Updates on THz Amplifiers and Transceiver Architecture

Sanggeun Jeon, Young-Chai Ko, Moonil Kim, Jae-Sung Rieh,
Jun Heo, Sangheon Pack, and Chulhee Kang

School of Electrical Engineering
Korea University
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- Introduction to THz Electronics Systems Lab at Korea University (KU)
- THz Electronics Overview and Current Status
- Updates on THz Amplifier Developments at KU
- THz Integrated Transceiver Systems
- Conclusion

THz Electronics Systems Lab at Korea University

- Object
  - Development of wireless LAN/PAN systems based on electronic devices at THz
- Members
  - 7 faculty members and 33 M.S./Ph.D. students at Korea University
    - Director: Prof. Chulhee Kang
    - PHY layer: Prof. Jun Heo and Prof. Young-Chai Ko
    - MAC layer: Prof. Sangheon Pack
    - RF electronics: Prof. Moonil Kim, Prof. Jae-Sung Rieh, Prof. Sanggeun Jeon
- Projects
  - Wireless Local Area Communication Systems at Terahertz Band (2008 ~ 2012)
  - Funding : 25M USD by Korea Government Funding Agency, IITA

On-Going Research Topics

- PHY layer
  - Techniques to overcome NLOS channel environment
  - Beamforming with low complexity
  - Relay schemes
- MAC layer
  - Improved MAC process to support THz communication systems
  - Distributed relay MAC protocol
- RF electronics
  - Development of RF front-end building blocks based on transistors
  - On-chip integration of THz transceiver system
  - Demonstration of data transmission over channel

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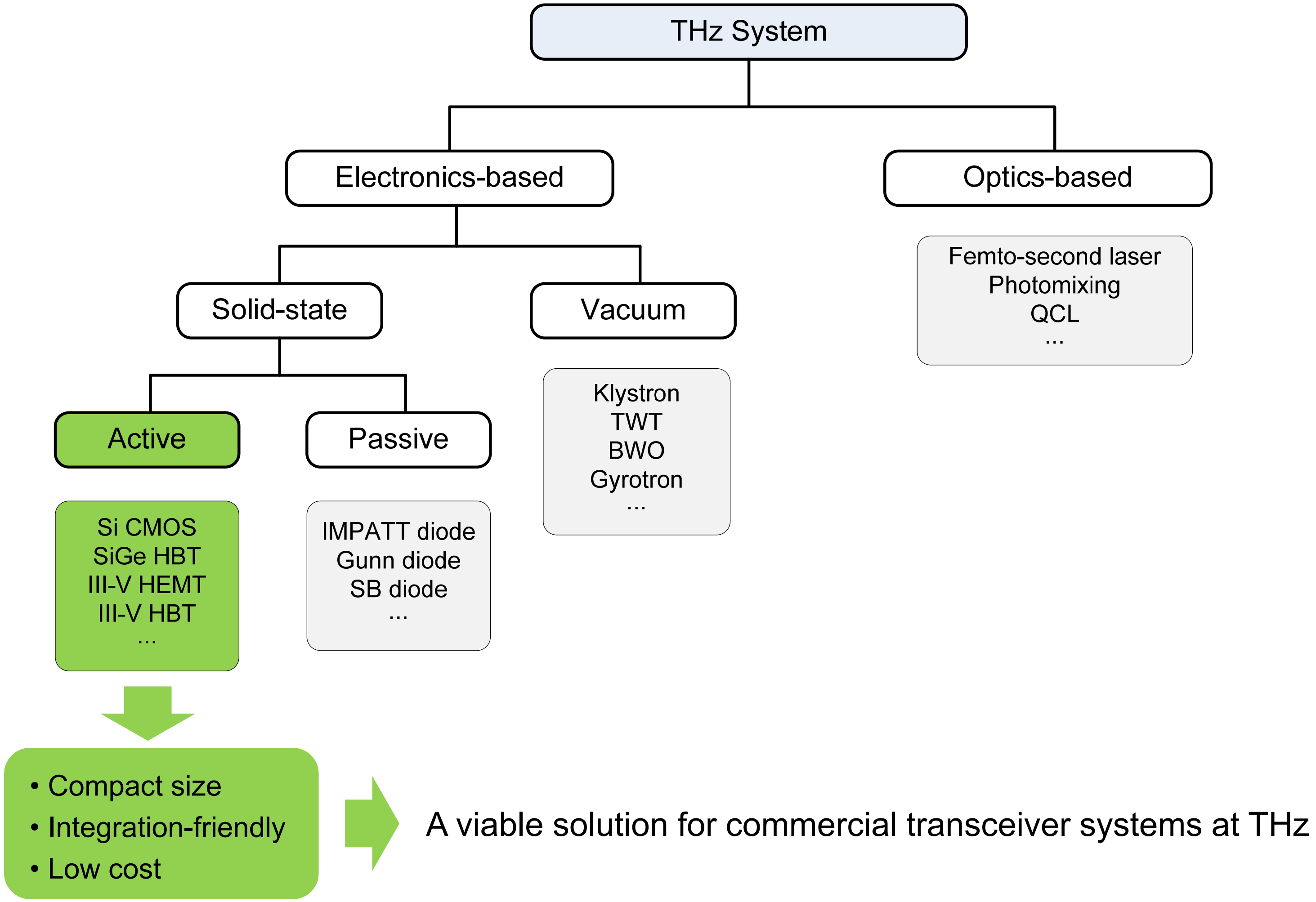
Approaches for THz System Implementation



