

BSIM IMPROVEMENTS

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Bug Fixes on BSIM4.5.0

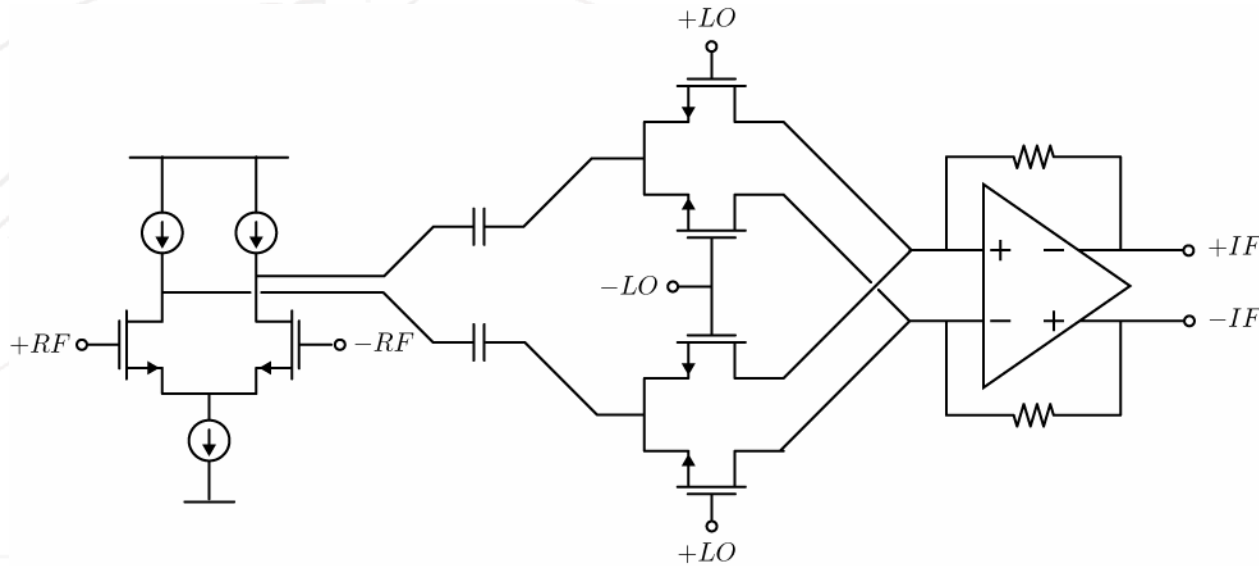
- Deletion of parameters of beta version of Impact Ionization model from the BSIM4 manual : "*BETA1, BETA2, VDSAT110, T11, L11, ESAT11, S110, S111, S112, S11D* "
 - Reported by **Daiyuan Wu, Cadence; Sungjoon Park, Samsung**
 - **BUG** : Beta version of Impact Ionization model was deleted from code. Corresponding parameters (listed above) need to be removed from manual.
 - **ACTION** : Parameters are simply deleted from the manual.
- The variable *ChargeComputationNeeded* is no longer set to 1 in b4ld.c :
 - Reported by **Yoichiro Niitsu, Toshiba Corp.**
 - **BUG** : *ChargeComputationNeeded* was set to be "1" by mistake forcing calculation of charge and capacitance even for DC simulations.
 - **EFFECT** : Only effect was the overload of DC running time.
 - **ACTION** : The following line has been deleted from code to rectify this error

ChargeComputationNeeded = 1;

Symmetric Realization of BSIM4

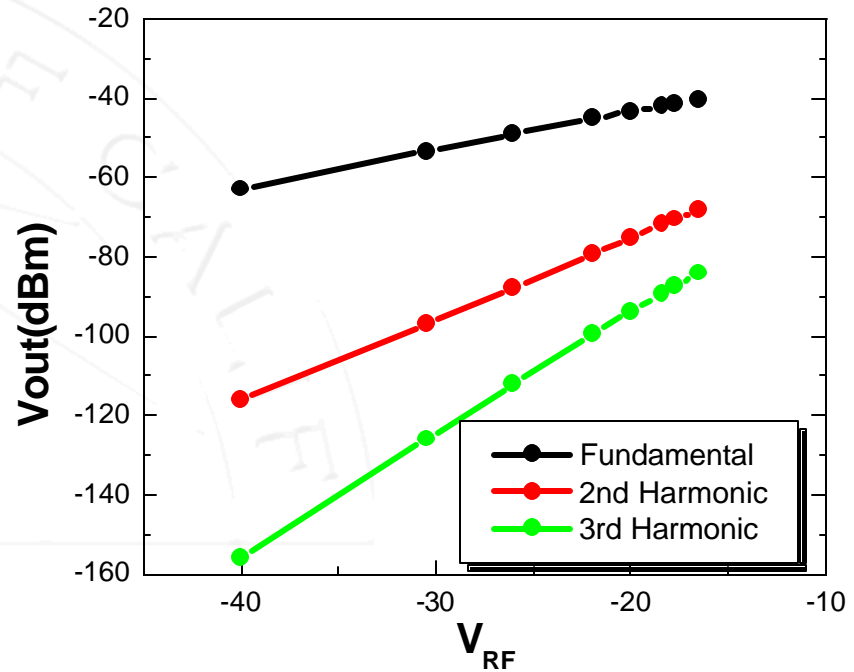
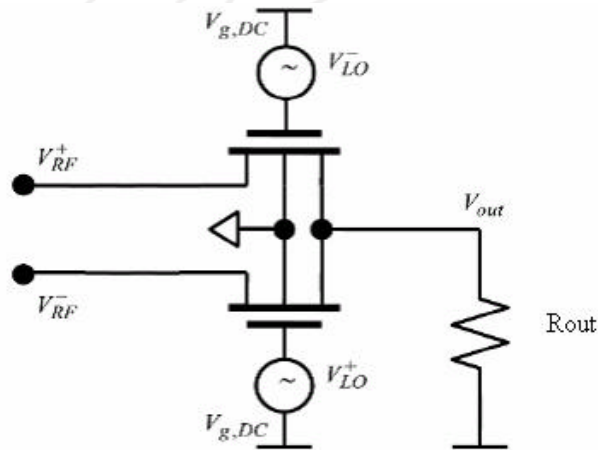
- Need for Symmetry
- Current BSIM4 Analog / RF issues
- A workaround approach to the issues
- Verification of the approach
- Summary and Future work

