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RF Pulse Spectral Measurements In The Vicinity Of Several Air Traffic Control Radars

U.S. ENVIRONMENTAL PROTECTION AGENCY

Office of Radiation Programs

RF PULSE SPECTRAL MEASUREMENTS IN THE VICINITY OF SEVERAL AIR TRAFFIC CONTROL RADARS

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U. S. ENVIRONMENTAL PROTECTION AGENCY
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FOREWORD

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W. A. Mills, Ph.D.
Acting Deputy Assistant Administrator
for Radiation Programs

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ABSTRACT

The purpose of this study was to determine the response characteristics of a microwave scanning spectrum analyzer in the presence of a relatively intense and complex electromagnetic environment. Measurements of ambient field intensities in the vicinity of three different ground radars used in air-traffic-control operations. Maximum peak field strengths of 960 V/m were measured about 1000 feet from the radar site. Characteristic radar spectrum signatures were recorded by photographing visual displays on the analyzer CRT.

BACKGROUND

The Office of Radiation Programs within EPA conducts an environmental nonionizing radiation program. Specific objectives of this program include: determination of requirements for environmental incident monitoring capabilities; evaluation of needs and requirements for environmental surveillance and inspection; evaluation of the needs and requirements to provide technology assessment; identification of nonionizing radiation effects research requirements; and the determination of needs, rationales, and alternatives for establishment of environmental nonionizing radiation guidelines or standards, and the effects of such guides or standards. Before environmental guides or standards can be developed the electromagnetic environment must be characterized in quantitative exposure terms. In support of these goals, the Electromagnetic Radiation Analysis Branch conducts a program of identification and investigation of radiofrequency and microwave sources whose environmental radiation fields may be potentially hazardous (1).

Ground-based, high-powered radars are a class of microwave emitting sources with potential for significant environmental exposure. Because of their pulsed nature and the rotation of the antenna, this class of source presents measurement problems which are not encountered when using the spectrum analyzer to measure the emission of continuous wave sources. Proper adjustment of spectrum analyzer controls, commensurate with the radars pulse spectrum, are required before accurate interpretation of the exposure fields are possible. To properly evaluate equipment and measurement techniques under field conditions, it is necessary to know the frequency of the source, its location, and to have control over the operation of the source. Thus the effects of rotation and other variables can be controlled and the results used to interpret real electromagnetic environments. Through the kind cooperation of the Federal Aviation Administration (FAA) we were able to conduct the field evaluations under the required conditions at the FAA Aeronautical Center, Oklahoma City, Oklahoma. The radars at this site are used for training purposes and not for air traffic control. The measurements reported in this study were made September 4-7, 1973.

OBJECTIVES

The objective of this study was to observe the response characteristics of a microwave spectrum analyzer to high level, pulsed fields with the analyzer when situated in an electromagnetically complex environment and to arrive at conclusions, based on our experience, which could be used in future measurements of this type to facilitate the data collection in the field.

No detailed attempt has been made to compare measured values of field intensity with expected values based upon calculation. Such calculations require more information than was possible to obtain at the time of this study and involve complex analytical approaches beyond the scope of this report. The reader is directed to appropriate reference material for accomplishing this additional task (2,3).

Values of measured radiation levels may be compared with existing RF exposure standards. Appendix A presents a summary of pertinent radiation standards.

FAA FACILITIES AND EQUIPMENT

One primary purpose of the FAA Aeronautical Center is training of personnel for subsequent jobs within the FAA (e.g., air traffic controllers, radar operators, and maintenance crews). In this context, the Air Navigation Facilities Training Branch currently maintains three different radars which are commonly used in daily ATC situations across the Nation. These three radars--the ASR-4B, ASR-7, and ARSR-1D--at different times of the day were made available to us for field measurements from various locations at the Center. The FAA Center, itself, is located in the southwestern part of Oklahoma City and is directly adjacent to the Oklahoma City Will Rogers World Airport. Though the Center is adjacent to the airport, the Center's radars are not used in any way for purposes of directing air traffic at Will Rogers--the airport maintaining its own radar equipment. Figure 1 is a map of the general layout for the Center with identification of the three measurement locations that were used and shows their proximity to the three radars located at the Center.

Prior to the field trip, a computer search was made of all unclassified RF sources in the vicinity of the Center. This source search, accomplished by the DOD's Electromagnetic Compatibility Analysis Center, Annapolis, Maryland (4), revealed the FAA Center to be in the midst of a very complex source environment. Forty-six sources were indicated as being within one mile of the ARSR-1D coordinates. These sources had transmitter powers between 1 W and 4 MW, and frequencies between 1.85 MHz and 2.82 GHz.

Specifications for each of the three radars measured were also obtained and these are indicated in table 1. The ARSR-1D is capable of operating at two power levels--500 kW and 4 MW--and represents the highest power radar unit in operation at the FAA Center and at most FAA airport installations across the Nation. Antennas employed with all of these radars were rectangular in shape and perforated for minimum wind loading. This perforation accounts, however, for reduced front-to-back ratios as opposed to solid reflectors. This observation is evident in data which will be presented shortly. Figures 2, 3, and 4 show the

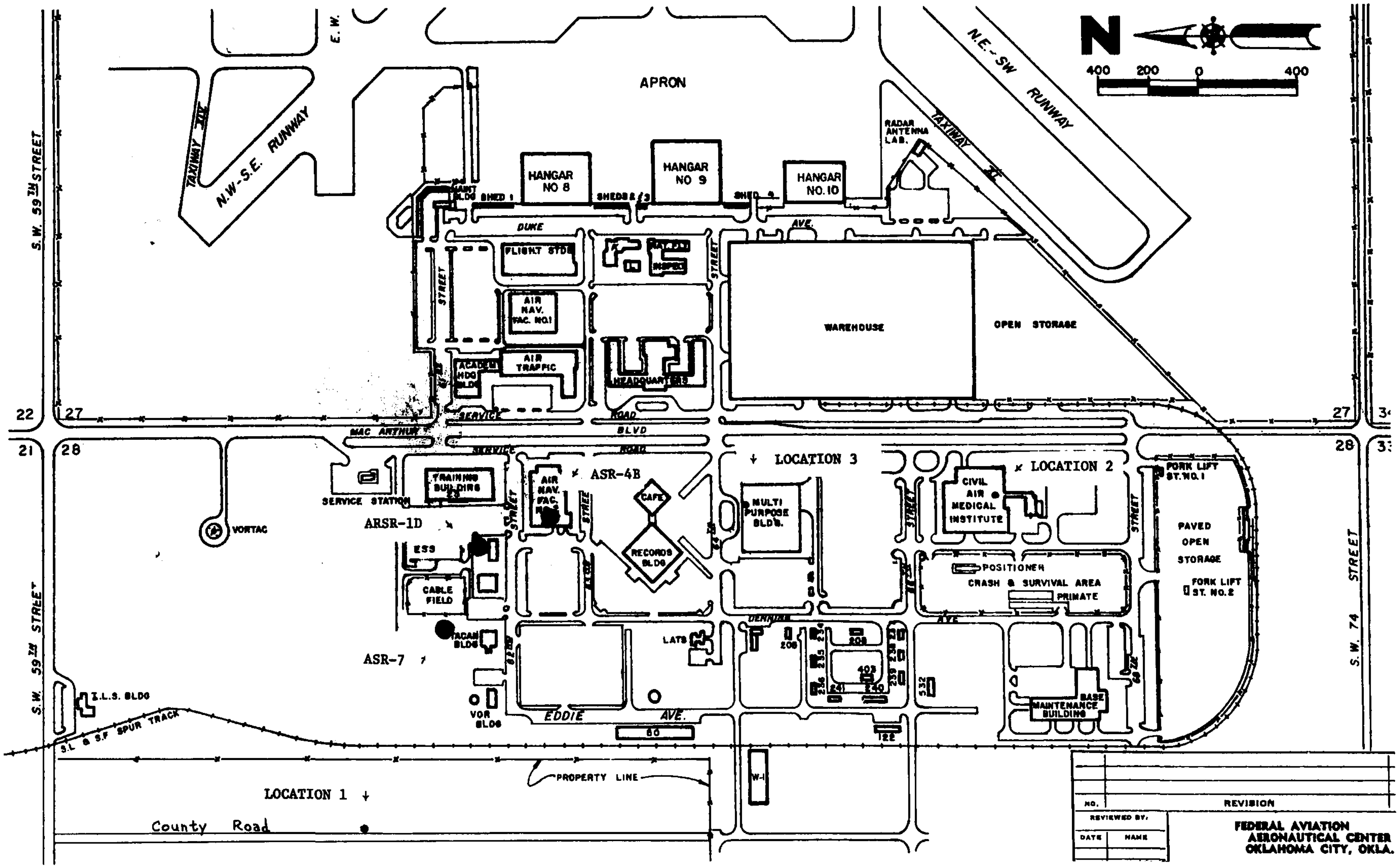

Figure 1. Map of FAA Aeronautical Center, Oklahoma City, Oklahoma, showing radar locations and measurement sites

Table 1. Specifications of radars at FAA Center

Specification	Radar Unit		
	ASR-7	ASR-4B	ARSR-1D
Frequency (MHz)	2820	2720	1335
Peak Power (kW)	425	425	500 ; 4000
Average Power (W)	336	403	360 ; 2880
Pulse Width (μsec)	0.833	0.833	2
Pulse Repetition Frequency (Hz)	950	1140	360
Duty Factor	0.00079	0.00095	0.00072
Antenna Gain (dBi)	34.0	34.0	34.2
Antenna Rotation Rate (RPM)	12.6	15	3 or 6
3dB Horizontal Beam Width (degrees)			
Pencil	1.4	1.4	1.35
CSC^2	4.9	4.9	6.2
Manufacturer	Texas Instruments	Texas Instruments	Ratheon
Antenna Height (ft.)	9.0	9.0	18.0
Antenna Width (ft.)	17.5	17.5	42.0
Height above Ground (ft.)	27	75	80

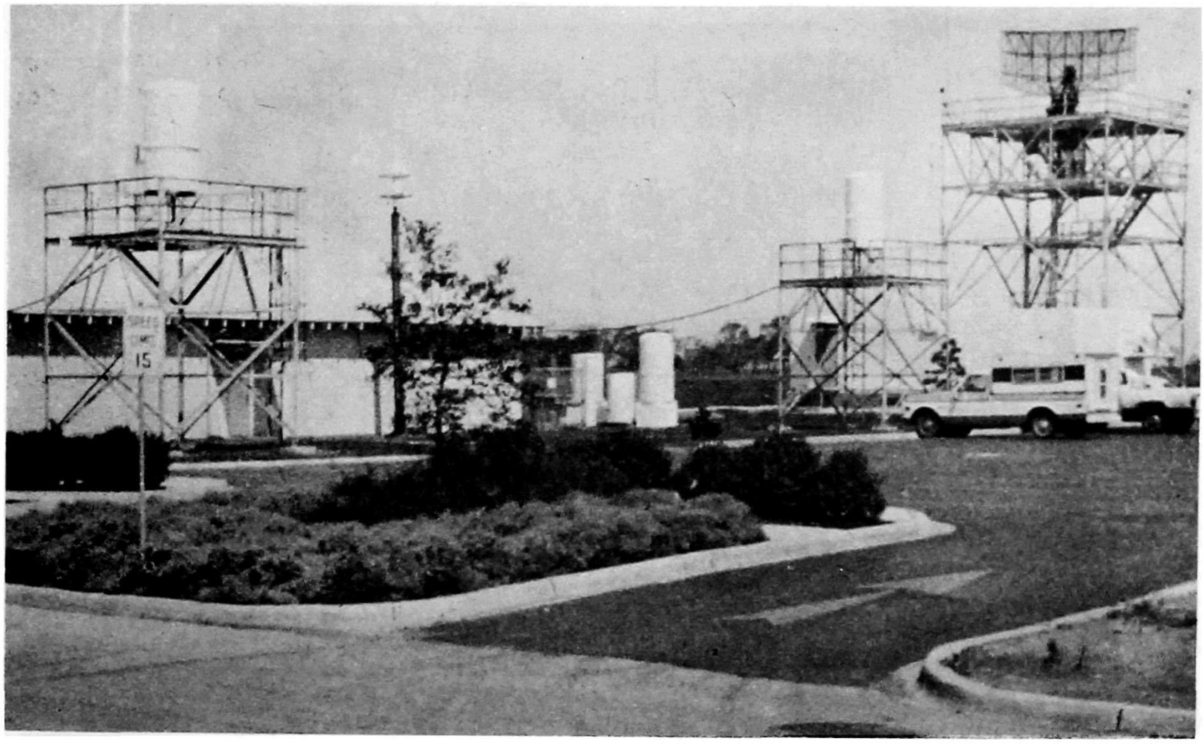

Figure 2. ASR-7 radar installation

Figure 3. ASR-4B radar installation

Figure 4. ARSR-1D radar installation

antenna-mount configurations for the ASR-7, ASR-4B, and the ARSR-1D, respectively. Individual antenna heights above ground may be found in table 1.

