Department of Physics
Microwave Laboratory

Science and Technology in the Submillimeter with High Resolution Techniques

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Abstract: With emphasis on high-resolution systems, the interaction of the physics of the spectral region with the physics of applications will be discussed. It will be shown how this leads to optimal choices for system strategies.

OCIS codes: 110.6795; 120.6200; 280.1545; 300.6495

Optical Society of America
Toronto
June 14, 2011

The Three Cultures*

THz/Optical

Optical Society of America,
"THz Spectroscopy and Imaging Applications"
Toronto, June 14, 2011

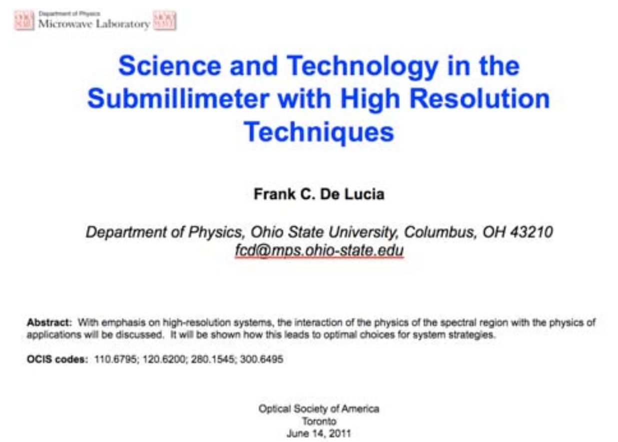
Millimeter/Electronic (Engineering)

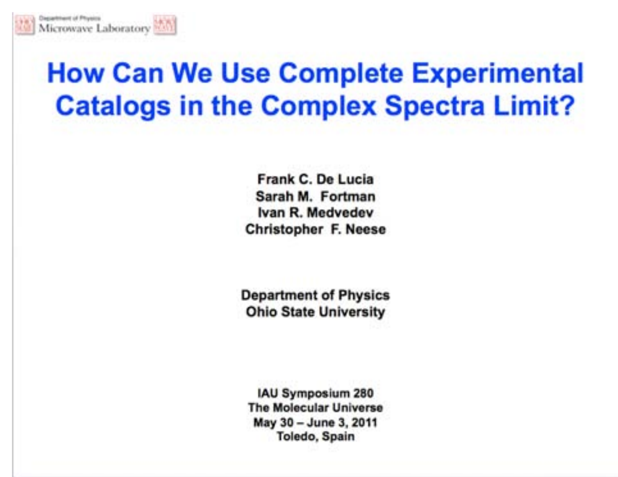
IEEE International Microwave Show 2011
"Workshop on MM-Wave and Terahertz Systems"
Baltimore, MD, June 6, 2011

Submillimeter/Electronic (Scientific)

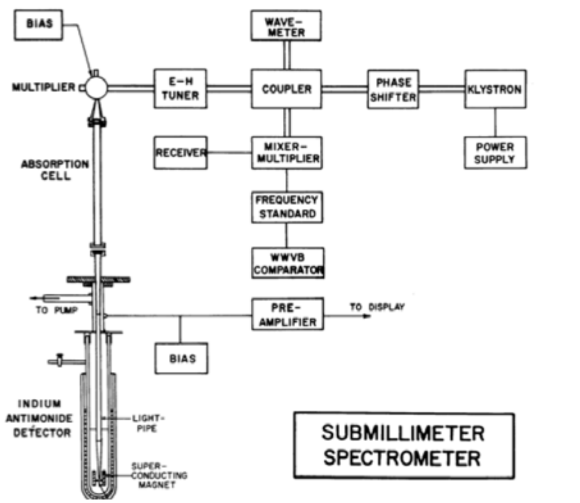
International Astronomical Union,
"The Molecular Universe"
Toledo Spain, June 2, 2011

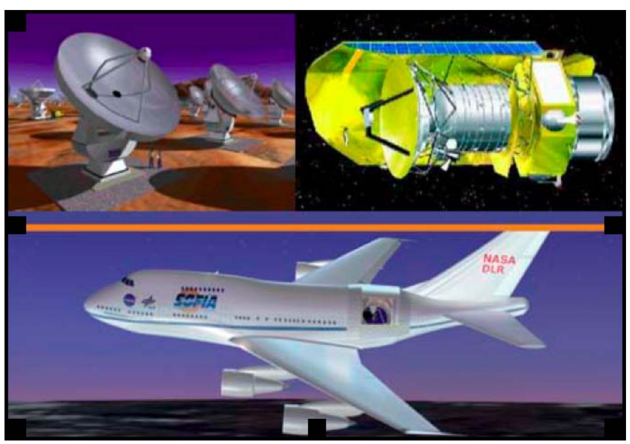
With apologies to C. P. Snow, "The Two Cultures"

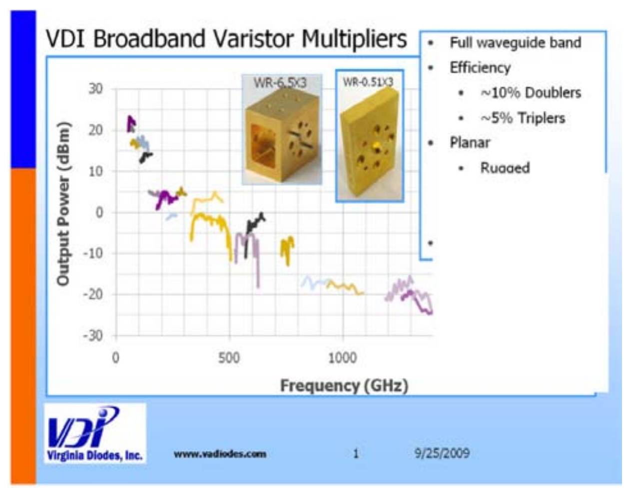




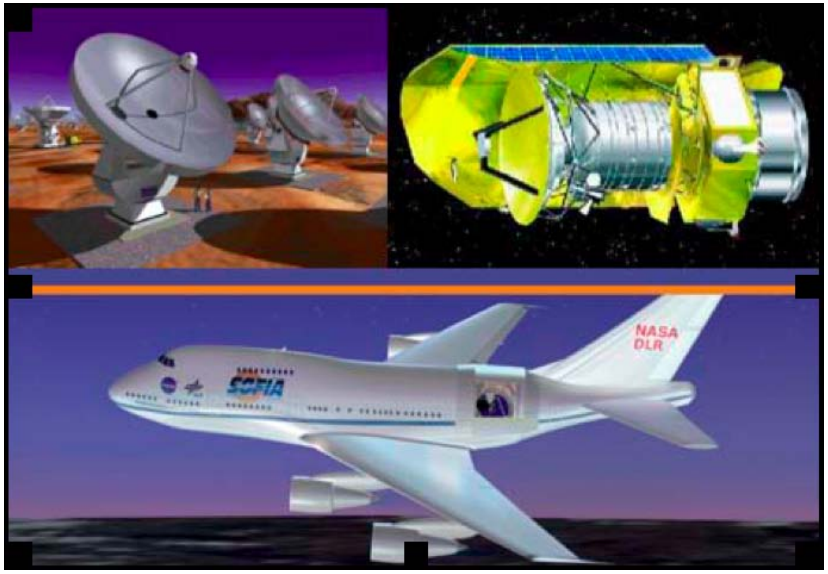
The THz has Come a Long Way (Incrementally)



