A Review of Compact Substrate Integrated Waveguide (SIW) Interconnects and Components

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OUTLINE

1 – Current Trends in Microwave Technology (**towards 5G**)

2 – **Substrate Integrated Waveguide** (SIW) Technology

3 – **Broadband and Miniaturized** SIW Interconnects

4 – **Miniaturization** of SIW Components

5 – New **Materials** (3D-Printed materials, Textile, Paper)

1 – Current Trends in Microwave Technology (towards 5G)

TRADITIONAL MICROWAVE TECHNOLOGIES

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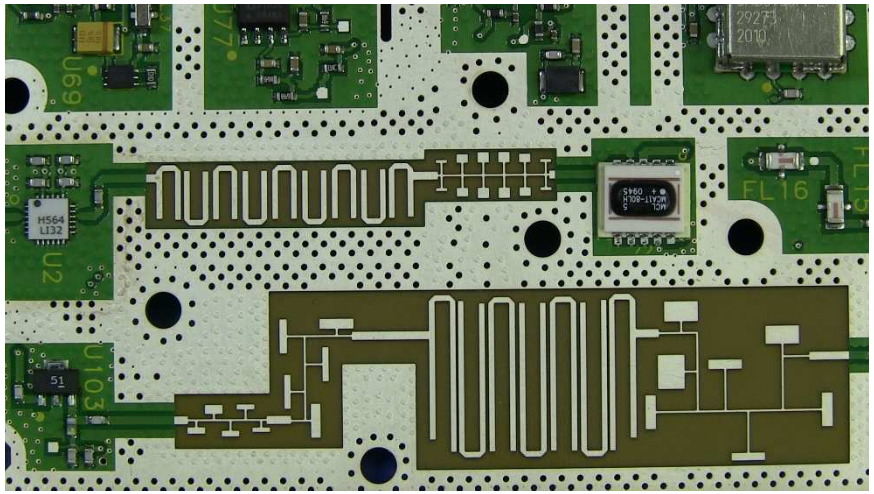
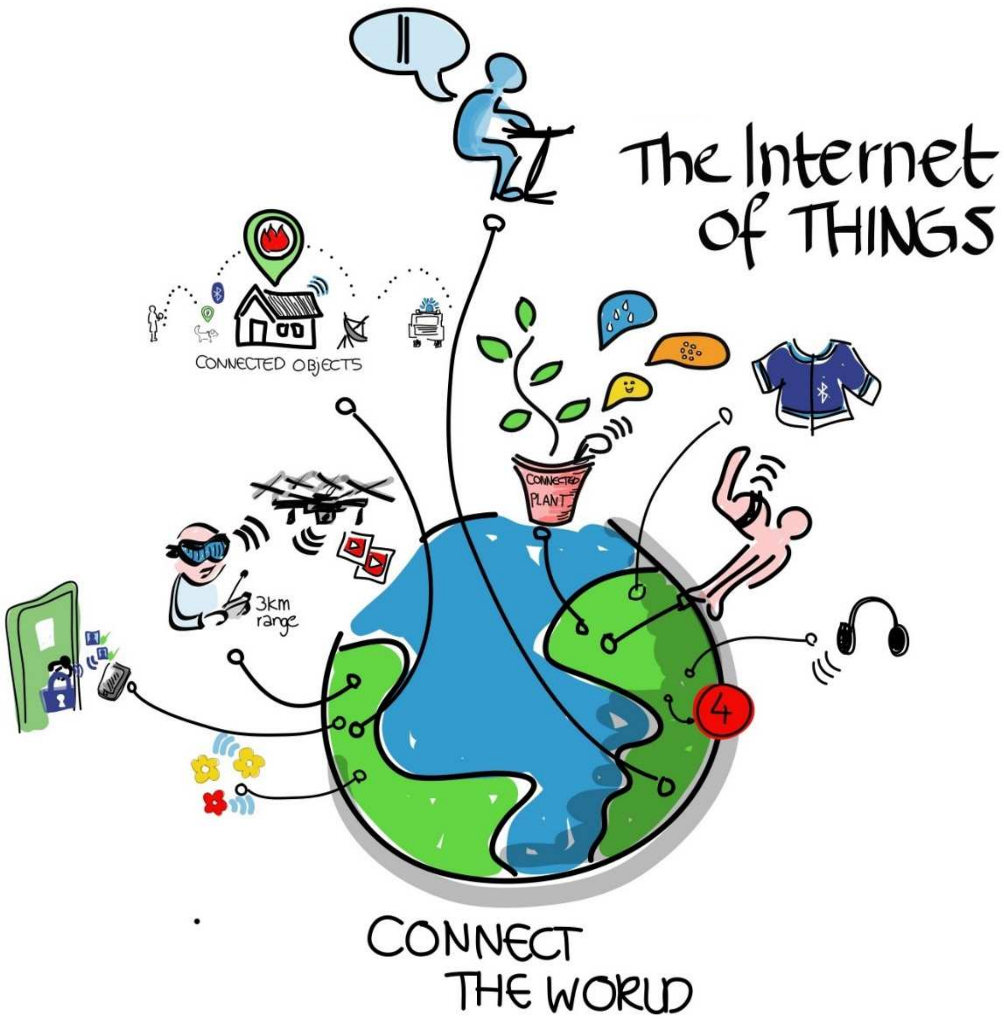
METALLIC WAVEGUIDES



PRINTED CIRCUIT BOARDS

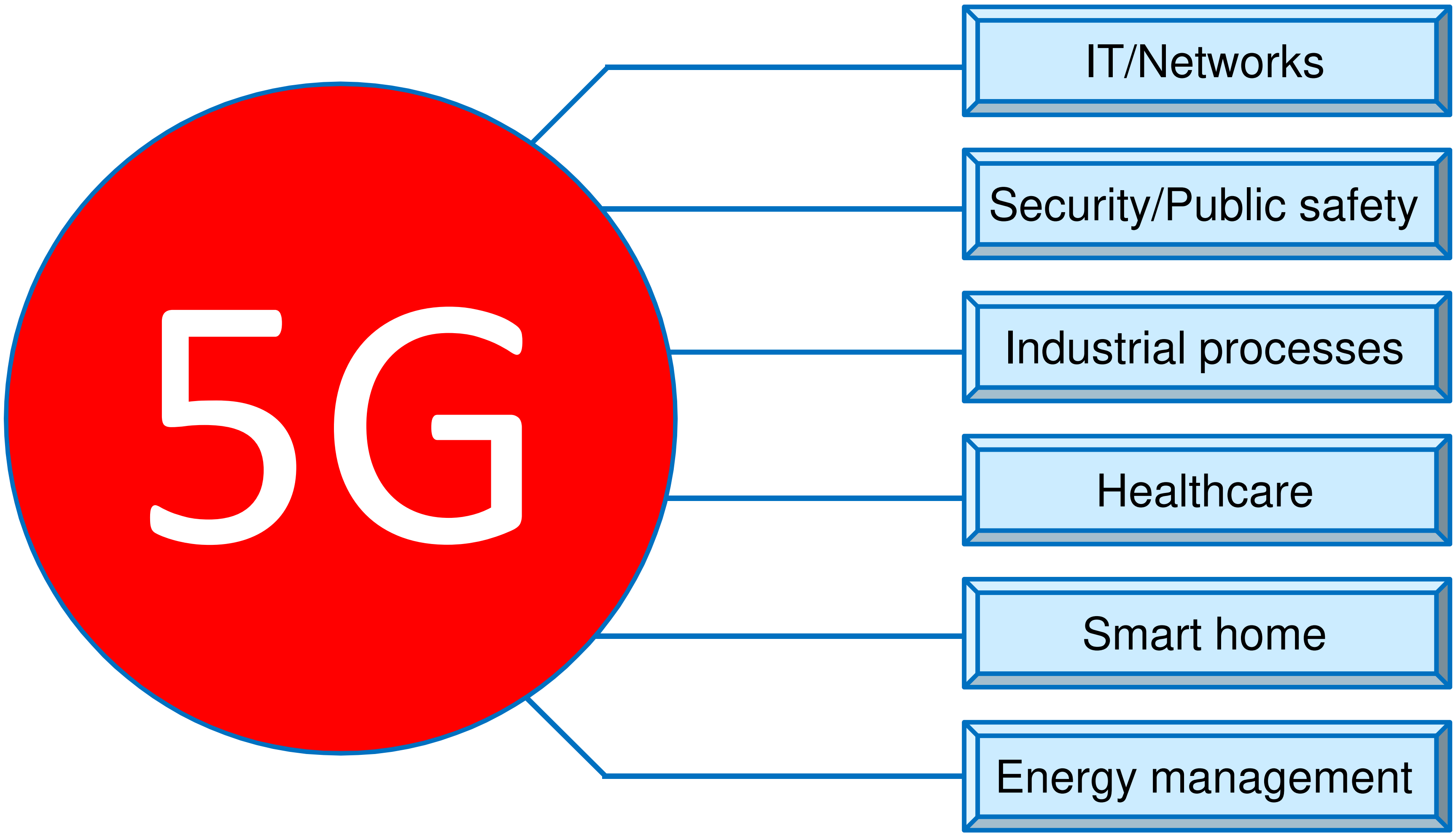
**DIELECTRIC RESONATORS,
ABSORBERS, RADOMES**

INTERNET OF THINGS (IOT)



- IT/Networks
- Security/Public safety
- Industrial processes
- Healthcare
- Smart home
- Energy management

INTERNET OF THINGS (IOT) & 5G



Can We Still Use These Technologies?

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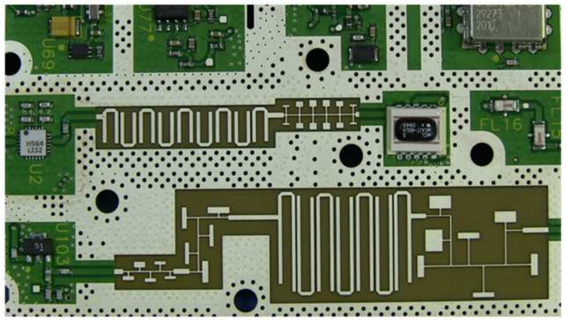
Metallic Waveguides



Printed Circuit Boards

Dielectric Resonators,
Absorbers, Radomes

Traditional microwave technologies are not suitable for the many emerging applications. **A new paradigm is needed!**

TECHNOLOGICAL REQUIREMENTS

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The key points for the development of Internet of Things/5G are:

low cost

easy integration of the complete wireless system

mm-wave frequency

simple design rules

self-powering (energy harvesting)

wearable devices

This leads to the selection of:

- An **integration technology** able to efficiently combine active elements, passive components, and antennas;
- Suitable **materials** for each application.

2 – Substrate Integrated Waveguide Technology

TRADITIONAL TRANSMISSION LINES

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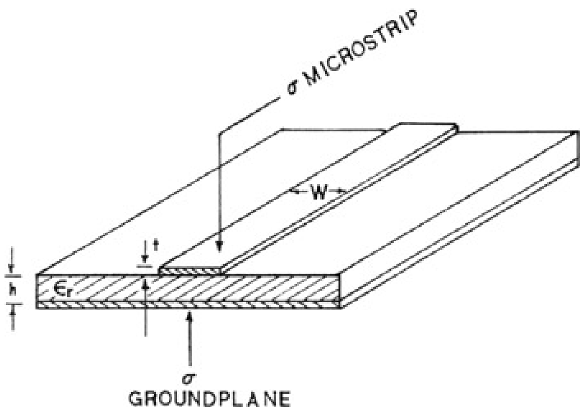
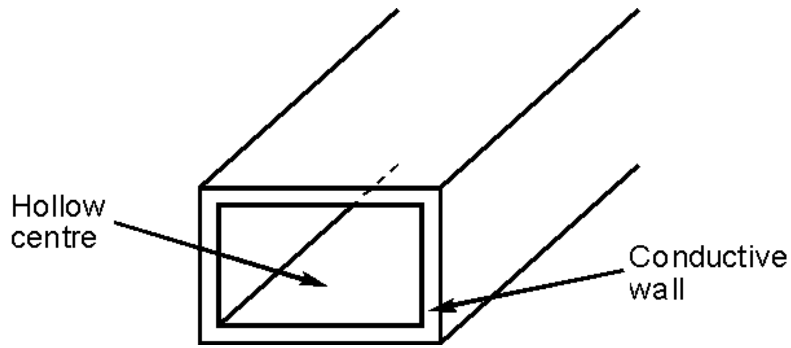
The guided wave propagation in the microwave region is preferably obtained by using microstrip lines and metallic waveguides.



