Broadcast Signal Lab

Final Test Report
on
A Survey of Radio Frequency Energy Field Emissions from the Cape Cod Air Force Station PAVE PAWS Radar Facility

Prepared for

PAVE PAWS Public Health Steering Group

June 2004

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1 Introduction

Broadcast Signal Lab has performed measurements, modeling, and analysis of the radio frequency emissions (RFE) of the PAVE PAWS AN/FPS-115 radar located at the Massachusetts Military Reservation on Cape Cod. This work was divided into three distinct task groups:

1) Measure the emissions of the radar in open, publicly accessible locations throughout Cape Cod. Fifty locations both on and near Cape Cod were selected.
2) Measure the ambient emissions from all other sources in the VHF and UHF radio frequency spectrum. Ten locations on Cape Cod were selected.
3) Using a mathematical model of the PAVE PAWS antenna supplied by the MITRE Corporation (not affiliated with Mitretek), prepare a radio frequency propagation plot of the emissions from the radar into the Cape Cod environment.[1]

1.1 Overview of the PAVE PAWS Radar

The Air Force Space Command operates the PAVE PAWS solid-state phased-array radar located atop Flatrock Hill on the Massachusetts Military Reservation to provide warning of intercontinental ballistic missile (ICBM) and sea-launched ballistic missile (SLBM) attacks against North America as part of an early warning network. The PAVE PAWS facilities also perform a space surveillance mission. In general, during the missile warning and space surveillance missions, the PAVE PAWS is actively transmitting less than 25 percent (typically 18 percent) of the time and is listening more than 75 percent (typically 82 percent) of the time. The specific duty cycles for missile warning and space surveillance missions are discussed below. The Cape Cod PAVE PAWS is one of two such early-warning radar installations and other similar types of installations around the world that complement one another in order to maximize their ability to perform these important national defense missions.

[1] Throughout this report we use the term “environment” to refer specifically to the environment on the ground, which is where the study is focused on determining human exposure to PAVE PAWS energy. Thus, “environment” means here, “the locations on land that are accessible to humans.”

To detect and determine attack characteristics of ICBMs and SLBMs aimed at North America, the radar generates what is called a "surveillance fence." This constitutes the center of the main beam scanning at elevations between 3 and 10 degrees above horizontal over a 240 degree scan azimuth (120 degrees per face of the radar). The RF signals transmitted from each of the array faces form one narrow main beam with a width of 2.2 degrees.

The surveillance fence is normally at 3 degrees above the horizon. In the missile warning mode, the direction of the beam is steered according to a computer-programmed pattern, moving from one beam position to another. In the surveillance mode, both faces of the radar are simultaneously active, sending out two beams separated by 120 degrees in azimuth moving in a fashion similar to automobile windshield wipers. Under normal operational circumstances, the radar is transmitting 11 percent of the time to maintain the surveillance fence, and waiting/receiving the returned signal 89 percent of the time. The PAVE PAWS is capable of transmitting for up to 18 percent of the time to perform the missile warning mission when there is no space surveillance mission. Details of the surveillance sweeping action are discussed in section 3.6.2 below.

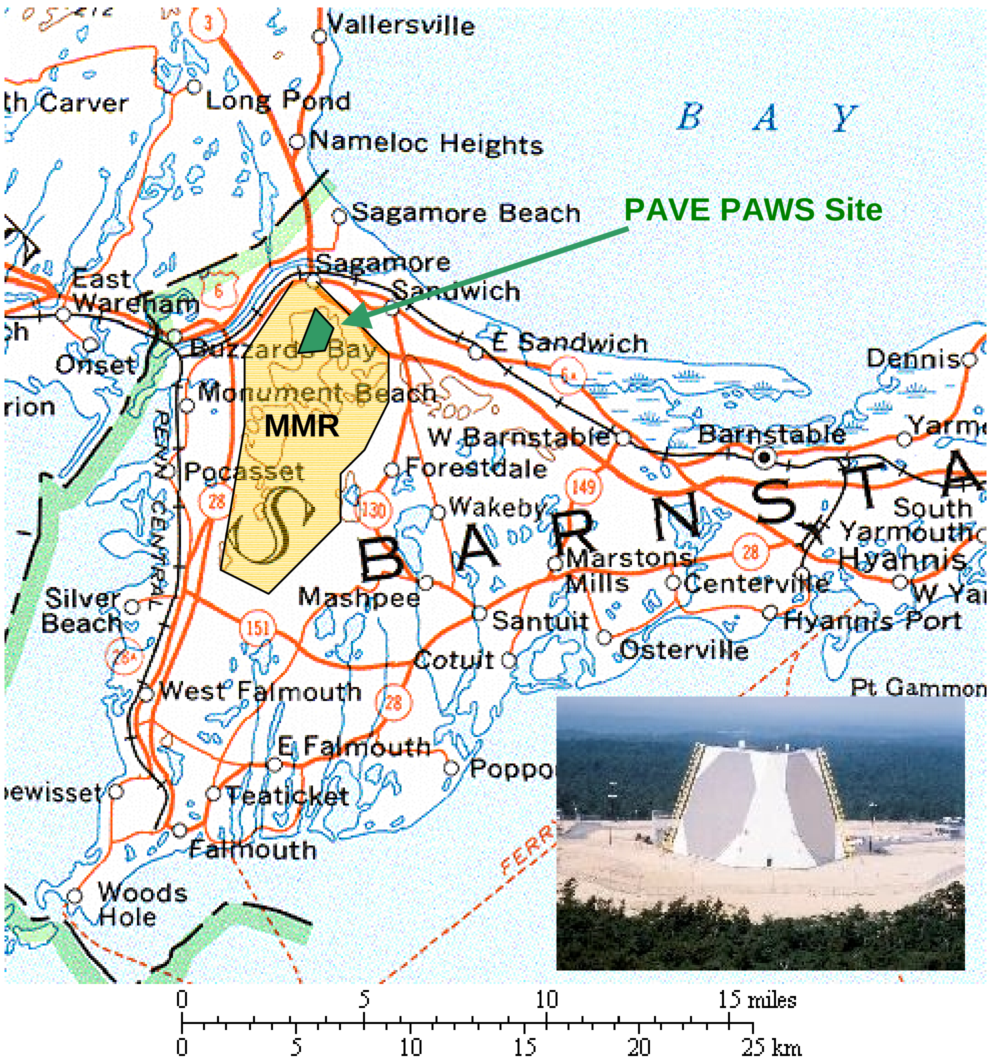
The space surveillance mission is conducted to track and catalog earth satellites and to identify other space objects. The radar is capable of focusing on particular objects or a small cluster of objects. The radar can transmit from 7 to 25 percent of the time, as long as the maximum average time, in any combination of modes (i.e., missile warning and space surveillance), does not exceed 25 percent.

The PAVE PAWS is a phased-array radar that transmits pulsed radio frequency (RF) signals within the frequency range of 420 to 450 megahertz (MHz). These signals are reflected back to the radar by objects of interest. The returned signals are analyzed to determine the location, distance, size, and speed of the object. The energy of the PAVE PAWS radar is emitted in the portion of the radio spectrum called *UHF* (Ultra-High Frequency). This band of radio frequencies contains other emissions more familiar to the general public, including UHF TV transmissions, public safety radio communications (police, fire, etc.), business communications, and wireless telephone communications, among many others.

The PAVE PAWS is housed in a 32-meter (105-foot) high building. Two flat antenna arrays transmit and receive the RF signals generated by the radar. Each array face contains 1,792 active antenna elements out of a total of 5,354 elements. The additional 3,562 elements per array face are not used. There are no plans to use these additional elements, and these elements cannot be easily activated due to a lack of solid-state transmitter/receiver modules, a lack of interconnecting cabling, and a lack of the necessary infrastructure for heating and cooling the elements. The computers, computer monitors, tape drives, disk drives, and associated equipment, which control the generation of the RF signals and then analyze the returned signals, are housed inside the radar building. The two array faces are 31 meters (102 feet) wide, and are tilted back 20 degrees from vertical. The active portion of each array face is situated in the center of a circle 22.1 meters (72.5 feet) in diameter. Each active antenna element is connected to a dedicated solid-state transmitter/receiver module located within the radar building that provides 322 watts of power for transmitting RF signals and amplifies the returning signal. The peak power output from the radar is determined by these solid-state modules which operated in "Class C" saturated mode. Software algorithms determine radar beam patterns, duty cycles, and pulse width.

The PAVE PAWS radar is located within the Massachusetts Military Reservation on the high ground of upper Cape Cod, near the Cape Cod Canal. See Figure 1-1.

Figure 1 -1 Locus Map of PAVE PAWS Radar Facility



Recall that the main beam never reaches the ground. As with any antenna used to focus energy in a beam, the phased array antenna "spills" out a small percentage of its energy into the local environment while it focuses the bulk of its energy in the airborne beam. This spillage is contained in what are effectively "mini-beams" called *sidelobes.* These sidelobes contain significantly less energy than the main beam. It is the sidelobe energy of the radar that has been a cause of concern to Cape Cod residents.

The radio frequency energy measurements described in the Final Test Plan are designed to obtain a validated characterization of the environmental levels of radar energy, and of other ambient radio frequency energy across Cape Cod. The measurements, predictions, and analysis produced data that will be utilized by an independent public health expert in its follow-on study.

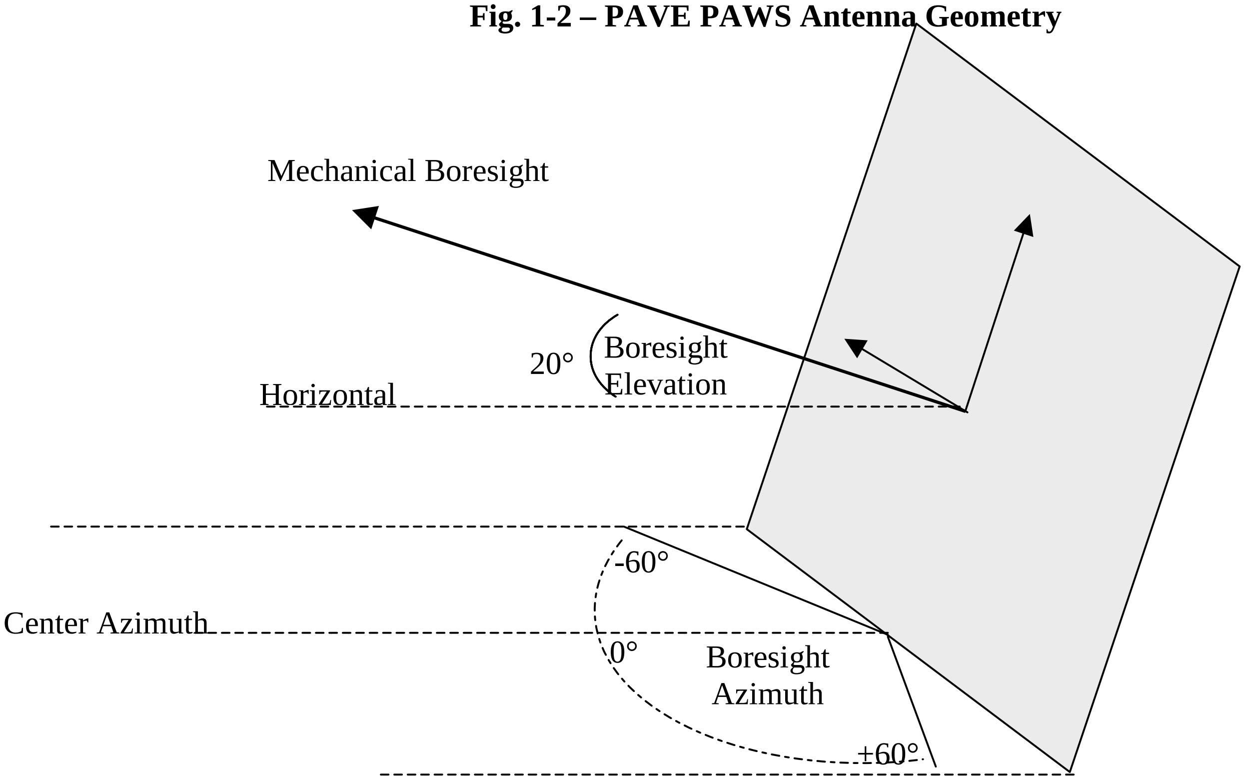
The antenna model utilized in this study approximates the PAVE PAWS antenna pattern in a fashion that creates a grid of estimated emissions for the antenna patterns for each beam position. The math describing the antenna pattern is an approximation of the manner in which the sidelobes are created by the ensemble consisting of 2677 antenna elements on each radar face (1792 "active" elements that emit energy and 885 "dummy" elements that do not, which together create a uniformly spaced grid of elements). The fact that the array consists of so many individual elements gives a degree of "fine structure" or "granularity" to the antenna pattern, much like a mosaic is composed of small tiles that together create an image.

This fine structure of the PAVE PAWS array makes the problem of modeling the antenna extremely complex. Nevertheless, a very useful model for the present purpose can be constructed by approximating the electrical current distribution of the 2677 individual array elements by a continuous distribution. Just as a series of many dots on a graph can be described as a line or a curve, the many antenna elements on the radar array can be described by a unified formula. Just as more dots form a smoother line, so, too, a large number of antenna elements permits the creation of a "smoother" unified antenna model. Since the number of elements is very large, this simpler model enables the construction of a model which will predict where the peaks and valleys of the sidelobes are and how strong they are. Over time, with the movement of the beam, these peaks and valleys average out to produce an "averaged" antenna model for computing RF exposure.

The PAVE PAWS radar has several key characteristics relating to its geometry and orientation that are described in the following paragraphs.

The two faces of the phased-array antenna are oriented to provide surveillance and tracking over a 240-degree arc of azimuth. Each face has a *mechanical boresight* (Figure 1-2) which is the direction perpendicular to that face, such that a line drawn at right angles to the surface of the face will point along the mechanical boresight (sometimes also called *broadside* to the array). The mechanical boresight of each face is tilted 20 degrees above the horizontal to provide radar coverage at elevation angles up to 85 degrees. For the purposes of site selection this *elevation* of the mechanical boresight is not relevant (it is relevant to the antenna modeling process, described elsewhere). However, the *azimuths* of the mechanical boresight of the two faces are important in the site selection process and will be discussed below. These two azimuths are located at 47 (approximately Northeasterly) and 167 degrees (approximately South by Southeasterly) from true north.

Fig. 1-2 – PAVE PAWS Antenna Geometry



At any moment in time each phased-array antenna creates one and only one narrow *main beam* that can be electrically steered to any elevation angle from 3 to 85 degrees above the horizon and to any azimuth up to + 60 or – 60 degrees from the boresight. When the radar is in operation, slightly over one-half of the time this beam systematically paints a *surveillance fence* that is approximately three degrees above the horizon. Hardware and software controls within the radar prevent pointing the beam below 3 degrees elevation. However, the process of generating the *main beam* also creates numerous *sidelobes* that are essentially very weak beams (20 to 40 dB weaker than the *main beam*). The direction and intensity of the sidelobes depends on the position of the beam. Because the *main beam* is swept in discrete steps across the sky, the sidelobes change with each step. Just as BSL's antenna model must account for the constantly changing sidelobe positions over time, the field measurements must take into account the variations in emissions in various directions.

Section 3 and Appendix A provide more details on the PAVE PAWS antenna. Section 5 and Appendix C provide details on the MITRE antenna model.

1.2 Overview of BSL's Work

BSL performed peak and average RF power density measurements of the PAVE PAWS signals as described in the Final Test Plan[2]. These measurements were conducted at 50 sites based on the test plan requirements and the exposure assessment objectives determined in coordination

[2] Ref. 5, Section 3

with the public health contractor. At all times during the measurements the radar was performing its normal search and tracking operations.

BSL performed 30 MHz to 3 GHz peak and average power density measurements at 10 locations, in order to establish an RFE baseline for comparison purposes with the PAVE PAWS emissions. All ten of these locations were on Cape Cod and were determined in coordination with the public health contractor. The site selection rationale was explained in the test plan[3]. The results of these measurements are presented in Section 4 of this report as a frequency-weighted computation of the measured fraction of the Maximum Permissible Exposure (MPE).

BSL utilized the ComStudy propagation modeling software[4] in conjunction with an analytical model of the PAVE PAWS antenna supplied by the MITRE Corporation[5] to estimate the radio frequency exposure from the PAVE PAWS in a matrix of 1.5-acre cells across Cape Cod and into Plymouth County. In addition, BSL performed a "drive test" which measured the signal strength of a 455 MHz radio beacon located atop the PAVE PAWS facility to provide validation of the computer propagation model.

1.3 Organization of the Report

This section (Section 1) of the Final Test Report provides an overview of the work done by Broadcast Signal Lab, gives a brief introduction to the PAVE PAWS phased array radar, describes the organization of this document, and lists the key supporting documents.

Section 2 of this document (Methods and Locations) summarizes the site selection and measurement philosophy for each of the three tasks.

Section 3 presents the results of the PAVE PAWS RFE measurements, provides information on the 50 measurement sites, describes how the data were taken, presents BSL's observations about the data, and provides a comparison with the results of measurements taken previously by others.

Section 4 presents the results of the ambient RFE measurements, provides information on the 10 measurement sites, describes how the data were taken, and presents BSL's observations about the data including a comparison of the RF exposure levels from the PAVE PAWS and the ambient environment.

Section 5 discusses the propagation modeling task, including presenting the results of measuring the signal strength of the propagation test beacon located atop the PAVE PAWS facility, description of the drive test route, description of the propagation modeling methodology, and BSL's observations including comparison with the PAVE PAWS RFE measurements reported in Section 3.

[3] Ref. 5, Section 4
[4] Ref. 45
[5] Ref. 6 and Appendix A

Section 6 concludes the body of the Final Test Report with a list of things accomplished in the course of this project.

Following the body of the report are numerous appendices. The first three appendices (Appendices A, B, and C) support the three major sections of the main body of the report. These three appendices supply more detail about the three task groups described above. The other appendices (Appendices D through L) provide further data, discussions of specialized topics, and information on calibration of the test equipment.

The goal of this radio frequency energy (RFE) measurement and prediction project is to provide a public health expert, International Epidemiology Institute (IEI), with validated geographic exposure data that supports the public health expert's epidemiological study. Broadcast Signal Lab and IEI collaborated in developing the criteria for the execution and output of this study.

The work conducted by Broadcast Signal Lab is described in detail in the Final Test Plan that was accepted by the PAVE PAWS Public Health Steering Group (PPPHSG) in January 2004. The Final Test Plan outlines the rationale and methods for obtaining the measurement data. This Final Report will not unnecessarily tread old ground and will rely on the foundation of the Test Plan to explain many of the nuances of the field work. Readers are encouraged to review and refer to the Test Plan for more detail on particular aspects of the measurement and propagation modeling processes. Where appropriate, this report provides a summary review of Test Plan specifics and gives additional details on the measurement and modeling processes not covered in the Test Plan.

There are numerous appendices that go into further detail on various aspects of the work listed in Table 1.

Table 1 Appendices

Appendix A	The PAVE PAWS RFE Measurement Task	Appendix H	Average Antenna Pattern Derivation
Appendix B	The Ambient RFE Measurement Task	Appendix I	Drive Test Consolidation Procedure
Appendix C	The Propagation Modeling Task	Appendix J	PAVE PAWS Site ID
Appendix D	Equipment Calibration and Measurement Accuracy	Appendix K	Ambient Site ID
Appendix E	Contents of the CD-ROM Data Set	Appendix L	Ambient Measurement Charts
Appendix F	Broadband RFE Survey	Appendix M	List of References
Appendix G	Computing the Effective Radius of the Earth from Surface Meteorological Data		

1.4 Other Supporting Documents

This study is the latest in a sequence of analyses of the emissions of the PAVE PAWS radar. Studies were conducted at the time that the radar was placed in operation in 1978-79 and again in 1986. The reports on these studies are:

1. "Final Environmental Impact Statement, Operation of the Pave Paws Radar System at Otis Air Force Base, Massachusetts, Part 1: Basic EIS and Appendices," Department of the Air Force, Document HQ AFS TR 79-04, Part 1 (May 1979)

2. "Radiation Intensity of the PAVE PAWS Radar System," National Research Council (NRC), Assembly of Engineering (1979)

3. "Analysis of Exposure Levels and Potential Biologic Effects of the PAVE PAWS Radar System," National Research Council (NRC), Assembly of Life Sciences Report No. HQ AFSC TR 79-07 (1979)

4. "Radio Frequency Radiation (RFR) Survey for the AN/FPS-115 PAVE PAWS Radar, Cape Cod AFS MA 18-30 Sep. 1986," Report #86-33, Air Force Communications Command, EMC/QFIRC Branch, Engineering Division, 1839 Engineering Installation Group, Keesler AFB, MS 39534-6348

5. "RF Power Density Exposure at Ground Level for the PAVE PAWS Radar at Cape Cod – Questions and Answers," MITRE Corporation, Bedford, MA (August 2000)

2 Methods and Locations

The details of methodology and siting of the measurements are presented in each section—PAVE PAWS Measurements, Ambient Measurements, and Propagation Analysis. A brief overview is presented here.

In summary, field measurements of power density of the PAVE PAWS emissions in the environment were conducted at fifty locations on and near Cape Cod. Measurements were conducted for 90-minute periods at each location to ensure that realistic average and peak emissions figures would be obtained. The methods employed are consistent with the methods employed in the previous studies.[6] Methods are also consistent with relevant guidelines and consensus standards[7], including IEEE/ANSI C95.3-2002. Section 3.6 of the Final Test Plan contains a detailed discussion of the rationale for the choice of the 50 PAVE PAWS RFE test sites. These sites were selected in consultation with IEI and the PPPHSG. Appendix J of this Final Report provides updated terrain path profiles, locus maps, and photographs for the sites.

Field measurements of ambient emissions of VHF and UHF energy in the Cape Cod environment were conducted at ten locations carefully selected to be at various distances from

[6] Ref. 1, 2, 3, 41
[7] Ref. 7, 8, 9, 44

the nearest sources of radio/TV broadcast and land mobile communications facilities. These ten sites ensured the measurement of a reasonably wide dynamic range of ambient emissions levels. As with the PAVE PAWS measurements, the ambient measurements were conducted in a manner consistent with relevant measurement guidelines and consensus standards. Section 4.6 of the Final Test Plan contains a detailed discussion of the rationale for the choice of the 10 Ambient RFE test sites. These sites were selected in consultation with IEI and the PPHSG. Appendix K of this Final Report provides updated locus maps and photographs for the sites.

Finally, field measurements were conducted of a test transmission from the roof of the PAVE PAWS radar facility. This test, called the Drive Test, was intended to evaluate the actual attenuation to a 456-MHz radio signal from the radar facility to points on Cape Cod. This test was conducted in a manner that is consistent with communications industry practice for evaluating the path loss between a transmitter and multiple receiving locations. A test vehicle was driven on 250 miles of roads on and near Cape Cod to sample the test emission and compute the path loss. The results of the Drive Test were compared with the results of computer estimated propagation model of test transmitter to determine the accuracy of the propagation model.

The data collection methods were outlined in the "Final Test Plan— Survey of RFE Field Emissions from the PAVE PAWS Radar Located at Cape Cod Air Force Station, Massachusetts."[8] The field tests were executed according to the Final Test Plan. This Final Report outlines in more detail the methodology employed to execute the measurements. Minor deviations in the Test Plan were limited to two changes. The final location of each measurement was adjusted as needed to ensure safety, accommodate site access issues, and/or improve measurement quality as determined by the field crew. There was also a minor change in the method of collecting PAVE PAWS measurements at the fifteen high-antenna sites. When it became apparent that there was a high degree of consistency between successive fifteen-measurement samples at high-antenna sites, Broadcast Signal Lab chose to take the sixth and final measurement at each site at a low antenna elevation for comparison. This resulted in the derivation of one additional factor in the analysis, a ground-clutter loss factor.

The following three sections contain the results, methodology, sites, and analysis for each of the measurement tasks.

[8] Ref. 5

3 PAVE PAWS Measurement Task

This section discusses the PAVE PAWS measurements. First, a general overview of the results is presented. The raw data are available in accompanying files. Then overviews of the sites and the measurement methodology are presented. Finally, this section culminates with an analysis of the results.

3.1 Results

Table 2 contains the peak and average power flux density obtained for each of the 50 sites. It presents the same value in three ways—microwatts per square centimeter ($\mu W/cm^2$), equivalent volts per meter (V/m), and decibels with respect to microwatts per square centimeter ($dB\mu W/cm^2$). Our measurements were directly in units of received power (microwatts), which lends itself to presentation of results in power density. Since the previous studies in 1978 and 1986 also reported field intensity in units of volts per meter, Table 2 includes columns of average and peak equivalent field intensity for reference. These values are computed directly from the power density by a simple conversion.

$$E_{(V/m)} = \sqrt{3.77 * S_{(\mu W/cm2)}}$$

IEEE refers to power density in units of mW/cm^2, but is often convenient to use microwatts instead when the measured levels are particularly low with respect to milliwatts. In the 1978 and 1986 studies of the Cape Cod PAVE PAWS installation the researchers employed $\mu W/cm^2$. When reporting power densities in this report, BSL will employ $\mu W/cm^2$.

Table 2 PAVE PAWS Measurement Summary

Site #	Zone #	Average uW/cm^2	Average EquivalentV/m	Average dBμW/cm^2	Peak uW/cm^2	Peak Equivalent V/m	Peak dBμW/cm^2	SiteName	Site Elevation Above Mean Sea Level (ft)	Distance (mi)
1	3	0.0000449	0.0130	-43.5	0.94500	1.89	-0.2	Pilgrim Monument site	49	27.38
2	3	0.0000093	0.0059	-50.3	0.15100	0.75	-8.2	Snows Field, Snowfield Rd	131	30.06
3	3	0.0000013	0.0022	-58.9	0.01130	0.21	-19.5	CCNS HQ	42	30.69
4	3	0.0000006	0.0015	-62.2	0.00013	0.02	-39.0	Nauset Light Parking	49	31.11
5	1	0.0000730	0.0166	-41.4	0.15300	0.76	-8.2	Rock Harbor parking	13	27.5
6	1	0.0000288	0.0104	-45.4	0.01590	0.24	-18.0	Great Hill	98	29.3
7	1	0.0000132	0.0071	-48.8	0.15600	0.77	-8.1	Keith Lane circle	108	23.6
8	1	0.0000004	0.0013	-63.7	0.00010	0.02	-40.0	Island Pond Cemetery Harwich Ctr	42	24.1
9	1	0.0038167	0.1200	-24.2	15.20000	7.57	11.8	Scargo Hill	65	18.5
10	1	0.0000026	0.0031	-55.9	0.01700	0.25	-17.7	Woodside Cemetery, Yarmouthport, off Summer Street	65	15.5
11	1	0.0000056	0.0046	-52.5	0.03060	0.34	-15.1	Main St Centerville	62	12.3
12	2	0.0000821	0.0176	-40.9	0.15700	0.77	-8.0	Athletic field Rt 130, north of Ashumet Rd	108	7.17
13	2	0.0000022	0.0029	-56.6	0.06290	0.49	-12.0	Davisville Rd E Falmouth school	36	12.3
14	4	0.0001590	0.0245	-38.0	1.48000	2.36	1.7	Mashnee Island Grill	6	5.58
15	3	0.0346000	0.3612	-14.6	14.70000	7.44	11.7	Shawme Crowell State Park	167	0.95
16	1	0.0007775	0.0541	-31.1	1.52000	2.39	1.8	Cardinal Rd Circle	252	2.8
17	1	0.0000104	0.0063	-49.8	0.15400	0.76	-8.1	Rt 130 @ Cotuit Rd	173	3.71
18	1	0.0001323	0.0223	-38.8	1.54000	2.41	1.9	Mt Hope Cemetery Rt 6A	22	2.75
19	1	0.0002228	0.0290	-36.5	1.53000	2.40	1.8	Jarves Rd @ Factory St	13	2.45
20	1	0.0000589	0.0149	-42.3	1.40000	2.30	1.5	Sandwich Public Library	9	2.07
21	1	0.0025595	0.0982	-25.9	15.00000	7.52	11.8	Holder Ln Circle	134	2.59
22	3	0.0001935	0.0270	-37.1	1.54000	2.41	1.9	Scusset Beach Parking 1	9	2.63
23	3	0.0049833	0.1371	-23.0	15.00000	7.52	11.8	Scusset Beach Parking 2	9	2.62
24	3	0.0000200	0.0087	-47.0	0.15300	0.76	-8.2	Sagamore athletic field	13	1.44
25	3	0.0006477	0.0494	-31.9	1.51000	2.39	1.8	Church Lane @ Cape Pine Rd	85	2.21
26	3	0.0002408	0.0301	-36.2	1.51000	2.39	1.8	Sagamore School, Williston Rd	68	1.83
27	5	0.0007808	0.0543	-31.1	1.51000	2.39	1.8	Brigantine Passage Dr	137	1.85
28	5	0.0000008	0.0018	-60.8	0.00037	0.04	-34.3	Eagle Rd	104	4.3

Site #	Zone #	Average uW/cm^2	Average EquivalentV/m	Average dBμW/cm²	Peak uW/cm^2	Peak Equivalent V/m	Peak dBμW/cm²	SiteName	Site Elevation Above Mean Sea Level (ft)	Distance (mi)
29	6	0.0000109	0.0064	-49.6	0.13500	0.71	-8.7	Rt 6E Canal overlook	124	1.9
30	6	0.0000010	0.0020	-59.8	0.00287	0.10	-25.4	Cypress St @ Rt 6 Bypass	32	3.28
31	4	0.0000107	0.0064	-49.7	0.15300	0.76	-8.2	Monument Beach former water tank	75	4.29
32	4	0.0000061	0.0048	-52.1	0.15100	0.75	-8.2	Wings Neck Road @ Harbor Drive	6	6.6
33	2	0.0000007	0.0016	-61.7	0.00433	0.13	-23.6	Scraggy Neck Rd at Cataumet Club	32	7.36
34	2	0.0000252	0.0098	-46.0	0.14900	0.75	-8.3	Carolyn Cir Forestdale	127	5.46
35	2	0.0000010	0.0020	-59.8	0.13000	0.70	-8.9	Barnstable County Fairgrounds	78	9.34
36	2	0.0000001	0.0007	-69.1	0.00024	0.03	-36.3	Falmouth HS, Brickkiln Rd	52	11.7
37	2	0.0000004	0.0012	-64.0	0.01220	0.21	-19.1	Mashpee Senior Center	29	9.28
38	2	0.0000002	0.0009	-66.9	0.00007	0.02	-41.7	N Falmouth School	26	9.05
39	1	0.0000002	0.0008	-67.2	0.00339	0.11	-24.7	Marstons Mills School, 2095 Main St	62	9.55
40	3	0.0039367	0.1218	-24.0	14.40000	7.37	11.6	Shawme Crowell State Park	167	0.95
41	3	0.0000572	0.0147	-42.4	0.15400	0.76	-8.1	Burbank St and Main (Rt 130)	72	1.31
42	1	0.0000003	0.0010	-65.9	0.05620	0.46	-12.5	Old County Rd, Near State Hatchery	42	5.68
43	6	0.0000000	0.0002	-78.3	0.00002	0.01	-46.6	Assawompset School	98	22.05
44	6	0.0000002	0.0009	-66.6	0.00005	0.01	-43.0	Onset School, Union Ave	32	6.3
45	3	0.0000777	0.0171	-41.1	0.15000	0.75	-8.2	Ellisville Rd	127	5.27
46	3	0.0000005	0.0014	-63.0	0.00079	0.05	-31.0	October Lane circle, Cedar Bushes	16	10.1
47	3	0.0004528	0.0413	-33.4	1.46000	2.35	1.6	Freezer Road @ Tupper Road	16	1.97
48	2	0.0000009	0.0019	-60.3	0.01170	0.21	-19.3	Stone School Circle, Otis AFB	98	6.96
49	5	0.0000264	0.0100	-45.8	0.00918	0.19	-20.4	Post 'n Rail Av Cedarville	59	4.02
50	1	0.0000002	0.0009	-66.5	0.00008	0.02	-40.7	Barnstable HS, rear, use Falmouth Rd entrance	65	13

Because of the wide range of exposure magnitudes, the power density is presented logarithmically in decibels to make presentation more compact. 0 dBμW/cm^2 is the same as one microwatt per square centimeter. Ten decibels (dB) represents a ten-fold change in power density, 20 dB represents a 100-fold change, 30 dB a thousand-fold change, and so on. For example, a site with a –60 dB dBμW/cm^2 figure would have a radar power density that is one-millionth of a microwatt per square centimeter, i.e. one nanowatt per square centimeter.

