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sense and simplicity

Towards THz spectroscopy and imaging in standard CMOS technology

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Philips Research Eindhoven, ESSI Group

Joint Wireless Sensing SIG and Short Range Wireless SIG, “Sensing from Radio” – Cambridge, 29 Sept. 2010

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Growing interest in THz radiation

- Interest in THz radiation started long ago
  - H. Rubens, E. Nichols “Heat Rays of Great Wave Length”, Phys. Rev. **4**, 314-323,1897
  - E. Nichols, J. Tear, “Joining the infrared and electric wave spectra”, Proc Natl Acad Sci U S A. 1923; 9(6): 211–214.

“[…] practically the last unexplored region in the whole extent of the electric wave spectrum […]”

- Slow progress for decades

- Progress accelerated in the last 15-20 years (TDS in 1995)
- B. Hu and M. Nuss “Imaging with terahertz waves” Opt. Lett. **20**(16), 1716–1718, 1995.
- P. Siegel “Terahertz Technology”, IEEE Trans. Microwave Theory Tech. **50**(3), 2002

“[…] the terahertz frequency range remains one of the least tapped regions of the electromagnetic spectrum[…]”

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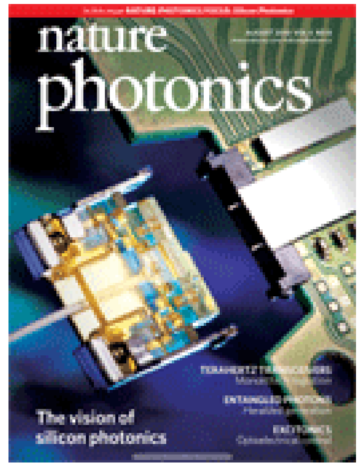
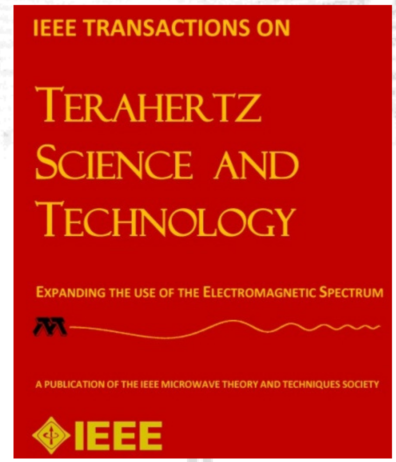
Growing interest in THz radiation

THz QCL 2002



THz QCL
transceiver 2010



Expected fall 2011

- A section dedicated to THz technology is very often present in recent conferences on Microwaves and RF
- New IEEE transaction is expected in fall 2011

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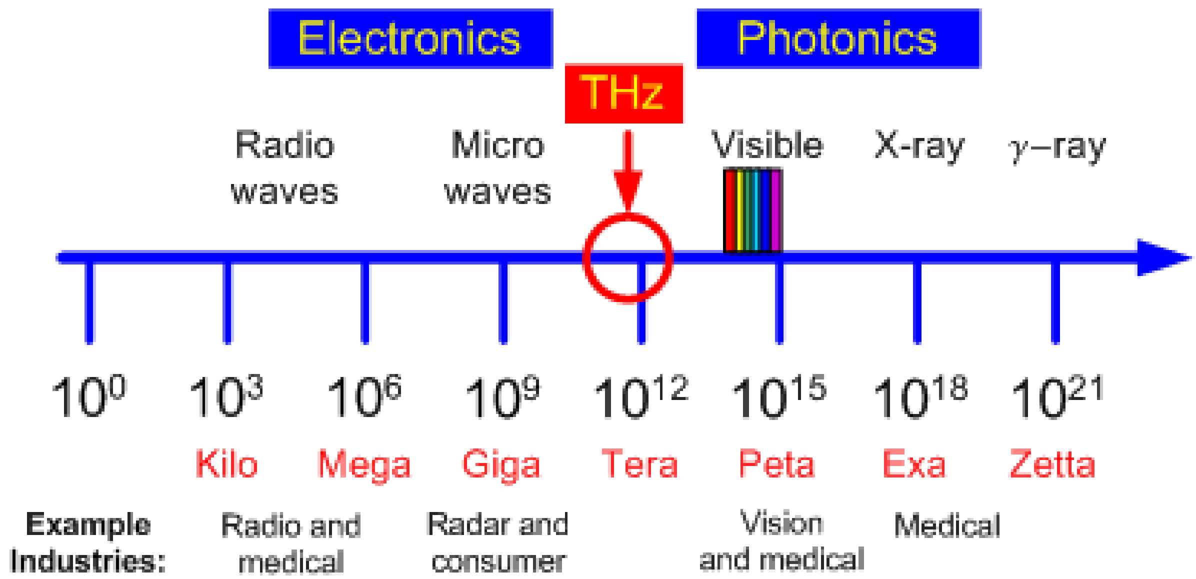
Terahertz radiation



