Limitations of Bipolar Compact Models for LF Noise
PART II – Answers to HICUM WS 2010 remarks

23rd ArbeitsKreis Bipolar (AKB) – Crolles – October 15th 2010

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Internal ref. : dm10.227

Outline

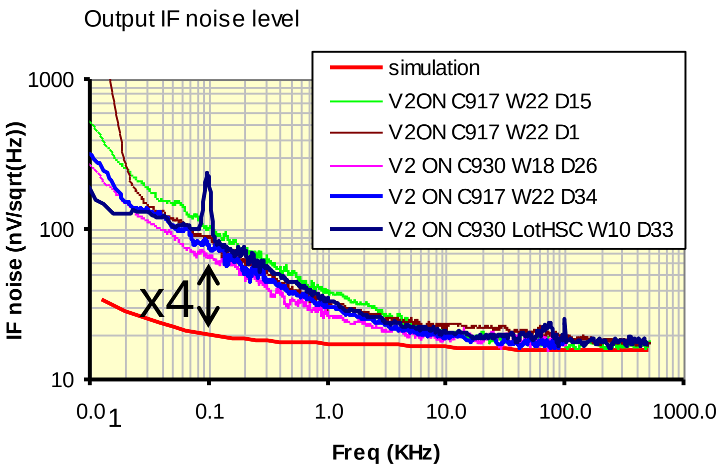
- Summary of the study presented at the HICUM WS 2010
- Remarks and questions opened at the HICUM WS
- Generalities and theory about LF noise measurements setup
- Detailed conditions and setup of our measurements and simulations
- Definitive conclusions

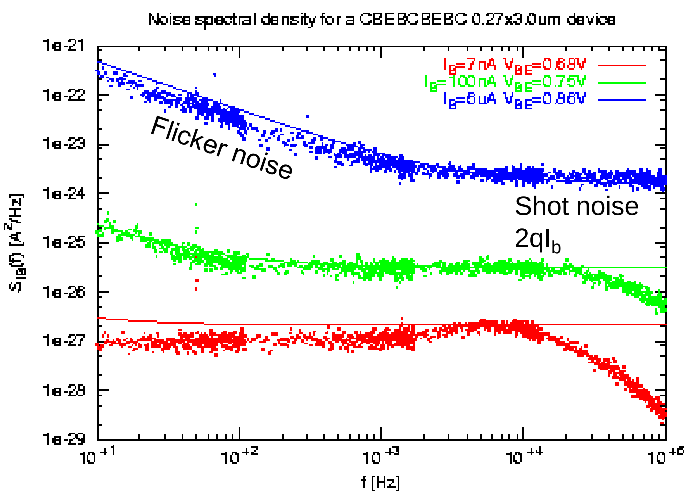
HICUM WS 2010 summary (1/4)

In [Derrier10], we showed that :

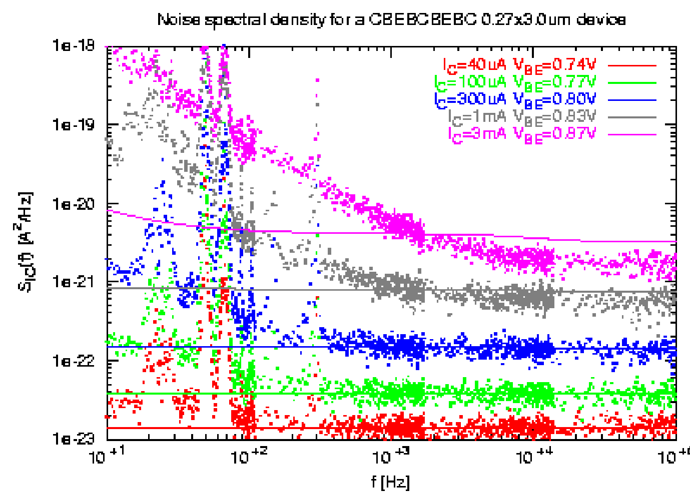
- Issue of 1/f Spice simulations at very low frequencies for an application designed with ST BiCMOS 0.13µm mmW technology

- Issue coming from the NPN High-Speed SiGe-C simulations
- 1/f simulations vs measurements OK on the Base
- 1/f simulations vs measurements NOT OK on the Collector





