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An Update On SAR Standards And The Basic Requirements For SAR Assessment

For many years the general public has been concerned about the possible health effects of exposure to radio frequency (RF) radiation. High levels of RF fields are known to cause a variety of physical effects on the human body. With the dramatic increase in public use of wireless devices, and particularly mobile telephones, it has become necessary to ensure that these products do not expose their users to potentially harmful levels. At the frequencies at which most of these devices operate, the known health effects center around tissue heating.

A measure of this heating effect is known as Specific Absorption Rate (SAR). As part of worldwide efforts to legislate on consumer health and safety aspects, many authorities now require products that are placed on the market to meet SAR limits. Measurement of SAR is therefore becoming a fast-growing requirement for companies that make such products.

Significant work has been accomplished over the past few years in both refining and updating SAR standards. This work has been centered in Europe and the United States with broad international participation at the committee level and within the working groups. The new requirements have seen close cooperation between the standards bodies with the goal of harmonization in the final standards.

Continued standards development will rest primarily with both the IEC TC106 WG4 and IEEE SCC34 SC2. The new work on measurement techniques and procedures will reside with the IEC Project Team 62209. This work will then be available to IEEE through a "Category D Liaison", which is now in place between the working groups. The IEEE is also pursuing a companion standard for the numerical modeling of SAR.

Status Of Current SAR Testing Procedure Standards

Table 1 summarizes the current standards and work in process of the main international standards bodies. A more detailed discussion follows.

European Regulations

The European Union put forward a Council Recommendation in 1999 which sets out the position that EU Member States are expected to take on EMF exposure limitation. This document recommends the basic restrictions given for the general public in the International Commission on Non-ionizing Radiation Protection (ICNIRP) document. It also states:

> "In order to assess compliance with the basic restrictions provided in this recommendation, the national and European bodies for standardization should be encouraged to develop standards within the framework of Community legislation for the purposes of the design and testing of equipment."

Test configuration	Standard	Lower frequency	Upper frequency	Status
Against the head	EN50361	300 MHz	3 GHz	Issued July 2001
Against the head	IEEE 1528	300 MHz	3 GHz	Published December 2003
Against the head	IEC 62209 Part 1	300 MHz	3 GHz	In final FDIS
Head and Flat phantom	IEC 62209 Part 2	30MHz	6GHz	In draft
Head and Flat phantom	IEEE 1528.X	30MHz	6GHz	Thru 62209 Part 2 Cat D Liaison

Table 1

CENELEC has developed standards in this area over the last few years. One of the first to appear was EN 50360: 2001 for mobile phones, which refers to the Council Recommendation for SAR limits. This mandates the measurement methods of EN 50361. EN 50360 is a harmonized standard under the Radio & Telecommunication Terminal Equipment (R&TTE) Directive, meaning that any product which is marketed in the EU and which falls within the scope of this standard must comply with its requirements. The measurement methodologies found in EN 50361 have been adopted or incorporated in many other national standards.

The latest work has been with the IEC TC106 WG4, whose first approved work is IEC 62209 Part I, "*Procedure to Measure the Specific Absorption Rate (SAR) in the Frequency Range 300MHz to 3GHz: Hand Held Mobile Wireless Devices*." As of this writing, this is in Final Draft International Standard (FDIS) format and is out for final ratification by the member countries of the IEC. Part 1 establishes the basic methodologies for SAR measurement but is limited to devices that are held next to the ear. IEC 62209 Part 2 is currently being drafted by the project team and will expand the scope of the standard to cover the frequency range of 30MHz to 6GHz. It will also address body worn and hand-held devices such as PTT (push-to-talk) radios. Additional devices will include laptops, PDAs, palmtops and other such products, which utilize transmitters in the 30MHz to 6GHz frequency range. The standard will also look at devices with simultaneous or multiple transmitters.

