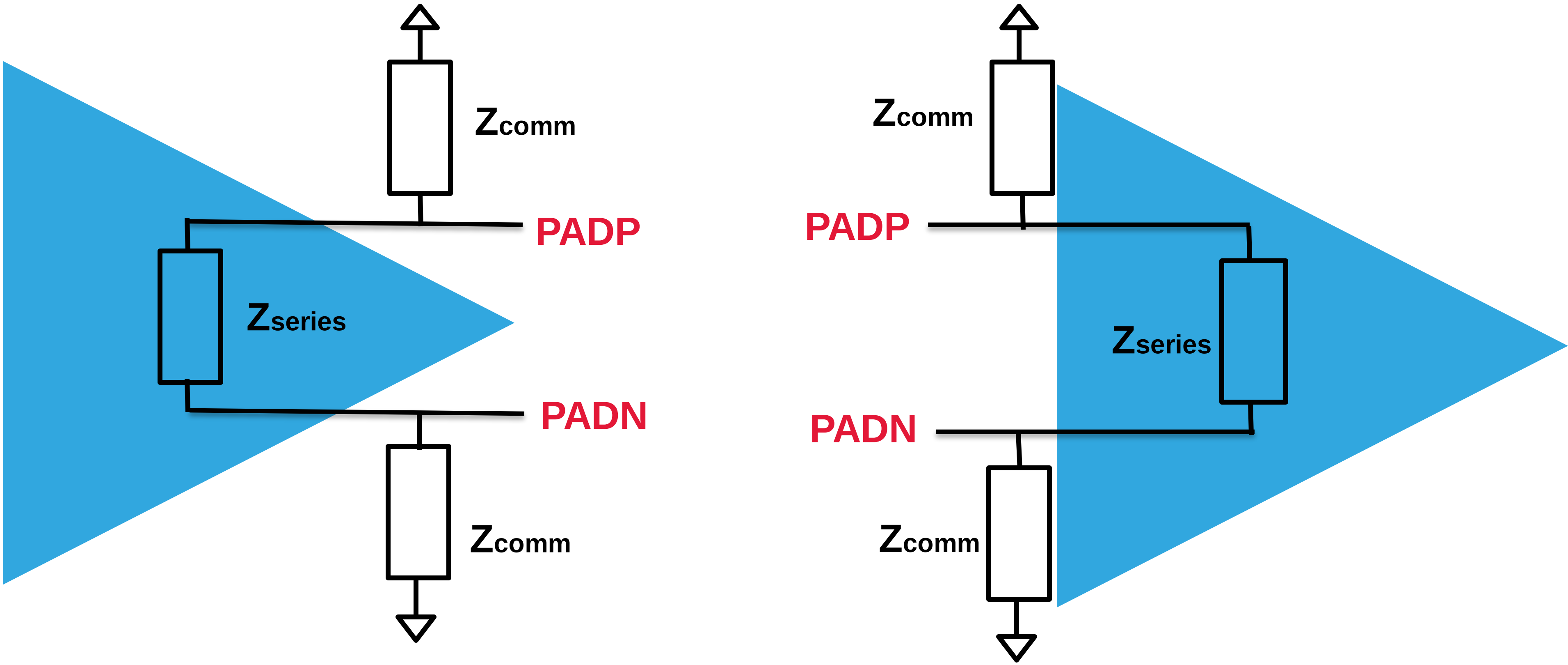
$$I\_Diff = I_{AC}(V_{DC})$$

$$I\_Comm = I_{AC}(V_{AC}) - I_{AC}(V_{DC})$$

-I_Diff flows through series element between inverting and non-inverting pins

-I_Comm flows only through common mode impedance

Flow used to create differential IBIS model
- True differential buffer with series element Z_{series}



Output Buffer

Input Buffer

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Flow used to create differential IBIS model
- Differential and common mode impedance calculations

