BSIM4.X NQS MODEL FOR AC ANALYSIS

CR&D DEVICE MODELLING TEAM

NQS Model Requirements for AC Analysis

NQS model:

- **Should be the same as QS one at low frequencies.**

- **Should provide correct high frequency trends.**

Exemple: When used in common source mode, the MOS transistor transconductance magnitude, |Ym| = |Y21 - Y12|, should decrease when frequency increases.

AC NQS Implementation in BSIM4.x

- **A time constant, τ, is introduced, which is bias dependent.**

- **Considering the small signal [Y] matrix, each element, except Ybx ones, is multiplied by $\frac{1}{1+j\tau\omega}$.**

- **For instance:**

$$\begin{cases} Y_{gd} = -j\omega C_{gd} \\ Y_{dg} = g_m - j\omega C_{dg} \end{cases}$$ **in QS model;**

$$\begin{cases} Y_{gd} = \dfrac{-j\omega C_{gd}}{1+j\tau\omega} \\ Y_{dg} = \dfrac{g_m - j\omega C_{dg}}{1+j\tau\omega} \end{cases}$$ **in NQS model.**

- **This implementation in BSIM4 leads to the following expressions of Ym:**

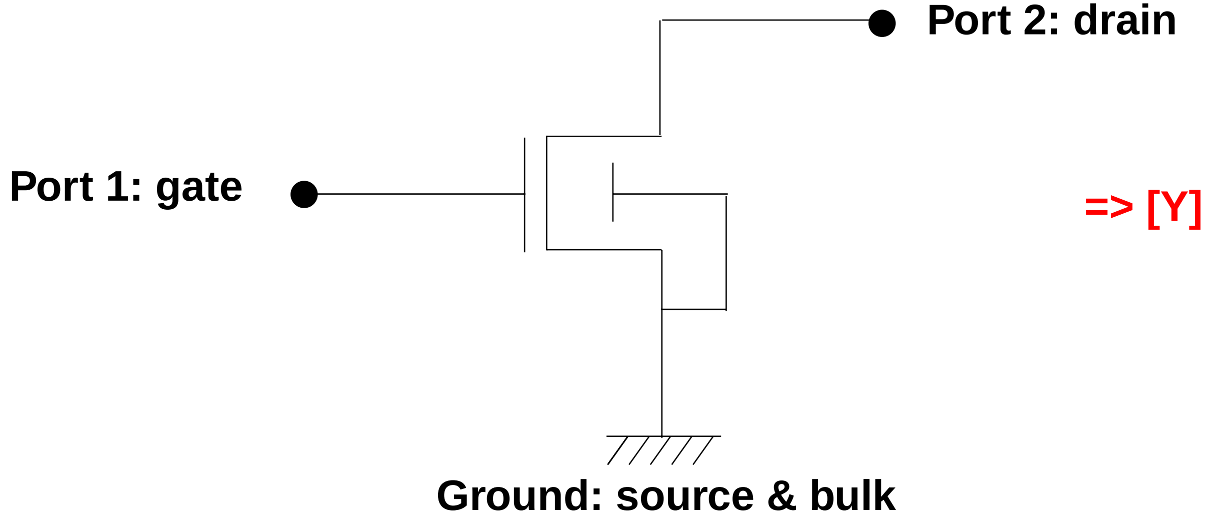
$$Y_m = g_m - j(C_{dg} - C_{gd})\omega$$ **in QS model;** $$Y_m = \frac{g_m - j(C_{dg} - C_{gd})\omega}{1+j\tau\omega}$$ **in NQS model.**

- **The term $-j(C_{dg} - C_{gd})\omega$ in the NQS expression should be removed since it corresponds to the low frequency approximation of $Y_m = \frac{g_m}{1+j\tau\omega} \cong g_m - jg_m\tau\omega = g_m - j(C_{dg} - C_{gd})\omega$ [1].**

[1] Y. Tsividis, *Operation and Modeling of The MOS Transistor*, Second Edition, Chap. 9, “HF small-signal models”.

