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Presented at the International Conference on Communications Boston, MA, June 11, 1979. Published in ICC '79 Conference Record, Vol. 2, paper 31.4. IEEE Publication No. 79CH1435-7, New York, 1979.

RADIOFREQUENCY ENVIRONMENTS IN THE UNITED STATES

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David E. Janes, Jr.

U.S. Environmental Protection Agency

DAVE JANES
U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS
Electromagnetic Radiation Analysis Branch
9100 Brookville Road, Silver Spring, Md. 20910
301—427-7604

ABSTRACT

As part of a program to determine the need for guidelines to control environmental levels of radiofrequency radiation (3 kHz-300 GHz), the Environmental Protection Agency began measuring levels in urban areas in October 1975. Data on environmental levels in the frequency range 0.5-900 MHz have been obtained for 15 urban areas. This paper summarizes the results of these measurements in the *general environment* and gives comparative data from other studies on levels near *specific sources* such as broadcast antennas, radars, walkie-talkies, medical diathermy units, and radiofrequency heat sealers.

INTRODUCTION

The entire population is exposed to radio waves, including microwaves, from a variety of sources. Examples include: radio and television broadcast systems, radars, radio telephones, citizen band radio, microwave relay links, medical diathermy units, heat sealers, and microwave ovens.

It is convenient to define two kinds of exposure. One occurs at distances far from individual sources, and the exposure is due to the superposition of the fields from many sources operating at different frequencies; we will call this the *general radiofrequency environment*. The other kind of exposure occurs so close to a

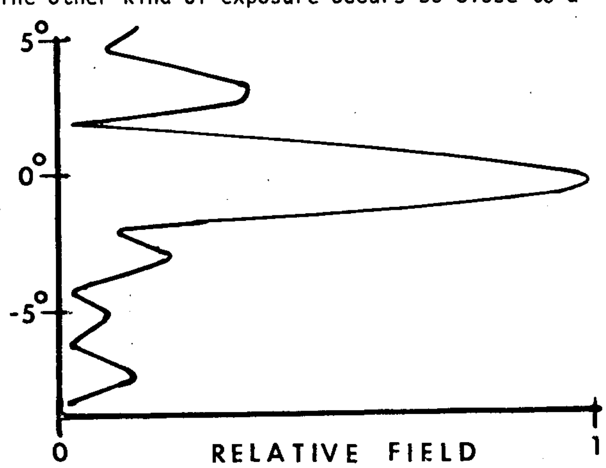

Fig. 1. Vertical Radiation Pattern for a UHF-TV Transmitting Antenna (Degrees above and below the horizontal plane)

source that the radiofrequency environment is dominated by the source (or sources) at that location; we will call this the *specific source environment*.

The commonly used quantity for specifying exposure to radio waves is power density, i.e., watts per square meter (W/m^2). For historical reasons exposure is often expressed in terms of milliwatts (mW) or microwatts (μW) per square centimeter (cm^2), i.e., 1 W/m^2 = 0.1 mW/cm^2 = 100 $\mu W/cm^2$.

GENERAL RADIOFREQUENCY ENVIRONMENTS

Broadcast Sources. The *general radiofrequency environment* is dominated by radio and television broadcast transmissions [1-5]. Based on measurements made at 486 different locations in 15 cities with a 1970 population of over 44 million, the median exposure in urban areas of the U.S. is 0.005 $\mu W/cm^2$ i.e., 50 percent of the population is exposed to higher and 50 percent is exposed to lower levels. The results of these studies, shown in Tables 1 and 2, indicate that 95 percent of the population is exposed to levels that are less than 0.1 $\mu W/cm^2$. These estimates do not include contributions from AM radio transmission because the absorption of energy by humans at AM frequencies (0.535-1.605 MHz) is orders of magnitude less than at FM and TV frequencies (54-890 MHz) [6]. These estimates do not include refinements such as accounting for population mobility, for exposures at heights greater than 6 meters (20 ft.), for building attenuation, or for periods of time when sources are not transmitting. The results are based on

Table 1. Cumulative Population Exposure for 15 U.S. Cities (54-900 MHz)

Power Density ($\mu W/cm^2$)	Cumulative Percent* of Population
0.002	19.5
0.005	49.5
0.01	68.7
0.02	82.4
0.05	91.4
0.1	94.7
0.2	97.
0.5	98.8
1.0	99.4

* For example, 19.5% are exposed to levels less than 0.002 $\mu W/cm^2$, 68.7% are exposed to levels less than 0.01 $\mu W/cm^2$, etc.