Transistor Developments Toward THz

- Si CMOS and SiGe HBT
  - f_{max} reaching over 500 GHz
  - Pros: low cost (bulk production), high reliability, high level of integrability with other circuit blocks
  - Cons: low f_T-BV product, low-Q passive elements, relatively inferior noise performance
- III-V HEMT and HBT
  - f_{max} reaching over 1 THz
  - Pros: high f_T-BV product, high-Q passive elements, good noise performance
  - Cons: high cost, relatively lower yield, less promising in full integration

Current Status of THz Electronics (I)

- Amplifiers
  - 550 GHz InP HEMT amplifier by NGC (Deal et al, CSIC 2010)
    - 3-stage cascode structure
    - 10 dB gain at 550 GHz
  - 325 GHz InP HBT amplifier by Korea University (Hacker et al, MWCL 2011)
    - 7-stage common-base structure
    - 25 dB gain at 325 GHz
  - 210 GHz SiGe HBT amplifier by U of Wuppertal (Ojefors et al, RFIC 2011)
    - 3-stage cascode structure
    - 15 dB gain at 210 GHz

Current Status of THz Electronics (II)

- Oscillators and PLLs
  - 346 GHz InP HBT oscillator by Teledyne (Seo et al, IMS 2010)
    - Fundamental oscillation with Colpitts structure
    - Pout = -11 dBm at 346 GHz
  - 300 GHz Si-CMOS oscillator by UCLA (Razavi et al, JSSC 2011)
    - Fundamental oscillation with buffer feedback structure
  - 482 GHz Si-CMOS VCO by Cornell Univ. (JSSC 2011)
    - Triple-push structure
    - Pout = -7.9 dBm at 482 GHz
  - 300 GHz InP HBT PLL by Teledyne (Seo et al, IMS 2011)
    - Divide ratio = 10, Pout = -23 dBm, Pdc = 301.6 mW
  - 163 GHz SiGe HBT PLL by U of Toronto (Shahramian et al, RFIC 2010)
    - Divide ratio = 128, Pout = -25 dBm, Pdc = 1.25 W

Current Status of THz Electronics (III)

- Mixers
  - 300 GHz mHEMT mixer by Fraunhofer (Kallfass et al, EuMC 2009)
    - Resistive mixer with frequency doubler
    - Conversion loss of 20 dB from 246 to 300 GHz
  - 220 GHz GaAs mHEMT mixer by Chalmers Univ (Gunnarsson, MWCL 2008)
    - Resistive mixer
    - Conversion loss of 8.9 dB from 200 to 220 GHz

