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MEASUREMENTS OF ENVIRONMENTAL ELECTROMAGNETIC FIELDS AT AMATEUR RADIO STATIONS

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EXECUTIVE SUMMARY

In order to obtain data on environmental radiofrequency (RF) fields in the vicinity of amateur radio stations, the Federal Communications Commission (FCC) and the U.S. Environmental Protection Agency (EPA) conducted a joint measurement study of nine amateur stations in southern California. This information will be useful to the FCC in determining how to implement newly revised guidelines for human exposure to RF energy. Amateur stations were chosen that represented a variety of antenna and equipment types, many of which are commonly used by amateur radio operators licensed by the FCC.

Measurements of electric and magnetic field strength were made in areas near amateur antennas and equipment in order to determine typical and "worst case" exposure levels of amateur radio operators, their families and other individuals who live or work in the vicinity of these stations. Measurements were made using instrumentation appropriate for the particular transmitting frequency being used at a given location. Both broadband and narrowband instruments were used.

For most of the stations surveyed, current RF protection guidelines for field strength and power density were not exceeded in accessible areas. The highest readings in accessible areas were generally associated with vehicle-mounted antennas. However, when "duty factors" are taken into account routine exposures from such antennas would be expected to comply with safety guidelines.

If maximum permissible power levels and different facility configurations are used, higher exposure levels than those measured here cannot be ruled out. Such exposures could affect the amateur operator or other individuals in the immediate vicinity of a station. However, it is concluded that appropriate precautionary measures and facility siting should be sufficient to prevent exposures that are in excess of safety guidelines.

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INTRODUCTION

There are more than 500,000 licensed amateur radio operators in the United States and many more throughout the world. Consequently, there is potential for human exposure to radiofrequency (RF) electromagnetic fields due to amateur radio stations. Because of its responsibilities under the terms of the National Environmental Policy Act (NEPA), the Federal Communications Commission (FCC) has an interest in ensuring that FCC-regulated transmitters do not expose the public to levels of RF energy in excess of accepted RF safety guidelines. Since 1985, human exposure to RF fields has been one of several environmental factors considered by the FCC in evaluating potential environmental impact from facilities and equipment it regulates.[1] More recently, as discussed later, the FCC has proposed to adopt new guidelines for evaluating human exposure to RF energy.

In order to obtain data on the potential environmental impact of transmissions from amateur radio stations, personnel from the FCC and the U.S. Environmental Protection Agency (EPA) measured electromagnetic fields at several stations in southern California in July, 1990. Measurements of electric and magnetic field strength were made in areas near antennas and transmitting equipment in order to determine potential levels of exposure to RF radiation for amateur operators and other individuals who may be present in the immediate vicinity of amateur stations. Some measurements of operator exposure to 60-hertz magnetic fields were also made because of interest by the EPA in the extremely-low-frequency (ELF) electromagnetic environment. Data obtained as a result of this study will assist the FCC in determining how to ensure compliance with new RF guidelines that may be adopted in the near future.

Nine amateur stations were selected for this study based on several factors, including availability of the operator during the study period, the variety of antennas and equipment at the station, the variety of available frequencies, and accessibility of the transmitting site. Participation in the study was voluntary. The southern California location was chosen primarily because of its proximity to the EPA laboratory in Las Vegas, Nevada, where the EPA personnel, measurement vehicle, and most of the measuring equipment were located.

It was desired to obtain as representative a sample of amateur installations as possible so that comparisons with other typical amateur stations could be made. However, it is recognized that no two amateur facilities are likely to be identical. Multiple frequency bands are allocated for amateur use between 1.8 MHz and 250 GHz, and the maximum allowable power for an amateur station is 1500 watts peak envelope power (PEP).

The stations visited ranged from simple to complex, and measurements of fields due to transmissions from vehicular-mounted antennas were also included. Electric

[1] FCC policy on RF exposure can be found in 47 CFR 1.1307(b).

and magnetic fields due to several different antenna types and configurations with various antenna gains were studied. Antennas used at the stations included Yagis, Quagis, "inverted-V" dipoles, horizontal dipoles, vertical radiators, VHF-discones, and others. Primarily, HF and VHF frequencies were used for transmissions. Operating powers ranged from below 100 watts to as much as 1400 watts.

MEASUREMENT PROCEDURES AND INSTRUMENTATION

Measurements were made using instrumentation appropriate for each particular transmitting frequency. Electric field strength for frequencies of 7.2 MHz and below was measured using an Instruments for Industry Model EFS-1 field intensity meter. This instrument consists of a single short monopole on a conductive box. The box contains the readout electronics and acts as an integral part of the antenna. The instrument detects only the component of the field aligned with the monopole. In this study, the instrument was oriented until a maximum reading was obtained.

For frequencies above 7.2 MHz, electric field strength was measured using a Holaday Industries Model HI-3001 isotropic, broadband, field intensity meter. Both of these instruments were calibrated in the EPA's transverse electromagnetic (TEM) cell. An automated, narrowband instrumentation system, incorporating a NanoFast fiber-optically isolated spherical dipole (FOISD) antenna and a Hewlett-Packard spectrum analyzer, was also used in a few cases for electric-field comparison measurements.

Magnetic field strength was measured using a calibrated loop antenna connected to a Hewlett-Packard, Model 435B, battery-operated power meter. Readings were converted from milliwatts to milliamperes per meter. The loop antenna was calibrated by the manufacturer. An Aeritalia Model TE 307 broadband field-intensity meter and a Narda Model 8631 broadband probe with a Model 8621 meter were also used for comparison with loop measurements.

Measurements were made at one or two meters above ground at various distances with respect to the antennas studied. Measurements were also made at various locations inside buildings and at operator locations ("ham shacks"). All measurements were made while operators transmitted in the "key down" position, i.e., continuous wave transmissions without modulation. Although this would not be a normal operating mode, it was used in order to obtain a stable reading on the measuring instruments. Electric and magnetic field strength values were corrected for calibration error and rounded off.

RESULTS AND DISCUSSION

An attempt was made to survey as many different types of antenna installations as possible and to take measurements at frequencies commonly used by amateur operators. A summary of the various amateur sites visited is given in Table 1, along with information on frequencies and powers used. The antennas that appear to be the most commonly used by amateurs are Yagi and dipole antennas. Several other antenna types were also encountered, including vertical radiators, whip antennas, a VHF discone, and a "Quagi" antenna. The highest operating power level observed during the study was 1400 watts, at Station "F." Attempts were made at other stations to use power levels that were as high as practical in order to create "worst case" situations.

Examples of maximum electric and magnetic field strength levels measured at the amateur sites are given in Tables 2-4.

Commonly encountered field strength readings in accessible areas near antennas and equipment generally were in the range of 1-20 V/m for the electric field and less than 50 mA/m for the magnetic field. Maximum readings obtained in accessible areas within a few meters of some antennas and equipment were as high as 237 V/m and 1350 mA/m, but readings this high were not common. In general, the highest readings in accessible areas were associated with vehicle-mounted antennas, which are generally located at or near ground-level, and wire antennas, such as dipoles, that may be mounted just above a roof or yard.

The values obtained in this study represent what we believe to be reasonable examples of "worst-case" exposure levels for the antenna sites surveyed. In particular, since transmissions were "key down," i.e., continuous-wave unmodulated signals, they would not be common during routine communications. Normally there would be a duty factor associated with an amateur transmission that should be significantly less than 100%. Safety guidelines incorporate time-averaging provisions for evaluating human exposure that would take into account duty factors.[2]

Tables 2-4 also show a comparison of measured maximum field-strength values with RF exposure guidelines issued by the American National Standards Institute (ANSI) in 1982 (ANSI C95.1-1982, see Reference 1) and also with recent guidelines issued by the Institute of Electrical and Electronics Engineers (IEEE C95.1-1991, see Reference 2) that replace the previous ANSI C95.1-1982 guidelines (ANSI adopted the IEEE guidelines in 1992 and designated them ANSI/IEEE C95.1-1992). The FCC currently applies the 1982 ANSI guidelines for purposes of evaluating RF exposure. However, in 1993 the Commission proposed to begin using the new ANSI/IEEE guidelines in the future.[3] Both exposure guidelines are frequency dependent and recommend safe levels that are based on averaging exposure over a given period of

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[2] See ANSI and IEEE guidelines (Appendix B).

[3] Federal Communications Commission Notice of Proposed Rule Making, ET Docket 93-62, 8 FCC Record 2849 (1993) 58 Federal Register 19393 (1993). Also, 8 FCC Record 5528 (1993), 9 FCC Record 317,985, 989 (1994), 58 Federal Register 43091, 60827 (1993) and 59 Federal Register 3050, 9171 (1994) [extension of comment deadlines].

time. A summary of major features of the ANSI/IEEE guidelines are given in Appendix B of this report.[4]

Although current FCC policy categorically excludes amateur operators from routine evaluation for compliance with RF guidelines, this policy is one of several items being reconsidered in the recent proposal to adopt new guidelines. In the tables, ANSI/IEEE limits specified for "uncontrolled environments" are used for comparison with measurements in publicly accessible areas, and limits specified for "controlled environments" are used for comparison with measured values obtained at the amateur station or "ham shack."

Table 2 lists examples of maximum electric field strengths measured in publicly accessible areas near the various antenna sites. The data are arranged in terms of increasing transmitter frequency. "Publicly" accessible areas are defined here as areas, other than the "ham shack," where it is reasonable to assume that persons who might not have control or knowledge of their exposure could have access. This is roughly equivalent to the definition of an "uncontrolled" environment given in the ANSI/IEEE guidelines.   Stricter exposure limits are specified for such situations than for "controlled" environments. According to the guidelines, an amateur operator would be in a "controlled" environment and subject to less restrictive limits (see Appendix B).

The exposure guidelines are frequency-dependent and recommend the strictest exposure limits for VHF frequencies, since these are the frequencies where the highest specific absorption rates (SARs) occur for human beings.[5]   Therefore, although some measured field strengths at HF frequencies may be relatively high, the percentage of the exposure limits may be less than for lower field strengths measured at VHF frequencies.

According to the new ANSI/IEEE exposure guidelines, it appears that vehicle-mounted amateur antennas can create the greatest possibility for significant exposure in publicly accessible areas. In fact, in several cases involving vehicle-mounted antennas, the maximum levels measured approached or exceeded the electric field strength limits recommended for "uncontrolled" environments. This also occurred in at least one other case, a center-fed dipole at Station E. However, it is important to

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[4] The ANSI/IEEE guidelines are the most commonly utilized exposure guides. However, exposure criteria have also been published by the National Council on Radiation Protection and Measurements (NCRP, Reference 3) and the International Radiation Protection Association (IRPA, Reference 4).   In general, the NCRP and IRPA guidelines are similar to the ANSI/IEEE C95.1-1992 recommendations with regard to power density and field strength values, particularly with regard to commonly-used amateur frequencies.

