Modeling of the SiGe power HBT IM Distortion

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Outline:

- Introduction
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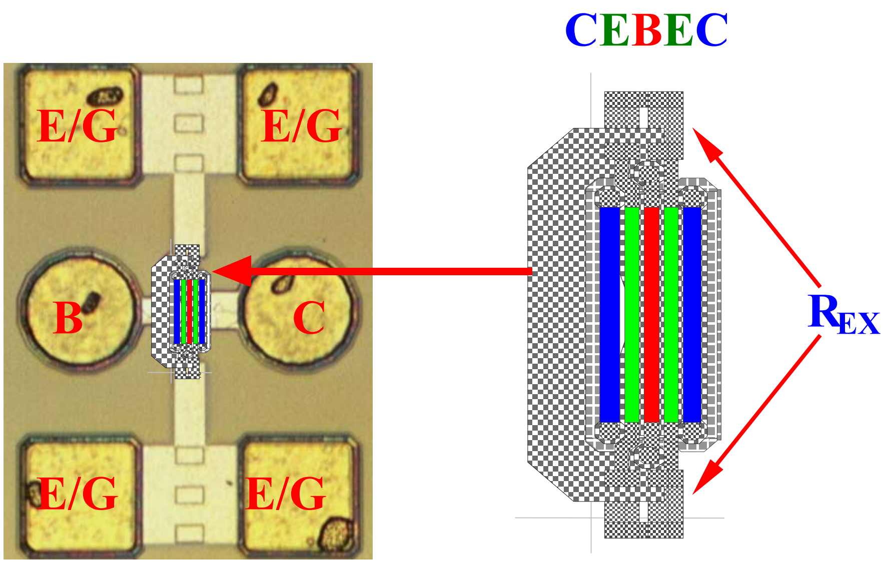
- device characteristics and model comparison
- IM Distortion and Power Spectrum measurement set-up
- Power and IMD Spectrum model comparison
- Summary

Introduction

- A result of the distortion of HBT or nonlinear circuit is that it generate frequency components in the output signal that are not present in the input.
- Bandpass filtering can eliminate much of the effects of harmonic distortion, while intermodulation distortion is difficult to filter out because the IMD components may be very close to the carrier frequency. Thus investigation of the common figure of merit, two-tone intermodulation distortion is of high importance for power amplifiers.
- Nowadays Si based power amplifiers enable system on a chip technology and low-cost lightweight communication systems. This attracts space enterprises, such as NASA, which rely on SiGe power Heterojunction Bipolar Transistors and passive circuit elements on silicon substrates.
- Thus intermodulation analysis of circuit basic elements, HBTs, with the help of advanced compact models, such as HICUM is of high scientific and commercial importance.

SiGe Power HBT basic cell

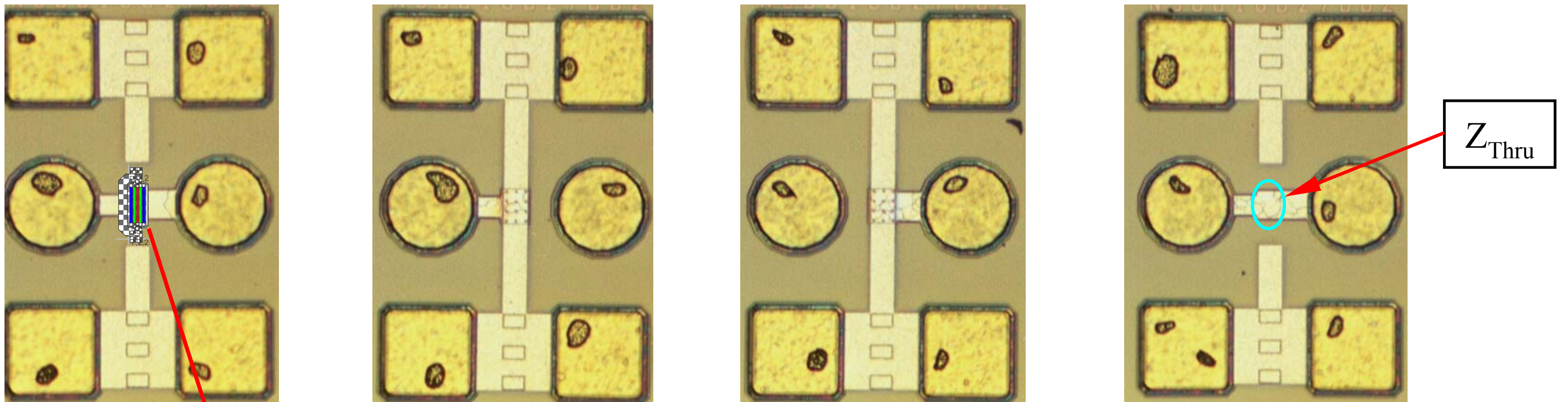


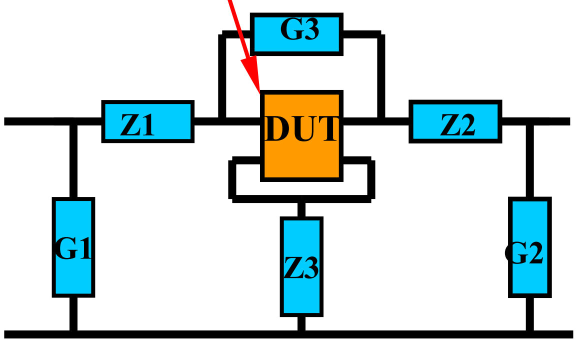
High voltage (power) device fabricated with Atmel's SIGE1 process:

- f_T=20 GHz and f_{max}=45 GHz
- emitter stripe window area is A_{E0}= 2x49.7x1.3μm^2
- emitter balast resistances R_{EX} (for thermal stability) included in layout

De-embedding of Pad parasitic Network

„open“ „short 1“ „short 2“ „thru“





Three step de-embedding

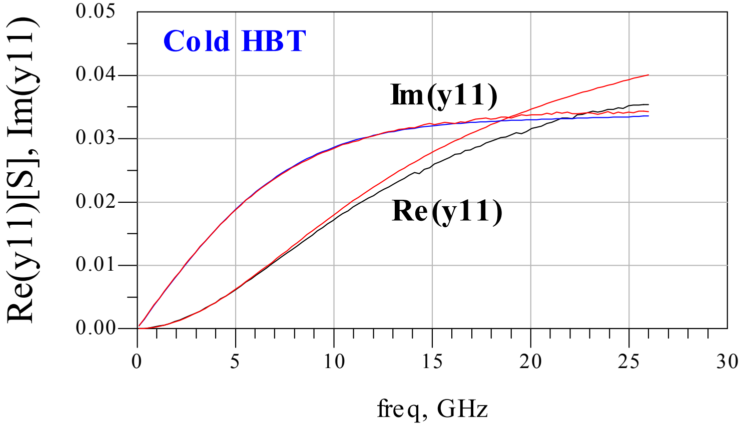
Assumptions: $[(1/G_3)+Z_1] >> Z_3$ => (f< 50 GHz)