Low 1/f Noise CMOS Mixer



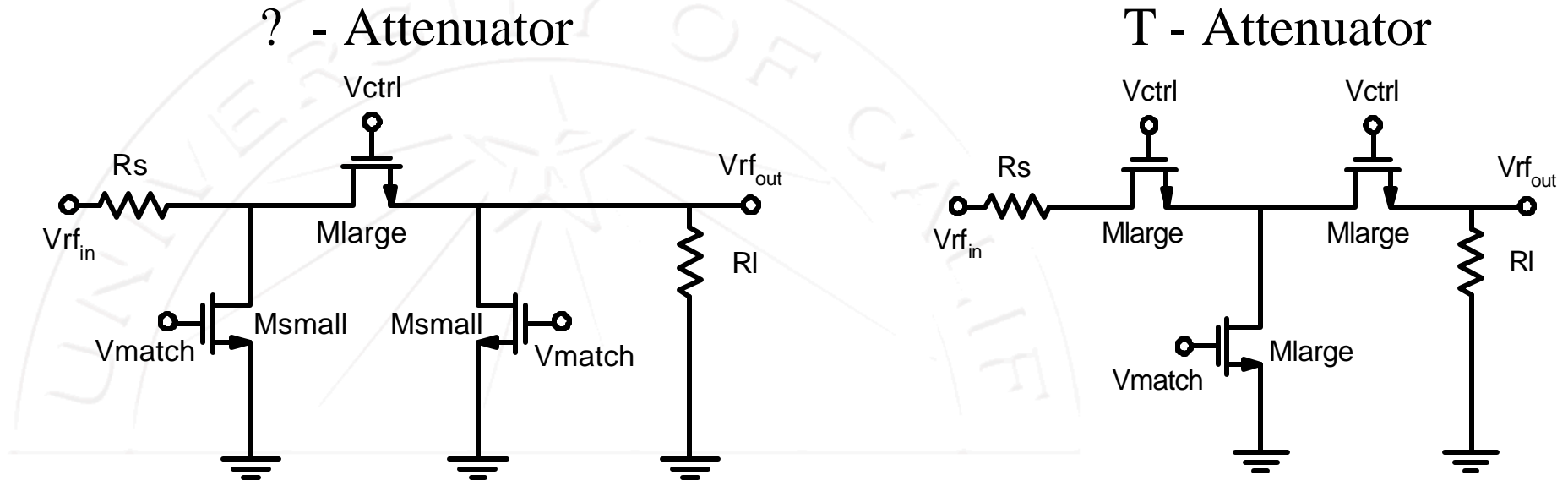
- Popular mixer topology employs MOSFET as a switch. The “Gilbert Quad” is run with zero DC current reducing the 1/f noise.
- The benefit of such a passive mixer is its high linearity.

CMOS Mixer Simulation



- The transistor switches about the operating point $V_{DS} = 0$.
- I-V and C-V model must be symmetric in order to predict IM2/IM3 properly.

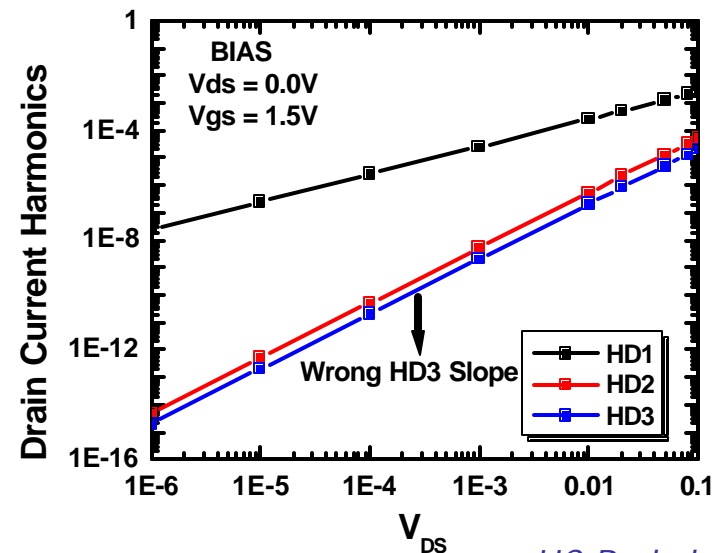
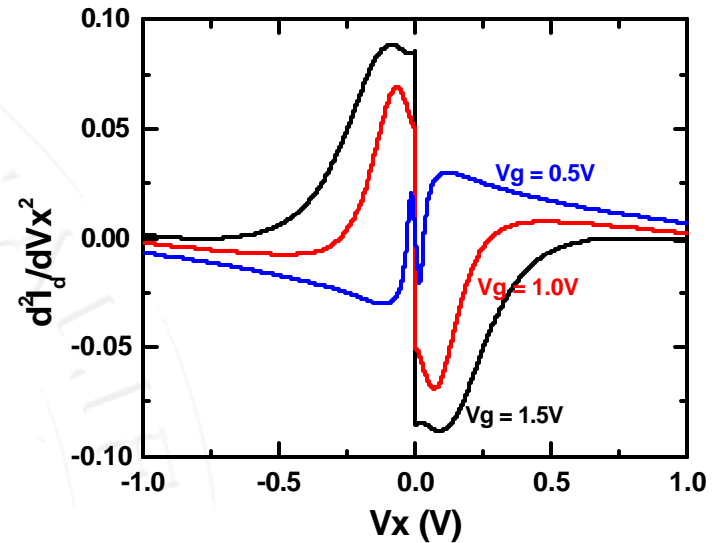
CMOS Attenuator Example