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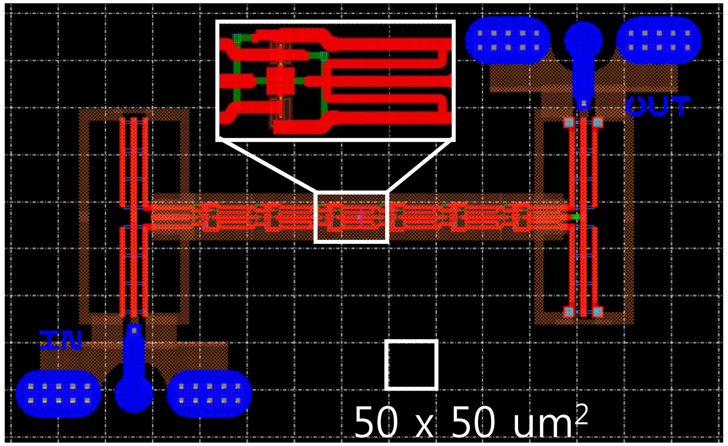
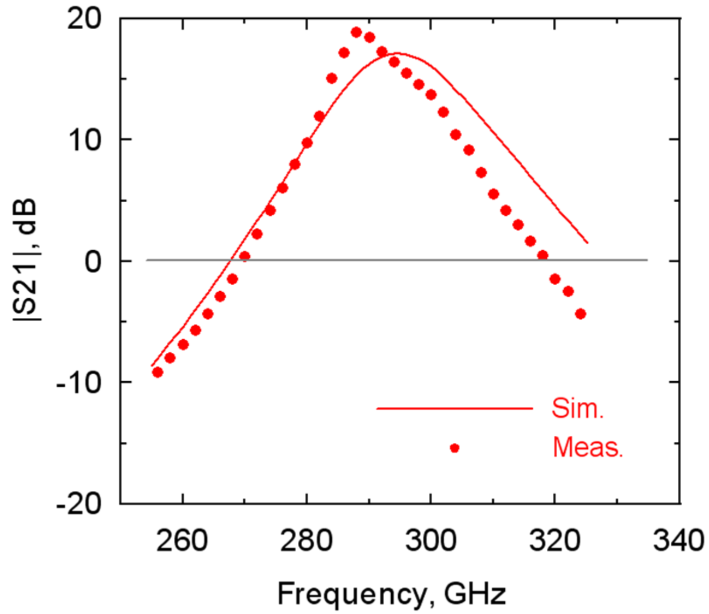
Development of THz Electronic Circuits at Korea University

- Device technology
  - InP DHBT process developed by Teledyne
    - Emitter width of 256 or 128 nm
    - f_T = 350 GHz, f_{max} = 750 GHz (estimated from 256nm model)
    - 3 metal layers with 1um thickness each
    - MIM capacitor (0.3 fF/um^2), TFR (50 ohm/sq)
- Development history
  - 1st phase (256 nm): 300 GHz amplifier (measurement done)
  - 2nd phase (256 nm): 325 GHz amplifier (measurement done)
  - 3rd phase (128 nm): 400 GHz amplifier (measurement done), 320 GHz oscillator (designed)
  - 4th phase (128 nm): over 500 GHz amplifier (in fab)
  - 5th phase (256 nm) : 300 GHz integrated transceiver (expected)

