POLYTECHNIQUE MONTRÉAL
LE GÉNIE EN PREMIÈRE CLASSE

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Multi-Dimensional and Multi-Functional Substrate Integrated Waveguide Antennas and Arrays for GHz and THz Applications: An Emerging Disruptive Technology

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Outline

- Introduction
- Substrate Integrated Waveguide (SIW) Techniques
- Integrated SIW Antennas and Arrays
- Multi-Dimensional Lego-Style Design
- Multi-Functional & Multi-Format Schemes
- Conclusion and Future Outlook

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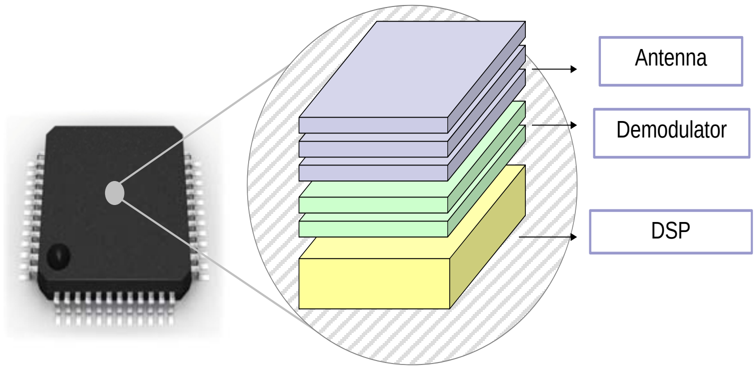
Introduction

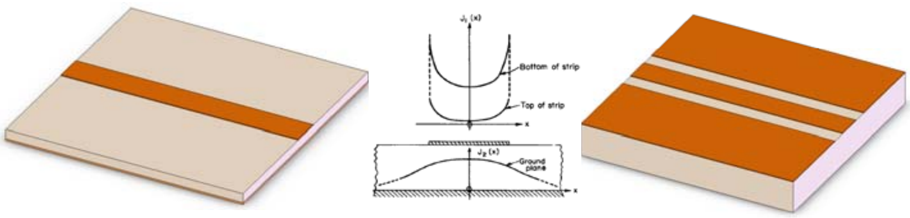
Sketched high-density fully Integrated GHz/THz platform for Machine-to-Machine (M2M) and Internet of Things (IoT)

- Interconnectivity of 5G Systems (5B people & 50B things) -



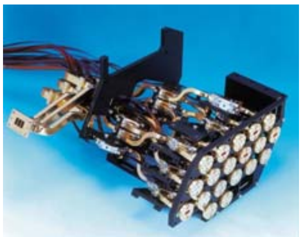
"**Good**", "**Bad**" and "**Ugly**"

Mainstream planar techniques



- Antenna design vs. array design (circuit effect)
- Integrated and easy-to-design radiating element
- Low-cost and small form factor
- Parasitic coupling and unwanted radiation
- Difficult-to-achieve large array efficiency
- Sensitive bandwidth and millimeter-wave hurdle

Typical Examples and Evolution



- Heavy
- Bulky
- Need annual assembly

- Loss -> gain saturation*
- Radiation loss -> SLL degradation and gain loss

- SIW loss < microstrip
- PCB process
- Light weight/low-profile

* P. S. Hall and C. M. Hall, "Coplanar corporate feed effects in microstrip patch array design," *Proc. Inst. Elect. Eng.*, vol. 135, pt. H, pp. 180–186, June 1988.

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Evolution of GHz/THz Technologies

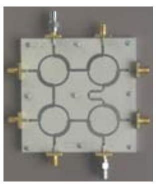
Dielectric waveguide →

Finline →

1st Generation

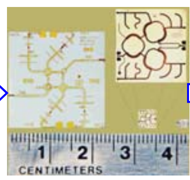
Metal waveguide and coaxial cable

2nd Generation



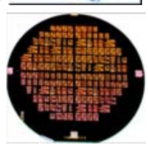
Microwave integrated Circuits (MICs)

3rd Generation



MHMIC and MMIC

4th Generation

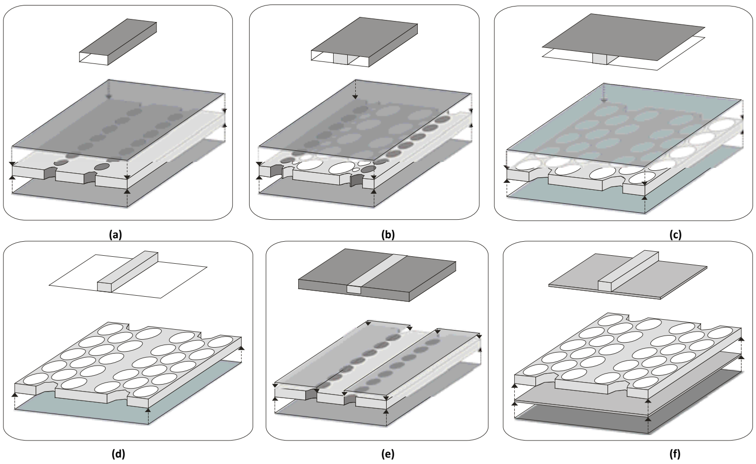


Multilayered LTCC/MMIC MEMS-RFIC

What's next ? ……

Substrate Integrated Circuits (SICs)!