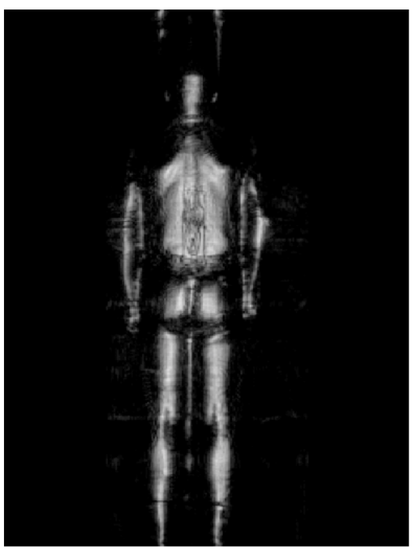




Already Considerable External Impact



Electronic implementations make possible sensitivities that approach fundamental limits, arbitrary and adjustable bandwidths, long term stability and absolute frequency calibration.



Not quite SMM/THz:
128 element phased array

Higher frequencies for greater resolution or standoff capability

In narrow bandwidths small amounts of power correspond to very high brightness

Absolute frequency reference makes possible phased array implementation

Clear Paths to Legacy Applications

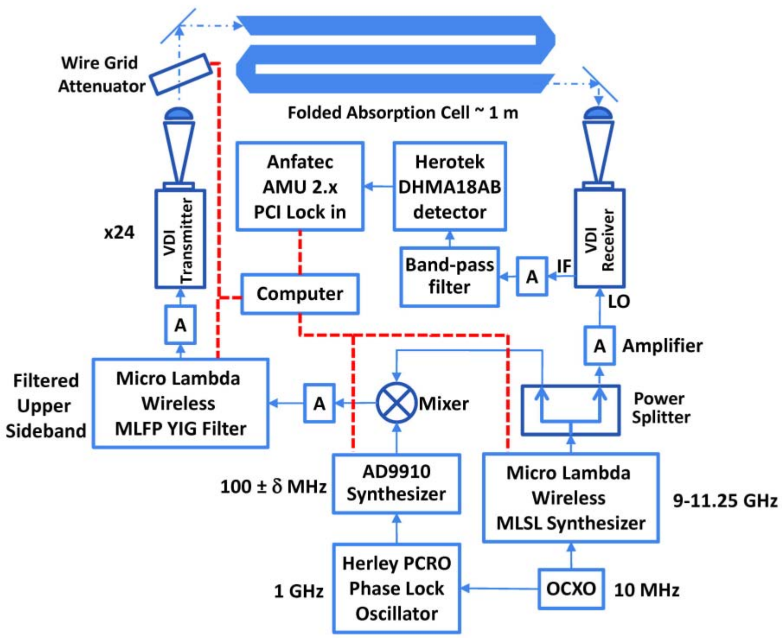
Chemical Sensors

Imaging

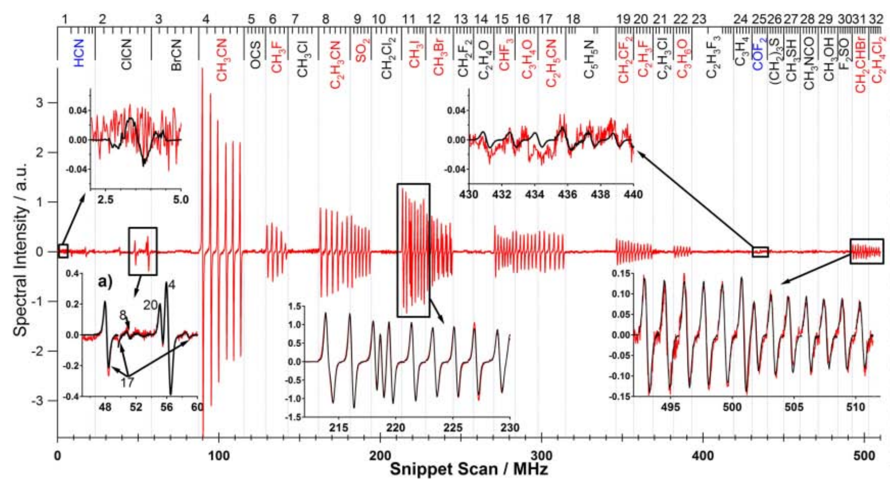
These are enabled by combination of technology advances and mass market (wireless) cost savings

Point Sensors

A Packaged Sensor



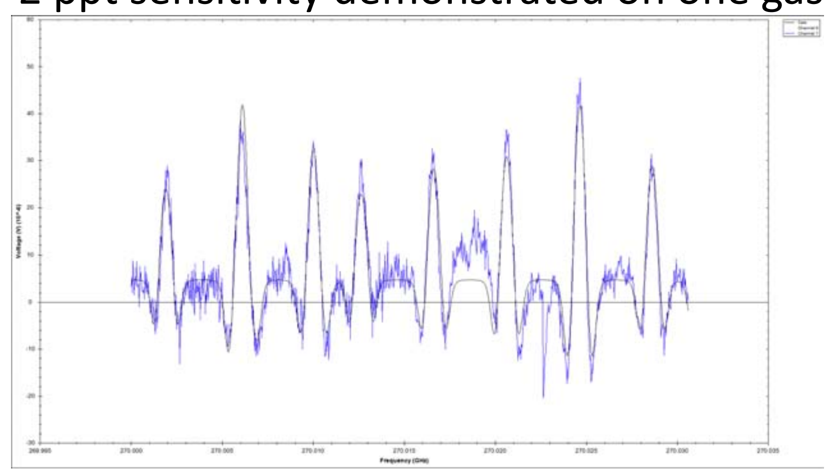
Absolute' specificity on mixture of 32 gases