	THz band
Frequency:	100GHz – 3THz
Wavelength:	3mm – 0.1mm
Energy:	1meV – 12.4meV

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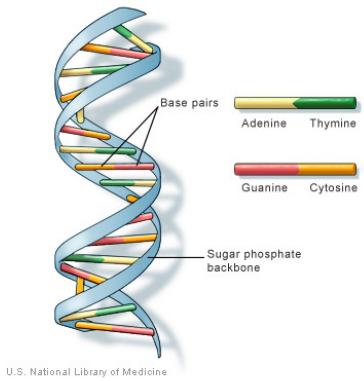
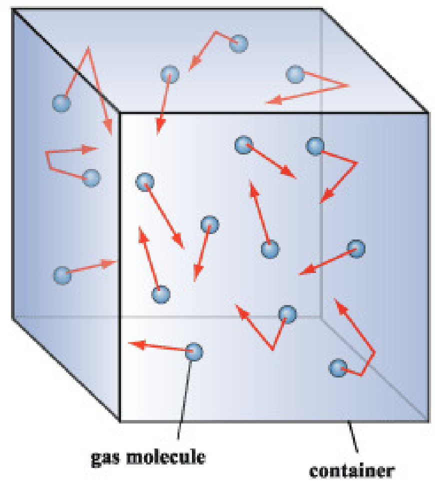
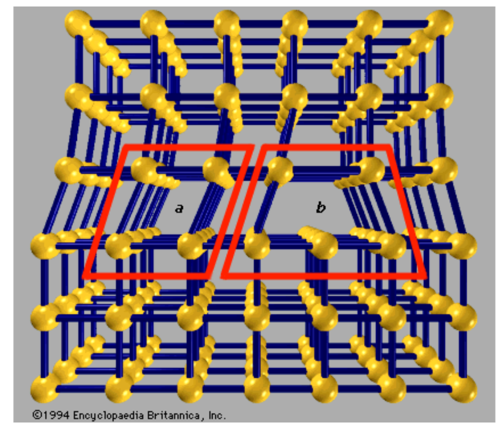
Terahertz vs. others in spectroscopy

THz | Visible/ IR / UV | X-Rays





www.phy.cuhk.edu.hk/



Terahertz vs. others in imaging

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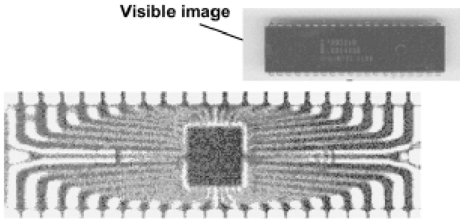
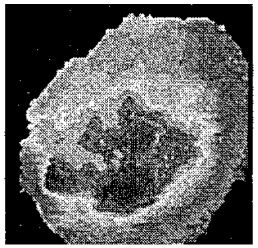
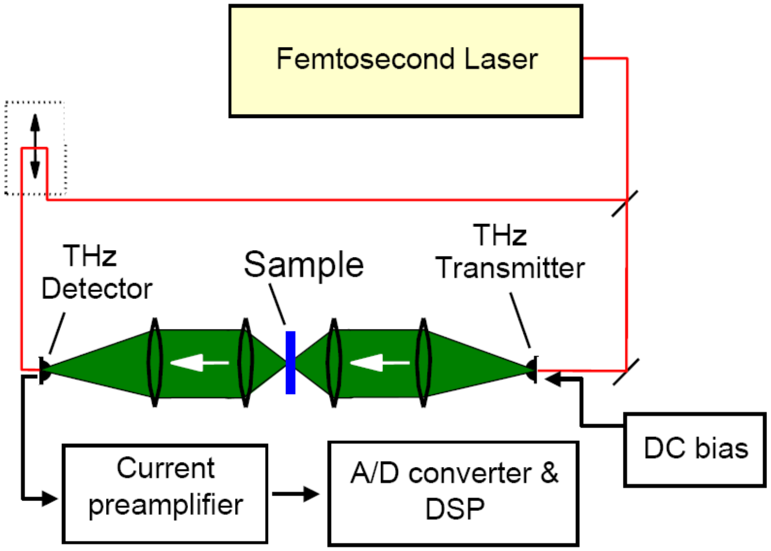
THz	Visible/ IR	X-Rays
 W.L. Chan et al., Rep. Prog. Phys. **70** (2007) 1325–1379	Blocked by opaque objects	
Not ionizing Absorbed by water	Not ionizing Not blocked by water	Ionizing Not absorbed by water
Surface imaging of the body [e.g. skin analysis]	Surface imaging of the body [e.g. skin analysis]	Deep imaging of the body [e.g. bone imaging]