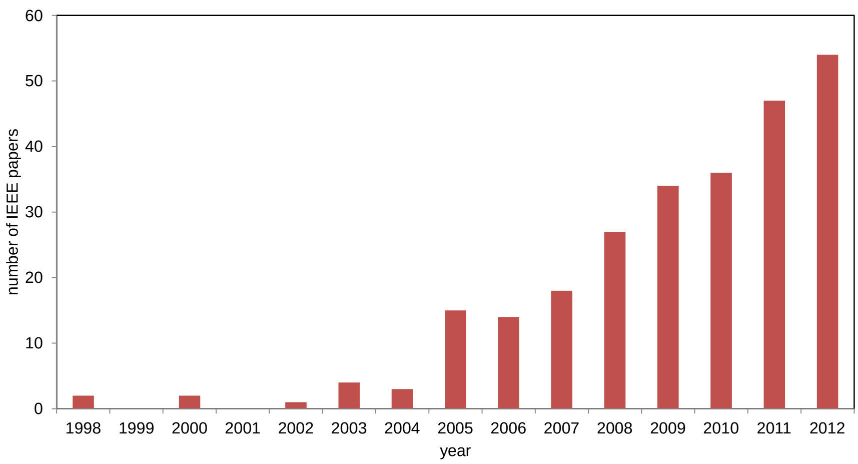
Substrate Integrated Waveguide (SIW) Techniques



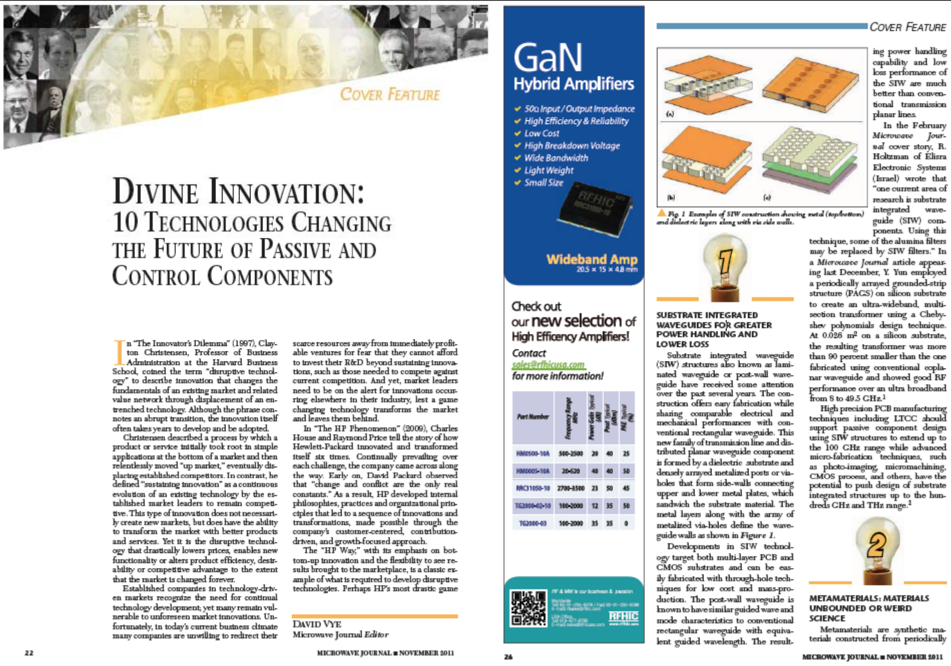
Synthesized Waveguides and Substrate Integrated Circuits (SICs)

non-planar structure in planar form

SICs-Related IEEE Publications

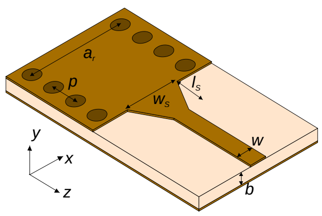


Courtesy of Maurizio Bozzi

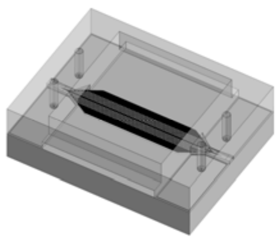


November Issue, Microwave Journal, 2011

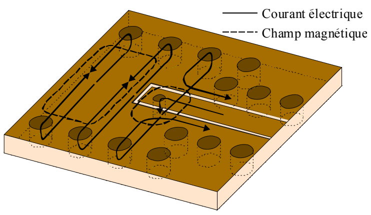
Interfaces/Transitions of Dissimilar Structures