In addition to its concerns about the risk of RF exposure to the general public, the European Union is also concerned about the role of RF energy in the workplace. Last year, Directive 2004/40/EC was created, which put in place specific limits for worker exposure to radio frequencies from very low frequencies to 300 GHz – nearly the proverbial "DC to daylight." These rules set limits on magnetic and electric fields, radiated power density, and, in some frequency ranges, on SAR.

US Regulations

The basis for US requirements are ANSI/IEEE C95.1 "*Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz*" which establishes exposure limits, and ANSI/IEEE C95.3 "*Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields – RF and Microwave*". These standards are reflected in the current FCC requirements found in 47 CFR §2.1091 and 2.1093. OET 65 Supplement C 01:01 "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields" gives guidance on the application of the FCC rules. (OET is the FCC's Office of Engineering and Technology).

Under the FCC's rules, the following types of devices are subject to routine environmental evaluation for RF exposure prior to equipment authorization or use:

- Fixed, mobile and portable transmitting devices that operate in the Cellular Radiotelephone, Personal Communications (PCS), Satellite Communications, General Wireless Communications, Wireless Communications, Maritime (ship earth stations only) and Specialized Mobile Radio Service authorized, respectively, under Part 22 (Subpart H), Part 24, Part 25, Part 26, Part 27, Part 80, and Part 90 of the FCC rules
- Portable devices operating in the Wireless Medical Telemetry Service (WMTS) and the Medical Implant Communications Service (MICS), authorized under Subparts H and I of Part 95 of the FCC Rules
- Unlicensed PCS, U-NII and millimeter wave devices authorized under Part 15 of the FCC Rules

All other mobile and portable devices are excluded from routine environmental evaluation for RF exposure.

The FCC rules for evaluating portable devices for RF exposure compliance are contained in 47 CFR §2.1093. For these purposes, a portable device is defined as a transmitting device designed to be used with any part of its radiating structure in direct contact with the user's body or within 20 centimeters of the body of a user or bystanders under normal operating conditions. For distances greater than 20 centimeters, exposure evaluation is determined by the maximum permissible exposure limits (MPE) provided in OET 65.

SAR & SAR Limits

Specific absorption rate or SAR is the time derivative of the incremental energy (dW) absorbed by or dissipated in an incremental mass (dm) contained in a volume (dV) of a given density (ρ):

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho dV}\right)$$

SAR should be considered an "absorbed dose rate" and is related to electric fields at a point by:

$$SAR = \frac{\sigma |E|^2}{\rho}$$

Where:
σ = conductivity of the tissue (S/m)
ρ = mass density of the tissue (kg/m^3)
E = rms electric field strength (V/m)

SAR can also be a calculated rate of temperature rise at a given point. This method is used in some basic research. However, for commercial testing of radiating devices, electric field measurements are normally used.

The limits, which apply in general for mobile telephones and similar apparatus, are drawn directly from the applicable source documents: ANSI/IEEE C95.1 for the US and ICNIRP for Europe and most of the rest of the world. Two limits are used: a lower value for exposure averaged over the whole body and a higher value

which is applicable to local exposure to parts of the body (e.g. the head). This partial-body SAR is averaged over a volume of tissue defined as a tissue volume in the shape of a cube. The US requirements differ from the international requirements (see Table 2) in their demand for a lower spatial average limit and that this limit is averaged over a smaller volume (1g of tissue as opposed to 10g). They also require a longer time over which the SAR is to be averaged, but since it is assumed that a user of a portable device will be exposed to the maximum power available from the device for the duration of the specified averaging time, the requirement for time averaging of the output during SAR measurement does not apply.

SAR Test Standards

The new IEEE and IEC standards (IEEE1528 and IEC62209) are similarly structured or harmonized with only minor variations in emphasis between them. The following shows the general format of this new work.

- Scope, normative references and definitions
- Measurement system specifications
- Phantoms
- Measurement probe and equipment
- Scanning system
- Protocol for SAR assessment
- Preparation
- Measurement procedure
- Post-processing
- Uncertainty assessment
- Measurement reporting requirement

The most important aspects are the requirements for the accuracy and performance of the test system and the method of carrying out the measurements. An innovation in each of these standards is an explicit and detailed requirement for performing an assessment of the measurement uncertainty budget and a limit on the maximum allowable uncertainty. This places requirements both on the equipment and on the laboratory's procedures.

