Inline density measurement for rock wool

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Outline

- Introduction
- Measurement system and configuration
- Results
  - Bloom defects
  - Surface weight
- Conclusion
Why should we measure in the microwave region?

- Many non-conducting materials are transparent in the microwave region.

- Microwave systems offer a high dynamic range in combination with low output power, the radiation is non-ionising and systems can be used under most environment conditions without special safety regulations.

- Communication applications created a mass market which allows the development of cheap radar and high frequency systems.
Advances in Silicon Technologies

Published in Silicon Transit frequencies over time

"Residue" of the digital processors: Integrated Millimeter Wave Circuits

First 77 GHz Radar-Circuits Published in Silicon

2003 First 77 GHz Radar-Circuits Published in Silicon

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Automotive Radar (77 GHz)

Gunn-Oscillator
Automotive Radar 2.
Generation Bosch, ACC2

SiGe VCO-Chip
published 2003
used in Bosch ACC3

Source: Infineon
Highly Integrated Radar System at 80 GHz

- Single Chip Radar Transceiver
- 1.9mm × 1.6mm
- Frequency: 80 GHz
- Ultra-wide Bandwidth of 25 GHz
- $P_{out} \approx 10$ dBm
- Power dissipation $P = 0.5$ W

Complete Radar-Module for Production

- Waveguide transition
- RF coupler
- SiGe-Chip
- PLL-Module
- Connector for DC supply and control
- Temperature range -40°C to 85°C
Miniaturized Radar Sensor

• *Ultra-Wideband 80 GHz Radar*

• *High Level of integration due to SiGe-Chip*

• *Flexible USB-Interface allows direct PC-connection*

• *Suitable for industrial temperature range (-40° C to 85° C)*
Radar Measurement: *Single-target* ($\Delta f = 25.6 \text{GHz}$)

Radar Stability: Reproducibility

- Short range (10 cm) measurements inside a waveguide
- Measurement duration 10 ms each
Which frequency range should we use?

- Frequency range between 10 GHz – 600 GHz.

- The concentration on the lower THz frequency range allows the realization of measurement systems with frequency multipliers which offer an output power of milliwatts for frequencies of up to several hundred GHz.

- Today, amplifiers are available for frequencies up to 700 GHz.

http://www.com.dtu.dk
Rock Wool Production

© http://www.eurima.org/about-mineral-wool/production-process.html
First Test series

- For a first test series a number of different rock wool plates were chosen.
- The measurements were performed in a transmission geometry, the measurement frequency was 94 GHz.
- For the first test measurements plates with blooming defects were used.
- In the amplitude image no defects are visible, the materials show only a minimal attenuation and fluctuation.
Additional information through the phase measurement

- In the phase measurement the complete image shows more fluctuation, which correlates with changes in the density of the material.

- The blooming defects under the surface can now easily be detected.
Can we measure the surface weight of rock wool?

For the second test series, four plates of rock wool with same thickness but different surface weight were chosen.

<table>
<thead>
<tr>
<th>Rock wool</th>
<th>weight [g]</th>
<th>area [m²]</th>
<th>Surface weight [Kg/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>35,1357</td>
<td>0,0225</td>
<td>1,5616</td>
</tr>
<tr>
<td>E</td>
<td>29,8223</td>
<td>0,0225</td>
<td>1,3254</td>
</tr>
<tr>
<td>B</td>
<td>40,7342</td>
<td>0,0225</td>
<td>1,8104</td>
</tr>
<tr>
<td>C</td>
<td>43,8869</td>
<td>0,0225</td>
<td>1,9505</td>
</tr>
</tbody>
</table>
Amplitude measurement
Average amplitude

amplitude [dB]

-37.3

-37.25

-37.2

-37.1

-37.05

-37

-37

-37

-37

surface weight [Kg/sqm]

1.3

1.4

1.5

1.6

1.7

1.8

1.9

2
Can we use the phase information?

- Unfortunately the initial phases of the measured data are obtained by a simple operation of arctangent from the raw complex images and are wrapped in the principal interval \([-\pi, \pi]\).

- To use phase we need the unknown true phase changes by \(2\pi\).

- It is necessary to unwrap the phases in order to remove the discontinuities and to obtain an estimate of the true phases.
Phase unwrapping

Wrapped phase

Unwrapped phase
Phase measurement
Average phase

Phase in Abh. des Flächegewichtes

Flächengewicht [Kg/m²]

Phasenmittelwert

Average phase

surface weight [Kg/sqm]
Conclusion

- Microwave systems can be used to look through rock wool or other isolating, non-conducting materials.

- Blooming defects inside from rock wool plates can be detected through mm-wave imaging systems.

- The density of rock wool correlates with the transition time of the electromagnetic wave.