Measurement locations, numerically designated and shown in the map of figure 1, are described as follows in the order in which they were surveyed:

Location 1. This location was on a service road of the Center generally to the west of the transmitter site and was used for measurements from the stationary ASR-7 radar antennas. Measurements were made at ground level with the radar antenna pointed directly toward us within the accuracy of visual means. A portable electric generating unit powered the measurement instrumentation contained in the rear of a station wagon vehicle. Figure 5 depicts the general measurement layout at location 1. Figure 6 shows the ASR-7 antenna in the background (the closest radar to our location) at a distance of approximately 880 feet.

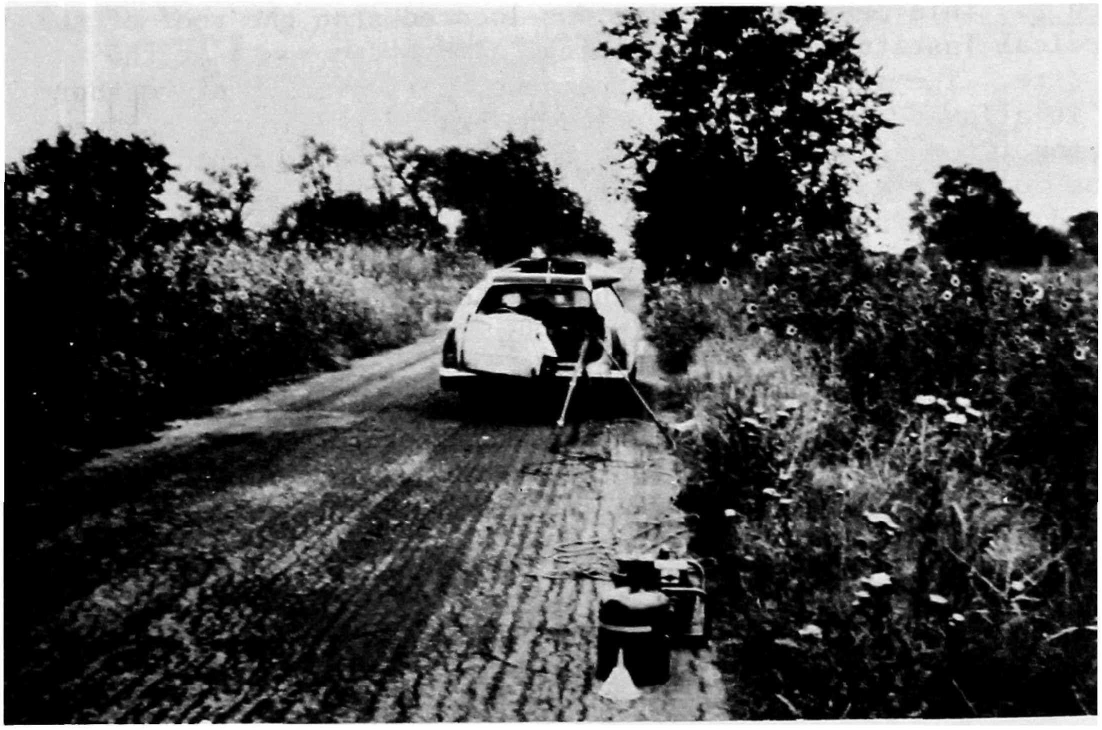

Figure 5. Measurement layout at location 1

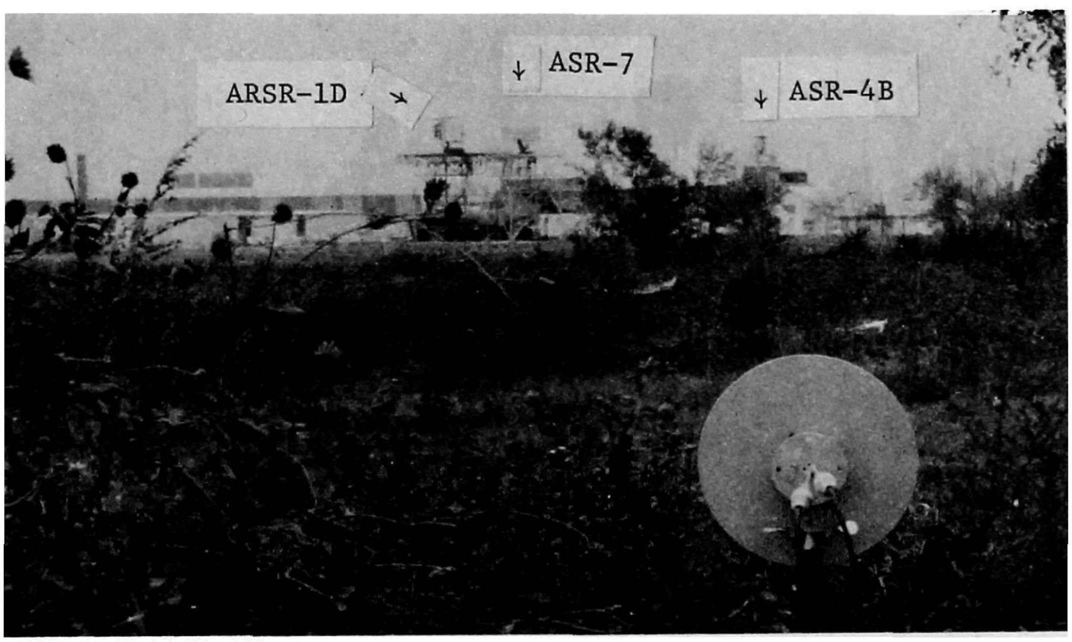

Figure 6. Three radars as viewed from location 1

Location 2. This measurement site was located atop the roof of the Civil Aeromedical Institute (CAMI) building, almost due south of the transmitter site. The site was chosen because of the inclement weather conditions; it allowed the instrumentation to be located in the hallway of the CAMI top floor (figure 7) and the reception antenna could be placed on the roof for correct alignment (figure 8). The signal cables were connected to the instrumentation via an access door in the roof and a janitor closet below, leading to the hallway (figure 9). This arrangement was convenient to carefully view the stationary ASR-4B radar antenna located atop the Air Navigation Facilities Building Number 2 approximately 1790 feet away. The receiving antenna height was approximately 45 feet as compared with the ASR-4B antenna height of 75 feet, placing us more into the radar antenna's main lobe than previously. At this position, a measurement was made of the ASR-4B front-to-back ratio by carefully rotating the antenna exactly 180 degrees from our monitoring location.

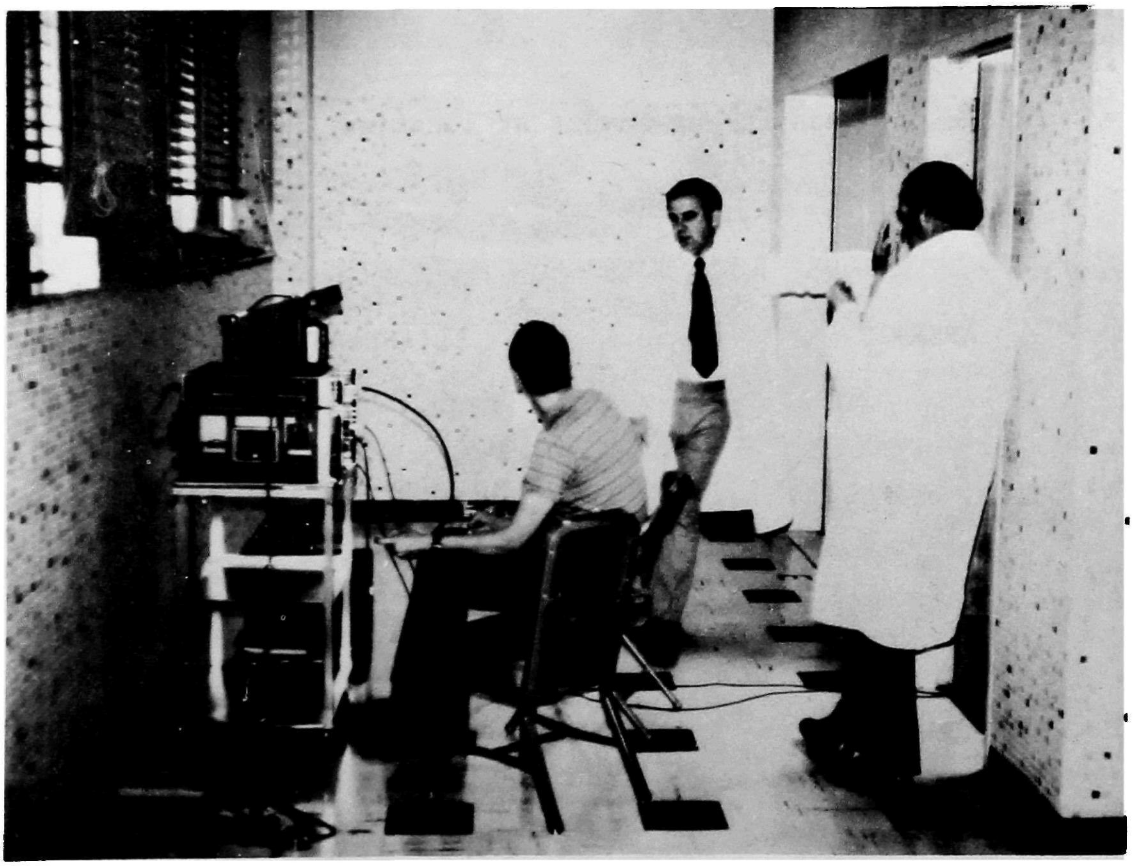

Figure 7. Equipment in hallway of CAMI top floor

Figure 8. Antenna on roof of CAMI

Figure 9. Roof access door at CAMI and signal cables

Location 3. The final measurement location consisted of three positions within the boundaries of the multiple purpose building (MPB). This building houses the FAA's extensive Oklahoma computing center. Concern over actual radar fields permeating this complex had been expressed by Data Services personnel prior to our field trip. This concern was directed toward the anticipated installation of a series of new computer terminals, with the possible consequent interference problems, in the second floor of the multiple purpose building. This area is directly in the line-of-sight to two of the three radars in daily operation and only about 750-1000 feet away, depending on the particular radar. Figure 10 shows the radar configuration as viewed from the second floor. The monitoring site elevation on the second floor was approximately 15 feet above ground as compared to the ARSR-1D antenna at 80 feet above ground. During the trip, coordination was made with the Data Services

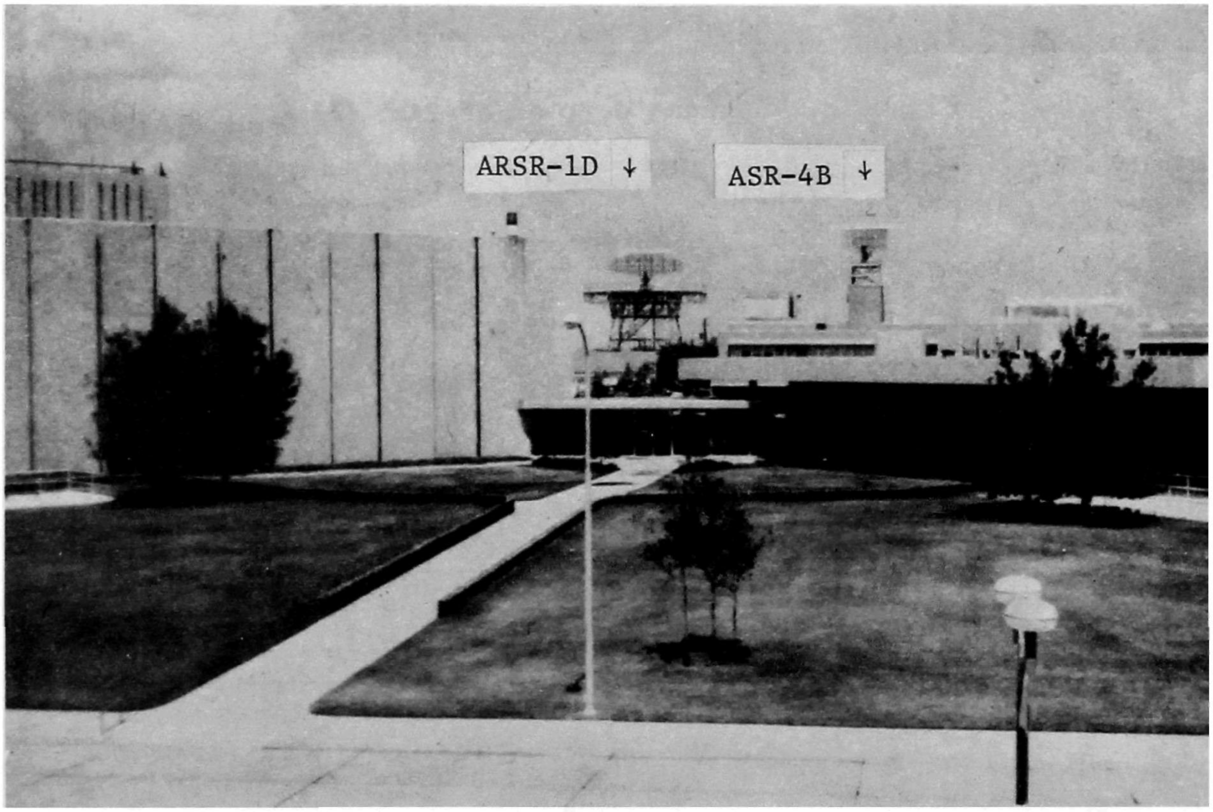

Figure 10. Radar configuration from second floor of MPB, location 3

Division, and field measurements were subsequently made in the ground floor computer operations room (see figure 11), the north ground level lobby, and the proposed terminal installation area. EMI potential to the terminals was of concern due to the existing radar installations and to the expectation of the installation of a new ARSR-3, more powerful than any the radars in current operation. Based on measurements of the presently used ARSR-1D and specifications for the new ARSR-3, it was hoped that estimates of anticipated radiated fields might be made prior to the new radar installation. A brief summary of the salient characteristics of the ARSR-3 is given in table 2. Spectral measurements in the computer room at location 3 included a look at the AM standard broadcast and the FM broadcast bands. Measurement data indicated the shielding effectiveness of the computer room itself. Figure 11 shows the vertical antenna setup for low frequency band measurements.

