SAR COMPLIANCE TESTING OF M/A-COM MODEL P-801T

PORTABLE PUSH-TO-TALK RADIO

FINAL TECHNICAL REPORT

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Summary

A widely-accepted finite-difference time-domain (FDTD) computational technique has been used for a heterogeneous, anatomically-based model of the human to determine maximum peak 1-g specific absorption rates (SAR) for four typical configurations of M/A-Com Model P-801T Portable Push-to-Talk Radio for two midband frequencies of the transmission bands. The FDTD-calculated gains of the two antennas of -0.1 and -3.2 dBi compare extremely well with gains of 0 and -3.0 dBi measured for these antennas. The maximum 1-g SARs for the four considered configurations of the radio for the analog (100% duty cycle mode) vary from 1.53 to 7.02 W/kg with the highest SAR when the "microphone" is mounted on the lapel at the shoulder. The SAR values are less than the FCC occupational limit of 8.0 W/kg for any 1-g of tissue. For a vast majority of situations, the radio will be used in the TDMA mode with 50% duty cycle. Under these conditions, the maximum 1-g SARs would be one-half of the above values and would vary from 0.77 to 3.51 W/kg for the four configurations, respectively.

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I. Introduction

The U.S. Federal Communications Commission (FCC) has adopted limits of human exposure to RF emissions from mobile and portable devices that are regulated by the FCC [1]. The FCC has also issued Supplement C (Edition 97-01) to OET Bulletin 65 defining both the measurement and the computational procedures that should be followed for evaluating compliance of mobile and portable devices with FCC limits for human exposure to radiofrequency emissions [2]. The partial-body SAR limits prescribed by the FCC are 8.0 W/kg for occupational/controlled exposures and 1.6 W/kg for general population/uncontrolled exposures. The maximum partial-body SAR is to be obtained by averaging over any 1 g of tissue defined as a tissue volume in the shape of a cube [1, 2].

The M/A-Com Model P-801T Two-Way Portable Radio FCC ID#BV8P-801T can radiate up to a maximum power of 3 W over the frequency bands 806-824 MHz and 851-870 MHz. According to the manufacturer, the equipment is to be sold exclusively to public safety/public service agencies and not to the general public. Training will be required on use of this equipment prior to issue to users. SAR compliance testing is thus required for the peak 1-g SAR of 8.0 W/kg for occupational/controlled exposures [1, 2]. According to FCC 96-326 [1], "use of appropriate numerical and computational techniques, such as FDTD analysis, is acceptable for demonstrating compliance with the SAR values. Studies by O. P. Gandhi and others indicate that such techniques offer valid means to determine energy absorption characteristics in exposed subjects."

For SAR compliance testing of the M/A-Com Model P-801T Portable Radio, we have used the widely accepted FDTD method for the anatomically-based model of the human body [3, 4]. Some reasons for selecting the numerical method, rather than the experimental phantom model, are as follows:

1. The experimental phantom models of the face or the human waist, two of the locations where the two-way radio is held in operation are not readily available.

2. Anatomically-based models have the advantage of modeling the curved shapes as well as the heterogeneities of the tissues.
3. Flat phantom models may be used. But, as given in Table 4, these models tend to grossly overestimate the SARs because of lack of curvature such as for the face and the body. Using the numerical method results in putting some of the tissues at realistic distances which are generally greater than those for a flat phantom model (see Figs. 3, 6, 9, 10 for visualization of the Radio P-801T vis à vis the human model).
4. Some individuals have alluded to leakage electromagnetic fields from the electronic components in the handset. There is, however, no proof for this allegation. In fact, as given in [5], the experimentally-determined SARs for 10 experimental wireless handsets five each at 835 and 1900 MHz were within ± 20 percent (± 1 dB) of those determined from the FDTD computational method. This slight difference of ± 1 dB may well be due to the fact that the numerical method uses a 15 tissue heterogeneous anatomic model of the head and neck while the experimental phantom uses a relatively thin shell with a homogeneous liquid in it.
5. Lastly, the manufacturer uses a well-shielded chassis of the handset thus minimizing any leakage radiation from the internal electronic components. This is described in detail in Section II.