Some of the more detailed and subject-specific material is relegated to annexes to the standards. This should not be taken to imply that it is less important; the annexes give crucial information both for the laboratory and for the supplier of the test system. An understanding of the whole standard, including its annexes, is necessary for its successful application.

The SAR Measurement System

According to IEC 62209 Para 5.1:

> "The test shall be performed using a miniature probe that is automatically positioned to measure the internal E-field distribution in a phantom model representing the human head exposed to the electromagnetic fields produced by wireless devices. From the measured E-field values, the SAR distribution and the maximum mass averaged SAR value shall be calculated."

Test systems should also include components for positioning the equipment under test and aligning the scanning system; for measuring the dielectric properties of the tissue simulant liquid; and for checking and validating the measurement accuracy.

Figure 1 shows the basic components of a complete SAR assessment system, with more detailed discussion of the major items following.

Phantom Requirements

Systems that are compliant to the standards will employ two types of phantoms. For testing a wireless device that is held against the head at the user's ear, a Specific Anthropomorphic Mannequin (SAM) phantom is required. For systems validation and for testing body mounted or hand held devices (not held next to the user's ear), a flat phantom is required. Flat phantoms vary is size and construction based on the test frequencies of the DUT.

The SAM phantom shown in Figure 2 contains the physical characteristics of

	Whole body SAR	Spatial peak SAR	Averaging time	Averaging mass
Europe	0.08 W/kg	2 W/kg	6 min	10gm
USA	0.08 W/kg	1.6 W/kg	30 min	1gm

Table 2

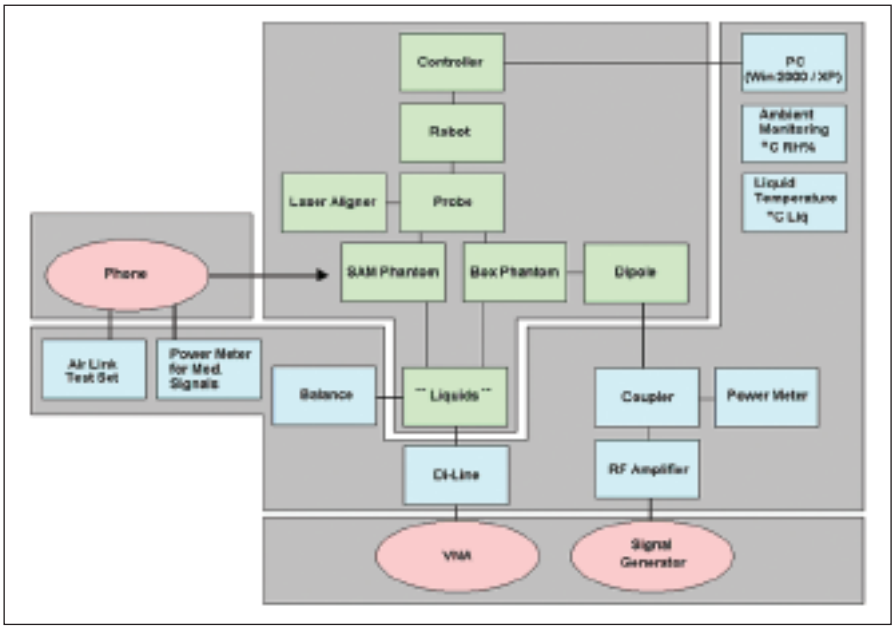


Figure 1

a phantom model (size and shape) to simulate the head of a user since the shape is a dominant parameter for exposure. The phantom is made from material with dielectric properties similar to those of head tissues. The shape of the Specific Anthropomorphic Mannequin is derived from the size and dimensions of the 90th percentile large adult male reported in a 1988 US Army study, adapted to represent the flattened ear of a wireless device user. CAD files of the inner and outer surfaces of the reference phantom are available in 3D-CAD formats with the standards.

