Swedish Microwave Days 2023

D-band LNA in Vertical III-V Nanowire Technology

May 23-25, 2023

Tobias Tired, NordAmps AB, Lund

Lund Nanowire Design
NordAmps

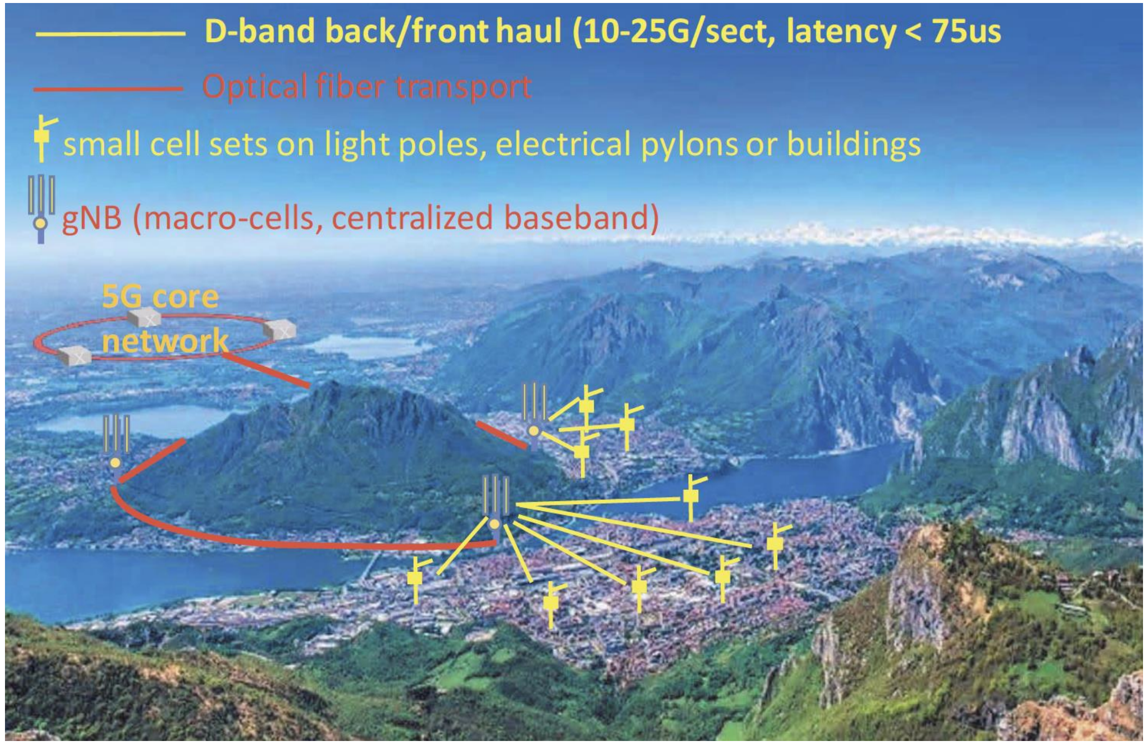
ERICSSON

LUNDS UNIVERSITET

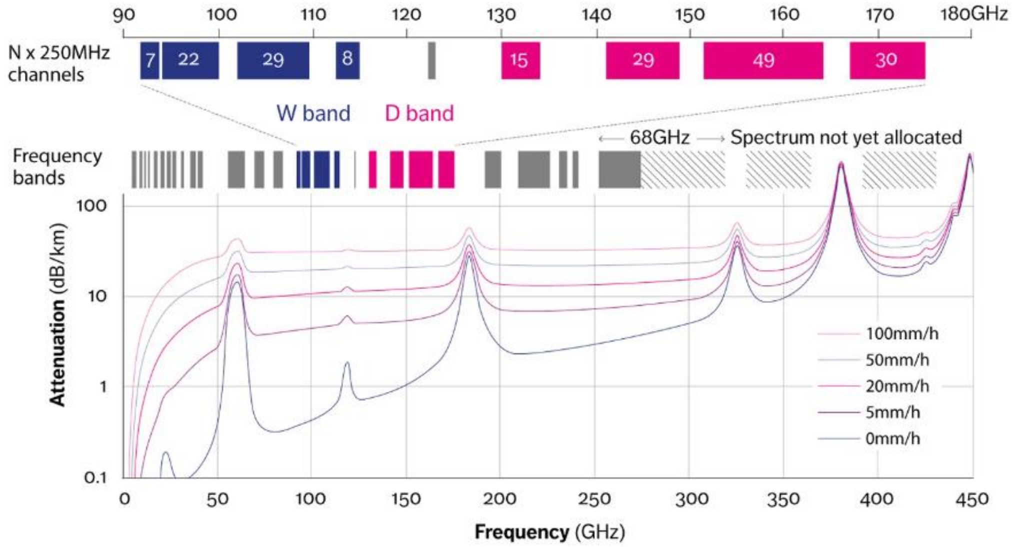
VINNOVA

Lomma. Analog & RF Consulting

Why D-band ?