The field measurements made at location 3, on the second floor, represented the highest intensities found at any of the locations and, consequently, were the most interesting.

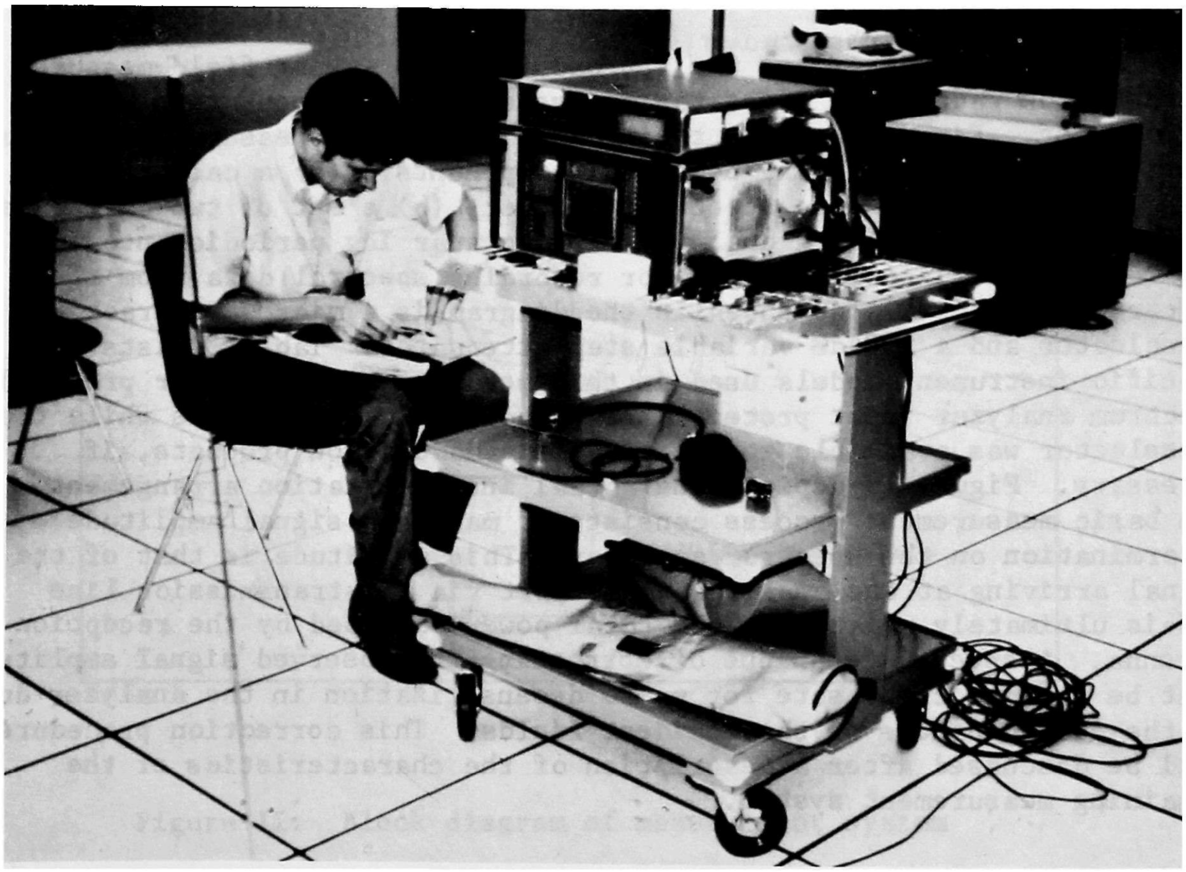

Figure 11. Measurement setup in computer room, ground floor MPB

Table 2. Salient characteristics of anticipated new ARSR-3

Approximate frequency	:	1260 MHz
Peak transmitter power	:	5 MW
Pulse width	:	2 sec
Pulse repetition frequency	:	294-389 Hz (nominally 350 Hz or more)
Antenna gain	:	34.5 dB

MEASUREMENT APPROACH

This section describes the approach used in making field measurements of the radars and gives the analysis of a representative sample measurement. Figure 12 presents in block format the measurement system consisting of the following essential components: (a) a calibrated microwave frequency range spectrum analyzer, (b) a set of two calibrated transmission lines, (c) a dual polarized planar log periodic antenna, and (d) an oscilloscopic camera for recording spectral data from the spectrum analyzer. Also shown in the diagram is a microwave tracking preselector and a 100 dB variable step attenuator. Table 3 lists specific instrument models used in this study. The attenuator provided spectrum analyzer input protection from unusually high fields while the preselector was available to minimize intermodulation products, if necessary. Figure 13 depicts the actual instrumentation arrangement. The basic measurement process consists of making a signal amplitude determination on the spectrum analyzer. This amplitude is that of the signal arriving at the analyzer input port via the transmission line and is ultimately related to the total power absorbed by the reception antenna. A special technique of correcting the observed signal amplitude must be made to compensate for pulse desensitization in the analyzer due to the pulsed nature of the incident fields. This correction procedure will be discussed after a description of the characteristics of the remaining measurement system.

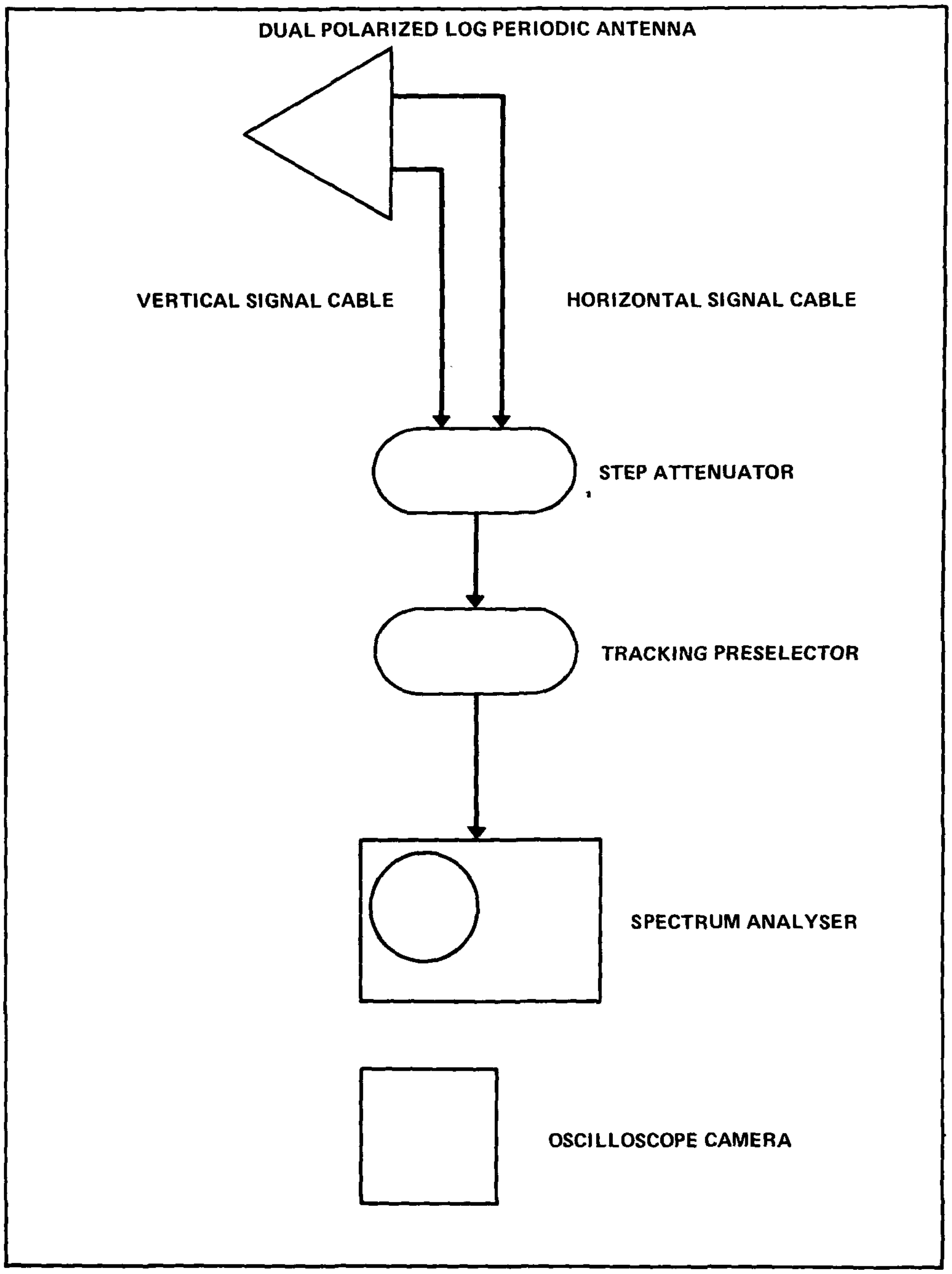

Figure 12. Block diagram of measurement system

Table 3. Measurement equipment summary

Equipment Designation	Model	Manufacturer
Spectrum analyzer:		
Variable persistence display	141T	HP
High resolution IF section	8552B	HP
RF tuning section (10 MHz-18 GHz)	8555A	HP
RF tuning section (500 kHz-1250 MHz)	8554L	HP
Tracking preselector	8445A	HP
Precision step attenuator	AE 119-99-01-01	Weinschel
Dual polarized planer log periodic antenna	APX-1293	AEL
Biconical dipole antenna	94455-1	Singer
Broadband rod antenna	95010-1	Singer

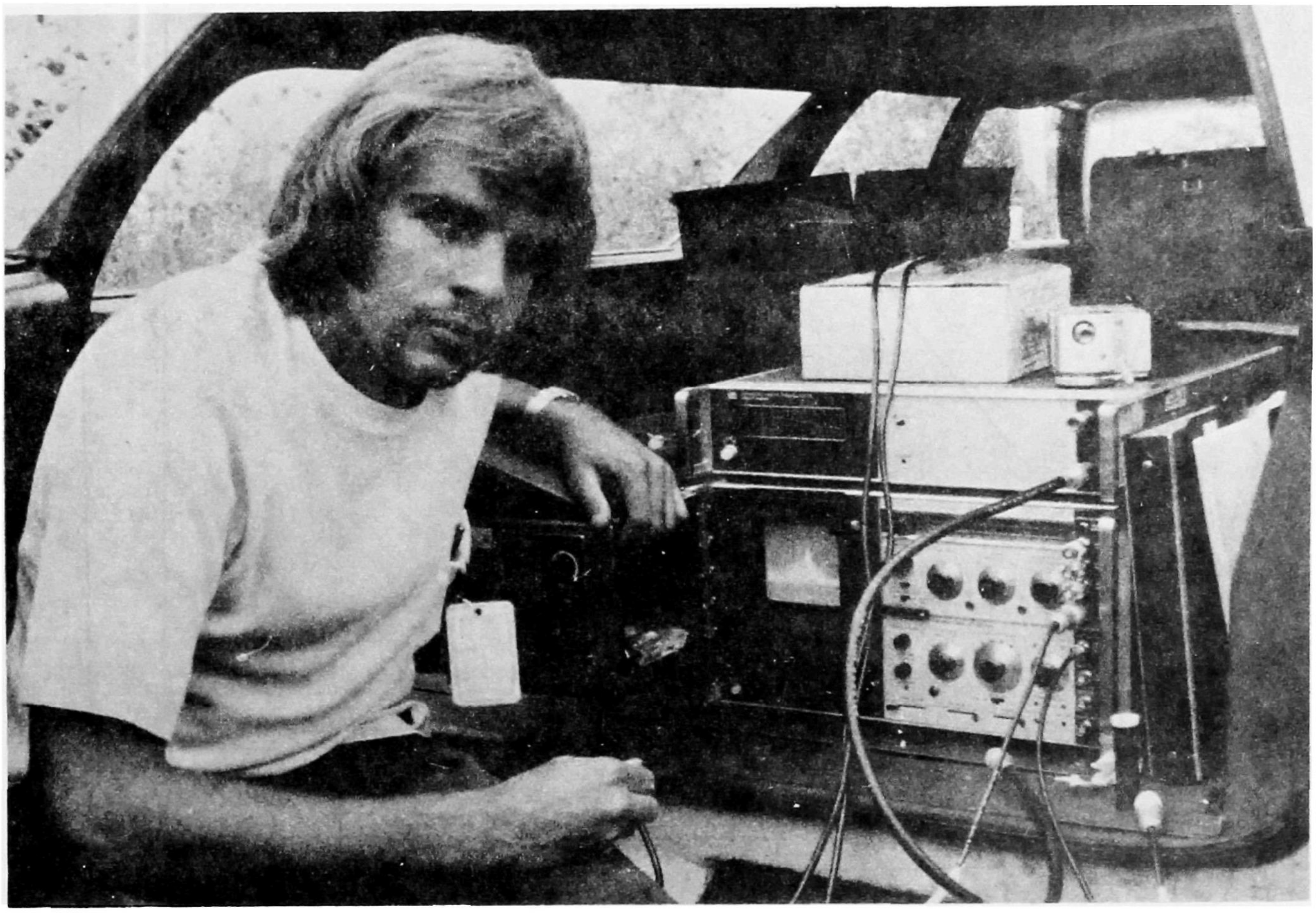

Figure 13. Arrangement of measurement equipment in station wagon

Through the relation between an antenna's effective capture area, Ae, and its gain, G, and the free space wavelength λ,

$$Ae = \frac{G \lambda^2}{4 \pi}$$

the effective area of the log periodic was obtained by reference to figure 14, a plot of antenna gain vs. frequency. Next the signal is coupled to the selected transmission line A or B and is fed to the analyzer input. In actuality, a part of this signal power is not effectively coupled into the analyzer due to both attenuation effects of the transmission line coax and mismatch losses, both at the antenna-coax junction and the coax-analyzer junction. Accordingly, a characterization of the signal cables was obtained through use of an automated microwave network analyzer to determine both loss (attenuation) and VSWR (a measure of mismatch); see figures 15 and 16, respectively.

