Assessing The Isotropy of Personal Electromagnetic Field Monitors

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Personal electromagnetic field monitors are widely used to protect workers from over exposure to electromagnetic fields, and also for dosimetric studies. These monitors are worn on the body and provide an audible warning when high exposures are encountered and some have data logging functions. This paper presents a test method for testing the isotropic performance of these monitors when worn on the body which utilizes a solid silicon-rubber head torso phantom exposed in a GTEM 1750, and presents results for a commercially available device. The techniques for assessing the dielectric properties of the phantom material are also presented.

1. INTRODUCTION

Personal electromagnetic field monitors are field sensors that are worn on the body to monitor a person's exposure. Typically, they are worn on a belt clip or shirt pocket, and some are worn on an arm band. These devices are used to protect workers who are potentially exposed to high levels of electromagnetic fields, such as those maintaining transmitter masts, or for monitoring peoples' exposure for research studies into the effects of EMFs. Devices used to protect workers provide an audible warning at predefined exposure levels (alarm threshold), and additionally they can provide data logging functions allowing exposure data to be compiled for each worker. The monitors have shaped-frequency response broadband detectors, so that the exposure data at any frequency is given in terms of a percentage of the applicable exposure limits for power density, for example [1], regardless of the transmission frequency. Monitors used for research studies are band-selective devices, so that the nature or source of the exposures can be determined. In the near-field of the transmitter or source, measurement of the incident E-field or H-field alone will not yield the power density as the wave impedance is not known. Therefore, some monitors use a surface charge sensor to measure the induced current in the body as this provides a better exposure metric, and it also yields greater sensitivity since effectively the body forms a receive antenna. For body-worn monitors it is important that the effect of the body on the sensitivity and receiving pattern of the sensors when the device is worn on the body is measured. This paper presents a measurement technique for determining the patterns of the body-mounted monitors and presents the results for a commercially available device over the frequency range 0.01 to 5.8 GHz.

2. EXPERIMENTAL METHOD

For this work we use a head and torso phantom which is made of carbon-loaded silicon rubber. Using a phantom allows measurements to be made at high exposure levels without the safety concerns, and also has practical advantages over mounting the monitors on a volunteer for the measurements. Also, it provides a standardized and repeatable test method. The target dielectric properties of the phantom are equivalent to those of dry-skin, as specified for over-the-air (OTA) testing of mobile telecommunications devices [2]. Accurate measurement of the dielectric properties of the solid phantom materials is difficult as they may be inhomogeneous and anisotropic, and direct conduction effects can occur in materials with high carbon loading, effectively shorting out the measurement probe. Here we use a waveguide fed cavity method to determine the dielectric properties of this material for 1.7 GHz to 4 GHz, as the near linear polarized field in the waveguide allow the material anisotropy to be assessed, and the method tests a larger volume of material than is the case for coaxial probe techniques [3]. Computer simulation showed that the side walls of the cavity have little effect for the measurement of the torso block (dimensions 300 mm by 300 mm by 185 mm), so that the material is measured between parallel metal plates, one of which has the waveguide feed at the center. The complex permittivity is obtained from the input reflection coefficient to the waveguide using a modal decomposition analysis [4].

For the azimuth pattern measurements, the phantom was mounted on a fiberglass tube to a floor-mounted motorized rotation stage, as shown in Fig 1. Up to 100 MHz, the assembly was exposed in a Gigahertz Transverse Electric and Magnetic (GTEM) cell [5], which is a tapered rectangular transmission line terminated with distributed load or a resistor board and pyramidal radio absorbing material (RAM). The maximum distance between the floor of the device and the inner conductor or septum is 1750 mm. The GTEM cell provides an approximately plane wave exposure up to 1.6 GHz, and has the advantage for this application that at low frequencies higher fields are generated for a given input power than is the case for an antenna in a fully anechoic room. At the midpoint between the floor and the inner conductor, the electric field in the GTEM is related to the input power, P_{in}, by

$$E = \frac{\sqrt{P_{in} Z_0}}{d} \tag{1}$$

where Z_0 is 50 Ω , the characteristic impedance of the GTEM, and d is the septum height at the position of the phantom. The phantom was connected to the floor of the GTEM using an earthing strap, so that the induced currents in the phantom flow to ground, which is what will happen for the person. This is particularly important, as the field monitor tested uses a surface charge sensor to detect the induced current in the body (rather than the incident field) at these frequencies, and will have lower sensitivity when used in free-space or on the unearthed phantom.