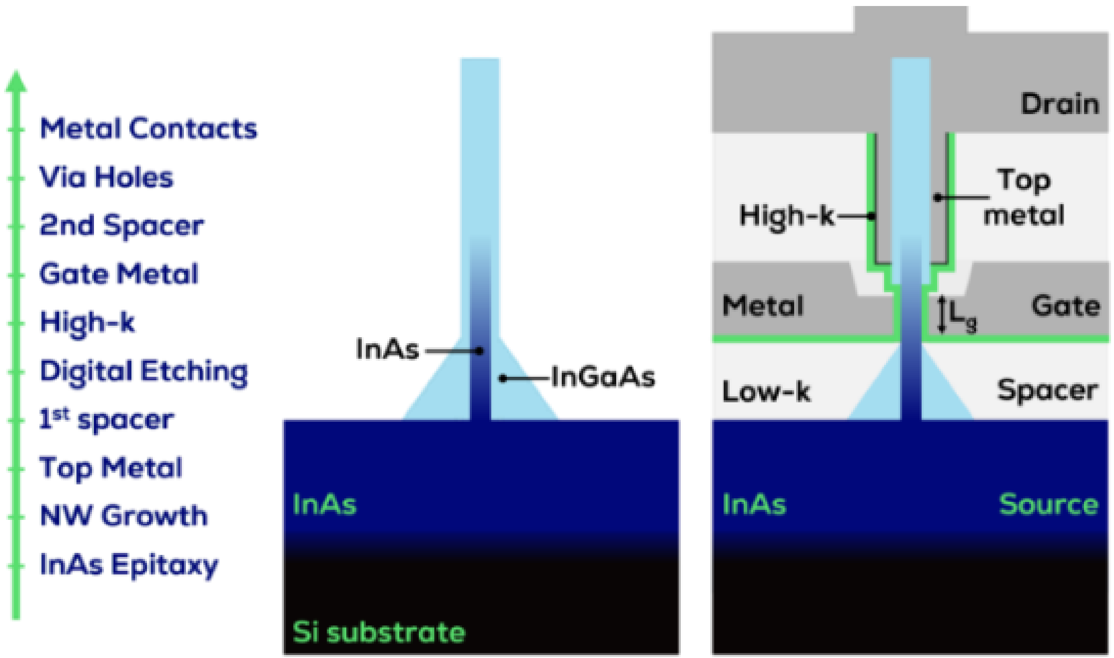


https://www.h2020-dragon.eu/overview/



Ericsson review, Microwave backhaul evolution – reaching beyond 100GHz, 2017

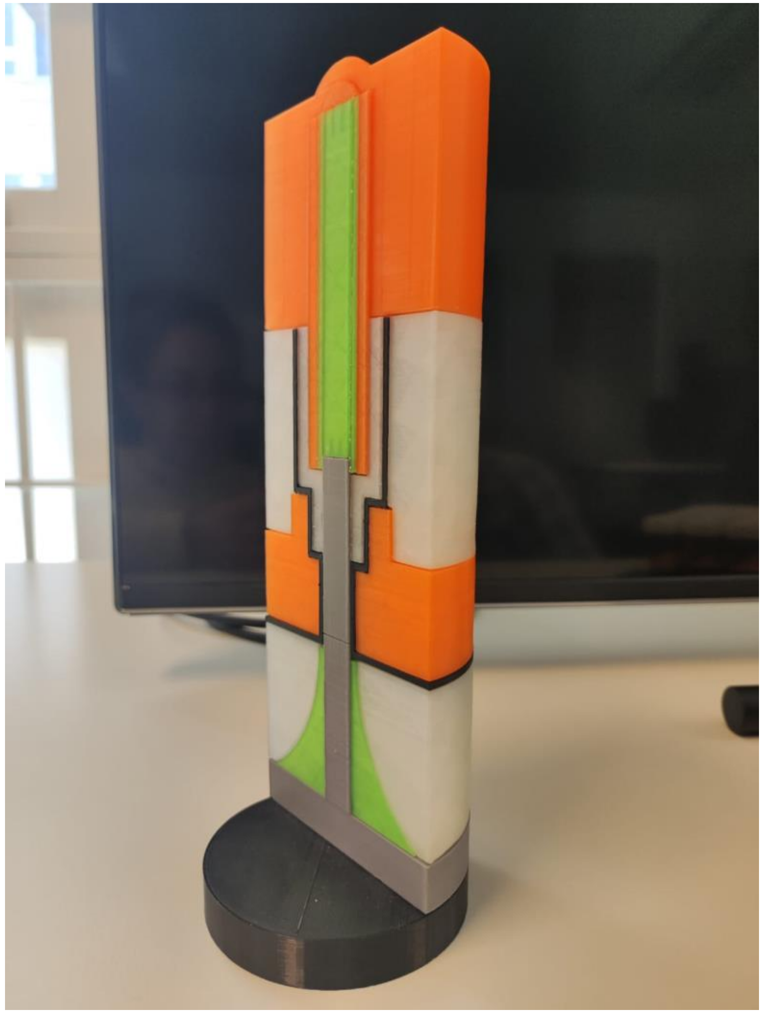
Semiconductor Technology



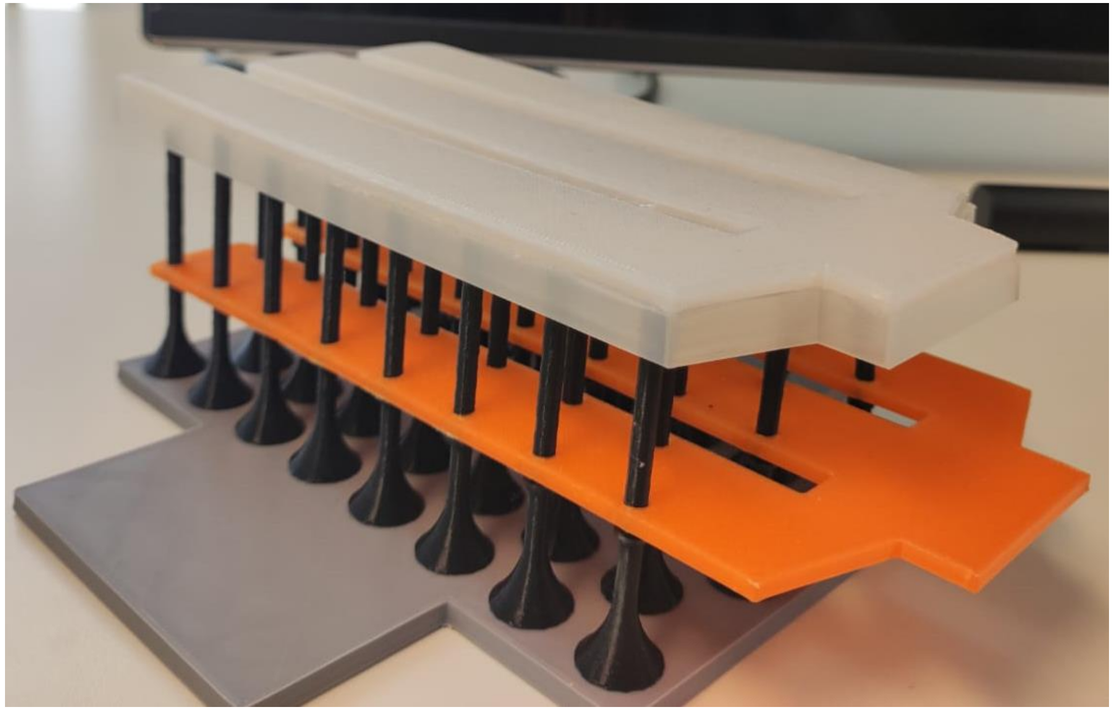
- Vertical structure ➡ low parasitics to substrate
- Simple manufacturing technology
- Higher mobility than Si
- Semi ballistic