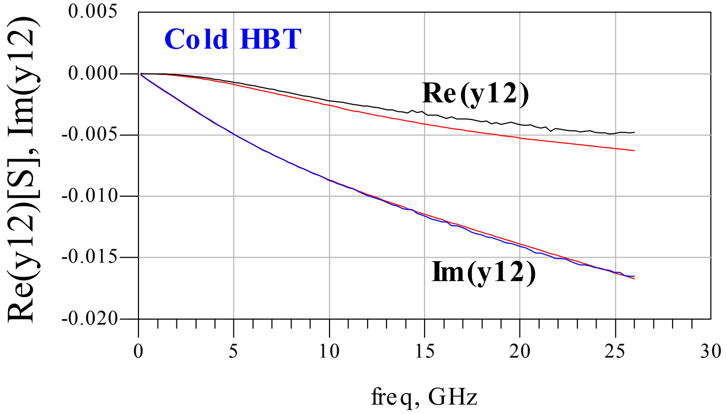
$Z_{Thru} << Z_1$ or Z_2

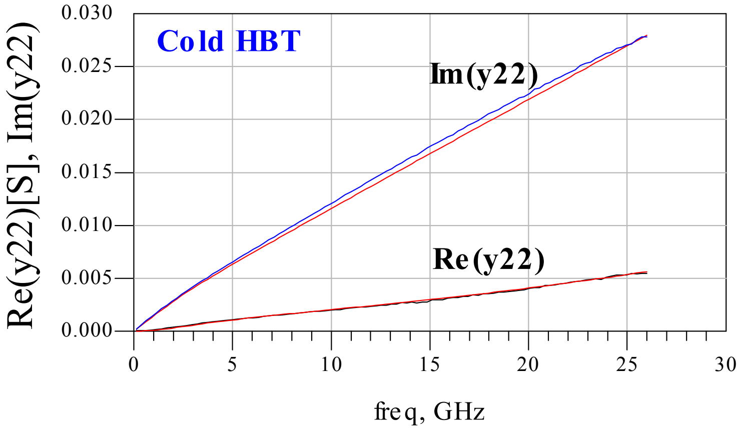
G1 is gate pad-source admittance,
G2 is drain pad-source admittance,
G3 is gate pad-drain pad admittance,
Z1, Z2 are metal interconnection series impedances between port 1 and port 2,
Z3 is series impedance of ground lead to DUT