300 GHz Amplifier in Phase 1 (Revisited)



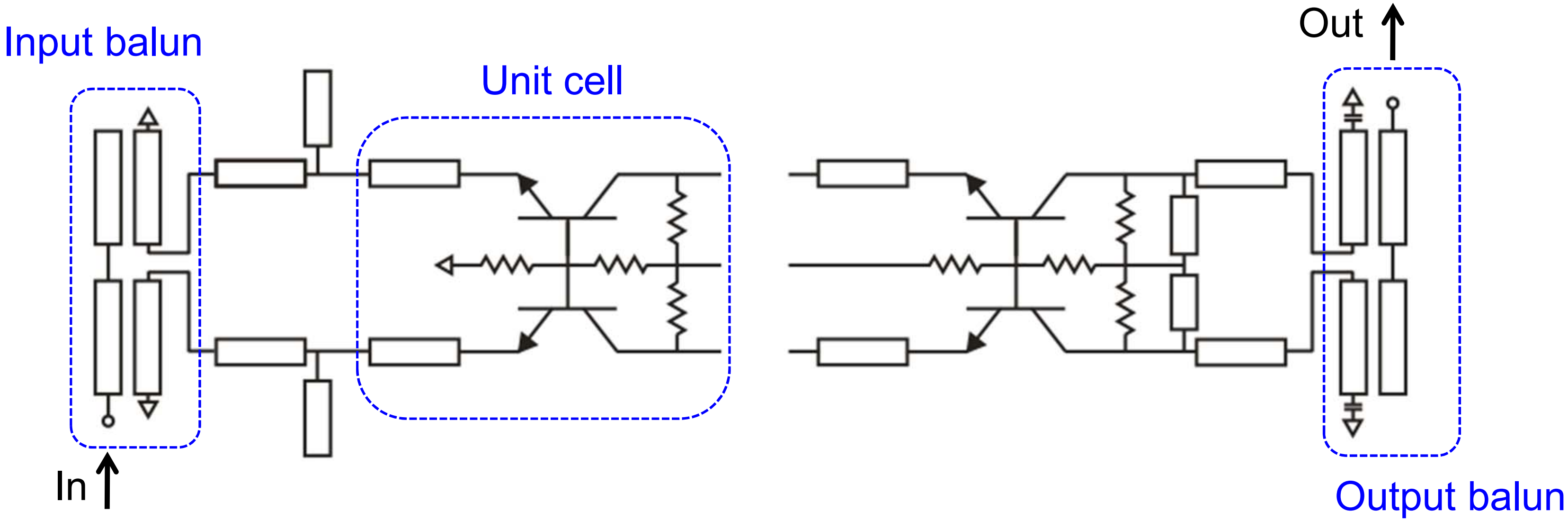


- 6-stage differential common-base amplifier
- Cross-connected negative feedback resistor
- Total circuit size: 0.73 x 0.45 mm^2 (with pads)

- 18.5 dB peak gain @ 289 GHz
- 14 dB gain @ 300 GHz

[Park et al, IMS 2010]

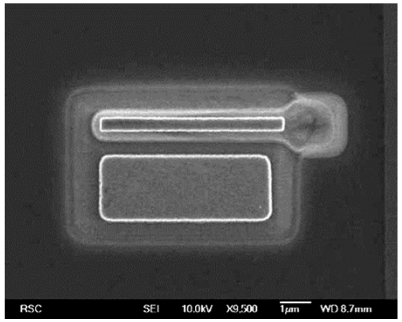
325 GHz Amplifier in Phase 2 (I)



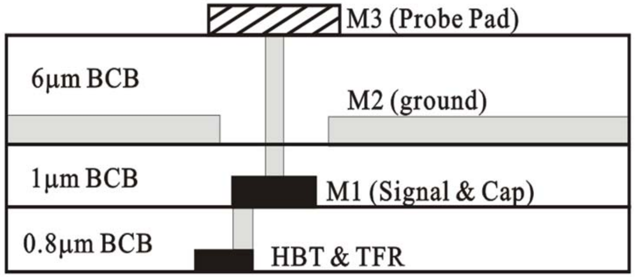
- Input balun + 7 cascaded unit cells + output balun
  - Unit cell: differential common-mode stage with self-biasing and stabilization resistors
  - In/out baluns: Marchand type
  - Single DC bias applied through the output balun

[Hacker et al, MWCL 2011]

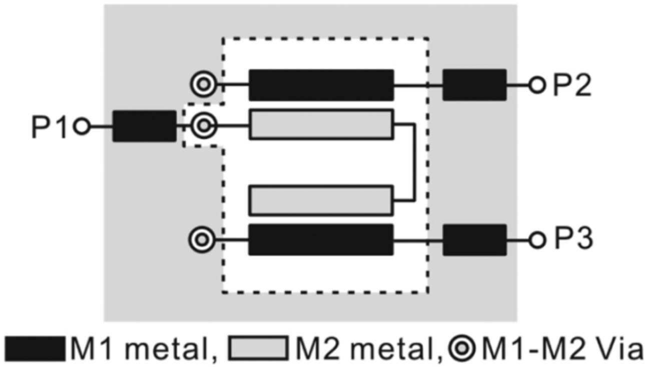
325 GHz Amplifier in Phase 2 (II)