MICROSTRIP LINES (planar)

- Light and compact
- Low fabrication cost
- High losses
- High cross-talk

TECHNOLOGICAL GAP

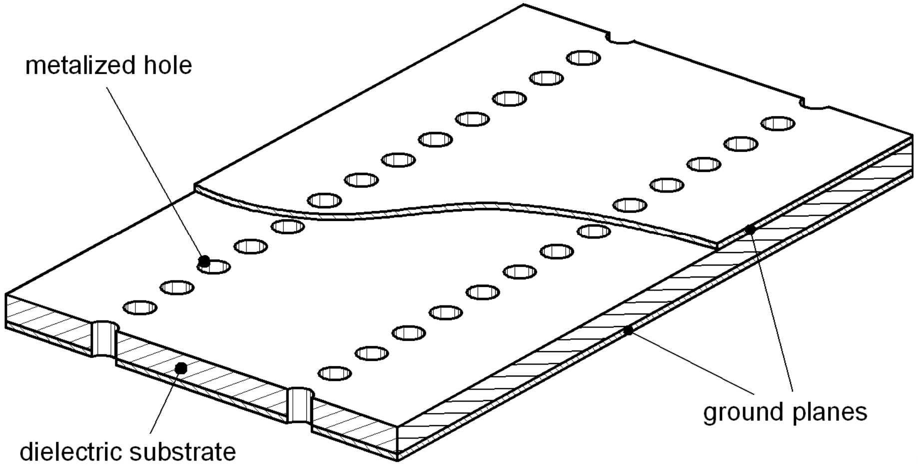


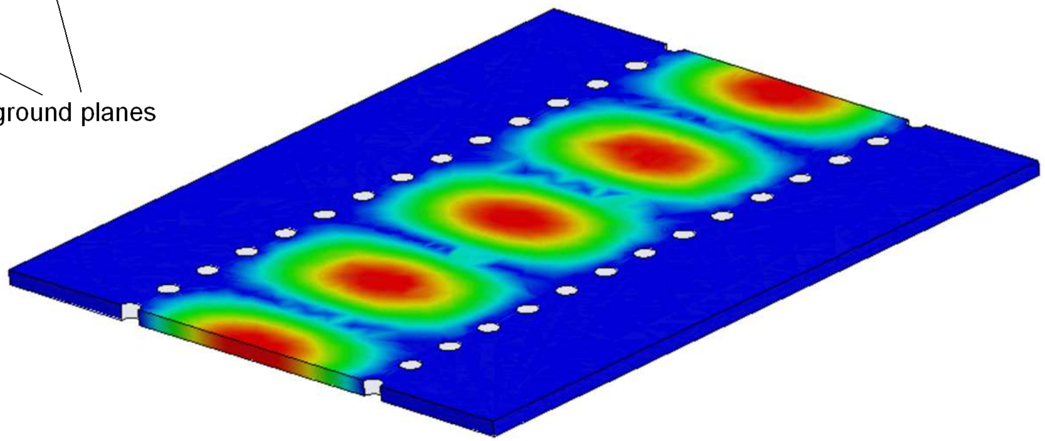
METALLIC WAVEGUIDES (non-planar)

- Low losses
- Completely shielded
- Bulky and expensive
- Difficulties with active components

SUBSTRATE INTEGRATED WAVEGUIDE

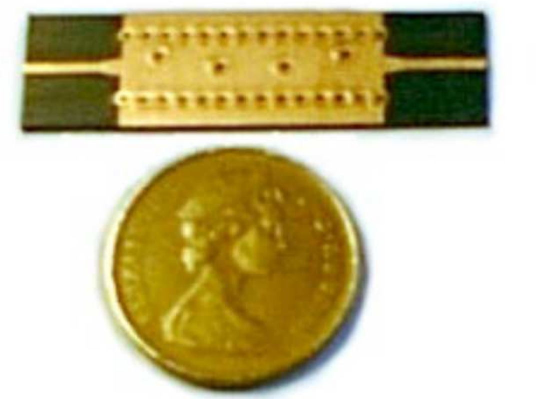
Substrate Integrated Waveguides (**SIW**) are novel transmission lines that implement rectangular waveguides in planar form.



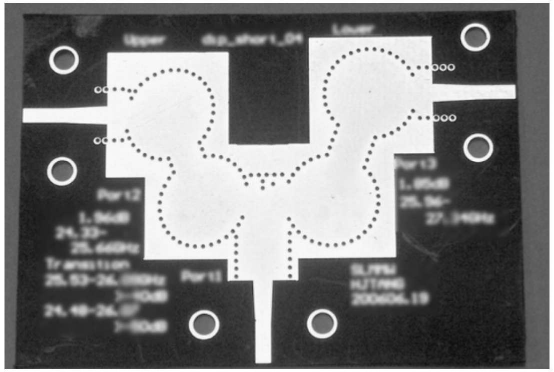


SIW consist of two rows of conducting cylinders embedded in a dielectric substrate that connect two parallel metal plates.

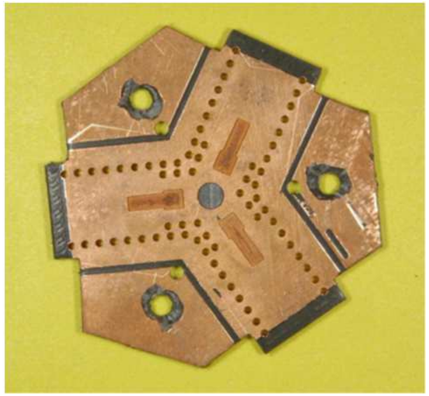
SIW Components



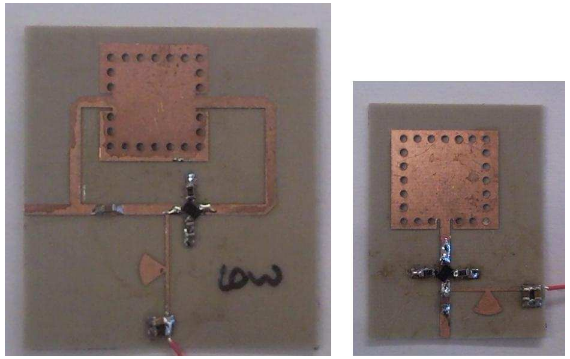
SIW post filter at 27 GHz



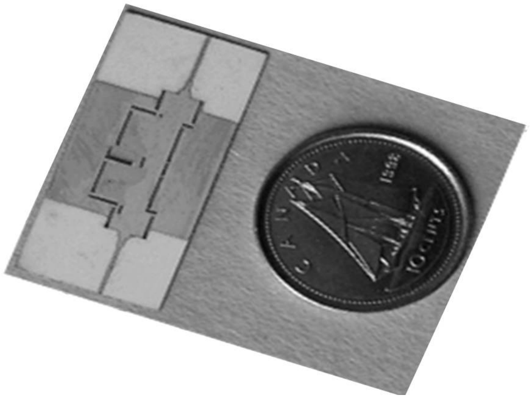
SIW diplexer at 26 GHz



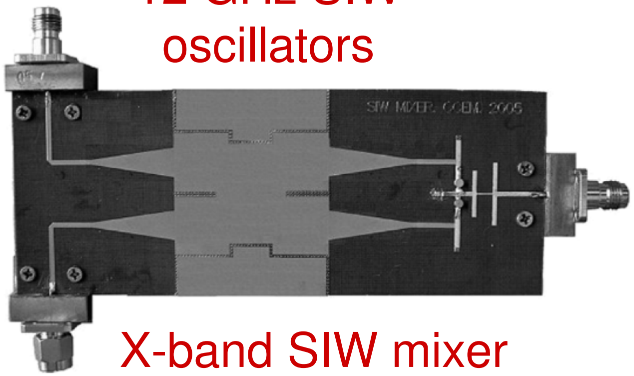
SIW circulator at 24 GHz



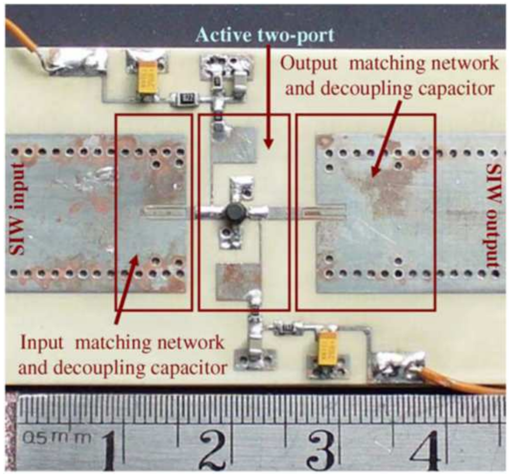
12 GHz SIW oscillators



SIW dual-mode filter at 24 GHz



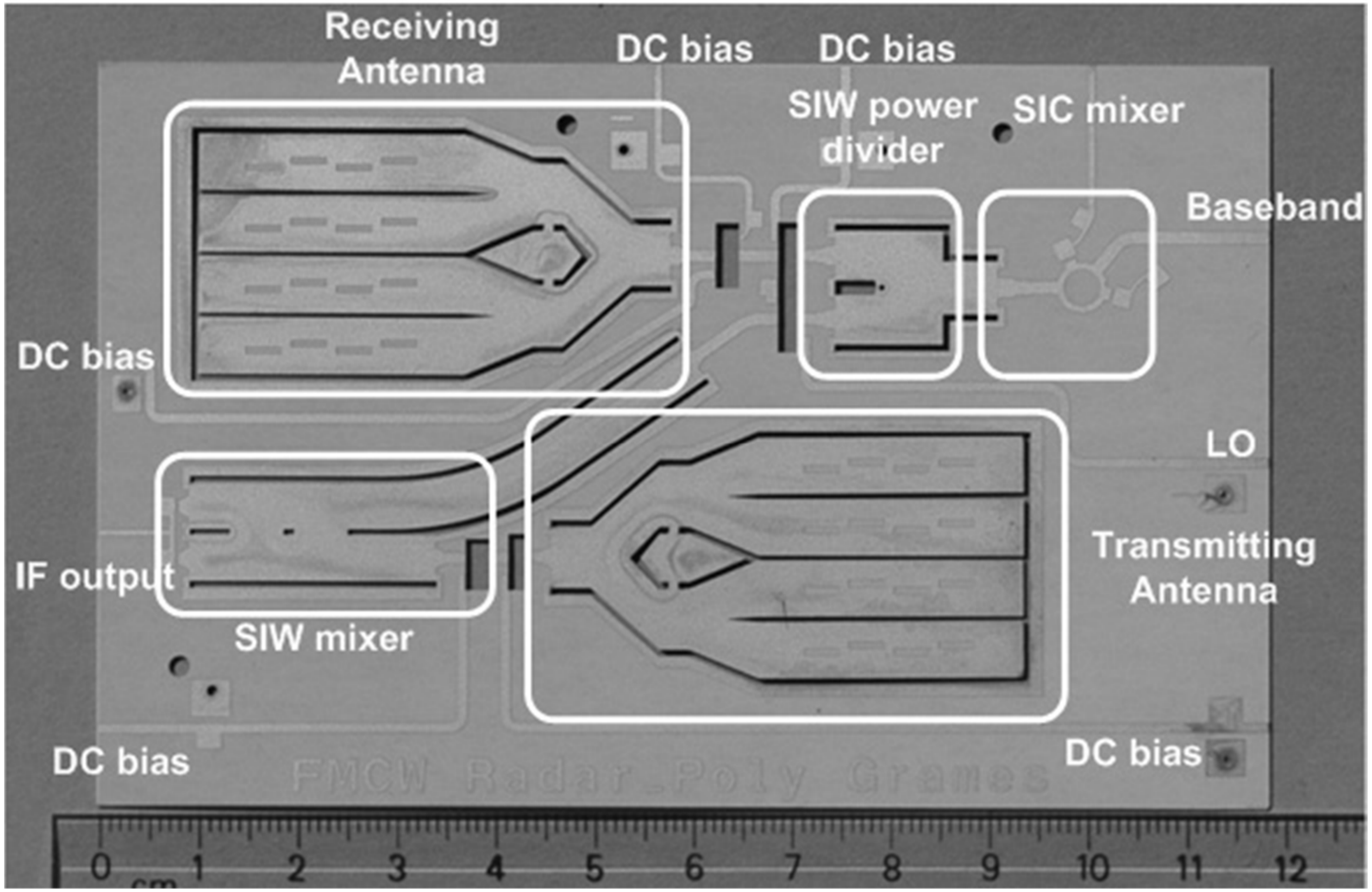
X-band SIW mixer



X-Band SIW amplifier

SYSTEMS-ON-SUBSTRATE (SOS)

Complete system integration by using one single technology!

