Millimeter-Wave Substrate-Integrated Circuits on Photo-imageable Substrate and LTCC

Ian Robertson (i.d.robertson@leeds.ac.uk)
Hizamel M. Hizan, Ian C. Hunter, Alaa I. Abunjaileh, M. Farhan Shafique
Institute of Microwave and Photonics, University of Leeds

Stepan Lucyszyn
Imperial College London

UNIVERSITY OF LEEDS
Imperial College London

EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

OUTLINE

Photoimageable thick film technology

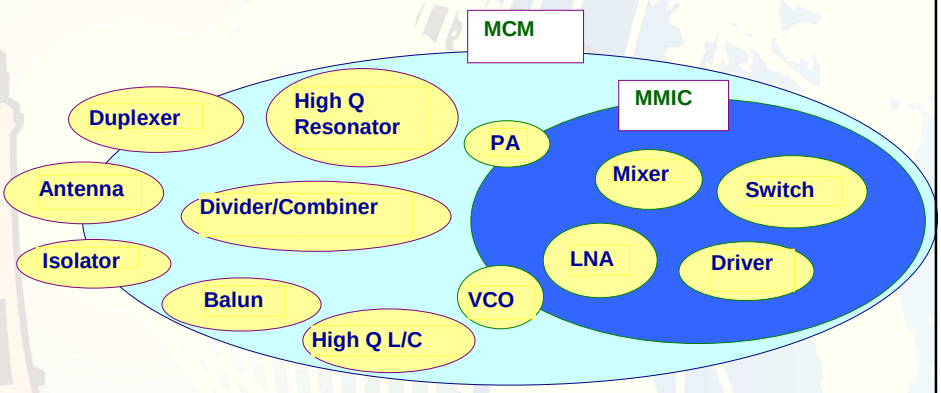
"Rapid Prototyping" LTCC Technology using LPKF Laser

Laser Machining of Microvias and Trenches

Future Work:-

- Novel filter topologies
- SIWs & Antennas
- Systems integration

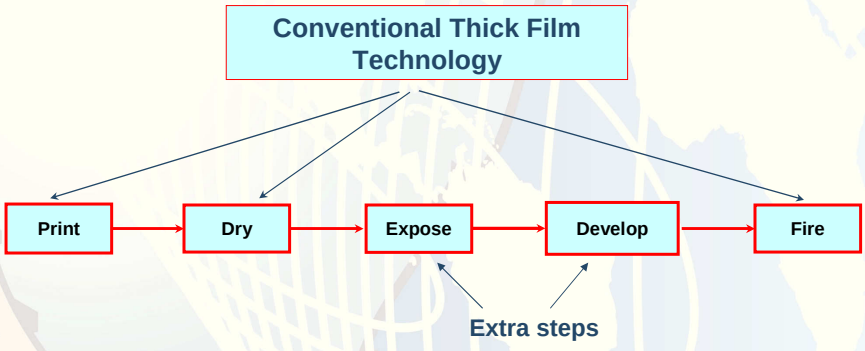
MOTIVATION



THICK-FILM TECHNOLOGY PURSUED FOR LOW COST FABRICATION OF LARGE AREA SYSTEM-ON-SUBSTRATE APPLICATION

EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

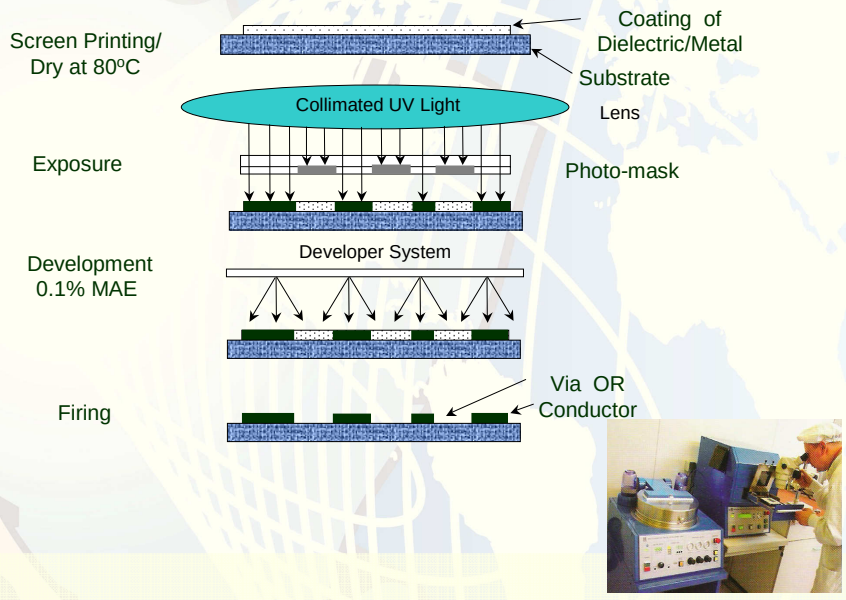
MULTILAYER PHOTOIMAGEABLE THICK FILM PROCESS