SI on the Base

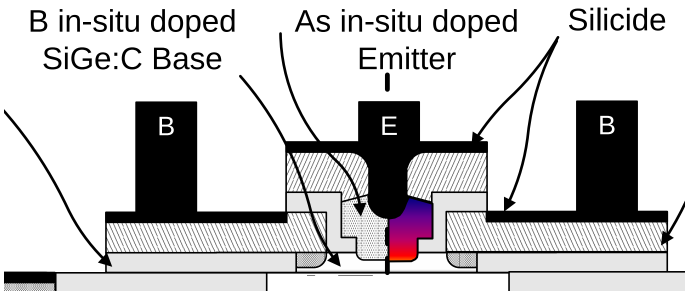


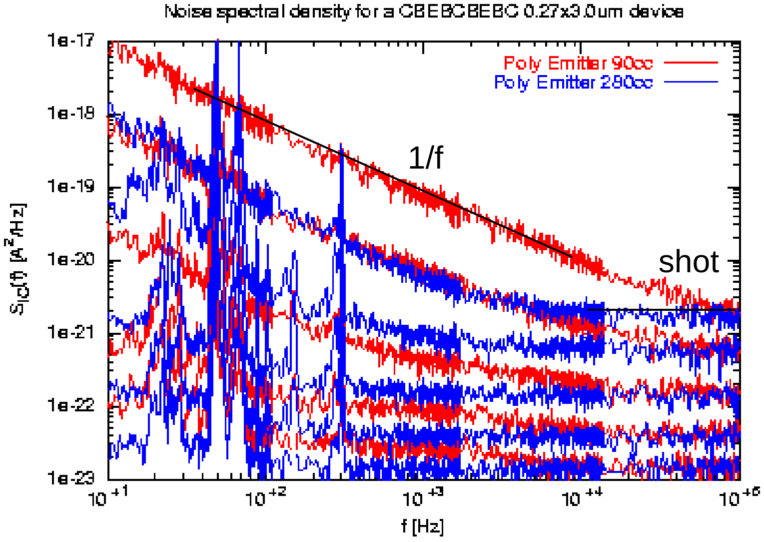
SI on the Collector

HICUM WS 2010 summary (2/4)

- Only 1 1/f noise source in compact models today : SI_{EB}
- Other 1/f noise sources in the HBT, not taken in account in Spice ?

- A Process DOE shows that the missing 1/f noise main contribution comes from the Emitter poly/mono interface (R_E)

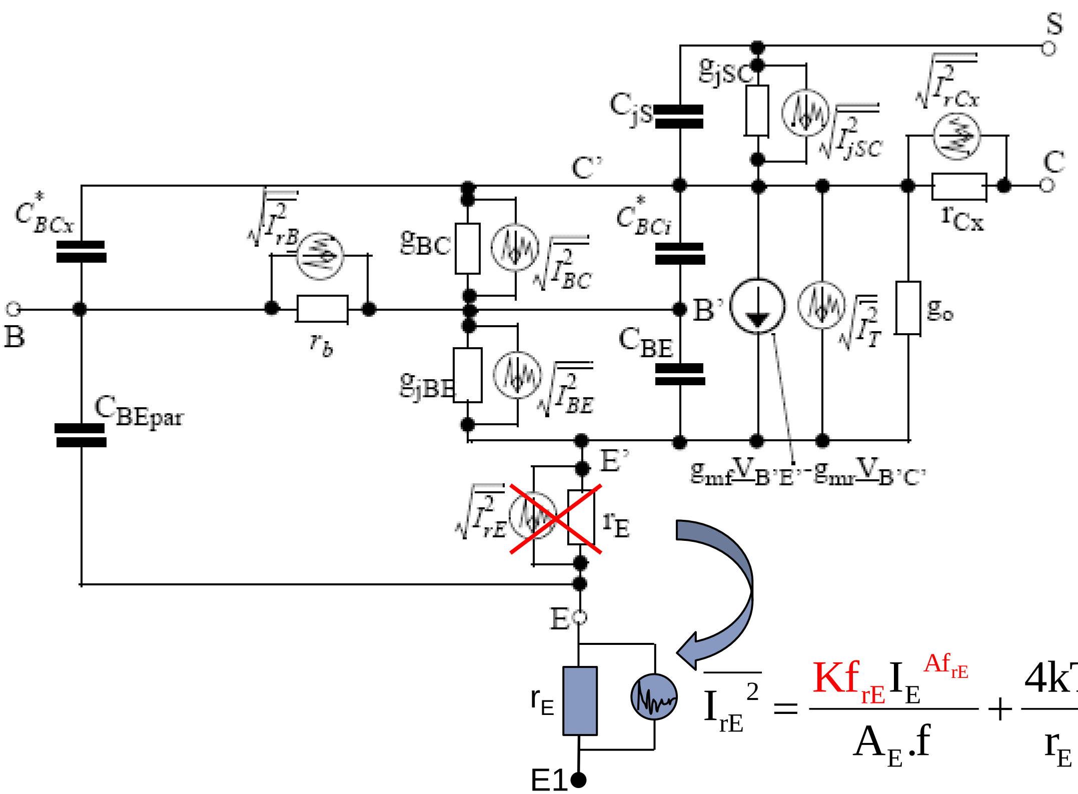




HICUM WS 2010 summary (3/4)

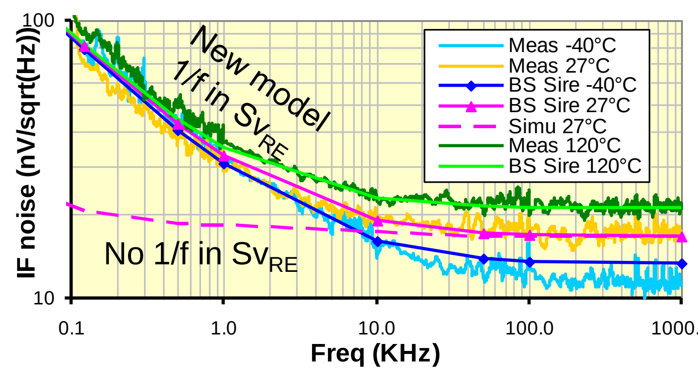
- Many papers showing also the limitations of actual compact models for 1/f noise, especially for series resistance
- [Ziel86&87], [Haaren98], [Tartarin99]], [Borgarino99], [Kirtania96], [Kleinpenning92&94&95], [Benoit05], [Nunez-Perez07]

