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# Safety Aspect Analysis of Helmet-Mounted Millimeter Wave Radios

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## ABSTRACT

Measurements of millimetric wave (MMW) power density from two-helmet-mounted MMW radiating horn antennas were made at various distances on the three axes. These three axes are representing three planes: *(i)* in the direction of propagation (Z-axis), *(ii)* horizontal axis perpendicular to the direction of propagation (Y-axis), *i.e.*, 15 cm to the left or right of Z-axis, and *(iii)* vertical axis (X-axis) also perpendicular to the direction of propagation and extending up and down an imaginary central reference line passing through the centre of the horn and the centre of the microwave measuring probe. Measurements were also made inside the helmet close to the metallic plate at 17 locations and 10 cm away from it. The Narda-8723 broadband isotropic microwave probe [frequency of operation (0.3-40 GHz) power density range 0.05-100 mW/cm$^2$] was placed at various distance points marked at 15 cm intervals and also at distances of relevance on Z-axis. For each of the distance points on Z-axis, measurements were taken at 7 probe locations on X-axis. For Y-axis measurements, 4 probe locations were selected (on vertical or X-axis). The results revealed no leakage of microwave power inside the helmets. In the transmitting mode of operation, there was a great variability of microwave power emitted closest to the horn antennas (2.5-5.0 mW/cm$^2$ and 6.0-10.5 mW/cm$^2$ for helmet Nos. 1 and 2, respectively). As the distance from the horn antenna increased in the direction of propagation, the power density dropped to 0.04 mW/cm$^2$ or 0.075 mW/cm$^2$ maximum value at 1 m. As the values recorded are within American National Standards Institute (ANSI) safety guidelines (10 mW/cm$^2$) at 35 GHz, there is no reason for any alarm. As a precautionary measure, a minimum safe distance of 1 m should be maintained from the horn antenna.

## 1. INTRODUCTION

The Defence Electronics & Applications Laboratory (DEAL), Dehradun, designed and fabricated helmet-mounted millimetric wave (MMW) radiating horn antennas for soldier-to-soldier communication in the field area.

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These helmets house the MMW source that operates at 35 GHz in the receiving and the transmitting modes. The source is shielded by a metallic plate which is nicely fixed to the sides inside the helmet. The metal being a good reflector of MMW prevents leakage towards the head of the wearer. However, the apprehensions expressed by the users of these helmets regarding their operational safety and concern for any leakage of MMW power towards the head of the wearer initiated this study. Such fears expressed by the soldiers could lead to delay in inducting the helmets into practice, and hence the Defence Institute of Physiology & Allied Sciences (DIPAS), Delhi, was requested by the DEAL, Dehradun, to carry out measurements of MMW power inside the helmets. Two helmets were provided for this study. It was also felt imperative to know the emission patterns from the horn antenna so as to establish the safety aspect of the helmets before inducting the same for soldier-to-soldier communication in the field areas. This study is an attempt to clear doubts and apprehensions in the minds of users along with a word of caution in terms of safe distance to be maintained from such a unit.

The interaction of MMW range of electromagnetic radiation with biological tissues is different from other types of nonionizing radiation, as almost all of the incident energy from MMW is absorbed within the first millimeter of the tissue as the wavelengths in tissues like skin become commensurate with skin pore diameter and thickness of epidermis[1], etc.

The biological tissues are non-homogeneous and do not have flat surfaces. Most of the experiments were conducted by irradiating objects in the near-field of horn antennas. Some horn antennas produce non-uniform patterns of energy distribution in the irradiated objects[2] and a slight shift in microwave frequency (0.5 per cent) can lead to marked change in the field distribution from a single sharp maximum located along the beam axis of the horn to two sharper maxima located at lateral distances of 5-7 mm from the centre[3]. Hot spots as big as 0.05-0.25 $cm^2$ with local synthetic aperture radar (SAR) values exceeding 1 kW/kg at 10 $mW/cm^2$ can be created under near-field exposure conditions with horn antennas having 1-10 $cm^2$ aperture.

## 2. MATERIALS & METHODS

The helmet-mounted microwave radiating horn antenna was placed on a wooden flat surface on which markings were made at intervals of 15 cm, up to a distance of 145 cm representing the direction of propagation/beam axis/Z-axis. Additional points marked were at 21, 26 and 29 cm, which are the distances of relevance as explained below and also at 100 cm. Markings were also made at 15, 30 and 45 cm to the left or right of each point on the Z-axis line, representing the Y-axis/horizontal axis. This axis is parallel to the smaller dimension or the breadth of the horn antenna. The magnetic field vector points in this direction. The third axis is a virtual axis and is imagined to extend vertically, perpendicular to the direction of propagation, representing the X-axis/vertical axis. This axis is parallel to the longer dimension/length of the horn antenna and the electrical field vector points in this direction. A central line of reference refers to an imaginary line presumed to be passing through the centre of the radiating horn antenna and the centre of the microwave measuring probe in the direction of propagation of MMW.

MMW power density measurements were carried out by placing Narda-8723 broadband isotropic microwave probe (frequency range 0.3-40 GHz, radiation measuring meter model-8711, driven by a 12 V power supply, power density range 0.05-100 $mW/cm^2$) at various locations as mentioned below. The sensitivity of the meter can be adjusted in 3 scales (1, 10 and 100 $mW/cm^2$).

