School of Electronic
& Electrical Engineering

UNIVERSITY OF LEEDS

PROSPECTS FOR TERAHERTZ SYSTEM-ON-SUBSTRATE TECHNOLOGY

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Outline

Introduction

Integrated RWGs: SIW and Hollow SIW

Dielectric guides for THz

3D packaging approaches

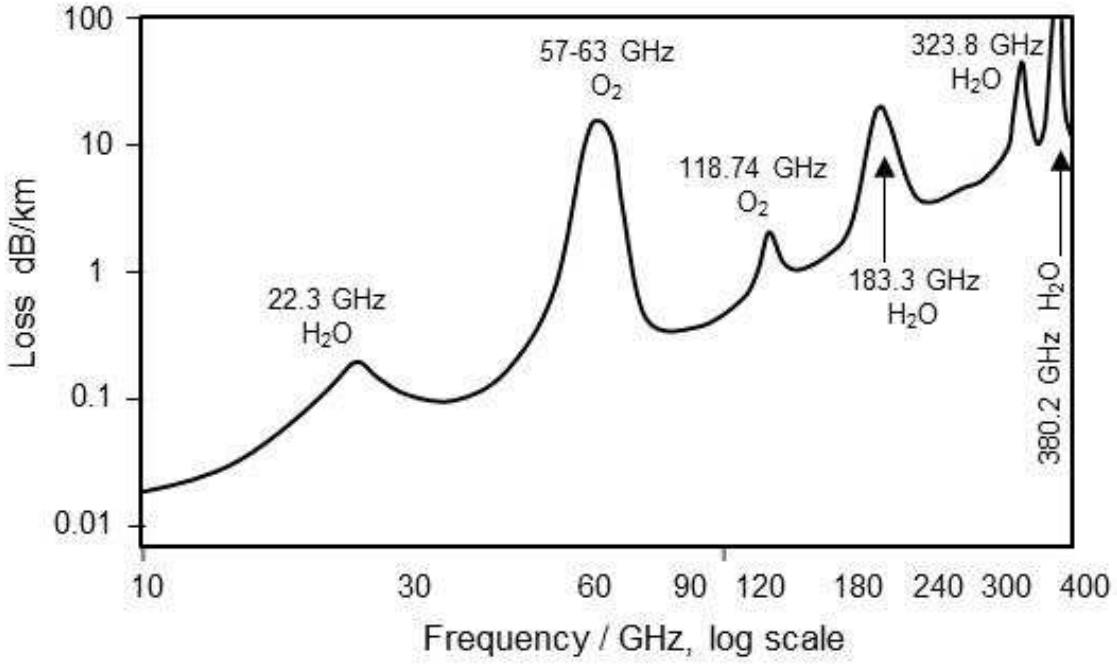
Conclusions

Why go > 100 GHz?

High bandwidth for communications

Small high-gain antennas

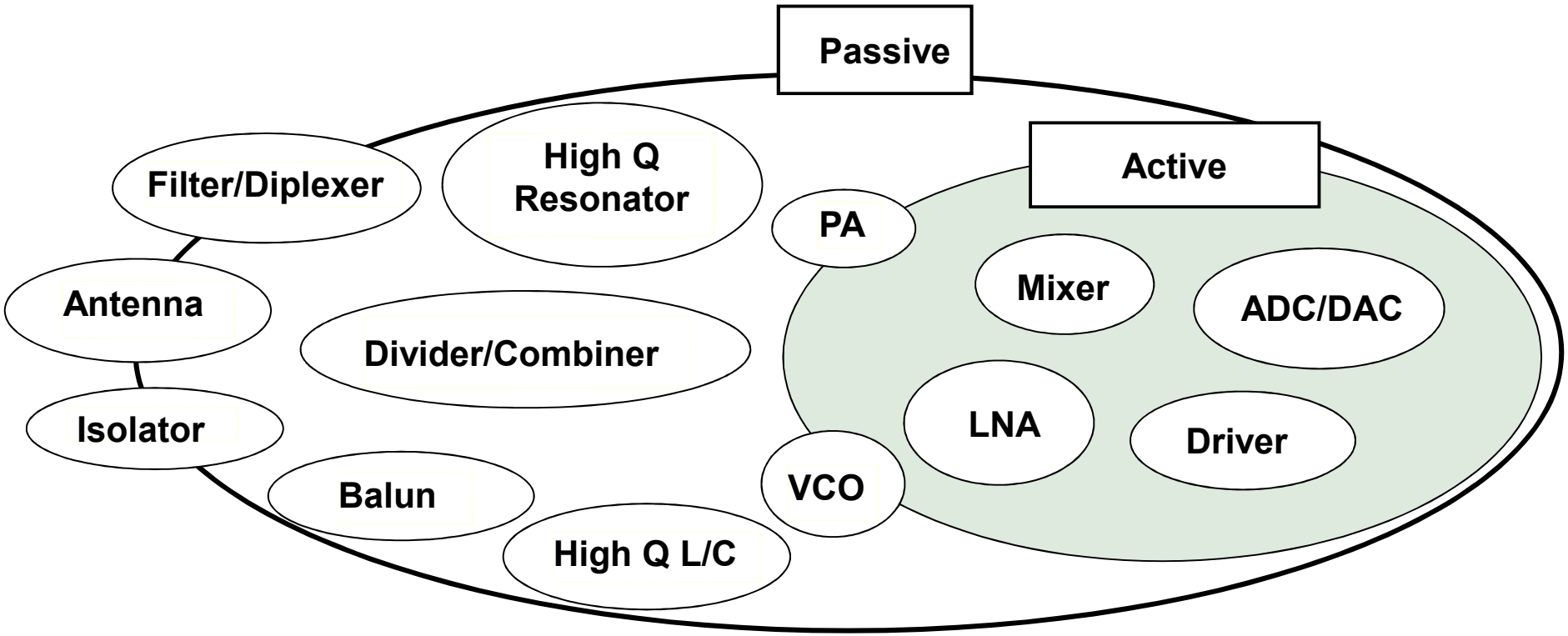
Special sensing capabilities



> 1 THz …..spectroscopy….

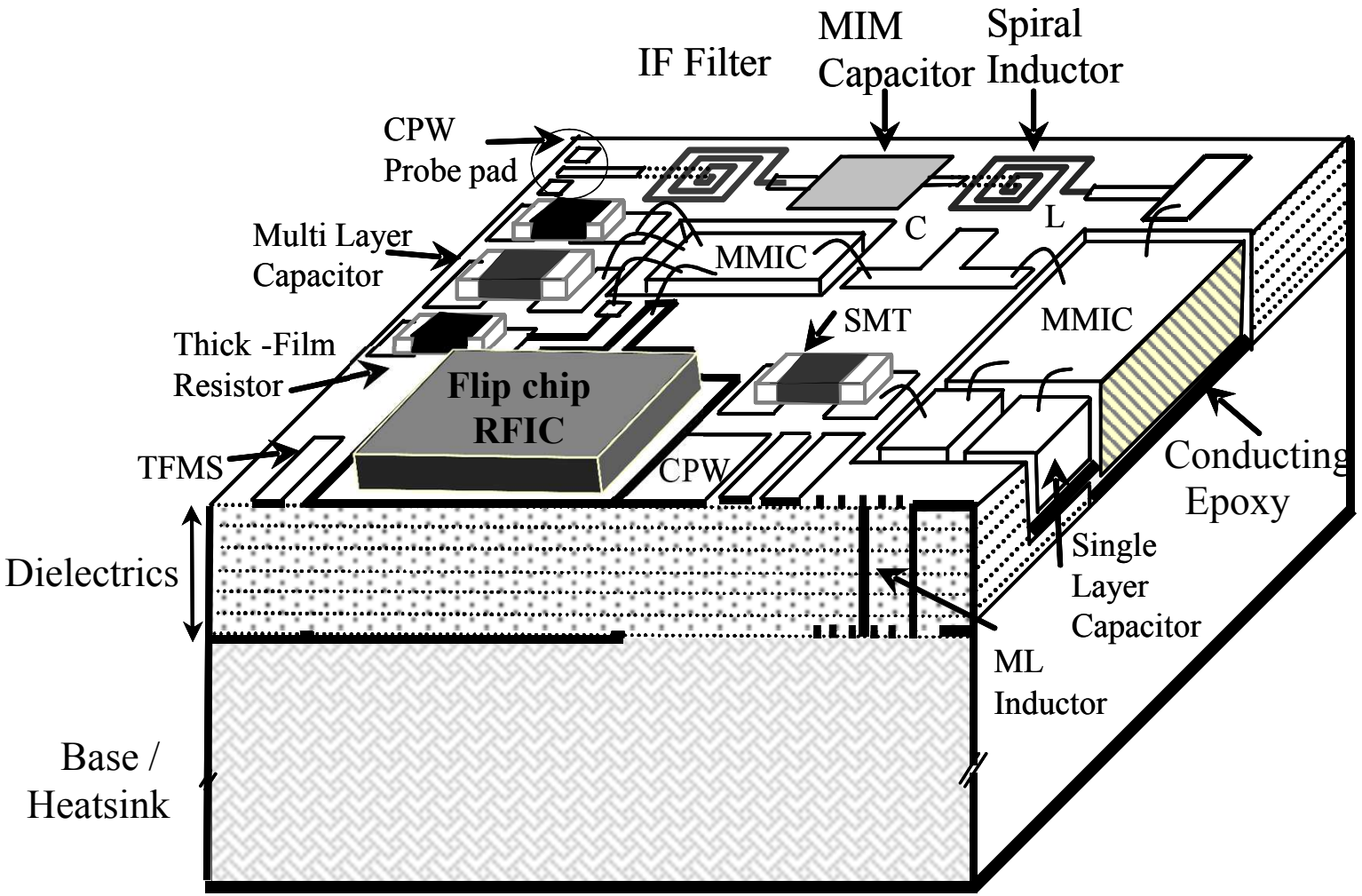
See ITU, Recommendation ITU-R P.676-10 (09/2013), *Attenuation by atmospheric gases*

Transceiver system partitioning



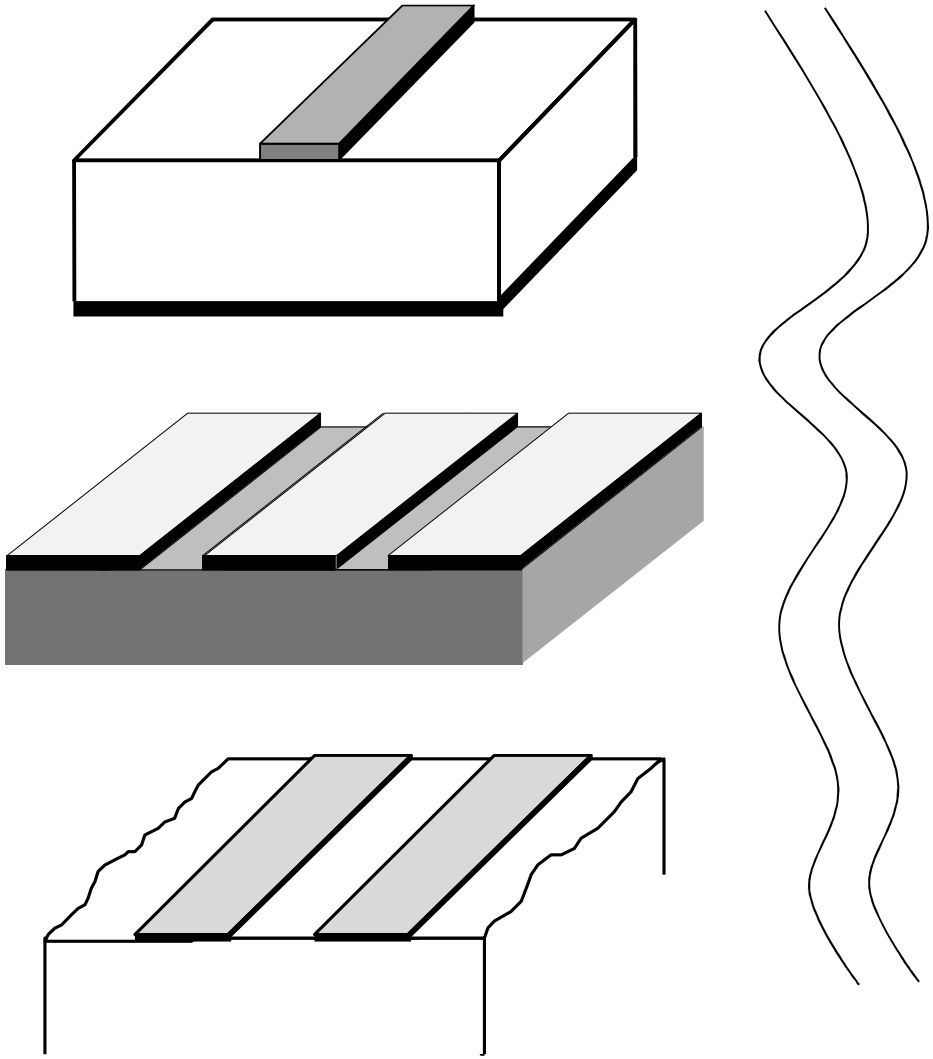
From *Microwave and Millimetre-Wave Design for Wireless Communications*, Wiley pub. 2016