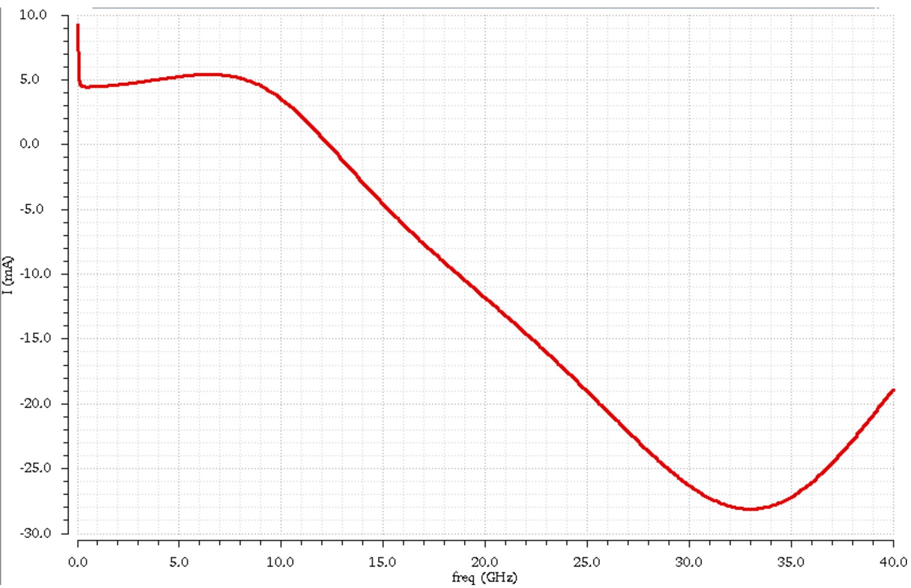
- Series Reactance = $$X_{series} = \frac{V_{AC}}{\mathrm{Im}(I\_Diff)}$$
- Series Resistance= $$R_{series} = \frac{V_{AC}}{\mathrm{Re}(I\_Diff)}$$
- Common mode Resistance= $$R_a = \frac{V_{AC}}{\mathrm{Re}(I\_Comm)}$$
- Common mode Reactance= $$X_a = \frac{V_{AC}}{\mathrm{Im}(I\_Comm)}$$

Flow used to create differential IBIS model
- Differential and common mode impedance calculations

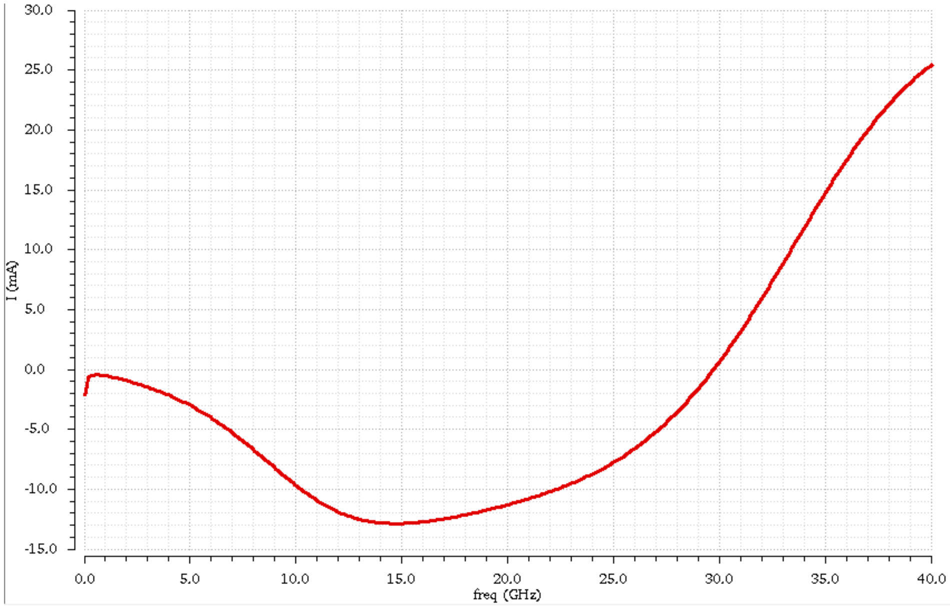
- Depending on sign, reactance could be inductive or capacitive
- Impedance to be calculated at most likely operating frequency of buffer
- For 10G serial link Rx buffer testcase