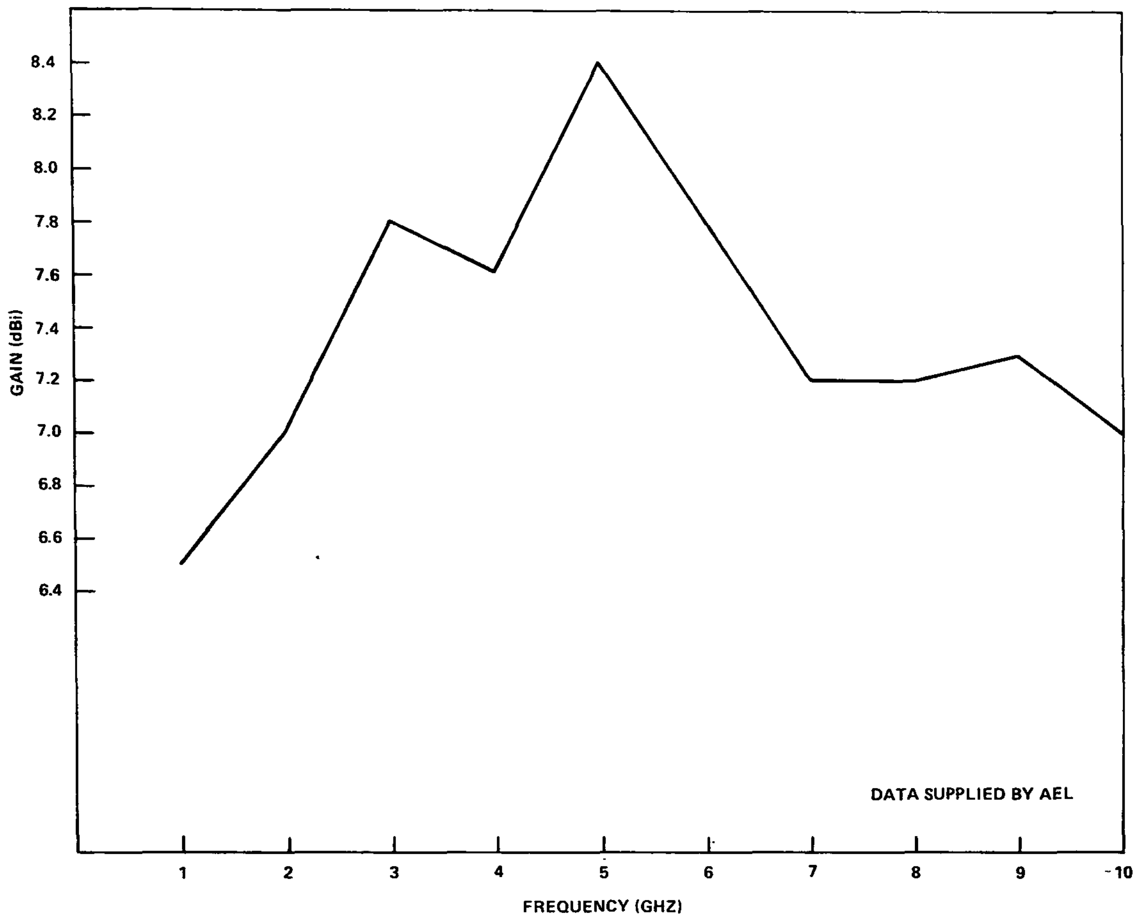

Figure 14. Mean gain of AEL APX-1293 crossed planar log periodic antenna

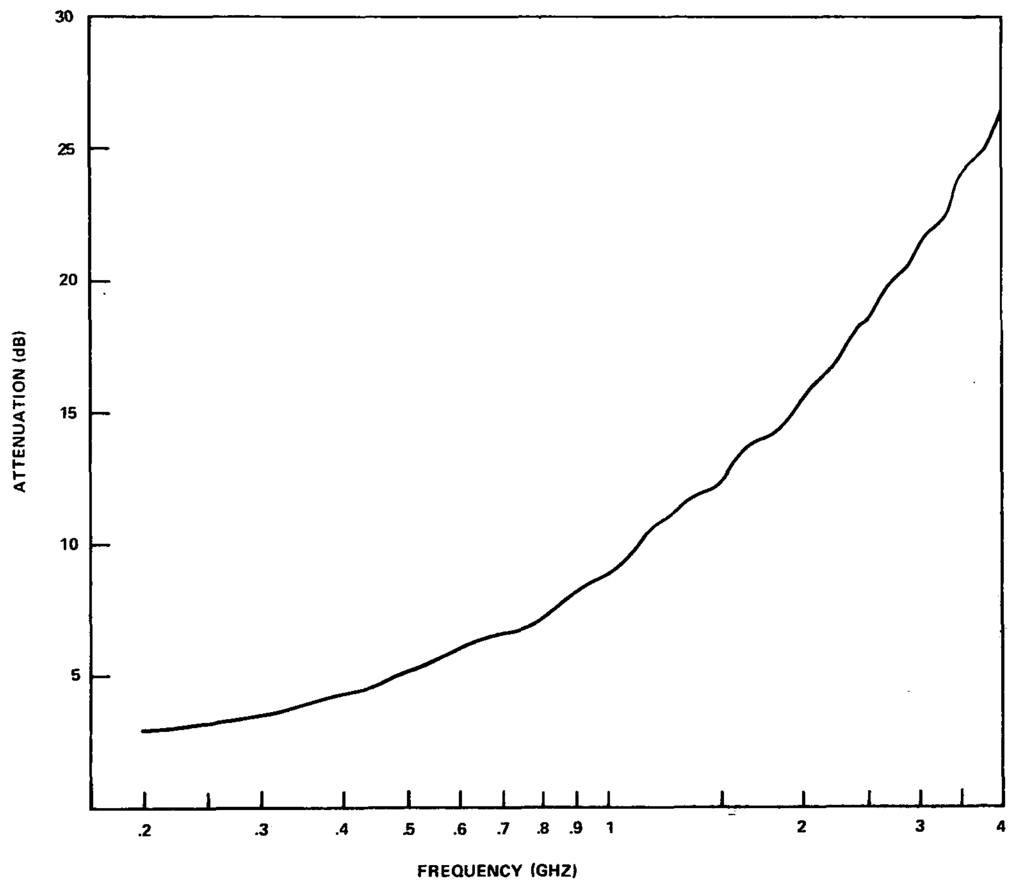

Figure 15. Typical signal cable loss

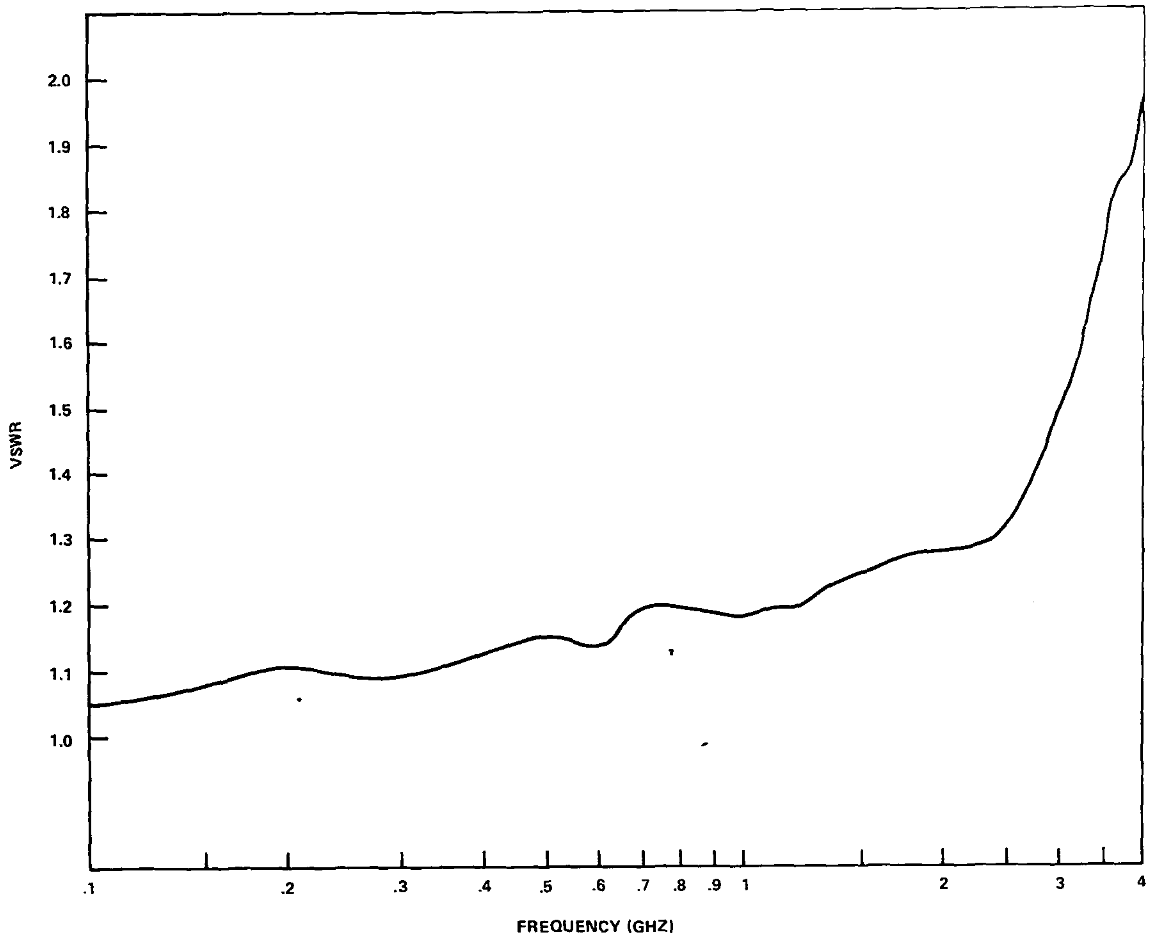

Figure 16. Typical signal cable VSWR

Using the VSWR calibration of the antenna from figure 17, a complete analysis of the signal path loss was obtained for each measurement frequency. In this fashion observed received powers could be related to the actual incident field densities. The dual polarized antenna was utilized to facilitate measurements of both horizontal and vertical field components of the incident radiation, and thus through addition of components arrive at the total radiated field intensity (expressed either in terms of power density or field strength--see appendix B for the relationship between field strength and power density in free space). In practice, the antenna was oriented such that one array was positioned vertically and the other horizontally.

Once the signal is applied to the spectrum analyzer input, a careful interpretation of the resulting pulsed spectrum must be made. Details of the theory of pulsed spectra analysis will not be given here but only the procedures for recording and reducing the collected data. Readers are referred to reference 4 for specific details regarding the theory.