NordAmps

3D-printed device models



- Single wire device cut in half

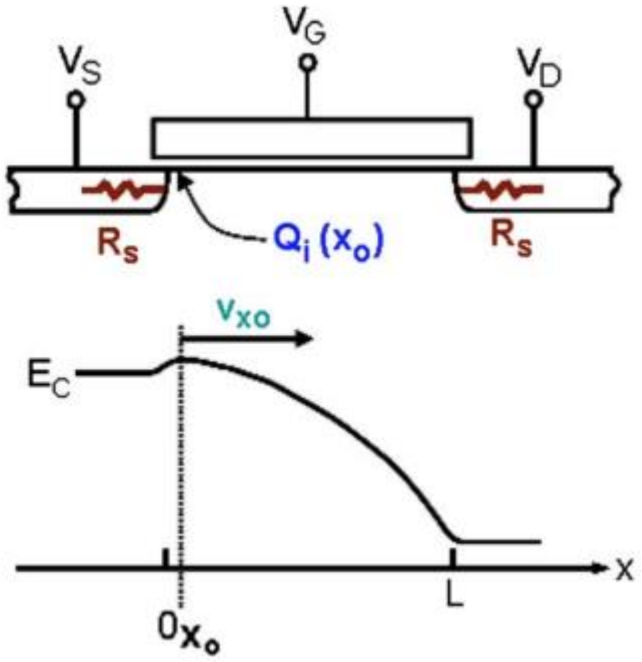


- LNA type device. Input device with:
  - 296 wires in parallel (black)
  - 8 fingers to reduce R_g (orange)
  - Drain fingers (white) to reduce parasitic capacitance
  - InAs mesa source layer (grey)

NordAmps

Device model

- **Virtual source model (from MIT)**
  - Semi-empirical model for quasi-ballistic transistors
  - Few physical parameters
  - Extrapolated from validated devices at L_g=120nm with f_T/f_{max}=123/130 GHz
  - This work: f_T/f_{max}=285/418 GHz for L_g=20nm



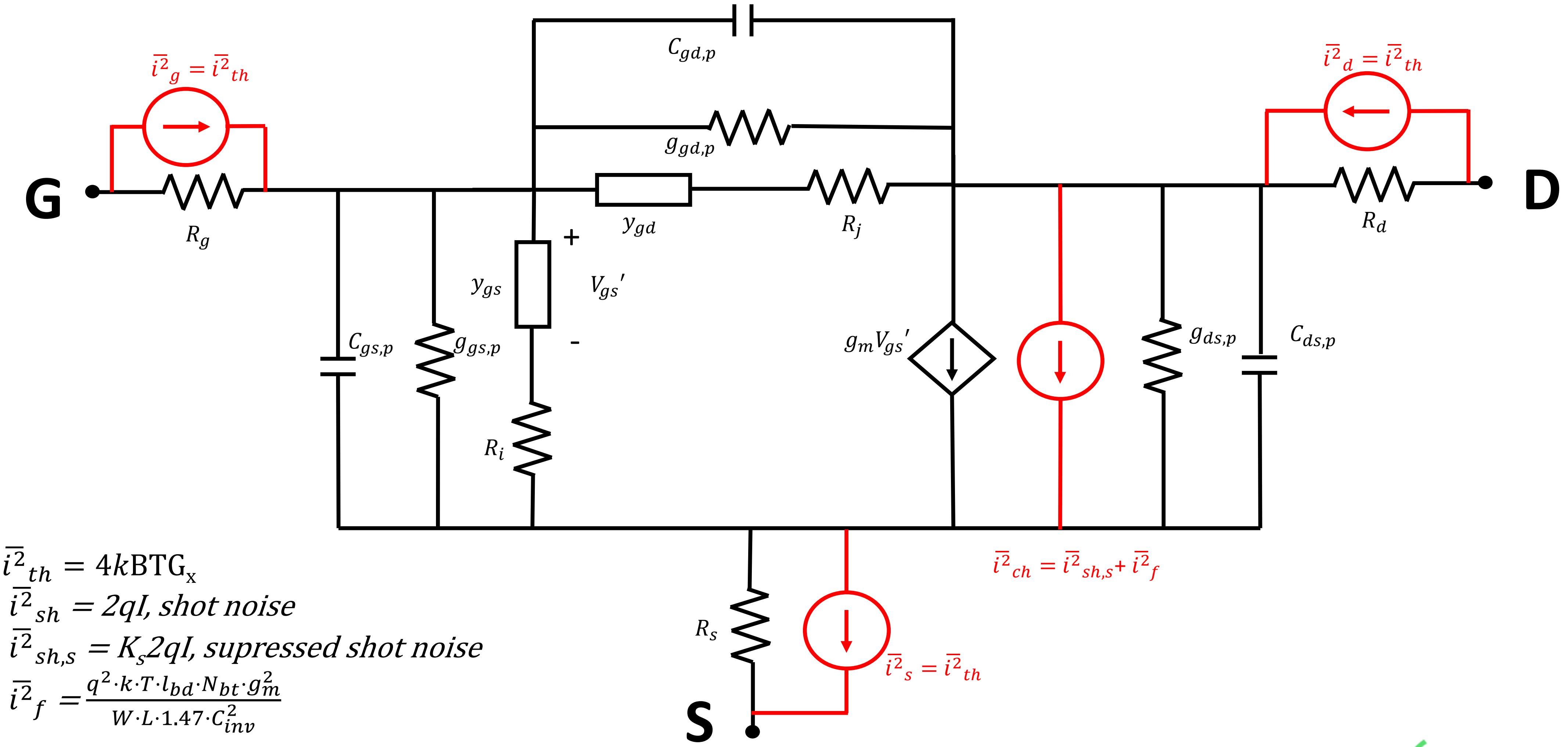
- Virtual-source point x_0: carrier charge and density defined at this point (at the peak of the conduction band)
- Easiest to calculate charge density at VS point.
- $\mathbf{I_d}$: product of local charge areal density times the local carrier velocity at any point in the channel.
- Id = $Q_i(x0) \times v_{xo} \times (F_{sat}) \times W$,

$$Fsat = \frac{Vdsi/Vdsat}{\left(1+\left(\frac{Vdsi}{Vdsat}\right)^{\beta}\right)^{\frac{1}{\beta}}}$$

S. Rakheja, "Silicon MIT Virtual Source Model (VERSION=1.0.1), Microsystems Technology Laboratories," Massachusetts Institute of Technology, Cambridge, MA

