Paper 5a.1

LNA in 130-nm InP HBT with 15.5 dB Gain and Record 5.3 dB Noise-Figure at 212 GHz

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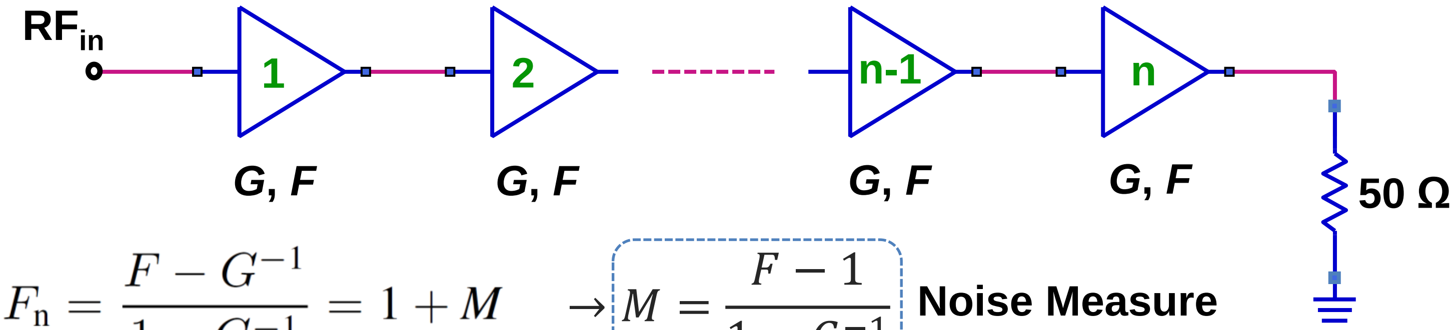
Outline

- Noise Measure
- Motivation / Technology
- Noise-Measure in TSC130
- Circuit Design
- Results
- Comparison
- Conclusion

Noise Measure

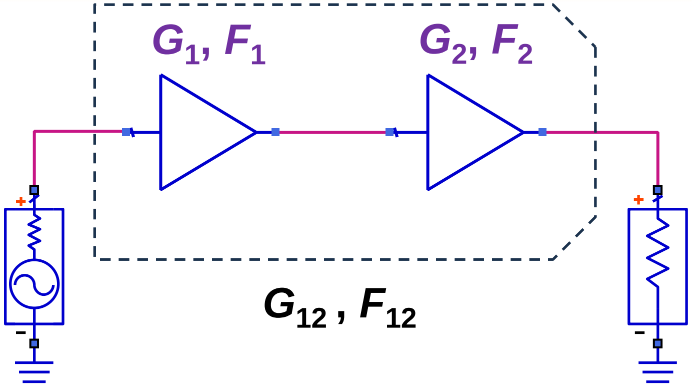


$$\lim_{n\to\infty} F_{\mathrm{n}} = \frac{F - G^{-1}}{1 - G^{-1}} = 1 + M \quad \rightarrow \boxed{M = \frac{F-1}{1-G^{-1}}}$$

Noise Measure

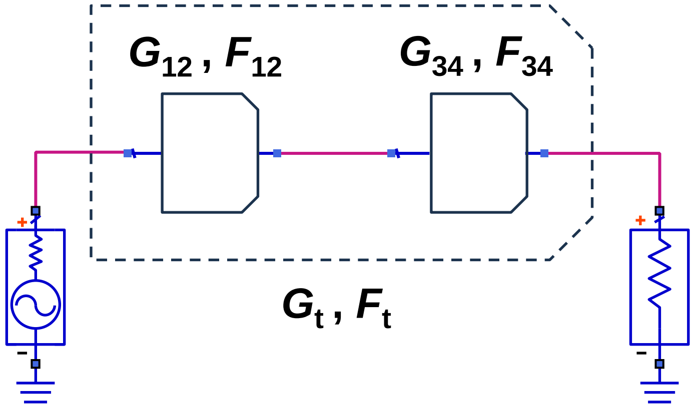
- *M* is independent of the circuit topology (e.g., common-emitter vs. common-base)
- *M* is independent of embedding or pre-embedding (passive, lossless) circuits that might be used for gain boosting or degeneration [11].
- A multi-stage LNA will have the same *M* as that of the transistors used in it.
- The goal is to find an LNA circuit whose passive element loss degrades *M* the least.

Noise Measure



$$M_{12} = \frac{F_{12} - 1}{1 - \frac{1}{G_1 G_2}} = M_1 + (M_2 - M_1)\frac{G_2 - 1}{G_1 G_2 - 1}$$

$$\text{If } \boxed{M_1 = M_2} \rightarrow M_{12} = M_1$$



$$M_t = \frac{F_t - 1}{1 - \frac{1}{G_1 G_2 G_3 G_4}} = M_{12} + (M_{34} - M_{12})\frac{G_3 G_4 - 1}{G_1 G_2 G_3 G_4 - 1}$$

$$M_t = M_{12} = M_1 \quad if \quad M_{12} = M_{34}$$

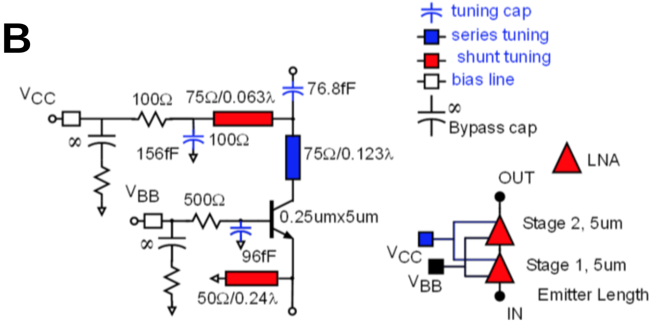
F_t is minimum if all stages have same noise measures.

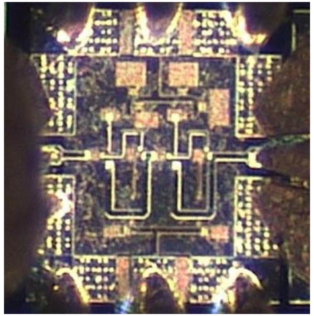
Only minimize the noise measure of the 1st stage.