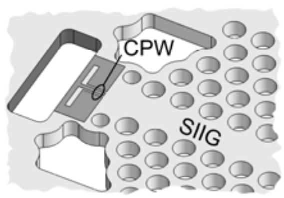
Microstrip ↔ SIW



Waveguide ↔ SIIG

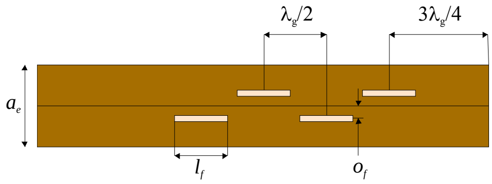


CPW ↔ SIW

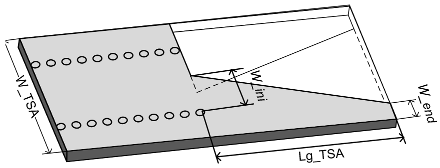


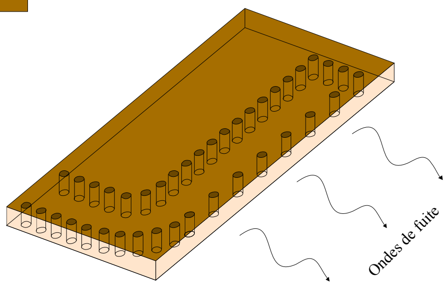
CPW ↔ SIIG

Basic SIW-based Antenna Elements



slotted antenna

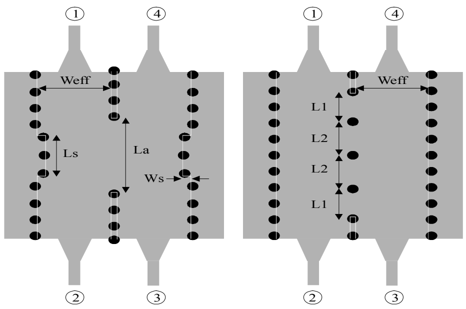




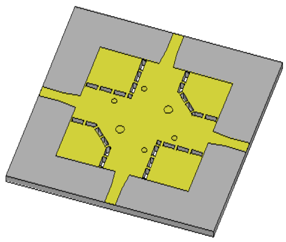
ALTSA

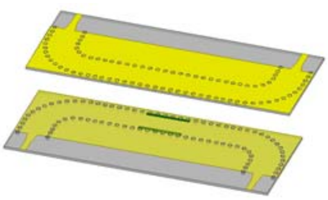
leaky-wave antenna

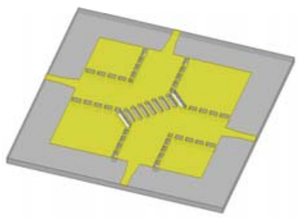
Basic SIW-based BFN Building Blocks



(a) (b)

