ELECTROMAGNETIC DESIGN OF W-BAND CIRCUITS IN LTCC TECHNOLOGY

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Summary

• Electromagnetic modelling and design of several millimetre wave components and circuits fabricated using Low-Temperature Co-fired Ceramic (LTCC) technology.

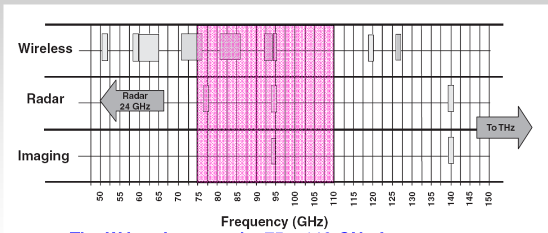
• The circuits include embedded transmission lines and vertical transitions designed to operate in the W band.

OUTLINE

- INTRODUCTION
- DESIGN AND TECHNOLOGICAL SETUP
- TRANSMISSION LINES AND VERTICAL TRANSITIONS
- EXPERIMENTAL RESULTS
- CONCLUSIONS

INTRODUCTION

Many millimeter-wave system applications such as **video transmission systems**, **broadband wireless**, **passive sensing** and **automotive radar** have been proposed in the last decade.



The W band covers the 75 – 110 GHz frequency range

INTRODUCTION

❑ Development of **compact** and **low cost** RF modules is necessary.

❑ **System-in/on-Package** (SiP/SoP) **approach** is widely regarded as an excellent means of realizing very compact multifunctional modules.

❑ A variety of technologies can be employed, including **Low-Temperature Co-fired Ceramic** (LTCC), **liquid crystal polymer** (LCP), organic and thin film on glass, etc.

❑ The **three-dimensional (3-D) integration** approach using multilayer **LTCC** technologies demonstrated a high level of compactness and mature multilayer fabrication capability (up to V band.

INTRODUCTION

❑ **LTCC technology** enables integration of **passive components** including antennas with **MMICs** in a single, cost-effective package.

❑ Passive structures, including transmission lines, can be placed at different layers, and three-dimensional integration enables miniaturization of modules.

❑ **LTCC** exhibits a **low dielectric loss, and conductor losses** are also low due to gold and silver conductors that can be used as metallization.

❑ The development of a **design library** of **basic circuits** for mm-wave frequency range is a essential.

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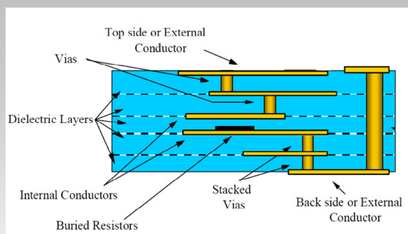
DESIGN AND TECHNOLOGICAL SETUP

❑ Low-Temperature Co-fired Ceramic (LTCC) technologies:

- high level of compactness and miniaturization
- mature multilayer fabrication capability (up to 70 layers)
- **three-dimensional (3-D) integration**
- cost-effective package with integrated antennas
- low dielectric loss, and conductor losses
- passive structures placed on different layers
- **Strip lines** and **Substrate Integrated Waveguides** (SIW) possible

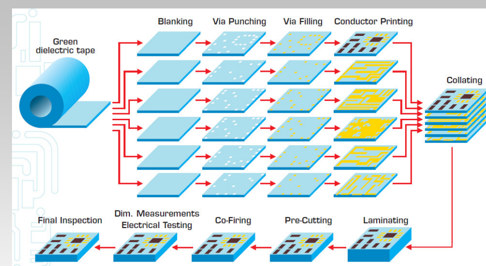
DESIGN AND TECHNOLOGICAL SETUP



Cross section of the LTCC structure

Advantages: low conductor and dielectric losses, good thermal conductivity, stability, hermeticity, low cost, air cavities and conducting vias.

DESIGN AND TECHNOLOGICAL SETUP



Disadvantages: **fabrication tolerances** at millimeter-wave region, high dielectric constant of the tape material (surface waves).

DESIGN AND TECHNOLOGICAL SETUP

- The test structures were **first** modeled and designed in frequency domains using the commercial **MoM** software package **Zeland IE3D**.

- In IE3D software the port definition and S parameter extraction is optimized for **current density distribution** and planar microwave circuits.

