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Technology Assessment Program

Field Strength Levels in Vehicles Resulting from Communications Transmitters

200-83

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James K. Stewart, Director
National Institute of Justice

Technology Assessment Program

Field Strength Levels in Vehicles Resulting from Communications Transmitters

NIJ Report 200-83

by

John F. Shafer
Electromagnetic Fields Division
Center for Electronics and Electrical Engineering
National Engineering Laboratory

and the

Law Enforcement Standards Laboratory
National Engineering Laboratory
National Bureau of Standards
Washington, DC 20234

prepared for the

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James K. Stewart
Director

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FOREWORD

The Law Enforcement Standards Laboratory (LESL) of the National Bureau of Standards (NBS) furnishes technical support to the National Institute of Justice (NIJ) program to strengthen law enforcement and criminal justice in the United States. LESL's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment.

LESL is: (1) Subjecting existing equipment to laboratory testing and evaluation and (2) conducting research leading to the development of several series of documents, including national voluntary equipment standards, user guides, and technical reports.

This document covers research on law enforcement equipment conducted by LESL under the sponsorship of NIJ. Additional documents are being issued under the LESL program in the areas of protective equipment, communications equipment, security systems, weapons, emergency equipment, investigative aids, vehicles, and clothing.

Technical comments and suggestions concerning this document are invited from all interested parties. They may be addressed to the Law Enforcement Standards Laboratory, National Bureau of Standards, Washington, DC 20234.

Lester D. Shubin
Program Manager for Standards
National Institute of Justice

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FIELD STRENGTH LEVELS IN VEHICLES RESULTING FROM COMMUNICATIONS TRANSMITTERS

John F. Shafer*

National Bureau of Standards, Boulder, CO 80803

This report provides the results of an exploratory study to measure the electric field strength levels inside an automobile from communications equipment (transmitters and associated antennas) typical of that likely to be operated in and around the automobile as a law-enforcement vehicle. Field strengths were measured with a calibrated probe at 10 locations within the test vehicle, with and without the driver's door open, and with and without front-seat occupants, at frequencies representing the frequency bands of 25 to 50, 150 to 174, 400 to 512, and 806 to 866 MHz. Levels of output power are given for the data presented. Field strength levels are also given for the situation when a metallic prisoner shield or a personal transceiver is used in a vehicle, together with a mobile transceiver, in some cases. Also included are field strength measurements of speed measuring radar devices used in vehicles.

Keywords: communications equipment; field strength; mobile transceiver; personal transceiver; speed measuring radar; transmitters.

1. INTRODUCTION

Law enforcement and other public safety personnel utilize various types of communications and electronic equipment in the performance of their normal day-to-day activities. Every patrol car has a minimum of one mobile transceiver in the vehicle; often there is more than one unit installed. Many officers carry personal transceivers so that they have communication capability wherever they may be. Officers assigned to traffic control often use speed measuring radar devices or other electronic devices to measure vehicle speed. Officers on special assignments are sometimes outfitted with concealed transmitters on their person. All of these electronic devices are used routinely in the performance of their duties.

The communication equipment utilized by law enforcement agencies operate over a broad frequency range. Transmitters are used at selected frequencies from about 25 to 900 MHz. Speed measuring radar devices operate at approximately 10 and 24 GHz. Mobile transmitters with output powers of 100 W are commonplace. Personal transceivers having output powers of 5 to 6 W are also becoming more commonplace.

The use of all of these items of electronic equipment in close proximity to each other may result in degraded communications system performance as a consequence of electromagnetic interference. System performance is also affected by other, less identifiable, sources of interference, such as automotive ignition systems, vehicle warning lights and sirens, and the changing mobile operating environment. In addition, in recent years there has been a great deal of concern about the possible effect on the human body of the various electromagnetic fields generated by electronic transmitting equipment [1,2].[1] Because of this concern, attention is being devoted to the problem of police operations in environments that contain radiated electromagnetic fields.

*Electromagnetic Fields Division, Center for Electronics and Electrical Engineering, National Engineering Laboratory.

[1] Numbers in brackets refer to references in section 6.

Toward this end, a program was undertaken by the Law Enforcement Standards Laboratory of the National Bureau of Standards (NBS) to develop standards that will minimize degradation in communications system performance caused by electromagnetic interference from all sources that affect such systems. An obvious by-product of this program will be a better definition of the electromagnetic environment in the vicinity of the transmitting devices, such as transceivers and radar devices, used by law enforcement personnel. The first phase of this program, which was undertaken at the request of the National Institute of Justice (NIJ), was to study and measure the field strength levels that are generated by typical transmitters used by law enforcement personnel, either in open space or in and around a vehicle. The publication of these measurement results in advance of the development of standards was requested by the NIJ Technology Assessment Program Advisory Council Communications/Electronics Committee. This report contains the results of tests conducted using these transmitters in and around a vehicle.

Several years ago work was carried out at the NBS under the sponsorship of the National Highway Traffic Safety Administration (NHTSA) of the Department of Transportation to identify the electromagnetic (EM) environment in order to estimate EM compatibility testing criteria for vehicles and their electronic systems [3]. Also, in 1981, NBS reported the results of field strength measurements made at a number of locations within a four-door sedan typically used as a police vehicle, resulting from the operation of radar devices in a variety of mounting positions [4]. This effort was conducted for the NHTSA, and a summary of the results are reproduced in this report as appendix A, with the permission of that agency.