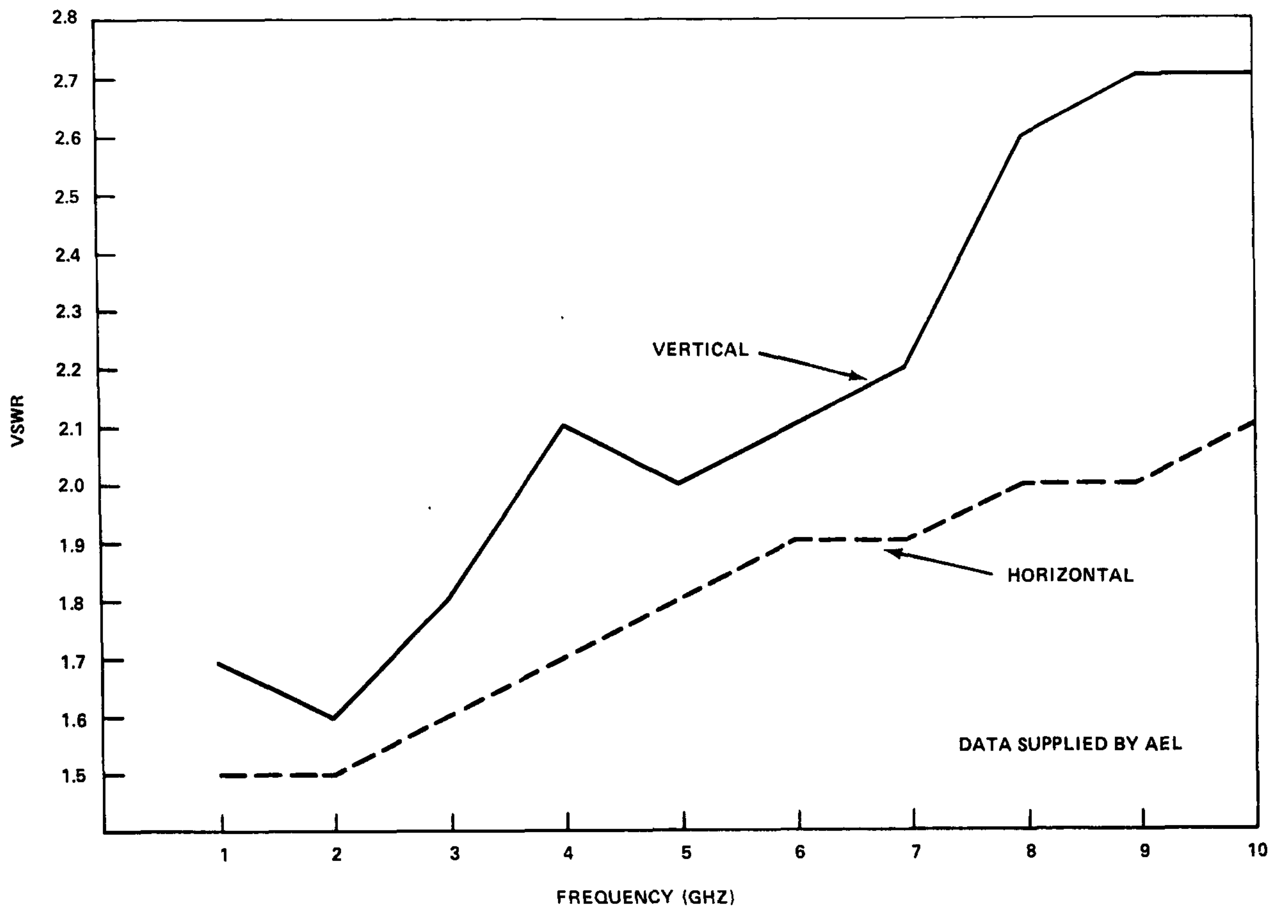

Figure 17. VSWR of AEL APX-1293 crossed planar log periodic antenna

In essence, a measurement of the signal's pulse width and PRF are made by observing the signal display with different analyzer settings. From these measurements and knowledge of the analyzer's bandwidth, the observed signal amplitude (power) may be corrected for the desensitization caused by application of pulsed, low-duty-cycle signals. In this process various conditions must be met to allow an accurate measurement of the signal power. These conditions can be found in reference 4. Nevertheless, two essential displays of the received signal must be produced: (1) the main lobe of the received pulsed spectrum from which the width is determined, allowing identification of the pulse width of the signal, and (2) the pulse repetition rate of the signal by looking in the time domain. Figure 18 shows a typical pulse spectrum from the analyzer's display. This display was produced from a laboratory microwave pulse generator. In practice, radars show nonsymmetrical spectra due to frequency modulation (FM) occurring during the pulse process. The dispersion in this example was 2 MHz/division. Figure 19 shows a more careful examination of the main lobe of a pulsed spectrum (ASR-7 as observed from location 1) where it is seen that the dispersion is approximately 2.6 MHz wide. Finally, in the time domain of the ARSR-1D, from Figure 20, we see the PRF to be about 356 Hz (a 5 msec/div. time base was employed for this case). From measurements similar to these

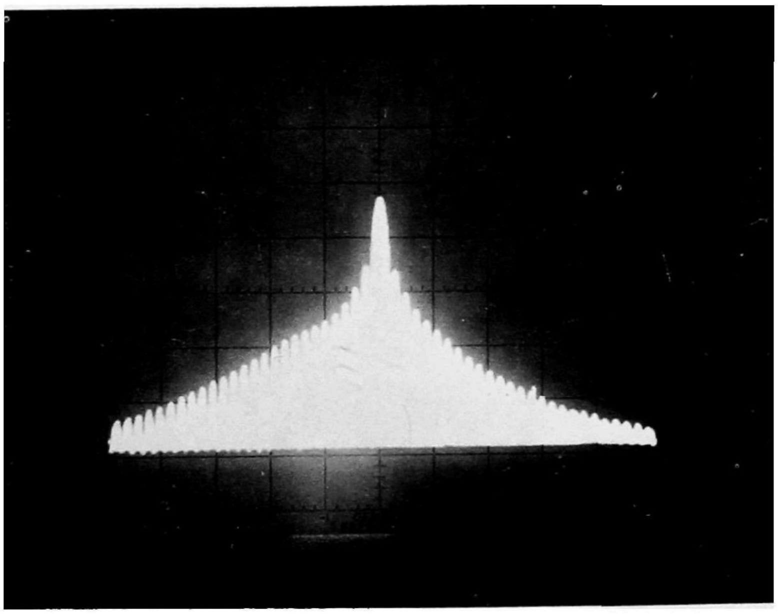

Figure 18. Typical pulse spectrum from laboratory generator

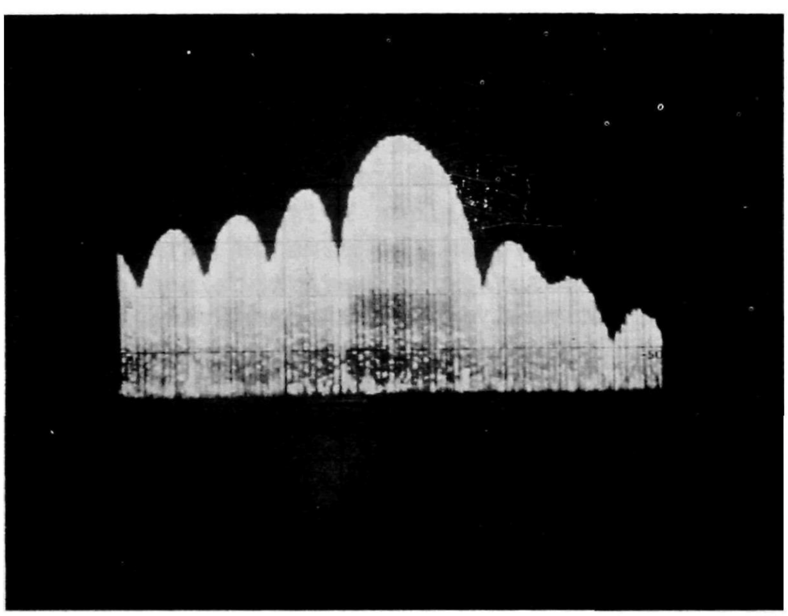

Figure 19. Main lobe of pulse spectrum. Spectrum analyzer scan width/division set at 1 MHz

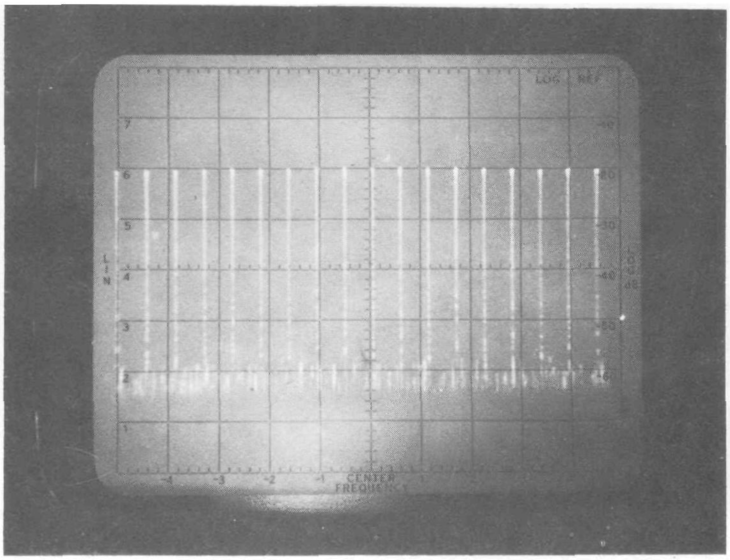

Figure 20. Picture in time domain of PRF

and relating to the analyzer's bandwidth characteristics, the peak and average power, pulse width, PRF, and duty factor of the observed signal may be determined.

Using this procedure, measurements were obtained on the radars described to determine principally the peak and average incident power density and field strength. Again, it must be stressed that proper operation of the spectrum analyzer must be maintained by carefully observing control settings for the specific analyzer function. For example, loading of the first mixer in the analyzer must be controlled in order that saturation does not occur, thereby, causing an erroneous indication of detected power.

When spectral observations were made at lower frequencies, two different antennas were available for use: (1) a biconical dipole for the VHF band and (2) a broadband vertical monopole for the MF-HF spectrum. A summary of the specific equipment which was used is given in table 3.

Table 4. Measurement system correction summary

Frequency (MHz)	Ae (cm^2)	Insertion Loss (dB) Cable A	Insertion Loss (dB) Cable B
1335	185.7	12.5	12.2
2720	55.2	21.6	20.8
2820	51.9	22.4	21.2

RESULTS AND OBSERVATIONS

Reduction of all data was done on the basis of the spectral photographs of oscilloscopic displays after returning from the field trip. As an aid in reducing the data, a system correction summary (see table 4) was prepared which incorporated the necessary correction terms for antenna effective area and cable insertion losses (both attenuation and mismatch loss). Table 5 gives a summary of the totality of field measurements made; principally the radar measurements are the only absolutely quantitative results, while any other measurements at lower frequencies were of a relative amplitude nature. Only relative field values were considered because of the problem of antenna directionality and source geographic distribution. To obtain absolute amplitude measurements of field intensity it is necessary to know the sensing antennas gain in the direction of each specific source. When making swept frequency measurements of signals arriving from many different directions, the use of an omni-directional antenna is necessary to allow accurate comparisons of signal intensities. Additionally, it was not the real purpose of this study to investigate non-radar signals. A listing of these supplementary measurements is given in table 6.

All results of radar field intensity measurements have been reported in terms of both incident power density and field strength. Values are indicated for measurements of peak and average field levels for each polarization component (vertical and horizontal) and the total resultant field levels. For convenience of the reader the measurements have been reported in the following manner:

Table 5. Summary of radars and measurement locations

Location	Radar Fields Measured					
	ASR-4B		ASR-7		ARSR-1D	
	Rotating	Stopped	Rotating	Stopped	Rotating	Stopped
1	X			X	X	
2		X				
3						
Computer room	X				X	
North lobby	X					
2nd floor	X					X

Table 6. List of supplementary measurements

1. Spectrum search of the frequency range 1160 MHz to 1360 MHz taken from the roof at location 2 with the reception antenna looking north.

2. Measurement of the front-to-back ratio of the ASR-4B antenna taken at location 2.

3. Spectral scan of frequency range ∿ 0 to 200 MHz taken in computer room at location 3.

4. Spectral scan of frequency range ∿ 0 to 2 MHz taken in computer room at location 3.

5. Spectral scan of portion of FM broadcast band taken in ground floor laboratory at location 2.

6. Spectral scan of frequency range ∿ 0 to 2 MHz taken in ground floor laboratory at location 2.

Power density : mW/cm^2 and dBm/cm^2
Field strength: V/m and dB/μV/m where

0 dBm/cm^2 is equivalent to 1 mW/cm^2 and 0 dB/μV/m is equivalent to 1 μV/m. Results are extensively recorded in tables 7 through 17.

Resultant peak power densities ranged from 90 $\mu W/cm^2$ to 245 mW/cm^2 and resultant average power densities ranged between 0.06 $\mu W/cm^2$ and 0.17 mW/cm^2. The highest fields measured were at the MPB location on the second floor level, looking out of the window directly toward the ARSR-1D antenna. After our initial measurements at this location with the receiving antenna tripod fixed in height, a survey of the room was accomplished by moving the antenna and looking for the maximum signal. In this fashion, it was observed that the highest power density that could be found was 245 mW/cm^2 peak or 961 V/meter. The repetitive automatic firing of the electronic shutter in our oscilloscope camera (due to RFI) attested to the fact that the fields permeating the room were high. Yet, in terms of levels which are considered thermally hazardous to humans, no fields which were monitored exceeded any U.S. safety standards on an average power density basis. Reference to appendix A will reveal some current RF safety standards. In comparing measured exposure values with various personnel exposure standards, it should be pointed out that the values indicated in tables 7 through 17 have not taken into account antenna rotation duty factor. If the ARSR-1D antenna is assumed to be rotating, the exposure at the MPB location would be approximately 3 $\mu W/cm^2$ when averaged over one rotation.