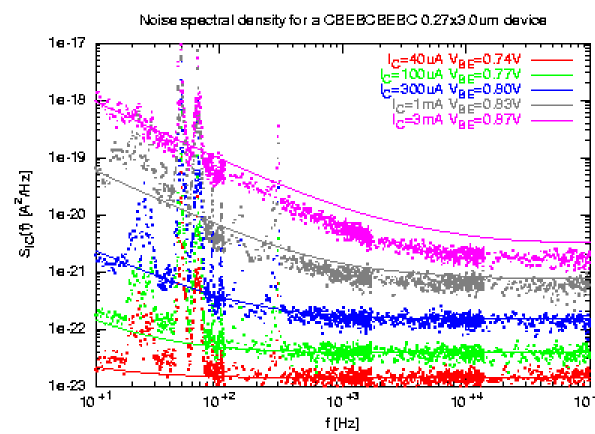
- Integrating an additional 1/f source on R_E works very fine



$$\overline{I_{rE}}^2 = \frac{Kf_{rE} I_E^{Af_{rE}}}{A_E . f} + \frac{4kT}{r_E}$$

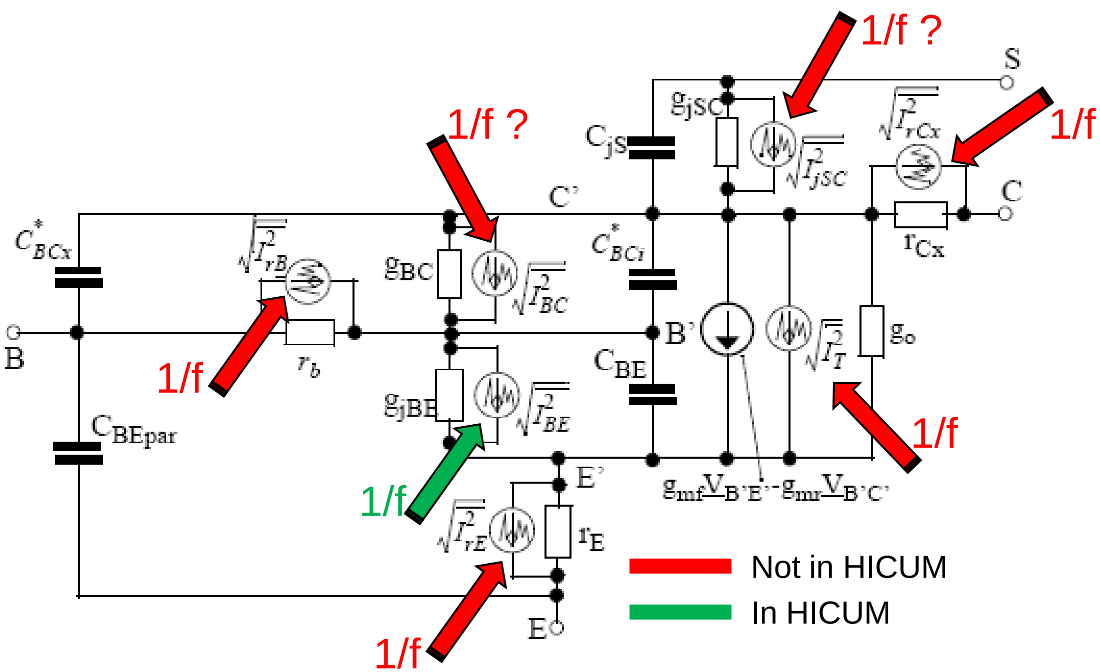
Output noise level LotHSC W10 D27 / LO&RF OFF





HICUM WS 2010 summary (4/4)

- Yes, but only a workaround
- Capacitances partitioning changed, RF model no more valid
- TUD to improve HICUM 1/f noise model, with new parameters ?



$$\overline{I^2_{r_B}} = \frac{4kT}{r_B} + \frac{k_{F_{rB}} I_B^{a_{F_{rB}}}}{f}$$

$$\overline{I^2_{r_E}} = \frac{4kT}{r_E} + \frac{k_{F_{rE}} I_E^{a_{F_{rE}}}}{f}$$

$$\overline{I^2_{r_{Cx}}} = \frac{4kT}{r_{Cx}} + \frac{k_{F_{rC}} I_C^{a_{F_{rC}}}}{f}$$

$$\overline{I^2_T} = 2qI_T + \frac{k_{F_{CE}} I_T^{a_{F_{CE}}}}{f}$$

$$\overline{I^2_{BC}} = 2q\left(I_{jBC} + I_{AVL}\right) + \frac{k_{F_{BC}} \left(I_{jBC} + I_{AVL}\right)^{a_{F_{BC}}}}{f}$$

$$\overline{I^2_{CS}} = 2qI_{jCS} + \frac{k_{F_{CS}} I_{jCS}^{a_{F_{CS}}}}{f}$$

$$\overline{I^2_{BE}} = 2qI_{jBE} + \frac{k_{F_{BE}} I_{jBE}^{a_{F_{BE}}}}{f} \quad (\text{in HL2, } I_{jBE} = I_{jBEi} + I_{jBEp})$$