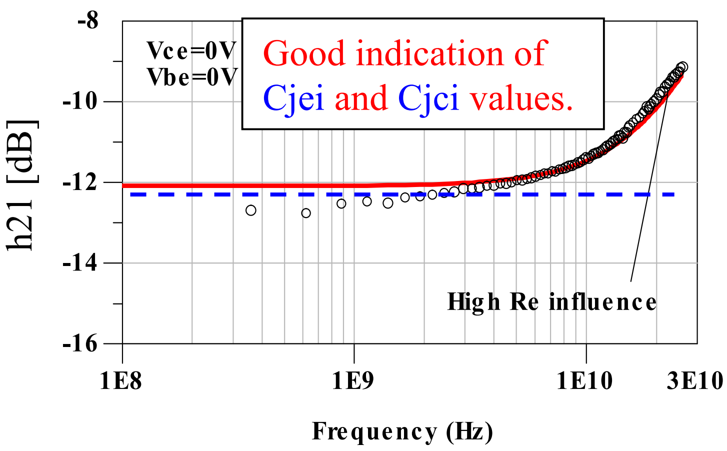
De-embedded „cold" HBT y-parameters

HICUM – red lines



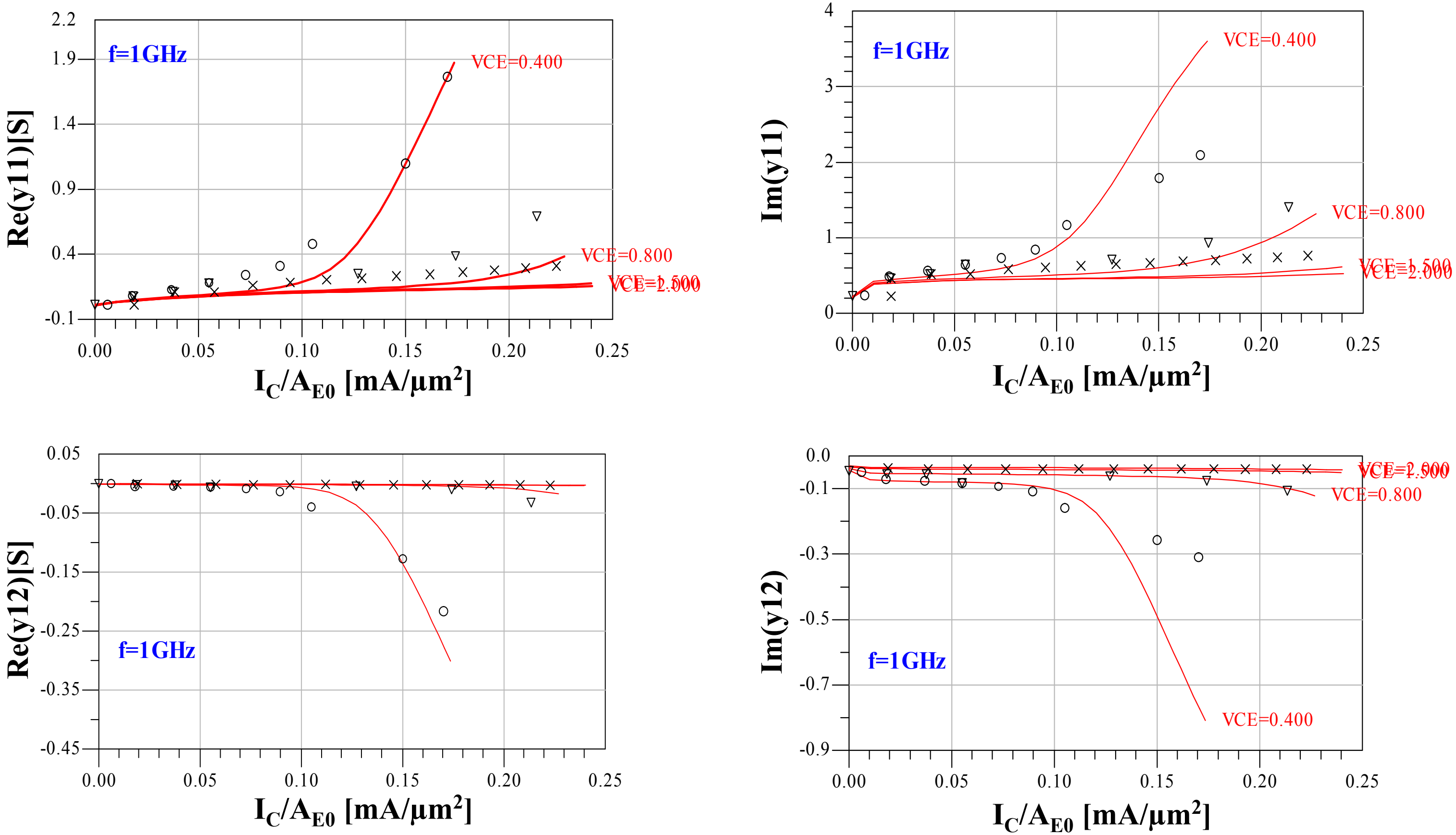






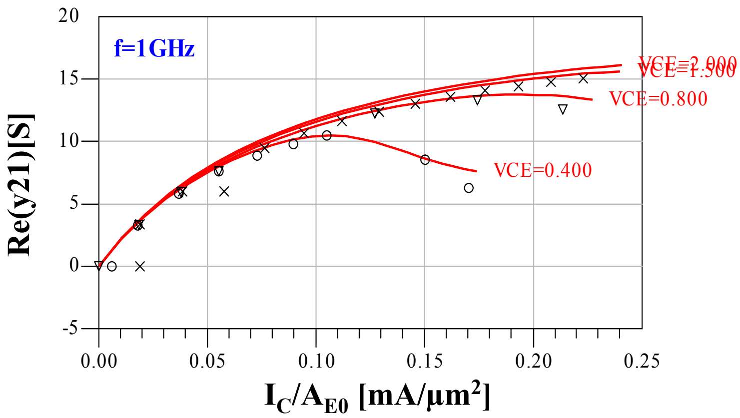
Bias dependent y11, y12

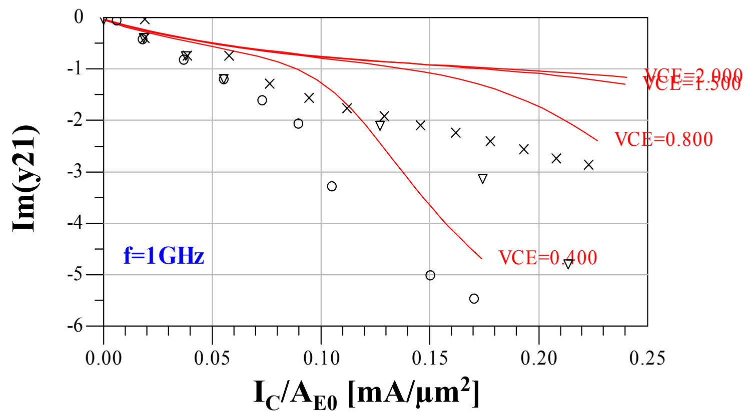
HICUM – red lines

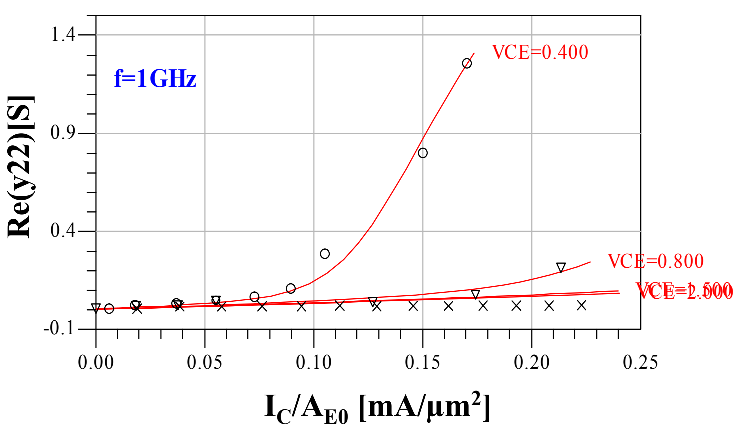