In computing the antenna rotation duty factor the 3 dB beam width of the ARSR-1D antenna, using a cosecant-squared beam, was used as the active part of the beam for calculation purposes, where

$$\text{Antenna duty factor} = \frac{\text{3 dB beam width in degrees}}{\text{360 degrees}}$$

With respect to the potential for RF interference to computer terminals which may be installed in the measurement area of the MPB second floor, the following information is taken from the AFSC Design Handbook on Electromagnetic Compatibility (6):

"In a typical computer many circuits of the computer do not malfunction under intense electromagnetic field radiation. Circuits in this category are high-level circuits such as flip-flops, AND and OR gates, pulse amplifiers, relay drivers, level inverters, and cathode followers. Low-level circuits of the computer, whose normal input is within the range of 50 mV to 2 V peak-to-peak, do malfunction when subjected to

Table 7. Results at location 1; ASR-7, antenna stopped

Field Component	Power Density		Field Strength	
	mW/cm^2	dBm/cm^2	V/m	dB/μV/m
Peak vertical	17.2	+12.3	255	168
Average vertical	0.0160	-17.9	7.80	138
Peak horizontal	0.180	- 7.5	26.0	148
Average horizontal	1.70 x 10^{-4}	-37.8	0.80	118
Total peak	17.4	+12.4	256	168
Total average	0.0160	-17.9	7.80	138

Table 8. Results at location 1; ASR-4B, antenna rotating

Field Component	Power Density		Field Strength	
	mW/cm^2	dBm/cm^2	V/m	dB/μV/m
Peak vertical	0.0340	-14.7	11.3	141
Average vertical	3.30 x 10^{-5}	-44.8	0.350	111
Peak horizontal	1.02 x 10^{-3}	-29.9	1.96	126
Average horizontal	5.50 x 10^{-5}	-42.6	0.460	113
Total peak	0.0350	-14.5	11.5	141
Total average	8.80 x 10^{-5}	-40.5	0.570	115

Table 9. Results at location 1; ARSR-1D, antenna rotating

Field Component	Power Density		Field Strength	
	mW/cm^2	dBm/cm^2	V/m	dB/μV/m
Peak vertical	0.350	- 4.6	36.3	151
Average vertical	2.30×10^{-4}	-36.4	0.930	119
Peak horizontal	1.48	+ 1.7	74.7	157
Average horizontal	9.80×10^{-4}	-30.1	1.92	126
Total peak	1.83	+ 2.6	83.1	158
Total average	1.21×10^{-3}	-29.2	2.10	126

Table 10. Results at location 2; ASR-4B, antenna stopped

Field Component	Power Density		Field Strength	
	mW/cm^2	dBm/cm^2	V/m	dB/μV/m
Peak vertical	5.30×10^{-3}	-22.7	4.47	133
Average vertical	5.20×10^{-6}	-52.8	0.140	103
Peak horizontal	5.10×10^{-4}	-32.9	1.38	123
Average horizontal	2.71×10^{-5}	-45.6	0.319	110
Total peak	5.82×10^{-3}	-22.4	4.68	133
Total average	3.20×10^{-5}	-44.9	0.347	111

Table 11. Results at location 3, computer room; ASR-4B, antenna rotating

Field Component	Power Density		Field Strength	
	mW/cm^2	dBm/cm^2	V/m	dB/μV/m
Peak vertical	2.71×10^{-4}	-35.7	1.01	120
Average vertical	2.60×10^{-7}	-65.8	0.0313	89.9
Peak horizontal	3.42×10^{-5}	-44.7	0.358	111
Average horizontal	3.31×10^{-8}	-74.8	0.0111	80.9
Total peak	3.00×10^{-4}	-35.2	1.06	120
Total average	2.90×10^{-7}	-65.3	0.0330	90.4

Table 12. Results at location 3, computer room; ARSR-1D, antenna rotating

Field Component	Power Density		Field Strength	
	mW/cm^2	dBm/cm^2	V/m	dB/μV/m
Peak vertical	3.50×10^{-5}	-44.6	0.363	111
Average vertical	2.30×10^{-8}	-76.4	9.30×10^{-3}	79.3
Peak horizontal	5.51×10^{-5}	-42.6	0.455	113
Average horizontal	3.60×10^{-8}	-74.4	0.0116	81.3
Total peak	9.01×10^{-5}	-40.5	0.582	115
Total average	5.93×10^{-8}	-72.3	0.0149	83.5

Table 13. Results at location 3, MPB-North Lobby; ASR-4B, antenna rotating

Field Component	Power Density		Field Strength	
	mW/cm^2	dBm/cm^2	V/m	dB/µV/m
Peak vertical	0.107	- 9.7	20.1	146
Average vertical	1.04×10^{-4}	-39.8	0.626	116
Peak horizontal	0.0337	-14.7	11.3	141
Average horizontal	3.30×10^{-5}	-44.8	0.353	111
Total peak	0.141	- 8.5	23.0	147
Total average	1.37×10^{-4}	-38.6	0.719	117

Table 14. Results at location 3, 2nd floor-MPB; ARSR-1D, (500 kW), antenna stopped

Field Component	Power Density		Field Strength	
	mW/cm^2	dBm/cm^2	V/m	dB/µV/m
Peak vertical	0.0778	-11.1	17.1	147
Average vertical	5.30×10^{-5}	-42.8	0.447	113
Peak horizontal	7.78	+ 8.9	171	165
Average horizontal	5.31×10^{-3}	-22.8	4.47	133
Total peak	7.90	+ 6.2	172	165
Total average	5.42×10^{-3}	-22.7	4.5	1.33

Table 15. Results at location 3, 2nd floor-MPB; ARSR-1D, (4 MW), antenna stopped

Field Component	Power Density		Field Strength	
	mW/cm^2	dBm/cm^2	V/m	dB/µV/m
Peak vertical	0.980	- 0.1	60.8	156
Average vertical	6.60 x 10^{-4}	-31.8	1.58	124
Peak horizontal	61.8	+17.9	483	174
Average horizontal	0.0418	-13.8	12.6	142
Total peak	62.8	+18.0	487	174
Total average	0.0425	-13.7	12.7	142

Table 16. Results at location 3, 2nd floor-MPB; ARSR-1D, (4 MW, maximum field), antenna stopped

Field Component	Power Density		Field Strength	
	mW/cm^2	dBm/cm^2	V/m	dB/µV/m
Peak vertical	49.1	+16.9	430	173
Average vertical	0.0332	-14.8	11.2	141
Peak horizontal	196	+22.9	860	179
Average horizontal	0.132	- 8.8	22.3	147
Total peak	245	+23.9	961	180
Total average	0.165	- 7.8	24.9	148

Table 17. Results at location 3, 2nd floor-MPB; ASR-4B, antenna rotating

Field Component	Power Density		Field Strength	
	mW/cm^2	dBm/cm^2	V/m	dB/μV/m
Peak vertical	0.673	- 1.7	50.4	154
Average vertical	6.61×10^{-4}	-31.8	1.6	1.24
Peak horizontal	0.0847	-10.7	17.9	145
Average horizontal	8.30×10^{-5}	-40.8	0.600	115
Total peak	0.758	- 1.2	53.5	155
Total average	7.43×10^{-4}	-31.3	1.7	125

moderate field intensities. Sense amplifiers of the memory element malfunction at a field intensity in the region of 15 V per meter peak; the tuning fork oscillator of the output section will malfunction near 40 V per meter peak. Data conversion receivers of the input section malfunction at 50 V per meter peak. The flux amplifier of the output section fails at 100 V per meter. In actual usage, the susceptibility data levels of malfunction must be identified with the specific parameters which characterize the radar."

The reference also states "In the remaining group, which represents most of the computer circuits, malfunction does not occur at field intensity levels as high as 400 V per meter peak." It is also noted that susceptible circuits are usually more sensitive when subjected to radiation nearer the low end of the 450-2900 MHz band than to higher frequencies. Polarization is said to be very significant, depending upon the particular computer unit but in general vertical polarization causes more problems than horizontal."

On the basis of this information it is not possible to say definitely that a computer terminal placed on the second floor of the MPB would experience interference, but certainly the possibility should be considered when locating the terminals. Peak fields nearing 1 kV/m are very intense fields from almost any electronic equipment interference standpoint.

By comparing measured field intensities from the ASR-4B radar made in the computer room vs. the north lobby of the MPB, an estimate of the building attenuation effectiveness was determined. A nominal 26 dB shielding effect was found at the ASR-4B frequency of 2720 MHz.

During the process of measuring field levels we also determined, by measurement, the observed PRF and pulse width of each radar. Table 18 reviews the observed values.

An interesting effect observed was that of signal polarization. It was found, as one would expect, that the extent of depolarization of the emitted radar signal seemed to be a function of the complexity of the surrounding reception environment; the more complex the environment, the more equal the two wave components became. For example, the ratio of vertical to horizontal field density was 15.2 dB at location 1 where the area was fairly in the clear. When determined at location 2 the ratio was 10.2 dB, apparently due to the roof top clutter of air conditioning equipment and other nearby obstacles. The computer room measurement made inside the MPB with building shielding showed the ratio to be only 9.0 dB.

Table 18. Measured PRF and pulse width

Location	Radar	Measured PRF (Hz)	Measured Pulse Width (μsec)
1	ASR-7	1185	0.77
1	ASR-4B	1079	0.91
1	ARSR-1D	356	1.85
2	ASR-4B	1083	0.91
3	ARSR-1D	355	1.90

Figures 21 and 22 are included for illustration of typical pulse spectra observed from the ARSR-1D and ASR-4B, respectively. Notice the effect of frequency modulation resulting in a nonsymmetrical signature.

A measure of the front-to-back ratio of the ASR-4B radar antenna was accomplished at location 2. A picture of the radar spectrum was taken when the antenna was pointed directly toward our reception antenna. Subsequently the same spectrum was photographed when the ASR-4B antenna was directed 180 degrees opposite to our location. An F/B ratio of 16 dB is apparent from the relative power at the peaks of each signal. F/B ratios on this order are typical when the paraboloidal reflector is not solid in construction.

It was noted in the course of these measurements, that when the radar antenna was rotating, it was much more difficult to generate a useful spectral display on the analyzer. This is related to the obvious interplay between spectrum analyzer scan time and antenna rotation rates. Thus, when the radar is beaming only momentarily toward the receiver, it rapidly becomes difficult to utilize appropriately fast enough scan rates on the analyzer to produce a meaningful display. Under these circumstances the use of a variable persistence oscilloscope screen becomes mandatory for meaningful and relatively rapid identification of radar spectra from rotating antennas. Once the primary peak of the radar spectrum signature was located, it was found that a useful technique for accurately determining the peak signal amplitude involved reducing the analyzer's

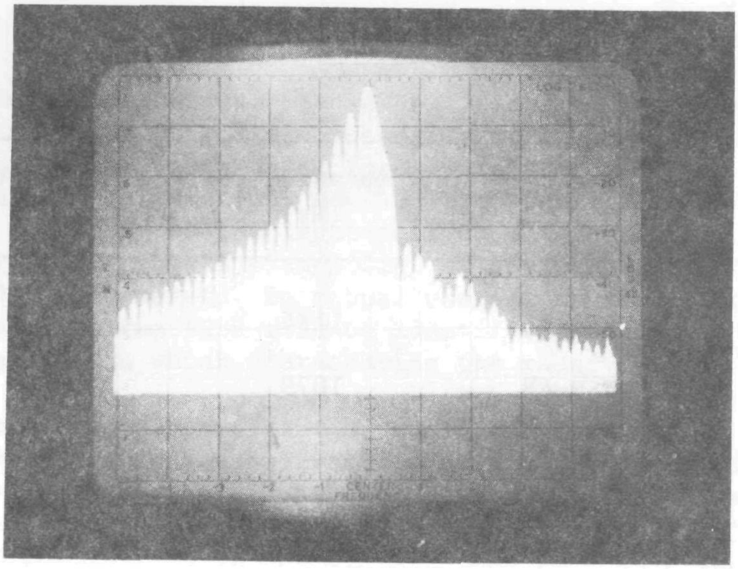

Figure 21. ARSR-1D pulse spectrum. Center frequency = 1335 MHz, 2 MHz/division

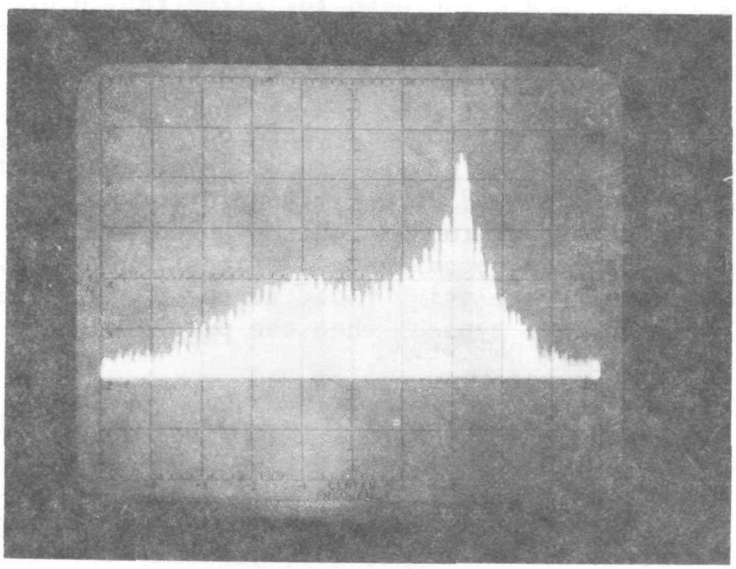

Figure 22. ASR-4B pulse spectrum. Center frequency = 2720 MHz, 5 MHz/division

frequency dispersion such that it was displaying essentially only the peak lobe of the pulse spectrum. Then the scan rate of the analyzer was increased until many repetitive frequency scans occurred during the time of radar field illumination thus raising the probability of detecting the actual peak power of the signal at precisely the time that the main beam of the radar was directed at the reception antenna. Of course, during this process care must be exercised that an uncalibrated condition does not develop (i.e., analyzer scan time does not become too fast for the bandwidth and scan width settings).

