THE 3 OMEGA TRANSIENT LINE METHOD FOR THERMAL CHARACTERIZATION OF SUPERINSULATOR MATERIALS DEVELOPED FOR SPACECRAFT THERMAL CONTROL

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Introduction: The 3-Omega technique
Instrumentation developed at Active Space Tech.
Developed under the European 7th framework Programme project, AerSUS
Results and Conclusions
The 3Omega Method

The 3Omega method is a form of the transient line method using sinusoidal current to heat a thin wire embedded in the sample. A current of frequency $\omega$

$$I(t) = I_0 \sin(\omega t)$$
generates heating in the wire at a frequency of $2\omega$. But the resistance of the wire depends on the temperature:

$$R(T) = R_0 (1 + \alpha \Delta T)$$

So the resistance then varies at a frequency of $2\omega$

$$R(t) = R_0 + \alpha \Delta T R_0 \sin (2\omega t)$$

Voltage is given as

$$V(t) = I(t)R(t)$$

The product of sines then gives the sum and difference frequencies and therefore a voltage component at the third harmonic of the input frequency (3$\omega$, hence the name).
The 3Omega Method

The frequency dependent thermal response of the sample will translate into a change in temperature and, therefore, in electrical resistance, across the wire.

Carefully measuring the frequency dependence of this thermal response yields a simultaneous measurement of the thermal conductivity and diffusivity of the sample.

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The 3Omega Method

The first prototype 3Omega instrument was developed at Active Space Technologies, based on the latest scientific research methods, under the AerSUS (Aerogel European Supplying Unit for Space Applications) project, an FP7 project (contract no: 284494), funded by the Seventh Framework Programme of the European Union.

Wide gauge speaker cables provide low resistance and signal distortion.

NI-Instrument to drive measurements and for data acquisition.

New prototype currently under construction by partners in Portugal.
The 3Omega Method

A copper wire of radius only 30 μm is used to heat the samples. Since the thermal penetration of heating wave is small, this method allows the measurement of very small samples.

Minimum size: 2 pieces each 6 cm X 0.5 cm X 0.5 cm

Aerogel testbed designed and developed at AST
The 3Omega Method

Additionally, a first prototype testbed for measuring thermal conductivities and diffusivities of liquids and phase change materials was tested at Active Space Technologies.
The 3Omega Method

Instrumentation and analysis methods are used to remove the first harmonic input signal and extract the third harmonic measurement signal.
The 3Omega Method: measurements

This allows the extraction of the third harmonic signal, giving highly accurate measurements of thermal conductivity and diffusivity.
The measurement technique was verified on a sample of Rohacell as compared to independent measurements by the Physikalische-Technische Bundesanstalt. Very similar results were obtained but with smaller measurement error and repeatability on the order of a few percent even when increasing the heating by a factor of 3 or more.

Additional measurement comparisons were made on aerogel samples measured by the Science and Technology Facilities Council in England, ARMINES in France and others giving consistent results, but higher reliability, flexibility and repeatability.
## Summary of Advantages of the $3\omega$ Method

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<tr>
<th>Traditional hot plate method</th>
<th>$3\omega$ method</th>
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<tr>
<td>Requires higher heating for lower conductivity samples (too much heating can change conductivity of sample)</td>
<td>Requires less heating for lower conductivity (normally less than 1W/m)</td>
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<td>Difficult to control for heat losses/convection</td>
<td>Heater is also the sensor and is embedded in the sample, so no convection losses</td>
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<td>Requires computer thermal model which must be verified for every temp/press/gas combination</td>
<td>Calculated based on first principles from voltage/frequency measurements, therefore model independent</td>
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<td>Requires more time to reach equilibrium for lower conductivities</td>
<td>Takes ~15 minutes per measurement (not counting sample preparation)</td>
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<td>Normally higher measurement uncertainty for conductivity (~15-20%) does not measure diffusivity. Becomes much less reliable at low conductivities</td>
<td>High accuracy for conductivity (~5%) and diffusivity (~15%), for conductivities as low as ~0.001 W/mK</td>
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<td>Large sample sizes (~30cm X 30cm)</td>
<td>Works with very small samples, Min size: 2 pieces 5cm X 0.5cm X 0.5cm</td>
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Summary and conclusions

1. Advanced thermal conductivity and diffusivity measurement station was developed as part of the AerSUS European 7th Framework funded project.

2. Very high accuracy was achieved for very small samples in short times with minimal sample preparation time/cost.

3. Service now offered commercially to several customers, primarily materials scientists and insulation (especially aerogel) manufacturers.

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