	Pressure /µtorr	S/N
1	0.06	5.0
2	0.00	0.4
3	0.02	1.3
4	61.79	598.2
5	-0.02	0.5
6	26.97	304.7
7	0.00	0.1
8	66.09	432.5
9	54.13	323.8
10	0.12	1.2
11	130.10	404.2
12	85.04	390.4
13	0.16	1.0
14	-0.02	0.1
15	70.05	273.0
16	58.93	281.2
17	60.61	321.7
18	-0.12	0.8
19	55.67	192.8
20	40.31	161.3
21	-0.55	2.0
22	30.09	92.8
23	-0.07	0.3
24	-0.16	0.5
25	4.68	9.5
26	-0.90	1.8
27	0.10	0.2
28	0.81	1.5
29	0.27	0.6
30	-0.63	1.1
31	71.78	123.2
32	73.12	82.6

∑ = 0.89 mtorr

2 ppt sensitivity demonstrated on one gas



Enabled by:

(1) High brightness temperature of electronic sources (~10^{14} K)

(2) Frequency accuracy and agility of Electronic synthesized sources

The U. S. Army Center for Health Promotion and Preventive Medicine Toxic Industrial Chemical (TIC) List

- Allyl alcohol
- Acrolein
- Acrylonitrile
- Ammonia
- Arsine
- Chlorine (HCl)
- Diborane
- Ethylene oxide
- Formldehyde
- Hydrogen bromide
- Hydrogen chloride
- Hydrogen cyanide
- Hydrogen fluoride
- Hydrogen selenide
- Hydrogen sulfide
- Methyl hydrazine
- Methyl isocyanate
- Methyl mercaptan
- Nitrogen dioxide
- Nitric acid
- Parathion (not a gas)
- Phosgene
- Phosphine
- Sulfuric acid (not a gas)
- Sulfur dioxide
- Toluene

