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Measurements of Electromagnetic Fields in the Close Proximity of CB Antennas

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Measurements of Electromagnetic Fields in the Close Proximity of CB Antennas

By

Paul S. Ruggera

Division of Electronic Products

bureau of radiological health

WHO Collaborating Center for
Standardization of Protection
Against Nonionizing Radiations

January 1979

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FOREWORD

The Bureau of Radiological Health conducts a national program to limit man's exposure to ionizing and nonionizing radiations. To this end, the Bureau (1) develops criteria and recommends standards for safe limits of radiation exposure, (2) develops methods and techniques for controlling radiation exposure, (3) plans and conducts research to determine health effects of radiation exposure, (4) provides technical assistance to agencies responsible for radiological health control programs, and (5) conducts an electronic product radiation control program to protect the public health and safety.

The Bureau publishes its findings in appropriate scientific journals and technical report and note series prepared by Bureau divisions and offices. Under a memorandum of agreement between the World Health Organization and the Department of Health, Education, and Welfare, three WHO Collaborating Centers have been established within the Bureau of Radiological Health, FDA:

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Readers are encouraged to report errors or omissions to the Bureau. Your comments or requests for further information are also solicited.

John C. Villforth
Director
Bureau of Radiological Health

PREFACE

Among the responsibilities of the Division of Electronic Products of the Bureau of Radiological Health is the physical evaluation of radiation emissions from electronic products, including emissions in the radiofrequency and microwave portions of the electromagnetic spectrum. Previous reports in this series have described measurements of emissions from marine radars, microwave ovens, and diathermy equipment. This report describes measurements of near fields generated by citizen band antennas operating at 27.12 MHz. The data indicate that field strength limits such as those recommended in the ANSI standard C95.1-1974 can be exceeded in the vicinity of these antennas under certain circumstances. The health implications of these observations are not clear at this time. The Bureau of Radiological Health is continuing investigations of this matter.

Roger H. Schneider
Director
Division of Electronic Products
Bureau of Radiological Health

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ABSTRACT

Citizen Band (CB) radios are in very wide use in the United States. In evaluating any possible radiation hazard associated with their normal use, the first step is to know the characteristics of the radiation typically emitted. The estimation of human exposure to the electromagnetic fields generated by these devices is complicated by the fact that exposure occurs in close proximity to the antenna or in the "near field." Instrumentation and techniques which can be used to measure these fields, along with figures illustrating the resulting near-field distributions for the most popular types of antennas, are discussed in this report.

The types of CB antennas for which data are presented with full legal power of 4 watts input, include 1/4-wavelength whip; base-, middle-, and top-loaded; two sets of twin antennas; and, a hand-held "walkie-talkie." Comparisons are made between the field distributions for different antenna designs and different mounting locations. The measured emission levels at 5 cm from all of the antennas tested exceeded either 200 V/m or 0.5 A/m or both at some point along the vertical height of the antenna. Levels of this magnitude persisted for some of the antennas at a 12 cm separation distance.

MEASUREMENTS OF ELECTROMAGNETIC FIELDS IN THE CLOSE PROXIMITY OF CB ANTENNAS

INTRODUCTION

In the last few years, the increase in use of the Citizen Band (CB) portion of the electromagnetic spectrum for personal communication has been phenomenal. Currently, the number of CB license applications processed by the FCC exceeds 14 million. Inherent in its wireless operation, the CB radio emits electromagnetic radiation at a frequency of approximately 27 MHz. This is, in essence, the first time that a moderately powerful (4 watt maximum) transmitter has been easily accessible to the average citizen.

Electronic products that emit electromagnetic radiation are usually classified in different bands of the spectrum depending on their operating frequency. The determining factor for field measurement in the different bands of the spectrum are (1) the operating frequency, or wavelength, and (2) the distance between the user and the source of emission. For example, the user of a microwave oven usually is located at a distance far enough away to be in the "far-radiation field." When operating a hand-held CB radio, or standing near a CB antenna that is mounted on an automobile, one is in the "near-radiation field." This report discusses a few basic concepts of near-field measurement and the results of measurements of such fields near a variety of CB antennas.

CONSIDERATIONS WHEN MEASURING NEAR RF SOURCES

Unlike analogous microwave-frequency situations where it is usually sufficient to measure only the electric field (E), in the RF region it is necessary to measure both the electric field (E) and the magnetic field (H). This is true because in the "near field," the ratio of E to H is neither constant nor equal to the 377 ohm impedance of "free space." To measure only one type of field and then mathematically transform its value to produce the "equivalent power density"--a term used often in the microwave radiation area--is not correct. In addition to this constraint, it also is necessary to account for the polarization of the fields. Therefore, three orthogonal antennas, or other means of obtaining the orientation of the field vectors, are necessary. The instruments which can be used for this purpose are discussed in the next section.

To demonstrate the relationships between operating frequency and source/subject separation distance, which together determine if "near-field" exposure conditions exist, consider two familiar products--the microwave oven and the CB radio. The microwave oven operates at a frequency of 2,450 MHz, and the CB radio operates at 27 MHz. Referring to Table 1, the corresponding wavelengths are shown respectively to be 0.12 meters (5 inches), and 11 meters (36 feet). Through the courtesy of Don White Consultants, Inc., Germantown, Maryland, Figure 1 and Figure 2 have been reproduced from their electromagnetic compatibility handbook series, which serves to illustrate near-field concepts. (These figures show only two of the field components; i.e., $H\phi$ and $E\theta$, which are not the complete picture near the antenna as will be shown later. For the general discussion that follows, it is sufficient to be concerned only with the relative magnitudes of E and H, and not their polarization.) Referring to Figure 1, one can see that the "near field" ends at approximately

2.0 "units" (i.e., substitute the abscissa value in the equation: $r=(2)\lambda/2\pi$ or $r=\lambda/3.14$), which is approximately 1/3 wavelength. Therefore, if measurements are made further than 4 cm (1.6 inches) from the microwave oven, and further than 3.6 meters (12 feet) from a CB antenna, the relationship between the electric and the magnetic field appears to be constant and their quotient is equal to 377 ohms. This is a practical constraint in the case of the microwave oven, as one seldom gets closer than 4 cm to the oven. This partially explains why all commercial survey instruments are calibrated to read in mW/cm^2 even though they measure only the electric field squared (i.e., the mathematical transformation between electric field strength and power density referred to earlier). In the case of lower-frequency emitters, such as the CB radios, close proximity to the antenna (much less than 3.6 meters (12 feet)) is more often the norm, and the fields must be quantified within this distance or in the "near field."

Another aspect to consider is the physical make-up of the emitter and its associated impedance. Two emitters, depicting the impedance extremes, are shown in Figure 2. (The monopole with its high impedance--high E/H ratio, and the loop with its low impedance--low E/H ratio.) Note that at a sufficient separation distance (approximately 1/3 wavelength) the electric and magnetic field strengths approach a constant ratio (depicted by equal line widths), regardless of the impedance of their origin. At this point it might easily have been assumed that the CB antenna is more representative of the monopole on the left; therefore, measurement of the electric field alone would suffice. In reality, as the following data will show, a typical CB antenna can exhibit the properties of both the monopole and the loop in terms of the fields it emits.

Table 1. Wavelength and frequency (F)

Wavelength = $3 \times 10^8/F$, in Meters (m) = 3×10^8/frequency ms^{-1}/s^{-1}
Wavelength at 2450 MHz = 0.12 m = 5 Inches (Microwave Oven)
Wavelength at 27 MHz = 11.0 m = 36 Feet (CB Radio)
Far Field (at 1/3 wavelength from antenna) where E/H = 377 Ohms
@ 2450 MHz = 0.04 m (1.6 inches)
@ 27 MHz = 3.6 m (12 feet)