2. FIELD STRENGTH MEASUREMENTS

2.1 Energy Sources and Instrumentation

Electric field strength measurements were taken at frequencies of 40.27, 162.475, 416.975, and 823 MHz using mobile transmitting equipment having output power levels of 80, 100, 100, and 40 W, respectively. Figure 1 shows the four transmitters rack mounted alongside a covert or disguised resonant-cavity antenna in the back of a production American hatchback vehicle. The antennas used with the transmitters were mounted on

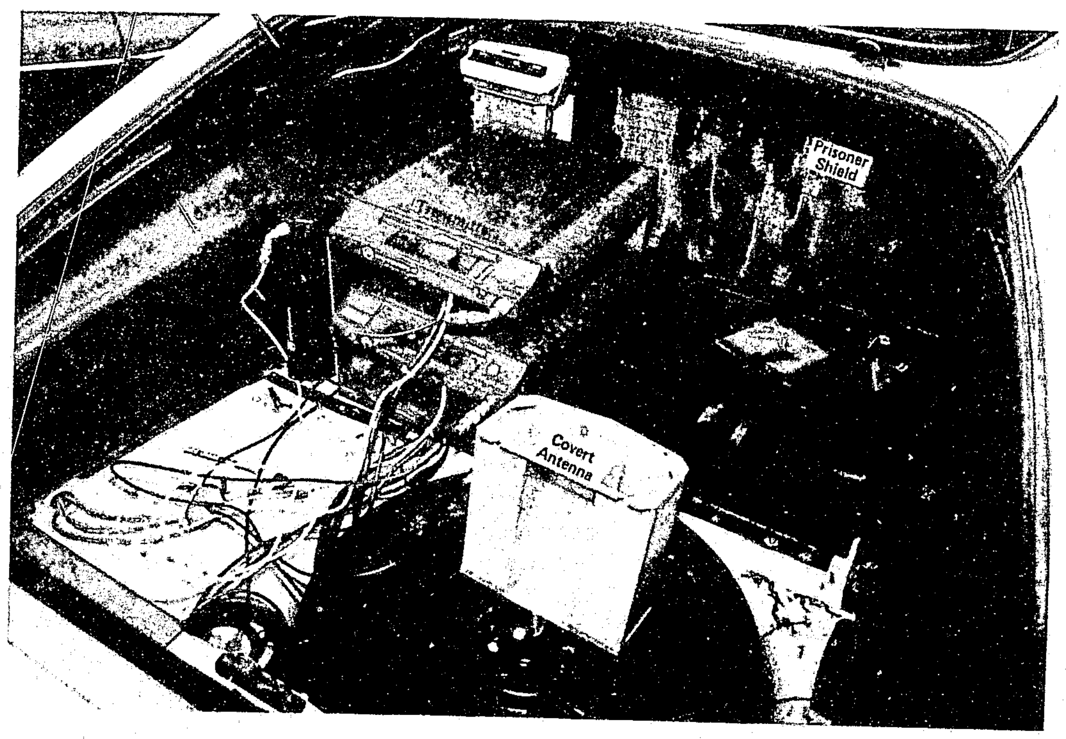

FIGURE 1. *Transmitters used for the field strength measurements.*

the vehicle roof with the interconnecting coaxial cables routed beneath the headliner and as close as possible to the vehicle's metallic body. No field strength measurements were made on a vehicle having other than a metallic roof.

The electric field strength levels were measured with an NBS energy density meter, the Energy Density Meter-3 (EDM-3) of the type shown in figure 2. The EDM-3, which was used with a 10 cm (4 in) diameter rigid foam plastic ball around the probe, is designed for use in near-field measurements. The calibration of the energy density meter was carried out by immersing the probe in a standard reference field [5]. Additional background information on this topic can be obtained from Larsen and Shafer [6].

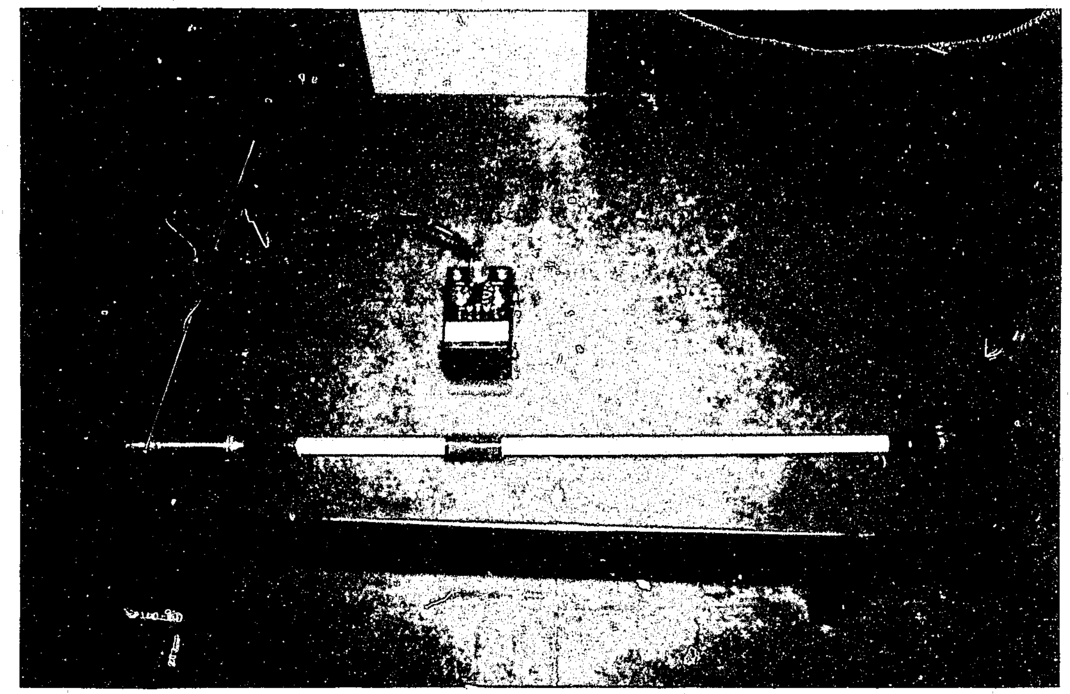

FIGURE 2. *NBS energy density meter and probe with 10 cm (4 in) diameter styrofoam ball.*