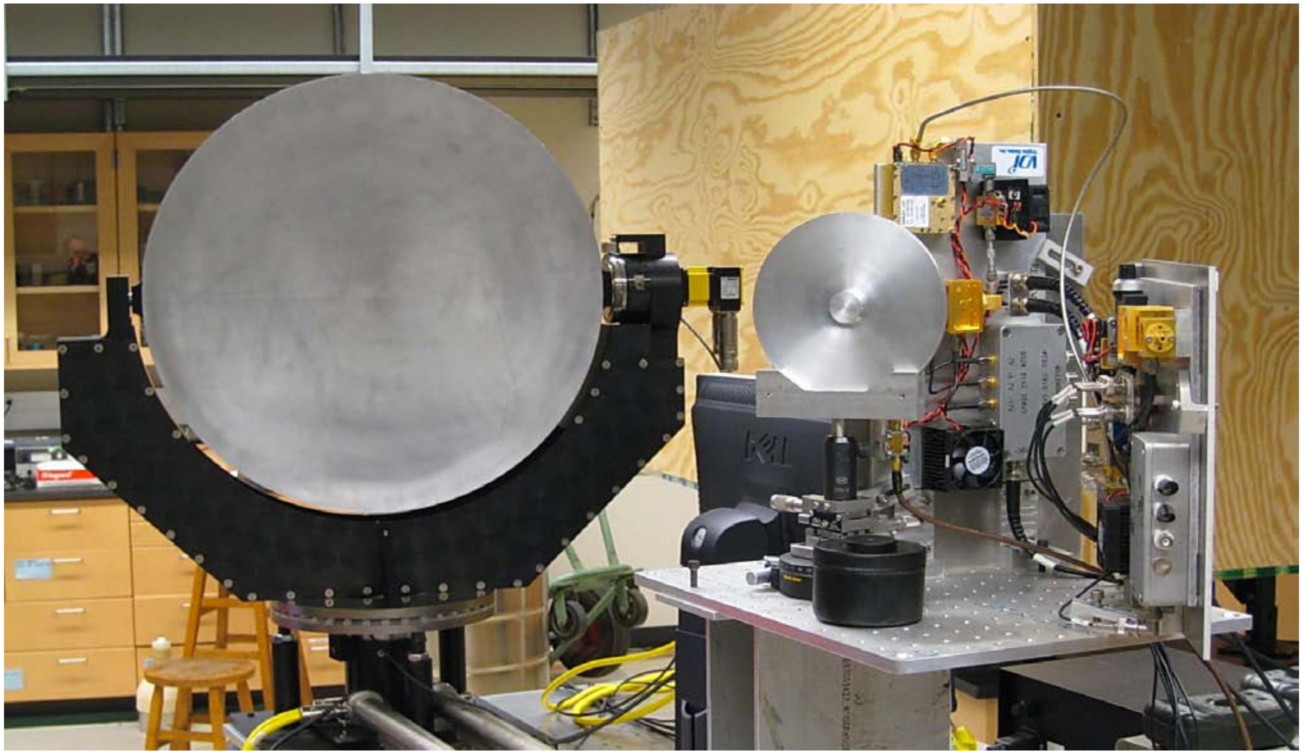
Green indicates a highly favorable gas

Orange indicates not a highly favorable gas

Red indicates not observable

Imaging

640 GHz Active Imager from DARPA TIFT Program



Incoherent 'Passive' Images: Angular Diversity

Cold Sky Illumination at 94 GHz

Incoherent Target Illumination

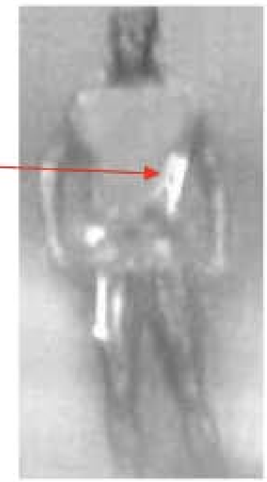
Multimode above

Multimode side

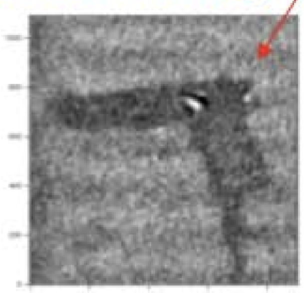
From ~blackbody room

Target emission into 2π steradians of modes

'Uniform' Passive Illumination at 94 GHz

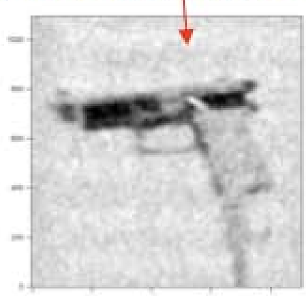


Thermal Emission on Warm at 650 GHz Background



Shadow gram of metallic object reflecting diffuse colder room

~15 Degree Thermal Illumination at 650 GHz

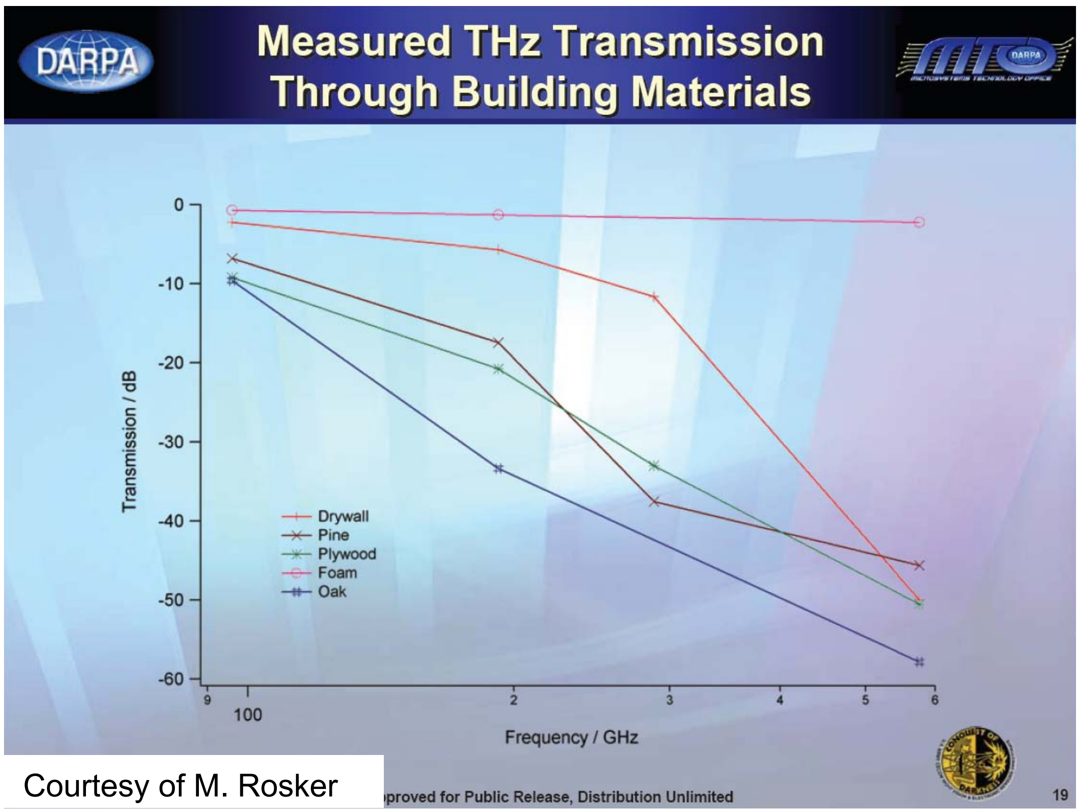


Contrast of metal within angular diversity of illuminator

THz Passive Thermal Emission

Thermal Radiation no special angle

Will THz photons generated by electronic techniques ‘see through walls’?

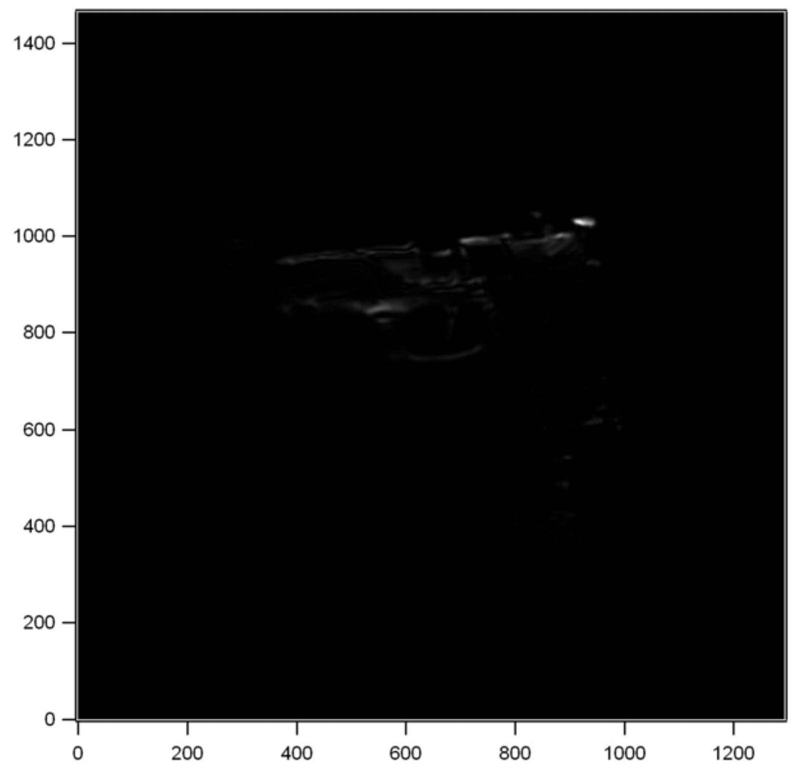


Courtesy of M. Rosker

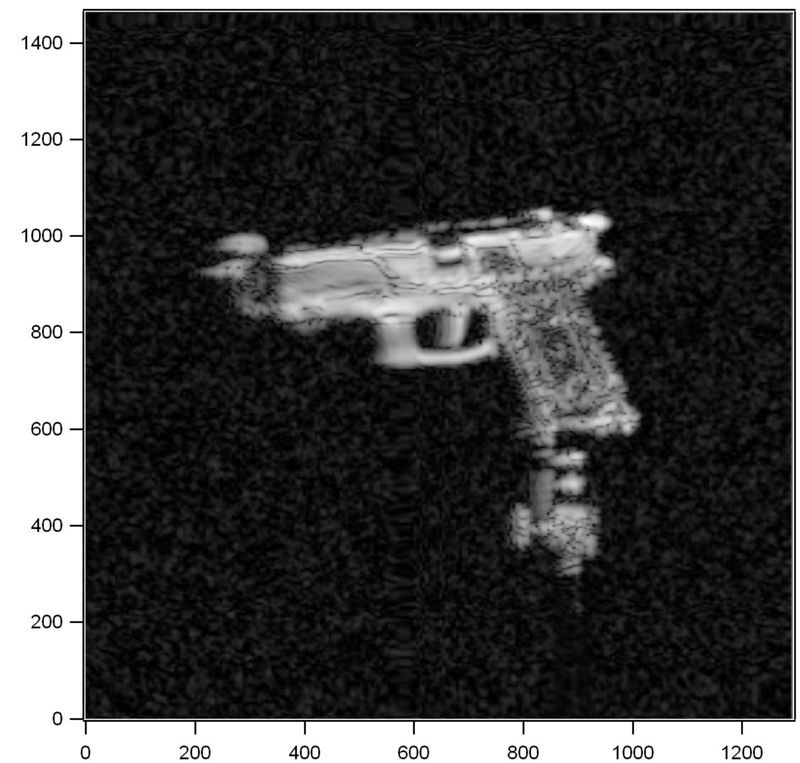
No, unless you live in a foam (or straw?) house!

