MMIC Activities at ASIAA

Chau Ching CHIONG

Institute of Astronomy and Astrophysics, Academia Sinica (ASIAA)

Contributions from …

- ASIAA
  - Microwave Group: Dr. Y.-J. Hwang, Dr. Y.-F. Kuo, Dr. C.-C. Lin, C.-C. Chuang, C.-T. Ho.
  - Receiver Group: Dr. M.-T. Chen, T.-S. Wei.

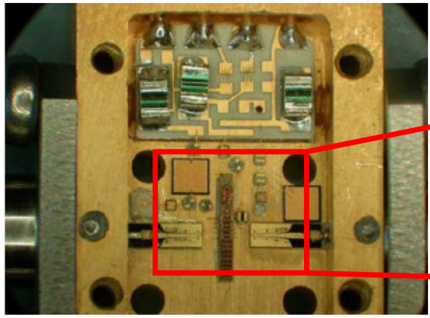
- National Taiwan University EE
  - Prof. H. Wang: Dr. Z.-M. Tsai, Dr. B.-J. Huang, W.-J. Tzeng, Y.-C. Wu, B.-H. Tsai, C.-C. Hung.

- National Central University EE
  - Prof. H.-Y. Chang: S.-H. Weng.
  - Prof. Y.-S. Lin: Y.-S. Hsieh.

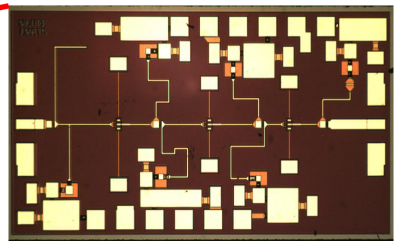
Reasons for MMIC Approach

- Easy integration
- High reliability
- Mass production (> 200 pcs.)
- Low cost
- But high noise.

	Hybrid IC	MMIC
Design Time	Fast	Slow
Noise	Low	High
Assembling & Mass Production	Hard	Easy
Integration	Hard	Easy
Local Support	No	Yes



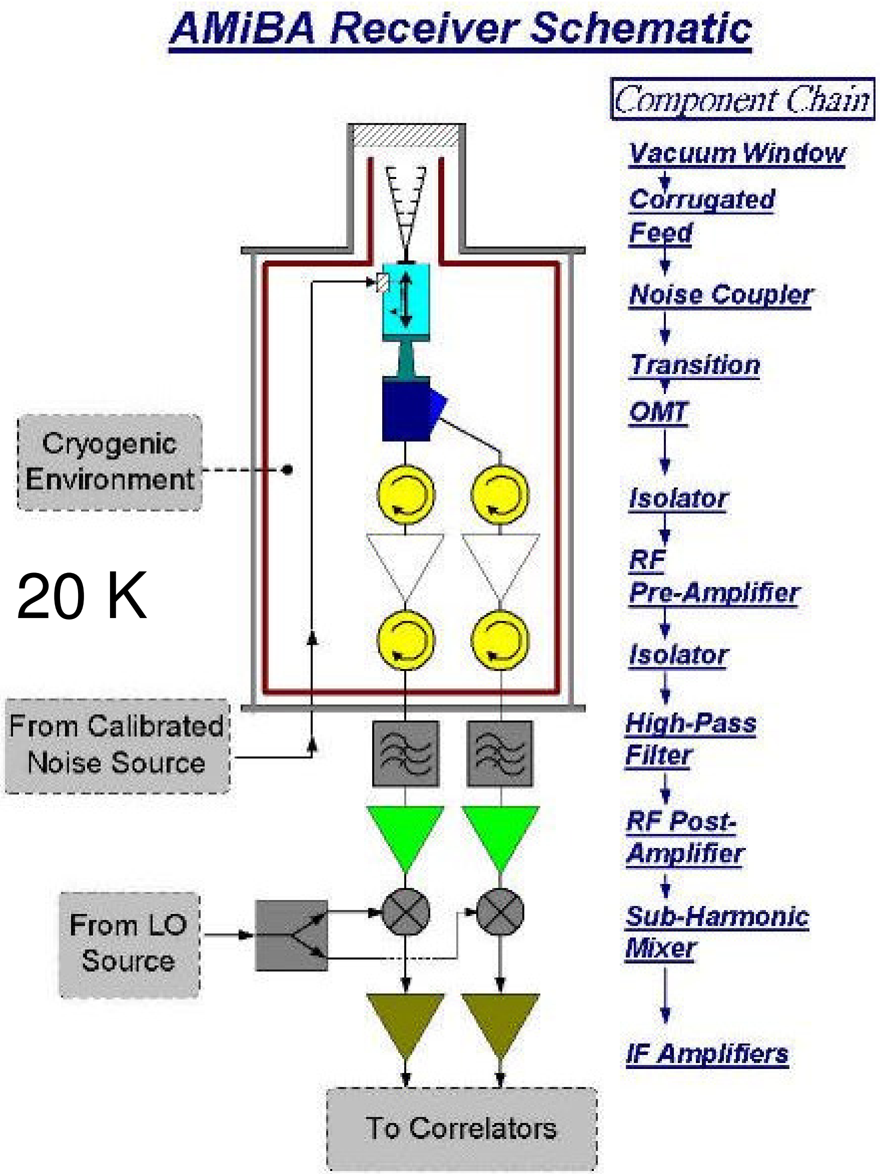
Hybrid X-band LNA from JPL, Weinreb (2007)



MMIC by ASIAA

Size 2mm x 1mm

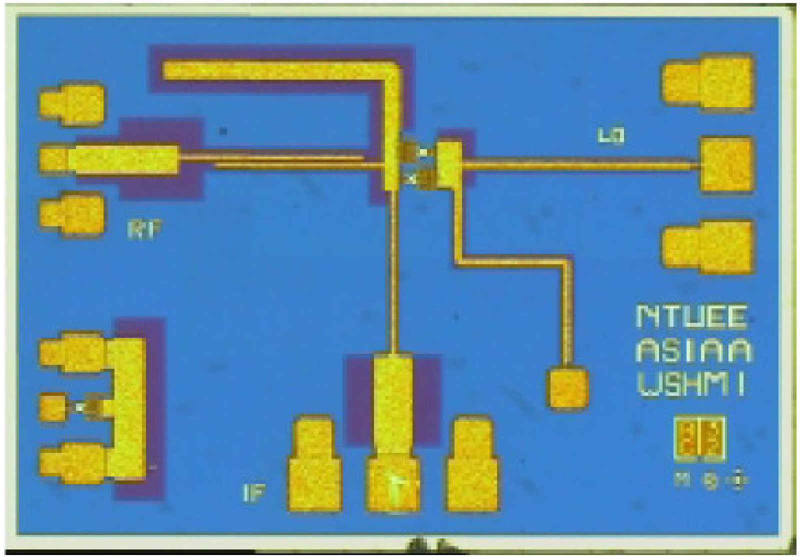
AMiBA Front End



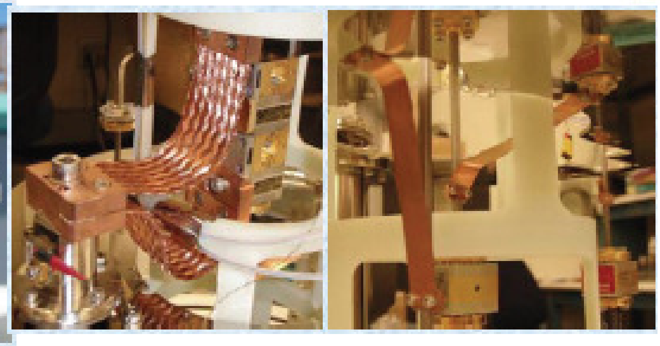
AMiBA Mixer

- Mixer designed by ASIAA, fabricated by NGST
- LNA provided by JPL

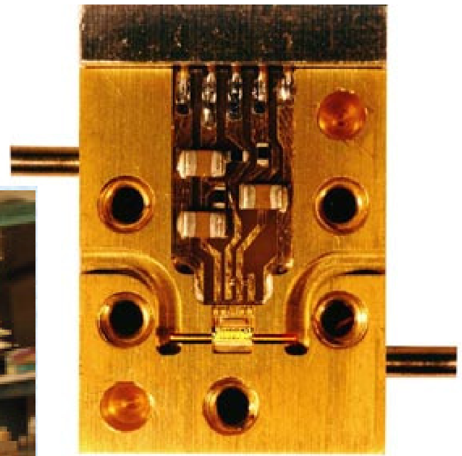
Chip Photo of Sub-harmonic mixer used in AMiBA. (Hwang et al. 2004) →



- System integration at ASIAA

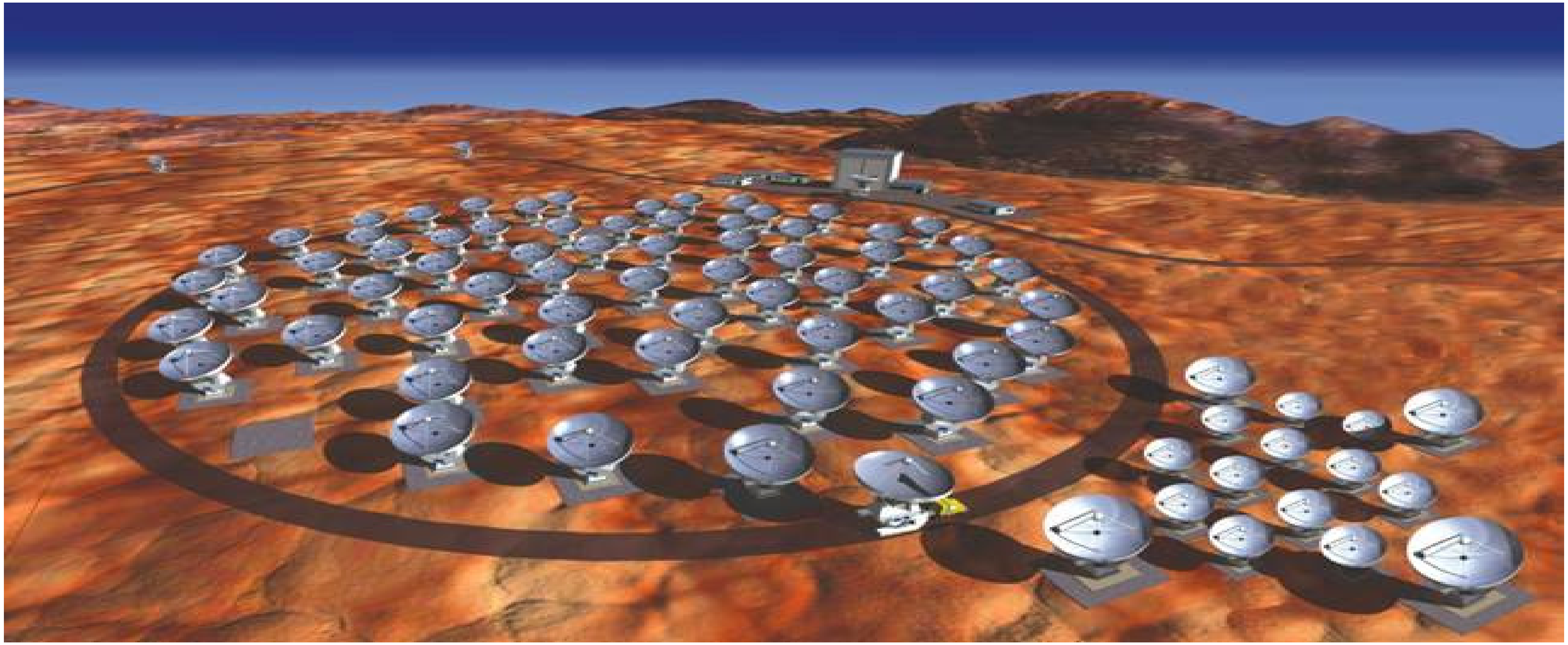


Housing of a LNA.