- The most accurate results are obtained for **in-plane differential ports** (like for CPW) and ports with **infinite ground extension**.

DESIGN AND TECHNOLOGICAL SETUP

- For **differential ports placed in different planes** (like those required for striplines with finite extensions for ground planes) the **IE3D** simulated results can be inaccurate for frequencies up to 100 GHz because of high order modes generation.

- A different commercial software package (**CST Microwave Studio**) was used to check the electromagnetic models and the designs.

- CST Microwave Studio uses **time domain** simulations and the port definition, S parameter extraction is optimized for **electric field distribution** (ideal for **waveguide port** and planar ports with multiple pins definition).

DESIGN AND TECHNOLOGICAL SETUP

❑ The circuits were designed using the **Ferro A6-S** LTCC tape system with a fired tape **thickness of 100 µm**.

❑ The diameter of all **vias is 100 µm** and the minimum spacing between two adjacent vias is **250 µm** (center to center).

❑ The electrical parameters:
- dielectric constant $\varepsilon_r = 5.9$
- loss tangent 0.001 (@10 GHz)
- silver paste conductivity $\sigma = 3\ 10^7$ S/m,
- conductor thickness t = 10 µm.

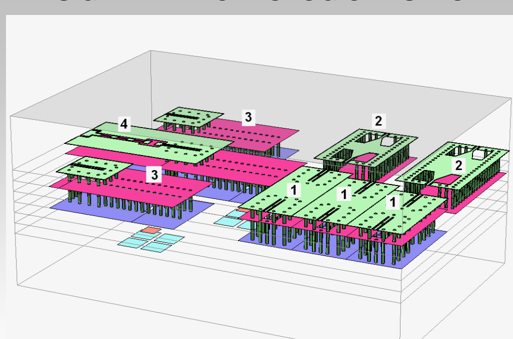
The main restriction from the design rules are the minimum conductor widths and spacing of 100 µm.

DESIGN AND TECHNOLOGICAL SETUP

The designed **test circuits** for the **W band** operation are:

1. **CPW-stripline-CPW**; three different lengths for the stripline between the two transitions
2. **CPW-SIW-CPW**; two lengths for the SIW (**Substrate Integrated Waveguide**)
3. **Antenna element** integrated with CPW-stripline transition
4. **Antenna element** integrated with vertical transition and pads for mounting of a mm-wave Schottky diode.

DESIGN AND TECHNOLOGICAL SETUP



3D view of the W band circuits for LTCC technology

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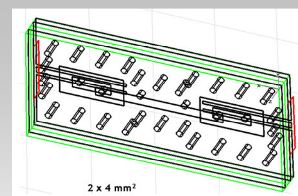
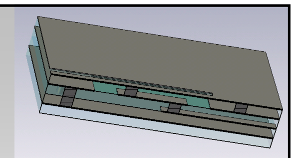
TRANSMISSION LINES AND VERTICAL TRANSITIONS

- At very high frequencies (up to 110 GHz) the modeling and design of the LTCC circuits is a challenge because the wavelength (**1235 µm at 100 GHz**, including the tape dielectric permittivity) have the same order of magnitude with the vertical transitions dimensions and the dimensions of other circuit components.
- The **0D (lumped elements) and even 1D (transmission lines)** equivalent circuit modeling approach can no longer be used
- **Full wave electromagnetic simulations** must be used in the design and optimization.

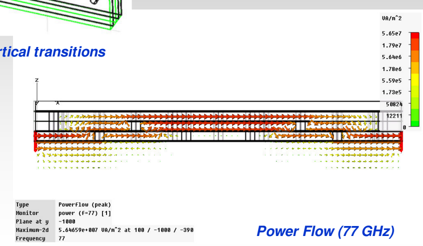
1. CPW – stripline – CPW test structure



3D view of the two vertical transitions

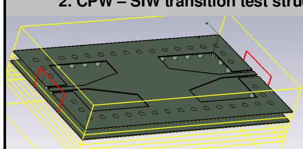


Cross section of the CPW to SL vertical transition

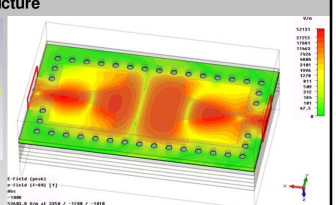


Power Flow (77 GHz)