[5] Specific Absorption Rate (SAR) is a measure of the rate of energy absorption per unit mass, usually expressed in watts per kilogram (W/kg). Exposure guidelines are based on SAR. For example, the ANSI/IEEE guidelines allow a whole-body SAR of 0.4 W/kg.

realize that the measured levels are peak levels, and time-averaging must also be considered when evaluating exposure. With respect to the 1982 ANSI guidelines (ANSI C95.1-1982), there was only one instance where a maximum level exceeded the recommended exposure limits (a vehicle-mounted quarter-wave whip antenna). More details on these measurement data are given in Appendix A, where descriptions of each station and the corresponding measurement results are discussed.

Table 3 lists examples of maximum magnetic field strength measured in areas near amateur installations considered to be publicly accessible. When compared to the exposure guidelines, there was only one instance where a maximum level exceeded exposure limits. This occurred near a vehicle-mounted, quarter-wave, whip antenna at Station D that also exceeded the electric field strength limit. As with the previous table, these measurements reflect peak readings, and when time-averaging is considered compliance with exposure guidelines would be expected.

Table 4 gives examples of measurements made at "ham shacks" where amateur operators are normally located when their stations are transmitting. In general, levels encountered at these locations were well below exposure limits recommended by either the 1982 ANSI guidelines or the new ANSI/IEEE guidelines for "controlled environments." Only with the vehicle-mounted, quarter-wave whip antenna did the RF levels approach exposure limits. As before, these readings were the maximum readings that could be obtained in the ham shacks.

Table 4 also shows readings of 60-hertz magnetic fields at operator locations. These measurements were made because the EPA has become interested in investigating whether exposures to these fields might be a potential health risk. The maximum 60-Hz readings obtained during transmission ranged from 0.1 to 12.5 milligauss (mG), with most readings being less than 4 mG. Guidelines for 60-Hz exposures have not been established.

Details of the results obtained in this study are given in Appendix A. A description is provided for each of the nine amateur stations visited (designated as Stations A, B, C, D, E, F, G, H and I), and results of measurements made at each station are tabulated.

In this study, measurement results were obtained both in areas considered to be publicly accessible and in "ham shacks" where operators are located during transmissions. Frequencies chosen for use in this study were those typically used by many amateur operators. Transmitter power levels were those normally used by the operator for the system being studied, although higher levels were used in some instances for "worst case" analysis. The use of power levels up to the allowed maximum of 1500 watts (PEP) could result in higher field values in some cases.

Amateur radio facilities can generate electric and magnetic fields near antennas and transmitting equipment that, in some cases, might approach or exceed recommended limits for human exposure. For most of the stations surveyed, RF protection guidelines for field strength and power density were not exceeded in accessible areas.[6] However, at higher power levels or with different facility configurations, higher exposure levels cannot be completely ruled out. Even though this study was designed to evaluate typical stations, it represents only a small sampling of many possible amateur radio facilities. There is a wide variety of possible amateur station characteristics and operating parameters.

It is important to emphasize that continuous "key down" amateur transmissions, such as those measured here, represent a worst-case and would not be typical of most amateur communications. Rather, a duty factor would be associated with routine amateur transmissions.

The ANSI/IEEE guidelines specify a six-minute period for time-averaging of field strength and power density levels at most frequencies and in "controlled" environments. Assuming that amateur stations fall under the "controlled" category, this means that during a given six-minute period if a station transmitted for only one minute of the six-minute period, the time-averaged exposure would actually be one-sixth of the exposure level resulting from the one-minute of signal transmission. During the one-minute of "on" time, the allowed exposure could be as high as six times the exposure limit (Maximum Permissible Exposure or "MPE") specified by the guidelines. For example, if the applicable limit were 1 milliwatt/cm^2 (1 mW/cm^2), or 1000 microwatts/cm^2 (1000 µW/cm^2), the allowed exposure during the one-minute period of transmission would be six times the limit or 6 mW/cm^2 (6000 µW/cm^2), so that the average over the six minutes would be 1 mW/cm^2.

An excellent discussion of controlling RF exposures at amateur radio stations can be found in the ARRL Handbook for Radio Amateurs (Reference 5). In general, precautionary measures should be sufficient to prevent exposure of the amateur operator or other persons to RF levels in excess of protection guidelines. Examples of such measures are:

- using only the minimum power necessary for a transmission;
- minimizing transmission time so that time-averaged exposures are acceptable;
- identifying high-field areas and restricting access to them while transmitting;
- mounting antennas as high above ground as practical.

We hope that this study will provide amateur radio operators with information on environmental RF fields that will help ensure the prudent and safe operation of amateur facilities. We encourage further study and research into the measurement

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[6] This study focused on field strength and power density measurements and how they compare with the RF protection guidelines. However, it should be noted that the ANSI/IEEE 1992 guidelines for Maximum Permissible Exposure (MPE) also include limits for induced and contact RF currents (see Appendix B). Measurements to determine such currents were not made as part of this survey, but this could be the subject of a future study.

and characterization of RF fields from amateur transmitters and invite input from the amateur community on this important topic.

This study was performed under the terms of an Inter-Agency Agreement between the Federal Communications Commission (Ref. No. RA-FCC-0148-0) and the U.S. Environmental Protection Agency (Ref. No. RW27931344-01-8). A preliminary report of these results was presented at the Thirteenth Annual Meeting of The Bioelectromagnetics Society held in Salt Lake City, Utah, in 1991 (Abstracts, page 6). Mention of commercial products does not constitute endorsement by either the Federal Communications Commission or the U.S. Environmental Protection Agency.

REFERENCES

(1) American National Standards Institute, New York, NY. "American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz," (ANSI C95.1-1982). Now replaced by ANSI/IEEE C95.1-1992 (below). Major features are summarized in Appendix B.

(2) Institute of Electrical and Electronics Engineers, Inc. (IEEE), New York, NY, IEEE Standards Coordinating Committee 28. "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz," (IEEE C95.1-1991). Adopted by ANSI as ANSI/IEEE C95.1-1992. Copies may be purchased from IEEE, telephone: 1-(800)-678-IEEE. Major features are summarized in Appendix B.

(3) National Council on Radiation Protection and Measurements (NCRP), Bethesda, MD. "Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields," NCRP Report No. 86 (1986). Information: NCRP Publications, (301) 657-2652.

(4) International Radiation Protection Association (IRPA). "Guidelines on Limits of Exposure to Radiofrequency Electromagnetic Fields in the Frequency Range from 100 kHz to 300 GHz," published in Health Physics, 54(1): 115-123 (1988).

(5) "RF Radiation Safety," Chapter 36 ("Assembling a Station"), The ARRL Handbook for Radio Amateurs, 1992 Sixty-ninth edition, ed. by C. L. Hutchinson and J.P. Kleinman. Copyright 1991 by The American Radio Relay League, Inc., Newington, Connecticut 06111.

TABLE 1: SUMMARY OF AMATEUR STATIONS SURVEYED

STATION	ANTENNA TYPE	FREQUENCIES (MHz)	POWER (W)
A	"Half-sloper" dipole	7.2, 14.2, 21.2, 28.2	100-1000
A	VHF discone (in attic)	52.0, 146.5, 440.0	25-250
A	Half-wave resonant dipoles (located in attic)	14.2, 21.2, 28.2	100
B	Roof-mtd Yagi (5 element)	21.2	1000
B	HF vertical radiator	3.8	800
C	Tri-band Yagi (on tower)	14.2	1000
C	Yagi (8 element, on tower)	50.0	100
C	Center-fed dipole	7.0	100-1000
D	1/4-wave whip (vehicle-mtd)	146.0	85 ± 10
D	Yagi (5 element; open-field test)	50.1	500
D	Quagi (8 element; open-field test)	144.2	550
D	Yagi (3 element; on tower)	14.2, 28.5	425-450
D	Yagi (3 element; on roof)	50.1	900
E	Center-fed, 1/2-wave dipole	7.1	120-500
E	Vertical radiator (on roof)	14.1	140-500
F	Open-line, "modified-T"	1.95	500
F	Yagi (13 element; on tower)	147.0	100
F	"Inverted-V" dipole ("40 m")	7.2	1400
F	"Inverted-V" dipole ("80 m")	3.8	1400
G	"Inverted-V" dipole ("80 m")	1.94-3.7	100
G	"Inverted-V" dipole ("40 m")	7.1	100
H	Horizontal loop ("80 m")	3.7, 7.1, 14.2, 21.0, 28.2	26-100
I	Yagi (3 element; on garage)	14.2	100
I	Dipole ("160 m")	1.95-3.7	80-100

TABLE 2: EXAMPLES OF MAXIMUM ELECTRIC FIELDS IN PUBLICLY ACCESSIBLE AREAS*

Antenna Type (Station)	Power (W)	Freq. (MHz)	E-Field (V/m)	%ANSI (1982)	%IEEE (1991)
Dipole ("160 meter") (I)	80	1.95	5-22	<1-3	1-5
Open-line, "modified T" (F)	500	1.95	52-237	8-37	12-56
"Inverted V" dipole (G)	100	3.7	1-13	<1-3	1-6
Horizontal loop (H)	100	3.7	7-85	1-17	3-38
Vertical radiator (B)	800	3.8	47	11	22
"Inverted V" dipole (F)	1400	3.8	6-16	1-3	3-7
Center-fed dipole (C)	100	7.0	14-25	5-9	12-21
Center-fed dipole (E)	120	7.1	47-203	18-76	41-176
"Inverted V" dipole (F)	1400	7.2	4-33	2-13	3-29
Vertical whip (roof-mt) (E)	140	14.1	2-9	1-7	3-15
Yagi (3 element) (I)	100	14.2	2-10	1-7	3-17
Tri-band Yagi (C)	1000	14.2	10-14	7-10	17-24
Horizontal loop (H)	100	21.0	1-23	1-25	3-64
Dipole (attic-mtd) (A)	100	21.2	30	33	77
Yagi (5 element) (B)	1000	21.2	15	17	39
"Half-sloper" Dipole (A)	100	28.2	23	34	79
Yagi (3 element) (D)	425	28.5	10-12	15-18	35-42
Yagi (5 el); vehicle-mt (D)	500	50.1	45-56	71-89	164-324
Quagi (8 el); vehicle-mt (D)	550	144.2	26-30	41-47	95-109
1/4-wave whip;vehicle-mt (D)	85 ± 10	146.0	15-84	24-133	87-305
VHF Discone (attic-mt) (A)	250	146.5	9-25	14-40	33-91
Yagi (13 element) (F)	100	147.0	2-5	3-8	7-18

*"Publicly accessible" areas other than "ham shack" where persons other than the amateur operator could have reasonable access. However, some areas were very close-in to subject antennas, and persons would ordinarily not be present. These are maximum readings and time-averaging aspects of exposure guidelines are not taken into account. IEEE (1991) limits used are those for "uncontrolled environments" (IEEE C95.1-1991 has been adopted by ANSI and designated ANSI/IEEE C95.1-1992).