Figure 2

The shell of the phantom including ear spacer is made of low permittivity and low loss material, with a relative permittivity <5 and a loss tangent <0.05. The phantom shell shape has a tolerance of less than ± 0.2 mm with respect to the CAD file of the SAM. In any area within the projection of the handset, the shell thickness is 2 ± 0.2 mm, except for the ear and the extended perimeter walls. The ear spacer provides a 6 mm spacing from the tissue boundary at the Ear Reference Point (ERP) within a tolerance of less than ± 0.2 mm. In the central strip within ± 1.0 cm of the central sagittal plane the tolerance is relaxed. Three points on the phantom are used to correlate with the positioning system. The point "M" is the reference point for the center of mouth, "LE" is the left ear reference point (ERP), and "RE" is the right ERP. These points are used to give reproducible positioning of the EUT against the phantom.

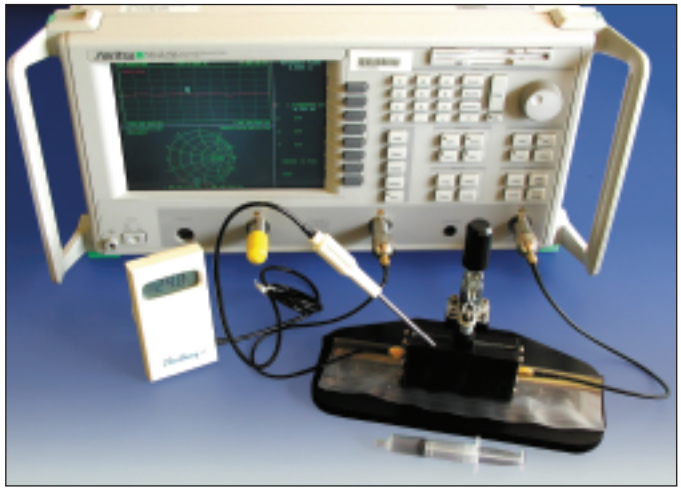


Figure 3: Fluid measurement with the TEM Line method

The SAM phantom can be either an upright head model or a dual sagittally bisected model, lying on its side or Twin phantom (the word "sagittal" refers to a join along the top of the skull between left and right halves). Both the upright and horizontal twin SAM phantoms are permitted under IEC62209 (Para 5.4.1) and IEEE1528-2003 (Para 5 .1.1). The upright phantom is more convenient with lower liquid volumes, exhibits minimal evaporation issues with organically based fluids, and greater ease of device positioning. As the measurement angle for the upright can be greater than 30 degrees to line normal to the surface of the phantom, additional measurement uncertainty needs to be analyzed and recorded.

Figure 4: Scanning an Upright SAM Phantom

Simulant Liquids

The phantom must contain a liquid whose dielectric properties are chosen to simulate human tissue – brain tissue for head measurements or body tissue for EUTs that are held next to or worn on the body. The liquid allows the probe to move freely within the phantom inner volume. Because these properties are frequency-dependent, a different liquid must be formulated for each test frequency band. The standards give specific requirements for conductivity and relative permittivity for each frequency. Since recipes for ingredients don't give exactly correct values, partly because of inaccuracies in mixing and partly because of variations in the properties of each ingredient, the actual values within a 5% tolerance must be measured and used in the testing.

There are three accepted methods in the standards for measuring the dielectric properties. They all require a vector network analyzer with S-parameter test set. The tissue sample holder can be either a slotted coaxial line with moveable probe, an open-ended coaxial transmission line probe, or a TEM-mode coaxial transmission line. The TEM Line technique is the most accurate as it is an absolute, not relative, method. (Figure 3)

Positioning Robot And Holder

The robotic system holding the probe has to be able to scan the whole

exposed volume of the phantom in order to evaluate the three-dimensional SAR distribution, without interfering with the SAR measurements. This requires a six axis fully articulated robot for SAM scanning. The accuracy of the probe tip positioning over the measurement area must be better than ± 0.2 mm. The positioning resolution – the step size at which the measurement system is able to perform measurements – should be 1 mm or less.