2.2 Measurement Conditions

Two primary transceiver measurement conditions were established. These were (1) measurement of field strength levels inside a vehicle with a driver and one passenger seated in the front seat and (2) measurement of the field strength levels inside a vehicle with a driver and one passenger seated in the front seat with the driver's door open. Measurements were taken at 10 selected locations inside the vehicle for each of these situations at each of the four transceiver test frequencies, using roof-mounted antennas.

In addition to these primary measurement conditions, several more specialized field strength measurements were made. The first of these had the driver standing outside the closed door of the vehicle using the transceiver microphone through an open window (fig. 3) with no passengers present. Because the field strength levels were greater at 40.27 MHz than at the other frequencies used, this measurement was made only at this frequency. In the second, measurements were made inside the vehicle with the vehicle parked on the center of a 30 by 60 m (98.5 by 187 ft) wire mesh ground screen to determine whether the field strength levels inside the vehicle would increase when the vehicle was parked on a metallic surface such as a bridge or overpass. In another test, field strength measurements were taken in the vehicle with a metallic prisoner shield located behind the driver and front seat passenger.

Measurements were also made with the metallic shield in place and two antennas that operate at frequencies in the 400–512 MHz frequency band mounted inside the vehicle.

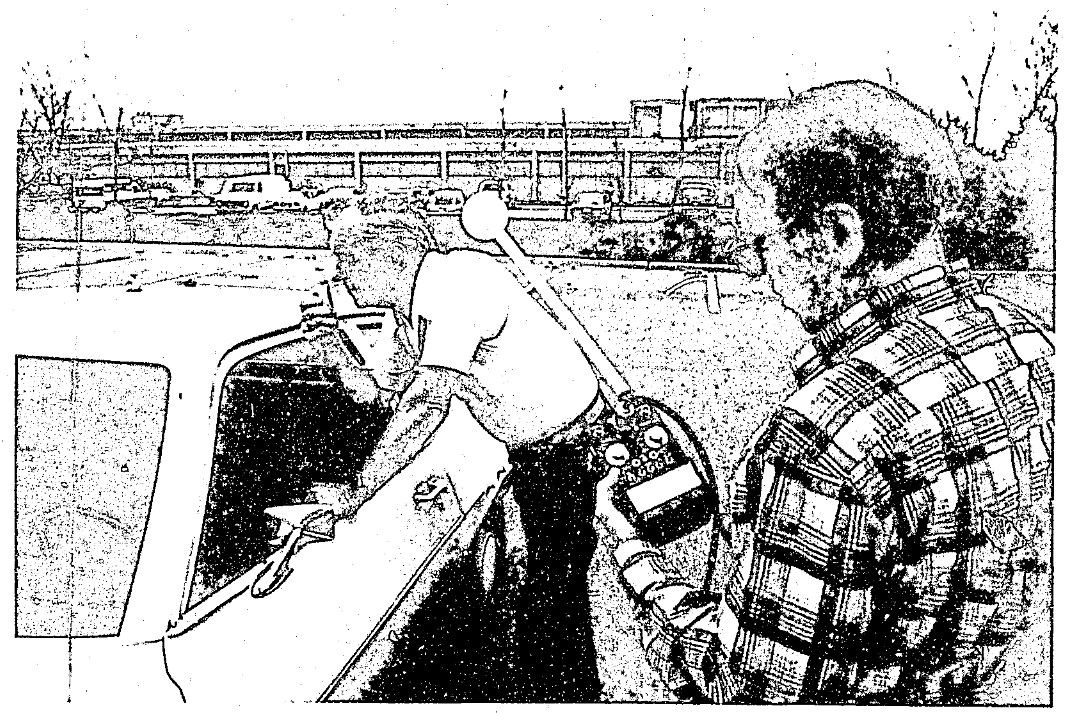

FIGURE 3. *Measurements taken when standing outside vehicle with door closed.*

One antenna, a one-quarter wavelength monopole, was mounted on the package shelf or deck behind the rear seat. The other antenna, a disguised resonant-cavity used in covert operations, was mounted in the trunk using the oval aperture normally used for a broadcast radio rear speaker. Measurements were made around the head area of the driver and front seat passenger using the monopole antenna and a transmitter output power of 30 W and using the resonant-cavity antenna and a transmitter output power of 100 W.

Field strength levels were measured near an operator using a personal transceiver inside the vehicle (fig. 4) with both the driver and the front seat passenger seated in the vehicle. The measurements were repeated with the driver standing outside the vehicle using the transceiver near the roof. Three 2-W transceivers operating at 162.475 MHz, 460.425 MHz, and 806.8125 MHz, respectively, were used in these measurements.