MCM, SiP, SoP, SoS

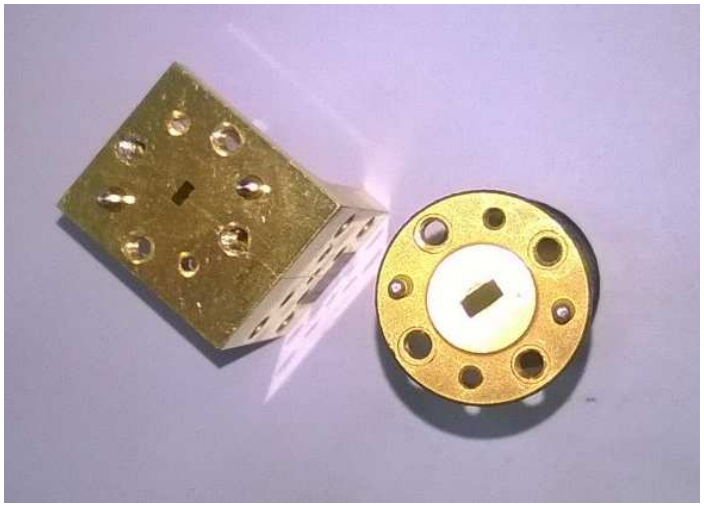


Samanta, K.K., and Robertson, I. D., "Advanced Multilayer Thick-Film System-on-Package Technology for Miniaturized and High Performance CPW Microwave Passive Components," IEEE Transactions on Components, Packaging and Manufacturing Technology, vol.1, no.11, pp.1695-1705, Nov. 2011, doi: 10.1109/TCPMT.2011.2167231

Q's of hundreds
Loss of order dB/cm

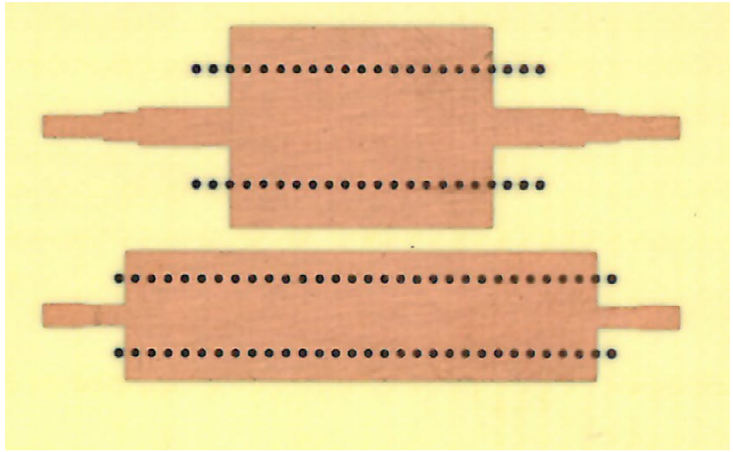


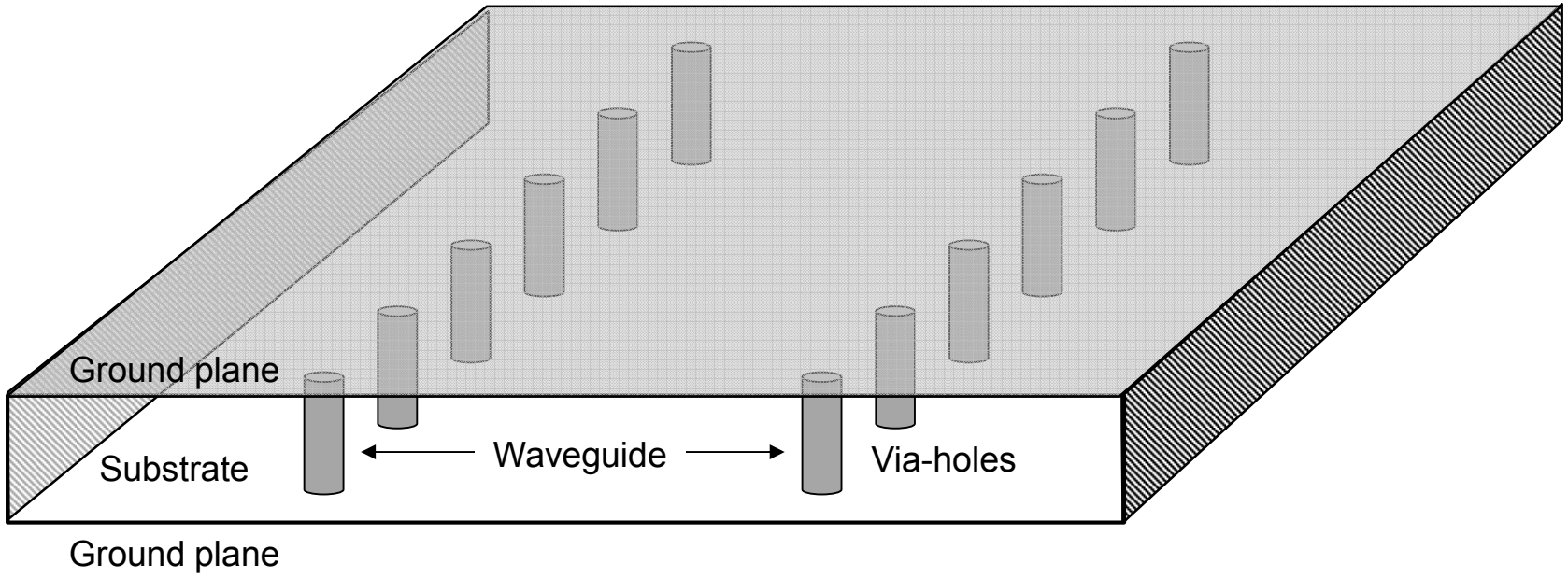
Q's of thousands
Loss of order dB/m



94 GHz Sub-System for Medical Research

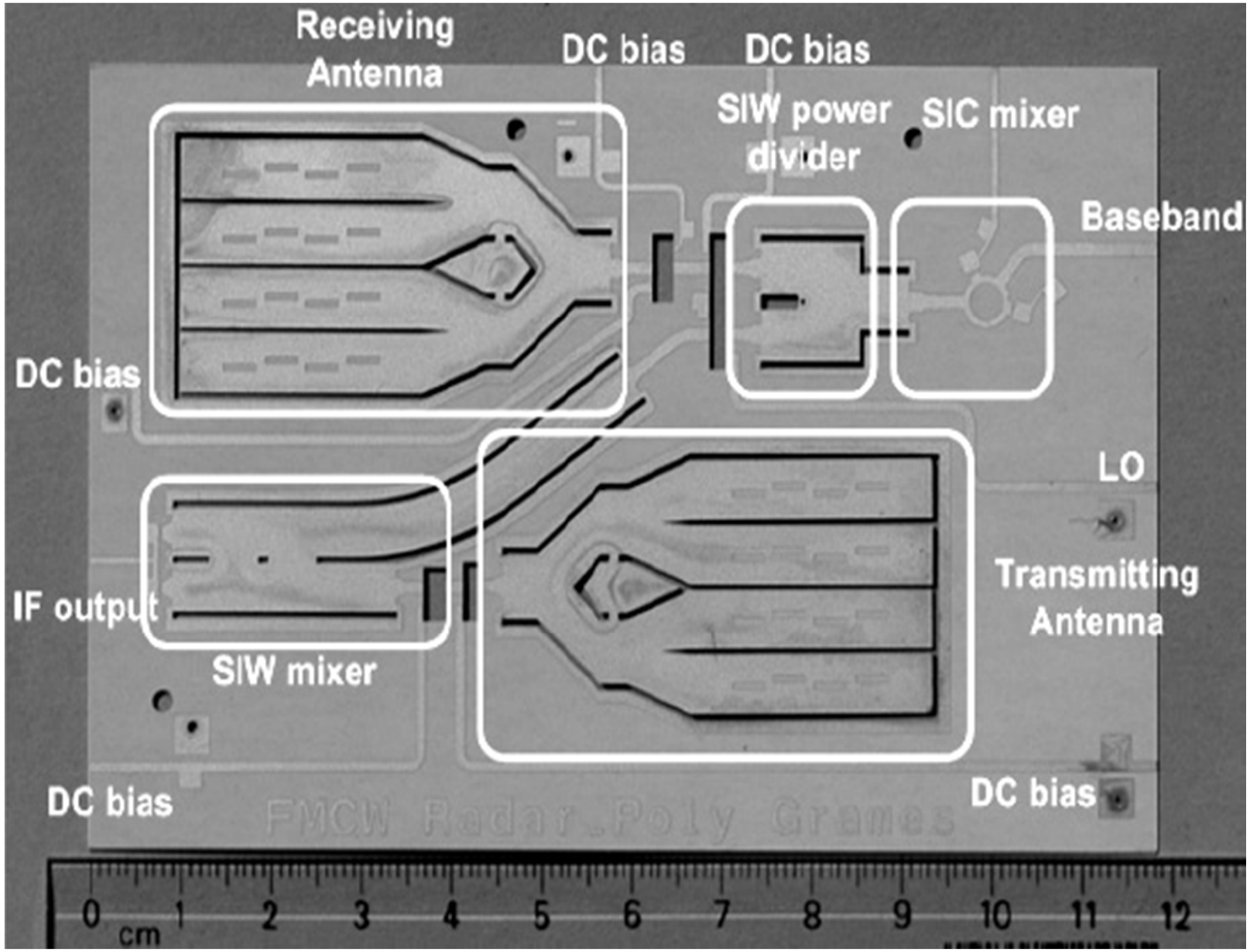
www.hxi.com





Substrate Integrated Waveguide

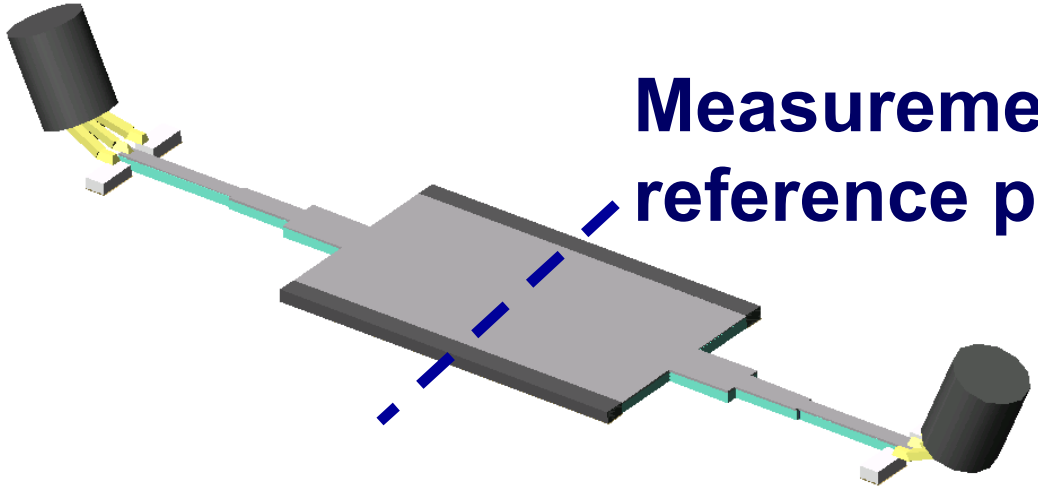
From *Microwave and Millimetre-Wave Design for Wireless Communications*, Wiley pub. 2016



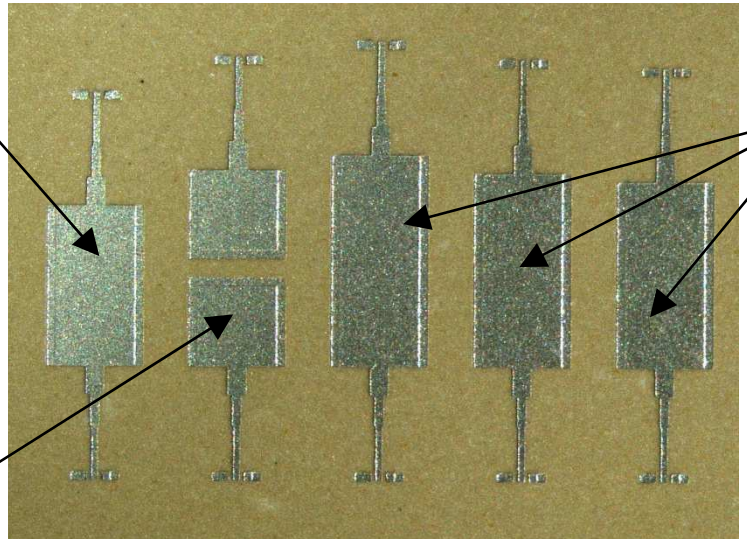
24GHz FMCW Radar Front-End System on Substrate