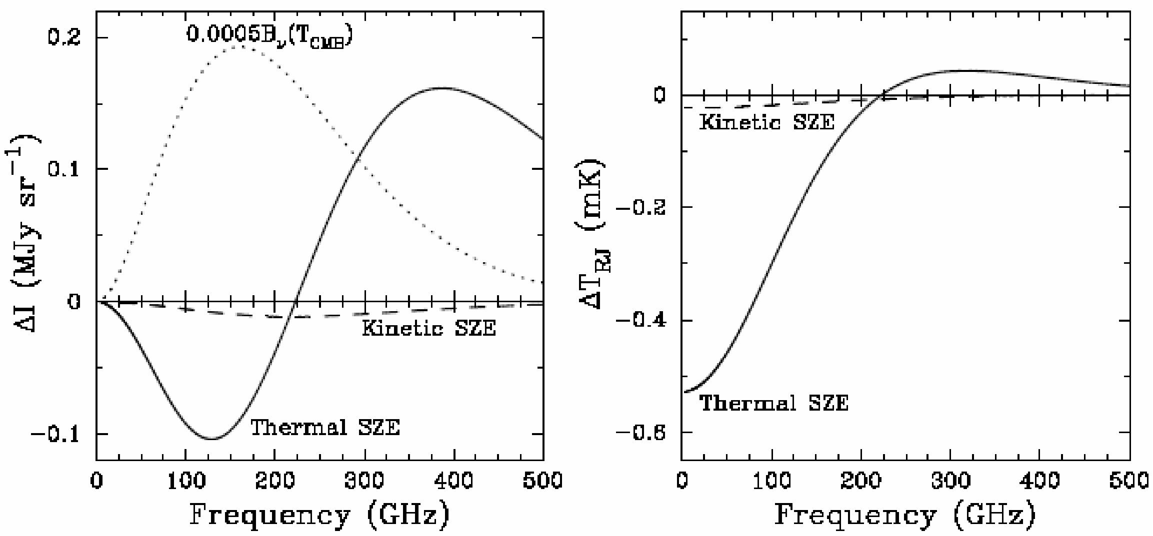
ALMA

- Northern Chile, above 5000 m
- 66 antennae, state-of-the-art performance (low noise, wide bandwidth etc.)
- 10 bands (30 to 950 GHz)
- MMIC for Band-1 front-end and LO



Science of ALMA Band 1 (30-45 GHz)

- High resolution Sunyaev-Zel'dovich effect imaging
- Anisotropy of cosmic microwave background radiation
- High-redshifted CO lines



Transistion	Redshift range
CO J=1-0	1.55 – 2.67
CO J=2-1	4.11 – 6.35

- Probing magnetic field strength via Zeeman measurement

Transistion	Frequency (GHz)	Zeeman splitting (Hz/uG)
CCS $J_N = 3_2\text{-}2_1$	33.75	0.70
CCS $J_N = 4_3\text{-}3_2$	45.38	0.63
SO $J_N = 1_0\text{-}0_1$	30.00	1.74
SiO *v*=1, J =1-0	43.12	Very small

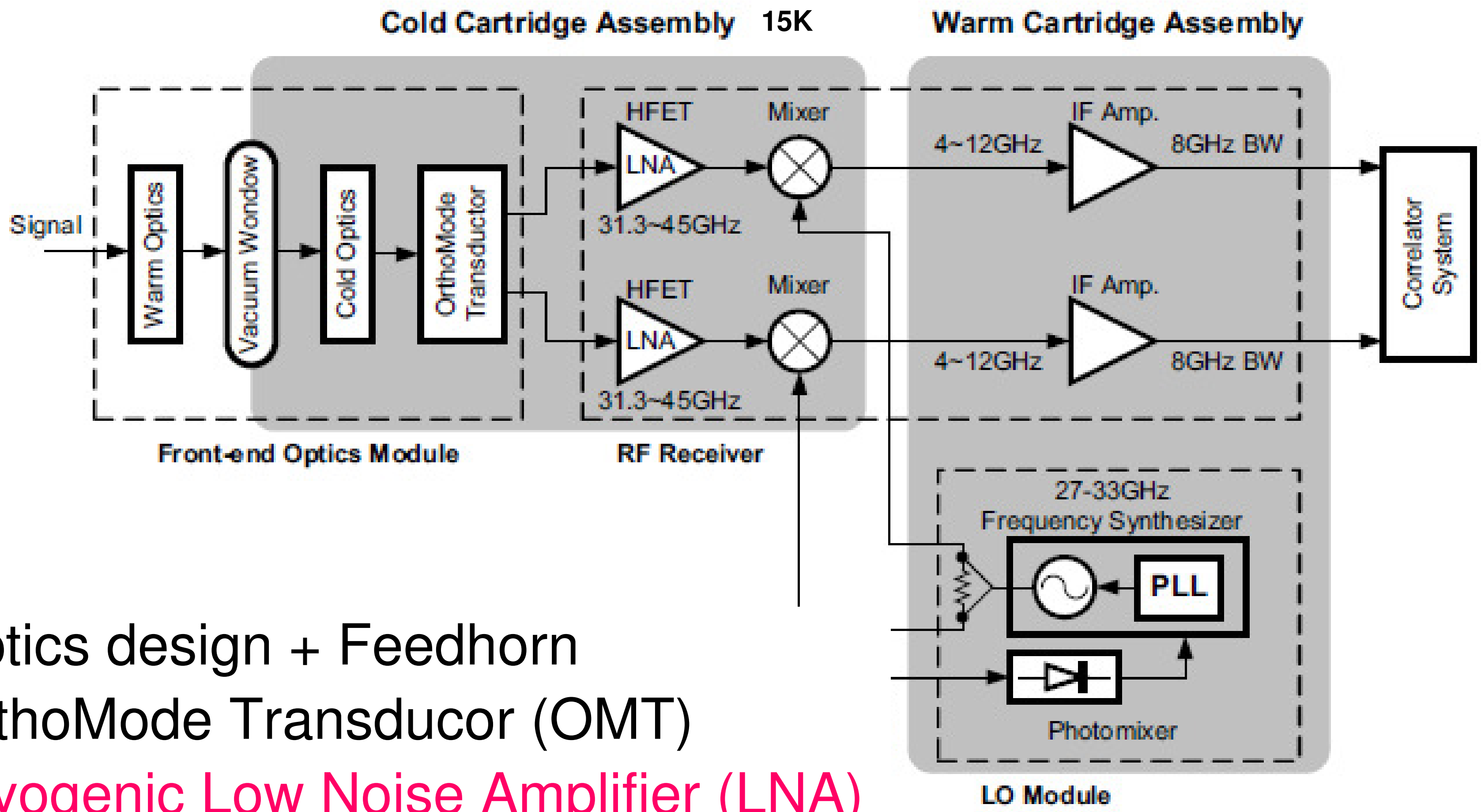
Band 1 System Requirements

- Observation frequency: 31.3-45 GHz (36%)
- IF bandwidth: 4-12 GHz
- Receiver noise temperature:
  17 K (80 % bandwidth) and 28 K (full bandwidth) when operating at 15 K.

- LO tuning range: 27.3-33 GHz (18.9%). No mechanical tuning
- RMS LO phase noise in jitter: 53 fs (short-term), 17.7 fs (long-term)

- International cooperation of Taiwan (ASIAA), Canada (HIA) and Chile (Uni. of Chile).
- ASIAA deliver key components, mostly in MMIC technologies (LNA, mixer, filter, IF amp.), while HIA focuses on optics, LNA (hybrid) and system integration.
- Proto-type receiver will be assembling in Chile.

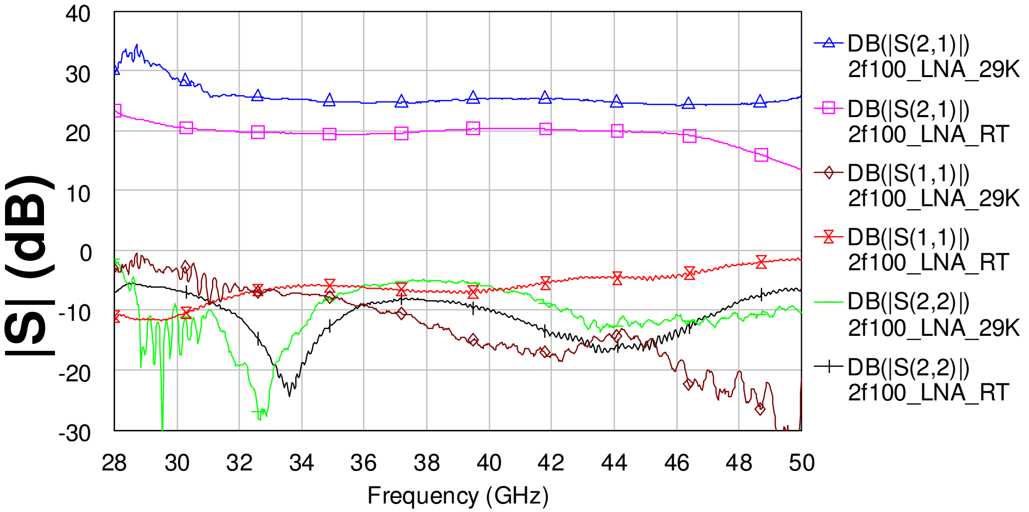
ALMA Band 1 Front-end System



- Optics design + Feedhorn
- OrthoMode Transducor (OMT)
- Cryogenic Low Noise Amplifier (LNA)
- Bandpass Filter + Mixer
- Intermediate Frequency (IF) Amplifier
- Local Oscillator (LO) + PLL