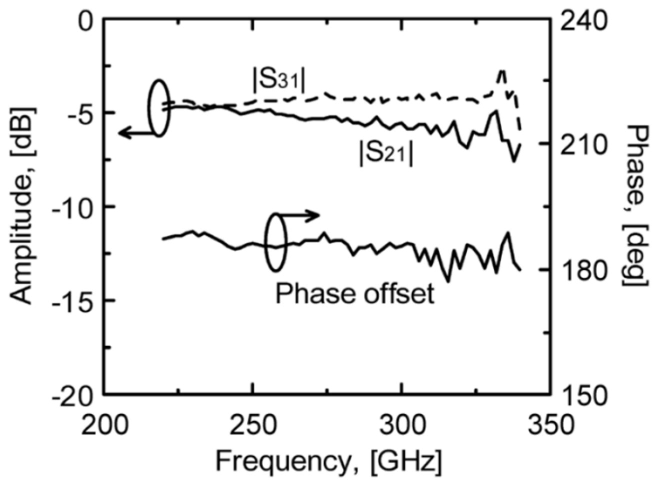
▪ InP DHBT with 256nm emitter width



▪ Inverted microstrip structure



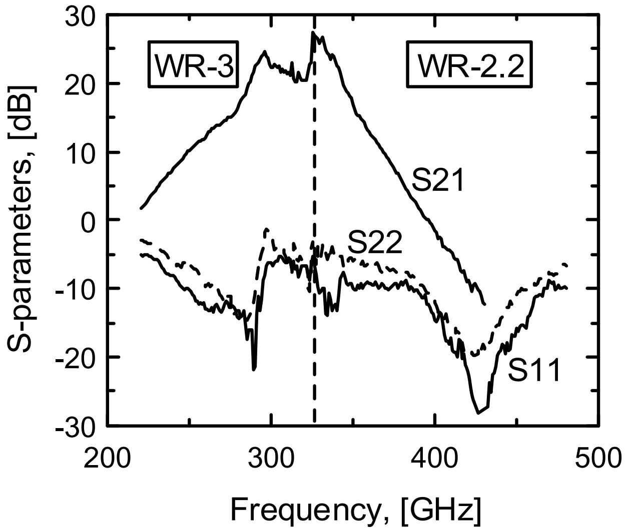
▪ Marchand balun

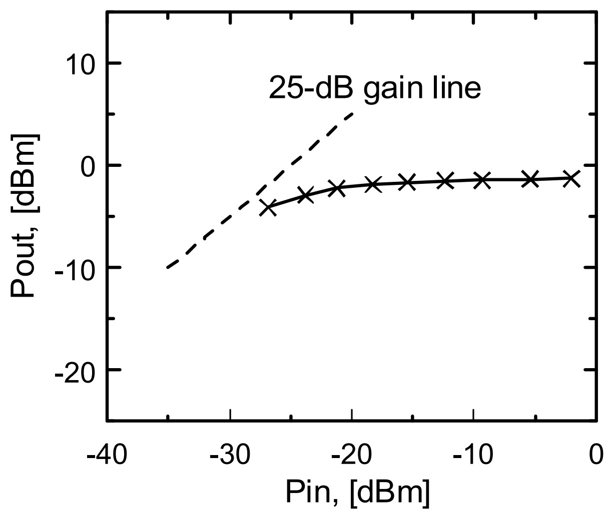


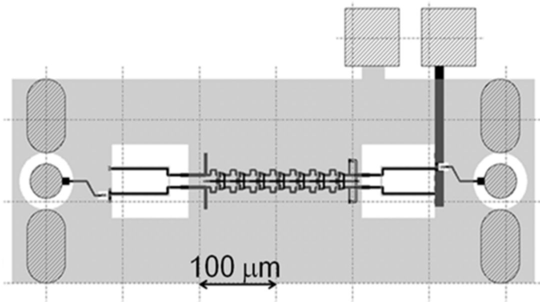
[Hacker et al, MWCL 2011]

325 GHz Amplifier in Phase 2 (III)

- Measurements







- Peak gain 25 dB @ 325 GHz
- Bandwidth for 20dB gain = 60 GHz
- P1dB_out = -5 dBm
- Pdc = 190 mW @ 9.5V
- Chip area = 680 x 340 um^2

[Hacker et al, MWCL 2011]

Amplifiers in Phase 3 and 4

- Phase 3
  - 400 GHz amplifier
  - Measurement done
- Phase 4
  - over 500 GHz amplifier
  - In fabrication

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Reported THz Integrated Transceivers