The EUT holder must permit the device to be positioned according to the standard definitions with a tolerance of ± 1° in the tilt angle. It should be made of low loss and low permittivity material(s): loss tangent <0.05 and permittivity < 5. Unfortunately for a mobile phone holder, this is not a sufficient criterion, as it is known that even low-loss plastic materials in the vicinity of certain types of handset antennas can have an influence on SAR measurements. The standards require a substitution test to verify that the holder does not perturb the readings.

E Field Measuring Probes

There are several important parameters to the measuring probe. It must be small enough to have no resonances over the frequency range of interest and so as to allow a precise spatial registration of the field. It must also not disturb the field structure in the liquid significantly. The measurement center should be as close to the tip of the probe as possible, to minimize the "dead volume" next to the phantom shell that cannot be measured directly.

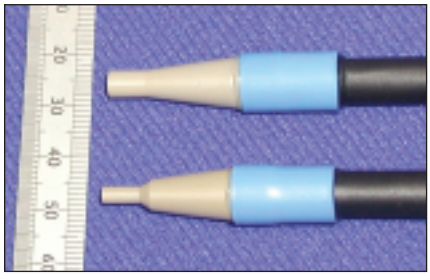


Figure 5

These features are provided by using very small, short dipole elements with integral diode detectors at their center, and taking the DC output from the diodes to a remote amplifier through high-resistance leads which are transparent to RF. The probe must also be sensitive, linear and isotropic. The minimum detection limit should be > 0.01W/kg and the maximum should be < 100W/kg. Within this range the linearity should be ±0.5dB.

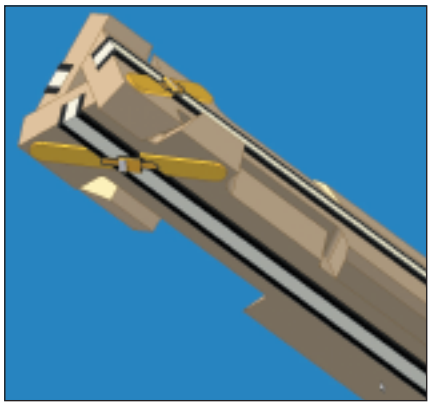


Figure 6

The standards recommend that the probe diameter should be no more than 8mm. Most systems have probe tip diameters of around 5mm. Probe size is especially critical for higher frequency SAR testing above 3GHz. The practical size limitation appears to be a 3mm diameter, which is sufficient to reduce uncertainties from field gradients and spatial disturbance.

Calibrating The Probe

To calibrate the probe it is necessary to apply a known SAR into the same dielectric liquid as will be used for the test. This normally is achieved using the waveguide method. Other methods include transfer calibration with temperature probes, and the use of reference antennas.

Figure 7

This method is the basis for providing an accurate calibration traceable to national standards for the probe.

Probe Linearity

Since the diode detectors used are non-linear – they respond to the square of the field at low levels, reducing to a direct proportionality at higher levels – a linearization process must be carried out on each of the three channels independently, in the measuring electronics. The linearization must be matched to each individual detector. The probe channel output signals are linearized using the following equation for each channel (x, y and z):

$$U_{lin} = U_{o/p} + (U_{o/p})^2 / DCP,$$

where U_{lin} is the linearized signal, $U_{o/p}$ is the raw output signal in voltage units and DCP is the diode compression potential in similar voltage units. DCP is determined from fitting this equation to measurements of U_{lin} versus source feed power over the full dynamic range of the probe.

Different calibration factors are needed for pulsed signals. At each power level, the individual channel outputs from the SAR probe are recorded at CW and then recorded again with pulsed modulation. The modulated power is calculated by applying a factor to the measured CW power (e.g. for GSM, this factor is 9.03dB). The DCP value for linearizing each of the individual channels is assessed separately and listed in the summary page of the calibration factors for each probe. Systems using probe amplifiers fast enough to measure the peaks of the modulation do not require correction for modulation.