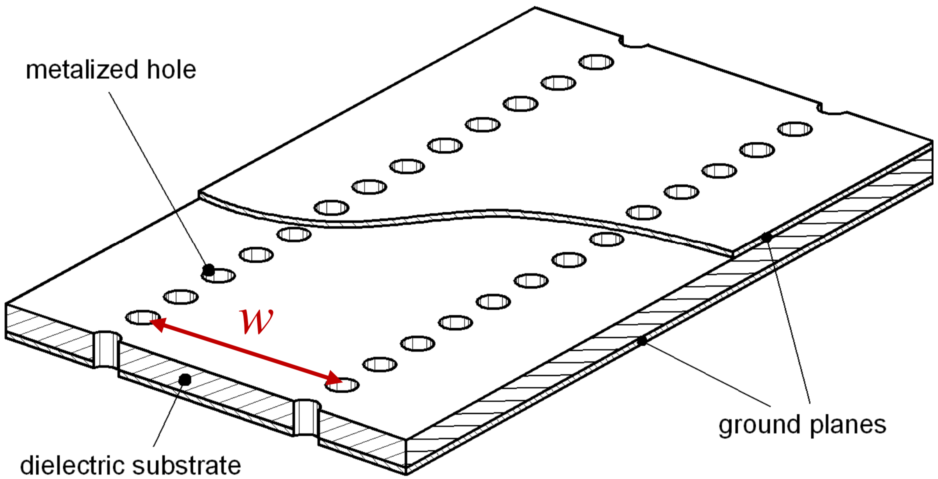


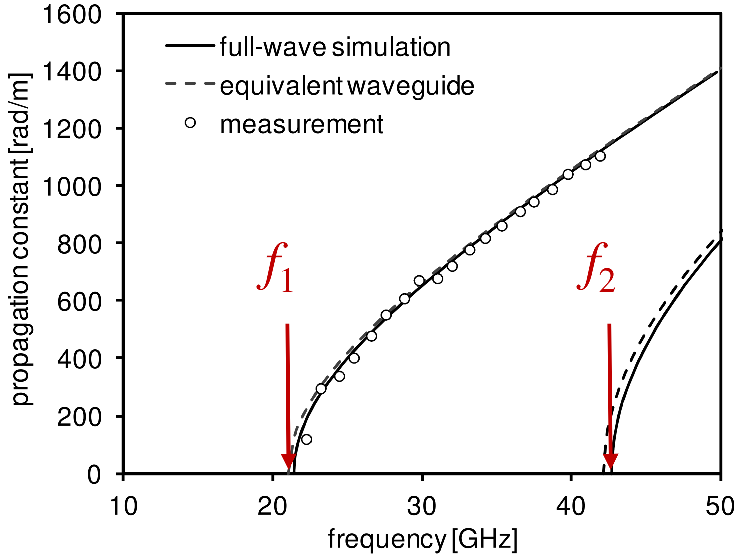
Z. Li and K. Wu, "24-GHz Frequency-Modulation Continuous-Wave Radar Front-End System-on-Substrate," *IEEE Trans. on Microwave Theory and Techniques*, Vol. 56, No. 2, pp. 278-285, Feb. 2008.

3 – Broadband and Miniaturized SIW Interconnects

SIW INTERCONNECTS

In classical SIW structures, **the single-mode bandwidth is limited to one octave** and **the width cannot be miniaturized**, except for the effect of the dielectric permittivity.

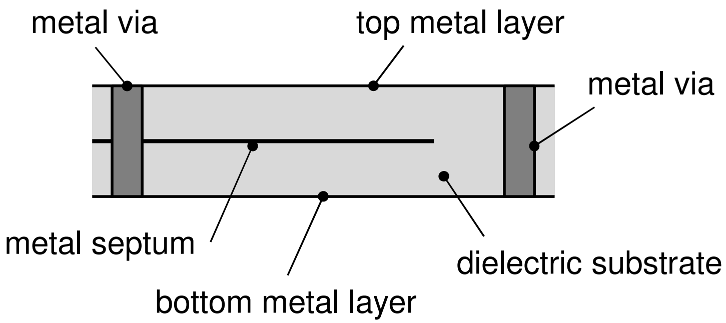




In some cases, wireless systems may require broader bandwidth and smaller dimensions

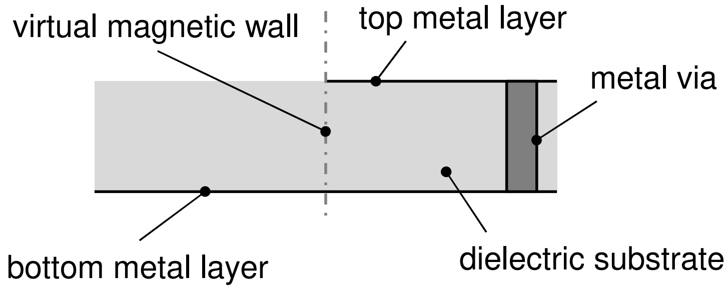
MINIATURIZED/BROADBAND SIW

FOLDED SIW



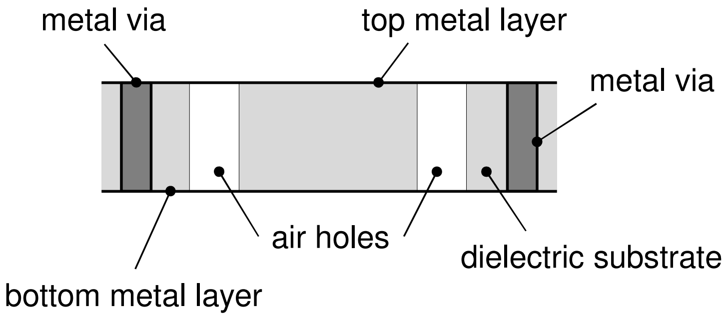
N. Grigoropoulos *et al.*, IEEE Microwave Wireless Comp. Letters, 2005.

HALF-MODE SIW



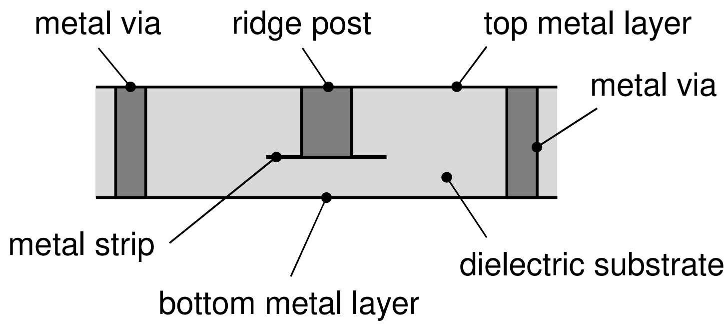
W. Hong *et al.*, 31th International Conference on Infrared Millimeter Waves, 2006.

SLAB SIW



M. Bozzi *et al.*, Intern. Journal RF & Microwave Computer–Aided Engineering, 2005.

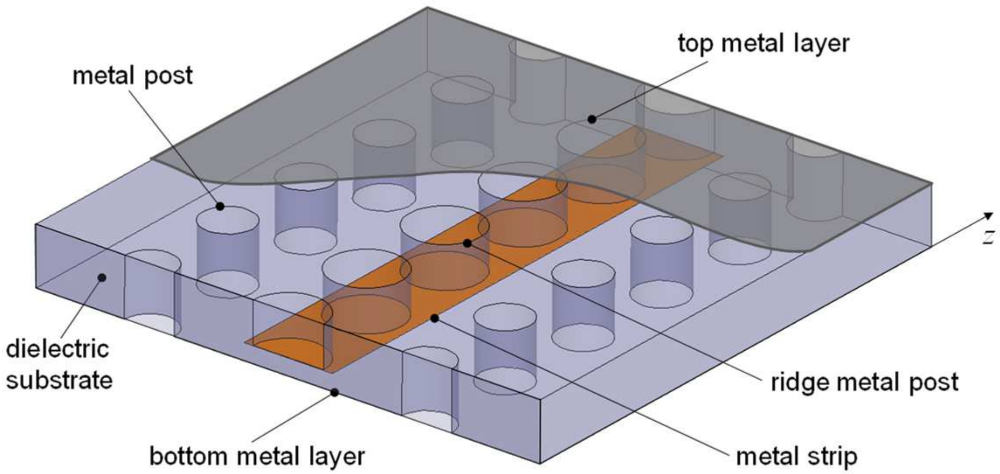
RIDGE SIW



M. Bozzi *et al.*, IET Microwave Antennas and Propagation, 2010.

RIDGE SIW

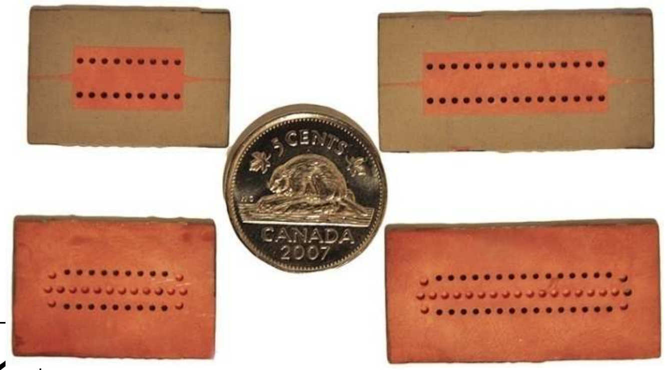
The ridge SIW is based on a row of partial height metal cylinders located in the broad side of an SIW and connected at their bottom with a metal strip.

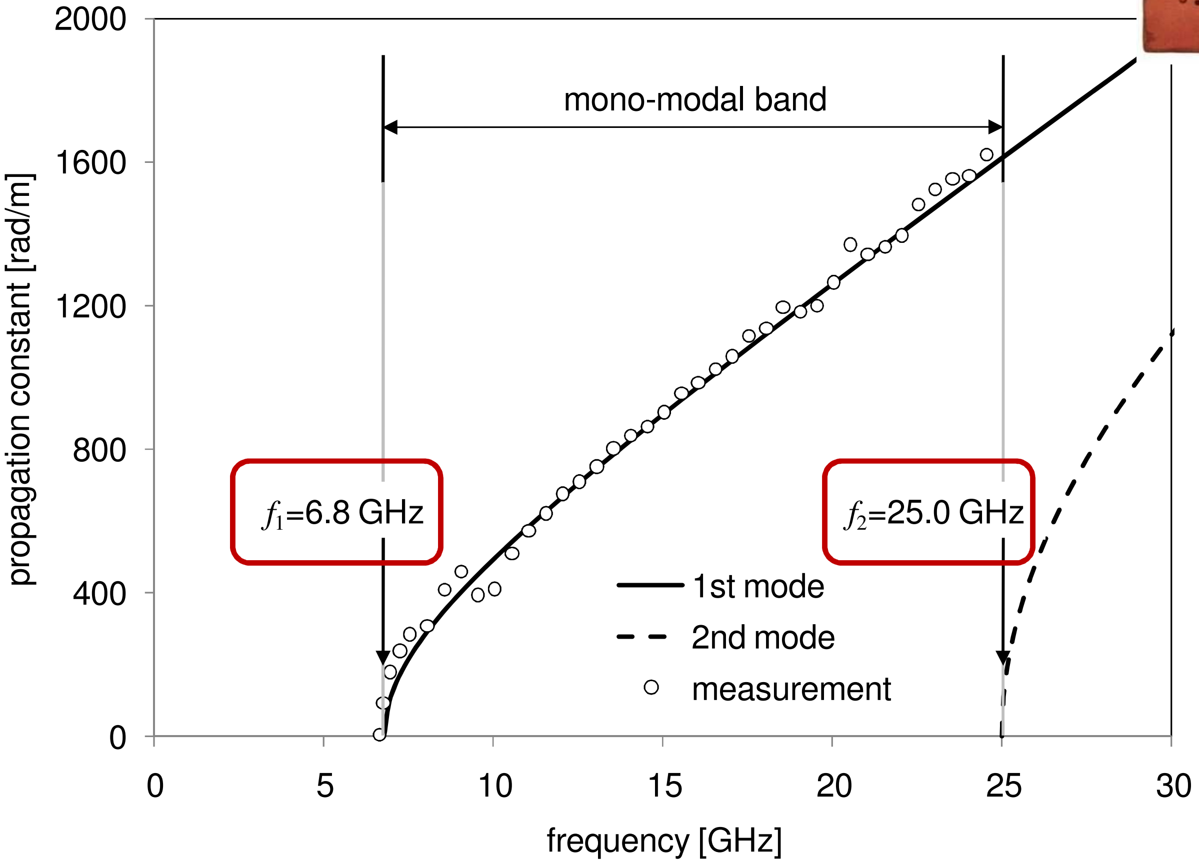


M. Bozzi, S.A. Winkler, and K. Wu, "Broadband and Compact Ridge Substrate Integrated Waveguides," *IET Microwave Antennas and Propagation*, Vol. 4, No. 11, pp. 1965–1973, Nov. 2010.

RIDGE SIW

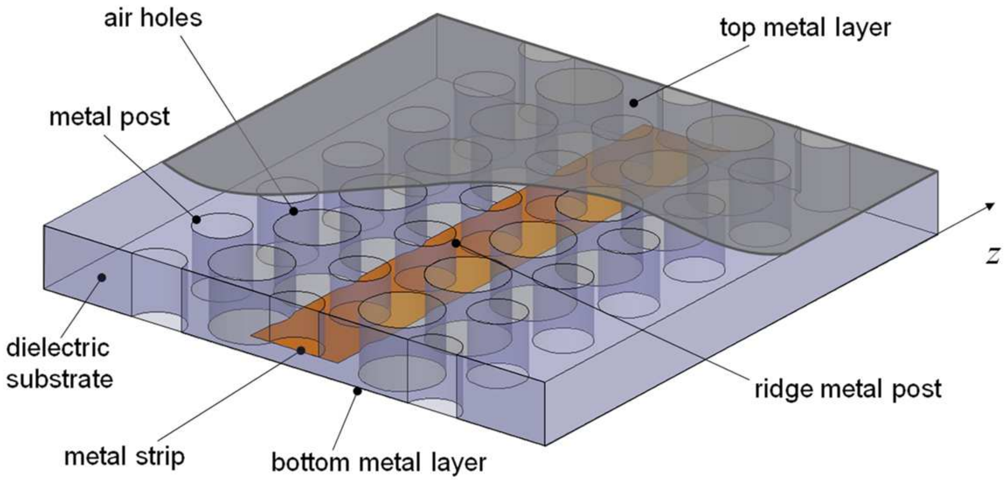
A ridge SIW covering the frequency band 6.8–25.0 GHz was designed and fabricated (with 168% bandwidth enhancement).