FIGURE 4. *Measurements taken when using personal transceiver inside a vehicle.*

3. MEASUREMENT RESULTS[2]

During the first primary transceiver measurement condition where the test vehicle had its doors closed, the occupants had the advantage of being shielded by the surrounding metal enclosure. However, field strengths were highest in locations where the occupants were in close proximity to metal surfaces. For example, the measured field strength between the head of a person and the inside roof of the vehicle at 40.27 MHz was 212 volts per meter (V/m). Yet, when this person was not seated in the vehicle, the field strength level was only about 20 V/m. The measurement results suggest that the human body behaves like a dielectric material filling the volume in the seat area much like the material placed in the inner region of an air-dielectric coaxial transmission line. When the height of the occupant was approximately 1 m (3.28 ft) from the seat surface to the top of the head with the 10 cm (4 in) probe positioned directly between the head and the metallic roof of the vehicle, it appears that the field between the top of the head and bottom side of the roof is approximately 60 percent of the total field strength. A summary of the typical values of field strength at the 10 selected locations within the vehicle with its doors closed is given on the left hand side of figures 5 through 8.

For the second primary transceiver measurement situation, with the vehicle driver's door open, a higher field existed inside the vehicle. For example, at 40.27 MHz a field strength of 281 V/m was measured between the top of the operator's head and the bottom of the car roof, an increase of 69 V/m over the reading with the door closed. Again, a summary of the values obtained at the 10 selected locations within the vehicle with the driver's door open is given in figures 5 through 8. The field strength levels inside the vehicle for the two primary measurement conditions varied from 5 to 281 V/m at 40.27 MHz, 12 to 58 V/m at 162.475 MHz, and 5 to 21 V/m at 416.975 MHz and at 823 MHz.

[2] These results are intended to be indicative, not definitive. Therefore, statistical estimates of measurement uncertainties and details of the measurement configurations are not provided.

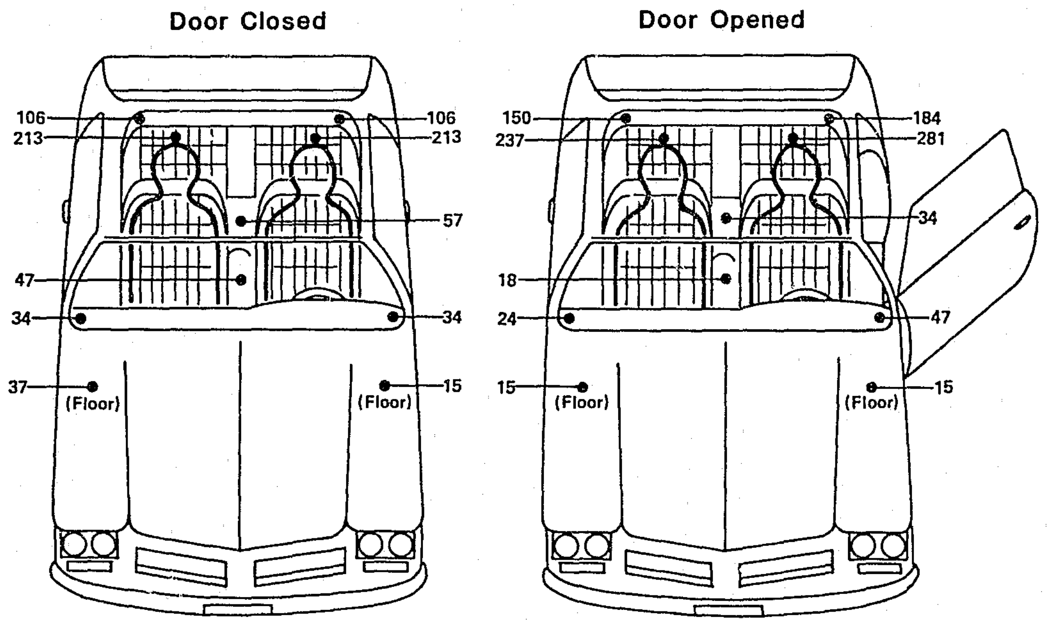

FIGURE 5. *Levels of field strength (V/m) taken at 10 selected locations inside a vehicle at 40.27 MHz and 80 W output with and without the driver's door open.*

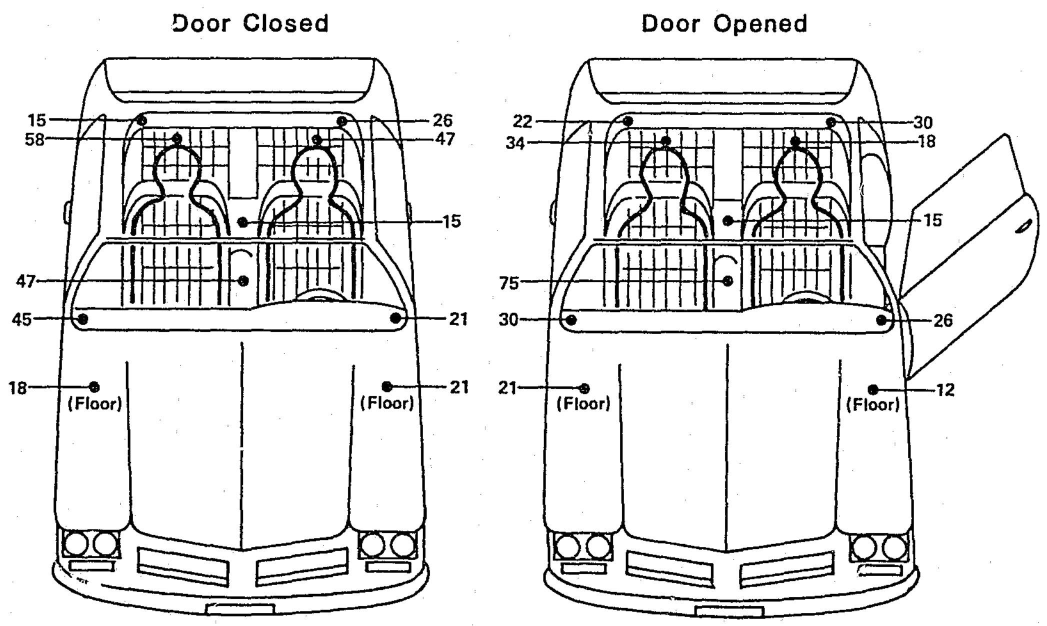

FIGURE 6. *Levels of field strength (V/m) taken at 10 selected locations inside a vehicle a' 162.475 MHz and 100 W output with and without the driver's door open.*