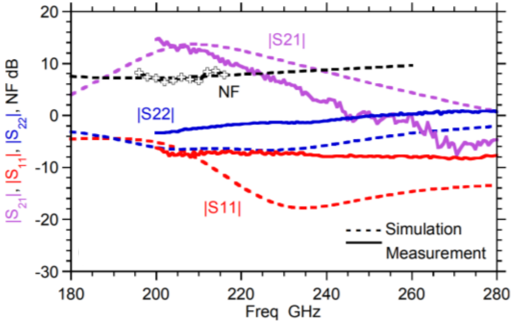
Motivation / Previous Work

Reference◇	Technology	f_T/f_{max} (GHz/GHz)	Topology	3-dB Gain BW (GHz)	Gain† (dB)	NF (dB)	P_{DC} (mW)	Area (mm^2)
EuMC-2022 [9]	250-nm InP HBT	350/650	2-stage CB	196–216	14.5	6.7–8.1	9.2	0.21
EuMC-2022 [9]	250-nm InP HBT	350/650	4-stage CE	196–216	13	6.8–7.6	19.2	0.28

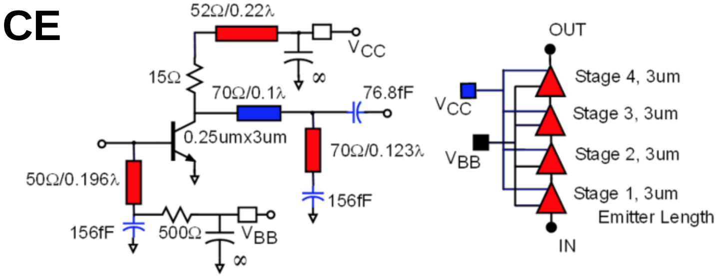
CB

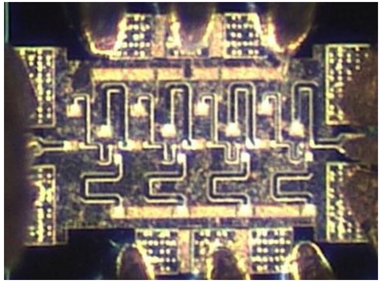


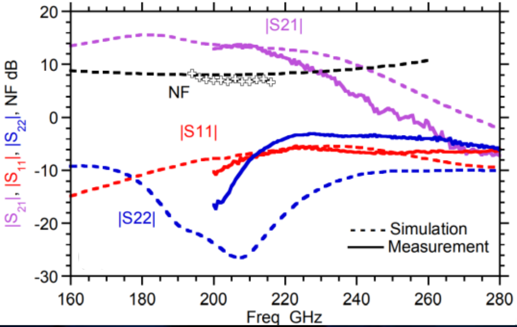




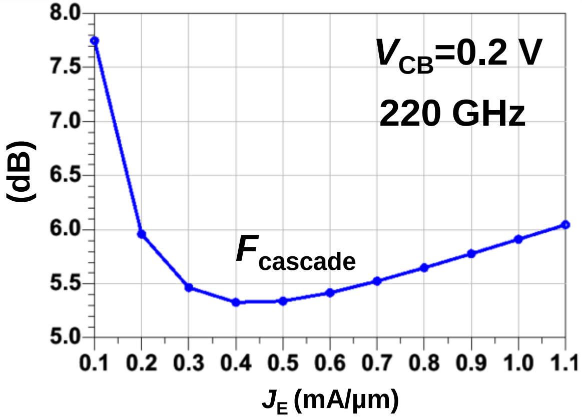
CE

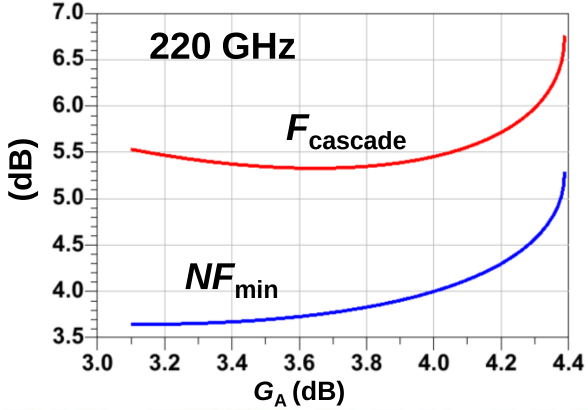




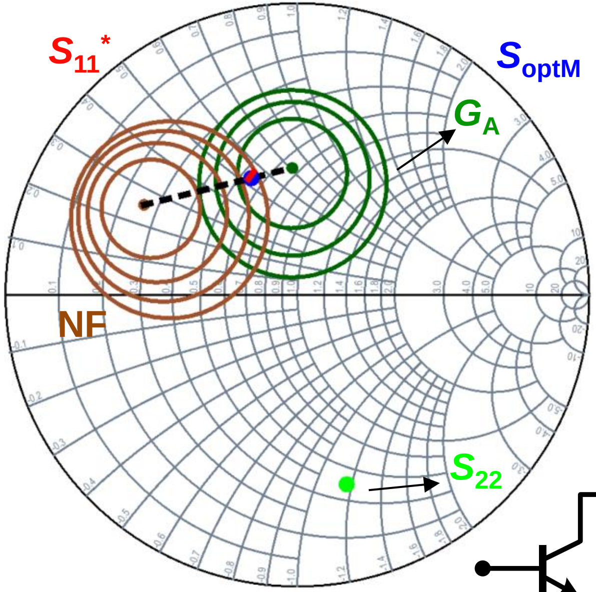


Noise Measure in TSC130



