

Status of HICUM/L0 Model

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Outline

- HICUM/L0 Version1.31 Model
- Implementation of vertical NQS modeling
- Operating points values in L0
- Conclusion

HICUM/L0 Version1.31 Model

- Released on December, 2012 => *code accessible only to cooperation partners*
- Latest additions
 - NQS effect
 - Operating point information directly in the VA code
 - A complete L0 documentation is on its way

Implementation of vertical NQS modeling

- Requested by SGPM users
 - to make simplified L0 identical to SGPM
 - to enable switch from SGPM and VBIC to HICUM/L0
 - initially omitted to reduce simulation time
- Vertical NQS-effects are implemented the same way as in HICUM/L2
=> for both minority charge and transfer current
 - if offered, then enable correct modeling of phase shift for small-signal frequency dependent transconductance, *mobile charge*, and *current gain*
- Frequency dependence of magnitude and phase of mobile base charge Q_{nB} is modeled with the transfer function

$$\frac{i_{nB}(\omega)}{i_{nB0}} = \frac{1}{1 + \alpha_{Qf}\omega\tau_{Bfd}}, \text{ where}$$

$i_{nB} = \frac{dQ_{nB}}{dt}$ is the dynamic base current related to the stored mobile charge

- VA implementation is done by single-pole RC circuit

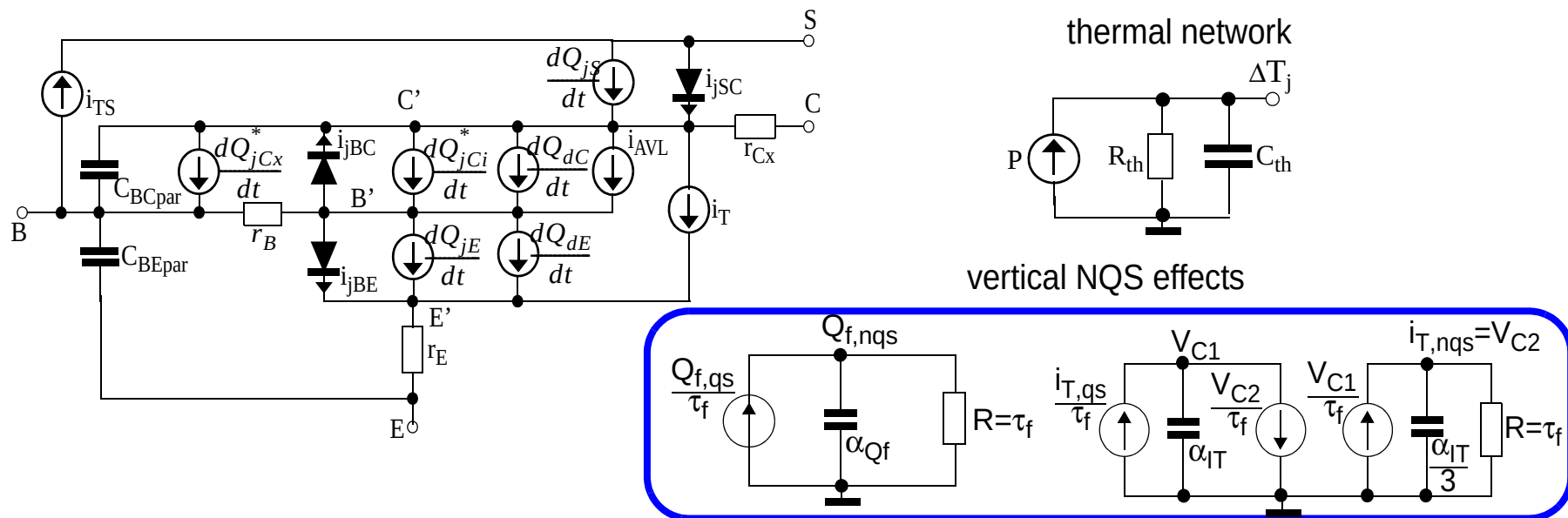
Implementation of vertical NQS modeling (cont'd)