- Like passive mixers, attenuators help reduce the dynamic range requirements in active circuits.
- The linearity of an attenuator is perhaps the most important metric. Only a fully symmetric model can predict the linearity.

BSIM4 Analog / RF Problems

- Discontinuity of 2nd derivative of drain current @ $V_{DS} = 0$
- Illustrated through the Gummel Symmetry test
- Incorrect slope of HD3 @ $V_{DS} = 0$ leads to incorrect IIP3 prediction.
- Illustrated through the distortion curves



Source of Error

- Structure of the I-V model in BSIM

$$I_{ds} = f(V_{gs}, V_{ds}, V_{bs}) \cdot V_{dseff}$$

- The function "f" is asymmetric w.r.t source and drain.
- The 2nd derivative of the term V_{dseff} also generates discontinuity @ $V_{DS} = 0$.
- Need to resolve both the functions "f" and " V_{dseff} ".

Dynamic Referencing Method

- Introduce a new symmetric function for V_{ds} and make other terminal voltages also symmetric w.r.t. V_{ds}

$$V_{dsx} = \sqrt{v_{ds}^2 + \delta^2}$$

$$V_{gsx} = v_{gs} + 0.5 (V_{dsx} - v_{ds})$$

$$V_{bsx} = v_{bs} + 0.5 (V_{dsx} - v_{bs})$$

- Redefine the function "f" in BSIM drain current model to make it symmetric.

$$I_{ds} = f(V_{gsx}, V_{dsx}, V_{bsx}) \cdot V_{dseff}$$

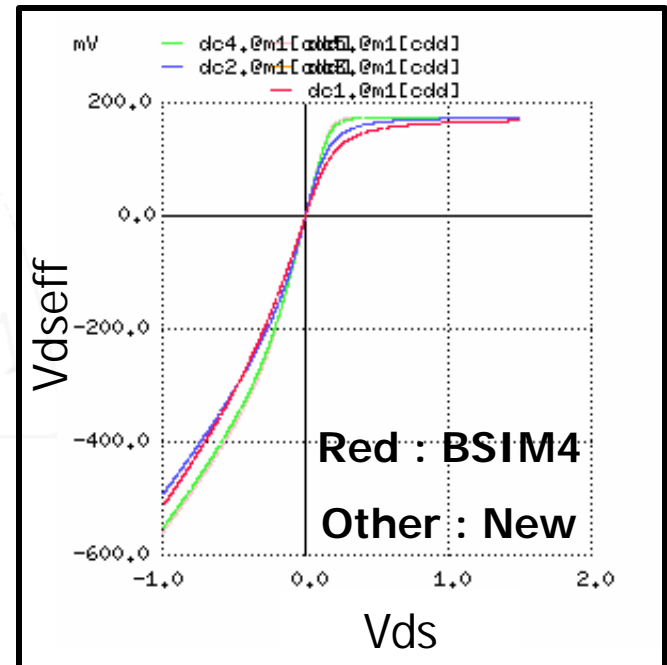
- How to chose δ ?
 - Large δ will change the electrical characteristics drastically.
 - Small δ will make the 3rd order derivative in I_{ds} large.
 - Choice is guided by simulation results as seen later.