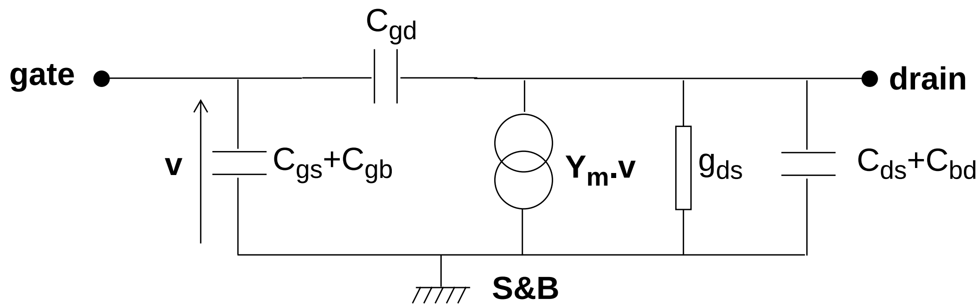
COMPARISON WITH MEASUREMENTS: SETUP

- **HF measurements were done on PMOS transistor biased common source:**



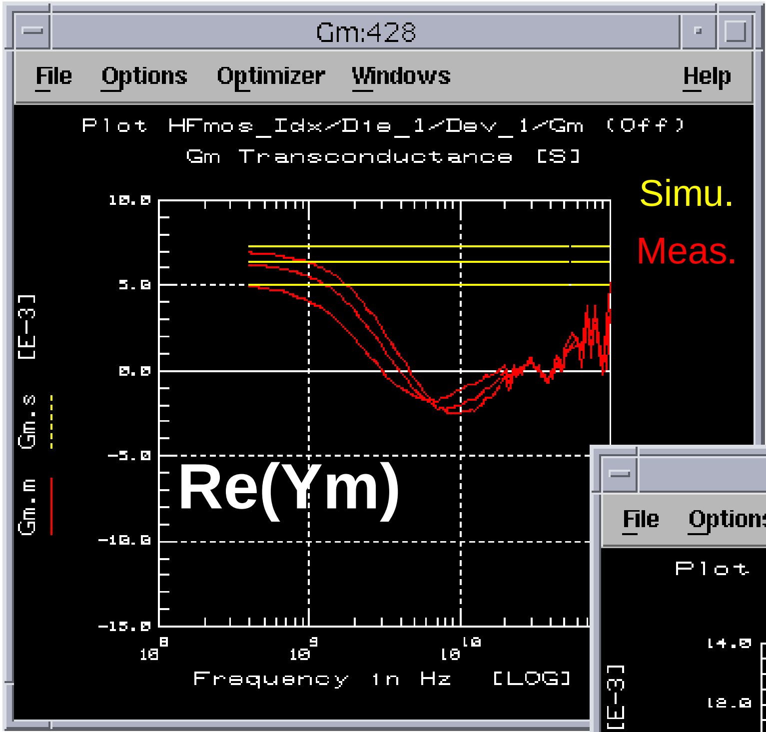
=> [Y] matrix is extracted

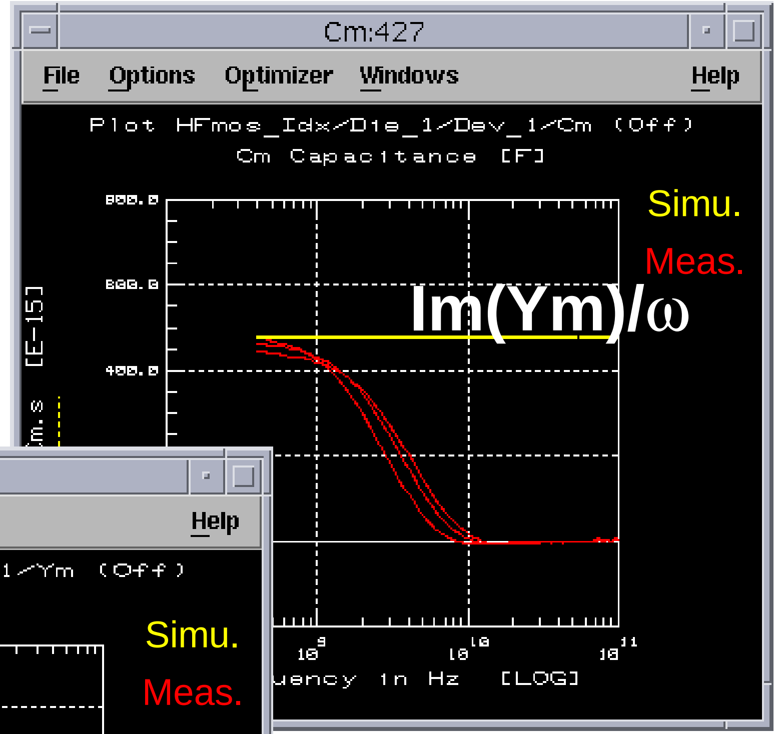
- **Transconductance definition: Ym = (Y21 - Y12).**

