THz Imaging Radar: Technology Development for Multi-pixel Multi-color Architectures

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WFC: Emerging Technology of THz Imaging Systems, Devices and Algorithms
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Outline

• Motivation
• Imaging arrays
  – Methodology
  – Technology
  – Roadmap
• Conclusion
Introduction and Motivation

- Submillimeter-wave heterodyne receivers have a long and noteworthy history in exploring our universe (MLS, MIRO, HIFI)
- Recent work has also demonstrated the use of this technology for concealed weapons detection (Cooper et al talk this conference)
- Most receivers deployed at these frequencies have been single pixel and fairly bulky systems
- Two important considerations require a paradigm shift in terms of how we build these receivers for the future
  - Large count arrays will require that each receiver is low-mass, low-power and extremely small.
  - A “batch level” technology is needed for manufacturing arrays.
Submm Imaging Radar

Visible, IR
- high resolution, but non-penetrating

Microwaves, RF
- penetrating, but low resolution
- THz Gap
- penetrating and high resolution

Range resolution: inversely proportional to chirp bandwidth

\[ K = \text{chirp rate (Hz/s)} \]

IF frequency
- \( f_{IF} = K\tau = \frac{2KR}{c} \)
- \( \delta r = \frac{c}{2\Delta F} \)
RF and LO simultaneously chirped by slowly (1 Hz) modulating 10MHz reference.
First results, 2008

630 GHz radar proof-of-principle achieved. First results:

\[ f_{IF} = f_0 + \frac{2KR}{c} = f_0 \pm 470 \text{ Hz} \]

\[ f_0 = 66.24 \text{ kHz} \quad R = 4.4 \text{ m} \]

\[ K = \pm \frac{8 \text{ GHz}}{0.5 \text{ s}} \quad c = 3e8 \text{ m/s} \]

Problems: very noisy receiver and very slow chirp speed.
THz Imaging Radar Layout

Operating Parameters

Standoff range: 4-25 meters

Operating frequency: 575-605 GHz

Range resolution: ~1 cm

Cross-range resolution: ~1 cm

Output power: ≤0.4 mW

Time per pixel: 6-25 m s
Detection of Concealed Objects on People

- plastic container of BB pellets
- BBs concealed by shirt
BBs over shirt

BBs behind shirt

no BBs

bright shirt reflection

nose is resolved

crucial 3D information
Recent imaging at 25 m standoff distance

<table>
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<th>Single pixel Radar</th>
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<td><strong>Spot size</strong></td>
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Image acquisition limited by switching mirror motor
Technological Roadmap

Develop an ultra-compact receiver which is compatible with array architecture

SOA 500-600 GHz Receiver Front End

Approx. 20 cm

x 50 reduction in volume & mass

1 cm
Radiometer-On-Chip (ROC) concept

- This novel architecture uses a stack of micro-machined wafers for waveguide components and interconnections, and MMIC based GaAs wafers for amplifiers, multipliers and mixers.
ROC modified for proof-of-concept

- Instead of more expensive GaAs wafers, use Si wafers with discretely mounted GaAs-based devices.
Si-metal waveguide interconnections

- 1st option: from the side of the Si wafer

- 2nd option: from the flat of the Si wafer.

Commonly used approach

Our approach for interfacing
Super compact W-band Amp

- 4 Si layers are required to package a pHEMT amplifier chip, waveguide transitions and bends.
- DC bias circuit is also included in the Si block.
Super compact PA module

pHEMT MMIC

Deep RIE technology used to fab Si

Completed module is only 7 g
Super compact 560 GHz RFE

- Integrate in a Si package (4 layers) a 300 GHz MMIC tripler and 600 GHz MMIC sub-harmonic mixer

(Design courtesy of Bertrand Thomas)
560 GHz RFE

- 20 x 25 x 3mm Si package
- WR-10 waveguide (input) & 560 GHz corrugated horn (output)
- SSMA and K-glass bead IF and DC connections
Measured Results

- IF frequency: 4 GHz. Not corrected for IF mismatch.
- Fundamental input power at W-band: 30-50 mW
Complete ROC front-end

• Si part is 8 mm thick.
• Size still dominated by UG387 flange.
Radiometer-on-a-chip

- Si part is 8 mm thick.
- Size still dominated by UG387 flange

* DRIE technology and wafer-bonding technology are combined to assemble silicon based waveguide blocks
  - Demonstrated with w-band power amp
  - Demonstrated with 600 GHz RFE
  - Provides technology to achieve massive power combining
Towards a 2D array...

- RF Si-lenses & spacer
- Submm multiplier & mixer
- W-band PA
- LO signal distribution
- W-band input waveguide
Development of Compact Integrated Receivers: Coupling feeds

-> Silicon lens used as antenna

Proof of concept: Single pixel @ 560GHz

Silicon lens fabricated with a laser machine outside of the lab

-> Work in progress for silicon lens micromachined with UV photolithography and DRIE techniques

In collaboration with Dr. Nuria Llombart and Maria Alonso from Universidad Complutense de Madrid; Spain
Development of Silicon Based Integrated Receivers

Proof of concept: Single pixel @ 560GHz

PO Analysis

\[ D = 28.5 \text{ dB} \]

Aperture Efficiency = 87%

In collaboration with Dr. Nuria Llombart and Maria Alonso from Universidad Complutense de Madrid; Spain
Conclusion

- THz imaging arrays continue to be challenging to implement
- Significant reduction of size and mass of current receiver front-end has been achieved with the new Si-based ROC technology
- Preliminary results are encouraging
- Development of an array is under-way