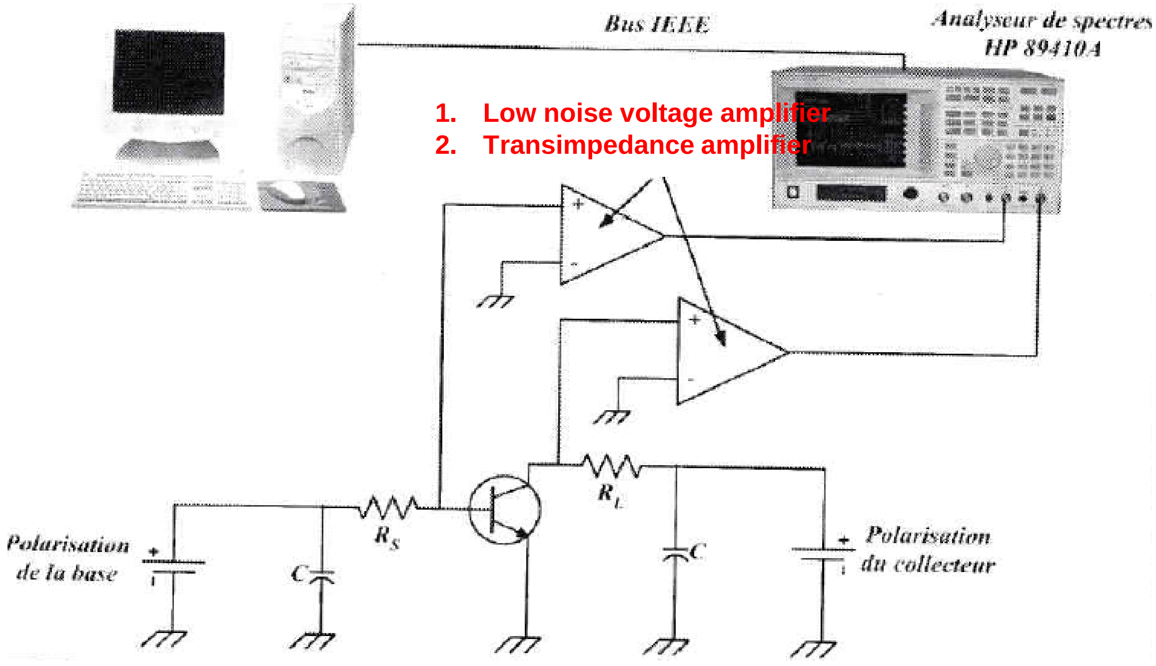
HICUM WS remarks or questions

- Some people skeptic in front of our results and conclusions
- However, many papers exist showing the same kind of conclusions

- Some questions or remarks about :
  - “What exact setup for measurements and simulations ?”
  - “Are you sure simulations have the same schematic as measurements ?”
  - “Influence of the source resistance ?”

Characterization setup – theory (1/3)

- 2 possible configurations for low frequency noise measurements (common emitter case) :
  1. Use low noise voltage amplifiers : ok for large currents (IB > 500nA)
  2. Use transimpedance amplifier : allows small currents too
- ST uses configuration 2. to measure all currents values



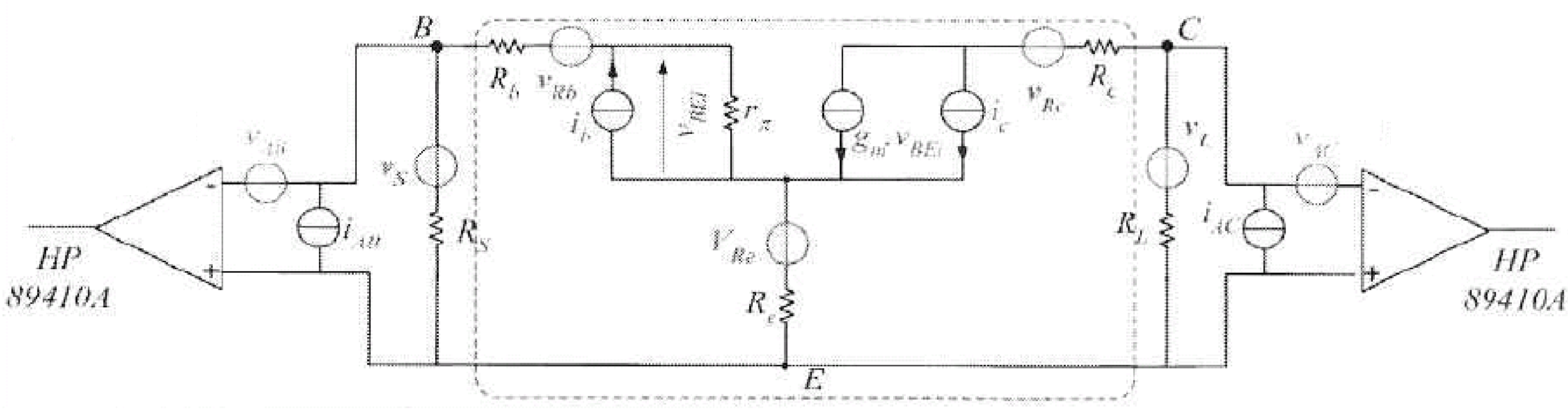
Low noise measurements setup

Characterization setup – theory (2/3)