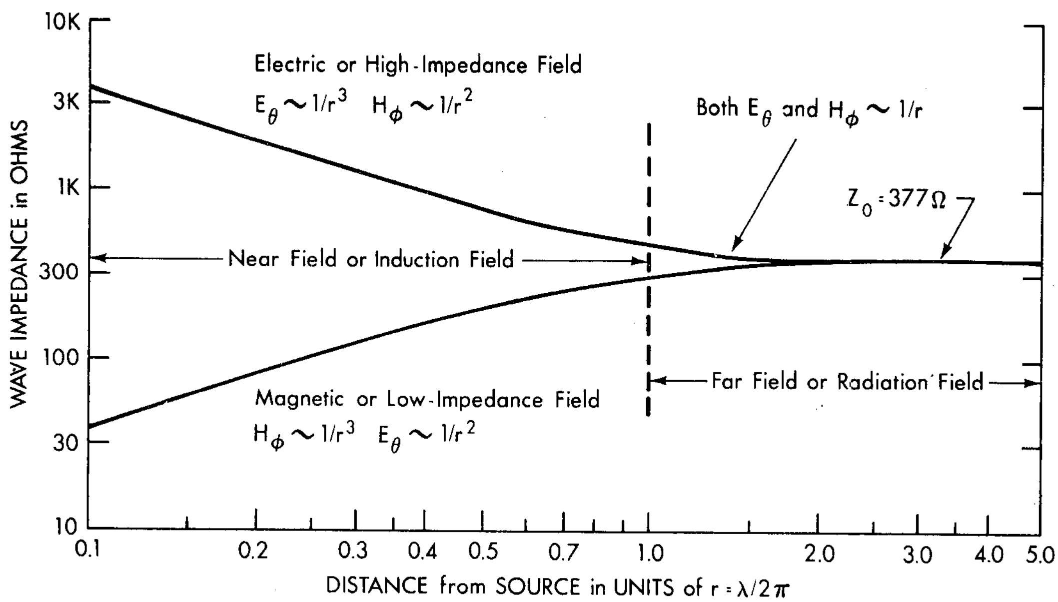

Figure 1. Wave impedance vs. source/subject separation

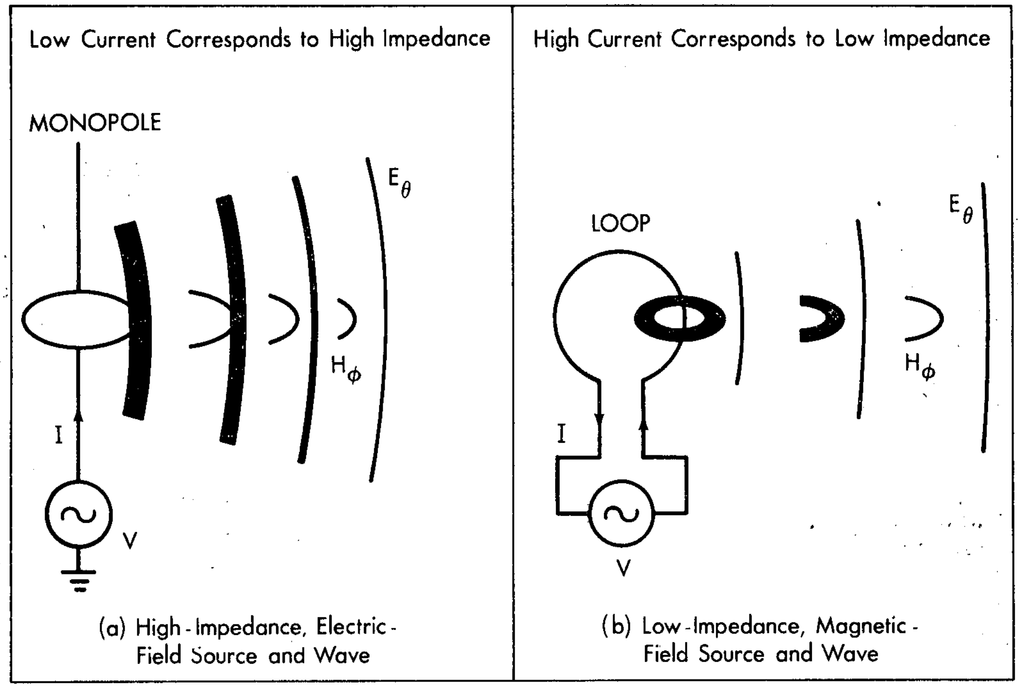

Figure 2. Source impedance and radiated fields

FIELD MEASUREMENT INSTRUMENTATION

To measure the field strengths surrounding CB antennas, two instruments each capable of measuring the total E or H field respectively were chosen.

For several years a commercial instrument manufactured by Instruments for Industry, Farmingdale, New York, the EFS-1 field strength meter (center instrument in Figure 3) had been used by BRH. This instrument was found to meet the manufacturers' specifications of full-scale accuracy at 27 MHz, the CB frequency within 5 percent (1). The instrument measures electric field strengths from 1 volt/meter (V/m) to 1000 V/m and does not respond to magnetic fields. The instrument, the RHM-2, shown to the left of the EFS-1 in Figure 3 is essentially three EFS-1's in one box. The RHM-2 has the capability of remote readout via a fiber-optic link that does not perturb the electric field being measured. The operation of the two units are identical, except for the fact that the RHM-2 can have more than one channel activated (through front panel switches). The resultant reading in V/m is the square root of the sum of the squares of the instantaneous individual field components being measured. This provides a measure of the total electric field strength regardless of its polarization. In the graphical material that follows, points at 60 and 130 cm from the base of the antennas were selected to quantify the measured orthogonal E-field components for different antenna designs.

The commercially available Narda Model 8607 Broadband Isotropic Radiation Monitor (Narda Microwave Corporation, Plainview, New York) was used to measure the total H field through use of concentric orthogonal loops, but it does not allow the operator to separate the field components. Using a BRH laboratory instrument, however, it was established that the H field's primary component was cylindrical for the various antennas tested. The Narda probe and its readout are shown on the right in Figure 3. The only readout available from the manufacturer is calibrated in mW/cm^2 which is the "equivalent free-space power density." The manufacturer has presented experimental evidence that the probe responds only to the magnetic field (2). In this paper, the magnetic field strength data are presented in units of amperes/meter (A/m).

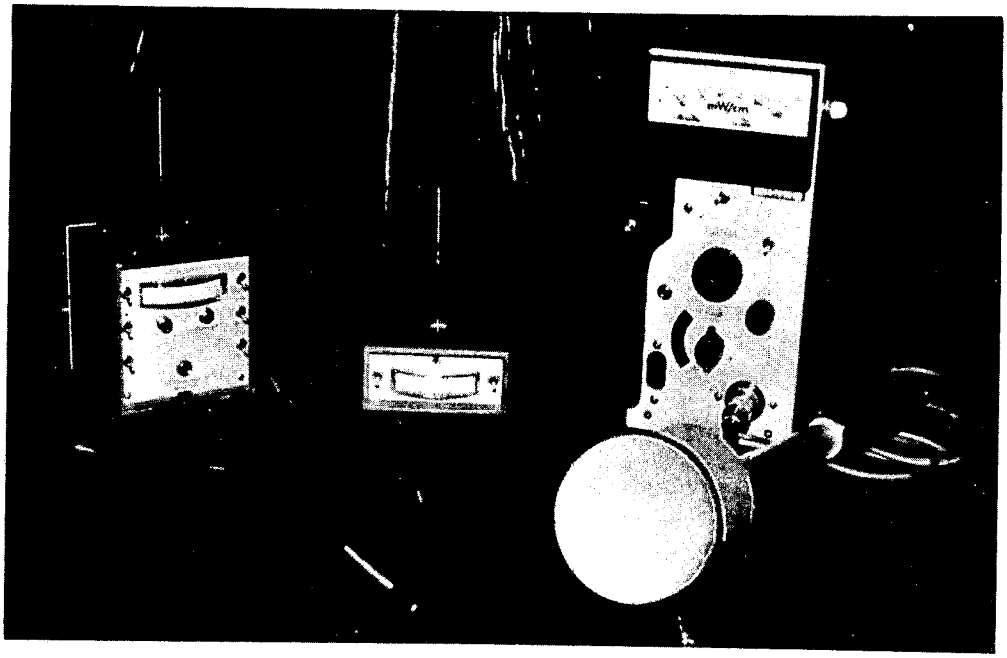

Figure 3. Electric and magnetic field measuring instruments

Both instruments have a "sensor volume" which is large compared to the 5 cm measurement separation distance for which some data are presented. It can be expected that instrumentation with a different sensor volume may produce somewhat different results at this distance. As a check on the magnitude of the differences that would result by the use of a smaller "sensor volume" electric field meter, a comparative set of data were taken with a small dipole antenna 3 cm in length, which used an integral diode detector and high resistance readout transmission line. This antenna is known to give highly accurate near-field data and is described in an earlier FDA report (1). Prior to taking the comparative measurements, this antenna was calibrated at 27 MHz at field strengths from 10 to 600 V/m, its linear region. Three orthogonal concentric orientations of this antenna were used to obtain data 5 cm from the top-loaded CB antenna in a screen room (where ambient noise levels were low enough to enable accurate data to be taken). A top-loaded CB antenna was selected because it is known to produce high E fields with steep gradients, and therefore, represents a severe test of the measurement systems. These data were compared with the RHM-2 electric field instrument's output taken under identical conditions. In the area of the CB antenna's maximum near field pattern (i.e. the maximum E-field exposure area), a comparison showed that the RHM-2 instrument's data (total field strength) was 2.5 percent below that obtained with three orthogonal measurements of the dipole/diode detector. At this location the field had a predominantly radial or "z" component, normal to the CB antenna structure. (Comparison of the measured peak "z" component alone for each system, which results in a secondary calibration point for the RHM-2, revealed a difference of only 1.4 percent, i.e. RHM-2 = 580 V/m; dipole/diode = 588 V/m.) For a predominantly vertical "y" field component, parallel to the CB antenna's structure and located in a region 60-80 cm from the CB antenna's base, the RHM-2 reads from 25 to 50 percent below the total field strength of the dipole/diode system. This was the area where the greatest difference in readings occurred. This difference is primarily due to the physical construction of the RHM-2. (Refer to the picture in Figure 3.) First, the "y" antenna's element (located on the top of the instrument), is positioned 5 cm away from the "ground" plane of the "z" antenna element, (the back surface of the instrument). The "z" antenna's tip determines the radiation measurment distance. It is located 5 cm from the CB antenna; as a result, the "y" element is actually 10 cm, or more, from the radiation source, and the result is a lower field strength reading. Secondly, the "y" antenna's "ground" plane is "off-centered" from the axis of the "z" element by approximately 5 cm. Individual component plots verified that the RHM-2 records the peak "y" field at a different point (displaced by 5-10 cm) relative to the CB antenna's base than does the small dipole/diode antenna, which has no "off center" displacement.

A similar discussion would hold for the "x" field; however, its magnitude is so low compared to the other two, that it does not significantly affect the total field measured.

In analyzing the potential error caused by this physical difference, it was noted that the "y" component predominates only along a small portion of the antenna's height, where the total field is also well below its maxima (i.e. less than 10 percent of the peak antenna field). It was decided that this second-order source of error, located in a 20 cm portion of the 120 cm CB antenna height, at a relatively low field strength, was off-set by the features of the RHM-2--portability, ease of use in outdoor situations, and total field and individual-field-vector measurement capabilities. Therefore, it was used for the data presented in this report. At the 12 cm measurement distance the total field discrepancy was reduced to less than 5 percent; and at the 60 cm measurement distance it was not observed.

FIELD GENERATING AND MONITORING EQUIPMENT

Several "full power" CB radios were measured to determine their output power into a 50 ohm load. Under these ideal conditions (VSWR = 1.0) none exceeded 4 watts forward power. As this is the legal maximum power set by the Federal Communications Commission, it was decided that this power would be used for all the tests. As the measurement required considerable amounts of time to perform, it was not practical to use actual radios for the extensive measurements. For the majority of the measurements, a laboratory radio frequency generator was used and set to 27.12 MHz as determined by a frequency counter. The generator's output was amplified and fed through a low-pass filter (to eliminate any harmonics). The signals then proceeded through a dual-directional coupler to the CB antenna.

The outputs of the directional coupler (coupled arms) were connected to two power meters to monitor the forward and reflected power. Prior to each set of measurements, the forward power was set to 4 watts when applied to a 50 ohm dummy load. The frequency was set to 27.12 MHz. The antenna was then connected in place of the dummy load, and the forward and reflected power were recorded. From this the VSWR for the CB antennas was determined. The magnetic and electric field measurements then followed.

