Keck Institute for Space Studies

MMIC Array Receivers and Spectrographs Workshop

Pasadena, CA, July 22, 2008

Prospects in Semiconductors for Focal Plane Arrays

Sander Weinreb,

California Institute of Technology

1. General comments
2. Wafer scale integration
3. Silicon SiGe LNAs'

Spin-On's

Technology development costs money.

Radio astronomy does not have the funding to make fundamental changes in technology and thus relies on developments funded for applications. However a shift has occurred:

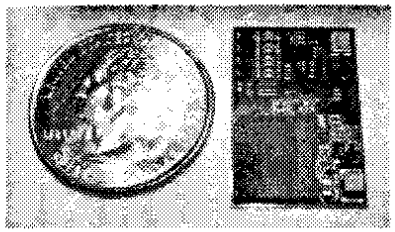
1957-2007 Defense systems, satellite communications

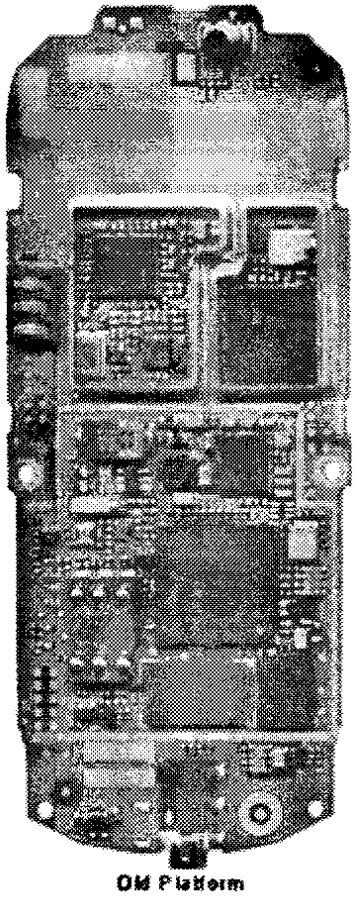
2007-2057 Wireless devices, games, internet service

System on Chip

Why Single-Chip Radio?

- "Integration is like gravity"
  - Already happened in hard-disk drives, ADSL, etc
  - Not a single example of reversal
- "$20 phones"
- Large untapped market in India and China
- More "real estate" space for advanced features
- Better reliability
  - Today, more than half of the total components on a board are analog RF components
- Longer talk time





Old Platform

Microwave semiconductor research relevant to radio astronomy is strong in Europe. These titles are of papers to be presented Oct 27, 2008 at European Microwave Conference in Amsterdam

EuMIC06

Focussed Session: Mm-Wave Technology Directions

Chair: John R. Long, Delft University of Technology

Co-Chair: Klaus Beilenhoff, United Monolithic Semiconductors

EuMIC03-2: Miniaturized Multilayer CPW PHEMT Amplifiers

Q. Sun[1], A. A. Rezazadeh[1], J. Tan[1], T. V. Vo[2], R. A. Davies[2]

[1]The University of Manchester, Manchester, United Kingdom, [2]Filtronic Compound Semiconductors Ltd, Newton Aycliffe, United Kingdom

EuMIC03-3: A Miniaturized Wafer-Scale-Package Demonstrated with Three Enhancement Mode Amplifiers

K. Phan[1], J. Kessler[1], H. Morkner[1], M. Vice[1], L. D. Nguyen[1], J. Roland[1,2]

[1]Avago Technologies, San Jose, USA, [2]Avago Technologies, Fort Collins, USA

EuMIC03-4: Millimetre-Wave Hot-Via Interconnect-based GaAs Chip-Set for Automotive RADAR and Security Sensors

P. Alléaume[1], C. Toussain[2,1], C. Auvinet[1], D. Domnesque[1], M. Camiade[1], P. Quentin[1]

[1]United Monolithic Semiconductors, Orsay, France, [2]XLIM - UMR CNRS

16:40 – 17:00

EuMIC11-3: HBV Quintuplers for Terahertz Applications

J. Stake[1,2], T. Bryllert[2], A. Olsen[2], J. Vukusic[1,2]

[1]Chalmers University of Technology, Göteborg, Sweden, [2]Wasa Millimeter Wave AB, Torslanda, Sweden

17:00 – 17:20

EuMIC11-4: Metamorphic MMICs for Operation Beyond 200 GHz

A. Tessmann, I. Kallfass, A. Leuther, H. Massler, M. Schlechtweg

Fraunhofer IAF, Freiburg, Germany

17:20 – 17:40

EuMIC11-5: Industrial MHEMT technologies for 80 - 220 GHz applications

D. Smith[1], G. Dambrine[2], J. Orlhac[3]

[1]OMMIC, Limeil Brevannes, France, [2]IEMN, Villeneuve d'Ascq, France, [3]EADS Astrium, Toulouse, France

WMO-5 (EuMC)
New RF Instruments for Astronomy

The Herschel Space Observatory: Unveiling the THz Universe

G. Pillbratt, ESA, The Netherlands

Developments in Microwave Technologies for HIFI

W. Jellema, SRON, The Netherlands

Coffee Break

The Planck Mission: The new ESA Cosmic Microwave Background Explorer

M. Bersanelli, University of Milan, Italy

The Atacama Large Millimeter Array (ALMA)

D. Kurz, ESO, Germany

EuMIC06-1: Opportunities at Mm-Wave Frequencies: SIGe or CMOS?

H. Veenstra, M. Notten

Philips, Eindhoven, The Netherlands

EuMIC06-2: Perspectives of (sub-) 32 nm CMOS for Analog/RF and Mm-Wave Applications

M. Dehan[1], B. Parvais[1], A. Mercha[1], V. Subramanian[2], G. Groeseneken[1,2], W. Sansen[2], S. Decoutere[1]

[1]IMEC, Heverlee, Belgium, [2]K.U.Leuven, Heverlee, Belgium

EuMIC06-3: Development of Ultrahigh-Speed InP/GaAsSb/InP DHBTs: Are Terahertz Bandwidth Transistors Realistic?

