SERENA webinar #2: GaN-on-Si for mm-wave applications

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60 nm GaN-on-Si based mm-wave amplifiers for RF sensing and wireless communication

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gan-on-Silicon Efficient mm-wave euRopean systEm iNtegration plAtform

Outline

- Introduction (background)
- 60 nm GaN-on-Silicon HEMT process
- Co-planar waveguide test structures (lines and transistors)
- Results of manufactured E/W-band amplifier MMICs (examples)
- Summary and conclusions

Introduction (mm-wave applications)

Figure 1. *An envisioned use case of massive MIMO in 5G.*

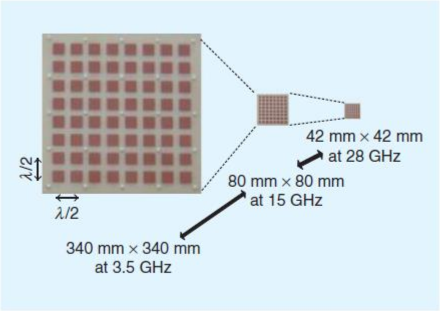
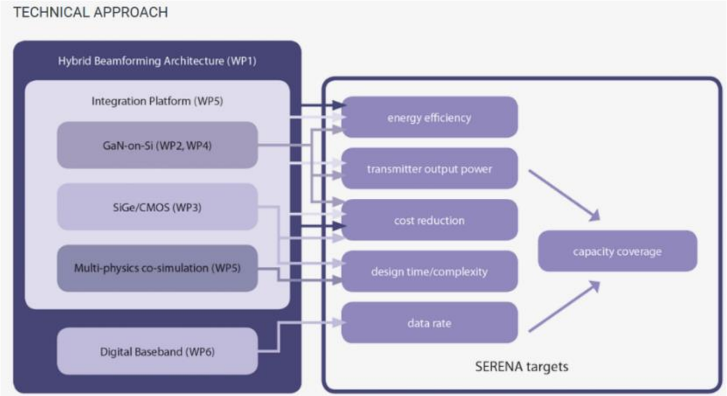


Figure 2. *An image showing the size of an RF front-end panel with 8 × 8 arrays for 3.5, 15, and 28 GHz.*

S. Shinjo et al., "Integrating the front-end," IEEE Microwave Mag. 2017

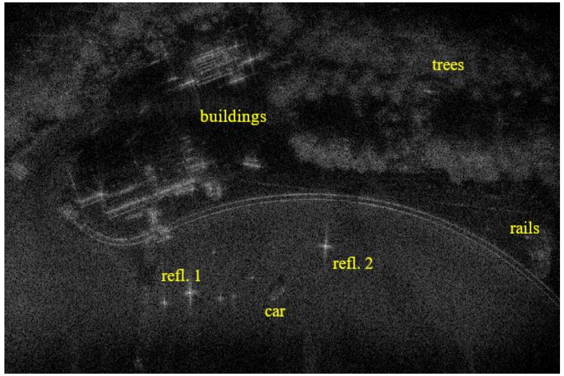


https://serena-h2020.eu/

- Millimetre-wave applications (e.g. 5G and short range radar sensors) will require compact, low-cost and power efficient electronic beam-steering systems (active phased arrays)

- SERENA project is targeting high-power and high-efficiency through the integration of Gallium Nitride on Silicon (GaN-on-Si) technology with ~10x higher output power than SiGe/CMOS

Short-range radar sensor (drone application)