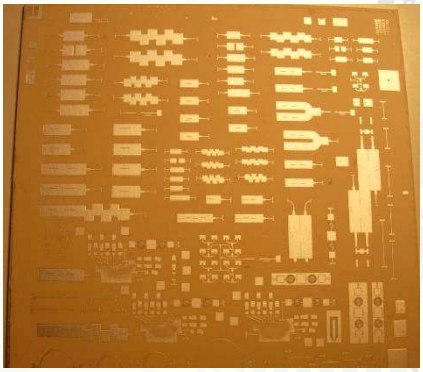


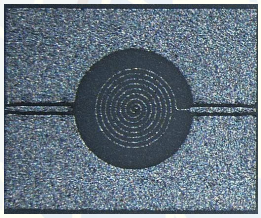
MULTILAYER PHOTOIMAGEABLE THICK FILM PROCESS

- Special type of photosensitive thick film material
- Features are defined by exposure of dry paste to UV light
- Gold, silver and dielectric pastes available
- Rheology of paste can be optimised for smooth finish
- Fine width/gap, easy to fabricate, low cost

EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

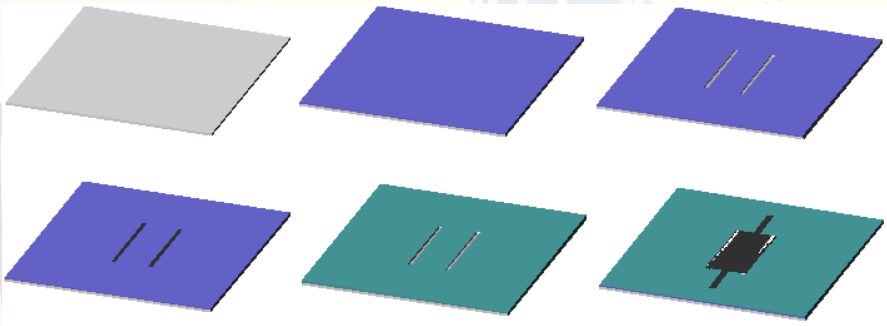






EUMW 2010
EUROPEAN MICROWAVE WEEK
CNIT Paris
26 September -1 October 2010
WWW.eumweek.com

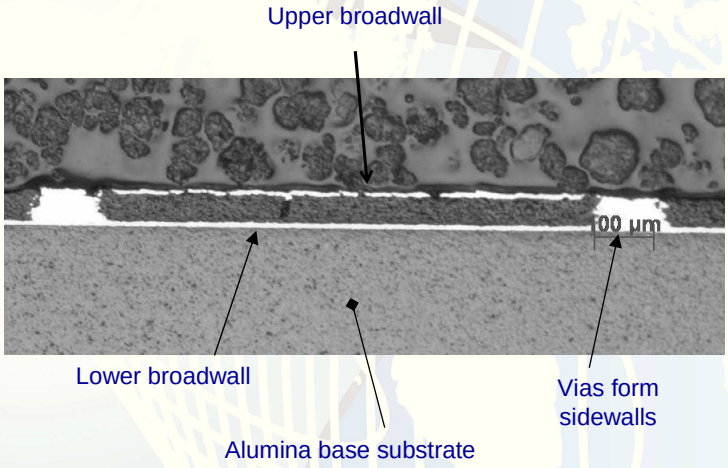
SIW Fabrication



- Conductor print defines ground plane
- Dielectric layer exposed & developed to create vias for sidewalls
- Conductor print forms guide sidewalls
- Repeat dielectric prints to build guide height
- Final conductor print forms upper broadwall

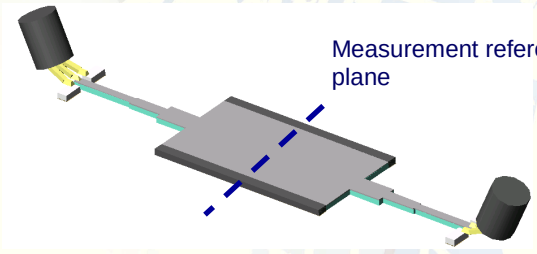
EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