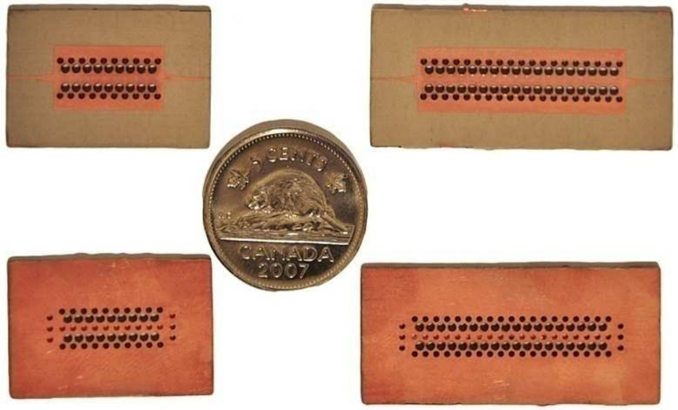
RIDGE SISW

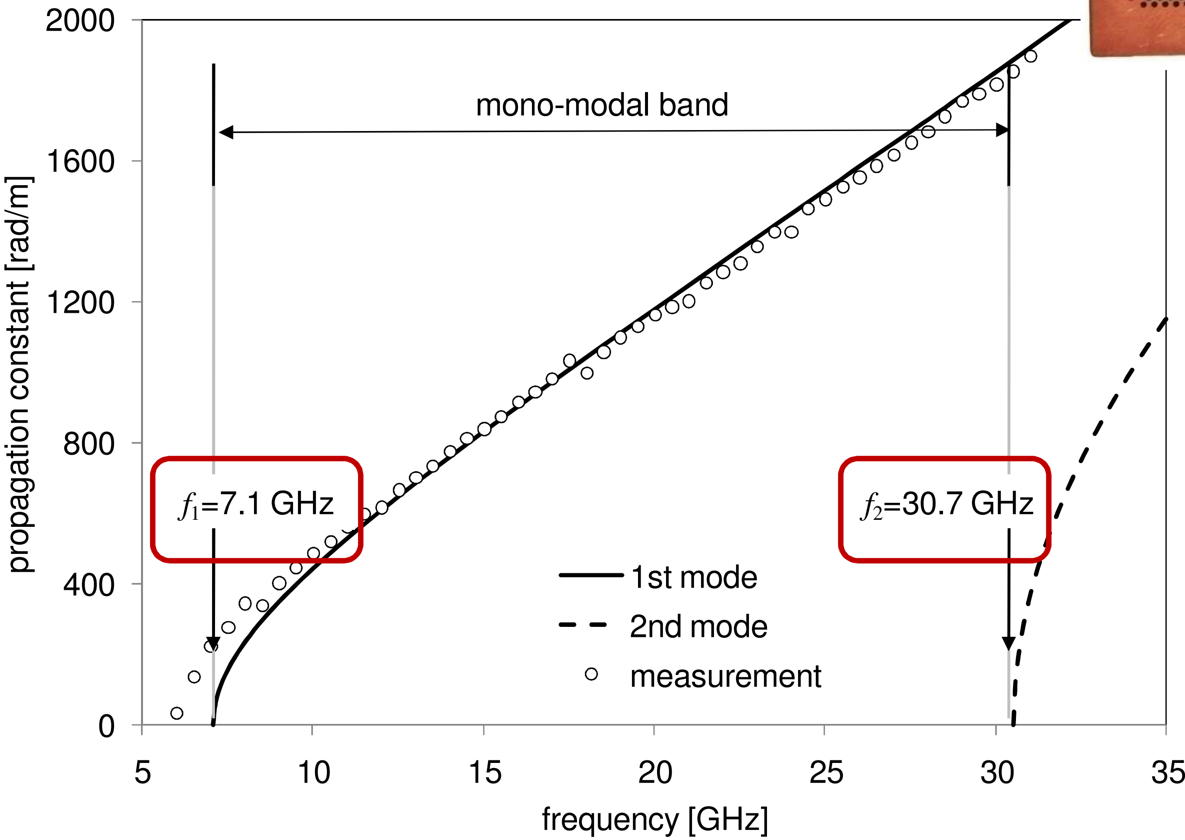
The bandwidth can be further improved by adding air holes in the lateral side of the ridge SIW, thus implementing a **ridge substrate integrated slab waveguide (SISW).**



RIDGE SISW

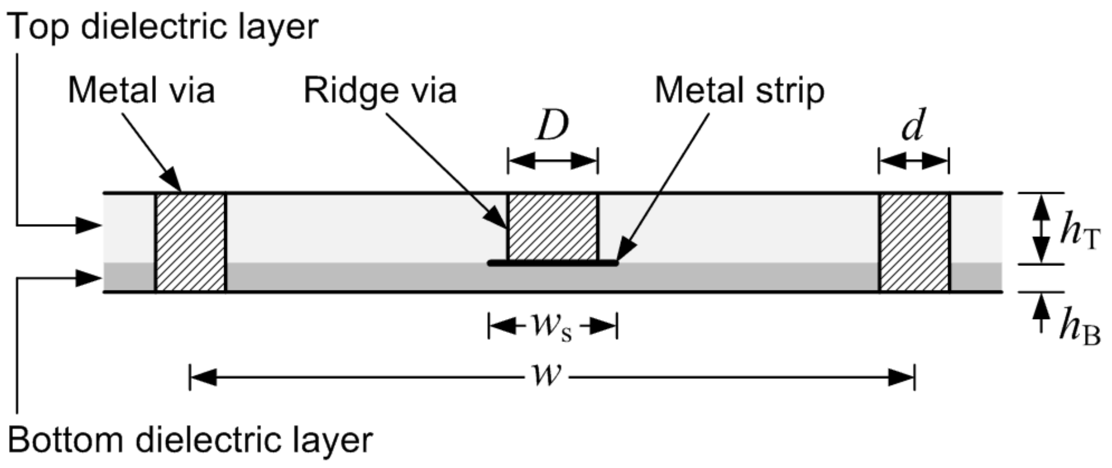
A ridge SISW covering the frequency band 7.1–30.7 GHz was designed and fabricated (with 232% bandwidth enhancement).

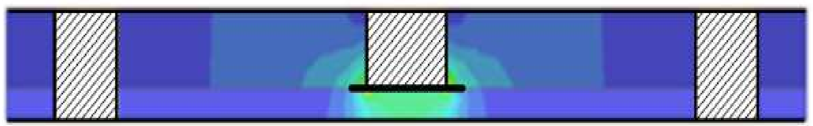




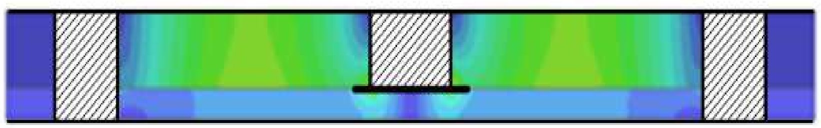
Two-Material Ridge SIW

The **ridge SIW** based on **two different substrate materials** has been proposed to increase the single-mode bandwidth of the classical SIW.





FUNDAMENTAL (TE_{10}) MODE



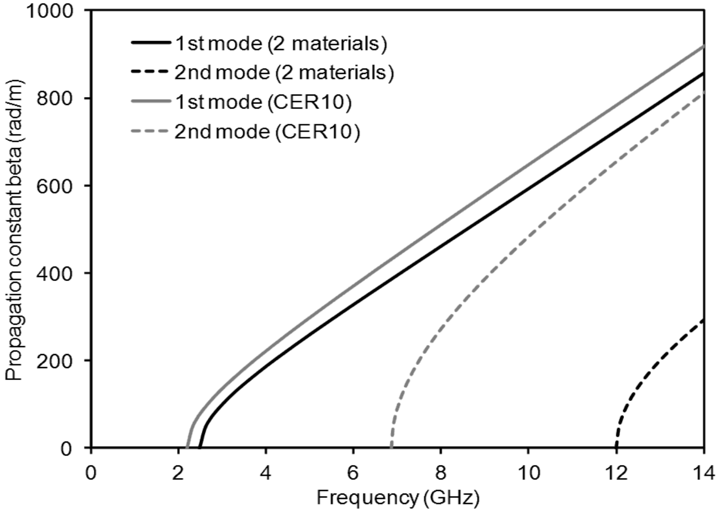
SECOND (TE_{20}) MODE

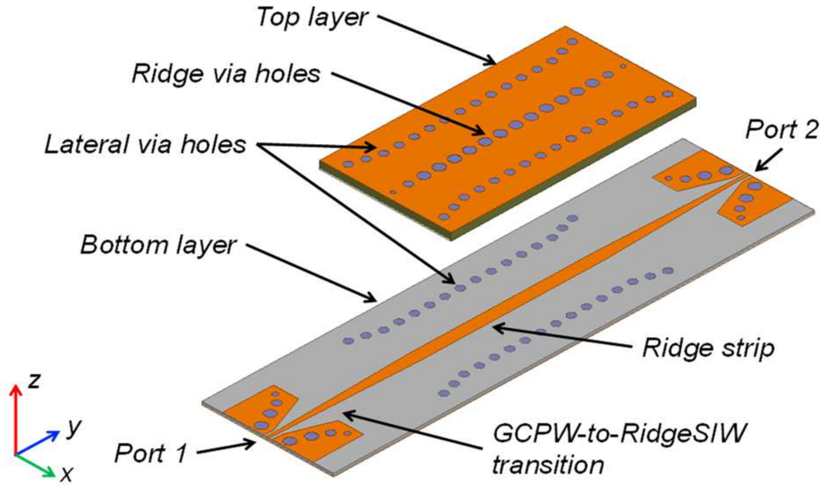
S. Moscato, R. Moro, M. Pasian, M. Bozzi, and L. Perregrini, "Two-Material Ridge Substrate Integrated Waveguide for Ultra-Wide Band Applications," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 63, No. 10, pp. 3175-3182, Oct. 2015.

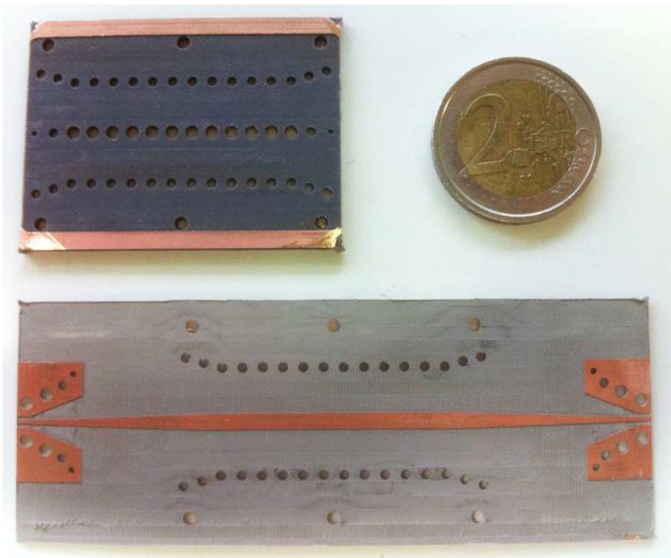
TWO-MATERIAL RIDGE SIW

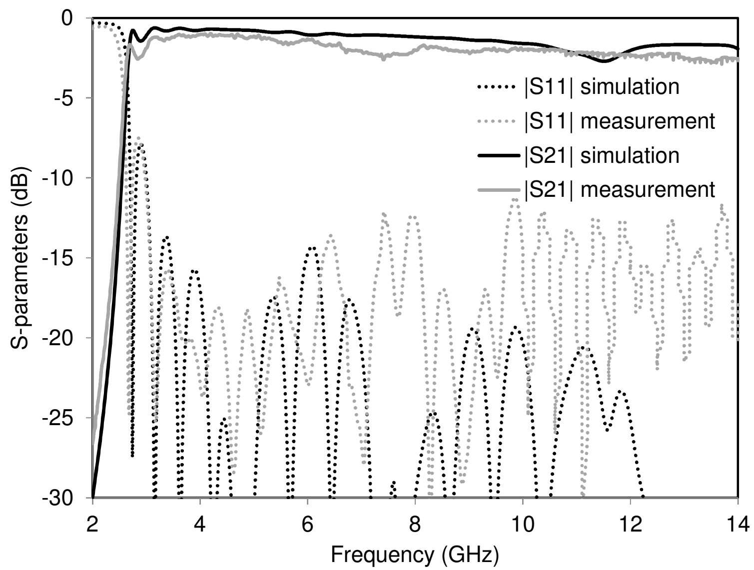
Top layer: Taconic TLY-5, thickness 1.52 mm, permittivity 2.2