Table 2. Population Exposure in 15 U.S. Cities (54-900 MHz)

City	Median Exposure (μW/cm²)	Percent Exposed ≤1 μW/cm²
Boston	0.018	98.50
Atlanta	0.016	99.20
Miami	0.0070	98.20
Philadelphia	0.0070	99.87
New York	0.0022	99.60
Chicago	0.0020	99.60
Washington	0.009	97.20
Las Vegas	0.012	99.10
San Diego	0.010	99.85
Portland	0.020	99.70
Houston	0.011	99.99
Los Angeles	0.0048	99.90
Denver	0.0074	99.85
Seattle	0.0071	99.81
San Francisco	0.002	97.66
All Cities	0.0048	99.44

the population that resides in areas more than several hundred feet from FM and TV broadcast antennas where an unobstructed measurement 6 meters above ground would result in the indicated values [4].

Other Sources. For a number of reasons both low- and high-power sources that operate outside of the broadcast frequency bands do not contribute very much to the *general radiofrequency environment*, although the contribution of the higher powered devices to *specific source environments* may be large. Examples of low-power devices include: microwave relay links, personal radios such as radio telephones and citizens band, and the traffic radars used by law enforcement agencies for measuring the speed of vehicles. Examples of high-power sources include: satellite communications systems, military acquisition and tracking radars, and civilian air traffic control, air route surveillance, and weather radars. Because all of the above mentioned high-power systems use highly directive antennas, their beams have small cross-sections, and only a small volume of space is irradiated at any instant of time. For many of the systems the antenna is high above ground or is angled 2 to 3 degrees above the horizon thereby making exposure to the main beam improbable. Most radar systems rotate which further reduces the average exposure. The contribution of radars to the *general radiofrequency environment* in one large urban area is summarized in Table 3 [7]. The largest value of the power density, 0.001 μW/cm², is less than the median value for the broadcast frequency bands.

Table 3. Typical Urban Radar Environments in San Francisco, CA

Location	No. of Radars Detected	Average Power Density (μW/cm²)
Mt. Diablo	8	2.6×10^{-5}
Palo Alto	10	2.7×10^{-4}
Bernal Heights	10	1.1×10^{-3}

SPECIFIC SOURCE RADIOFREQUENCY ENVIRONMENTS

Broadcast Sources. The antennas used for VHF- and UHF-TV broadcasting are highly directive as illustrated in Fig. 1. With antenna patterns such as this, levels at high elevations close to the source can be considerably greater than those found at ground level [8]. Measurements have been made in tall buildings that either support broadcast antennas or are within a city block or so of another tall building that supports a broadcast antenna and the results are summarized in Table 4 [9-10]. The values range from less than 1 μW/cm² to 97 μW/cm² inside buildings to 230 μW/cm² at an unshielded location on the roof of one building. Note that two things are required to obtain these higher levels, high elevation and close proximity (a few hundred ft. or less) to an antenna of a high-power source. The upper floors of tall buildings located far from broadcast antennas are not exposed to levels that differ significantly (factors of 10) from those found near the ground at equivalent distances.