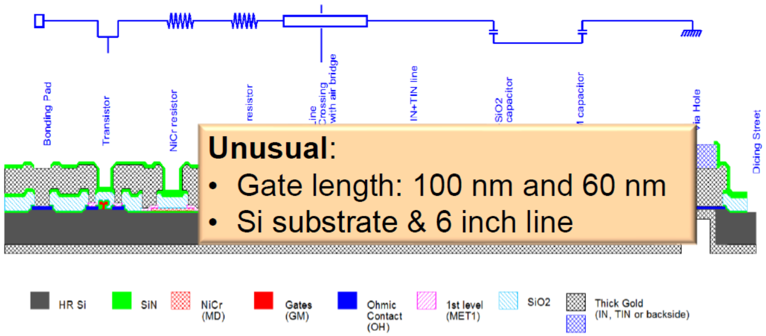


J. Svedin et al., “Small UAV-based High Resolution SAR using Low-Cost Radar, GNSS/RTK and IMU Sensors,” EuRAD 2020

- Small drone with a 5-6 GHz radar sensor unit developed at FOI and used for SAR measurements
- Move to higher frequencies (mm-wave) to enable active phased array antenna to fit a smaller platform

OMMIC's 60 nm GaN-on-Si process (D006GH)

Full MMIC Process for mm-wave designs
Via holes, air-bridges, metal resistors, MIM capacitors



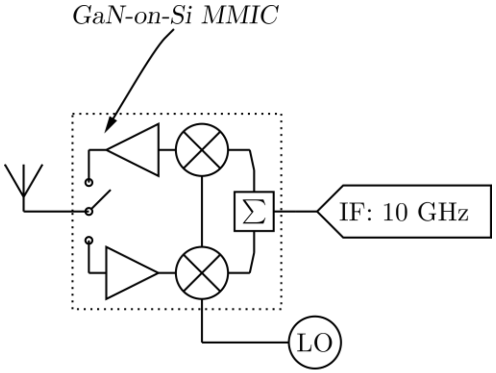
Unusual:
- Gate length: 100 nm and 60 nm
- Si substrate & 6 inch line

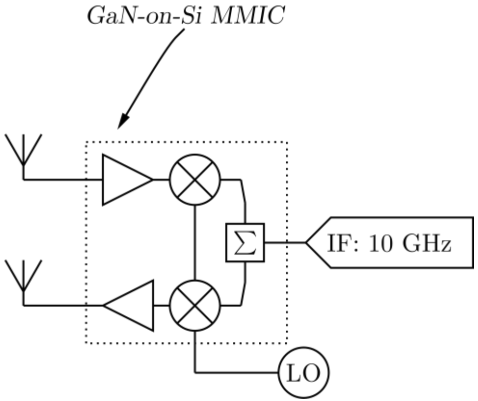
- 0.5 W W-band PA MMIC

R. Leblanc et al., "Ka to W Band GaN/Si Power Amplifiers," EuMIC 2019

- OMMIC has developed 100 nm and 60 nm GaN-on-Si HEMT processes (D01GH and D006GH)
- Compared with a 70 nm GaAs mHEMT process (D007IH) the 60 nm GaN-on-Si process has comparable noise figure and gain at 35 GHz and much higher breakdown-voltage/power handling

Single-chip transceiver architectures





- Single-chip transceiver architectures for E/W-band multifunctional front-ends incl. PA/LNA and up/down-converter (wireless communication and short-range radar applications)

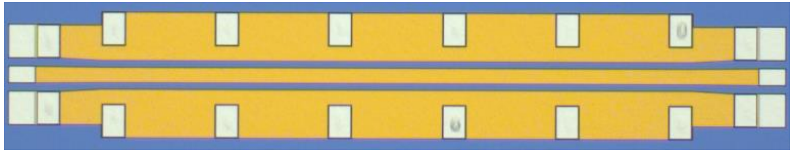
- Focus in this presentation is on the validation of fabricated 60 nm GaN-on-Si passive and active test circuits (transmission lines, transistors and amplifier circuits)

GaN E/W-band MMICs (SERENA/state-of-the-art)