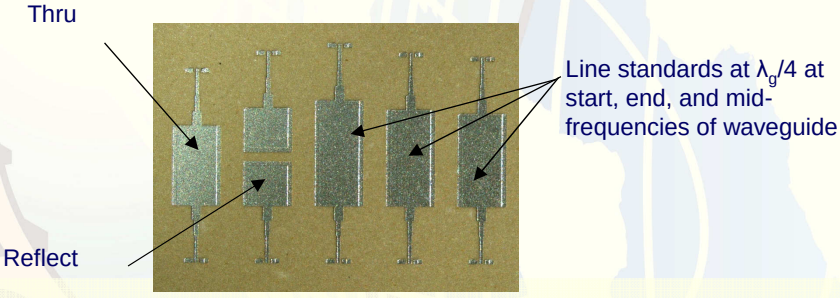
Fabricated waveguide



EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

TRL calibration

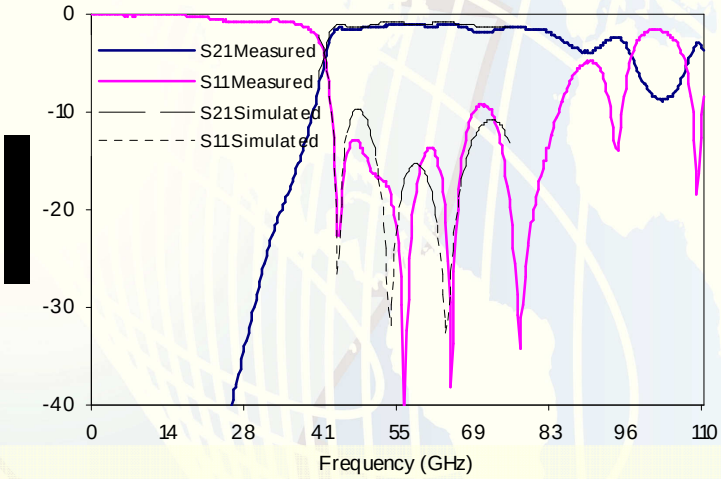




EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

EuMW 2010 CONNECTING THE WORLD

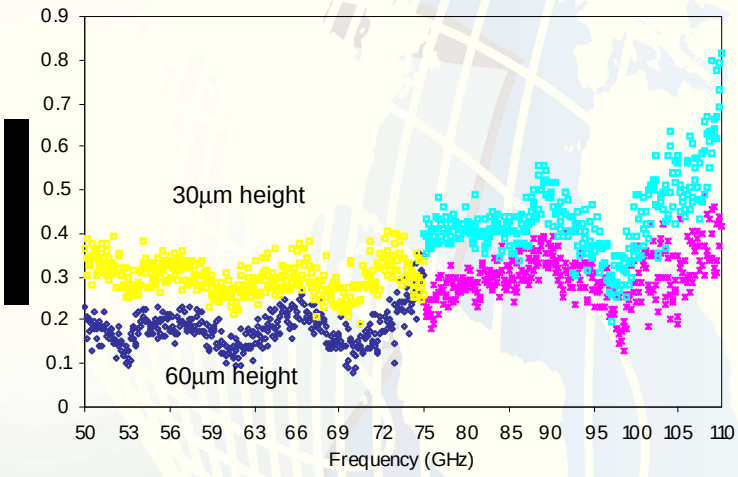
V band waveguide back-to-back transition measurements



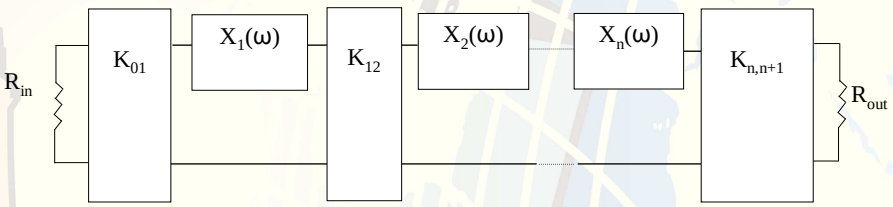
EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

EuMW 2010 CONNECTING THE WORLD

Measured attenuation (dB/mm) for V and W-band waveguides.

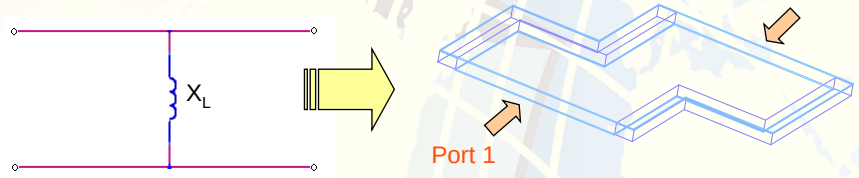


Inverter-coupled filter



- K_{ij} impedance inverters and $X_n(\omega)$ resonator sections are series connected

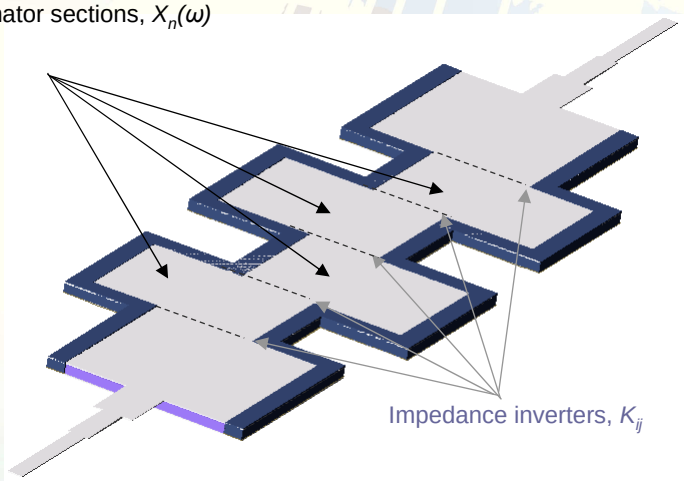
Inverter



- Inductive reactance readily realized by a H-plane offset
- Displaced junction characterized in HFSS