What if Target is not at the 'Special Angle?' Log and Linear Scales (Problems and Solutions)

Linear Scale

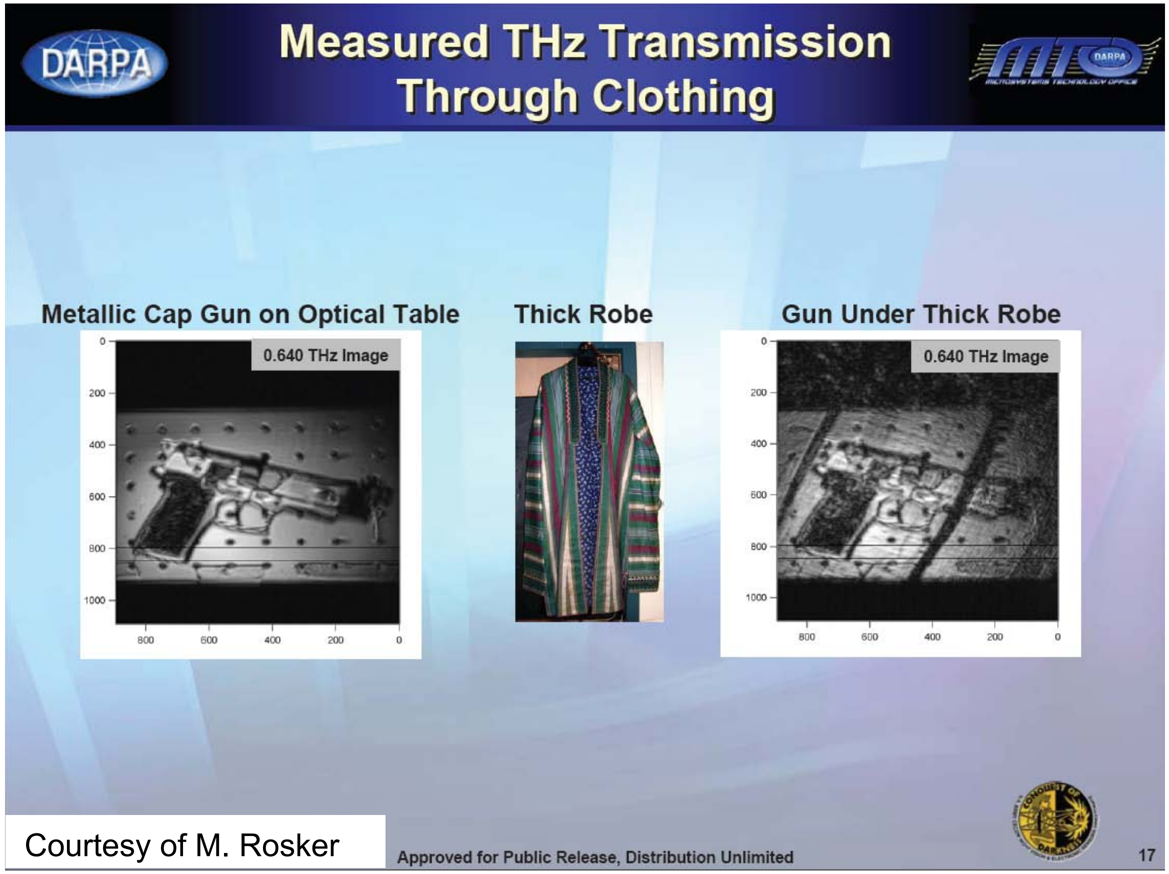


Log Scale



Small target rotation against non-specular background significantly reduces linear target contrast, but log processing in heterodyne system recovers image.

What about Transmission?



With Gun and background are strategically angled, targets stand out under obstruction.

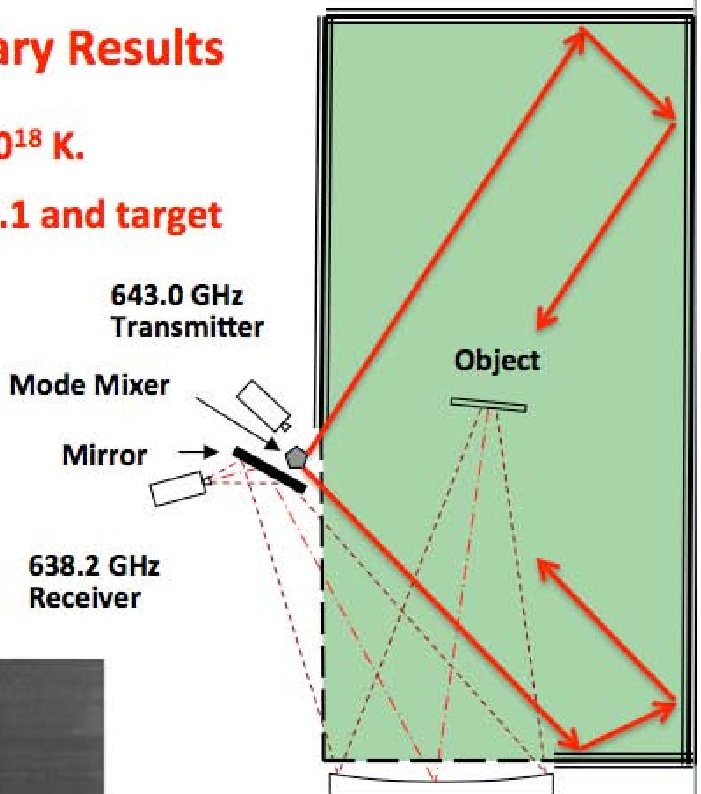
What if not statically angled and target down ~30 db?

Can we use active illumination to make very hot 'passive' pictures and remove the need for 'special orientation: Multimode Illumination – Preliminary Results

1 mW in 100 Hz in a single mode corresponds to a temperature of 10^{18} K.