TABLE 3: EXAMPLES OF MAXIMUM MAGNETIC FIELDS IN PUBLICLY ACCESSIBLE AREAS*

Antenna Type (Station)	Power (W)	Freq. (MHz)	H Field (mA/m)	%ANSI (1982)	%IEEE (1991)
Dipole ("160 meter") (I)	80	1.95	13-78	1-5	<1-1
Open-line, "modified T" (F)	500	1.95	37-307	2-19	<1-4
"Inverted V" dipole (G)	100	3.7	4-123	<1-10	<1-3
Horizontal loop (H)	100	3.7	18-130	1-10	<1-3
Vertical radiator (B)	800	3.8	140-1350	11-108	3-31
"Inverted V" dipole (F)	1400	3.8	20-69	2-6	<1-2
Center-fed dipole (E)	120	7.1	9-256	1-38	<1-11
"Inverted V" dipole (F)	1400	7.2	53-122	8-19	2-5
Vertical whip (roof-mt) (E)	140	14.1	12-28	4-8	4-8
Yagi (3 element) (I)	100	14.2	8-16	2-5	<1-1
Horizontal loop (H)	100	21.0	5-24	2-11	<1-3
Dipole (attic-mtd) (A)	100	21.2	10-70	4-31	1-9
Yagi (5 element) (B)	1000	21.2	40-50	18-22	5-7
"Half-sloper" Dipole (A)	100	28.2	20-90	12-53	3-16
Horizontal loop (H)	100	28.2	2-33	1-20	<1-6
Yagi (3 element) (D)	450	28.5	10-18	6-11	2-3
1/4-wave whip;vehicle-mt (D)	85 ± 10	146.0	50-160	31-101	69-219
VHF Discone (attic-mt) (A)	250	146.5	40-60	25-38	55-82

*"Publicly accessible" areas other than "ham shack" where persons other than the amateur operator could have reasonable access. However, some areas were very close-in to subject antennas, and persons would ordinarily not be present. These are maximum readings, and time-averaging aspects of exposure guidelines are not taken into account. IEEE (1991) limits used are those for "uncontrolled environments" (IEEE C95.1-1991 has been adopted by ANSI and designated ANSI/IEEE C95.1-1992).

TABLE 4: EXAMPLES OF FIELDS AT OPERATOR LOCATIONS

I. RF MEASUREMENTS

Station	Power (W)	Freq. (MHz)	E Field (V/m)	H Field (mA/m)	%ANSI (1982)	%IEEE (1991)[1]
(a) General ambient level in ham shack or at other operator location						
C	1000	50.0	1.4	--	2	2
D	500	50.1	3-16	--	5-25	5-26
D	500	144.2	3-7	--	5-11	5-11
D	450	28.5	10-21	12	7-31	2-32
D	900	50.1	2-4	--	3-6	3-7
E	500	14.1	3-7	--	2-5	2-5
G	100	3.7	2-9	--	<1-2	<1-2
H	100	21.0	1-3	6	1-3	1-3
I	100	3.7	3-6	79-94	<1-1	<1-1
(b) At actual operator position (generally waist up to head level)						
A	800	21.2	1-2	--	1-2	1-2
B	1000	21.2	10-19	40	11-21	5-22
D	450	28.5	3-15	9	4-22	2-23
D(vehicle)	85±10	146.0	21-56	100	33-89	34-91
E	500	7.1	9-18	13-32	2-7	<1-7
E	140	14.1	3-7	17-24	2-7	1-5
E	500	14.1	10	--	7	8
F	500	1.95	5-14	56-72	<1-5	<1-2
G	100	3.7	7-13	39	1-3	<1-3
H	100	21.0	4-9	8-12	4-10	1-10
I	100	3.7	2-9	53	<1-4	<1-2
(c) Localized ("hot spots") near transceivers/tuners & other equipment						
C	1000	14.2	97	--	n/a	n/a
C	1000	14.2	38-43	--	n/a	n/a
C	1000	7.0	58	--	n/a	n/a
D	500	50.1	30	--	n/a	n/a
D	500	144.2	>94	--	n/a	n/a
D	450	28.5	21-53	--	n/a	n/a
D	900	50.1	21	--	n/a	n/a
E	500	7.1	42	317-449	n/a	n/a
E	140	14.1	36-97	--	n/a	n/a
F	500	1.95	28	186-288	n/a	n/a
G	100	3.7	34-43	42	n/a	n/a
H	100	21.0	22	--	n/a	n/a
I	100	3.7	64	--	n/a	n/a

NOTES:
Dashes = not measured; n/a = not applicable to whole-body exposure.
[1] IEEE (1991) limits used are those for "controlled environments" which are identical to the ANSI 1982 limits for many frequencies. IEEE C95.1-1991 has been adopted by ANSI as ANSI/IEEE C95.1-1992.

(continued next page)

TABLE 4 (contd.)

II. 60 HERTZ MEASUREMENTS

(d) 60 Hz readings; operator's position

Station	Power (W)	Freq (MHz)	E Field (V/m)	H Field (mG)
A	800	21.2	--	1-2.3
B	1000	21.0	--	1.9-3.8
C	1000	14.1	--	0.6-3.5
D	450	28.5	--	1.2-3.2
D	500	144.2	--	2-12.5
E	500	7.1	--	0.9-2.2
F	500	1.95	--	0.3-14
G	100	3.7	--	0.1-1.5
H	100	21.0	--	0.4-3.5
I	80	1.95	--	0.4-2.3

NOTES: Dashes = not measured; mG = milligauss.

APPENDIX A

STATION DESCRIPTIONS
AND
MEASUREMENT RESULTS
(Tables 5 - 29)

AMATEUR STATION A

Amateur Station A was located in a multi-story condominium townhouse. Three antenna systems were surveyed at this station. Measurements were also made at the location normally occupied by the operator during transmission, which was in the first floor garage of the townhouse.

(1) Half-sloper Antenna

The first antenna system studied was a bottom-fed quarter-wave wire antenna of the type referred to as a "half-sloper." This type of antenna consists basically of a wire strung between the ground and some higher point so that the wire has a particular slope with respect to vertical and is essentially one-half of a dipole operated against ground. The antenna studied was separated into sections by "traps" to allow quarter-wave, resonant operation at four different frequencies: 7, 14, 21, and 28 MHz. The total length of the antenna was about 14 meters (m). The upper end of the antenna was supported by trees near the condominium building with the lower end attached to a ground rod. Six ground radials extended about 8 m from the ground rod in a soil strip between a masonry wall and parking lot pavement. The parking lot separated the building from the antenna and trees. The results of electric and magnetic field measurements at various distances along three radial lines at 1 meter above ground are given in Tables 5 and 6.

(2) Attic-mounted Dipole Antennas

A second antenna system at Station A consisted of dipole antennas located in the attic of the townhouse above a top-floor bedroom and stairway. Three different horizontal, half-wave, resonant, dipole antennas met at their centers where they were fed. The three antennas were resonant for 14, 21, and 28 MHz, respectively. Electric and magnetic fields measured in the rooms below the dipole antennas are given in Tables 7 and 8.

(3) Attic-mounted Discone Antenna

A VHF/UHF "discone" antenna was mounted in the attic, near the dipole antennas. This antenna was designed for transmitting at frequencies between 50 and 1300 MHz. At Station A it was primarily used for transmitting at 50, 144, 220, and 440 MHz. Field measurements results using the discone antenna are given in Table 9.

TABLE 5: STATION A

ELECTRIC FIELD STRENGTH: "HALF-SLOPER" DIPOLE ANTENNA

FREQ (POWER)/ RADIAL DIRECTION OR LOCATION (see notes)	INSTR. USED	FIELD STRENGTH (V/m) [1 m above grd] DISTANCE ALONG RADIAL (m) [if applicable] <0.5	0.5	1.0	2.0	3.0	4.0	5.0	10.0
7.15 MHz (1000 W)									
Under antenna	IFI	--	--	(50)	(21)	(11)	--	--	--
Opposite antenna	IFI	(59)	--	(14)	(9)	--	--	--	--
Perpen. to antenna	IFI	211	(87)	(32)	(14)	(9)	--	7	--
14.15 MHz (1000 W)									
Under antenna	HI	--	--	46	22	14	8	5	--
Opposite antenna	HI	39	--	12	6	3	--	--	--
Perpen. to antenna	IFI/HI	--	--	(40)	16	11	--	8	4
21.15 MHz (800 W)									
Under antenna	HI	--	--	57	36	25	15	10	--
Opposite antenna	HI	57	--	9	3	--	--	--	--
In "ham shack"	HI	[1-1.7 V/m @ operator position] [4.5 V/m localized in front of amplifier]							
21.15 MHz (1000 W)*									
Under antenna	HI	--	--	64*	40*	27*	17*	11	--
Opposite antenna	HI	64*	--	10*	3*	--	--	--	--
21.15 MHz (1000 W)									
Perpen. to antenna	HI	--	96	48	21	14	--	7	3
28.15 MHz (100 W)									
Under antenna	HI	--	--	26	15	9	3	--	--
Opposite antenna	HI	23	--	11	7	4	3	--	--
Perpen. to antenna	HI	84	--	23	11	6	--	--	--
28.15 MHz (1000 W)*									
Under antenna	HI	71*	--	82*	47*	28*	9*	--	--
Opposite antenna	HI	--	--	33*	22*	13*	9*	--	--
Perpen. to antenna	HI	266*	--	73*	35*	17*	--	--	--

NOTES:

(1) Radial directions from antenna base were: (a) parallel to ground and directly under sloped antenna; (b) parallel to ground and away from antenna in opposite direction; (c) parallel to ground and perpendicular to antenna.

(2) Measured values corrected using calibration factors and rounded off. Parentheses indicate average of two or more corrected readings.

(3) * = estimated values (not measurements), for purpose of comparison, based on normalization from 800 W (21.15 MHz) data or from 100 W (28.15 MHz) data.

(4) Dashes = not measured.

(5) IFI = Instruments for Industry Model EFS-1 field strength meter; HI = Holaday Industries Model HI-3001 broadband field intensity meter.

TABLE 6: STATION A

MAGNETIC FIELD STRENGTH: "HALF-SLOPER" DIPOLE ANTENNA

FREQ (POWER)/ RADIAL DIRECTION (see notes)	EQUIPMENT USED	FIELD STRENGTH (A/m) [1 m above grd] DISTANCE ALONG RADIAL (m) <0.5	0.5	1.0	2.0	3.0
7.15 MHz (1000 W)						
Perpendicular to antenna	HI/AR/NR	(0.8)	(0.23)	(0.09)	--	--
14.15 MHz (1000 W)						
Perpendicular to antenna	HI/AR/NR	(0.21)	--	0.05	--	--
21.15 MHz (1000 W)						
Perpendicular to antenna	NR	0.7	--	0.16	0.05	0.03
28.15 MHz (100 W)						
Under antenna	NR	--	--	0.08	0.04	0.02
Opposite antenna	NR	--	--	0.04	0.03	0.02
Perpendicular to antenna	NR	0.39	--	0.09	0.03	--
28.15 MHz (1000 W)*						
Under antenna	NR	--	--	0.24*	0.13*	0.05*
Opposite antenna	NR	--	--	0.13*	0.08*	0.05*
Perpendicular to antenna	NR	1.2*	--	0.28*	0.09*	--

NOTES:

(1) Radial directions from antenna base were: (a) parallel to ground and directly under sloped antenna; (b) parallel to ground and away from antenna in opposite direction; (c) parallel to ground and perpendicular to antenna.
(2) Measured values corrected using calibration factors and rounded off. Parentheses indicate average of two or more corrected readings.
(3) * = estimated values (not measurements), for purpose of comparison, based on normalization from 100 W (28.15 MHz) data.
(4) Dashes = not measured.
(5) HI = Holaday Industries Model HI-3006 broadband field intensity meter; AR = Aeritalia Model TE 307 meter; NR = Narda Model 8631 meter.

