APPLICATIONS OF LTCC CERAMICS IN MICROWAVE

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- Introduction
- Materials and Buried Elements in LTCC
- Transmission Lines and Waveguides in LTCC
- Examples of LTCC Devices
- Summary
Resistors in LTCC

Caused by the conductance mechanism in thick film resistor layers and by the geometrical sizes of the resistor areas:

\[ Z = R + jB = f(\text{frequency, sheet resistance, geometrical size}) \]

Universal equivalent circuit for resistors in microstrip environment
Frequency behaviour up to 3 GHz (Locus diagram) of resistor (l=2 mm, w=1 mm) before and after trimming with high voltage pulses.
Inductors in LTCC

in the range of
5 nH to about 200 nH
with reasonable
consumption of space.

Inductor design in LTCC
and a foto of 4,5 turns buried coil

Fine-line laser patterned
top layer inductor spiral

rectangular or
circle flat coil
outsites or
in inner layers

3-d-coil
(a half winding
in each layer)

3-d-coil
(with alternated or
shifted windings
for smaller
capacitances)
Inductors in LTCC

General 3D-inductor equivalent circuit

Inductivity vs. frequency for a 3D-coil with distributed (solid line) and lumped (dashed line) character
Capacitors in LTCC

1.: normal tape is used
   a) interdigital-capacitor: top-site or in inner layer
   b) multilayer-capacitor

2.: high \( \varepsilon \)-materials are used
   a) ink or tape filled vias
   b) high \( \varepsilon \)-inlay or layer
   d) high \( \varepsilon \)-ink or added thin tape
   solution if mismatch between tapes/inks
   solution with problems for production
   good practicable for production: printable capacitor-ink

Principal design of capacitors in LTCC

Capacitor model for wide-band simulations
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TRANSMISSION LINES IN LTCC

- Off center stripline x-and y-direction
- Meshed ground layers
- Microstrip
- RF/high-speed-line

- Shielded stripline
- Meshed ground layers with partially full metallization
- Microstrip
- Microwave-stripline

- LTCC filled waveguide
- Meshed ground layers with partially full metallization
- Microstrip
- Waveguide

via-rows
LTCC-RF-benchmarking,
DLR-project „EASTON“, leadership: IMST

microstrip line

- h = 130µm
- h = 200µm

DuPont 951:
εᵣ = 7.8

- h = 200µm
- h = 130µm
- h = 130µm
- h = 200µm

ground

VISPRO Division

ThinkCera

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Microstrip Line (MS)

MS Line Losses [dB/cm]

- Ferro A6M, Au
- Ferro A6S, Ag
- Samsung G6, Ag
- DuPont 943, Au
- DuPont 943, Ag

Frequency / GHz

0 5 10 15 20 25 30 35 40

0 0,1 0,2 0,3 0,4 0,5 0,6
LC-filter

LC filter (surface layer) compared with 1204 chip capacitor

LC filter (surface layer) compared with microstrip line filter (grey)
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LTCC technology flow

- Blanking
- Via, hole punching
- Via Filling
- Printing of metalization and elements
- Laminating
- Cutting
- Co-firing

**Postprocessing**
- Thick film, postfiring
- Thin film
- Chip, SMD bonding
- Assembly
Advantages of LTCC

general:
- easy structuring of unfired tapes,
- parallel production,
  inspection of the layers, high yield
- buried printed elements and structures,
- nearly unlimited number of layers
- economical production of small and medium number of circuits

for microwave applications:
- low tan δ, permittivity of LTCC between 5 and 30
- better controlled εᵣ and tan δ,
- better controlled geometrical dimensions/ cross sections,
- better EMV behaviour (short connection to ground, shielding metallization)
- 3-dimensional construction with high numbers of layers, mouldings and cavities,
Examples of available LTCC tape materials

