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An Analysis of Radar Exposure in the San Francisco Area

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AN ANALYSIS OF RADAR EXPOSURE IN THE SAN FRANCISCO AREA

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PREFACE

The Office of Radiation Programs of the U.S. Environmental Protection Agency carries out a national program designed to evaluate population exposure to ionizing and nonionizing radiation, and to promote development of controls necessary to protect the public health and safety. This report describes an analysis of radar measurements performed and reported on by the Institute for Telecommunications, Department of Commerce. This analysis addresses the microwave exposure aspects of radars to the general populace. Readers of this report are encouraged to inform the Office of Radiation Programs of any omissions or errors. Comments or requests for further information are also invited.

Floyd L. Galpin, Director
Environmental Analysis Division
Office of Radiation Programs

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The author would also like to extend his grateful appreciation to Mr. Bob Mathison, Radio Spectrum Occupancy Group Leader, Institute for Telecommunications Sciences, Office of Telecommunications, Boulder, Colorado for his cooperation and assistance in interpretation of data contained in the San Francisco area radar report.

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AN ANALYSIS OF RADAR EXPOSURE IN THE SAN FRANCISCO AREA

Introduction and Description of Data Base

The Institute for Telecommunications Sciences (ITS), Department of Commerce, Boulder, Colorado conducts a program of determining spectrum usage in the major radar bands in various metropolitan areas. This analysis is based on measurement data contained within the ITS report on San Francisco area measurements, OT/ITS Control Number 05150 (1). The data was taken during the period June-August 1975 and includes measurements in the 1030 radar beacon band (interrogators), and the 1215-1400 MHz, 2700-3700 MHz, 5250-5925 MHz, and 8500-10,500 MHz radar bands. The intention of this report is to assess exposure intensities from the radars observed and reported on in the ITS report. The ITS report format indicates only the signal power delivered to the receiver (in actuality, the power delivered by the receiving antenna to the transmission line connecting the antenna to the receiver). Thus, it was necessary to obtain from ITS information on antenna apertures as a function of frequency to allow correction of the reported data and consequent interpretation of absolute field intensities. For the purpose of this report all field intensities are defined in terms of power densities.

Antenna Corrections and Procedures

Graphs were provided by ITS showing antenna aperture vs. frequency for the different antenna systems employed during the radar measurements. The two principal antenna systems used consisted of cavity backed spirals (CBS) and a 1 meter diameter steerable parabolic dish. The CBS antenna system was composed of 4 pairs of CBS antennas, one right hand circularily polarized and the other left hand circularily polarized, each pair oriented in one of four quandrants, north, east, south, and west. Each CBS antenna has a 3 dB beam width of 70-90 degrees which assures that signals from any direction will be detected with essentially uniform gain. In practice, spectral measurements were made with the antennas looking at each quadrant to ensure capture of the radar signals arriving from any direction.

For each of the major radar bands, the aperture of the ASN-116A CBS antenna was determined from the ITS information and a single value was identified as being appropriate for use throughout the given band. Table 1 shows the aperture values as used for the analysis in this report. Total variation of aperture across any of the four bands is no greater than approximately 1 dB.

The steerable 1 meter diameter dish exhibits a nearly constant aperture across the entire 1-10.5 GHz band of 10.5 dB>1 m^2. The aperture of this antenna varies only from -10.0 dB>1 m^2 at 1 GHz to -11.2 dB>1 m^2 at

Table 1. ANTENNA APERTURE CALIBRATION FOR ASN-116A CAVITY BACKED SPIRAL
LINEAR POLARIZATION

FREQ. BAND (MHz)	APERTURE (dB>1 m^2)	APERTURE (dB>1 cm^2)	APERTURE (cm^2)
1260-1338	-25.6	14.4∼14	27.5
2720-3062	-29.0	11.0∼11	12.6
5386-5660	-32.2	7.8∼8	6.0
8618-9450	-36.2	3.8∼4	2.4

10.5 GHz. All antenna calibration data used was for the case of linear polarization. According to ITS personnel most radars observed and reported on in their report were predominantly linearly polarized.

The data correctional procedure consisted of applying the antenna aperture to the received power as shown in the ITS data in the following manner:

$$P\ (dBm) + 3\ dB - A\ (dB>1\ cm^2) - \gamma(dB) - R\ (dB) = S\ (dBm/cm^2)$$ where

P = received power in dBm as reported by ITS

3 dB = correction factor for angle of arrival

A = antenna aperature in ($dB>1\ cm^2$)

S = exposure power density in (dBm/cm^2)

γ = transmitter duty factor (dB)

R = antenna effective duty factor due to rotation (dB)

The 3 dB correction factor is used since it was assumed that the signals detected could be due to arrival from a direction corresponding to the 3 dB point on the receiving antenna's pattern. The factor R, the antenna's effective duty factor due to rotation, was a measured parameter in many cases but for the purposes of this analysis an assumed value of -22 dB was applied to all of the data. This value corresponds closely with measured values on other antennas and is on the conservative side in that it will probably overestimate the actual averaging effect of the antenna's rotation. The value of -22 dB was arrived at by examining the statistical antenna patterns in the ITS report. In the event that the transmitter's duty cycle was not known, a value of -30 dB was used.