TABLE 7: STATION A

ELECTRIC FIELD STRENGTH: ATTIC-MOUNTED DIPOLE ANTENNA

LOCATION	Electric Field Strength (V/m) 14.15 MHz (100 W)	21.15 MHz (100 W)	28.15 MHz (100 W)
(1) Near bedroom doorway, appx. 3-5 m from closest section of antenna located above ceiling	14-17	10-14	7-12
(2) Above bedroom doorway near heating/cooling vent (localized) appx. 2-3 m from antenna	19	17-19	17
(3) Near ceiling duct (localized)	38	--	--
(4) Top of hall stairway & almost directly beneath antenna (appx. 1-2 m); localized near smoke alarm	75	30	14-17
(5) Bedroom corner closest to antenna (appx. 2-3 m)	22-24	--	--
(6) Near middle of bedroom	7-10	30	5-12
(7) Near bedroom intercom (localized)	--	75-81	--
(8) In hatchway leading to attic (appx. 1-2 m from closest antenna section)	43-97	81-91	22-37

NOTES:
(1) Measurements made using Holaday Model HI-3001 field intensity meter.
(2) Measured values corrected using calibration factors and rounded off.
(3) Dashes = not measured.

TABLE 8: STATION A

MAGNETIC FIELD STRENGTH: ATTIC-MOUNTED DIPOLE ANTENNA

LOCATION	Magnetic Field Strength (A/m) 14.15 MHz (100 W)	 21.15 MHz (100 W)	 28.15 MHz (100 W)
(1) Near bedroom doorway, appx. 3-5 m from closest section of attic-mounted antenna located above ceiling	--	0.01-0.02	--
(2) Top of hall stairway & almost directly beneath antenna (appx. 1-2 m); localized near smoke alarm	0.1	0.07	--
(3) Bedroom corner closest to antenna (appx. 2-3 m)	--	--	--
(4) Near middle of bedroom	0.02-0.03	0.02-0.03	0.02
(5) Near bedroom intercom (localized)	--	0.07	0.07
(6) Near bedroom light switch (localized)	0.07	--	0.03-0.04
(7) In hatchway leading to attic (appx. 1-2 m from closest antenna section)	--	0.05-0.06	--

NOTES:
(1) Measurements made with Narda Model 8631 meter.
(2) Measured values corrected using calibration factors and rounded off.
(3) Dashes = not measured.

TABLE 9: STATION A

FIELD STRENGTH: ATTIC-MOUNTED VHF DISCONE ANTENNA

I. Electric Field Strength (V/m)

LOCATION	52 MHz 100 W	146.52 MHz 250 W	440 MHz 25 W
(1) Vicinity of bedroom doorway, appx. 3-5 m from attic-mounted antenna located above room	3-10	9-25	--
(2) Above bedroom doorway near heating/cooling vent (appx. 2-3 m from antenna)	25-27	--	13
(3) Top of stairway outside bedroom & almost directly beneath antenna location (appx. 1-2 m from antenna)	--	--	7
(4) Same as (3) except near ceiling heating/cooling vent	30	--	--
(5) Between bedroom doorway & bed (appx. 5-7 m from antenna location)	--	--	8

II. Magnetic Field Strength (A/m)

LOCATION	52 MHz 100 W	146.52 MHz 250 W
Same as (1) above	--	0.04-0.06
Same as (2) above	0.016-0.022	--
Same as (3) above	0.07	0.05

NOTES:
(1) Electric field measurements made using Holaday Model HI-3001. Magnetic field measurements made using Narda Model 8631.
(2) Measured values corrected using calibration factors and rounded off.
(3) Dashes = not measured.

AMATEUR STATION B

Station B was located at a single-story home in a suburban residential neighborhood. The operator controlled transmissions from a room inside the house. Measurements were made with respect to two antenna systems

(1) Vertical Radiator

The first antenna used was a vertical, steel, radiating tower (height about 16 m) that can be used for transmitting on a number of bands between about 1.8 and 50 MHz. The antenna approximates a quarter-wave resonator at 3.8 MHz, and measurements were made in this frequency band. This antenna was mounted in a side yard between the operator's house and a neighboring home. Ground rods were buried approximately two feet from each corner of the radiator. Results of measurements with respect to the vertical radiator are given in Table 10.

(2) Yagi Antenna

The other antenna studied at Station B was a five-element, Yagi HF beam antenna with a boom length of about 7.3 m. This antenna was one of three Yagi antennas located on a tower mounted on the roof of the house. The Yagi antenna used in the survey was approximately 12 m above ground level. Results of measurements made for the Yagi antenna are given in Table 11.

TABLE 10: STATION B

FIELD STRENGTH: HF VERTICAL RADIATOR
(3.8 MHz, 800 W)

DISTANCE (m)	Electric Field (V/m)	Magnetic Field (A/m)
0.5	161	1.35
1	47	0.54
2	21	0.27
3	13	0.19
4	--	0.14
5	7	--
6	--	<0.14
10	3.5	--

NOTES:
(1) Measurements made approximately 1 m above ground.
(2) Electric field measured using Instruments for Industry Model EFS-1 field strength meter. Magnetic field measured using Aeritalia Model TE 307 field intensity meter.
(3) Electrical height of antenna at 3.8 MHz approximately = 0.2 wavelengths.
(4) Measured values corrected using calibration factors and rounded off.
(5) Dashes = not measured.

<u>TABLE 11</u>: STATION B

MEASURED FIELD STRENGTH: YAGI (5 ELEMENT) HF BEAM ANTENNA (21.2 MHz, 1000 W)

Distance (m) (see notes)	Electric Field (V/m)	Magnetic Field (A/m)
10	11.7	0.04
11	13.6	0.04
12	13.6	0.04
15	15.2	0.05

NOTES:
(1) Antenna mounted on roof of single story residence. Distances measured from point inside house directly under antenna mount.
(2) Measurements made approximately 1 m above ground level outside of house. However, measurements at 15 m made approximately 1-2 m higher than other readings (relative to antenna) due to higher ground elevation at that point.
(3) Electric field measured using Holaday Model HI-3001. Magnetic field measured using Narda Model 8631.
(4) Measured values corrected using calibration factors and rounded off.

AMATEUR STATION C

Station C was located at a two-story home in a suburban residential neighborhood. The station was controlled by the operator from a room on the second floor, which was near the support tower for three Yagi antennas. Electric fields due to transmissions from each of four antenna systems were measured.

(1) Tri-band Yagi Antenna (20 m band)

The first antenna system studied was a tri-band, Yagi, HF beam antenna mounted on a tower that was located immediately adjacent to the house. This antenna was located approximately 18 m above ground level and was one of three Yagi antennas mounted on the tower. Four or five elements were used for transmission on each of the three bands. Measurement results for the tri-band Yagi transmitting at 14.15 MHz are given in Table 12.

(2) Yagi Antenna (6 m band)

Measurements were also made with respect to an eight-element Yagi antenna with boom-length of about 4.5 m. This antenna was mounted on the tower about 3 m above the tri-band HF antenna. A frequency near 50 MHz was used for these transmissions. Measurement results for this Yagi antenna are also given in Table 12.

(3) Dipole Antenna (40 m)

Two center-fed, dipole, wire antennas were also studied at Station C. One antenna extended from a point approximately mid-way up on the tower mentioned above, over a deck attached to the residence, and down to an attachment point near a railing on the deck. This antenna had sections that were approximately 10 m on either side of the feed-point, resulting in half-wave resonance at about 7 MHz. Measurement results are given in Table 13.

(4) Dipole Antenna (160 m)

The other dipole antenna extended from a point near the top of the tower down the side of a hill on which the operator's house is located to an attachment point. Each section of this dipole extended about 38 m on either side of the feed-point, providing for an approximately half-wave antenna at 1.8 MHz. Measurement results from this dipole antenna are also given in Tables 13.

TABLE 12: STATION C

ELECTRIC FIELD STRENGTH: YAGI BEAM ANTENNAS

I. TRI-BAND HF ANTENNA (14.15 MHz; 1000 W)

	MEASUREMENT LOCATION	Electric Field (V/m)
(1)	Along 2nd floor balcony appx. 16-18 m below antenna	9.6 - 13.6
(2)	Corner of room appx. 15-16 m below antenna	7.1 - 37.5
(3)	Localized near feed-line on floor of ham shack	97
(4)	Localized readings in immediate vicinity of transceiver in ham shack	37.5 - 43.4

II. EIGHT-ELEMENT YAGI ANTENNA (50 MHz; 100 W):

	MEASUREMENT LOCATION	Electric Field (V/m)
(1)	Along 2nd floor balcony railing appx. 20-22 m from antenna	2.2
(2)	Inside 2nd floor ham shack appx. 22-24 m from antenna	1.4

NOTES:
(1) Antennas mounted on tower adjacent to house.
(2) Measurements made using Holaday Industries Model HI-3001 broadband field intensity meter.
(3) Measured values corrected for calibration error and rounded off.

TABLE 13: STATION C

ELECTRIC FIELD STRENGTH: CENTER-FED DIPOLE ANTENNAS (40 m and 160 m)

I. 40 m antenna (7.0 MHz)

100 W POWER:

LOCATION	E FIELD (V/m)
(1) Appx. 0.5 m from end of antenna near deck railing	88
(2) Along deck railing appx. 1.5 m from antenna	25
(3) On deck appx. 2.5 m from antenna	18
(4) On deck appx. 3.5 m from antenna	14

1000 W POWER:

LOCATION	E FIELD (V/m)
(1) Localized immediately in front of transceiver in ham shack	58

II. 160 m antenna (1.8 MHz); 100 W

LOCATION	E FIELD (V/m)
(1) Under end of wire antenna appx. 30 cm from end	9 - 14
(2) Appx. 15-20 m below antenna on deck	2 (max.)

NOTES:

(1) Measurements made with Instruments for Industry (IFI) Model EFS-1 field strength meter.

(2) Measured values corrected for calibration error and rounded off.

AMATEUR STATION D

Station D was located at a two-story residence. Two antenna systems were studied.