Power densities near the bases of FM towers are typically 1 to 10 μW/cm² [Fig. 9 in Ref. 4]. However, some FM antennas have a grating lobe that is coaxial with the tower in addition to the main lobe illustrated for a TV antenna in Fig. 1 [11]. Fields of 100 to 350 μW/cm² have

Table 4. Radiofrequency Levels in Tall Buildings That Are Located Close to FM and TV Antennas

Location	Power Density (μW/cm²)		
	FM	TV	TOTAL
EMPIRE STATE BUILDING (1)			
86th Floor Observatory	15.2		
102nd Floor Observatory			
Near Window	30.7	1.79	32.5
Near Elevator	1.35		
WORLD TRADE CENTER (1)			
107th Floor Observatory	0.10	1.10	1.20
Roof Observatory	0.15	7.18	7.33
PAN AM BUILDING (1)			
54th Floor	3.76	6.52	10.3
ONE BISCAYNE TOWER (2)			
26th Floor	7		
30th Floor	5		
34th Floor	62		
38th Floor	97		
Roof (shielded area)	134		
Roof	148		
SEARS BUILDING (3)			
50th Floor	32	34	66
Roof	201	29	230
FEDERAL BUILDING (3)			
39th Floor	5.7	.73	6.5
HOME TOWER (4)			
10th Floor	18		
17th Floor	0.2		
Roof	119		
Roof	180		
MILAM BUILDING (5)			
47th Floor	35.8	31.6	67

(1) New York (2) Miami (3) Chicago (4) San Diego (5) Houston

been measured in areas that are accessible to transient foot traffic [12]. These levels fall off rapidly with distance from the antenna tower, but levels near a few residences may range from 50 to 100 $\mu W/cm^2$. In a single unusual case, fields near the base of an FM antenna tower ranged between 1000-7000 $\mu W/cm^2$; exposures in open areas, i.e., not close to conducting structures did not exceed 2000 $\mu W/cm^2$ [13].

Low-Power Sources. For purposes of discussion it is convenient to distinguish between low- and high-power source contributions to the *specific environment*. The distinction is somewhat arbitrary and contains some implicit assumptions on how devices are used and controlled. The four types of low-power sources that will be discussed here are microwave relay links, low-power radar, mobile communications equipment, i.e., radio telephones, citizens band radios, hand-held walkie-talkies, etc., and microwave ovens for home use. The high-power sources remaining to be discussed are: satellite communications, radar, industrial, and diathermy sources.

Microwave relay links used for long distance communications have transmitter powers that usually are 5 watts or less. The maximum power density is calculated to be about 700 $\mu W/cm^2$; except for service personnel these fields do not occur in accessible locations. Maximum values at ground level are calculated to be less than 1 $\mu W/cm^2$ [14].

The radars used for measuring the speed of vehicles have transmiter powers of about 100 milliwatts (0.1 watts). These devices are either hand-held or vehicle mounted. They are continuous wave rather than pulse modulated and determine speed from the Doppler frequency shift of the returned signal. The maximum calculated power density for typical devices ranges from 170 to 400 $\mu W/cm^2$ at the face of the device and decreases to less than 24 $\mu W/cm^2$ and 0.2 $\mu W/cm^2$ at distances of 3 meters and 30 meters, respectively [15].

Two other low-power radars that are in common use are weather radar in aircraft and navigational radar on small boats. Normally, aircraft radar are not operated on the ground. When they are, power densities for a number of radar-aircraft combinations were less than 10,000 $\mu W/cm^2$ everywhere except directly on the surface of the radome housing one system [16]. Values were less than 1,000 $\mu W/cm^2$ at distances greater than 3.5 meters (11.5 feet) for all 5 systems studied [16]. For marine radars the computed average power density for any of the 6 units that were studied is less than 50 $\mu W/cm^2$ at the antenna's turning circle radius [17]. One of the units has an option for sector scanning, and when operated in this mode the maximum power density was about 250 $\mu W/cm^2$ [17].

Most of the information for the *specific source environments* produced by personal radio devices is for systems mounted on vehicles or for hand-held walkie-talkies. Interpretation of this data is difficult because most of the measurements are made in the near-field and these fields are not uniform over volumes comparable to the size of humans. The absorption patterns for these complex near-fields may differ appreciably from those produced by far-field whole body exposures; the absorption may be higher or lower and the sites of maximum absorption may be different.