The fields were measured from the antennas that were mounted, according to the manufacturer's instruction, on the rear bumper and trunk of a 1970 Ford Maverick. The VSWR was then calculated, and no special techniques or adjustments were made to minimize it. The field patterns were measured at instrument-to-antenna separation distances of 5 cm and 12 cm. (The spacing was maintained by using 5 cm and 12 cm styrofoam blocks taped to the measuring instrument.) The instrument was then vertically moved along the height of the antennas (i.e., whip, base-loaded, top-loaded, and middle-loaded). Two sets of twin antennas designed for bumper mounting were measured. A hand-held "walkie-talkie" type unit with its standard telescoping antenna and an optional base-loaded antenna also was measured.

RESULTS AND ANALYSIS

All of the graphical representations of the measured emissions follow the format defined in the "Magnitude Key" of Figure 4. The total electric field $|E|$ outline is shown by a solid line to the left of the "antenna" structure; the total magnetic field $|H|$ outline is shown by a dashed line to the right of the "antenna" structure. The respective field strength magnitudes, in volts/meter (V/m) and amperes/meter (A/m), are quantified by a scale at the bottom of each graph. The vertical height of the antenna from its base is shown by a vertical scale in centimeters (cm).

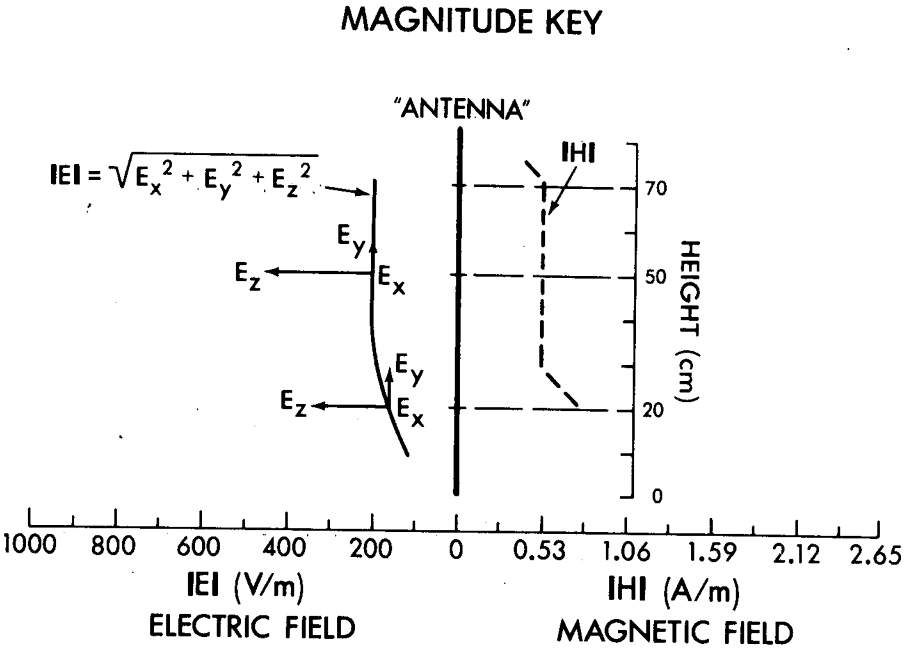

Figure 4. Graphical representation of measured fields

In addition, to supplement the total E-field data $(E_x^2 + E_y^2 + E_z^2)^{1/2}$ the three orthogonal components of the electric field are presented individually as a set of vectors at two points on each graph. These are the magnitudes of the individual components (i.e., E_x, E_y, and E_z) of the electric field where E_z = a radial component, E_y is oriented vertically, and E_x is oriented horizontally. (On this figure these are shown at distances of 20 cm and 50 cm from the base of the "antenna.") The separation distance, between the measurement instrument and antenna on any one figure, remains constant; therefore, the field pattern dimensions are proportional to the magnitude of the respective fields at different positions along the antenna's height.

Each figure also has the following information: Separation distance between measurement instrument and antenna (either 5 cm or 12 cm); location on the automobile (bumper, middle trunk); antenna design (whip, base-, top-, or middle-loaded); and VSWR. For twin antennas, both antennas are shown on the same figure.

An electric field pattern also was taken at a distance of 60 cm from the antennas that were mounted on the automobile. (The magnetic field at that distance was below 0.04 A/m, the lower sensitivity limit of the instrument.) The E-field pattern was generally the same in shape as the one taken at 12 cm; but as expected, its magnitude was much lower. The 60 cm data are not included; however, the maximum E field at this distance will be given in the discussion of the individual associated figures.

Since the "loading" of the antennas that are less than 1/4 wavelength in physical length seems to greatly affect the radiated emission patterns, these areas have been emphasized on the applicable figures. "Loading" is accomplished by adding an inductive or capacitive circuit to the antenna to match its impedance (or the VSWR) with respect to the transmitter.

A few observations and comments are presented regarding the results for various antennas and primarily for the purpose of establishing a unified picture of the data. Data which summarizes the maximum field strengths measured for each class of antenna is presented in Table 2.

Table 2. Summary of maximum measured fields near CB antennas

Antenna type and vertical height	Location of Mount	Maximum values of E & H* (27.12 MHz at Watts Input)		
		Distance from antenna (cm)	E (V/m)	H (A/m)
Quarter wavelength whip 276 cm	Rear bumper	5	225	0.53
		12	100	0.3
		60	21	---
Base-loaded 112 cm	Middle trunk lip	5	990	1.3
		12	310	0.8
		60	60	---
Top-loaded 120 cm	Rear bumper	5	1350**	0.67
		12	610	0.42
		60	42	---
Top-loaded 120 cm	Middle trunk lip	5	1305**	0.79
		12	600	0.5
		60	31	---
Twin top-loaded 120 cm	Rear bumper	5	580L/570R	0.38L/0.41R
		12	220L/220R	0.20L/0.20R
		60	23L/23R	---
Twin middle-loaded 193 cm	Rear bumper	5	417L/417R	0.29L/0.29R
		12	114L/114R	0.20L/0.20R
		60	23L/18R	---
Walkie-talkie telescoping 92 cm	Hand-held	5	225	0.1
		12	90	0.05
Walkie-talkie base-loaded 55 cm	Hand-held	5	960	0.2
		12	200	0.1

*The maximum values of E & H are not necessarily coincident in space
**Calculated from lower value of input power

BUMPER MOUNTED QUARTER-WAVELENGTH WHIP

In Figure 5, the 1/4 wavelength whip uses no "loading." As a result the field patterns are fairly uniform along the antenna's height. The electric field predominates near the tip (high-impedance point); whereas, the magnetic field is more dominant near the base (low-impedance point). The maximum field strengths measured at 5 cm were 225 V/m and 0.53 A/m.

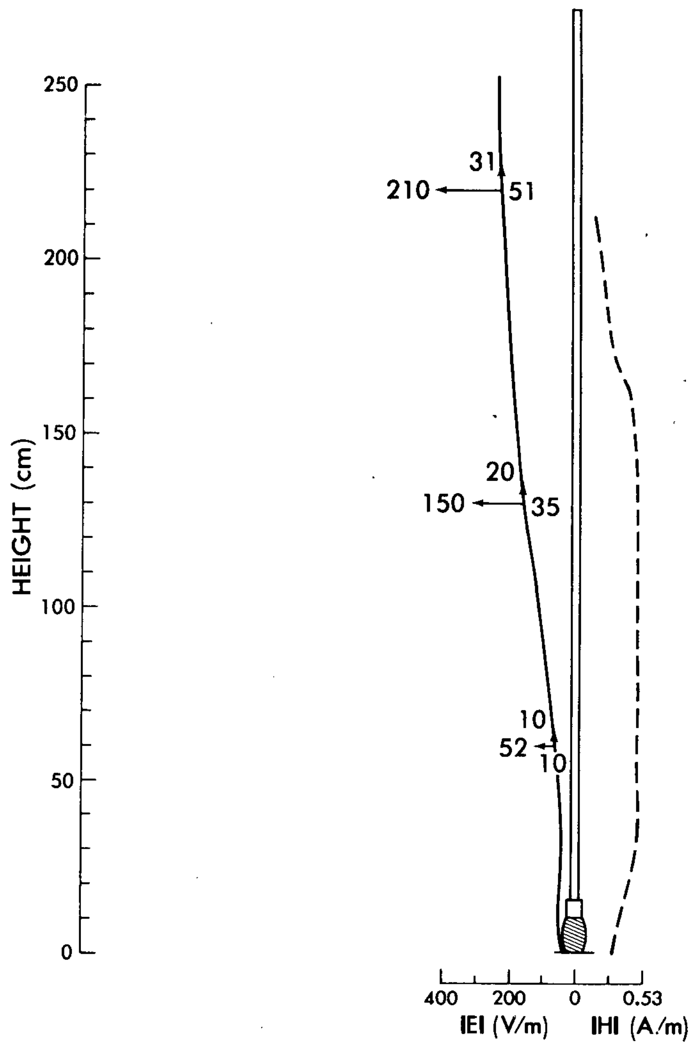

Figure 5. Electric and magnetic fields at 5 cm bumper mounted (whip) VSWR=1.71:1

The maximum fields at 12 cm were 100 V/m and 0.3 A/m. Measurements made at 12 cm show that field strengths fall-off approximately as the inverse of the distance, as shown in Figure 6. That is, with distance roughly doubled, the fields are halved. As will be obvious for subsequent "loaded" designs, this is not the general rule at these measurement distances. For this antenna, the maximum-field strength at a distance of 60 cm was

21 V/m--again, within experimental prediction on the basis of separation distance. This result provides a verification of the near-field accuracy of the measurement instruments selected for this study (i.e., the field strengths that the instruments measure are accurately determined even at 5 cm, and no "coupling" error between instrument and the antenna under study occurs).