C. R. Bolognesi, H. Liu, O. Ostinelli, Y. Zeng

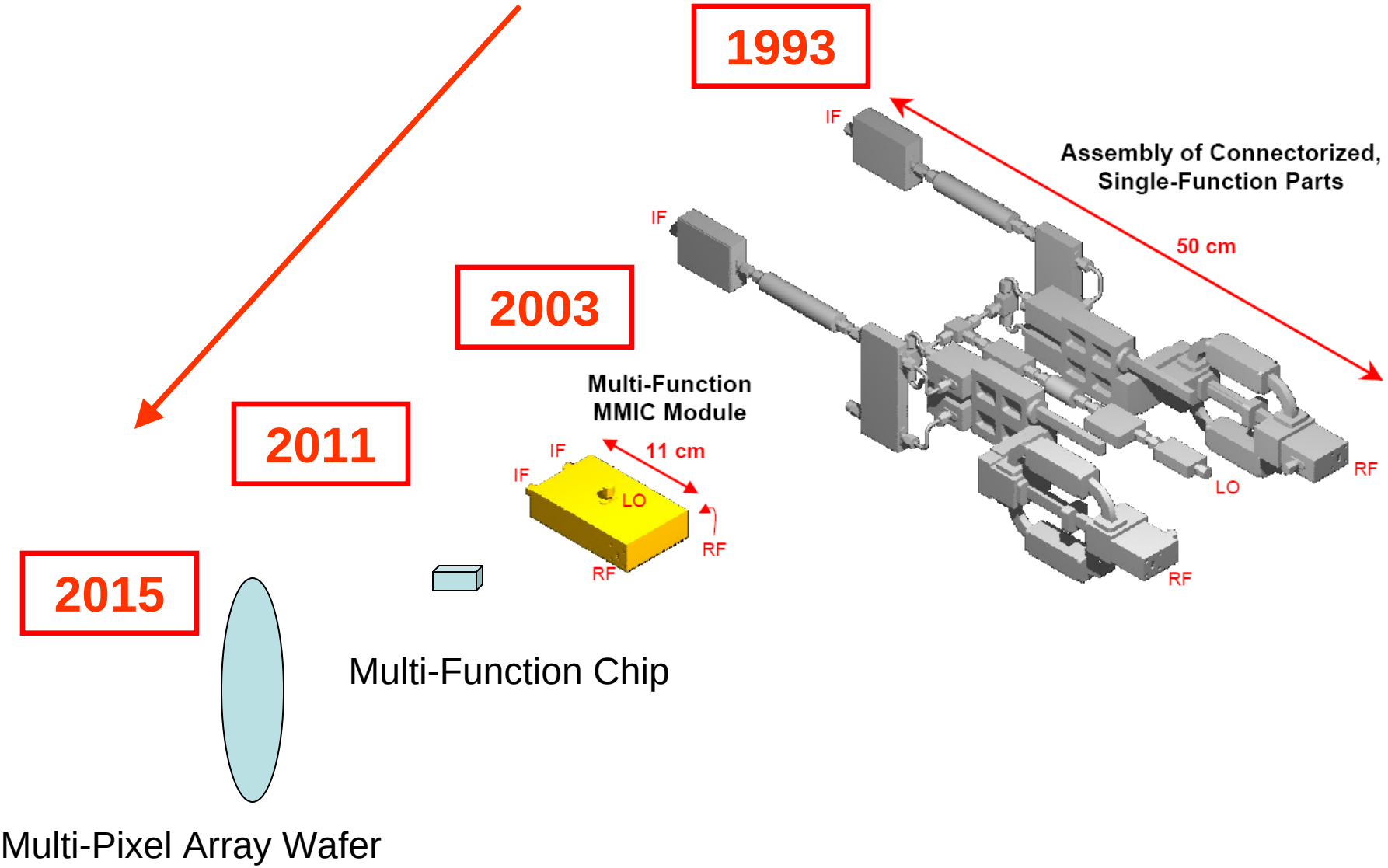
ETH-Zurich, Zurich, Switzerland

MMIC Array Receivers and Spectrographs Workshop

Questions and **my answers**

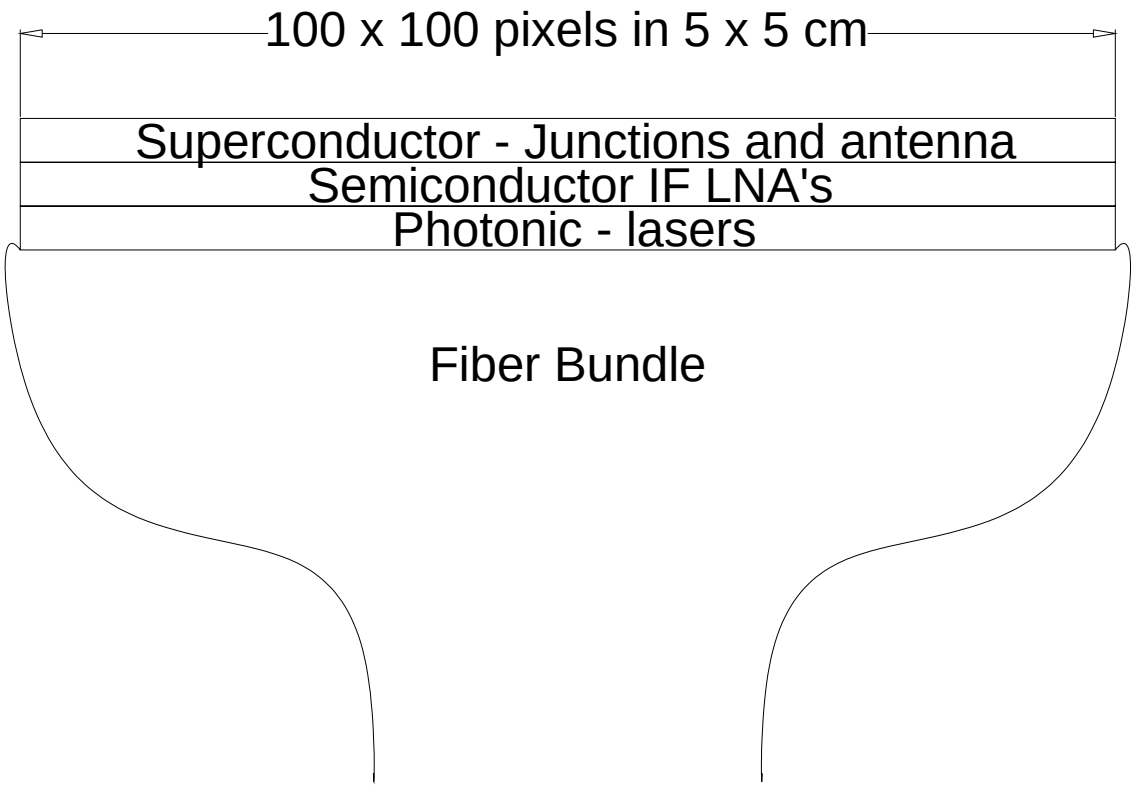
- For continuum, coherent vs incoherent receivers
  - **Crossover frequency dependent upon RFI environment**
- SIS mixers or LNA's
  - **SIS above 100 GHz**
- Downconverters or direct to digital
  - **downconvert to < 10 GHz**
- For LNA's, HEMT, SiGe HBT, or CMOS
  - **SiGe below 10 GHz, HEMT above 10 GHz**
- For LNA's, MMIC or discrete.
  - **discrete below 5 GHz**
- Feed clusters or phased-array feeds
  - **clusters**
- Planar or 3-D (micromachined or lens) feeds
  - **needs optics study**