- Frequency dependence of magnitude and phase of collector current (i.e. transconductance) are modeled by inverted polynomial approach (Bessel polynomial)

$$\frac{i_T(\omega)}{i_{T0}} = \frac{1}{1 + \alpha_{iT}\omega\tau_{Bfd} + \frac{\alpha_{iT}}{3}(\omega\tau_{Bfd})^2} \Rightarrow \text{second-order DE in time-domain}$$

- time-domain VA implementation is done by a gyrator equivalent of a LCR circuit

=> new equivalent circuit of HICUM/L0



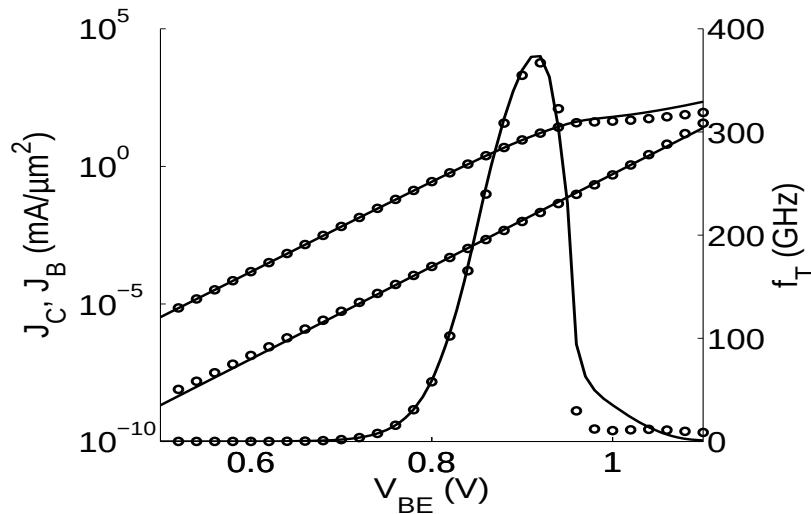
Implementation of vertical NQS modeling (cont'd)

- New model parameters

Parameter	Default	Range	Description
flnqs	0	[0:1]	Flag for turning on and off of vertical NQS effects
alit	0.333	(0:1]	Factor for additional delay time of transfer current
alqf	0.167	(0:1]	Factor for additional delay time of mobile charge

Verification

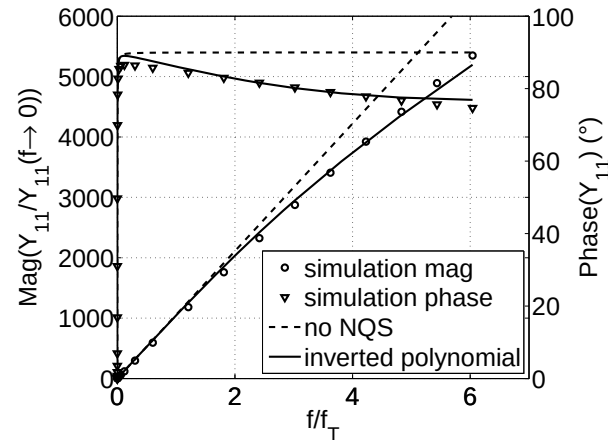
- model card extracted from *1D numerical Device* simulation