Table 2 reveals that the radar emission power densities measured throughout the region span a range of about 10^6:1, which is a range of about one million to one or 60 dB. The highest radar level measured is –15 dBμW/cm^2. This was taken 30 feet above ground at Shawme Crowell State Park. At ground level at the same location, where human exposure occurs, the measured level was diminished by about ten dB due to ground clutter (vegetation, ground interaction, structures, etc.). Hence, the greatest measured human exposure potential was about –23 to –26 dBμW/cm^2, near the ground at Shawme Crowell, and at Scusset Beach and Scargo Hill.

At the other extreme, the lowest measured level, radar energy reaching behind the radar to Lakeville was measured at –78 dBμW/cm^2. In front of the radar, the lowest levels recorded were about –67 to –69 dBμW/cm^2 at locations in Falmouth, Barnstable, Eastham, and Wellfleet.

3.2 Sites

The PAVE PAWS measurements were conducted to obtain a representative sampling of the emissions of the radar that reach the Cape Cod environment. The 50 sites were selected to provide a cross section of variables that determine the radio frequency energy levels arriving in the human-occupied environment. Among these variables are:

1) The variations in the radar's emissions relating to the various "zones" of emissions around the radar—beneath the beam, beneath the beam with overlapping sidelobes, beyond the beam and still in front of the face, and behind the radar. (Figures 2 and 3)
2) The characteristics of the radar antenna pattern and the variations in pattern as the beam is swept across the sky,
3) The effects of distance from the radar to the observer, including free space loss and atmospheric refraction,
4) The effects of land cover, including vegetation and structures that can impede and scatter radio waves,
5) The effects of terrain that can obstruct or cause diffraction losses to radio waves approaching an observer.

Figure 2 Radar Zones

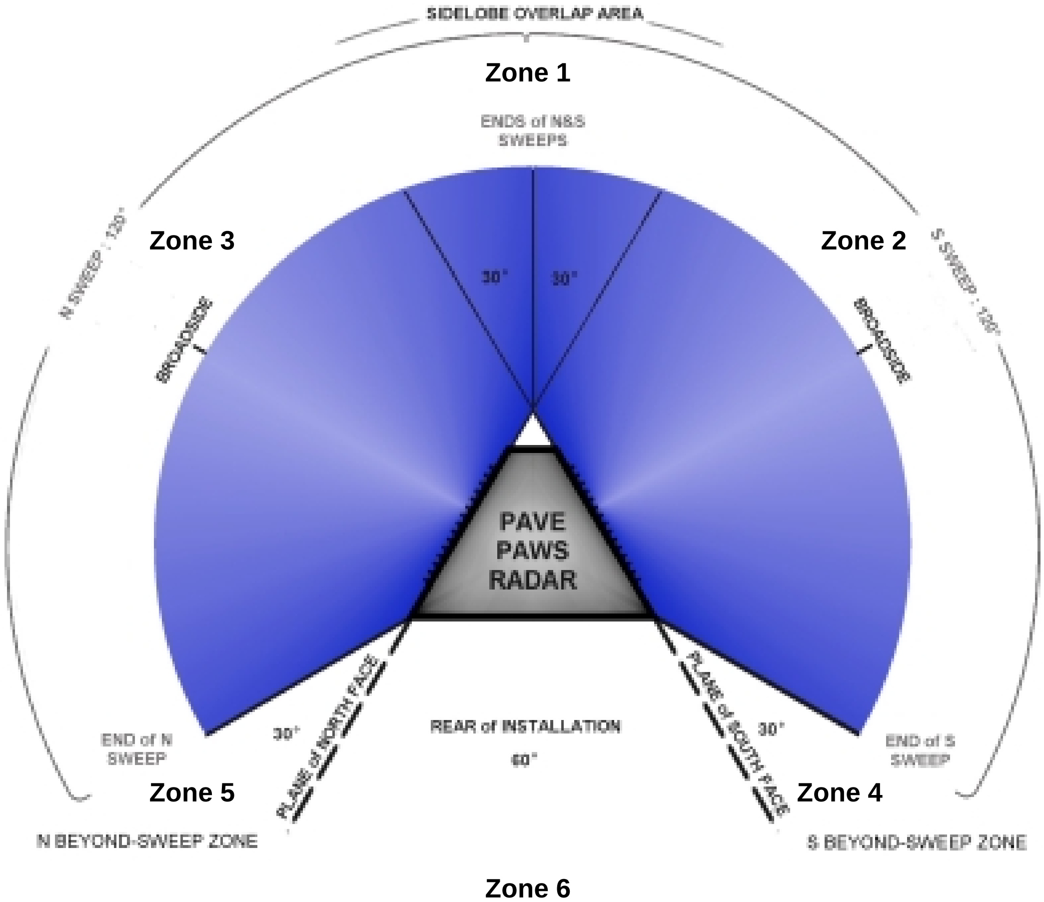
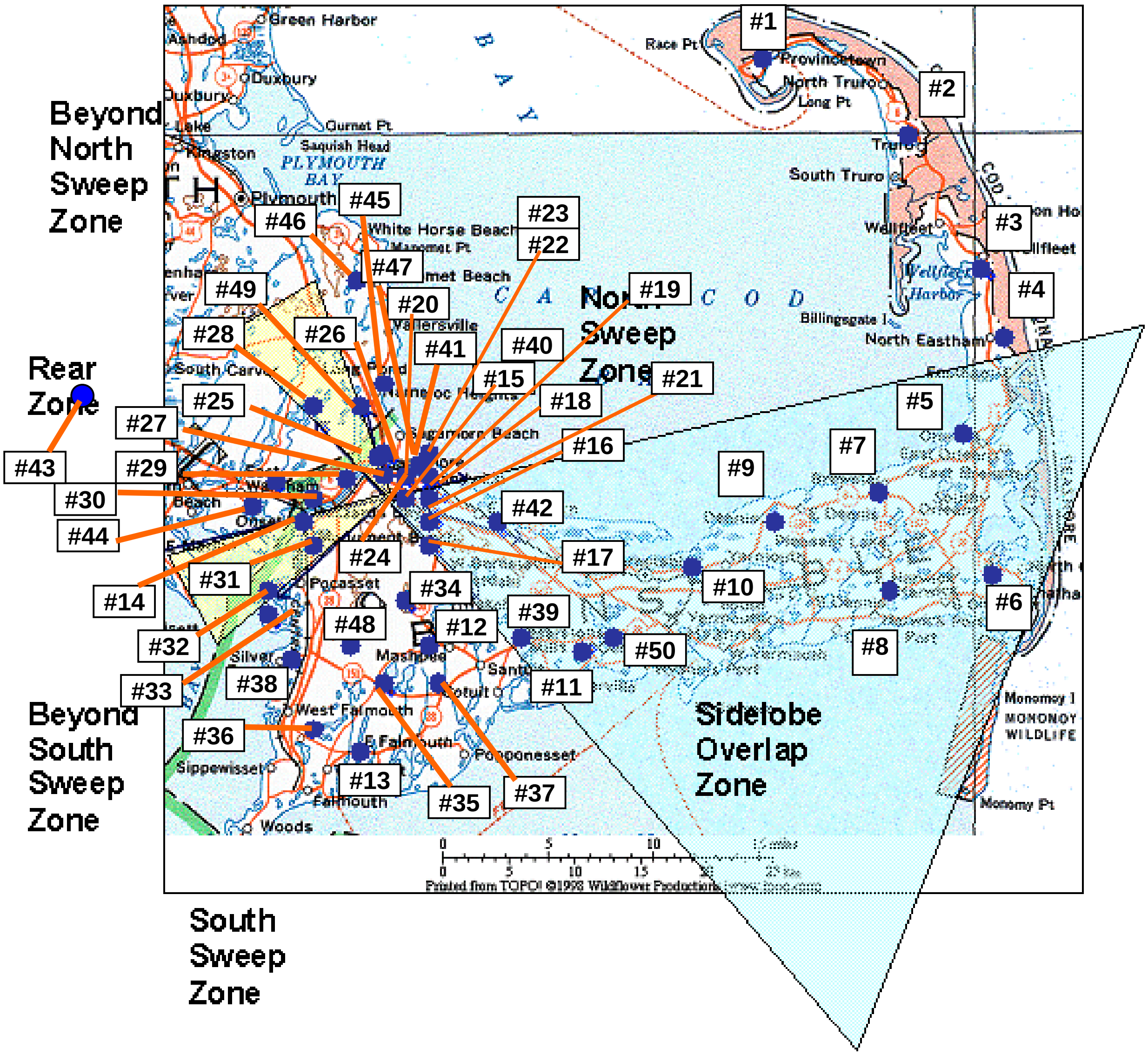

SIDELOBE OVERLAP AREA
Zone 1
ENDS of N&S SWEEPS
Zone 3
Zone 2
N SWEEP : 120°
S SWEEP : 120°
BROADSIDE
BROADSIDE
30°
30°
PAVE PAWS RADAR
PLANE of NORTH FACE
PLANE of SOUTH FACE
REAR of INSTALLATION
60°
30°
30°
END of N SWEEP
END of S SWEEP
Zone 5
Zone 4
N BEYOND-SWEEP ZONE
S BEYOND-SWEEP ZONE
Zone 6

Figure 3 50 PAVE PAWS Measurement Sites with Zones



The 50 measurement sites were selected to provide a variety of the conditions described above. The initial site locations were tentatively chosen from maps. The actual sites differ slightly from the initial sites in the Test Plan when engineers adapted to local conditions for safety, measurement quality, accessibility or other reasons. These final sites are summarized in Table 1, and detailed in Appendix A.

Sites 1-15 are the sites at which the measuring antenna was raised 30 feet above ground to clear local clutter ("high" sites). At the remaining 35 sites the antenna was placed about 8 feet above the ground ("low" sites).

3.3 Measurement Methodology

The measurement routines were not detailed in the Test Plan and are presented here. A more detailed presentation of the measurement process, including computer software methodology, accuracies, and data collection procedures is presented in Appendix A.

At the low sites a series of six 15-minute measurement routines were conducted. Each 15-minute routine took five minutes of measurement data at each of three orthogonal polarization angles. The antenna was moved approximately three feet between routines, covering a total of about 15 linear feet at each low site. Table 3 shows the sequence and timing of the measurements.

Table 3 Antenna Positioning Sequence

Antenna Positioning Sequence for Low Measurements (8 feet above ground)																		
Polarization	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Measurement Number	1			2			3			4			5			6		
Horizontal Distance from 1st Antenna Position	1st position			3 feet			6 feet			9 feet			12 feet			15 feet		
Duration	**15 minutes**			**15 minutes**			**15 minutes**			**15 minutes**			**15 minutes**			**15 minutes**		
Peak Data Collected (qty. of samples stored)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Average Data Collected (qty. of samples stored)	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500

At the high sites, six fifteen-minute measurement routines were also conducted. However, the antenna remained in the high position for five of the routines to obtain a longer-term analysis in one position. The sixth measurement was taken with the antenna mast retracted to about ten feet above ground. This provided a contrasting sample that reveals the impact of lowering the antenna from its high position above local clutter to being lower within the local clutter. Table 4 shows the sequence and timing of the measurements.

Table 4 Antenna Positioning Sequence

Antenna Positioning Sequence for High Measurements (30 & 10 feet above ground)																		
Polarization	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Measurement Number	1			2			3			4			5			6		
Horizontal Distance from 1st Antenna Position	1st position			0 feet			0 feet			0 feet			0 feet			0 feet		
Antenna Height	**30 feet**			**30 feet**			**30 feet**			**30 feet**			**30 feet**			**10 feet**		
Peak Data Collected (qty. of samples saved)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Average Data Collected (qty. of samples saved)	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
Duration	**15 minutes**			**15 minutes**			**15 minutes**			**15 minutes**			**15 minutes**			**15 minutes**		

Peak and average power density measurements were derived for each site. Measurement procedures, including field calibration and zeroing, dynamic range setting, data collection procedures and system operation are contained in Appendix A. The measurement setup, a functional description of the data collection software, and the algorithms for processing the data are presented in Appendix A as well.

In summary, the Agilent power meter sampled the true average power continuously, reporting the average to the computer about 25 times a second. During each 5-minute sample of one polarization angle the power meter was also configured to store the largest peak power value that occurred in one 20-millionth of a second interval (approximately 22 cycles of a 435 MHz emission, which is 1/100,000th of a 5 millisecond radar pulse). This fast peak power measurement should not be confused with the familiar radar value—peak pulse power—which is the average power of the entire pulse. Brief power excursions above the peak pulse power that BSL has captured by the fast method would be lost in a longer time sample averaging the entire pulse.[9]

Data files of each measurement routine are included in the data CD provided with this report. A readme file is stored on the CD describing the file structure and nomenclature. The data

[9] The fast power sample in this study also should not be confused with the extremely high speed sampling of the rate of change of each individual cycle of the radar waveform conducted in a separate study by others of the "time domain" of the radar waveform close to the facility. The measurements in this study measure true power rather than rate of change in the electric or magnetic fields; however in the far field there is a direct relationship among the three.

files for each 15-minute measurement routine were processed to create a composite power density (summing the average power in each of three orthogonal polarizations), yielding six average power densities per site. At the low-antenna sites these six average power densities were then combined to yield a median power density, a standard deviation, and an average power density for the site.

At the high-antenna sites, the five high measurements were processed in the same manner as the six measurements at the low sites. The sixth measurement at each high site was taken at a lower level and is processed separately for comparison.

Attention was paid to the noise floor of the instrumentation to ensure that the instrument noise did not falsely elevate any of the lower level measurements. This method is described in Appendix A with the data collection methodology and further with the post processing discussion.

The peak power density at each site was also derived from each set of six low-site routines and five high-site routines, as well as from the single low measurement at the high sites. The peak power densities were derived by taking the highest peak in each of three antenna orientations and summing them, even though they occurred at different times, under the assumption that a peak in the electric field in one polarization will be accompanied by a peak in the other two polarizations. A discussion of the rationale for this peak power density derivation is contained in Appendix A.

3.4 Observations

3.4.1 Antenna Position Variations at Individual Sites

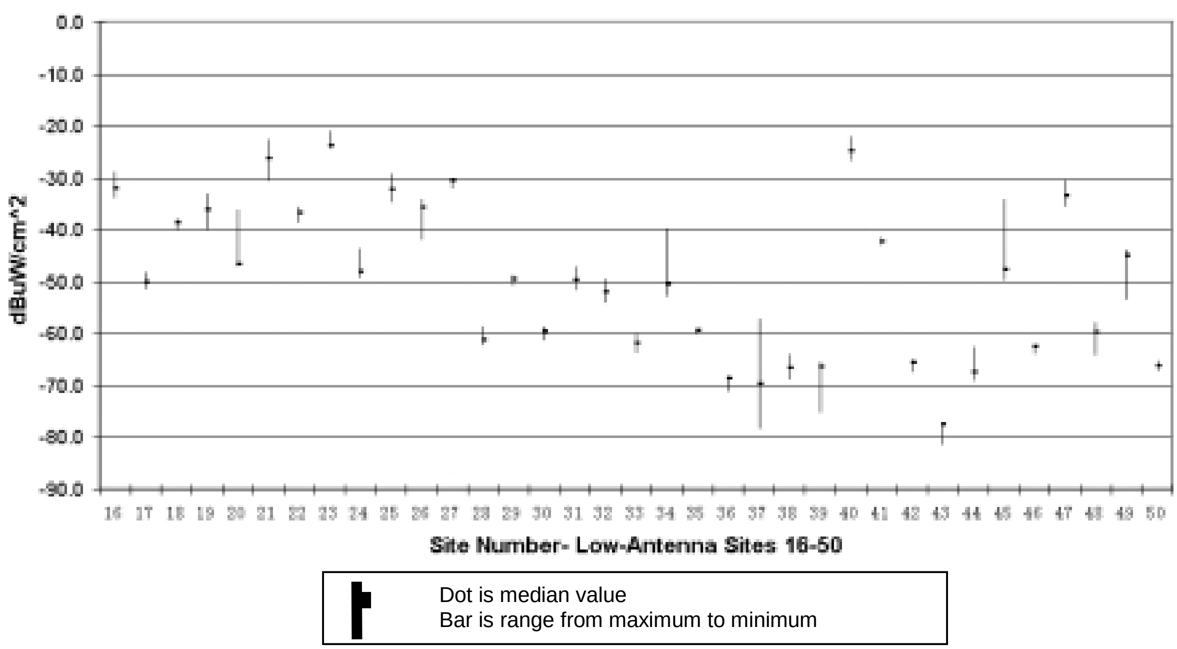
In the graphics below the data are presented in decibels with respect to one microwatt per square centimeter (dBµW/cm^2) for convenience in presenting data visually.

Figure 4 displays the maxima, minima, and median values of each of the low-antenna sites' six measurements. Recall that the receiving antenna was moved in three-foot increments every fifteen minutes during the measurement period. Figure 4 shows the median as a dot, and a line connects the median to the maximum and the minimum measurements. The figure reveals that for the most part, that there is minimal variation in power density (<<10 dB) as the antenna is moved in three-foot increments.

There are several possible causes of the variations in levels at a site. First, the position of the antenna is suspected as a factor due to its interaction with local reflection peaks and nulls. This phase cancellation/addition phenomenon is what prompted the six, three-foot-spaced measurements at each site. This phenomenon appears to be one of the lesser contributing factors.

A second cause could be interruptions in the emission of the radar. The radar emissions were monitored and notes were taken when radar emissions seemed unusual. Several times during the month of conducting measurements we were confronted with a brief cessation of radar emissions and phone calls to the facility confirmed the interruptions. While we believe our data collection supervision and our data processing have avoided false low values, we may have missed some interruptions that pulled down average powers. Such interruptions would create an artificially low average power for one of the six measurement cycles at a site, causing the “minimum” bar to extend asymmetrically below the median data point.

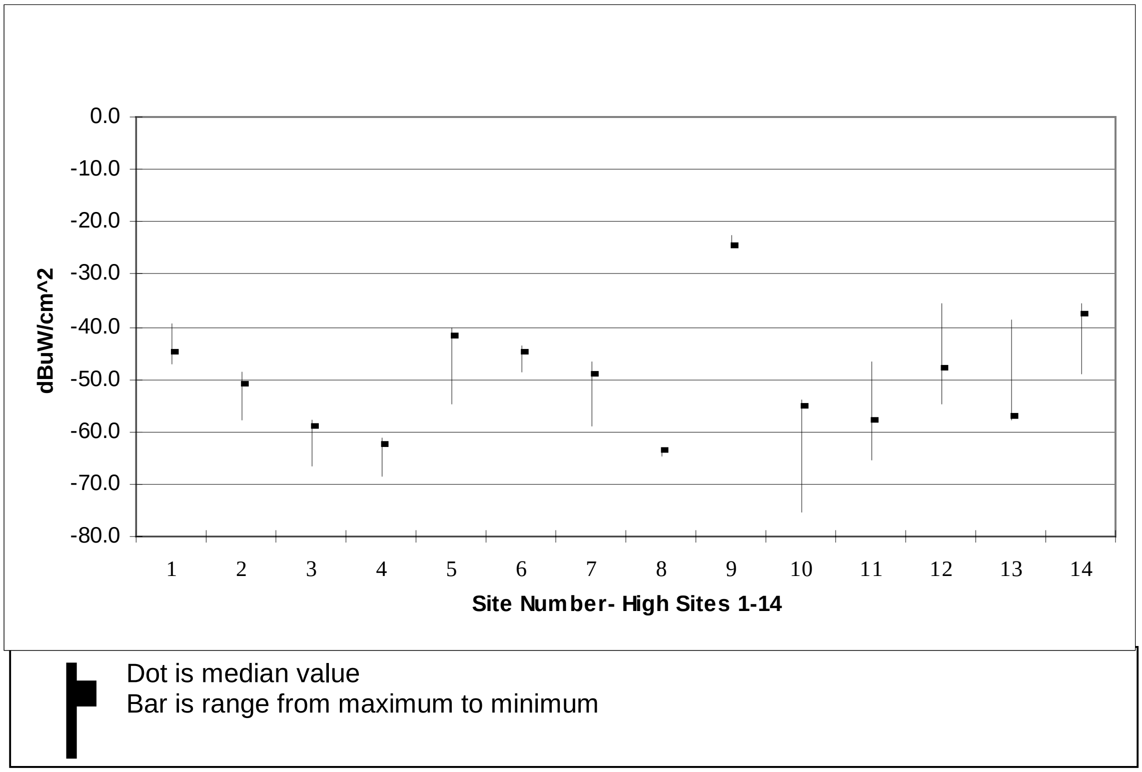
Figure 4 Spatial Power Density Distribution of Low PAVE PAWS Measurements



A third factor would be variations in the propagation of energy to the site during the time of the measurements. This factor would affect a series of fifteen-minute measurements even if the antenna were not moved laterally between each measurement. The antenna was not moved laterally during the high antenna measurements, in which five separate measurements were conducted in the same position. This enables the time variation (short-term) of the average level to be analyzed.

Figure 5 shows the fourteen high-antenna sites at which five fifteen-minute measurements were made in one antenna position. (Measurement at Site 15 was conducted with a single longer measurement that does not apply to this analysis). It appears that there is more variation (5 to 20 dB) in these sets of fixed-position measurements than in the low-antenna measurements in Figure 4. The two exceptions, Scargo Hill, Site 9, and Harwich Center, Site 8, had very little variation over time.

Figure 5 Time Variation in Power Density with Fixed Antenna Position



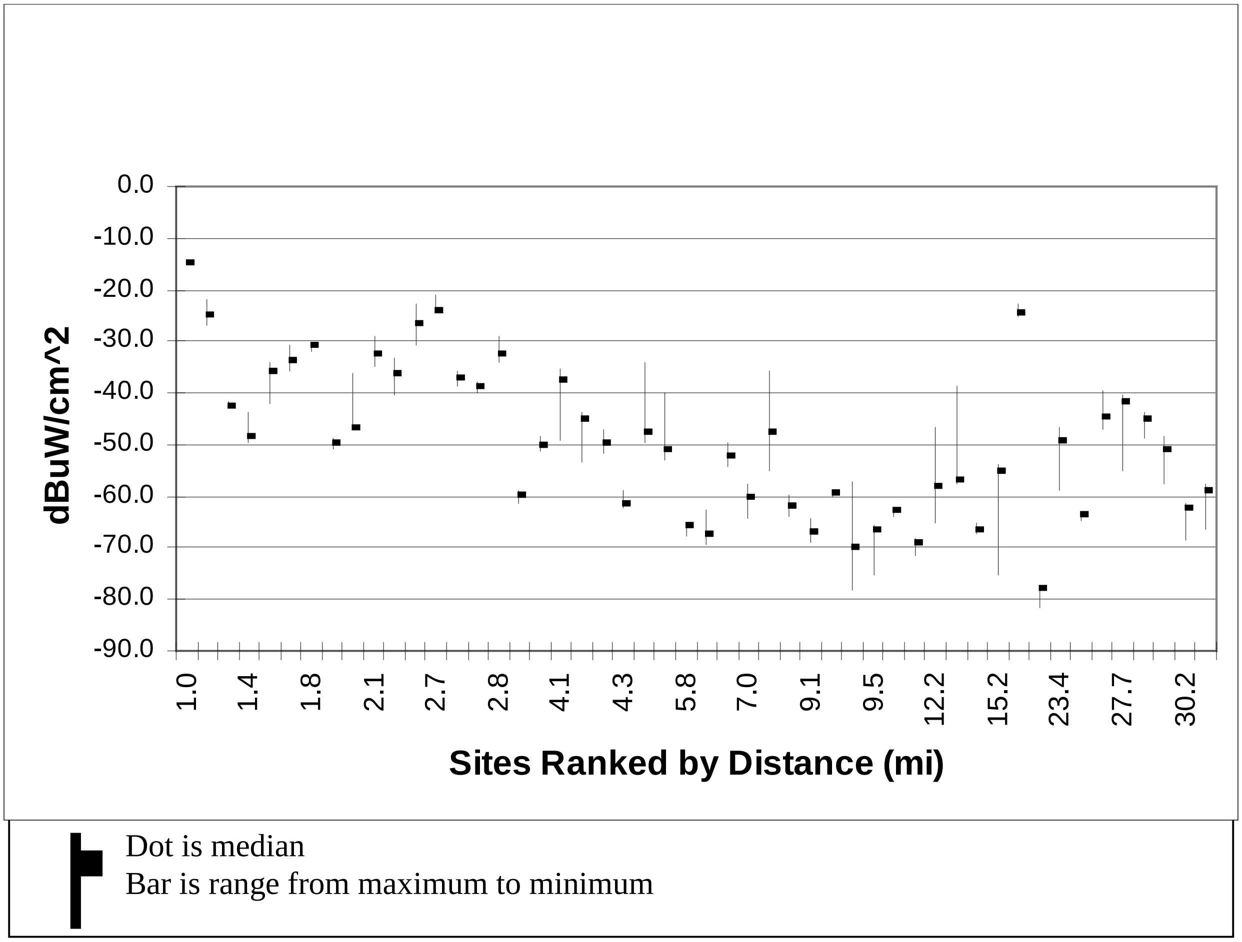
A distinguishing characteristic of most of the high-antenna sites is their greater distances from the radar than the majority of the low measurements. To consider this factor, the data for all 50 sites are reorganized in order of distance and presented in Figure 6. There does not appear to be a strong relationship between distance and temporal variation in power density at the high-antenna sites, although from 1 to 15 miles there is a hint of increasing variation in received level. Some site geometries may be more susceptible to temporal propagation variations than others.

For instance, sites from 7 to 15 miles were arbitrarily selected for examination because of the mixture of high and low variations among these sites. Four of the five sites with the high variations (~20 dB), numbers 10, 11, 12, 13, and 37, were high antenna measurements and had no apparent diffraction path between the radar and the receiving antenna. In contrast, six of the seven lower-variation sites, numbers 33, 35, 36, 38, 39, 46, and 50, have terrain-diffracted paths (and all were low-antenna sites).

Meanwhile, all but one site greater than 15 miles are high-antenna sites, each exhibiting lower variations than the high measurements at 7 to 15 miles. These sites beyond 15 miles have clear over-water paths or they have over-land paths with some diffraction.

It is hypothesized that over-land paths with no diffraction are most susceptible to short-term variations in incident power density, particularly more than a few miles from the radar. While over-water Fresnel effects may be relatively stable in a 90-minute period in winter, the over-land Fresnel effects may be more variable in such time periods. Similarly, the contribution of diffraction loss in diffracted over-land paths may diminish the relative impact of Fresnel losses, and therefore the degree of temporal variation due to variations in Fresnel losses. This hypothesis is by no means a certainty based on the data here, however it is consistent with our understanding of UHF propagation.

Figure 6 Spatial and/or Temporal Variations in Radar Average Power Density



The variations do not appear to be related to the radar antenna zone within which the site is located. Nor do the variations appear to be related to the local clutter at each site, as both built-up and more rural areas appear in both sets. Aircraft reflections could cause short-term variability in a site's radar power density, particularly in cases where the incident energy from the radar is surpassed by the intensity of the reflection arriving at the site. The possibility that aircraft reflections play a role in exposure is considered in Appendix A6. A shadowed site with its weaker radar energy may be more susceptible to the strength of an aircraft reflection, yet it is the non-shadowed sites that seem to exhibit the most variation. This would suggest that the most likely cause of the variations is the fluctuation of the energy over non-diffracted and non-water paths.