Li, Zhaolong; Wu, Ke; Ecole Polytechnique, Canada

SIW Characterisation



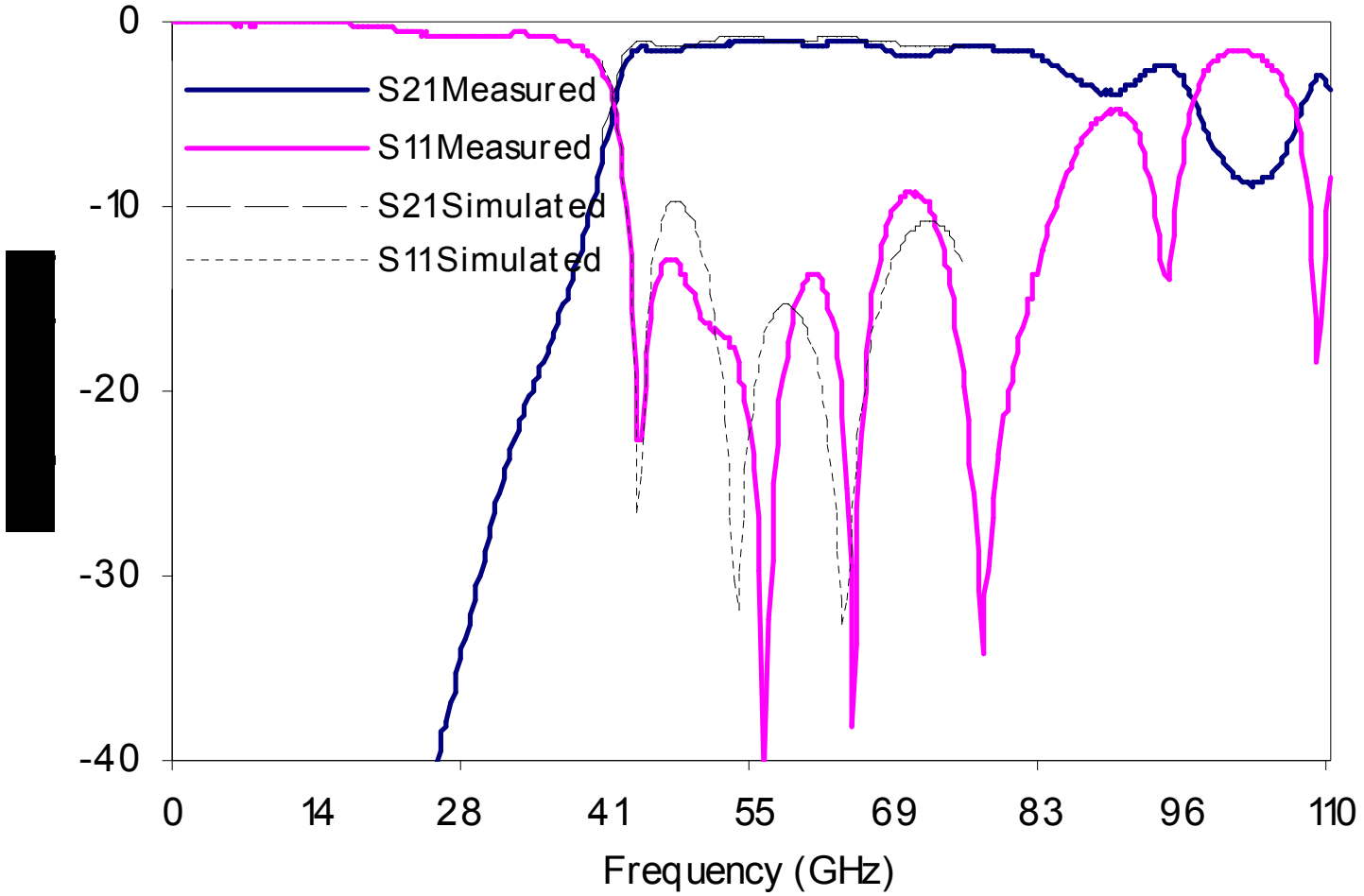
Thru



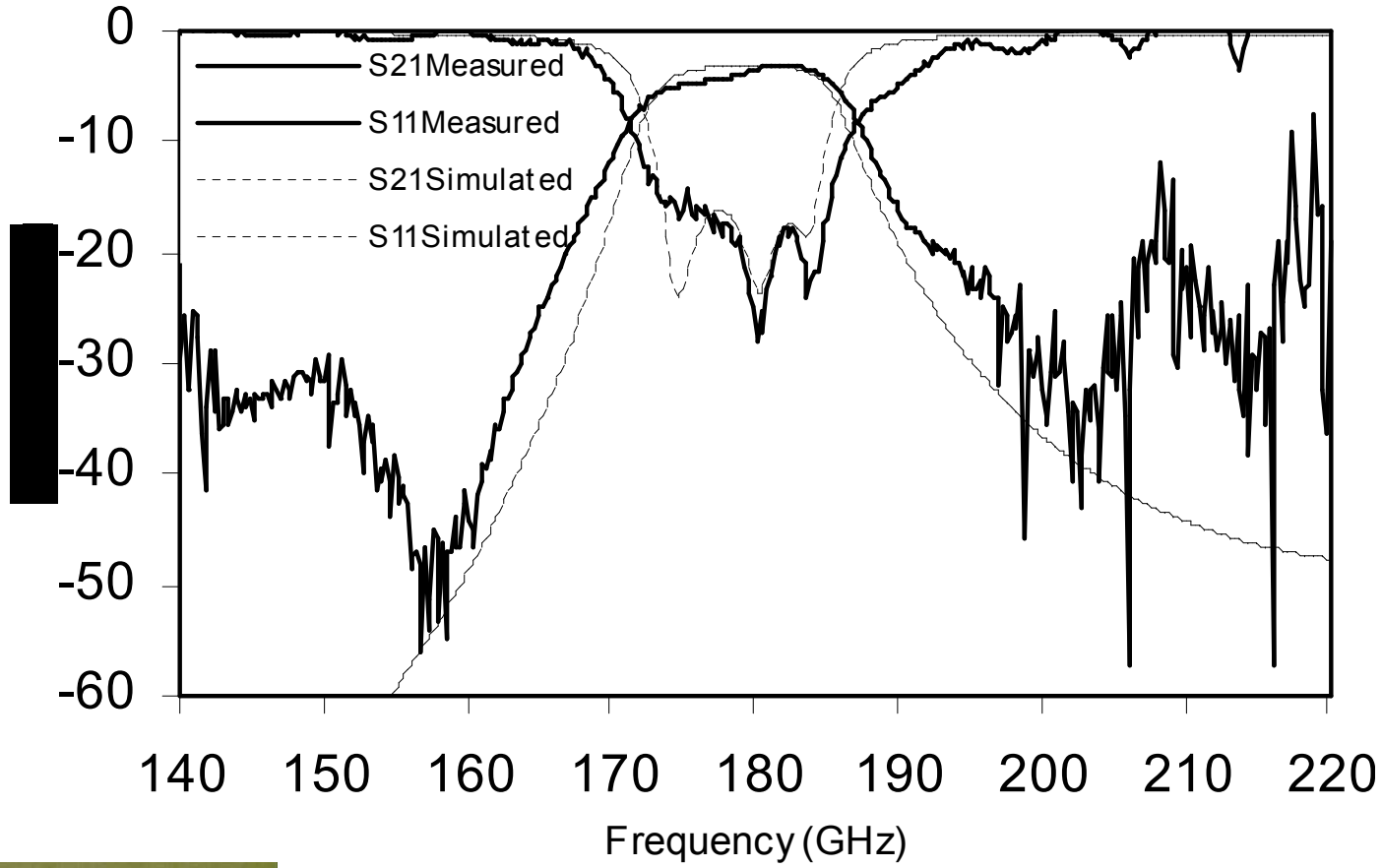
Reflect

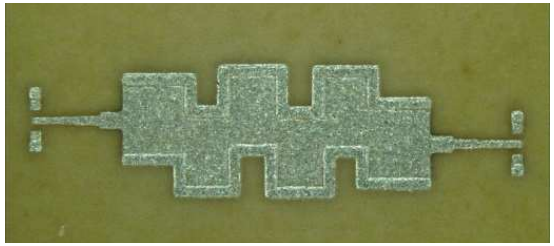
Line standards at $\lambda_g/4$ at start, end, and mid-frequencies of waveguide

V-band waveguide-microstrip transition back-to-back measurements

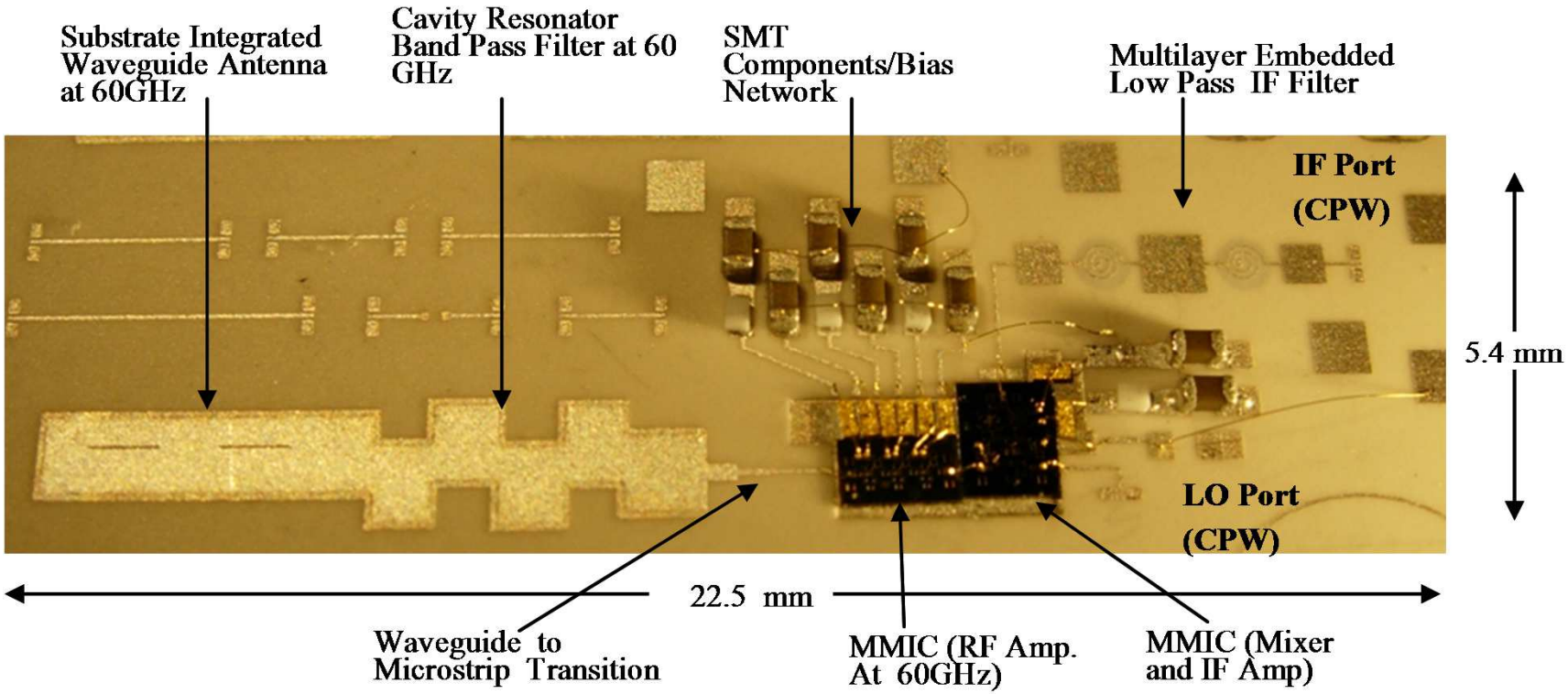


Measured results
180 GHz filter





60 GHz Receiver



LTCC Process

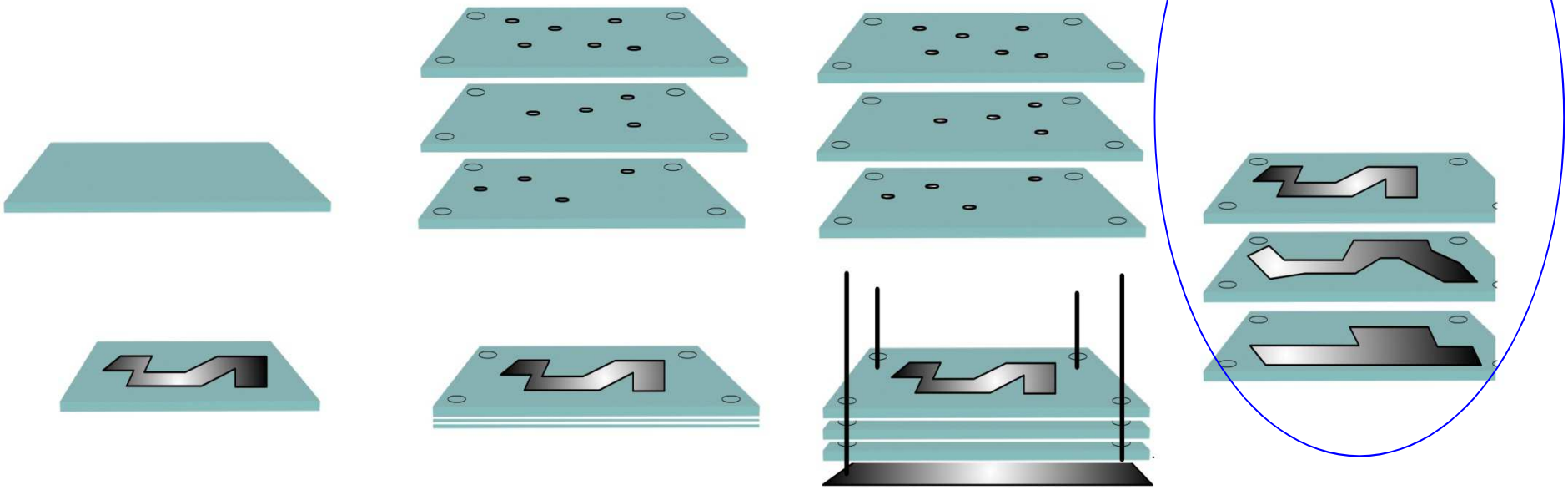
Many screens/stencils
= slow turnaround
and high prototyping cost