For a 'room/canyon' of scale l = 100 m, with 'wall' reflectivity R_w = 0.1 and target reflectivity R_o = 0.1

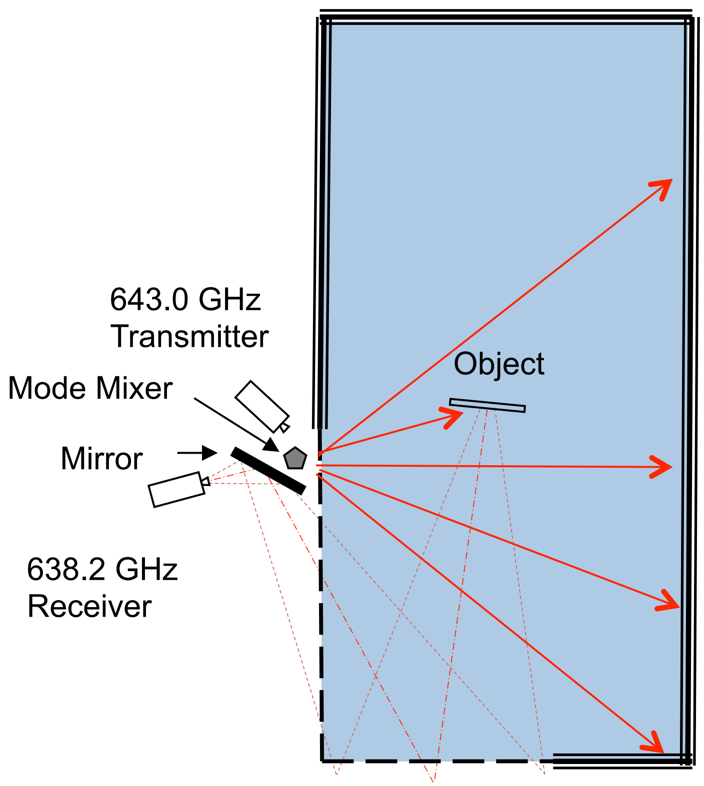
$$T_o = 10^{18} K \left(\frac{\lambda}{l}\right)^2 R_w R_o \sim 2.5 \times 10^5 K$$



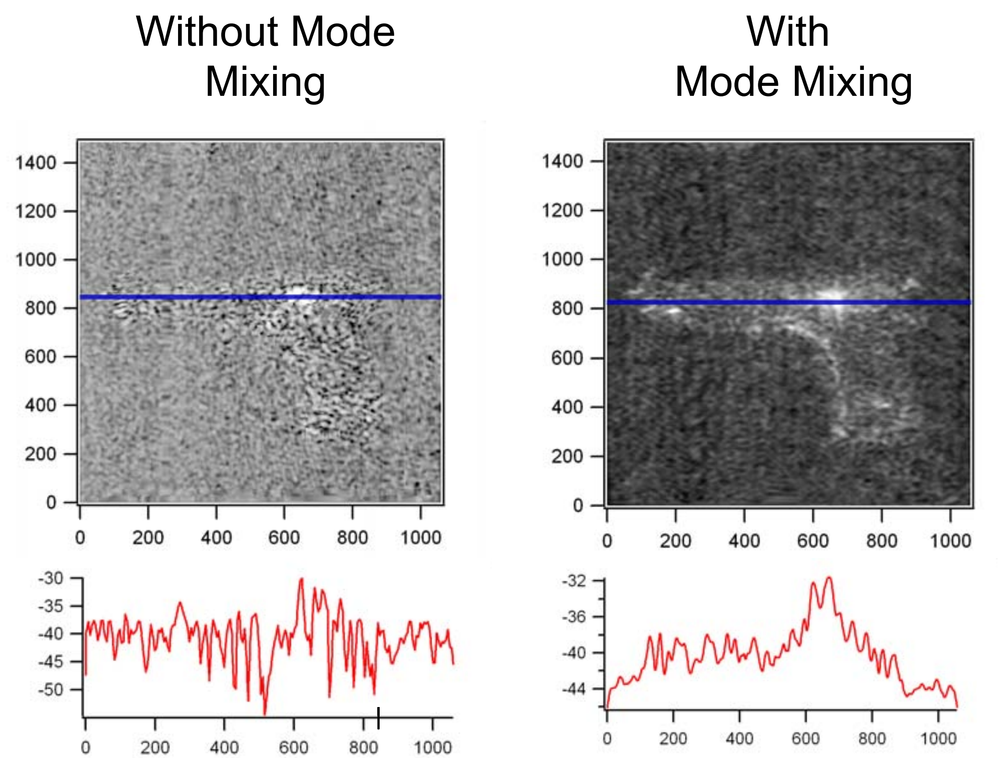
More power: larger volumes, less cooperative reflections, more Doppler bandwidth, shorter integration times

maging at mm-wave and beyond.

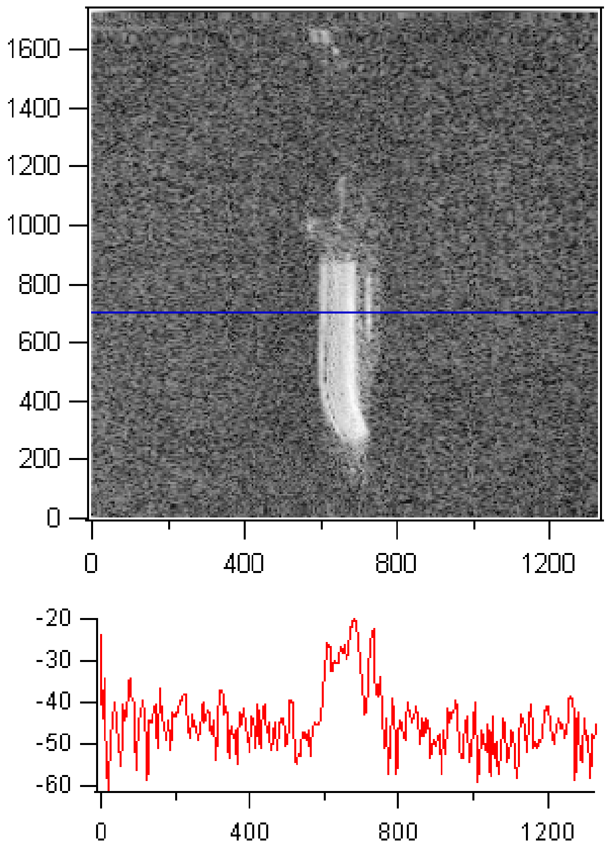
Phase Incoherent Multimode Imaging for “hot” images with speckle minimization