- The values of the voltage spectral density on the Base and on the Collector are the following [Benoit05] :

$$Sv_B = \frac{R_S^{\,2}}{(R_S + R_d)^2}\left[\begin{array}{l} 4kT\dfrac{R_d^{\,2}}{R_S} + Sv_{RE} + Sv_{RB} + (r_\pi + R_E h_{fe})^2 Si_B + R_E^{\,2} Si_C \\ +2R_E(r_\pi + R_E h_{fe})PR(Si_B i_C) \end{array}\right]$$

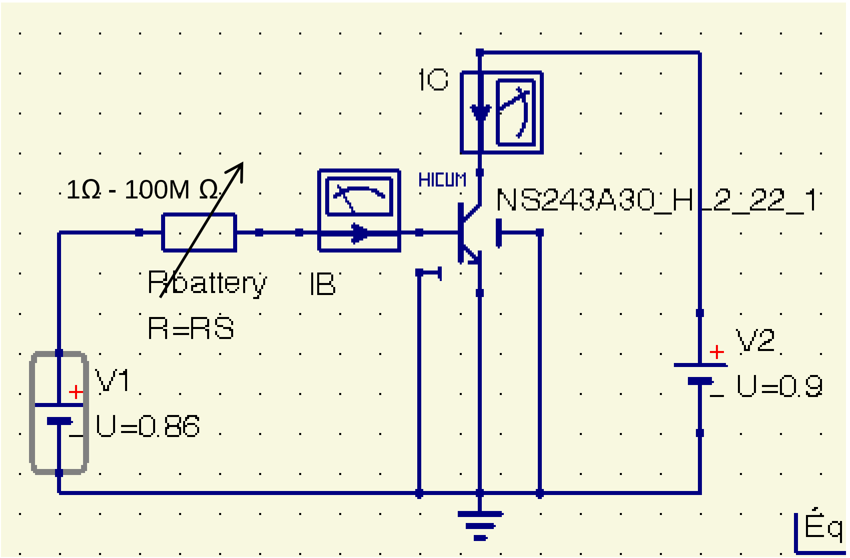
$$Sv_C = 4kTR_L + \frac{h_{fe}^{\,2} R_L^{\,2}}{(R_S + R_d)^2}\left[\begin{array}{l} 4kTR_S + Sv_{RE} + Sv_{RB} + (R_S + R_B + R_E)^2 Si_B + \dfrac{(R_S + R_B + R_E + r_\pi)^2}{h_{fe}^{\,2}} Si_C \\ + \dfrac{2(R_S + R_B + R_E)(R_S + R_B + R_E + r_\pi)}{h_{fe}} PR(Si_B i_C) \end{array}\right]$$

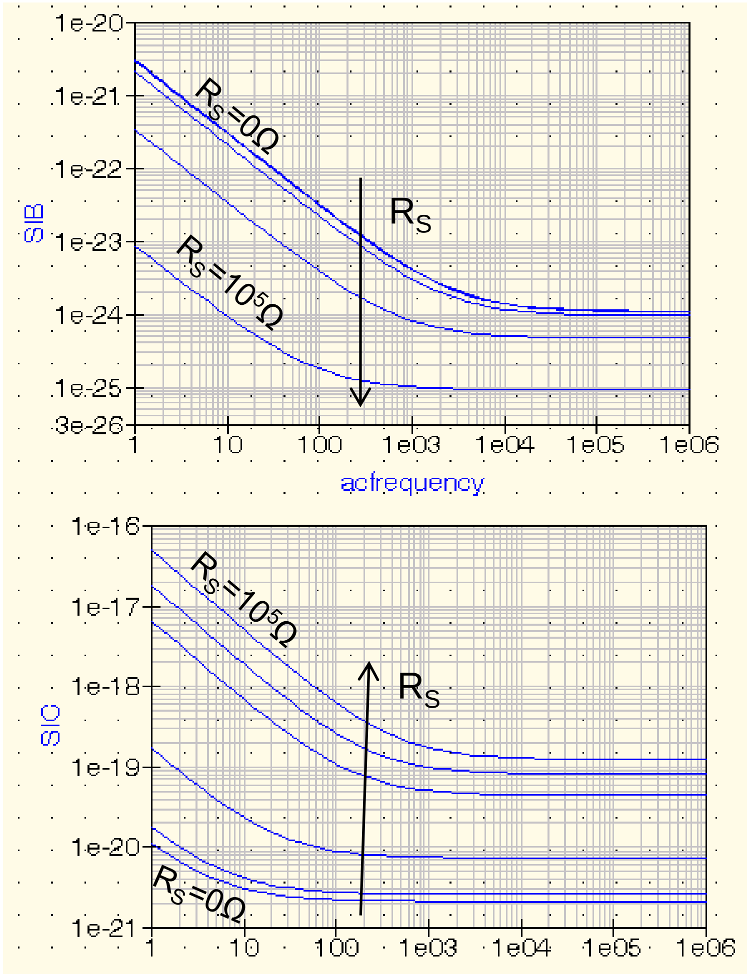


Small signal scheme of the measurements chain

Characterization setup – theory (3/3)

- The source resistance $\mathbf{R_S}$ is very important and plays on the spectral density on the Base and on the Collector
- 2 cases are often considered :
  - High impedance setup ($R_S >> R_d$)
  - Null impedance setup (R_S=0Ω)