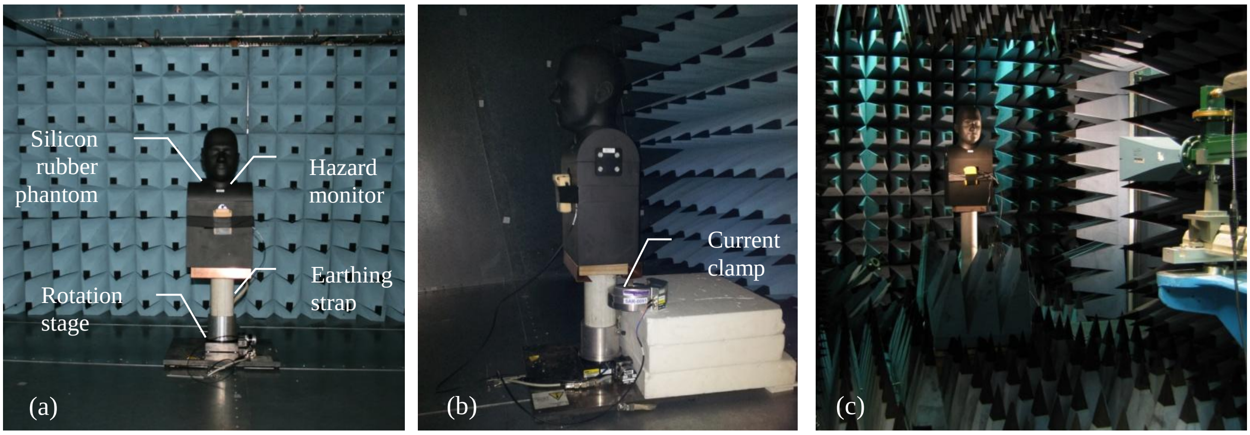

Figure 1: (a) Personal hazard monitor mounted on phantom inside the GTEM1750, (b) Current clamp used to monitor the current flowing through the earthing strap to ground (c) Phantom in anechoic room with transmit horn antenna.

Measurements were made with the monitor mounted on the front and also the side of the phantom, and the input power adjusted to give readings of approximately 50% of the occupational exposure limit [1]. The field in the GTEM was calibrated, without the phantom present, against the input power using a field meter. The phantom was rotated in 15-degree steps to obtain the azimuth patterns at frequencies of 10 MHz, 13.56 MHz, 27.12 MHz, 40.68 MHz and 100 MHz. In addition, a limb current meter was used to measure the current that was flowing to ground through the earth strap, so that the personal monitor readings could be related to the induced current in the phantom.

For frequencies of 2.4 GHz, 3.5 GHz and 5.8 GHz the phantom was placed in an anechoic room and the field was generated using a standard gain horn antenna, Fig 1(c). Azimuth patterns were measured with the monitor in free-space as well as mounted on the front of the phantom torso.

3. MEASUREMENT RESULTS

Fig. 2 shows the results of the dielectric measurements made at the end of the torso block for two source polarizations. The results indicate that over the frequency range 1.7 GHz to 4 GHz the real permittivity and conductivity correspond to approximately 2/3rds of the values for muscle, which is close to the body-averaged values for a male. The standard deviation for the measurements made on all sides and orientations of the block is 2.5 for real permittivity and 0.25 S/m for conductivity, indicating that the material is inhomogeneous.

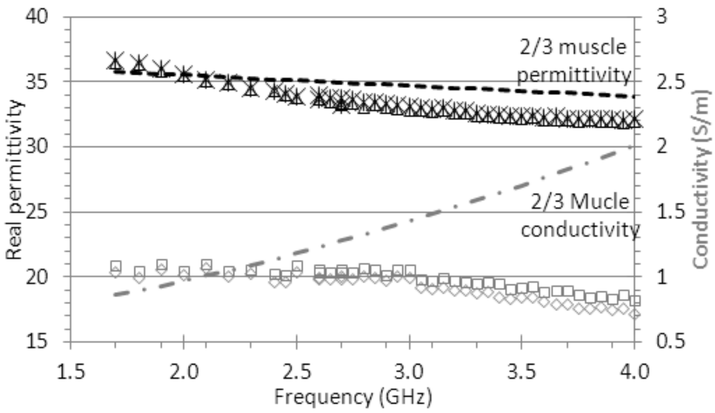

Figure 2. Measured dielectric properties of the phantom torso.