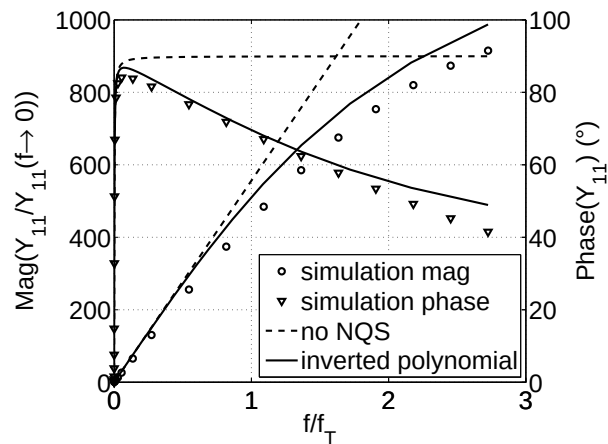
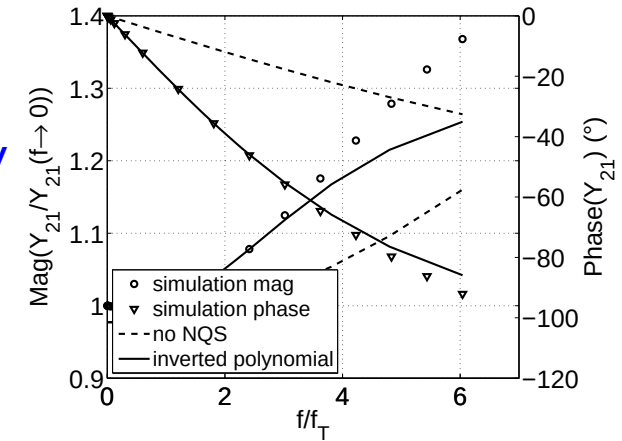
- Peak f_T (~ 380 GHz) of this transistor is at $V_{BE} = 0.92$ V

Verification of vertical NQS effects (cont'd)

Small signal y-parameters



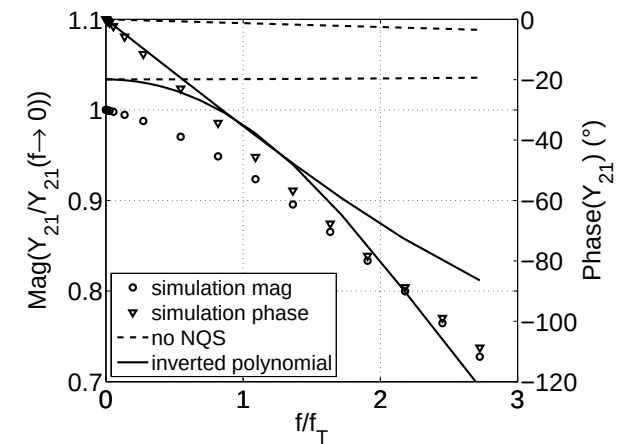
$$V_{BE} = 0.84V, V_{BC} = 0V$$



$$V_{BE} = 0.92V, V_{BC} = 0V$$

($f_{T,peak}$)

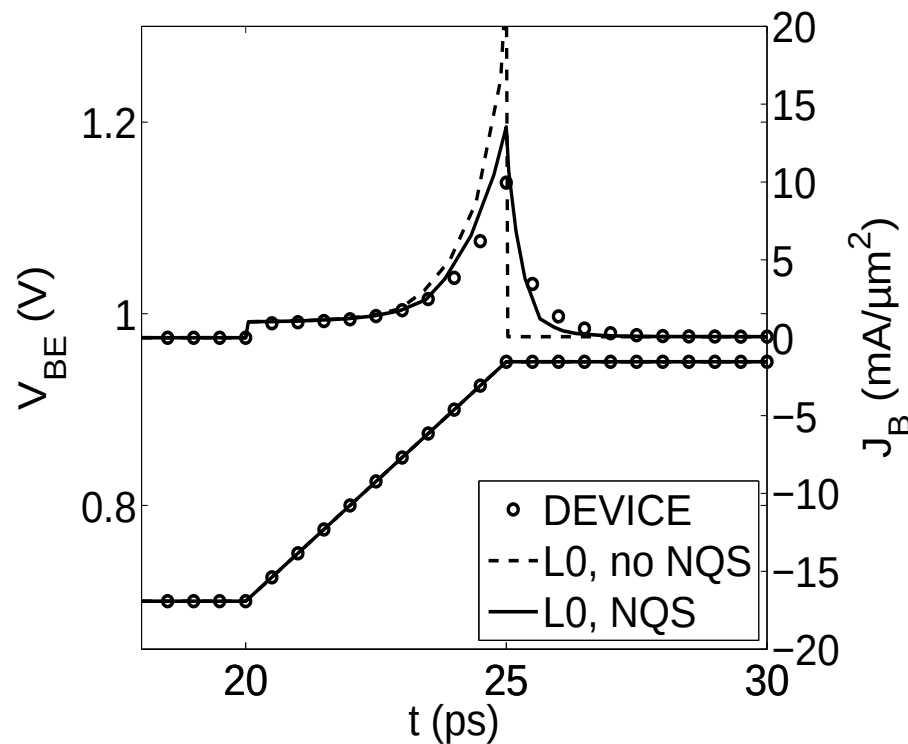
(deviations caused by
simplified input EC
compared to L2)