Packaging Progression



Wafer Scale Integration of SIS/LNA/Photonic 300 GHz Spectrometer Array

1) Hot via interconnections
2) Needs feasibility study leading to 5 year plan
3) Alternative to photonics is miniature flexible printed-circuit ribbons

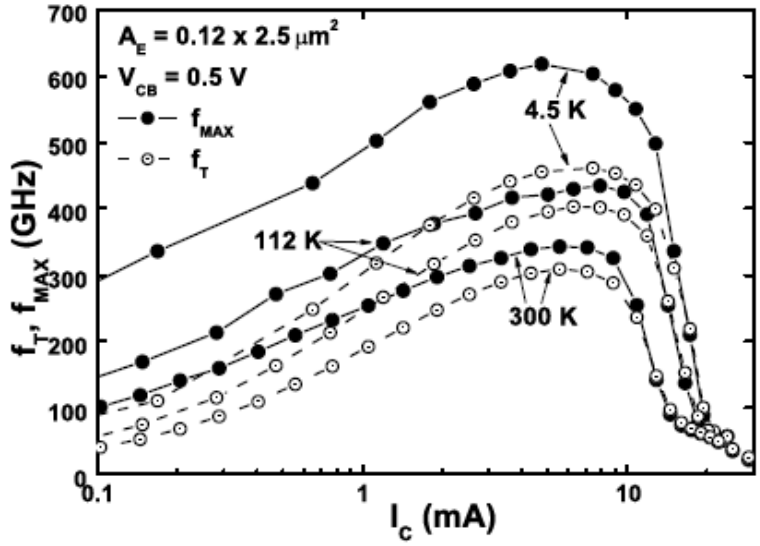


The Case for Silicon (SiGe) HBT and CMOS Transistors

- Very low noise, both HBT and CMOS
- Rapidly improving due to competition for the millimeter wireless and very high data rate digital systems.
- Integrates with CMOS digital systems in the same chip
- Operates from <2K to 470K. Highly radiation tolerant. JPL program for robust electronics.
- Very compact and high yield. Thousands of transistors per chip feasible.
- Very low 1/F gain fluctuations compared to HEMTs. Use of feedback (the microwave op amp) further improves stability.

On the Frequency Limits of SiGe HBTs for TeraHertz Applications

Jiahui Yuan, Ram Krithivasan, John D. Cressler, Marwan H. Khater [1], David C. Ahlgren [2], and Alvin J. Joseph [3]