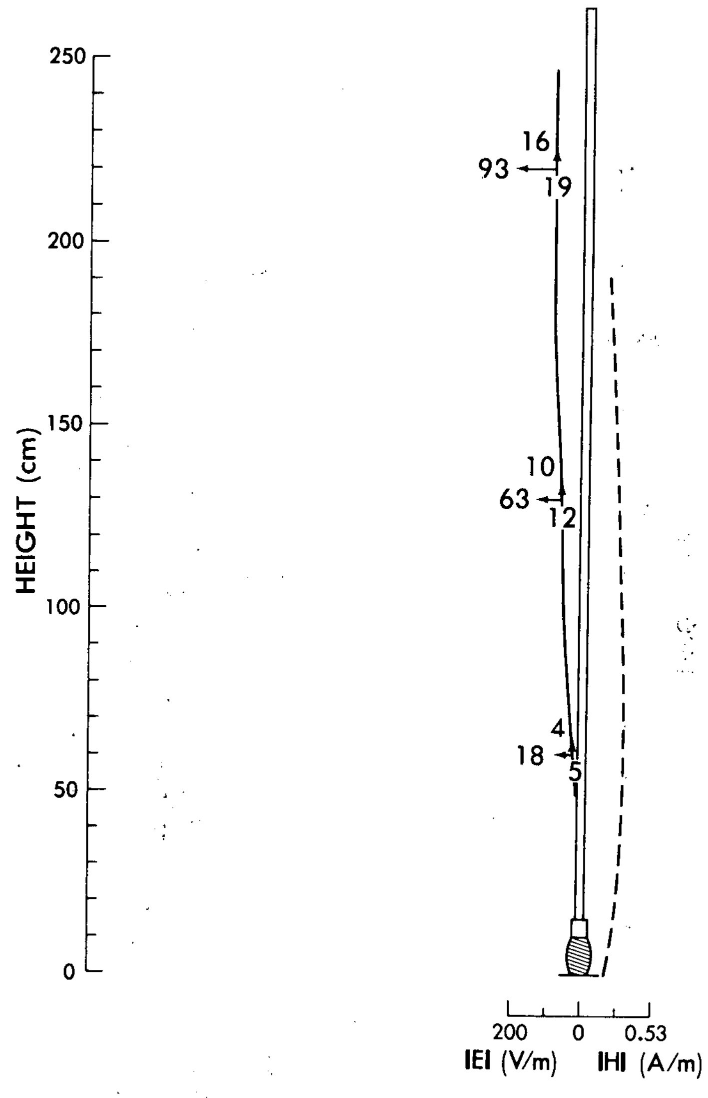

Figure 6. Electric and magnetic fields at 12 cm bumper mounted (whip) VSWR=1.71:1

TRUNK MOUNTED BASE-LOADED ANTENNA

The base-loaded antenna is probably one of the more popular types in use (Fig 7). Its radiation pattern is similar to the whip in relative uniformity, especially the electric field pattern; however, the field strength magnitudes are much larger. The loading coil at the base seems to lower the impedance and concentrate the magnetic field there (its magnitude being 1.3 A/m at 5 cm). The maximum electric field at 5 cm was 990 V/m, 20 cm above the base.

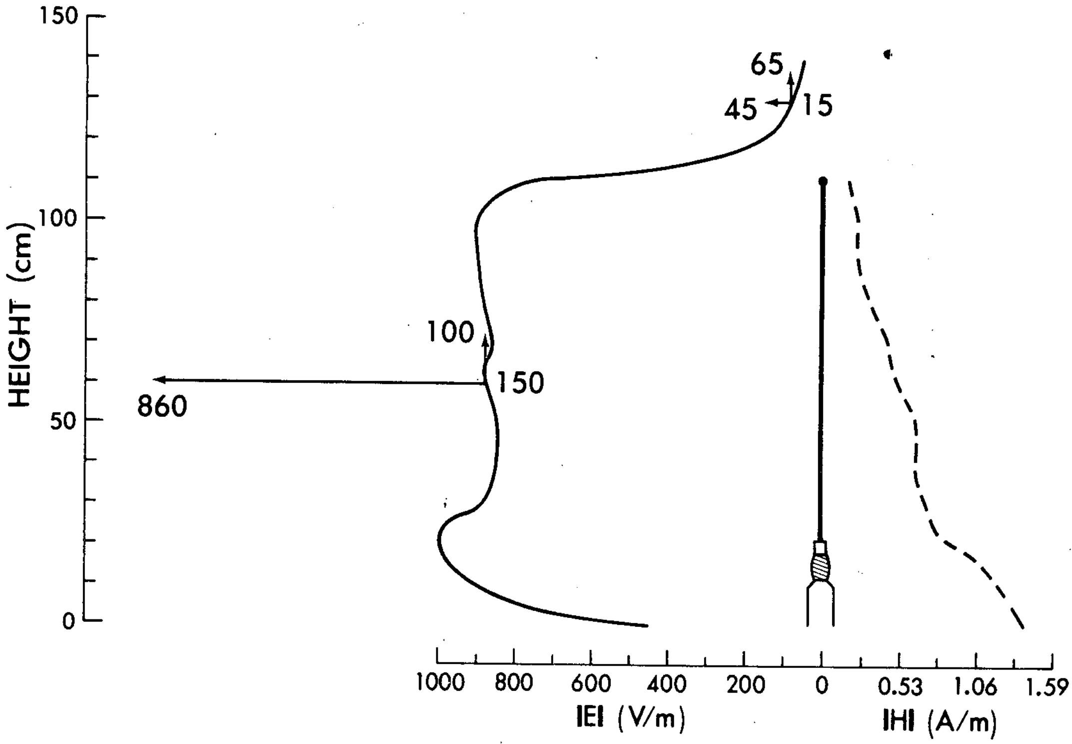

Figure 7. Electric and magnetic fields at 5 cm middle trunk mounted (base-loaded) VSWR=1.81:1

From a radiation hazard viewpoint, of all the antennas measured, this design was the only one in which both the magnetic and the electric fields simultaneously exceeded 200 V/m and 0.5 A/m in the same region along the antenna. Other antennas exceeded these field strengths, with either E or H, individually, and at different heights. This base-loaded design produced the maximum magnetic field strengths recorded in the study.

Measurements taken at 12 cm from the antenna resulted in the same general pattern--high values of E and H coexisting in the same area; however, the magnitudes were reduced to 310 V/m and 0.8 A/m maximas (Fig. 8). The maximum electric field strength at 60 cm was 46 V/m.

This type of antenna often is mounted on the trunk or roof of an automobile. In these locations, it is unlikely that a person would be as close as 12 cm to the antenna. With a bumper or rain gutter mounting, however, personnel can be in much closer proximity. Nevertheless, the high levels of coexisting fields are located at a height to expose both head and trunk of persons standing near the car (as opposed to the whip antenna where the maximum electric field is well above the head of a standing person).

With the base-loaded antenna mounted on the center of the trunk-lip, nearest the rear window, measurements were made by scanning the area inside the automobile, in the vicinity of the rear seat and its head rest. This resulted in no measurable field for the instruments being used ($E < 1$ V/m, $H < 0.04$ A/m). A report (3) exists in which field strengths were measured on the inside of an automobile that were on the order of 200 V/m near the steering wheel. In that study, a 100-watt amplifier was used, as opposed to the 4-watt power level used here.

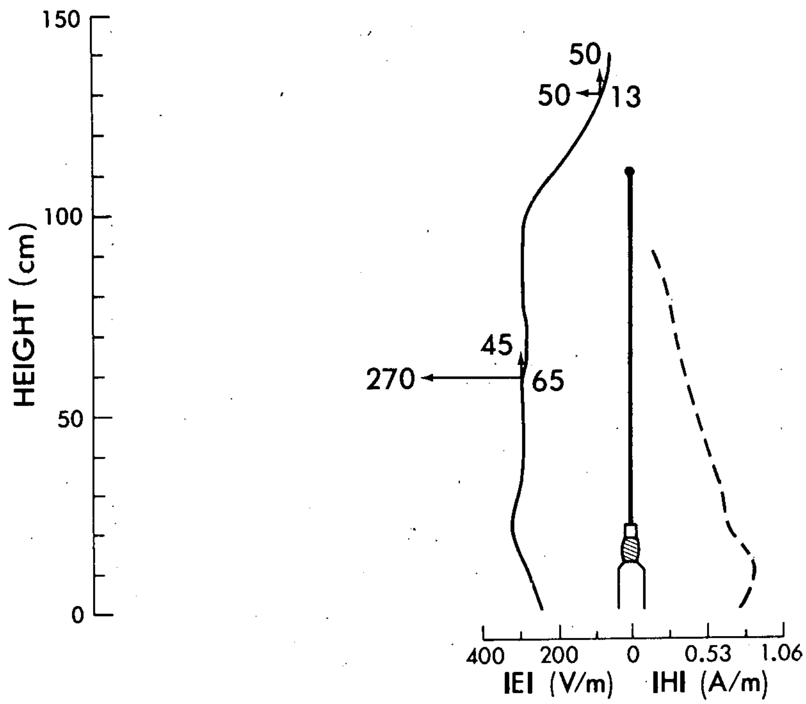

Figure 8. Electric and magnetic fields at 12 cm middle trunk mounted (base-loaded) VSWR=1.81:1

BUMPER MOUNTED TOP-LOADED ANTENNA

The top-loaded antenna exhibits field patterns that are quite different from either the whip or the base-loaded units (Fig. 9). This antenna is the one that illustrates how a single antenna can possess both the radiation properties of a high impedance monopole and a low-impedance loop of Figure 2. Contrary to the base-loaded, where coexistence of large E and H fields were observed at the same point, in this design it appears that E and H are mutually exclusive of each other.

The maximum E field that was recorded occurred 110 cm above the base and was calculated to be 1,350 V/m, measured at 5 cm. (Power to the antenna was reduced to obtain a reading with the instrument, whose maximum indication was 1,000 V/m. This was then extrapolated to the actual value at full power.) This was the highest electric field recorded during this study. The maxima would be at a standing person's head level for this mounting position on the automobile. The maximum H field was 0.67 A/m, at 50 cm above the base, again measured at 5 cm.

It should be noted that the magnetic field does not go to zero as implied by the absence of the dashed line in the vicinity of the loaded portion of the antenna. During the experiment it was observed that when extreme source impedance characteristics occurred--in this case very high E/H ratio--the magnetic field probe's reading was highly erratic. The transmitter reflected power also increased significantly. "Coupling" between antenna and probe, at the 5 cm distance, appeared to be taking place; therefore, no values of H are shown in this figure, or in subsequent ones where this condition existed. At 12 cm, as will be shown, this measurement was possible.