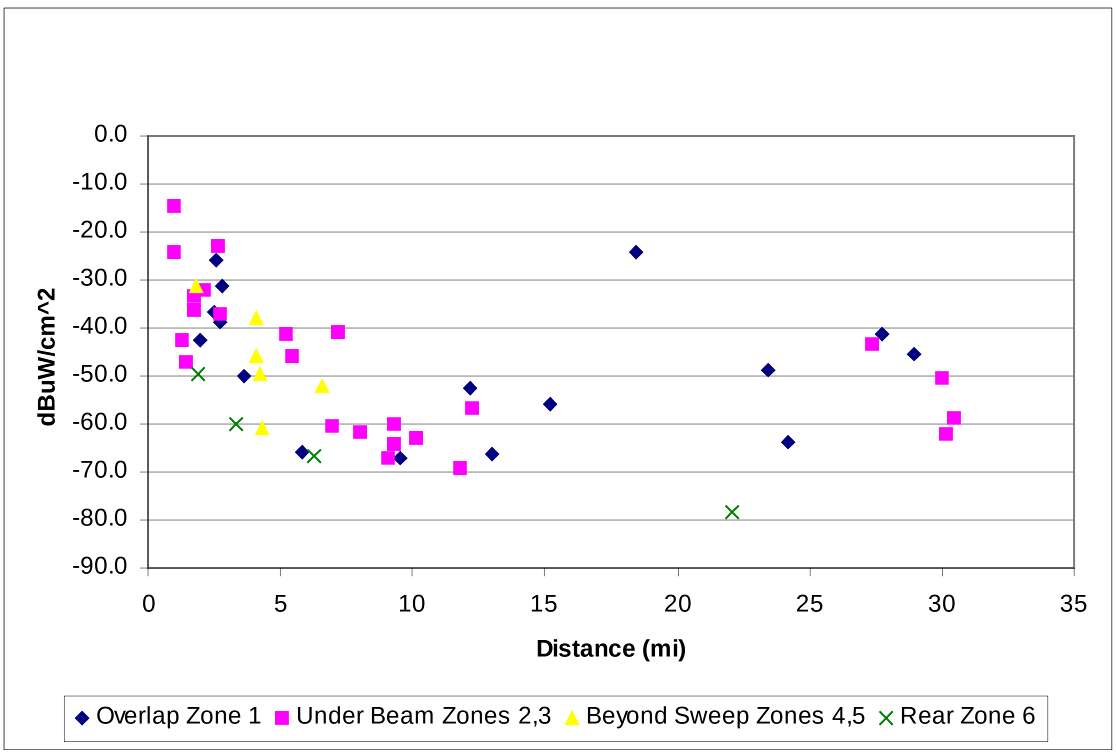
3.4.2 Propagation Characteristics Evident in Power Density Values

The shape of the curve formed by the median levels on Figure 6 suggests some characteristics of the measured levels with respect to distance, terrain and depression angle. First, while the most distant sites, are generally lower in level than those closest to the radar as would also be expected, they also tend to be higher than the sites in the middle. This is due to the distant sites being measured at locations where there were clear radio lines of sight and in several cases, unimpeded over-water paths.

Second, those sites closest to the radar exhibited a 30-dB range of levels, demonstrating the two other characteristics that have a strong impact on exposure to the radar—terrain obstruction and depression angle below the radar.

The combination of the above factors creates the undulating curve of the average power densities over distance in Figure 6. (The sites above are sorted by distance but are not proportionally spaced by distance). Figure 7 plots the site averages for each set of six measurements per site, with distance represented linearly. The data are grouped by zone.

Figure 7 Average Antenna Power Density by Zone and Distance



The highest signal levels are obtained generally close to the radar, (less than 3 miles) at Shawme Crowell, Holder Lane, Cardinal Road, Scusset Beach, Church Lane, and Brigantine Drive. One exception is the Scargo Hill lookout tower, eighteen miles away, appearing as a high point near the center of Figure 7. From Scargo Hill the radar was clearly visible to the naked eye and both Scargo Hill and the radar are well above the intervening terrain. There is also no ground clutter at the site to diminish the incident energy. Finally, the depression angle from the radar to Scargo Hill is about one-tenth of a degree, which means it is closer to the edges of the first sidelobe than sites at deeper depression angles. Clear line of sight to other prominent reflecting objects may also contribute to the power density at the site. With the proportionally higher intensity of first sidelobe energy, the ideal signal path, and the potentially strong incoming reflections, Scargo Hill can be expected to see relatively strong average power densities from the radar, despite its distance.

The lowest signal level was obtained 22 miles west of the radar in Lakeville. This location is directly off the rear of the radar and does not have line of sight to it. Other sites with the lowest power density levels are in the 6 to 12 mile distance and are shielded by terrain from the radar line of sight. Sites in Barnstable, Falmouth and Plymouth are among this group.

3.4.3 Path Loss Exponent

The propagation characteristics of an environment can be illustrated by a propagation analysis of the measured data. Figure 9 incorporates path loss exponent lines to illustrate the approximate effect of the terrain and clutter on the propagation of the received signal at each site. To facilitate this representation, the distance scale is compressed logarithmically. This enables easy comparison of the data using path loss exponents.

In free space, radio waves diminish proportionally to the square of the distance. The square-law path loss exponent (n = 2) is the fundamental loss component in any propagating radio wave in space. To factor in terrain and ground clutter losses in a coarse estimate of path loss, one means is to increase the path loss exponent from the square for free space to a higher value. Table 5 shows some common path loss exponents.

Table 5 Path Loss Exponents for Different Environments[10]

Environment	Path Loss Exponent, *n*
Free Space	2
Urban Area Cellular Radio	2.7 to 3.5
Shadowed Urban Cellular Radio	3 to 5
In building Line of Sight	1.6 to 1.8
Obstructed in Building	4 to 6
Obstructed in Factories	2 to 3

Figure 9 contains the same distance and power density values of the PAVE PAWS measurements, as in Figure 7, but with the change to a logarithmic distance scale and the addition of three path loss exponent lines. The upper line represents square-law free space loss. The middle and lower lines represent cube and fourth-power losses respectively.

The high-antenna measurement at Shawme Crowell, one mile from the radar, is employed as the reference for the square law line because of the clear line of sight and the thirty-foot high

[10] Reference 53

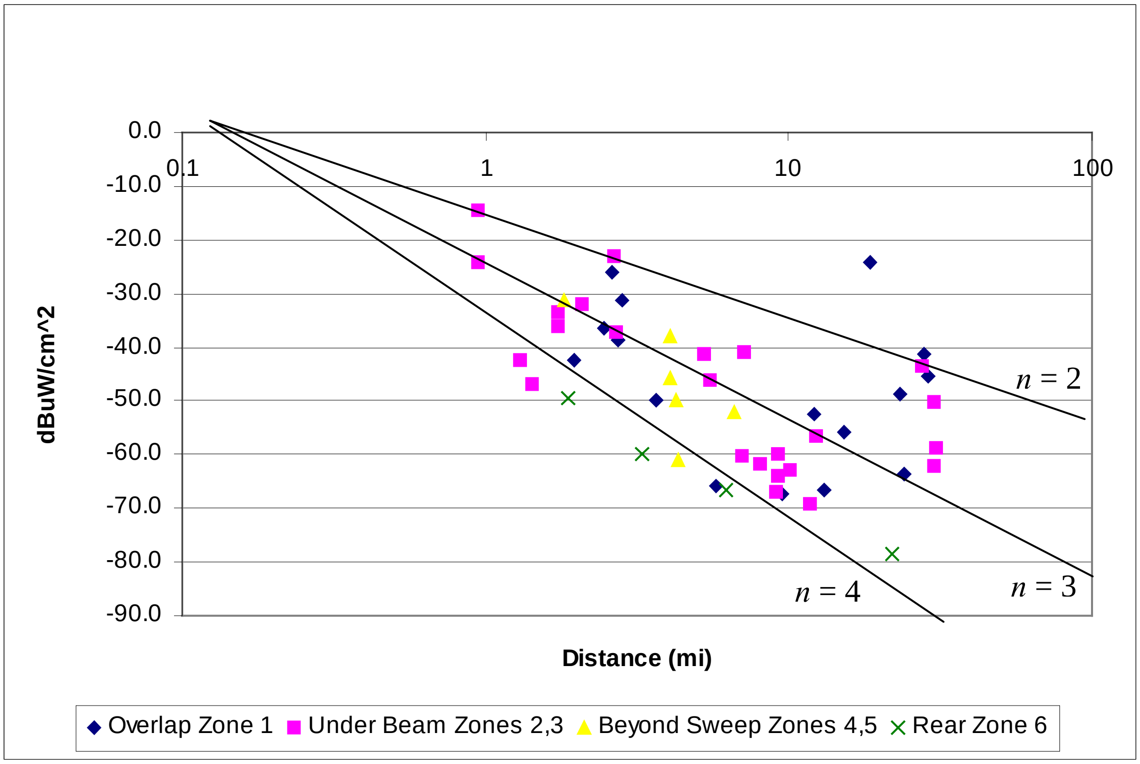
antenna. The photo of the radar facility in Figure 8 was taken from a height of approximately 20 feet above ground, about ten feet lower than the high antenna measurement.

Figure 8 Views of PAVE PAWS Facility from Treetops at Shawme Crowell State Park and Ground Clutter at Site

A further assumption is made that the low antenna height measurement at Shawme Crowell represents a point on the cube line because there is still geographic line of sight, but Fresnel and clutter losses play a more significant role at this antenna elevation. The cube line is referenced to the lower Shawme Crowell measurement. The fourth-power line is referenced to the origin of the other two.

The zones 1, 2, and 3 are the locations above which the beams pass during each sweep cycle. (Figures 1 and 2) Zone 1 is distinguished from zones 2 and 3 by the geometry of sidelobes both faces having an opportunity to overlap their emissions. With the exception of Scargo Hill, the upper right hand marker on Figure 9, the distributions of zone 1 and zones 2 and 3 measured levels appear to the eye to be quite similar. It supports a rationalization that at most, the energy in the overlap zone represents a potential doubling of the average exposure in zones 2 and 3 where there is presumed to be negligible overlap. A doubling of power is about a 3 dB increase, a relatively minor fluctuation compared to the other causes of variation in exposure under the sweeps of the beams.

Figure 9 Average Power Density by Zone and Log Distance,



The zones 4 and 5 sites mostly have a radio line of sight (not including ground clutter, which may be a factor in the results) and fall mostly around the n=3 exponent on Figure 9. If this analysis is realistic, then the average emissions beyond the beam sweep regions are comparable to those beneath the beam. That is, from the perspective of an observer on the ground it would appear that the average radar emissions are the same to zones 1 through 5. Accounting for distance and obstructions, being beneath the beam or beyond the beam does not appear to affect the average exposure. This discussion continues in the section on antenna modeling, which addresses the relationship between depression angle below the radar and the higher order low-level sidelobe power.

In a nutshell, it appears that most locations avoid being illuminated by any substantial first sidelobe energy and the higher order sidelobe energy controls the average all around the front of the radar.

Finally, the four locations behind the radar are consistently the lowest levels of all the zones, after taking distance into account. If the average environmental emissions off the rear of the radar were comparable to the front, then the Zone 6 data would be more evenly distributed between the square and fourth power lines. It is reasonable to assume, based on the path loss exponents of the other data that the average environmental emissions behind the radar may be 20 to 30 dB less than in front.

Also, the left three data points of the Zone 6 measurements (on Figures 7 and 9) were taken at locations with radio line of sight that could be expected to show 2^{nd} to 3^{rd} power losses comparable to similar locations in front. This further reinforces the observation that the emissions behind the radar are substantially less than in front.

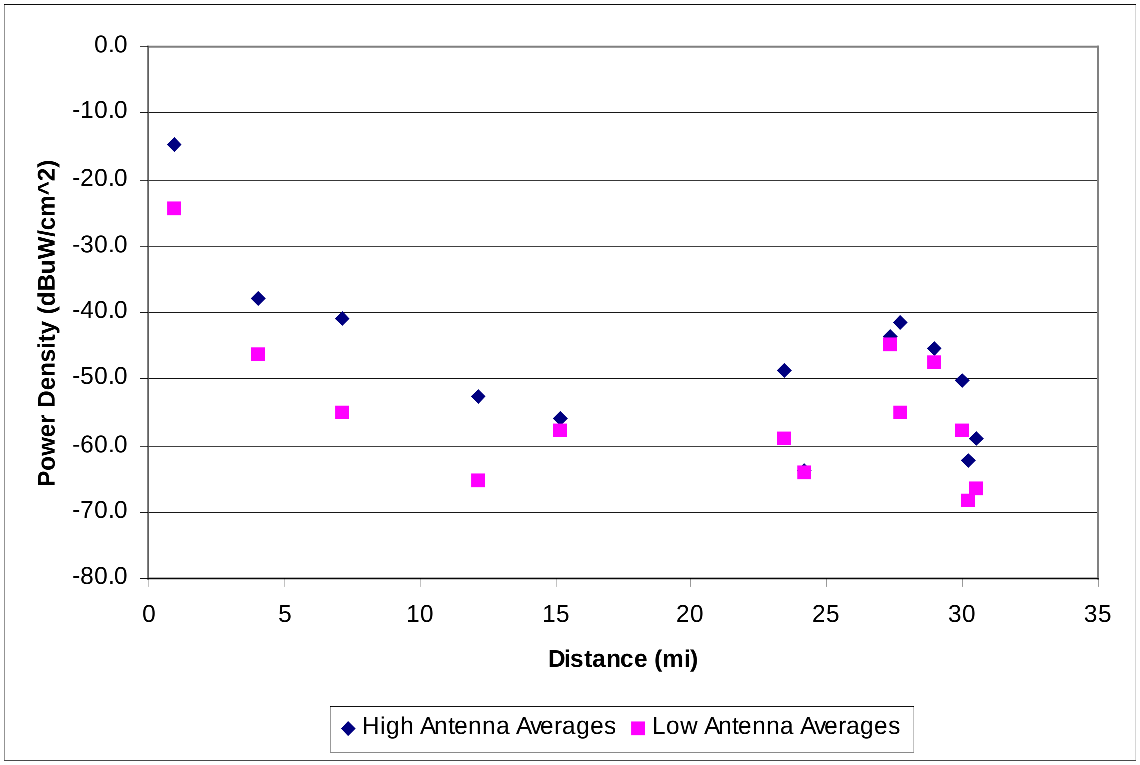
The emissions encountered behind the radar may be partly or substantially from environmental reflections rather than solely from emission off the rear of the structure. Appendix A6 discusses the role of the radar's reflections in the environment.

It is hypothesized that the reflections off the 500-foot high smokestack direct more radar energy to the rear of the radar than the radar itself does. This would be due to the manner in which the stack intercepts more powerful first-sidelobe energy and redirects some of it to locations that are receiving only second sidelobe or no sidelobe emissions. The height of the stack is also a key element because radar reflections off the stack, in effect, "broadcast" in a manner that is similar to FM and TV transmissions from similar tower heights. The reflections off such prominent structures do increase environmental levels of radar emissions where they would otherwise be lower, but they do not have enough power to exceed the 60-dB range of exposure levels observed in this study.

3.4.4 High versus low measurements

Another aspect of the measurements is the distinction between high and low antenna heights. The 30-foot high measurements were each complemented by a ten-foot high measurement at the same position. Figure 10 compares the 30-foot averages for each site with their corresponding ten-foot height measurements. It shows that the local clutter, which should affect the lower antenna height measurements the most, reduces the incident energy from the radar by 0.3 to 13.6 dB. The median is 7.6 dB and standard deviation is 4.7 dB.

Figure 10 Paired Average levels at 30-ft and 10-ft AGL Antenna Heights



3.4.5 Peak to Average Ratios

Peak exposure values are also a required component of the study. The peak value from each site is presented in Table 2. Some discussion of peak-to-average ratios will be helpful to illuminate later discussions of the peak antenna pattern in the third portion of this report.

As described above, the peak values that Broadcast Signal Lab recorded represent peaks within individual radar pulses. If an individual pulse is not uniform in amplitude upon arrival at the measurement site the measured peak values will not relate to the average power levels in proportion to the radar duty factor. If pulses were generated perfectly and propagated perfectly, the pulse duty factor would determine the peak-to-average ratio. As a superficial first pass at the pulse duty cycle, consider the radar operating continuously with 15-16 ms pulses in every other 54 ms resource interval. The duty factor would be about 0.15. That is, the average power would be about 1-2 tenths of the "peak" pulse power, given perfect pulses, resulting in an 8 dB peak-to-average ratio. At the extreme, consider a case that no long-range surveillance pulses are emitted, and each 54 ms resource window contains three 0.9 ms short-range surveillance pulses. This most extreme case peak-to-average ratio would be 13 dB. The measured peak to average ratios are about two orders of magnitude greater than these hypothetical limit values.

Analysis of the peak-to-average ratios at the various sites reveals very consistent results as shown in Table 6. Treating the high antenna sites as a separate data set, it turns out the variation in peak-to-average levels is nearly identical when comparing the high antenna sites as a group with the low antenna sites. The median values and the standard deviations for each set are within 1 dB of each other. This helps confirm that using the peak-to-average approach is reasonable and repeatable, and that the peak to average ratios are unaffected by the immersion of the receiver in local clutter or not.

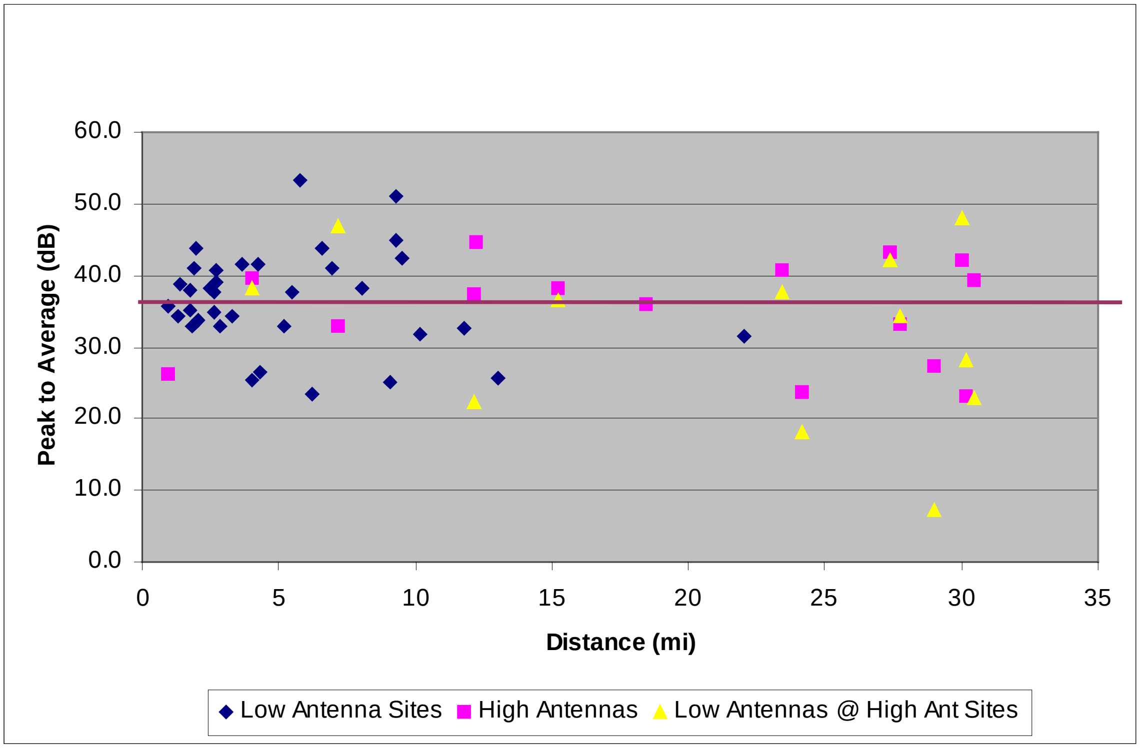
Table 6 Peak-to-Average Ratios

Site	Pk/Avg (dB)	Site	Pk/Avg (dB)	Site	Pk/Avg (dB)
1	43.2	18	40.7	35	51.0
2	42.1	19	38.4	36	32.8
3	39.4	20	43.8	37	44.9
4	23.3	21	37.7	38	25.2
5	33.2	22	39.0	39	42.5
6	27.4	23	34.8	40	35.6
7	40.7	24	38.8	41	34.3
8	23.7	25	33.7	42	53.4
9	36.0	26	38.0	43	31.7
10	38.2	27	32.9	44	23.6
11	37.4	28	26.5	45	32.9
12	33.8	29	40.9	46	31.9
13	44.6	30	34.4	47	35.1
14	39.7	31	41.6	48	40.9
15	26.3	32	43.9	49	25.4
16	32.9	33	38.1	50	25.7
17	41.7	34	37.7		

Peak-to-Average Ratios (dB)		
	High Antenna Sites	Low Antenna Sites
Average	35.3	36.6
Median	37.4	37.7
Standard Dev	7.1	6.8

To consider the relationship between the location of the measurement and the peak-to-average ratios, Figures 11 and 12 were plotted. Figure 11 shows the relationship between the ratios and distance and antenna height. Figure 12 shows the relationship between the ratios and distance and antenna zone. There appears to be no particular relationship between antenna height, or antenna zone, and the peak-to-average ratio. There does appear to be a stabilizing effect when within three miles of the radar. These data points are clustered around the same median as the rest of the points, but they show substantially less variation among them. This suggests that there are propagation effects that modify the peak-to-average ratios at greater distances, but in a manner that is just as likely to increase the ratio as decrease it.

Figure 11 Peak-to-Average Ratios by Distance and Antenna Height



Reference line placed at 37.7 dB median value

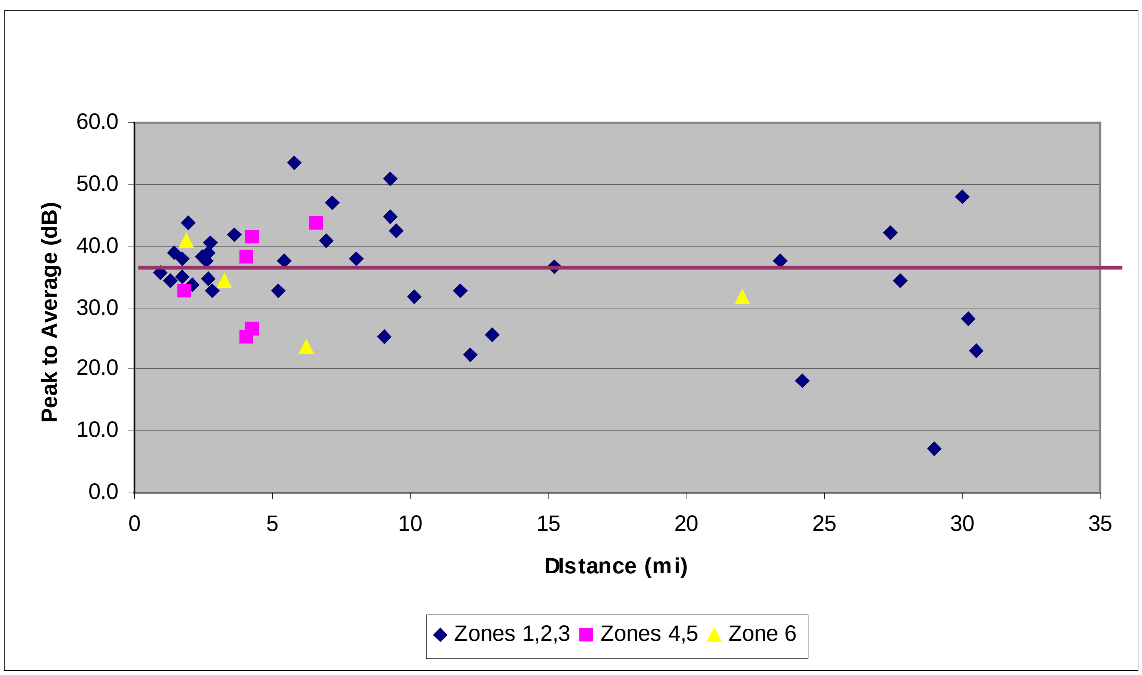
Figure 12 Peak-to-Average Ratios by Distance and Zones

3.4.6 Reflections

Reflections from structures were also a subject of concern to some participants in the PPPHSG process. The literature (EPA, reference 54) contains information about likely increases in UHF power density due to reflections. Localized increases in power density of no more than a factor of 2.56 (i.e. 4 dB) may occur in occupied space. This is due to reflection phenomena in the vicinity of the observer, and indeed, the median variation in sets of six PAVE PAWS measurements at 3-foot increments at each site was 4.3 dB. The most extreme variation was 21.2 dB and the least was 0.9 dB. The standard deviation of the variations at the 35 low-antenna sites was 4.1 dB.

While the six spatial measurements at 35 sites illustrate the effects of local scattering phenomena in a small area, this analysis does not necessarily account for potential reflections on a larger space scale resulting from reflections off very large structures. However, while observing incoming radar pulses during the entire measurement process, Broadcast Signal Lab identified a means for evaluating strong reflections off distant objects. As discussed in further detail in Appendix A6, the chirped waveform of the radar pulses provides a means to estimate the path delay of an interfering pulse reflection.

In addition to the path delay analysis in Appendix A6, there is a way to estimate the ratio of the reflection power to the energy incident from the radar. Several pulse samples are presented below in Figures 13 and 14. They have the various beat frequencies described Appendix A6. These beats also have a modulation depth that indicates the ratio between the direct and reflected pulses. Taking the ratio of one half the height of the ripple that is the beat frequency



and dividing by the height of the actual pulse, to the center of the ripple, provides the ratio between the two interfering copies of the pulse. In the first image, the ripple is shallow, representing an approximate 8:1 ratio in two pulses and perhaps 20:1 in the third pulse. This means there is a 9 to 13 dB difference between the direct and reflected pulses arriving at the observation point.

In a more extreme example, Figure 14 shows a modulation depth of nearly 100 percent which means the reflected and direct copies of the arriving pulses are about the same level, or 0 to 2 dB apart. While there is no way to tell from the images collected when the reflected pulse is greater than the direct pulse or vice versa, the modulation depth of nearly 100% in Figure 14 demonstrates that at a minimum, a reflected pulse can rival the direct pulse in strength. At a location where a reflecting structure is exposed to substantially greater radar energy than is emitted directly toward the location, it is conceivable that the reflection arriving at the location may be stronger than the direct energy.

Appendix A6 hypothesizes that such a reflection from the Canal Electric smokestack could be the primary source of energy at the Canal overlook directly behind the radar. Reflections from prominent structures (and aircraft) in front of the radar are more likely to be evident behind the radar with its reduced emissions than elsewhere in front of the radar where a consistent background level of secondary sidelobe energy is already present. If these reflections are indeed a substantial contributor to the exposure conditions in the region, then our measurements have captured them in both the peak and average readings.

Figure 13 Pulse Triplet Modulated by Delayed Reflection

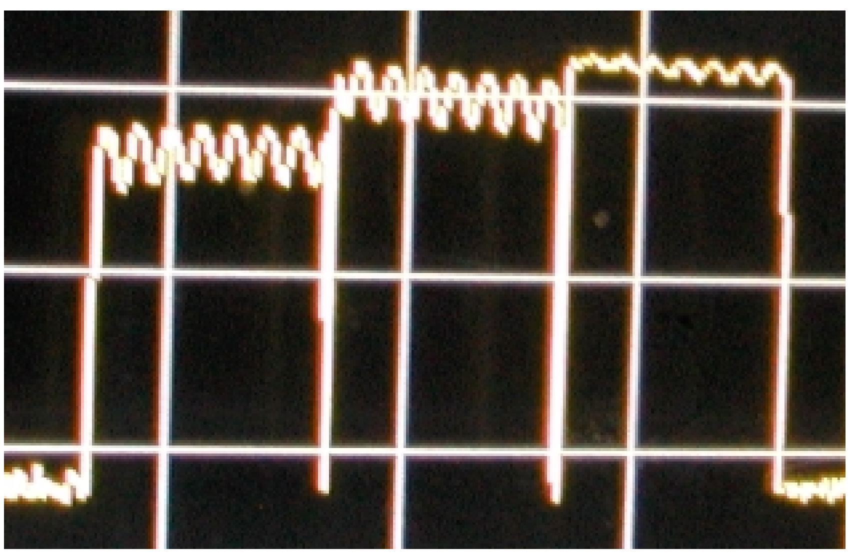
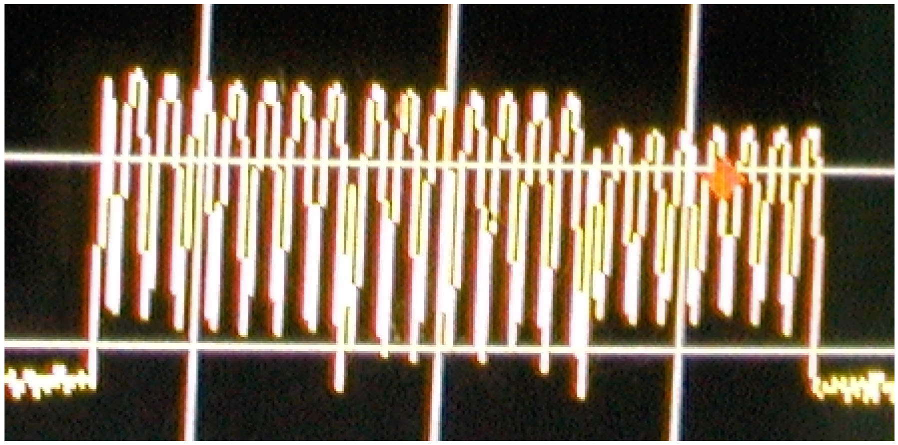


Figure 14 Pulse Triplet Deeply Modulated by Delayed Reflection



3.5 Summary Values

Table 7 contains a summary of some key characteristics observed in the peak and average measurements taken at the 50 sites.

Table 7 Table of Variations

Type of Variation	Source Data	Value	Standard Deviation
Signal losses due to local clutter	Compare high to low measurements at same site	7.6 dB	4.7 dB
Variations in signal level at a site	Median of the variances of 6-position measurements at individual sites	4.3 dB	4.1 dB
Ratio of major long distance reflection to incident energy	Modulation depth of beat frequencies in chirped pulses	100% or more	
Peak-to-average ratio	Peak-to-average analysis	37.5 dB	7 dB
Highest average power density observed	Shawme Crowell at 30 ft AGL	-15 dBuW/cm^2	

Highest human exposure observed	Scusset Beach parking lot near ground	-23 $dBuW/cm^2$	
Lowest power density observed	Lakeville near ground	-78 $dBuW/cm^2$	
Range of measured power densities	Highest – lowest	63 dB	
Range of measured human exposures	Highest – lowest	55 dB	

Figure 15 compares the measurements from the current study with those taken in 1978 and 1986. Of the present study's measurements, only sites out to seven miles distance are shown because the previous studies were conducted at less than that distance.

It is evident that the present study, using state of the art equipment, was able to delve more deeply into weaker signal areas to obtain measurements where the instrumentation noise of two decades ago would have precluded it. The noise floors of the previous tests precluded the taking of any data at levels less than –30 $dB\mu W/cm^2$.

Overall, the previous measurements appear to be generally higher than the current ones. There could be several reasons for this difference, including limitations of the previous test systems, or the manner in which the power density was derived from the measurements (the system operation and measurement philosophy were not clearly described in the test reports).