SiGe HBT Technology Cross-Section

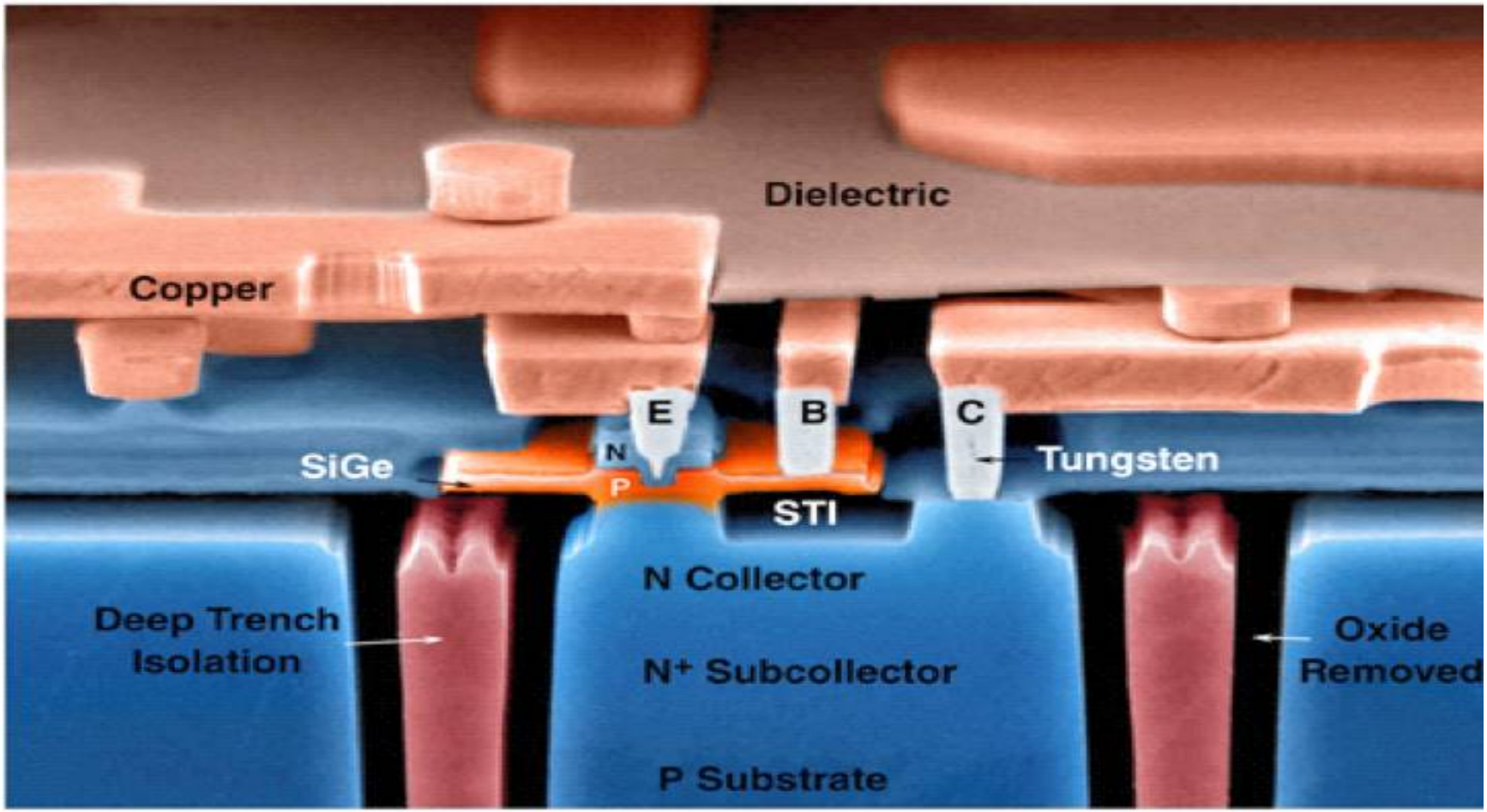
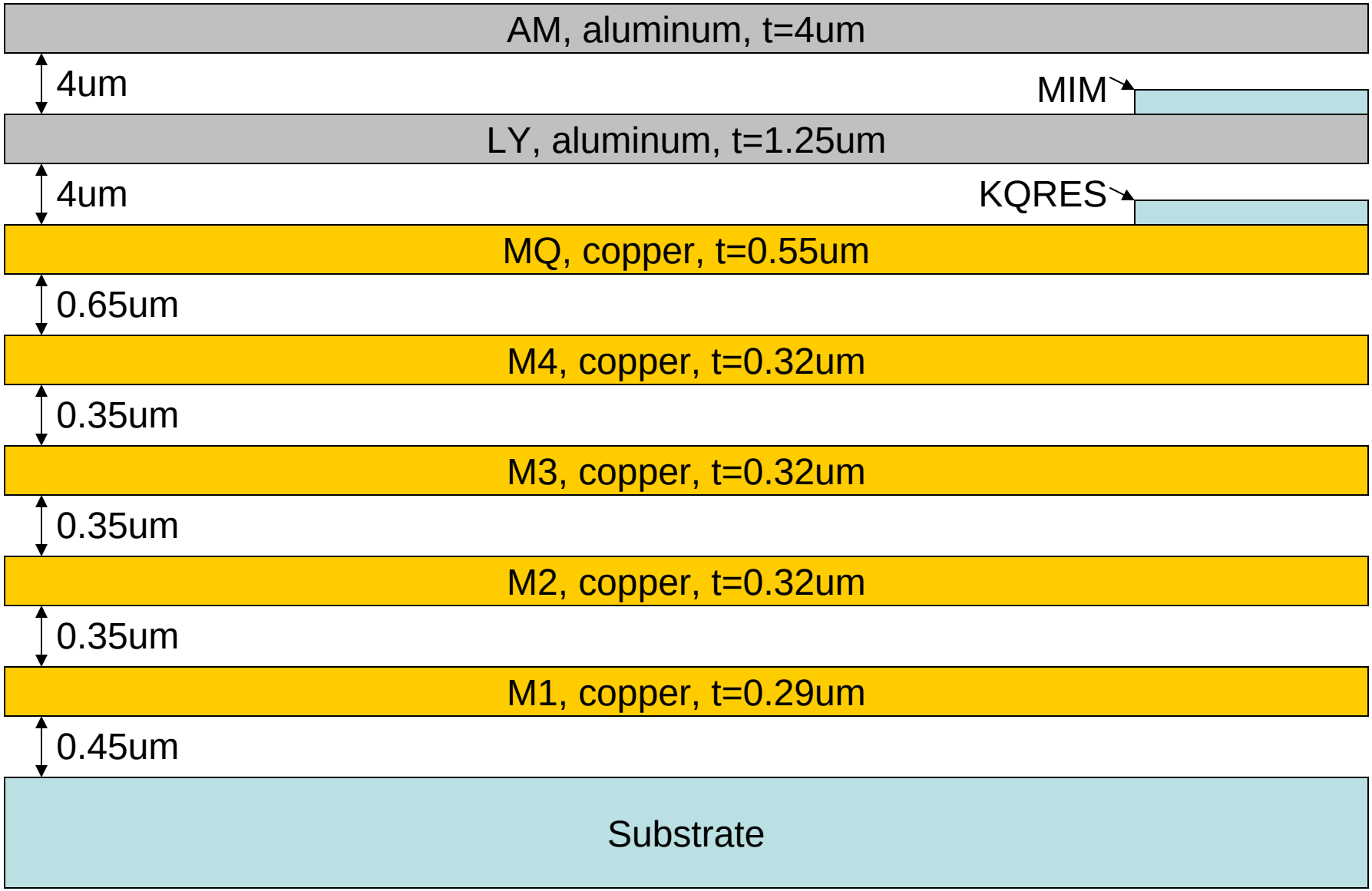
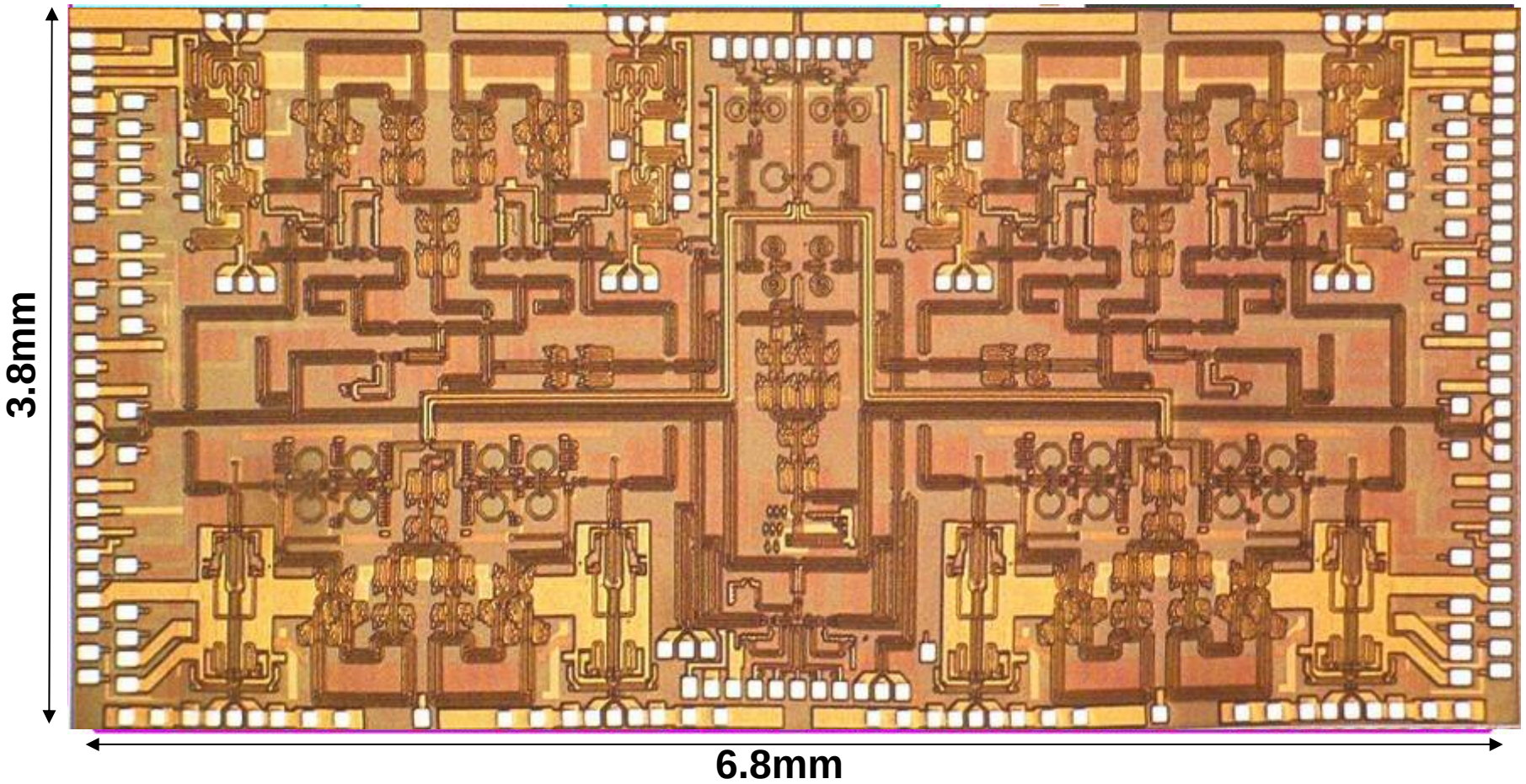