### 2.1. Probe Locations

(*a*) Inside the helmet, the microwave probe was placed closest to the metallic plate and measurements were made at 17 locations (the centre of the probe matching with each point, Fig. 1).

(b) Approximately 10 cm away from the metallic plate at the above locations.

(c) Closest to the radiating horn antenna in the direction of propagation, the probe was moved up and down to record the maximum and minimum readings in the vertical axis. In the horizontal axis, *i.e.* 3 cm to the left and 4 cm to the right, no field could be detected and hence no measurements were carried out beyond this point.

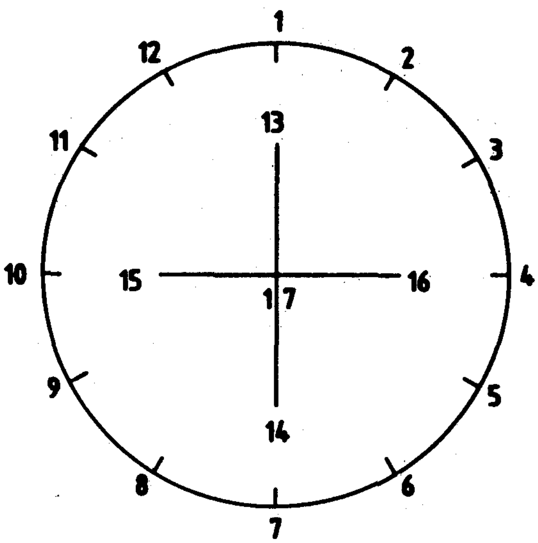


**Figure 1. Measurements made inside the helmet (Nos. 1 and 2) at various positions.**

| Position | | Power density (mW/cm$^2$) |
|---|---|---|
| 1 | 12 O' Clock | 0.00 |
| 2 | 1 O' Clock | 0.00 |
| 3 | 2 O' Clock | 0.00 |
| 4 | 3 O' Clock | 0.00 |
| 5 | 4 O' Clock | 0.00 |
| 6 | 5 O' Clock | 0.00 |
| 7 | 6 O' Clock | 0.00 |
| 8 | 7 O' Clock | 0.00 |
| 9 | 8 O' Clock | 0.00 |
| 10 | 9 O' Clock | 0.00 |
| 11 | 10 O' Clock | 0.00 |
| 12 | 11 O' Clock | 0.00 |
| 13 | In between 1 and 17 | |
| 14 | In between 7 and 17 | |
| 15 | In between 10 and 17 | |
| 16 | In between 4 and 17 | |
| 17 | Central point | |

**Table 1(a). Measurements made in beam axis/Z-axis/direction of propagation of helmet-mounted microwave radiating horn antenna (helmet No. 1)**

| Distance from the horn (cm) | Range (mW/cm$^2$) | | Mean values (mW/cm$^2$) |
|---|---|---|---|
| | Min. | Max. | |
| Closest to horn | 2.500 | 5.000 | 4.180 |
| 15 | 0.500 | 0.750 | 0.650 |
| 30 | 0.175 | 0.250 | 0.230 |
| 45 | 0.075 | 0.140 | 0.107 |
| 60 | 0.050 | 0.090 | 0.067 |
| 75 | 0.025 | 0.060 | 0.043 |
| 90 | 0.010 | 0.040 | 0.026 |
| 100 | 0.013 | 0.040 | 0.022 |
| 105 | 0.013 | 0.025 | 0.017 |
| 120 | 0.010 | 0.020 | 0.014 |
| 135 | 0.010 | 0.013 | 0.011 |
| 145 | – | No deflection | – |

**Table 1 (b). Measurements made in beam axis/Z-axis/direction of propagation of helmet-mounted microwave radiating horn antenna (helmet No. 2)**

| Distance from the horn (cm) | Range (mW/cm$^2$) | | Mean values (mW/cm$^2$) |
|---|---|---|---|
| | Min. | Max. | |
| Closest to horn | 6.000 | 10.500 | 8.160 |
| 15 | 1.500 | 2.500 | 1.770 |
| 30 | 0.425 | 0.600 | 0.480 |
| 45 | 0.200 | 0.300 | 0.250 |
| 60 | 0.150 | 0.200 | 0.165 |
| 75 | 0.100 | 0.125 | 0.105 |
| 90 | 0.075 | 0.100 | 0.095 |
| 100 | 0.075 | 0.075 | 0.075 |
| 105 | 0.050 | 0.075 | 0.060 |
| 120 | 0.025 | 0.050 | 0.045 |
| 135 | 0.025 | 0.050 | 0.040 |
| 145 | 0.025 | 0.050 | 0.035 |

*(d)* At various distance points on the Z-axis (15 cm intervals and distances of relevance up to a distance of 145 cm) as shown in Tables 1 and 3 and Fig. 2.

*(e)* In the Y-axis, 15, 30 and 45 cm to the left and right of each Z-axis point as mentioned in Tables 2 and 3 (no field could be detected at or beyond 30 cm, except negligible values at three places either to the left or right of the Z-axis. Hence only 15 cm values are mentioned).

*(f)* In the X-axis, measurements were carried out at 7 probe locations, 3 each up (7 cm) or down (8 cm) the central probe location (probe location 4, where the centres of the measuring probe and the horn antenna are in alignment with each other and a central reference line is imagined to be passing through their centres) at each distance point on the Z-axis (Table 4 and Fig. 3).