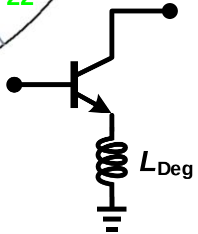


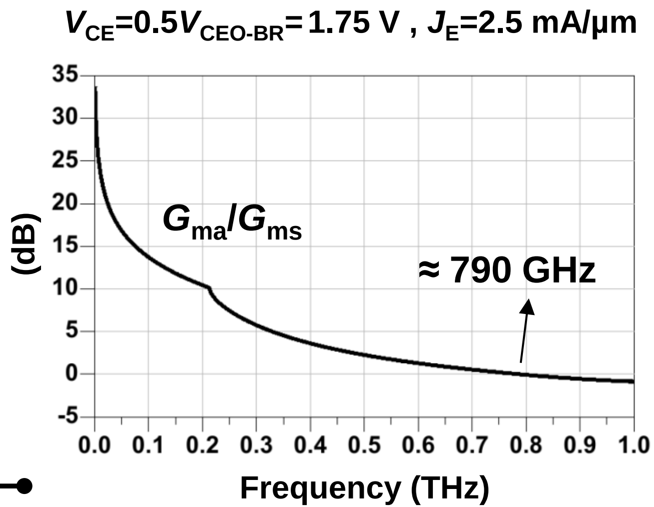
Common Emitter Transistor



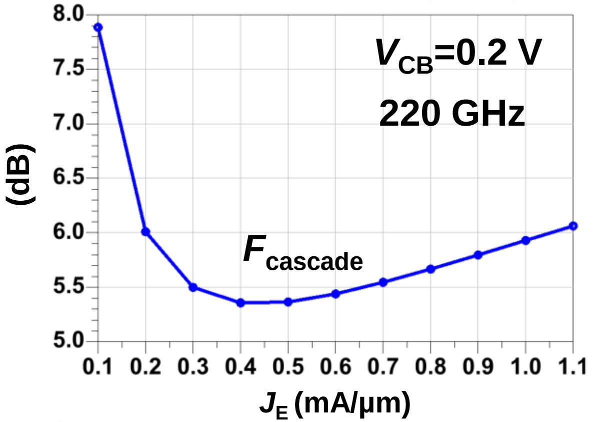
220 GHz

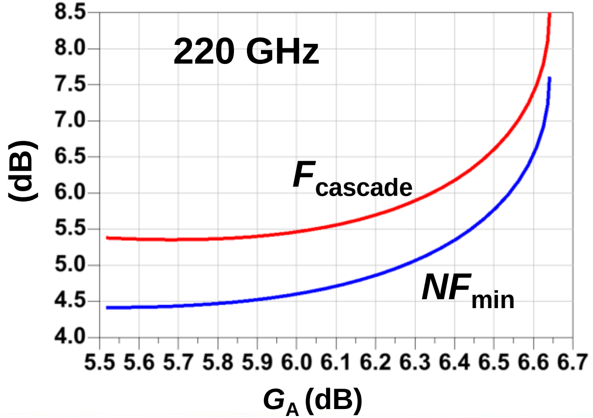
L_{deg}=8 fH



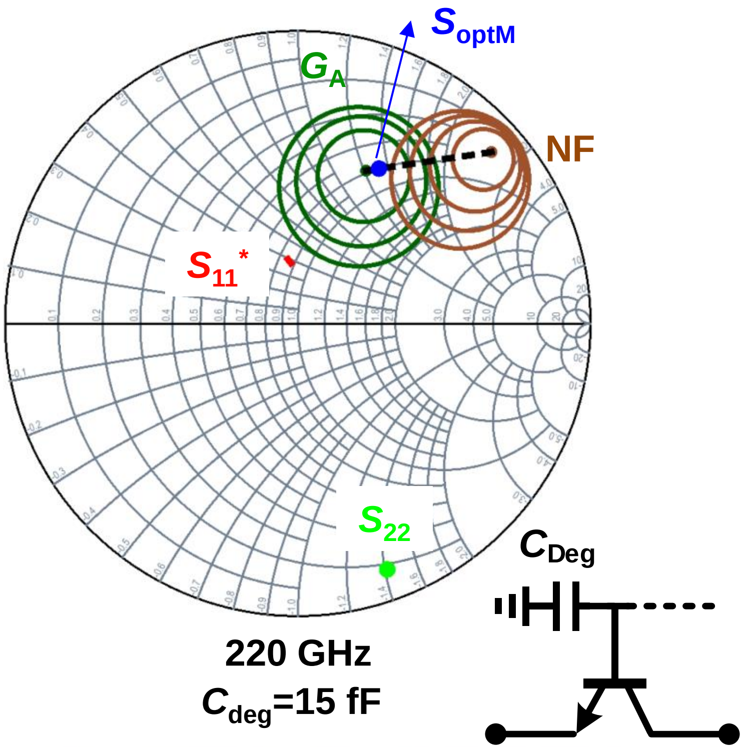


Noise Measure in TSC130

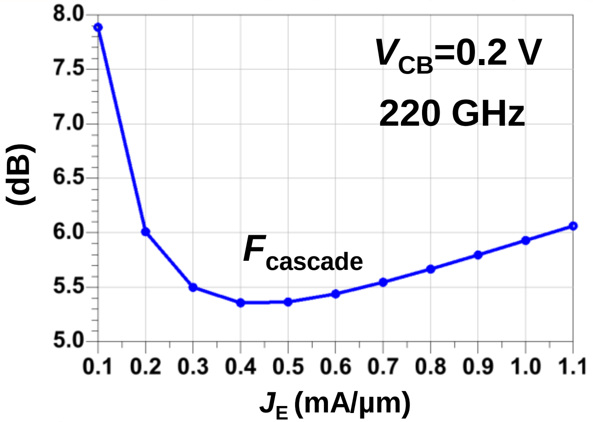