Bottom layer: Taconic CER-10, thickness 0.64 mm, permittivity 9.5

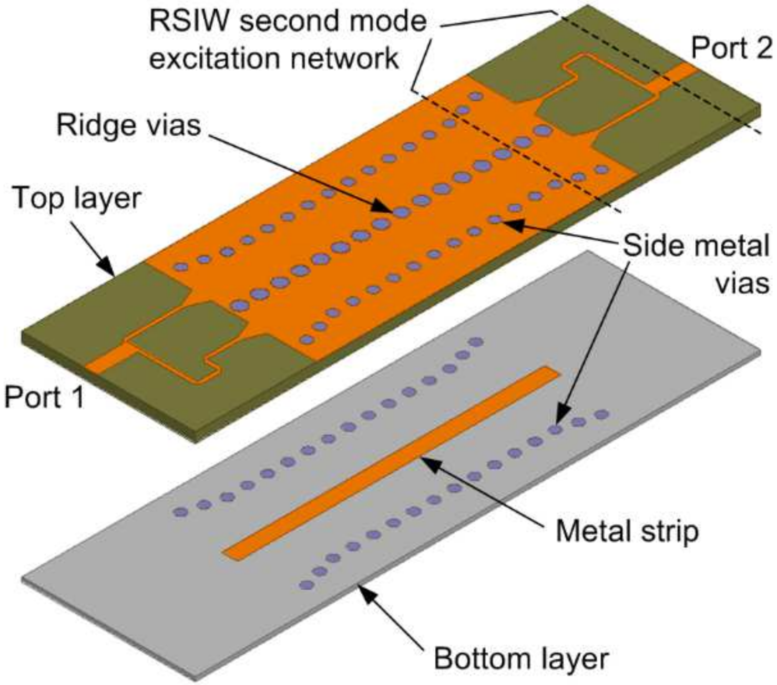


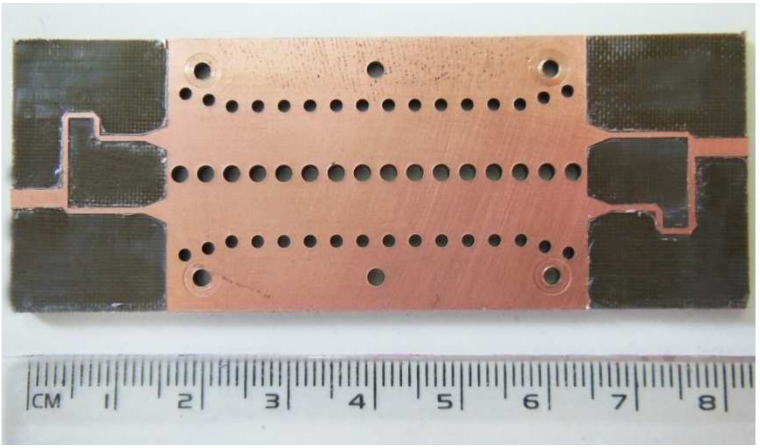




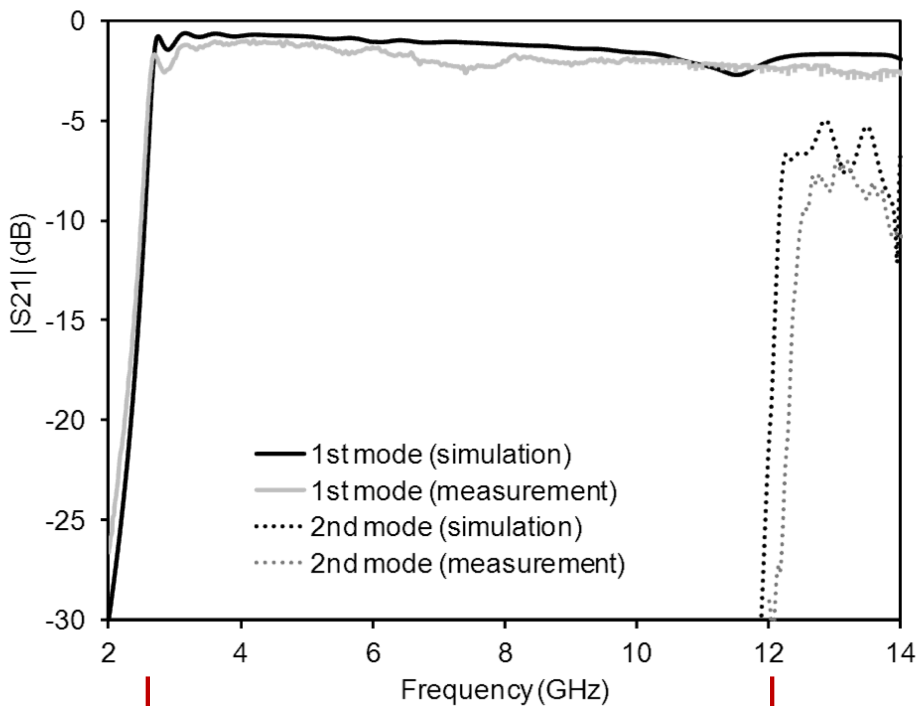


TWO-MATERIAL RIDGE SIW





Measurement of the **second mode**



Single mode bandwidth

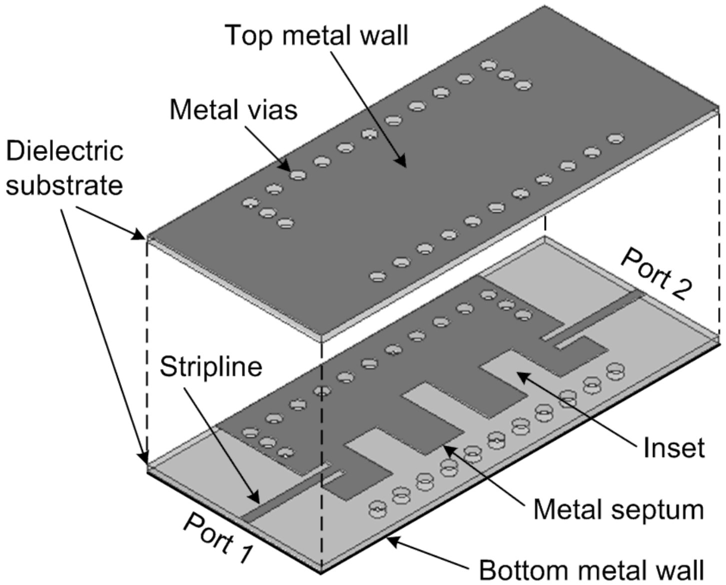
almost 10 GHz (2.5-12 GHz)

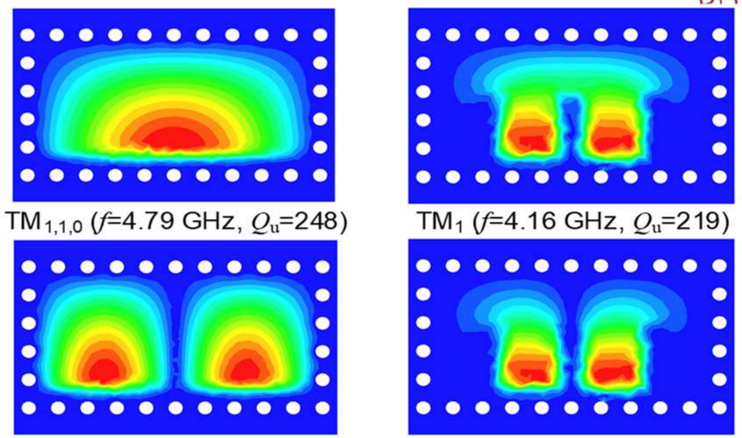
4 – Miniaturization of SIW Components

FOLDED SIW FILTER

This filter is based on a folded SIW dual-mode cavity, with insets in the central metal septum.

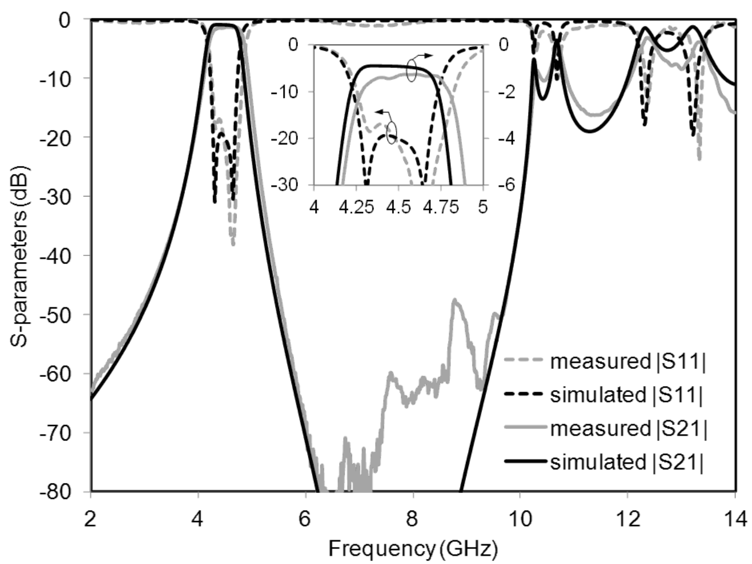
The size of the filter is **$0.45\lambda_0 \times 0.24\lambda_0$**.





$TM_{1,1,0}$ (f=4.79 GHz, Q_u=248) TM_1 (f=4.16 GHz, Q_u=219)

$TM_{1,2,0}$ (f=7.40 GHz, Q_u=271) TM_2 (f=4.70 GHz, Q_u=213)

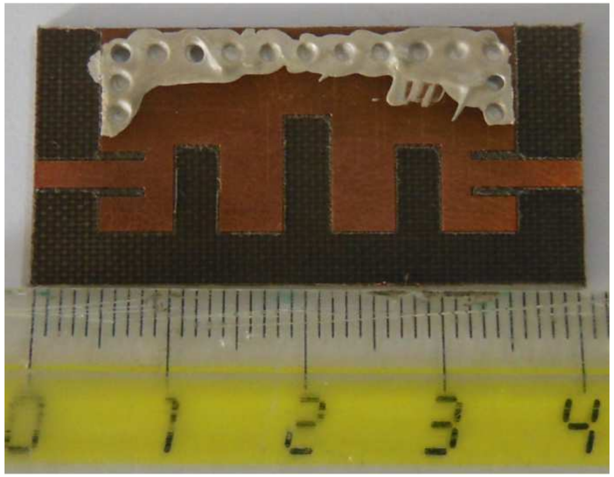


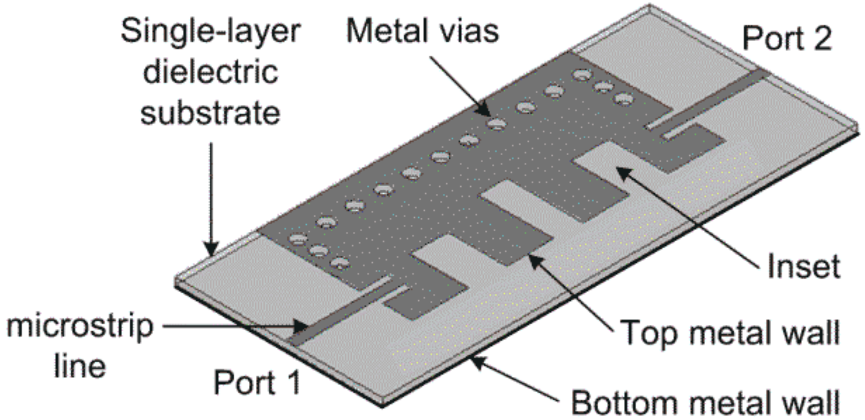
R. Moro, S. Moscato, M. Bozzi, L. Perregrini, "Substrate Integrated Folded Waveguide Filter with Out-of-Band Rejection Controlled by Resonant-Mode Suppression," *IEEE Microwave Wireless Comp. Letters*, Vol. 25, No. 4, pp. 214-216, April 2015.

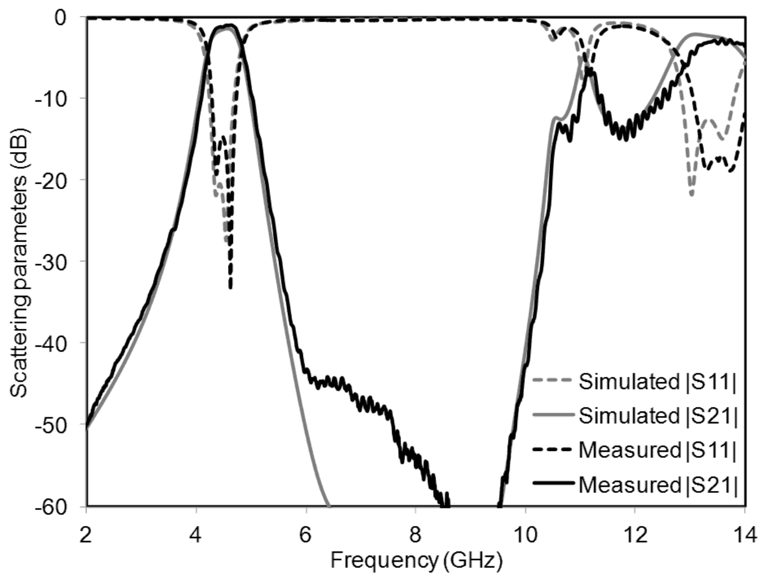
HALF-MODE SIW FILTER

The same filter can be implemented in half-mode SIW, based on a single-layer technology.

The size of the filter is **$0.42\lambda_0 \times 0.20\lambda_0$**.



