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MAINTENANCE OF TISSUE SIMULATING LIQUIDS

1 COMPOSITION OF TISSUE SIMULATING LIQUIDS

Tissue simulating liquids are based on a mixture of water with other components. Target parameters for the permittivity and conductivity of head and body tissue simulating liquids as well as sample recipes are given in the related SAR measurement standards and/or guidelines (e.g., [1] to [4]).

A concentration of at least 40% water (permittivity approx. 80) is contained to achieve the desired permittivity at an environmental temperature of 22°C. In addition to water, a further component is used to limit the permittivity without increasing the conductivity above the required value. The parameters of the selected component determine the limitations of its useful frequency range.

The following components are commonly used, but different chemicals are possible:

- **Sugar** for frequencies < 1 GHz
- **DGBE** Diethylene-Glycol-Monobutyl-Ether, for frequencies from 1.0 to 2.5 GHz
- **POEM** Polyoxyethylenesorbitan monolaurate for frequencies < 5 GHz
- **Oil** with emulgators, for frequencies from 0.6 to 6.0 GHz

Further, minor additives serve the following purposes:

- **NaCl** to increase the conductivity to the target value
- **Cellulose** to keep the sugar solved
- **Preservative** to prevent the solutions from degrading due to bacterial and fungal growth

During the usage of tissue simulating liquids, with a large surface area exposed to the air, mainly water evaporates; other liquid ingredients evaporate to a much lower extent. Solid ingredients and other additives will rarely evaporate and rather tend to cling to the phantom surface or the edges.

As a result of the water evaporation, the dielectric parameters will change with exposure time. Depending on the liquid type, it also influences the conductivity. Permittivity will decrease and need to be corrected to the target values (within the required tolerance). Note that apparent differences might also result from poor dielectric parameter measurements: Permittivity may appear lower, e.g. if air bubbles or an oily layer are present. Add de-ionized water to re-establish the permittivity according to the following rules:

- Measure the liquid parameters and calculate the deviation from permittivity and conductivity. Be aware of your measurement uncertainty, the effect of the temperature gradients and the quality on your results.
- Calculate the required amount of missing water (in percentage of the total weight) to obtain the desired permittivity. The permittivity can be measured with higher reliability than conductivity and is dominantly affected in most cases. Be aware that the conductivity may change in either direction with the evaporation, depending on liquid type and frequency.
- If you are not experienced, use a liquid sample for any kind of correction first. Add first 50% of the amount required for correction to the liquid and mix it well.
- Repeat the measurement, verify the effect and calculate the figures for further correction.

It is important to always keep in mind that the parameters will change with temperature. The temperature sensitivity of permittivity and conductivity depends both on the liquid type and the frequency. It is usually higher for conductivity and also for very low or very high frequencies. It is assumed that liquid parameters are measured at the nominal temperature. Solid material contaminants like hair, dust, etc. may be filtered out if needed. Before using samples for measurement, make sure the liquid is homogeneous so that it represents the necessary average characteristics. It is also important to homogenize the liquid before returning it into its storage container in order to maintain these average characteristics.

The following subsections contain liquid specific characteristics. The measures described in the Material Safety Data Sheets (MSDS) must be observed. Many liquids are skin irritants and must not be disposed of simply via the sewerage system or into the environment.

2 SUGAR BASED LIQUIDS

Preservative is contained in this type of liquid to suppress bacterial and fungal growth. After storage as well as between periods of usage, the liquid can become inhomogeneous due to the sugar settling at the bottom and near surfaces. If the liquid begins to become lumpy after a very long storage time, heating and stirring is recommended to re-dissolve the lumps. Otherwise, stirring is sufficient for homogenization. Shaking will lead to air bubbles, which may require considerable time to dissipate; foam may need one or more hours to disappear.

The sensitivities of sugar based SPEAG tissue simulating liquids at the frequencies of interest are typically in the following range:

HSLxxxV2: permittivity +1.0 to +1.6 per % of water, conductivity -0.02 to +0.1 per % of water

MSLxxxV2: permittivity +0.7 to +1.0 per % of water, conductivity +0 to +0.06 per % of water

Example: Adding 10 g of water to 1 kg (1.0 weight %) of MSL900V2 liquid is expected to increase the permittivity by 0.9 (from 45.0 to 45.9) and the conductivity by 0.01 (from 1.00 to 1.01).