New V_{dseff}

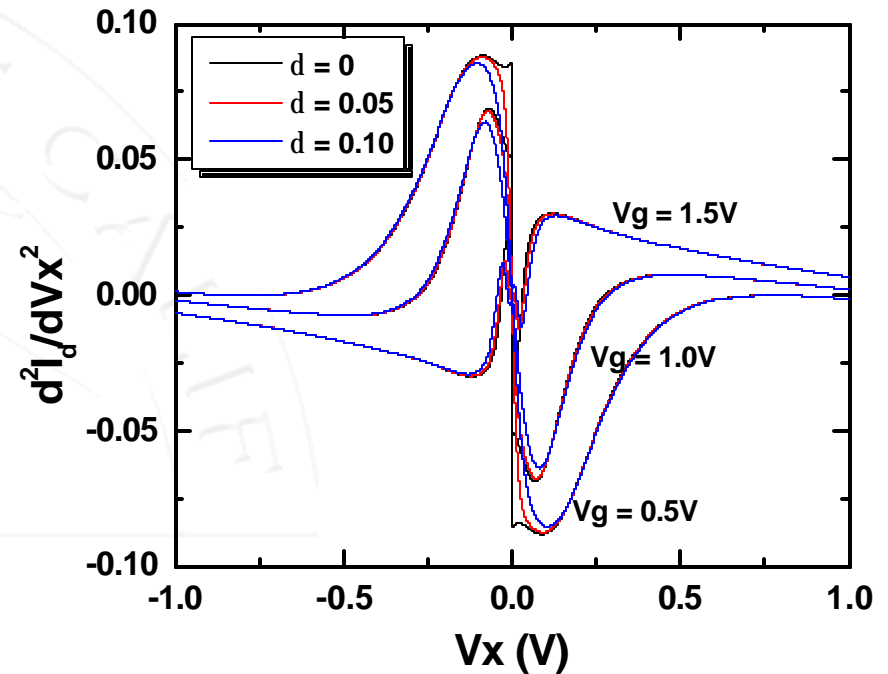
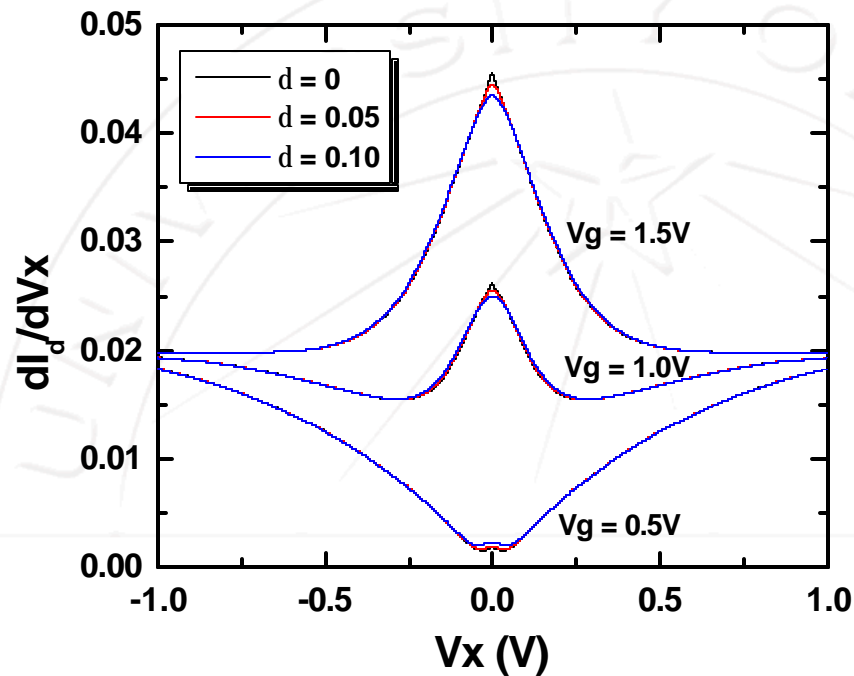
- Introduce a new smoothing function for V_{dseff} to solve the discontinuity in 2nd derivative. (VDSMOD = 1)

$$V_{dseff} = \frac{V_{ds} \cdot V_{dsat}}{(V_{ds}^m + V_{dsat}^m)^{\frac{1}{m}}}$$

- Model introduces significant change in V_{dseff} and hence G_{ds} .
- Efforts are on to find a better solution closer to the current V_{dseff} .
- The following simulation results compare only the effect of different " δ " in the presence of the new V_{dseff} definition.