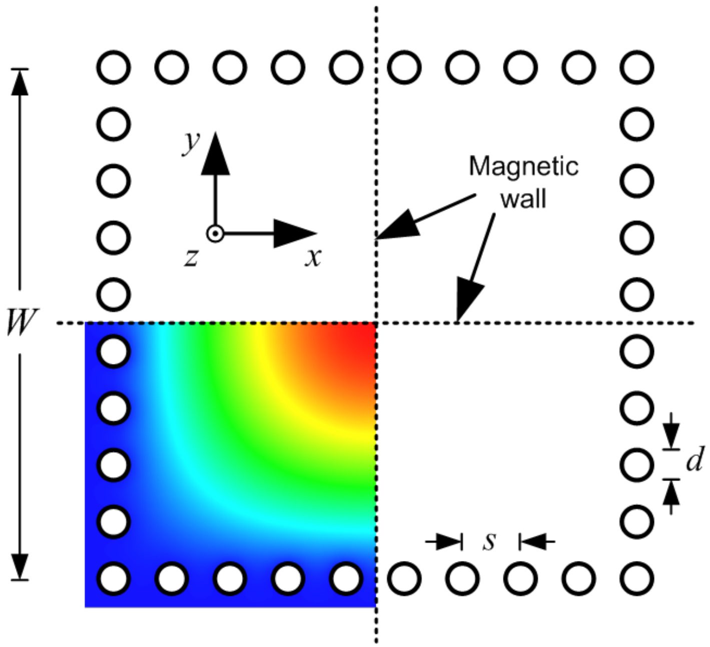


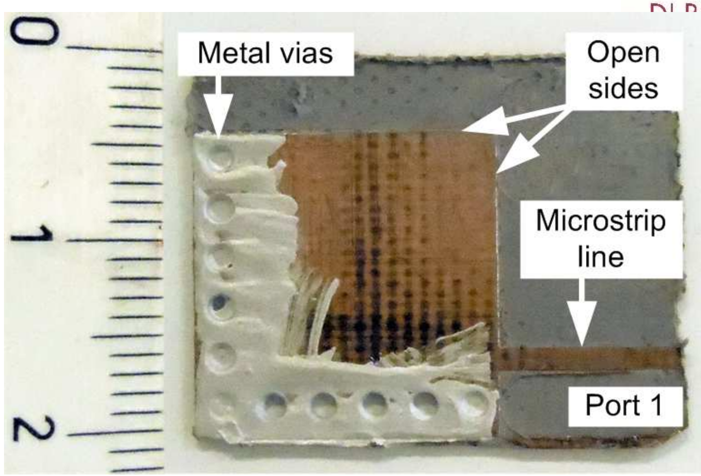


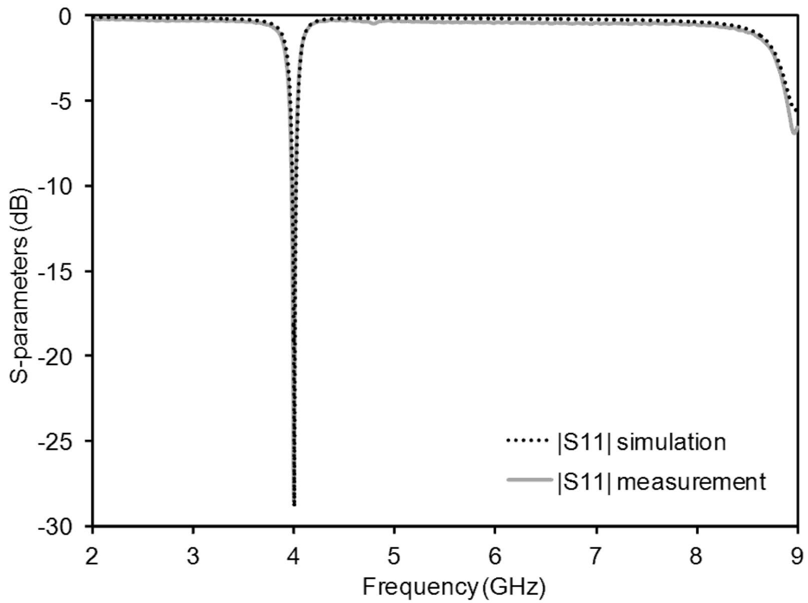
N. Delmonte, L. Silvestri, M. Bozzi, and L. Perregrini, "Compact Half-Mode SIW Cavity Filters Designed by Exploiting Resonant Mode Control," *International Journal of RF and Microwave Computer-Aided Engineering,* Vol. 26, No. 1, pp. 72–79, Jan. 2016.

QUARTER-MODE SIW FILTERS

Quarter-mode cavities allow a **size reduction** of a factor 4 and **selection of the resonant modes**.







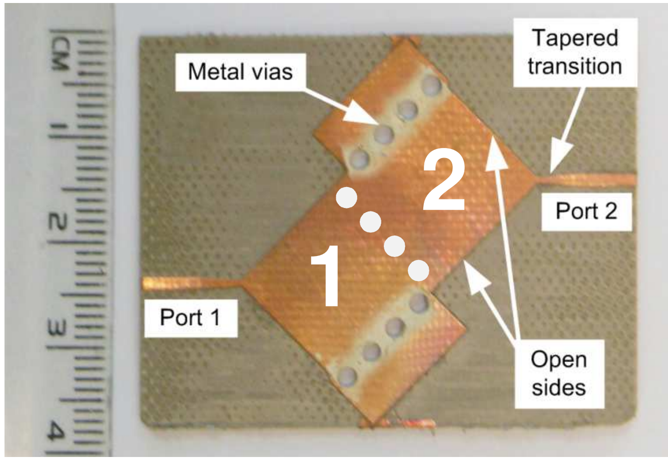
S. Moscato, C. Tomassoni, M. Bozzi, and L. Perregrini, "Quarter-Mode Cavity Filters in Substrate Integrated Waveguide Technology," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 64, No. 8, pp. 2538-2547, Aug. 2016.

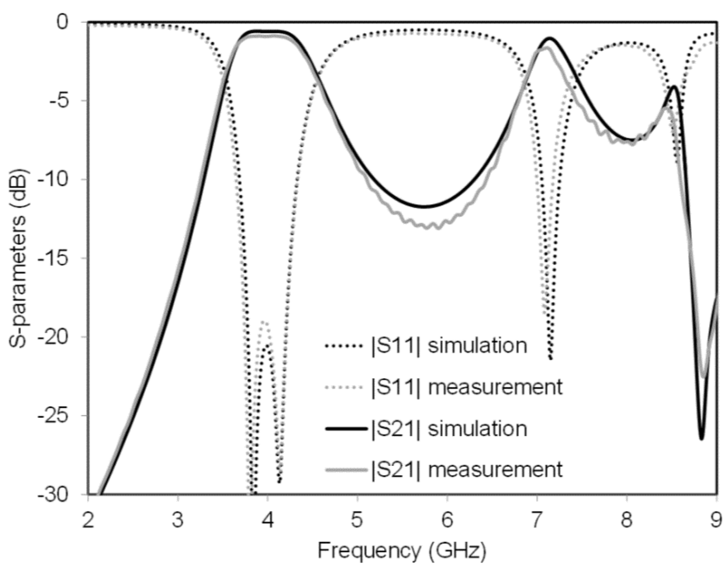
Quarter-Mode SIW Filters

Università di Pavia

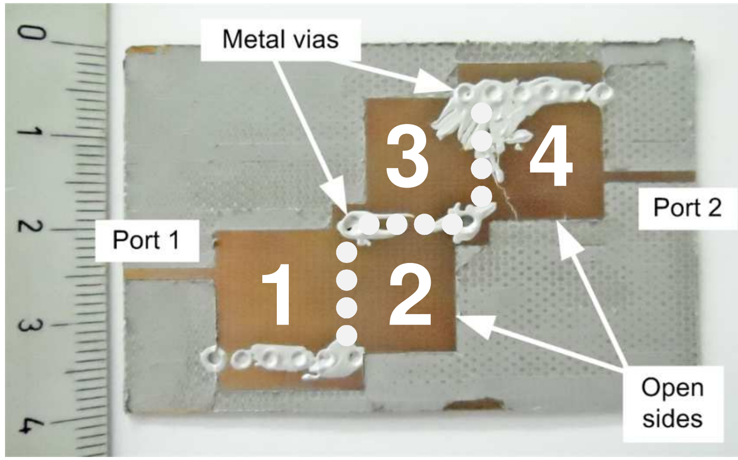
Size reduction of a factor 4 and **selection of the resonant modes**.

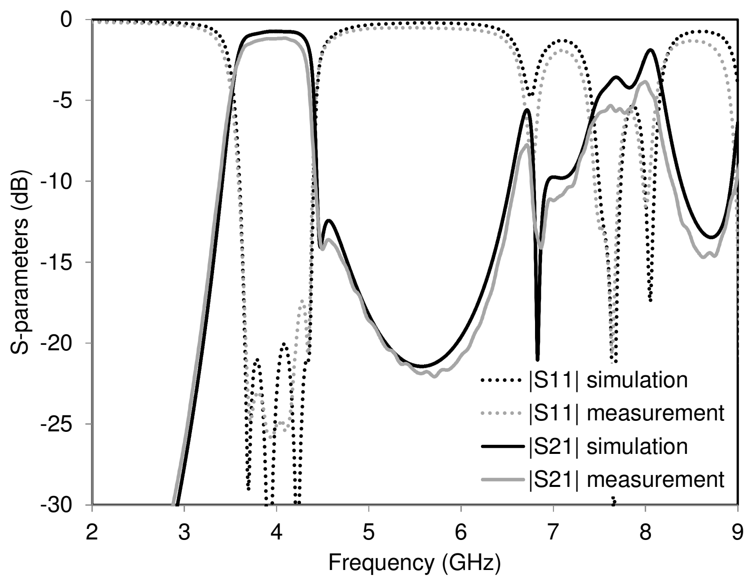
2-pole filter





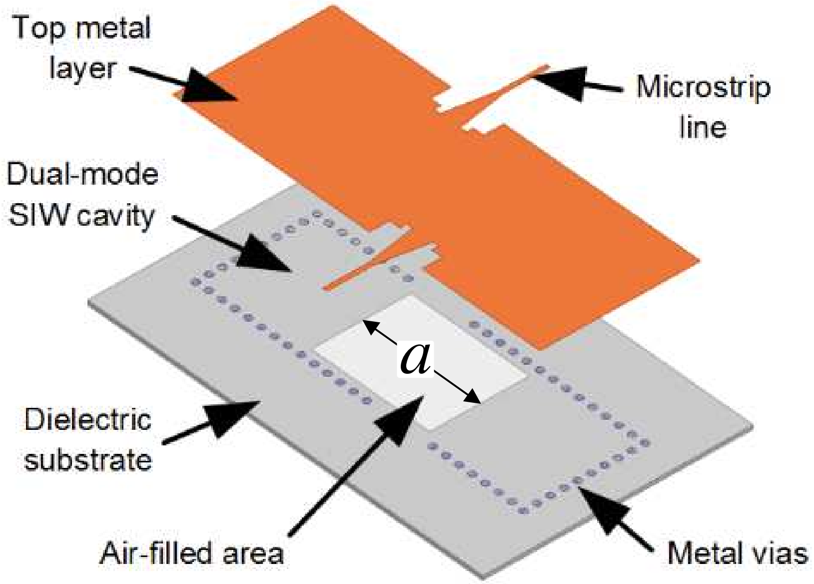
4-pole filter





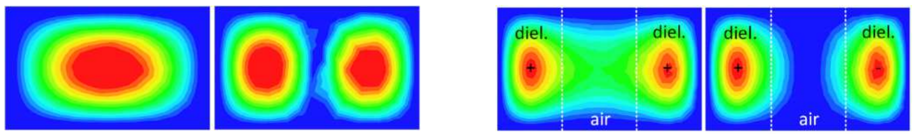
AIR-FILLED SIW FILTERS

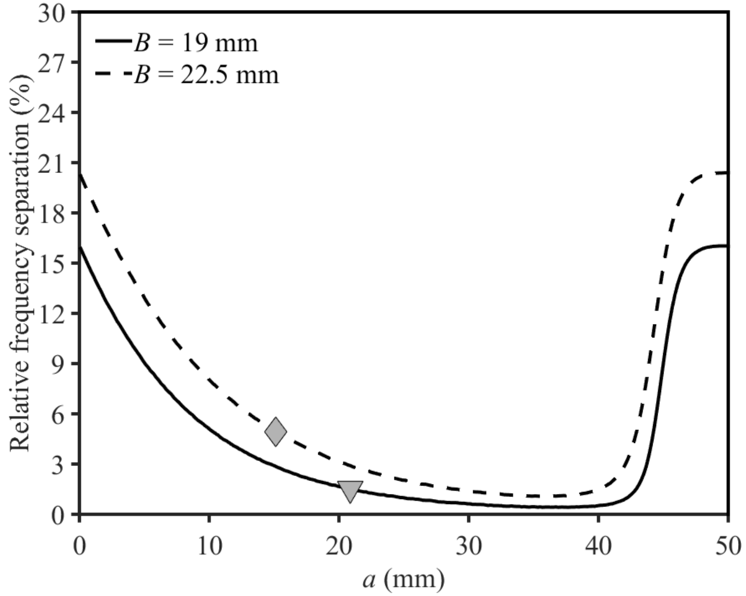
Partially air-filled SIW cavities can be exploited to design band-pass filters with transmission zeros. The relative frequency separation can be controlled by changing the size a of the air filled portion.