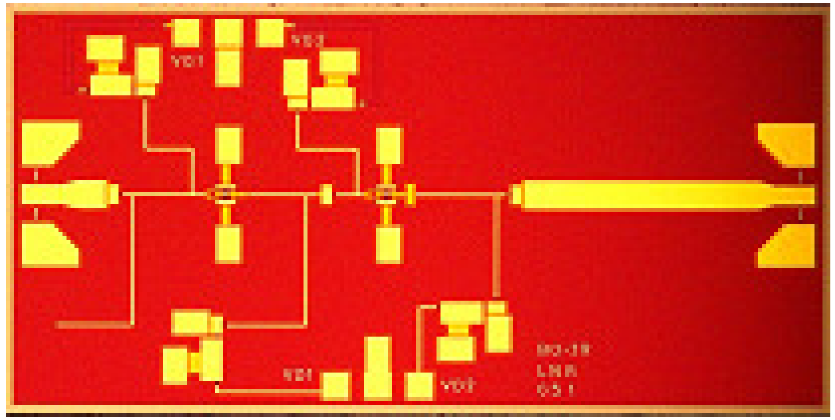
MMICs for Front End

31-45 GHz 0.15 um MHEMT LNA

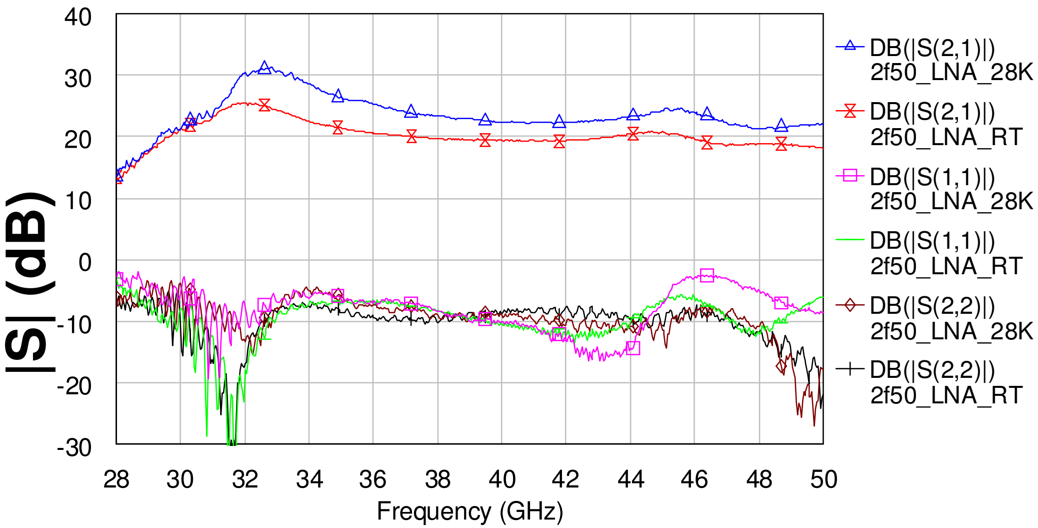


Vd=2V, Id_dev=37mA, Id_mea=30, 33mA

2f100μm 2-stage mHEMT LNA

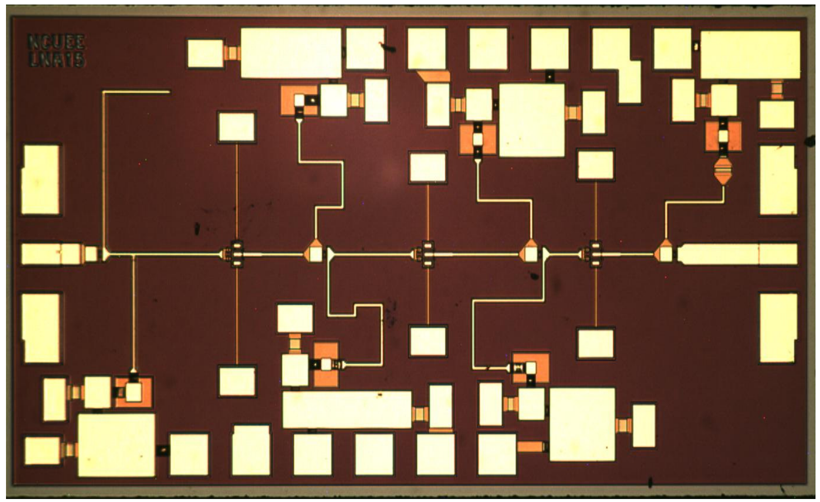


Both with 2 mm x 1 mm



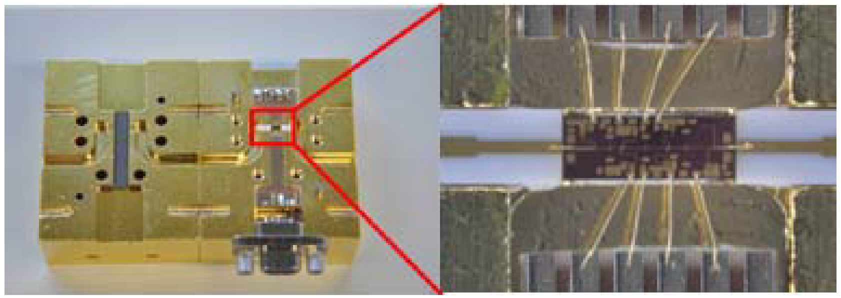
Vd1=Vd2=Vd3=1V, Id1=Id2=Id3=10mA

2f50μm 3-stage mHEMT LNA

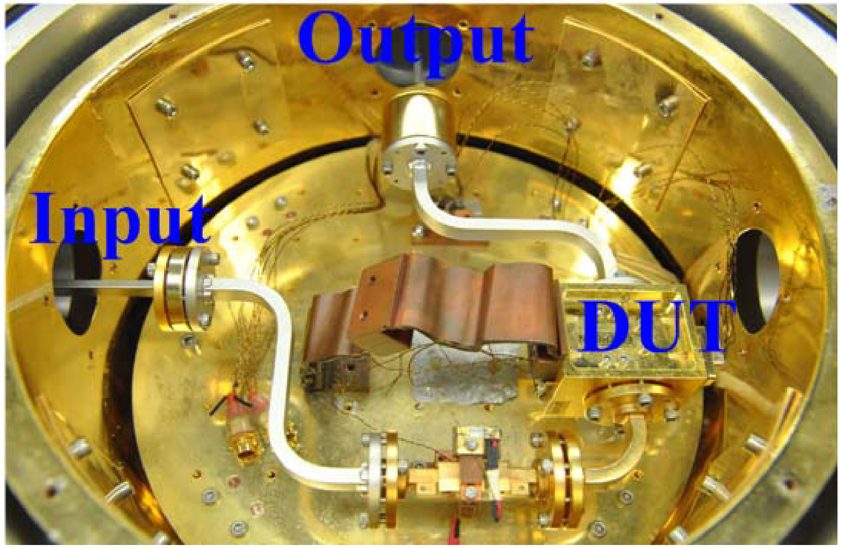


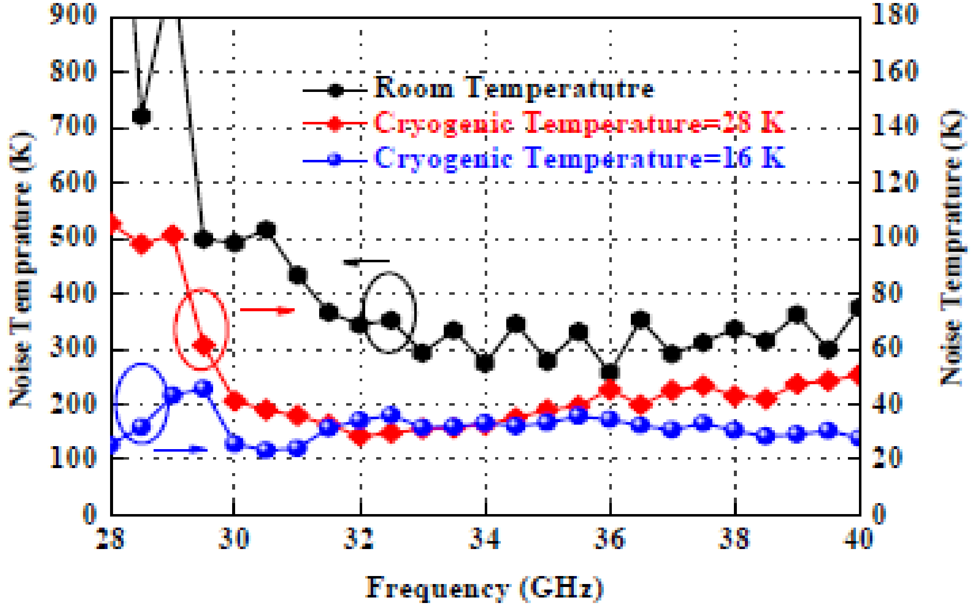
Cryogenic Measurements

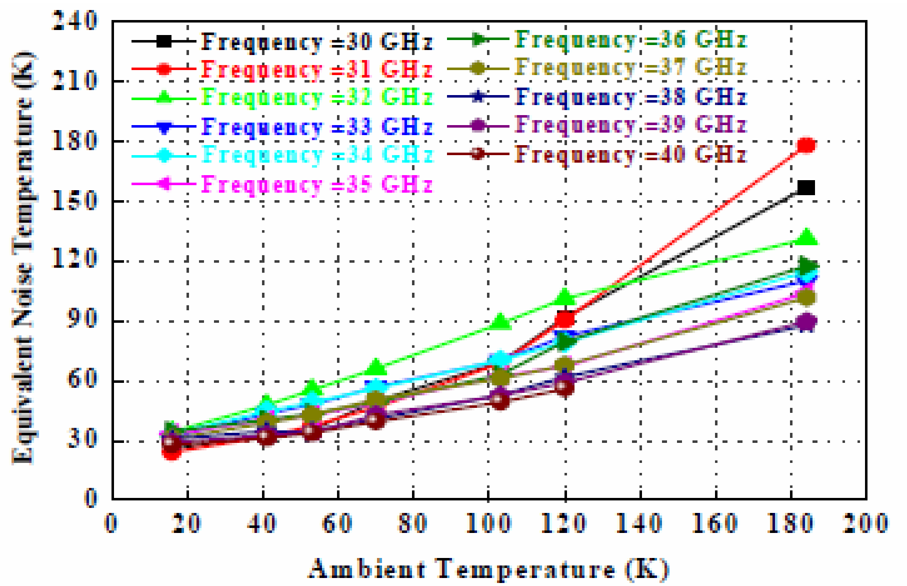
Packaging



Test Dewar

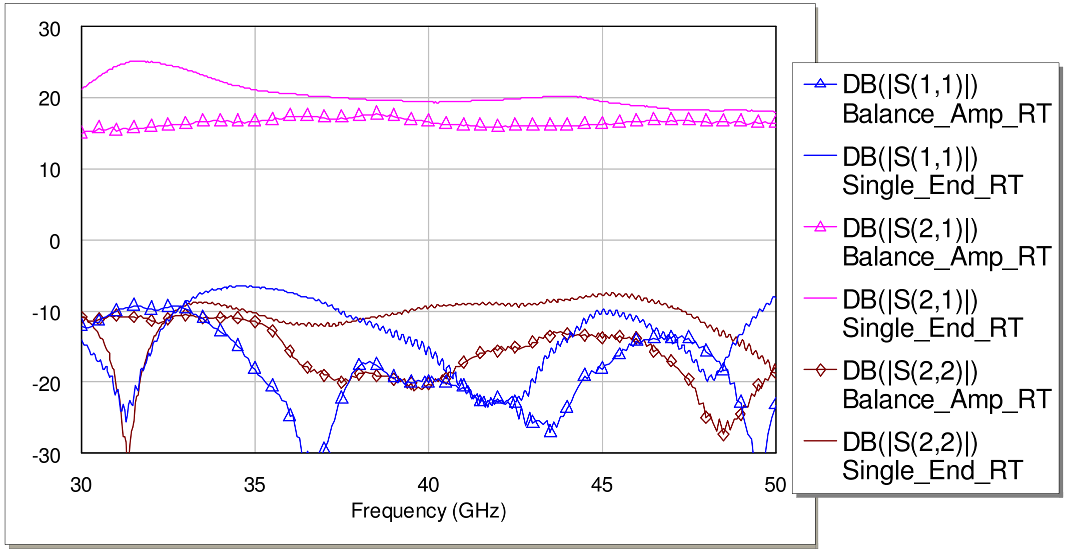




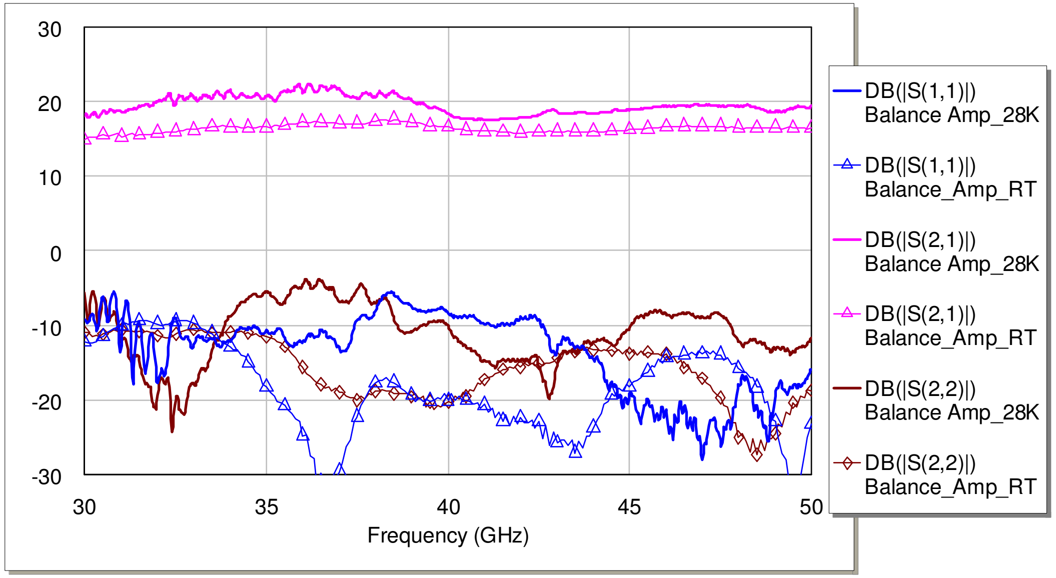


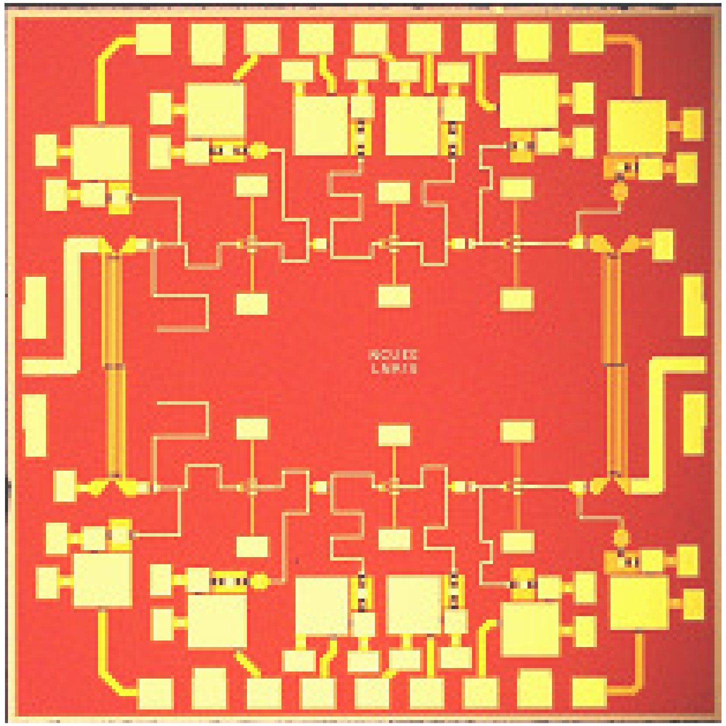
Weng et al., EuMIC, 2011

Balanced LNA as Second Stage



- The same design of the 3-stage version. Better input/output matching.
- Worse matching in Cryogenic. Need cryogenic model to improve matching.