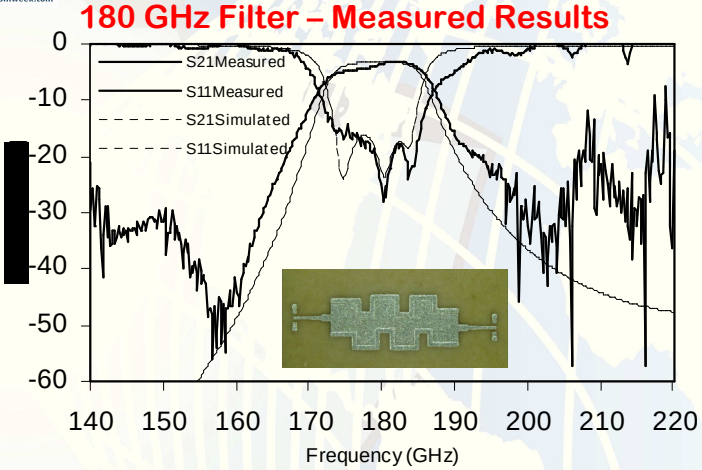
SIW filter synthesized

Resonator sections, $X_n(\omega)$



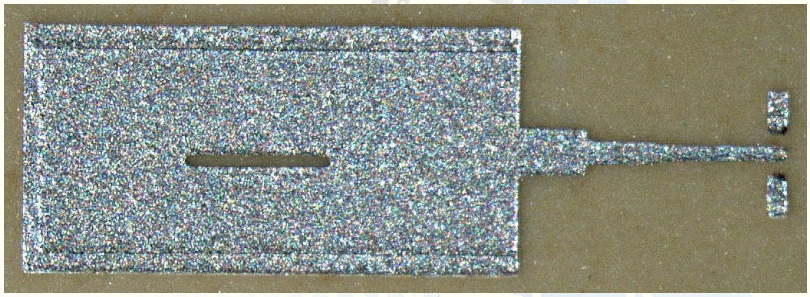
EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

180 GHz Filter – Measured Results



Stephens, D.; Young, P.R.; Robertson, I.D., **"Design and characterization of 180 GHz filters in photoimageable thick-film technology"** IEEE MTT-S IMS, 2005, vol. 1, pp. 451-454

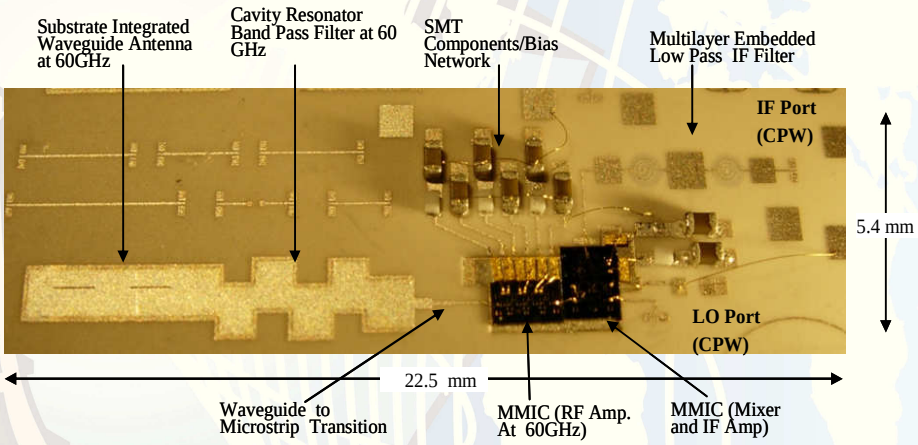
W-band Antenna



Stephens, D.; Young, P.R.; Robertson, I.D. (2005) **W-band substrate integrated waveguide slot antenna.** Electronics Letters, 41(4), pp.165-167.

EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

Complete SIW/MMIC 60GHz Receiver



Major drawback of thick film photoimageable approach for SIWs

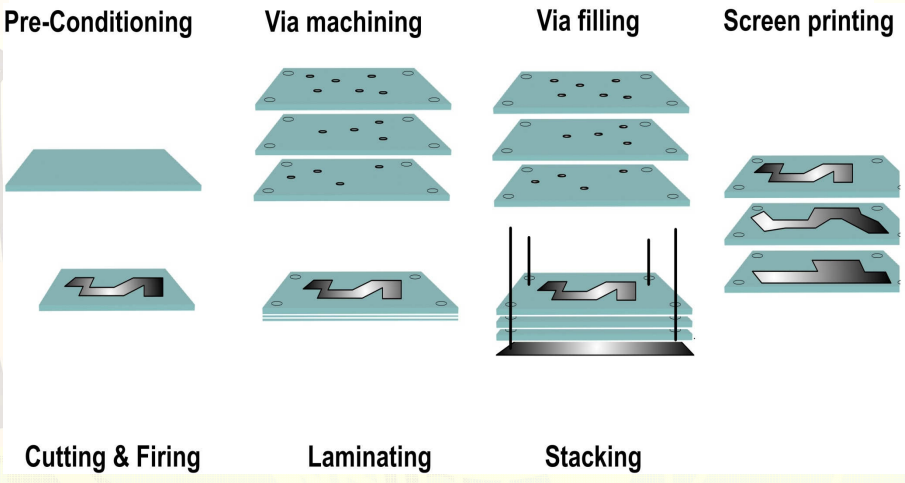
Waveguide height!