Homogeneous cavity

Partially air-filled cavity

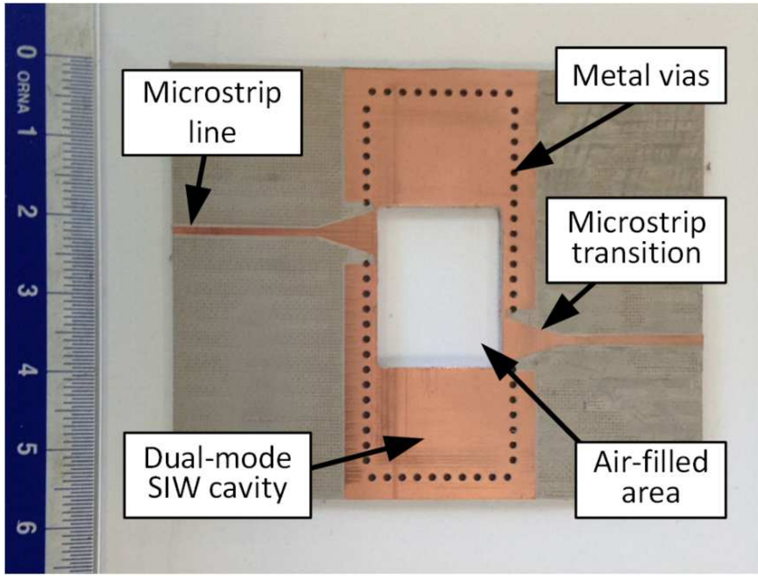


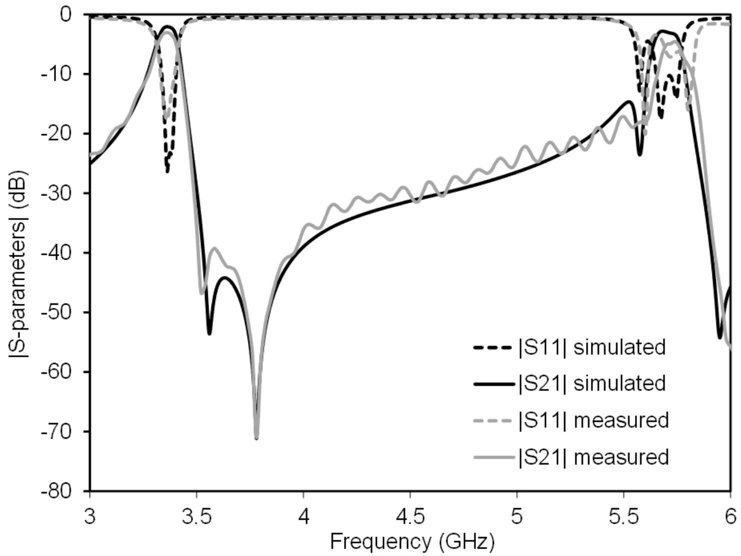


C. Tomassoni, L. Silvestri, A. Ghiotto, M. Bozzi, and L. Perregrini, "Substrate Integrated Waveguide Filters Based on Dual-Mode Air-Filled Resonant Cavities," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 66, No. 2, pp. 726-736, Feb. 2018.

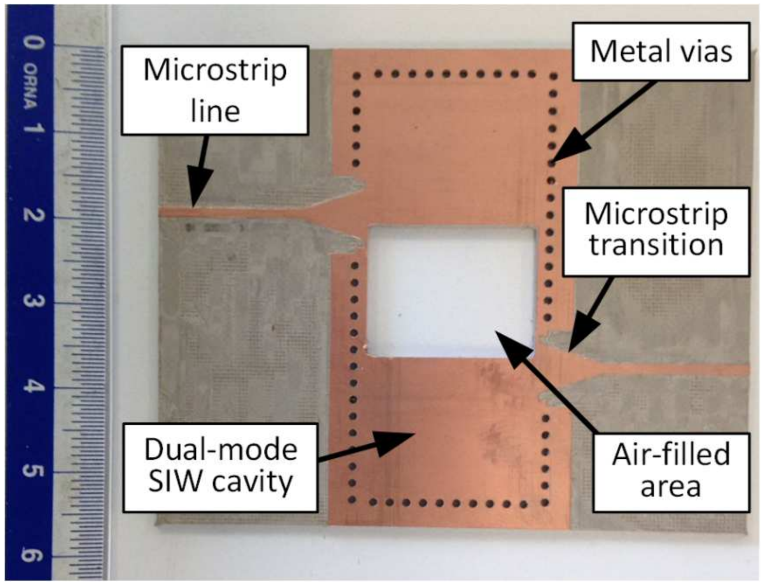
AIR-FILLED SIW FILTERS

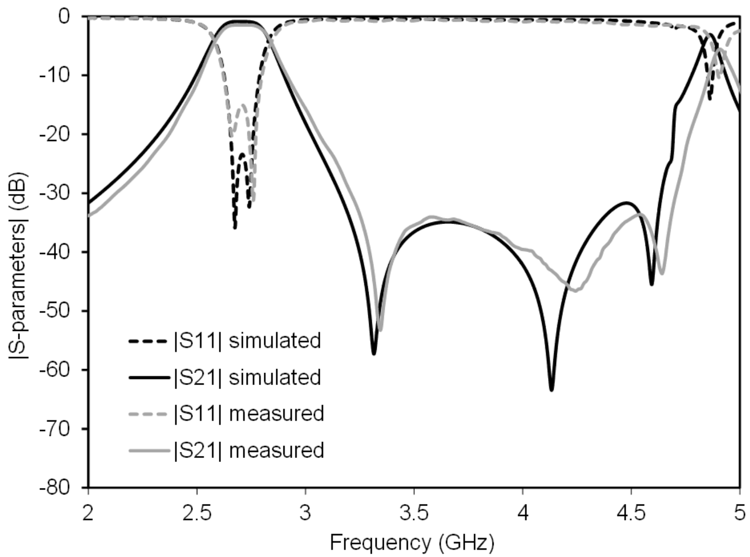
Narrow-band filter



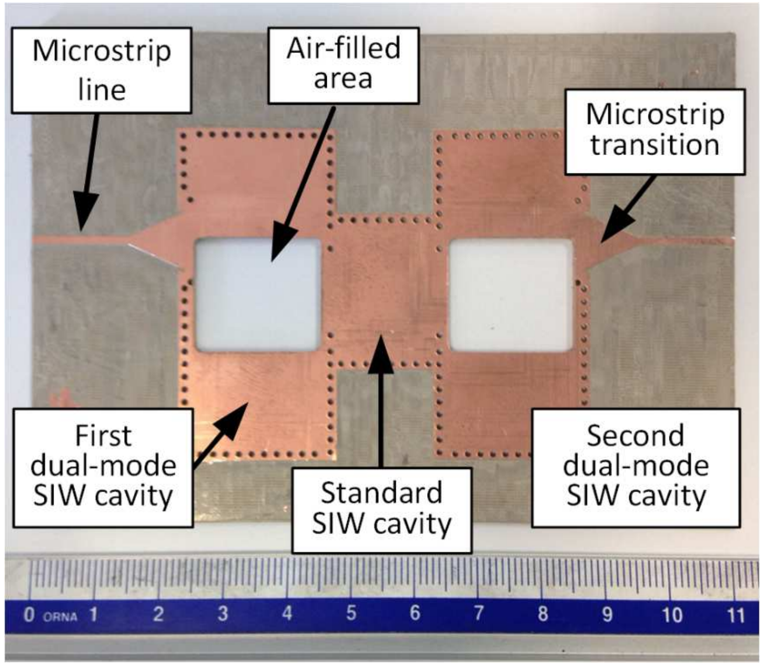


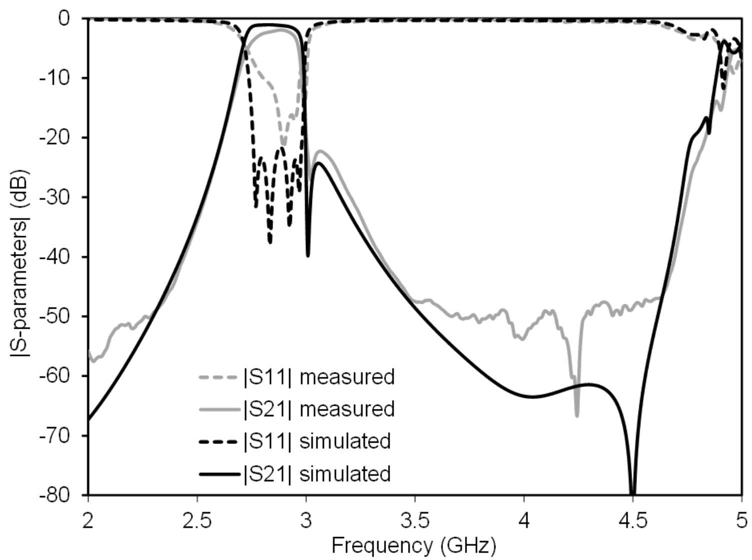
Broad-band filter

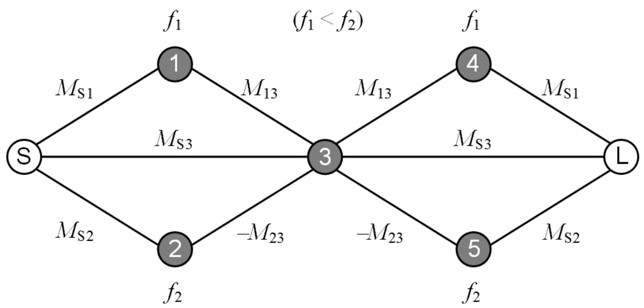




AIR-FILLED SIW FILTERS







5 – New Materials:

3D-Printing, Textile, Paper

3D-Printed Slab SIW

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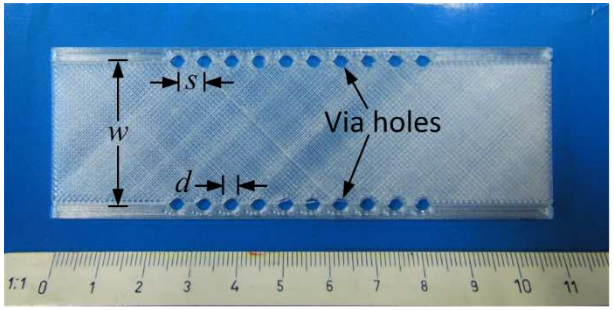
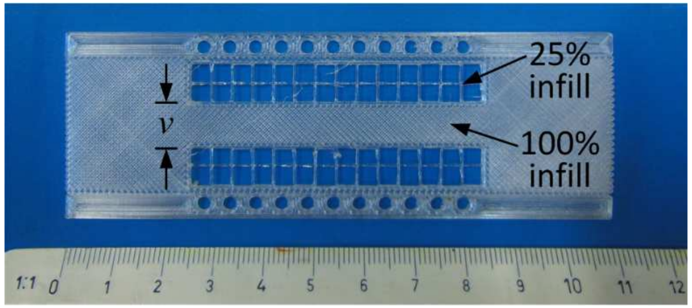
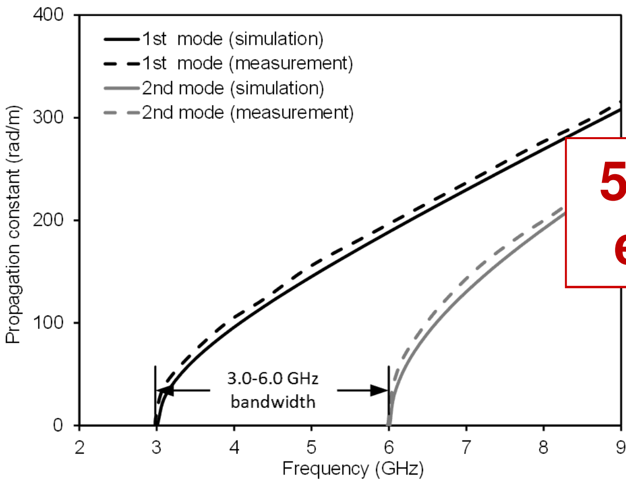
A **substrate integrated slab waveguide** (SISW) was implemented by FDM by using **ABS filament**, by modifying the permittivity in the side portions.