Series Model	R=220ohms	L=9.8nH
Common mode Model	R=80ohms	C=0.223pF

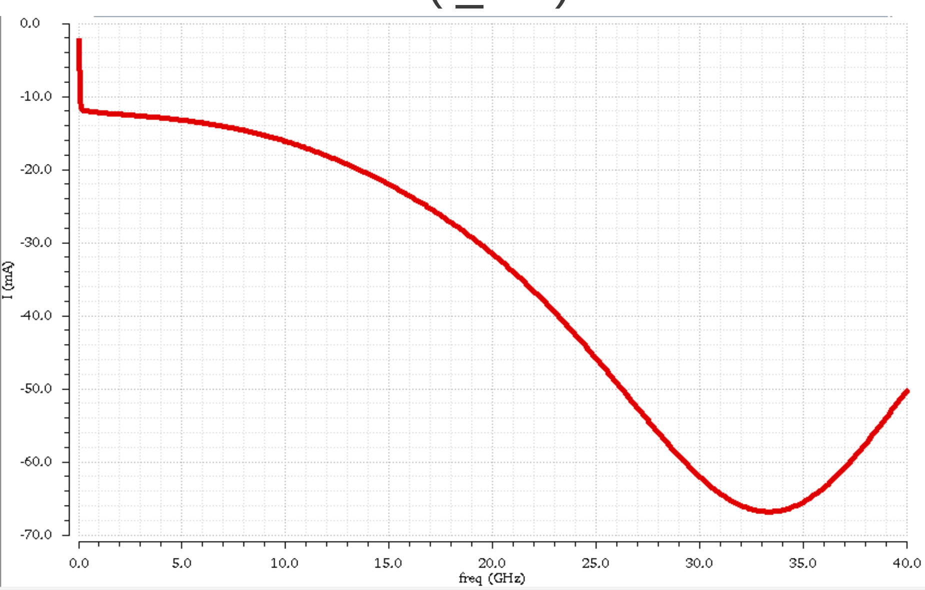
Common mode and differential currents



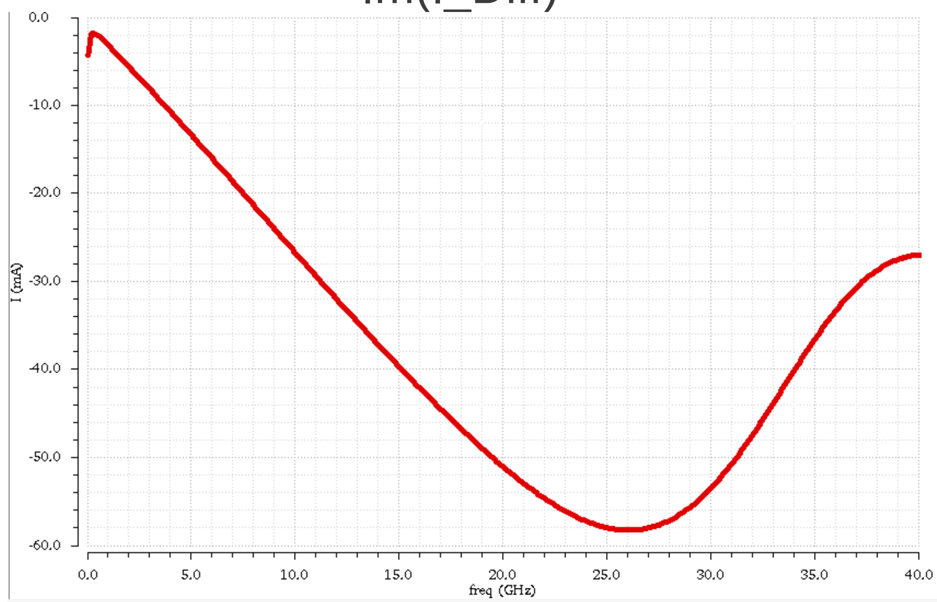
Re(I_Diff)