Operating freq. (GHz)	Technology ft / fmax (GHz)	Architecture	LO source	NF (dB)	RX Conv gain(dB)	TX Pout (dBm)	Communication demo	Ref
220	• 100nm GaAs mHEMT	• Single-chip heterodyne TRX with low IF • RF: LNA + subharmonic mixer • LO: Frequency doubler + buffer amp	External 55 GHz	7.4	3.5	-7.1	• NRZ pulse train • 0.5 m link • 12.5 Gbps	[1]
200	• 100nm GaAs mHEMT • 220 / 300	• Single-chip heterodyne RX • RF: LNA + mixer • LO : MPA + freq doubler + buffer	External 100 GHz	6.9	7.7	N/A	N/A	[2]
260 – 304	• 100 / 50 nm mHEMT • 200/300 • 400/420	• Heterodyne RX chipset • RF: LNA + mixer • LO: 6x freq multiplier + PA + freq doubler	External 18.3 – 25.3 GHz	7.6 (Est)	3 (Est)	N/A	N/A	[3]
170	• 130 nm SiGe • 270/340	• TRX chipset for imaging • RX RF: RF amp + balun + mixer • RX LO: VCO + LO amp + balun • TX RF : (VCO) + amp	On-chip push-push VCO	21	-5	-5	N/A	[4]
140	• 130 nm SiGe • 230/280	• Single-chip TRX • RX RF: RF amp + balun + mixer + IF VGA • RX LO: VCO + LO amp + balun • TX RF: (VCO) + amp	On-chip push-push VCO	12.3	32*	-8	• ASK • 1.1m NLOS link • 4 Gbps achieved	[5]
122	• 130 nm SiGe • 255/315	• Single-chip TRX • RX RF: RF amp + balun + mixer + IF VGA • RX LO: VCO + LO amp + balun • TX RF: (VCO) + amp	On-chip push-push VCO + SHM	11	31	N/A	• ASK with PRBS data sequence • 1.1m NLOS link • 4 Gbps achieved	[6]