Even achieving 100 microns height requires many print-expose-fire cycles

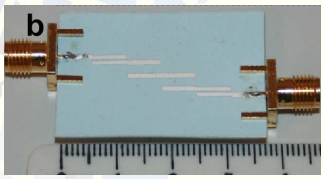
Alignment becomes challenging

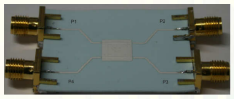
EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

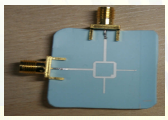
LTCC Process



LTCC prototyping using LPKF laser system

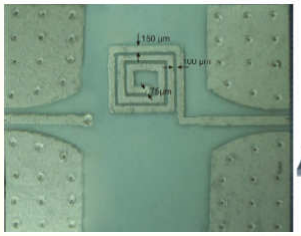


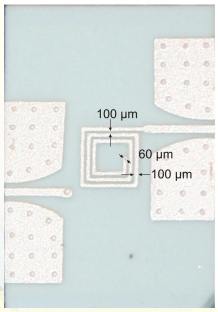


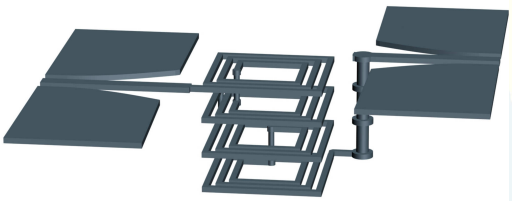


Equipment and Material

- Protolaser 200 Nd:Yag Laser etching machine from LPKF
- 943PX, 254 µm green tape from DuPont
- HF612 silver paste from DuPont
- HF600 via filling paste from DuPont





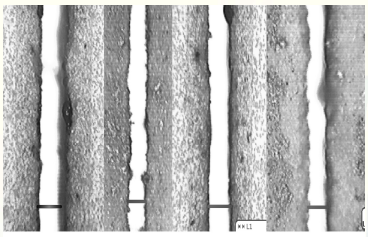


EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

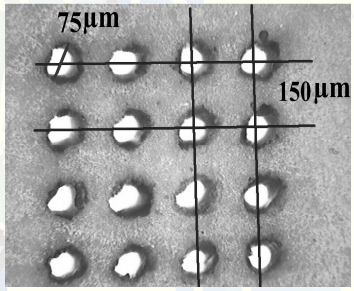
Via machining

Mechanical drill and punches	Laser machining
Low capital cost	High capital cost
Single use	Multipurpose
Low punching rate	High punching rate
Clean and precise diameter	Not very clean, precision suffers
Holes only	Arbitrary shape possible
No optimization required	Hard to optimize
Direct contact with the material	No direct contact with material
Short tool life	Long life