Fig. 3 (a) and (b) show the azimuth pattern (dB) at the different frequencies measured in the GTEM cell with (a) the monitor mounted on the front of the torso, and (b) the monitor mounted on the side of the torso. Better isotropic performance is obtained when the monitor is mounted on the front of the torso than is the case for when mounted on the side of the torso. For the front-mounted position, the isotropy is within ± 3 dB of the mean sensitivity in the azimuth plane. This device has the alarm threshold at 50% of the relevant limit, so that is conservative with respect to the limits even accounting for the isotropy error, provided that the calibration of sensitivity corresponds to the mean of the azimuth rotation.

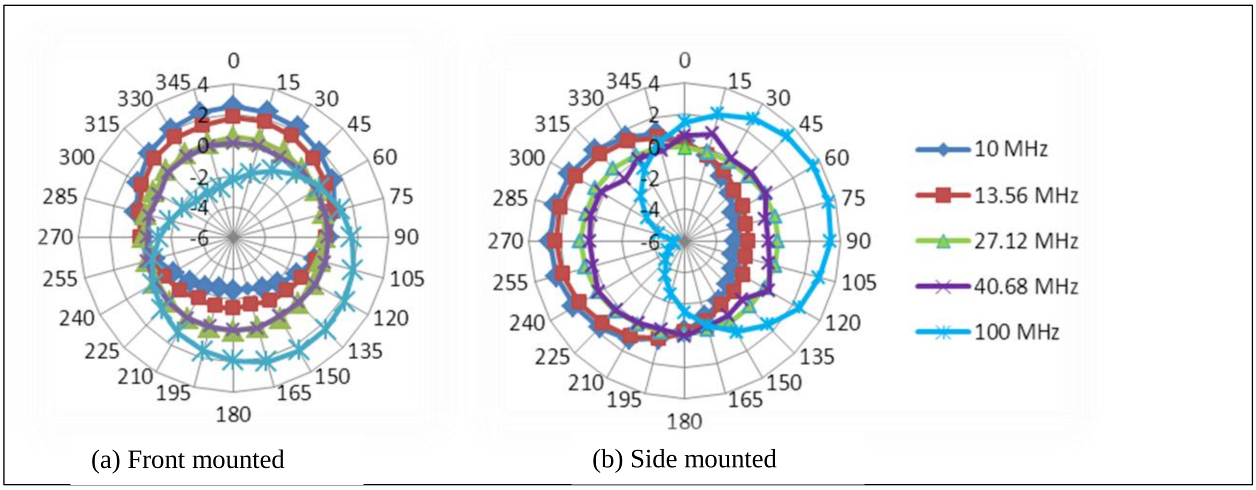

Figure 3. Isotropic performance of the personal hazard monitor when mounted on (a) the front of the phantom torso, and (b) when mounted on the side of the phantom torso at different frequencies.

Fig.4 shows the azimuth pattern (dB) of the monitor at 2.45 GHz, 3.5 GHz and 5.8 GHz in free-space and when mounted on the front of the torso. The sensor has a directive pattern in free-space, probably to minimize the change in sensitivity when worn in proximity to the body. The phantom effectively blocks the signals for rotation angles greater than ± 90º, and the isotropy is within ± 3 dB only over azimuth rotations of ± 30º from the position where the phantom faces the transmit antenna. Thus, for line-of-sight transmissions the monitor must be located on the side of the person that is facing the source to correctly monitor the exposure level. It would be expected that the isotropic performance would be better in multi-path environments.