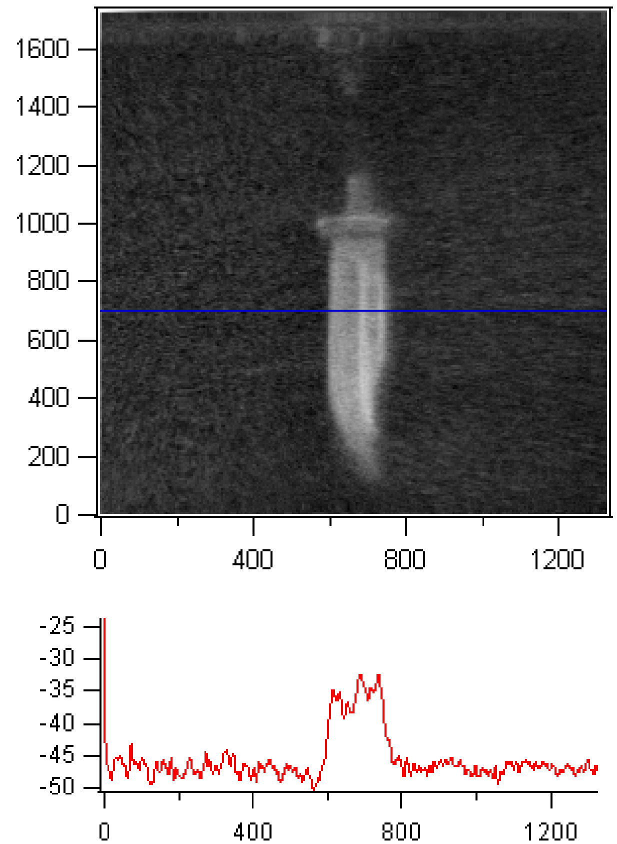
Diameter = 30 cm
Focal Length = 50 cm



Brown robe, Log images



1 image at 0 degrees



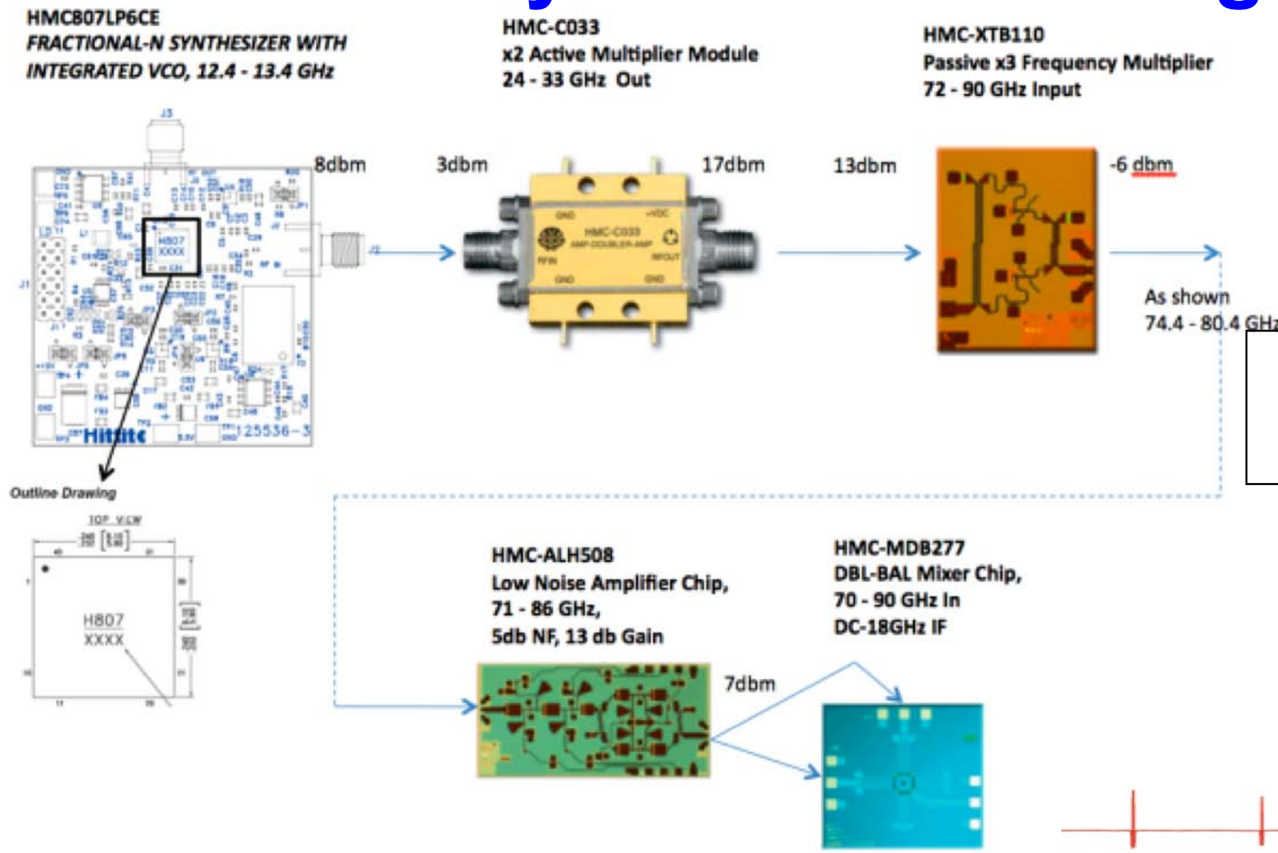
41 images averaged from
-20 to +20 degrees

The power of vacuum electronic sources has the potential to make very hot 'passive' (multimode) images using natural reflections

Goal: The SMM equivalent of turning the lights on in this room!

Advances in Electronic Technology

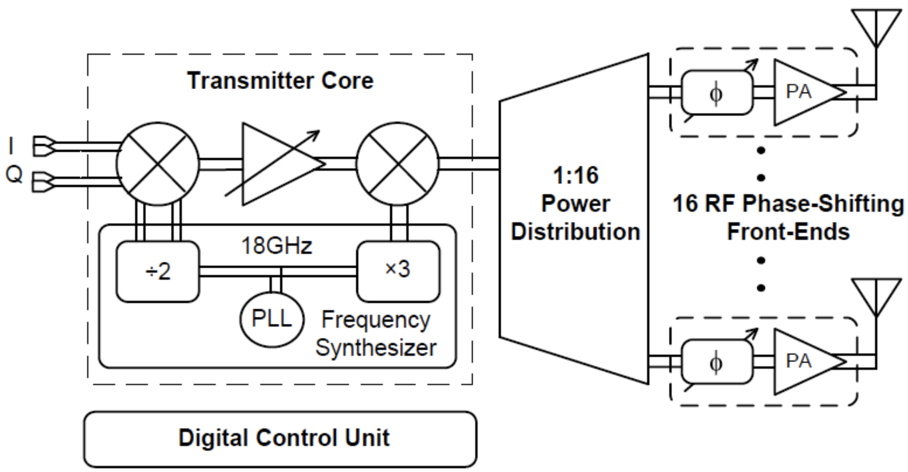
Broad Line of Chip Level IC Through 100 GHz Commercially Available in Large Quantity