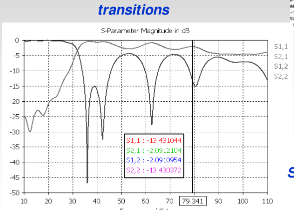
2. CPW – SIW transition test structure



3D view of the two CPW to SIW transitions



Simulated electric field distribution



Simulated S parameters of the two CPW to SIW transitions connected by a SIW segment

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EXPERIMENTAL RESULTS

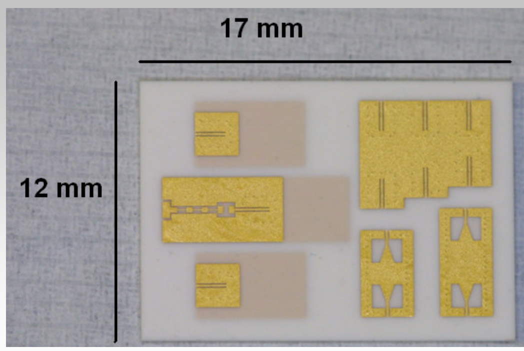
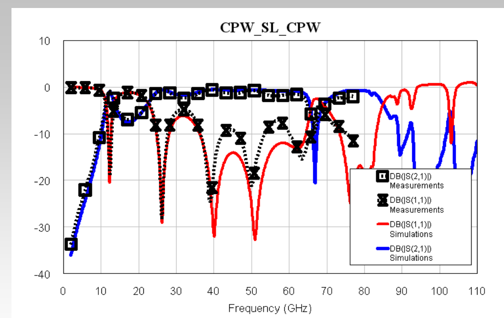


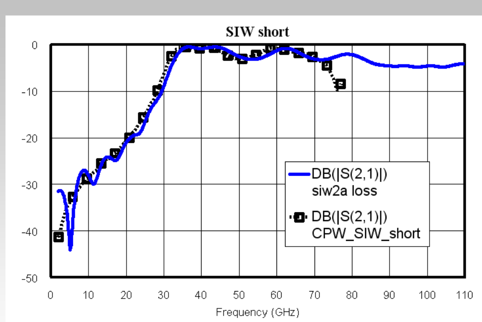
Photo of the fabricated LTCC test structures

EXPERIMENTAL RESULTS



Simulated and measured S parameters for the two vertical transitions connected by an embedded stripline (long line)

EXPERIMENTAL RESULTS



Simulated and measured S parameters for the two CPW – SIW transitions connected by SIW (short line)

CONCLUSIONS

❑ Based on LTCC technology, embedded transmission lines and their transition to grounded CPW were designed.

❑ Test circuits were fabricated using the LTCC technology available at VTT, Finland.

❑ From measurements the LTCC material parameters can be extracted and the electromagnetic models can be refined.

ACKNOWLEDGMENT

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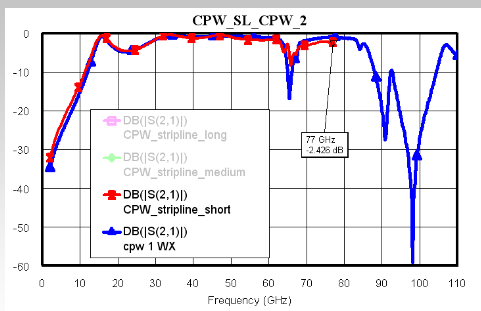
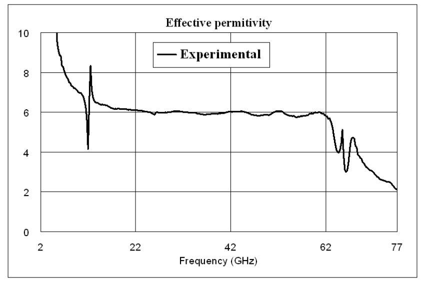
Thank you





$$\gamma = \frac{1}{\Delta L} \arg ch\left(\frac{S_{11}^{B} S_{22}^{A} + S_{11}^{A} S_{22}^{B} - \Delta_A - \Delta_B}{2 - S_{21}^{B} S_{12}^{A}} \right)$$

$$\Delta L = L_B - L_A$$

$$\Delta_A = S_{11}^{A} S_{22}^{A} - S_{12}^{A} S_{21}^{A}$$

$$\Delta_B = S_{11}^{B} S_{22}^{B} - S_{12}^{B} S_{21}^{B}$$