Recent Developments in HEMT Cryogenic Low-noise Amplifiers

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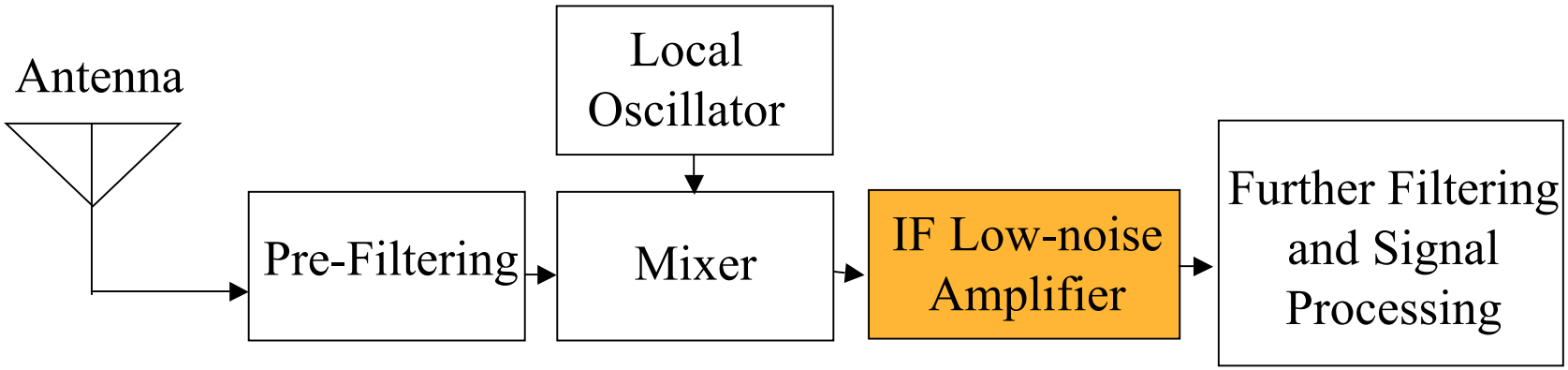
Low-noise Amplifiers for Space Research

- In radio astronomy, observations at radio wavelengths are made to probe our galaxy: planets, stars, black holes, etc.
- Ultra-low-noise amplification is part of a crucial step to detect the small signals from the sky.



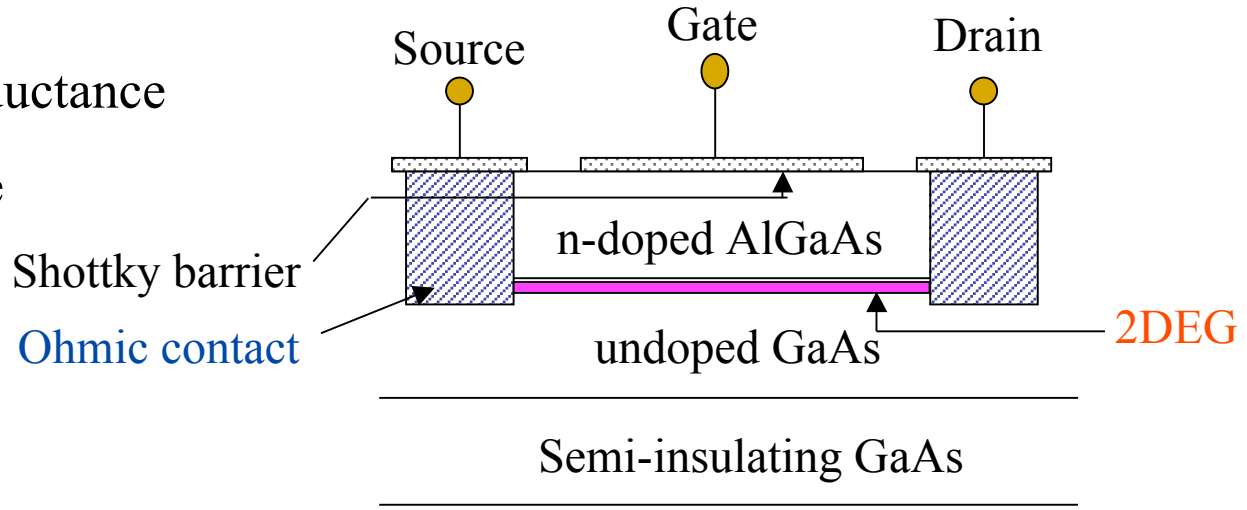
Outline

- High Electron Mobility Transistors (HEMTs)
  - Heterojunction Structure
  - Energy Bands
  - Two-dimensional Electron Gas (2DEG)
- HEMTs for cryogenic low-noise amplifications
- Recent development:

  State-of-the-art LNAs in Radio Astronomy Receivers

From MESFETs to HEMTs…

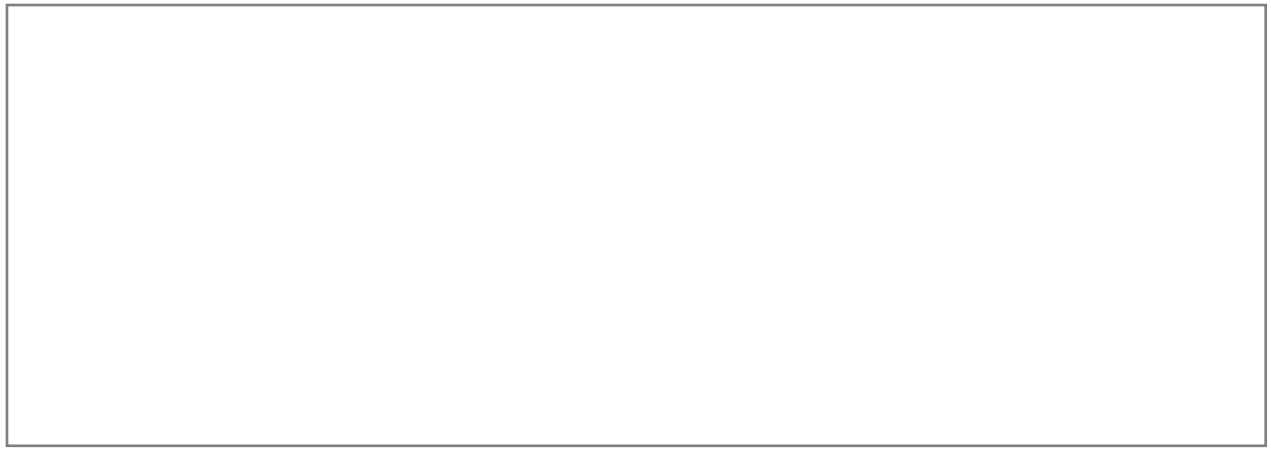
- *High Mobility Electron Transistors* (HEMTs) outperform MESFETs in noise figure, output power and high frequency operations.
- *Heterojunction* in HEMT replaces Schottky barrier in MESFET
- Superior electron transport properties due to formation of two-dimensional electron gas (2DEG)
  - High mobility
  - High transconductance
  - Ultra low noise



Energy Bands of HEMT/p-HEMT

Heterojunction: AlGaAs/GaAs

Pseudomorphic HEMT (p-HEMT)
Heterojunction: AlGaAs/InGaAs increases 2DEG sheet density)



Cryogenic LNA with HEMT (1)

- In a HEMT, conduction electrons are *spatially separated* from the donor impurities

  ➡ ionized scattering is suppressed

- Electrons in a 2DEG exhibit very high mobility

<u>High Gain:</u>

High electron mobility leads to high transconductance g_m and high operation frequency (millimeter wavelengths)

<u>Low-noise:</u>

Superior noise temperatures, especially In-P based HEMTs

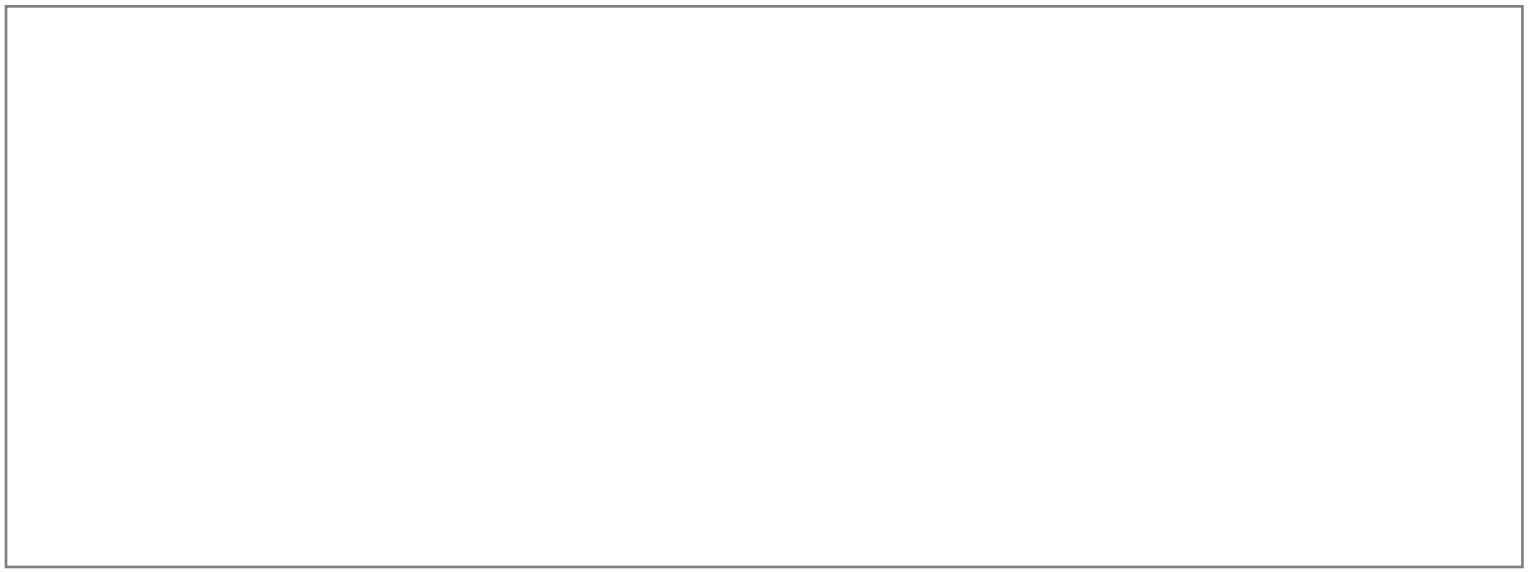
Cryogenic LNA with HEMT (2)