It would be interesting to determine which electric field pattern, of the three antennas discussed so far, actually provides better far-field coverage from a communication viewpoint. This question was not addressed here, but near-field (magnitude only) mapping might provide antenna designers with a convenient optimization tool.

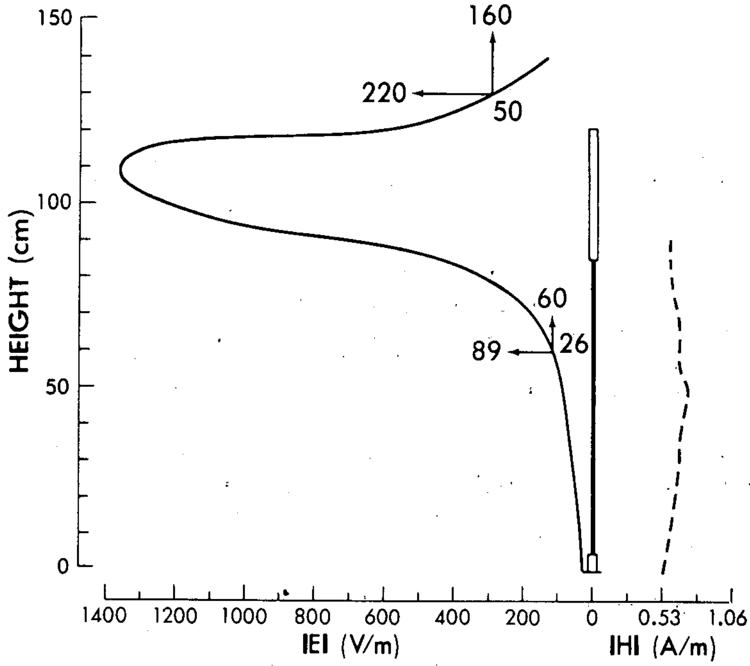

Figure 9. Electric and magnetic fields at 5 cm bumper mounted (top-loaded) VSWR=1.62.1

The main points of Figure 10 would be that the magnetic field now is shown to exist in the loaded portion, and, is measurable at this 12 cm distance since the extreme E/H ratio of the previous figure is reduced. The maximum H field at this distance was 0.42 A/m. The E-field maximum was 610 V/m. At a distance of 60 cm this maximum is reduced to 42 V/m.

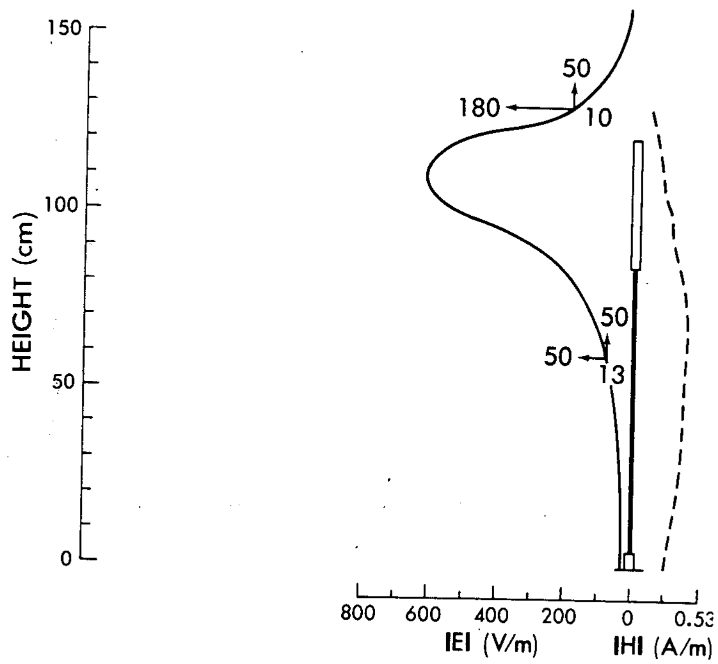

Figure 10. Electric and magnetic fields at 12 cm bumper mounted (top-loaded) VSWR=1.62.1

TRUNK MOUNTED TOP-LOADED ANTENNA

The top-loaded antenna also can be mounted on the trunk lip (Fig. 11). In this position, its characteristic radiation patterns were only slightly changed when compared to the bumper-mounting condition of Figure 9. The magnetic field appears to have less severe gradients, and the maximum value recorded was increased to 0.79 A/m at the base. The electric field maximum occurs at the same location as in bumper mounting (Fig. 9), but down slightly at 1,305 V/m. The larger ground plane of the trunk lid seems to affect the pattern by increasing the H field and decreasing in the E field. This same effect has been observed with even a greater extent when measurements of this antenna were performed in a screen room, the results of which are published elsewhere (4).

Figure 12 shows a comparison of the radiation patterns for trunk-lip mounting at 12 cm with Figure 10 (bumper-mounted) which shows similar results. Namely, the maximum E field was 600 V/m, and the maximum H field was 0.5 A/m. The maximum field strength at 60 cm from the antenna was 39 V/m.

In the case of the top-loaded antenna data illustrated in Figures 9,10,11 and 12, it appears that essentially no changes occur in the field patterns when the antenna is moved from the bumper to the mid-trunk location on the automobile. As a result of the greater separation distance from personnel at the mid-trunk location, possible exposure would be reduced. The added height of the antenna also would move the E-field maxima higher, and possibly above, the heads of nearby persons.

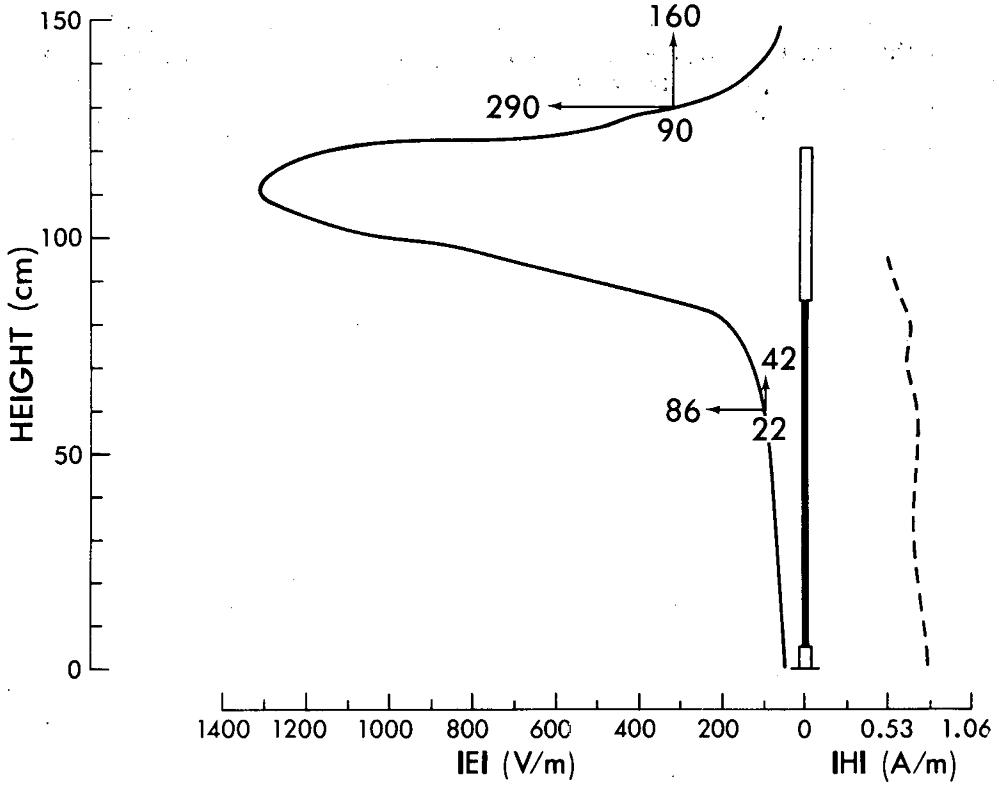

Figure 11. Electric and magnetic fields at 5 cm middle trunk mounted (top-loaded) VSWR=1.50:1

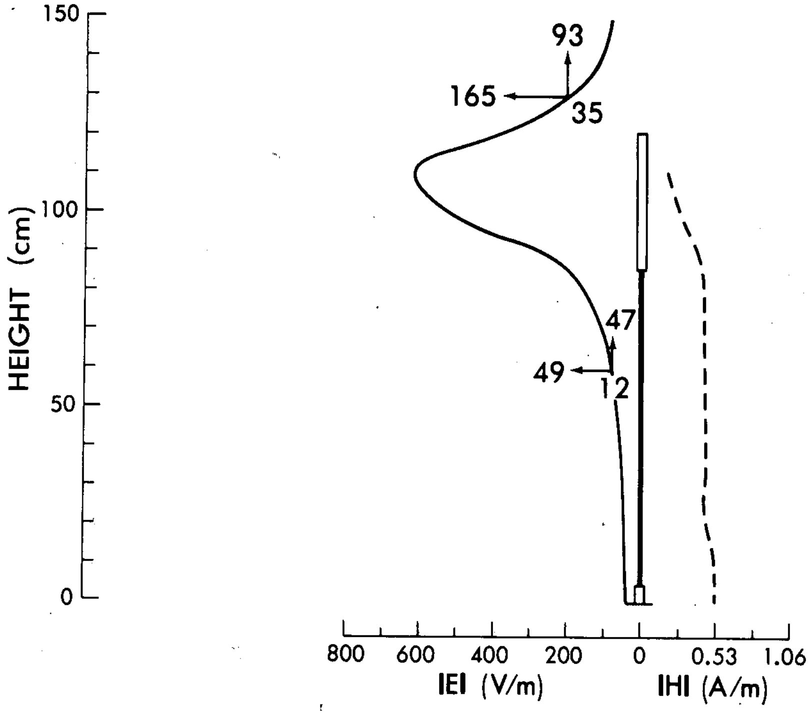

Figure 12. Electric and magnetic fields at 12 cm middle trunk mounted (top-loaded) VSWR=1.50:1

BUMPER MOUNTED TOP-LOADED TWIN ANTENNAS

The first set of twin antennas to be discussed were top-loaded antennas (Fig. 13). (They are a pair of the same top-loaded antenna discussed previously, but sold as a set with a special "cophased" harness, or cable.) The purpose of "cophased" antennas is to achieve some degree of directivity, in this case forward and backward, ahead and behind the vehicle with lower far-field radiation to the sides of the automobile.