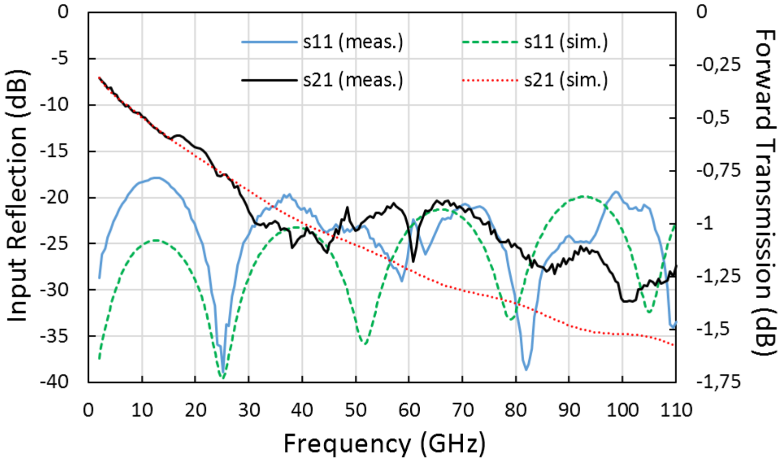
[1] W. Shaobing et al., "W-band AlGaN/GaN MMIC PA with 3.1W output Power," in Proc. 2017 14th China Int. Forum on Solid State Lighting: Int. Forum on Wide Bandgap Semiconductors China.
[2] A. Kurdoghlian et al., "First demonstration of broadband W-band and D-band GaN MMICs for next generation communication systems", Proc. IEEE MTT-S IMS' 2017, 2017, pp. 1126-1128.
[3] I. Kallfass et al., "A single-chip 77 GHz heterodyne receiver MMIC in 100 nm AlGaN/GaN HEMT technology," Proc. IEEE MTT-S IMS'2011', 2011, pp. 1-4.
[4] R. Leblanc et al., "An industrial foundry offer for a 100 nm GaN/Si process for applications up to V band," ESA workshop 2018.
[5] X. Tong et al., "Low-noise amplifiers using 100-nm gate length GaN-on-Silicon process in W-band," IEEE Microwave and Wireless Comp. Lett., Vol. 30, pp. 957-960, Oct. 2020.
R. Malmqvist, R. Jonsson, A. Bernland, M. Bao, R. LeBlanc, K. Buisman, C. Fager, K. Andersson, "E/W-band CPW-based amplifier MMICs fabricated in a 60 nm GaN-on-Silicon foundry process," in Proc. EuMIC'2020, 2020, pp. 1-4. (SERENA)
M. Bao, R. Malmqvist, R. Jonsson, J. Hansryd, K. Andersson, "A W-band up-conversion mixer with integrated LO frequency doubler in a 60 nm GaN technology," accepted for presentation at EuMIC'2021. (SERENA)
R. Malmqvist, R. Jonsson, M. Bao, R. LeBlanc, K. Buisman, C. Fager, K. Andersson, "W-band single-chip receiver in a 60 nm GaN-on-Silicon foundry process," accepted for presentation at EuMIC'2021. (SERENA)

- SERENA has confirmed the feasibility of E/W-band multifunctional single-chip front-ends in a 60 nm GaN-Si process
- 60 nm GaN-Si amplifiers with a measured NF and P1dB of 3-5 dB and 9-13 dBm up to 95 GHz, respectively
- W-band up/down-conversion mixer circuits with integrated LO frequency doubler were realised in the same process
- Final demonstration: evaluate GaN-Si W-band transmitter and receiver MMICs (in assembled waveguide modules)

Fabricated passive test structures (line)