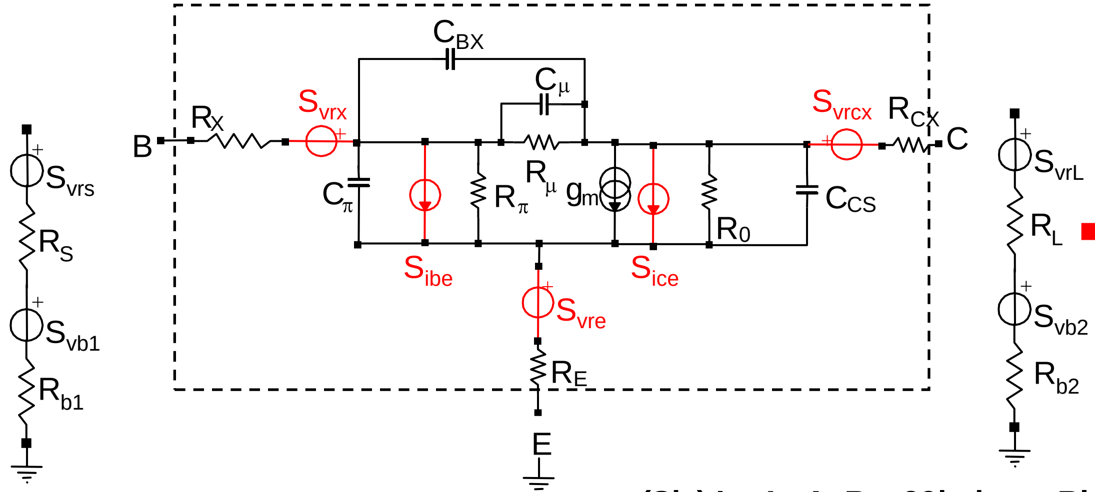




Characterization setup – practice (1/4)

- 1^{st} case : high impedance setup, R_s=39kΩ
- Simulations vs measurements S_{VC}/S_{IC} OK on the Collector

S_{VB} and S_{iB} ⬅



➡ **S_{VC} and S_{iC}**

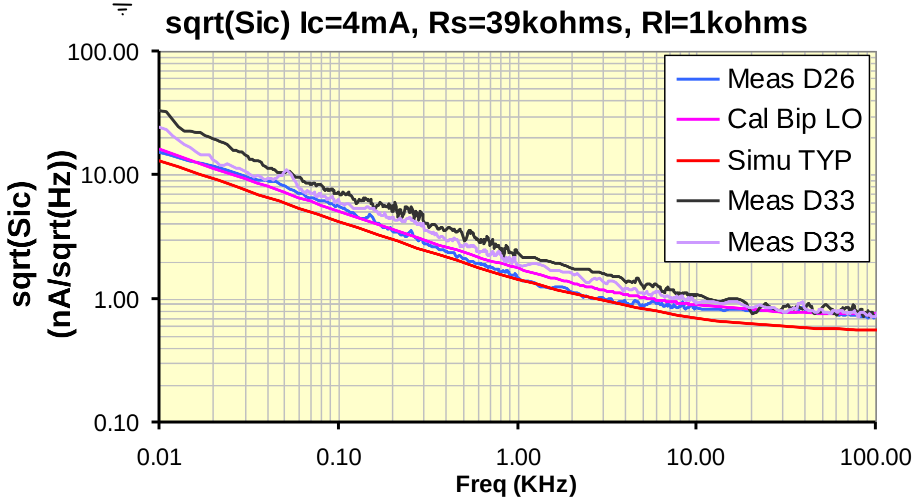
- <u>Conditions :</u>

R_s=39kΩ ; R_L=1kΩ

R_{b1}=149Ω ; R_{b2}=407Ω

- <u>Measurements :</u>

$S_{ic} \approx \beta_{noise}^{2} * S_{ibe}$ [Benoit05]



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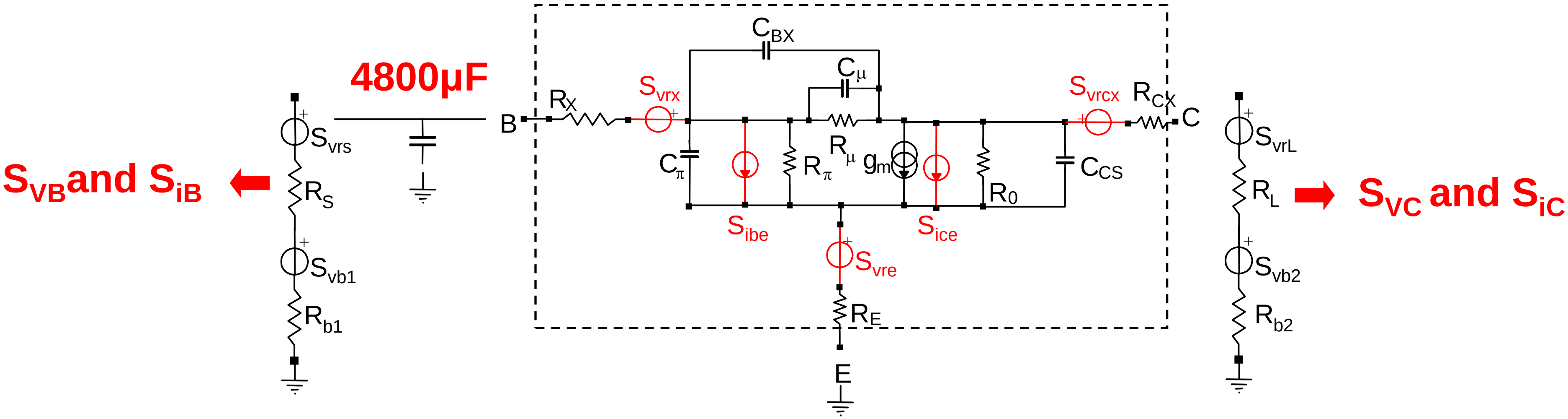
Characterization setup – practice (2/4)