The antenna sets evaluated in this report are sold for automobile bumper mounted use, and no attempt was made to simulate the twin antenna sets sold for use on trucks. (The principle is the same in either case, but the basic difference is that trucks are wider--requiring different antennas--especially when "mirror mounts" are used.) In theory, 1/4 wavelength antennas (these are electrically equivalent because of "loading"), that are operated in phase and separated by 1/2 wavelength have maximum gain normal to the plane in which they are located; i.e., up and down the road for antennas mounted on the rear bumper. As the distance between the antennas is reduced, the directivity decreases until essentially none exists for separations of 1/8th wavelength. On the test vehicle (1970 Maverick), the greatest separation distance achievable was 1.2 meters (4 feet). The half-wavelength distance at 27 MHz is 5.5 meters (18 feet). The maximum E fields at 5 cm are 580 V/m for the left antenna and 570 V/m from the right antenna. The maximum H was 0.38 A/m for the left antenna and 0.41 A/m for the right antenna.

From a radiation safety viewpoint, the maximum exposure possible from the twin antennas is less; however, a standing person has a greater chance of being exposed in a high-field strength area since both antennas are closer to the edge of a vehicle where pedestrians are located.

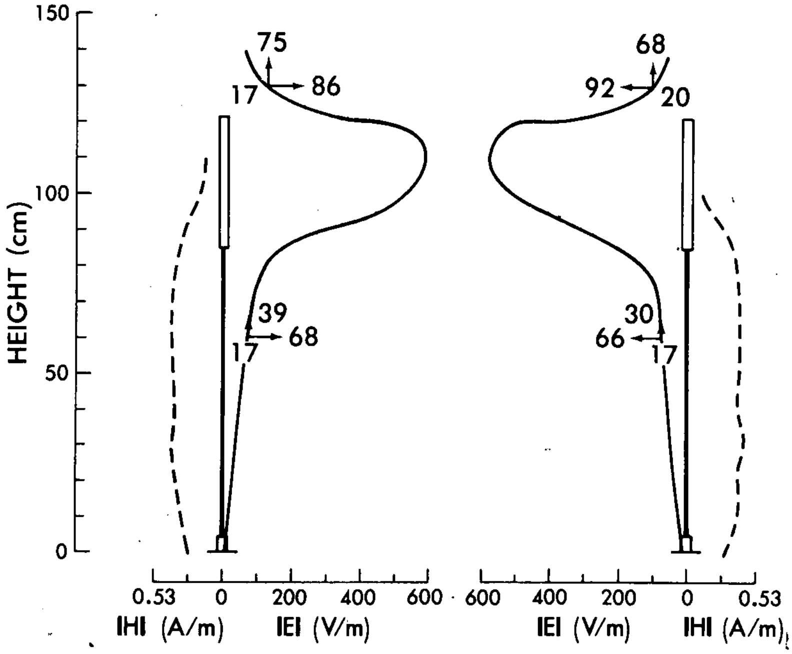

Figure 13. Electric and magnetic fields at 5 cm bumper mounted (top-loaded) VSWR=1.54:1

As shown in Figure 14, 12 centimeters from the twin, top-loaded antennas, the maximum fields are as follows: left antenna E = 220 V/m, H = 0.23 A/m; right antenna E = 220 V/m, H = 0.27 A/m. At 60 cm from either antenna the maximum E field was 23 V/m.

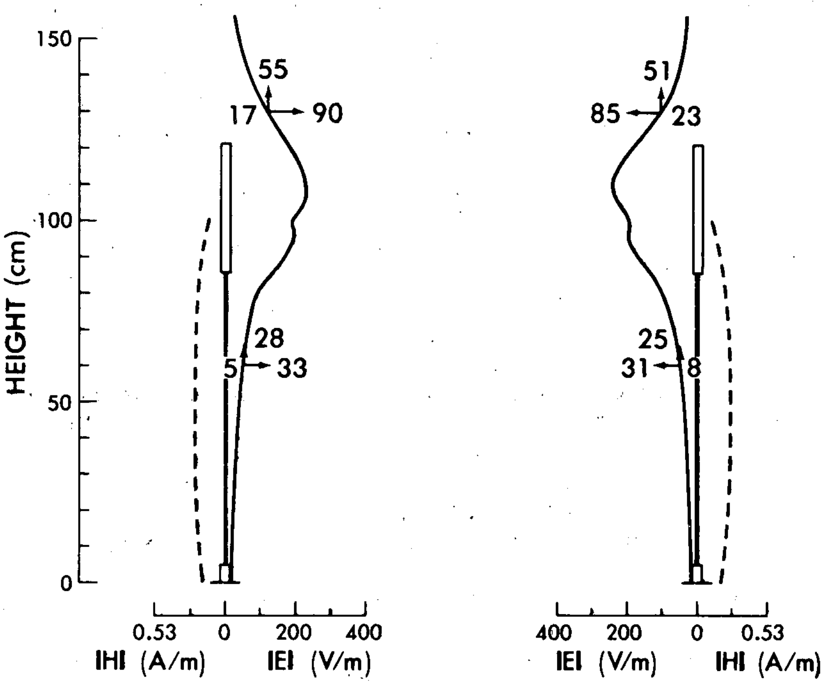

Figure 14. Electric and magnetic fields at 12 cm bumper mounted (top-loaded) VSWR=1.54:1

BUMPER MOUNTED MIDDLE-LOADED TWIN ANTENNAS

Experimentally undifferentiable radiation patterns were measured from this set of twin antennas (Fig. 15). The VSWR was the lowest of all the antennas tested. The electric field pattern was quite uniform with the exception of the convolutions along the middle-loaded portion. The only measureable magnetic fields were also in this area. The maximum electric field (at 5 cm spacing) was 417 V/m; the maximum H field was 0.29 A/m.

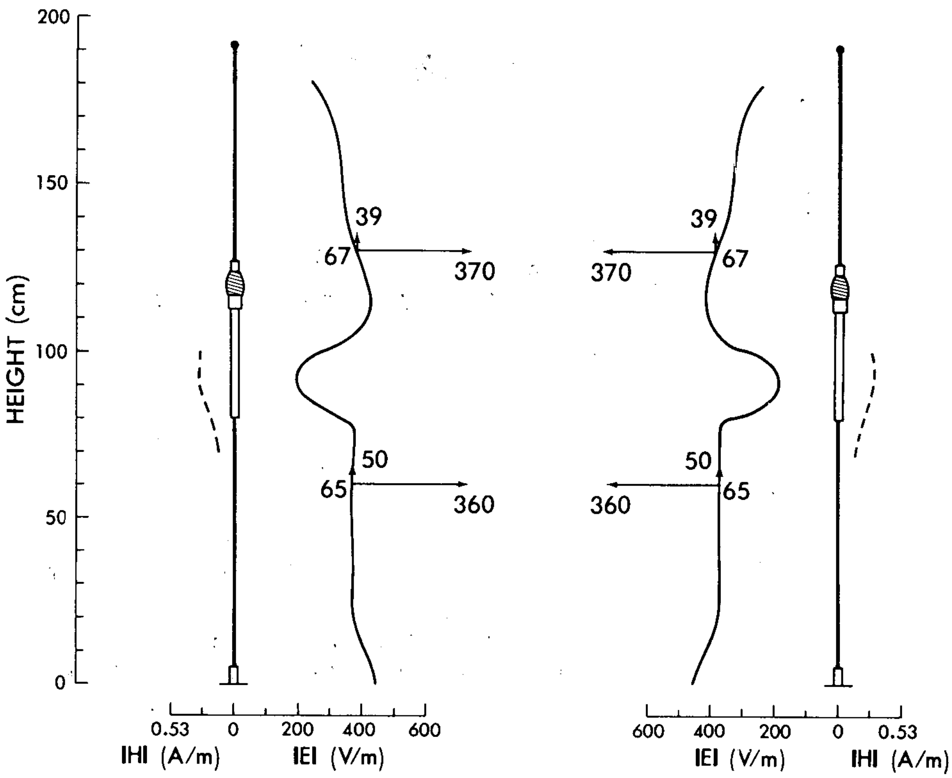

Figure 15. Electric and magnetic fields at 5 cm bumper mounted (middle-loaded) VSWR=1.24:1

During the course of the experiments a problem developed. Figure 16 illustrates the results. This set of antennas was mounted on the rear bumper and measurements were taken. The VSWR was high but not considered unreasonable. The radiation measurements, however, showed that there was a great difference in the patterns of the two antennas. The harness (cable) was reversed, the antennas interchanged, and even the automobile's location in the parking lot was changed in attempts to identify the problem. The only difference that remained was discovered to be in the spacer's physical make-up. Spacers are non-conducting "washers" that physically and electrically separate the antenna from its mount on the automobile. Apparently, the spacers that came with this particular set of antennas was critical to their performance. (This did not show up in radiation pattern differences when the previous set of top-loaded antennas were substituted in these mounts.) Figures 17 and 18 are photographs of the antenna mounts as they appeared during the measurements of Figure 16. The correct spacer is the one in Figure 18. The interesting point is the large effect that 1/4 inch of spacer had on the resulting patterns. Without radiation pattern measurements, this probably would not have been discovered.