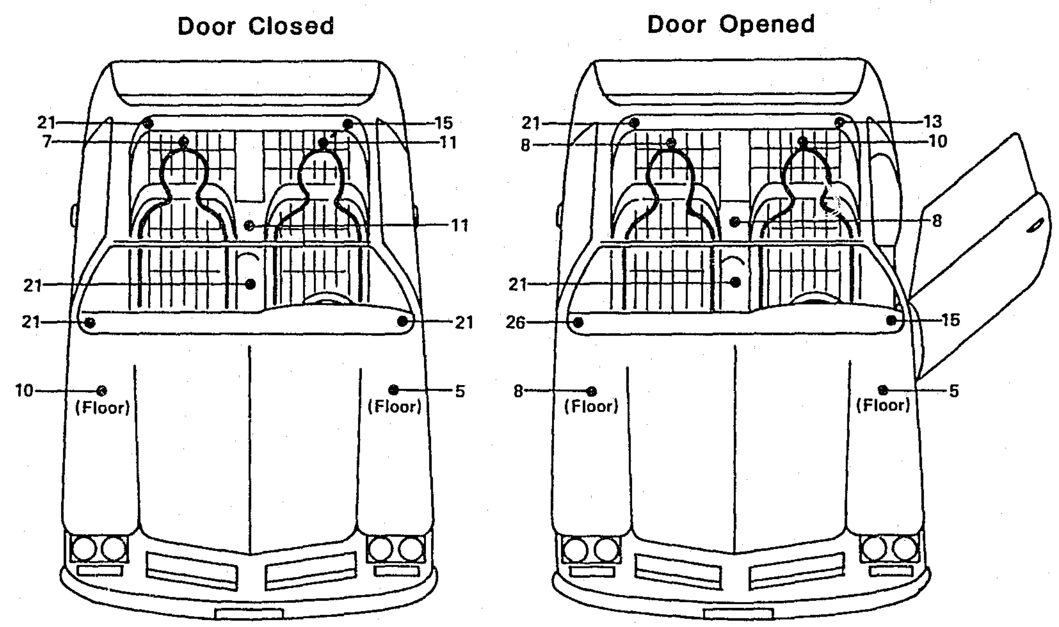

FIGURE 7. *Levels of field strength (V/m) taken at 10 selected locations inside a vehicle at 416.975 MHz and 100 W output with and without the driver's door open.*

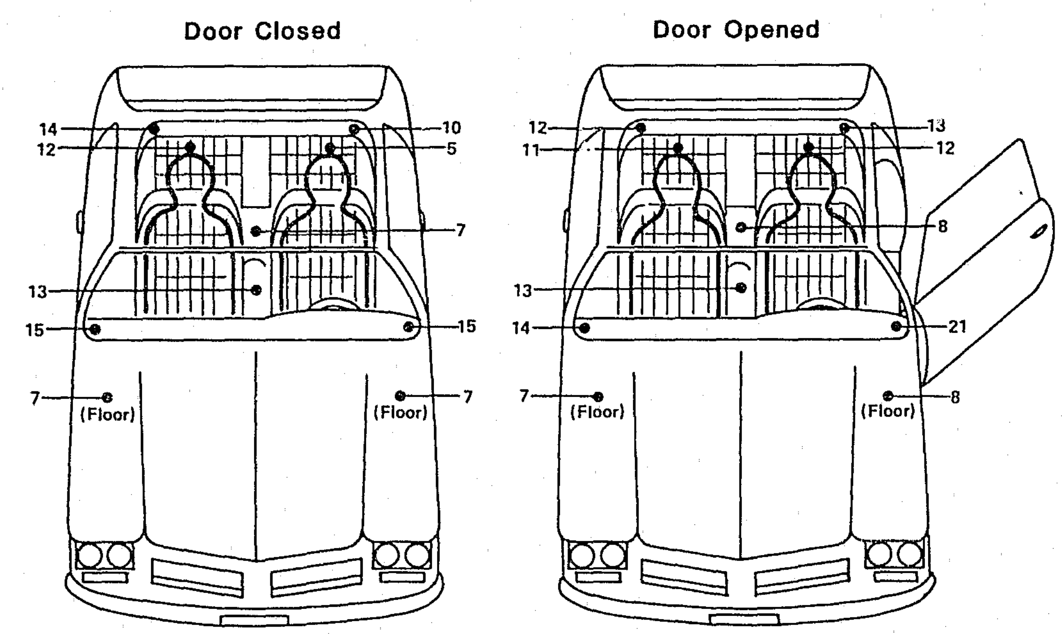

FIGURE 8. *Levels of field strength (V/m) taken at 10 selected locations inside a vehicle at 823.000 MHz and 40 W output with and without the driver's door open.*

At 40.27 MHz, a reading of 250 V/m was obtained at the head level of a person standing near the closed driver's door. When the vehicle was parked on the 30×60 m wire mesh ground screen, the fields beneath the vehicle were found to be greater than those obtained when parked on a nonmetallic surface. However, this phenomenon did not influence the fields within the vehicle.