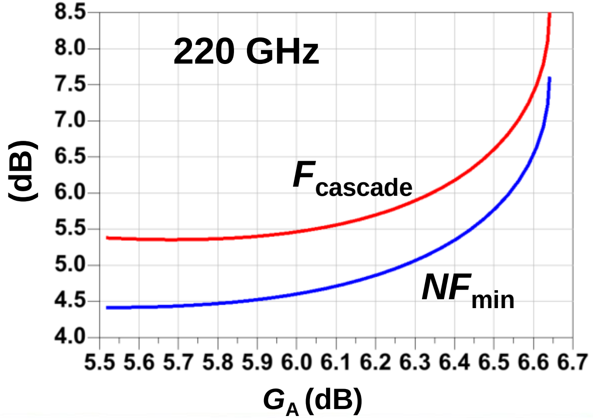


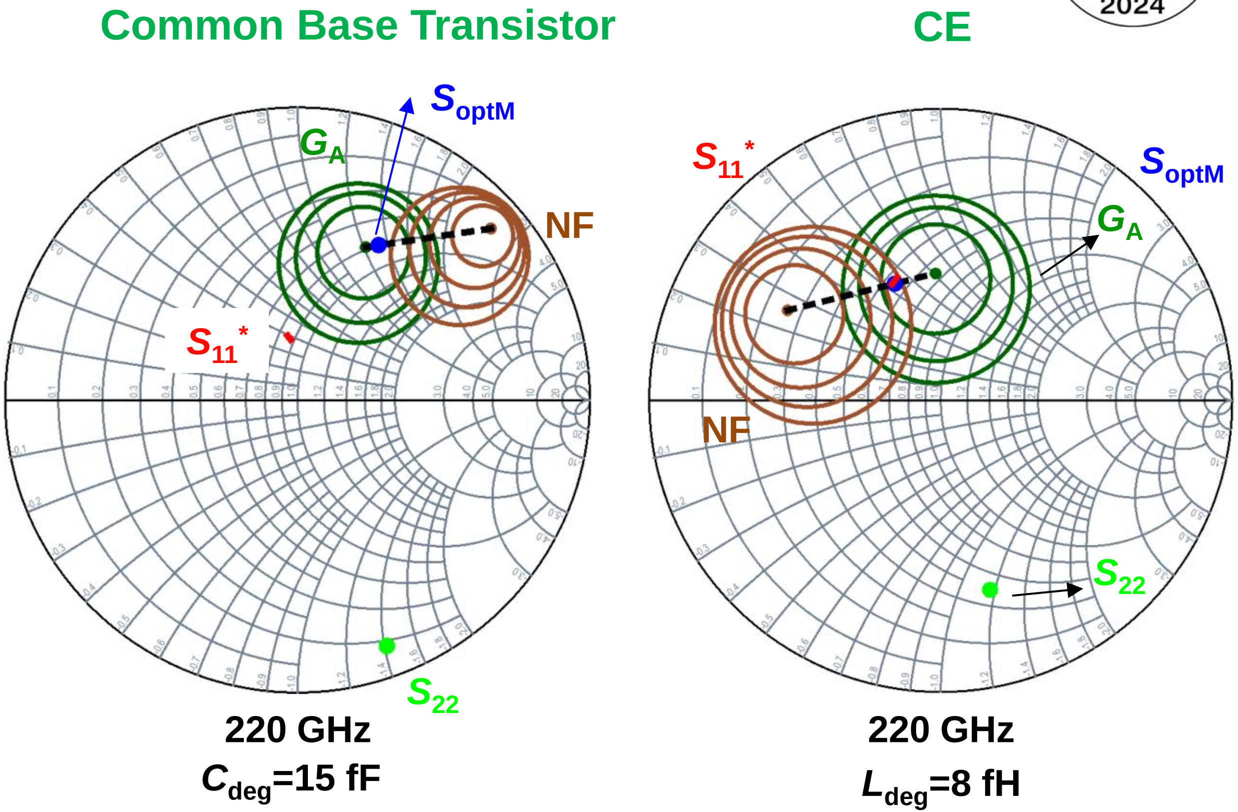
Common Base Transistor



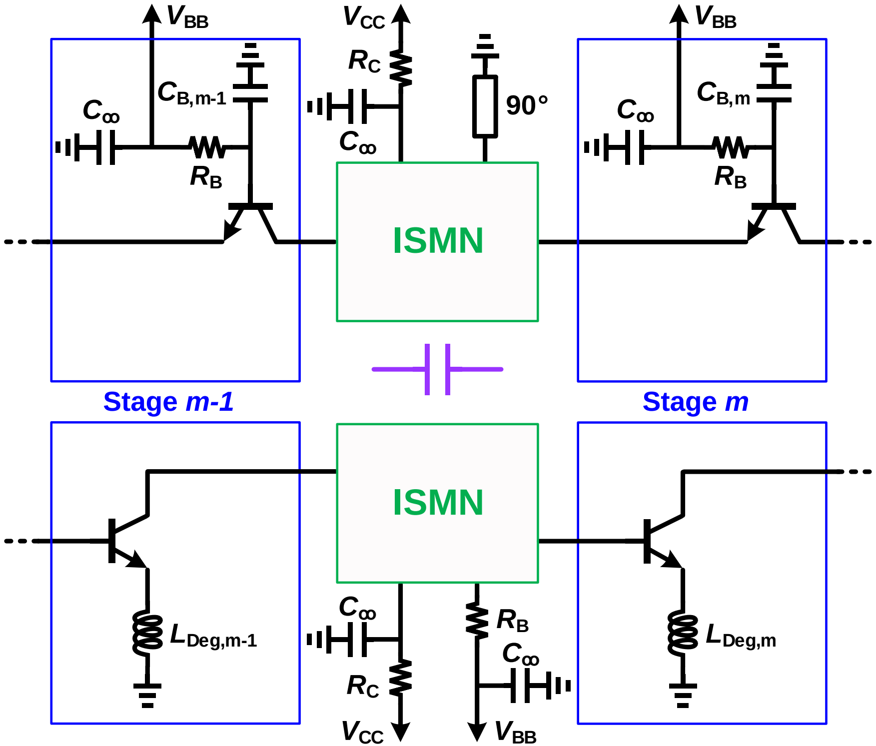
Noise Measure in TSC130

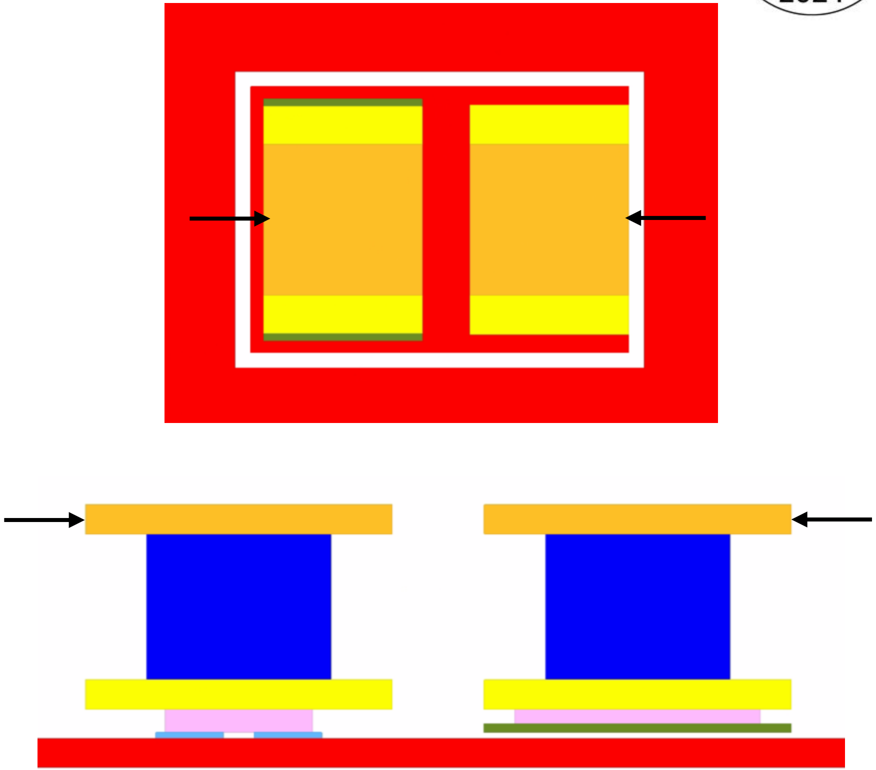




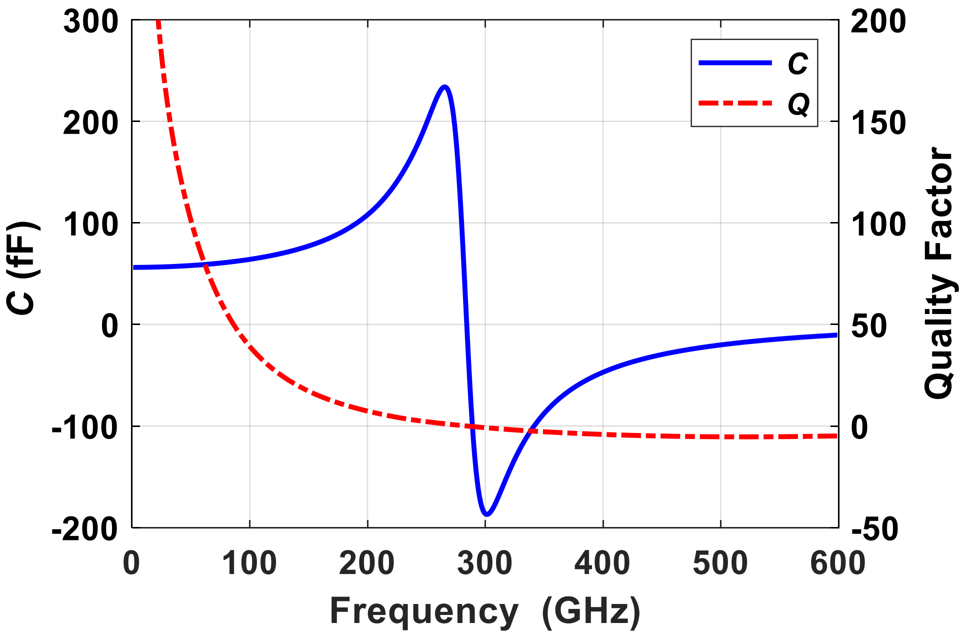


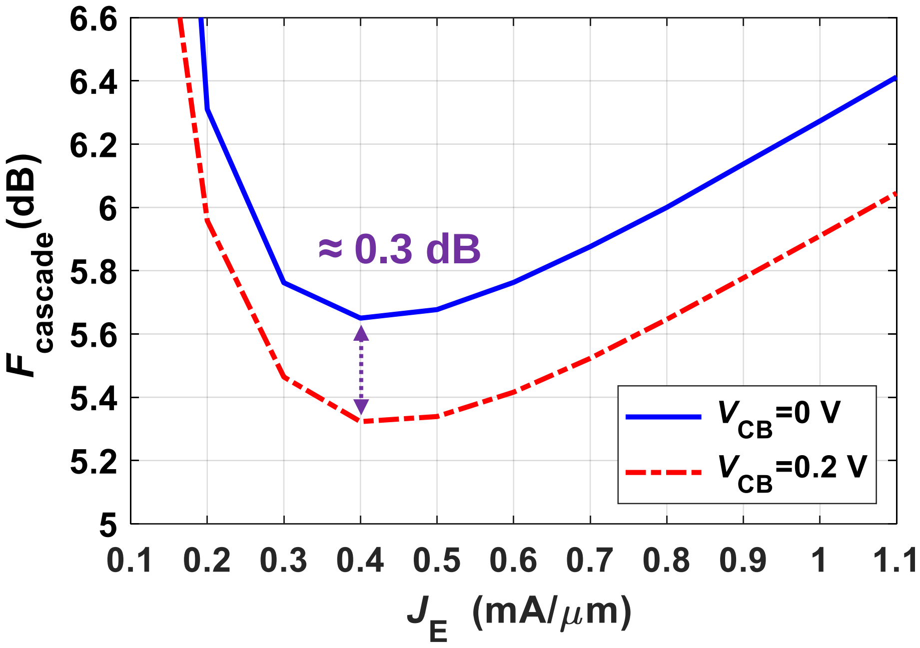
Design Considerations