Photo reproduced from: http://users.ece.gatech.edu/~cressler/

8HP Metal Stack



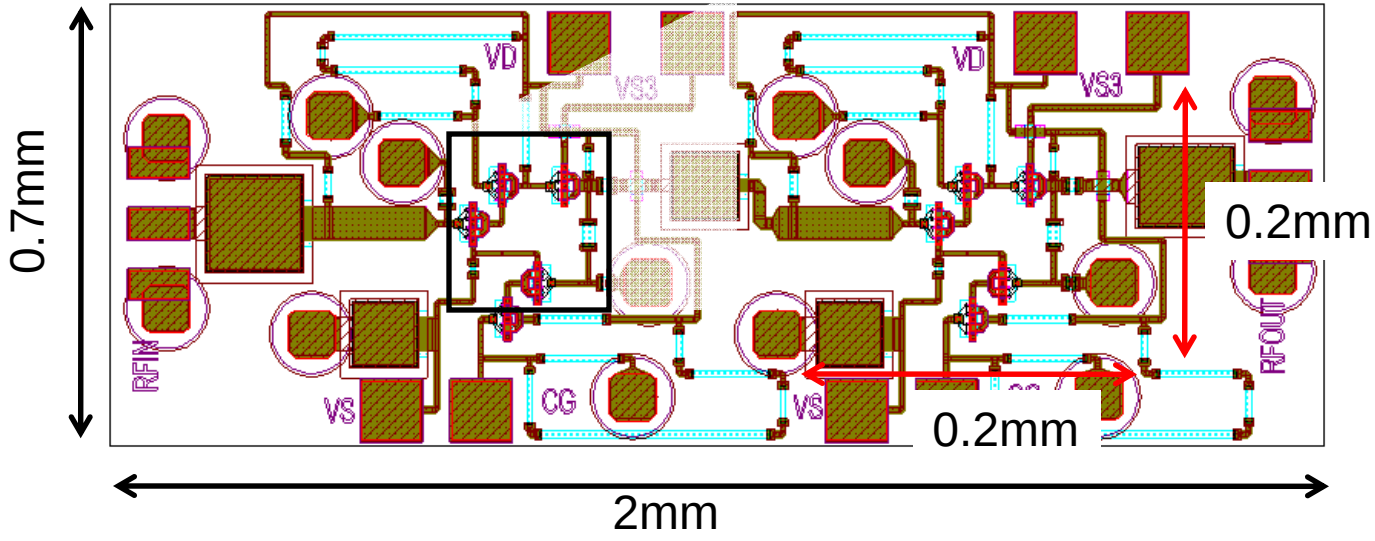
Example of a 77 GHz Transceiver Designed by Hajimiri Group at Caltech



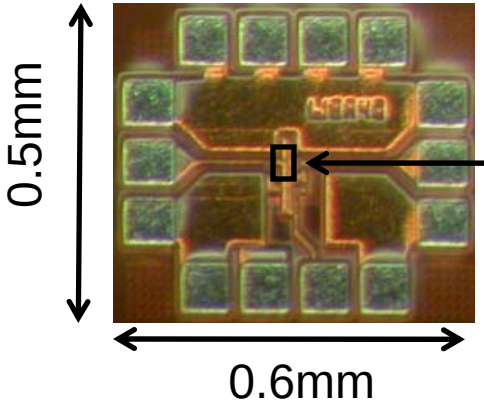
- Process : 0.13µm SiGe BiCMOS process.
- Transistor count: 10,000
- Complete 77GHz phased array transceiver with on-chip antennas

Small Size SiGe Circuits Makes Microwave Feedback Amplifiers Feasible

iii-v MMIC



SiGe MMIC



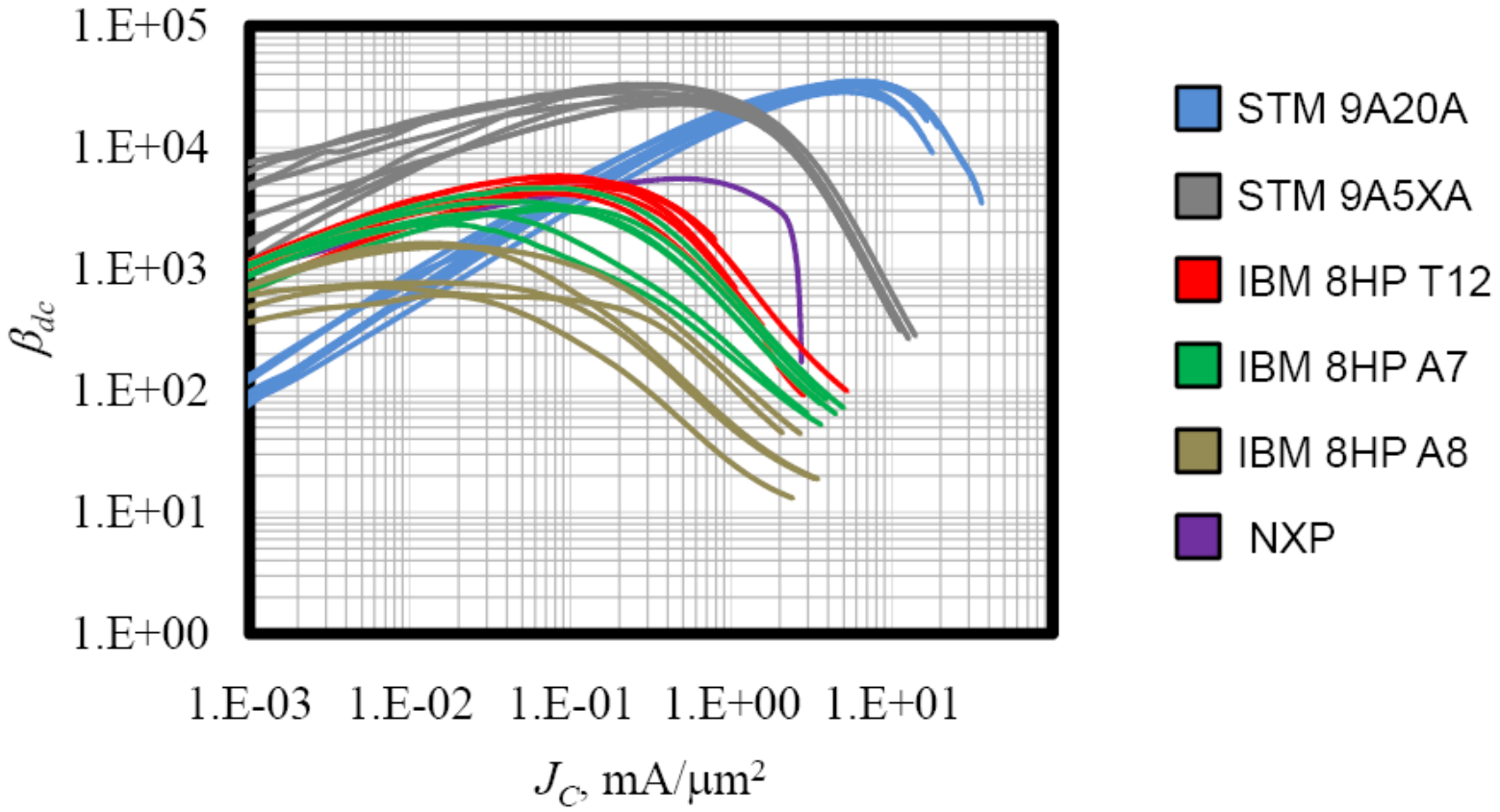
Entire active part of 2 stage amplifier
Including feedback loop within 50umx40um