(1) Tower-mounted Yagi

A three-element, tri-band, Yagi antenna was mounted on a tower next to the house. The height of the tower could be adjusted so that the height above ground of the antenna ranged from about 8 m to about 21.6 m. Frequencies examined using this antenna were 14.15 MHz and 28.5 MHz, and measurements were made both inside and outside the house. Measurement results are given in Table 14.

(2) Roof-mounted Yagi

Also at Station D, field strength levels resulting from a roof-mounted, Yagi antenna operating at 50.12 MHz were examined. This antenna was mounted approximately 3 m above the roof and almost directly above the second-story "ham shack." Measurements with respect to this antenna were made only in the ham shack. Measurement results are given in Table 15.

TABLE 14: STATION D

FIELD STRENGTH: YAGI (3 ELEMENT) HF BEAM ANTENNA

(a) Antenna position 8 m above ground; 28.5 MHz

DISTANCE (m)	E FIELD (V/m) [425 W]	H FIELD (mA/m) [450 W]
10	10.5	18.2
11	11.7	14.8
12	8.3	12.8
13	5.9	11.7
15	4.7	9.9
19	5.0	10.5
25	3.5	--
30	1.4	--

(b) Antenna position 8 m above ground; 14.15 MHz; 450 W

DISTANCE (m)	E FIELD (V/m)	H FIELD (mA/m)
10	8.7	--
11	7.4	--
12	6.7	--
13	6.7	--
15	5.9	--
19	3.9	--

(c) Antenna position 14.6 m above ground; 28.5 MHz; 450 W

DISTANCE (m)	E FIELD (V/m)	H FIELD (mA/m)
15	6.7	13.9
19	7.4	12.6
25	6.5	10.7
30	5.0	7.8

(d) Antenna position 21.6 m above ground; 28.5 MHz; 450 W

DISTANCE (m)	E FIELD (V/m)	H FIELD (mA/m)
15	6.6	13.2
19	6.7	11.5
25	5.5	10.7
30	4.5	9.1

NOTES:

(1) Readings taken appx. 1 m height above ground.
(2) Model HI-3001 field intensity meter used for E field readings.
(3) Calibrated loop antenna + HP power meter used for H field readings.
(4) Measured values corrected for calibration error and rounded off.
(5) Dashes = not measured.

TABLE 15: STATION D

FIELD STRENGTH INSIDE HOUSE AND IN HAM SHACK DUE TO NEARBY ANTENNAS

(a) Transmission from tower-mounted Yagi (3 element) antenna adjacent to house and slightly above level of second floor (location of ham shack); 28.5 MHz; 450 W:

LOCATION	E FIELD (V/m)	H FIELD (mA/m)
(1) Directly in front of transceiver/amplifier in ham shack (localized)	21 - 53	--
(2) Typical operator's position in ham shack	3 - 15	9.1
(3) Ambient in middle of ham shack	10 - 21	11.7
(4) In doorway of ham shack	14 - 25	--
(5) Ambient in hallway	--- 10.5 - 12.8	
(6) Localized at ceiling in hallway appx. 3-5 m from antenna location	68	--
(7) Doorway to bathroom close to antenna location	10 - 19	18.2
(8) Localized near wall next to antenna location	---	46.9

(b) Transmission from roof-mounted Yagi antenna (3 element) located appx. 3 m above roof over ham shack; 50.12 MHz; 900 W:

LOCATION	E FIELD (V/m)	H FIELD (mA/m)
(1) Ambient in ham shack	2.2 - 3.8	--
(2) Immediate vicinity of amplifier (localized)	21	--
(3) Corner of ham shack closest to antenna	6.2 - 8.2	--

NOTES:
(1) Model HI-3001 field intensity meter used to measure E field.
(2) Calibrated loop antenna + HP power meter used to measure H field.
(3) Measured values corrected for calibration error and rounded off.

AMATEUR STATION E

Station E was located at a single-story residence. Two antenna systems were examined.

(1) 40 m Wire Antenna

One antenna was a "40-meter," center-fed, half-wave dipole antenna (total length approximately 20 m). This antenna extended out over a sidewalk located next to the residence. The dipole was roughly horizontal, with the two ends being about 2.5 m above ground and the center located about 4 m above ground. This antenna was used by the operator to transmit at HF frequencies of about 7 and 21 MHz. The ham shack was located inside the house about 5 m from the closest segment of this antenna. Measurements were made both inside and outside the house. Results are given in Table 16.

(2) Multi-band Vertical Radiator

Field strength was also measured relative to a multi-band "trapped" vertical radiator mounted on the roof of the house above the ham shack. It was attached to a chimney and was positioned approximately 2-3 m above the ceiling of the ham shack. This antenna was used to transmit at HF frequencies of about 14, 21, and 28 MHz. Results are given in Table 17.

TABLE 16: STATION E

FIELD STRENGTH: CENTER-FED, HALF-WAVE DIPOLE ANTENNA*

(a) 7.14 MHz; 120 W; appx. 1 m ht above ground

DISTANCE (m)	E FIELD (V/m)	H FIELD (mA/m)
0	1.4	114.5
1	7.0	116.6
2	13.3	110.0
3	19.5	102.9
4	24.8	92.5
5	33.3	86.9
6	41.7	74.4
7	46.7	55.0
8	46.7	36.2
9	41.7	21.3
10	33.3	8.7

(b) 7.14 MHz; 120 W; appx. 2 m ht above ground

DISTANCE (m)	E FIELD (V/m)	H FIELD (mA/m)
0	6.5	224.5**
1	15.1	224.5
2	29.2	237.5
3	50.0	255.9
4	66.7	250.9
5	105.6	233.3
6	132.0	212.9
7	167.3	166.5
8	193.7	122.9
9	202.5	80.9
10	140.8	22.4 (unstable)

(c) 7.14 MHz; 500 W; inside ham shack, appx. 5 m from antenna

LOCATION	E FIELD (V/m	H FIELD (mA/m)
Operator's position	8.9-17.7	31.7-40.2
Localized, front of amplifier	41.7	317-449

NOTES:

(1) * Antenna above and parallel to sidewalk next to house with feed-point at center (appx. 4 m ht above ground) and each end 10 m from center and appx. 2.5 m ht above ground. Measurements made appx. underneath antenna starting at feed-pt (0 m) and extending out to one end of antenna (@10 m).

(2) ** Confirmation reading with Aeritalia TE 307 = 208 mA/m.

(3) Model HI-3001 field intensity meter used to measure E field. Calibrated loop antenna + HP power meter used to measure H field.

(4) Measured values corrected for calibration error and rounded off.

TABLE 17: STATION E

FIELD STRENGTH: ROOF-MOUNTED, VERTICAL WHIP ANTENNA

(a) Inside house & in yard; 14.11 MHz; 140 W; appx. 1 m ht above ground

DISTANCE (m)*	E FIELD (V/m)	H FIELD (mA/m)
2	4.5	26.1
4	8.7	27.7
6	6.0	17.7
7	3.9	--
8	2.2	14.9
10	1.7	12.4

(b) Inside ham shack; 14.11 MHz; 140 W & 500 W

LOCATION	E (V/m) (140 W)	E (V/m) (500 W)	H (mA/m) (140 W)
(1) Operator position	3.2 - 7.1	10	16.8 - 23.8
(2) Ceiling above operator position	15.2	--	--
(3) Ambient in room	--	3.2 - 7.1	--
(4) Corner of room nearest antenna	13.6	22.4 - 31.6	11.9
(5) Localized "hot spots" next to tuner and transceiver	36.3 - 97.0	--	--

---

NOTES:
(1) * Horizontal distance; 0 m = location appx. underneath antenna and inside house. Edge of roof was located above point that was appx. 4-5 m horizontal distance from 0 m point. Beyond that point measurements were outside house.
(2) Model HI-3001 field intensity meter used for E field readings.
(3) Calibrated loop antenna+HP power meter used for H field readings.
(4) Measured values corrected for calibration error and rounded off.
(5) Dashes = not measured.

AMATEUR STATION F

Station F was a relatively complex station with several different antenna systems at various locations on a large residential lot occupied by a single-story residence and a few smaller buildings. A few of these antennas were selected for study during the survey. These included two "inverted V" (sloped) dipole antennas, a "modified T" antenna, and a Yagi antenna with "log-periodic cell" feed.

(1) Modified-T Antenna (160 m)

The "modified-T" antenna was fed by a two wire open line shorted at the transmitter end in the ham shack located inside the house. This wire feed, which was also a radiating element, extended horizontally next to and about 2-3 m above a sidewalk for about 50 m before curving around and turning upward to become the vertical segment of the antenna. The vertical segment was directed up for about 21 m to a point where it met a perpendicular radiator (the top of the "T"). The top of the "T" had a total length of about 41 m. This antenna was used primarily for operating at about 1.9 MHz. However, with the feedline unshorted it can be used as a center fed dipole on 3.8 MHz or as two half-waves in phase at 7.2 MHz. Results of field measurements are given in Tables 18 and 19.

(2) Inverted-V Dipole Antennas (40 m and 80 m)

Two "inverted V" dipole antennas were also studied. The first antenna extended at a slope on both sides of a pole from approximately 14 m high on the pole down to about 6 m above ground at each end. Each segment of the antenna was approximately 10.5 m in length. This resulted in an angle of about 45 degrees. This antenna was operated at 7.2 MHz with a coaxial feed and balun at its apex.

The second "inverted V" dipole extended down at a depression angle with respect to the horizontal of about 60 degrees from a pole approximately 25 m high. Each of the two segments was about 20 m long, and the ends of the segments were about 8 m above ground. Measurements were made when the antenna was transmitting at a frequency of about 3.8 MHz and fed with a coaxial feed and balun at its apex. Results of field measurements for these two antennas are given in Table 20.

(3) Yagi Antenna (2 m)

Another antenna studied was a 13-element, vertically-polarized Yagi with "log-periodic cell" feed via coaxial cable. This antenna was mounted just outside the residence on a tower approximately 6 m high. The boom length of the antenna was about 6.5 m, and the operating frequency used was about 147 MHz. Measurement results are given in Table 21.

TABLE 18: STATION F

FIELD STRENGTH: "MODIFIED T" ANTENNA*
(1.945 MHz; 500 W)

DISTANCE (m)**	E FIELD (V/m)	H FIELD (mA/m)
0	52	159
2	110	283
4	128	307
6	137	302
8	146	283
10	128	251
12	100	212
13 (antenna changes direction)	91	192
14	110	204
16	100	161
18	137	156
20	137	140
22	137	125
24	201	63
26	237	49
28	228	37
30	228	49
32	228	73
>32 (antenna changes direction & loops around to enter ham shack)	183	202***
>32 (at feed-point where antenna enters ham shack	--	561

NOTES:

(1) IFI Model EFS-1 field intensity meter used for E field readings.
(2) Calibrated loop antenna+HP power meter used for H field readings.
(3) Measurements made appx. 1 m height above ground.
(4) Measured values corrected for calibration error and rounded off.
(5) Dashes = not measured.
(6) * Antenna consisted of two-wire, open-line shorted at transmitter end. Antenna extended horizontally out from ham shack, curved around to follow walkway, and curved again before turning upward to meet perpendicular "T" radiator 21 m above ground.
(7) ** Ground-level distance underneath horizontal portion of antenna with 0 m = point beneath vertical segment. Height above ground of horizontal segment generally varied from 2 to 3 meters.
(8) ***Confirmation reading with Aeritalia Model TE 307 = 259 mA/m.