NordAmps

Device model with parasitics and noise sources



$\overline{i^2}_{th} = 4kBTG_x$

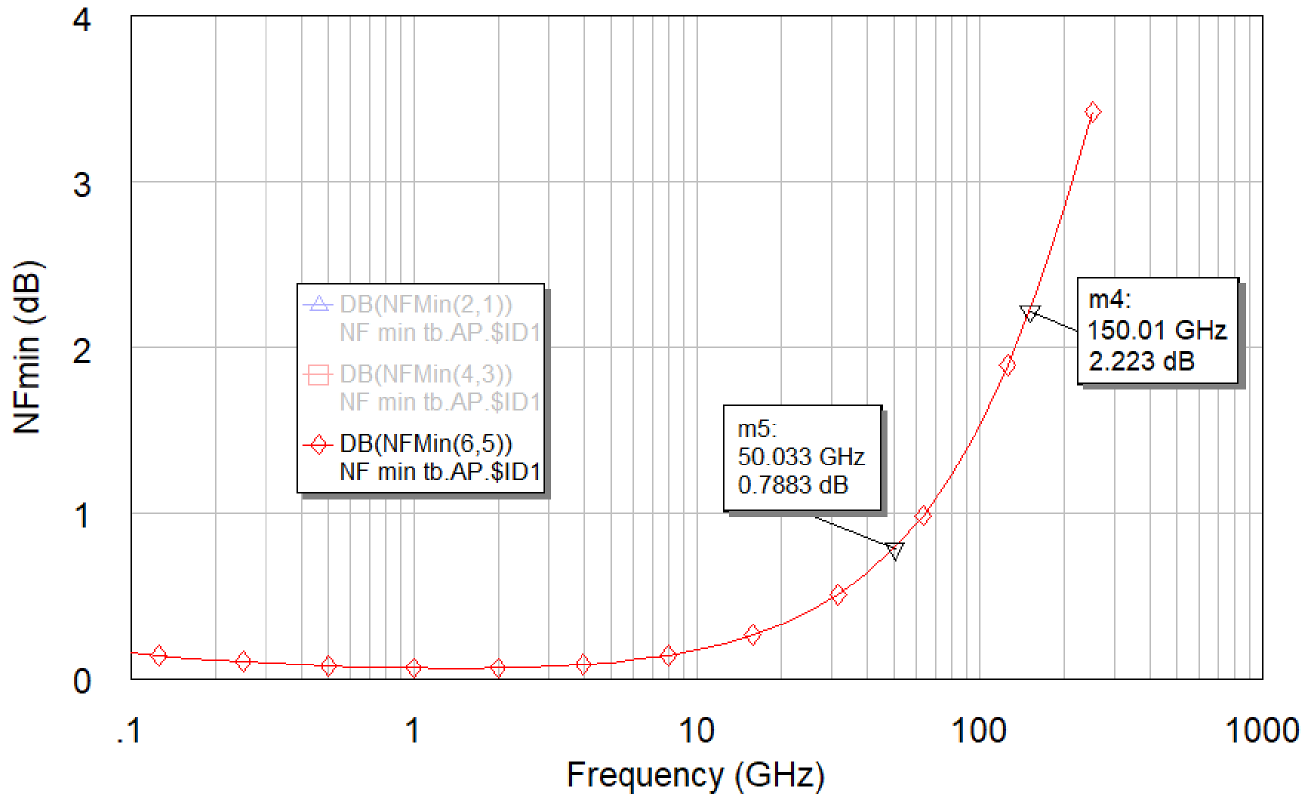
$\overline{i^2}_{sh} = 2qI$, *shot noise*

$\overline{i^2}_{sh,s} = K_s 2qI$, *supressed shot noise*

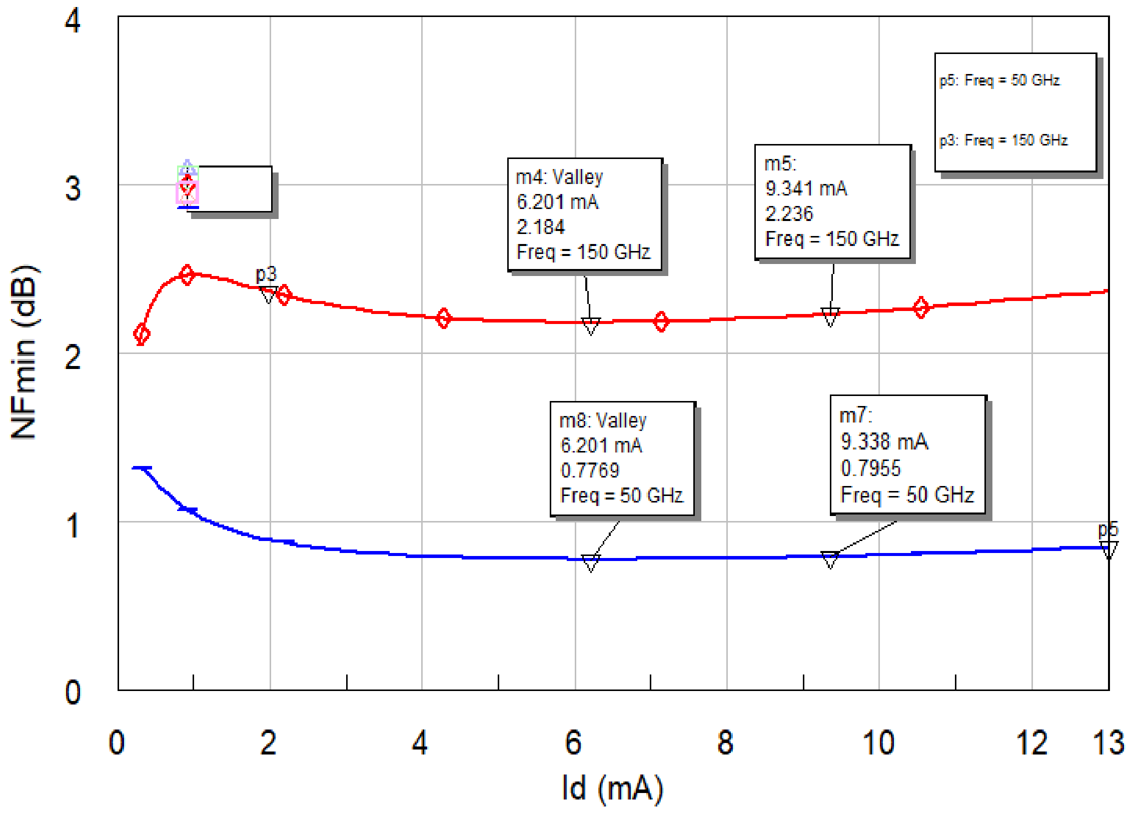
$$\overline{i^2}_f = \frac{q^2 \cdot k \cdot T \cdot l_{bd} \cdot N_{bt} \cdot g_m^2}{W \cdot L \cdot 1.47 \cdot C_{inv}^2}$$

Device model-NF_{min}

- NF_{min} vs frequency for Id=9.3 mA (input stage, NW=296, NF=8)