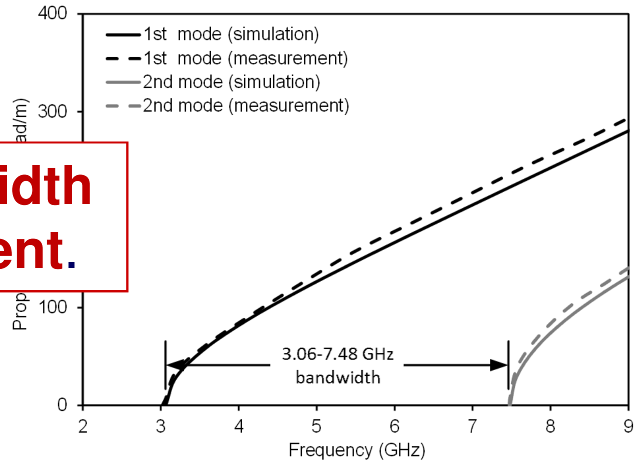
Standard 3D-printed SIW



3D-printed slab SIW

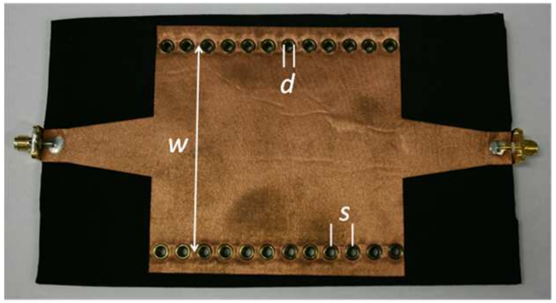


50% bandwidth enhancement.

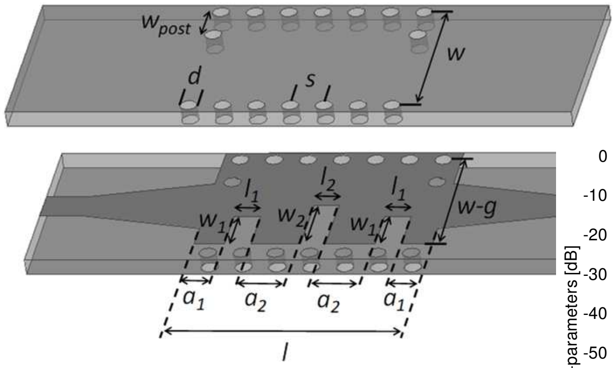


E. Massoni, L. Silvestri, G. Alaimo, S. Marconi, M. Bozzi, L. Perregrini, and F. Auricchio, "3D-Printed Substrate Integrated Slab Waveguide for Single-Mode Bandwidth Enhancement," *IEEE Microwave and Wireless Components Letters*, 2017.

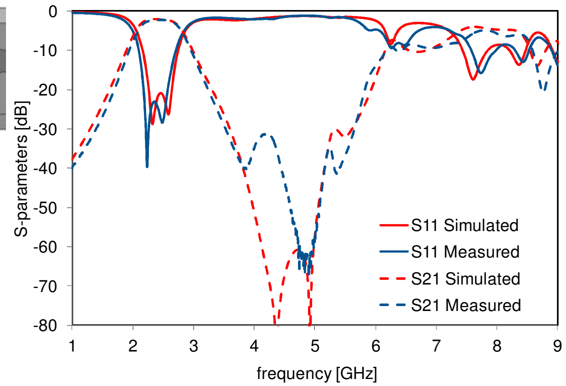
TEXTILE COMPONENTS & ANTENNAS

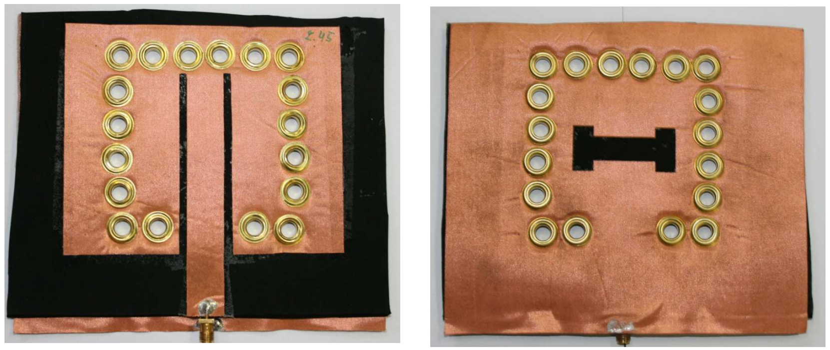


INTERCONNECT



FOLDED FILTER





R. Moro, S. Agneessens, H. Rogier, M. Bozzi, "Wearable Textile Antenna in Substrate Integrated Waveguide Technology," *Electronics Letters,* 2012

2014 Premium Award for Best Paper in Electronics Letters

CAVITY-BACKED ANTENNA

INK-JET PRINTING ON PAPER SUBSTRATES

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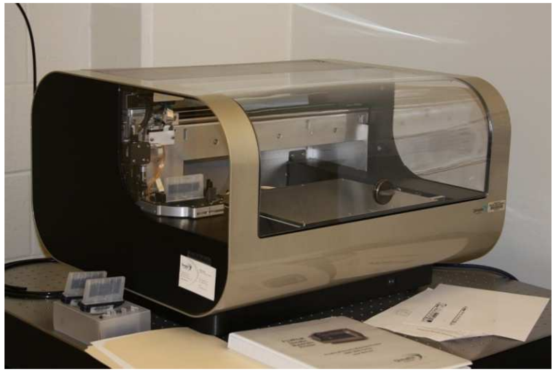
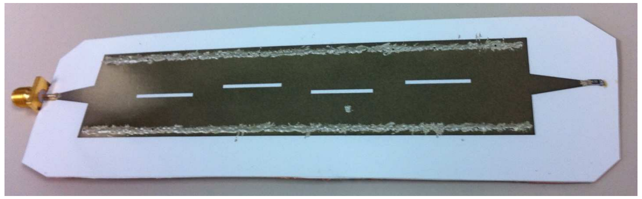
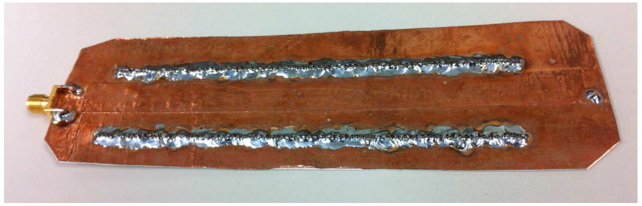
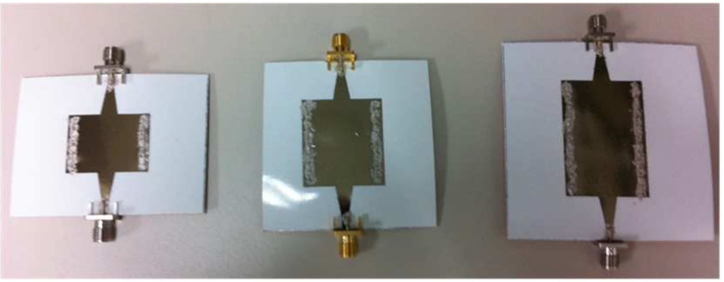


Collaboration with
GATech, Atlanta





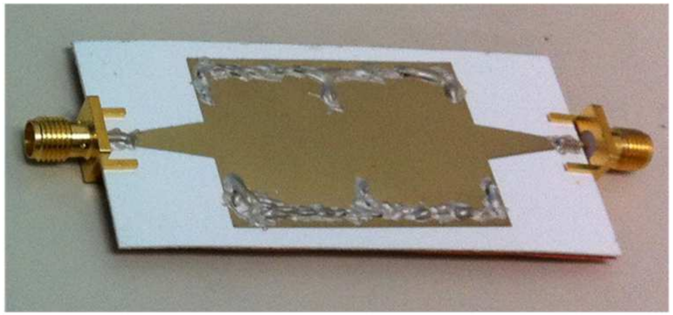
SLOTTED WAVEGUIDE ANTENNA



INTERCONNECTS

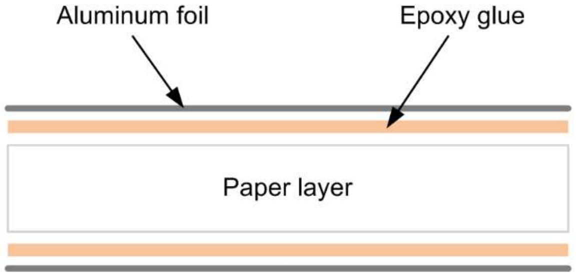
S. Kim, B. Cook, T. Le, J. Cooper, H. Lee, V. Lakafosis, R. Vyas, R. Moro, M. Bozzi, A. Georgiadis, A. Collado, and M. Tentzeris, "Inkjet-printed Antennas, Sensors and Circuits on Paper Substrate," *IET Microwaves, Antennas and Propagation*, Vol. 7, No. 10, pp. 858–868, July 16, 2013.

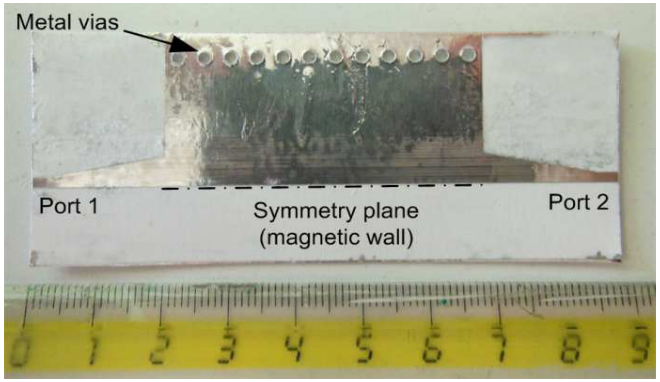
2015 Premium Award for Best Paper
in IET Microwave Antennas & Propagation



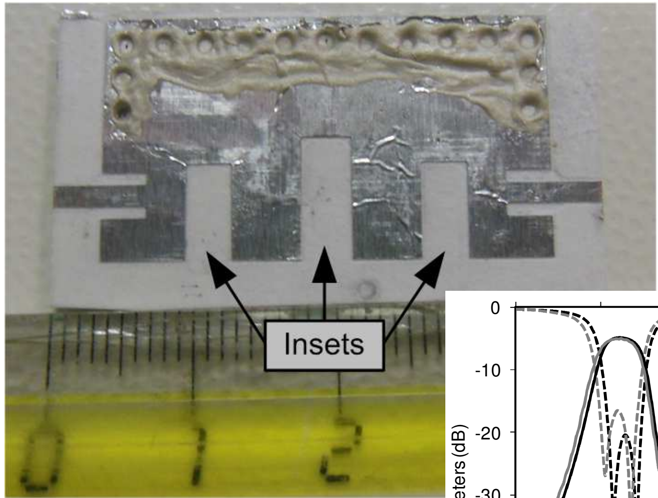
CAVITY FILTER

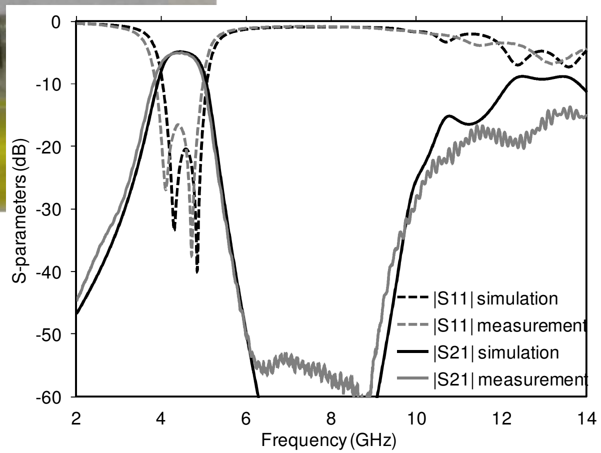
MILLING OF PAPER SUBSTRATES



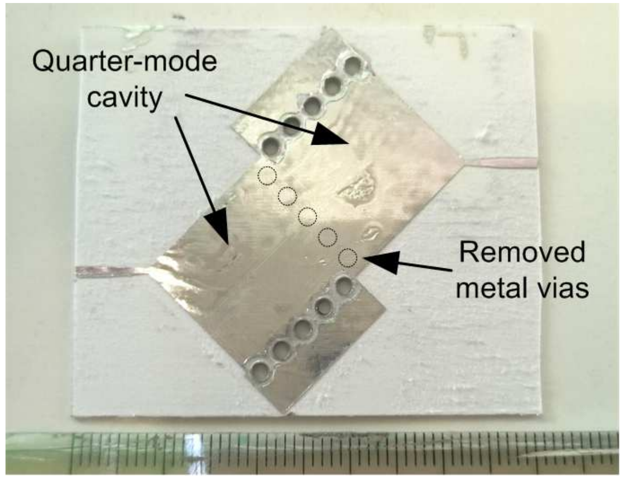


HALF-MODE SIW





HALF-MODE SIW FILTER



QUARTER-MODE SIW FILTER

S. Moscato, R. Moro, M. Pasian, M. Bozzi, and L. Perregrini, “An Innovative Manufacturing Approach for Paper-based Substrate Integrated Waveguide Components and Antennas,” *IET Microwaves, Antennas and Propagation*, Vol. 10, No. 3, pp. 256–263, 19 Feb. 2016.

CONCLUSION

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- The next generation of wireless systems for application in the **Internet of Things** and **5G** will require a completely new approach for the **integration technology** and **material selection**.
- **Substrate Integrated Waveguide** is an excellent candidate to integrate complete systems at microwave and millimeter waves.
- The use of novel materials like **paper**, **textile**, and **3D-printed materials** has been demonstrated for the manufacturing of SIW components and antennas.

Chambéry, France
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A REVIEW OF COMPACT SUBSTRATE INTEGRATED WAVEGUIDE (SIW) INTERCONNECTS AND COMPONENTS

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