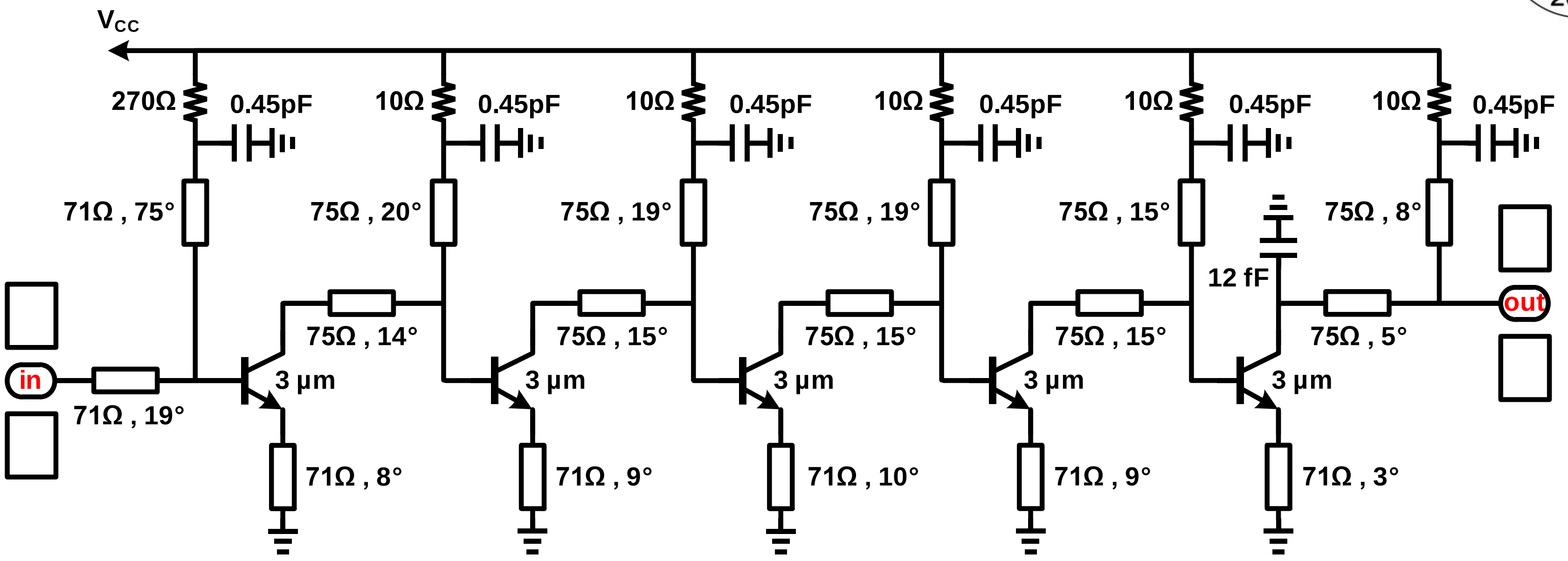


Design Considerations





LNA Schematic



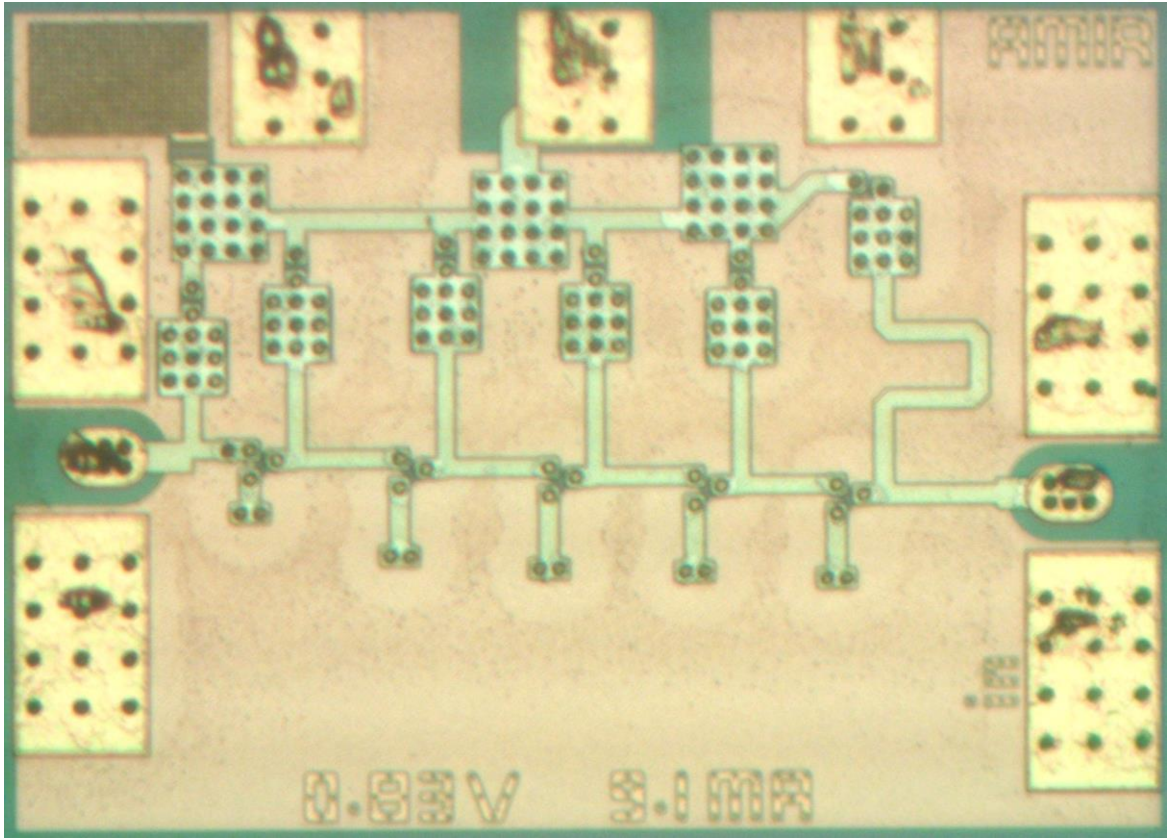
- Identical Stages.
- Slight tuning to compensate for coupling and EM parasitic.

LNA Layout

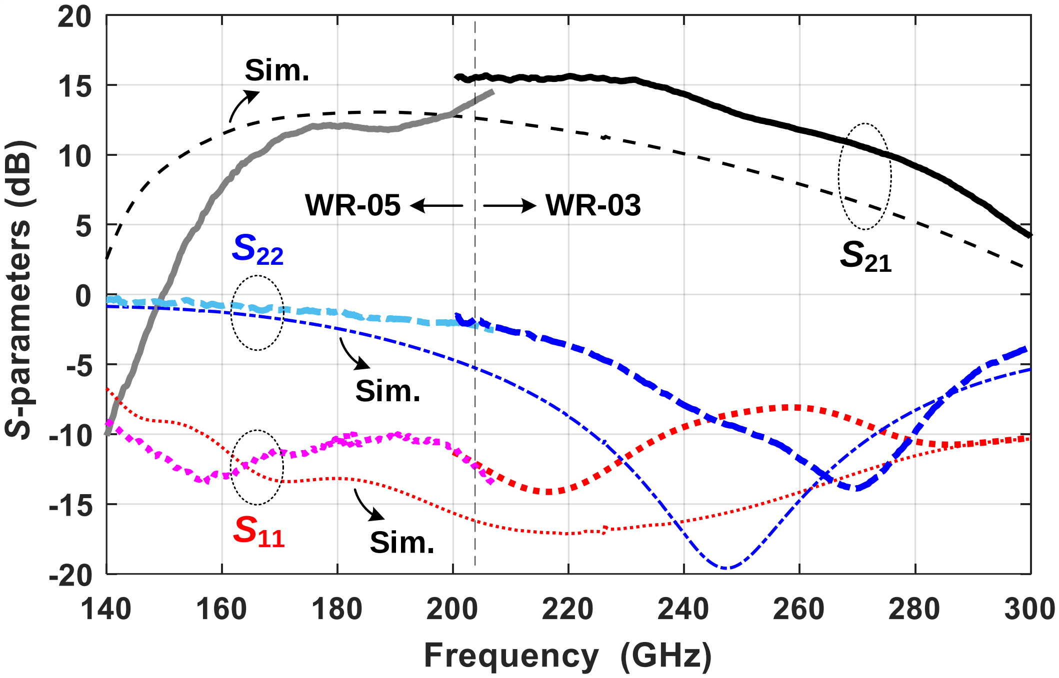
Technology:
Teledyne Scientific
130-nm InP DHBT