- NF_{min} vs I_d for f=50 and 150 GHz



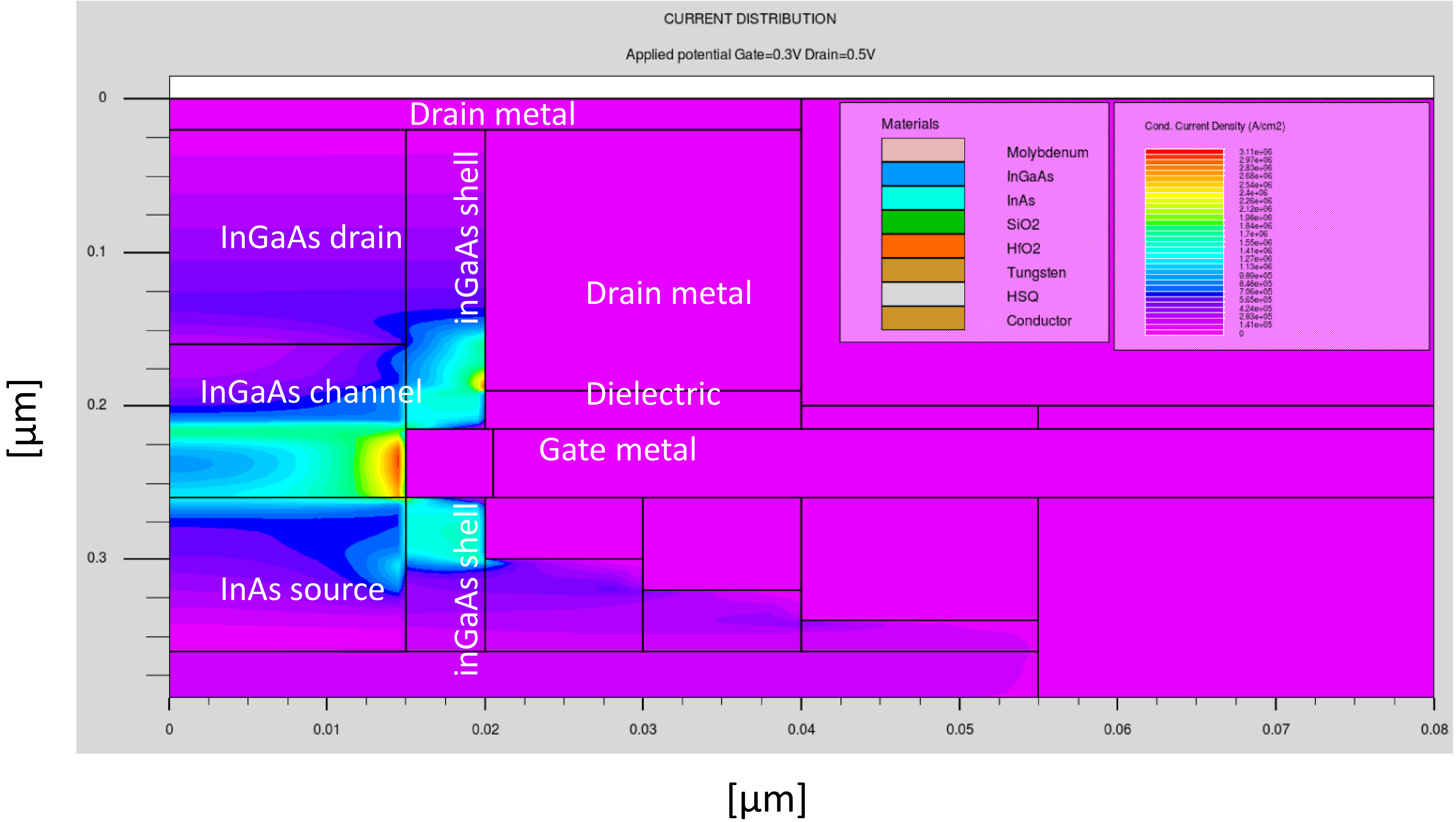
NordAmps

Technology benchmark-NF_{min} @ 50 GHz

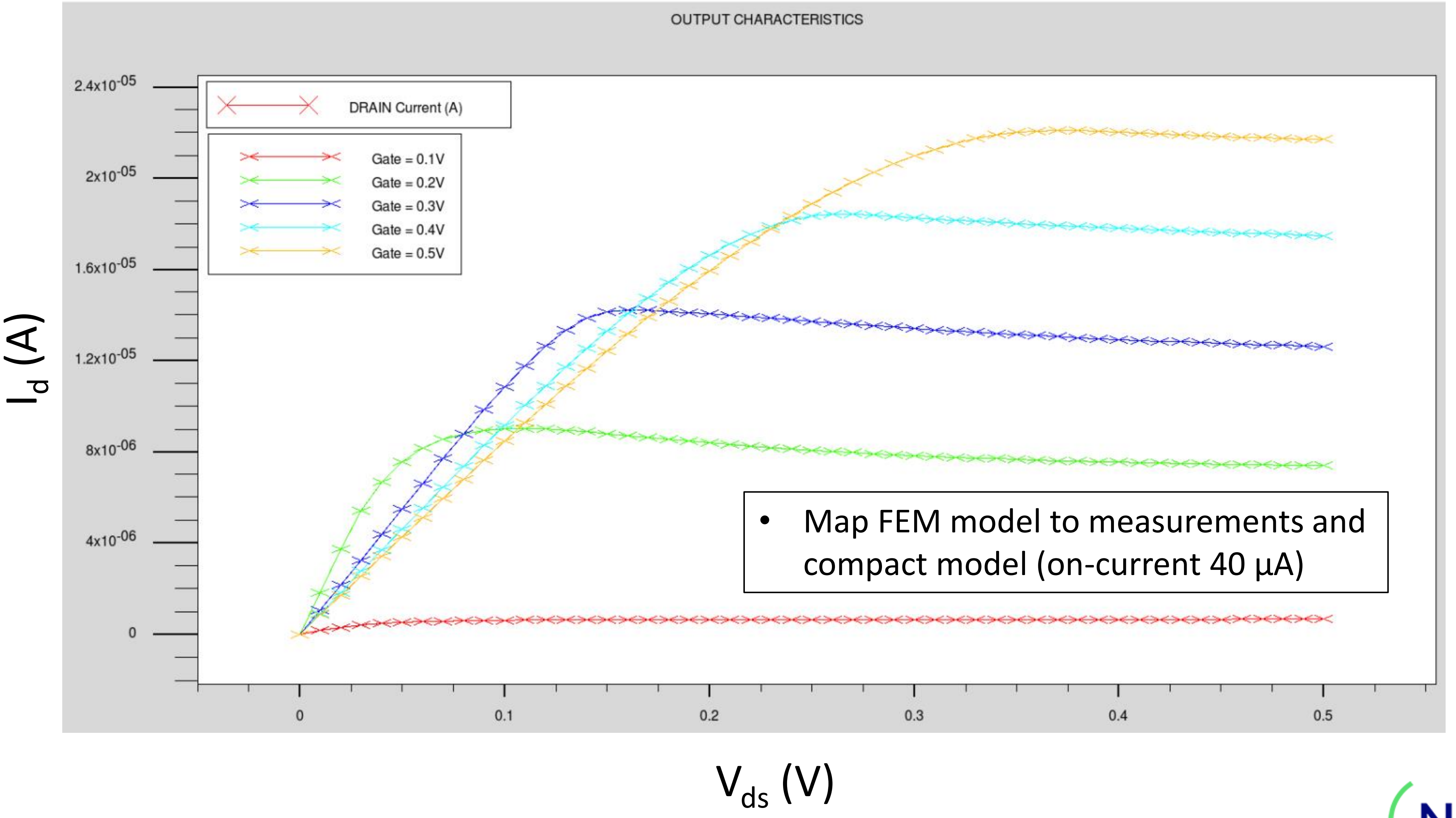
Technology	Feature size (nm)	fMAX (GHz)	Vbr (V)	NFmin (dB) at 50GHz**	Production or research?
GaAs pHEMT	100	185	7	0.5	P
GaAs mHEMT	70	450	3	0.5	R*
GaAs mHEMT	35	900	2	1	R
InP HEMT	130	380	1	<1	R
InP HEMT	30	1200	1	<1	R
GaN HEMT	60	250	20	1	R
GaN HEMT	40	400	42	1.2	R
SOI CMOS	45	280	1	2–3	P
SiGe-HBT	130	400	1.4	2	P
InP DHBT	250	650	4	3	R*
InP DHBT	130	1100	3		R
NordAmps	20	418	0.6	0.8	R