Assuming an effective dielectric constant of 9, a 0.5mm path length will contribute a 90° phase shift at 40GHz!

SiGe and CMOS processes allow for much more compact feedback loops!

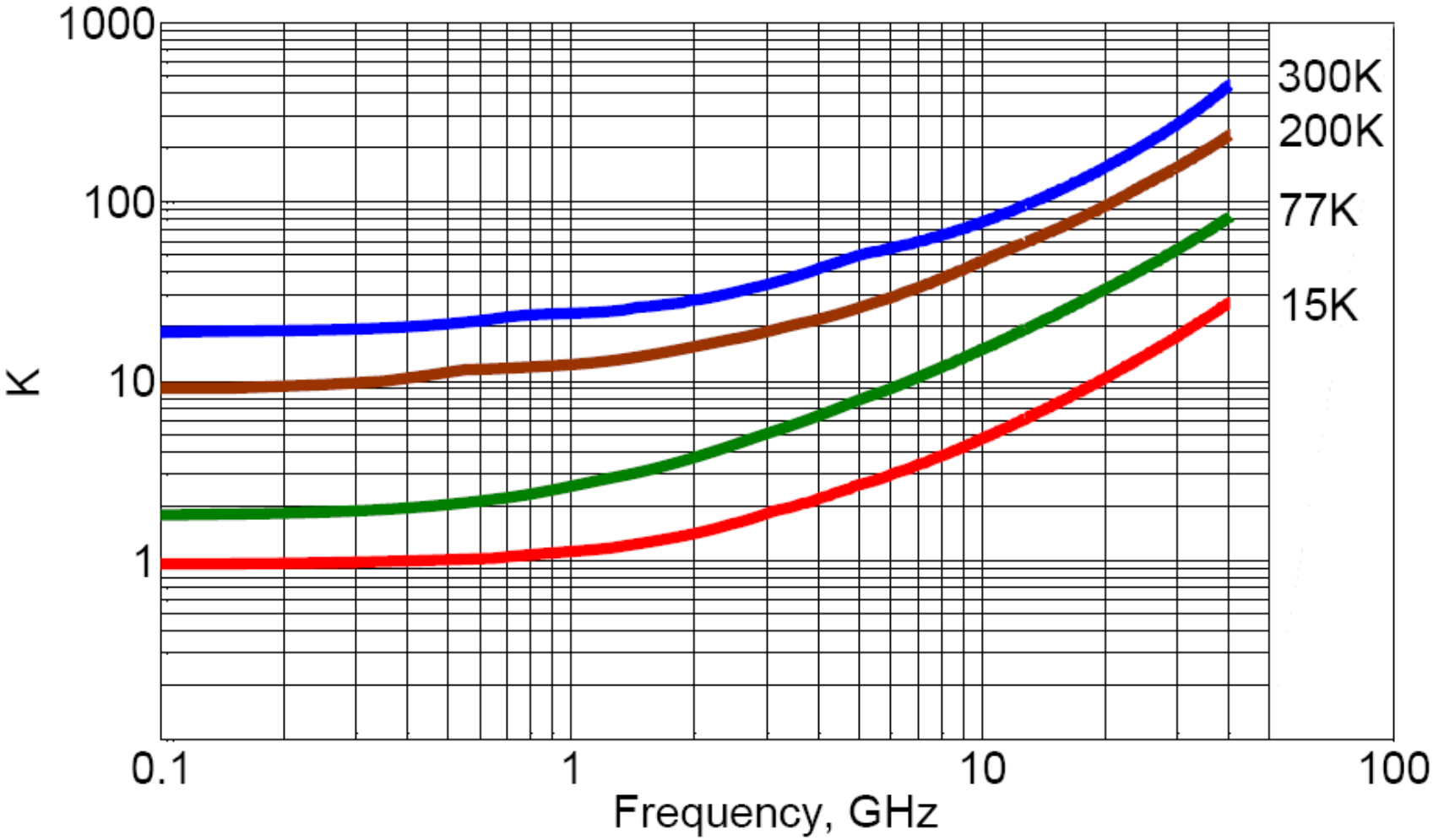
SiGe Cryogenic Low Noise Amplifier Work at Caltech

SiGe LNA's are the Ph.D. topic of Joe Bardin with recent publications on the noise based upon DC measurements, modeling, and wideband mixers. He has designed several wideband and differential LNA's and has measured the current gain of many transistors at 15K as shown below. A low frequency (< 3 GHz) noise temperature as low as 0.6K is predicted.