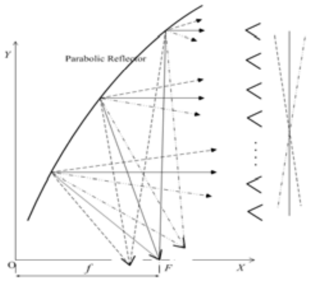


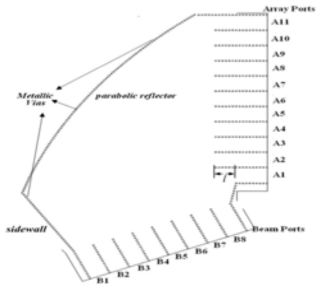


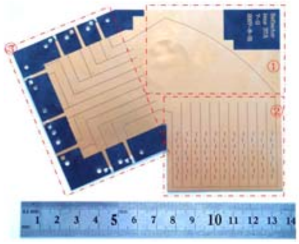


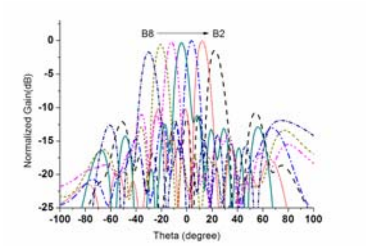
Integrated SIW Antennas and Arrays

Substrate Integrated Parabolic Reflector and Multibeam Antenna

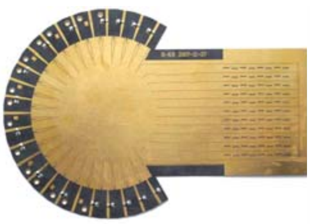


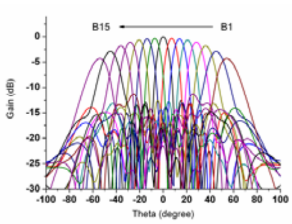


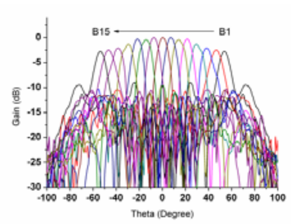


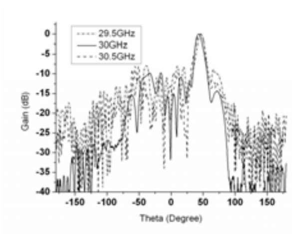


Substrate Integrated R-KR Lens

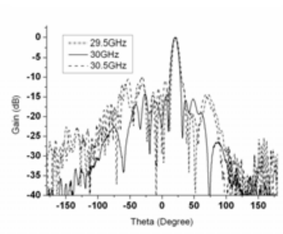




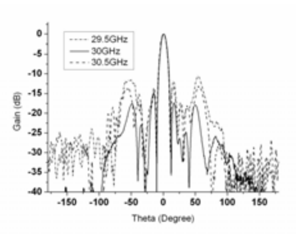




Port B2

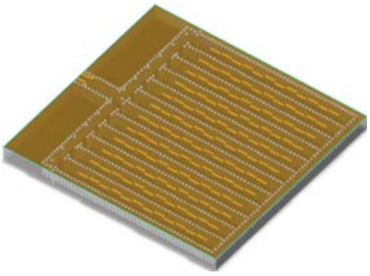


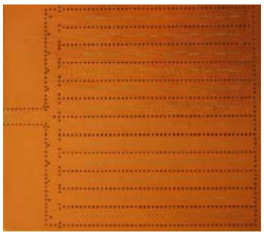
Port B5

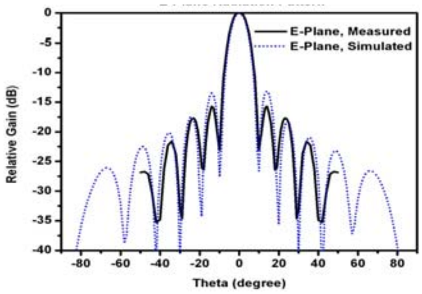


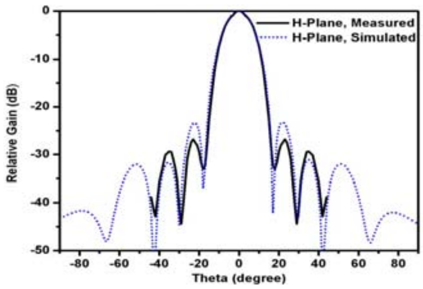
Port B8

60-GHz High-Gain SIW Antenna Array System



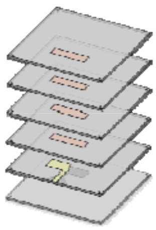




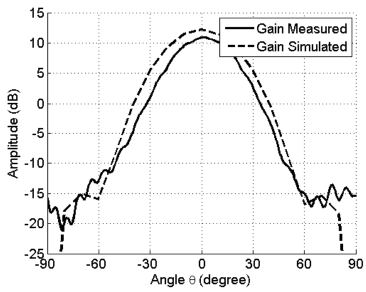


First Vertically Stacked Yagi-like Antenna

- Designed at 5.8 GHz
- Measured gain: 11 dBi
- Bandwidth: 17%
- Elements can be: dipole, patch…
- Different polarisations can be used



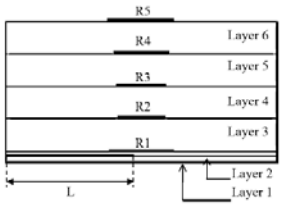
Photography of the prototype
(80x80x29mm3)

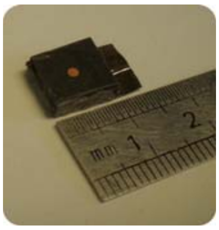


Radiation Pattern

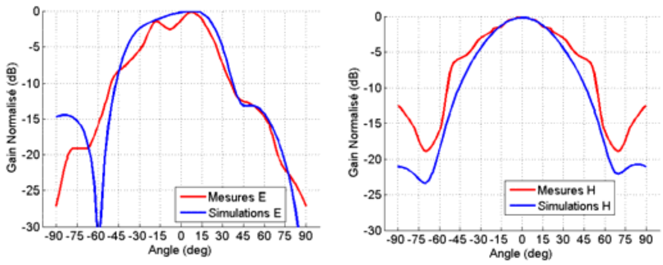
60 GHz Vertically Integrated Yagi-like Antenna

- Bandwidth: 4.2%
- Circular patch is used (driver & director)
- Measured gain: 11 dB





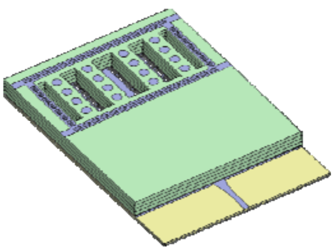
Prototype

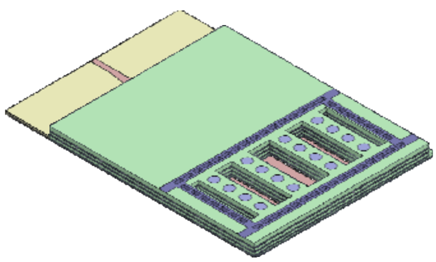


Radiation Pattern

Vertically Stacked Yagi-like Antenna Array

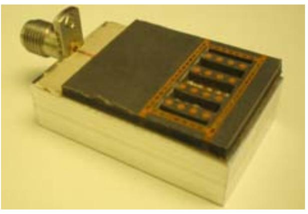
- SIW feeder
- 4x4 array of Yagi antenna at 60 GHz
- Array branch spacing ~0.9λ
- Air slots used to reduce coupling
- Metalized slot around patch structure

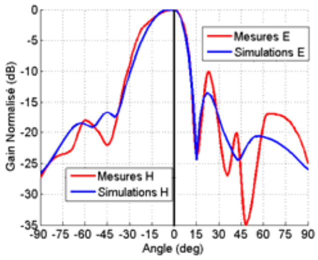




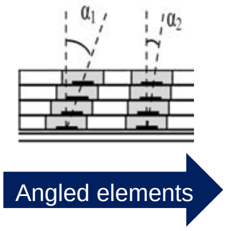
Prototypes and Results

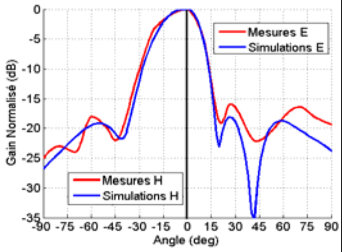
- Bandwidth: 10% à 60 GHz
- Size: 28 x 24 x 2.4 mm
- Measured gain: 18 dBi (simulated: 19dBi)
- High SLL (can be reduced)