Chip Dimensions:
0.6 mm × 0.41 mm

Power Dissipation:
0.83 × 9.1=7.55 mW

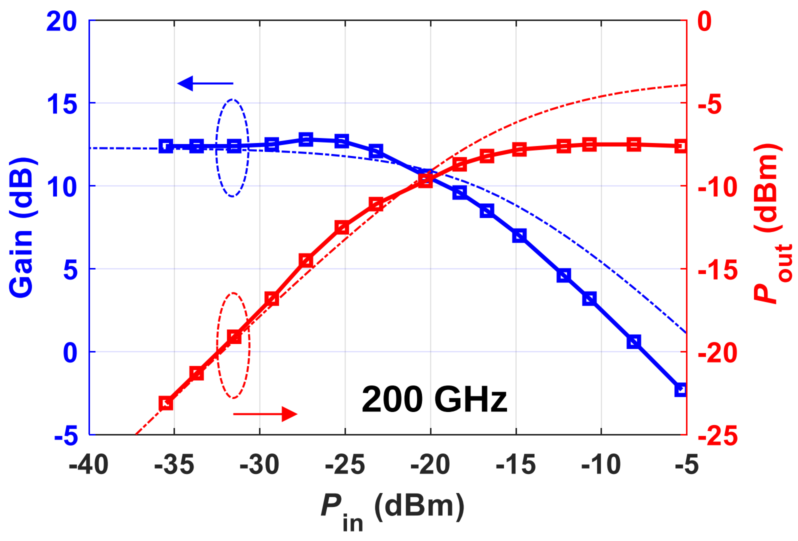


Results

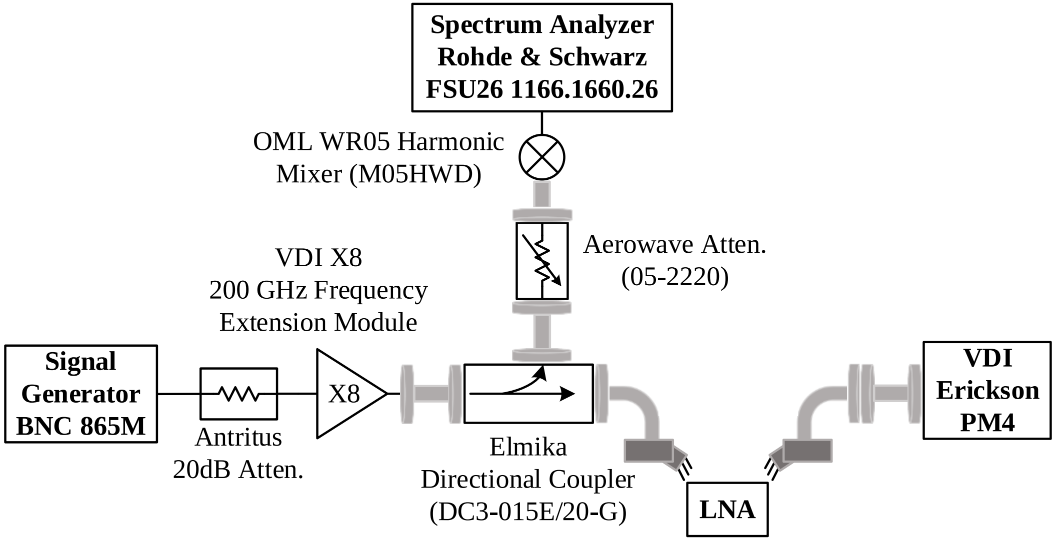


- Keysight PNA-X (N5245A) and OML extenders used.
- For WR-05 Measurements: power at probe tip (−15 dBm) > LNA's input $P_{1\text{-dB}}$ (−23 dBm).

Results

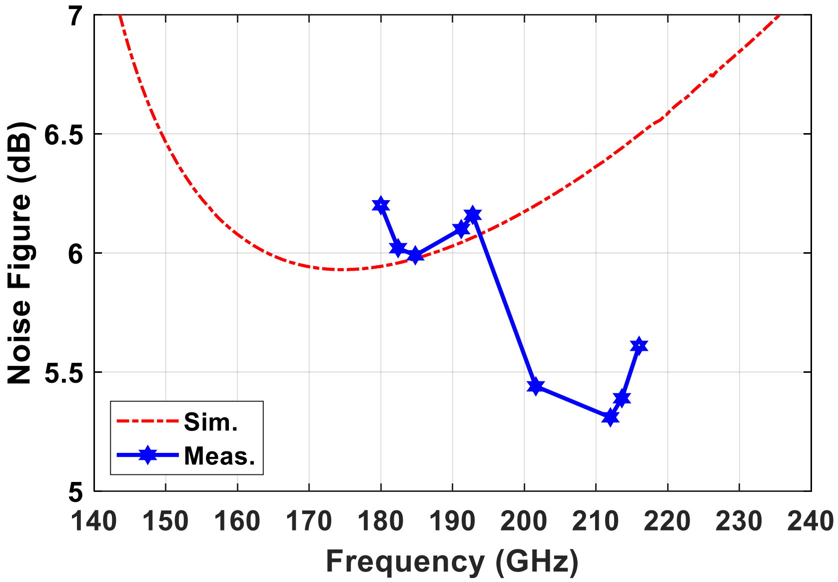


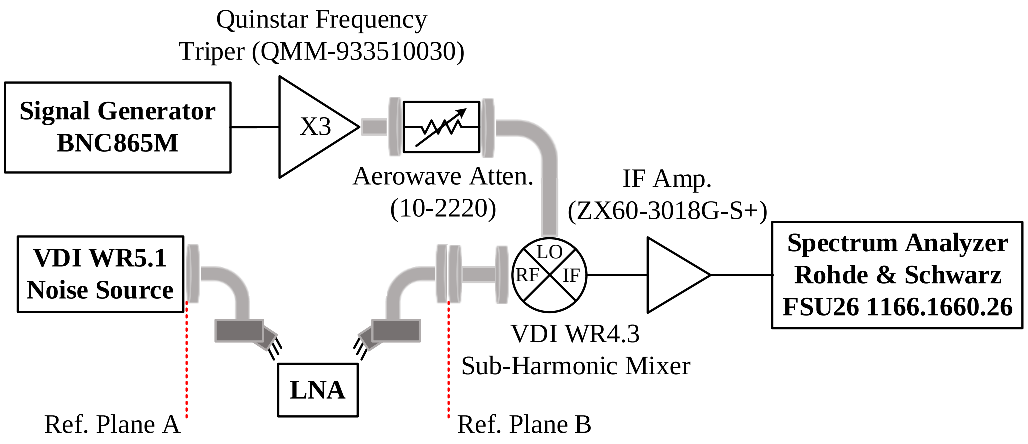
20
15
10
5
0
-5
Gain (dB)
0
-5
-10
-15
-20
-25
P_{out} (dBm)
200 GHz
-40 -35 -30 -25 -20 -15 -10 -5
P_{in} (dBm)



Spectrum Analyzer
Rohde & Schwarz
FSU26 1166.1660.26
OML WR05 Harmonic
Mixer (M05HWD)
Aerowave Atten.
(05-2220)
VDI X8
200 GHz Frequency
Extension Module
Signal
Generator
BNC 865M
Antritus
20dB Atten.
X8
Elmika
Directional Coupler
(DC3-015E/20-G)
LNA
VDI
Erickson
PM4

Results





- TSC's InP HBT processes have consistently shown a lower NF in measurements.
- This includes designs reported by UCSB [9], [15], Teledyne [7], [16], and others [17].

Comparison

Performance Summary of Recently Published Low-Noise Amplifiers Operating Around 200-GHz.