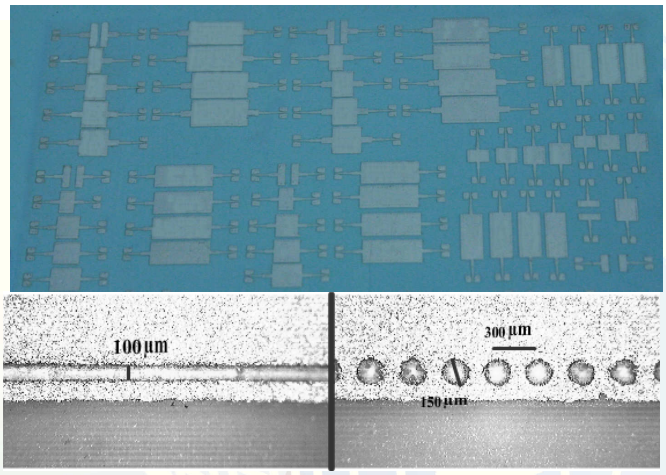
Minimum dimensions

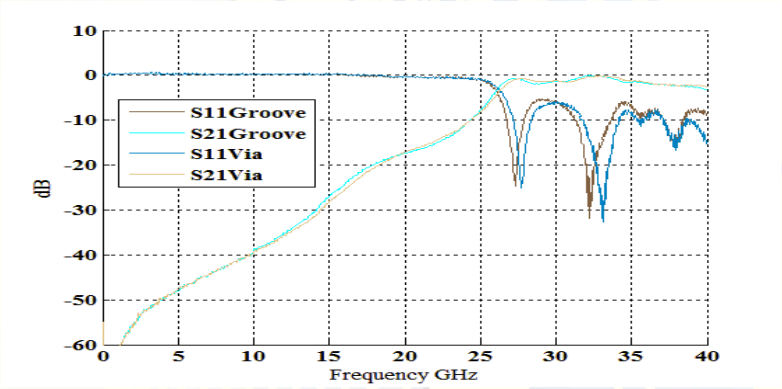


76µm 67µm 59µm 46µm



SIW with solid wall and via posts





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

EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

Further Developments

Novel filter topologies

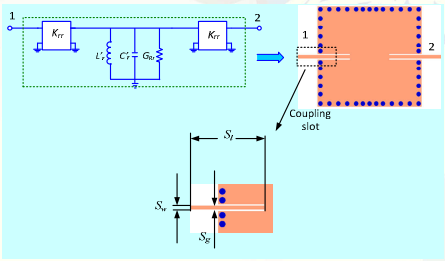
SIW / Antenna integration

Higher frequencies

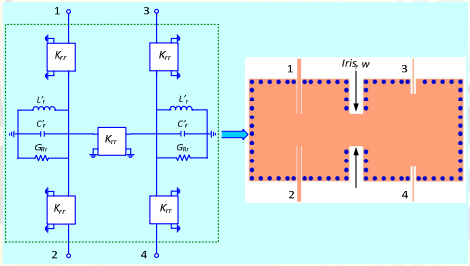
Novel reconfigurable systems

EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

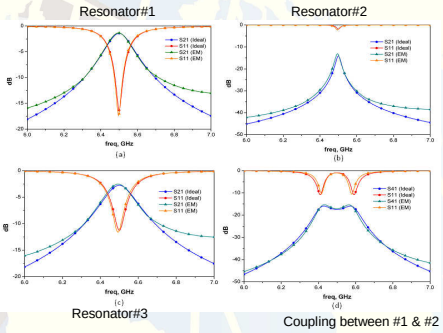
SIW Resonator



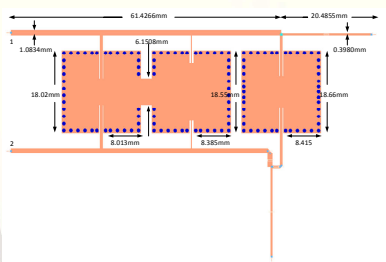
Inter-Resonator Coupling



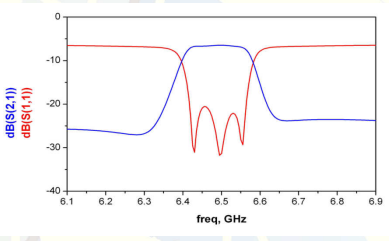
Ideal vs EM



EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

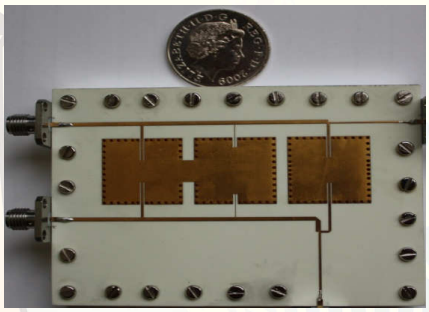


Layout

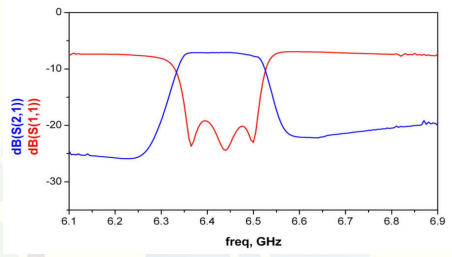


Simulated response

Results



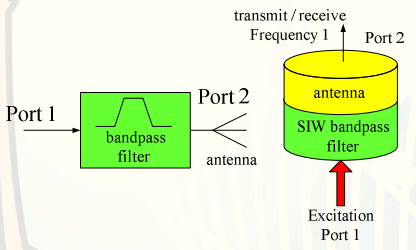
Photograph of the fabricated filter



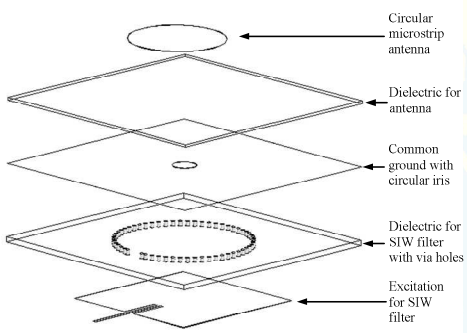
Measured response

EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

INTEGRATED MICROWAVE FILTER AND ANTENNA



Block diagram

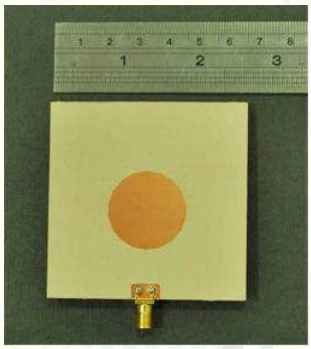


Exploded view

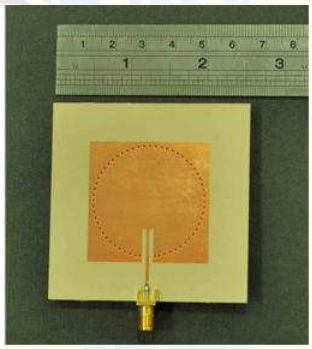
EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