*(g)* On the Y-axis, the vertical field measurements (X-axis measurements) were taken for 15 cm distance points (Table 2). Only 4 probe locations were chosen (location 1 is at the same level as location 4 on the Z-axis but perpendicular to it. The fourth position is 8 cm below this level. The field was negligible above the probe location 1).

## 3. RESULTS & DISCUSSION

Certain predictions for worst situations of inadvertent MMW exposure arising with the horn antennas operating in the transmitting mode are enumerated.

The worst situation of inadvertent exposure occurs when two persons both wearing the helmet-mounted radios operating in the transmission mode stand close to each other at a minimum convenient distance. This distance was

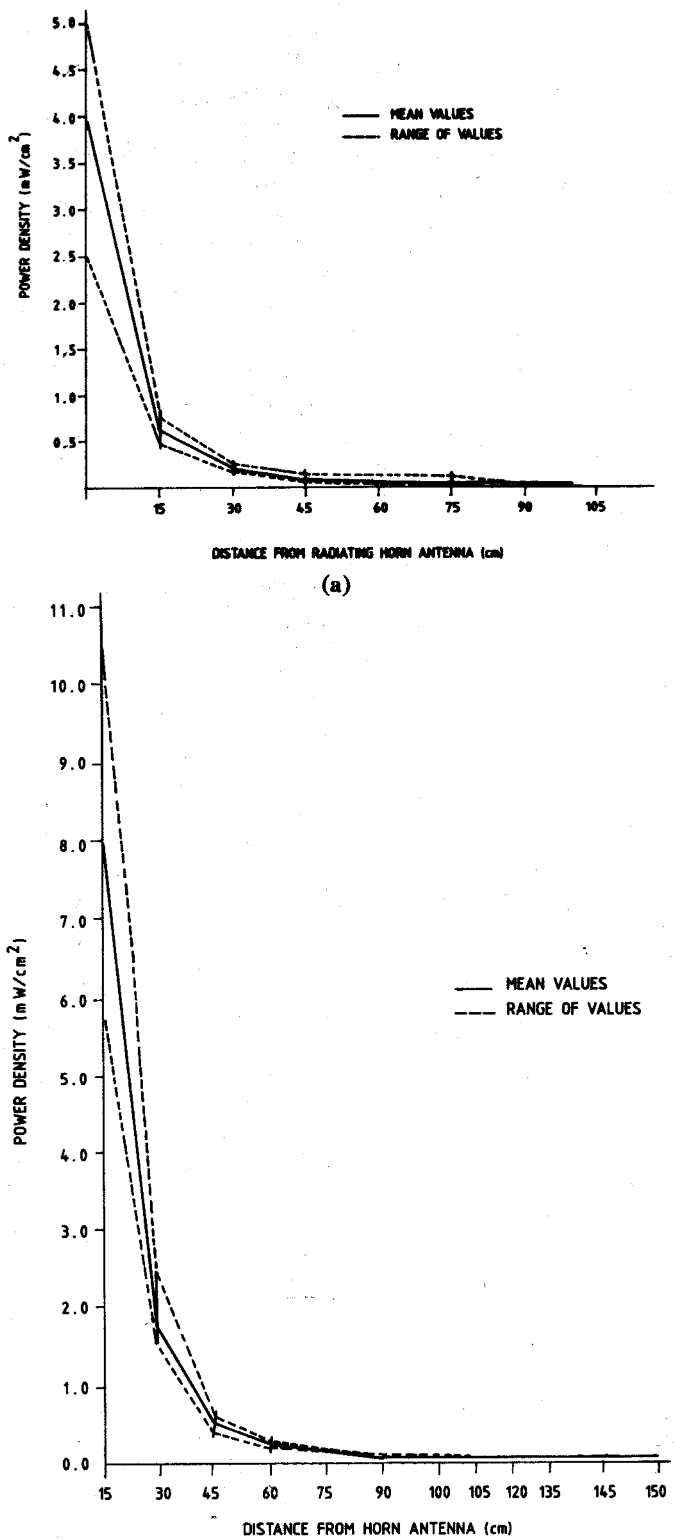


**Figure 2. Measurements of microwave power density (mW/cm$^2$) made at various distances in the direction of propagation from microwave radiating helmet-mounted horn antenna. (a) helmet No. 1, and (b) helmet No. 2.**

**Table 2 (a). Horizontal axis/Y-axis measurements of microwave power density (mean values, mW/cm$^2$) at various distance points on the Z-axis (helmet No. 1)**

| Y-axis | Probe locations | Distance on Z-axis (cm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *15 | 30 | 45 | 60 | 75 | 90 | 100 | 105 | 120 | 135 | 145* |
| 15 cm (left) | 1 | 0.0 | 0.008 | 0.017 | 0.025 | 0.020 | 0.020 | 0.018 | 0.015 | 0.003 | 0.015 | 0.003 |
| | 2 | 0.0 | 0.000 | 0.013 | 0.038 | 0.013 | 0.020 | 0.025 | 0.015 | 0.010 | 0.010 | 0.003 |
| | 3 | 0.0 | 0.000 | 0.011 | 0.037 | 0.013 | 0.025 | 0.025 | 0.015 | 0.010 | 0.013 | 0.003 |
| | 4 | 0.0 | 0.000 | 0.017 | 0.042 | 0.033 | 0.038 | 0.033 | 0.025 | 0.025 | 0.013 | 0.003 |
| 15 cm (right) | 1 | 0.0 | 0.013 | 0.003 | 0.012 | 0.030 | 0.019 | 0.020 | 0.020 | 0.020 | 0.012 | 0.003 |
| | 2 | 0.0 | 0.000 | 0.019 | 0.033 | 0.031 | 0.021 | 0.020 | 0.020 | 0.015 | 0.015 | 0.008 |
| | 3 | 0.0 | 0.000 | 0.008 | 0.037 | 0.031 | 0.026 | 0.025 | 0.025 | 0.02 | 0.025 | 0.008 |
| | 4 | 0.0 | 0.000 | 0.011 | 0.050 | 0.050 | 0.043 | 0.050 | 0.050 | 0.036 | 0.028 | 0.008 |