Ericsson review, Microwave backhaul evolution – reaching beyond 100GHz, 2017

Rotational symmetric FEM structure: Current density

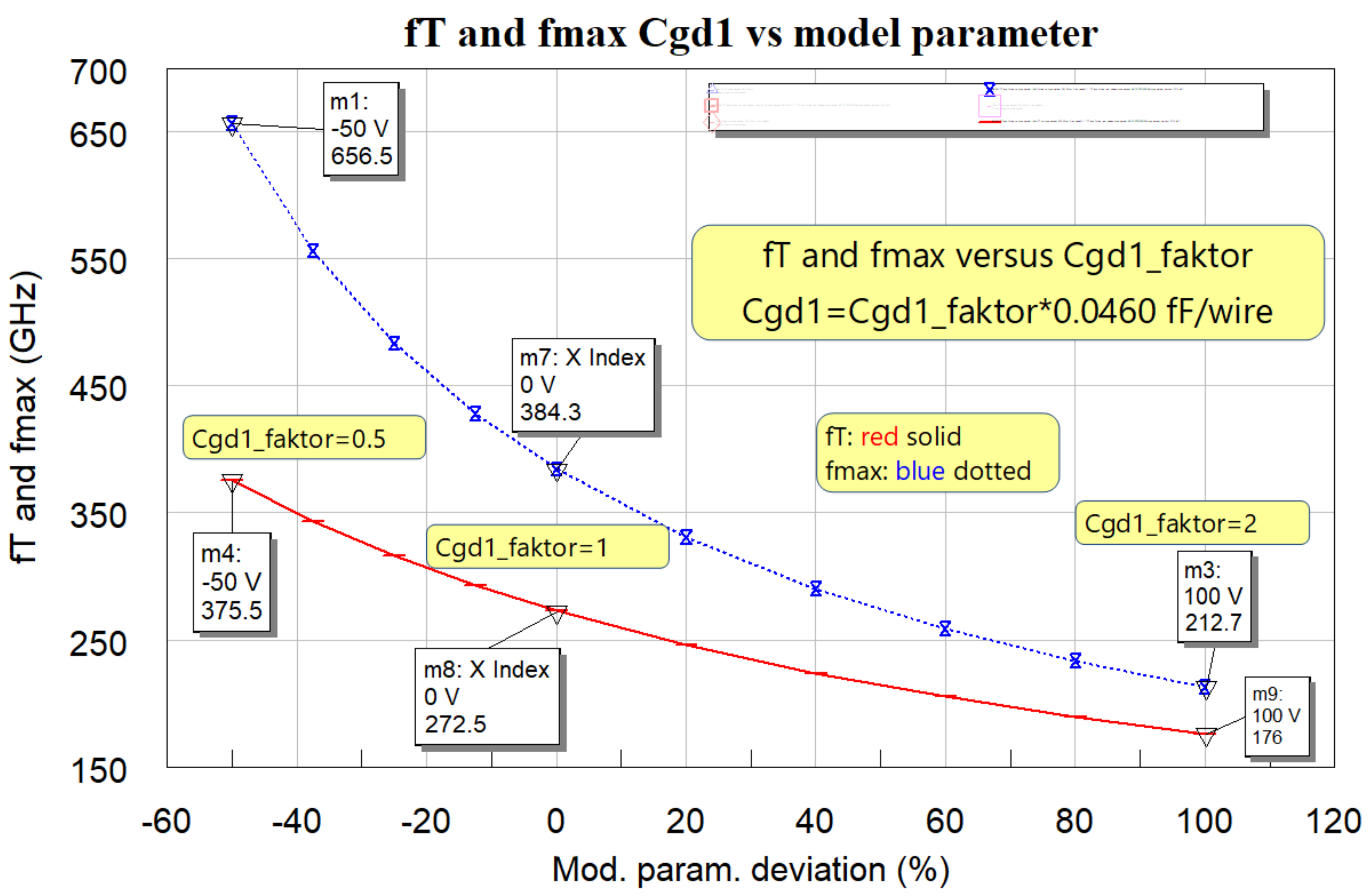


FEM: Silvaco Blaze output characteristics



- Map FEM model to measurements and compact model (on-current 40 µA)

Device optimization with VerilogA compact model



- **Starting point:**
  NW=300 wires
  NF=6 fingers
  L_g=25nm

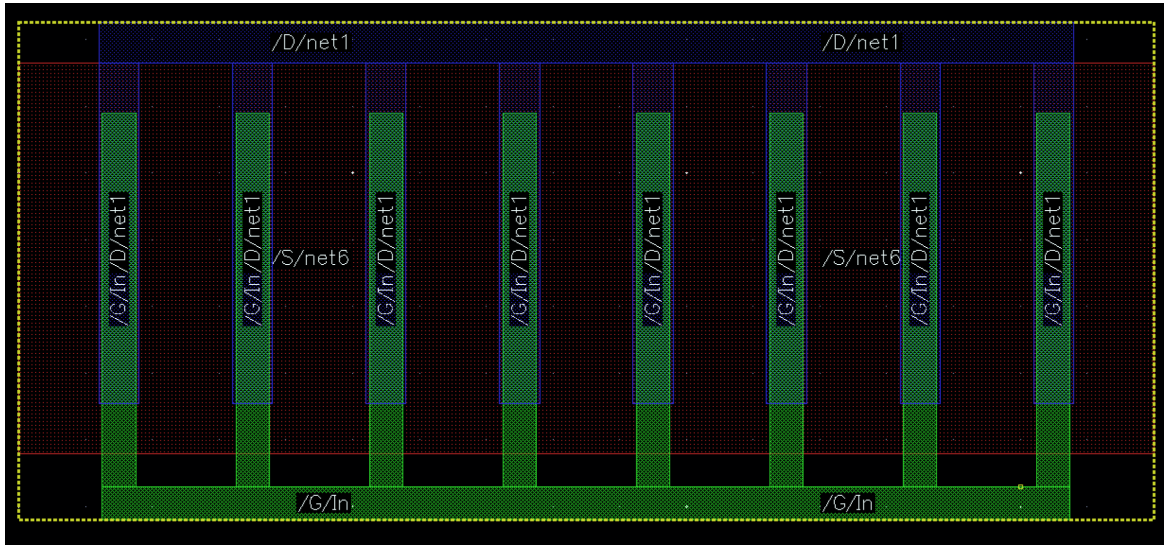
  f_T= 272 GHz and
  f_{max}= 384 GHz

- Simulate sensitivity in maximum f_T/f_{max} vs I_d for 11 model parameters
- Highest sens. for C_{gd}