Our experiences with using a spectrum analyzer for these types of field measurements did not reveal a significant problem with intermodulation products giving rise to erroneous signals on the spectrum display. One good test for determining the validity of the observed signals is to insert a fixed amount of attenuation into the input port and look for a corresponding decrease in measured signal amplitude. Spurious responses will decrease by significantly more than the amount of added attenuation. In certain circumstances intermod was observed when all three radars were operating simultaneously and all three antennas became momentarily synchronized and illuminated our sampling locations at the same time. Under such conditions it became tedious to extract a good spectrum signature from a revolving antenna.

Figure 23 shows the spectrum, $\sim$0 to 2 MHz, observed inside the building, on the ground floor at location 2. The local standard AM broadcast stations are visible with the center frequency on the display set at 1.0 MHz. Local radio station KOMA transmitting on 1.520 MHz is seen as the strongest signal being received at that location. Figure 23 is a plot of the relative power of the received signals and shows that KOMA had a signal strength on the order of 10 times that of any other broadcast signal (a 20 dB greater received power). Also notice, though, the extensive noise peaks, particularly below about 600 kHz. A similar measurement in the computer room at location 3 showed essentially no AM radio signal reception but a lot of broadband noise across the band. Such noise pickup was probably due to the electric motors used in air conditioning equipment located inside the room at many locations for maintaining correct room temperature.

A scan around 100 MHz in the computer room (figure 24) showed large amounts of broadband noise and what appeared to be some FM signals penetrating the building shielding.

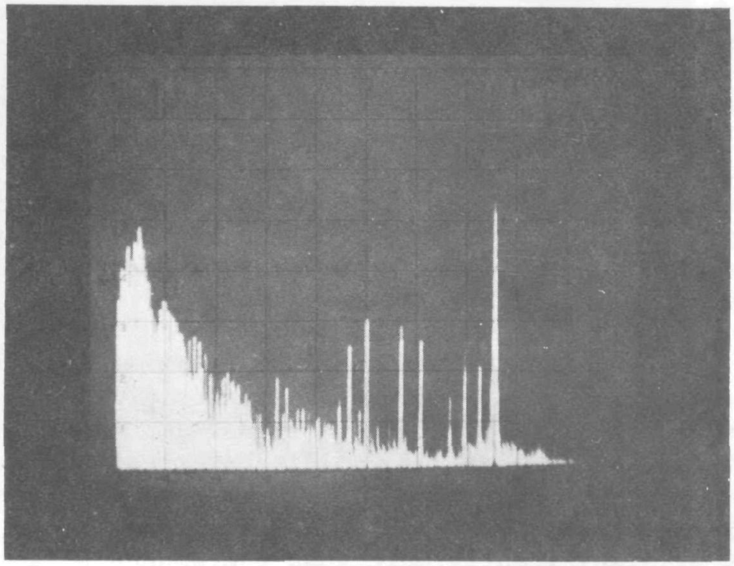

Figure 23. Spectrum scan, 0-2 MHz, observed inside building, on ground floor at location 2

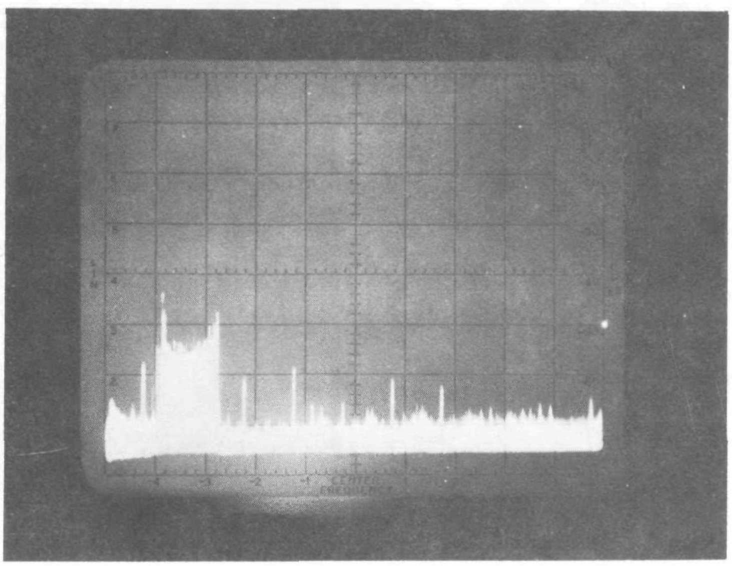

Figure 24. VHF scan en computer room, center frequency 100 MHz, 2 MHz/division

CONCLUSIONS

Experience obtained during this field study verified that the use of spectrum analyzers as sensitive scanning detectors is required for accurate and meaningful quantitation of microwave exposure from radar. The spectrum analyzer allows accurate determination of exposure levels from rapidly rotating radar antennas unlike conventional microwave hazard survey meters with fairly long response times. The high sensitivity provides a capability of examining radiation levels, significantly below thermalizing levels, which may be significant in device interference problems. Additionally the spectrum analyzer provides a means of searching through a wide spectrum of frequencies for identification of particular radiofrequency sources of interest from an exposure standpoint.

Though spectrum analyzers provide a practical means of monitoring environmental electromagnetic radiation exposures, accurate determination of mean exposure levels from bands containing a multiplicity of intermittent radiofrequency signals (not under the observer's control) requires the addition of some form of automated spectral data collection system with an interface to the analyzer. A description of such a system currently under development by EPA will be forthcoming in the near future.

Typical fields and specific technical comments on the application of spectrum analyzers to their measurement as determined in this study are summarized below.

(a) Accurate radar field measurements from rotating antennas are possible though more difficult than from non-rotating antennas. Appropriately narrow frequency scans facilitate accurate identification of the spectrum signatures of individual radars when the antennas are rotating and more than one radar is operating in the same general geographic vicinity and frequency range.

(b) When making measurements in an area of relatively intense radar fields, appropriate shielding of the equipment is useful to prevent inadvertent radiofrequency interference to the spectrum analyzer itself and consequent erroneous signal power determination.

(c) For relatively wide frequency scans, the use of frequency pre-selection via filters is useful to prevent intermodulation products from occurring in the spectrum analyzer and consequent indication of false signals.

(d) Exposure field distributions, particularly inside of buildings, may be very complex with the resulting field intensity being extremely dependent on position. Thus, a careful survey of the general area of interest may reveal significantly different exposure levels.

(e) Ground level peak field intensities from any one of the radars monitored are high enough to warrant consideration of the potential for interference to susceptible electronic equipment.

In addition to these conclusions, several observations were made which may have practical implications in terms of FAA operations at the Center. The relatively high levels of radiation found on the second floor of the MPB may degrade terminal performance due to radiofrequency interference. Peak field strengths as high as 961 V/m were observed on the second floor of the MPB due to the ARSR-1D radar where new computer terminals may be situated in the future. Maximum average power density was measured as 0.165 mW/cm^2 at this location. The planned installation of a new ARSR-3 in the near vicinity with its higher peak power, will add to the potential for equipment degradation. Shielding could be an effective way to reduce radiofrequency interference by covering windows with a fine wire mesh. A significant reduction in electromagnetic fields in the shielded computer room of the MPB is demonstrated by the 65 dB lower intensity values as compared with those on the second floor. Appendix D contains shielding data for two types of wire mesh for a wide range of frequencies.

Ground level peak field strengths as high as 256 V/m were measured from the ASR-7 radar. Average power density was 0.0160 mW/cm^2 at this location. Radiation levels found in any location measured from any source did not exceed the OSHA guide (8) for occupational personnel microwave exposure.

RECOMMENDATIONS

Since all high power civilian ATC radar installations are operated by the FAA, a review of records might not prove too difficult to attempt identification of other geographic areas where unusual exposure conditions may exist. For example, a search for radar installations in close proximity to multi-story buildings might reveal areas where potential RFI could be detrimental to critical electronic systems.

For purposes of relating measured field intensities to predicted values based on the radar's power and antenna characteristics, it is important to be able to accurately determine the elevation angle from the reception point to the radar antenna. This would probably best be accomplished by use of a precision transit. Additionally, some means must be provided for accurately measuring the distance from the radar to the reception site. Finally, as an aid in precisely directing the main antenna lobe toward the measurement location, some form of convenient communication should be available, such as walkie-talkies, so that measurement personnel may indicate to the radar operator when maximum signal strength is observed.

ACKNOWLEDGMENTS

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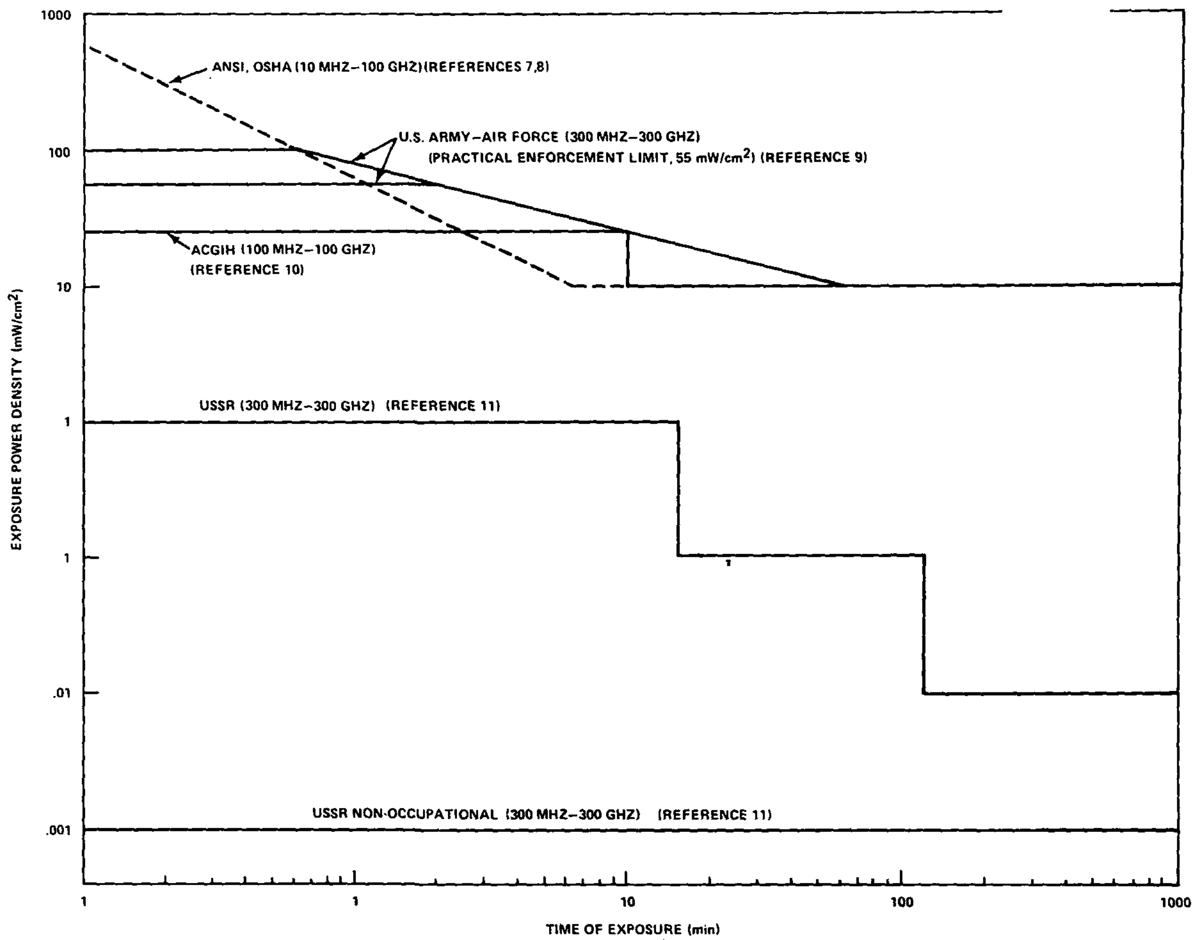
APPENDIX A.

SOME SELECTED MICROWAVE EXPOSURE STANDARDS



Notes on Exposure Standards

U.S. Army-Air Force

The exposure power density may increase to a maximum of 100 mW/cm^2 for periods of exposure less than 60 minutes according to the relationship:

$$T = \frac{6000}{w^2} \quad \text{where}$$

T = time for exposure permitted

w = power density in mW/cm^2

Under no circumstances may the exposure exceed 100 mW/cm^2. In actual practice the maximum allowable exposure is limited to 55 mW/cm^2 which corresponds to a 2 minute duration from the above formula. For scanning antennas, the stationary exposure is first determined and then the rotational property of the antenna is taken into account to arrive at a calculated time-averaged exposure. However, if the stationary exposure is 100 mW/cm^2 or greater access is forbidden and the reduction in exposure which might be obtained by taking rotation into account is not allowed. The higher exposures may occur during a one-hour period after which it may be repeated.