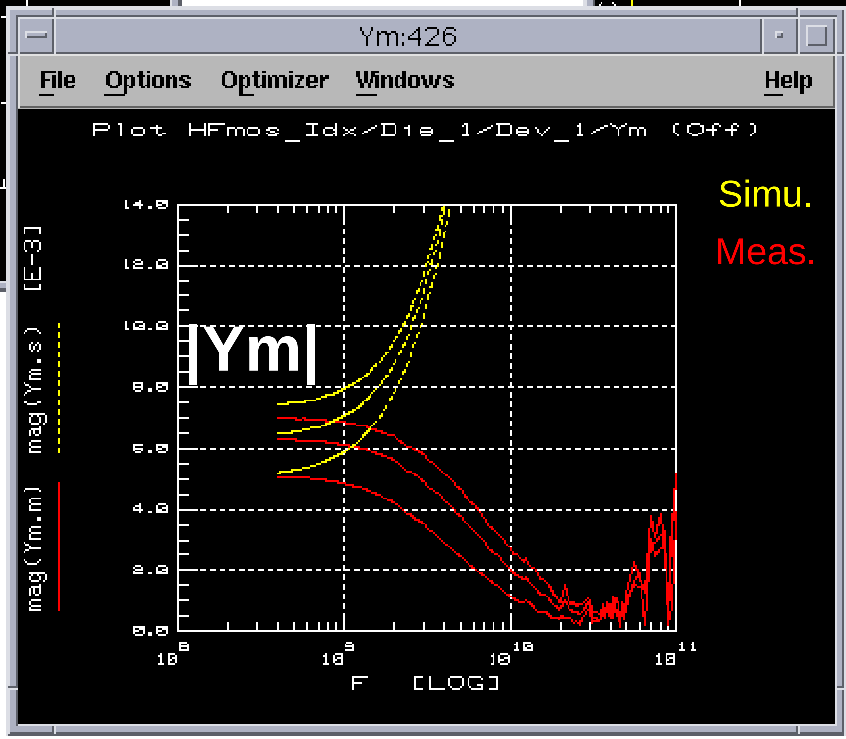


QS BSIM4.x Model vs. HF Measurements

acnqsmod = 0





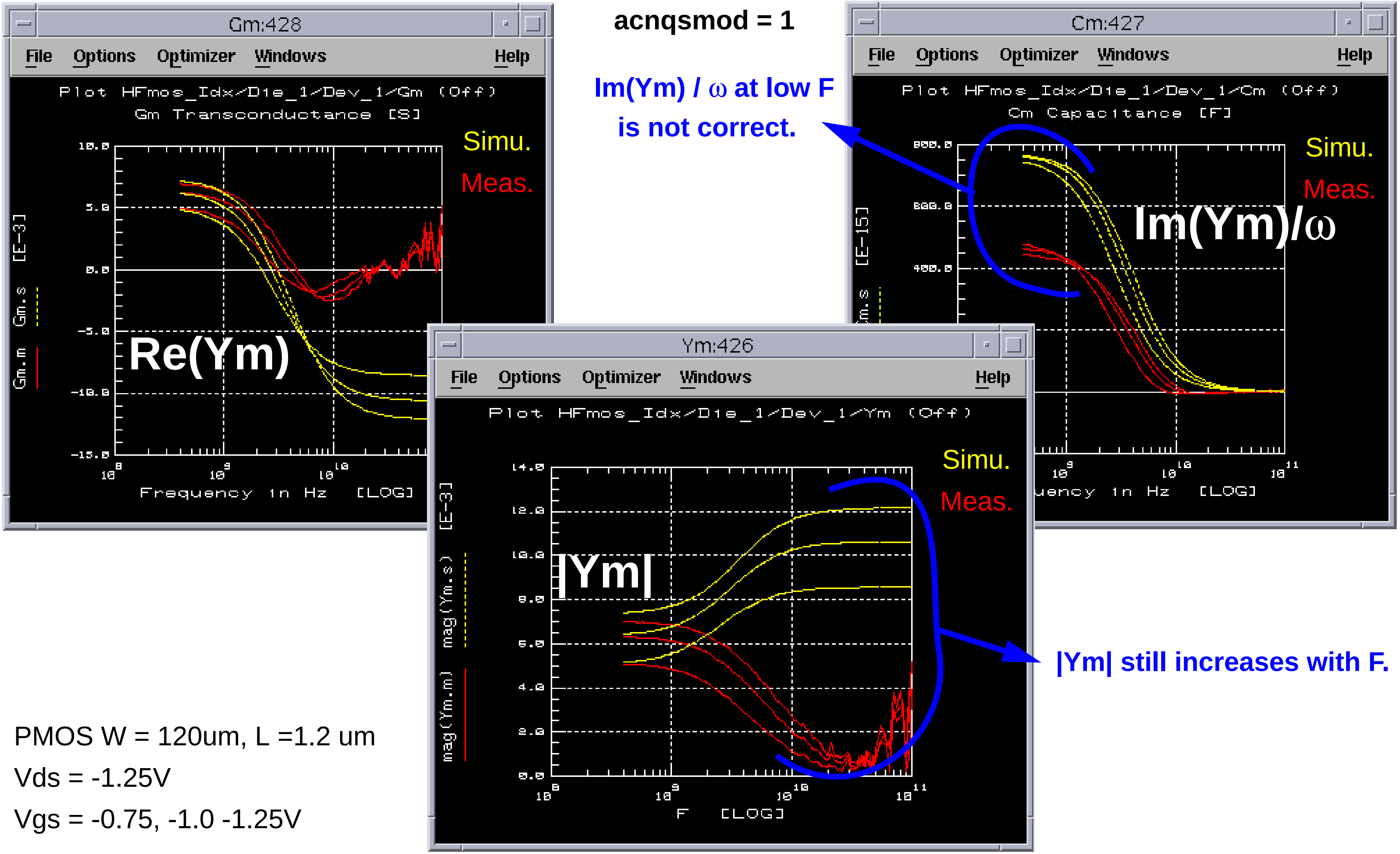


PMOS W = 120um, L =1.2 um

Vds = -1.25V

Vgs = -0.75, -1.0 -1.25V

NQS BSIM4.X MODEL VS. HF MEASUREMENTS

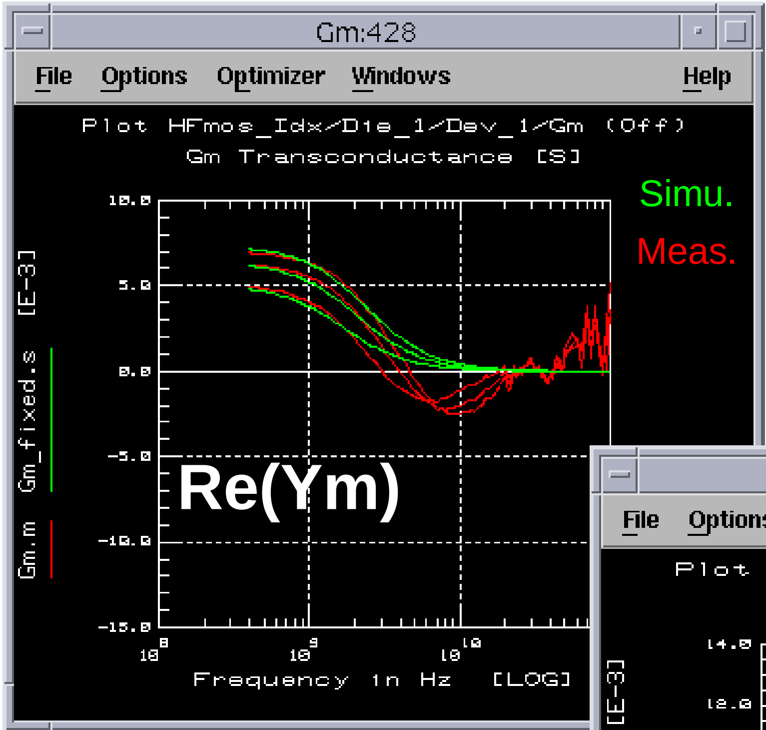


PMOS W = 120um, L =1.2 um

Vds = -1.25V

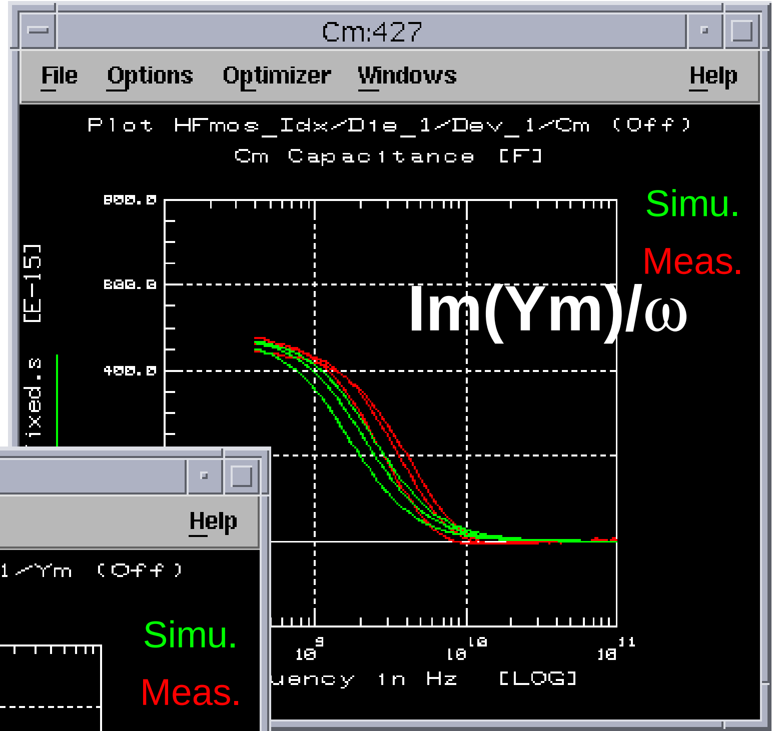
Vgs = -0.75, -1.0 -1.25V

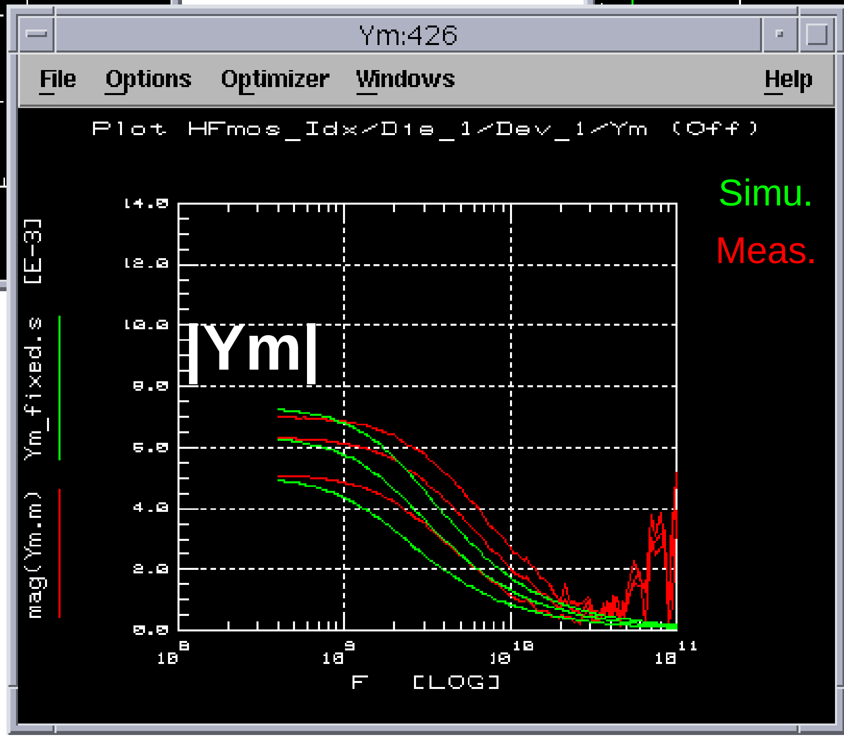
"FIXED" BSIM4.X MODEL VS. HF MEASUREMENTS



Ym with $-j(C_{dg}-C_{gd})\omega$ term removed:

$$Y_m = \frac{g_m}{1 + j\tau\omega}$$





PMOS W = 120um, L =1.2 um

Vds = -1.25V

Vgs = -0.75, -1.0 -1.25V

WHICH PART OF BSIM4.X C CODE SHOULD BE FIXED?

- **Source code file is b4acld.c (same file for BSIM4.2.1, BSIM4.3.0, BSIM4.4.0):**

```
if (here->BSIM4acnqsMod)
{   T0 = omega * here->BSIM4taunet;
    T1 = T0 * T0;
    T2 = 1.0 / (1.0 + T1);
    T3 = T0 * T2;

    gmr = here->BSIM4gm * T2;
    gmbsr = here->BSIM4gmbs * T2;
    gdsr = here->BSIM4gds * T2;

    gmi = -here->BSIM4gm * T3;
    gmbsi = -here->BSIM4gmbs * T3;
    gdsi = -here->BSIM4gds * T3;

    Cddr = here->BSIM4cddb * T2;
    Cdgr = here->BSIM4cdgb * T2;
    Cdsr = here->BSIM4cdsb * T2;
    Cdbr = -(Cddr + Cdgr + Cdsr);

    /* WDLiu: Cxyi mulitplied by jomega below, and actually to be of conductance */
    Cddi = here->BSIM4cddb * T3 * omega;
    Cdgi = here->BSIM4cdgb * T3 * omega;
    Cdsi = here->BSIM4cdsb * T3 * omega;
    Cdbi = -(Cddi + Cdgi + Cdsi);

    Csdr = Csd * T2;
    Csgr = Csg * T2;
    Cssr = Css * T2;
    Csbr = -(Csdr + Csgr + Cssr);

    Csdi = Csd * T3 * omega;
    Csgi = Csg * T3 * omega;
    Cssi = Css * T3 * omega;
```

Terms to be set to 0 ?

CONCLUSION

- A BSIM4.x NQS model implementation inconsistency has been shown for AC analysis.
- This leads to both incorrect high frequency trends and wrong imaginary parts at low frequencies.
- This has been illustrated for PMOS on Ym transconductance frequency behavior.
- Similar observations were made on NMOS and other small-signal quantities than Ym.
- A way to improve BSIM4.x NQS model codes capability is suggested.
- The whole BSIM4.x NQS model has to be checked, corrected and validated.