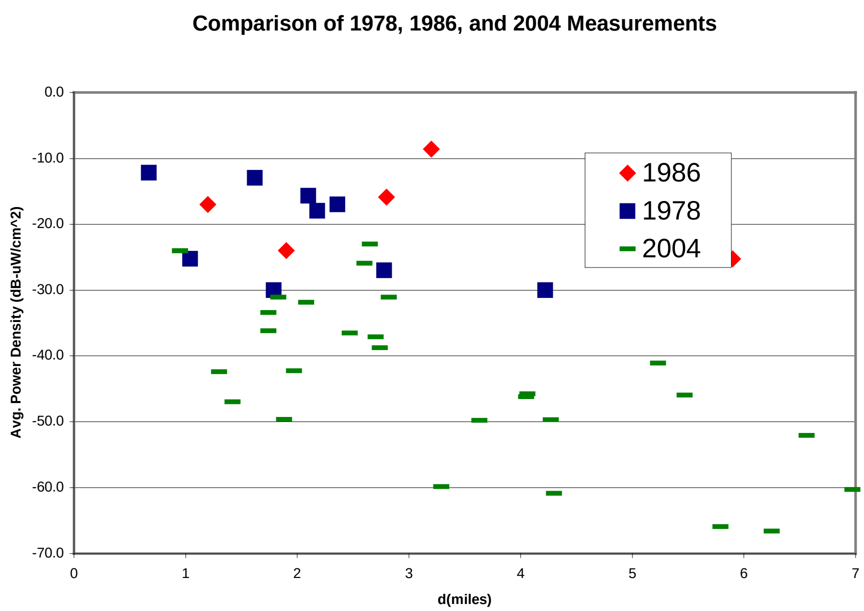
Table 8 compares measurements made at sites in 2004 that were the same as or near to sites measured in either 1978 or 1986. Both in 1986 and 1978 the instrumentation noise prevented measurement at sites with levels below –30 $dB\mu W/cm^2$. At these sites Broadcast Signal Lab obtained levels in the negative 40's of dB, confirming the levels were below –30.

The 1986 measurements taken at three sites similar to 2004 locations were consistently higher than the 2004 measurements.

Table 8 Previous Measurements at Comparable Sites

	1978	1986	2004 Avg	2004 Peak
Crowell State Park		-17 dBuW/cm^2	-24.4	-14.6
Scusset Pier		-24	-37.1	1.9
Cardinal Rd		-15.9	-31.1	1.8
Sagamore Athletic Field	< -30 In system noise- not measurable		-47	
Sandwich Library		<-30 In system noise- not measurable	-42	

Figure 15 Comparison with Previous Measurements



4 Ambient Measurements

Ambient site measurements were taken at the ten locations as called for in the Statement of Work. The Test Plan describes how the sites were selected to sample the range of broadcast and land mobile signal levels expected in the region. BSL hypothesized that broadcast emissions of FM and Television signals would dominate ambient emissions throughout much of Cape Cod.

4.1 Results

Table 9 shows the composite fraction of the public Maximum Permissible Exposure (MPE)[11] for each frequency band. It also includes a total composite value for the three bands combined. Note that the total value for each site is not the sum of the individual band values because the values are presented logarithmically in decibels. The data are presented graphically in Figure 16.

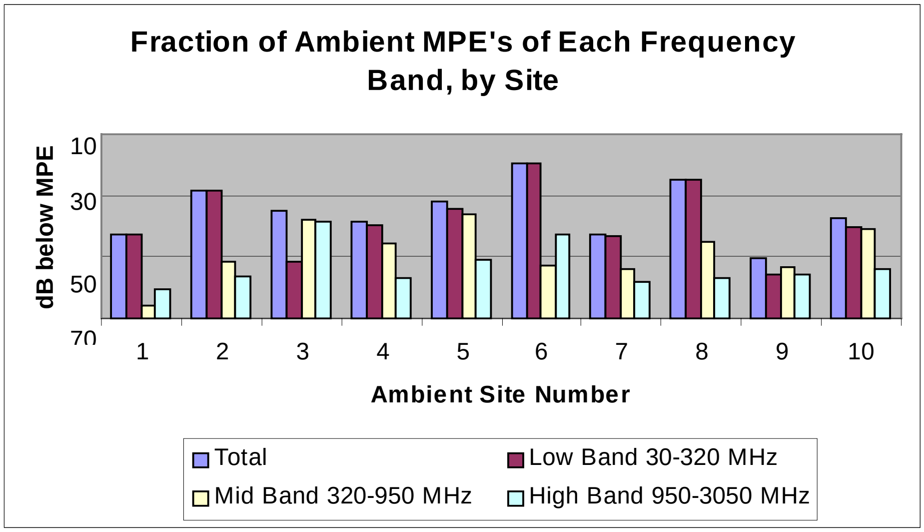
Table 9 Fractions of Ambient MPE at Each Site (dBMPE)

Site no.	Low band	Mid Band	High Band	Total
001	-43	-66	-60	-42.6
002	-29	-52	-56	-28.7
003	-52	-38	-38	-34.9
004	-40	-46	-57	-38.6
005	-34	-36	-51	-32.2
006	-19	-53	-43	-19.2
007	-43	-54	-58	-42.7
008	-25	-45	-57	-25.0
009	-56	-53	-56	-50.2
010	-40	-41	-54	-37.5

The figure shows that the low band (which includes the FM band among other things) dominates the ambient field of VHF and UHF signals at six sites. At two sites the low band has a slight lead over the middle band. At the remaining two sites, the low band is below the middle band. Meanwhile, the high band and middle band compete for second place, with the middle band having a slight edge.

[11] The MPE is based on IEEE Std. C95.1-1999 for uncontrolled environments. The MPE is weighted on the frequency of each emission. Ref. 8

Figure 16 Fractions of Ambient MPE at Each Site (dBMPE)



Overall, the most energetic site was near the FM tower at the Route 6 Exit 6 commuter parking lot, where the total ambient energy was about 100 times weaker than the permissible value for exposure of the general population. In other words, it would require 100 identically-outfitted towers within about ½ mile to reach the limit established in IEEE C95.1.

Other sites were an additional 10 to 1000 times less exposed to VHU/UHF emissions. Table 10 summarizes the Ambient measurements and compares to the PAVE PAWS measurements. The highest average PAVE PAWS emissions level at any PAVE PAWS measurement site was comparable to the lowest ambient level observed among the ambient sites. (Of course, these contrasting levels occurred in different locations).

Table 10 Comparison of Ambient and PAVE PAWS Human Exposure Potential

on and near Cape Cod

	PAVE PAWS	Ambient
Maximum Measured Human Exposure Potential	-48 dBMPE	-19 dBMPE
Minimum Measured Potential Human Exposure	-103 dBMPE	-50 dBMPE
Range	55 dB	31 dB

The dynamic range of the PAVE PAWS emissions throughout the Cape Cod environment, as would be expected from a single emitter at one location, was found to be nearly 60 dB. That is, the lowest observed level was about one million times weaker than the highest.

In contrast, with the ubiquitous use of the UHF and VHF spectrum for broadcast and many other forms of communication, there is a fairly consistent background level both near and far from radio towers and communications sites. The result is that the exposures from ambient VHF-UHF emissions have a dynamic range of about 30 dB. That is, the variation in exposure to ambient VHF-UHF emissions spans a relatively narrow range of 1000:1.

4.2 Sites

The ten sites are tabulated below.

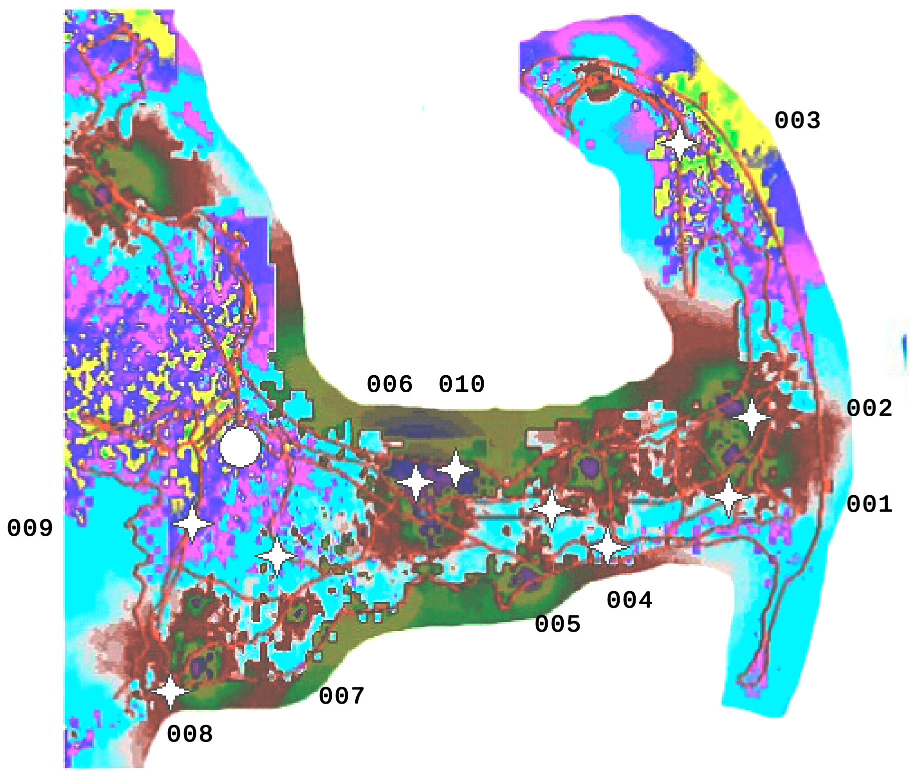
Table 11 Ambient Measurement Sites

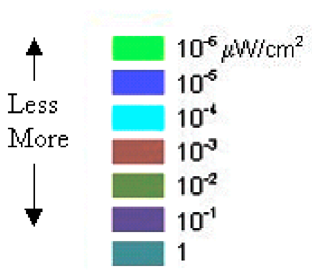
Site no.	Date	Location	Latitude			Longitude		
001	28-Feb-04	Rt 137 @ Rt 39, Harwich	41	42	32.2	70	1	22.2
002	26-Feb-04	Route 6 Westbound rest Area, Orleans	41	45	13.8	70	0	8.8
003	4-Mar-04	Cemetery and Rt 6, Truro	42	1	25.4	70	4	24.6
004	3-Mar-04	Baker School Rt 28	41	40	5.4	70	9	17
005	27-Feb-04	Whites Path, Yarmouth	41	41	26.3	70	11	44.5
006	25-Feb-04	Barnstable Commuter Lot, Rt 6 Exit 6	41	41	14.9	70	20	28.2
007	23-Feb-04	Athl field Rt 130, N of Ashumet Rd	41	39	16.1	70	29	42.9
008	2-Mar-04	Jones Rd School, Falmouth	41	34	2.6	70	36	23.7
009	2-Mar-04	Rt 28, Bourne, Near Otis Rotary	41	41	40.7	70	36	12.1
010	25-Feb-04	Barnstable County Court	41	42	1.2	70	18	16.8

Note: The site numbering convention assigns a three-digit number to ambient sites, e.g. 005, and one- or two-digit numbers to the PAVE PAWS sites to distinguish between them.

The sites were mapped for the Test Plan as shown in Figure 17. The map also plots estimations of the composite power density of FM radio broadcasts (and one TV broadcast) on the Cape.

Figure 17 Power Density of Cape Cod FM and TV Transmissions





At FM frequencies, 200 µW/cm² is the Maximum Permissible Public Exposure

Note: the pink hue is an artifact of blending between the 10^{-4} light blue and the 10^{-5}middle blue. Similarly, the transition from 10^{-5} middle blue and 10^{-6} light green appears as yellow. This graphic was originally published in the Final Test Plan and is reproduced here for convenience.

4.3 Measurement Methodology

The measurement methodology is described in detail in Appendix B. The data are consolidated into totals for each of the three spectral bands that were employed for the measurements. These are then combined into a final figure for each site. The data are presented in dBMPE which accounts for the different weight the IEEE standard assigns to the various radio frequencies (Figure 18). This is discussed in detail in the Test Plan.

Figure 18 IEEE Std C95.1-1999 Exposure Curve for Uncontrolled Environments

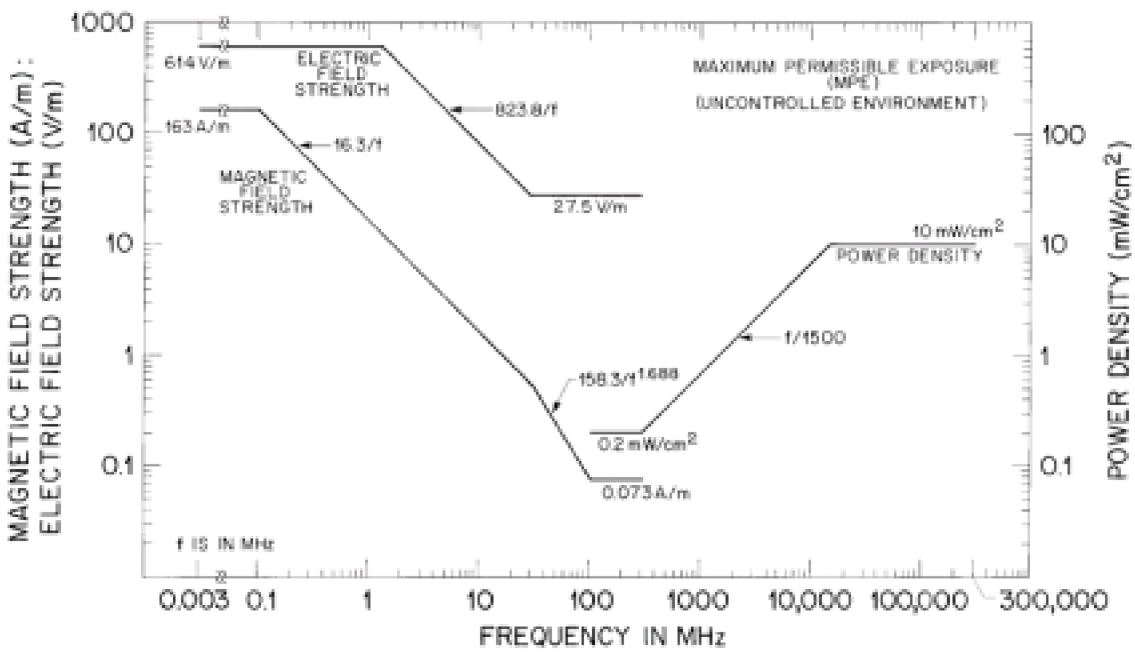
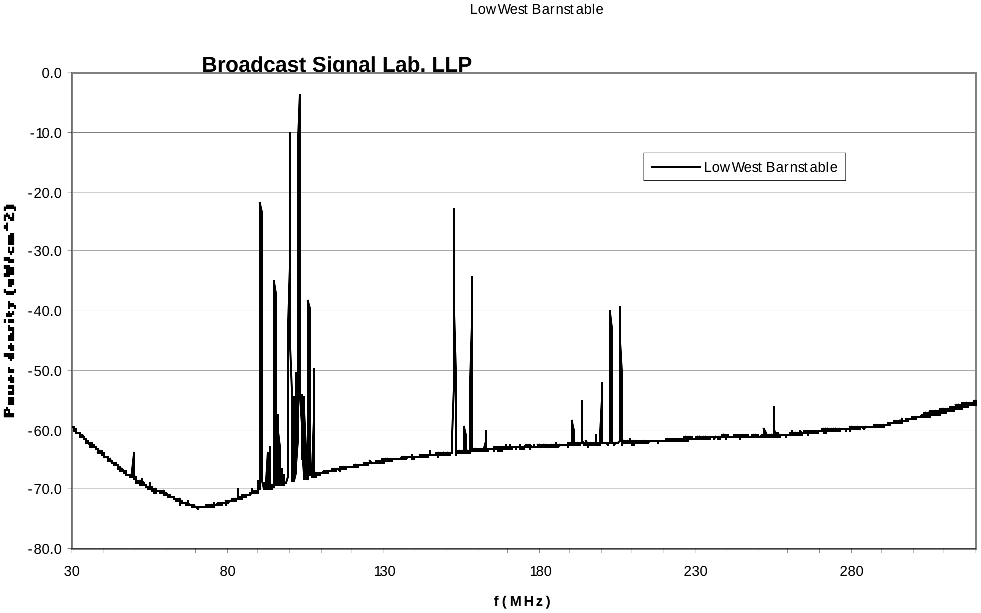


Figure E.4—Graphic representation of maximum permissible exposure in terms of fields and power density for an uncontrolled environment

The PAVE PAWS field measurements are reported in dBμW/cm^2. To make a comparison with the wide range of frequencies measured in the Ambient test, the PAVE PAWS measurements should also be converted to fractional MPE values. This conversion is performed by applying the IEEE weighting for the 420-450 MHz radar band. Using a center frequency of 435 MHz and dividing by 1.5, the general population MPE in microwatts per square centimeter is obtained—290 μW/cm^2. Converting to decibels, the MPE is 24.6 dB greater than 1 μW/cm^2. Therefore, at the PAVE PAWS frequencies,

$$S_{dBMPE} = S_{db\mu W/cm}{}^{2} - 24.6$$



4.4 Observations

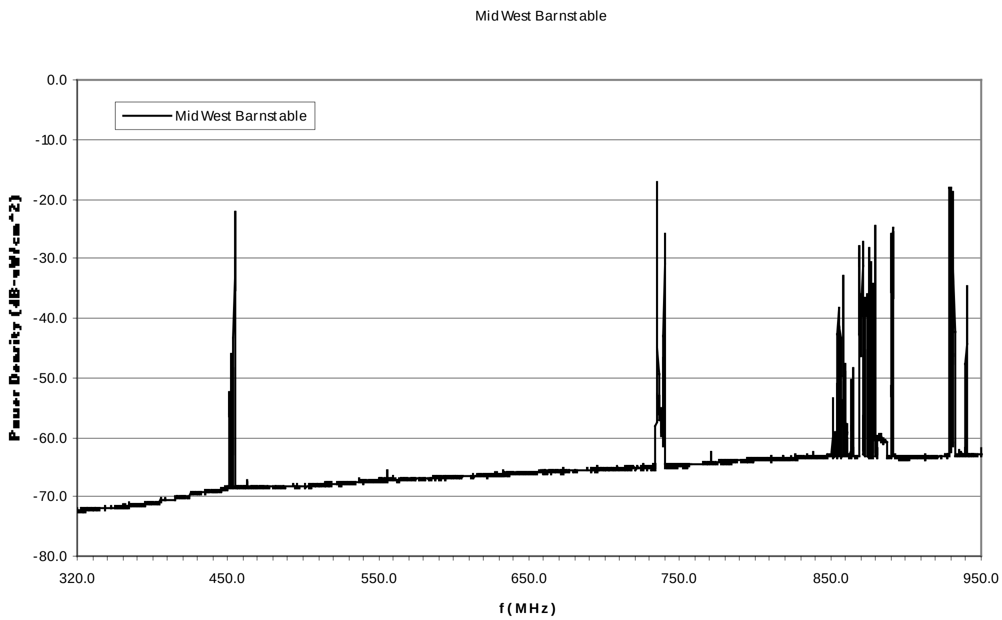
To illustrate the spectral occupancy, below are several graphs of the bands of emissions taken at one site. Additional graphs are presented in Appendix B.

Figure 19 Route 6 Exit 6 Commuter Lot, Low Band

Figure 19 was taken on the low frequency band and shows the effect of being within a half mile of the broadcast tower for WQRC and WPXC, two FM radio stations. These two signals dominate the spectrum at this site.

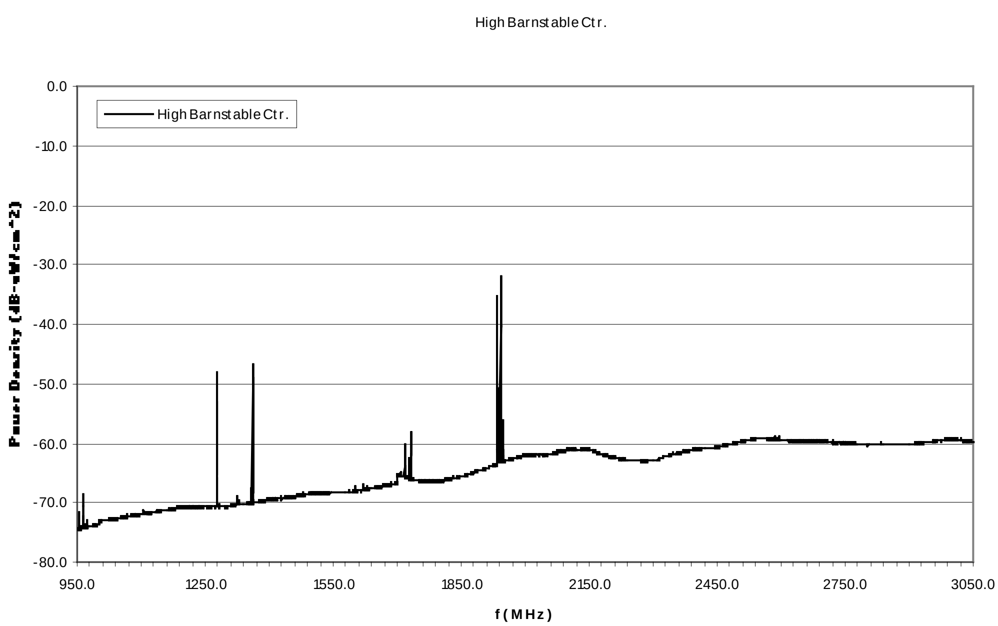
Continuing along in the spectrum, Figure 20 is a plot at the same site showing the middle frequency band. It reveals some activity at the 450 MHz land mobile band and substantially more activity in the cellular band above 850 MHz. Several paging transmitters operate near 925 MHz. The Channel 58 television station in Barnstable is evident at 734-740 MHz.

Figure 20 Route 6 Exit 6 Commuter Lot, Mid Band



Finishing the survey of the spectrum at this site, Figure 21 is a plot of the high band. It shows some activity that may be radar (not PAVE PAWS) or other radiolocation transmissions around 1300 MHz. The PCS wireless telephone spectrum is active around 1950 MHz.

Figure 21 Route 6 Exit 6 Commuter Lot, High Band



The frequencies discussed above tend to be the ones with the most activity and the strongest signals at each of the sites. At sites close to active communications towers the ambient land mobile emissions can exceed the ambient FM broadcast energy if there is no FM broadcast present on the tower. Such is the case at site 003 in Truro. The dominant signals are from the active wireless telephone tower behind the Public Safety Building. There are no powerful FM stations nearby. It may be concluded from this comparison that being near a busy non-broadcast wireless communications tower such as in Truro can result in ambient emissions that are still one or two orders of magnitude less than being near an active broadcast tower on Cape Cod.

The measurements spanned from -19 dBMPE, about two orders of magnitude lower than the MPE, to –50 dBMPE, five orders of magnitude less. This is reasonably reflected in the original estimation in the Test Plan and shown on the map above. There, the highest predicted levels near broadcast towers are also about two orders of magnitude below the MPE for FM, and the lowest levels are 5 to 6 orders of magnitude below the MPE. At locations where the FM levels are low, the presence of other communications not modeled on the map would have an increased impact on the accuracy of the map estimate.

The result is a relatively narrow range of exposures to the entire VHF-UHF spectrum—about 30 dB. In comparison, the PAVE PAWS emissions were observed in a range of about 60 dB throughout the region, and the highest human exposure potential among the radar measurements was –48 dBMPE.

5 Propagation Modeling Task

The propagation modeling task consists of several components. A prediction of the coverage of a drive test beacon was created with ComStudy propagation modeling software. The drive test was conducted with the actual test beacon operating on top of the PAVE PAWS building. The difference between the measured and predicted values was compared. This information provides a verification of the accuracy of the propagation model. Finally, the MITRE antenna pattern is employed to create an antenna model for the ComStudy propagation modeling software.

5.1 Results

There are three results of the propagation modeling task—a propagation model, an antenna model, and a matrix of predicted public exposure to the emissions of the PAVE PAWS radar.

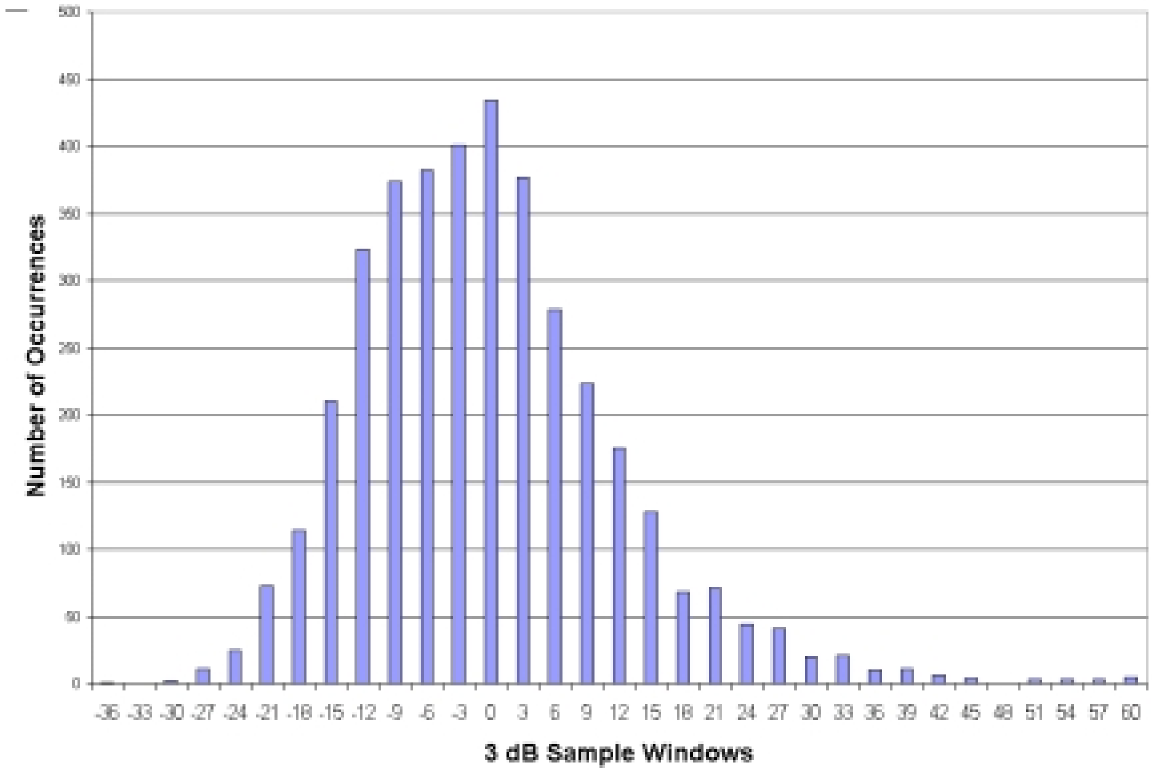
5.1.1 Propagation Model Results

The propagation model was compared to a drive test to see how accurate the model is for the Cape Cod environment. The results show that the propagation model is accurate to within the uncertainty of the measurement equipment. The average departure of a sample in the propagation model from the corresponding sample in the drive test was –1.6 dB and the mode is zero. The results are shown in Tables 12 and 13 and in Figure 22.

Table 12 Statistics on the Performance of the Propagation Model versus the Drive Test

Value	Result (dB)
Average variance	-1.6
Median	-2.9
Mode	0.0
Maximum	75.1
Minimum	-36.0
Std Dev	12.6

Figure 22 Distribution of the Departures of Computer Estimated Test Beacon Coverage from Corresponding Drive Test Measurements



There were a total of 3,849 individual latitude-longitude cells in which the 250-mile drive test obtained samples. The computer-predicted signal strength in each of these cells was compared to the measured signal strengths of the same cells from the drive test. A histogram of the departures between prediction samples and corresponding measurements is presented in Figure 22. The data are collected in 3-dB bins and their frequencies are displayed as vertical bars. The data for Figure 22 are presented in Table 13.

Table 13 Table of Propagation Model Variances (Drive Test)

Variance: Drive test – estimate (dB)	-36	-33	-30	-27	-24	-21	-18	-15	-12	-9	-6	-3	0	3
No. of samples	1	0	2	11	25	73	114	210	323	374	382	401	434	377

Variance: Drive test – estimate (dB)	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
No. of samples	278	223	175	128	68	71	44	41	20	21	10	11	6	4	0	3	3	3	5

5.1.2 PAVE PAWS Antenna Model Results

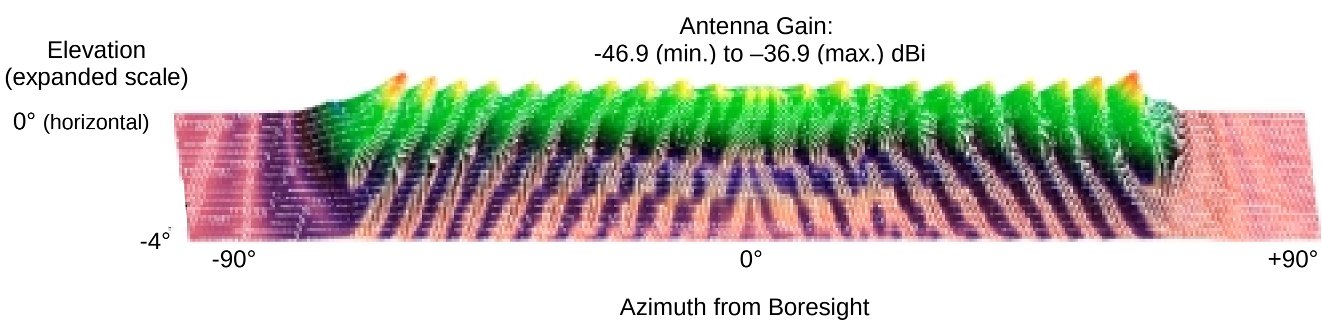
The PAVE PAWS average antenna model employed in the propagation modeling software is the result of a series of processing steps described in section 5.3. The average antenna model is focused on the Exposure Window, which spans the 180 degrees of the azimuth of each face of the array, and 4 degrees of elevation from horizontal to 4 degrees below horizontal. This is the region in which the emissions of the radar will touch down in the environment or reflect off large stationary objects. The characteristics of the average emissions through the exposure window of one radar face are shown in Table 14. In the overlap zone of both faces, the average values will increase by 3 dB.