Im(I_Diff)



Re(I_Comm)



Re(I_Diff)

Flow used to create differential IBIS model

- IBIS model

```
|***************************************************************************
***********
[Series Pin Mapping]    pin_2    model_name   function_table_group
4                        5          Rpath
4                        5          Lpath

|***************************************************************************
```

```
**********
[Model] Rpath
Model_type Series
Polarity Non-Inverting
Enable Active-High
|
|                typ   min   max
 C_comp          0.0pF 0.0pF 0.0pF
|
|                typ    min    max
[Voltage Range] 1.0    NA     NA
|***************************************************************************
|            R(typ)   R(min)  R(max)
[R Series]  220       NA     NA

|
|***************************************************************************
**********
[Model] Lpath
Model_type Series
Polarity Non-Inverting
Enable Active-High
|
|                typ   min   max
 C_comp          0.0pF 0.0pF 0.0pF
|
|                typ    min    max
[Voltage Range] 1.0    NA     NA
|

|***************************************************************************
***********

|            R(typ)   R(min)  R(max)
[L Series]  9.8nH       NA     NA
|
```

- Parallel RL network present as Zseries, modeled using "Model_type Series"

Flow used to create differential IBIS model
- IBIS model

- Parallel RC network present as Zcomm, modeled using clamp I-V table and C_comp

```
[Model]     Rx_in
Model_type  Input
Vinl=1.5
Vinh=2.5
|
| variable                        typ         min          max
C_comp                            0.223pF     NA           NA
[Temperature Range]                70         NA           NA
[Voltage range]                   3.3         NA           NA
|
|*****************************************************************
**************
[POWER Clamp]
|
|  Voltage              I(typ)       I(min)       I(max)
|
  -3.3000e+00          20.6250e-03    NA          NA
   0.0000e-00          00.0000e-00    NA          NA
   3.3000e-00         -20.6250e-03    NA          NA

|*****************************************************************
**************
[GND Clamp]

|  Voltage              I(typ)       I(min)       I(max)

 -3.3000e+00         -20.6250e-03    NA            NA
  0.0000e-00          00.0000e-00    NA            NA
  3.3000e-00          20.6250e-03    NA            NA
|
|*****************************************************************
**************
```

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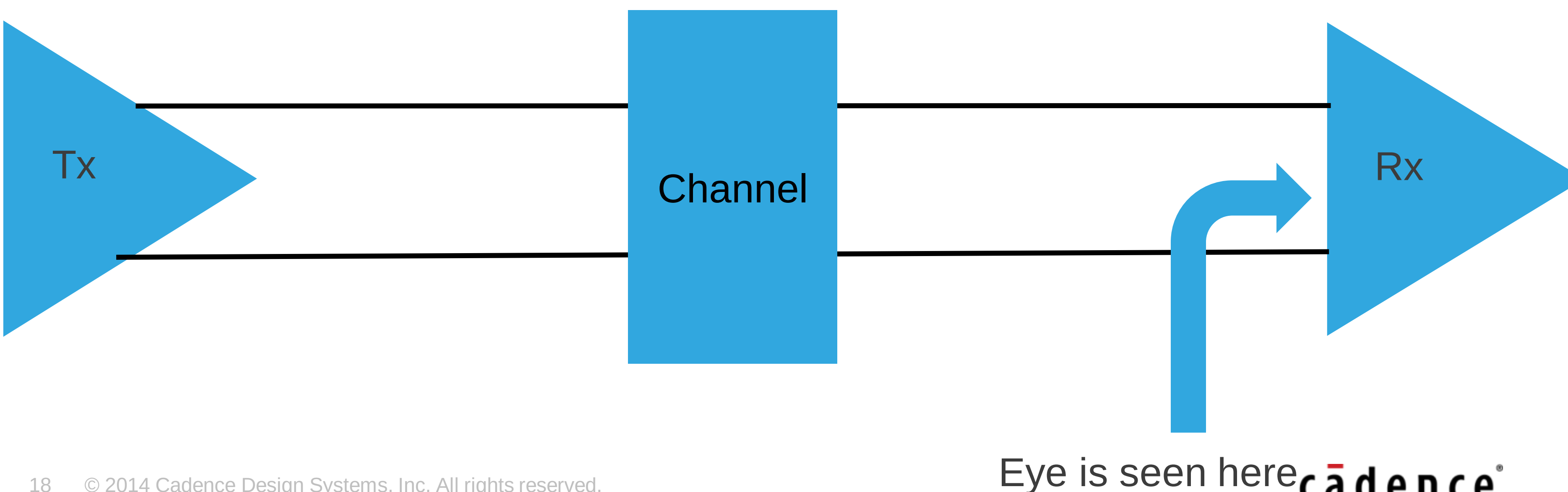
Comparison: Pseudo-differential vs. True-Differential IBIS simulations