Probe Isotropy

Probe isotropy is the degree to which the response of the probe is independent of the polarization and direction of propagation of the incident wave.

Axial isotropy is defined as "the maximum deviation of the SAR when rotating the probe along its main axis

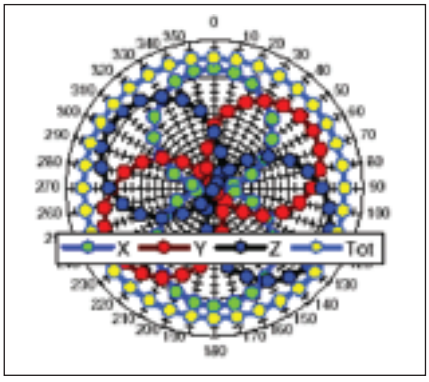


Figure 8

with the probe exposed to a reference wave impinging from a direction along the axis of the probe."

Hemispherical isotropy is "the maximum deviation of the SAR when rotating the probe along its main axis with the probe exposed to a reference wave with varying angles of incidence with regard to the axis of the probe in the half space in front of the probe." Isotropy checks can be performed in the calibration waveguide or in a jig which rotates the probe about the relevant axis.

The diagrams in Figure 9 show the probe response to fields applied from each direction: the first diagram shows the individual response characteristics of each of the three channels and the second diagram on the right shows the resulting probe sensitivity in each direction. The lowest values are blue and the maximum values are red. For this probe, the range is ± 0.43 dB.