If it is not possible to correct the liquid solely by adding water, other measures should be taken after verifying their effectiveness on a sample.

- Adding Sugar will have the inverse effect of adding water. To dissolve the sugar, a long stirring time and preferably elevated temperature is required. Alternatively, it may be easier to leave the liquid in an open phantom for some time during which time water will evaporate.
- Adding NaCl will mainly increase the conductivity. Permittivity may also be influenced by higher or lower values. Note that NaCl will usually not be missing.

3 DGBE BASED LIQUIDS

DGBE is easily dissolved in water. Given a DGBE-water mixture, mainly water will evaporate, however DGBE will evaporate to a smaller percentage. For the frequency liquids around 2.5 GHz, no NaCl is contained and should therefore not be added for any corrections.

Evaporated water can be replaced and will mainly increase the permittivity, and to a small extent the conductivity, typically as follows:

HSLxxxxV2: permittivity 0.8 to 1.0 per % of water, conductivity 0 to 0.1 per % of water

MSLxxxxV2: permittivity 0.8 per % of water, conductivity 0 to 0.01 per % of water

Observe the instructions in the MSDS when handling the liquid. Measures should be taken to protect the eyes and skin. DGBE has some characteristics similar to the brake-fluid used in automobiles and should be handled carefully.

4 POEM BASED LIQUIDS

POEM (e.g. Tween) is a solvent also used in food industry and leads to liquids similar to the sugar based ones. It requires the same handling, and their appearance is yellow transparent. Preservative is contained to prevent degradation due to bacteria and fungus.

Evaporated water can be replaced and will increase mainly the permittivity. The effect on the conductivity depends on the liquid type and frequency and is smaller. Be aware that at high frequencies, the measurement uncertainty tends to increase, especially for the conductivity.

The **sensitivities to water addition** (% parameter increase per weight% water added) of POEM based SPEAG broadband tissue simulating liquids at the frequencies of interest are typically in the following range:

HSL-LF @ 100 MHz:	permittivity +0.9, conductivity +1.5
HBBL1350-1850V3:	permittivity +0.9, conductivity +0.2
HBBL1550-1950V3:	permittivity +0.9, conductivity +0.1
HBBL1900-3800V3:	permittivity +0.9, conductivity +0.1
MBBLxxxx-xxxxV3:	permittivity +0.5, conductivity –0.15

Example: For MBBL types, 5% too low permittivity can be compensated by adding approx. +10% of water, which will decrease the conductivity by -1.5%.

5 OIL BASED LIQUIDS

Oil based liquids are an emulsion of a complex mixture of ingredients. Their appearance is yellow or brown transparent or slightly opaque / milky in most cases. Some older liquids may show a non-transparent upper zone with a creamy appearance after some time without stirring. Before using or handling the liquid, it must therefore be stirred to become entirely homogeneous. An opaque appearance is possible but will not influence the dielectric parameters if it is homogeneous during the measurement at the probe surface.

Evaporated water can be replaced and will increase the permittivity, and to a smaller extent the conductivity at frequency >3GHz. At high frequencies, the measurement uncertainty tends to increase, especially for the conductivity. Corrections should therefore be made in several steps. Reduction of the water content is only possible by evaporation in a container or phantom with a large surface area exposed to air.

Version 5/6 liquids are yellow (MBBL3500-5800V5, MBBL600-6000V6) or dark brown (HBBL3500-5800V5, HBBL600-6000V6) and slightly opaque with a high long-time stability.

Storage is recommended in the closed containers in dark environment and at low temperatures (10 - 20°C). Avoid freezing and high temperatures > 25°C. At low temperatures < 15°C, the liquids appear opaque. When exposed to high temperatures e.g. during transportation, the emulsions may de-stabilize and separate into different phases (bottom transparent, center milky, top creamy). Returning to nominal operating temperature at 22 °C, they may stay milky. Before using them for measurements, they must be homogenized again and appear mainly transparent. This is possible by repeating the following sequence one or more times: Shake / stir well several times the de-stabilized liquid in the container while cooling down in a refrigerator to approx. 5 °C (no freezing!). Keep it cooled during several hours. Remove it from the refrigerator and leave it warming up in the laboratory environment to > 15°C, only stirring slightly few times. Verify if it has become transparent. Repeat this procedure if it is still milky or opaque.