Table 14 Characteristics of the Average Antenna Pattern

Antenna Gain	Full Window, from 0 to –4 degrees elevation	Partial Window, from 0 to –1 degrees elevation	Partial Window, from –1.25 to –4 degrees elevation
Max dBi[12]	-36.9	-36.9	-40.7
Min dBi	-46.9	-46.9	-46.9
Max-Min	10	10	6.2
Avg dBi	-43.2	-40.7	-45.0

A graphical representation of the PAVE PAWS average antenna pattern in the Exposure Window is shown in Figure 23.

Figure 23 PAVE PAWS Average Antenna Pattern – Exposure Window



The average antenna pattern reveals how, as the observer rises from being 4 degrees below horizontal to being at the horizontal with the radar, the average emissions of the radar increase up to 10 dB. Above the horizontal, that is, above the peaks shown on the upper edge of the pattern, the average level of the radar emissions would continue to increase until the peak of the radar average level would appear at about three degrees above the horizontal. Energy

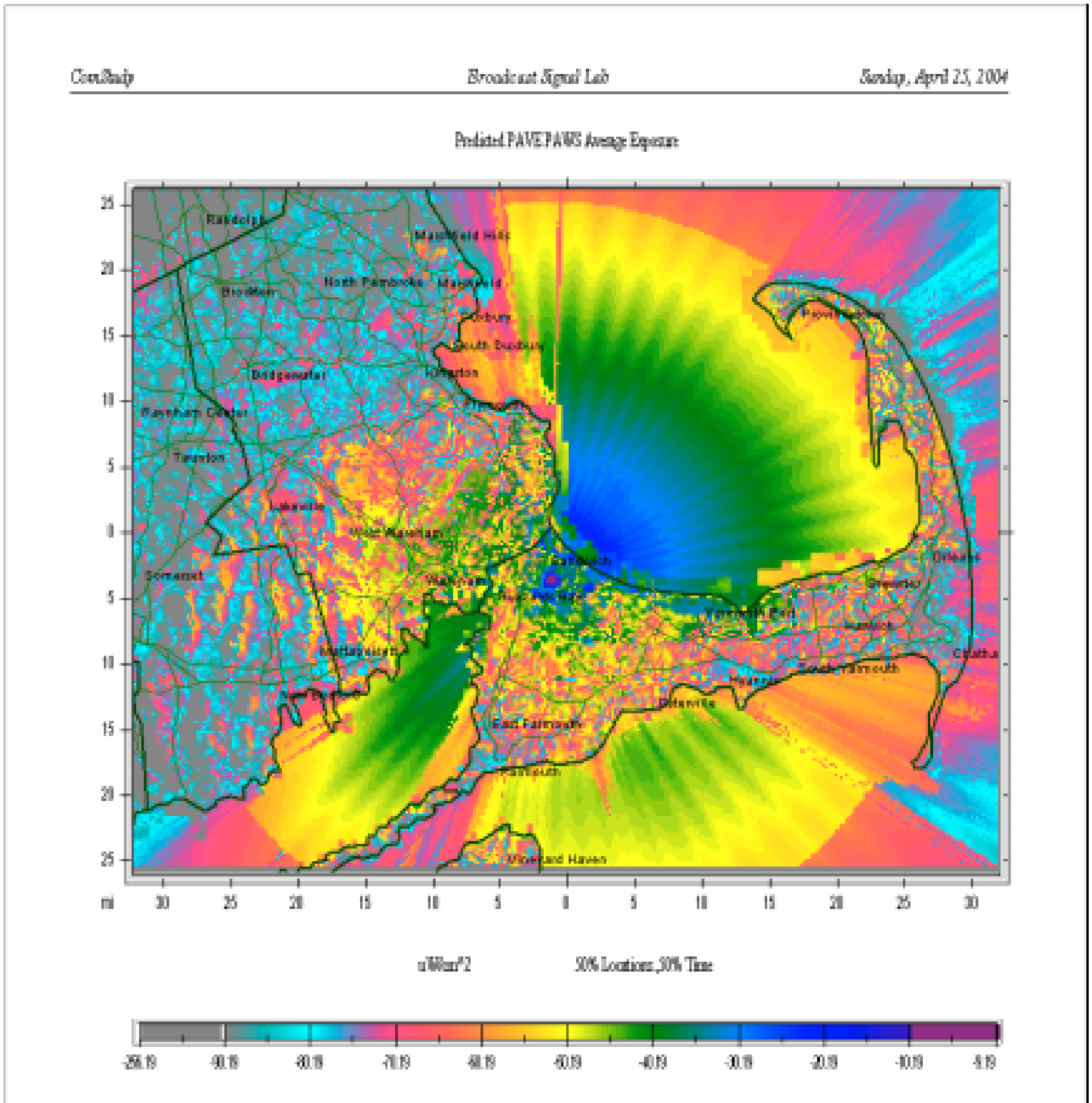
[12] dBi: decibels with respect to the gain of an isotropic radiator, a universal reference for reporting antenna gain. See also Appendix C.

above the horizontal is not directed at the local environment and it is therefore not necessary to model it for the purposes of computing exposure.

5.1.3 PAVE PAWS Public Exposure Matrix

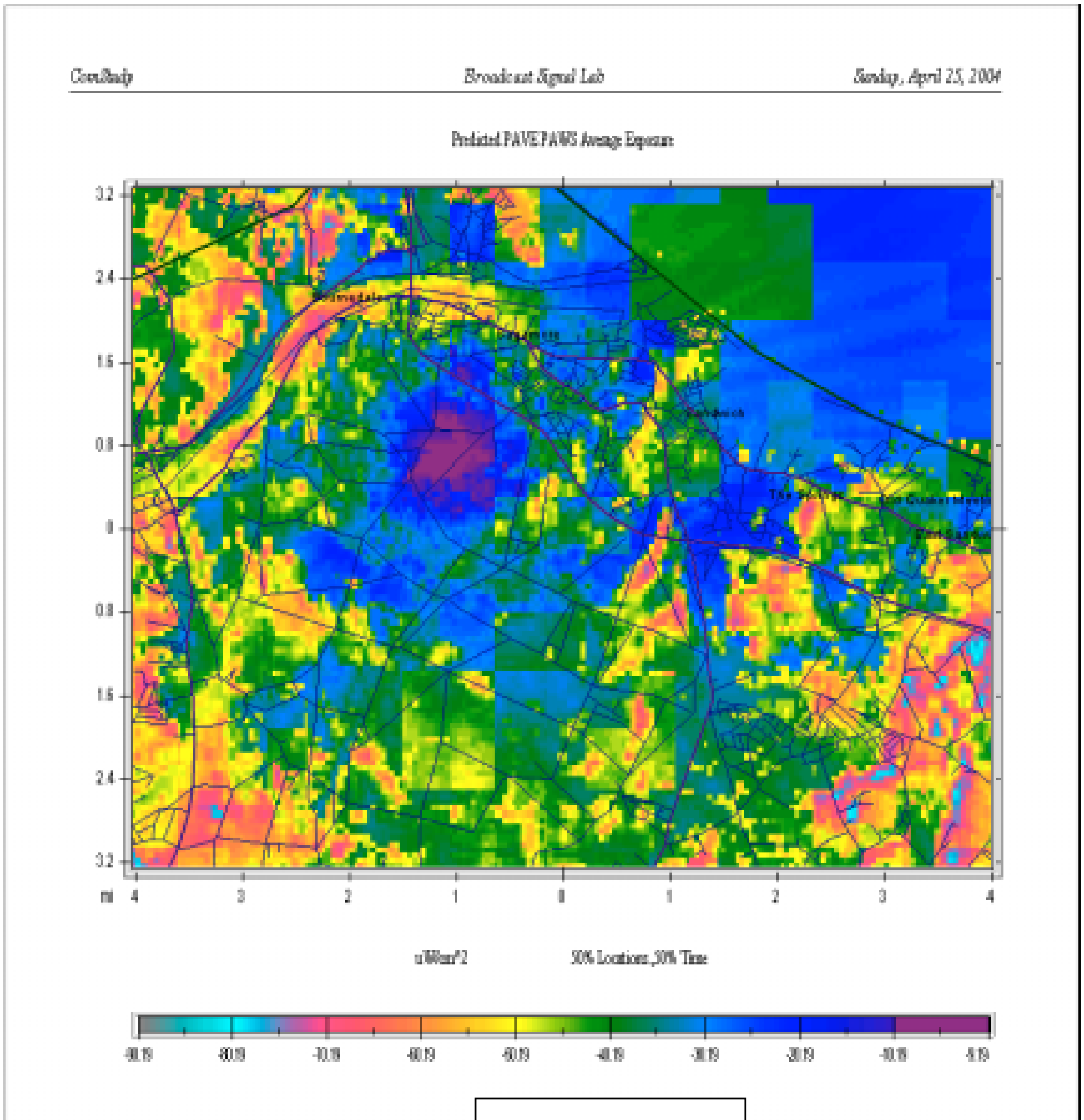
The PAVE PAWS antenna model and the ITM 1.2.2 propagation model were combined in ComStudy to produce a propagation model of the environmental emissions of the PAVE PAWS radar. The resulting data are contained in a text file PAVE PAWS Average Exposure.RMX. This is the data file that may be utilized for evaluations of public exposure to PAVE PAWS emissions. For illustration, the data from this file are presented geographically in Figures 24 and 25.

Figure 24 PAVE PAWS Average Public Exposure



dBuW/cm^2

Figure 25 PAVE PAWS Average Public Exposure (Detail)



dBuW/cm^2

5.2 Drive Test Sites

The Drive Test was conducted on approximately 250 miles of roads on and near Cape Cod. Routes 6 and 6A were traveled for extended lengths, as well as Route 28 and many of the interconnecting state roads. The Drive Test extended as far as Provincetown on Cape Cod and Lakeville, 20 miles west of the Cape Cod canal. The Drive Test route is described in Appendix C.

5.3 Propagation Modeling Methodology

5.3.1 Propagation Model

ComStudy software[13] was employed using the ITM 1.2.2 (i.e. Longley-Rice) propagation model. The USGS 3-second terrain database was employed by ComStudy to obtain terrain elevation data. USGS land-use/land-cover data are employed by the software to estimate the effects of land clutter on the propagation of the emissions.

The variables set in Comstudy include the Effective Radiated Power (ERP) of the signal source, its antenna pattern, its geographic coordinates, its elevation above ground (and ground elevation above mean sea level if necessary), and its radio frequency. Also, the ITM 1.2.2 algorithm is set to the median number of locations and median time (50^{th} percentile values referred to as f(50,50)). A propagation model is executed for a defined geographic area, resulting in a signal level prediction in the form of a matrix of signal strengths computed for each 3-arcsecond geographic cell.

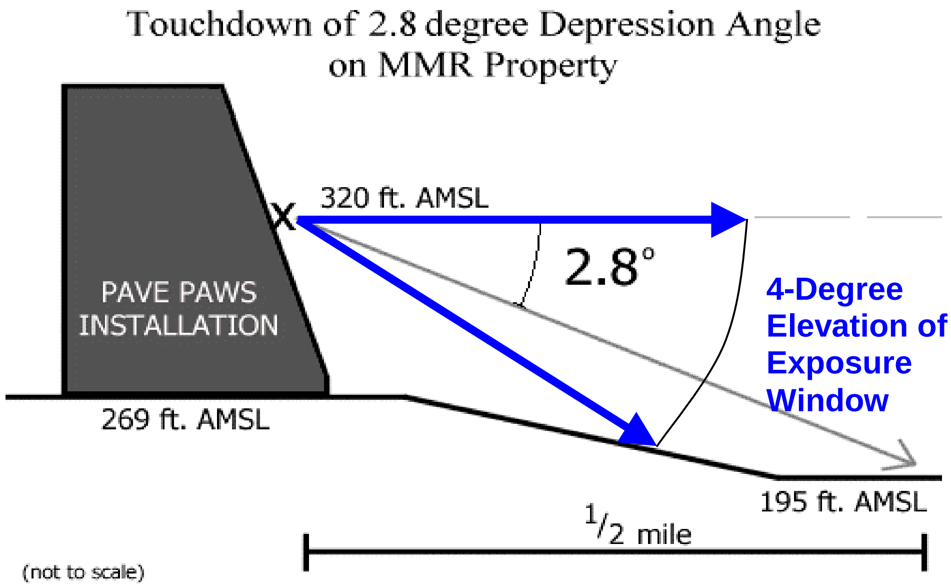
The propagation model was first executed for the drive test beacon in order to compare it with the measurements taken in the drive test.

The antenna model was supplied by MITRE Corporation and reviewed in detail by Broadcast Signal Lab. The final antenna model formula was iterated for each beam pointing angle of the Long Rang Surveillance sweep and weighted for pulse duration and repetition. The result was coded into an antenna pattern for use in the ComStudy software program. The output of the pattern was confined to the “Exposure Window” through which emissions into the environment would emanate.

The elevation of the Exposure Window is illustrated in the modification of a figure in the Final Test Plan as shown in Figure 26.

[13] Ref 45

Figure 26 Exposure Window Derivation—Based on Analysis in Final Test Plan



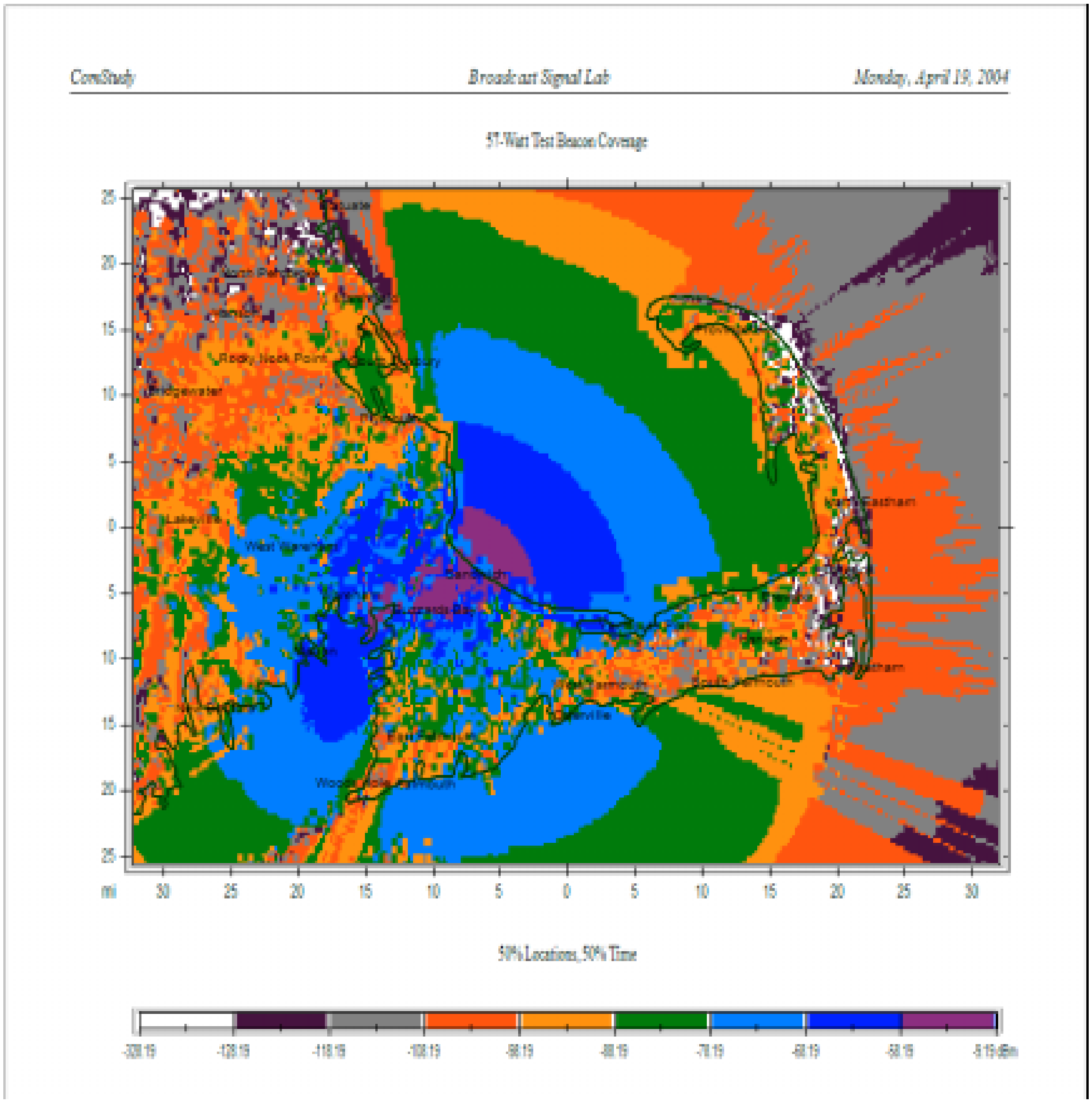
5.3.2 Prediction of Drive Test Beacon Coverage

The emission of the drive test beacon was modeled on Comstudy and the resulting data were filtered for predictions whose geo-cells matched the geo-cells of the actual drive test. This process is described in more detail in Appendix C and Appendix I. Figure 27 contains a representation of the drive test beacon computer estimated propagation.

The resulting matrix of beacon signal strength estimates was compared to the drive test data and variances derived.

The beacon signal strength estimates had approximately a 12.6 dB standard deviation from the drive test measurements. The median was within 2.9 dB while the average variance was 1.6 dB and the mode was 0 dB. These results are very good for propagation modeling. Also, consider that the standard deviation of each group of drive test measurements was typically 5 dB, showing the variability of signal levels within a small portion of a 3-arcsecond geographic cell as the vehicle passed through it. The accuracy of the model is better than anticipated, so no “tuning” of the model was necessary.

Figure 27 Predicted Coverage of Test Beacon



5.4 Drive Test

The methodology for conducting the drive test is contained in Appendix C. The methodology for post-processing the data is contained in Appendix I.

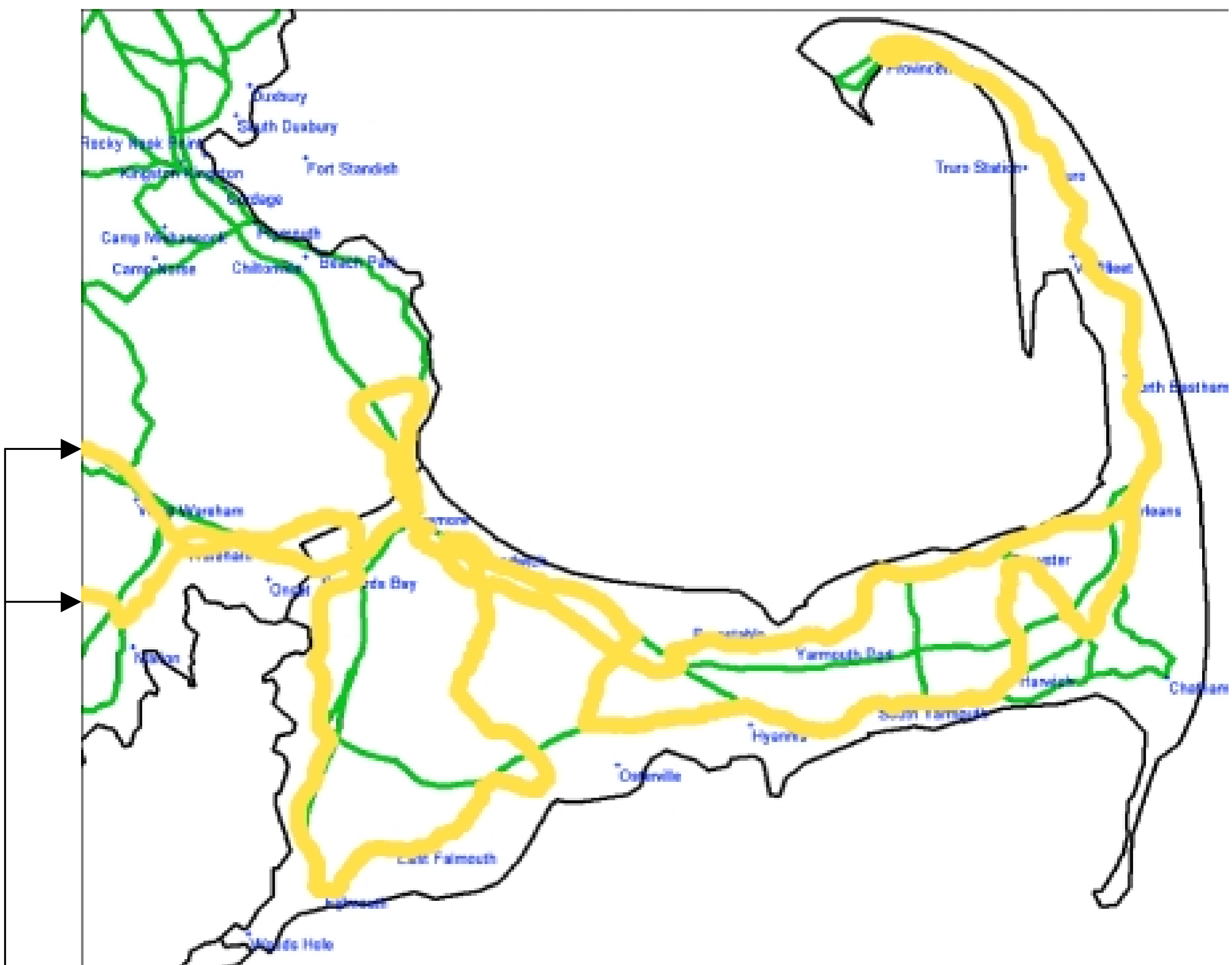
In summary, a broadcast auxiliary service transmitter and antenna were installed on top of the PAVE PAWS building (and tested to confirm no interference with the radar). This transmitter operates just above the radar band, at 455.9 MHz. A test vehicle was equipped with a ¼-

wavelength whip antenna on a ground plane, narrow bandpass filter, spectrum analyzer, and WAAS-enhanced GPS unit. A computer logged location and blocks of 1000 measurements repeatedly taken in short intervals. Each 1000-measurement block was preprocessed into a single signal strength value and recorded by the computer.

The test vehicle was driven over approximately 250 miles of roads on Cape Cod and on the neighboring mainland. The route is shown in Figure 28.

The data were collected in a series of text files that are included in the Drive Test Data folder and combined into a single composite data file, Drive Test Combined Data.xls. These data points were processed as described in Appendix I and compared to the beacon predicted coverage data to arrive at the results described in the preceding section.

Figure 28 Drive Test Route



Route loops through Lakeville

5.5 Antenna Model

The technical background of the MITRE antenna model task is described in Appendix C. The actual modeling process is described in Appendix H. In summary, the MITRE antenna model was employed to create an antenna pattern for the ComStudy software to implement. The result of this process is a radar exposure matrix PAVE PAWS Exposure Matrix.RMX. It is a text data file indexed by longitude and latitude containing values in dBμW/cm^2.

As a cross check of the results of combining the antenna model and propagation model, the measurements at the 35 low antenna sites were compared with the corresponding points on the PAVE PAWS propagation model. The propagation model treats high antenna elevations differently, so a comparison with the high antenna measurements would be less meaningful. The low site comparisons are presented in Table 15.

All of the above analysis is performed on the average exposure antenna model. No separate model of the peak emissions was performed because the peaks are not a function of antenna pattern or propagation. Rather they appear to be distributed in a general way that is best described statistically as discussed in section 2.3.5.

5.6 Comparison of Estimate with Field Measurements

The computer estimation is compared with corresponding field-measured values in Table 15. Only the low antenna sites are compared because the propagation model estimates the emissions low to the ground.

Table 15 Differences between Radar Propagation Model Estimates and Field Measurements at 35 Sites

Zone No.	Site No.	Site Location	Computer Estimate (dBuW/cm^2)	Estimate minus Meas'd Average (dB)	Measured in Field Test dBuW/cm² Avg	Max	Min	Std Dev
1	16	Cardinal Rd Circle	-23	8.1	-31.1	-28.9	-34.0	2.1
1	17	Rt 130 @ Cotuit Rd	-35	14.8	-49.8	-48.2	-51.5	1.3
1	18	Mt Hope Cemetery Rt 6A	-28	10.8	-38.8	-37.9	-39.9	0.9
1	19	Jarves Rd @ Factory St	-31	5.5	-36.5	-33.1	-40.2	2.9
1	20	Sandwich Public Library	-46	-3.7	-42.3	-36.3	-47.1	4.3
1	21	Holder Ln Circle	-20	5.9	-25.9	-22.7	-30.8	2.7
3	22	Scusset Beach Parking 1	-40	-2.9	-37.1	-35.7	-38.8	1.1
3	23	Scusset Beach Parking 2	-41	-18.0	-23.0	-21.0	-24.6	1.6
3	24	Sagamore athletic field	-55	-8.0	-47.0	-43.6	-49.4	2.2
3	25	Church Lane @ Cape Pine Rd	-21	10.9	-31.9	-29.2	-34.8	1.9
3	26	Sagamore School, Williston Rd	-21	15.2	-36.2	-34.2	-41.9	2.9
5	27	Brigantine Passage Dr	-29	2.1	-31.1	-30.3	-32.2	0.9
5	28	Long Pond Rd	-37	23.8	-60.8	-58.7	-62.3	1.3
6	29	Rt 6E Canal overlook	-32	17.6	-49.6	-48.8	-50.9	0.8
6	30	Cypress St @ Rt 6 Bypass	-46	13.8	-59.8	-58.8	-61.4	1.0
4	31	Monument Beach, Tower Circle	-49	0.7	-49.7	-47.1	-51.6	1.6
4	32	Wings Neck Rd near Harbor Dr	-43	9.1	-52.1	-49.7	-54.2	1.7
2	33	Cataumet Club, Scraggy Nk Rd	-52	9.7	-61.7	-59.9	-63.9	1.5
2	34	Carolyn Cir Forestdale	-39	7.0	-46.0	-39.7	-52.9	4.8
2	35	Barnstable County Fairgrounds	-48	11.8	-59.8	-59.4	-60.3	0.4
2	36	Falmouth HS, Brickkiln Rd	-68	1.1	-69.1	-68.2	-71.4	1.1
2	37	Mashpee Senior Center	-57	7.0	-64.0	-57.2	-78.4	6.8
2	38	N Falmouth School	-64	2.9	-66.9	-64.1	-69.0	1.9
1	39	Marstons Mills Sch, 2095 Main	-53	14.2	-67.2	-65.4	-75.4	4.1
3	40	Shawme Crowell State Park	-24	0.0	-24.0	-22.0	-26.8	2.0
3	41	Burbank St and Main (Rt 130)	-40	2.4	-42.4	-41.6	-43.0	0.5
1	42	Old County Rd, State Hatchery	-48	17.9	-65.9	-65.1	-67.6	1.0
6	43	Assawompset School	-63	15.3	-78.3	-77.3	-81.6	1.6
6	44	Onset School, Union Ave	-50	16.6	-66.6	-62.6	-69.2	2.4
3	45	Ellisville Rd	-34	7.1	-41.1	-34.1	-49.7	5.8
3	46	October Lane cir, Cedar Bushes	-53	10.0	-63.0	-62.1	-64.1	0.8
3	47	Freezer Rd near Ed Mofitt Dr	-34	-0.6	-33.4	-30.6	-35.6	1.9
2	48	Stone School Circle, Otis AFB	-59	1.3	-60.3	-57.8	-64.2	2.2
5	49	Post 'n Rail Av Cedarville	-44	1.8	-45.8	-43.8	-53.5	3.6
1	50	Barnstable HS, rear	-71	-4.5	-66.5	-65.3	-67.3	0.7

Table 15 contains a column of computer estimated average power density for each measurement site. There are four columns of data on the average, maximum, minimum, and standard deviation of the six field measurements per site. Between these two sets of data is a column marked "Estimate Minus Meas'd Average." This column contains the difference between the average value measured at each site and the value predicted by the computer. The measured average is subtracted from the predicted value to obtain the difference. A positive difference indicates the prediction is stronger than the measurement, and vice versa.

The standard deviation of all the departures of the estimates from their corresponding measurements is 8.5, while the median and average of the departures is 7 and 6.5 respectively. Discounting the four sites behind the radar, the median and average values fall to 5.9 and 5.3 dB respectively, while the standard deviation reduces only two tenths. These figures are presented in Table 16.

Table 16 Relationship of PAVE PAWS Propagation Estimates to Field Measurements

	All 35 Sites	Excluding 4 Sites Behind Radar
Standard Deviation	8.5 dB	8.3
Median	7.0	5.9
Average	6.5	5.3

It appears that on the whole, if the limited comparison is valid, the computer estimate of PAVE PAWS emissions errs on the side of slightly overstating the levels in the environment. However a comparison of the standard deviation between this limited sample of field measurements and corresponding propagation estimates is encouragingly less than the 12 dB that occurred with the drive test.[14]

5.7 Peak Exposure

The best way to address any peak exposure analysis is to employ the ComStudy radar average exposure matrix as a baseline to which the 37.7 dB peak-to-average ratio derived in section 3 of this report may be added (with a 7 dB standard deviation).

[14] See further discussion in the Broadcast Signal Lab Response to Comments received on the Draft Test Report

6 Project Highlights

This section highlights some of the project's more noteworthy events and findings.

1. *Radar Power Density Measured at Great Distances*
   BSL was able to measure both peak and average power density and to observe in both the frequency and time domain PAVE PAWS radio frequency emissions at all 50 test site locations, including one site located 20+ miles off the back of the radar in Lakeville, Plymouth County.

2. *Radar and Ambient RFE*
   At all of the 50 PAVE PAWS test sites the radar's average power density was well below the Maximum Permissible Exposure specified by any known safety standard. At all 50 sites, the total MPE measured with a NARDA broadband instrument covering 300 kHz to 50 GHz was below the noise level of the instrument, and fully compliant with applicable standards.

3. *Antenna Height versus Received Signal Strength*
   The difference in power density measured at an antenna height of 30 feet (to minimize local ground effects) and at a height of 8 feet was highly variable. However, when averaged over 14 measurement sites, the high sites showed approximately 5 dB greater signal, consistent with the "rule of thumb" that doubling the height of a VHF or UHF antenna in proximity to the earth's surface approximately doubles the signal strength.

4. *Signature of Radar at the Sites*
   At all PAVE PAWS test sites where time domain waveforms were observed on the spectrum analyzer (these measurements were not part of the Final Test Plan, but were performed to insure that the radar was operational), samples of all classes of the PAVE PAWS waveform were observed (and in some cases recorded photographically). Perhaps the most significant observation is that long range search doublets and triplets were observed independent of the azimuth from the radar antenna, indicating the presence of secondary sidelobes and/or reflections. In other words, signals are received at the test site when the radar's search azimuth is not aligned with the test site.