The procedure used in extracting measurement data from the ITS report consisted of examining each radar spectrum shown and identifying the maximum level signal observed from each radar shown, depending on which direction the radar was strongest. Three main sites were used in the San Francisco area for general radar spectrum measurements; Palo Alto, Bernal Heights, and Mt. Diablo. A relatively large number of radars were detected at each site. For this analysis, all detectable radars were used in determining exposure.

The ITS measurement system is very sensitive and revealed the presence of a relatively large number of radar signals; most of these signals were quite weak, however. The following chart shows the number of radars detected in each band at each location and subsequently used for exposure determination.

Frequency Range (MHz)	Number of Radars Detected		
	Palo Alto	Bernal Heights	Mt. Diablo
1260-1338	2	3	N/A
2729-3062	13	28	8
5386-5660	10	4	N/A
8618-9450	21	16	N/A

At the Mt. Diablo site the only band monitored was the 2700-3900 MHz band. No radars were seen above 9.5 GHz at any of the measurement sites and many of the radars seen in the 8500-9500 MHz band were aircraft weather radars from airborne aircraft transiting the general area.

Each radar measurement used in the analysis was corrected as indicated above yielding an average power density (averaged due to transmitter duty cycle and antenna rotational duty factor). On the basis of these average power densities a table was compiled showing the sources contributing most to the overall radar exposure at each of the above three sites in order of decreasing average power density.

Results:

Table 2 provides these exposure results for the Palo Alto site showing the top 10 contributors to the over all exposure. The last ranked source was 32 dB down from the top ranked source. Total exposure for the site was 2.7×10^{-4} μW/cm² or -65.7 dBm/cm². The first three sources account for greater than 99 percent of the total of 2.7×10^{-4} μW/cm². Columns are shown for S_{PK} (the peak pulse power density), Sav_{XMTR} (the average power density corrected for transmitter duty cycle), and Sav_{ANT} (the average power density corrected for both transmitter and antenna rotational duty cycles.

Table 3 provides a similar description of the over-all radar exposure at the Bernal Heights site where the total exposure from the top 10 source contributors was 1.1×10^{-3} μW/cm². At this site the first five sources account for greater than 97 per cent of the total and the 10th ranked source was 26 dB down from the highest intensity source.

Table 4 provides the exposure results for the 2700-2900 MHz radar measurements at the Mt. Diablo site. Accumulative exposure from the eight radars observed there was 2.6×10^{-5} μW/cm². In this case the first three sources account for greater than 95 per cent of the total for this band.

In addition to the general spectrum measurements made at Palo Alto, Bernal Heights, and Mt. Diablo, special measurements were made at a number

Table 2. RADAR EXPOSURE - PALO ALTO

RANKED IN ORDER OF DECREASING AVERAGE POWER DENSITY A/

Name	Freq. (MHz)	S_{PK} (dBm/cm^2)	$S_{AV_{XMTR}}$ (dBm/cm^2)	$S_{AV_{ANT}}$ (dBm/cm^2) C/	$S_{AV_{ANT}}$ (μW/cm^2)
ASR-7	2729	-17	-47	-69	1.3×10^{-4}
ASR-5	2750	-17	-47	-69	1.3×10^{-4}
FPS-107	1310	-28	-56	-78	1.6×10^{-5}
FPS-90	2738	-35	-67	-89	1.3×10^{-6}
ARSR-1E	1338	-37	-69	-91	7.9×10^{-7}
G B/	8970-9000	-40	-70	-92	6.3×10^{-7}
T	9392	-41	-72	-94	4.0×10^{-7}
I	9239	-46	-73	-95	3.2×10^{-7}
B	8673	-44	-75	-97	2.0×10^{-7}
G	5837	-44	-79	-101	7.9×10^{-8}
Total Power Density		-13.7	-43.7	-65.7	2.7×10^{-4}

A/The average power density is defined here to be the peak power density corrected for transmitter duty cycle and antenna rotational duty cycle.
B/No transmitter duty cycle information was available so a duty cycle of -30 dB was assumed.
C/ The Antenna rotational duty cycle was assumed to be -22 dB in all cases.