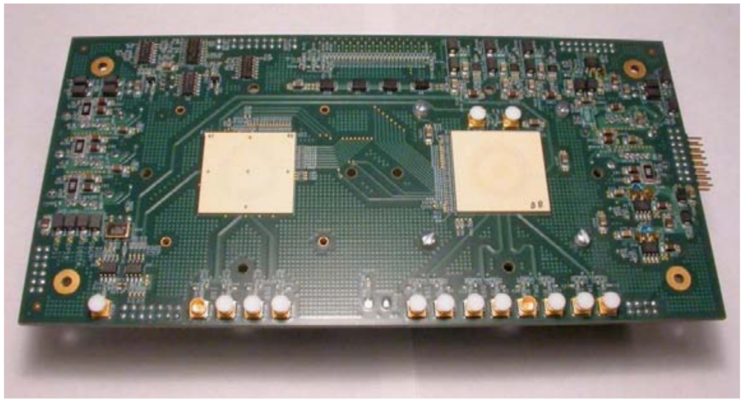
Experimental demonstration at 600 GHz of spectral purity of chip level synthesizer

A SiGe BiCMOS 16-Element Phased-Array Transmitter for 60GHz Communications*

16 Element Phased Array TX Architecture



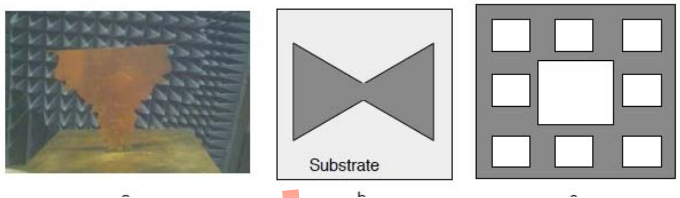
The IC integrates 2240 NPNs, 323,000 FETs and is fabricated in IBM 8HP 0.12um SiGe BiCMOS (f_T=200GHz)



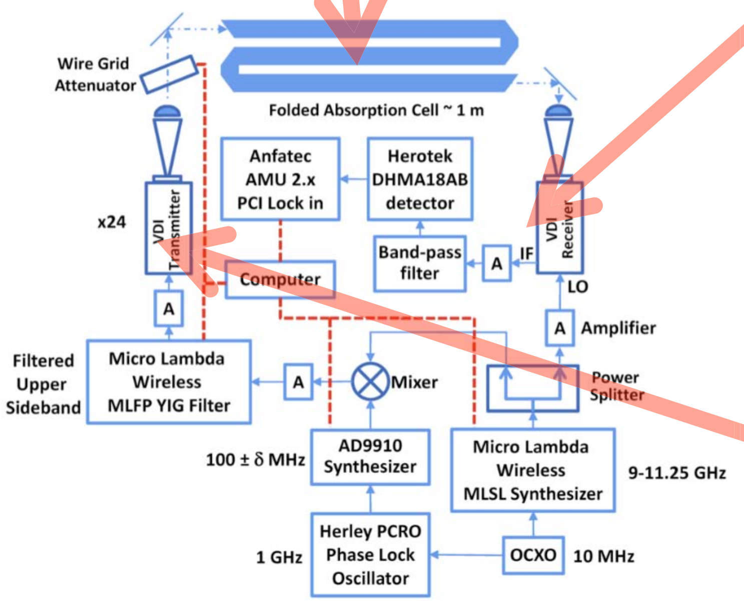
Combined Tx/Rx 16 Channel Evaluation Board

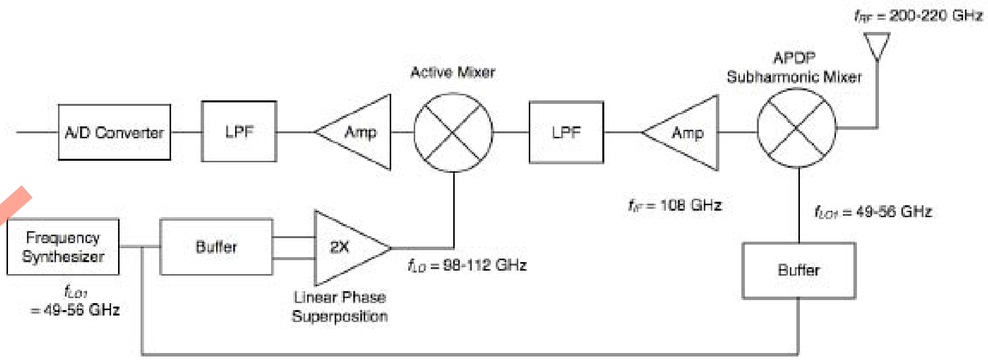
*Courtesy of Alberto Valdes-Garcia and Arun Natarajan, Watson Laboratory, IBM

CMOS Integration for 240 GHz*

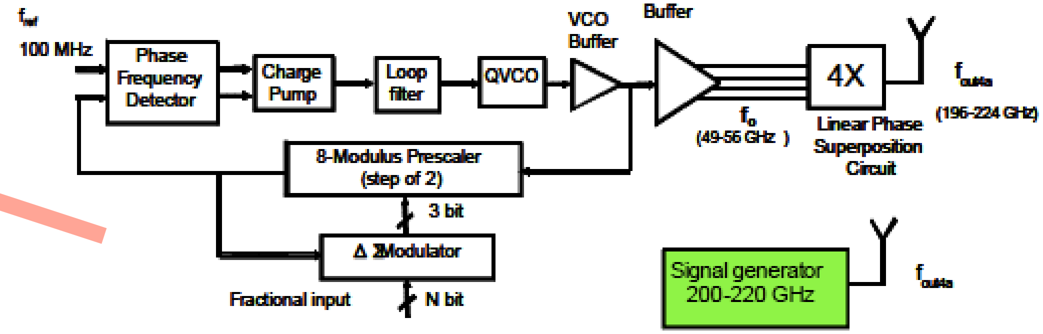


Antennas: Rashaunda Henderson (UT-





Receiver: Bhaskar Banerjee (UT-D)



Transmitter: Kenneth O (UT-D)

*Sponsored by the Semiconductor Research Corporation

Summary

Incremental advances over 40 years have brought us to the threshold of a THz revolution

- **Technology**
- **Science and phenomenology**

Recent advances in technology will both

- **Provide a step function in capability**
- **Enable the mass market**

We should be grateful to the optical THz community for bringing the THz spectral region to broader attention

(but we have to be careful not to be tarred by some of their claims)

Microwave electronics approaches are *very* competitive

Applications (from ‘one-off’ to ‘public’)

- **Submillimeter Astronomy (>$10^9) instruments**
- **Atmospheric remote sensing**
- **Laboratory science (both basic and to support applications)**
- **Radar (providing mass market to drive technology)**
- **Communications (providing mass market to drive technology)**
- **Imaging (through obstruction)**
- **Gas sensors (point and remote)**
- **Analytical chemistry**
- **Process diagnostics and control**