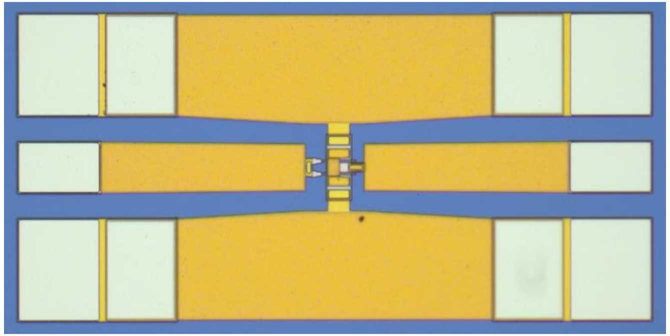


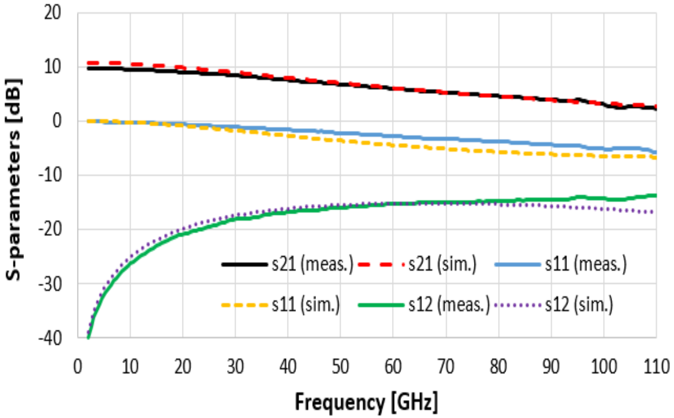
2 mm CPWG transmission line



- Grounded co-planar waveguides are used to prevent undesired higher-order transmission modes from occurring at E/W-band (the substrate thickness is 100 μm)
- The measured transmission losses are below 1.4 dB at 2-110 GHz (≤0.6 dB/mm) and the measured s_{11} is -18 dB or less in this frequency range (not too high impact on amplifier gain)

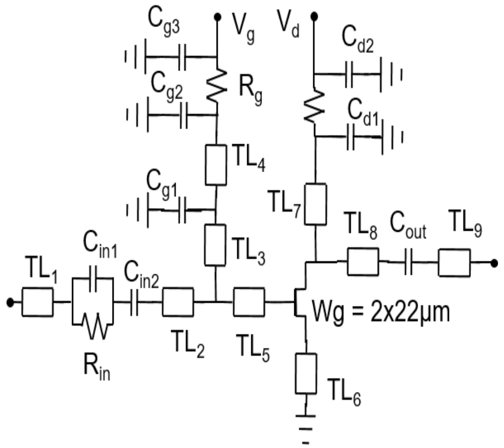
Fabricated active test structures (transistor)

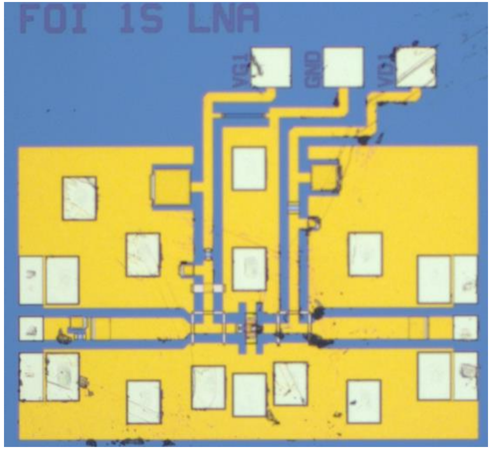




- A 2x22 μm HEMT device is used in high-gain/low-noise amplifier circuits up to E/W-band (70-95 GHz)
- The measured s_{21} is between 2-10 dB @ 2-110 GHz when V_{DS}=5.5 V and I_{DS}=16 mA
- A relatively close agreement between measured and simulated s-parameters in dB (somewhat larger offset in phase)

60 nm GaN-on-Si amplifier (1-stage)