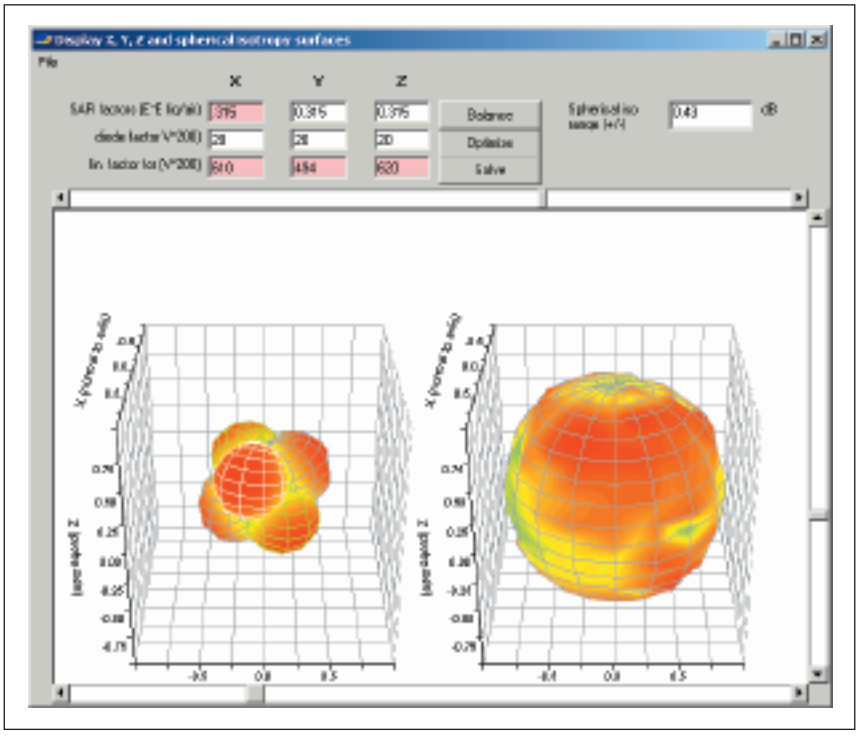


Figure 9

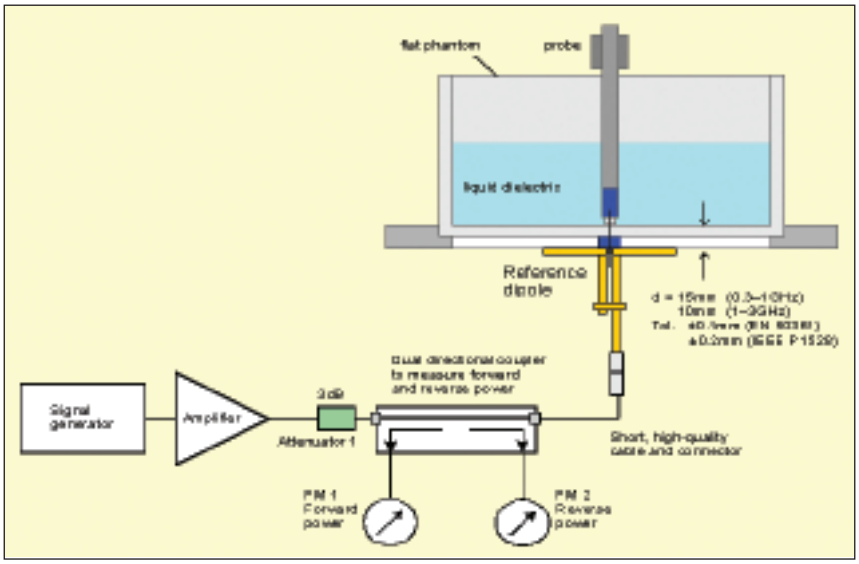


Figure 10

Control And Post-processing

The software package in a SAR measurement system has several important functions. It must decide the actual measurement grid based upon input from the test operator and knowledge of the shape of the phantom shell. This grid must then be used to control the position of the measurement probe through the positioning robot. The test operator has the opportunity to modify the geometrical data (grid position and spacing) before the control process. Registration of the probe position in relation to the shell is a vital part of this process. The software algorithm has to derive the expected worst-case locations within the phantom in the area of the EUT by interpolation and extrapolation from the initial results, and then control the three-dimensional final scan. Having acquired the final values within a limited volume, the spatial average and maximum levels then have to be calculated according to the methods allowed in the standards.

The standards require that the software's calculation algorithms are validated, i.e. that they produce correct results from a set of known input data. Four separate data files are available with the standards, with correct reference output values, to achieve this. Last but not least, the software must interface with the test operator in a user-friendly way. Visual representation of key stages of the process is important.

Validation And System Check

Validation is performed annually or whenever a major component of the system is changed. The system check or verification is performed whenever a compliance measurement is made.

The systems check set-up proves the operation and accuracy of the probe and positioner, and the correct composition of the liquid dielectric. It is performed before a compliance test at a frequency within ±10% of the test frequency of the target value of a 1 or 10g averaged SAR.

The target values are provided in the standards through calculation with specific phantom properties and separation distances. The validation system uses a flat phantom and the target values are listed for 1W power into reference dipoles of specified design. Thus validation tests the accuracy of the measuring probe and electronics, but not of the mechanical registration of the real phantom and scanning system.

Conclusion

With the continued proliferation of RF transmitting devices in a myriad of products that are demanded by modern society, the need for well-defined and repeatable measurement test procedures is paramount. Fortunately there has been significant progress with the international standards committees in this regard as it applies to safety and exposure aspects to the user and compatibility with other devices. The newly published SAR standards have provided a firm basis for the testing of most handset devices. Continued work by the project teams will encompass all other existing transmitting devices.

As new technologies and product applications enter the market, these standards will need to be reviewed and evolve. Concurrently, there is a continuing international effort to examine the possible effects of RF exposure over today's range of transmission and modulation schemes. ■

About The Author

David Seabury *is a Senior Business Development Manager for ETS-Lindgren and has been active with EMC and RF exposure products and markets since 1990. He is a member of SCC34SC2 and also the US TAG to IEC TC106 WG4.*