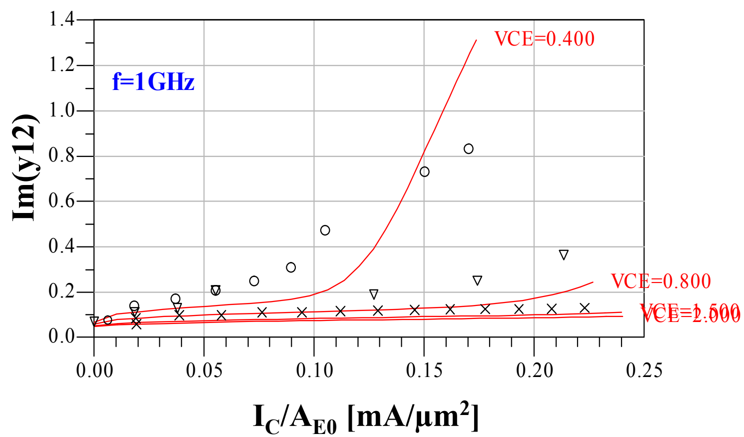
Bias dependent y21, y22

HICUM – red lines





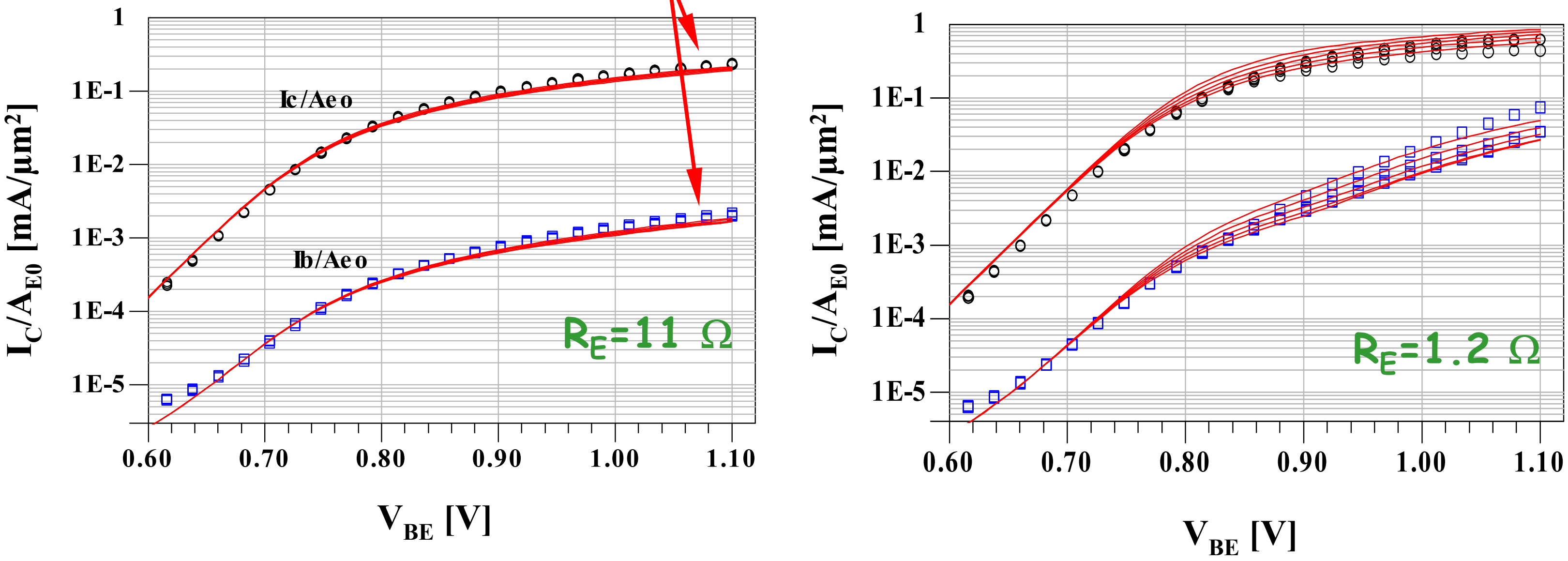




Gummel forward characteristic

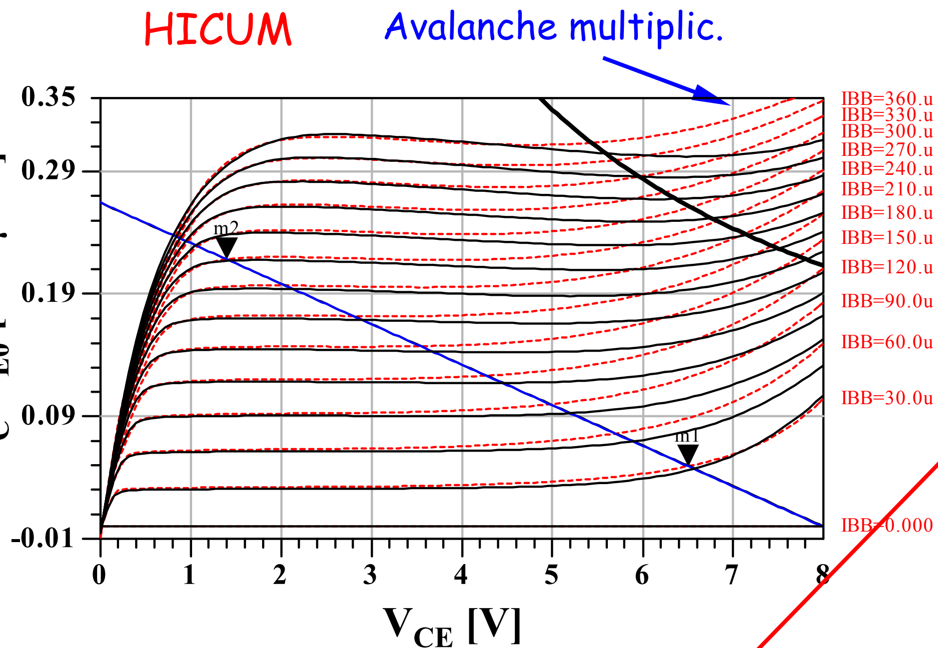
HICUM is red lines.

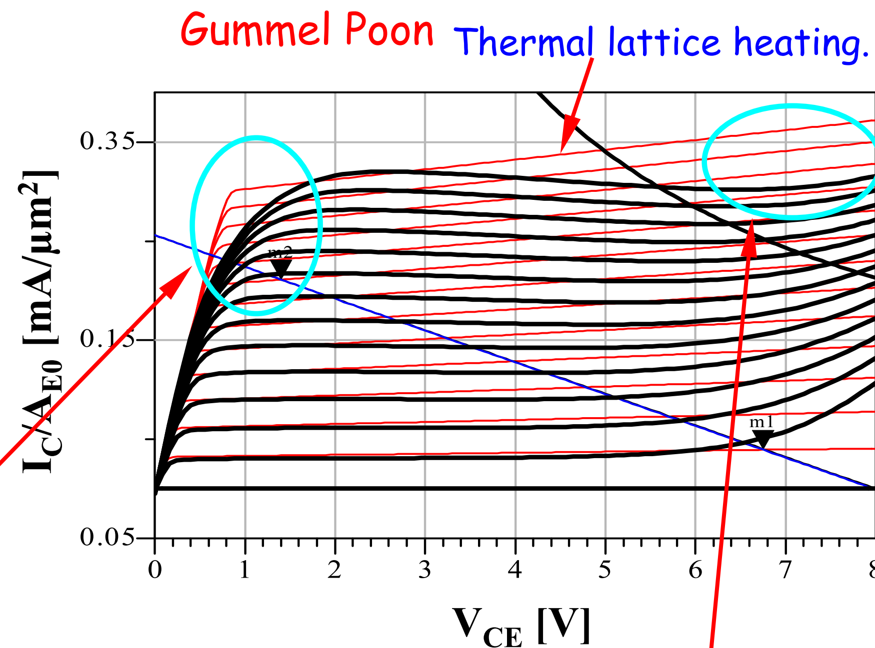
High R_E reduce I_C.



Gummel plots for higher and lower R_E values.