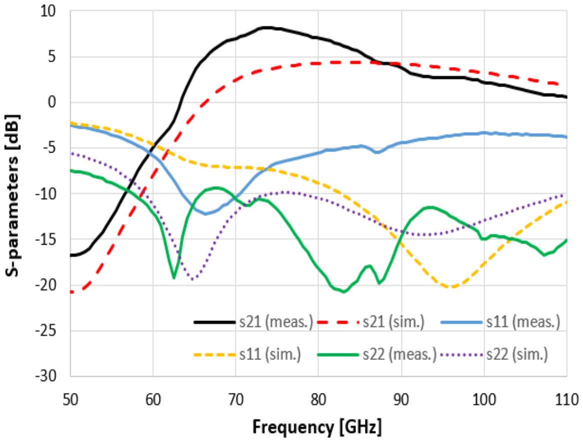




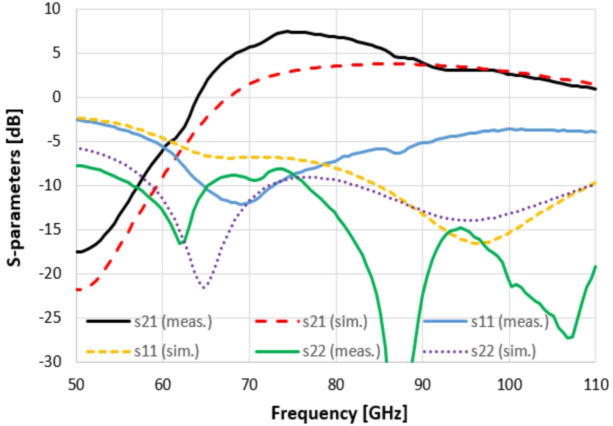
950×814 μm²

- A one-stage low-noise amplifier circuit with DC bias line connections at the tee-junctions
- The matching networks include transmission lines, capacitors and resistors to ensure unconditional stability

60 nm GaN-on-Si amplifier (1-stage)