Measurements taken with the metallic prisoner shield in place produced a field strength level of 106 V/m at 40.27 MHz using the roof-mounted antenna. Field strengths of 50 to 80 V/m were measured in the driver and passenger head area when transmitting at 30 W at 460.425 MHz using the quarter-wave monopole antenna, also with the metallic shield in place. Transmitting at 100 W at the same frequency with the resonant-cavity antenna produced measured field strength levels of 50 to 150 V/m at the regular passenger seating position under the same set of circumstances.

Use of the 2-W, 162.475 MHz personal transceiver inside the vehicle yielded a reading of 100 V/m between the operator's head and the roof and its use outside the vehicle yielded a reading of 180 V/m near the operator's head. The field strengths recorded using the 2-W, 460.425 MHz personal transceiver were 70 V/m inside the vehicle and 120 V/m outside the vehicle while the field strengths recorded using the 2-W, 806.8125 MHz personal transceiver were 43 V/m inside the vehicle and 45 V/m outside the vehicle for the same situations.

4. CONCLUSIONS

The results given above apply to the actual measurement conditions and configurations, for a single specific vehicle, and for given test occupants. For example, as noted, the test automobile is a hatchback type; the same transmitters mounted in a different type of vehicle with the same antennas mounted on the roof may produce different field strength levels.

The field strength levels measured inside the vehicle at 40.27 MHz were much greater than those measured at the three higher frequencies. As the frequency was raised, the levels measured inside the vehicle tended to decrease. At 40.27 MHz, the maximum level inside the vehicle increased when measured with one door open. Operation of a typical personal transceiver or a speed measuring radar device in or near the vehicle did not produce field strength levels nearly as high as those produced by the mobile transceivers normally used.

5. RADIATION EXPOSURE STANDARDS

It is not the purpose of this report to state what levels of electromagnetic fields constitute a health hazard. Such issues are outside the mission of the NBS and are best left to those organizations and committees that have been established to perform and interpret research on the biological effects of electromagnetic waves and to set exposure limits based on the results of such research.

Section 1910.97 of the Occupational Safety and Health Act contains a Radiation Protection Guide (RPG) that applies to exposure to electromagnetic radiation at various frequencies. At frequencies of 10 MHz to 100 GHz, which include the frequencies of interest in this report, the RPG allows exposure up to a power density of 10 milliwatts per square centimeter (mW/cm^2) over any 0.1-hour period, or up to a power density of 10 mW/cm^2 averaged over any 0.1-hour period or more. Meanwhile, a voluntary Radio Frequency Protection Guide of 1 mW/cm^2 for the 30 MHz to 300 MHz frequency range has been adopted by the American National Standards Institute, also averaged over any 0.1-hour period [2].

If a comparison of the results presented in this report with power density units is desired, the reader is cautioned that this comparison can be made correctly only if the electromagnetic radio wave measured is truly a far-field measurement, that is, the wave is planar in nature. These measurements cannot be assumed to have been made in a plane wave, far-field condition, and, therefore, the power density values are not reported. When far-field conditions apply, the power density value in microwatts per square centimeter (μW/cm^2) can be computed from the electric field strength values by using the following relationship:

$$\text{Power Density in } \mu\text{W/cm}^2 = E^2/3.7673,$$

where E is the electric field strength in V/m. For example, the approximate power density for a field strength of 100 V/m is:

$$\frac{100^2}{3.7673} = 2654\ \mu\text{W/cm}^2 = 2.65\ \text{mW/cm}^2$$

6. REFERENCES

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[6] Larsen, E. B.; Shafer, J. F. Surveys of electromagnetic field intensities near representative higher-power FAA transmitting antennas. FAA-RD-77-179. Federal Aviation Administration; 1977 December.

APPENDIX A—FIELD STRENGTH MEASUREMENTS OF SPEED MEASURING RADAR DEVICES

The results reported on in this appendix are a summary of measurements previously conducted on vehicle-mounted speed measuring radar devices and published as part of NBSIR 81-2225 and DOT HS-805 928.

Instrumentation

Each of the 22 radar devices tested was mounted in the position(s) in which it is normally used, and calibrated field probes were used to measure the field strength levels throughout the interior of the car, paying attention to regions where the head and groin would be located. Two different probes were used for these measurements. An NBS Model EDM-1C Electric Energy Density Meter was used for the measurements involving the X-Band (10.525 GHz) radars. This NBS probe does not operate above X-band, so a commercial Electromagnetic Radiation Monitor was used for the K-Band (24.15 GHz) measurements. The sensor antennas in both probes consisted of three orthogonal dipoles in order to achieve isotropic response patterns. The measurements are, therefore, quite insensitive to the orientation of the probe with respect to the field being measured, as long as the probe handle is not pointed toward the radiation source. The NBS probe uses diodes for the detecting elements, while the commercial unit employs thermocouples. The NBS probe has greater sensitivity; its threshold response being 2 V/m. With the commercial meter, the minimum detectable field strength level was 6 V/m.

Measurement Conditions

The speed measuring radar devices were positioned in eight different locations in a four-door sedan. Five of these locations were in the front seat area, two in the rear seat area and one outside the vehicle. Prior to making measurements inside the sedan, the field strength level in the main beam, close to the aperture, was determined by holding the probe directly in front of the aperture as shown in figure A-1. These results are listed in column 2 of table 1. The maximum field strength radiated to the sides and rear of each unit was also determined by moving the probe over the surface of the unit as shown in figure A-2 and observing the maximum indication. These values are listed in column 3 of table 1.