At < 30 cm distance on the Z-axis, microwave power measured 15 cm to the left or right (Y-axis) was negligible.

Probe location 1 is the central probe location on Y-axis.

*_* Distance points on Z-axis.

**Table 2 (b). Horizontal axis/Y-axis measurements of microwave power density (mean values, mW/cm$^2$) at various distance points on the Z-axis (helmet No. 2)**

| Y-axis | Probe locations | Distance on Z-axis (cm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 15* | 30 | 45 | 60 | 75 | 90 | 100 | 105 | 120 | 135 | 145* |
| 15 cm (left) | 1 | 0.0 | 0.000 | 0.025 | 0.062 | 0.056 | 0.056 | 0.043 | 0.043 | 0.043 | 0.025 | 0.012 |
| | 2 | 0.0 | 0.018 | 0.093 | 0.100 | 0.075 | 0.068 | 0.056 | 0.050 | 0.056 | 0.050 | 0.050 |
| | 3 | 0.0 | 0.012 | 0.093 | 0.100 | 0.100 | 0.087 | 0.075 | 0.075 | 0.062 | 0.050 | 0.056 |
| | 4 | 0.0 | 0.006 | 0.093 | 0.150 | 0.150 | 0.118 | 0.100 | 0.106 | 0.081 | 0.062 | 0.075 |
| 15 cm (right) | 1 | 0.0 | 0.000 | 0.006 | 0.031 | 0.037 | 0.037 | 0.031 | 0.037 | 0.025 | 0.025 | 0.006 |
| | 2 | 0.0 | 0.000 | 0.018 | 0.043 | 0.050 | 0.050 | 0.043 | 0.050 | 0.050 | 0.043 | 0.030 |
| | 3 | 0.0 | 0.000 | 0.018 | 0.043 | 0.043 | 0.043 | 0.050 | 0.050 | 0.050 | 0.043 | 0.050 |
| | 4 | 0.0 | 0.000 | 0.012 | 0.043 | 0.062 | 0.056 | 0.056 | 0.075 | 0.050 | 0.050 | 0.050 |

At < 30 cm distances on the Z-axis, microwave power measured 15 cm to the left or right (Y-axis) was negligible.

Probe location 1 is the central probe location on Y-axis.

*_* Distance points, on Z-axis.