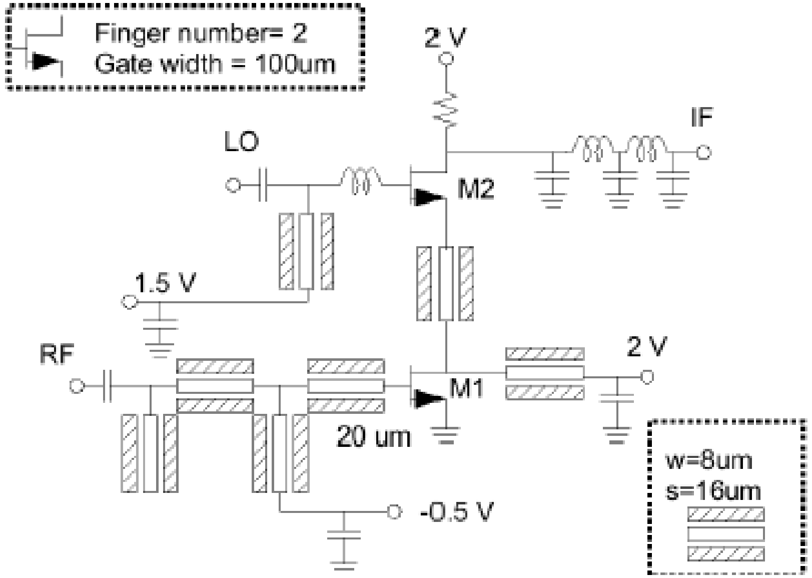


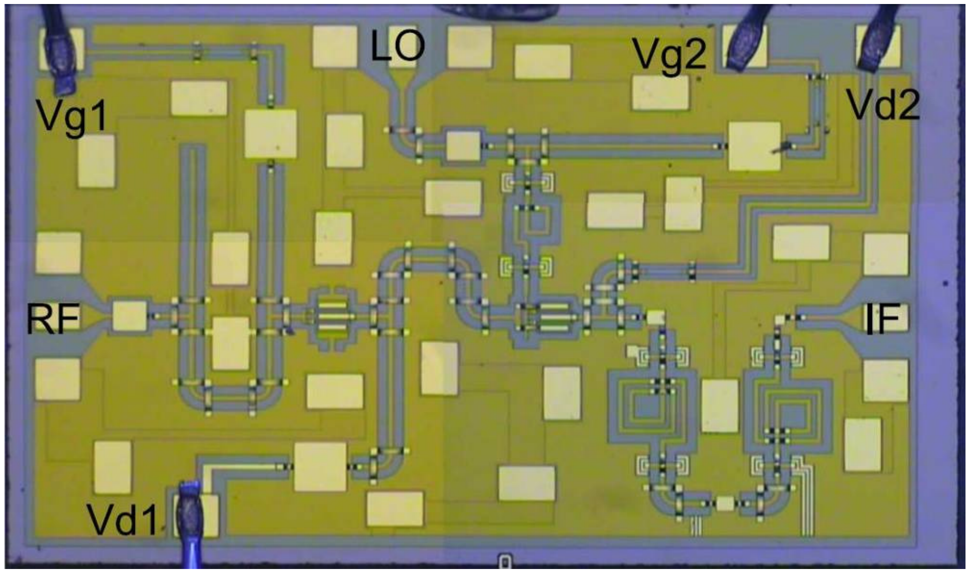


Q-band Cascode PHEMT Mixer

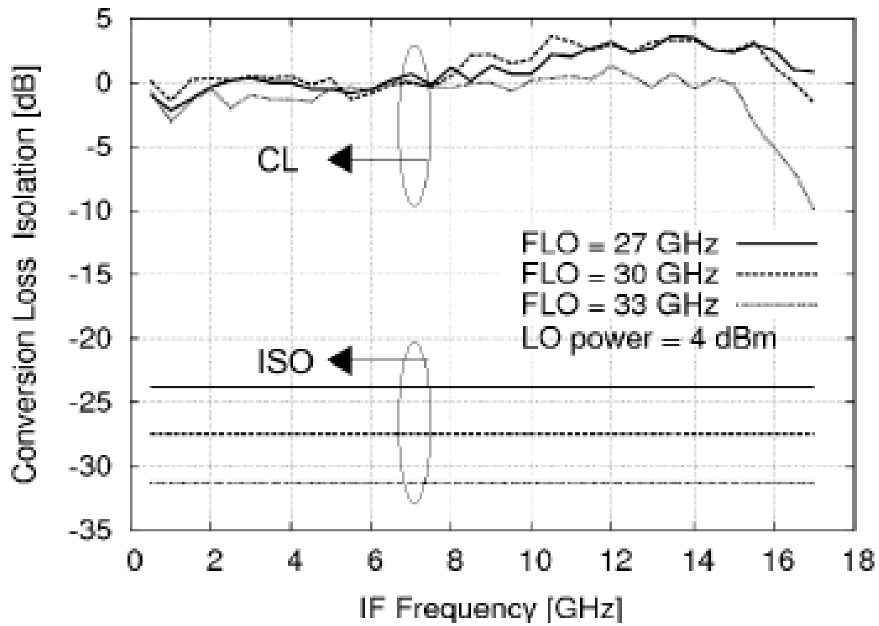
The cascode mixer using WIN 0.15 um pHEMT shows

- Good conversion gain flatness over 4-12GHz IF frequency.
- Low LO power drive.