Output characteristic, measured versus simulated

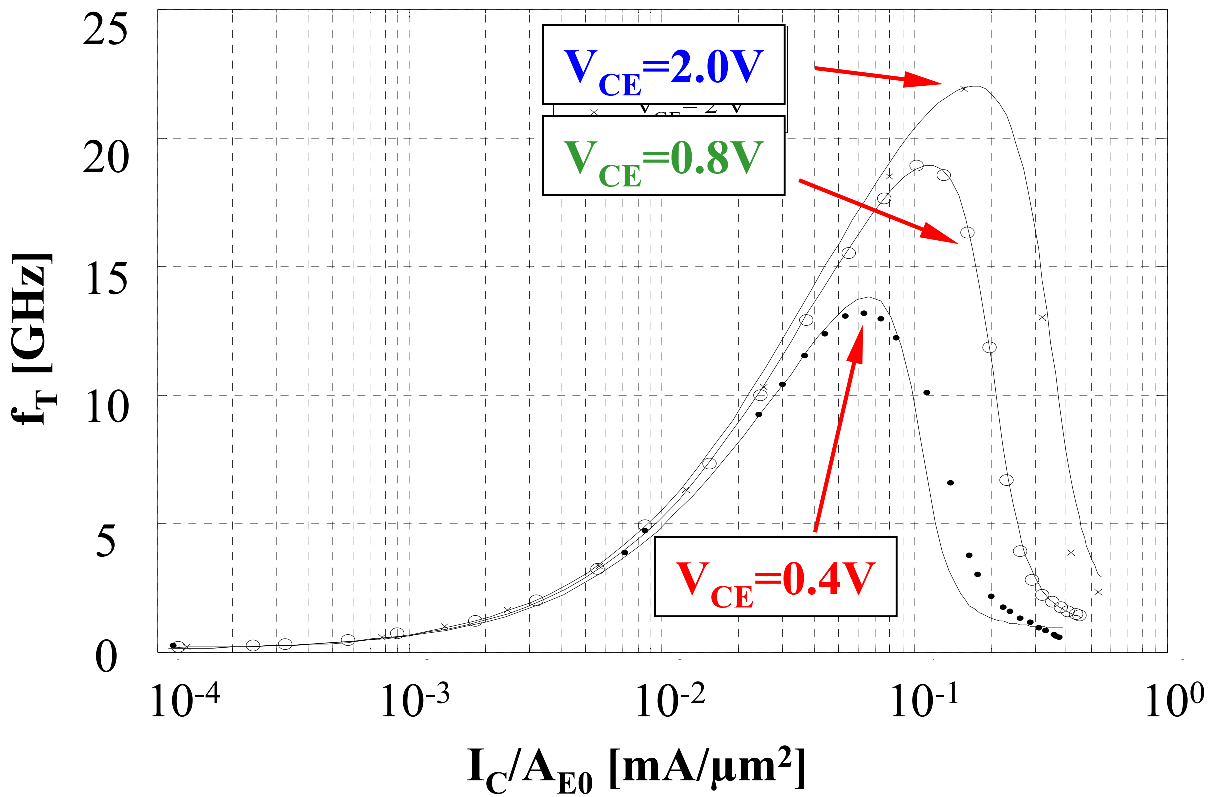




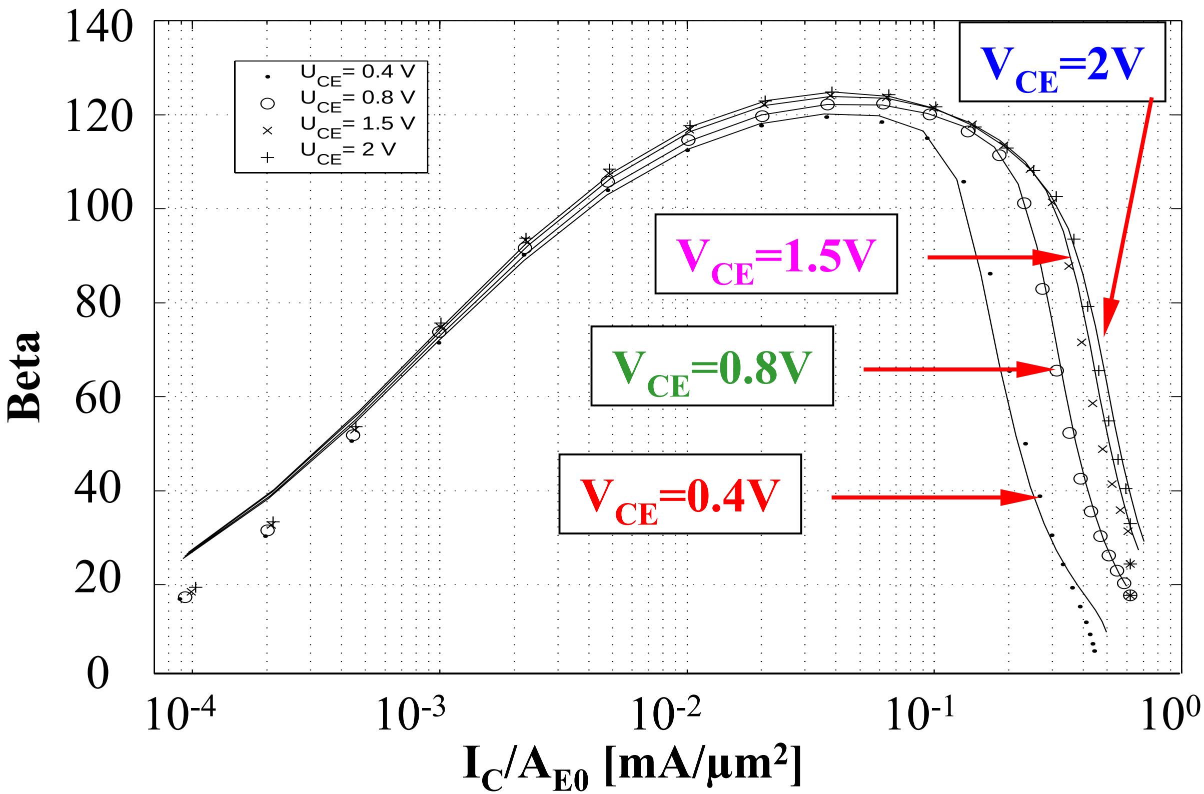
HICUM yields good agreement with measured data, except at V_{CE}>5 V @ I_B>90 µA, where discrepance is due to simplified expression of avalanche multiplication current (for saving CPU time!).

Gummel Poon model overestimates I_C due to missing internal R_{CI} bias dependence. At V_{CE} > 3 V self-heating causes decrease of I_C; both effects are not accounted for by the model.