References

[1] M. Abbasi et al, TMTT, Feb. 2011

[2] I. Kallfass et al, EuMC, Sep. 2009

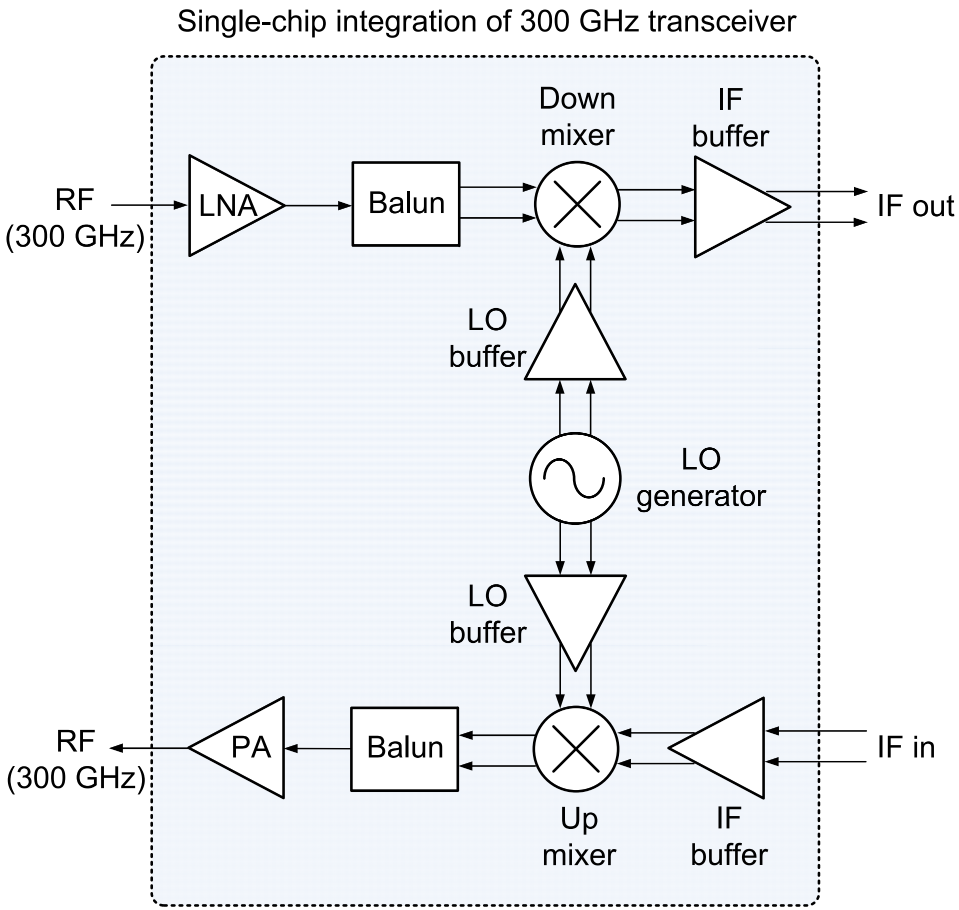
[3] I. Kallfass et al, EuMC, Sep. 2010

[4] E. Laskin et al, JSSC, 2008

[5] E. Laskin, et al, BCTM, 2009

[6] K. Schmalz et al, IMS, 2010

300 GHz Integrated Transceiver at KU

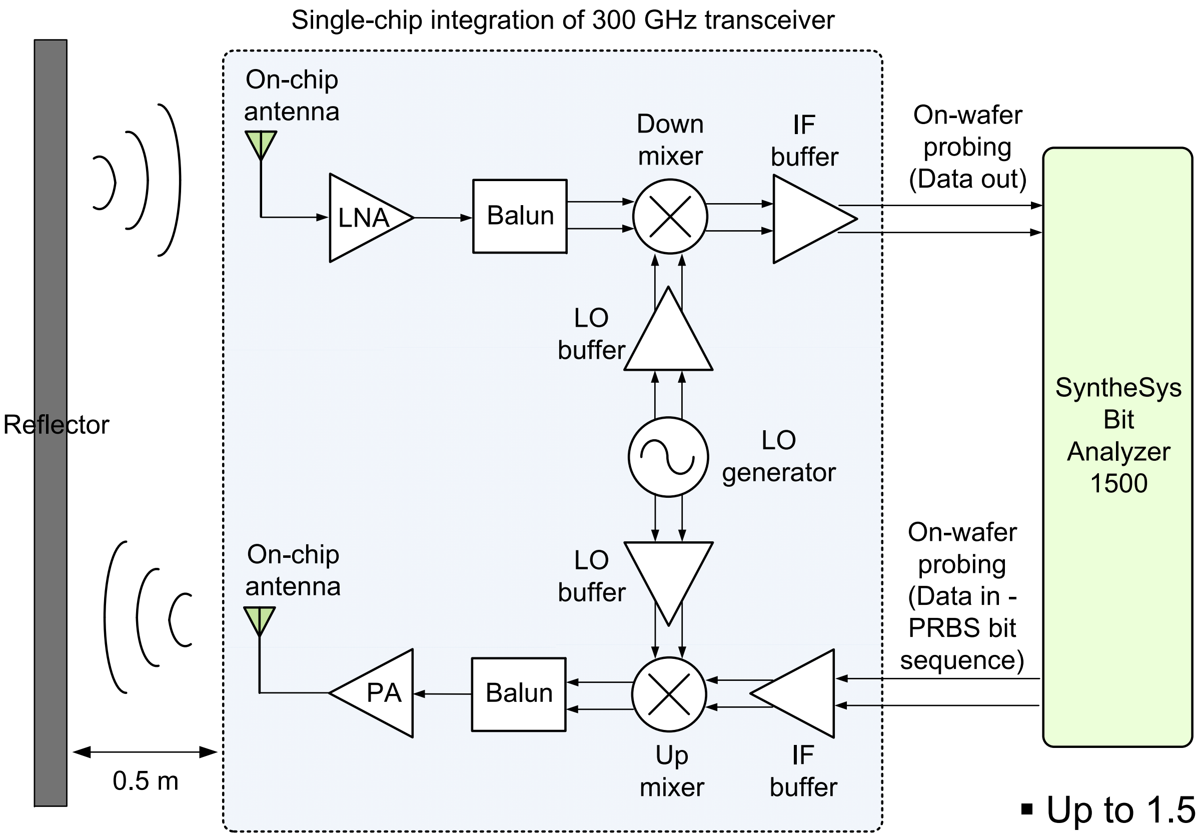


- Heterodyne with low IF
- Simple functionalities adopted to ease data communication demo.
  - Single-step up/down conversion
  - Single phase/gain/LO
- Differential architecture except for LNA/PA
  - Superior noise and power performance
  - Virtual ground exploited in design
  - Balun required