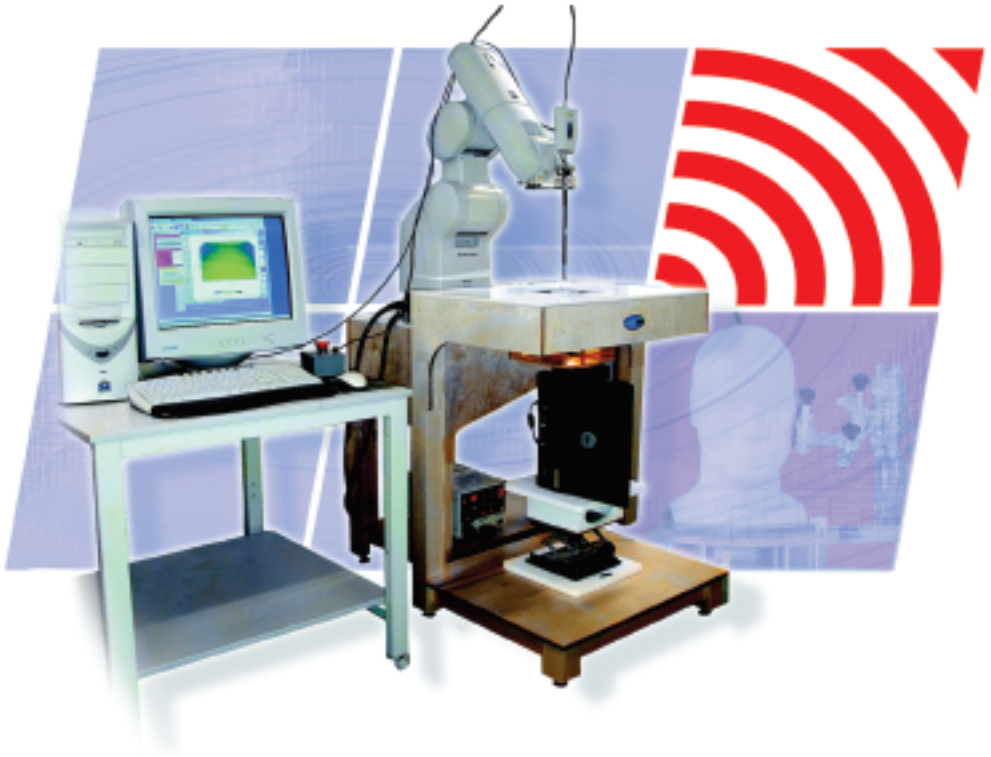
Additional Test Requirements For Wireless Devices Hearing Aid Compatibility (HAC)

As wireless device manufacturers and the carriers work to keep their products in compliance with the newly upgraded SAR requirements, they now have an additional deadline from the FCC for HAC. This applies to those devices held against the users head only and which have the potential to interact with hearing aids.

The basis of the requirement is ANSI C63.19: 2001, Methods of Measurement of Compatibility between Wireless Communications Devices and Hearing Aids. The FCC will require that manufacturers provide, starting in September 2005, a percentage of their offerings to meet certain E and H field emissions levels in the frequency range of 800 to 3000MHz. Additional requirements kick in the following year for magnetic field compatibility for handsets equipment with T-coils. The ANSI standard also contains procedures to evaluate hearing aid immunity to the wireless devices.

As the scanning and positioning requirements can be handled by most SAR systems, the vendors of those systems are offering additional hardware and software to meet the new standard along with suppliers of dedicated systems. HAC will utilize the SAR E and H field probes as they meet the requirements of a diameter less than 10mm and are fully isotropic. These probes will require additional calibration for scanning in air and not in the SAR simulant fluids. The SAR device holders and validation dipoles are also common. Essentially only new control and reporting software is required. In many cases both at the manufacturers and independent labs, the SAR compliance groups will provide this testing. It also is probable that in time reporting to the FCC will be accomplished through the Telecommunications Certifications Bodies (TCB) currently handling the SAR applications.

As of this writing, ANSI C63.19 is under revision consideration and the committee is working with the Alliance for Telecommunications Industry Solutions (ATIS) to refine the testing procedures of the standard.



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