Pre-Conditioning

Via machining

Via filling

Screen printing



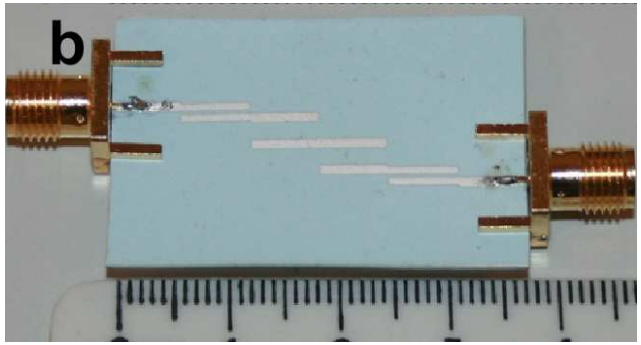
Laser patterning for rapid
prototyping and finer feature sizes

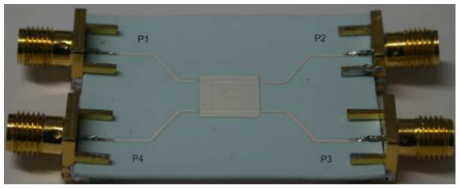
Cutting & Firing

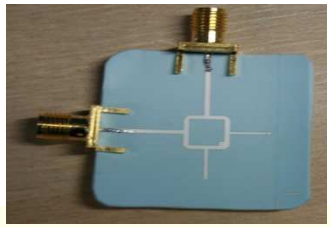
Laminating

Stacking

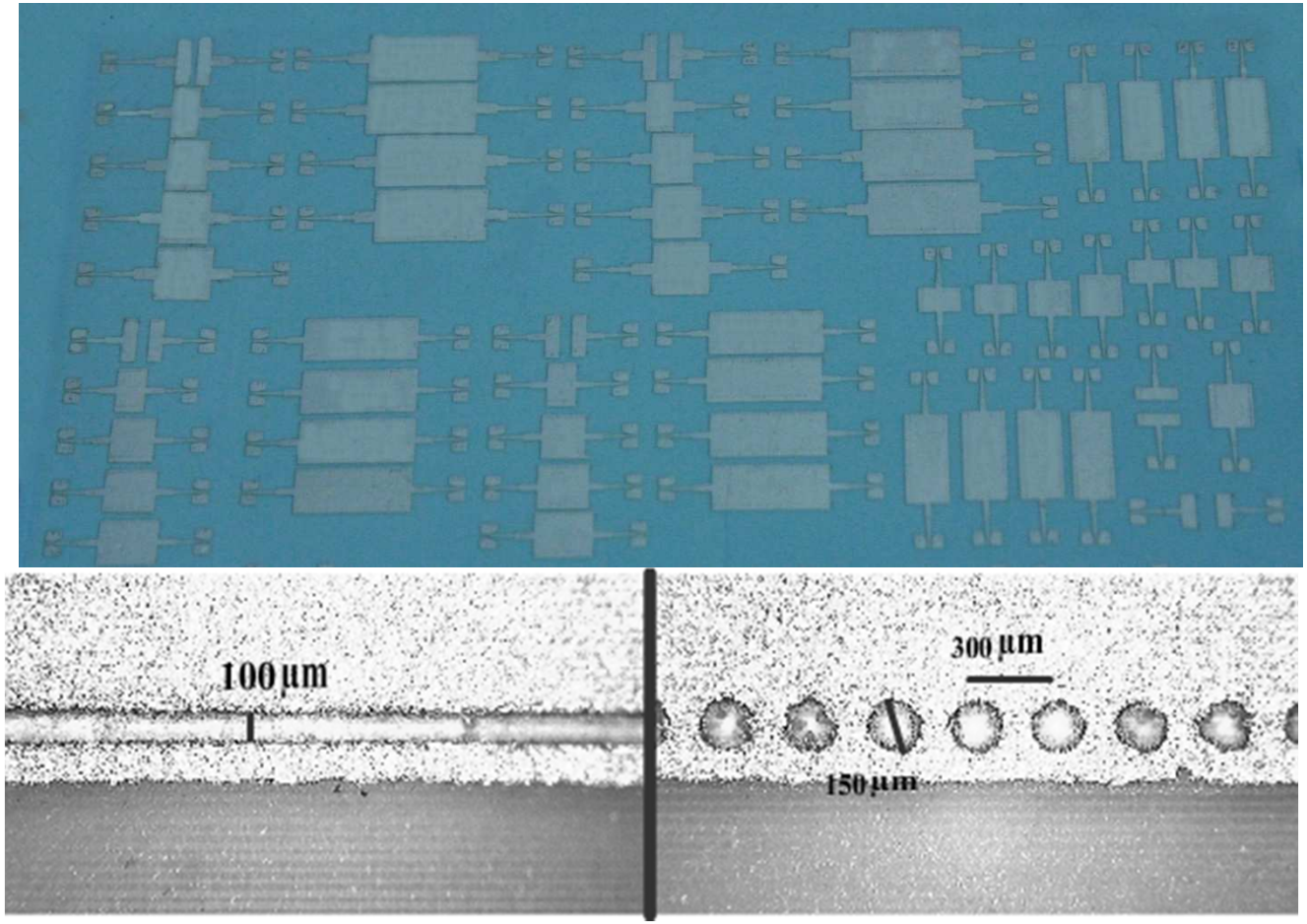
LTCC prototyping using LPKF laser system