V. Wallace et al., 2nd Joint Conf. IEEE Eng. In Med. and Biology Soc. And the Biomed. Eng. Soc. Oct. 2002, pp.2333-2334

Search of THz killer application still going on

Time-domain spectroscopy: lab instruments

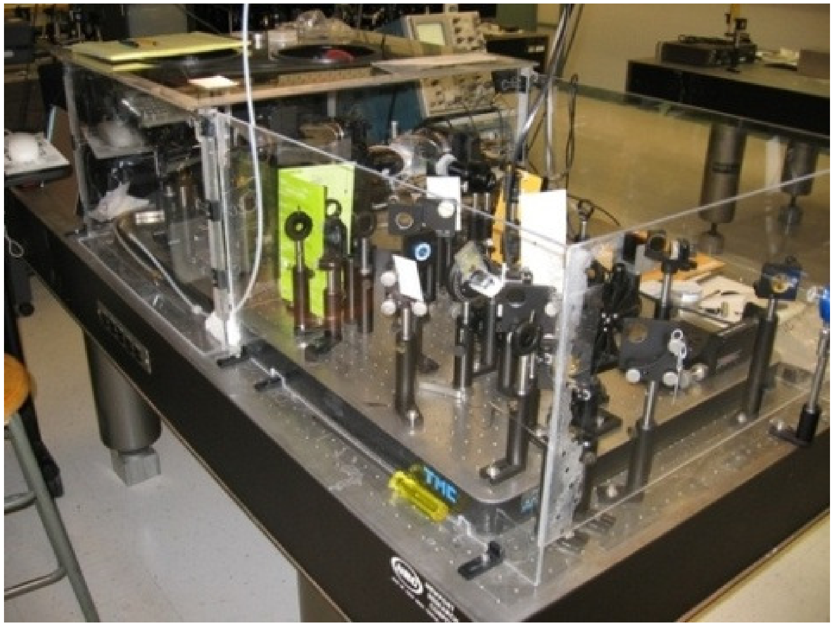


D. M. Mittleman
cm.physics.tamu.edu/seminars/D_Mittleman_02_02_05.pdf

This electro-optical technique has largely contributed to the development of new THz applications.
Even commercial products based on TDS are available.

What about solid-state techniques?

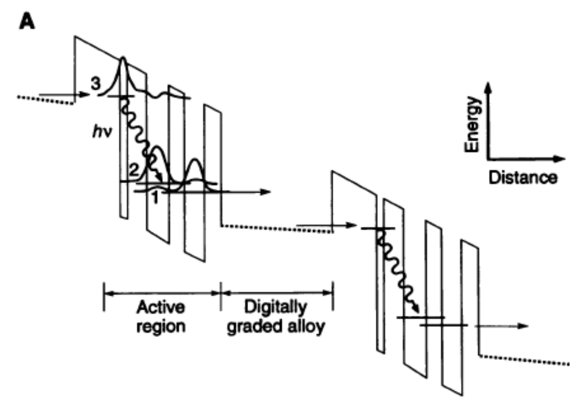
NIST, Boulder, Colorado



THz solid-state devices: QCL

- Quantum cascade lasers
  - Very successful, fast development
  - Based on quantum well engineering
  - Mid-IR and THz sources
  - Low-temperature devices
  - Narrow band
  - Small
  - Magnetic field assistance required for f<1THz
  - DFG QCL 300nW @ 300 K and 4.5 THz

Quantum well engineering allows to overcome limitations due to band-gaps in standard (not engineered) materials.