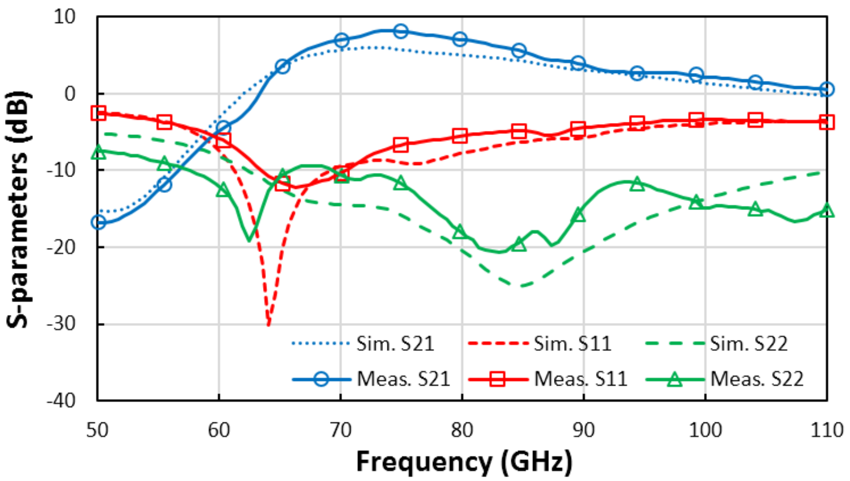
V_D=5.5 V, I_D=18 mA



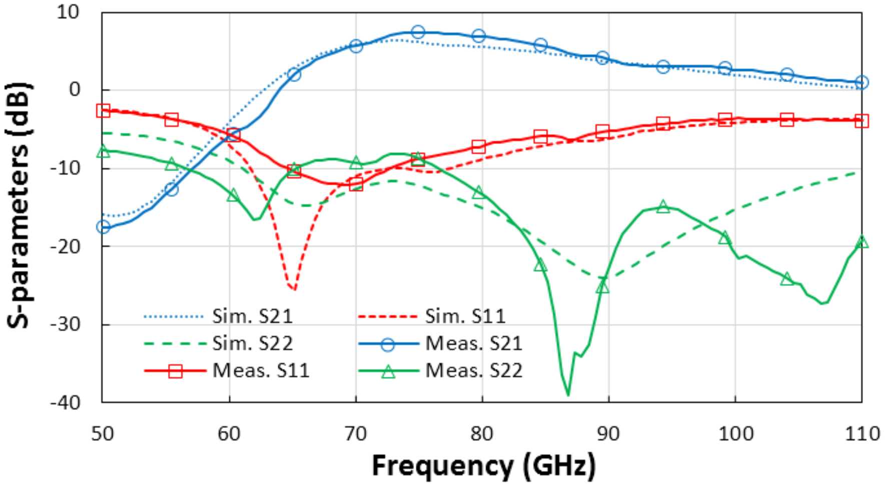
V_D=10 V, I_D=15 mA

- The measured gain is 8 dB @ 74 GHz and around 3 dB @ 92-95 GHz (V_d=5.5 V I_d=18mA)
- s_{21} is slightly higher @92-95 GHz while gain is reduced at lower freq when V_d=10 V and I_d=15 mA
- Compared with simulations the measured s_{11} and s_{22} are shifted towards lower frequencies

60 nm GaN-on-Si amplifier (1-stage)



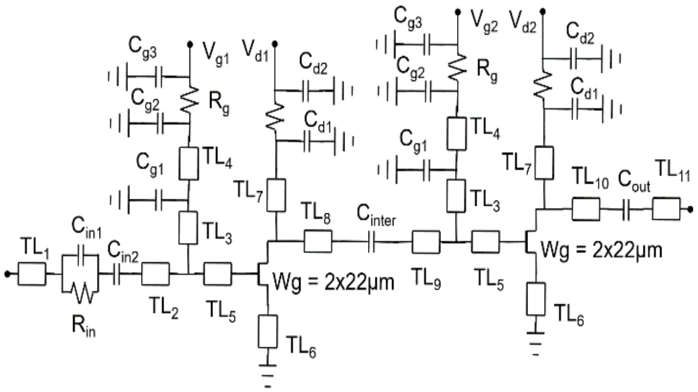
V_D=5.5 V, I_D=18 mA

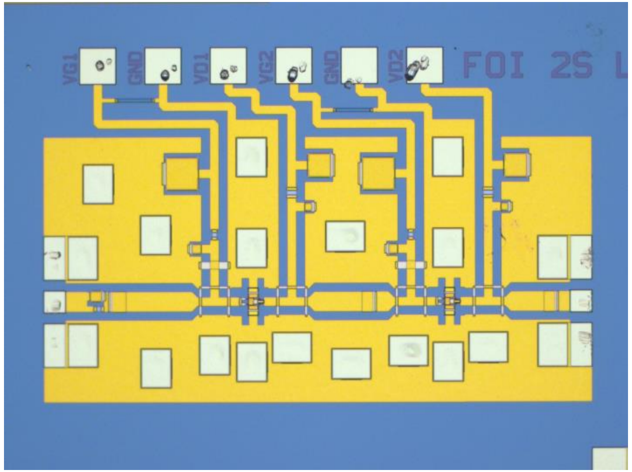


V_D=10 V, I_D=15 mA

- A closer agreement between measured and simulated results is obtained with a later version of the foundry PDK

60 nm GaN-on-Si amplifier (2-stage)