TABLE 19: STATION F

FIELD STRENGTH INSIDE HAM SHACK: "MODIFIED T" ANTENNA
(see notes Table 18 & text for details of antenna)

1.945 MHz; 500 W:

H FIELD (mA/m)

	LOCATION	**E FIELD (V/m)**	**Loop Antenna**	**TE 307**
288	Immediately in front of (unshielded) tuner	27.5	186	
	Operator's position	4.5 - 13.7	56-69	72

NOTES:

(1) IFI Model EFS-1 field intensity meter used for E-field readings.
(2) Calibrated loop antenna+HP power meter and Aeritalia Model TE 307 used for H-field readings.

(3) Measured values corrected for calibration error and rounded off.

TABLE 20: STATION F

FIELD STRENGTH: CENTER-FED, "INVERTED V" DIPOLE ANTENNAS

(a) "40 Meter" Antenna; 7.232 MHz; 1400 W; appx. 1 m ht abv grd*

DISTANCE (m)	E FIELD (V/m)	H FIELD (mA/m)
0	4.3	122
2	4.3	87
3	7.8	82
4	8.7	74
6	21.3	69
8 (beneath end)	23.9	53
8 (beneath end)	33.3 (@2 m ht abv grd)	--

(b) "80 Meter" Antenna; 3.8 MHz; 1400 W; appx. 1 m ht abv grd:**

DISTANCE (m)	E FIELD (V/m)	H FIELD (mA/m)
0 (near cable feed)	34.0	66
2	5.7	69
4	6.6	63
6	7.9	59
8	13.4	54
10	14.3	46
12	16.1	39
14 (beneath end)	16.1	36
16	15.2	31
18	14.3	26
20	13.4	20

NOTES:
(1) * Antenna fed from center and attached to pole appx. 14 m ht above ground. Each segment appx. 10.5 m; each end appx. 6 m ht above ground.
(2) ** Antenna fed from center and attached to pole appx. 25 m ht above ground. Each segment appx. 20 m; each end appx. 8 m ht above ground.
(3) Measurements made underneath one segment from pole toward one end with 0 m = bottom of pole.
(4) IFI Model EFS-1 field intensity meter used for E field readings.
(5) Calibrated loop antenna + HP power meter used for H field readings.
(6) Measured values corrected for calibration error and rounded off.
(7) Dashes = not measured.

TABLE 21: STATION F

FIELD STRENGTH: 13-ELEMENT, YAGI ANTENNA

147 MHz; 100 W; appx. 1 m ht above grd

DISTANCE (m)	E FIELD (V/m)
0	1.9
1	n/d
2	2.6
3	3.4
4	4.1
5	5.1
6	4.9
7	3.6
8	1.9
9	4.1
10	4.7

NOTES:
(1) Antenna vertically polarized; mounted on pole appx. 6 m ht above ground.
(2) Distance measured from pole outward in direction of propagation with 0 m = bottom of pole.
(3) Model HI-3001 field intensity meter used for E field readings.
(4) Magnetic field was not measurable.
(5) n/d = not detectable.
(6) Measured values corrected for calibration error and rounded off.

AMATEUR STATION G

Station G was located at a single-story residence with the ham shack inside the house. Measurements at this station were made with respect to two "inverted-V" dipole antennas. Measurements were also made in the ham shack. The two antennas were fed in parallel and were mounted on a self-supporting aluminum tower at a point about 14 m above ground. One antenna (an "80 m dipole" or "160 m short dipole") was oriented in a north-south direction, and the other (a "40 m" dipole) was directed approximately east-west. The supporting tower was located immediately adjacent to one side of the house in the yard between the house and two smaller buildings. The tower also supported a tri-band Yagi antenna at a higher elevation, but that antenna was not surveyed in this study.

The north end of the north-south antenna was about 5 m above ground and was positioned about 1 m above the roof of the house. The two wire segments of the antenna were each about 20 m in length. The south half of this antenna extended over one of the smaller buildings and ended about 8 m above ground. Measurements were made with this antenna transmitting in the 1.9 and 3.7 MHz bands.

The east-west antenna (a "40 m" dipole) had segments of about 10 m each, ending at points about 9 m above ground. Measurements with respect to this antenna were made in the 7 MHz band. Results of all measurements are given in Tables 22-24.

TABLE 22: STATION G

FIELD STRENGTH: "80 METER", "INVERTED V" DIPOLE ANTENNA*

(a) 1.94 MHz; 100 W; @ appx. 1 m ht abv grd

DISTANCE (m)**	E FIELD (V/m)	H FIELD (mA/m)
1	3.6	104
2	1.6	49
4	1.6	28
6	2.1	19
8	1.2	15
[NOTE: 10-17 m readings taken inside guest house]		
10	0.7	10
11	1.4	8
12 (near cooling vent)	5.4	11
13 (near wall/vent)	4.0	7
15	1.3	6
17	1.8	6
[NOTE: 18-20 m readings taken outside guest house]		
18 (slightly past end of dipole segment)	0.9	4
20	0.9	<4

(b) 1.94 MHz; 100 W; misc. readings inside house & guest house

LOCATION	E FIELD (V/m)	H FIELD (mA/m)
Ambient; living room in house	0.5 - 5.4	8 - 9
Living room in house; corner nearest end of dipole segment	--	17
Top of lamp in living room (localized)	43.0 (plugged in) 1.9 (unplugged)	--
Ambient; loft in guest house	0.2 - 1.2	13 - 15
Near light fixture; in loft of guest house	9.0	--

NOTES:

(1) * Antenna attached to tower appx. 14 m above ground; each dipole segment appx. 20 m long; one segment extended over roof of house; other segment over roof of guest house; ends of segments were appx. 5 m (house) and 8 m (guest house) above ground.
(2) ** Distance from base of support tower toward guest house.
(3) IFI Model EFS-1 field intensity meter used for measuring E field.
(4) Calibrated loop antenna+HP power meter used for measuring H field.
(4) Measured values corrected for calibration error and rounded off.
(5) Dashes = not measured.

TABLE 23: STATION G

FIELD STRENGTH: "80 METER", "INVERTED V" DIPOLE ANTENNA*

(a) 3.7 MHz; 100 W; @ appx. 1 m ht abv grd

DISTANCE (m) ** **E FIELD (V/m)** **H FIELD (mA/m)**

1 1.2
12
2 1.4
16
4 2.1
27
6 4.0
29
8 3.5
30
[NOTE: 10-17 m readings taken inside guest house]
10 7.5
20
11 7.0
21
12 (near cooling vent) 55.3
123
13 (near wall/vent) 23.8
18
15 5.7
14
17 4.0
9
[NOTE: 18-22 m readings taken outside guest house]
18 (just past end of dipole) 3.1
5
20 2.8
4
22 2.2
4

(b) 3.7 MHz; 100 W; misc. readings inside house

LOCATION	E FIELD (V/m)	H FIELD (mA/m)
(1) Ambient; living room	2.6 - 13.4	25 - 27
(2) Living room corner nearest end of dipole segment	--	36 - 51
(3) Above living room lamp (localized)	26.9 (plugged in) 13.4 (unplugged)	--
(4) Ceiling near TV cable (localized) 73	--	

(c) 3.7 MHz; 100 W; inside ham shack (located in main house)

LOCATION	E FIELD (V/m)	H FIELD (mA/m)

(1) Ambient in room	1.9 - 8.8	--
(2) Operator's position	7.0 - 13.4	39
(3) Front of tuner (localized)	34.0 - 43.0	42
(4) Ceiling (near cable)	--	63

NOTES:

(1) * See notes in previous table for details of antenna.
(2) ** Distance from base of support tower toward guest house.
(3) IFI Model EFS-1 field intensity meter for measuring E field.
(4) Calibrated loop antenna+HP power meter used for measuring H field.
(5) Measured values corrected for calibration error and rounded off.
(6) Dashes = not measured.

TABLE 24: STATION G

FIELD STRENGTH: "40 METER", "INVERTED V" DIPOLE ANTENNA*

(a) 7.1 MHz; 100 W; @ appx. 1 m ht abv grd

DISTANCE (m)**	E FIELD (V/m)	H FIELD (mA/m)
1	3.9	34
2	1.7	18
4	1.9	21
6	3.5	23
8	3.9	21
9 (beneath end of antenna)	3.9	19

(b) 7.1 MHz; 100 W; @ appx. 2 m ht abv grd

DISTANCE (m)**	E FIELD (V/m)	H FIELD (mA/m)
1	7.4	28
2	2.3	18
4	3.0	21
6	4.8	21
8	6.0	19
9 (beneath end of antenna)	5.9	19

NOTES:

(1) * Antenna attached to tower appx. 14 m above ground. Each dipole segment appx. 10 m long. Each segment extends over yard between house and guest house. Segment ends are appx. 9 m above ground.
(2) ** Distance from base of support tower toward one end of dipole.
(3) IFI Model EFS-1 field intensity meter used to measure E field.
(4) Calibrated loop antenna+HP power meter used to measure H field.
(5) Measured values corrected for calibration error and rounded off.
(6) Dashes = not measured.

AMATEUR STATION H

Station H was located at a single-story residence. A large horizontal loop antenna was the subject of measurements at this station.   Its shape was that of a large rectangle extending around the perimeter of the back yard and over the roof the residence. This antenna is essentially omni-directional. It can be used for several frequency bands and has been referred to as a "loop skywire" antenna.   The leg of the rectangle extending over the roof of the house was about 20 m in length. The two perpendicular segments were each about 21 m in length and extended back across the roof toward the backyard, over the respective edges of the yard, and up the rather steep slope of a hill at the rear of the yard. The remaining segment of the rectangle was about 20 m long and followed the ridge of the hill to complete the loop. The antenna was fed at a corner of the antenna over the roof. The height above ground to the antenna ranged from about 8 m at the feed point to as little as 1-2 m along the ridge of the hill. The antenna constituted a full-wave loop at about 80 m wavelength (3.75 MHz). Measurements were made both inside and outside the house at transmitting frequencies of approximately 3.7, 7.1, 14.1, 21, and 28 MHz. Results are given in Table 25.