ANSI-OSHA

The ANSI and OSHA standards are practically the same and specify that for exposure periods less than 0.1 hour, an exposure energy density of 1 $\frac{mW\text{-}hr}{cm^2}$ shall not be exceeded. These standards, then, place no upper limit on the allowable exposure as long as an appropriately short period is used. The higher exposure may occur during a 0.1 hour period after which it may be repeated. Exposure for periods greater than 0.1 is 10 mW/cm^2.

USSR

The Soviet standard also specifies allowable exposure fields for other frequency bands:

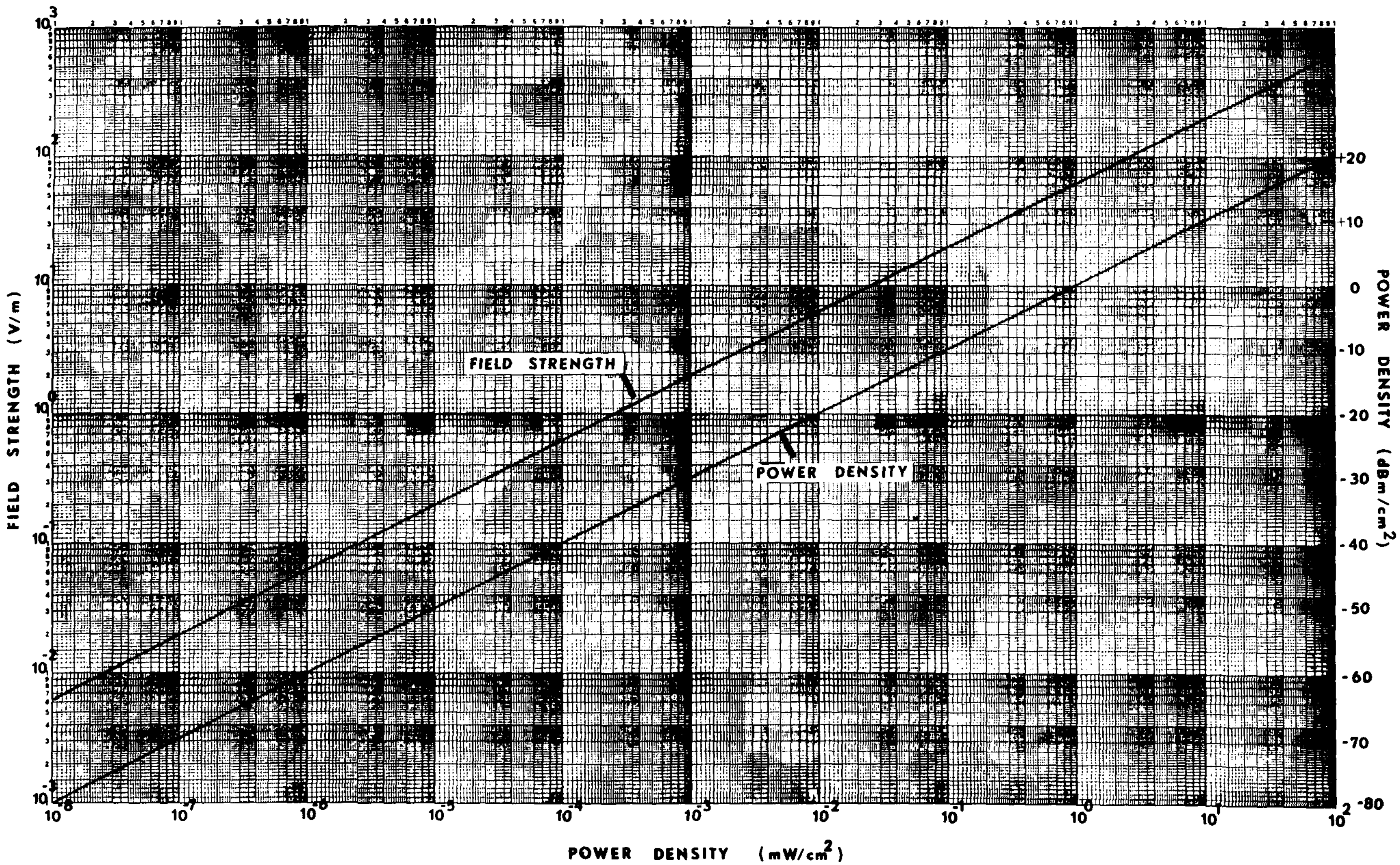
100 kHz - 30 MHz, 20 V/m electric field

100 kHz - 1.5 MHz, 5 A/m magnetic field

30-300 MHz, 5 V/m electric field.

In the frequency range of 300 MHz to 300 GHz, occupationally exposed individuals are limited to 10 $\mu W/cm^2$ for periods greater than 2 hours; from 15 minutes to 2 hours the limit is 100 $\mu W/cm^2$, and for exposures shorter than 15 minutes, 1 mW/cm^2. For non-occupationally exposed persons the Soviet standard specifies an upper limit of 1 $\mu W/cm^2$ (this level might be interpreted as an environmental level standard for the public as a whole).

Appendix B. Field strength and power density in free space



Appendix C. Voltage and power ratios to dB

VOLTAGE RATIO	POWER RATIO	dB	VOLTAGE RATIO	POWER RATIO	VOLTAGE RATIO	POWER RATIO	dB	VOLTAGE RATIO	POWER RATIO
1.0000	1.0000	0.00	1.0000	1.0000	.5129	.2630	5.8	1.950	3.802
.9988	.9977	0.01	1.0012	1.0023	.5070	.2570	5.9	1.972	3.890
.9977	.9954	0.02	1.0023	1.0046	.5012	.2512	6.0	1.995	3.931
.9966	.9931	0.03	1.0035	1.0069	.4955	.2455	6.1	2.018	4.074
.9954	.9908	0.04	1.0046	1.0093	.4898	.2399	6.2	2.042	4.169
.9943	.9886	0.05	1.0058	1.0116	.4842	.2344	6.3	2.065	4.266
.9931	.9863	0.06	1.0069	1.0139	.4786	.2291	6.4	2.089	4.365
.9920	.9840	0.07	1.0081	1.0162	.4732	.2239	6.5	2.113	4.467
.9908	.9817	0.08	1.0093	1.0186	.4677	.2188	6.6	2.138	4.571
.9897	.9795	0.09	1.0104	1.0209	.4624	.2138	6.7	2.163	4.677
.9886	.9772	0.1	1.012	1.023	.4571	.2089	6.8	2.188	4.786
.9772	.9550	0.2	1.023	1.047	.4519	.2042	6.9	2.213	4.898
.9661	.9333	0.3	1.035	1.072	.4467	.1995	7.0	2.239	5.012
.9550	.9120	0.4	1.047	1.096	.4416	.1950	7.1	2.265	5.129
.9441	.8913	0.5	1.059	1.122	.4365	.1905	7.2	2.291	5.248
.9333	.8710	0.6	1.072	1.148	.4315	.1862	7.3	2.317	5.370
.9226	.8511	0.7	1.084	1.175	.4266	.1820	7.4	2.344	5.495
.9120	.8318	0.8	1.096	1.202	.4217	.1778	7.5	2.371	5.623
.9016	.8128	0.9	1.109	1.230	.4169	.1738	7.6	2.399	5.754
.8913	.7943	1.0	1.122	1.259	.4121	.1698	7.7	2.427	5.888
.8810	.7762	1.1	1.135	1.288	.4074	.1660	7.8	2.455	6.026
.8710	.7586	1.2	1.148	1.318	.4027	.1622	7.9	2.483	6.166
.8610	.7413	1.3	1.161	1.349	.3981	.1585	8.0	2.512	6.310
.8511	.7244	1.4	1.175	1.380	.3936	.1549	8.1	2.541	6.457
.8414	.7079	1.5	1.189	1.413	.3890	.1514	8.2	2.570	6.607
.8318	.6918	1.6	1.202	1.445	.3846	.1479	8.3	2.600	6.761
.8222	.6761	1.7	1.216	1.479	.3802	.1445	8.4	2.630	6.918
.8128	.6607	1.8	1.230	1.514	.3758	.1413	8.5	2.661	7.079
.8035	.6457	1.9	1.245	1.549	.3715	.1380	8.6	2.692	7.244
.7943	.6310	2.0	1.259	1.585	.3673	.1349	8.7	2.723	7.413
.7852	.6166	2.1	1.274	1.622	.3631	.1318	8.8	2.754	7.586
.7762	.6026	2.2	1.288	1.660	.3589	.1288	8.9	2.786	7.762
.7674	.5888	2.3	1.303	1.698	.3548	.1259	9.0	2.818	7.943
.7586	.5754	2.4	1.318	1.738	.3508	.1230	9.1	2.851	8.128
.7499	.5623	2.5	1.334	1.778	.3467	.1202	9.2	2.884	8.318
.7413	.5495	2.6	1.349	1.820	.3428	.1175	9.3	2.917	8.511
.7328	.5370	2.7	1.365	1.862	.3388	.1148	9.4	2.951	8.710
.7244	.5248	2.8	1.380	1.905	.3350	.1122	9.5	2.985	8.913
.7161	.5129	2.9	1.396	1.950	.3311	.1096	9.6	3.020	9.120
.7079	.5012	3.0	1.413	1.995	.3273	.1072	9.7	3.055	9.333
.6998	.4898	3.1	1.429	2.042	.3236	.1047	9.8	3.090	9.550
.6918	.4786	3.2	1.445	2.089	.3199	.1023	9.9	3.126	9.772
.6839	.4677	3.3	1.462	2.138	.3162	.1000	10.0	3.162	10.000
.6761	.4571	3.4	1.479	2.188	.2985	.08913	10.5	3.350	11.22
.6683	.4467	3.5	1.496	2.239	.2818	.07943	11.0	3.548	12.59
.6607	.4365	3.6	1.514	2.291	.2661	.07079	11.5	3.758	14.13
.6531	.4266	3.7	1.531	2.344	.2512	.06310	12.0	3.981	15.85
.6457	.4169	3.8	1.549	2.399	.2371	.05623	12.5	4.217	17.78
.6383	.4074	3.9	1.567	2.455	.2239	.05012	13.0	4.467	19.95
.6310	.3981	4.0	1.585	2.512	.2113	.04467	13.5	4.732	22.39
.6237	.3890	4.1	1.603	2.570	.1995	.03981	14.0	5.012	25.12
.6166	.3802	4.2	1.622	2.630	.1884	.03548	14.5	5.309	28.18
.6095	.3715	4.3	1.641	2.692	.1778	.03162	15.0	5.623	31.62
.6026	.3631	4.4	1.660	2.754	.1585	.02512	16.0	6.310	39.81
.5957	.3548	4.5	1.679	2.818	.1413	.01995	17.0	7.079	50.12
.5888	.3467	4.6	1.698	2.884	.1259	.01585	18.0	7.943	63.10
.5821	.3388	4.7	1.718	2.951	.1122	.01259	19.0	8.913	79.43
.5754	.3311	4.8	1.738	3.020	.1000	.01000	20.0	10.000	100.00
.5689	.3236	4.9	1.758	3.090	.03162	.00100	30.0	31.620	1,000.00
.5623	.3162	5.0	1.778	3.162	.01	.00010	40.0	100.00	10,000.00
.5559	.3090	5.1	1.799	3.236	.003162	.00001	50.0	316.20	10^5
.5495	.3020	5.2	1.820	3.311	.001	10^{-6}	60.0	1,000.00	10^6
.5433	.2951	5.3	1.841	3.388	.0003162	10^{-7}	70.0	3,162.00	10^7
.5370	.2884	5.4	1.862	3.467	.0001	10^{-8}	80.0	10,000.00	10^8
.5309	.2818	5.5	1.884	3.548	.00003162	10^{-9}	90.0	31,620.00	10^9
.5248	.2754	5.6	1.905	3.631	10^{-5}	10^{-10}	100.0	10^5	10^{10}
.5188	.2692	5.7	1.928	3.715					

Appendix D. Attenuation effectiveness of wire mesh cloth[a]

Frequency (MHz)	Attenuation of Radiated Field (dB)			
	Copper		Galvanized Steel	
	18x18	22x22	22x22	26x26
0.01	103.6	109.1	137.7	143.9
0.03	104.7	110.2	135.4	141.6
0.06	105.4	110.2	132.1	138.3
0.1	105.4	113.6	129.1	135.3
0.3	105.0	110.5	120.8	127.0
0.6	103.4	108.9	115.1	121.3
1.0	101.3	106.8	110.8	117.0
3.0	94.5	100.0	101.4	107.6
6.0	89.3	94.8	95.4	101.6
10.0	85.1	90.6	91.0	97.2
30.0	75.8	81.3	81.4	87.6
60.0	69.9	75.4	75.4	81.6
100.0	65.6	71.0	71.0	77.2
300.0	55.9	61.4	61.4	67.6
600.0	49.9	55.4	55.4	61.6
1000	45.5	51.0	51.0	57.2
3000	35.9	41.4	41.4	47.6
6000	29.9	35.4	35.4	41.6
10000	25.5	31.0	31.0	37.2

[a]Data taken from reference 6.

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KEY WORDS: Microwave exposure; nonionizing radiation; radar; radiofrequency hazard.

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