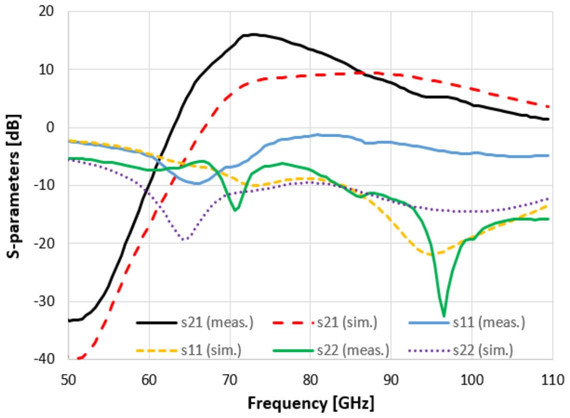




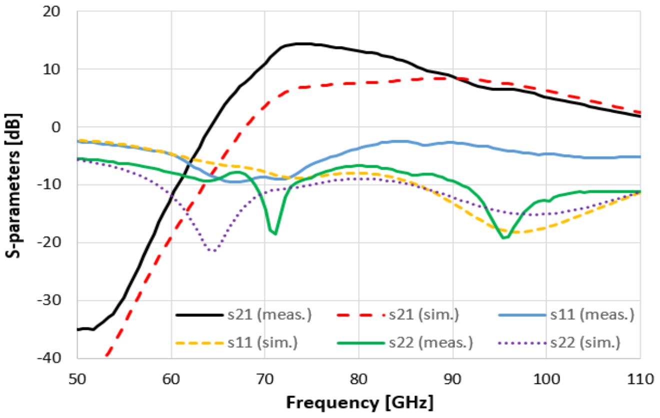
1256 × 814 μm^2

- A cascaded 2-stage low-noise amplifier (inter-stage matching is implemented using lines and a series capacitor)
- The output matching network is made somewhat shorter to fit with another circuit

60 nm GaN-on-Si amplifier (2-stage)



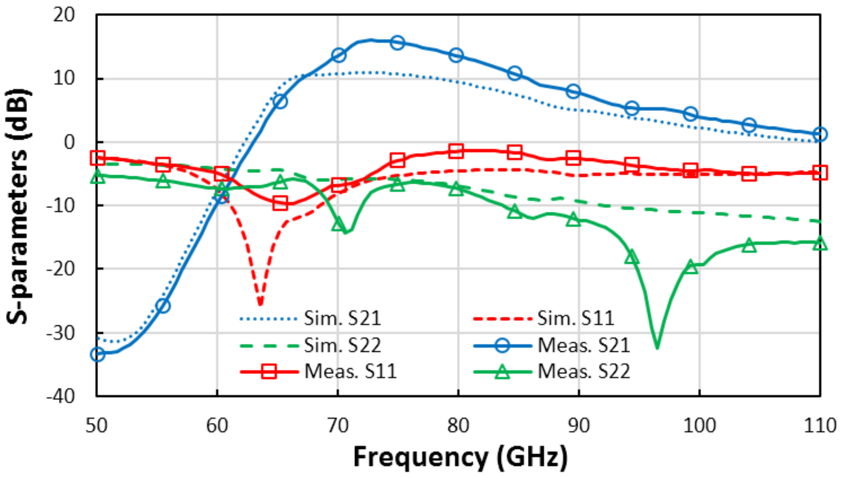
V_D=5.5 V, I_D=36 mA



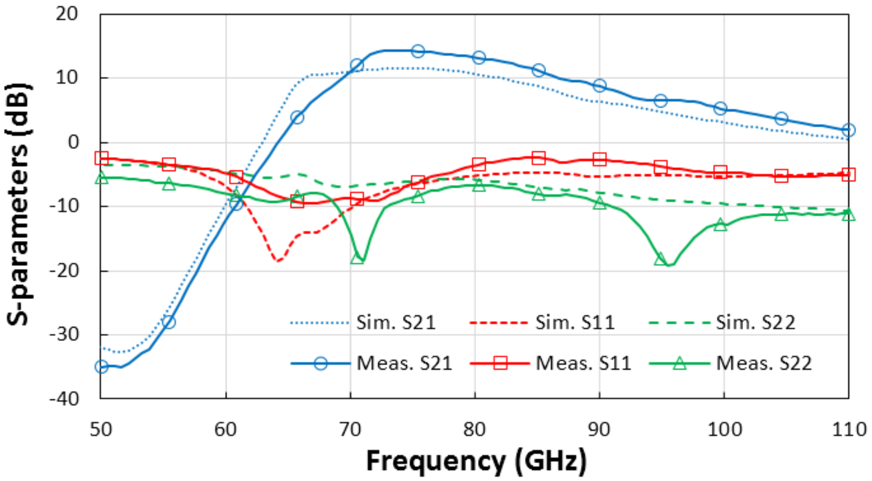
V_D=10 V, I_D=30 mA

- The measured gain is 16 dB @ 73 GHz and 5-6 dB @ 92-95 GHz (V_d=5.5 V I_d=36 mA)
- s_{21} is 1 dB higher @92-95 GHz when V_d=10 V and I_d=30 mA
- Compared with simulations the measured s_{11} and s_{22} are shifted towards lower frequencies