Cut-off frequency



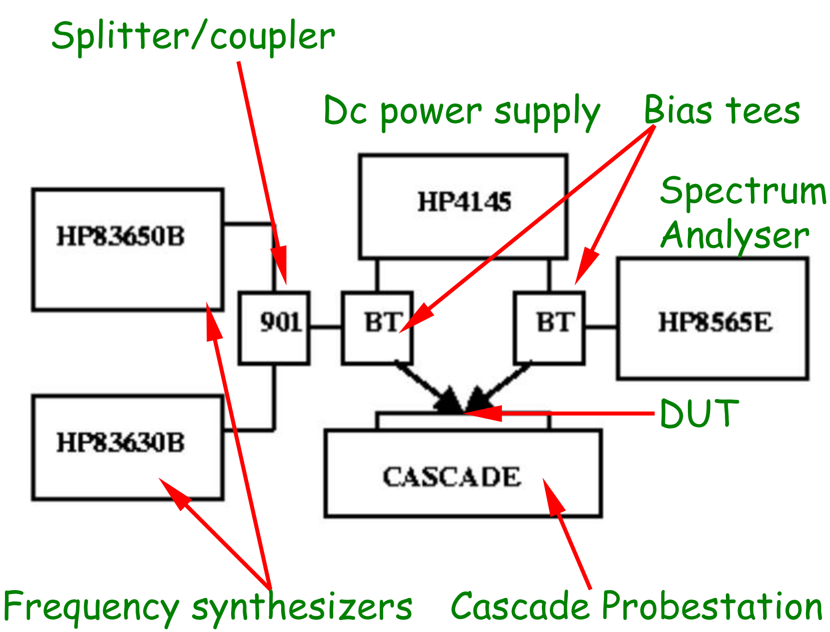
Beta



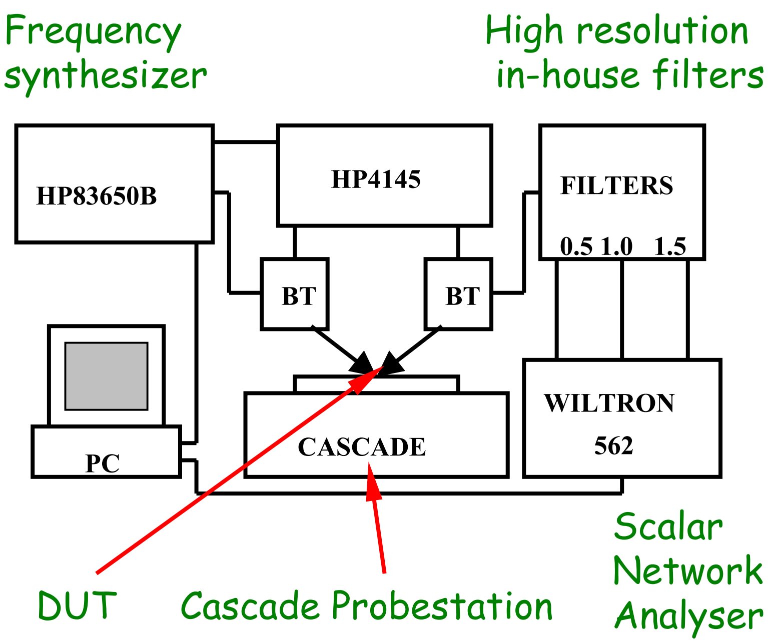
140
120
100
80
60
40
20
0
Beta
U_{CE}= 0.4 V
U_{CE}= 0.8 V
U_{CE}= 1.5 V
U_{CE}= 2 V
V_{CE}=2V
V_{CE}=1.5V
V_{CE}=0.8V
V_{CE}=0.4V
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
I_C/A_{E0} [mA/µm²]