Radiation Pattern

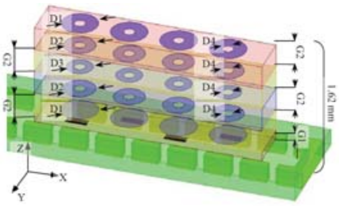


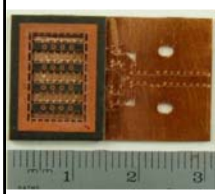


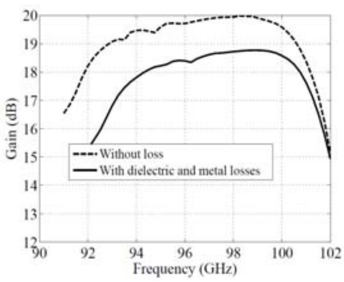
Radiation Pattern

98 GHz Vertically Stacked Yagi-like Array

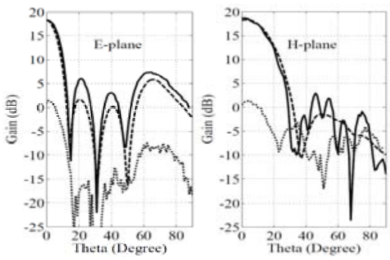
- Wide bandwidth (7.5 GHz at 98 GHz)
- 19 dBi Gain
- Stable gain & radiation pattern
- Estimated 90% radiation efficiency







Gain variation

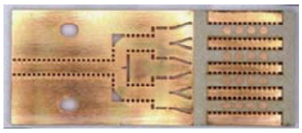


Radiation patterns at 98.75 GHz
(sold: measured, dashed: simulated)

Multi-Dimensional Lego-Style Design

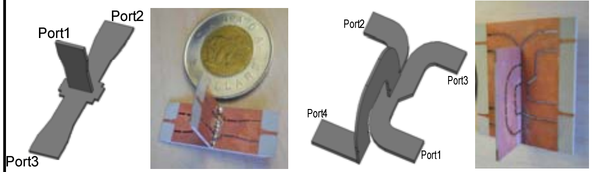
Compelling advantages of multilayered and 3-D structures:

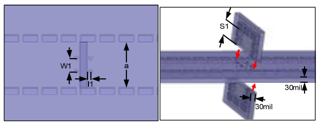
- Small footprint
- Higher array gain
- Different polarization
- Wide bandwidth
- Multi-beam
- Possible E-plane expansion with Lego-style design



E-band array prototype

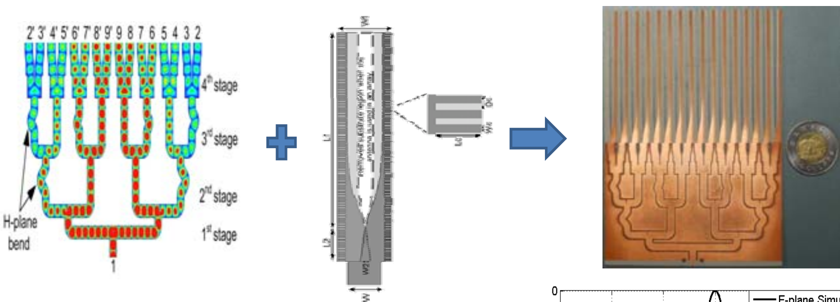
70-105 GHz integrated horn



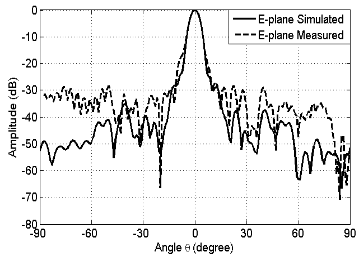


SIW-Lego Building Blocks

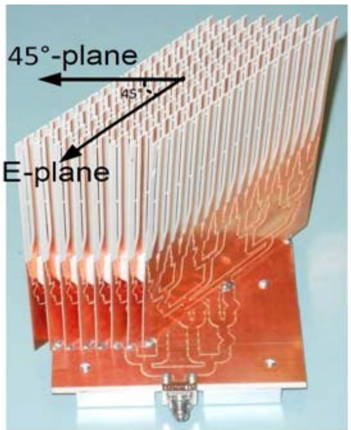
SIW Feeder for Fermi Tapered Slot Array

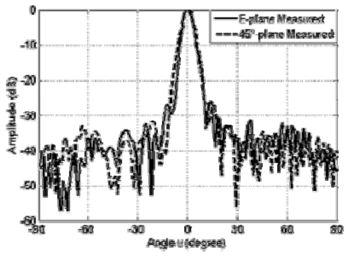


- Bandwidth of 21.1% at 35GHz
- Design spacing at 0.68 λ
- Measured gain of 23.4 dBi (simulated 24.5 dBi)
- SLL of 27 dB
- Bandwidth of 5.3° in E-plane



3-D SIW Fermi Tapered Slot Array

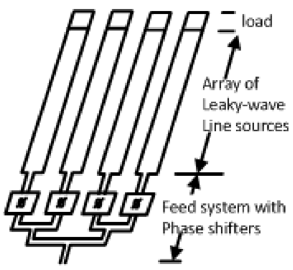




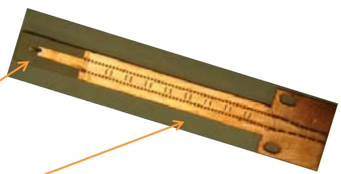
- Bandwidth: 21.1%
- Gain: 27 dBi.
- SLL of 26 dB in two planes.
- Beamwidth of 5.15° in E-plane and 6.20° in D-plane (45°).
- Network efficiency of 61%
- Weight: 175g

Two-Dimensional SIW Scan Array Antenna

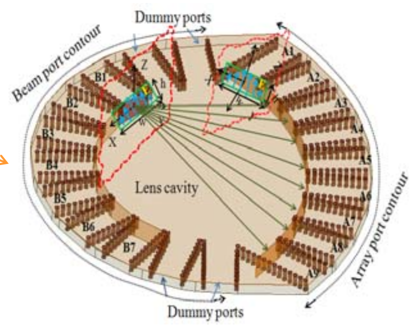
- Frequency scan in one plane
- Phase shift control in the orthogonal plane