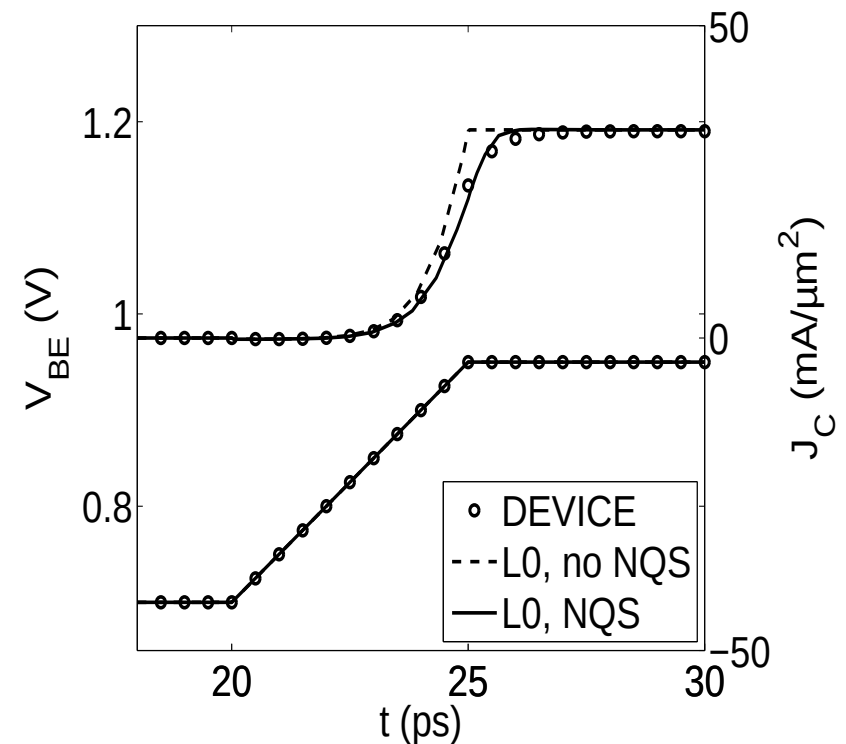
Verification of vertical NQS effects (cont'd)

transient simulation results

dynamic base current
includes mobile charge change



dynamic collector current



=> good agreement for both I_B & I_C for a turn-on process

Operating points values in L0

- Same like in L2 model; they are calculated directly inside the L0 VA code
=> problem: increase in code size and computation time
- Introduction of compiler flag CALC_OP
=> calculations are included in the code only if CALC_OP is turned-on
- Definition of operating point values follows the VA standard

```

`ifdef CALC_OP
    (* desc="Base terminal current", units="A" *) real IB;
    ...
`endif

```

- Simulation time with CALC_OP turned on & off:
=> 10 transistors in parallel were simulated in 7881 DC operating points

CALC_OP	Simulator	Size C-code	Size compiled code	Simulation time ^a
yes	ADS	763 KB	365 KB	10.95
	Spectre	1.8 MB	649 KB	48.8 s
no	ADS	499 KB	324 KB	9.4 s
	Spectre	1.4 MB	572 KB	27.4 s

a. Mean value from 10 simulations.

Conclusion

- L0 code is accessible only to cooperation partners (i.e. based on financial support or other criteria, since L0 is not supported by the CMC)
- Calculation of operating point inside Verilog-A code
 - same as in L2 model
 - increases compiled code size and computation time
- Inclusion of complete NQS effect in L0 model adds 3 more nodes to the EC
 - both mobile charge and transfer current NQS effect now included
 - full compatibility with SGPM at low current densities if $ALQF = 0$
- An updated L0 documentation will be available soon