Reference◇	Technology	f_T/f_{max} (GHz/GHz)	Topology	3-dB Gain BW (GHz)	Gain† (dB)	NF (dB)	P_{DC} (mW)	Area (mm^2)
EuMC-2022 [9]	250-nm InP HBT	350/650	2-stage CB	196–216	14.5	6.7–8.1	9.2	0.21
EuMC-2022 [9]	250-nm InP HBT	350/650	4-stage CE	196–216	13	6.8–7.6	19.2	0.28
EuMC-2021 [18]	130-nm SiGe BiCMOS	300/500	7-stage Cascode	236.8–250.8	28.5	13.7–14.2‡	97.2	0.45
IMS-2023 [8]	130-nm SiGe BiCMOS	300/500	3-stage Cascode	183–208	18.1	9–10	35	0.55
IMS-2019 [4]	25-nm InP HEMT	NA	NA	215–225	20	3.9–4.5	NA	NA
MWTL-2024 [19]	35-nm InP HEMT	NA/866	4-stage CE	175–200	19.6	9.8–11.4	22	0.77
JSSC-2021 [20]	35-nm InGaAs mHEMT	> 500/1000	Distributed Amplifier	1–335	11	4.9⋆ @ 160–205 GHz	90	0.53
This Work	130-nm InP HBT	500/1000	5-stage CE	>200–250	15.6	5.3–6.2 @ 180–216 GHz	7.6	0.25

◇Spec values for other works were extracted/estimated from their text or plots. †Peak S_{21}. ‡Simulation result. *BW: Bandwidth. ⋆Average NF.

CONCLUSION

- Common-emitter is the optimal choice for mm-wave LNA design.
  - ✓ Better noise-measure and S_{11} match, better S_{22}, wideband, lower matching losses
- DC coupled design results in a lower NF by eliminating series capacitors.
- At 220-GHz, a 3-µm device in TSC130 features a simulated noise-measure of 5.3 dB, which is ≈1.5 lower than its counterparts in TSC250.
- An LNA with NF of 5.3~6.2 dB over 180-216 GHz, and ≈12~15 dB gain over 180-250 GHz were presented.
  - ✓ Lowest NF reported above 200-GHz for bipolar LNAs

References

[1] G. Xu *et al.*, "THz for 6G communications: vision and challenges," presented at the *IEEE Int. Solid-State Circuits Conf.*, San Francisco, CA, USA, Feb. 20-24, 2022.

[2] M. Elkhouly *et al.*, "Highly integrated *D*-band phased-arrays for 6G wireless communications," presented at the *IEEE Int. Solid-State Circuits Conf.*, San Francisco, CA, USA, Feb. 20-24, 2022.

[3] M. J. W. Rodwell *et al.*, "IC and Array Technologies for 100-300GHz Wireless," 2022 IEEE Custom Integrated Circuits Conference (CICC), Newport Beach, CA, USA, 2022, pp. 01-05.

[4] C. M. Cooke *et al.*, "A 220 GHz dual channel LNA front-end for a direct detection polarimetric receiver," in *IEEE MTT-S Int. Microw. Symp. (IMS)*, Boston, MA, USA, 2-7 June 2019, pp. 508-511

[5] M. Varonen *et al.*, "200-GHz CMOS amplifier with 9-dB noise figure for atmospheric remote sensing," *Electron. Lett.*, vol. 52, no. 5, pp. 369–371, 2016.

[6] E. Chou *et al.*, "Comparative performance of 100–200 GHz wideband transceivers: CMOS vs compound semiconductors," in *IEEE BiCMOS Comp. Semicond. Integr. Circuits Techn. Symp. (BCICTS)*, Monterey, CA, USA, 16-18 Oct. 2023, pp. 292-299.

[7] M. Urteaga, Z. Griffith, M. Seo, J. Hacker, and M. J. W. Rodwell, "InP HBT Technologies for THz Integrated Circuits," *Proceedings of the IEEE*, vol. 105, no. 6, pp. 1051-1067, June 2017.

[8] A. Urain, D. D. Río, R. Torres, and R. Berenguer, "A G-band SiGe BiCMOS LNA with an on-chip and compact temperature compensation biasing circuit," in *IEEE MTT-S Int. Microw. Symp. (IMS)*, San Diego, CA, USA, 11-16 June 2023, pp. 1132-1135.

[9] U. Soylu, A. S.H. Ahmed, M. Seo, A. Farid, and M. J.W. Rodwell, "200-GHz low-noise amplifiers in 250 nm InP HBT technology," in *Europ. Microw. Integr. Circuits Conf. (EuMIC)*, London, United Kingdom, 03-04 April 2022, pp. 129-132.

[10] M. Urteaga *et al.*, "130-nm InP DHBTs with ft >0.52THz and fmax >1.1THz," in *Proc. 69th Annu. Device Res. Conf.*, Santa Barbara, CA, USA, Jun. 2011, pp. 281–282.

[11] H. Haus and R. Adler, "Optimum noise performance of linear amplifiers," *Proc. IRE*, vol. 46, no. 8, pp. 1517-1533, Aug. 1958.

[12] H. Fukui, "Available power gain, noise figure, and noise measure of two-ports and their graphical representations," *IEEE Transactions on Circuit Theory*, vol. 13, no. 2, pp. 137-142, June 1966.

[13] A. Singhakowinta and A. R. Boothroyd, "Gain Capability of Two-port Amplifiers," *Int. J. Electron.*, vol. 21, no. 6, pp. 549-560, Aug. 1966.

[14] N. Baniasadi and A. M. Niknejad, "Noise measure revisited for design of amplifiers close to activity limits," *IEEE Trans. Circuits Systems I, Reg. Papers*, vol. 69, no. 6, pp. 2276-2283, June 2022.

[15] M. Seo *et al.*,"A 200 GHz InP HBT direct-conversion LO-phase-shifted transmitter/receiver with 15 dBm output power," in *IEEE MTT-S Int. Microw. Symp. (IMS)*, Atlanta, GA, USA, 6-11 June 2021, pp. 378-381.

[16] J. Hacker *et al.*, "THz MMICs based on InP HBT technology," in *Proc. IEEE Int. Microw. Symp.*, Anaheim, CA, USA, May 2010, pp. 1126–1129.

[17] K. Eriksson, S.E. Gunnarsson, V. Vassilev, and H. Zirath, "Characterization of *H*-Band (220–325 GHz) amplifiers in a 250-nm InP DHBT technology," *IEEE Trans. THz Science Techn.*, vol. 4, no. 1, pp. 56–64, Jan. 2014.

[18] Md. Najmussadat *et al.*, "Design of a 240-GHz LNA in 0.13 μm SiGe BiCMOS Technology," in *Europ. Microw. Integr. Circuits Conf. (EuMIC)*, Utrecht, Netherlands, 10-15 Jan. 2021, pp. 17-20.

[19] J. Tao, W. Lee, J. S. Chien, and J. F. Buckwalter, "A 185-GHz low-noise amplifier using a 35-nm InP HEMT process," *IEEE Microw. Wireless Compon. Lett.*, Early Access, pp. 1–3, Jan. 2024.

[20] F. Thome and A. Leuther, "First demonstration of distributed amplifier MMICs with more than 300-GHz bandwidth," *IEEE J. Solid-State Circuits*, vol. 56, no. 9, pp. 2647-2655, Sept. 2021.

Thank You!

Questions?