5. *Multiple Paths from Radar to Sites*
   At many PAVE PAWS test sites, numerous received pulses appeared to have amplitude modulation imposed upon them. Other pulses observed at the same site were quite clean, or modulated in a different fashion. The frequency of this modulation ranged from a few Hz up to tens of kHz. The choice of spectrum analyzer parameters precluded observing higher frequency modulation. The modulation depth was highly variable. Since the steady-state amplitude of the transmitted PAVE PAWS signal is constant (all transmitter modules are saturated

class-C amplifiers), this "amplitude modulation" can only be produced by the environment. The most likely source is reflection from a multitude of "targets" including aircraft, water tanks, radio communication towers, the smokestack at the Sandwich power plant, etc.

6. *Frequency Selective Fading*
   When observing the 24 PAVE PAWS channels in a "max hold" mode on the spectrum analyzer for extended periods, frequency-selective fading produced by multiple transmission paths was frequently observed. The depth of these fades was highly site dependent. A quantitative measurement of the frequency-selective fading parameters (e.g., depth of fade, correlation bandwidth) was not performed. However, they exhibited fairly broad "flat fading" characteristics over portions of the radar band.

7. *Alternate Interpretation of Emissions Behind Radar*
   The signals observed off the back of the radar are most likely produced from backscatter from the main beam of the radar, rather than from "behind the array" sidelobes or "edge diffraction" effects.

8. *Rear of Radar Similar to Land Mobile Emissions*
   Behind the radar, the received signal level measured from the 455 MHz beacon antenna mounted above the roof of the PAVE PAWS facility was within 0 to 20 dB of the measured radar emissions at similar locations. Since the emission of the test beacon was 58 watts ERP, the emission of the radar in the same direction would be equivalent to a level of from 58 watts to 5800 watts. This is not unlike the power of paging, land mobile, and lower powered FM station transmitters, suggesting that considering the power of the radar, there is little radiation "behind" the plane of the antenna.

9. *Radar Building Obstructs Rearward Propagation*
   On the roof of the PAVE PAWS facility, with the broadband survey instrument above the radar array (that is, penetrating the plane of the radar face from behind), the measured RFE occasionally peaked to 5 % of the occupational MPE limit. With the instrument repositioned above the roof, just behind, the plane of the radar face, the RFE level fell below the sensitivity of the instrument. These characteristics at the radar structure further support point 8 above.

10. *Amateur Radio Operation in Band Caused no Interference to Measurements*
    At no time was significant in-band interference from Amateur Radio operations observed, even at times when one of the local Amateur repeater stations was observed to be active.

11. *Out of Band Interference Not Significant*
    There may have been some instances when intermittent and very strong out of band interference from neighboring land mobile operations "rode through" the bandpass

filters into the test instruments. However, such events appeared to be highly transient in nature and of short duration.

12. *First Sidelobe Energy not Particularly Distinguishable from the Background of Secondary Sidelobe Energy.*
40 of the 50 test sites were located where the primary sidelobe of a few beams per sweep cycle might appear. It is not possible to distinguish first sidelobe pulses from secondary sidelobe pulses received at a test site. There are variations in signal level from pulse to pulse caused by beam pointing, propagation and the like that blur the distinction between received first sidelobe energy and received secondary sidelobe energy.

13. *Main Beam not Involved in Direct Emission toward the Ground*
None of the test sites fell within the envelope of the main beam. The first null of the main beam is at a minimum of 0.4 degrees above horizontal. Therefore no portion of the main beam ever intersects the surface of the earth, since the PAVE PAWS is situated on the highest hill on Cape Cod.

14. *Radar Interruptions Observed.*
On three occasions, the radar was observed to be "off the air" for brief periods. These events were noted in the data logs. The shortest of these outages was approximately one minute. There may have been other brief outages of which BSL was unaware. The long time samples of the survey reduce the impact of short interruptions to the radar emissions.

15. *The Radar Is Designed to Reflect Energy Back into the Environment*
Even when scores of miles away, a large commercial aircraft such as a Boeing 747 has sufficient radar cross section to return a measurable signal to BSL instrumentation via "backscatter" when the plane is illuminated by the PAVE PAWS main beam. Literally dozens of such aircraft traverse the airspace near Cape Cod flying to and from Europe every day. No effort was made to correlate the observed signals with aircraft traffic.

16. *Public Exposure Analysis*
This may be the first time that a conventional propagation modeling system was employed to evaluate the emissions of a radar reaching the public, particularly over a wide geographic area.

17. Long *Term Averaging Captures Consistency of Radar Emissions*
The 90-minute sampling times enabled the measurements to capture time variables, position variables, and radar emission variables, unlike the shorter duration measurements taken in the previous studies. Consequently, the average levels obtained at each site have a degree of consistency that diminishes uncertainties about the consistency not only of the radar operation but also of propagation.

APPENDIX A
The PAVE PAWS RFE Measurement Task

A1 Method for Computing the Peak and Average Power Density

A1.1 Reference to the Final Test Plan

Section 3.1 of the Final Test Plan[1] contains a detailed discussion of the measurement rationale for the PAVE PAWS RFE test, and that discussion will not be repeated here. To summarize that discussion, BSL proposed to construct a radiometer covering the frequency band 420 to 450 MHz that would operate under computer control to make a very large number of average and peak power measurements of the PAVE PAWS radar signal at each of 50 test sites. The average and peak power density at each test location would be computed from the received power measured at the output of the test antenna. Appendix D describes the equipment calibration and calculation of the estimated measurement uncertainly. The results of these measurements are presented in the body of this Final Test Report.

A1.2 Conversion from Received Signal Power to Power Density

All field measurements made by BSL in the PAVE PAWS RFE study (PAVE PAWS, Ambient, and Drive Test) recorded the value of the received signal power at the input to the receiver preamplifier. In other words, the standard interface for all measurements was at the junction of the antenna feedline and the receiver preamplifier. The data contained in the data files was recorded in decibels referenced to one milliwatt (dBm) at the specified reference point.

On the other hand, human exposure to radio frequency emissions at VHF (30 to 300 MHz) and UHF (300 to 3000 MHz) frequencies and beyond is measured as power density[2], that is, the power transmitted in an electromagnetic wave which traverses a specified area. In this report, all power density measurements are expressed in units of microwatts per square centimeter, or equivalently in decibels referenced to 1 microwatt per square centimeter. (Alternative units that are sometimes used in the literature are watts per square meter or milliwatts per square centimeter.)

The following discussion shows how the received power data are converted to power density. This discussion applies to both the PAVE PAWS and Ambient measurements.

---

[1] Ref 5
[2] Refs 7, 8, 9, 44

The fundamental relationship between power density S and electric field intensity E is

$$S(W/m^2) = E^2(V/m) / Z_0$$

where

$$Z_0 = 120\,\pi$$

$$= 377 \text{ ohms, the characteristic impedance of free space.}$$

BSL has chosen to report all power density numbers in decibels referenced to one microwatt per square centimeter. This was done 1) to be consistent with the units used in the 1979 PAVE PAWS *Environmental Impact Statement*[3], and 2) to use a logarithmic unit of measure to conveniently deal with small numbers ranging over several orders of magnitude.

Therefore the above equation can be rewritten (in decibels) as follows:

$$S(dB\mu W/cm^2) = 10 \log [E^2(V/m) / 1.2\pi]$$

$$= 20 \log E(V/m) - 10 \log (1.2\pi)$$

$$= E(dBV/m) - 5.76 \text{ dB}$$

and

$$E(dBV/m) = E(dB\mu V/m) - 120.0 \text{ dB}$$

$$= V_r(dB\mu V) + AF(dBV/m/V) + L_f(dB) - 120.0 \text{ dB}$$

where

V_r = the signal voltage at the receiver input,

AF = the antenna factor, and

L_f = the feedline loss.

$$E(dBV/m) = P_r(dBm) + 107.0 \text{ dB} + AF(dBV/m/V) + L_f(dB) - 120.0 \text{ dB}$$

$$= P_r(dBm) + AF(dBV/m/V) + L_f(dB) - 13.0 \text{ dB}$$

This relationship applies to both the peak and average measurements, where E and P are peak or average, respectively.

---

[3] Ref 1

Therefore

$$S(dB\mu W/cm^2) \quad = \quad P_r(dBm) + AF(dBV/m/V) + L_f(dB) - 18.76\ dB$$

In summary, the conversion from received power in dBm to power density in microwatts per square centimeter is performed by means of the above equation: Add the received signal power in dBm, the antenna factor in dB(V/m/V), and the feedline loss in dB, and subtract 18.76 dB.

The Antenna Factor for the Schwarzbeck 60-600 MHz antenna is 23.2 dB at the center of the PAVE PAWS frequency band (435 MHz). The calibration data for this antenna is presented in Appendix D. The feedline loss was measured to be 2.3 dB. The following relationship applies to both the peak and average measurements.

$$S_{PAVEPAWS}\ (dB\mu W/cm^2) \quad = \quad P_r\ (dBm) + 23.2 + 2.3 - 18.76$$

$$= \quad \mathrm{P_r\ (dBm) + 6.7dB}$$

A2 PAVE PAWS DATA COLLECTION

A2.1 Reference to the Final Test Plan

Section 3.2 of the Final Test Plan[4] contains a detailed discussion of the rationale for the equipment and instrumentation for the PAVE PAWS RFE test, and that discussion will not be repeated here. Instead, this section provides additional details on the actual test hardware and software that were not included in the Test Plan. To summarize that discussion, the Agilent E4416A peak and average reading RF power meter[5] in conjunction with a low-noise preamplifier and 420 to 450 MHz bandpass filters were used to measure the total power, both peak and average values, in the 420 to 450 MHz spectrum. Signal levels measured by the Agilent RF power meter, in units of dBm referenced to the preamplifier input, were transferred to a laptop computer via the IEEE-488 bus[6] where the unprocessed data were then recorded in a series of data files. An ASCII text file format was utilized in the interest of simplicity. A description of the contents of these data files appears below.

[4] Ref 5
[5] Refs 31, 32, 36, 37
[6] Ref 38, 50

A2.2 Equipment Configuration for Measuring the Average and Peak Power Density

This section provides details on the implementation of the instrumentation used to make the PAVE PAWS power density measurements. At the time the Final Test Plan was prepared, the hardware and software were still being assembled by Broadcast Signal Lab. Although in concept the measurement system is not changed from that described in the test plan, there are some details in which it differed. The following discussion describes the system, shown in the block diagram in Figure A2-1, as actually implemented and used in the field. Each component shown in the block diagram is described in the following paragraphs.

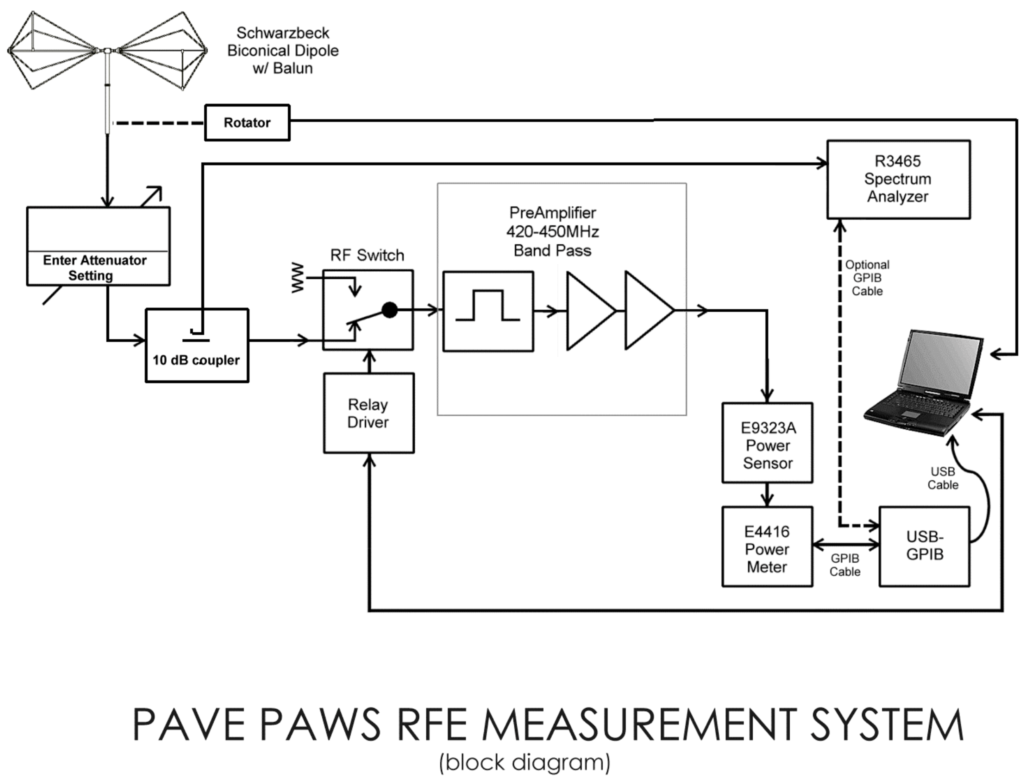


Figure A2-1 – System Block Diagram for PAVE PAWS RFE Measurement

A2.2.1 RF Power Meter

The primary data collection instrument for the PAVE PAWS RFE measurements was the Agilent E4416A peak and average reading RF power meter. When used in conjunction with the E9323A peak and average power sensor, this instrument is specified by the manufacturer to provide a peak power dynamic range of –32 dBm to +20 dBm at video bandwidths up to 5 MHz. The dynamic range of this instrument for average power measurements is specified to be –52 dBm to +20 dBm[7]. BSL observed the instrument to meet or exceed the specified performance.

The RF Power Meter samples the RF waveform input to its power sensor at 20 million samples per second. It then processes these samples to produce both peak and average power readings. Additionally, it internally averages the readings to reduce the standard deviation of the measured values. Typically, 500 to 1000 power readings are averaged internally in the instrument for each value delivered to the instrument's display and digital output.

The rate at which the power meter is capable of delivering data to an attached computer is much smaller than the 20 million samples per second that are performed in the instrument. Ultimately, the limiting factor in making power measurements with this instrument is the speed at which data can be transferred over the IEEE-488 instrument bus. Following much experimentation, BSL determined that it was feasible to transfer about 25 average power readings to the computer over the IEEE-488 bus. BSL determined that if it were desired to make an equal number of peak and average measurements, the throughput rate was substantially less than one-half of 25 measurements per second because of increased overhead in communicating with the IEEE-488 bus.

Consequently, the measurement software, as described functionally below, instructed the power meter to make peak and average power measurements for the 5 minute observation interval, but to only ship the largest peak value (the "peak of the peaks" in other words) to the computer at the end of each measurement cycle. The resources of the IEEE-488 bus were focused on the collection of the maximum amount of average power data possible in a 5-minute interval. By doing so, BSL insured that there would be at least one average power measurement every 54 msec "resource period" of the PAVE PAWS radar signal[8].

A2.2.2 Low Noise Radiometer Preamplifier

BSL assembled a low-noise preamplifier (referred to here as the "radiometer preamplifier" to distinguish it from the preamplifiers used for the ambient RFE measurements) having a band-pass from 420 to 450 MHz from off-the-shelf monolithic microwave integrated circuit (MMIC) amplifiers. This amplifier had a nominal gain of 40 dB, including the loss in the bandpass filters, thus extending the measurement

[7] Refs 31, 32, 36, 37
[8] Ref 1, Appendix C

sensitivity of the power meter by approximately 40 dB. This enabled BSL to make average power measurements to signal levels approaching –90 dBm.

Two four-section tubular bandpass filters were incorporated in the preamplifier assembly. These filters were custom-built by Trilithic to BSL's specification. Each filter provided a nominal 3 dB pass band of 420 to 450 MHz, an insertion loss of 1.2 dB, and nearly 50 dB rejection of out of band signals below 360 MHz and above 500 MHz. Of interest is the fact that these filters are about one-half of the bandwidth of the filters (FSN 5915-01-056-5140) used in the PAVE PAWS transmitter and receiver[9].

The cascade of the two bandpass filters thus provides out of band attenuation approaching 100 dB. It should be noted that land mobile signals in the frequency range 450 to 500 MHz do have the potential to be rejected by less than this amount because of falling on the "skirt" of the filter. This did not appear to be a major problem in the field, because the PAVE PAWS measurement sites were chosen to be away from the location of potential interferers. This is discussed in more detail below.

Should a passing mobile transmitter overload the preamplifier for a brief period, this event can be readily ascertained upon examining the recorded data. Since the radar only operates with a pulsed transmission, any string of consecutive data points having only small changes in signal levels would represent an interfering signal. To date, only one data record has been identified in which such is the case.

A2.2.3 60 to 600 MHz Antenna

A broadband biconical dipole antenna covering the frequency range 60 to 600 MHz was used for the PAVE PAWS RFE measurements. By employing a broadband design, the antenna gain remains reasonably constant over the 420 to 450 MHz frequency band occupied by the PAVE PAWS, more so than would be the case if a simple linear dipole antenna tuned to 435 MHz were to be used. In order to approximate the full-hemisphere coverage of an isotropic antenna, it was necessary to make measurements in three mutually orthogonal orientations of the antenna. This process was described in the Final Test Plan[10] and will not be repeated here.

A.2.2.4 Antenna Rotator

A commercially available antenna rotator (CDR/Hy-Gain Model TR-44) was used to provide rotation of the test antenna in azimuth. As a consequence of mounting the test antenna at the "magic angle" of approximately 55 degrees, this azimuth rotation in steps of 120 degrees translates antenna motion into three mutually orthogonal orientations. The control box for this rotator was modified by BSL to enable operating the rotator under computer control, relieving the operator of the burden of periodically having to reorient the antenna.

[9] Ref. 51, pp. 246-250
[10] Ref. 5, Sec. 3.1.2.3

A.2.2.5 Antenna Masts

Two different antenna-mounting arrangements were used. For the "high" measurements at a height of 30 feet above ground level, the antenna rotator was mounted on a platform on the rear of the test vehicle, and a 30 telescoping fiberglass mast was used to support the antenna. Temporary guy lines were anchored to concrete blocks to stabilize the mast. For the "low" measurements, the rotator was mounted to a small wheeled dolly, and a short length of PVC pipe was used as the mast.

A.2.2.6 Antenna Feedline

A 45 foot length of RG-214/U double-shielded coaxial cable was used as the feedline. The measured loss of this cable at the center-band frequency of 435 MHz was 2.3 dB.

A.2.3 The Modified Dicke Radiometer

The instrument assembled by BSL and described in the above paragraphs is properly called a radiometer: Such an instrument consists of an antenna (the Schwarzbeck biconical dipole), a receiver (the preamplifier and bandpass filters), a square-law detector (the Agilent RF power meter effectively measures the square of the RF voltage impressed upon its power sensor), and an integrator (the combination of the internal averaging in the power meter and the post-processing averaging performed on the recorded data). The ultimate sensitivity of any radiometer is determined by the system noise power (equivalently, its noise temperature) divided by the square root of the number of statistically independent power samples made at the square-law detector.

In the Final Test Plan[11], it was proposed to implement a Dicke (pronounced "dickey") radiometer to overcome variations in the overall gain of the receiver preamplifier during the measurement period. However, the classic Dicke approach requires doubling the observation interval so that every other power sample is of only the front-end noise of the receiver. It further requires a high degree of synchronization between the post-detection processing and the RF switching.

BSL was also concerned at the time that the Final Test Plan was written that the simpler total power radiometer might not have adequate sensitivity to measure PAVE PAWS signals at large distances from the radar. This has turned out not to be the case. At every measurement site, the total power radiometer was able to detect and measure PAVE PAWS RFE.

Bench measurements performed by BSL demonstrated that over a 5-minute measurement interval, the gain of the MMIC preamplifiers was stable to within a few hundredths of a dB. Consequently, a modified Dicke approach was implemented in which only one minute of front-end noise was recorded for each 15 minutes of PAVE PAWS data, reducing the Dicke overhead from 50 % to approximately 6%.

[11] Ref. 5, Sect. 3.1ff

Instead of a Dicke modulator which switches the receiver input between the antenna and a constant reference noise source (consisting of a resistive termination of known resistance at a known temperature) at an audio rate, the same front end switch was activated for a one-minute period at the beginning of each 15 minute measurement cycle. This approach eliminated the need to implement a synchronous demodulator in the computer software that would have to operate in real-time.

A2.4 Software Functional Description for PAVE PAWS RFE Data Collection

The following subsections describe the BSL-developed software that was used to control the test instruments and collect the data. The design objective for this software was to implement a data collection process that required a minimal amount of operator intervention, in an effort to maximize the amount of data captured and to minimize the opportunity for operator-induced errors to occur.

PROGRAM: PAVEPAWSNoiseRFE (Visual Basic)

PURPOSE: Measures receiver noise and RF exposure from the Pave PAWS radar using the Agilent Power Meter (Model E4416) and records data to disk file.

OPERATOR INPUT:

- ENTER:
  - Site description from predefined list
  - Actual site Latitude from GPS Receiver
  - Actual site Longitude from GPS Receiver
  - Preamp gain
  - Antenna being used
  - Feedline description
  - Any desired comments for data file

PROGRAM OPERATION:

- Zero Power Meter
  - Remove signal source/antenna from power meter
  - Execute Zero Power Meter command
  - Reconnect signal source to power meter
  - Point antenna to North for consistency
  - Initialize the power meter
  - Point antenna to 240 degrees
  - Measure receiver noise for approximately one minute
  - Measure Pave PAWS signal continuously for five minutes
  - Rotate antenna to 0 degrees

- Measure Pave PAWS signal continuously for five minutes
- Rotate antenna to 120 degrees
- Measure Pave PAWS data continuously for five minutes
- Write data to disk file and close file
- Return antenna to North
- Return to Windows Desktop

A2.5 System Operation for PAVE PAWS RFE Measurement

This section provides a narrative description in outline form of the operation of the BSL test equipment (described above in Section A2.2) in the in the field.

A2.5.1 Equipment Setup

- Locate target test site using GPS coordinates and local maps.

- Survey the site to determine the best location for the measurement, considering proximity to overhead wires, traffic flow, emergency access, handicap access, etc.
- Change the test site location if necessary, while maintaining the test objectives for that site.

- Ensure that the vehicle is safely positioned away from traffic.
- When appropriate, place orange traffic cones in the roadway and have personnel wear an orange traffic vest when outside the vehicle.

- Determine that the total RF environment is compliant with occupational exposure standards by means of the Narda instrument to evaluate RF exposure potential (over the frequency range from 300 kHz to 50 GHz) and record the reading in percent of the occupational MPE limits. In no case was a proposed measurement site determined to be non-compliant with occupational MPE limits (including a measurement made on the roof of the PAVE PAWS building).

- Set up the 60-600 MHz Schwarzbeck test antenna on the “low” or “high” antenna mount as appropriate, connect the coaxial cable to the input of the radiometer preamplifier unit and connect antenna rotator cable to the control box.
- In the case of the low antenna mount, position it as far from the vehicle as practical, and on (reasonably) level ground.
- Orient the antenna to true north. (Precision is not necessary in this step of the setup because of the wide azimuthal pattern of the test antenna.).

A2.5.2 Equipment Operation

- Power up the test equipment (if not already powered up prior to arrival on site) and perform the Power Meter “calibrate and zero” procedure (Note: The power meter automatically enforces this step in the procedure).
- Connect the power meter to the output of the radiometer preamplifier unit. Check all other cable connections in the test equipment suite.

- Connect the spectrum analyzer to the –10 dB test port on the radiometer preamplifier assembly and manually set the spectrum analyzer to sweep the PAVE PAWS band of 420-450 MHz with a resolution bandwidth of 100kHz in “max hold” mode.
- If necessary, insert 10 or 20 dB of attenuation in front of the preamplifier to keep the peaks of the PAVE PAWS signal from overloading the preamplifier. Attenuator settings other than 0dB were necessary only at sites that are line-of-site to the radar.

- Start the computer program PAVEPAWSNoiseRFE.exe. From this point until the program terminates, the computer controls all equipment operation and all operator actions are at the direction of prompts on the computer screen.
- See the software functional description above for details. Each measurement sequence will take slightly longer than 15 minutes.

- The 15-minute measurement sequences are repeated six times.

- At the end of the day, make two backup copies of all data files on CD-ROM.

A2.5.3 Site Data Forms

- Take the following readings manually from the GPS receiver: Latitude, Longitude, Elevation, Bearing and distance to the PAWE PAWS, barometric pressure, and record on the site data form.
- Obtain temperature, dew point, and wind data (when available) from the National Weather Service broadcast on 162.550 MHz and record on the site data form.

- Provide a brief description of the test site location.
- Note the attenuator setting on the site data form.
- Make notes of any unusual circumstances with regard to the test equipment or site. Log any photographs taken.

[Site data forms were transcribed to a spreadsheet file PP Site Data Transcription.xls]

A2.5.4 Site Photographs

At each site at least one photograph was made showing the test vehicle, antenna, and the local environment. The only exception was on a day when it was raining heavily. Additional photographs were made showing the PAVE PAWS waveforms in both the frequency and time domain to illustrate 1) normal operation of the radar, 2) the absence of in-band interference, and 3) to permit BSL personnel to study the details of the PAVE PAWS signal.

A3 Measurement Uncertainty for PAVE PAWS RFE Measurements

The following table provides a tabulation of the individual components of the measurement uncertainty for the PAVE PAWS RFE measurements. The manufacturers' specifications were used for the antenna, power meter, and power sensor. Broadcast Signal Lab measured all other components.

Table A3-1 - Pave Paws RFE Measurement Uncertainty Budget

Pave Paws RFE Measurement Uncertainty Budget				
Parameter	Source	RSS Error (dB)	Power ratio	RSS component
Power meter and sensor	Specification	0.4	1.10	0.0093
Preamplifier (420 to 450 MHz)	Measurement	0.5	1.12	0.0149
Step Attenuator	Measurement	0.3	1.07	0.0051
Feedline - 45 ft RG-214/U	Measurement	0.1	1.02	0.0005
Biconical Dipole Antenna (60-600 MHz)	Specification	0.7	1.17	0.0306
		RSS Uncertainty (ratio)		0.25
		RSS Uncertainty (dB)		0.95

As was predicted in the Final Test Plan[12], the uncertainty in the antenna factor dominates the overall measurement uncertainty. The predicted RSS uncertainty is slightly less than the target value of 1.0 dB specified in the Statement of Work[13].

The following is a brief summary of the procedure specified in the ANSI/NCSL Z540.2-1996 standard as it applies to the power density measurements performed in this study. This procedure was used to estimate the measurement uncertainties for both the PAVE PAWS and ambient measurements made by BSL.

[12] Ref 5, Sect. 3.3.2
[13] Ref. 6

1) Compile a list of the error components of the individual measurement uncertainties, expressed in dB. These are obtained from manufacturers' specifications or by measurement, as appropriate.

$$i^{th}\ \text{Error Component (dB)} = 10 \log (1 + \Delta x_i/x_i)$$

2) Convert the individual error components to a power ratio:

$$\text{Error Component} = 10\text{^}[\text{Error Component(dB)} / 10]$$

3) Subtract 1.000 from the *Error Component* to obtain the fractional error $(\Delta x_i/x_i)$

4) Square the fractional errors to get the root-sum-square (RSS) components $(\Delta x_i/x_i)^2$

5) Add all of the RSS components to obtain the sum of the squares:

$$SS = \Sigma\, (\Delta x_i/x_i)^2$$

6) Take the square root to get the RSS error

$$\text{RSS Error} = [\Sigma\, (\Delta x_i/x_i)^2]^{0.5}$$

7) Add 1.000 to the RSS error and convert the result back dB to obtain the *RSS Error* in dB

$$\text{RSS Error(dB)} = 10 \log (1 + \text{RSS Error})$$

A4 Post Processing the PAVE PAWS RFE Data

A4.1 Reference to the Final Test Plan

Section 3.7 of the Final Test Plan[14] presented the format in which the summary data would be presented in this Test Report. This section of the Final Test Report describes the means for reducing the tens of thousands of data values contained in each data file

[14] Ref. 5, Sect. 3.7

(with six data files per site) to a single peak and average power density value for each site, as required by the Statement of Work[15].

The functional description of the Visual Basic post-processing program Process PP Data.vbp given below provides a concise step-by-step description of the steps performed in post processing the data. The final output of this program is one text file containing the average and peak power density computed from one data file. This one file contains one pair of numbers (peak and average power density) for each of the six measurements made at each site. (In a few cases, there were fewer than six measurements made for one site because of time constraints.)

The final step in the data reduction was to import the data from this summary output text file into an MS-Excel spreadsheet in which the data from the separate measurements are averaged. The output from this spreadsheet appears as a table in the main body of this report.

A4.2 Data Reduction for PAVE PAWS RFE

A4.2.1 Software Functional Description

Two Visual Basic programs were used to post-process the PAVE PAWS data. The first program (Process PP Data.vbp) converts the received power measurements (in units of dBm) contained in the approximately 300 PAVE PAWS Data files to power density (in units of microwatts per square centimeter), combines the power measured in the three orthogonal antenna orientations, searches for the peak value of the power density, and computes average power density.

The second Visual Basic program (PP Data File Summary.vbp) collects the headers and footers from all 50 Pave PAWS measurement sites (approximately 300 data files) and summarizes them into one text file. This was done for the convenience of BSL to prevent having to open multiple data files in order to locate a specific piece of information about multiple sites.

These two programs are described below.

PROGRAM: Process PP Data.vbp

PURPOSE: Converts the Pave PAWS Data files to power density, searches for peaks, and computes averages.

OPERATOR INPUT: Select site to be converted from drop down list of sites.

PROGRAM OPERATION:

[15] Ref. 6

1. On startup, loads list of sites for operator to select from file “PP data directory paths.txt”
2. Opens summary file “PP Peaks and Aves.txt” for output
3. Opens text file containing list of data files to be processed
4. Opens input file
5. Opens output file in folder “PP Power Density Files” using the site name and the data file name to create a unique output file for each individual converted data file
6. Reads input file and write headers to the output file

DATA CONVERSION LOOP:

7. Reads one line of data from input file. Each line contains 5 columns including a counter, noise measurement, and a reading taken at each of three antenna headings (240, 0, and 120 degrees.)
8. Converts the measurements from the three antenna headings individually to power density
9. Adds the three power density values for total power density
10. Writes the three power density values and the total power density to output file
11. Repeats steps 7 through 10 7500 times
12. Computes the average power density for the 7500 totals
13. Writes average power density to output file
14. Reads the peak power from the input file
15. Converts the peak to power density
16. Writes peak power density to output file
17. Closes output file
18. Opens next input file from specified site
19. Repeats steps 5 through 17 for all data files recorded at the specified site
20. When all files from specified site are complete, computes average power density and peak density for the site
21. Writes site name, peak, and average power density to the summary output file “PP Peaks and Aves.txt”
22. Asks operator if he wishes to convert any more files. If Yes, repeats steps 3 through 20. If No, exits the program.