- Serial Link Simulation Test-bench
  - 10Gbps
  - No Equalization
  - PRBS23
  - Tested on different channels



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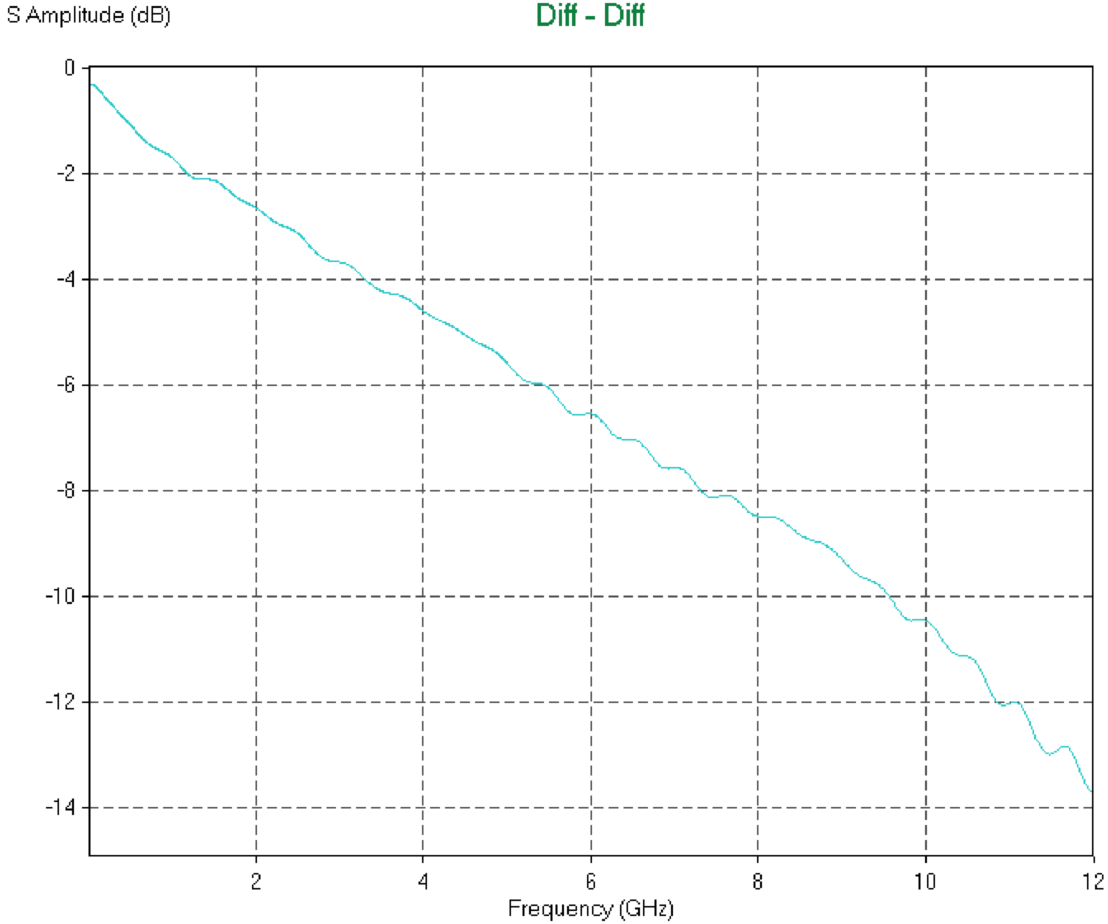
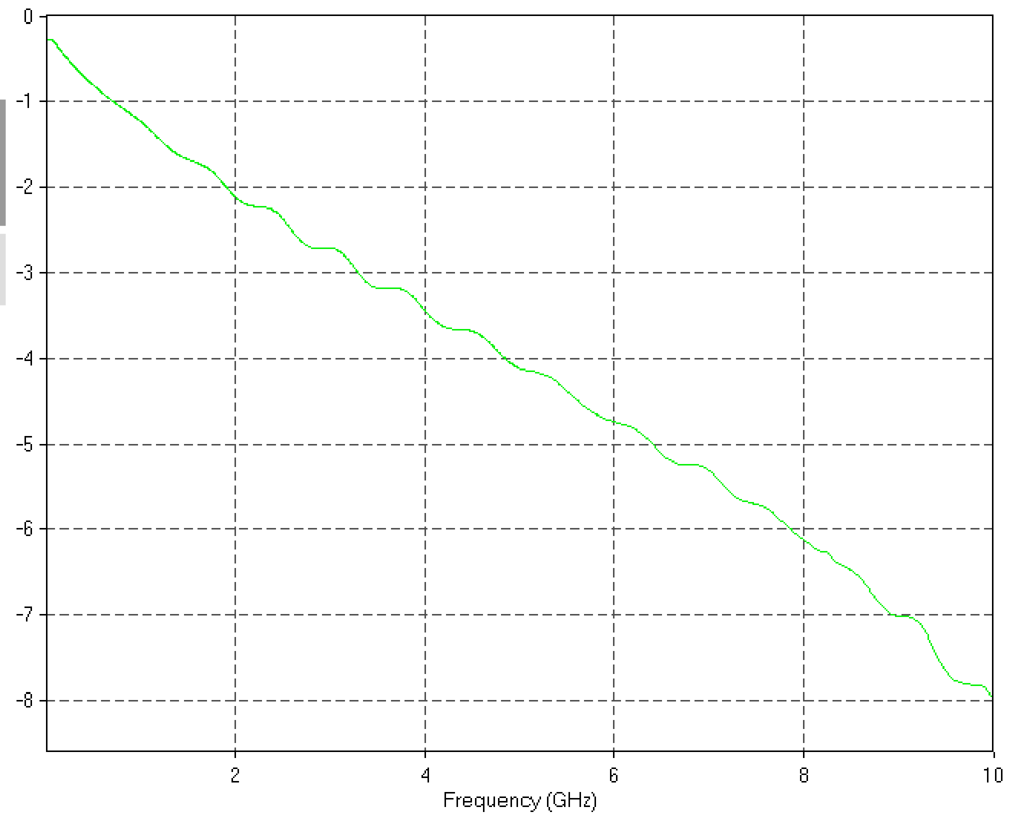
Channel 1