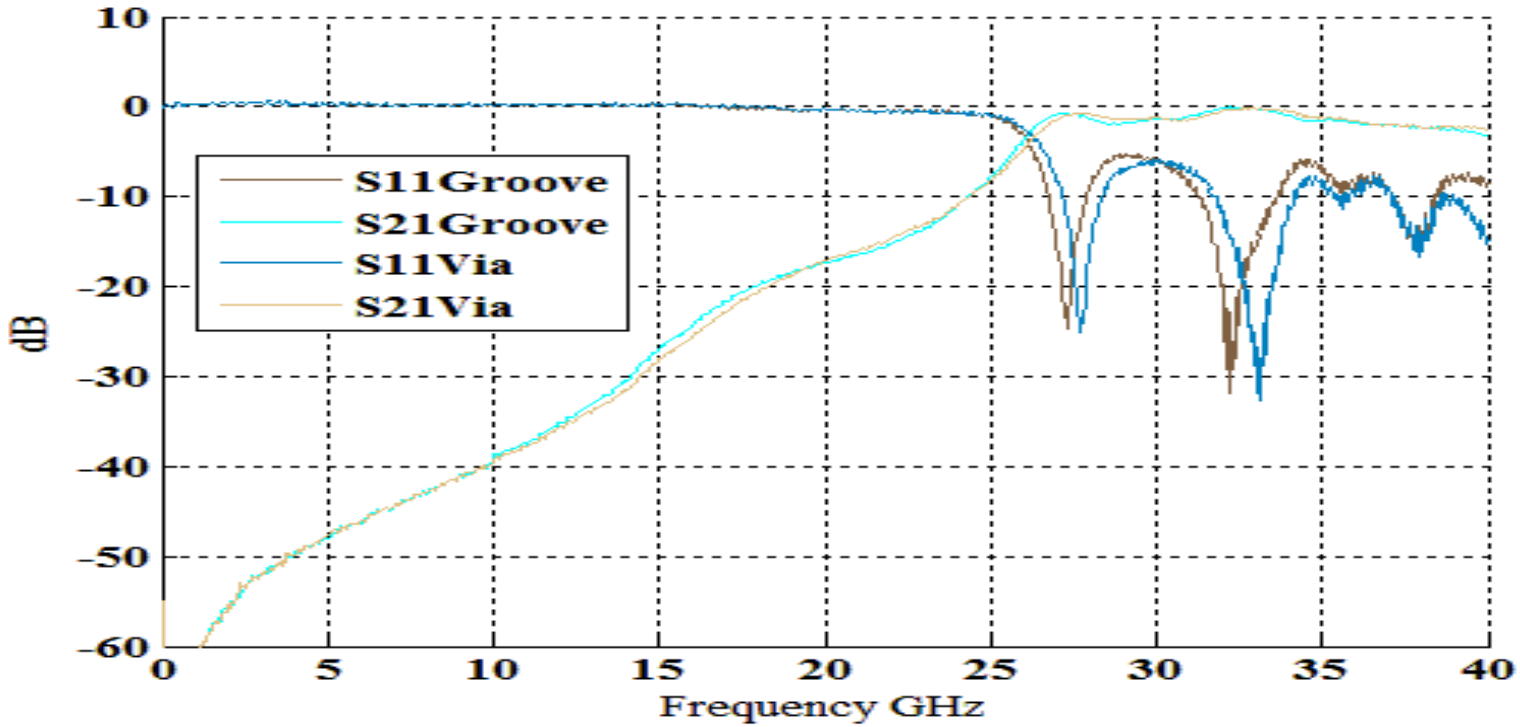




SIW with solid wall and via posts



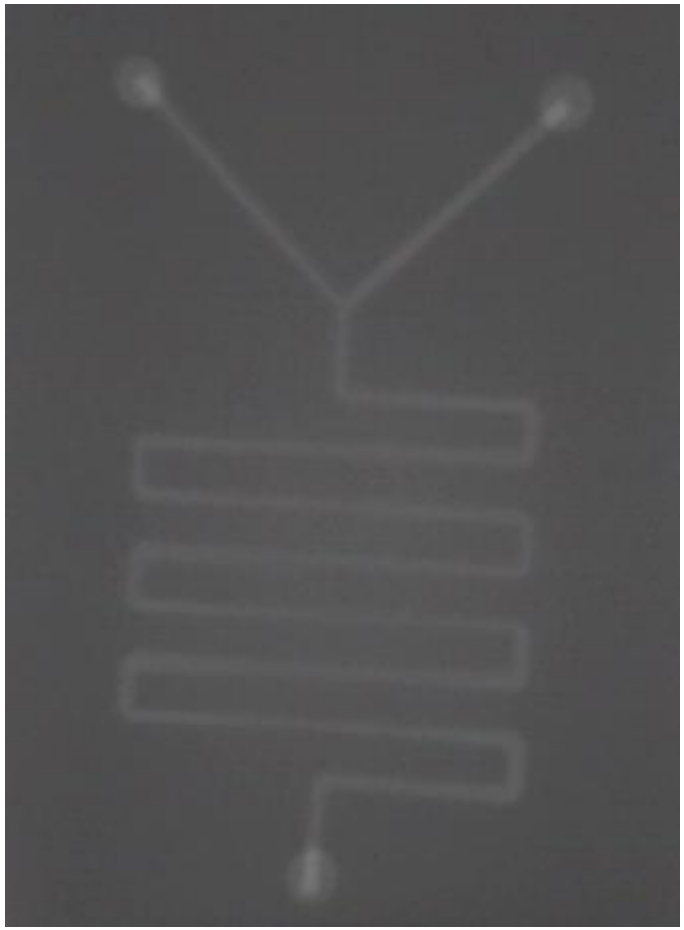
Measurement Results

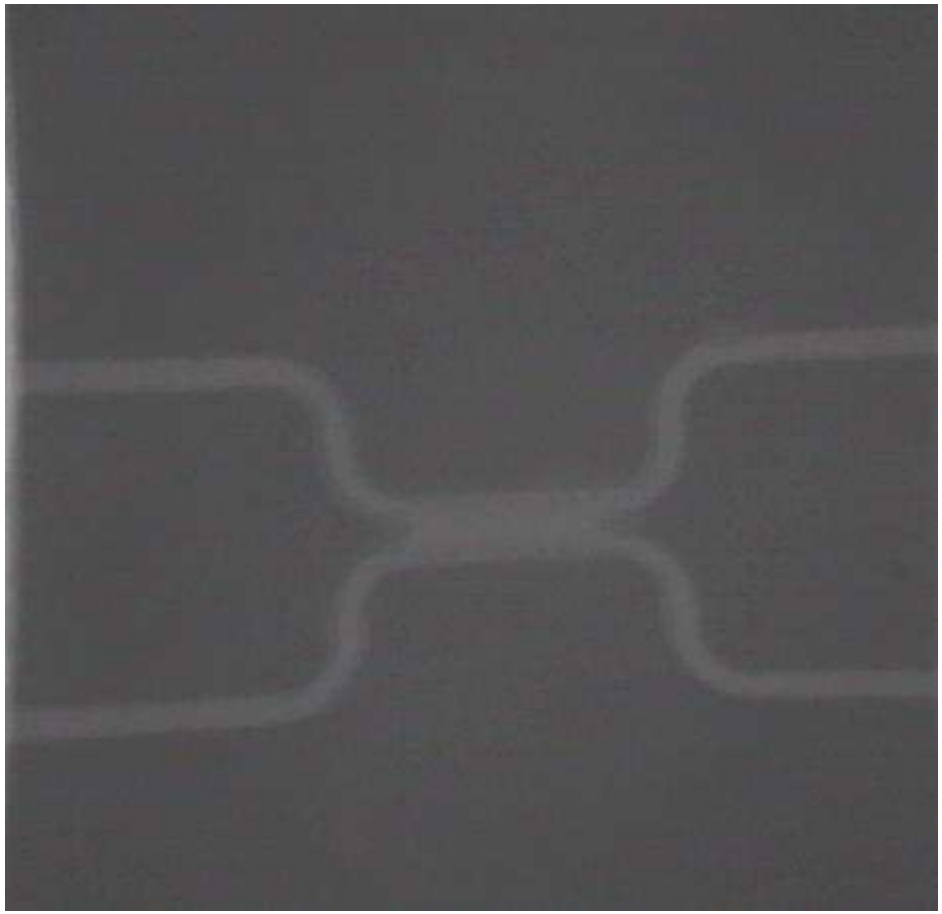


- Both solid walled (groove based) and via post SIW can achieve similar performance

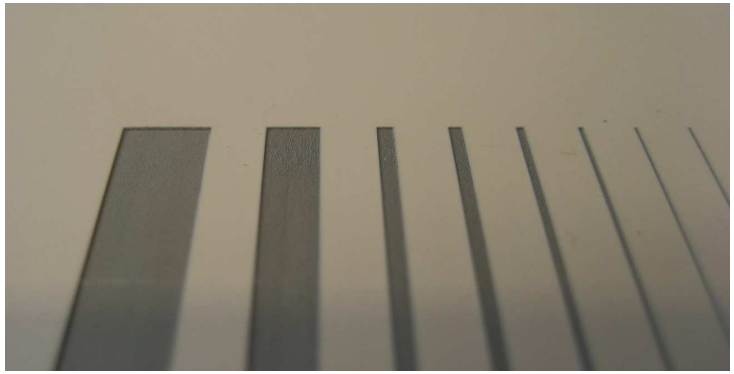
Hollow SIWs

LTCC Microfluidic Channels





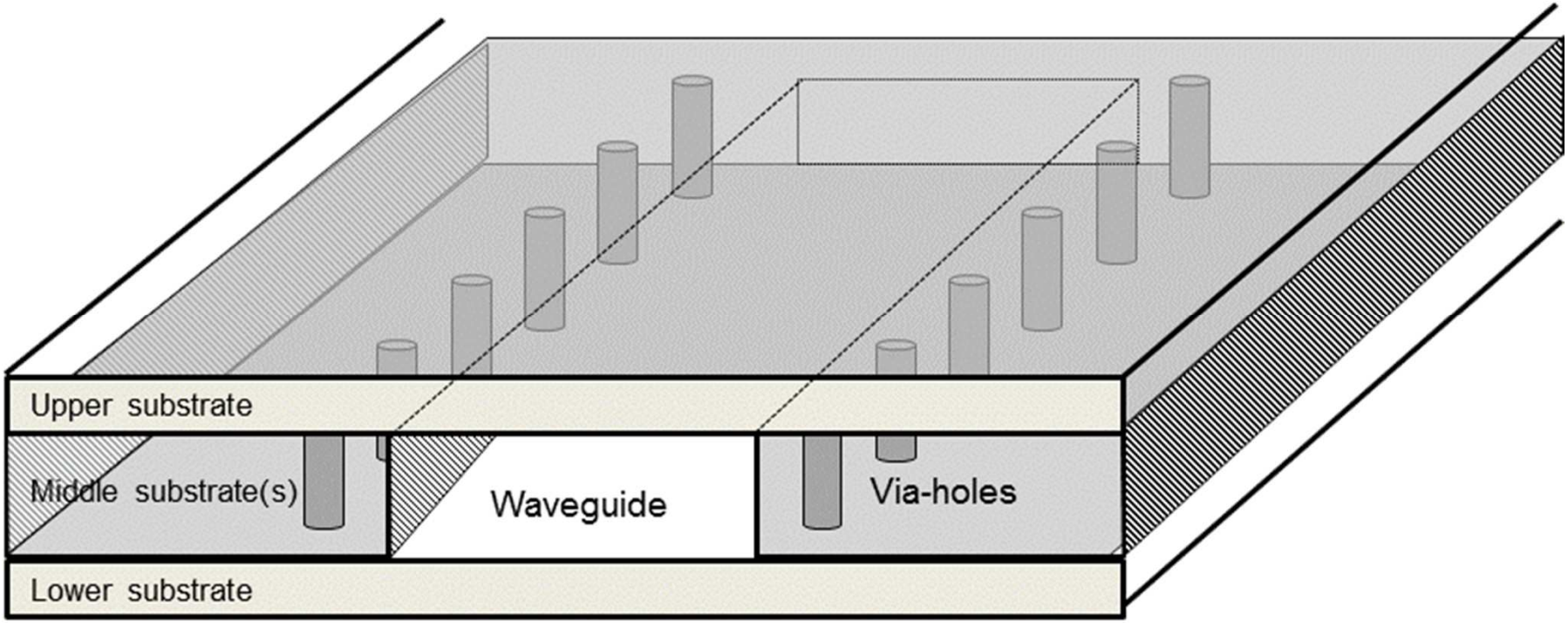
LTCC Channel Laser Machining



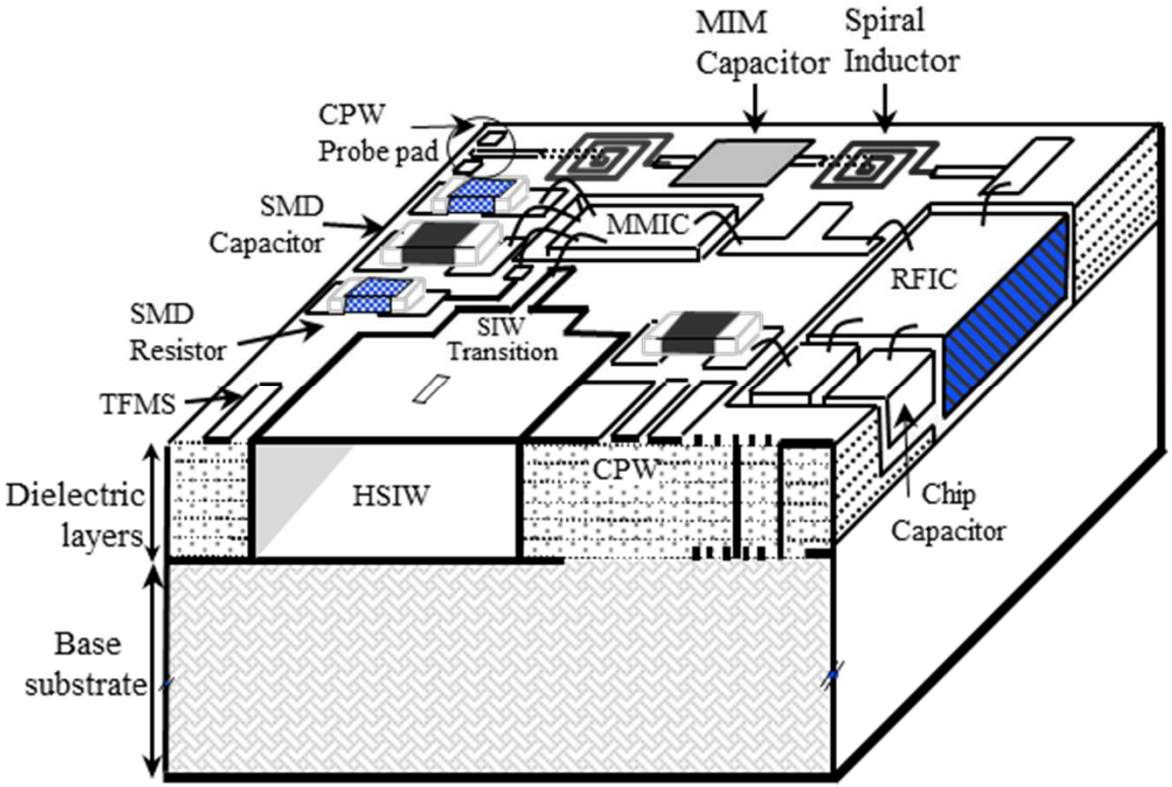
Plain waveguides

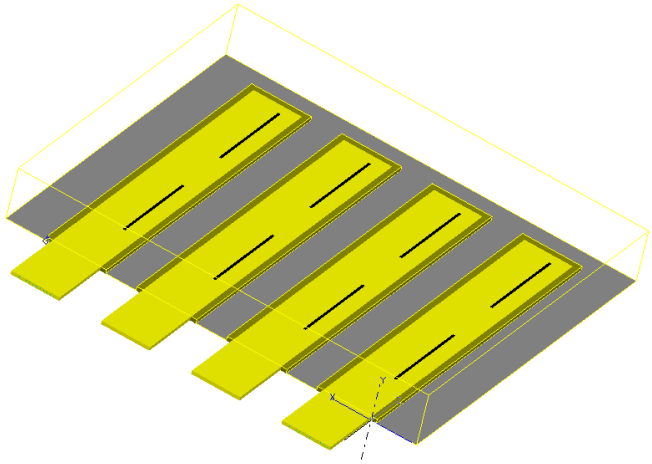
Slot Antenna Array
(lower layers)

Hollow SIW


Upper substrate
Middle substrate(s)
Waveguide
Via-holes
Lower substrate

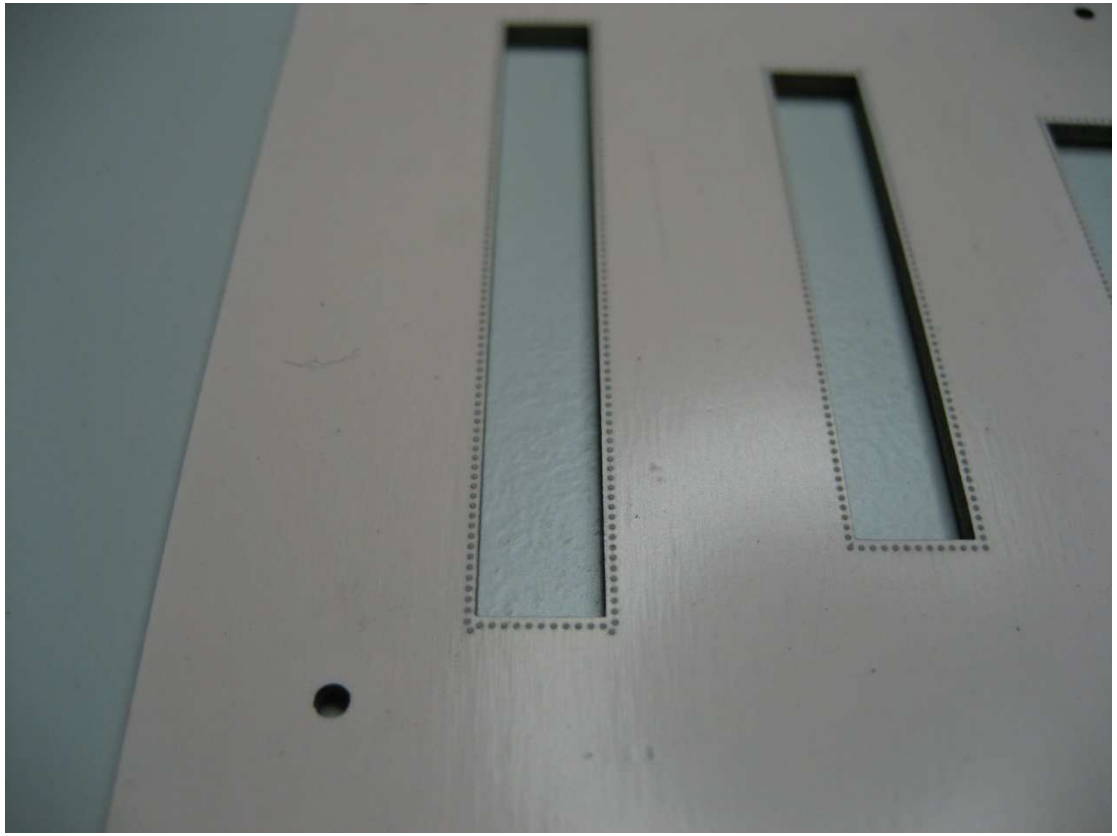
SoS using Hollow SIWs



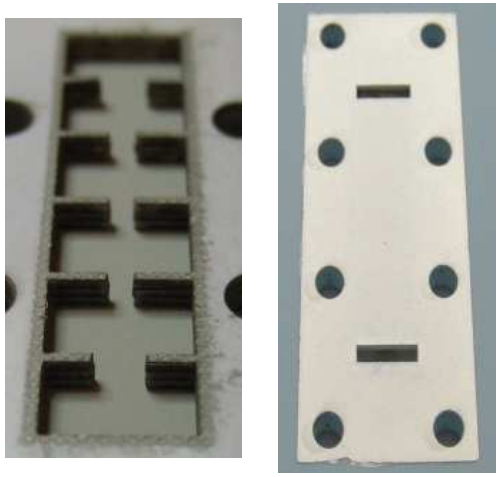


From *Microwave and Millimetre-Wave Design for Wireless Communications*, Wiley pub. 2016