Some values for fields in and around vehicles equipped with radios are presented in Table 5. The values range from a few volts per meter to 1,350 volts per meter [18-21]. Except for Ref. 19, only electric fields have been measured. To obtain power density, the magnetic fields also must be known since the impedance of these fields is not, in general, 120π Ohms, the free space impedance for a plane wave. Some authors have defined an "equivalent" free field power density by assuming the impedance value for free space and calculating the power density, S, according to the equations,

$$S(W/m^2) = E^2(V/m)^2/120\pi(\Omega) \quad (1)$$
$$= 120\pi(\Omega)H^2(A/m)^2 \quad (2)$$

However, when used in this manner "equivalent" does not necessarily mean an equivalent heating power density. If one ignores this complication and performs the calculation, then the 2 to 1,350 V/m range corresponds to an "equivalent" power density range of 1 $\mu W/cm^2$ to 483 mW/cm^2.

Only minimal data is available for the fields produced by hand-held walkie-talkies. In one study electric fields 12 cm from a 2.5 Watt hand-held unit operating at 27.12 MHz were

Table 5. Electric Field Strength In and Around Radio Equipped Vehicles

Frequency (MHz)	Power (watts)	Veh. Type	Field (V/m)	Dist. (m)	Ref.
27.075	4	Sedan	2-7	1	[18]
27.12	4	Sedan	225-1350	0.05	[19]
27.12	4	Sedan	100-610	0.13	[19]
27.12	4	Sedan	21-60	0.6	[19]
27.61	80[a]	Sedan	21-251[b]	(c)	[20]
40.27	110	Sedan	10-190	(c)	[20]
40.27	110	Sedan	75-368[b]	(c)	[20]
40.27	110	Semi	5-475	(c)	[20]
41.31	100	Comp.	5-106[d]	(c)	[21]
41.31	100	Pickup	7-165[d]	(c)	[21]
162.475	110	Sedan	8-201	(c)	[20]
164.45	60	Sedan	5-52[d]	(c)	[21]
164.45	60	S.Wag.	5-64[d]	(c)	[21]
164.45	60	Van	5-95[d]	(c)	[21]

a. Power level used with special authorization of the Interagency Radio Advisory Committee; legal power is 4 watts.
b. Vehicle was placed on a ground plane.
c. See cited reference for antenna type and location.
d. Calculated from the reported electric energy density, U_E, given in the original report from the equation $U_E(nJ/m^3) = 0.0043E^2(V^2/m^2)$.

measured to be as much as 205 V/m, which has an "equivalent" power density of 11 mW/cm^2 [22]. The measured magnetic field was 0.9 A/m which from equation (2) is "equivalent" to 31 mW/cm^2 [21]. Similar values are given for a 4 Watt transmitter [19]. Maximum fields of 200 nJ/m^3 (212 V/m or 11.9 mW/cm^2 "equivalent") have been measured for a 1.8 Watt hand-held unit operating at 164.45 MHz [21]. The measured exposure diminishes by a factor of 10 at distances of 1 or 2 inches from the site of maximum exposure [21].

In the earlier discussion it was noted that the complex near-fields were not well characterized by power density and predictions of thermal impact could not be directly extrapolated from far-field whole body exposures. One study using dielectric phantom models of human heads predicts temperature increases of less than 0.1°C in the region of the eye for a 6 Watt, 150 MHz hand-held unit whose antenna was positioned 0.5 cm from the eye [23]. These techniques have also been extended to higher frequencies [22-25].

Microwave ovens can be considered as low power devices if they meet the performance standard of the Food and Drug Administration which specifies that under standard test conditions, the oven when new, may not leak more than 1000 $\mu W/cm^2$ at any point 5 cm from the oven [26]. This performance may degrade to 5000 $\mu W/cm^2$ over the lifetime of the oven. Simple inverse square calculations show that an oven leaking 5000 $\mu W/cm^2$ at 5 cm will produce levels of about 4 $\mu W/cm^2$ at six feet and 1 $\mu W/cm^2$ at ten feet.