PHOTOGRAPH OF FABRICATED INTEGRATED SIW FILTER AND MICROSTRIP ANTENNA

Fabricated on Rogers Duroid 6010 of ε_r=10.2



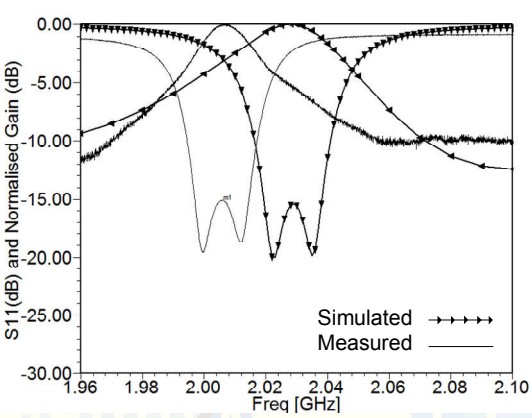
Top View



Side View

EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

SIMULATED AND MEASURED RESULTS

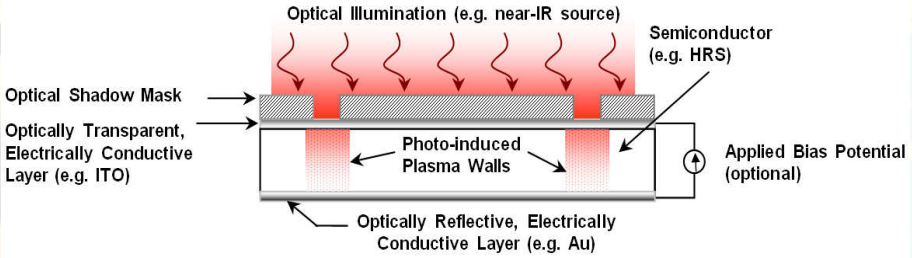


EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

The RETINA concept

Imperial College London

REconfigurable Terahertz INtegrated Architecture (RETINA)

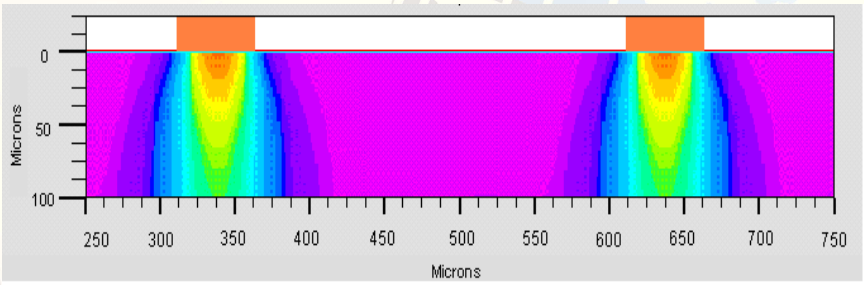


Basic RETINA concept is based on creating virtual side walls using optical illumination and the photoconductivity effect

Y. Zhou and S. Lucyszyn, "Modelling of reconfigurable terahertz integrated architecture (RETINA) SIW structures", EM Academy's PIER Journal, vol. 105, pp. 71-92, Jun. 2010

EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

Silvaco™ TCAD simulations: 2D Luminous

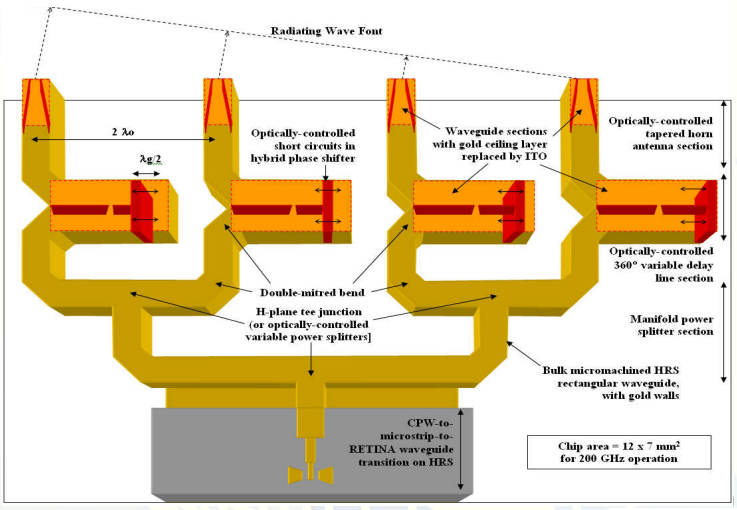


Beam Width = 50 µm
Wafer Thickness = 100 µm
Optical Incident Power Range: 10-100 W/cm^2