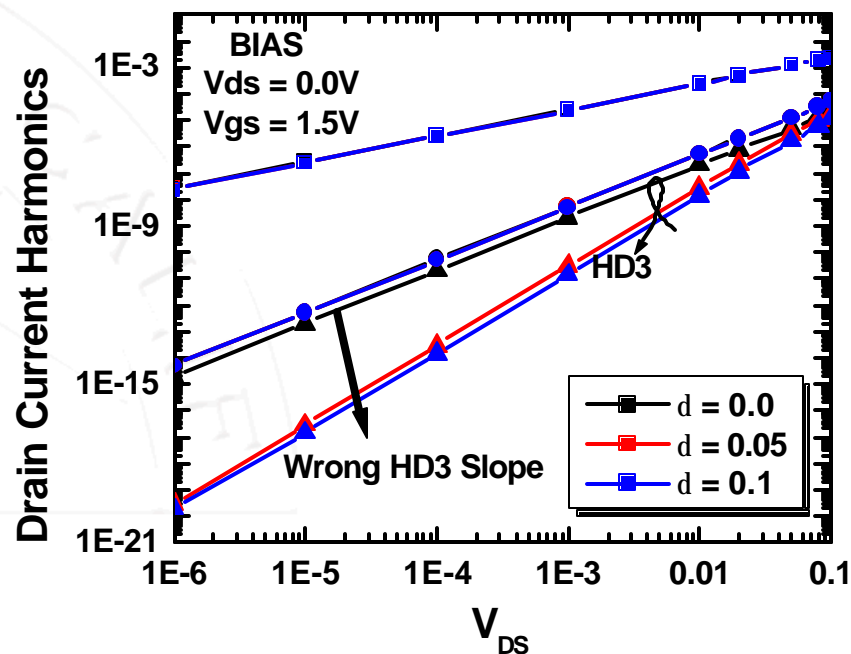
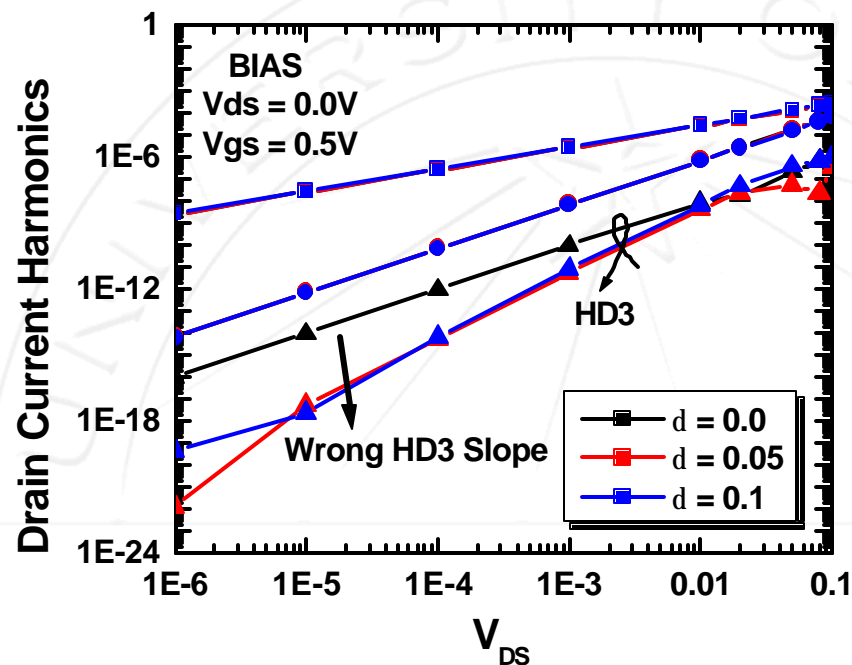


Gummel Symmetry Results



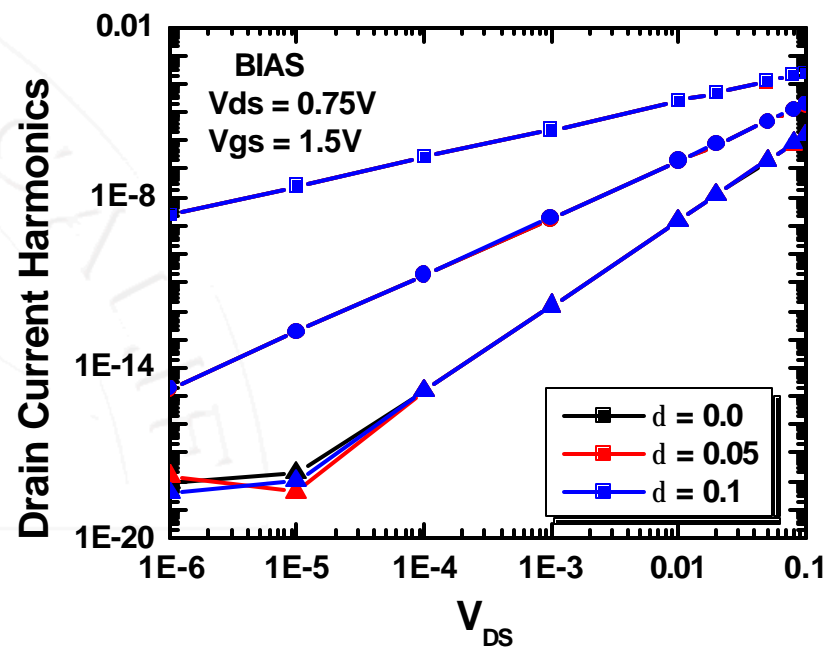
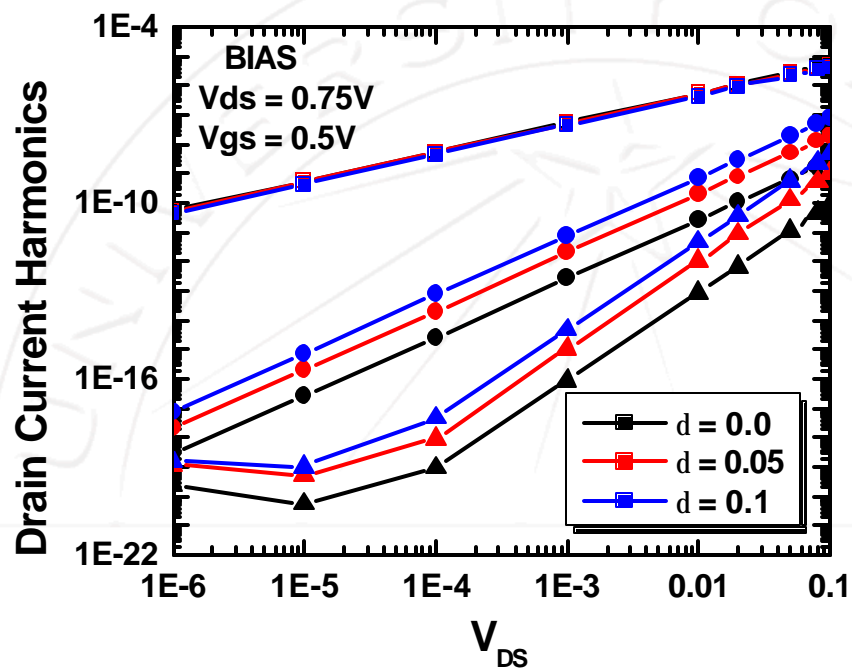
- Discontinuity in the second derivative removed with finite δ .
- For large V_{DS} , the derivatives are independent of δ as desired.