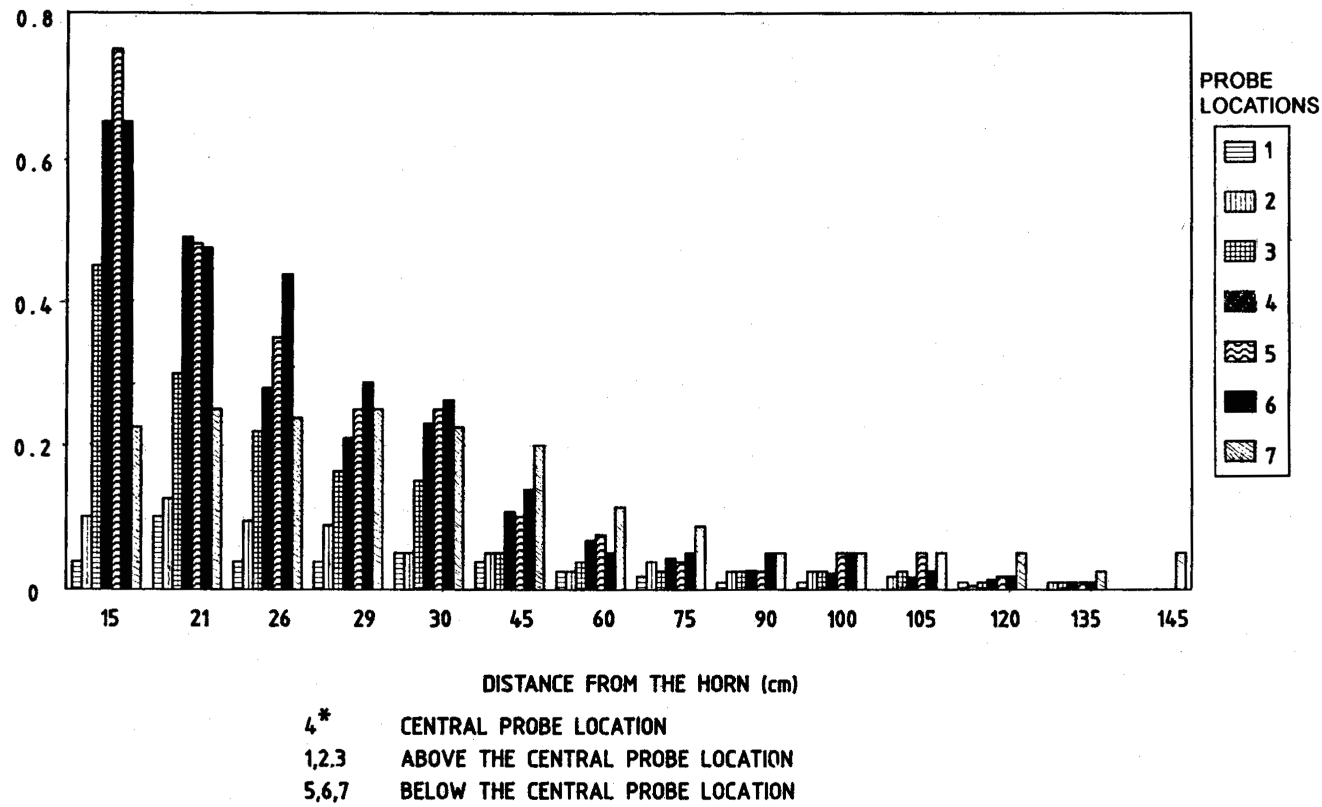


**Figure 3(a).** **Mean values of X-axis/vertical axis readings ($mW/cm^2$) at various distances from the helmet-mounted microwave radiating horn antenna (helmet No. 1).**

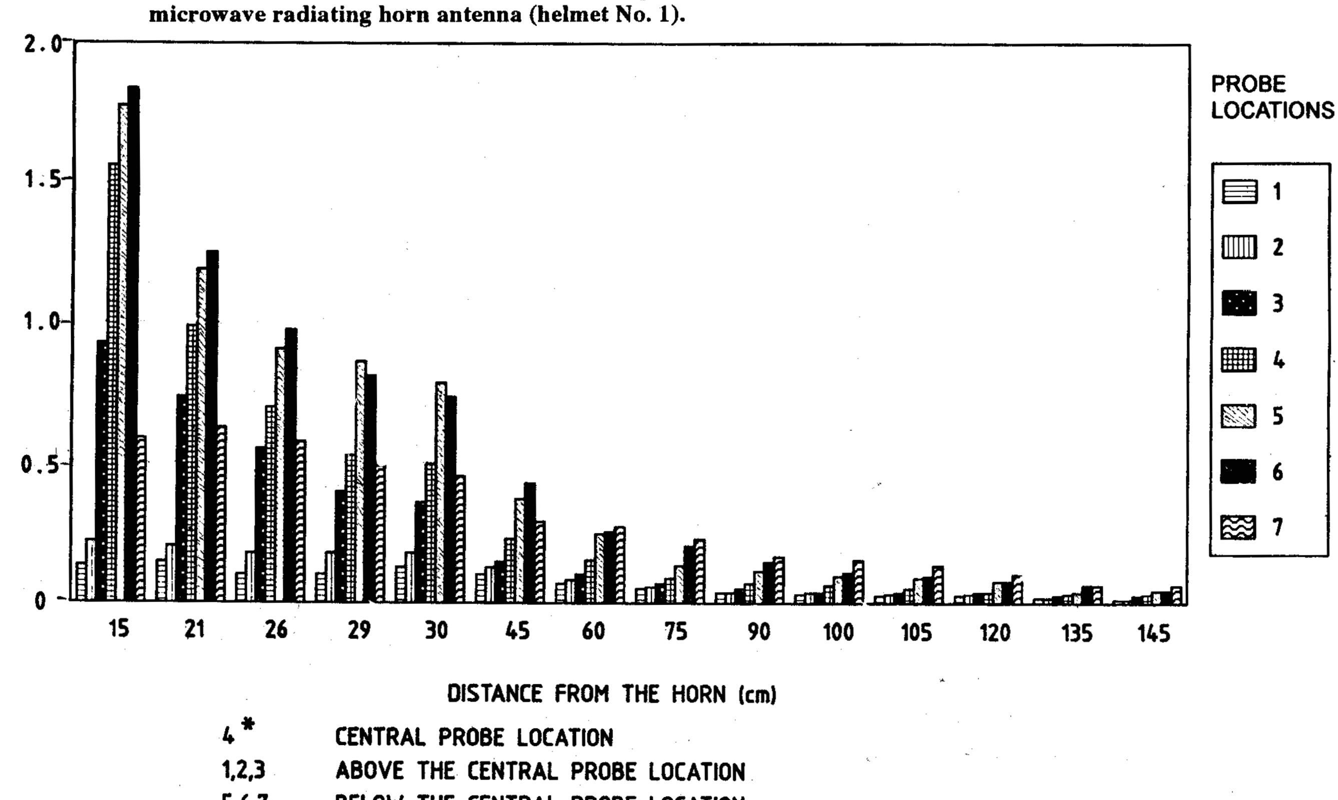


**Figure 3(b).** **Mean values of X-axis/vertical axis readings ($mW/cm^2$) at various distances from the helmet-mounted microwave radiating horn antenna (helmet No. 2).**

**Table 3 (a). Measurements of microwave power density (mean values, mW/cm$^2$) made in Z-axis* and Y-axis** at distances of relevance from the helmet-mounted microwave radiating horn antenna (central probe location) for helmet No. 1**

| Distance (cm) | 15 cm left (on Y-axis) (mW/cm$^2$) | At the centre (on Z-axis) (mW/cm$^2$) | 15 cm right (on Y-axis) (mW/cm$^2$) |
|---|---|---|---|
| 21 *(a)* | 0.000 | 0.49 | 0.000 |
| 26 *(c)* | 0.000 | 0.28 | 0.000 |
| 29 *(d)* | 0.000 | 0.21 | 0.000 |
| 30 *(b)* | 0.008 | 0.23 | 0.013 |

Z-axis*: Axis in the direction of propagation.
Y-axis**: Horizontal axis, perpendicular to Z-axis.