Schematic for simple 2D scanning



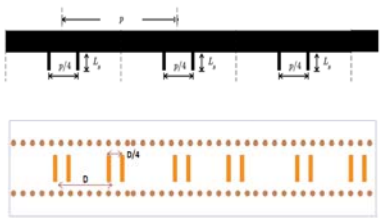
Leak-wave antenna



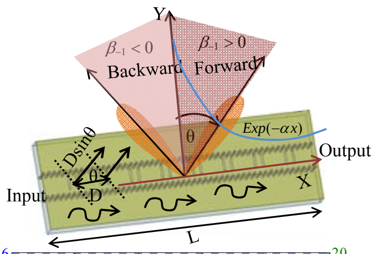
Simulated SIW Rotman lens diagram

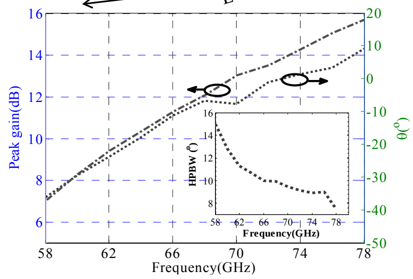
Leaky-Wave Antenna (LWA) Block

- Angle of the main beam is a function of the first radiating space harmonic
- Gain increases with *f* due to a larger electrical length of antenna at higher *f*



Reflection cancellation forward wave LWA

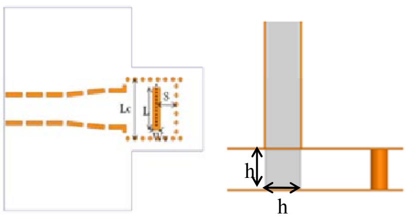




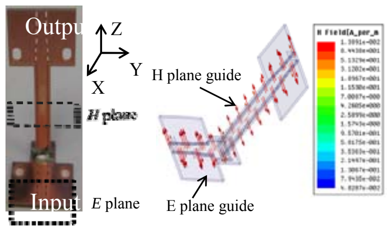
Calculated scanning angle and peak gain

25

2-D Scan Array Antenna Element

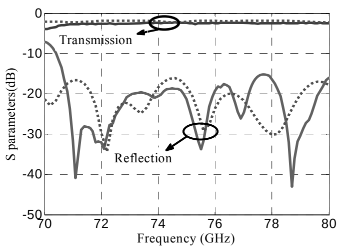


Proposed E2H corner



H fields coupling through corner for TE_{10} mode

- Measured bandwidth (return loss ≤ - 15dB) of 11.9% covers frequency range from 71 GHz to 80 GHz
- Measured insertion loss is ≤ -2.3 dB over the entire bandwidth



Simulated (dashed) & measured (solid)

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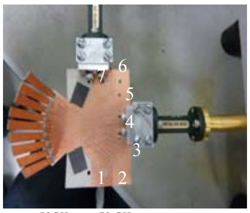
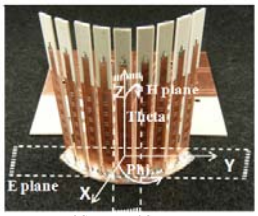
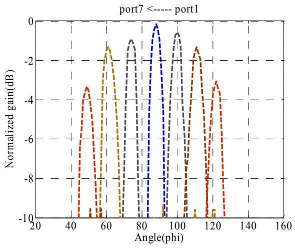
2-D Scan Array Antenna Prototype

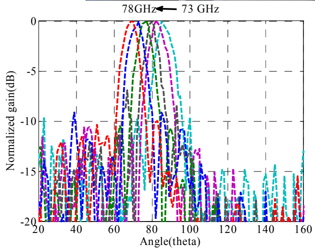
Multibeam antenna can efficiently cover a solid angle of (49°,84.5°) to (120°, 70°) with multiple beams



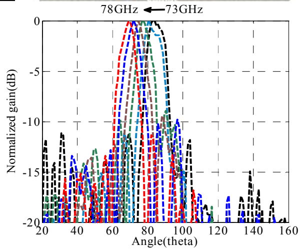




Measured E-plane patterns excited from ports 1-7 at 75 GHz



Measured H-plane patterns excited Input port 1



Input port 4

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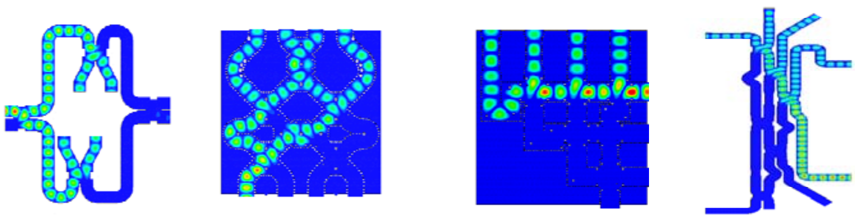
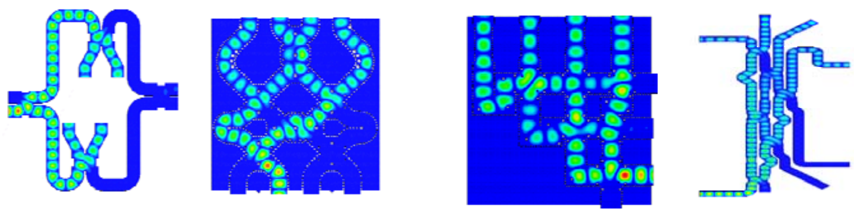
Different SIW-based Beamforming Networks