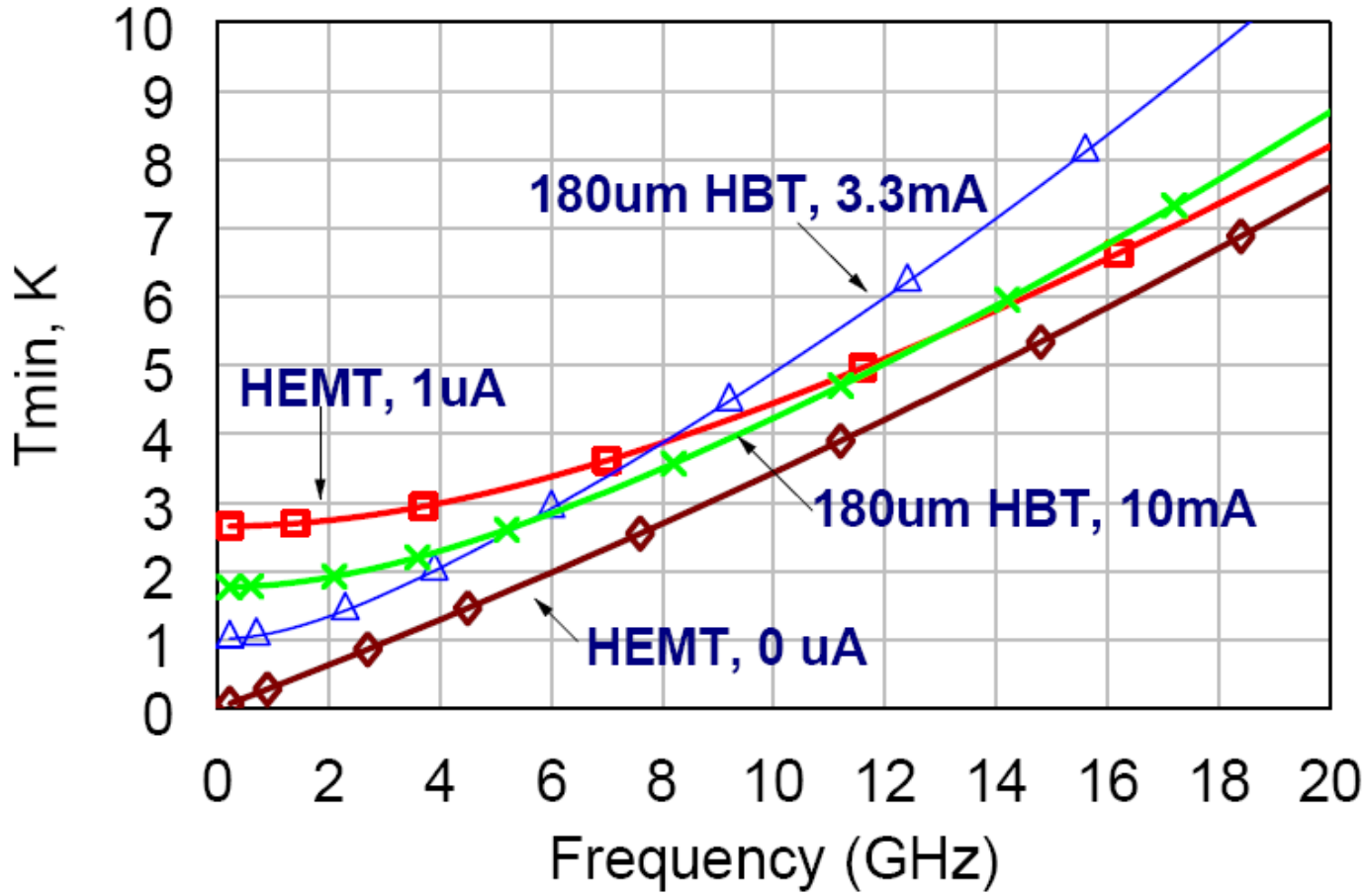
Noise Temperature vs Frequency and Temperature

Cascaded Stages of IBM SiGe Transistors with optimum bias
and generator impedance

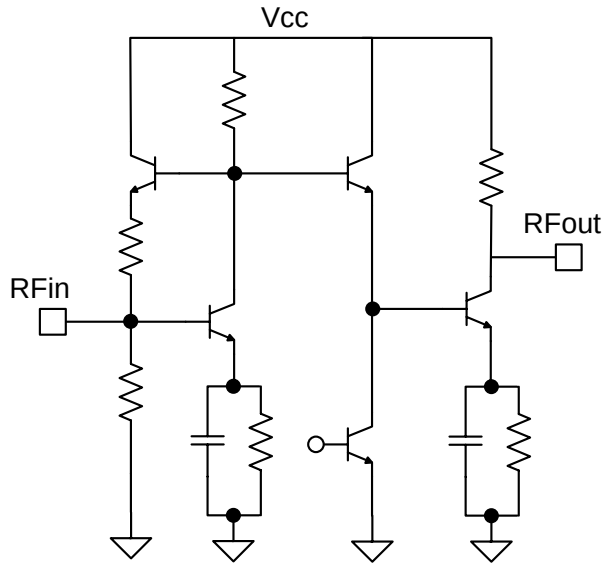


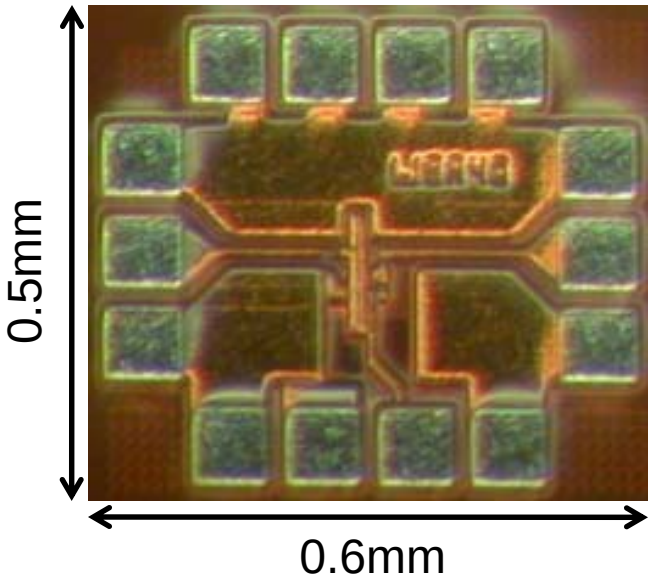
SiGe HBT and InP HEMT Minimum Noise at 15K