**Table 3 (b). Measurements of microwave power density (mean values, mW/cm$^2$) made in Z-axis* and Y-axis** at distances of relevance from the helmet-mounted microwave radiating horn antenna (central probe location) for helmet No. 2.**

| Distance (cm) | 15 cm left (on Y-axis) (mW/cm$^2$) | At the centre (on Z-axis) (mW/cm$^2$) | 15 cm right (on Y-axis) (mW/cm$^2$) |
|---|---|---|---|
| 21 *(a)* | 0.0 | 0.97 | 0.0 |
| 26 *(c)* | 0.0 | 0.71 | 0.0 |
| 29 *(d)* | 0.0 | 0.55 | 0.0 |
| 30 *(b)* | 0.0 | 0.48 | 0.0 |

Z-axis* : Axis in the direction of propagation.
Y-axis** : Horizontal axis perpendicular to Z-axis.

measured in 5 pairs of subjects of similar and dissimilar heights (> 1 in.). The distance (a) was measured approximately from the base of the horn of the helmet of wearer No. 1 to the base of the horn of the helmet of wearer No. 2. In case of dissimilar heights, the taller person was taken as wearer No. 1. The distance varied with various positions of the head. With maximum flexion of the head of wearer No. 1, the microwave beam falls invariably on the middle of the chest (distance b) of wearer No. 2, who is made to look straight. However, if wearer No. 2 also changes his head position, thus projecting another beam of microwaves, intersecting the first one from the other wearer, then more complicated standing waves are created whose power intensities are difficult to predict. With two persons of dissimilar heights, the beam from the horn of the helmet from the taller person falls on the nose of the shorter person with maximum flexion of the head. With intermediate positions of the head, the beam falls on the eyes of the shorter person. There is also a possibility of greater exposure risk to the eyes of the shorter person as the taller one has a natural tendency to look down and the shorter one to look up while talking. The distances (c & d) with two intermediate positions of the head were also noted in five pairs of subjects.

**Table 4(a). Vertical axis/X-axis measurements of microwave power density (mean values, mW/cm$^2$) at various distances from the helmet-mounted microwave radiating horn antenna (helmet No. 1)**

| Distance from the horn (cm) | Mean values (mW/cm$^2$) at different probe locations | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4* | 5 | 6 | 7 |
| 15 | 0.038 | 0.100 | 0.450 | 0.650 | 0.750 | 0.650 | 0.225 |
| 21 | 0.100 | 0.125 | 0.300 | 0.490 | 0.481 | 0.475 | 0.250 |
| 26 | 0.038 | 0.094 | 0.219 | 0.280 | 0.350 | 0.438 | 0.238 |
| 29 | 0.038 | 0.088 | 0.163 | 0.210 | 0.250 | 0.288 | 0.250 |
| 30 | 0.050 | 0.050 | 0.150 | 0.230 | 0.250 | 0.263 | 0.225 |
| 45 | 0.038 | 0.050 | 0.050 | 0.107 | 0.100 | 0.138 | 0.200 |
| 60 | 0.025 | 0.025 | 0.038 | 0.067 | 0.075 | 0.050 | 0.113 |
| 75 | 0.018 | 0.038 | 0.025 | 0.043 | 0.038 | 0.050 | 0.087 |
| 90 | 0.010 | 0.025 | 0.025 | 0.026 | 0.025 | 0.050 | 0.050 |
| 100 | 0.010 | 0.025 | 0.025 | 0.022 | 0.050 | 0.050 | 0.050 |
| 105 | 0.000 | 0.018 | 0.025 | 0.017 | 0.050 | 0.025 | 0.050 |
| 120 | 0.010 | 0.005 | 0.010 | 0.014 | 0.018 | 0.018 | 0.050 |
| 135 | 0.000 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.025 |
| 145 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.050 |

4* Central probe location
1, 2, 3 Above the central probe location
5, 6, 7 Below the central probe location

The measured distances were approximately: *(i)* 21 cm, *(ii)* 30 cm, *(iii)* 26 cm and *(iv)* 29 cm.

Theoretical calculations for the power densities were taken at various distances from the source (measurements taken from the base of the horn antenna).

The major specification parameters are:

(a) RF frequency - 35 GHz

(b) Transmitted power - 20 dB (100 mW).

For the calculation of far-field distance:

$R = 2D^2$, where $D$ is the largest dimension of radiator.