Butler Matrices **Nolen Matrices**



Without cross | Ultra wideband (30%) | Beam squint control | Delay compensation



K. Wu, et al., "Substrate integrated millimeter-wave and terahertz antenna technology," **Proceedings of the IEEE**, pp. 2219-2232, Vol. 100, No. 7, July 2012

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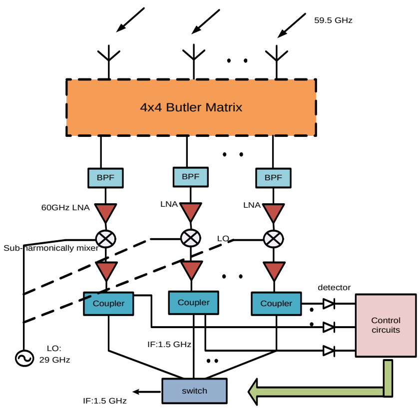
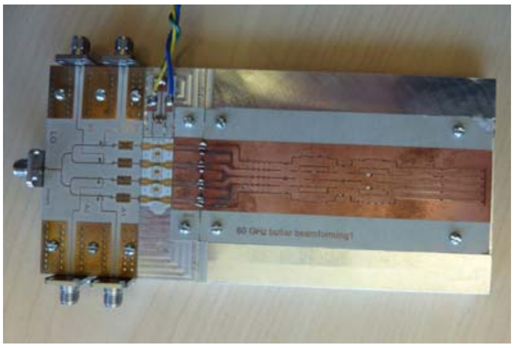
Multi-Functional & Multi-Format Schemes

- Dual-polarization systems
- Circular polarization techniques
- Millimeter-wave MIMO systems
- Active and smart antennas
- Tunable and reconfigurable antennas and arrays
- Multi-band and multi-beam systems
- Mixed waveguide design platforms
- Hybrid radio and radar antenna architectures

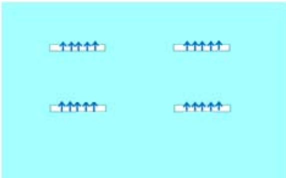
Millimeter-Wave (60 GHz) Smart Array System

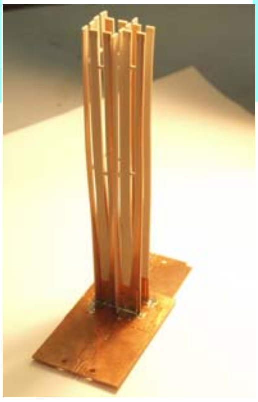




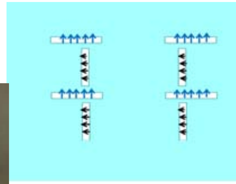
Dual-Linearly Polarized Antenna Design

Single Linearly Polarized Array





Dual Linearly Polarized Array



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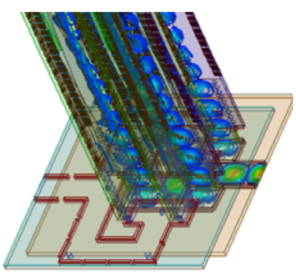
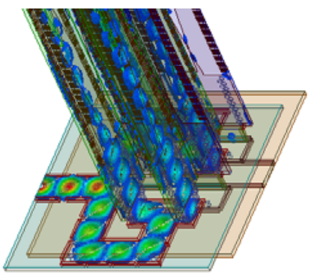
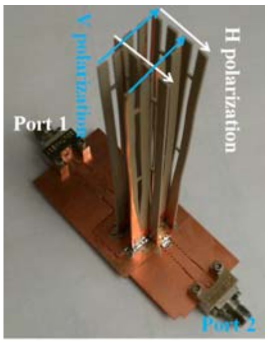
V-pol and H-pol High-Gain Antennas



V-Polarization



H-Polarization



Experimental Prototype

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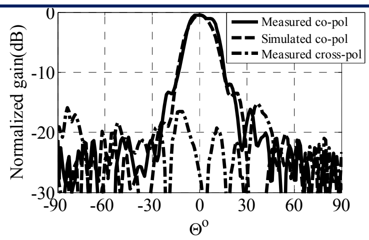
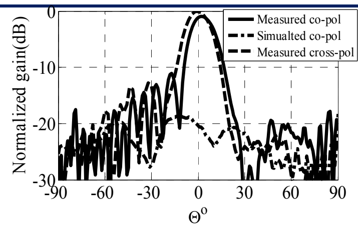
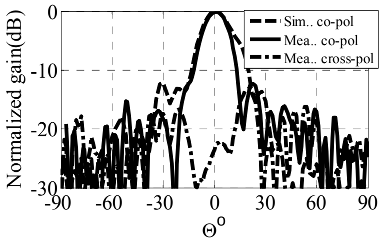
Simulated and Measured Results



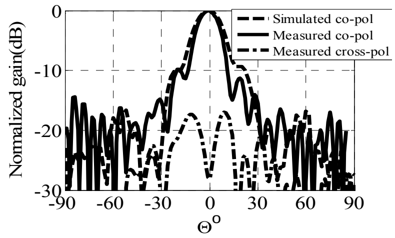
H-Polarized antenna (E plane)



V-Polarized antenna (E plane)



H-Polarized antenna (H plane)