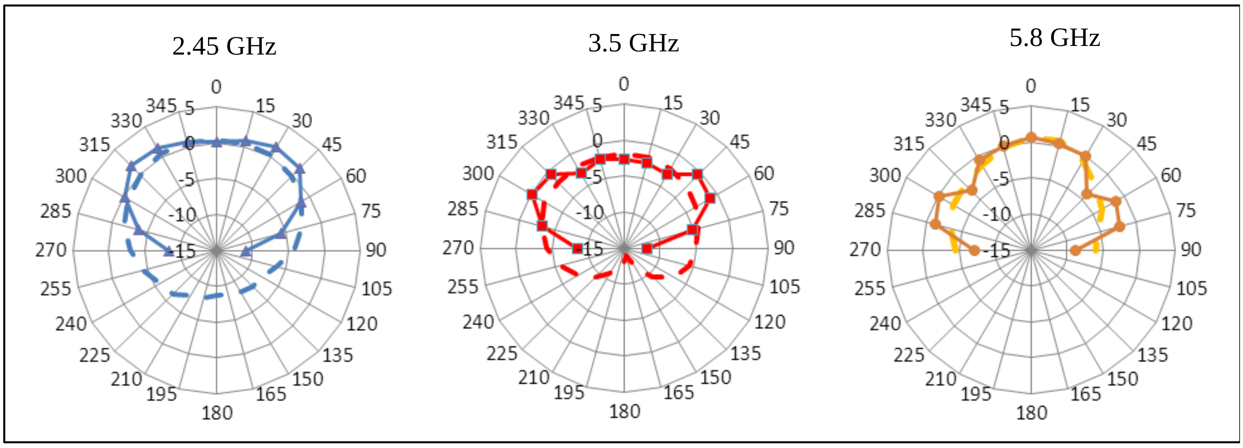

Figure 4. Isotropic performance of the personal hazard monitor in free-space (dashed line) and mounted on the front of the phantom torso (solid line).

In the GTEM, the incident unperturbed field strength which cause the alarm to sound (5 W/m^2 threshold setting) is shown in Fig. 5, for the monitor mounted on the front of the torso and facing the source. An incident power density of 2.5 to 3 W/m^2 is required to make the alarm sound at the position of maximum sensitivity, so that the mean level for the azimuth rotation will be close to 5 W/m^2 as required. It is apparent that the grounded phantom acts as a monopole antenna, with resonant frequency at 40 MHz, and that the monitor responds to the induced current rather than the incident power density at these frequencies. Note that the current to ground are considerably higher for this set up than the contact currents that would be expected for the person (the occupational exposure limit is 40 mA [1]) as the conducing earth strap has much higher conductivity that the lower body of a person. The height of the person might be expected to affect the sensitivity of the monitor for frequencies where the height is close to $\lambda/4$.

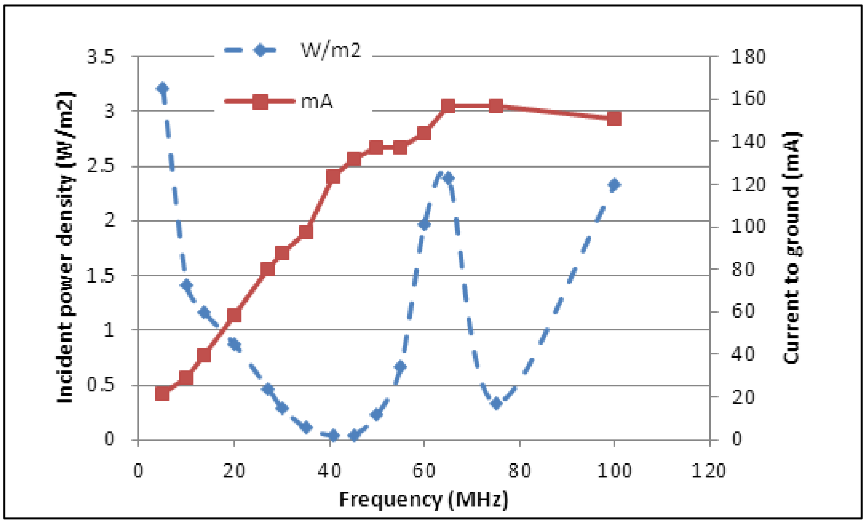

Figure 5. Graph of the incident power density and current to ground when the monitor indicates 50% of occupational limit. The head torso acts as a monopole antenna with resonant frequency of 40 MHz (the overall height of the phantom from the floor was 1.1m)

4. CONCLUSIONS

We have presented a measurement technique for assessing the isotropic performance of personal electromagnetic field monitors that are worn on the body, based on the use of a solid silicon rubber head plus torso phantom exposed in a GTEM 1750 cell. This technique allows the azimuth patterns to be measured quickly, and high field levels can be generated efficiently. Tests made on a commercially available monitor indicate the isotropic performance is better when the device is worn on the front of the torso compared to the side of the torso, and that the isotropy error is within ± 3dB, giving confidence in the validity of the alarm for preventing exposures above the occupational limits. At microwave frequencies, the monitor must be on the side of the person facing the transmitter to give correct readings, as the torso effectively blocks the signals from the transmitter.

ACKNOWLEDGMENT

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