Here

$D = 5.5$ cm approx., the broadside dimension of the horn antenna

$$\lambda = \frac{3 \times 10^{10}}{35 \times 10^9} = 0.85 \text{ cm}$$

hence

$$R = \frac{2 \times 5.5 \times 5.5}{0.85} = 71 \text{ cm}$$

As long as any soldier is at a distance beyond 71 cm, he is in the far-field. According to power-density formula for far-fields, at a distance $R$ ($R = 1$ m) if $R$ is in cm

$$\text{Power density} \quad P = \frac{P_T G}{\frac{4 \times 22 R^2}{7}}$$

where $P_T$ = Transmitted power

$G$ = Antenna gain (20 dB)

$$= \frac{100 \times 100}{\frac{4 \times 22 \times R^2}{7}} = \frac{795}{R^2} \text{ mW/cm}^2,$$

| $R$ (cm) | 100 | 200 | 300 | 400 |
|---|---|---|---|---|
| $P$ (mW/cm$^2$) | 0.0795 | 0.0196 | 0.0097 | 0.0049 |

Tables 1*(a)* and *(b)* and Figs 2*(a)* and *(b)* show the mean values and the range of microwave power density (minimum and maximum values) in the beam axis of the horn antenna at the closest point and at varying distances on the Z-axis for helmet Nos. 1 and 2, respectively. The microwave field varied from 2.5–5.0 mW/cm$^2$ [Table 1*(a)* and Fig. 2*(a)*] and 6.0–10.5 mW/cm$^2$ [Table 1*(b)* and Fig. 2*(b)*] closest to the horn antenna, respectively. The mean values for the same were 4.18 mW/cm$^2$ and 8.16 mW/cm$^2$, respectively. As expected, there is a great variability and inconsistency in the near-field close to the horn antenna. This variability decreases as the distance increases from the horn antenna to a mean value of 0.65 mW/cm$^2$ and 1.77 mW/cm$^2$ at 15 cm from the horn antennas and the range (variation) also reduces to 0.5–0.75 mW/cm$^2$ or 1.5–2.5 mW/cm$^2$ [Tables 1*(a)* and *(b)*]. As the far-field approached (> 71 cm as per the earlier theoretical calculations) the MMW power density recorded at 1m was 0.013–0.04 mW/cm$^2$ with an average value of 0.022 mW/cm$^2$ and 0.075 for helmet Nos. 1 and 2, respectively. As per the theoretical calculations, it was predicted that the power density would be 0.079 mW/cm$^2$ at this distance. The prediction matches very well with the measured values for helmet No. 2. The measurements were carried out under free-field conditions where the field perturbations could be caused by the objects/subjects in the environment. Ideally, these should have been carried out in anechoic chambers where no microwave power is attenuated by the surroundings. As the soldiers are exposed to free-field conditions, the measurements under free-field conditions were preferred. The microwave probe-used could only record up to a minimum value of 0.05 mW/cm$^2$. The values mentioned below this value are approx. beyond 75 cm and hence not plotted in Fig. 2. However, the values are mentioned in the tables.

As mentioned above, there was variation close to the horn antenna and approx. 3 cm to the left and

4 cm to the right, the microwave power density was zero. This was also true at 15 cm on the Z-axis (Tables 2*(a)* and *(b)*) where no microwave power was detected at 15, 30 and 45 cm either to the left or right on the Y-axis. This suggests that the microwave beam is narrow at this point. Slight divergence of the microwave beam is suggested at 30 cm on the Z-axis where microwave power could be detected at a lateral distance of 15 cm to the left and right on the Y-axis (mean value 0.008 and 0.013 mW/cm$^2$ for helmet No. 1 and 0.006-0.018, 15 cm left for helmet No. 2). As the distance increased, the divergence increased (some microwave power could be detected 30 cm laterally at 45 and 60 cm distance points, which is not mentioned here). The maximum mean values of microwave power detected on Y-axis were at 60 cm distance point at the fourth position of the probe (8 cm below the central probe location), 15 cm to the left (0.042 mW/cm$^2$), 15 cm to the right (0.05 mW/cm$^2$) at 60, 75, 100 and 105 cm and 0.043 at 90 cm distance point) for helmet No. 1 [Table 2*(a)*]. For helmet No. 2, as the longitudinal distance increased beyond 75 cm, some microwave power could be detected 30 cm laterally also. From the data [Table 2*(b)*], it is obvious that the maximum values recorded (0.15 mW/cm$^2$) were at the fourth location of the probe, 15 cm to the left of the distance points 60 and 75 cm indicating that the microwave beam is pointing downwards and to the left and is narrow to begin with. However, for helmet No. 1, the higher values were recorded 15 cm laterally on the right side. At distances of relevance [Tables 3*(a)* and *(b)*], with two persons standing at convenient distance from each other, the microwave beam from the horn antenna of the helmet worn by wearer No. 1 falls at different locations, *i.e.*, on the eyes, chin, nose and chest of wearer No. 2 with various positions of the head. The microwave power detected was 0.49, 0.28, 0.21 and 0.23 mW/cm$^2$ for helmet No. 1 and 0.97, 0.71, 0.55 and 0.48 for helmet No. 2 at distances 21 *(a)*, 26 *(c)*, 29 *(d)* and 30 cm *(b)*, respectively.

As mentioned above, no microwave power could be detected 15 cm to the left or right of the Z-axis up to 30 cm. Tables 4*(a)* and *(b)* and Figs 3*(a)* and *(b)* show the vertical axis/X-axis measurements at various distance points on the Z-axis at 7 probe locations. At 15 and 21 cm distance points, the highest values were observed at probe locations 4, 5 and 6. At 26 cm, the highest values were observed at probe position 6 for both helmets. At 30 cm, the highest values were recorded at positions 6 and 5 for helmet Nos. 1 and 2, respectively. At or beyond 45 cm on the Z-axis up to 145 cm, the mean values recorded at probe location 7 were 1.5-3 times the values recorded at central probe location indicating thereby that the microwave beam was directed downwards as the distance increased.