Cryogenic operations:

HEMT amplifiers are cooled to cryogenic temperatures for 2 reasons:

(1) Improvement in electron transport properties

(2) Reduction of thermal noise generated by parasitics



Amplifiers for Radio Astronomy Receivers (1)

Onsala Space Observatory in Sweden

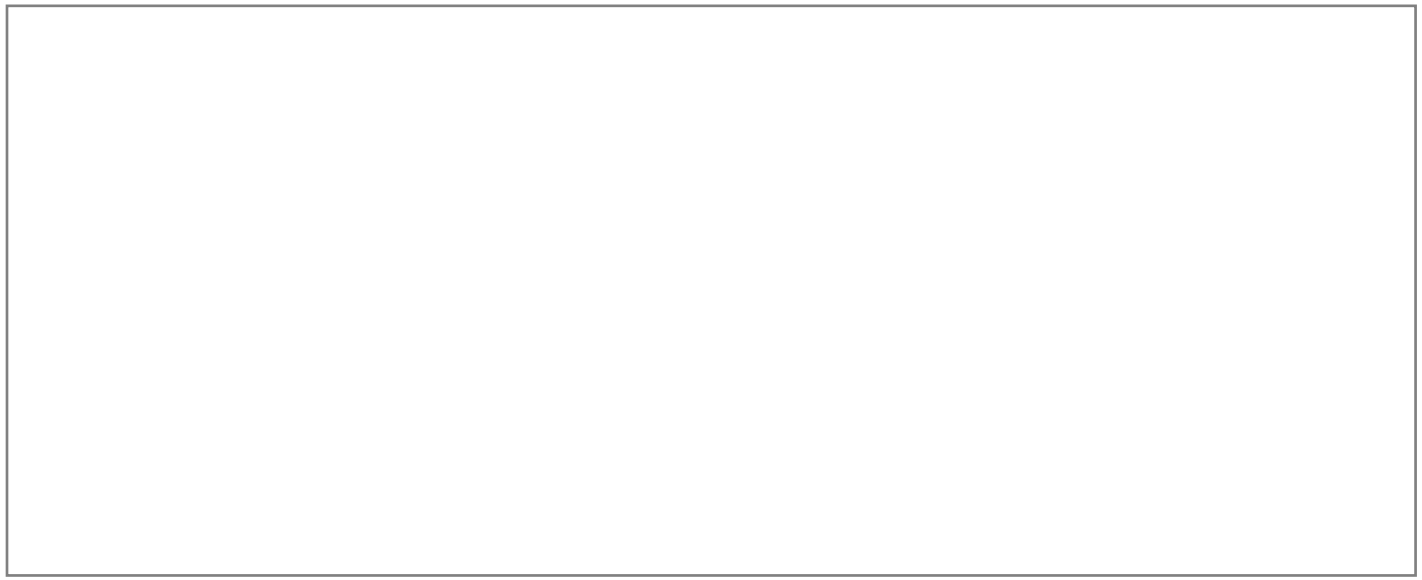
- They developed two state-of-the-art GaAs-based pHEMT (Mitsubishi MGFC4419G) amplifiers.
- Impedance transformation at input/output stages to ensure optimum noise match to the transistor.

BW: 4-8GHz →

BW: 3.4-4.6GHz →

Christophe Risacher, Victor Belitsky, "GaAs HEMT Low-Noise Cryogenic Amplifiers from C-Band to X-Band with 0.7K/GHz Noise Temperature", IEEE Microwave and Wireless Components Letters, vol. 13, no. 3, March 2003.

Amplifiers for Radio Astronomy Receivers (2)



At T= 12K,

- Gain: 26dB±1dB
- Noise temperature: 2.8K
- Gain: 25dB±1.5dB
- Noise temperature: 5.0K

➡ InP (solid) is better then GaAs (dotted) in gain and noise, worse in gain stability

Christophe Risacher, Victor Belitsky, IEEE Microwave and Wireless Components Letters, vol. 13, no. 3, March 2003.

Conclusion

- For low noise and power amplifications, p-HEMT is generally recognized as the best choice.
- InP-HEMTs are promising in better gain and noise, but still await commercialization
- Amplification up to 40GHz: GaAs-HEMTs and p-HEMTs

  above 40GHz: InP-based HEMTs

  100GHz –1 THz: superconductor-insulator-superconductor (SIS) junction devices

  above 1THz: Hot electron bolometers (HEB)