PROGRAM: PP Data File Summary.vbp

PURPOSE: Collect the headers and footers from all 50 Pave PAWS measurement sites and summarize into one file

PROGRAM OPERATION:

1. Opens file “PP Datafile Summaries.txt” for output
2. Opens file containing list of all site file names
3. Opens individual site data file

4. Reads headers from input file
5. Writes headers to output file
6. Reads and ignores measurement data
7. Reads summary footers from bottom of input file
8. Writes footers to output file
9. Closes input file
10. Repeats steps 2 through 9 until all data files from all 50 sites have been processed
11. Closes all open files
12. Exits program

A4.2.2 Spreadsheet Manipulation of Results

Results were inserted onto a spreadsheet named PP Peaks And Aves.xls. It contains worksheets that compute the various tables and graphs presented in this report.

A4.3 The Noise Floor and Dynamic Range of the PAVE PAWS Radiometer

A4.3.1 Noise Floor of the PAVE PAWS RFE Measurements

Each 15-minute PAVE PAWS measurement sequence began with the recording of the radiometer noise floor for a period of 1 minute. Approximately 300 minutes of noise floor data were recorded over the month of field measurements. BSL has taken a representative sampling of 100 of those noise records and computed the average and standard deviation of the radiometer noise floor.

The result of this computation is that the average noise power of the PAVE PAWS radiometer, measured at the receiver front end, is

$$P_{noise} \quad = \quad -90.0 \text{ dBm}$$

with a standard deviation of

$$\sigma(P_{noise}) \quad = \quad 1.1 \ dB$$

This noise power is related to the "noise floor" of the power density measurement as follows[16]:

$$\begin{aligned} S_{noise}\ (dB\mu W/cm^2) \quad &= \quad P_{noie}\ (dBm) + 6.7dB \\ &= \quad -90.0 + 6.7 \\ &= \quad -83.3 \quad dB\mu W/cm^2 \end{aligned}$$

[16] See Section A1.2 above

The smallest power density measured in the field was –73.8 dBμW/cm^2 at the site in Lakeville, Plymouth County. This represents a "signal-plus-noise to noise" ratio that is 9.5 dB, equivalent to a numeric power ratio of 8.9. Consequently, the actual signal-to-noise ratio is (8.9 – 1) = 7.9, or 9.0 dB.

Therefore the maximum error caused by measuring "signal plus noise" rather than measuring the signal alone is the difference, or 9.5 – 9.0 = 0.5 dB. The error will be smaller at any of the other 49 measurement sites, because those all have signal-plus-noise to noise levels greater than 9.5 dB

The conclusion from this calculation is that at every one of the 50 sites where PAVE PAWS RFE was measured in this study, the error introduced by not compensating for the noise floor of the instrumentation was less than 0.5 dB. It was deemed to be not worth the effort required to correct each of the thousands of data points for the noise contribution, since in nearly every case, doing so would have no perceptible effect on the final result. For example, at the site with the second smallest power density measurement, Falmouth High School, the correction for measuring signal-plus-noise is only 0.1 dB.

A4.3.2 Dynamic Range of the PAVE PAWS RFE Measurements

There are three factors that determine the dynamic range of the PAVE PAWS RFE Measurements: 1) The dynamic range of the preamplifier, 2) the dynamic range of the power sensor, and 3) the amount of attenuation inserted in front of the receiver.

A4.3.2.1 Preamplifier Dynamic Range

The dynamic range of the preamplifier in the PAVE PAWS radiometer is the difference between the noise floor and the 1-dB output compression point of the preamplifier[17].

As shown above, the measured noise floor is –90.0 dBm. The Mini-Circuit Labs ZFL-1000VH2 that comprises the output stage of the preamplifier has a specified 1-dB compression point of +26 dBm. Referred back to the input of the two stage preamplifier, this is equivalent to an input 1-dB compression point of –14 dBm. Thus the dynamic range of the preamplifier is 90 dBm – 14 dBm = 76 dB.

A4.3.2.2 Power Sensor Dynamic Range

The Agilent E9323A RF power sensor has a specified dynamic range of –60 to +20 dBm, for a dynamic range of 80 dB[18]. Therefore the low-noise preamplifier that precedes the power sensor sets the dynamic range of the instrumentation.

A4.3.2.3 Fixed Attenuator

[17] Mini-Circuit Labs Data Sheet for ZFL-1000VH2 MMIC Amplifier
[18] Refs 36 and 37

In order to be able to measure signals that are more than 76 dB above the noise floor of the preamplifier, a manually adjustable precision attenuator was inserted in front of the preamplifier. This is the same technique that is used in spectrum analyzers to extend their strong-signal-handling capability. The attenuator does not change the dynamic range, but it does permit measuring signals that would overload either the preamplifier or the power sensor. Effectively, the noise floor is raised by the same amount that the overall gain is reduced.

At some measurement locations, it was necessary to insert 10 to 20 dB of attenuation before the preamplifier. Most sites were measured with 0 dB of attenuation.

A4.4 Elimination of Interfering Signals in Post Processing

As described in the Final Test Plan[19], two measures were taken to monitor for in-band (420-450 MHz) interference during the field measurements: 1) The spectrum analyzer's visual display was used to enable the operator to monitor the full 420-450 MHz band for the presence of signals other than the PAVE PAWS, and 2) a hand-held radio (Radio Shack Model HTX-404) was used to monitor for activity on known active Amateur Radio frequencies[20]. On those few occasions when activity was noted with on the Amateur frequencies, the spectrum analyzer was used to determine the relative signal strengths of the Amateur and PAVE PAWS signals. It was determined that the relative amplitudes of the in-band Amateur Radio signals were well below the level of the PAVE PAWS signals being measured.

There also is the possibility for very strong out-of-band signals to "ride through" the filters in the radiometer preamplifier unit. The transition band of the tubular bandpass filters in the preamplifier unit extends through the 406-420 and 450-470 MHz land mobile allocations. Although the 50 measurement sites were chosen taking into account proximity to strong local fixed sources of potential interference (i.e., land mobile base stations), there is no way to be sure that a vehicle containing a 406-420 MHz (US Government Land Mobile frequency allocation) or 450 to 470 MHz (Non-government Land Mobile frequency allocation) did not pass near the measurement site and happen have its mobile transmitter activated during the brief interval that it was within close proximity to the measurement site.

Strong interfering signals (i.e., signals originating close to the measurement site) manifest their presence in two ways: 1) As a burst of received signal much longer in duration than any of the pulsed emissions of the PAVE PAWS (A PAVE PAWS "resource" is 54 milliseconds long). A typical land mobile transmission might last 30 to 120 seconds, although a vehicle in motion would likely present a very strong signal to BSL's equipment for only a fraction of that interval. Since the RF power meter is sampling the received signal at approximately 25 times per second, there potentially would be several

[19] Ref 5, Section 3.1
[20] Ref. 5, Appendix C

hundred PAVE PAWS data samples corrupted by such a "continuous wave" transmission.

Recall that the radiometer used to measure the PAVE PAWS RFE simply measures the total power within the bandwidth defined by its bandpass filters. The instrumentation has no way to determine whether the input signal is pulsed, continuous wave, or broadband noise.

A strong interfering signal can manifest its presence in two ways. The most likely form of interference is to provide a burst of "continuous wave" signal for an interval that is much longer than a single radar "resource period." These events can be readily ascertained by examining the data records for the presence of a (nearly) constant signal level extending over a number of samples. In other words, the "time signature" of an interfering signal will be very different from the PAVE PAWS pulsed radar transmission.

Since multiple (in most cases, six) independent measurements were taken over 15 minute intervals at each PAVE PAWS measurement site, the easiest way to ascertain whether there are any corrupted data is to see whether any one of the three records shows a significantly higher (or lower) signal level than the others. Then manually go back to the raw data files and scan the data for periods of interference.

The one such record identified in post-processing to contain interference was the sixth measurement made at Site 13 (Davisville Road, East Falmouth School), where a portion of the measurement made at 120 degrees azimuth was clearly contaminated. This site was on a busy street near State Route 28. The measurements were made from the school parking lot, which was being plowed by the highway department during part of the measurement sequence. It is not known whether the snowplow operator had a land-mobile transmitter. On another occasion, a police cruiser passed through the parking lot. It was not known whether its operator activated his radio at the time. Nevertheless, there was a constant stream of vehicular traffic on the adjacent street, offering numerous possibilities for interference. This one contaminated data record was not included in the PAVE PAWS RFE data reported in the main body of this report, although it would be feasible to manually "scrub" the contaminated record of the portion with interference and process the remainder if that were deemed to be of value.

Another mechanism by which a strong adjacent-band interferer can corrupt the PAVE PAWS RFE data is by overloading the radiometer preamplifier with a signal sufficiently strong to cause the receiver gain to be "compressed." This would only occur if the interfering transmitter were extremely close to the measurement site, and would likely be of extremely short duration (unless the vehicle were parked nearby). Upon examining the data records, there were an extremely small number of power measurement samples in which the power meter recorded signal levels below the documented noise floor of the instrumentation. These were sufficiently few in number that they had no significant effect on the average power density calculations. The averaging of a very large number of samples of the power measurements (22,500 independent samples for each 15 minute measurement interval) effectively removed these few events.

A5 The Role of Reflections in the PAVE PAWS RFE Environment

A5.1 Reflections from Aircraft

Although aircraft are not the target of the PAVE PAWS mission, aircraft will pass through the PAVE PAWS field of view. The following paragraphs consider the case of a jumbo jetliner (e.g., a Boeing 747) flying at 35,000 feet to illustrate the expected signal levels that would be returned from such a target. Numerous of these planes traverse the airspace over eastern New England each day on their trips to and from Europe.

A straightforward exercise in trigonometry shows that an aircraft flying at an altitude of 35,000 ft (10.7 km) will pass through the PAVE PAWS +3 degree elevation search fence at a distance of approximately 101 miles (163 km) from the radar. Planes flying at lower altitudes will pass through the search fence at correspondingly shorter distances. For example, a plane flying at 20,000 ft will pass through the search fence at a distance of 63 miles. Table A5-1 below gives results for other altitudes.

Aircraft altitude (kft)	Distance (km)	Distance (mi)
5	28	17
10	54	34
15	78	48
20	101	63
25	123	76
30	143	89
35	163	101
40	182	113

Table A5-1 – Distance to an Aircraft 3 Degrees Above the Horizon

Rather than blindly plugging the numbers into the radar search equation, we shall proceed from basic principles to illustrate the mechanism responsible for the returned signal.

Assuming the peak PAVE PAWS transmitter power of P_t = +57.7 dBW and an antenna gain of G_t = +37.9 dBi at the center of the main beam of its antenna array, the peak power density S_{target} at the aircraft at a distance of 163 km will be

$$S_{target} = P_t + G_t - 10 \log (4 \pi R^2)$$

$$= +57.7\text{dBW} + 37.9 \text{ dBi} - 115.2 \text{ dB/m\^{}2}$$

$$= -19.6 \text{ dBW/m\^{}2}$$

Assuming a radar cross section σ = 1000 sq. m (+30 dB-m^2) for the aircraft, the power density $S_{receiver}$ returned to the receiving antenna on the ground will be

$$S_{receiver} = S_{target} + \sigma - 10 \log (4 \pi R^2)$$

$$= -19.6 \text{ dBW/m^2} + 30 \text{ dB-m^2} - 115.2 \text{ dB/m}^2$$

$$= -104.8 \text{ dBW/m}^2$$

$$= -84.8 \text{ dB}\mu\text{W/cm}^2$$

The assumption of a +30 dBsm[21] radar cross section for the aircraft is conservative by at least 10 dB for a jumbo jet such as the 747 flying broadside to the radar. Even at a nose-on aspect, the 747's radar cross section can be as large as 35 dBsm[22].

The important conclusion from this computation is that aircraft reflections of the PAVE PAWS main beam signal result in measurable power density values on the ground.

The second conclusion is that there will be no location within the line-of-sight of a high-altitude aircraft flying through the PAVE PAWS search fence that does not have some level of exposure to PAVE PAWS radio frequency emissions. Recalling that the radio horizon D in miles for an antenna of height h feet above the earth is given by

$$D = [\,2\,h\,]^{0.5}$$

$$= [\,70{,}000\,]^{0.5}$$

$$= 264 \text{ miles}$$

for an airplane at flying at 35,000 feet.

At a frequency of 435 MHz, the Schwarzbeck 60-600 MHz broadband dipole has a gain that is within a few tenths of a dB of unity. Therefore we shall assume that the receiver uses a zero gain (isotropic) antenna, so that its effective receiving area is

$$A_{eff} = G_r\,\lambda^2 / 4\,\pi$$

$$= 1 \times (0.69 \text{ m})^2 / (4\,\pi)$$

$$= -14.2 \text{ dB m}^2$$

[21] dBsm = dB referenced to one square meter
[22] A. G. Kramer, MITRE Corporation, Bedford, MA personal communication

and the received signal power is

$$P_r = S_{receiver} + A_{eff}$$

$$= -104.8 \text{ dBW/m}^2 - 14.2 \text{ dB-m}^2$$

$$= -119.0 \text{ dBW}$$

$$= -89.0 \text{ dBm}$$

Now suppose that for a receiver we are using a preamplifier having a 6dB noise figure and a spectrum analyzer with 100 kHz (+50 dB-Hz) resolution bandwidth, and that the preamplifier has sufficient gain to override the mixer noise of the spectrum analyzer.

The receiver noise power (referenced to the antenna input) in the IF bandwidth is

$$P_n = -174 \text{ dBm/Hz} + 6 \text{ dB} + 50 \text{ dB-Hz}$$

$$= -118 \text{ dBm}$$

The resulting single-pulse signal-to-noise ratio for this aircraft reflection is

$$P_r/P_n = -89.0 \text{ dBm} + 118 \text{ dBm}$$

$$= +29.0 \text{ dB}$$

There will be no difficulty observing this signal on the spectrum analyzer display, even if a wider resolution bandwidth (e.g., 1 MHz) were to be used, or if the aircraft were flying obliquely to the radar. [23]

It should be emphasized that aircraft reflections will not substantially increase the level of the PAVE PAWS RFE at locations where there is line-of-sight (or near line-of-sight) propagation to the receiving location. However, these reflections will result in the reception of PAVE PAWS signals at locations beyond line-of-sight where it would reasonably be expected that no PAVE PAWS energy would be present.

A5.2 Frequency Offset of a Reflected PAVE PAWS Signal Resulting from "Chirp" Modulation of the Transmitted Signal

The fundamental principle behind the operation of any radar system is that the radar's transmitter must illuminate the target with sufficient power density that the signal

[23] These calculations simplify the radar equation by overlooking small losses (system, scan and atmospheric losses) which would be utilized in the process of designing a radar. For our purposes here, these factors are minimal in comparison to the potential variation in the radar cross section of a jumbo jet depending on its orientation to the radar.

reflected back to the radar receiver will be detectable by the radar's receiver. In most radar applications, it is desired to ascertain other information from the received signal, such as range to the target, the angular coordinates of the target, and the rates of change of the those parameters, which may require stronger signals than those required to simply ascertain that the target is present.

But the energy delivered to the target by the radar's transmitter is not only reflected back to the radar receiver, but it is also reflected, scattered, and diffracted by the target in most other directions as well. Only in the "shadow zone" directly behind the target will the energy be substantially attenuated. Consequently, another receiver at a location different from the radar tuned to the radar's operating frequency may receive the reflected radar signal. This principle is used to implement bistatic radars where the radar's receiver and transmitter are intentionally sited at different locations.

A5.2.1 Discussion

Now consider the environment in which the PAVE PAWS RFE measurements were taken. At the 50 test locations, we can reasonably expect to receive a signal emitted by the PAVE PAWS that propagates directly from the radar antenna to the measurement site via the shortest possible path. In some cases, this shortest path is clearly line-of-sight. In other cases, there may be shadowing by intervening terrain, but we would still expect that there would be a received signal propagated via a path that approximates the line-of-sight path in length, although weaker than the line-of-sight signal.

Furthermore, from simple geometric considerations and the specifications for the PAVE PAWS antenna (see for example, Appendix A of the 1979 *Environmental Impact Statement*)[24], we do not expect to ever receive a signal from the main beam of the radar at ground level since the main beam is never steered below +3 degrees elevation. Instead, at ground level the received signals will predominantly be from the secondary sidelobes of the antenna. Because of the large number of radiating elements that comprise the PAVE PAWS facility (1792 active elements on each face of the radar, plus approximately twice as many "dummy" elements that are not connected to a transmitter or receiver), there will be hundreds of secondary sidelobes radiated at any instant of time. The amplitude and position of these sidelobes will appear to the observer to be random. Averaged over time and space, the level of these secondary sidelobes is –38 dB (nearly four orders of magnitude) smaller than the peak of the main beam[25]. However, the total power in all of the sidelobes is nearly as great as that that in the main beam, but it is distributed over a full hemisphere rather than being concentrated in a narrow beam that is 2-degrees wide.

In the Cape Cod environment there are numerous man-made structures that are capable of reflecting the PAVE PAWS signal. The most obvious of these are the water tanks situated on many Cape Cod hilltops. Other structures that also may reflect the signal

[24] Ref. 1
[25] Ref. 1, Table A-1 and associated text

include wireless and broadcast towers, bridges, and smokestacks. The specific case of the Canal Electric smokestack is discussed in more detail below.

Just as a ground-based observer will only receive sidelobe energy from the radar, these ground-based reflecting objects will only reflect sidelobe energy.

In addition, aircraft flying in the airspace over and near the Cape are capable of reflecting the much stronger main beam signal back to the ground. The reflections from aircraft were discussed in detail in the previous section.

In either case, a ground-based observer can reasonably expect to receive signals both directly from the radar (via the shortest possible path) and via reflection from other objects in the environment. The reflected signal will always traverse a path that is longer than the direct path from the radar to the observer. The only way the reflected path could be the same length as the direct path would be for the reflecting object to be directly in line with the line-of-sight from the radar to the observer.

If the radar signal were simply a sinusoidal carrier wave, there would be constructive and destructive interference between the direct and reflected signals. There would then be locations where the observed signal was stronger than expected from the direct path alone, and other places where it would be weaker.

However the situation with PAVE PAWS is not that simple. In order to accomplish its mission of detecting and tracking rather small targets at ranges up to 3000 miles, the carrier frequency of the transmitted pulse is “chirped,” or in other words, linearly swept upwards in frequency over the duration of each transmitted pulse. The result of this “chirping” is that the instantaneous frequency of the signal received from the radar via a direct path (and consequently arriving slightly earlier than a reflected signal) will be incrementally higher in frequency than the reflected signal. Instead of seeing constructive or destructive interference on the received pulse, the observer will see a “beat frequency” (or low-frequency amplitude modulation) imposed upon the received signal.

The frequency of this beat depends on the path length difference between the direct and reflected signals.

A5.2.2 Calculation of the Frequency Shift

If we denote the difference in path length between the direct and reflected signals in miles as Δd_{mi} then the difference in time of arrival Δt (in seconds) between the two pulses will be given by

$$\Delta t = \Delta d_{mi} / c$$

Where c = the speed of light

$$= \quad 186{,}000 \text{ miles/sec}$$

If we denote the amount of frequency modulation (i.e., the chirp) by Δf_{chirp}, and the duration of the transmitted pulse by T_{pulse}, then the amount of frequency offset between the direct and reflected signal is

$$\Delta f_{reflection} = (\Delta d_{mi} / c)\ x(\Delta f_{chirp} / T_{pulse})$$

The numerical results from this equation are presented in Table A5-2 for each of the PAVE PAWS waveforms.

Waveform	Pulse duration (msec)	Chirp bandwidth (MHz)	Frequency Shift (kHz/mile)
Short Range Search	0.3	0.1	1.79
Long Range Search (Triplet)	5	0.1	0.11
Long Range Search (Doublet)	8	0.1	0.07
Tracking	2	1.0	2.69
Tracking	4	1.0	1.34
Tracking	8	1.0	0.67
Tracking	16	1.0	0.34

Table A5-2 – Chirp Frequency Shift for Different PAVE PAWS Waveforms

The Table A5-2 shows that close-in reflections will cause audio "beats" on the received signals on the order of tens to hundreds of Hz. More distant reflections, which in many cases will be weaker because of the longer path traversed, are in the kHz region.

It should be pointed out that in a location that is totally devoid of direct-path propagation from the radar, there still might be energy received from the reflected path. In this case there will be no audio-frequency beat signals observed, unless there are multiple reflected paths of different lengths.

A5.2.3 Field Observations

At several of the 50 field measurement sites, the spectrum analyzer was operated as an "A-scope" radar display to permit viewing the received pulses in the time domain. The primary reason for doing this was simply to verify that the PAVE PAWS and the measurement equipment were operating normally.

The A-scope radar display is the simplest of all radar displays, in which the received signal amplitude is displayed on the vertical axis and time (equivalently range to the target) is displayed on the horizontal axis.

For the sequence of A-scope photos to be shown below, the spectrum analyzer was operated with the settings shown in Table H2-3 below

Parameter	Setting
Center frequency	435 MHz (center of the PAVE PAWS band)
Span width	0 Hz (zero span mode)
Resolution (IF) bandwidth	5 MHz (the maximum available)
Video (post-detection) bandwidth	10 kHz
Sweep rate	5 msec per division (the minimum available)
Vertical scale	10 dB/division
Reference level	-10 dBm

Table A5-3 – Spectrum Analyzer Settings for A-scope Display

Fortuitously, the highest sweep rate available on the Advantest spectrum analyzer permitted observing nearly all (50 msec) of one 54 msec PAVE PAWS resource period. The choice of a 5 MHz IF bandwidth permitted capturing signals from 4 contiguous PAVE PAWS frequency channels at once while still providing adequate signal-to-noise ratio for viewing the pulses. The 10 kHz video bandwidth provided a reduction in the noise floor, while still preserving the significant characteristics of the pulsed waveforms. (It also prevents observing beat frequencies above 10 kHz).

The sequence of photographs that follow were all made on February 24, 2004 at Scargo Hill in Dennis. Scargo Hill features a stone observation tower atop a 160 ft AMSL hill. It is line-of-sight to the PAVE PAWS at a distance of approximately 18 miles. The top of the tower (where the antenna was located) is well above the tree line and all nearby structures.

Each photograph shows one “triplet” long-range search waveform, consisting of three 5 msec pulses. The interesting aspect of all of these photographs is the apparent amplitude modulation of the pulses. Additionally, there are small amplitude variations from pulse to pulse. In most cases, the peak signal to noise ratio is 20 dB or more. The frequency of the beat can be estimated by counting the number of cycles in each 5 msec pulse.

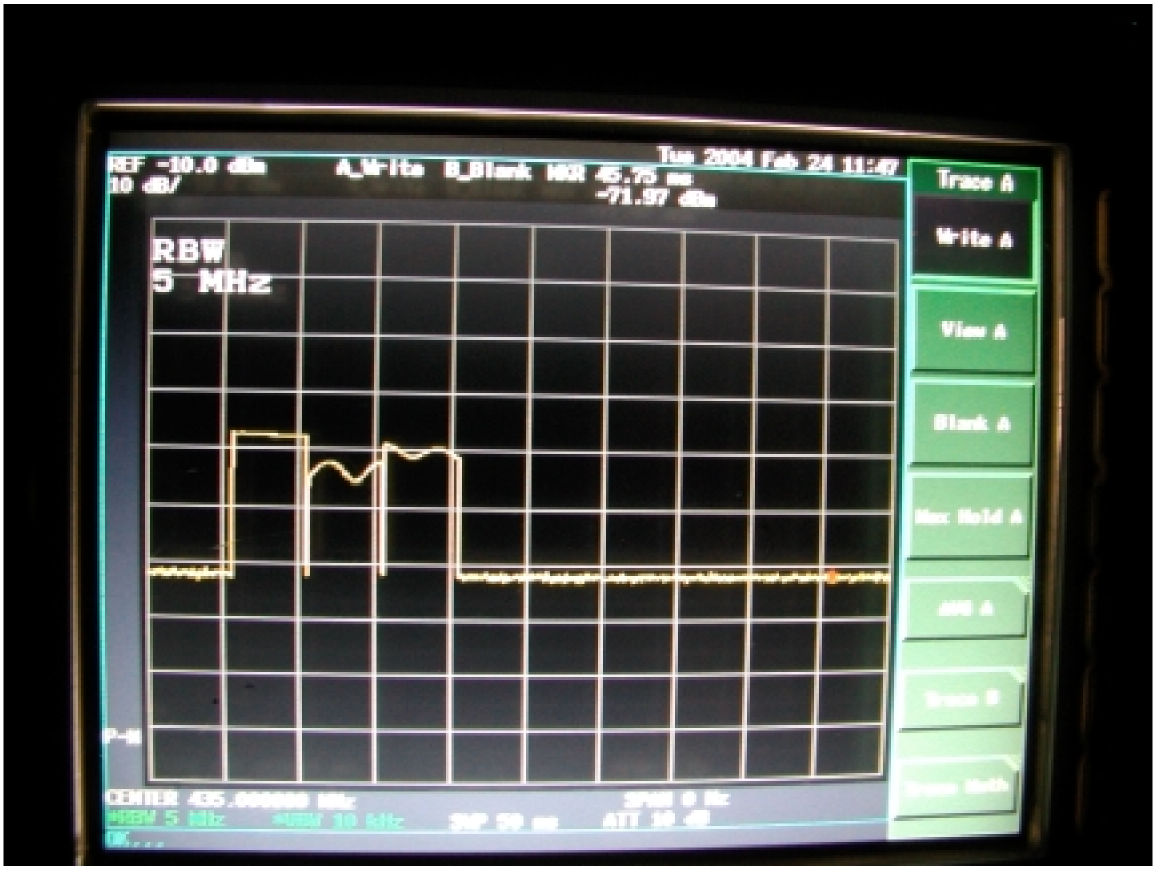


Figure A5-1 – Low Frequency Beat

In this figure, the beat frequency (on two of the three pulses of the triplet) is approximately 330 Hz. Apparently there was no significant reflection of the first pulse of the triplet. Referring to Table A5-3 above, this offset represents a path difference between the direct and reflected signals of approximately 3 miles. There may be a very low frequency beat in the first pulse of the triplet, but the 5 msec observation period is insufficient to be sure.

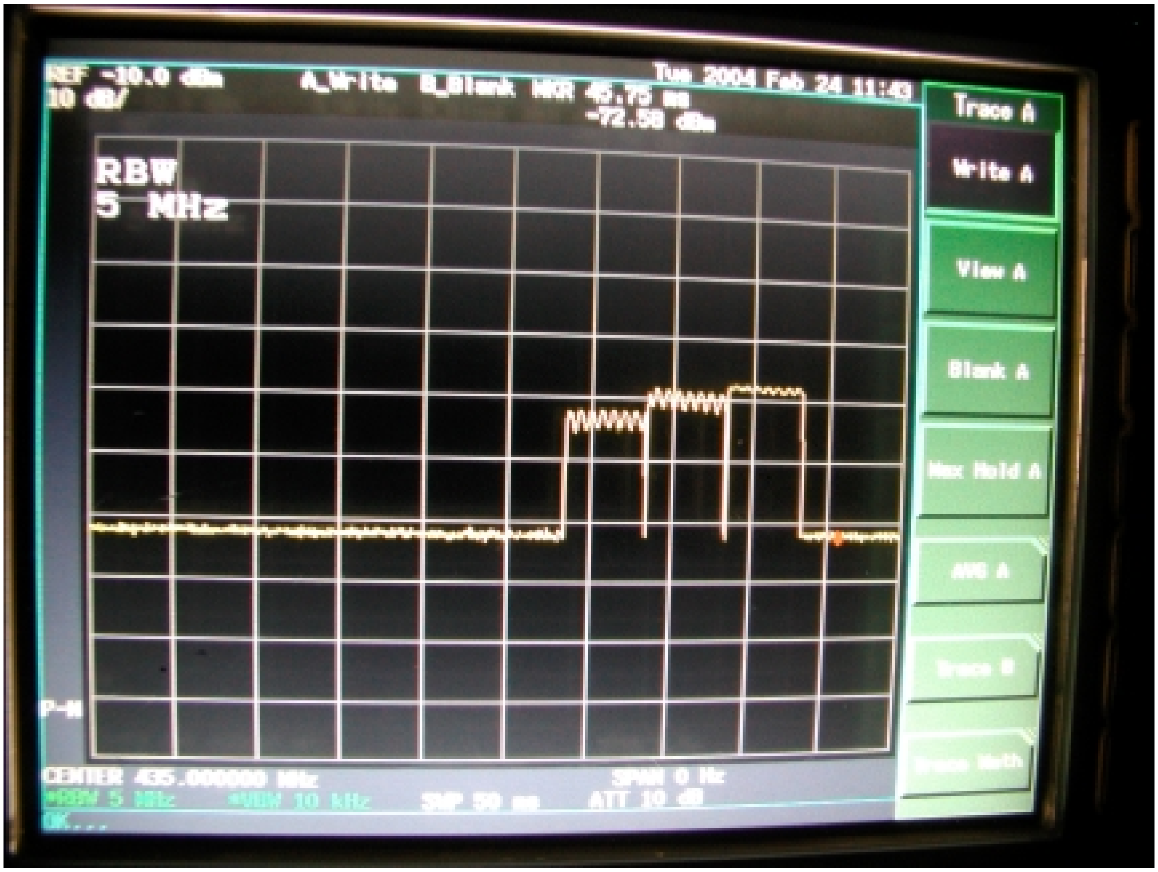


Figure A5-2 – Medium Frequency Beat

In Figure A5-2, the beat frequency is approximately 1.6 kHz. Referring to Table A5-3 above, this represents a path difference between the direct and reflected signal of approximately 14.5 miles.