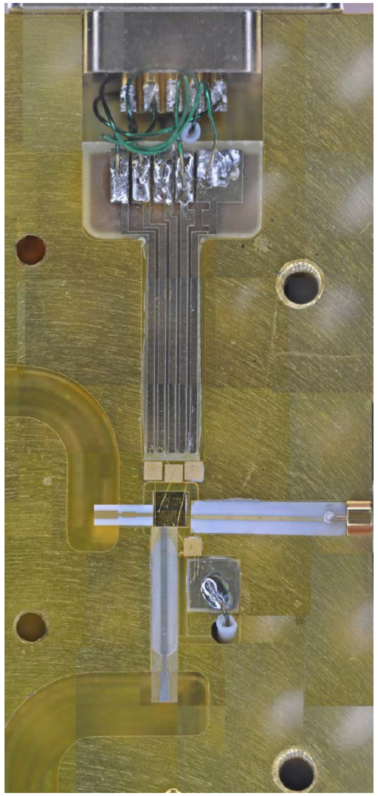


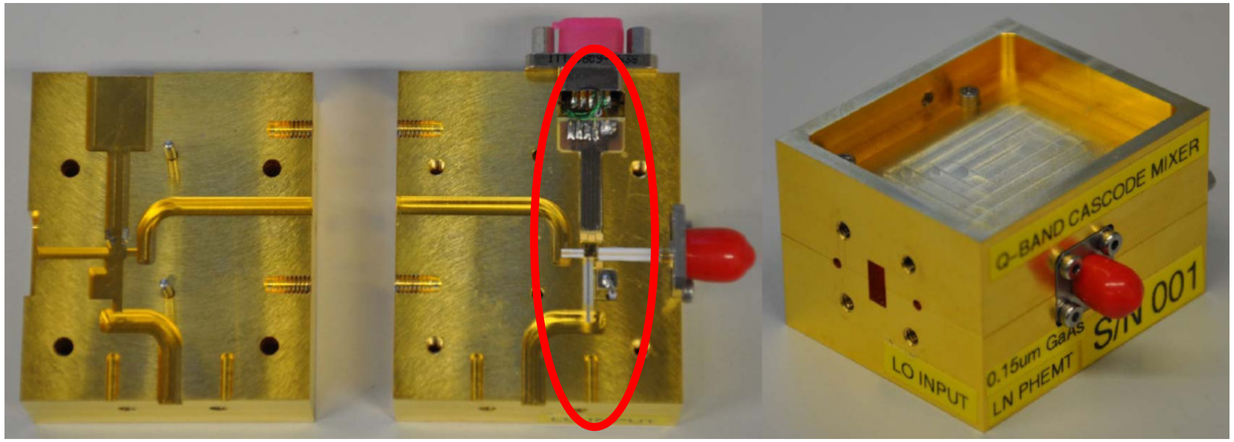


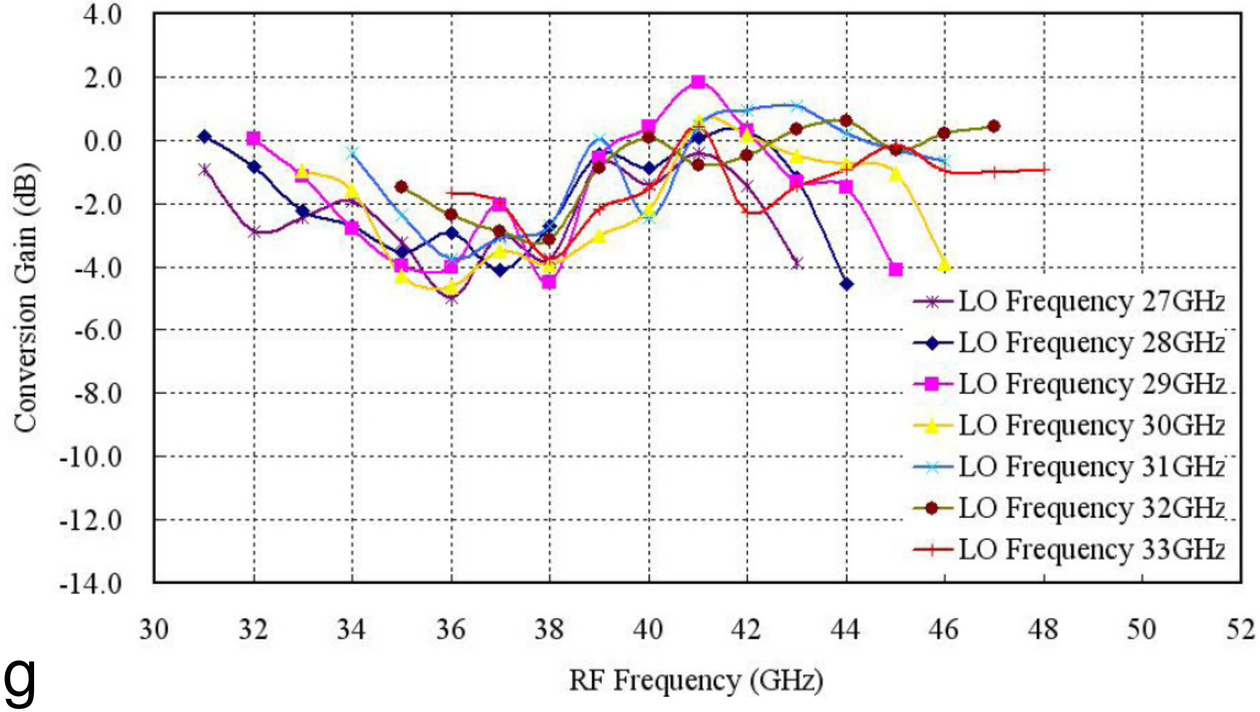
Z.-M. Tsai et. al, *EuMIC*, 2009



Mixer Packaging

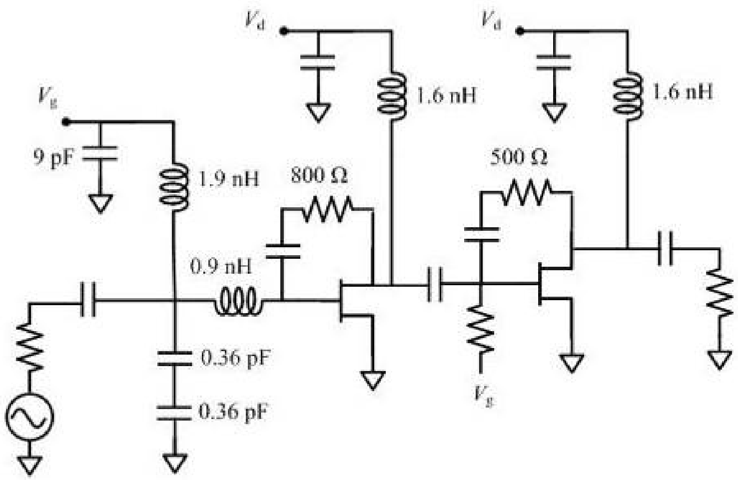


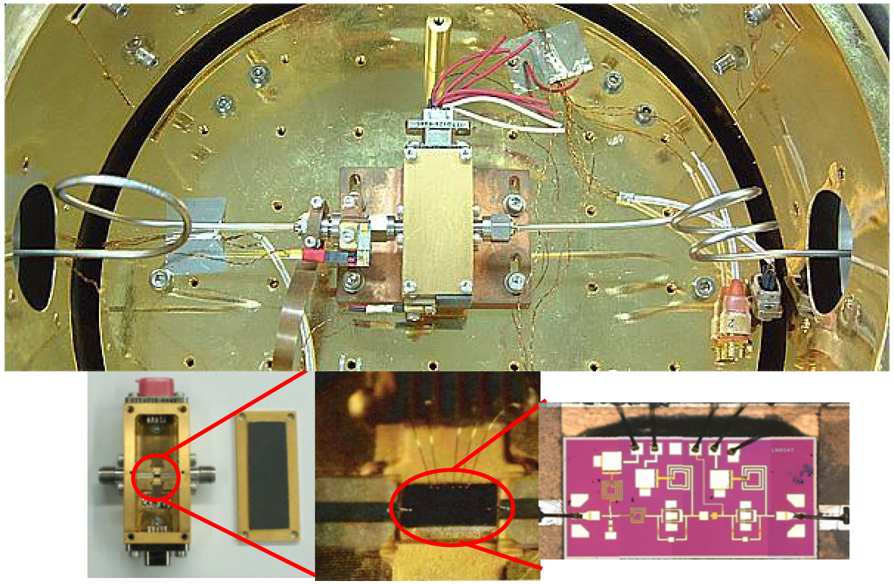


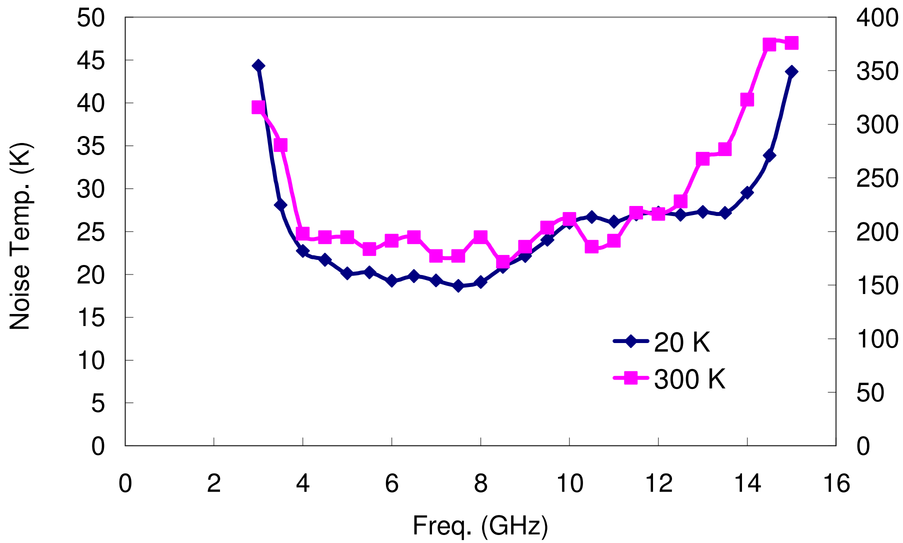


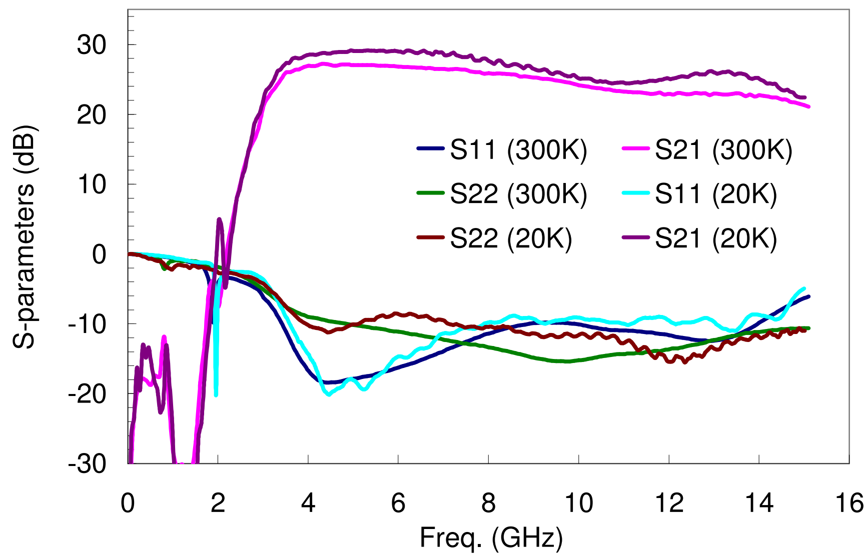
Waiting for cryogenic testing

IF Amplifier



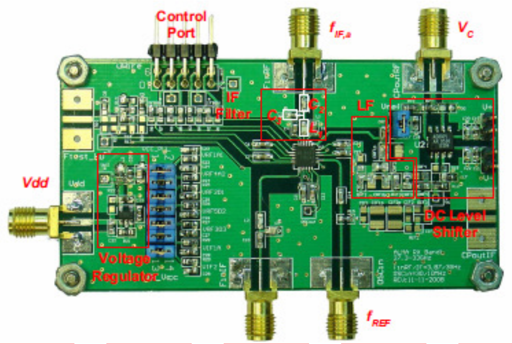


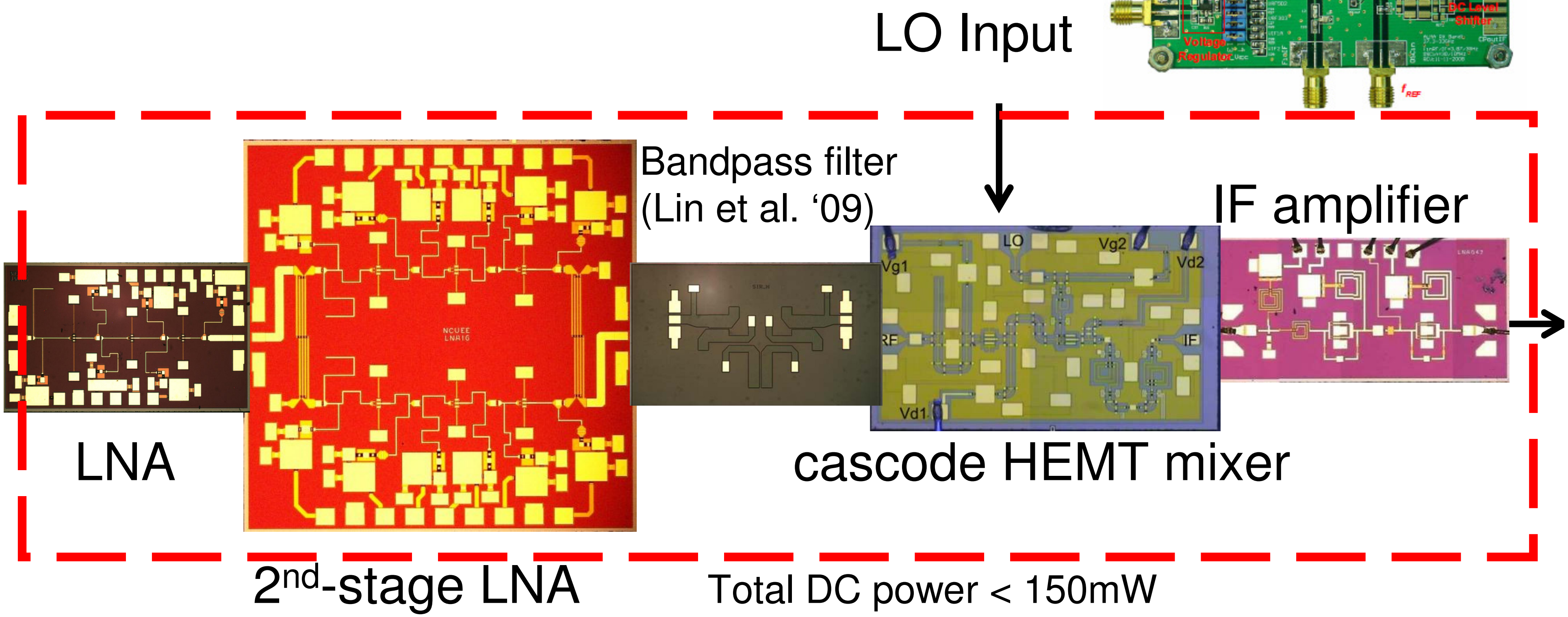




Chiong et al., EuMIC, 2009

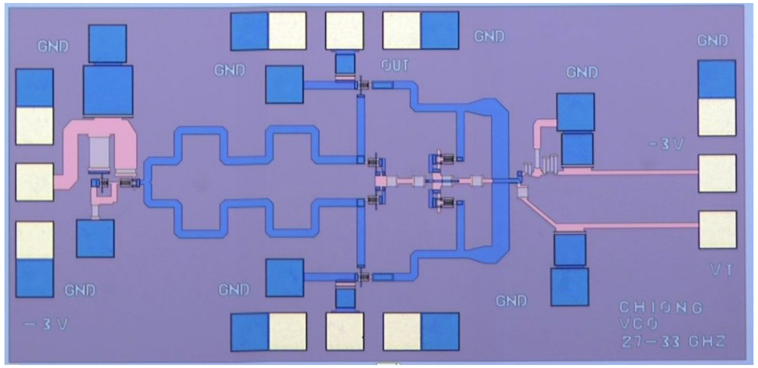
Integrated LNA-Mixer-Filter-IFA Chip



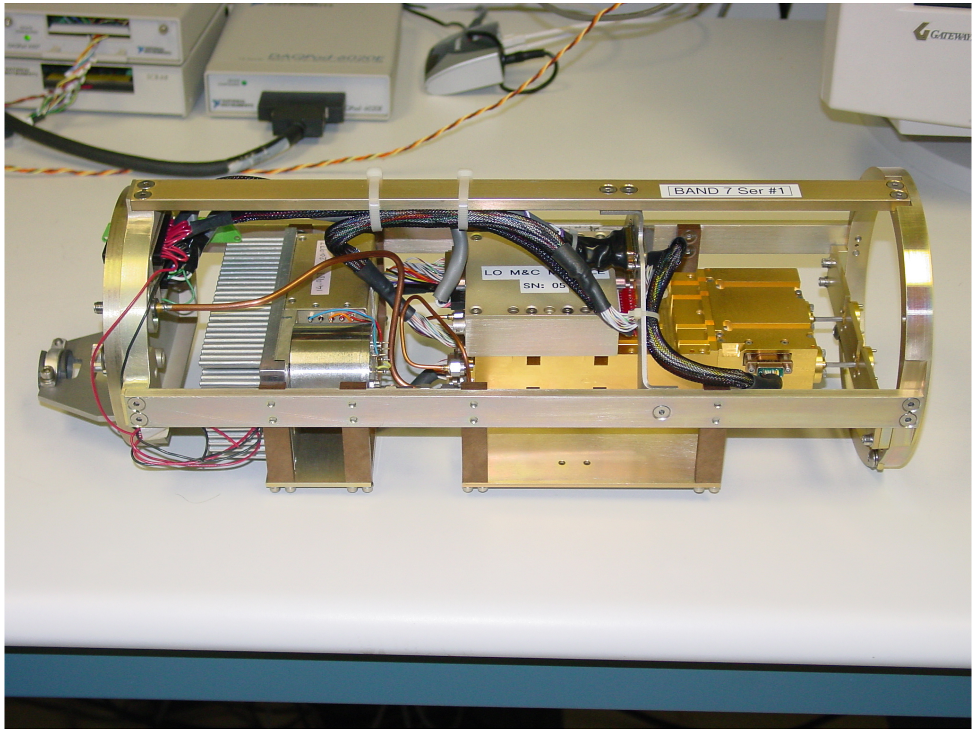


- Highly integrated design of the module.
- Saving space inside the cryogenic section of the front-end cartridge.
- Reducing the possibility of failure in assembling.