Table 3. RADAR EXPOSURE - BERNAL HEIGHTS

RANKED IN ORDER OF DECREASING AVERAGE POWER DENSITY[A/]

Name	Freq. (MHz)	S_{PK} (dBm/cm^2)	$S_{AV_{XMTR}}$ (dBm/cm^2)	$S_{AV_{ANT}}$ (dBm/cm^2)[C/]	$S_{AV_{ANT}}$ (μW/cm^2)
FPS-107	1260	-13	-41	-63	5.0x10^{-4}
ASR-7	2729	-13	-43	-65	3.2x10^{-4}
C	5665-5812	-13	-48	-70	1.0x10^{-4}
FPS-107	1310	-20	-48	-70	1.0x10^{-4}
I	9364	-19	-49	-71	7.9x10^{-5}
MPN-11D	2798	-30	-61	-83	5.0x10^{-6}
M	9406	-32	-62	-84	4.0x10^{-6}
ASR-5	2750	-33	-63	-85	3.2x10^{-6}
C[B/]	8930-9500	-35	-65	-87	2.0x10^{-6}
ARSR-1E	1338	-35	-67	-89	1.3x10^{-6}
Total Power Density		-7.6 (174 μW/cm^2)	-37.5 (0.18 μW/cm^2)	-59.5	1.1x10^{-3}

[A/] The average power density is defined here to be the peak power density corrected for transmitter duty cycle and antenna rotational duty cycle.

[B/] No transmitter duty cycle information was available so a duty cycle of -30 db was assumed.

[C/] The antenna rotational duty cycle was assumed to be -22 dB in all cases.

Table 4. RADAR EXPOSURE - MT. DIABLO (2700-2900 MHZ ONLY)

RANKED IN ORDER OF DECREASING AVERAGE POWER DENSITY[A/]

Name	S_{PK} (dBm/cm²)	$S_{AV_{XMTR}}$ (dBm/cm²)	$S_{AV_{ANT}}$ (dBm/cm²)[C/]	$S_{AV_{ANT}}$ (μW/cm²)
MPS-14	-24.0	-55.6	-77.6	1.7×10^{-5}
ASR-7	-30.5	-60.7	-82.7	5.4×10^{-6}
FPN-55[B/]	-35.0	-65.0	-87.0	2.0×10^{-6}
ASR-4	-38.0	-68.2	-90.2	9.5×10^{-7}
ASR-5	-42.0	-72.3	-99.3	1.2×10^{-7}
ASR-5	-48.5	-78.8	-100.8	8.3×10^{-8}
FPN-47	-49.5	-79.5	-101.5	7.1×10^{-8}
WRS-57	-52.0	-83.8	-105.8	2.6×10^{-8}
Total Power Density Density	-22.6 (5.5 μW/cm²)	-53.8 (4.2×10^{-3} μW/cm²)	-75.8	2.6×10^{-5}

A/ The average power density is defined to be the peak power density corrected for transmitter duty cycle and antenna rotational duty cycle.

B/ No transmitter duty cycle information was available so a duty cycle of -30 dB was assumed.

C/ The antenna rotational duty cycle was assumed to be -22 dB in all cases.

of other locations for the purpose of determining the characteristic emission spectra of various radars and to determine the radars transmitting antenna pattern. From these measurements, exposure values were also determined by appropriate correction procedures. In these cases, distances to the radars were determined by ITS. Table 5 presents the results of these measurements, listed in order of increasing distance from the radar being studied. This table provides information about the maximum observed power densities for various radars at distances ranging from immediately next to the radar to 147.7 km. No value greater than 2.0×10^{-5} μW/cm² for a single radar was seen regardless of the closeness to the source.

Summary and Discussion

This report has analyzed the measurements reported in the ITS San Francisco radar report in terms of resulting microwave exposure. Radar exposure, determined at the Palo Alto Site was 2.7×10^{-4} μW/cm² and at the Bernal Heights site 1.1×10^{-3} μW/cm² for the top 10 contributing sources at each location. Exposure in the 2700-2900 MHz band at the Mt. Diablo site was 2.6×10^{-5} μW/cm². These values are generally equal to or lower than commonly existing radio-frequency fields from signals in the broadcast service on the basis of past EPA measurements. Based on an analysis of EPA measurement data at 72 sites in four major east coast cities only 4 sites had total exposures (broadcast plus land mobile bands) which were as low as the maximum average radar exposure found from the ITS radar data in San Francisco. For these 72 sites a median total exposure of 0.03 μW/cm² was found. Certainly, ambient RF fields many times greater than these values are commonly found in the environment near radio and television broadcasting installations. The ITS San Francisco radar report indicates that time averaged power density levels from the observed radars are well below the present guideline for occupational microwave exposure of 10 mW/cm² (3).