<table>
<thead>
<tr>
<th>Specifications</th>
<th>BAM</th>
<th>Dupont DP 951</th>
<th>Dupont DP943</th>
<th>Northrop Grumman</th>
<th>Ferro A6S</th>
<th>HeraeusC T2000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical Properties</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dielectric Constant</td>
<td>25 - 40</td>
<td>7.85</td>
<td>7.5</td>
<td>3.9</td>
<td>5.9</td>
<td>9.1</td>
</tr>
<tr>
<td>Dissipation Factor [V/mil]</td>
<td>&lt;1x10⁻³</td>
<td>4.5x10⁻³</td>
<td>1x10⁻³</td>
<td>&lt;7x10⁻⁴</td>
<td>&lt;2x10⁻³</td>
<td>&lt;2x10⁻³</td>
</tr>
<tr>
<td>Breakdown Voltage [Ω]</td>
<td>&gt;1000</td>
<td>&gt;1000</td>
<td>&gt;1000</td>
<td>&gt;10¹²</td>
<td>&gt;10¹²</td>
<td>&gt;10¹³</td>
</tr>
<tr>
<td>Insulation Resistance [Ω]</td>
<td>&gt;10¹²</td>
<td>&gt;10¹²</td>
<td>&gt;10¹²</td>
<td>&gt;10¹²</td>
<td>&gt;10¹²</td>
<td>&gt;10¹³</td>
</tr>
<tr>
<td><strong>Dimens. Charact.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrinkage x,y [%]</td>
<td>12.7±0.3</td>
<td>9.5 ± 0.3</td>
<td>14.8±0.2</td>
<td>11.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness - fired [mils]</td>
<td>1.7, 3.8, 5.5, 8.5</td>
<td>4.5</td>
<td>3.7, 7.4</td>
<td>1.77, 3.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrinkage z [%]</td>
<td>15.0±0.5</td>
<td>10.3 ±0.3</td>
<td>27 ± 0.5</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Thermal Properties</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coeff. of Thermal Cond. [K]</td>
<td>3</td>
<td>4.4</td>
<td>2</td>
<td>4.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Coefficient [ppm/K]</td>
<td>5.8</td>
<td>4.5</td>
<td>Si or GaAs to match</td>
<td>9</td>
<td>8.5</td>
<td></td>
</tr>
</tbody>
</table>
Frequency bands for RF and microwave applications

- 300 MHz: 1 m
- 1 GHz: 30 cm
- 3 GHz: 10 cm
- 10 GHz: 3 cm
- 30 GHz: 1 cm
- 100 GHz: 3 mm

Applications:
- Mobile
- Bluetooth/ISM
- Point-to-multipoint
- Satellite communication
- Point-to-point
- Radar
- Car sensors
### Methods of patterning

<table>
<thead>
<tr>
<th>Method</th>
<th>inner layer</th>
<th>surface layer</th>
<th>cofire</th>
<th>postfire</th>
<th>minimal sizes line/space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard screen printing</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>90/100 µm</td>
</tr>
<tr>
<td>Fine line screen printing</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>50/75 µm</td>
</tr>
<tr>
<td>Photoimageable inks</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>50/50 µm</td>
</tr>
<tr>
<td>Etched screen printed</td>
<td>-</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>25/25 µm</td>
</tr>
<tr>
<td>Etched thin film layers</td>
<td>-</td>
<td>●</td>
<td>-</td>
<td>●</td>
<td>&lt;20/20 mm</td>
</tr>
</tbody>
</table>
## Resistors in LTCC

<table>
<thead>
<tr>
<th>Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postfire</td>
<td>- like thick film</td>
<td>- demand of surface</td>
</tr>
<tr>
<td>Cofire (surface)</td>
<td>- trimming possible</td>
<td>- influenced by cofiring</td>
</tr>
<tr>
<td>Cofire (buried)</td>
<td>- saving of surface, free for active components</td>
<td>- problems for many inks/sheet resistances</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- influenced by cofiring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- limited available inks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- limited performance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- trimming by HVP</td>
</tr>
</tbody>
</table>

### Diagram

- **a)** buried under top layer cofired
- **b)** buried under two layers cofired
- **c)** buried cofired

- Laser through the top layer
- Laser through a hole in top layer
- High voltage pulses
BGA-pitch 0.8 mm /
300 µm solder-bumps

Layers of duplexer filter
( MSE GmbH)

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**25 GHz- BP- Filter**

Comparison with very good correspondence

- Specification
- 3D-simulation by EMPIRE™
- S-parameter measuring

![Graph showing insertion losses in dB vs frequency with S11_sim, S21_sim, S11_meas, S21_meas, and Specs plotted.