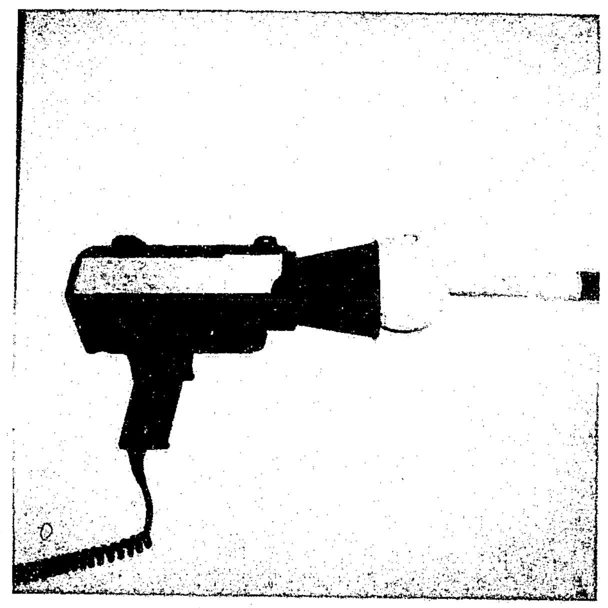

FIGURE A-1. *Measurement of main-beam field strength level in the aperture region.*

This table contains results of measurements of field intensities produced by the various radar units inside an automobile. The radar code numbers are given in the first column, with the K-Band units (24.15 GHz) designated by K-1 to K-7 and the X-Band units (10.525 GHz) by X-1 to X-15. Column 2 gives the field strength level in the aperture, and column 3 the maximum field strength in the back hemisphere. The mounting positions of column 4 correspond to the numbered positions of figure A-3 as described in the text. The interior vehicular data are given in columns 5 to 8. Blank entries in these columns mean that the field intensities were too low to read with the meters used for these tests; i.e., the fields were <6 V/m for K-Band and <2 V/m for X-Band.

TABLE 1. *Results of radar field strength measurements.*

Radar code number	Aperture field strength levels (V/m)	Maximum back-lobe field strength levels (V/m)	Radar mounting position	Maximum field strength levels at positions A, B, C, and D of figure A-3 (V/m)			
				A	B	C	D
K-1	86	<6	5				
			8				
K-2	95	9	1				
			2				
			5				
			5R[a]	6	6		
			8				
K-3	92	<6	1				
			2				
			5				
K-4	83	<6	1				
			2				
			5				
K-5	31	<6	1				
			2				
			5				
			5R[a]				
K-6	102	9	1				
			2				
			5				
K-7	79	<6	1				
			2				
			5				
X-1	46	<2	1	2			
			2				
			3	23	2	3	3
			4		2		
X-2	52	2	1	2	2		
			2				
			3	37	3	2	2
			4		3		
X-3	103	8	1	3	3		2
			2	2	9	2	2
			5	3	2	2	
X-4	98	8	1	3	2		2
			2	2	3	2	2
			5	2	2		2
X-5	37	2	1				
			2				
			5				
X-6	67	3	1				
			2				
			5				
			6		2		
			7				

TABLE 1. *Results of radar field strength measurements. (Continued)*

Radar code number	Aperture field strength levels (V/m)	Maximum back-lobe field strength levels (V/m)	Radar mounting position	Maximum field strength levels at positions A, B, C, and D of figure A-3 (V/m)			
				A	B	C	D
X-7	64	4	1	2			
			7	3	2		
			2				
			6	2	3		
			5		2	2	
X-8	58	3	1				
			7				
			2				
			6				
			5				
X-9	60	4	1	2			
			7				
			2				
			6				
			5				
			5R[a]				
X-10	81	5	1	2			
			7				
			2				
			6				
			5	2			
X-11	42	2	1				
			7	2			
			2		2		
			6				
			5				
X-12	47	4	5				
X-13	59	3	1				
			2				
			5				
			6				
			7				
X-14	42	2	1				
			2				
			5				
			6				
			7				
X-15	93	8	1				
			2				
			5				
			6		3		
			7	3			

[a] Same location as radar mounting position 5 except that the radar is pointed toward the rear of the vehicle.

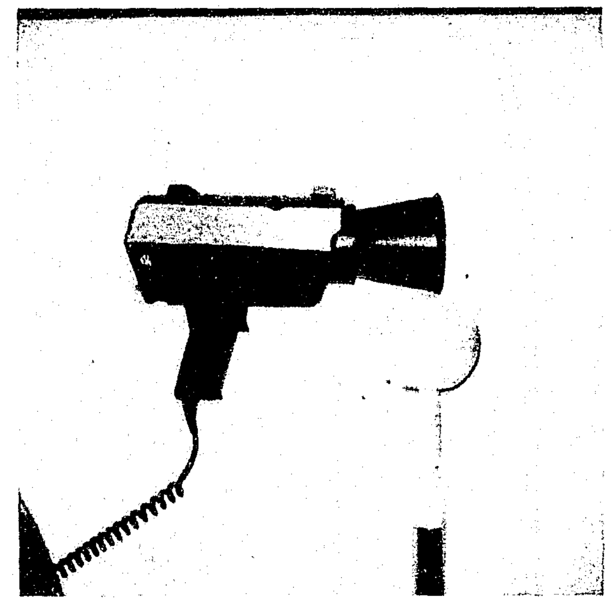

FIGURE A-2. *Measurement of field strength in the side- and back-lobe regions.*

Following the above tests, the radars were mounted in, on, or hand-held in a four-door sedan in the various operating positions indicated by the numbers in figure A-3. In positions 1 and 2, the radars were hand-held and aimed through the windshield. Position 5 is the common dashboard mount with the radar aimed forward, and 5R is the same arrangement with the radar aimed to the rear through the back window. In positions 6 and 7, the radars were hand-held and aimed out the left and right front side windows, respectively. For position 3, the radar was attached to the inside of the right rear window and aimed forward through the windshield while, in position 4, the radar was attached outside the left rear window and aimed forward. In position 8, the radar was aimed to the rear through the back window. Each radar unit was mounted in each of the positions in which it was designed to operate, as indicated in column 4 of table 1. With the radar in each position, the appropriate probe was used to survey the field intensity throughout the interior of the automobile, paying particular attention to the regions usually occupied by the driver and three passengers (locations A through D of fig. A-3). No individuals were actually inside the vehicle when these measurements were made.