J. Faist *et al.* Science, vol. 264 April 22, 1994
R. Köhler *et al.* Nature, vol. 417 May 9, 2002

THz CMOS circuits

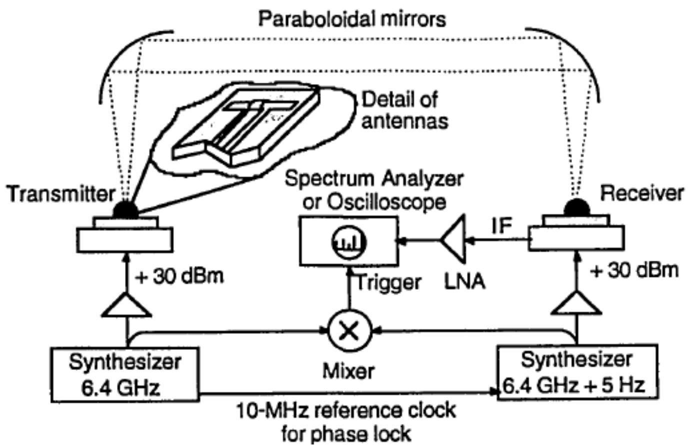
U. Pfeiffer and E. Öjefors,
"A 600 GHz CMOS Focal-Plane Array for THz Imaging Applications", ESSCIRC 2008.

- *0.25 µm CMOS with f_T=35 GHz used to receive 600 GHz signal*
- *Distributed resistive self mixing concept used*

D. Huang et al.,
"THz CMOS Frequency Generator Using Linear Superposition Technique",
IEEE J. Solid-State Circuits, vol. 43, No. 12, Dec. 2008

- *90 nm CMOS with f_{max}<160 GHz used to generate -46 dBm at 324 GHz*
- *Linear superposition technique used*