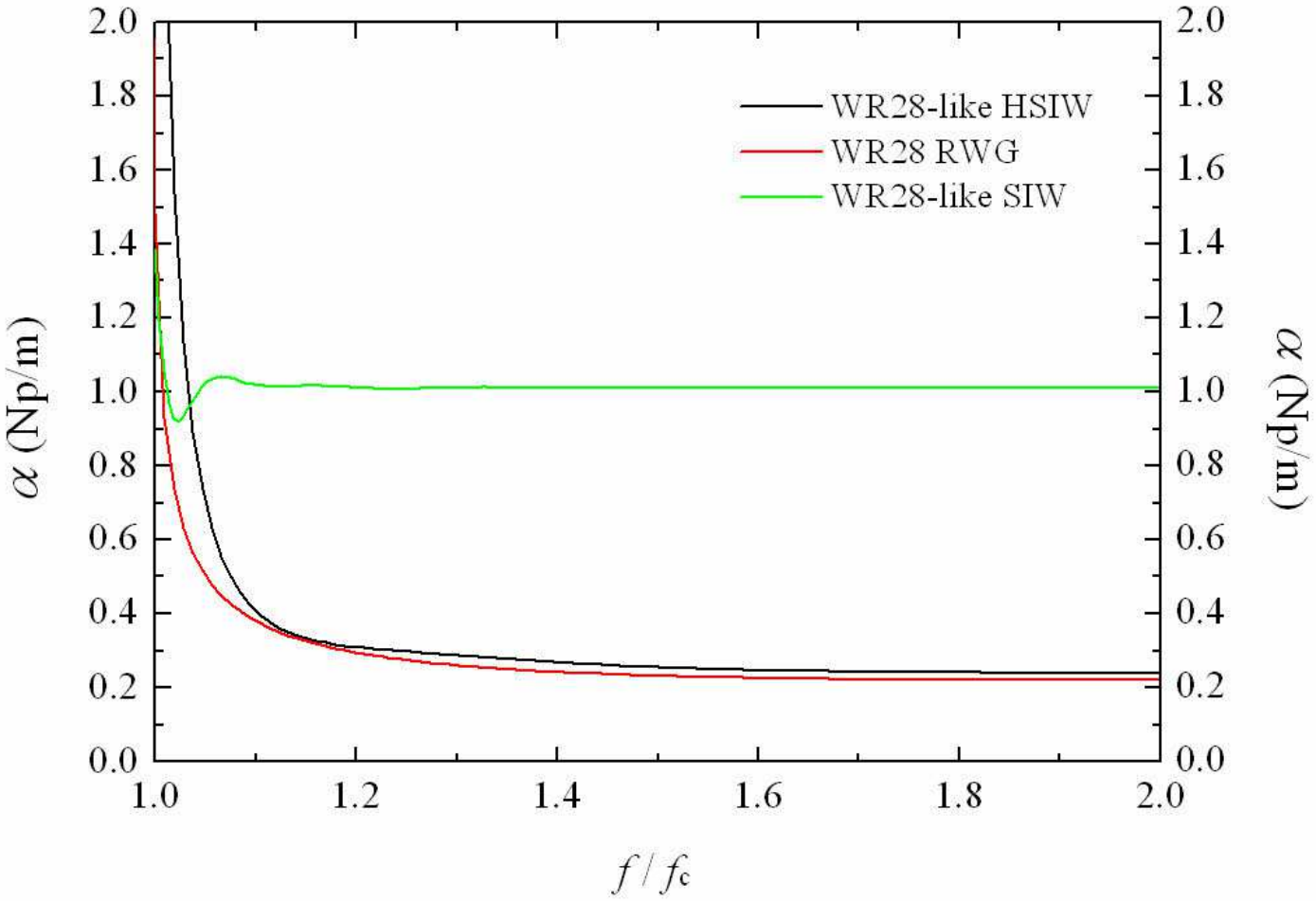
Hollow Substrate Integrated Waveguide (HSIW) - progressive lamination technique



HSIW: inner layers before lamination



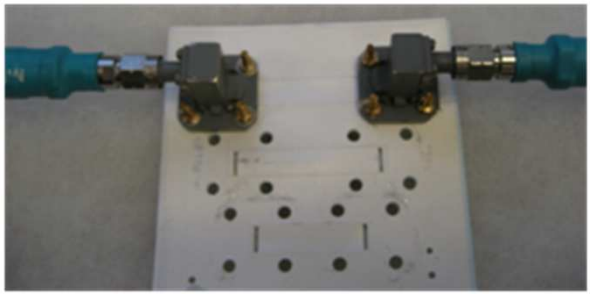
Filter

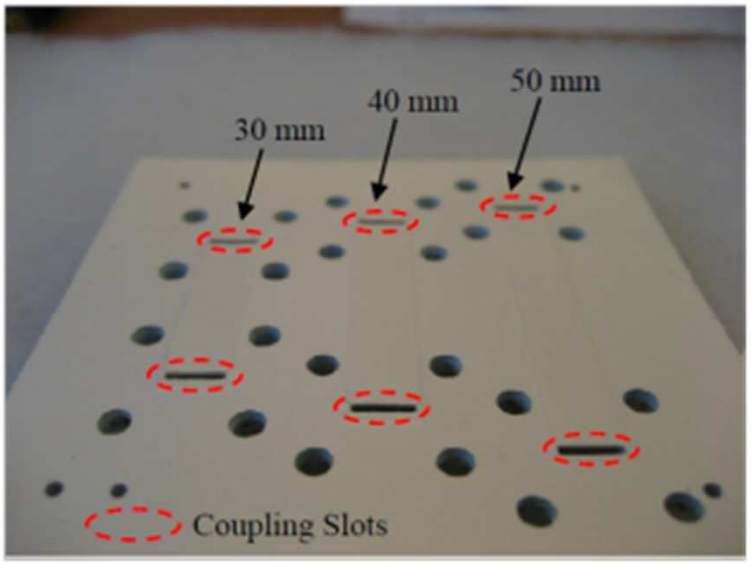


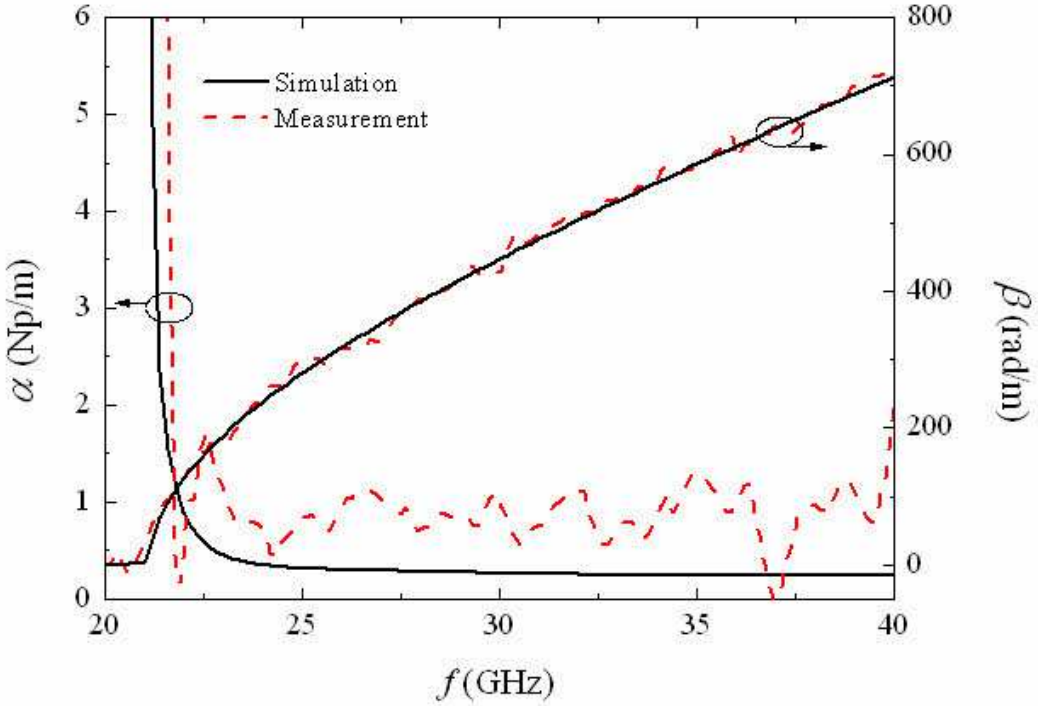
Modelled loss

Jin, Lukui, Lee, R.M.A., and Robertson, I.D., “Analysis and Design of a Novel Low-Loss Hollow Substrate Integrated Waveguide”, IEEE Transactions on Microwave Theory and Techniques, vol.62, no.8, pp.1616-1624, Aug. 2014, doi: 10.1109/TMTT.2014.2328555