Imperial College London

EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

Scanning phased Array Antenna Concept at 200 GHz



Imperial College London

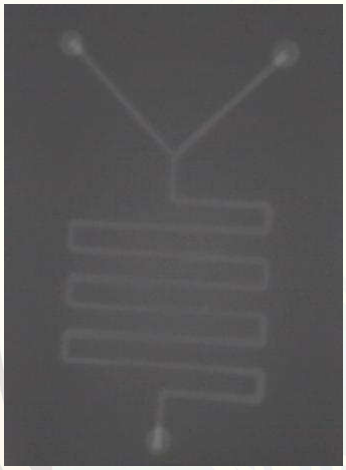
EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

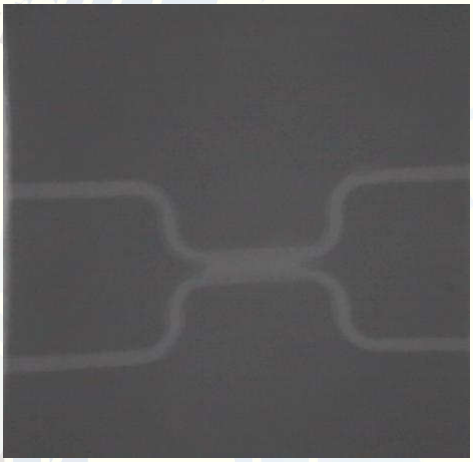
Loss Comparison with Various SIW Technologies

Technology	Frequency (GHz)	Insertion loss (dB/mm)	Conductor loss scaling to 300 GHz (dB/mm)
Alumina SIW	50	0.03	0.07
Ceramic (HT1000) SIW	60	0.20	0.45
Ceramic (QM44F) SIW	74	0.70	1.41
Polyimide (Kapton HN) SIW	79	0.17	0.33
Photoimageable Dielectric HD1000-filled MPRWG	83	1.2	2.3
Air-filled MPRWG	100	0.01	0.017
Polyimide-filled MPRWG	105	8.98	15.18
Air-filled MPRWG	400	0.086	0.074
RETINA (simulated)	300	3.88	3.88

Imperial College London

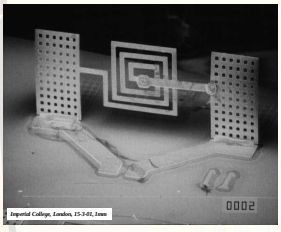
LTCC Microfluidic Channels

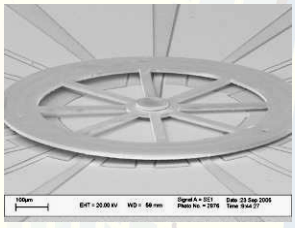


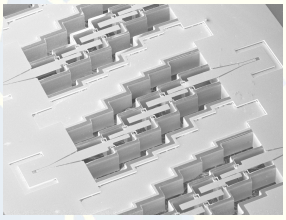


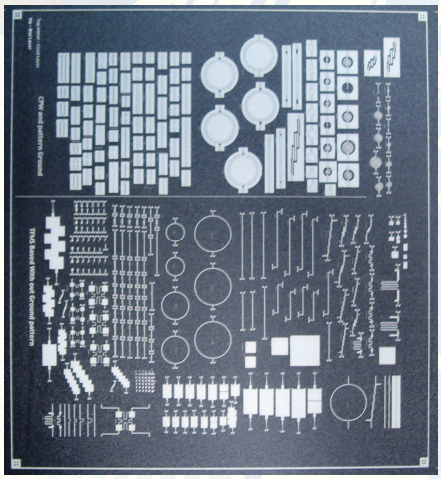
EUMW 2010
EUROPEAN MICROWAVE WEEK
CNIT Paris
26 September -1 October 2010
WWW.eumweek.com

Previous Imperial-Leeds collaboration in RF MEMS & Micromachined Components









Collaboration with Mechanical Engineering on Large Area Screen Printing

EUMW 2010 EUROPEAN MICROWAVE WEEK CNIT Paris 26 September -1 October 2010 WWW.eumweek.com

Conclusions

Ceramic technologies are highly suited to the realisation of SIW filters and circuits

To go significantly beyond 100 GHz requires research into improved materials and fabrication techniques

In LTCC, a wide range of microfluidic and mechanical components can be integrated to form a truly multifunctional system-on-substrate

A major challenge for the next few years is to study the feasibility of realising screen-printed RF MEMS integrated with SIWs to make tuneable filters

Addressing these challenges can lead to highly novel large-area SIW-based systems

Acknowledgments

This work is supported by the
Science and Engineering Research Council
and by the
Innovative Manufacturing Research Centre (IeMRC)
based at Loughborough University.