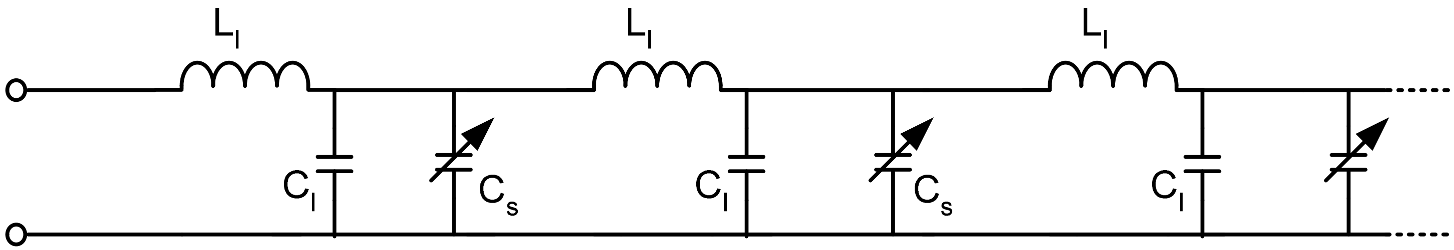
NLTL-based THz systems

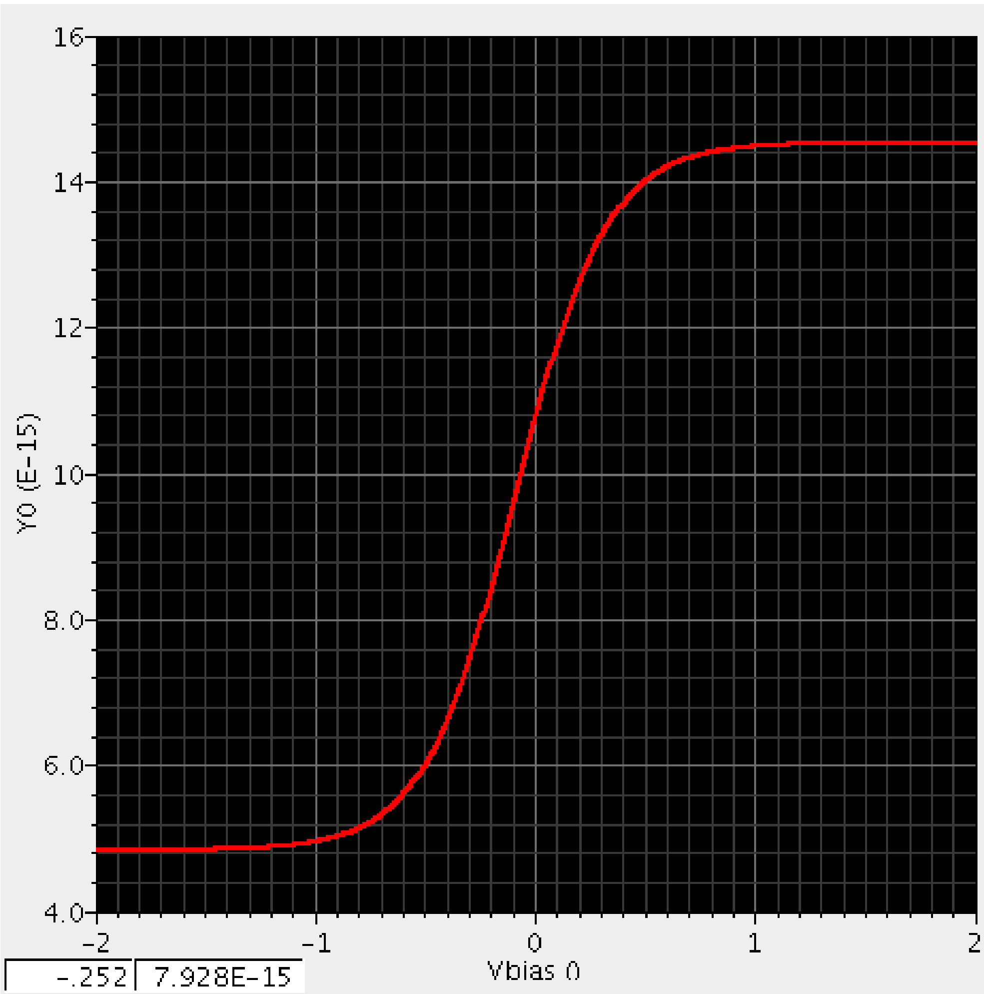


J.S.Bostak *et al., J. Opt. Soc. Am. B,*
vol. 11, no. 12,December 1994

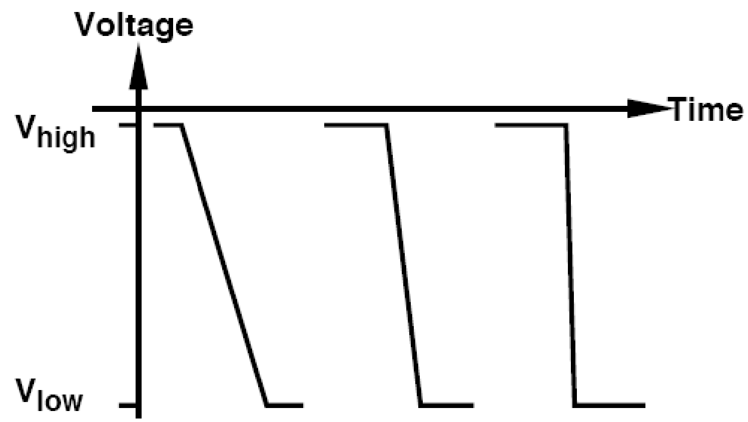
- GaAs nonlinear transmission line-based spectrometers have been demonstrated in the lab
- Nonlinear transmission lines are used in the source and the detector
- Coherent detection
- Further example: Y. Konishi et al., Appl. Phys. Lett. 61 (23), 7 December 1992