TABLE 25: STATION H

FIELD STRENGTH: HORIZONTAL LOOP ANTENNA[1]

I. Measurements under antenna segment along side of house

(a) E FIELD (V/m); @ appx. 1 m ht abv grd

DIST (m)[2]	3.7 MHz (100 W)	7.1 MHz (100 W)	14.15 MHz (26 W)	14.15 MHz (100 W)[3]	21.02 MHz (100 W)[4]	28.2 MHz (100W)
1	7.9	2.1	2.2	4.3	6.0(6.3)	5.6
2	8.8	4.2	1.9	3.7	4.5(5.0)	3.9
4	7.9	4.5	1.7	3.7	1.6(1.4)	1.4
6	8.4	4.3	1.2	2.4	0.5 0.9	
8	11.6	3.5	1.1	2.2	0.8 0.6	
10 (corner of house)	10.8	5.2	2.4	4.7	2.2(2.2)	3.4
12	7.0	9.8	1.1	2.2	1.6(2.2)	2.1

(b) H FIELD (mA/m); @ appx. 1 m ht abv grd

DIST (m)[2]	3.7 MHz (100 W)	7.1 MHz (100 W)	14.15 MHz (26 W)	14.15 MHz (100 W)[3]	21.02 MHz (100 W)	28.2 MHz (100W)
1	21	11	3	7	12	15
2	18	11	4	8	9	13
4	29	11	3	7	5	9
6	40	10	4	7	5	5
8	31	13	4	8	5	2
10 (corner of house)	34	12	12	24	8	8
12	31	12	8	15	10	5

II. Ambient measurements in backyard at appx. center of loop

E FIELD: 1 - 3 V/m **H FIELD:** 3 - 5 mA/m

NOTES:

IFI Model EFS-1 field intensity meter used to measure E field (except see note 4 below).
Calibrated loop antenna+HP power meter used to measure H field.
Readings corrected for calibration error & rounded off.
Dashes = not measured.

[1] Full-wave loop (appx. 80 m wavelength @ 3.75 MHz). Large rectangular antenna extending over single-story house and around edge of backyard.

[2] Distance measured under antenna segment along side of house with 0 = appx. location under antenna feed-point (appx. NW corner of antenna). Total length of antenna segment (one of four) = appx. 21 m.

[3] Field strength normalized to 100 W.

[4] Values in parentheses obtained using HI-3001 meter for comparison.

[TABLE 25 continued next page)

TABLE 25: STATION H (continued):

III. Measurements under antenna segment along top of hill in backyard

(a) E FIELD (V/m); @ appx. 1 m under wire segment

LOCATION[5]	3.7 MHz (100 W)	7.1 MHz (100 W)	14.15 MHz (26 W)	14.15 MHz (100 W)[6]	21.02 MHz (100 W)	28.2 MHz (100 W)
N-E Corner[7]	85.1	13.3	7.7	15.5	23.0	17.6
Middle[8]	63.8	56.7	5.6	11.2	23.0	12.3
S-E Corner	17.0	33.3	9.7	19.0	21.3	16.7

(b) H FIELD (mA/m); @ appx. 1 m under wire segment

LOCATION[5]	3.7 MHz (100 W)	7.1 MHz (100 W)	14.15 MHz (26 W)	14.15 MHz (100 W)[6]	21.02 MHz (100 W)	28.2 MHz (100 W)
N-E Corner[7]	87	98	18	35	21	8
Middle[8]	109	37	21	40	24	33
S-E Corner	130	88	10	20	24	23

IV. Inside ham shack (21.02 MHz, 100 W)

	E FIELD (V/m)	H FIELD (mA/m)
(1) Operator's position	4.3 - 8.6	8 - 12
(2) Ambient in room	0.9 - 2.7	6
(3) Front of transceiver (localized)	22.2	--
(4) Over lamp (localized)	13.3	--

NOTES:

IFI Model EFS-1 field intensity meter used to measure E field.
Calibrated loop antenna+HP power meter used to measure H field.
Measured values corrected for calibration error and rounded off.
Dashes = not measured.

[5] Locations under antenna segment along top of hill in backyard. Total length of this antenna segment (one of four) = appx. 20 m. See text for further details.
[6] Field strength normalized to 100 W.
[7] Part of antenna segment closest to feed-point.
[8] Appx. 10 m from each corner of this antenna segment.

AMATEUR STATION I

Station I was located at a single-story residence with a detached garage within twenty feet of the main house. Measurements were made using two types of antennas, a tri-band Yagi and an inverted dipole antenna.

(1) Tri-band Yagi Antenna

The first antenna studied was a tri-band Yagi antenna mounted on a pole over the garage. The antenna had three elements and was approximately 8-9 m above ground. Measurements with respect to this antenna were made in the 14 MHz band in the direction of propagation. Results of the measurements are given in Table 26.

(2) Dipole Wire Antenna

The other antenna studied was a dipole wire antenna that can best be described as a flattened, "inverted V," except that the two sections of the dipole were not straight. One end of the antenna was located at a point near a corner of the garage roof. From there it extended along the edge of the garage roof to another corner and then changed direction at approximately a 120° angle toward and over the roof of the house several meters away to the point where the antenna was fed. It continued over the roof of the house and, at the opposite corner of the house, made another sharp turn about 300° to the backyard of the house, where it ended. The dipole antenna was close to half-wave resonant at 160 m (1.88 MHz). Measurements were made at transmitting frequencies of 1.95 and 3.65 MHz, respectively. Results of the measurements are given in Table 27.

TABLE 26: STATION I

FIELD STRENGTH: YAGI (3 ELEMENT) HF BEAM ANTENNA[1]

(a) 14.15 MHz, 100 W, @ appx. 1 m ht abv gd

DISTANCE (m)[2]	E FIELD (V/m) EFS-1	E FIELD (V/m) HI-3001	H FIELD (mA/m)
3	3.4	2.2	10
5	4.3	4.6	9
7	3.4	2.8	10
9	2.8	3.3	12
11	3.3	3.2	15
13	3.3	2.8	16
15	3.2	2.6	14
17	3.8	2.2	10

(b) 14.15 MHz, 100 W, @ appx. 2 m ht abv gd

DISTANCE (m)[2]	E FIELD (V/m) EFS-1	E FIELD (V/m) HI-3001	H FIELD (mA/m)
3	8.6	10.0	10
5	5.6	7.7	8
7	4.6	5.4	8
9	4.0	5.1	9
11	4.3	4.4	11
13	4.3	4.4	11
15	4.2	4.2	11
17	5.1	4.1	8

NOTES:

IFI Model EFS-1 and Holaday Model HI-3001 field intensity meters used to measure E field.
Calibrated loop antenna+HP power meter used to measure H field.
Measured values corrected for calibration error and rounded off.

[1]Tri-band, Yagi, HF antenna mounted on a pole over a garage near single-story house. Antenna appx. 8-9 m above ground.

[2]Distance measured from appx. location under antenna base and in direction of maximum propagation.

TABLE 27: STATION I

FIELD STRENGTH: "160 METER" DIPOLE ANTENNA[1]

(a) 1.95 MHz, 80 W (near resonant frequency):

LOCATION	E FIELD (V/m)	H FIELD (mA/m)
Appx. under antenna feed-pt (located appx. 4.5 m abv gd)		
@ 1 m ht abv gd	11.0	
	78	
@ 2 m ht abv gd	19.2	
	--	
Under one end of antenna (located appx. 3 m abv gd)		
@ 1 m ht abv gd	9.0	
	25	
@ 2 m ht abv gd	22.0	
	--	
Under other end (appx. 3 m above gd)		
@ 1 m ht abv gd	5.4	13 - 15
@ 2 m ht abv gd	9.0	
	--	

(b) 3.65 MHz, 100 W:

LOCATION	E FIELD (V/m)	H FIELD (mA/m)
Appx. under antenna feed-pt (located appx. 4.5 m abv gd)		
@ 1 m ht abv gd	2.6	
--		
@ 2 m ht abv gd	5.3	
94		
Under one end of antenna (located appx. 3 m abv gd)		
@ 1 m ht abv gd	22.4	
16		
@ 2 m ht abv gd	51.1	
21		
Under other end (appx. 3 m above gd)		
@ 1 m ht abv gd	8.8	
	7	
@ 2 m ht abv gd	51.1	
	8	
In ham shack:		
Operator's position	1.9 - 8.8	
53		
Ambient in room	2.8 - 6.2	79 - 94

Front of tuner (localized)	--	63.8

NOTES:

IFI Model EFS-1 field intensity meter used to measure E field.
Calibrated loop antenna+HP power meter used to measure H field.
Measured values corrected for calibration error and rounded off.
Dashes = not measured.

[1] Almost horizontal "inverted V" dipole antenna extending over a garage and a single-story house.

VEHICLE-MOUNTED ANTENNAS

Because many amateur operators use mobile and portable transmitting units, an effort was made to obtain representative field measurements near some of these sources. Measurements were made inside and outside of vehicles on which various antennas were mounted. These measurements were made in cooperation with the licensee of Station D, both near his residence and in an open field.

(1) 2 m Band Whip Antenna

The first series of measurements was made relative to a 48 centimeter (cm) quarter-wave, vertical, whip antenna mounted on a small compact car. The antenna was mounted at the center of the rear of the roof just above the hatchback. It was operated with about 85 watts of transmitter output power at a frequency of 146 MHz. Measurements were made in the driver's position, in front and rear passenger locations, and around the outside of the vehicle. The measurements were made while the car was parked on the concrete driveway of a private residence. A van was parked directly beside the car during one set of measurements. Results of the measurements are given in Table 28.

(2) Open Field Test (Yagi and Quagi Antennas)

The second series of vehicle measurements was designed to determine typical field strength readings in an "open-field" environment, such as might be encountered as part of an outdoor amateur radio event. For these measurements two antennas were mounted on a single, rotatable pole attached to the roof of a van. The van was positioned in the middle of a large, open field with a dirt surface.

The antennas used were a five-element Yagi transmitting at approximately 50 MHz and an eight-element "Quagi" transmitting at about 144 MHz. The height of the Yagi antenna was approximately 4 m above ground, and the Quaqi antenna was mounted approximately 1.5 m directly above the Yagi antenna. Measurements were made using various powers and with respect to various orientations of the antennas. Results of the measurements for these two vehicle-mounted antennas are given in Table 29.

TABLE 28

FIELD STRENGTH: VEHICLE-MOUNTED,* QUARTER-WAVE, WHIP ANTENNA (146 MHz; POWER OUTPUT: 85±10 W)

MEASUREMENT LOCATION	E FIELD (V/m)	H FIELD (mA/m)
I. OUTSIDE VEHICLE (passenger side adjacent to & appx. 2 m from panel van):		
(1) 0.5 m from antenna toward rear of vehicle	73	50
(2) 1 m from antenna toward rear	32**	60
(3) 2 m from antenna toward rear	21	50
(4) 1 m from antenna toward adjacent van	63	--
(5) 1 m from antenna toward front of vehicle (over roof)	52	--
(6) 1 m from antenna in direction opposite to adjacent van	47	--
II. OUTSIDE VEHICLE (no adjacent vehicle)		
(1) 1 m from antenna toward rear of vehicle	33	--
(2) 1 m from antenna toward passenger side	56	--
(3) 1 m from antenna toward front of vehicle (over roof)	60	--
(4) 1 m from antenna toward driver's side	56	--
III. INSIDE VEHICLE:		
(1) Driver's position (higher readings near roof)	21 - 56	100
(2) Front passenger location	15 - 26	70

(3) Various locations in rear seat and close to antenna	30 - 84	60 - 160

NOTES:

(1) Measured values corrected for calibration error and rounded off.