An additional factor is involved with radar exposure in that if one is not close to line of sight (LOS) transmission to the radar, signal levels will be significantly reduced. It should be pointed out that the three sites mentioned above were chosen on the basis of maximizing the number of radars which would be LOS from each point. In fact, if the distance between the chosen monitoring point and the strongest radar had been shortened, the measured level may have decreased because of intervening terrain obstacles. In general, it appears that the total exposure is predominated by a few sources with other detectable radars adding very little.

If one closely approaches a radar, however, it is entirely possible that the resulting ambient field from the radar will exceed the exposure due to other types of sources, e.g., the broadcast service. Based on what is seen in these results, though not conclusive by any means, it seems as though the contention that radars are not a major perturbation of the ambient electromagnetic radiation exposure picture, on the average, is correct. On the average means at randomly picked locations in a metropolitan area.

The results of the other ITS radar reports should be analyzed to determine conformity with these conclusions.

Table 5. SUMMARY OF ALL ANTENNA PATTERN AND RADAR SPECTRA MEASUREMENTS

Name	Dist. (km)	S_{PK} (dBm/cm²)	$S_{AV_{XMTR}}$ (dBm/cm²)	$S_{AV_{ANT}}$ (dBm/cm²)[A/]	$S_{AV_{ANT}}$ (μW/cm²)[A/]
FPN-55[B/]	Next to	+ 0.5	-29.5	-51.5	7.1×10^{-3}
ASR-5	Next to	- 1.5	-31.8	-53.8	4.2×10^{-3}
MPN-11	Near	+ 0.5	-27.7	-49.7	1.1×10^{-2}
WSR-57	1.0	+ 1.5	-30.3	-57.3	5.9×10^{-3}
FPN-55[B/]	1.2	+ 5.1	-24.9	-46.9	2.0×10^{-2}
FPN-55[B/]	1.2	- 0.5	-30.5	-52.5	5.6×10^{-3}
ASR-7	12.2	-41.2	-71.4	-93.4	4.6×10^{-7}
ASR-7	14.4	-19.8	-50.1	-72.1	6.2×10^{-5}
ASR-5	14.4	-20.5	-50.8	-72.8	5.2×10^{-5}
ASR-7	17.5	-38.0	-68.2	-90.2	9.5×10^{-7}
C/	22.2	-24.8	-53.2	-75.2	3.0×10^{-5}
FPS-90	25.4	- 5.5	-37.1	-59.1	1.2×10^{-3}
ARSR-1E	27.4	-66.5	-98.0	-120.0	1.0×10^{-9}
ARSR-1E	29.2	-19.6	-51.1	-73.1	4.9×10^{-5}
ARSR-1E	29.2	-22.5	-54.0	-76.0	2.5×10^{-5}
ASR-7	33.4	-21.2	-51.4	-73.4	4.6×10^{-5}
ASR-7	36.5	-54.3	-84.5	-106.5	2.2×10^{-8}
FPS-90	38.4	-25.5	-57.1	-79.1	1.2×10^{-5}
ASR-5	48.6	-54.6	-84.9	-106.9	2.0×10^{-8}
ASR-5	50.2	-70.8	-101.1	-123.1	4.9×10^{-10}
ASR-5	50.2	-51.8	-82.1	-104.1	3.9×10^{-8}
MPN-13[B/]	68.6	-66.9	-99.9	-121.9	6.5×10^{-10}
C/	68.4	-32.7	-61.1	-83.1	4.9×10^{-6}
FPS-107	68.7	-36.5	-64.9	-86.0	2.0×10^{-6}
WSR-57	87.4	-55.7	-87.5	-109.5	1.1×10^{-8}
WSR-57	147.7	-69.9	-101.7	-123.7	4.3×10^{-10}

A/ Average power density is defined as the peak power density corrected for transmitting duty cycle and antenna rotational duty cycle. Antenna duty cycle is assumed to be -22 dB.

B/ Duty cycle of -30 dB assumed for transmitter.

C/ Unidentified source.

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16. ABSTRACT

This report provides an analysis of ambient microwave field intensities produced by radar equipment in the San Francisco area. The original data on which this report is based is contained in a report prepared by the Institute for Telecommunication Sciences (ITS), Department of Commerce, Boulder, Colorado. System characteristics were taken into account to determine actual field power densities illuminating the ITS monitoring antennas. The purpose of this analysis was to determine the extent of ambient exposure which may be attributed to radar installations in metropolitan areas. Radar exposure at the Palo Alto site was 2.7×10^{-3} mW/m^2 and at the Bernal Heights site 1.1×10^{-3} mW/m^2 for the top 10 contributing radars at each location. These values are generally equal to or lower than commonly existing radio-frequency fields from signals in the broadcast service on the basis of past EPA measurements.

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