Process optimization

NordAmps

Process Design Kit (PDK)



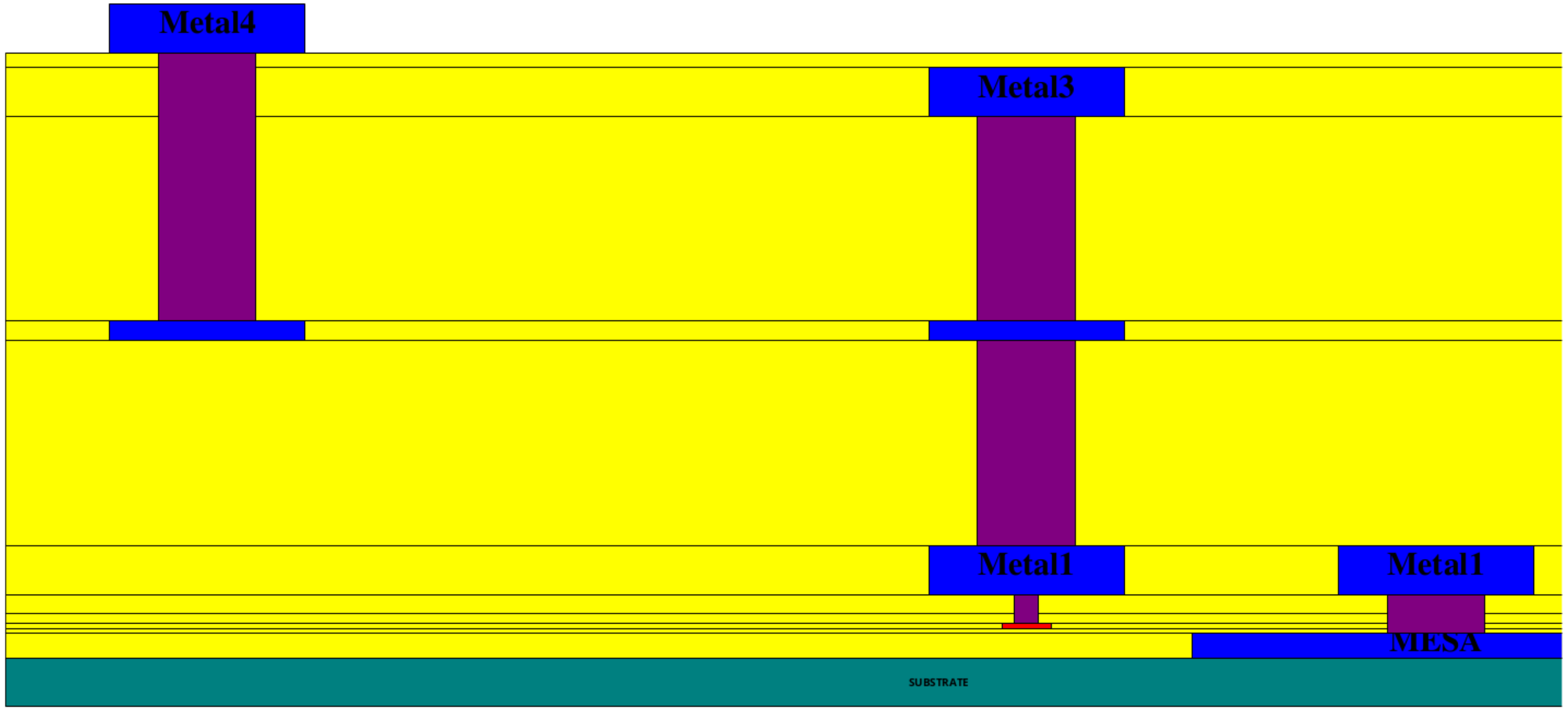
- **PDK in Cadence**
  - VerilogA model code
  - Parasitic extraction in Quantus
  - Electromagnetic simulations in EMX
  - Fast convergence, both in Periodic Steady State and Harmonic Balance

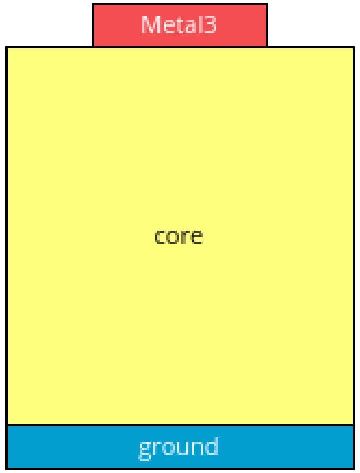
- Model code also for Microwave Office (AWR)

- **Scalable P-cells**
  - N-type transistor
  - MIM- capacitors: 15 and 200nm dielectrics
  - Thin Film Resistor (TFR): 50 Ω/□
  - Transmission lines
  - Inductors

NordAmps

Back End of Line (BEOL)