Two-tone IM Distortion and Power Spectrum measurement set-up

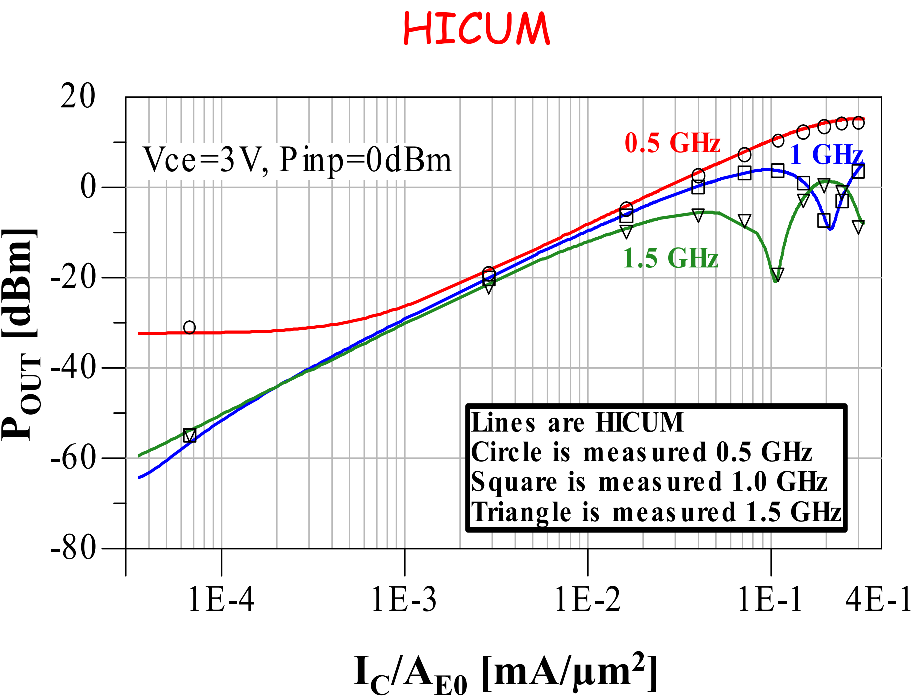
Two-tone measurement setup

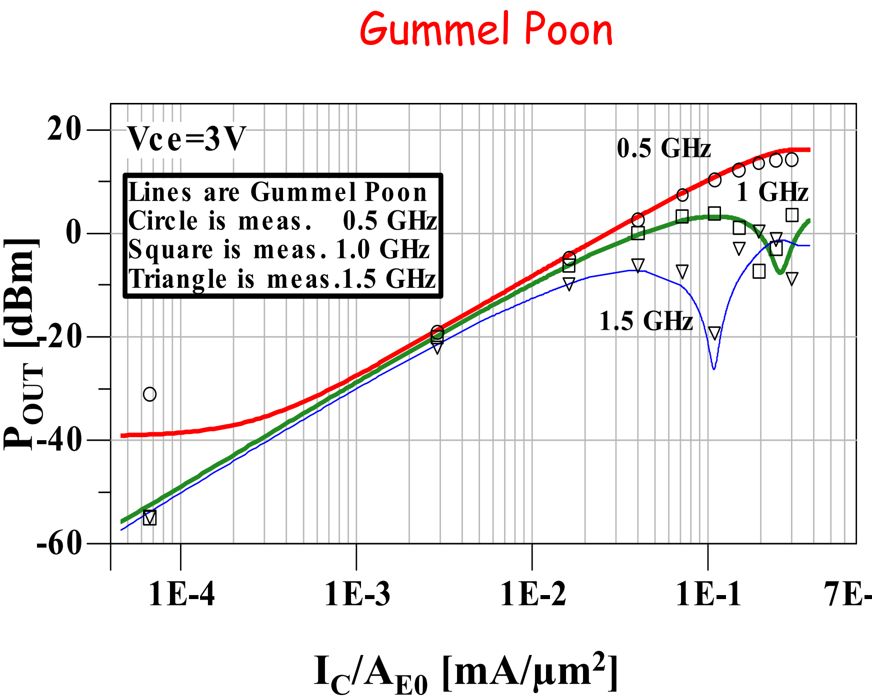


Power spectrum measurement setup



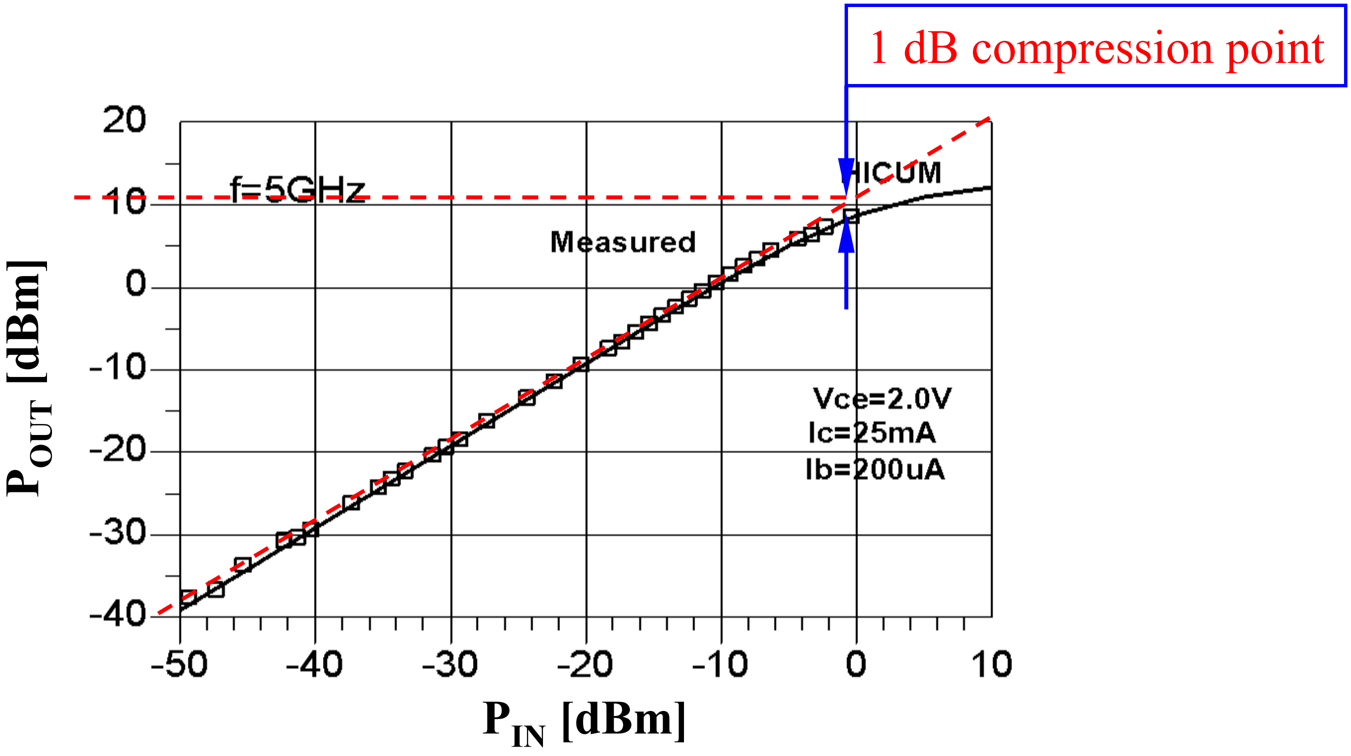
Power Spectrum





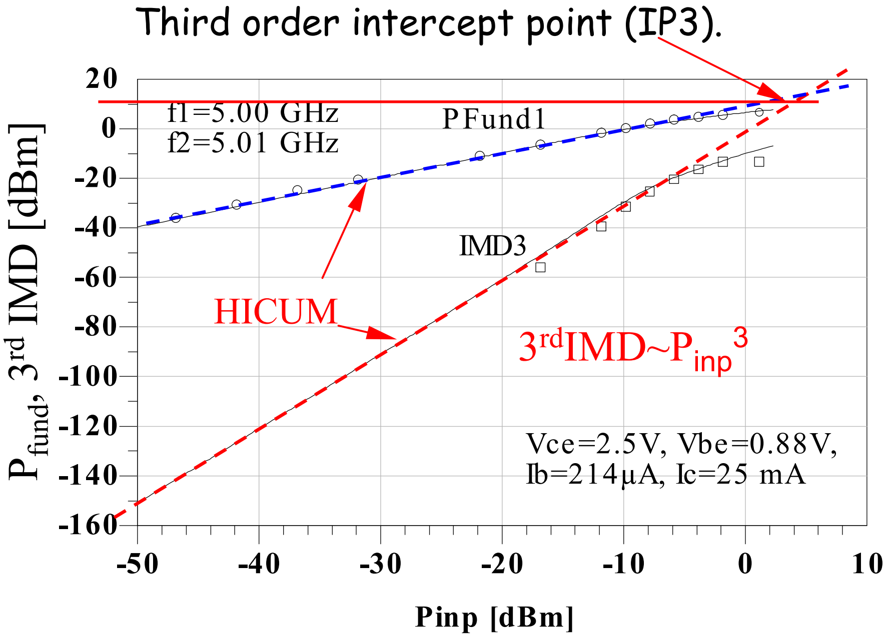
HICUM gives better agreement compared to Gummel Poon model at low and high I_C/A_{E0}.
Gummel Poon harmonic Balance simulation convergence is faster (simulator dependent though) at the cost of accuracy.