HSIW Measurements

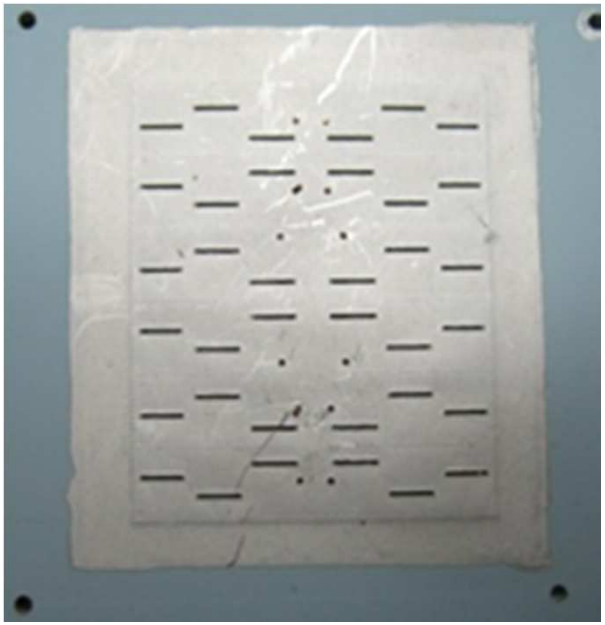


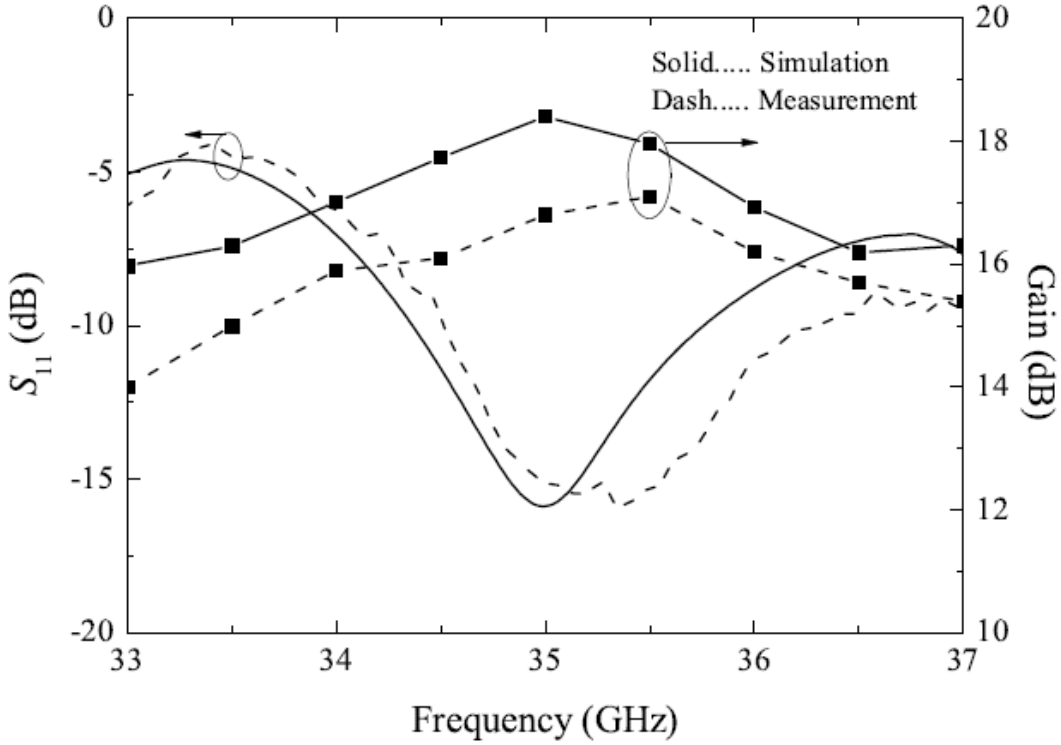




Through line measurement

HSIW 6x6 Slot Antenna Array

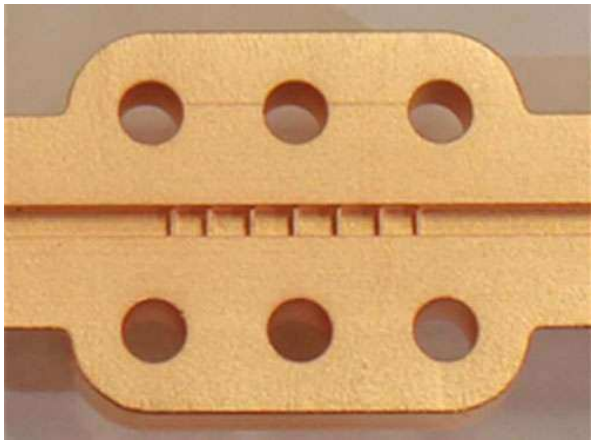




35 GHz HSIW Slot Antenna Array

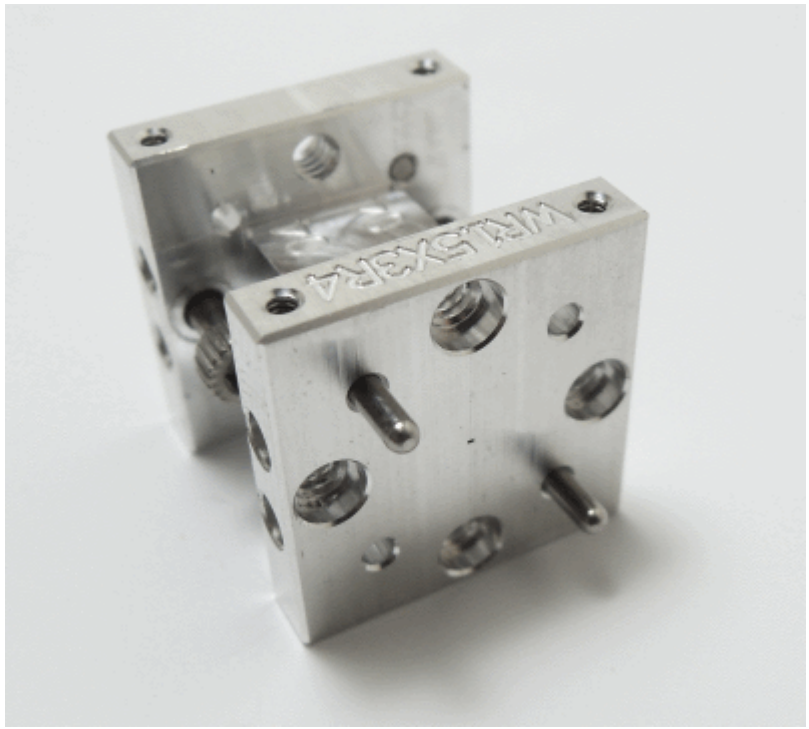
L. Jin, R. M. Lee, I. D. Robertson, “Analysis and Design of a Slotted Waveguide Antenna Array using Hollow Substrate Integrated Waveguide”, European Microwave Conference, September 2015

Micromachined Waveguides using SU8
Steenson *et al*., 1998



3D printed waveguide filter
Courtesy Stepan Lucyszyn, Imperial College
Reference 5 of paper

D'Auria, M.; Otter, W.J.; Hazell, J.; Gillatt, B.T.W.; Long-Collins, C.; Ridler, N.M.; Lucyszyn, S., "**3-D Printed Metal-Pipe Rectangular Waveguides**", IEEE Transactions on Components, Packaging and Manufacturing Technology, Sept. 2015



WR-1 waveguide
1.92 – 1.35 dB/cm calculated for gold, rgh=1.5
(VDI)

Circa 10 dB loss reported for a 1 inch guide

Dielectric Waveguides

Planar Dielectric Guides: Key Candidates

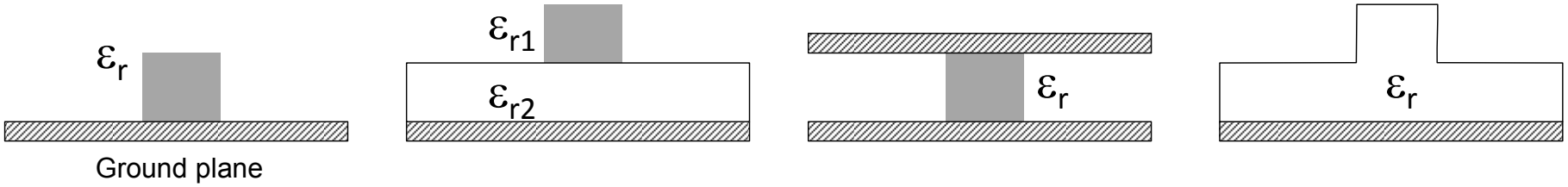
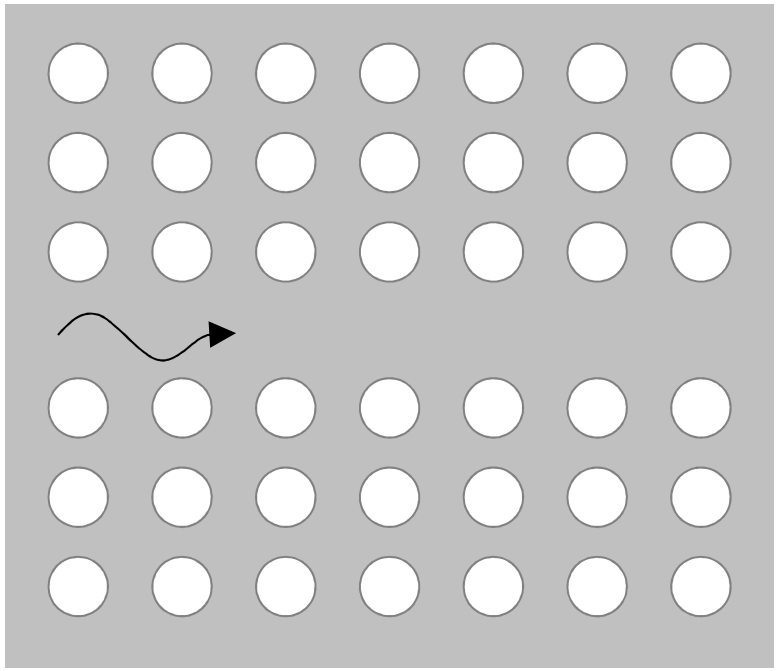
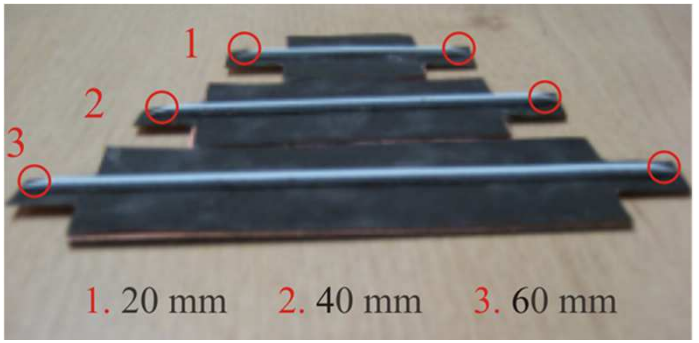


Image guide **insular image guide** **NRD** **Rib image guide**

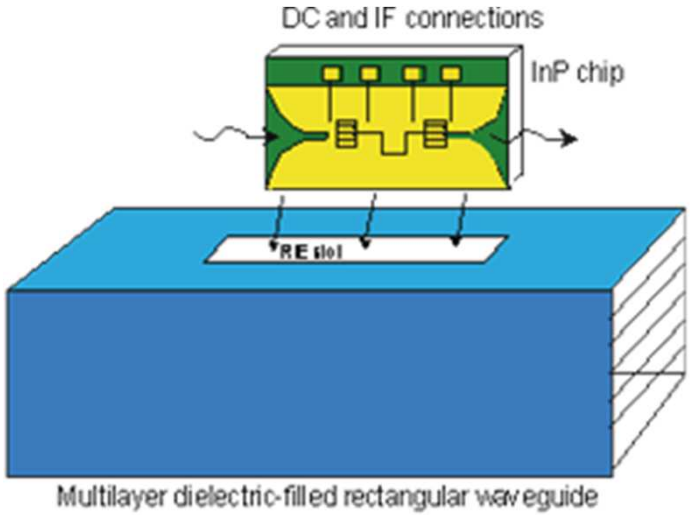
From *Microwave and Millimetre-Wave Design for Wireless Communications*, Wiley pub. 2016