VCO-based LO System (instead of YTO)



MMIC VCO



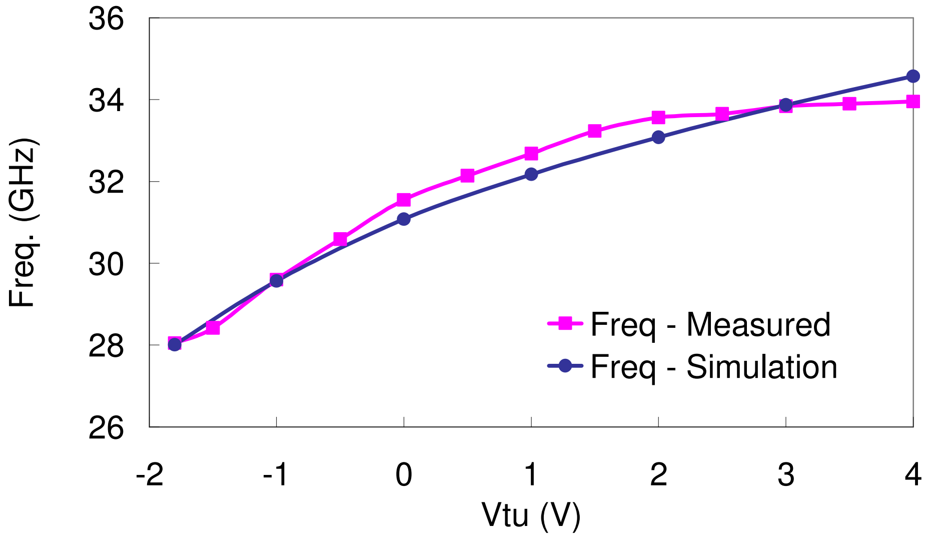
YIG-tuned oscillator (YTO)

VCO vs. YTO

Module	Tuning range (GHz)	Module Size (cm^3)	Power Dissipation (mW)	Phase Noise (dBc/Hz) @1MHz	Tuning Scheme	Cost (USD)
YTO	13~17	213 (11.8 x 4.3 x 4.2)	21350	-120 @1MHz	●12-bit coarse tune ● Fine tune	4000 (High)
VCO	28~34	16 (4.3 x 2 x 1.9)	90	-96 @1MHz	●One single tune	100 (Low)

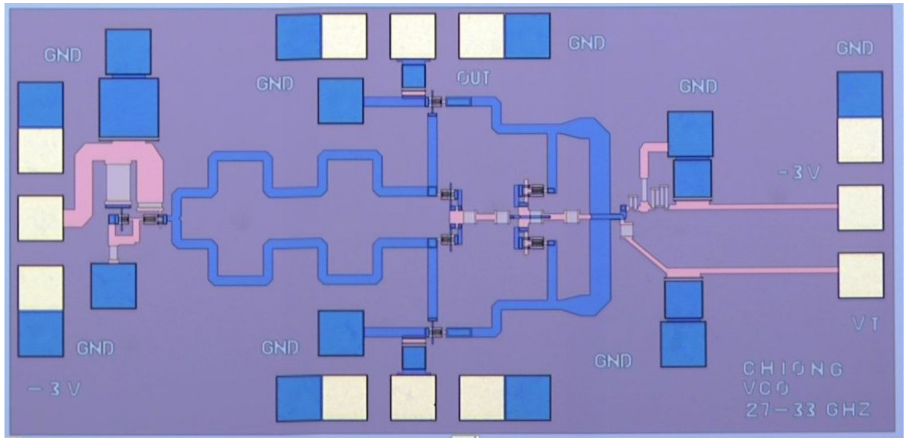
- VCO and YTO (+ doubler) can both cover Band-1 LO tuning range.
- VCO has small size, low cost, low power consumption.
- VCO can be easily integrated with the following frequency multipliers and amplifiers.
- VCO has almost all advantages over YTO except phase noise.