NLTL-based THz systems





$$v(V) = \frac{d}{\sqrt{L_l(C_l + C_s(V))}}$$



Cut-off frequency of
- CMOS varactors: ~500 GHz
- CMOS Schottky diodes: ~850 GHz

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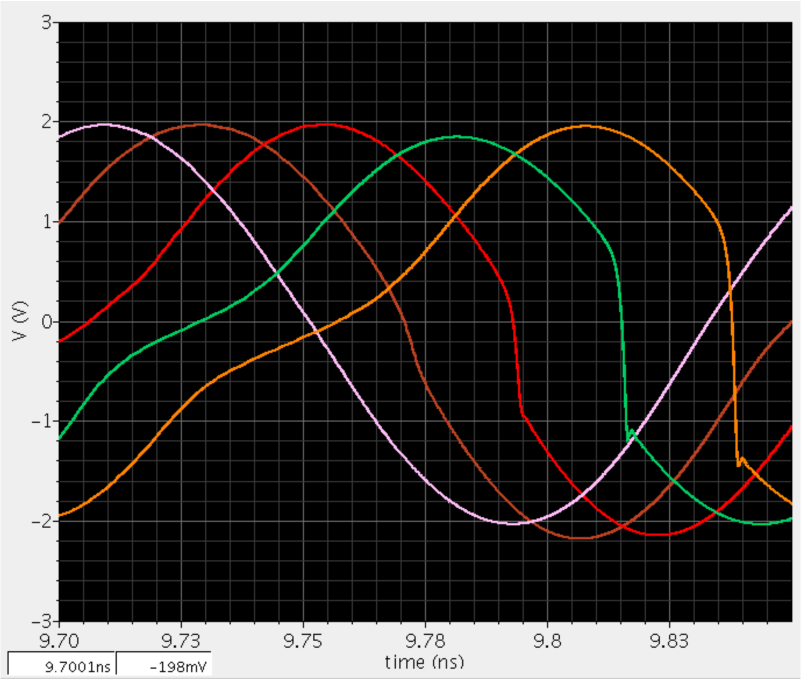
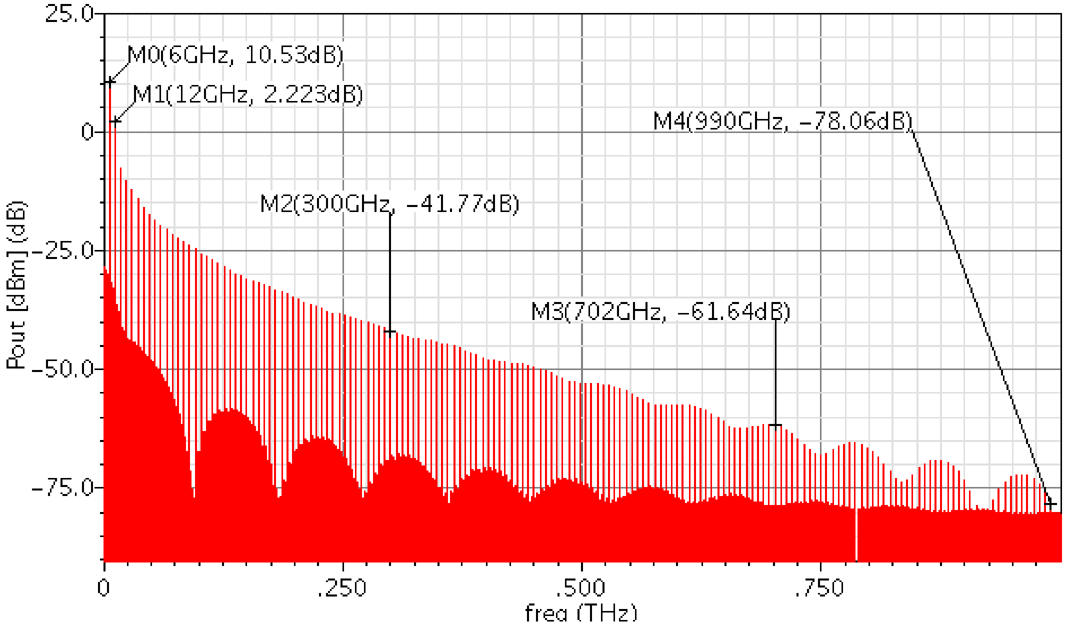
NLTL-based THz systems