II. The M/A-Com Model P-801T Portable Push-to-Talk Radio

A photograph of the M/A-Com Model P-801T Radio is given in Fig. 1. As aforementioned, the radio transmits in the frequency band 806-824 MHz and 851-870 MHz with a maximum ERP of three watts or 34.8 dBm. The approximate dimensions of the radio are as follows: width 2.3", depth 1.5" and height 6.1". As seen in Fig. 1, a sleeve type, nominal half wave dipole antenna is mounted in the back right-hand corner at the top of the die cast aluminum chassis in rugged polycarbonate housing of the handset. The sleeve type antenna has the following dimensions:

Diameter of unshielded wire (for the upper part of the antenna) = 1.7 mm
Diameter of the rubber sheathing around the antenna = 0.22" (5.6 mm)
Unshielded length of the antenna = 159 mm
Length of the metallic shielding sleeve (at the base of the antenna) = 16 mm
Diameter of the shielding sleeve = 0.75" (19.05 mm)
Thickness of the rubber sheathing around the sleeve = 2 mm (approximately)
Prescribed minimum distance* of the radio from the mouth (see Appendix A) = 1"

Radio Case Shielding

A cross sectional diagram of the P-801T handset showing the shielding is attached as Fig. 2. The high-power amplifier (HPA) is enclosed in a 0.008" thick aluminum shield. The minimum shielding effectiveness occurs at the lowest frequency, 806 MHz. At this frequency, the shield attenuates the energy 8.7 dB for each 0.000118 inch of aluminum thickness. Therefore, the theoretical HPA shield effectiveness is over 500 dB. Taking into account shield discontinuities, the minimum expected shield attenuation is 40 dB. Therefore, the signal level leaking out of the HPA shield will not exceed -3.5 dBm or less than one-half milliwatt..

The HPA driving circuitry is on the bottom of the transceiver board (as shown in Fig. 2). Above the transceiver, it sees the PK groundplane (0.0007 inches of copper thickness) plus two additional groundplanes in the transceiver board for a total thickness of 0.0021" of copper. The maximum drive level to the HPA is +17 dBm when the drive amplifier is saturated. The groundplanes will also give about 40 dB isolation due to discontinuities. Therefore, the leakage signal due to the HPA drive circuitry will be -23 dBm.

Below the HPA and HPA drive circuitry is a solid aluminum chassis, which provides complete shielding. Therefore, the maximum signal leakage will be out of the top of the radio (as shown in Fig. 2) and to the extent discussed above, as a worst case.

The two configurations tested for the P-801T Portable Radio of Fig. 1 are as follows:

Configuration 1. The model P-801T Radio with "1/2 wave" antenna held at 1" in front of the mouth. A visualization of this configuration in front of the Utah anatomic model of the head is given in Fig. 3.

* Because of the depth of the radio (1.5"), this implies a minimum distance of the antenna from the mouth of about 2.5".

Configuration 2. The radio with "1/2 wave" antenna in a holster for belt mounting at waist against say, the back left side of the body. A photograph of the holster for belt mounting the equipment is shown in Fig. 4. Figure 5 gives dimensions of the holster, indicating minimum separation of the back of the equipment from the user's garments. Figure 5 also provides a detail of the metal swivel that is part of the holster. A visualization of this configuration as against the Utah anatomic model of the body is given in Fig. 6. As seen in Fig. 5, there is a belt clip metallic component of square dimensions 1.5" $\times$ 1.5" and thickness 1.25". This metallic clip of detailed shape given in Fig. 5b was modeled by voxels of dimensions 2.961 $\times$ 2.961 $\times$ 3 mm for a complete geometry that is visualized in Fig. 6.

Microphone With Nominal "1/4 Wave" Antenna

An accessory for the Model P-801T Radio is a microphone with nominal "1/4 wave" antenna as shown in Fig. 7. The remote microphone is an assembly that integrates a microphone, speaker, antenna, and control switches into a single small unit. The microphone is connected to the P-801T Radio by way of a cable that contains the low-frequency (audio) and control cables and a shielded RF cable. The RF signal is conducted to the antenna by way of a shielded cable within the microphone body. A photograph of the interior of the microphone illustrating this connection is shown in Fig. 8. The dimensions of the microphone are as follows: width 2.25", depth 1", and height 2.5". Similar to the Model P-801T, this microphone is to be held no closer than 1" from the mouth (see Appendix A).