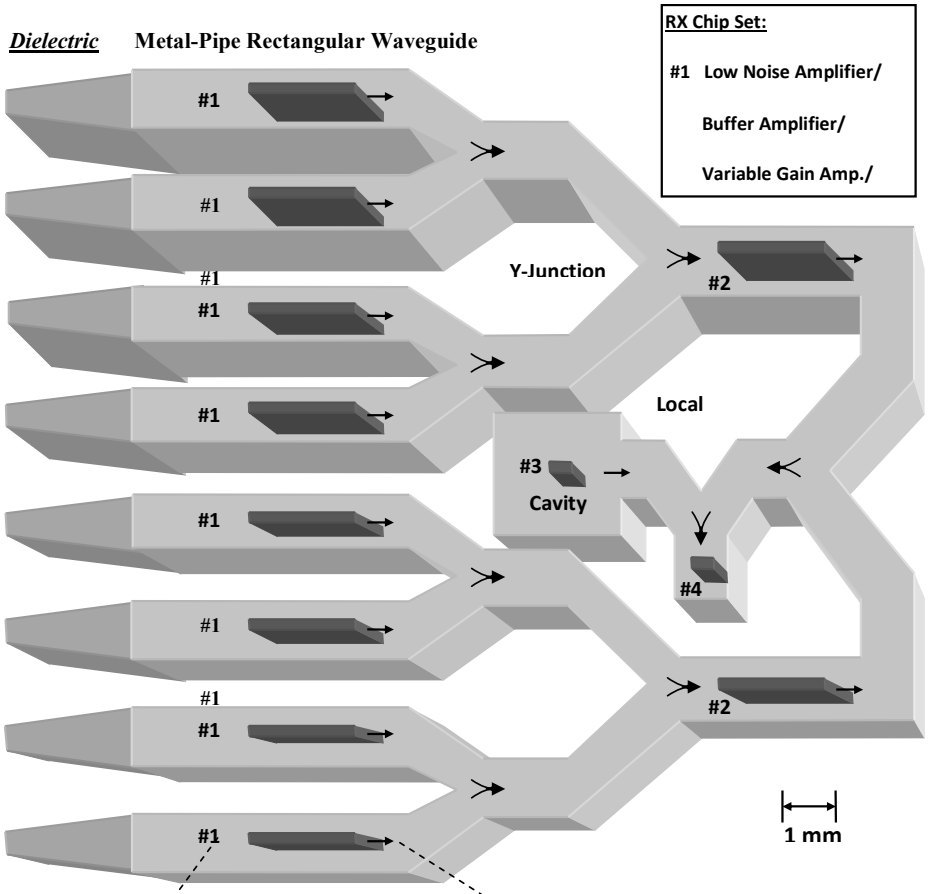


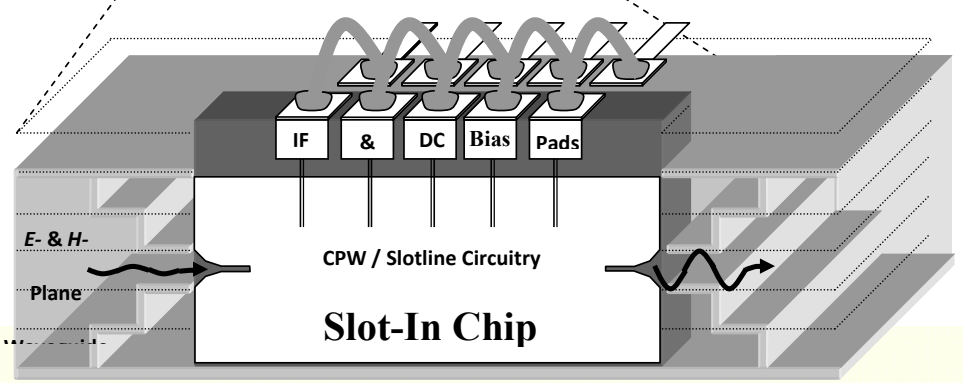


EM bandgap structure

“New” Chip Interfaces

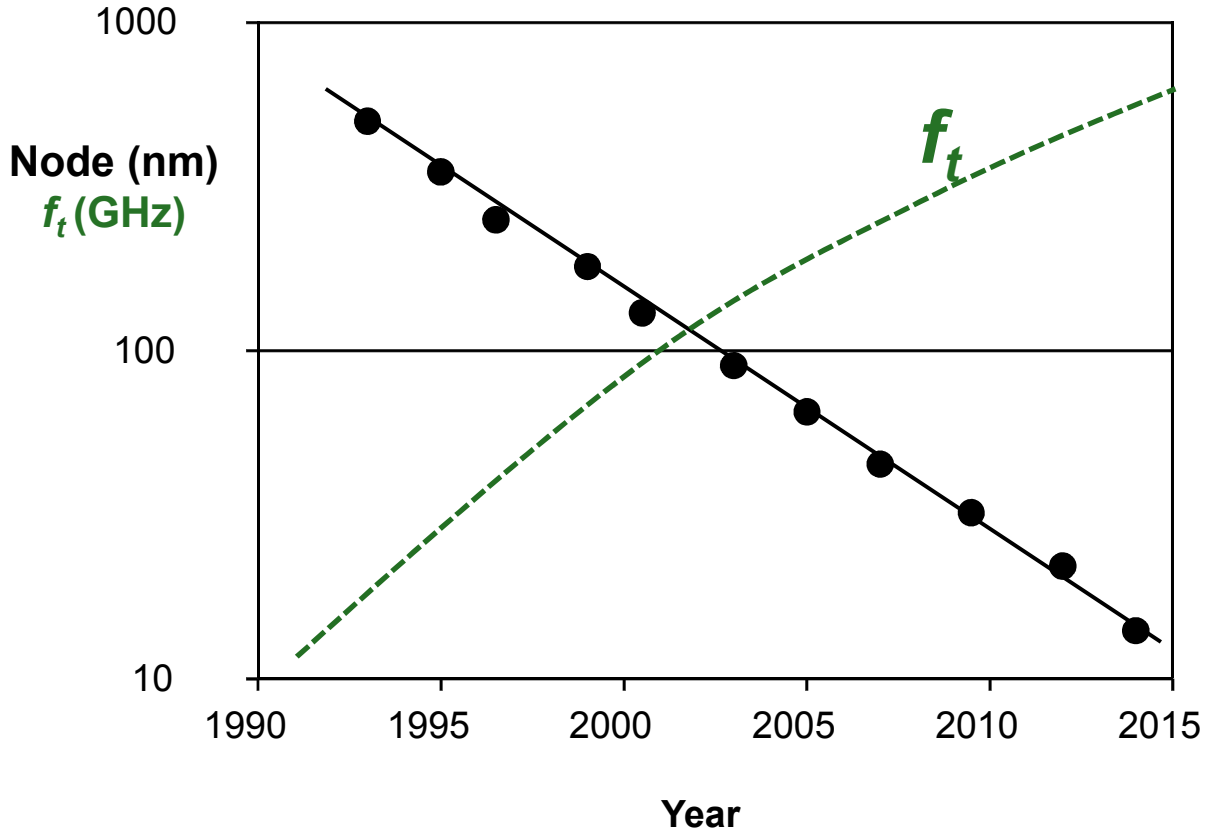




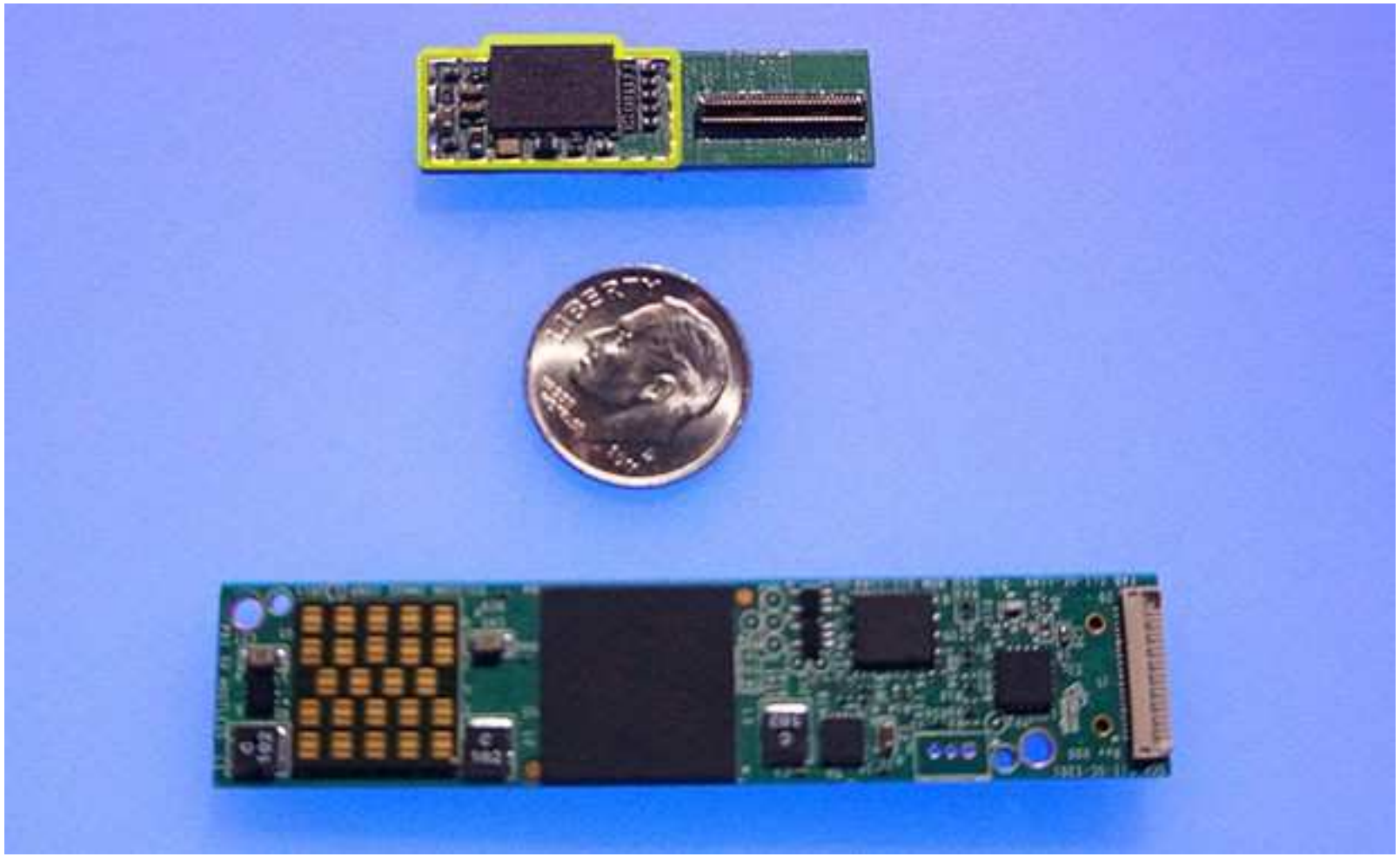


Lucyszyn, S.; Silva, S.R.P.; Robertson, I.D.; Collier, R.J.; Jastrzebski, A.K.; Thayne, I.G.; Beaumont, S.P., "Terahertz multi-chip module (T-MCM) technology for the 21st century?," in Multi-Chip Modules and RFICs (Ref. No. 1998/231), IEE Colloquium on , vol., no., pp.6/1-6/8, 5 May 1998

Package-Level Integration



CMOS Technology Development and f_t



http://www.engadget.com/2013/01/10/silicon-image-ultragig-6400-wireless-hdmi-hands-on-video/

Also see:

Wilocity (now part of Qualcomm) IEEE802.11ad module (google..)

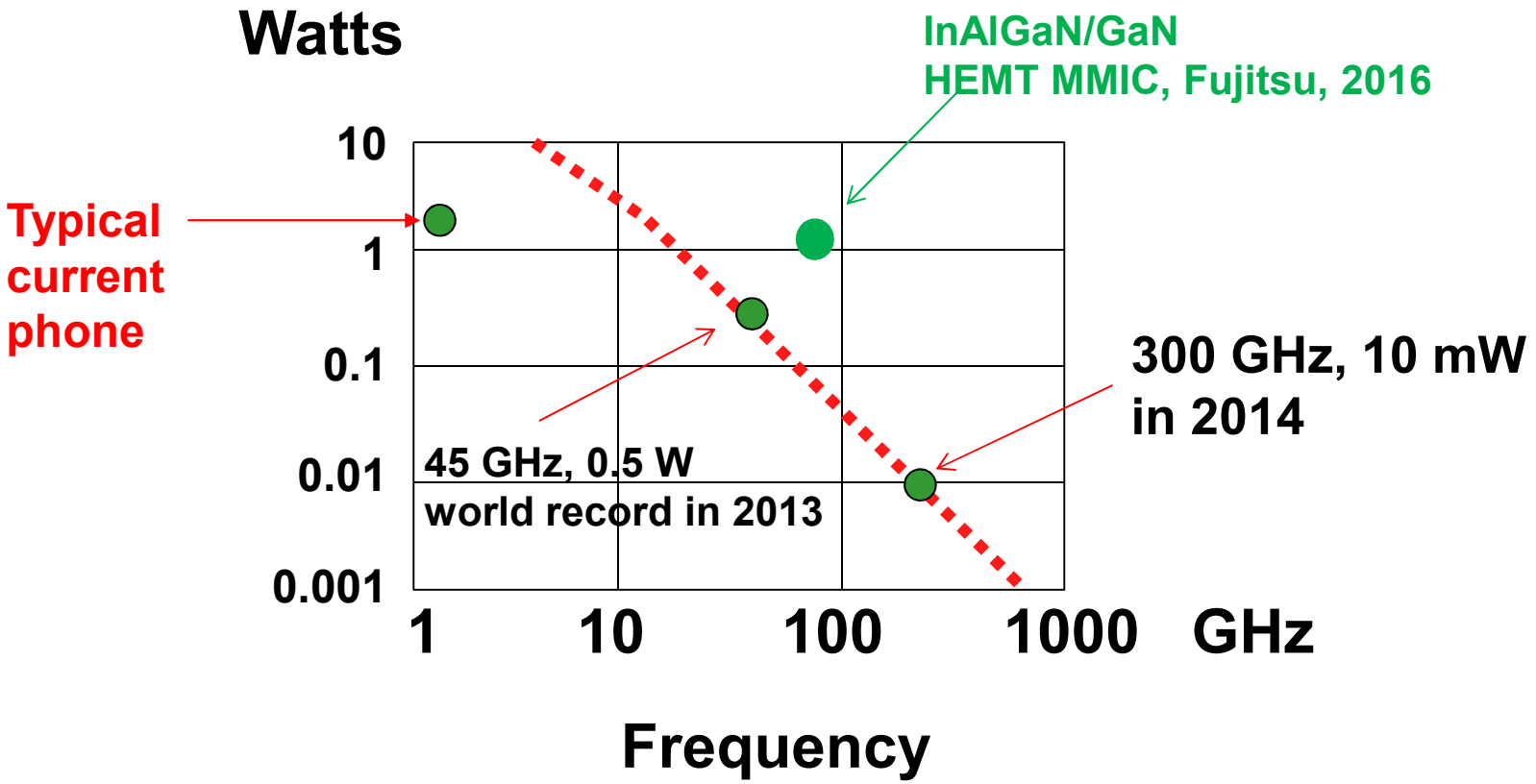
ITRS White Paper
The next Step in Assembly and Packaging:
System Level Integration in the package (SiP)

"A 37.5-mW 8-dBm-EIRP 15.5° -HPBW 338-GHz Terahertz Transmitter Using SoP Heterogeneous System Integration", Chun-Hsing Li, et al IEEE MTT Trans 2015

NGST InP "chiplets" on CMOS

"Sub-Millimeter Wave InP Technologies and Integration Techniques"
Vesna Radisic et al., 2015 IEEE MTT-S International Microwave Symposium

III-V technologies needed to deliver any significant power beyond 100 GHz



+ a whole host of specialist THz devices

Conclusions

To go significantly beyond 100 GHz with SoS requires hollow SIW or dielectric waveguides

Silicon / III-V both have key roles to play in realising affordable THz systems

3D PACKAGING TECHNOLOGY is key to exploitation of diverse semiconductor technologies in THz systems

Addressing these challenges can lead to highly novel large-area SiP and SoS systems

Acknowledgments

Contributors:
M. F. Shafique, K. K. Samanta, D. Stephens, M.S. Aftanasar, Razak M. A. Lee, M. Chongcheawchamnan, C.Y. Ng, Lukui Jin, Ayodeji Sunday, P. R. Young, Isibor Obuh, Nutapong Somjit, Paul Steenson, Mario D'Auria, Stepan Lucyszyn, Dilshani N. Rathnayake-Arachchige, David Hutt, Paul Conway

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Engineering and Physical Sciences Research Council
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