**Table 4 (b). Vertical axis/X axis measurements of microwave power density (mean values, mW/cm$^2$) at various distances from the helmet-mounted microwave radiating horn antenna - helment no.2**

| Distance from the horn (cm) | Mean values (mW/cm$^2$) at different probe locations | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4* | 5 | 6 | 7 |
| 15 | 0.131 | 0.215 | 0.925 | 1.562 | 1.775 | 1.837 | 0.587 |
| 21 | 0.143 | 0.200 | 0.737 | 0.987 | 1.187 | 1.25 | 0.625 |
| 26 | 0.10 | 0.175 | 0.55 | 0.700 | 0.906 | 0.975 | 0.575 |
| 29 | 0.10 | 0.175 | 0.395 | 0.525 | 0.862 | 0.812 | 0.487 |
| 30 | 0.125 | 0.175 | 0.356 | 0.493 | 0.787 | 0.737 | 0.45 |
| 45 | 0.10 | 0.125 | 0.143 | 0.225 | 0.368 | 0.425 | 0.287 |
| 60 | 0.068 | 0.081 | 0.10 | 0.15 | 0.243 | 0.25 | 0.268 |
| 75 | 0.05 | 0.056 | 0.068 | 0.087 | 0.131 | 0.20 | 0.225 |
| 90 | 0.037 | 0.037 | 0.05 | 0.068 | 0.112 | 0.143 | 0.162 |
| 100 | 0.031 | 0.037 | 0.037 | 0.062 | 0.093 | 0.106 | 0.15 |
| 105 | 0.025 | 0.031 | 0.037 | 0.05 | 0.087 | 0.093 | 0.131 |
| 120 | 0.025 | 0.031 | 0.037 | 0.037 | 0.075 | 0.075 | 0.10 |
| 135 | 0.018 | 0.018 | 0.025 | 0.031 | 0.037 | 0.062 | 0.062 |
| 145 | 0.012 | 0.012 | 0.025 | 0.031 | 0.043 | 0.043 | 0.062 |

4* Central probe location

1, 2, 3 above the central probe location

5, 6, 7 below the central probe location

Inside the helmet, close to the metallic plate, no microwave power could be detected at any of the 17 locations close to or 10 cm away from the metallic plate as mentioned in Fig. 1. Hence, there is no possibility of any leakage towards the head of the wearer.

Only a few reports are available in the literature that are many-a-times controversial. Most of the work is reported from the erstwhile USSR. Two studies conducted at 36 GHz, very close to the operating frequency of the helmets, are worth mentioning in this context.

The microvilli on the surface of pre-implantation mouse embryos and organelles of the blastomeres were found to change markedly *in vitro*, and to a lesser degree, *in vivo* with exposure to 36.11 GHz, 2-8 $mW/cm^2$ MMW. Irradiated pregnant mice exhibited a decrease of early embryo implantation rate and a loss in body weight of foetus. The inhibitory effect of 8 mm waves on the development of embryos comes chiefly from damage to the surface structure and mitochondria of the embryos[4].

One hundred and ten mice were exposed to MMW at 36.7 GHz, 4 $mW/cm^2$ power density, 30 min/d for 5 days. Histological changes were found in bone marrow, testes and livers of all the mice tested. No significant elevation in the rectal temperature was found in the experimental animals. There was no effect of local blockade on the changes observed in tissues. It was concluded that the indirect bioeffects of MMW are not due to elevation of body temperature and the local blockade also does not influence tissue changes after irradiation[5].

## 4. CONCLUSIONS

- Under the near-field exposure conditions (<71 cm), the horn antennas produce non-uniform energy deposition resulting in hot spots, where the local SAR values can exceed many-a-time the measured values.
- There is an induction field and there may be geometrical resonance due to secondary wave-mode interactions between the horn antenna and the nonuniformly irradiated biological objects in the near-field.
- Such hot spots created in a vascular tissue like cornea can result in sharp rise in the local temperature, thereby resulting in damage to the corneal epithelium. Studies indicate damage to the corneal epithelium at power levels as low as 1 $mW/cm^2$, the threshold for damage being lowered with the use of certain drugs[6].
- Non-uniform energy deposition in the near-field within non-homogeneous biological tissue models not possessing flat surfaces, complicates the computation of microwave intensities further.
- The microwave power intensities decreased with distance as per the inverse square law. Beyond 75 cm from horn antenna, the microwave power detected was negligible. Hence, it is advisable to stay beyond this distance.
- Theoretical predictions of the intensity levels indicate 0.079 $mW/cm^2$ at 1 m distance. However, the maximum values recorded were 0.04 $mW/cm^2$ and 0.075 $mW/cm^2$ at this distance for helmet Nos. 1 and 2, respectively. Measurements under free-field conditions were carried out for the simple reason that the soldier is exposed under free-field conditions only. Measurements in anechoic chambers could have yielded higher values, where there is no perturbation of the field by surrounding objects/ subjects.

## 5. RECOMMENDATIONS

- It is safe to operate the helmet-mounted MMW radio as there is no leakage towards the head of the wearer.
- It is better to remain in the far-field zone, *i.e.*, at a distance beyond 71 cm.

- The wearer should not flex the head so as to focus the microwave beam onto the eyes of any person standing nearby in the near-field, especially in the transmitting mode.
- Clear written instructions with suitable warning signals should be given to this effect.

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