Satellite Communications and Radar Systems. Satellite communications systems are continuous wave sources and radars are usually pulse modulated. A study done by the Electromagnetic Compatibility Analysis Center in 1972 identified 223 continuous wave sources with effective radiated powers greater than 1 megawatt and 375 pulsed sources with *peak* effective radiated powers of 10 gigawatts or greater [27]. The power density in the main beam of these systems can be greater than 10 mW/cm^2 [28,29]. However, as discussed above, the probability of being irradiated by the *main* beam of one of these sources is quite small. Persons who live or work near high power sources, e.g., near airports or military bases, may be exposed to sidelobe or secondary radiation from systems having stationary or slowly moving antennas as well as from many types of radars with rapidly moving antennas. Calculated exposures fall into the range of 10 to 100 $\mu W/cm^2$ at distances up to one-half mile from some of these systems [30]. The motion of the antennas of acquisition radars reduces the time-averaged power density from these systems. For high-power radars, a combination of mitigating factors, i.e., beam motion and antenna elevation angle, make it unlikely that power densities will exceed 50 $\mu W/cm^2$ at distances greater than one-half mile, at least in locations that are accessible to people [29].

Diathermy Units. Both efficiency and leakage of microwave diathermy applicators have been the subjects of recent studies [31,32]. The leakage results are summarized in Table 6 [32]. The measurements were made 5 cm from the interface between the tissue equivalent phantom and the applicator. Under test conditions, conventional applicators had leakage fields 2 to about 9 times the allowable leakage for microwave ovens. Leakage is considerably lower when using one type of contact applicator under the same test conditions.

Table 6. Leakage from Diathermy Applicators[a]

Applicator Type	Leakage (mW/cm^2) Nominal[b]	Maximum[c]
Burdick "B"	10.4	35.5
Burdick "E"	19.0	44.0
Transco[d]	-	0.2

a. Determined using a planar phantom of muscle equivalent material with a 1 cm simulated fat layer.

b. Determined using net power recommended by manufacturer for lower back treatments, 45 and 70 Watts net power for types "B" and "E", respectively.

c. Extrapolated for "effective treatment" conditions as defined by Lehmann et al. [33], i.e., an absorption rate of 235 W/kg.

d. Contact applicator.

Industrial Radio Frequency Sources. High-powered sources are used extensively in industry for heating and drying. The data presented in Table 7 is taken from a study of two synthetic fiber dryers used in the textile industry, an edge gluer from the lumber industry and seven heat sealers used in the plastics industry. The results in Table 7 are presented in terms of field strength and may be expressed in "equivalent" power density using equations 1 or 2 above as appropriate. The cautions in interpreting this "equivalent" power density that were discussed earlier must also be observed here.

Table 7. Electric and Magnetic Fields at Operator Positions near Industrial Radio Frequency Sources. (Selected maximum values from Reference 34).

Source	Power (kw)	Freq. (MHz)	Field Strength[a] Electric (V/m)	Magnetic (A/m)
Fiber Dryer	20	41	319	13.2
Glue Dryer	20	27	221	1.0
Heat Sealer	10	15	831	.5
Heat Sealer	2	22	493	12.1
Heat Sealer	4	30	973	.4

a. Average of two values given in [34].

SUMMARY AND CONCLUSIONS

The low-levels in the *general radiofrequency environment* are dominated by radio and television transmissions. Microwave relay links, low-power radars, mobile communications systems, microwave ovens, etc. make almost negligible contributions. Most of the population (99%) is exposed to levels less than 1 μW/cm². The largest radar field measured in the *general environment* of one urban area was less than the median value for the broadcast band.

The *specific source environment* for most broadcast sources is well below 100 μW/cm². The only fields in excess of this value occur in the immediate vicinity of a few FM antenna towers and on the roofs of tall buildings that are located within a city block or so of FM and TV broadcast antennas. When considering other high-power sources such as radars and satellite communications systems, the potential for exposure of persons to obviously high levels of radiation is small.

Leakage from medical diathermy units can exceed 40 mW/cm² and fields in the vicinity of some industrial sources can exceed 10 mW/cm² in "equivalent" power density. Of the low-power sources, only portable communications equipment produces fields that, at least on cursory examination, appear high, but tissue temperature elevation should not exceed 0.1°C. The interpretation of these "equivalent" power densities is difficult and the difficulty is confounded by partial body exposure and intermittent operation.

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