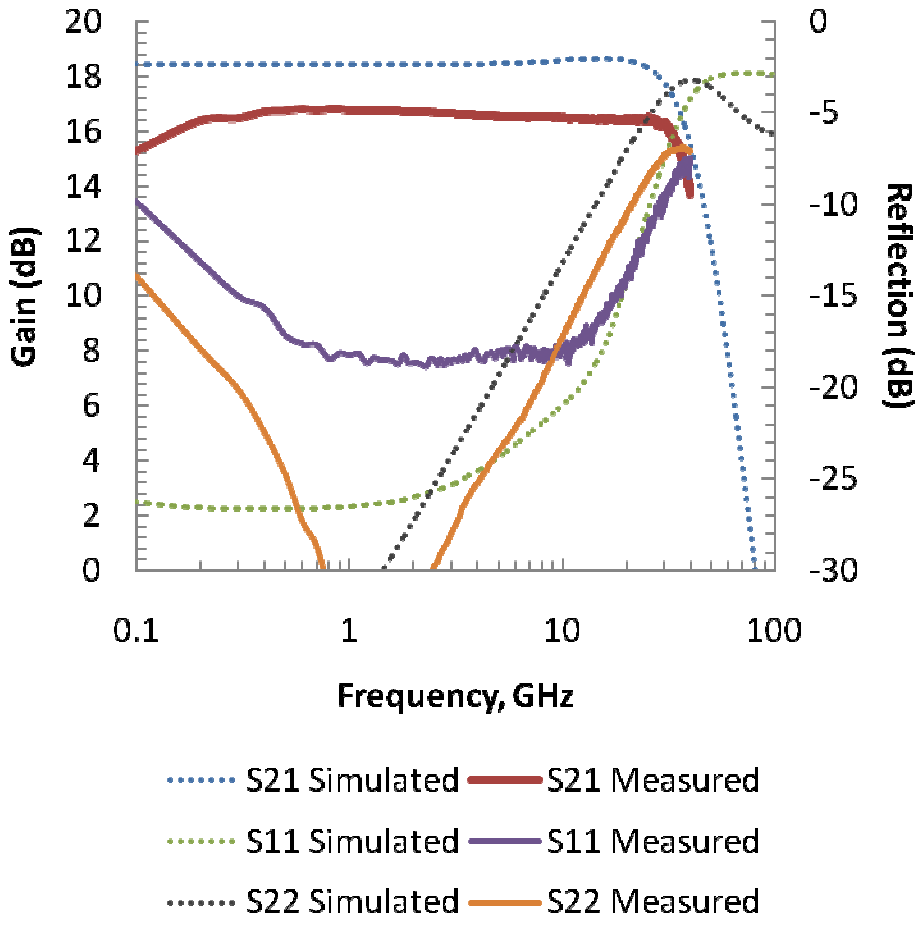
Results below are modeled. As a confirmation of the model an HBT single-stage cascode amplifier has been measured with 2K noise temperature and 28 dB gain at 1 GHz.



WBA40 DC-40GHz Gain Block



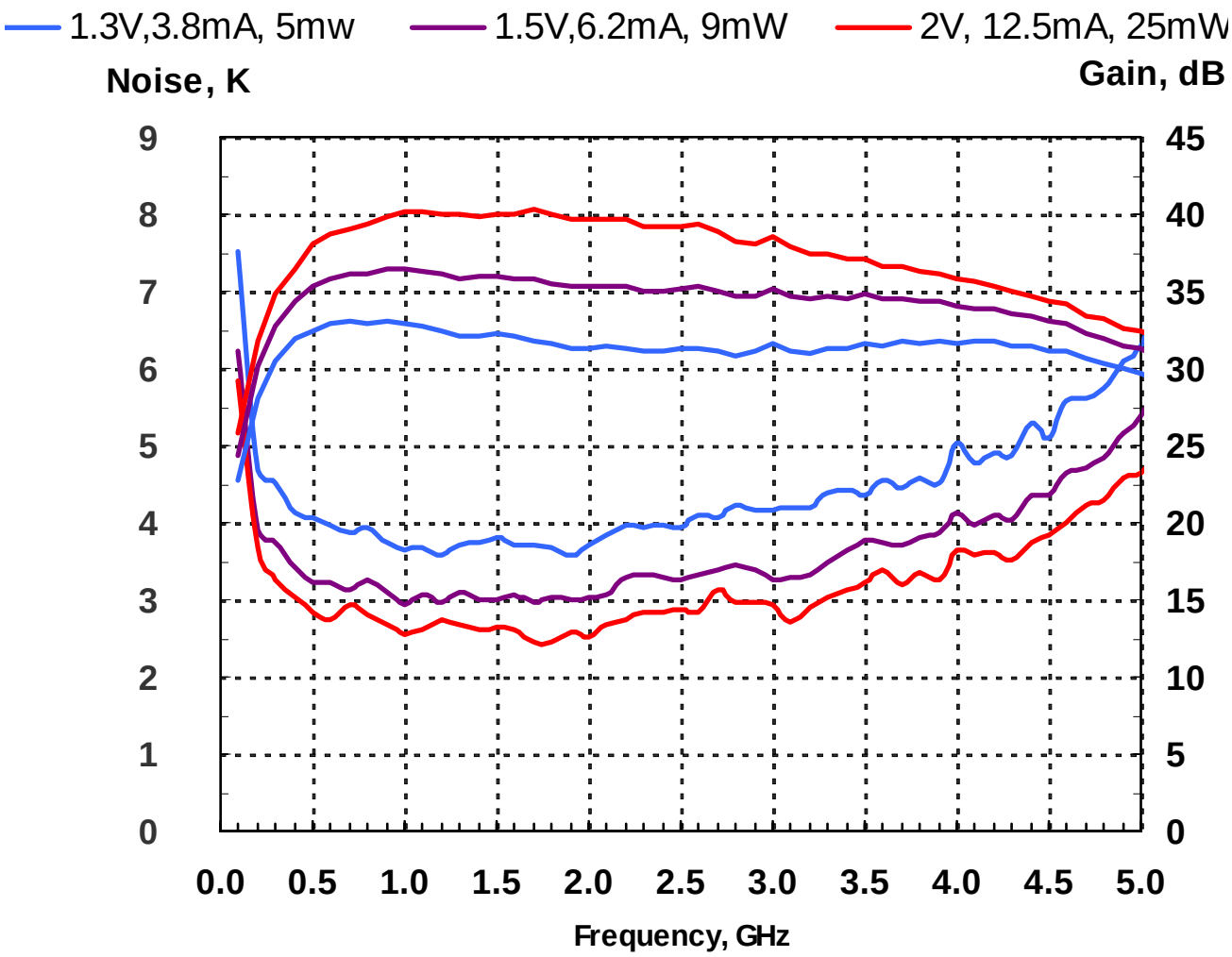




Gain stability measurement still needed.

Noise and Gain of SiGe LNA at 17K at 3 Bias Settings

2-Stage STM / NXP Discrete Transistors, Matched Feedback, May 24, 2008



SiGe 0.5 to 4 GHz Cryogenic LNA on a PC Board

Noise is <4K, gain 35 +/- 1 dB, at 9mW DC power.