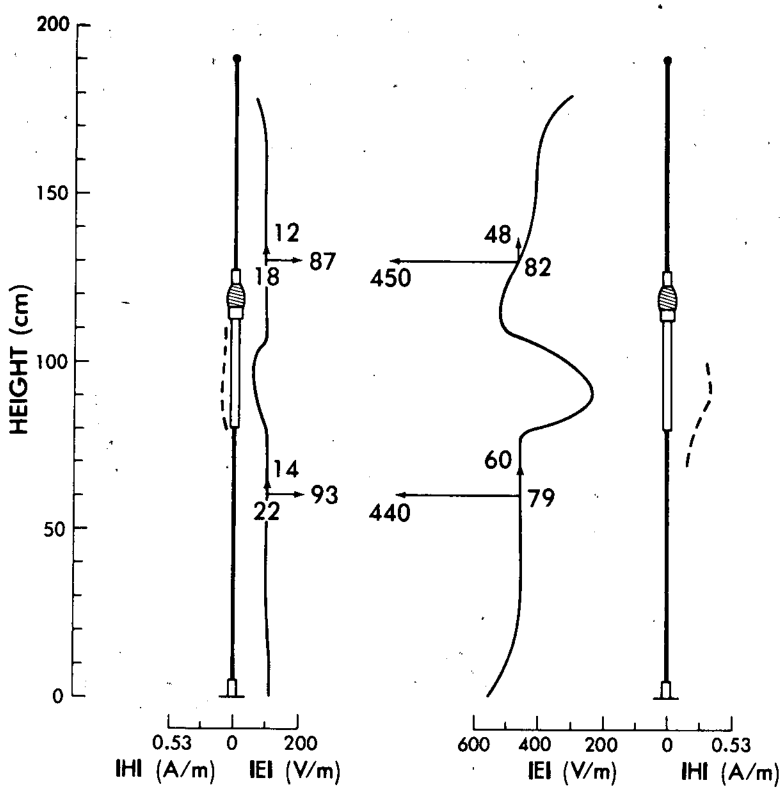

Figure 16. Electric and magnetic fields at 5 cm bumper mounted (middle-loaded) mismatched VSWR=1.84:1

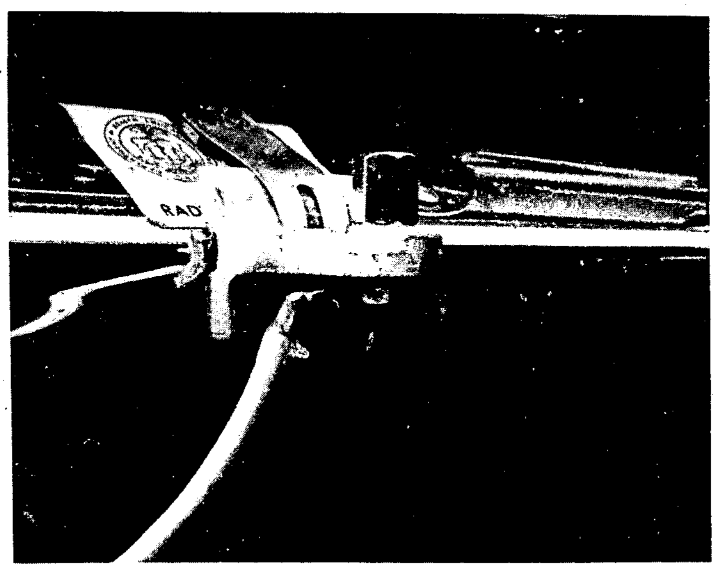

Figure 17. Left mount for twin antenna array illustrating improper spacer

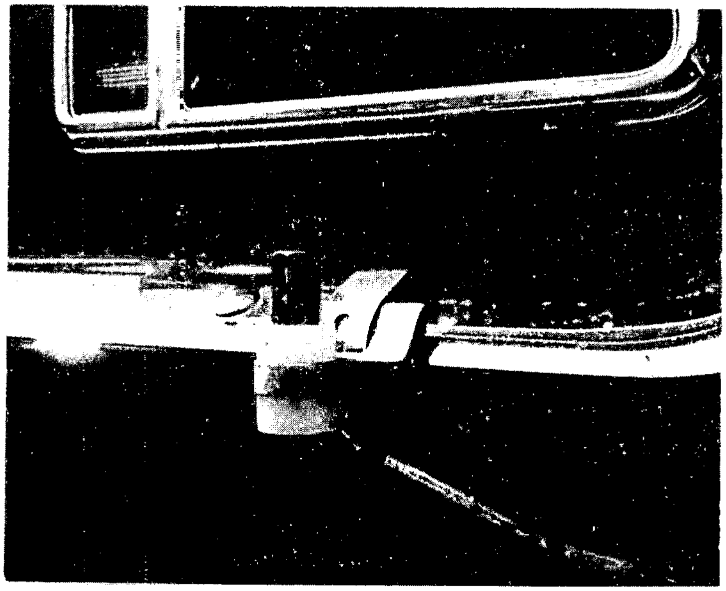

Figure 18. Right mount for twin antenna array illustrating proper spacer

At 12 cm the following maximum fields from each antenna were measured: E = 114 V/m and H = 0.2 A/m (Fig. 19). At 60 cm from each antenna the maximum electric field strength was 18 V/m. Comparing this set to the other set of twin antennas, the conclusion is that the field strengths are lower in magnitude; however, because of the relative pattern uniformity of Figures 15 and 19 (the middle-loaded antennas), the potential exposure area is greater and approaches a "whole body" condition.

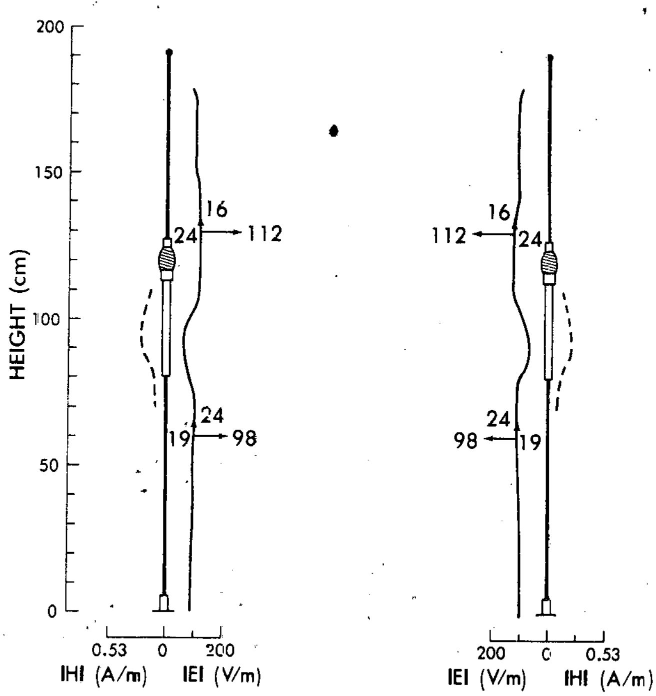

Figure 19. Electric and magnetic fields at 12 cm bumper mounted (middle-loaded) VSWR=1.24:1

HAND-HELD WALKIE-TALKIE

A hand-held walkie-talkie operating at 4 watts in the CB portion of the spectrum was measured for its emission characteristics (for comparison with the other measurements taken and to simulate free-field exposure, this unit was mounted on a tripod). In Figure 20 the telescoping antenna, common to units of this type, is shown. The telescoping antenna provides a uniform wave-front very similar to the whip of Figure 5. In comparison with vehicle-mounted antennas, the magnetic fields are much less for this portable transmitter. This is probably because there is much less of a ground plane to directly affect the magnetic field (Fig. 11). The maximum E and H fields occurred at about 10 cm above the junction of the antenna with the transmitter; they were respectively 225 V/m and 0.1 A/m at 5 cm from the antenna. At 12 cm from the antenna, the maximum field strengths were 90 V/m and 0.05 A/m (Fig. 21).

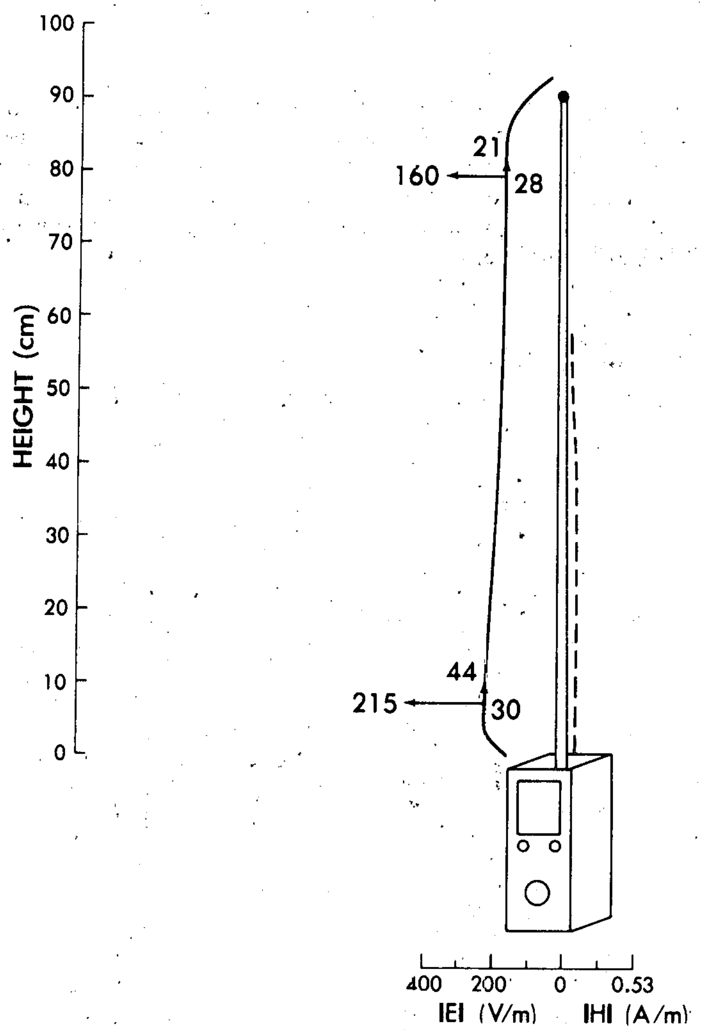

Figure 20. Electric and magnetic fields at 5 cm hand-held walkie-talkie (whip) four watts