Frequency	Insertion Loss
5.15GHz	-5.861dB



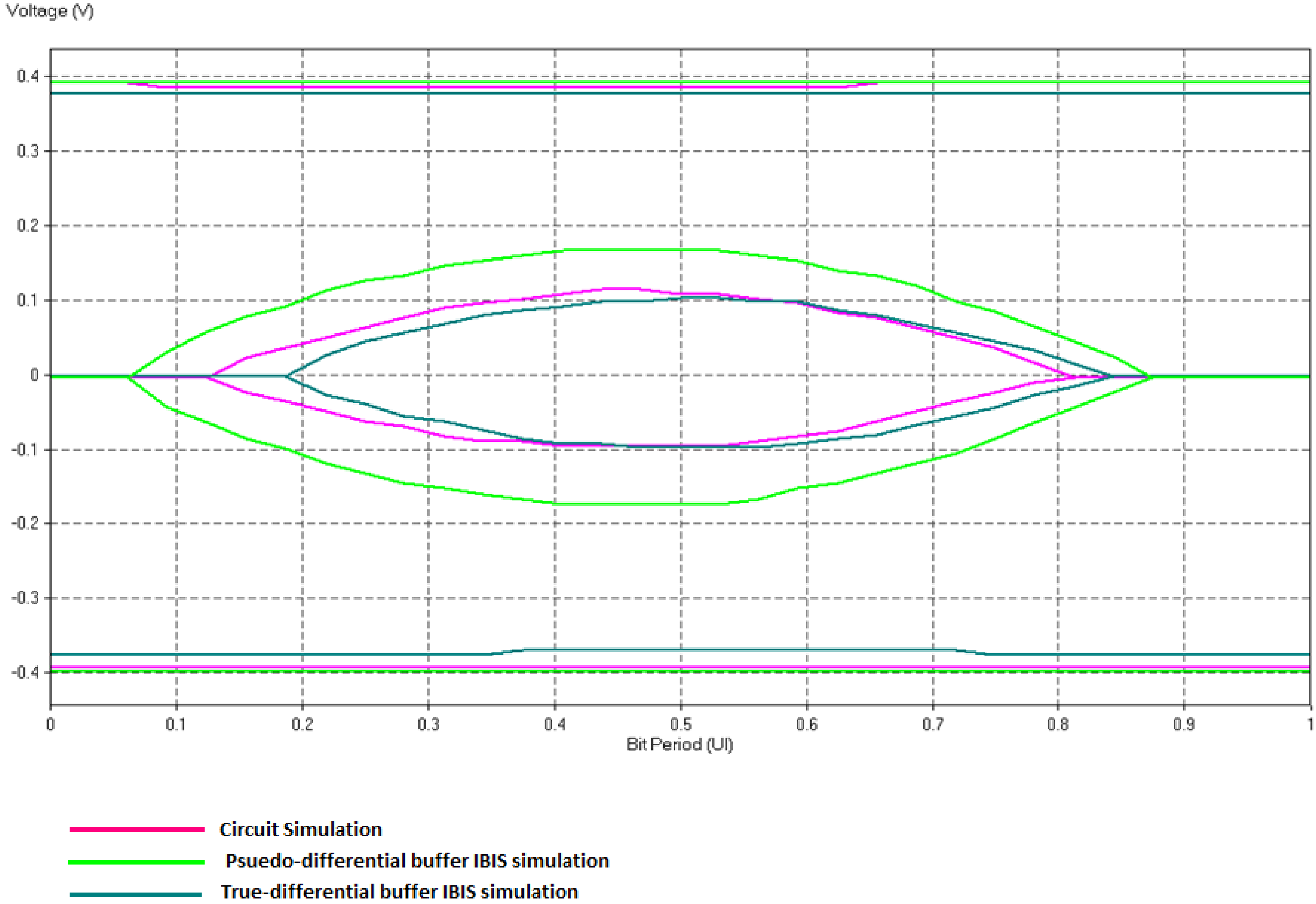
Channel 2

Frequency	Insertion Loss
5.1GHz	-4.14dB



Comparison: Pseudo-differential IBIS vs. True-Differential IBIS vs. Circuit simulations