- 2nd case : null impedance $R_s = 0\Omega$



• <u>Conditions :</u>

Rs=0Ω ; $R_L = 1k\Omega$

R_{b1}=149Ω ; $R_{b2} = 407\Omega$

Impedance=0 on the base means coupling capa needed to avoid the battery R_{b1}

C=4800µF → fc=0.22Hz

• <u>Measurements :</u> $$S_{vc} \approx R_L \left(S_{ibe}\beta_{noise} + \frac{1}{(1+g_m R_E)^2}(S_{ice} + g_m^2 (S_{vre} + S_{vrb})) \right)$$ [Benoit05]

β_{noise} small

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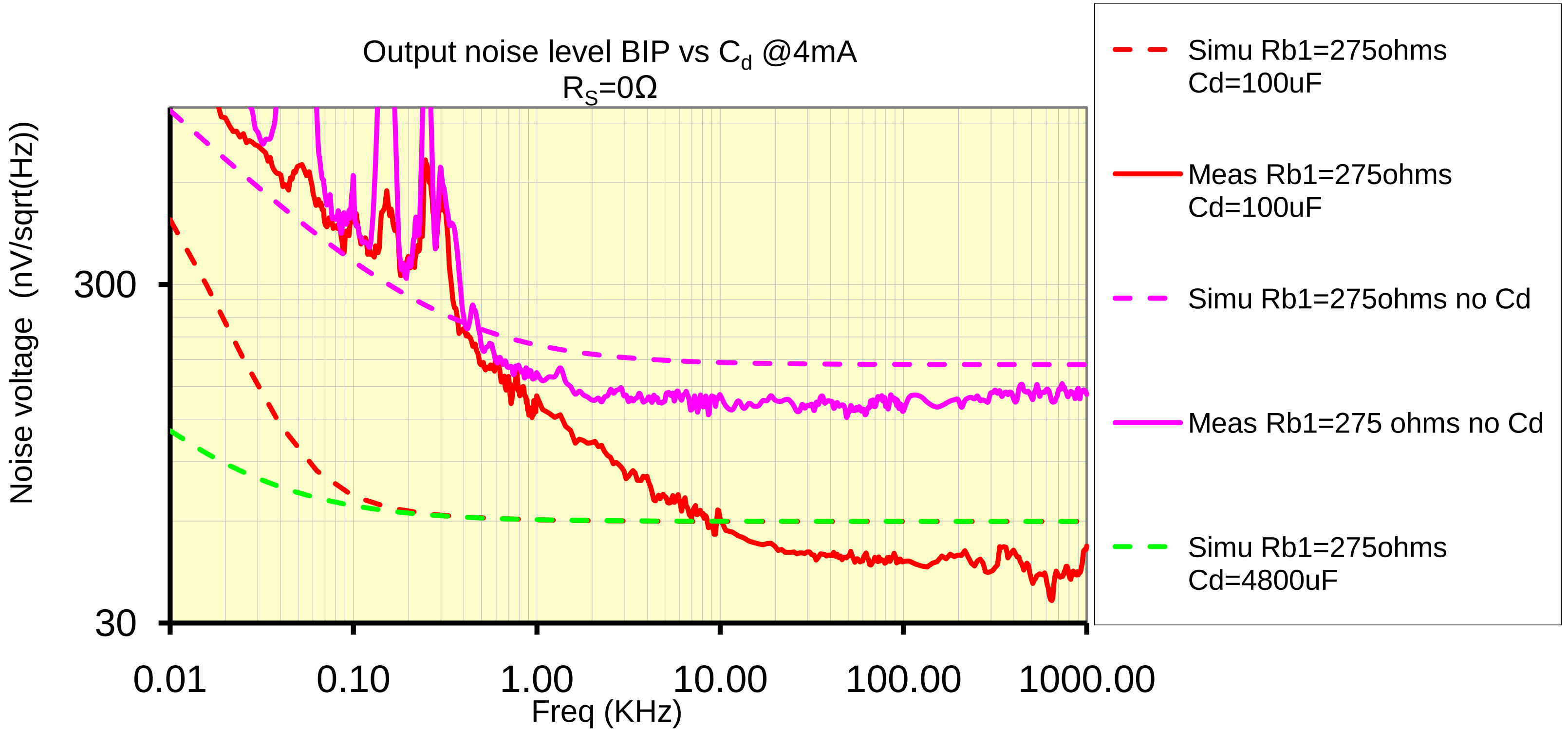
Characterization setup – practice (3/4)

- Results for R_s=0Ω
  - There is still the resistance coming from the battery on the Base R_{b1}
  - A decoupling capacitance C_d is needed to filter R_{b1}
  - C_d has no influence on measurements < 1kHz !!!
  - Confirms the existence of preponderant 1/f noise source other than SI_{EB}