This microphone also uses a sleeve-type antenna with the following dimensions:

Diameter of unshielded wire (for the upper part of the antenna) = 1.7 mm
Diameter of the rubber sheathing around the antenna = 0.22" (5.6 mm)
Unshielded length of the antenna = 69 mm
Length of the metallic shielding sleeve (at the base of the antenna) = 16 mm
Diameter of the shielding sleeve = 0.75" (19.05 mm)
Thickness of the rubber sheathing around the sleeve = 2 mm (approximately)

The two configurations tested for the radiating microphone are as follows:

Configuration 3. The microphone of Fig. 7 held at 1" in front of the mouth (antenna 2" away from the face). A visualization of the microphone in front of the Utah anatomic model of the head is given in Fig. 9.

Configuration 4. The microphone clipped to the lapel at the shoulder at a location shown in Fig. 10. Because of the thickness of the clip and the clothing, this produces a minimum distance of 11 mm from the body tissues.

III. A High Resolution Anatomic Model of the Human Body

We have developed a millimeter-resolution model of the human body from the magnetic resonance imaging (MRI) scans of a male volunteer of height 176.4 cm and weight 64 kg. The MRI scans were taken with a resolution of 3 mm along the height of the body and 1.875 mm for the orthogonal axes in the cross-sectional planes [3, 4, 6]. Even though the height of the volunteer was quite appropriate for an average adult male, the weight was somewhat lower than an average of 71 Kg, which is generally assumed for an average male. This problem can, to some extent, be ameliorated by assuming that the cell dimensions for the cross sections are larger than 1.875 mm by the ratio of $(71/64)^{1/2} = 1.053$. By taking the larger cell dimensions of $1.053 \times 1.875 = 1.974$ mm for the cross-sectional axes, the volume of the model can be increased by $(1.053)^2 = 1.109$, i.e., by about 10.9 percent which results in an increase of its weight by approximately the same percentage, i.e., to a new weight of approximately 71 Kg. The MRI sections were converted into images involving 30 tissue types whose electrical properties can then be prescribed at the irradiation frequency. The tissue types are fat, muscle, (cancellous) bone, cartilage, skin, brain, pineal gland, pituitary gland, nerve, cerebrospinal fluid (CSF), intestine, spleen, pancreas, heart, blood, eye, eye humor, eye sclera, eye lens, liver, kidney, lung, bladder, stomach, ligament, compact bone, testicle, spermatic cord, prostate gland, and erectile tissue. For the present calculations, we have used truncated parts of the model as necessary for Configurations 1 to 4 above (see Figs. 3, 6, 9, and 10) for the partial body models used for these cases). The SAR calculations have been done for the center band frequencies for both of the transmission bands i.e. at 815 MHz and 860.5 MHz for the transmit bands 806-824 and 851-870

MHz, respectively. The electrical properties ε_r, σ for the various tissues at the two bands taken from the FCC web site [7] are given in Table 1.

IV. The Finite Difference Time-Domain Method

One of the most successful and versatile methods for SAR calculations is the finite-difference time-domain (FDTD) method. This method was first proposed by Yee [8] and later developed by Taflove and colleagues [9-11], Holland [12], and Kunz and Lee [13]. This method has been extensively used for calculations of the distributions of electromagnetic (EM) fields and SARs in anatomically-based models of the human body for whole-body or partial-body exposures due to far-field or near-field irradiation conditions [3,4]. In this method, the time-dependent Maxwell's curl equations

$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t} \ , \quad \nabla \times \mathbf{H} = \sigma \mathbf{E} + \varepsilon \frac{\partial \mathbf{E}}{\partial t} \tag{1}$$

are implemented for a lattice of subvolumes or "cells" that may be cubical or parallelepiped with different dimensions δ_x, δ_y, and δ_z in x-, y-, or z-directions, respectively. The components of **E** and **H** are positioned about each of the cells as shown in Fig. 11 and calculated alternately with half-time steps where the time step $\delta t = \delta/2c$ where δ is the smallest of the dimensions used for each of the cells and c is the maximum phase velocity of the fields in the modeled space. Since some of the modeled volume is air, c corresponds to the velocity of EM waves in air. The details of the method are given in several of the above referenced publications [8-13] and will, therefore, not be repeated here.