60 nm GaN-on-Si amplifier (2-stage)



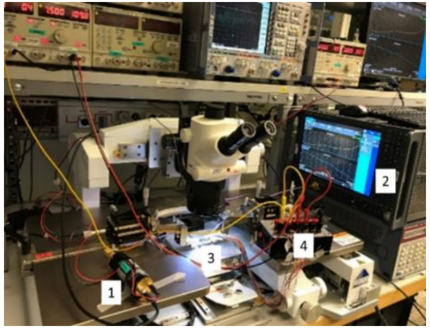
V_D=5.5 V, I_D=36 mA



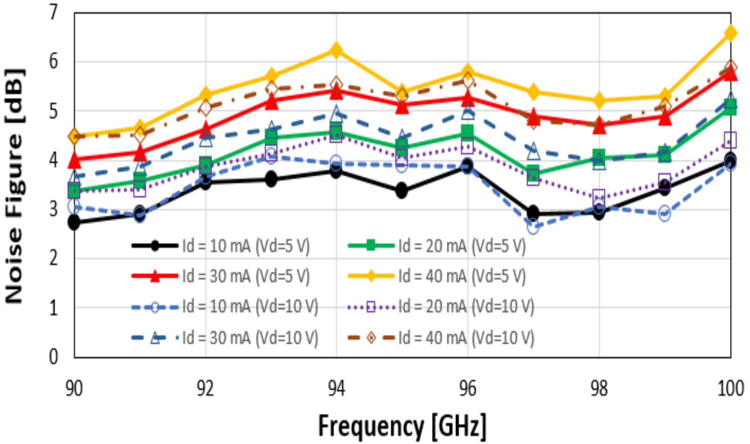
V_D=10 V, I_D=30 mA

- A closer agreement between measured and simulated results is obtained with a later version of the foundry PDK

60 nm GaN-on-Si amplifier (2-stage)



NF measurement setup (1. noise source, 2. spectrum analyser, 3. Probe station and 4. DC bias connections)



- Measured NF ≤ 3-4 dB @ 90-95 GHz when I_d=10 mA and V_d=5V/10V
- Measured NF is 3-5 dB @ 90-99 GHz when I_d is 20-30 mA (10-15 mA per stage) to provide a higher amplifier gain (meas. P_{1dB}=9/13 dBm when V_d=10V and I_d=14/28 mA per stage)
- Results show the feasibility of 60 nm GaN-on-Si amplifiers with a measured NF of 3-5 dB up to 95 GHz

Summary and conclusions

- 60 nm GaN-on-Si amplifiers with a measured NF and P_{1dB} of 3-5 dB and 9-13 dBm up to 95 GHz
- A closer agreement btw measurements/sim. is obtained with a later version of the foundry PDK
- E/W-band up/down-converter mixer circuits and single-chip front-ends have also been successfully validated in the same 60 nm GaN-Si process (D006GH)
- As a final demonstration 60 nm GaN-on-Si transmitter and receiver circuits will be characterized after assembly in waveguide modules

Acknowledgements

- E/W-band MMICs evaluated within the framework of the SERENA project were fabricated in OMMIC's 60 nm GaN-on-Si process (D006GH)

- The noise figure and large-signal characterization of the fabricated 60 nm GaN-on-Si based amplifier circuits were done at Ericsson Research and Chalmers University (Sweden)

- Rolf Jonsson is acknowledged for performing measurements on 60 nm GaN-on-Si MMICs and Stig Leijon is acknowledged for the assembly work on E/W-band amplifier MMICs into DC bias test fixtures

- The European Union is acknowledged for the funding and support of the H2020 ICT project SERENA (Grant Agreement no.779305)

SERENA Grant Agreement No. 779305

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