Single tone 1 dB compression point

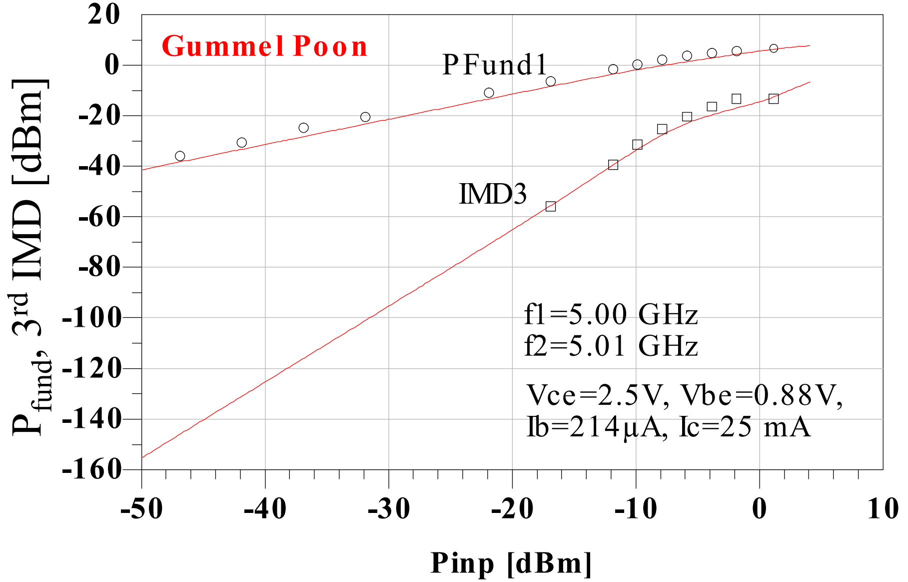


Two-tone IM Distortion

HICUM

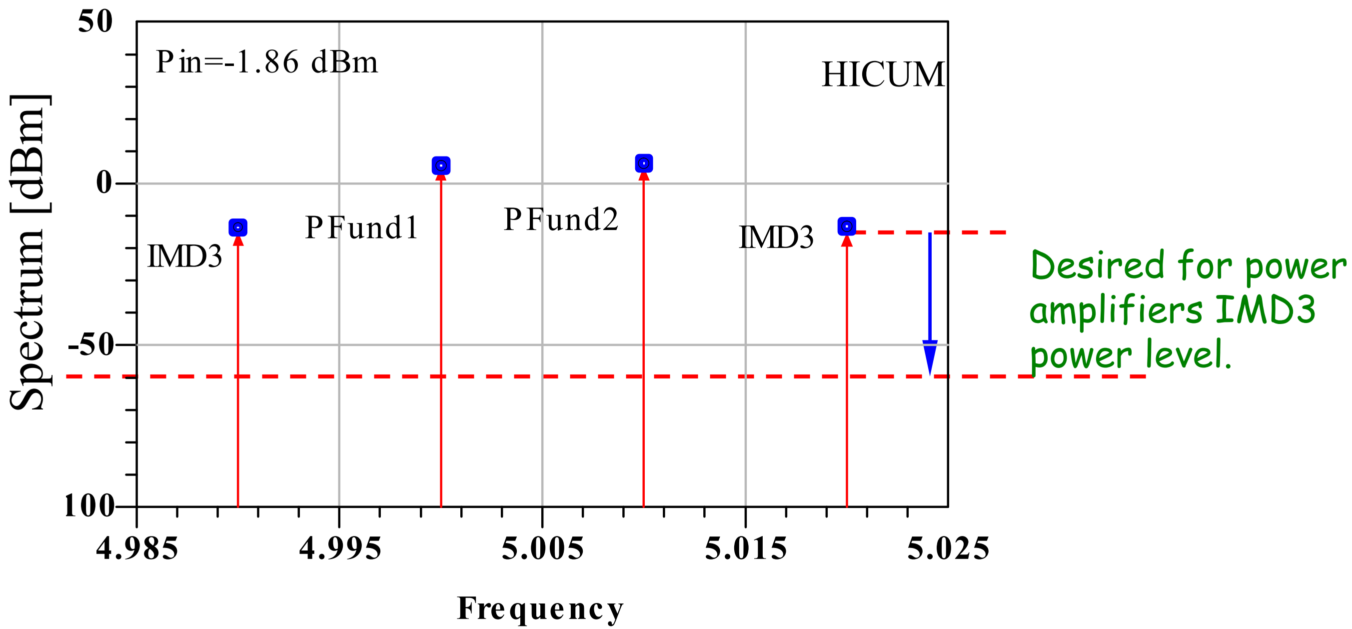


Gummel Poon



Output power at f_1, f_2 and IMD3 vs two-tone input power. V_{CE}=2.5 V, I_C/A_{E0}=0.38 mA/μm^2.
Frequency spacing Δf=10 MHz between input signals => f_2=5.01 GHz.
The input power of both signals ($P_{in,1}=P_{in,2}$) was swept from -49.35 to -1.35 dBm.
HICUM yields good agreement over a large input power range, while beyond Pinp=-10dBm Gummel Poon starts to slightly underestimate measured IMD3.
If intercept point is known, IMD level related to output signal level can be calculated from:
$IMD_{dBC}=2(P_{OUT,dBm}-IP3_{,dBm})$.

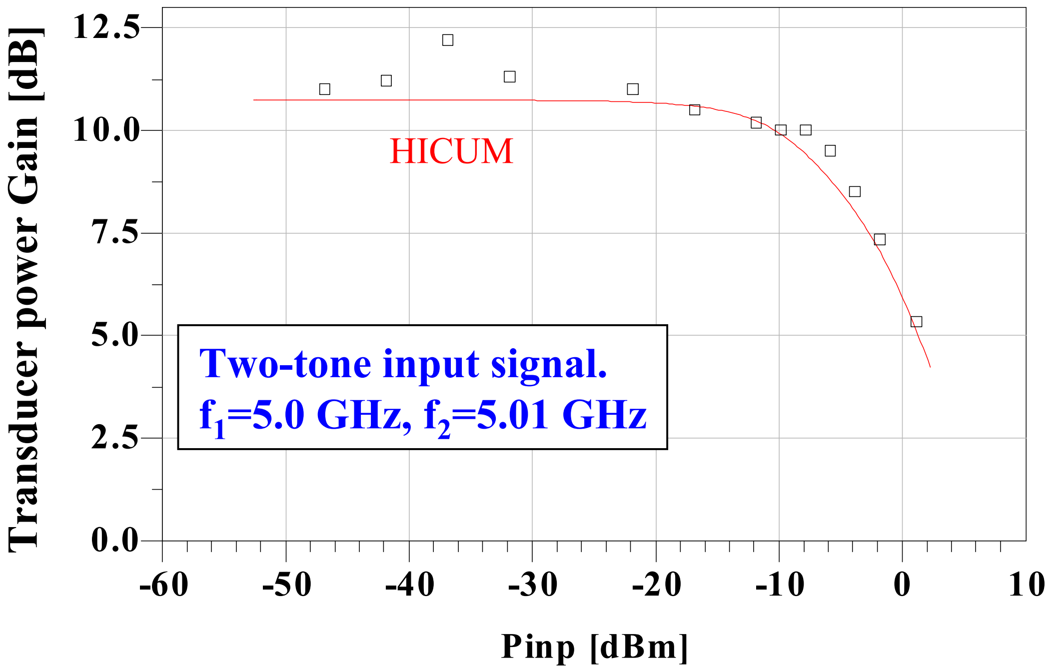
Two-tone Fine Spectrum



Two-tone measured and simulated output fine spectrum at V_{CE}=2.5 V, I_C/A_{E0}=0.192 mA/µm^2

Since IMD3 increases with increasing signal levels it can be used for to establish dynamic range of the amplifier: DR={2*IP3-2[10log(k*T_{EQV}*B)+NF+G]}/3.

Transducer Power Gain



Transducer Power Gain versus two-tone input power. V_{CE}=2.5 V, I_C=25 mA, I_B=214 μA.

G_T is flat at 10.5 dB until about P_{in}=-15 dBm, and then decreases rapidly down to 5 dB at 1dBm. Analytical calculations using de-embedded measured y-parameters yield G_T=10.6 dB, which agrees fairly well with both HICUM and measurements.

Summary

•IV, S-parameters, single tone power spectrum 1-dB compression, intermodulation distortion, resulting from two-tone input signals with fundamental frequencies up to 5 GHz were measured on a "real" Si/SiGe HBT, fabricated in a production process.

•Geometry scalable HICUM parameters were extracted.

•Good agreement between model and measurements was obtained, demonstrating the suitability of HICUM for critical high-frequency applications.

Acknowledgments

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