VCO: 28-34 GHz



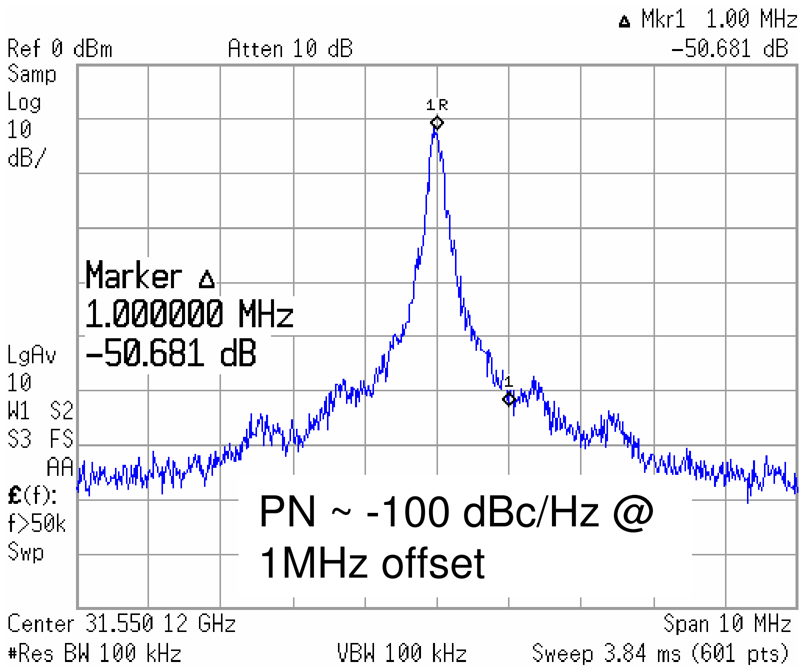
WIN 0.15 um HBT

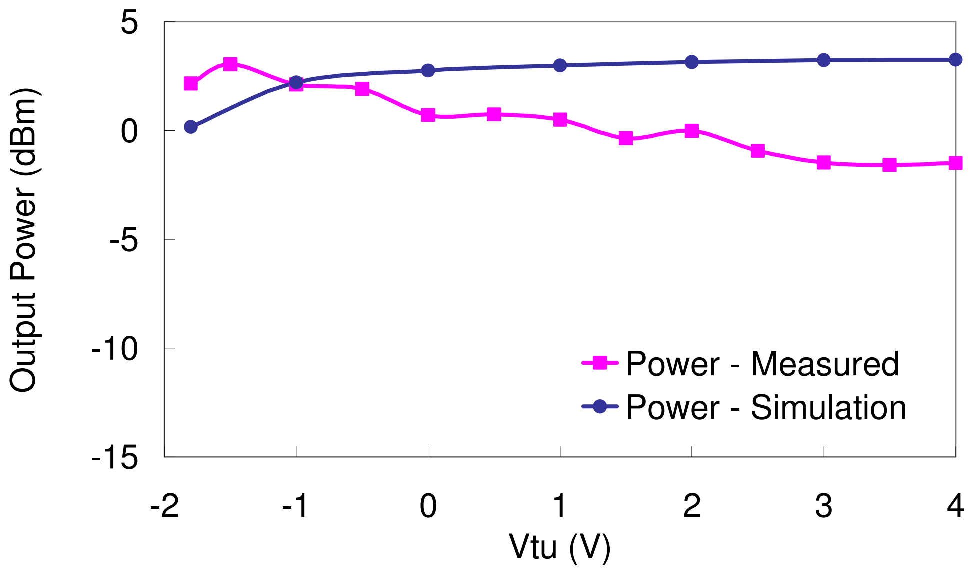
P_{dc}: 85 mW



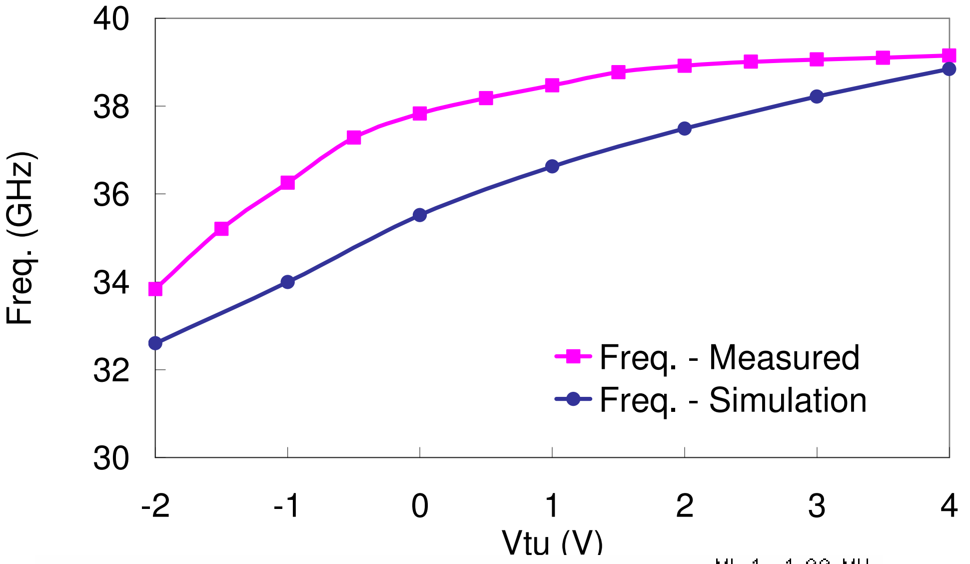
Chip size: 2 x 1 mm^2

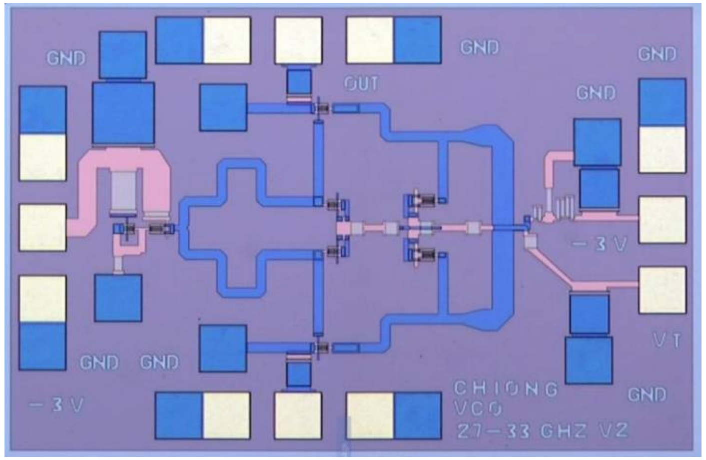
Chiong et al., EuMIC, 2008



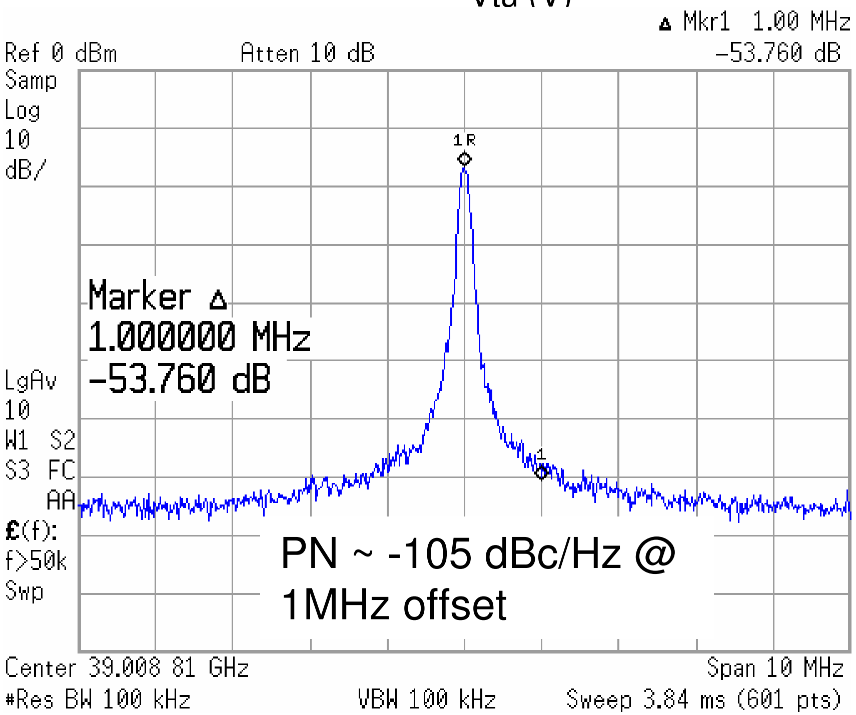


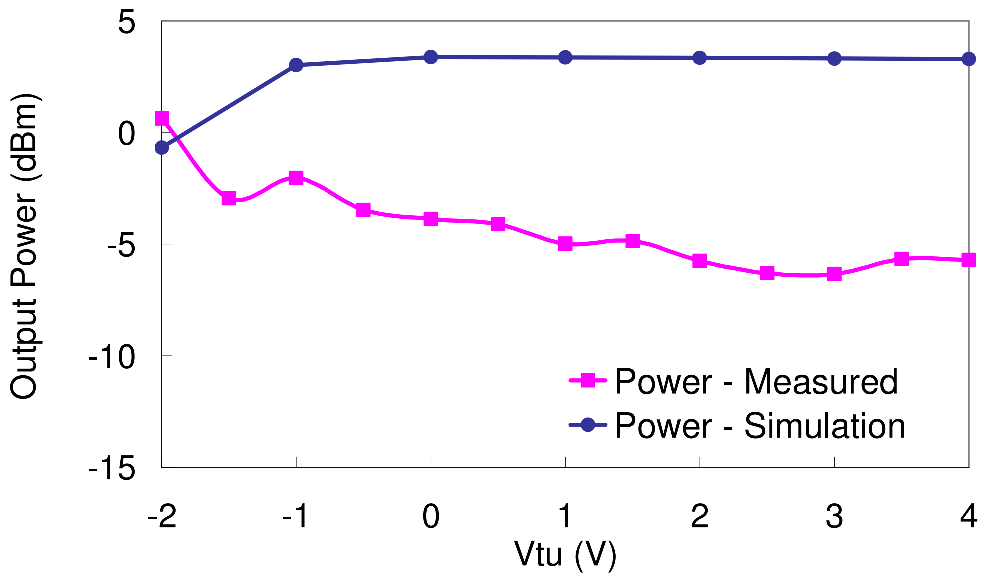
VCO: 34-39 GHz



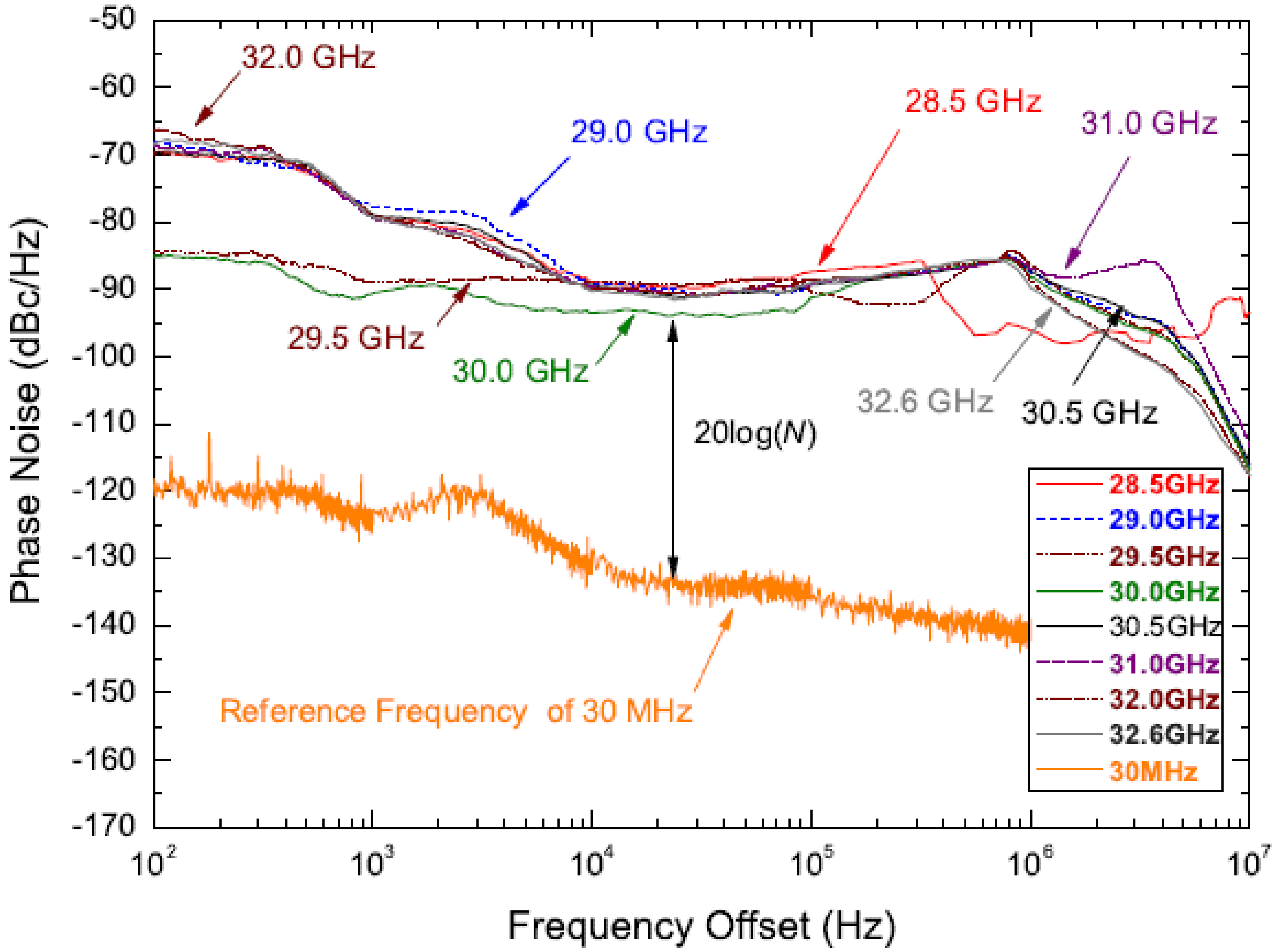


Chip size: 1.5 x 1 mm^2





Phase Locked Spectra of VCO



Summary of local oscillator (LO) modules

❖ List of LO modules

LO Module	Multiplier 26.5-40GHz	Amplifier 26.5-40GHz	Coupler 18-40GHz	Isolator 26.5-40GHz	Mixer
Phase-locked YTO	Active Multiplier		1pcs	2pcs	1pcs
Phase-locked VCO		1 pcs	1pcs	2pcs	1pcs

❖ Performance summary of LO modules

LO Module	Locking range (GHz)	Phase Noise		RMS@1k~1MHz		REF Spur (dBc)	P_{diss} (W)
		@10kHz (dBc/Hz)	@1MHz (dBc/Hz)	Jitter (fs)	Degree (Deg)		
Phase-locked YTO[a]	26~34 (8)	-100~-96 (-98±2)	-134~-128 (-131±3)	40.6~45.6 (43.1±2.5)	0.40~0.54 (0.47+0.07)	<-70~-57 (-63.5±7.5)	28.2
Phase-locked VCO[b]	28.5~33.8 (5.3)	-98~-90 (-94±4)	-104~-84 (-94±10)	54~333	0.6~3.4 (2±1.4)	<-52~-25 (38.5±13.5)	9.9

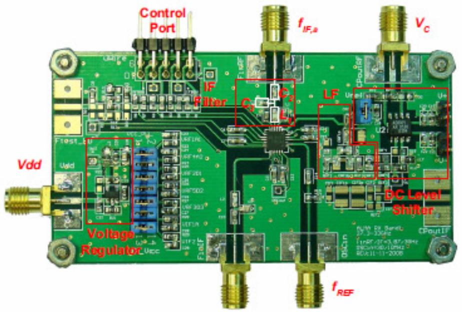
[a]. YTO measured in shielding room

[b]. VCO measured in the laboratory

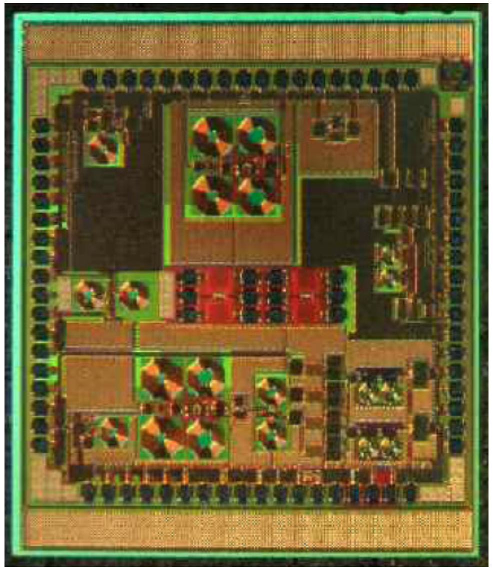
Plans for SKA

- Wideband
- Low noise
- Mass production

- Low band (~ < 2 GHz): Surface-mount
- Mid band (~ 2-10GHz): Hybrid IC
- High band (~ > 10 GHz): MMIC



+ Digital Signal Processing
-> MMIC as Rx module



Jackson 2004

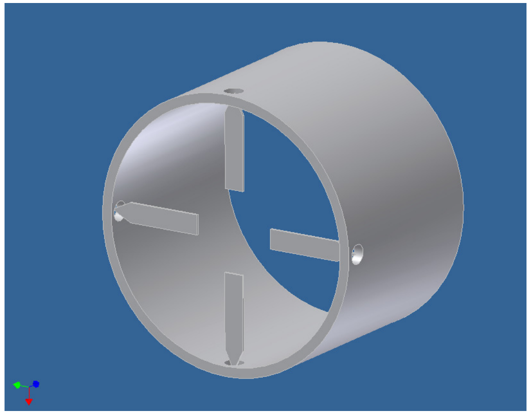
MMICs for SKA (High Band)

Integrated with dual-polarized antenna

- LNA
- Planar Filter
- High speed, wide bandwidth ADC
- Wide tuning bandwidth LO
- ADC as early as possible

- Cooled or Not-cooled
- CMOS/SiGe or GaAs/InP/GaN
- Low power consumption

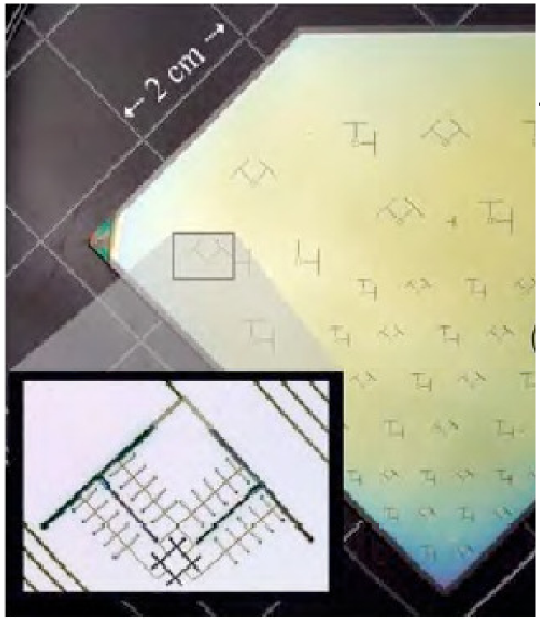
Antenna integrated Rx Module



SIW with
planar probe

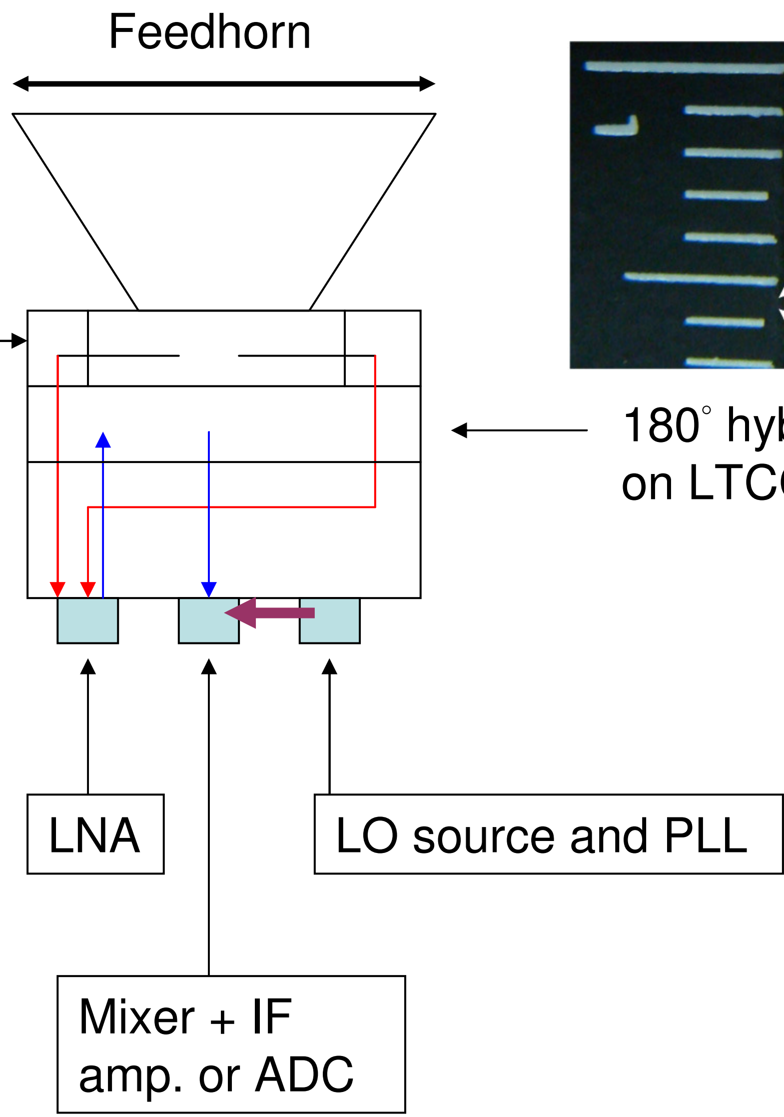
(NRAO)