- Design completed : LNA, balun, LO
- Fab-in expected in Oct. 2011

Data Communication Demo Plan (I)

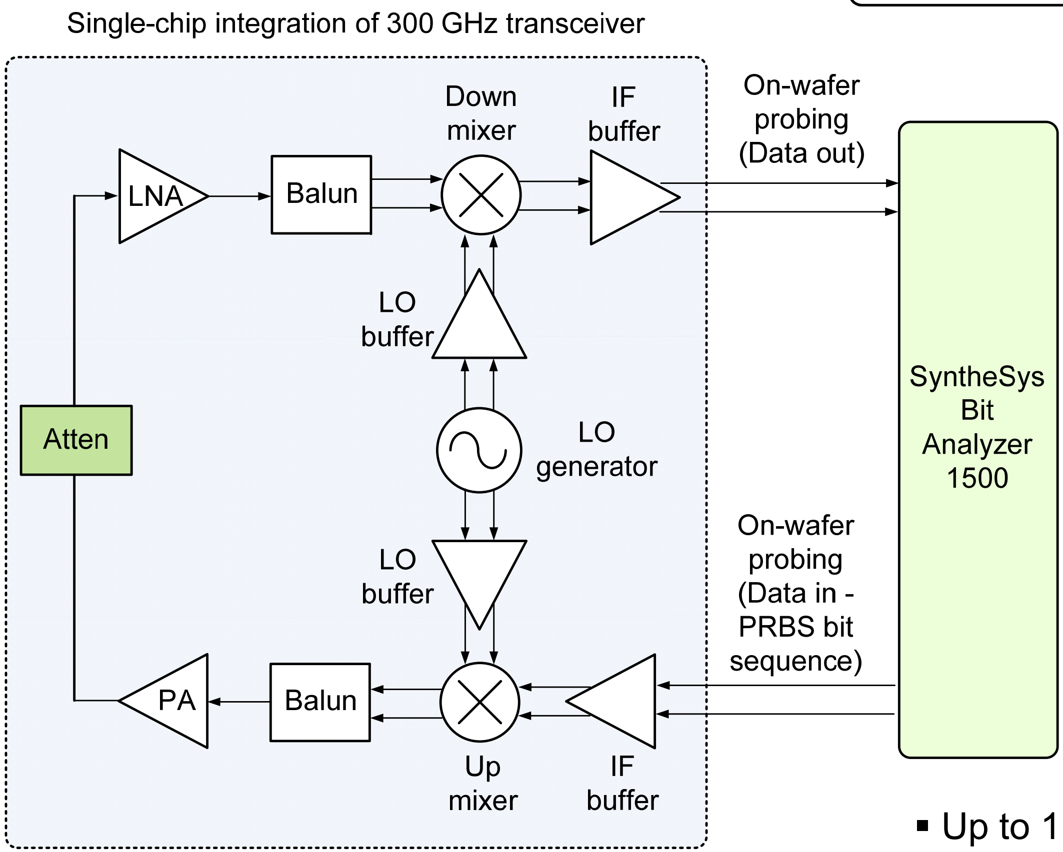
With On-chip antenna installed



- Up to 1.5 Gbps pattern generation (PRBS)
- Eye-diagram display with automatic measurements

Data Communication Demo Plan (II)

With loop-back configuration



- Up to 1.5 Gbps pattern generation (PRBS)
- Eye-diagram display with automatic measurements

Conclusion

- Recently, remarkable achievements have been made in developing THz transceiver systems based on active electronic devices
  - Transistors: f_{max} exceeds 1 THz already.
  - Circuit blocks: operating at hundreds of GHz
  - Integrated transceiver systems: data transmission demonstrated up to 12.5 Gbps at 220 GHz
  - On-going contribution of Korea Univ to development of THz amplifiers and transceiver systems
- There are several challenges in realizing “practical” THz communication systems (e.g. device/circuit/packaging issues etc), and now more innovative techniques are needed to make it finally.