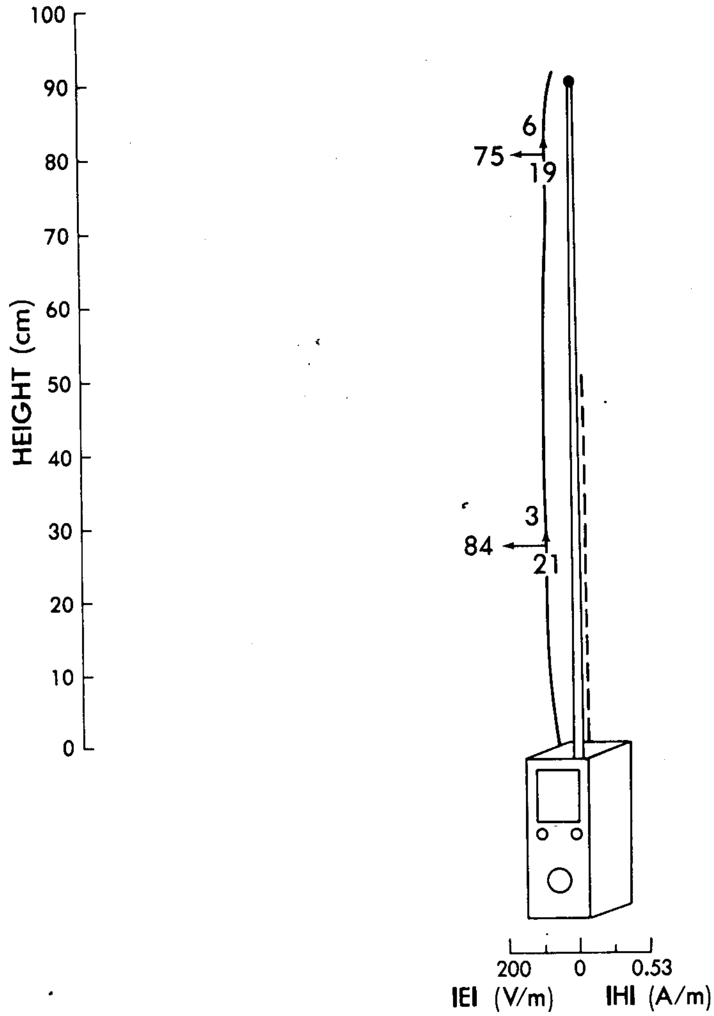

Figure 21. Electric and magnetic fields at 12 cm hand-held walkie-talkie (whip) four watts

It was not possible to measure the VSWR associated witn this portable unit.

A base-loaded antenna also is sold for use with this portable unit. With this optional antenna, the radiation pattern is much stronger and not as uniform (Fig. 22). Approximately 10 cm above the junction of the antenna with the transmitter, the field strengths were 960 V/m and 0.2 A/m at 5 cm from the antenna. At 12 cm the maximum E and H fields were 200 V/m and 0.11 A/m (Fig. 23). Along most of the antenna heignt the electric field is quite strong. The electric field is quite similar to the automobile-mounted base-loaded antenna of Figure 7. The magnetic field is similar in form but much lower in magnitude.

What may be significant, in this instance, is that under normal use conditions the antenna of portable units is 5 to 12 cm from the face of the operator. This creates a much higher probability of exposure to high-level fields compared to vehicle-mounted CB systems. There has been a study (5) that concerns itself with the relationships of external field strengths, the resultant temperature rise and energy deposition in simulated tissue for portable hand-held units operating at 150 MHz and 450 MHz. A study at 30 MHz is planned by the same group.

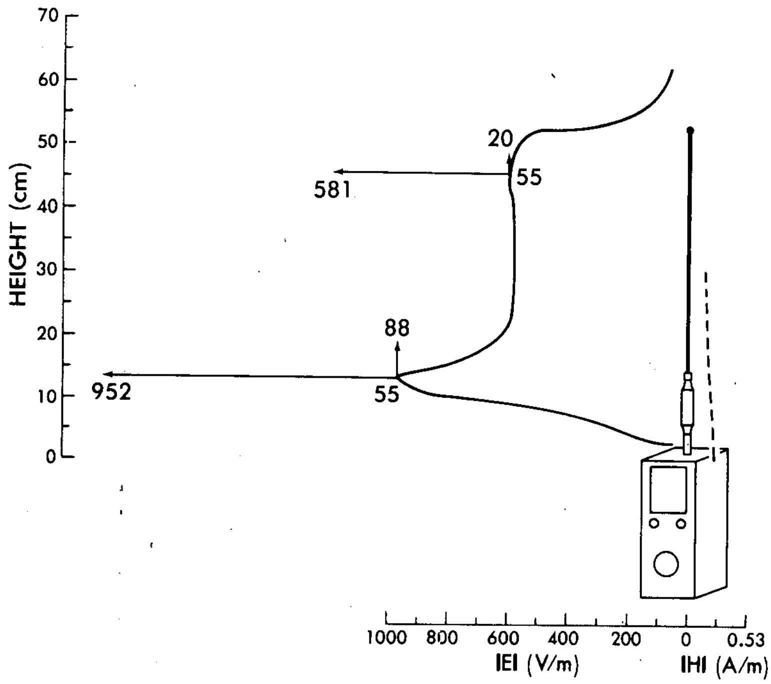

Figure 22. Electric and magnetic fields at 5 cm hand-held walkie-talkie (base-loaded) four watts

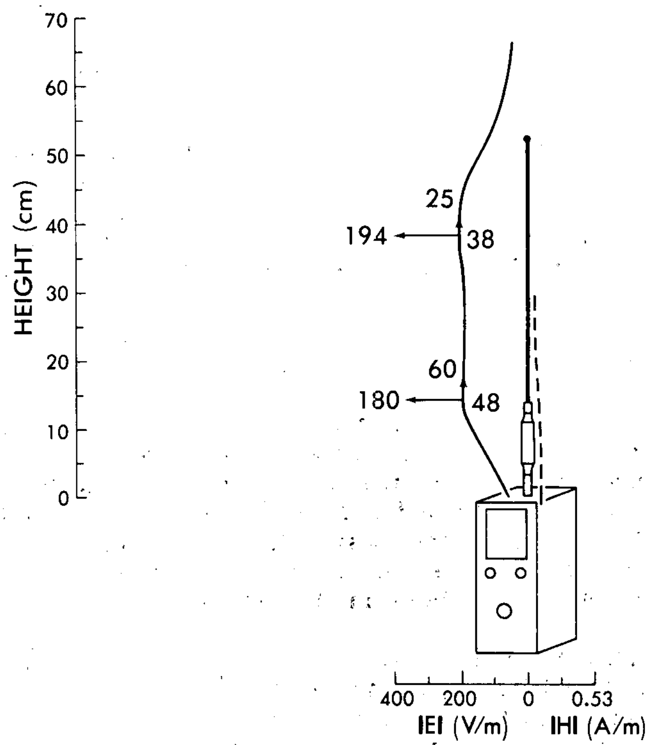

Figure 23. Electric and magnetic fields at 12 cm hand-held walkie-talkie (base-loaded) four watts

CONCLUSIONS

The legal maximum output transmitter power of 4 watts was used throughout this study. Should one be using a "toy" type walkie-talkie--i.e., one not requiring a license, the field strengths should be appropriately reduced. A 100-milliwatt unit, for example, would produce field strengths 0.16 times those reported. (The power is 0.025 of 4 watts. This results in a field strength reduction of $(0.025^{1/2}$ or 0.16.) On the other hand, if one were using an illegal "linear amplifier" of 100 watts, the field strengths in this report would be multiplied by 5.0. (Power increase is 25 times resulting in field strength increase of $(25)^{1/2}=5$.) For example, several antennas measured 200 V/m at 12 cm. With a linear 100-watt amplifier this becomes 1,000 V/m, which is equal to a free-space equivalent power density of 265 mW/cm^2. It logically follows that the operators of these illegal units are creating proportionately higher exposures which may create an associated greater health risk.

All of the field strengths reported represented actual measurements under the installation conditions recommended by the manufacturer of the antennas. As was shown in Figure 16, small deviations (in this case interchanging spacers) can result in significant changes in radiated pattern. Also, the proximity to metal objects (a truck in an adjacent lane) may cause significant variation. Internal energy deposition, environmental conditions, and the bioeffects of CB radiation, which were not studied, will introduce other unknowns into the problem of ascertaining the public health risk.

What has not been stated until this point is that the field strengths of 200 V/m and 0.5 A/m, (equivalent to a far-field power density of 10 mw/cm^2), are the radiation protection guides for continuous unmodulated field strengths recommended by the American National Standards Institute (ANSI) (6) with respect to personnel exposure of 0.1 hour or more. The ANSI standard also addresses modulated fields." . . . For modulated fields, the power density and the squares of the field strengths are averaged over any 0.1 hour period;..." The ANSI standard further recommends that "radiation characterized by a power level ten-fold smaller will not result in any noticeable effect on mankind. Radiation levels which are tenfold larger than recommended are certainly dangerous." The ANSI standard, therefore, for uncontrolled populations subjected to unknown stress conditions, has been interpreted by some to be applicable at a level of no more than 1 mW/cm for continuous exposure durations of 0.1 hours or more, with equivalent recommended field strengths of 60 V/m and 0.15 A/m.

As has been shown, under some conditions of exposure, (i.e., specific separation distances and personnel location, with respect to the antenna), the recommended continuous exposure limits can be significantly exceeded. The amount of time spent in these high fields during CB transmissions is, of course, highly variable. It could extend from a brief "10-20" request lasting for a few seconds (FCC class D operation), to periods of several minutes when flying a model airplane or controlling a model car (FCC class C operation) via radio control. It should be noted that the field strength and equivalent power density limits in ANSI C95.1 were not derived from biological data obtained from 27 MHz exposures and the actual health significance of the field strength data in this report is not known at this time.

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Department of Health, Education, and Welfare, PHS, Food and Drug Administration, Bureau of Radiological Health - HEW Publication (FDA) 79-8080 (January 1979) 23 pp. (limited distribution).

ABSTRACT: Citizen Band (CB) radios are in very wide use in the United States. In evaluating any possible radiation hazard associated with their normal use, the first step is to know the characteristics of the radiation typically emitted. The estimation of human exposure to the electromagnetic fields generated by these devices is complicated by the fact that exposure occurs in close proximity to the antenna or in the

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KEYWORDS: CB; near-field measurement; E-field; H-field; radiofrequency measurement instruments; electromagnetic radiation; citizen band radio.

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