In the FDTD method, it is necessary to represent not only the scatterer/absorber such as the human body or a part thereof, but also any near-field sources/s such as the P-801T Radio or the Microphone, including the respective antennas, by means of the volume-averaged electrical properties (ε_r, σ). The source-body interaction volume is subdivided into the Yee cells of the type shown in Fig. 11. The interaction space consisting of a grid is truncated by means of PML absorbing boundaries [14].

The cell sizes, the modeled volumes, and the computing requirements used for SAR calculations for Configurations 1-4 are given in Table 2. The $1.974 \times 1.974 \times 2$ mm model is created by subdividing each of the voxels of the original MRI-based model (with resolution $1.974 \times 1.974 \times 3$ mm) into $2 \times 2 \times 3$ voxels and then combining $2 \times 2 \times 2$ smaller voxels into the new voxels. The $2.961 \times 2.961 \times 3$ mm models needed for representing the larger exposed volumes of the body (see Figs. 6 and 10) are similarly created by combining $3 \times 3 \times 3$ or 27 of the smaller voxels into the new voxels of these dimensions, respectively.

V. Modeling of the Radio, the Microphone, and the Sleeve Antennas

The models used to represent the P-801T Radio with a nominal "1/2 wave" antenna and its accessory microphone with a nominal "1/4 wave" antenna are described in Table 3. Additional 1 + 1 cells along each of the directions are taken because of the need to represent plastic covering of the handsets used for P-801T Radio and the accessory microphone, respectively. For the sleeve part of the antennas, the number of metal cells (6×6) used for each of the cross sections is such as to obtain an outer perimeter which would be very close to the circumference of the cylindrical sleeve. Also, both the sleeves and the antennas are assumed to be covered with one cell of dielectric on each of the sides to represent the rubber sheathing used for the two antennas, respectively, (see Figs. 1, 7).

VI. Calculation of Antenna Patterns in Free Space

The FDTD method may be used for the models detailed in Table 3 to calculate the radiation patterns and the gains [15] of both the P-801T Radio and the Microphone so that they may be compared with data available from the manufacturer. The radiation patterns calculated for the M/A-Com Model P-801T Radio with the nominal "1/2 wave" antenna and the Microphone with the nominal "1/4 wave" antenna are shown in Figs. 12 and 13, respectively. The calculated gains of the two antennas of approximately -0.1 and -3.2 dBi compare extremely well with gains of 0 and -3.0 dBi measured for these antennas by the manufacturer.

VII. The Calculated Peak 1-g SARs

The calculated maximum 1-g SARs for the body (face in Configurations 1 and 3) and the left and right eyes for the four configurations of the M/A-Com Model P-801T Portable Radio relative to the body both at 815 and 860.5 MHz are given in Table 2. In addition to considering the anatomic model of the human body for all four configurations, we have also used a flat phantom model for Configurations 1 and 3 where, as expected, unrealistically higher SARs are obtained because of lack of a curved shape that is typical of the face. The minimum distances taken for each of the four configurations were prescribed by the manufacturer. As given in Appendix A, these minimum distances to the face or the body will be spelled out in the marketing literature for this radio. Also mentioned in Appendix A is that this radio is to be used for work-related communications. Training will be required on the use of this equipment prior to issue to users.

As seen from Table 4, the maximum 1-g SARs for the four configurations vary from 1.53-7.02 W/kg with the highest SARs for Configuration 4 when the "microphone" with "1/4 wave" antenna is mounted on the lapel at the shoulder for a distance of 11 mm from the body (due to thickness of the clip and the clothing). All of these values are less than the FCC occupational limit of 8.0 W/kg for any 1-g of tissue.

VIII. Comparison of the Data With the Safety Guidelines

The M/A-Com Model P-801T Portable Radio is to be marketed as a device to be used for occupational/controlled environments (see Appendix A). The maximum 1-g SARs for the four considered configurations for the analog (100% duty cycle mode) vary from 1.53 to 7.02 W/kg with the highest SAR when the "microphone" is mounted on the lapel at the shoulder. All of the SAR values are less than the FCC occupational limit of 8.0 W/kg for any 1-g of tissue. Furthermore, the manufacturer reports that in a vast majority of cases, the radio will be used in the TDMA system which reduces the transmit duty cycle to 50%. Under these conditions, the maximum 1-g SARs would be one-half of the above values and would vary from 0.77 to 3.51 W/kg for the four configurations, respectively.

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