Distortion Curves : @ $V_{ds} = 0$



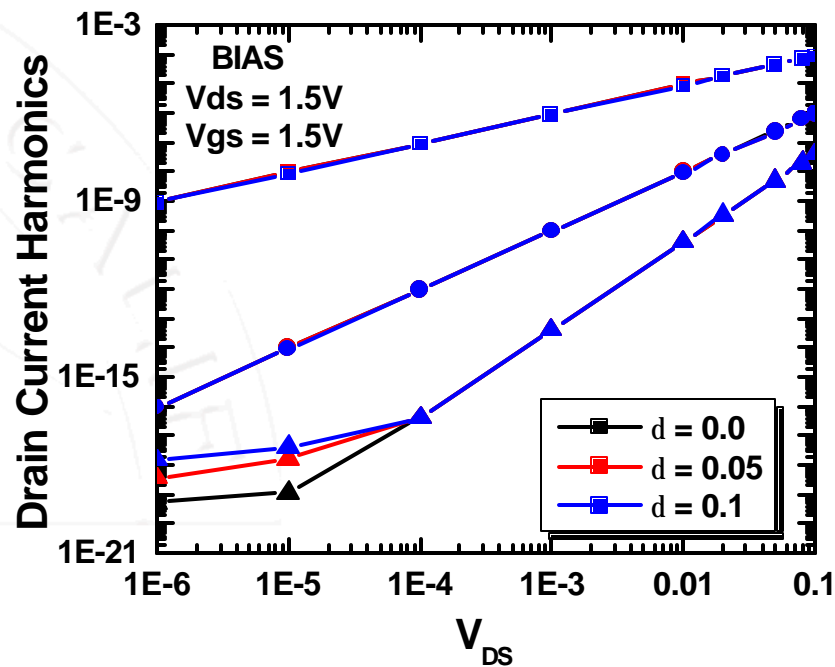
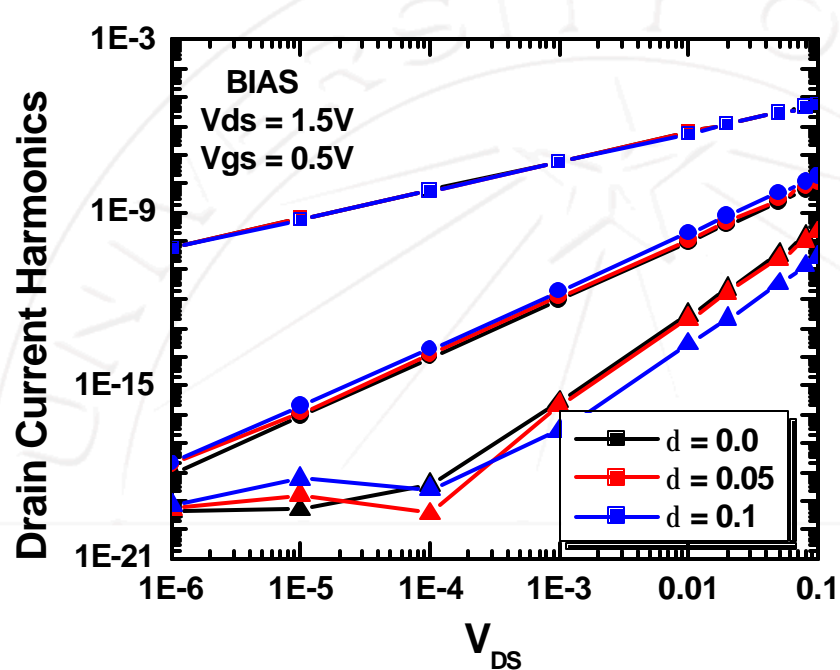
- Correct slope of HD3 with finite δ both near threshold and in strong inversion.
- HD1 and HD2 almost unchanged with changing δ .

Distortion Curves : @ $V_{ds} = 0.75$



- For lower V_{gs} , HD1 and HD2 change with changing δ .
- Correct slopes are retained in all the cases.