Simulated NLTL with varactor losses

No metal losses included



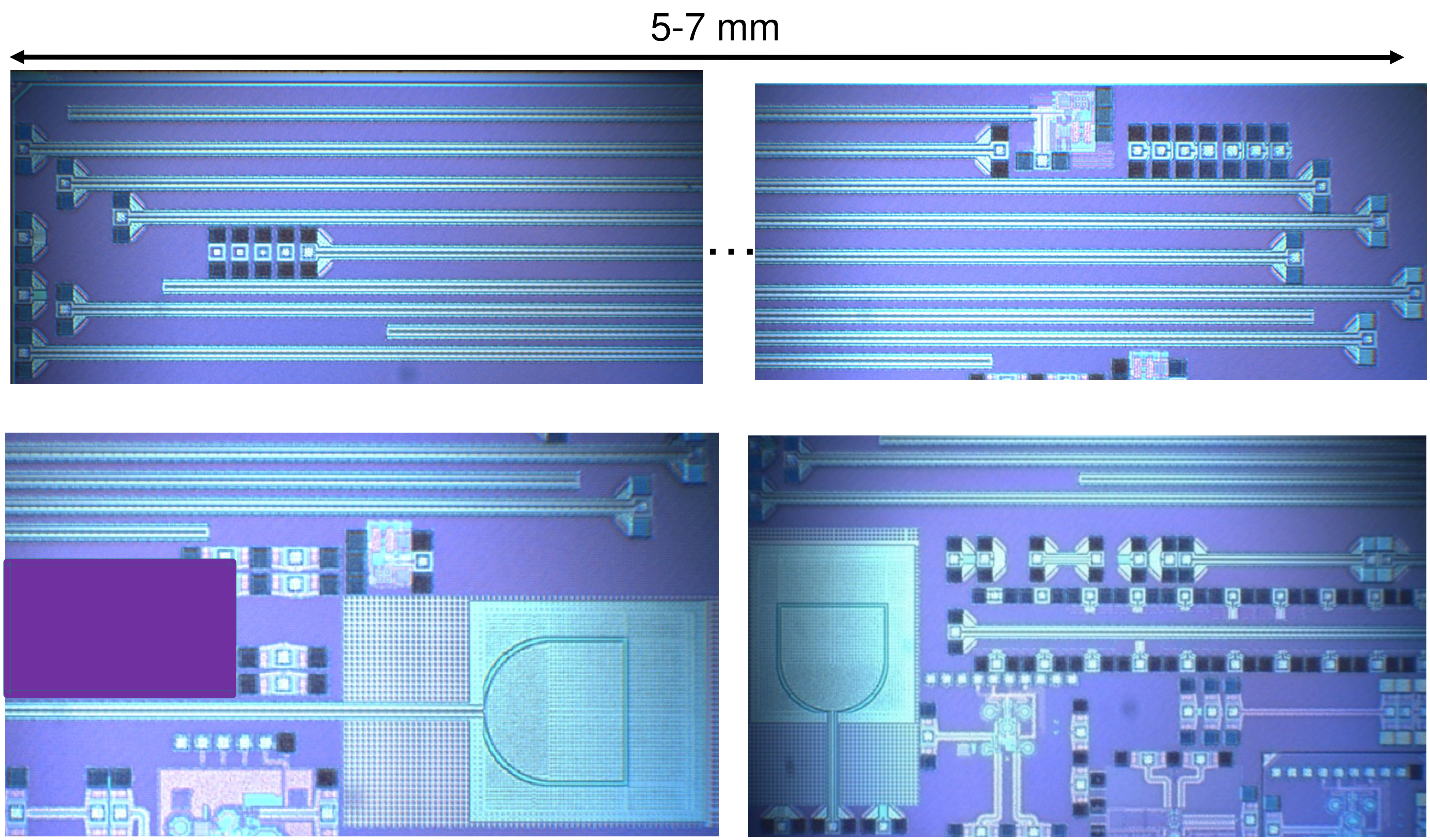
Power level expressed in dBm
(marked dB by the software)