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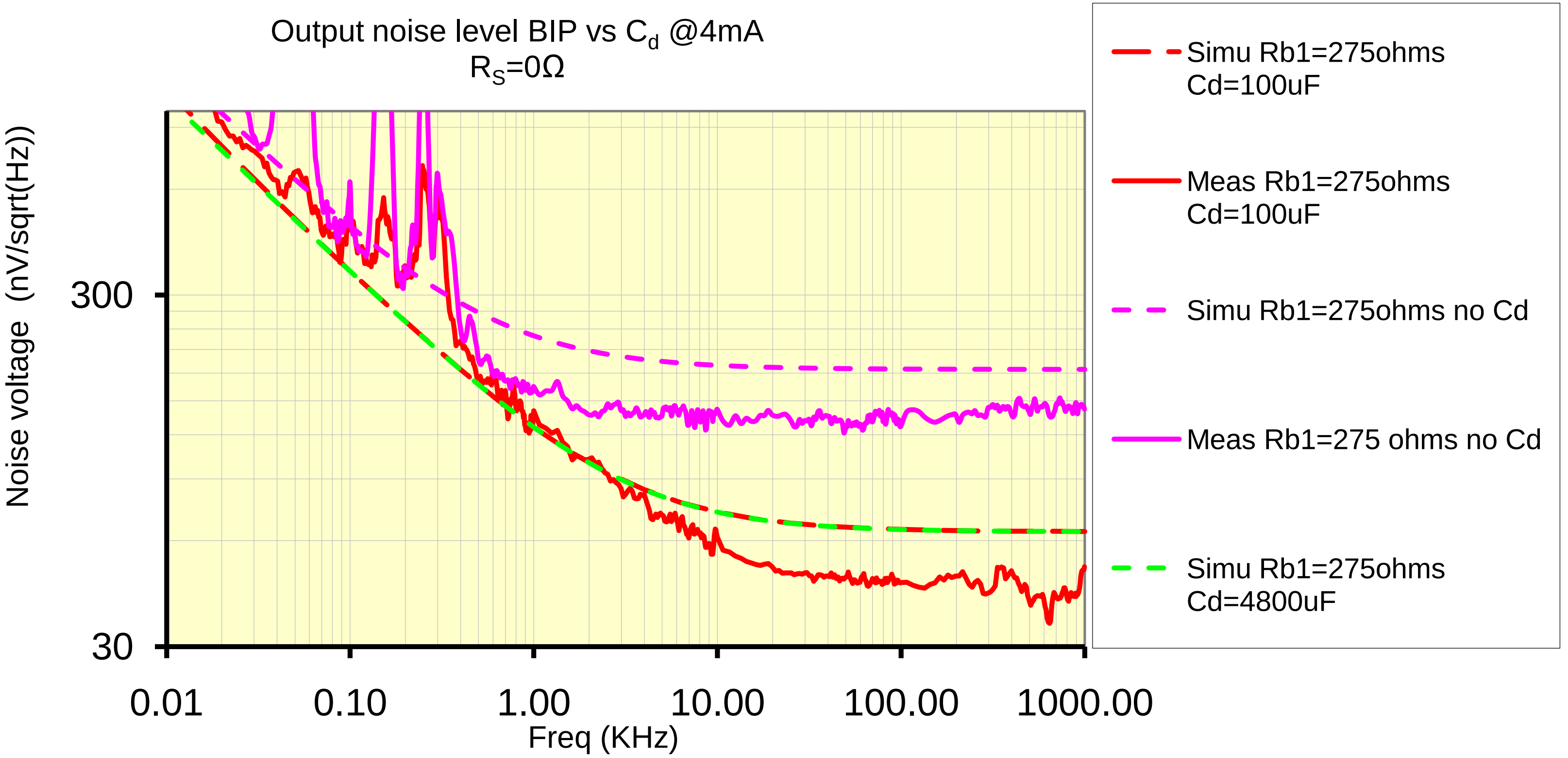
Characterization setup – practice (4/4)

- Results for R_s=0Ω
  - The same simulations with our additional 1/f noise source in subcircuit R_E works fine !



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Conclusions

- Summarized the HICUM WS 2010 presentation about ST 1/f noise issue in compact models
- Shown that our LF noise simulations and measurements on HBT are consistent

- R_S influence and variation taken in account in both measurements and simulations
- Investigated both cases $R_S=0\Omega$ and large R_S ($\gg R_d$)
  - $R_S \gg R_d$ works fine, since LF noise measured on the collector comes mainly for SI_{EB}, which is correctly modeled
  - Our issue comes from the $R_S=0\Omega$ configuration, where we clearly see that another 1/f source than Si_{EB} is visible on the device output

- ST definitive conclusions are the same as in HICUM WS :
  - Other 1/f noise source than SI_{EB} (BE junction) is present in ST BiCMOS 130nm mmw HBT High-Speed
  - Seems to be located in the emitter poly/mono interface (on R_E in small signal scheme)
  - Actual compact models are too much simplifed to correctly match 1/f noise simulations vs measurements on the Collector for this advanced HBT
  - Critical issue for some advanced mmw designs and applications
  - Possibility for TUD to add 1/f components in the existing HICUM noise sources ?

Special thanks to…

- Zoltan Huszka (AustriaMS) for his email exchanges on that topic.
- L. Moquillon & P. Garcia (ST) for their design expertise.
- S. Haendler (ST) for his characterizations.

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