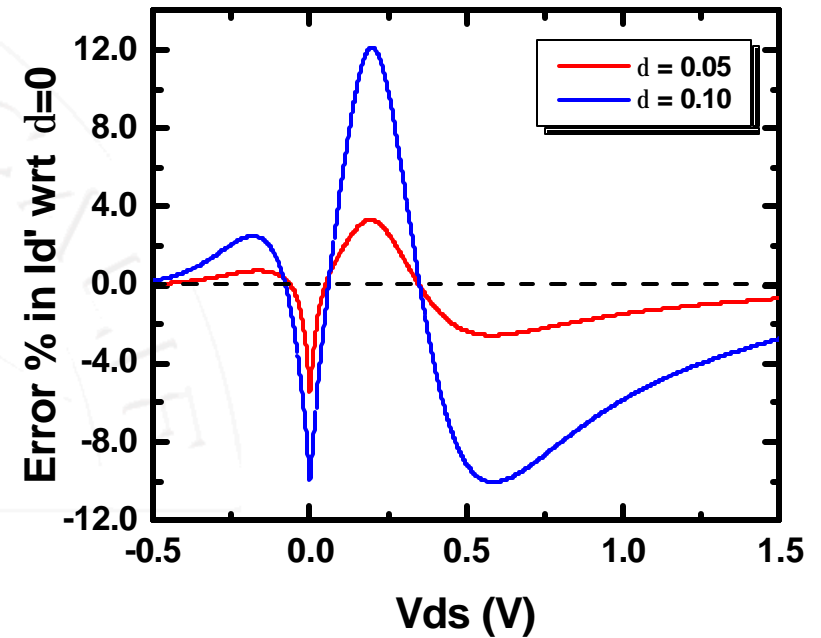
Distortion Curves : @ $V_{ds} = 1.5$



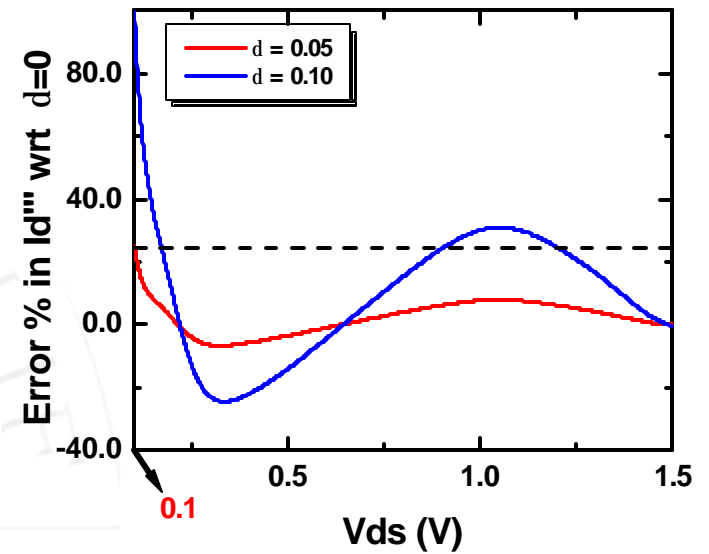
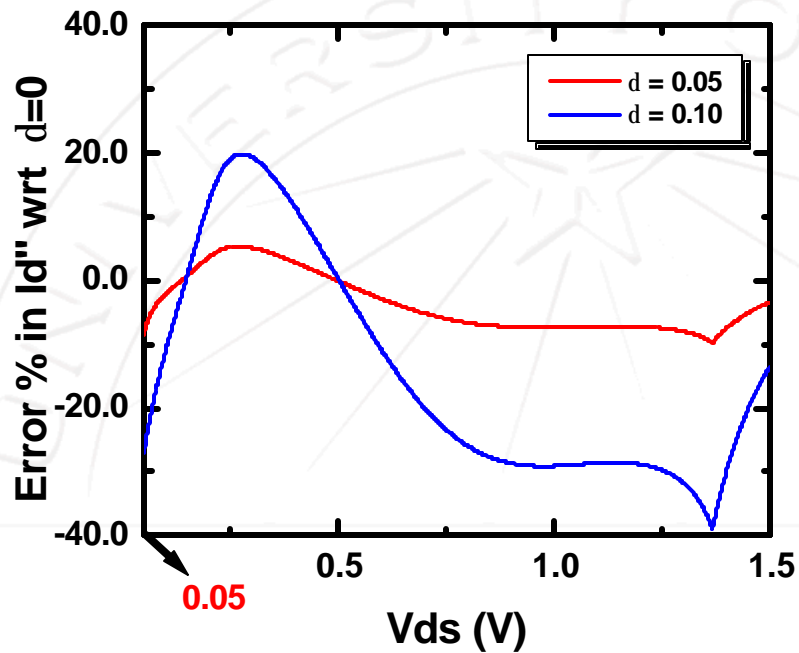
- $\delta = 0.05$ gives correct slope with least deviation in harmonics magnitude compared to $\delta = 0$.

Gds Error Plot

- VDSMOD = 1 for all simulations.
- Error in drain conductance due to non-zero δ is plotted.
- Error in Gds increases for large δ .