V-Polarized antenna (H plane)

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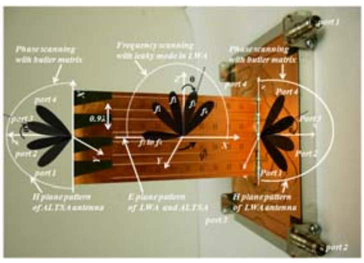
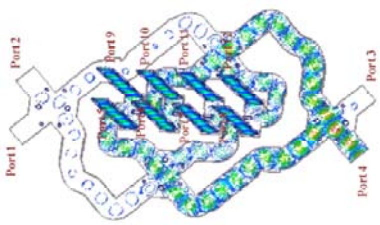
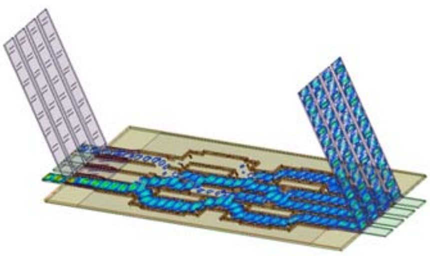
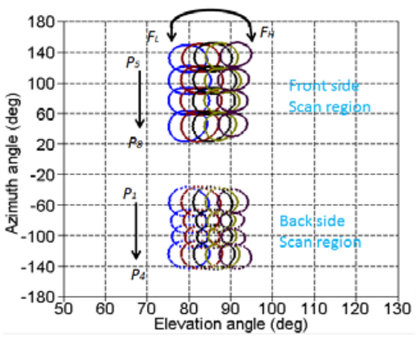
30 GHz Multi-Dimensional Scan Phased Array System









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Conclusion and Future Outlook

- Recent achievements are presented in connection with the design and development of low-cost SIW antenna and array architectures.
- Multi-dimensional small-footprint and high-gain antenna arrays are shown for millimeter-wave applications.
- Vertically expanded LEGO building blocks and multi-format/multi-functional design techniques are demonstrated for various system developments.
- Future GHz and THz systems will benefit from this research with a further expansion of SICs-based mixed waveguide techniques in conjunction with emerging materials.

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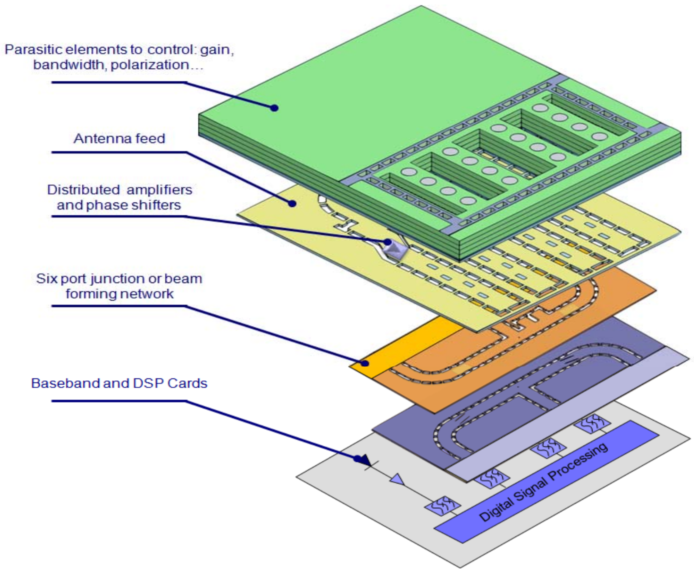
Example of Stacked Multilayered SIW Integrated Antenna Arrays



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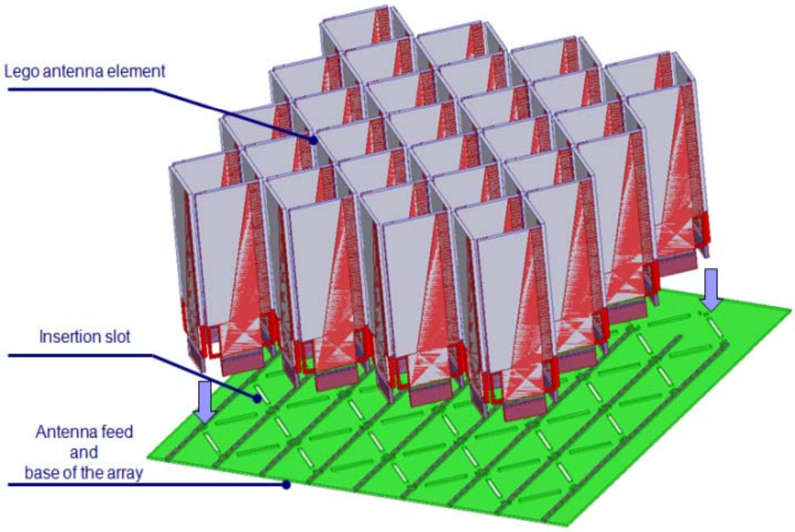
Illustrative LEGO-style Design of an Antenna Array System



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Acknowledgements

- ☺ Many year contributions by the speaker's students and research fellows as well as technical support of technologists at the Poly-Grames Research Center have made this presentation possible
- ☺ The speaker is grateful to Canadian NSERC (Natural Sciences and Engineering Research Council) and Quebecois funding agency (FQRNT) for their financial support through multiple grants
- ☺ Research collaborators including Dr. Wei Hong and his team at Southeast University, Dr. Maurizio Bozzi and his colleagues at University of Pavia and others have made contributions to this presentation