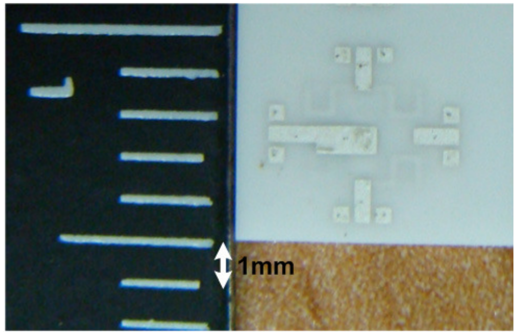
Or



Slot antenna
for two
polarizations

(UC Berkeley)





180° hybrid + filter
on LTCC (NTUEE)

Cooled or Not-Cooled

- Cooling to reduce thermal noise (300K vs. 15K).

  $T_n(300K) \sim 10 \times T_n(15K)$.
- To have compatible noise level,

  $N(300K) \sim 100 \times N(15K)$.
- Cost of 100 times of Rx. vs. Cryogenic system (cold-head, pump, dewar, interconnector).

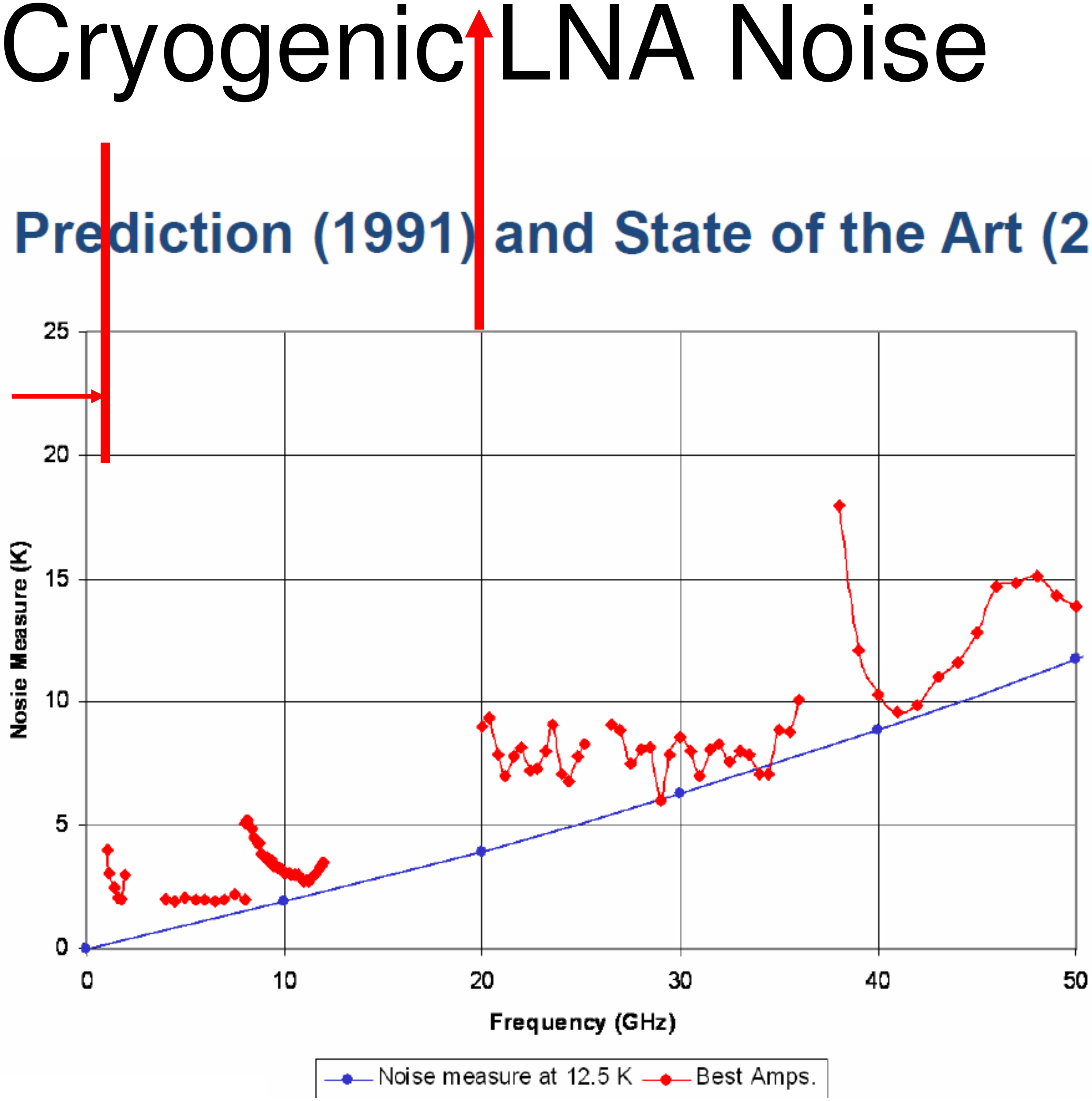
Cryogenic LNA Noise

M_{min} Prediction (1991) and State of the Art (2009)

CMOS LNA
1.4GHz@RT

~ 20-35K

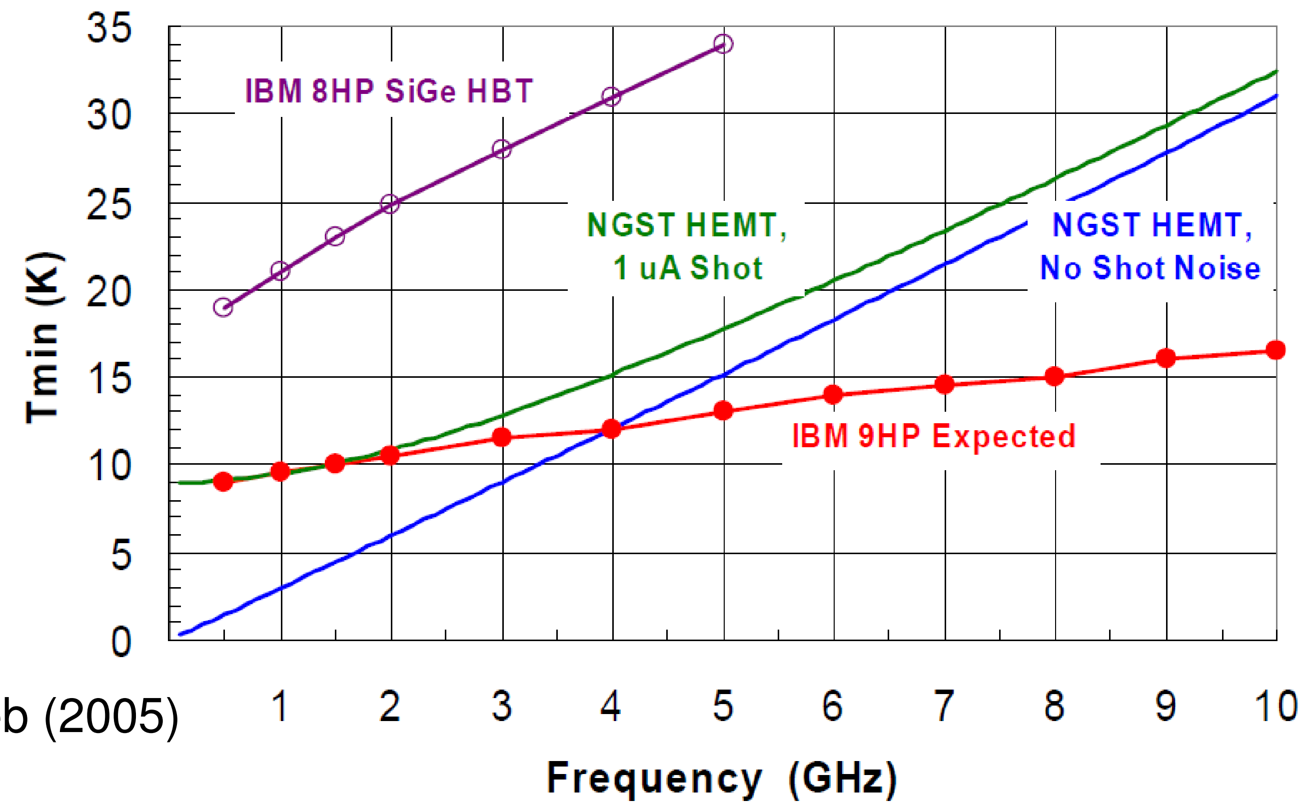
Woestenburg
(2011)



Pospieszalski (2009)

Silicon or III-V

- III-V is though to have better noise performance, but no serious effort in improving device noise in the past 10 years.
- Performance of silicon-based devices is driven by commercial applications.
- For low dc power consumption, CMOS and InP are preferred



Weinreb (2005)

Comparison of CMOS and GaAs

- III-V is expected to have more improvement after cooling.
- CMOS/SiGe is better for digital circuit integration.
- GaAs seems still a better choice in noise right now at ~ 20 GHz.

COMPARISON WITH PREVIOUSLY REPORTED LNAS FOR FREQUENCIES AROUND 20 GHZ

Process	Bandwidth (GHz)	Gain (dB)	NF (dB)	Chip Size (mm^2)	P_{DC} (mW)	Supply Voltage (V)	Topology*	Ref.
0.18-μm CMOS	-	15	6 (22 GHz)	0.05#	24	1.5	3 stages, CGRF+CS+CS	[2]
0.18-μm CMOS	22 ~ 25	12.86	5.6 ~ 7 (23 ~ 24 GHz)	0.735	54	1.8	3 stages, CS+CS+CS	[3]
0.18-μm CMOS	23 ~ 28	8.9	6.9 ~ 8 (24 ~ 26 GHz)	0.735	54	1.8	3 stages, CS+CS+CS	[3]
90-nm CMOS	17 ~ 28	6	5 ~ 7 (17 ~ 20 GHz)	0.56	10	1.5	1 stage, CS, TFMS	[4]
0.15-μm InGaP/InGaAs HEMT	23 ~ 30	14.5	1.6 ~ 1.9 (19 ~ 33 GHz)	0.9	37.5	2.5	2 stages, CS+CS	[8]
130-nm CMOS	18.6 ~ 26.3	12.9	4.4 ~ 5.4 (20 ~ 26 GHz)	0.3	16.8	1.2	2 stages, CS+CS, TFMS	This Work
90-nm CMOS	18 ~ 26	16.2	2.5 ~ 4 (18 ~ 26 GHz)	0.8	26.4	1.2	2 stages, CS+CS, CPW	This Work

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Conclusions

- MMICs for LNA, mixer, IF amplifier, and VCO have been designed and fabricated at ASIAA in the last 10 years.
- MMIC is appealing options for all frequency band in SKA.
- Module of integrated antenna and MMIC using multi-layer structure is good for mass production.
- Trade-off in cooling or not for high band.
- CMOS is supposed to have bright future but not yet better than GaAs.