![Image of a 25 GHz BP Filter with text BP25.
Advantage of LTCC-filter:
smaller size in multilayer

Conventional parallel coupled filter layout

Parallel coupled "folded" filter and full vertical "folded" filter
Principal design of aperture coupled 2 x 2 patch antennas

Wilkinson divider
Resistors in LTCC

Caused by the conductance mechanism in thick film resistor layers and by the geometrical sizes of the resistor areas:

\[ Z = R + jB = f \text{ (frequency, sheet resistance, geometrical size)} \]

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**WAVEGUIDES IN LTCC**

Waveguide construction in LTCC

Loss (dB/in) vs ground spacing (mil) compare stripline-waveguide

Inductive window filter in LTCC and rectangular LTCC waveguide dimensions (X-band)
Novel and advanced thick film materials together with photo processing will provide better line and via resolution and improve dielectric characteristics.

### TRENDS IN DEVELOPMENT OF LTCC FOR MICROWAVE

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1998</th>
<th>2003</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. via size [µm]</td>
<td>250</td>
<td>40-25</td>
<td>25</td>
</tr>
<tr>
<td>Min. via pitch [µm]</td>
<td>500</td>
<td>125</td>
<td>75</td>
</tr>
<tr>
<td>Min. line width [µm]</td>
<td>125</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Min. line pitch [µm]</td>
<td>250</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Line density [cm/cm²]</td>
<td>40</td>
<td>200</td>
<td>267</td>
</tr>
<tr>
<td>Max. module size [cm²]</td>
<td>130</td>
<td>360</td>
<td>645</td>
</tr>
<tr>
<td>Max. working freq. [GHz]</td>
<td>10</td>
<td>38</td>
<td>80</td>
</tr>
<tr>
<td>Max. working temp. [°C]</td>
<td>125</td>
<td>160</td>
<td>200</td>
</tr>
</tbody>
</table>

Photoimageable tape (75 µm vias) and etched lines (50 µm Ag lines and spaces DP 6453)
3D CONSTRUCTION

Cavities and channels

Layout (grey: line + resistor, black: cooling channel),

\[ P_v = 2 \text{ W} \]
without waterflow \[\rightarrow + 230 \degree \text{C} \]
with only 2 ml / min waterflow \[\rightarrow + 25 \degree \text{C} \]

Photo of a micro channel

Laser structuring

Laser ditches before filling with conductor ink to manufacture coils of high quality factor

The ditches may also be filled with a pure glass to form integrated optical interconnections.

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MEMS

PZT- pump with passive vents

500 to 1000 ml / min, Counter-pressure 2 kPa

Cross section of membrane and canal

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Future Technologies on LTCC

- New screens, inks and printing methods for fineline screen printing
- Photoimageable LTCC-Systems (conductor-, dielectric and resistor- inks and tapes)
- Zero-shrinking
  - Zero-shrinking including cavities and windows
- Pressure less lamination
- One process step for via forming and filling
- Inks/tapes for integrate optical components
APPLICATIONS OF LTCC CERAMICS IN MICROWAVE

• LTCC technology and the materials are excellent suitable for microwave applications
• applications up to very high frequencies are known, produced and in industrial operation
• there are some problems in microwave applications of LTCC:
  • not all materials and technologies are mature for production
  • investigations and developments are still going on,
  • RF and microwave characterisation data for both the integral passive components and the materials themselves are not readily available
  • some investigations and characterisations have to be made by users

Summary