- Channel 1



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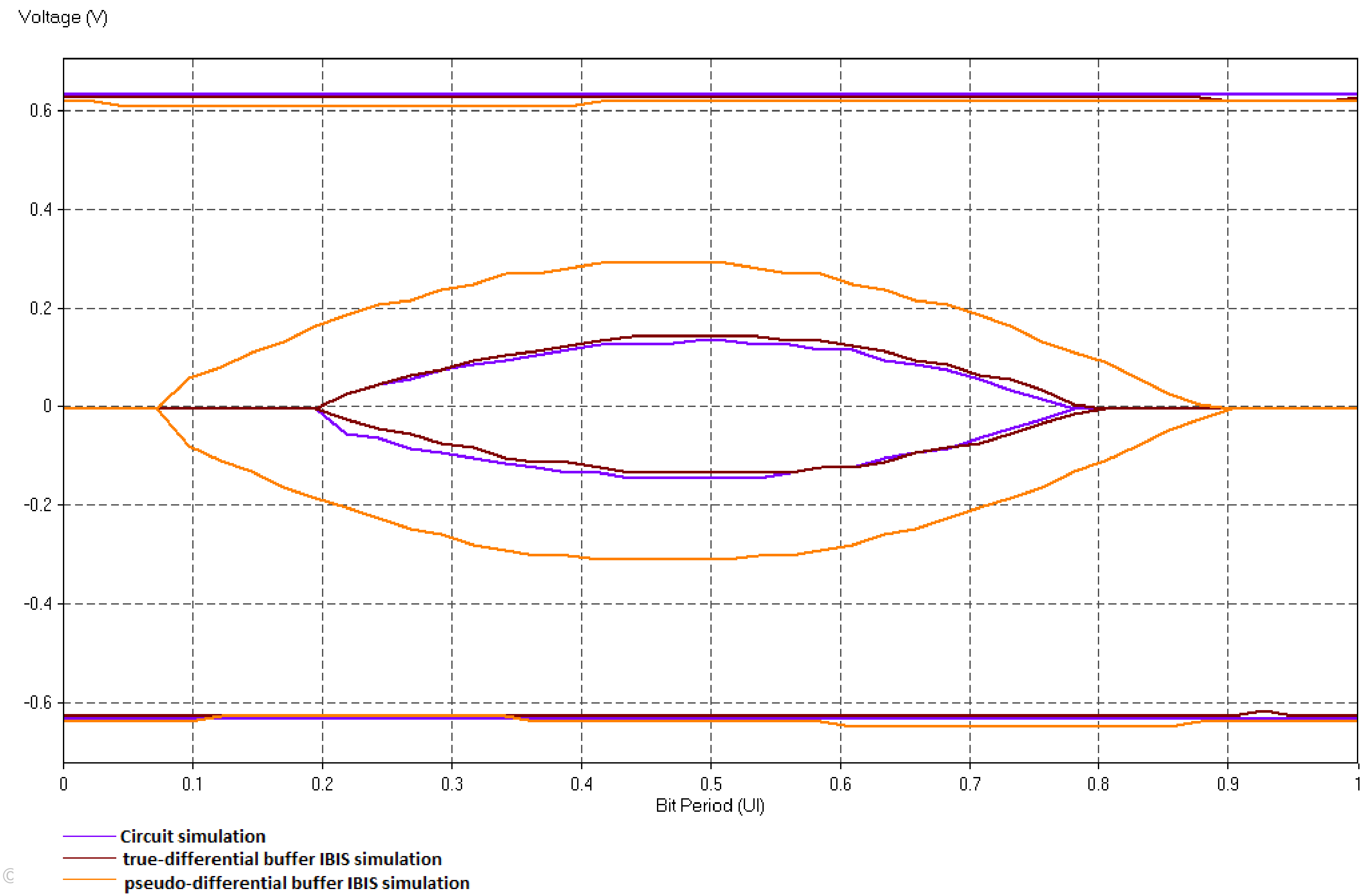
Comparison: Pseudo-differential IBIS vs. True-Differential IBIS vs. Circuit simulations

- Channel 2



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Conclusion

- Extended “Series Model Approach” in Cookbook for IBIS Version 4.0 to model differential and common-mode impedances for SERDES analog buffer.
- True differential model provides much better accuracy than pseudo differential IBIS for channel simulations in terms of
  - Jitter and eye opening
  - Reflection losses