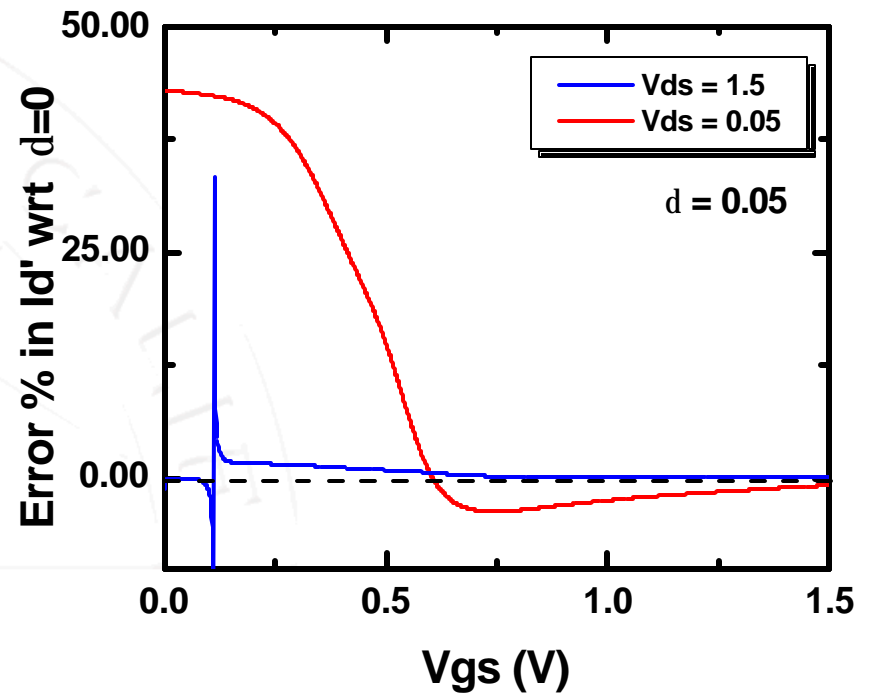
Gds' and Gds'' Error Plots



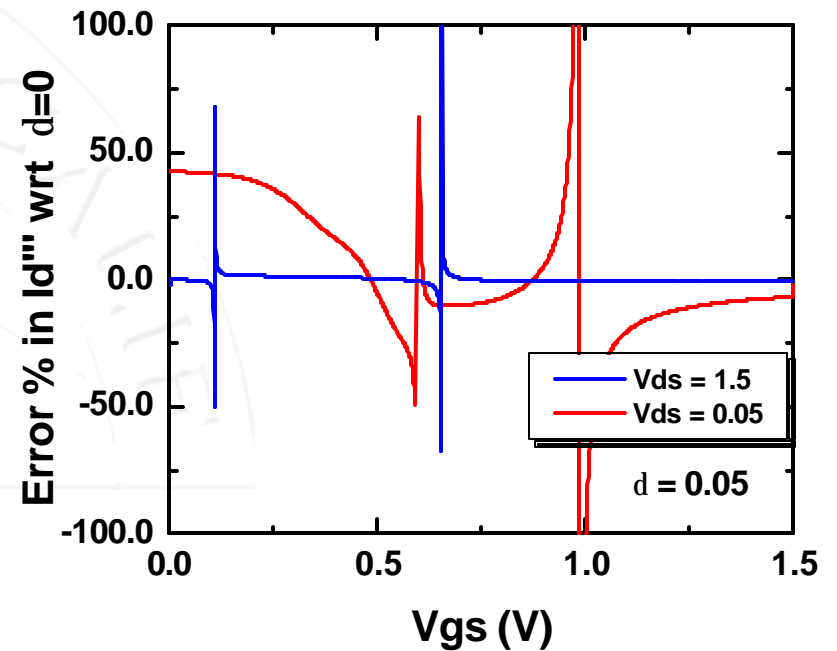
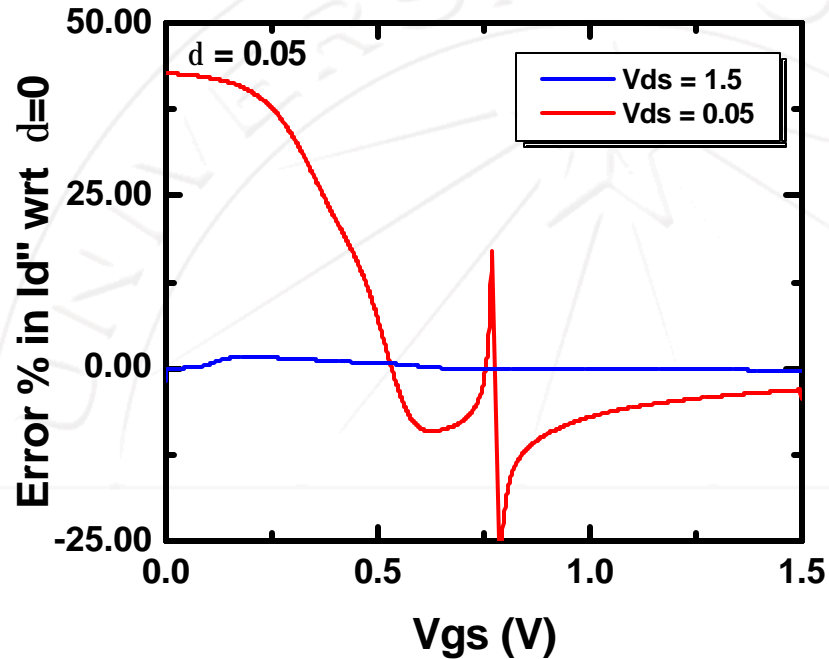
- With $\delta=0.05$, error in Gds and its derivatives is $<10\%$.

Gm Error Plot

- VDSMOD = 1 for all simulations.
- Error in transconductance due to non-zero δ is plotted.
- Very small error in Gm for large V_{DS} .
- Significant error in Gm for small V_{DS} at lower V_{GS} (near threshold).



Gm' and Gm'' Error Plots



- Sharp spikes occur when the reference value while calculating error fraction is very close to zero.

Summary and Future Work

- A possible workaround for the symmetry issue is presented.
- Correct distortion slope is obtained using the dynamic reference method.
- Magnitude of the distortion and errors in derivatives depend on δ . Error introduced by new V_{dseff} has not been accounted yet.
- Will look for a better solution to the V_{dseff} issue.
- If the I-V workaround is deemed useful, the asymmetry in the C-V model will be addressed next.

BSIM team would like to thank Ben Gu and Brian Mulvaney in Freescale's circuit simulation (Mica) group for the invaluable discussions and help with simulations.

SUGGESTIONS / FEEDBACK ?