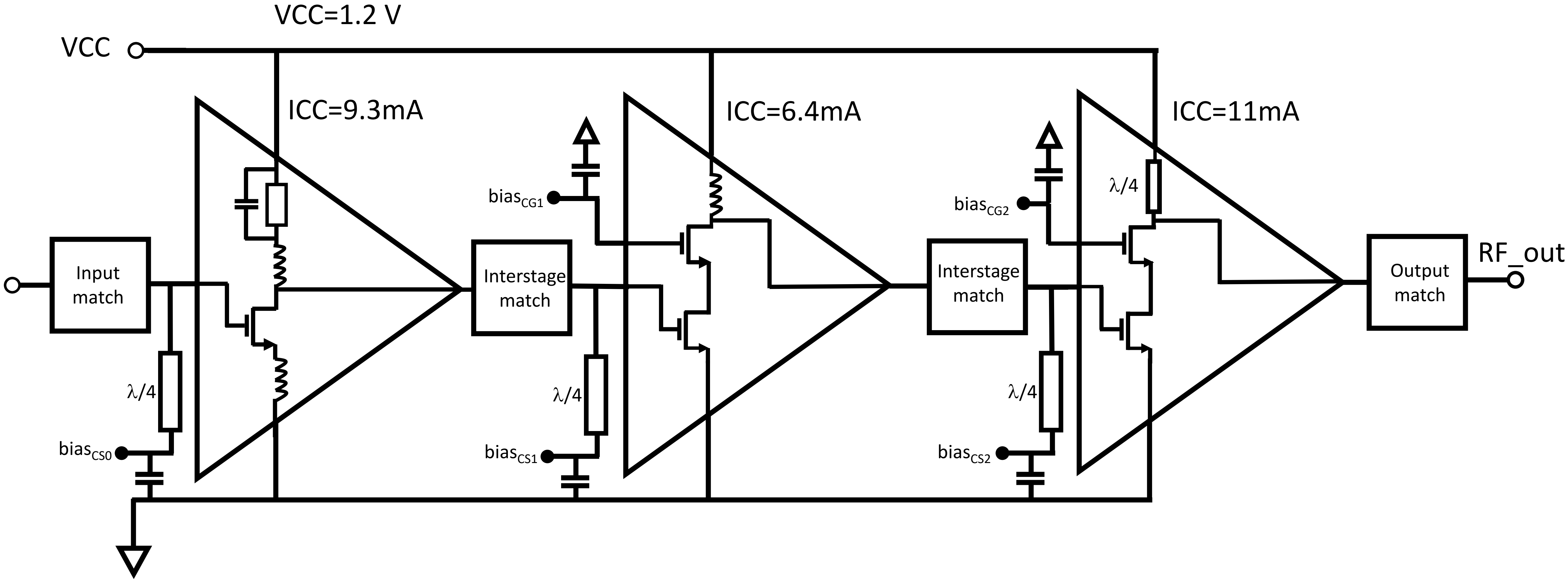




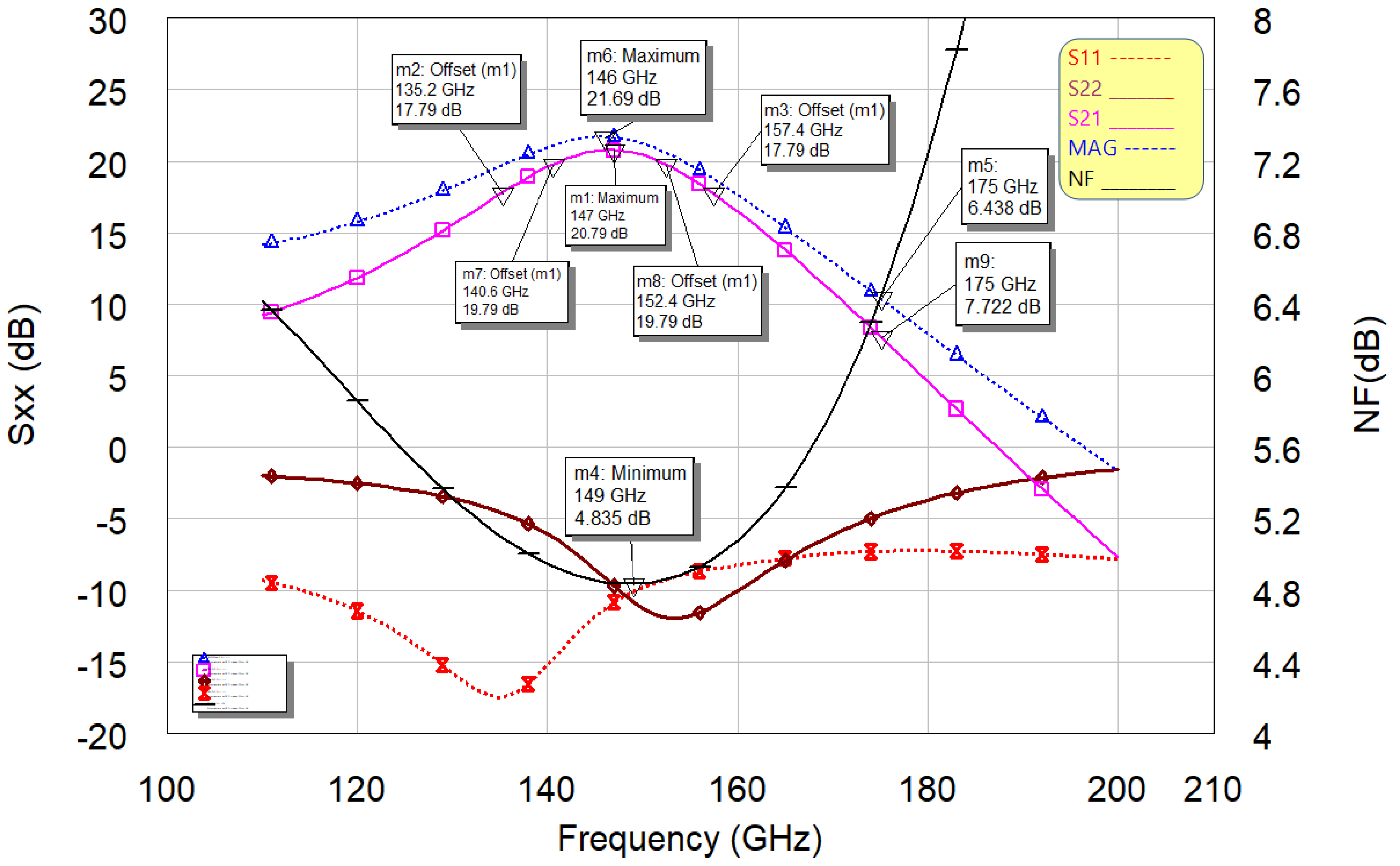
Type	Layer Name	Thickness	Material
Conductor	Metal3	0.5e-6	mCond1
Dielectric	core	4.2e-6	mDiel1
Reference	ground	0.5e-6	mCond1

- 0.5µm Au with BCB dielectric ε_r=2.65
- 4.2 µm to ground plane

3-stage LNA design



Simulation results 3-stage LNA



- S21=20.8 dB@147 GHz
  NF=4.8 dB@149 GHz
  Broadband S11

- Low gain @ 175 GHz
  → NF increase

- **Compression point and linearity:**
  ICP_{1dB}=-21 dBm @ 146 GHz
  IIP_3=-11 dBm for two tones @146 and 147 GHz.

NordAmps

Conclusions

D-band LNA in Vertical III-V Nanowire Technology

- Compact model + Cadence PDK
- Predictive modeling → close to commercial NF performance @ lower D-band frequencies
- III-V technology with f_T/f_{max}=f_T/f_{max}= 285/418 GHz
- Minimum NF=4.8 dB @ 149 GHz
- Further process optimization → Increased competitiveness

An interesting technology for future millimeter wave applications !

NordAmps