(2) * Sub-compact hatchback with antenna roof-mounted above center rear window.

(3) ** Average of two or more readings.

(4) Dashes = not measured.

TABLE 29

"OPEN FIELD" TEST USING VEHICLE-MOUNTED ANTENNAS

I. FIVE-ELEMENT YAGI ANTENNA (mounted appx 4 m above ground level on rotatable pole attached to top of panel van):

(a) 50.125 MHz; 500 W; 10 m horiz dist from pt below antenna center:

AZIMUTHAL ANGLE (0E=to rear of van)	E FIELD (V/m)[1]
0E	36 - 48
45E	15 - 21
90E	2 (max.)
135E	2 - 4
180E	1 - 2
225E	3 - 6
270E	1 - 2
315E	19 - 28
360E	37 - 50

(b) 50.125 MHz; 1000 W; @10 m horiz dist from pt below appx. center of antenna; in direction of max propagation:

HGT ABOVE GROUND	E FIELD (V/m)
1 m	48
2 m	67
3 m (appx)	71

(c) 50.125 MHz; 500 W; various horiz dist from pt below appx. center of antenna; in direction of max propagation:

DISTANCE	E FIELD (V/m AT GIVEN HGT ABOVE GROUND (1 m)	(2 m)
2 m	13	18
5 m	45	56
10 m	34[2]	48
15 m	21	29
20 m	12	18
25 m	8	13
50 m	2	2

(d) 50.125 MHz; 500 W; measurements inside van

Ambient 3-16 V/m with localized "hot spot" of appx 30 V/m in front of amplifier (antenna pole-mounted appx 2 m abv van)

NOTES:

[1] Measured @1-2 m hgt above ground; higher readings at 2 m.

[2] Also made confirmation reading of 31 V/m (avg) using FOISD (see text).

Model HI-3001 field intensity meter used for all readings.

Measured values corrected for calibration error and rounded off.

[TABLE 29 continued next page]

TABLE 29: [continued]

II. EIGHT-ELEMENT QUAGI ANTENNA (mounted appx. 5.5 m above ground level on rotatable pole attached to top of panel van):

(a) 144.2 MHz; 550 W; 10 m horiz. distance from point below appx. center of antenna

AZIMUTHAL ANGLE (0E=to rear of van)	E FIELD (V/m)[3]
0E	22 - 26
45E	9 - 19
90E	7 - 10
135E	2 - 2.5
180E	2 - 4
225E	3 - 5
270E	5 - 7
315E	4 - 9
360E	22 - 26

(b) 144.2 MHz; 550 W; various horiz. distances from point below appx. center of antenna; direction of max. propagation

DISTANCE	E FIELD (V/m AT GIVEN HGT ABOVE GROUND (1 m)	(2 m)
2 m	10	16
5 m	11	15
10 m	21	24
15 m	30	23
20 m	24	26
25 m	20	25
50 m	6	10

(c) 144.2 MHz; 500 W; measurements inside van

Ambient 3-7 V/m with localized "hot spot" of >94 V/m immediately in front of amplifier (antenna pole-mounted appx. 3.5 m above van)

NOTES:

[3] Measured @1-2 m hgt above ground; higher readings at 2 m.
Model HI-3001 field intensity meter used for all readings.
Measured values corrected for calibration error and rounded off.

APPENDIX B

SUMMARY OF ANSI AND IEEE RECOMMENDED FIELD LIMITS

The Institute of Electrical and Electronics Engineers (IEEE) and the American National Standards Institute (ANSI) have developed widely used radiofrequency (RF) exposure guidelines. Major features of the ANSI and IEEE RF guidelines discussed in this publication are given below. For complete information on either standard consult IEEE or ANSI.

For more details on IEEE guidelines and for ordering complete copies, contact the Institute of Electrical and Electronics Engineers, Inc. (IEEE), Standards Dept., 445 Hoes Lane, P.O. Box 1331, Piscataway, N.J. 08855-1331. Telephone: 1-800-678-IEEE.

For information on ANSI standards contact the American National Standards Institute (ANSI), 11 West 42nd St., New York, N.Y. 10036. Telephone: (212) 642-4900. Information on ANSI RF exposure guidelines may also be available from the IEEE.

(1) ANSI C95.1-1982 RADIOFREQUENCY PROTECTION GUIDES

"AMERICAN NATIONAL STANDARD SAFETY LEVELS WITH RESPECT TO HUMAN EXPOSURE TO RADIO FREQUENCY ELECTROMAGNETIC FIELDS, 300 KHZ TO 100 GHZ." ANSI C95.1-1982. Copyright (1982) by the Institute of Electrical and Electronics Engineers, Inc., New York, N.Y.

Frequency Range (MHz)	Electric Field Strength $E^2(V^2/m^2)$	Magnetic Field Strength $H^2(A^2/m^2)$	Power Density (S) E-field; H-field (mW/cm^2)	Averaging Time (minutes) $\|E\|^2$; S; or $\|H\|^2$
0.3-3	400,000	2.5	100	6
3-30	400,000 ($900/f^2$)	0.025 ($900/f^2$)	$900/f^2$	6
30-300	4,000	0.025	1.0	6
300-1500	4,000 (f/300)	0.025(f/300)	f/300	6
1500-100,000	20,000	0.125	5.0	6

f = frequency in megahertz (MHz)
E^2 = electric field strength squared
H^2 = magnetic field strength squared
V^2/m^2 = volts squared per meter squared
A^2/m^2 = amperes squared per meter squared
mW/cm^2 = milliwatts per centimeter squared

NOTES for ANSI C95.1-1982

(1) The squares of the field strengths or the power density, as applicable, are to be averaged over any six-minute period, and these time-averaged values should not exceed the values given in the table.

(2) For near field exposures, the only applicable protection guides are the mean squared electric and magnetic field strengths as given in the table above, columns 2 and 3. For convenience, these guides may be expressed as the equivalent plane wave power density, given in the fourth column of the table.

(3) Note that these guidelines have been replaced by the ANSI/IEEE C95.1-1992 (IEEE C95.1-1991) guidelines that follow. The FCC adopted the 1982 guidelines in 1985 for use in evaluating RF exposure. In 1993, the FCC proposed to adopt the new ANSI/IEEE guidelines. An FCC decision in that proceeding is expected by the middle of 1996.

(2) ANSI/IEEE C95.1-1992 (IEEE C95.1-1991) RADIOFREQUENCY PROTECTION GUIDES

Issued by the IEEE in 1991 as IEEE C95.1-1991. Adopted as an ANSI standard (ANSI/IEEE C95.1-1992) in 1992. For a complete copy of these guidelines or for more information contact the IEEE or ANSI (see first page of this Appendix).

"IEEE STANDARD FOR SAFETY LEVELS WITH RESPECT TO HUMAN EXPOSURE TO RADIO FREQUENCY ELECTROMAGNETIC FIELDS, 3 KHZ TO 300 GHZ." ANSI/IEEE C95.1-1992 (IEEE C95.1-1991). Copyright (1992) by the Institute of Electrical and Electronics Engineers, Inc., 345 East 47th St. New York, N.Y. 10017-2394.

SOME GENERAL FEATURES:

(1) "Controlled Environment" defined as "locations where there is exposure that may be incurred by persons who are aware of the potential for exposure as a concomitant of employment, by other cognizant persons, or as the incidental result of transient passage through areas where analysis shows the exposure levels may be above those shown in [Section II, p. 55] but do not exceed those in [Section I, p.54] . . ."

(2) "Uncontrolled Environment" defined as "locations where there is the exposure of individuals who have no knowledge or control of their exposure. The exposures may occur in living quarters or workplaces where there are no expectations that the exposure levels may exceed those shown in [Section II, p. 55] . . ."

(3) Various periods of time are specified for averaging exposures.

(4) Induced current and contact current limits are also part of ANSI/IEEE MPEs.

I. ANSI/IEEE 1992 Maximum Permissible Exposure (MPE) for Controlled Environments

Electromagnetic Fields

Frequency Range (MHz)	Electric Field Strength E (V/m)	Magnetic Field Strength H (A/m)	Power Density (S) E-field; H-field (mW/cm^2)	Averaging Time (minutes) $\|E\|^2$; S; or $\|H\|^2$
0.003-0.1	614	163	(100; 1,000,000)*	6
0.1-3.0	614	16.3/f	(100; $10,000/f^2$)*	6
3.0-30	1842/f	16.3/f	($900/f^2$; $10,000/f^2$)*	6
30-100	61.4	16.3/f	(1.0; $10,000/f^2$)*	6
100-300	61.4	0.163	1.0	6
300-3000	--	--	f/300	6
3000-15,000	--	--	10	6
15,000-300,000 --	--	10	$616,000/f^{1.2}$	

* Plane-wave equivalent power density; not appropriate for near-field conditions, but sometimes used for comparison purposes.
f = frequency in megahertz (MHz)
V/m = volts per meter
A/m = amperes per meter
mW/cm^2 = milliwatts per centimeter squared

Induced and Contact Radiofrequency Currents

Frequency Range (MHz)	Maximum Current (milliamps) Through both feet	Through each foot	Contact Current
0.003-0.1	2000f	1000f	1000f
0.1-100	200	100	100

II. ANSI/IEEE 1992 Maximum Permissible Exposure (MPE) for Uncontrolled Environments

Electromagnetic Fields

Frequency Range (MHz)	Electric Field Strength E (V/m)	Magnetic Field Strength H (A/m)	Power Density (S) E-field; H-field (mW/cm^2)	Averaging Time (minutes) $\|E\|^2$; S; or $\|H\|^2$	
0.003-0.1	614	163	(100; 1,000,000)*	6	6
0.1-1.34	614	16.3/f	(100; $10,000/f^2$)*	6	6
1.34-3.0	823.8/f	16.3/f	($180/f^2$; $10,000/f^2$)*	$f^2/0.3$	6
3.0-30	823.8/f	16.3/f	($180/f^2$; $10,000/f^2$)*	30	6
30-100	27.5	$158.3/f^{1.668}$	(0.2; $940,000/f^{3.336}$)*	30	$0.0636f^{1.337}$
100-300	27.5	0.0729	0.2	30	30
300-3000	--	--	f/1500	30	--
3000-15,000	--	--	f/1500	90,000/f	--
15,000-300,000 --	--	10	$616,000/f^{1.2}$	--	

* Plane-wave equivalent power density; not appropriate for near-field conditions, but sometimes used for comparison purposes.

f = frequency in megahertz (MHz)
V/m = volts per meter
A/m = amperes per meter
mW/cm^2 = milliwatts per centimeter squared

Induced and Contact Radiofrequency Currents

Frequency Range (MHz)	Maximum Current (milliamps) Through both feet	Through each foot	Contact Current
0.003-0.1	900f	450f	450f
0.1-100	90	45	45