Lorei

CMOS NLTL fabrication

Commercial 65-nm CMOS technology



CMOS THz system

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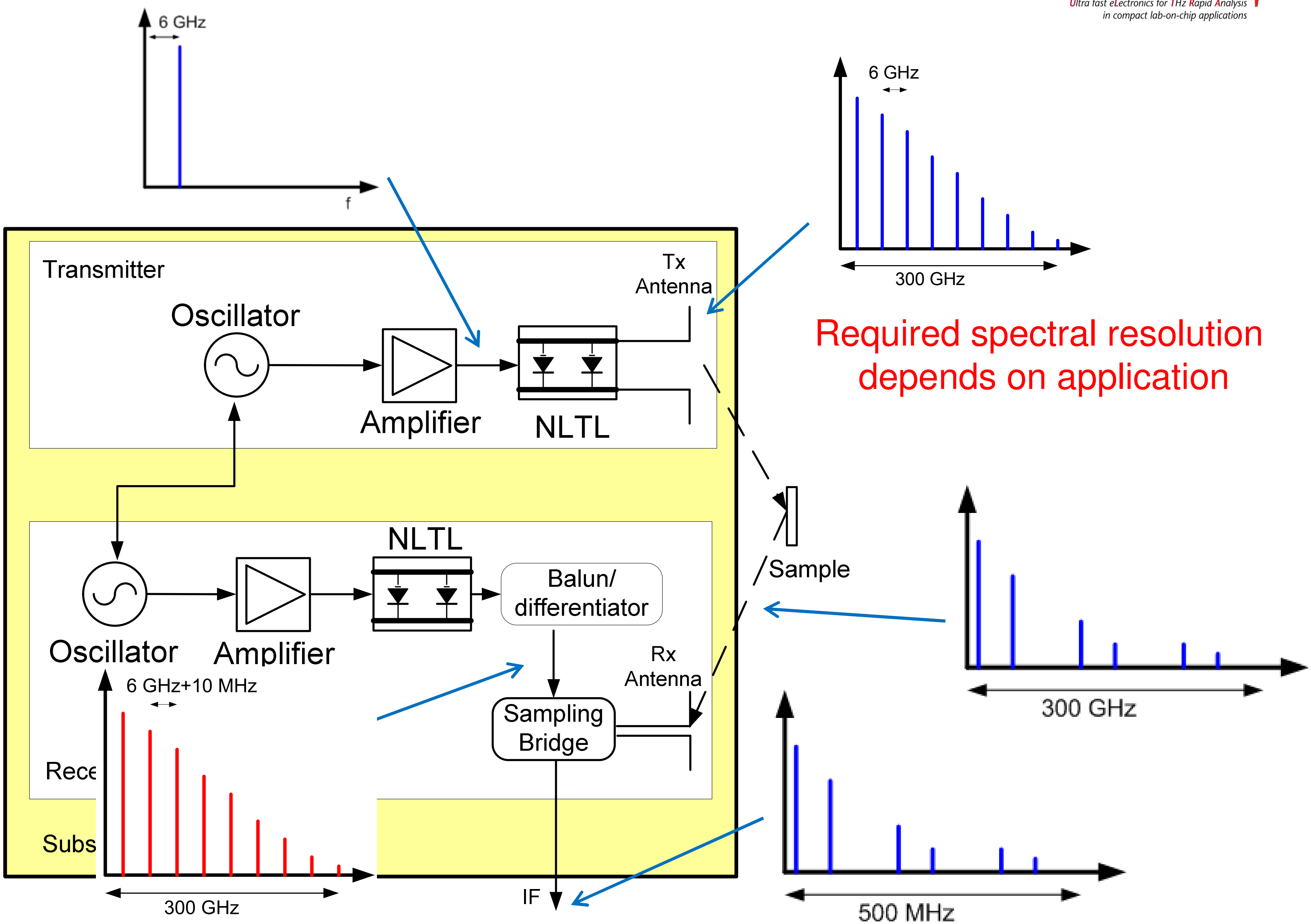

Required spectral resolution depends on application

L. Tripodi, Integrated all-electronic THz imaging/spectroscopy device, WO2009013681 A1

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Conclusions

- THz radiation is a promising new scientific and business opportunity
- CMOS THz microelectronics is a very active research topic
- An integrated imager/spectrometer in the low THz band (<300 GHz) is currently under development

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