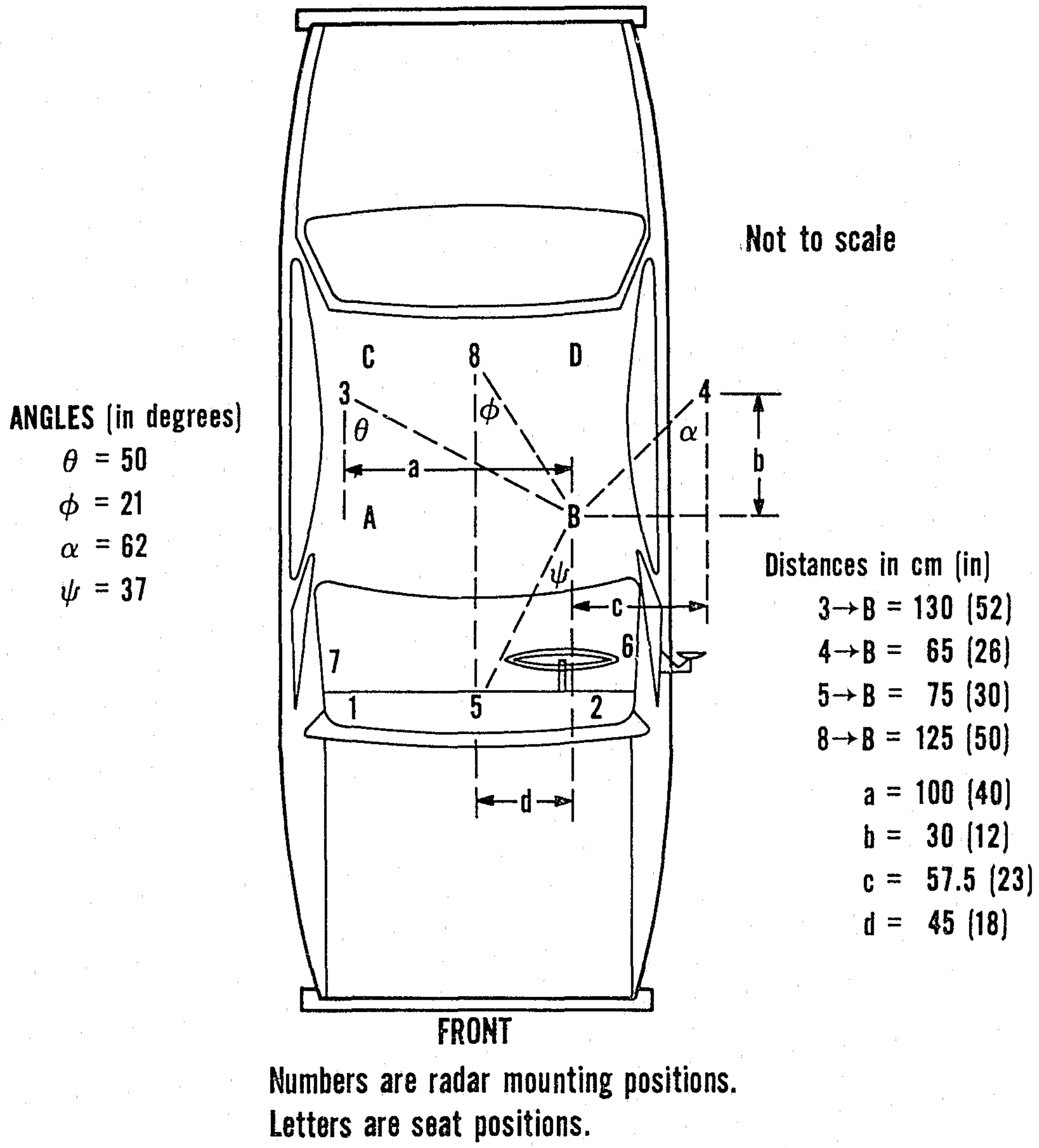

FIGURE A-3. *Diagram showing the location of radar mounting positions (1-8), seat locations (A-D), and distances between selected radar positions and seat locations used in describing field intensity distributions inside the automobile.*

Measurement Results

During the speed measuring radar device testing, the values of field strength measured at the aperture of individual radar devices varied between 31 and 103 V/m, while the values measured in the back-lobe region varied between the minimum detectable level and a maximum of 9 V/m. As noted previously, these results are given in columns 2 and 3 of table 1.

The maximum field strengths observed in the general regions occupied by the driver and three passengers are given in table 1, columns 5–8. These recorded values represent the maximum levels observed, that is, there were no values of higher radiation intensity in locations other than those whose field strength levels are listed in table 1.

The values measured at the location of the heads of the driver and passengers never exceeded 37 V/m. Excluding the situation where the radar device was attached to the inside rear window (mounting position 3), the field strengths measured at the driver and passenger locations were always below 6 V/m (K-band) or 3 V/m (X-band). Even with the radar device located in mounting position 3, the field intensity recorded at the driver location is only 2 or 3 V/m.

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