During **operation** of the liquid, it shall be stirred regularly. If exposed for longer time to air, a jelly-like phase may deposit at the air / phantom interface and must be re-mixed and into the liquid with a soft spatula and fully dissolved. The same applies for deposits on field probes, whereby an oily film on the probe enclosure surface can be formed. Dissolve this film in the equivalent way by stirring well.

The **sensitivities to water addition** (% parameter increase per weight% water added) of oil based SPEAG broadband tissue simulating liquids at the frequencies of interest are typically in the following range:

HBBL3500-5800V5	at 3.5 GHz:	permittivity +0.79, conductivity +0.14
	at 5.5 GHz:	permittivity +0.83, conductivity +0.41
HBBL600-6000V6	at 0.9 GHz:	permittivity +0.73, conductivity -0.23
	at 1.8 GHz:	permittivity +0.77, conductivity -0.03
	at 2.6 GHz:	permittivity +0.79, conductivity +0.11
	at 3.5 GHz:	permittivity +0.81, conductivity +0.21
	at 5.5 GHz:	permittivity +0.83, conductivity +0.45
MBBL3500-5800V5	at 3.5 GHz:	permittivity +0.44, conductivity +0.00
	at 5.5 GHz:	permittivity +0.48, conductivity +0.18
MBBL600-6000V6	at 0.9 GHz:	permittivity +0.38, conductivity -0.42
	at 1.8 GHz:	permittivity +0.40, conductivity -0.23
	at 2.6 GHz:	permittivity +0.41, conductivity -0.10
	at 3.5 GHz:	permittivity +0.42, conductivity +0.01
	at 5.5 GHz:	permittivity +0.44, conductivity +0.17

The **temperature gradients** shall be observed especially during conductivity measurement:

HBBL3500-5800V5	at 3.5 GHz:	permittivity -0.13, conductivity -0.45 %/°C
	at 5.5 GHz:	permittivity +0.16, conductivity -1.02 %/°C
HBBL600-6000V6	at 0.9 GHz:	permittivity -0.32, conductivity +1.30 %/°C
	at 1.8 GHz:	permittivity -0.27, conductivity +0.17 %/°C
	at 2.6 GHz:	permittivity -0.19, conductivity -0.57 %/°C
	at 3.5 GHz:	permittivity -0.05, conductivity -1.10 %/°C
	at 5.5 GHz:	permittivity +0.31, conductivity -1.43 %/°C
MBBL3500-5800V5	at 3.5 GHz:	permittivity -0.37, conductivity -1.19 %/°C
	at 5.5 GHz:	permittivity -0.08, conductivity -1.67 %/°C
MBBL600-6000V6	at 0.9 GHz:	permittivity -0.39, conductivity +1.29 %/°C
	at 1.8 GHz:	permittivity -0.34, conductivity +0.01 %/°C
	at 2.6 GHz:	permittivity -0.26, conductivity -0.76 %/°C
	at 3.5 GHz:	permittivity -0.15, conductivity -1.28 %/°C
	at 5.5 GHz:	permittivity +0.17, conductivity -1.57 %/°C

Disposal of oil-based liquids must not be in the environment or in the sewage or wastewater. Use disposable paper towels to clean surfaces before final washing of equipment with soapy water.

6 REFERENCES

[1] IEEE Std 1528-2013, “IEEE Recommended Practice for Determining the Peak Spatial-Averaged Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques”, June 2013

[2] IEC 62209-1, "Procedure to measure the Specific Absorption Rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz)", February 2005

[3] IEC 62209-2, "Procedure to determine the Specific Absorption Rate (SAR) for wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz)", March 2010

[4] KDB 865664, “SAR Measurement Requirements for 100 MHz to 6 GHz”