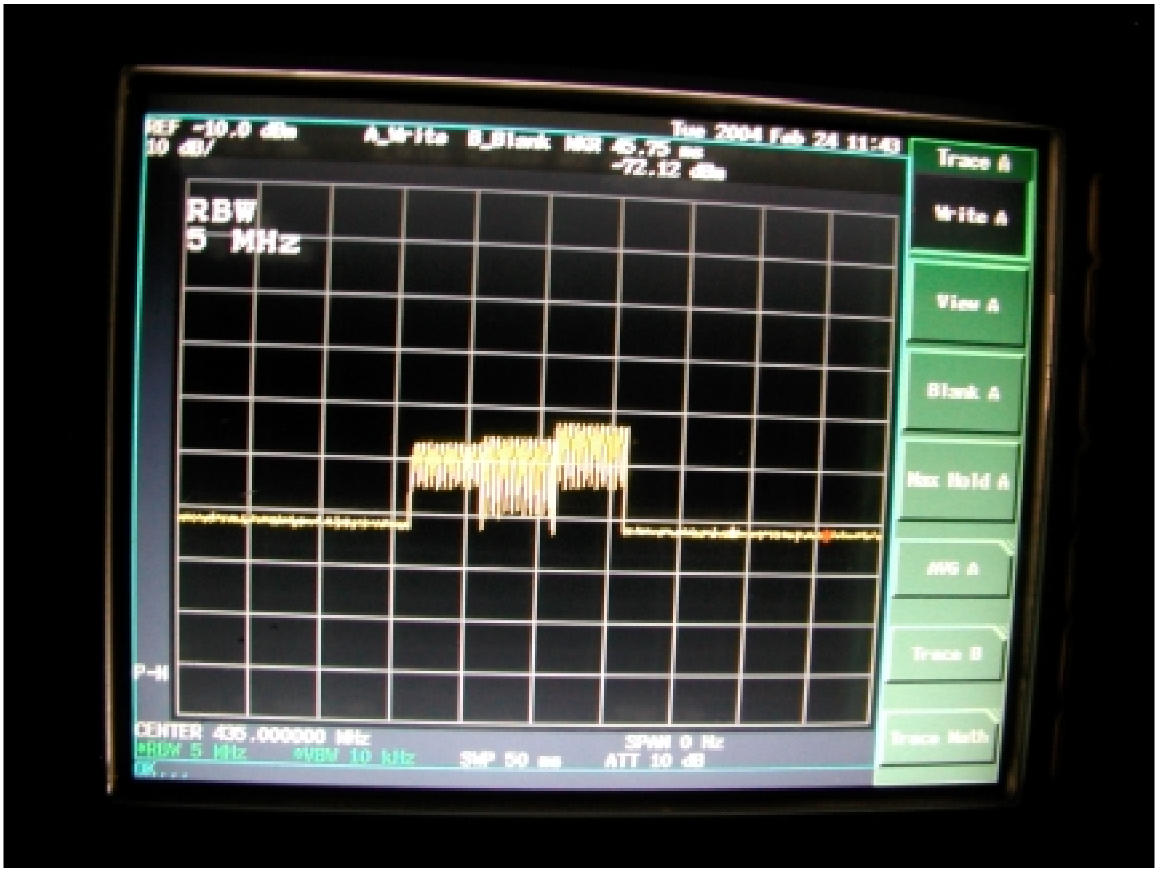


Figure A5-3 – High Frequency Beat

In Figure A5-3, the beat frequency is approximately 2.4 kHz. Referring to Table A5-3 above, this represents a path length difference between the direct and reflected signal of approximately 22 miles.

Although only three of these A-scope photographs are shown here, the results shown are typical of literally thousands of pulse sequences that were observed in the course of making the 50 sets of PAVE PAWS RFE measurements.

The conclusion from this exercise is that at many of the 50 PAVE PAWS measurement sites, there was significant reflected energy received in addition to that received directly from the radar antenna. Based upon the calculation made in the previous section, one source of these reflections is aircraft traversing the airspace over Cape Cod. In the next section, we examine a specific ground-based potential source of significant reflections of the PAVE PAWS signal.

A5.3 Analysis of Reflections from the Canal Electric Plant

The smokestack at the Canal Electric power plant is located at 41 deg 46 min 11 sec North, 70 deg 30 min 35 sec W (NAD 27)[26]. It is approximately 500 feet high (above ground level) and 60 feet in diameter[27]. The base of the stack is at 12 feet above mean sea level, for an overall height of 512 feet above mean sea level. The upper portion of the stack extends well into the antenna pattern of the PAVE PAWS radar, which has the center of its antenna array at 322 feet above mean sea level.

Figure A5.4 – Canal Electric Stack viewed from PAVE PAWS Roof

The distance from PAVE PAWS to the smokestack is 1.87 miles (9.9 kft or 3.01 km).

The reflections from the stack which reach the ground will not come from the main beam of the PAVE PAWS, which is tilted upwards nominally at 3 deg above the horizon, but instead will come from the first sidelobe, which has its peak at –0.4 degrees below the horizon. The energy in the primary sidelobe is concentrated within an approximately 2.2 degree elevation sector extending from +0.4 deg to –1.8 deg from the horizontal.

[26] Coordinates and height from FCC Antenna Structure Database (http://www.fcc.gov)
[27] Diameter estimated from photographs

Because the Canal Electric stack is approximately 9,900 feet from the PAVE PAWS, the secondary sidelobe will intersect only a portion of the total height of the stack, approximately

$$h_{effective} = 9{,}900 \tan (2.2 \text{ deg})$$

$$= 380 \text{ feet}$$

$$= 116 \text{ m.}$$

The diameter of the stack is approximately 60 feet, equivalent to a radius of 9 m.

The radar cross section of the "active" portion of the stack is given by[28]

$$\sigma = 2 \pi a b^2 / \lambda$$

where

$$a = \text{radius}$$

$$= 9 \text{ m}$$

$$b = \text{effective height}$$

$$= 116 \text{ m}$$

$$\lambda = \text{wavelength}$$

$$= 0.69 \text{ m}$$

Substituting these values,

$$\sigma = 1.10 \times 10^6 \text{ m}^2$$

$$= +60.4 \text{ dB-m}^2$$

Assuming a peak transmitter power of +57.7 dBW and an antenna gain of +17.9 dBi at the center of the first sidelobe of the PAVE PAWS array, the peak power density S_{target} at the stack ("the target" in the above equations) at distance of 9900 ft = 3.01 km from the radar will be

$$S_{target} = P_t + G_t - 10 \log (4 \pi R^2)$$

$$= +57.7\text{dBW} + 17.9 \text{ dBi} - 80.5 \text{ dB/m}^2$$

[28] Ref. 20, Chapter 8

$$= \quad -4.9 \text{ dBW/m}^2$$

The peak power density $S_{receiver}$ returned to a receiving antenna on the ground at a distance of 5.5 km from the stack (the Rt. 6 overlook parking area in Bourne) will be

$$S_{receiver} = S_{target} + \sigma - 10 \log (4 \pi R^2)$$

$$= -4.9 \text{ dBW/m}^2 + 60.4 \text{ dB-m}^2 - 85.8 \text{ dB/m}^2$$

$$= -30.3 \text{ dBW/m}^2$$

$$= -10.3 \text{ dB}\mu\text{W/cm}^2$$

It must be emphasized that the above is a peak power calculation based upon the PAVE PAWS beam being directed at the stack. The average power density will be reduced by both the radar's duty cycle and the antenna scan factor.

BSL measured a peak power density at the Rt. 6 Canal Overlook parking area of –8.7 dBμW/cm^2, which is well within the expected uncertainty in the measurements and the accuracy of this simple prediction.

The important conclusion to be drawn from this computation is that reflections of the PAVE PAWS first sidelobe signal for the Canal Electric smokestack result in measurable power density values to a ground-based observer, even at locations directly behind the radar antenna.

A5.4 Field Observations at Freezer Road, Sandwich

Early in the PAVE PAWS RFE measurement program, field measurements were made at Site 47, Freezer Road in Sandwich (Latitude 41 46 06.2 N, Longitude 70 30 22.3 W, NAD27) which is approximately 300 m from the Canal Electric smokestack and 3170 m from the PAVE PAWS. The difference in the antenna bearings from the measurement site to the stack and to the radar was approximately 60 degrees.

By using the Schwarzbeck log-periodic antenna (which has an E-plane 3-dB beamwidth of approximately 60 degrees) it was determined that PAVE PAWS signals were being received at the measurement location from both the direct path and from the smokestack. However the angular resolution of the measurement antenna's pattern was insufficient to make quantitative measurements of the relative strengths of the direct and reflected signals at this location.

A6.1 Measurement Summary

A6.1 Site Information Table

Site #	Zone #	Average dBMPE	Average uW/cm^2	Peak dBMPE	Peak uW/cm^2	SiteName	Town	Final Type	Radar Depression Angle (deg)	Site AMSL	Distance (mi)	Bearing (deg)
1	3	**-68.1**	4.5E-05	**-24.9**	9.5E-01	Pilgrim Monument site	Provincetown	H	0.094	49	27.38	41
2	3	**-74.9**	9.3E-06	**-32.8**	1.5E-01	Snows Field, Snowfield Rd	Truro	H	0.056	131	30.06	55
3	3	**-83.5**	1.3E-06	**-44.1**	1.1E-02	CCNS HQ	Wellfleet	H	0.087	42	30.69	70
4	3	**-86.9**	6.0E-07	**-63.6**	1.3E-04	Nauset Light Parking	Eastham	H	0.083	49	31.11	77
5	1	**-66**	7.3E-05	**-32.8**	1.5E-01	Rock Harbor parking	Orleans	H	0.108	13	27.5	83
6	1	**-70**	2.9E-05	**-42.6**	1.6E-02	Great Hill	Chatham	H	0.07	98	29.3	98
7	1	**-73.4**	1.3E-05	**-32.7**	1.6E-01	Keith Lane circle	Brewster	H	0.082	108	23.6	90
8	1	**-88.3**	4.2E-07	**-64.6**	1.0E-04	Cemetery, Harwich Ctr	Harwich	H	0.11	42	24.1	101
9	1	**-48.8**	3.8E-03	**-12.8**	1.5E+01	Scargo Hill	Dennis	H	0.13	65	18.5	93
10	1	**-80.5**	2.6E-06	**-42.3**	1.7E-02	Woodside Cemetery, Yarmouthport, off Summer Street	Yarmouth	H	0.155	65	15.5	76
11	1	**-77.1**	5.6E-06	**-39.8**	3.1E-02	Main St Centerville	Barnstable	H	0.199	62	12.3	117
12	2	**-54.9**	8.2E-05	**-32.7**	1.6E-01	Athletic field Rt 130, north of Ashumet Rd	Mashpee	H	0.271	108	7.17	162
13	2	**-81.2**	2.2E-06	**-36.6**	6.3E-02	Davisville Rd E Falmouth school	Falmouth	H	0.221	36	12.3	185
14	4	**-62.6**	1.6E-04	**-22.9**	1.5E+00	Mashnee Island Grill	Bourne	H	0.546	6	5.58	244
15	3	**-39.2**	3.5E-02	**-12.9**	1.5E+01	Shawme Crowell State Park (Site A-10?)	Sandwich	H	1.37	167	0.95	46.13
16	1	-55.7	7.8E-04	-22.8	1.5E+00	Cardinal Rd Circle	Sandwich	L	0.229	252	2.8	119
17	1	-74.5	1.0E-05	-32.7	1.5E-01	Rt 130 @ Cotuit Rd	Sandwich	L	0.404	173	3.71	138
18	1	-63.4	1.3E-04	-22.7	1.5E+00	Mt Hope Cemetery Rt 6A	Sandwich	L	1.14	22	2.75	92.39
19	1	-61.1	2.2E-04	-22.8	1.5E+00	Jarves Rd @ Factory St	Sandwich	L	1.32	13	2.45	78.33

Site #	Zone #	Average dBMPE	Average uW/cm^2	Peak dBMPE	Peak uW/cm^2	SiteName	Town	Final Type	Radar Depression Angle (deg)	Site AMSL	Distance (mi)	Bearing (deg)
20	1	-66.9	5.9E-05	-23.2	1.4E+00	Sandwich Public Library	Sandwich	S(43)	1.583	9	2.07	81
21	1	-50.5	2.6E-03	-12.9	1.5E+01	Holder Ln Circle	Sandwich	L	0.742	134	2.59	108
22	3	-61.8	1.9E-04	-22.7	1.5E+00	Scusset Beach Parking 1	Sandwich	S	1.246	9	2.63	50
23	3	-47.6	5.0E-03	-12.9	1.5E+01	Scusset Beach Parking 2	Sandwich	L	1.251	9	2.62	47
24	3	-71.6	2.0E-05	-32.8	1.5E-01	Sagamore athletic field	Bourne	S(108)	2.245	13	1.44	357
25	3	-56.5	6.5E-04	-22.8	1.5E+00	Church Lane @ Cape Pine Rd	Bourne	L	1.11	85	2.21	350
26	3	-60.8	2.4E-04	-22.8	1.5E+00	Sagamore School, Williston Rd	Bourne	L	1.441	68	1.83	11
27	5	-55.7	7.8E-04	-22.8	1.5E+00	Brigantine Passage Dr	Bourne	L	1.021	137	1.85	339
28	5	-85.5	8.2E-07	-58.9	3.7E-04	Eagle Rd	Plymouth	L	0.522	104	4.3	317
29	6	-74.3	1.1E-05	-33.3	1.4E-01	Rt 6E Canal overlook	Bourne	L	1.068	124	1.9	291
30	6	-84.4	1.0E-06	-50.0	2.9E-03	Cypress St @ Rt 6 Bypass	Bourne	L	0.923	32	3.28	269
31	4	-74.3	1.1E-05	-32.8	1.5E-01	Monument Beach former water tank	Bourne	L	0.597	75	4.29	235
32	4	-76.7	6.1E-06	-32.8	1.5E-01	Wings Neck Road @ Harbor Drive	Bourne	L	0.501	6	6.6	331
33	2	-86.3	6.7E-07	-48.3	4.3E-03	Scraggy Neck Rd at Cataumet Club	Bourne	S(102)	0.411	32	7.36	215
34	2	-70.6	2.5E-05	-32.9	1.5E-01	Carolyn Cir Forestdale	Sandwich	L	0.366	127	5.46	117
35	2	-84.5	1.0E-06	-33.5	1.3E-01	Barnstable County Fairgrounds	Falmouth	L	0.271	78	9.34	179
36	2	-93.7	1.2E-07	-60.9	2.4E-04	Falmouth HS, Brickkiln Rd	Falmouth	S(105)	0.24	52	11.7	198
37	2	-88.6	4.0E-07	-43.8	1.2E-02	Mashpee Senior Center	Mashpee	S(39)	0.33	29	9.28	164
38	2	-91.5	2.1E-07	-66.3	6.8E-05	N Falmouth School	Falmouth	S(141)	0.342	26	9.05	208

Site #	Zone #	Average dBMPE	Average uW/cm^2	Peak dBMPE	Peak uW/cm^2	SiteName	Town	Final Type	Radar Depression Angle (deg)	Site AMSL	Distance (mi)	Bearing (deg)
39	1	-91.8	1.9E-07	-49.3	3.4E-03	Marstons Mills School, 2095 Main St	Barnstable	S(26)	0.283	62	9.55	136
40	3	-48.7	3.9E-03	-13.0	1.4E+01	Shawme Crowell State Park (Site A-10?)	Sandwich	L	1.644	167	0.95	46.13
41	3	-67	5.7E-05	-32.7	1.5E-01	Burbank St and Main (Rt 130)	Sandwich	S(16)	1.979	72	1.31	64.63
42	1	-90.5	2.6E-07	-37.1	5.6E-02	Old County Rd, Near State Hatchery	Sandwich	S(79)	0.514	42	5.68	107
43	6	-102.9	1.5E-08	-71.3	2.2E-05	Assawompset School	Lakeville	S(92)	0.105	98	22.05	287
44	6	-91.2	2.2E-07	-67.6	5.0E-05	Onset School, Union Ave	Wareham	L	0.481	32	6.3	264
45	3	-65.7	7.8E-05	-32.9	1.5E-01	Ellisville Rd	Plymouth	L	0.379	127	5.27	356
46	3	-87.6	5.1E-07	-55.6	7.9E-04	October Lane circle, Cedar Bushes	Plymouth	S(79)	0.317	16	10.1	353
47	3	-58.1	4.5E-04	-23.0	1.5E+00	Freezer Road @ Tupper Road	Sandwich	S(10)	1.625	16	1.97	58
48	2	-84.9	9.4E-07	-43.9	1.2E-02	Stone School Circle, Otis AFB	Bourne (MMR)	S(72)	0.332	98	6.96	196
49	5	-70.4	2.6E-05	-45.0	9.2E-03	Post 'n Rail Ave Cedarville	Plymouth	L	0.68	59	4.02	343
50	1	-91.1	2.3E-07	-65.4	8.4E-05	Barnstable HS, rear, use Falmouth Rd entrance	Barnstable	S(79)	0.205	65	13	121

A6.2 Table of Individual Measurements

Site No.	Description	Town	Average Power Density (dB-uW/cm^2)						MAX-MIN	MAX	MIN	SD	Average (dB-uW/cm^2)
			Position 1	Position 2	Position 3	Position 4	Position 5	Position 6					
1	Pilgrim Monument site	Provincetown	-44.1	-45.7	-39.6	-47.0	-45.4	-44.7	7.4	-39.6	-47.0	2.6	-43.5
2	Snows Field, Snowfield Rd	Truro	-50.9	-51.2	-51.0	-48.5	-50.6	-57.8	9.3	-48.5	-57.8	3.2	-50.3
3	CCNS HQ	Welfleet	-59.1	-57.8	-59.0	-59.2	-59.7	-66.5	8.7	-57.8	-66.5	3.1	-58.9
4	Nauset Light parking	Eastham	-62.2	-63.2	-63.2	-61.4	-61.5	-68.4	6.9	-61.4	-68.4	2.6	-62.2
5	Rock Harbor Rd	Orleans	-40.3	-40.6	-41.6	-43.7		-54.9	14.6	-40.3	-54.9	6.1	-41.4
6	Great Hill	Chatham	-43.6	-46.9	-48.8	-44.9	-44.6	-47.5	5.1	-43.6	-48.8	2.0	-45.4
7	Keith Lane	Brewster	-50.6	-46.8	-49.1	-49.6	-48.8	-59.0	12.2	-46.8	-59.0	4.3	-48.8
8	Cemetery, Harwich Ctr	Harwich	-64.6	-63.3	-63.3	-63.6	-63.9	-64.0	1.3	-63.3	-64.6	0.5	-63.7
9	Scargo Hill	Dennis	-25.0	-24.4	-24.4	-24.2	-22.7	-24.7	2.3	-22.7	-25.0	0.8	-24.2
10	Carriage Ln @ Sandyside Ln triangle, Yarmouthport	Yarmouth	-53.9	-66.6	-75.4	-55.1	-55.2	-57.7	21.4	-53.9	-75.4	8.6	-55.9
11	Main St Centerville	Barnstable	-57.9	-46.7	-58.0	-58.2	-58.0	-65.4	18.7	-46.7	-65.4	6.0	-52.5
12	Athletic field Rt 130, north of Ashumet Rd	Mashpee	-44.5		-50.0	-35.8	-47.7	-54.9	19.2	-35.8	-54.9	7.2	-40.9
13	Davisville Rd E Falmouth school	Falmouth	-57.8	-57.0	-57.1	-54.7	-57.0	-38.7	19.1	-38.7	-57.8	7.4	-56.6
14	Shore Rd @ Old Dam Rd, triangle	Bourne	-49.2	-37.2	-37.4	-38.9	-35.5	-46.2	13.7	-35.5	-49.2	5.6	-38.0
15	Shawme Crowell State Park	Sandwich	-14.6							-14.6	-14.6		-14.6
16	Cardinal Rd Circle	Sandwich	-28.9	-32.7	-32.4	-29.0	-32.2	-34.0	5.1	-28.9	-34.0	2.1	-31.1
17	Rt 130 @ Cotuit Rd	Sandwich	-50.6	-48.7	-48.2	-50.2	-50.6	-51.5	3.2	-48.2	-51.5	1.3	-49.8
18	Mt Hope Cemetery Rt 6A	Sandwich	-37.9	-38.8	-37.9	-38.9	-39.9	-39.8	2.0	-37.9	-39.9	0.9	-38.8
19	Jarves Rd @ Factory St	Sandwich	-35.4	-33.1	-39.8	-39.4	-36.2	-40.2	7.2	-33.1	-40.2	2.9	-36.5
20	Sandwich Public Library	Sandwich	-36.3	-46.7	-44.4	-46.9	-47.1	-47.1	10.9	-36.3	-47.1	4.3	-42.3
21	Holder Ln Circle	Sandwich	-30.8	-25.3	-22.7	-27.1	-26.4	-27.3	8.1	-22.7	-30.8	2.7	-25.9
22	Scusset Beach Parking 1	Sandwich	-35.7	-36.9	-37.1	-38.3	-36.8	-38.8	3.1	-35.7	-38.8	1.1	-37.1
23	Scusset Beach Parking 2	Sandwich	-21.5	-24.2	-24.0	-24.3	-24.6	-21.0	3.5	-21.0	-24.6	1.6	-23.0
24	Sagamore athletic field	Bourne	-43.6	-46.1	-48.4	-49.2	-49.4	-48.3	5.8	-43.6	-49.4	2.2	-47.0
25	Church Lane @ Cape Pine Rd	Bourne	-29.2	-32.4	-32.4	-34.8	-33.3	-31.3	5.6	-29.2	-34.8	1.9	-31.9
26	Sagamore School, Williston Rd	Bourne	-34.2	-41.9	-35.8	-34.2	-36.9	-38.0	7.7	-34.2	-41.9	2.9	-36.2
27	Brigantine Passage Dr	Bourne	-30.3	-30.9	-32.2	-30.3	-32.1		1.9	-30.3	-32.2	0.9	-31.1
28	Eagle Rd	Plymouth	-58.7	-60.3	-61.4	-61.6	-62.3	-61.8	3.6	-58.7	-62.3	1.3	-60.8

Site No.	Description	Town	Average Power Density (dB-uW/cm^2) Position 1	Position 2	Position 3	Position 4	Position 5	Position 6	MAX-MIN	MAX	MIN	SD	Average (dB-uW/cm^2)
29	Rt 6E Canal overlook	Bourne	-50.1	-48.8	-48.9	-49.6	-50.9	-50.0	2.1	-48.8	-50.9	0.8	-49.6
30	Cypress St @ Rt 6 Bypass	Bourne	-61.4	-60.6	-60.2	-59.7	-58.8	-58.8	2.7	-58.8	-61.4	1.0	-59.8
31	Monument Beach, Tower Circle	Bourne	-51.0	-47.1	-49.7	-51.6	-49.6	-50.8	4.5	-47.1	-51.6	1.6	-49.7
32	Wings Neck Rd near Harbor Dr	Bourne	-49.7	-52.4	-52.1	-52.0	-54.2	-54.0	4.6	-49.7	-54.2	1.7	-52.1
33	Cataumet Club, Scraggy Neck Rd	Bourne	-62.8	-63.9	-62.0	-60.4	-62.8	-59.9	3.9	-59.9	-63.9	1.5	-61.7
34	Carolyn Cir Forestdale	Sandwich	-39.7	-52.9	-47.9	-50.7	-51.6	-50.7	13.2	-39.7	-52.9	4.8	-46.0
35	Barnstable County Fairgrounds	Falmouth	-59.5	-59.4	-59.5	-60.3	-60.3	-60.1	0.9	-59.4	-60.3	0.4	-59.8
36	Falmouth HS, Brickkiln Rd	Falmouth	-71.4	-68.8	-68.2	-68.6	-68.8	-69.2	3.2	-68.2	-71.4	1.1	-69.1
37	Mashpee Senior Center	Mashpee	-69.8	-57.2	-78.4	-70.0	-67.7	-69.8	21.2	-57.2	-78.4	6.8	-64.0
38	N Falmouth School	Falmouth	-64.1	-66.2	-66.8	-68.7	-69.0	-68.8	4.9	-64.1	-69.0	1.9	-66.9
39	Marstons Mills School, 2095 Main St	Barnstable	-65.4	-66.0	-66.9	-67.4	-75.4		10.0	-65.4	-75.4	4.1	-67.2
40	Shawme Crowell State Park	Sandwich	-25.6	-24.8	-22.0	-25.3	-26.8	-22.1	4.9	-22.0	-26.8	2.0	-24.0
41	Burbank St and Main (Rt 130)	Sandwich	-42.8	-42.1	-42.6	-41.6	-43.0	-42.5	1.4	-41.6	-43.0	0.5	-42.4
42	Old County Rd, Near State Hatchery	Sandwich	-65.3	-67.6	-65.6	-66.6	-65.1	-65.7	2.5	-65.1	-67.6	1.0	-65.9
43	Assawompset School	Lakeville	-78.7	-77.3	-77.7	-81.6	-78.0	-77.7	4.3	-77.3	-81.6	1.6	-78.3
44	Onset School, Union Ave	Wareham	-67.5	-68.2	-62.6	-69.2	-67.4	-68.6	6.7	-62.6	-69.2	2.4	-66.6
45	Ellisville Rd	Plymouth	-49.7	-47.7	-46.9	-48.4	-34.1	-48.4	15.6	-34.1	-49.7	5.8	-41.1
46	October Lane circle, Cedar Bushes	Plymouth	-62.5	-63.9	-62.1	-62.9	-62.6	-64.1	2.0	-62.1	-64.1	0.8	-63.0
47	Freezer Rd near Ed Mofitt Dr	Sandwich	-30.6	-33.5	-35.6	-35.2	-34.9	-33.1	5.0	-30.6	-35.6	1.9	-33.4
48	Stone School Circle, Otis AFB	Bourne (MMR)	-61.8	-57.8	-59.7	-60.0	-60.6	-64.2	6.5	-57.8	-64.2	2.2	-60.3
49	Post 'n Rail Av Cedarville	Plymouth	-53.5	-45.8	-47.2	-44.4	-43.8	-45.1	9.7	-43.8	-53.5	3.6	-45.8
50	Barnstable HS, rear	Barnstable	-65.3	-66.8	-67.3	-66.1	-67.2	-66.3	1.9	-65.3	-67.3	0.7	-66.5

Broadcast Signal Lab

APPENDIX B
The Ambient RFE Measurement Task

B1 Method for Computing the Peak and Average Power Density

B1.1 Reference to the Final Test Plan

Section 4.1 of the Final Test Plan[1] contains a detailed discussion of the measurement rationale for the Ambient RFE test, and that discussion will not be repeated here. To summarize that discussion, BSL proposed to use a spectrum analyzer which covers the 30 to 3000 MHz frequency band that would operate under computer control to make a large number of average and peak power measurements of the ambient radio frequency signals at ten test sites. The average and peak power density at each test location would be computed from the power measured at the output of the test antenna. Section B2 of this Appendix contains the details of the equipment configuration as it was implemented. Appendix D of this document describes the equipment calibration. Section B3 provides a calculation of the estimated measurement accuracy of the test instrumentation. The results of the Ambient RFE measurements are presented in the body of the Final Test Report.

B1.2 Conversion from Received Signal Power to Power Density

Note: This section repeats the discussion of Appendix A1.2, in order that Appendix B contains a complete discussion of the Ambient Measurements. The reader who has already read Appendix A in its entirety can skip to Section B1.3 below.

All field measurements made by BSL in the PAVE PAWS RFE study (PAVE PAWS, Ambient, and Drive Test) provide the value of the received signal power at the input to the receiver preamplifier. In other words, the standard interface for all measurements was defined to be at the junction of the antenna feedline and the receiver preamplifier. The data recorded in the data files was recorded in decibels referenced to one milliwatt (dBm) at the specified reference point.

On the other hand, exposure to radio frequency emissions at VHF (30 to 300 MHz) and UHF (300 to 3000 MHz) frequencies and beyond is defined in terms of power density, that is, the power transmitted in an electromagnetic wave which traverses a specified area[2]. In this report, all power density measurements are expressed in units of microwatts per square centimeter, or equivalently in decibels referenced to 1 microwatt per square centimeter. (Alternative units for power density that are sometimes used in the literature are watts per square meter or milliwatts per square centimeter.)

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[1] Ref. 5, Sect. 4.1

[2] Refs 7, 8, and 9

The following discussion shows how the received signal power data are converted to power density. This discussion in this section applies to both the PAVE PAWS and Ambient measurements. Section B1.3 below applies specifically to the Ambient measurements.

The fundamental relationship between power density *S* and electric field intensity *E* is

$$S(W/m^2) = E^2(V/m) / Z_0$$

where

$$Z_0 = 120\ \pi$$

$$= 377 \text{ ohms, the characteristic impedance of free space.}$$

BSL has chosen to report all power density numbers in decibels referenced to one microwatt per square centimeter. This was done 1) to be consistent with the units used in the 1979 PAVE PAWS *Environmental Impact Statement*, and 2) to use a logarithmic unit of measure to conveniently deal with numbers ranging over several orders of magnitude.

Therefore the above equation can be rewritten (in decibels) as follows:

$$S(dB\mu W/cm^2) = 10 \log [E^2(V/m) /1.2\pi]$$

$$= 20 \log E(V/m) – 10 \log (1.2\pi)$$

$$= E(dBV/m) – 5.76\ dB$$

and

$$E(dBV/m) = E(dB\mu V/m) – 120.0\ dB$$

$$= V_r(dB\mu V) + AF(dBV/m/V) + L_f(dB) -120.0\ dB$$

where

V_r = the signal voltage at the receiver input,

AF = the antenna factor, and

L_f = the feedline loss.

$$E(dBV/m) = P_r(dBm) +107.0\ dB+ AF(dBV/m/V) + L_f(dB) -120.0\ dB$$

$$= P_r(dBm) + AF(dBV/m/V) + L_f(dB) -13.0\ dB$$

This relationship applies to both the peak and average measurements, where E and P refer to peak and average values, respectively.

B1.3 Peak and Average Power Density for Ambient RFE Measurements

The situation is slightly more complicated for the ambient measurements than for the PAVE PAWS measurements, since the ambient measurements cover a much wider range of frequencies (2,970 MHz vs 30 MHz). Both the antenna factor and feedline loss are frequency-dependent.

Therefore the computation of power density for ambient measurements must include the specific value of antenna factor and feedline loss at the measurement frequency. We shall rewrite the general equation given above to explicitly remind us that the factors on the right-hand side are now frequency dependent.

$$S(dB\mu W/cm^2) \quad = \quad P_r(f{:}dBm) + AF(f{:}dBV/m/V) + L_f(f{:}dB) - 18.76\ dB$$

The antenna factor versus frequency for the antennas used for the ambient measurements is included in the calibration data in Appendix D. The same relationship between received signal power and power density applies to both the peak and average measurements.

B2 Ambient RFE Data Collection

B2.1 Reference to the Final Test Plan

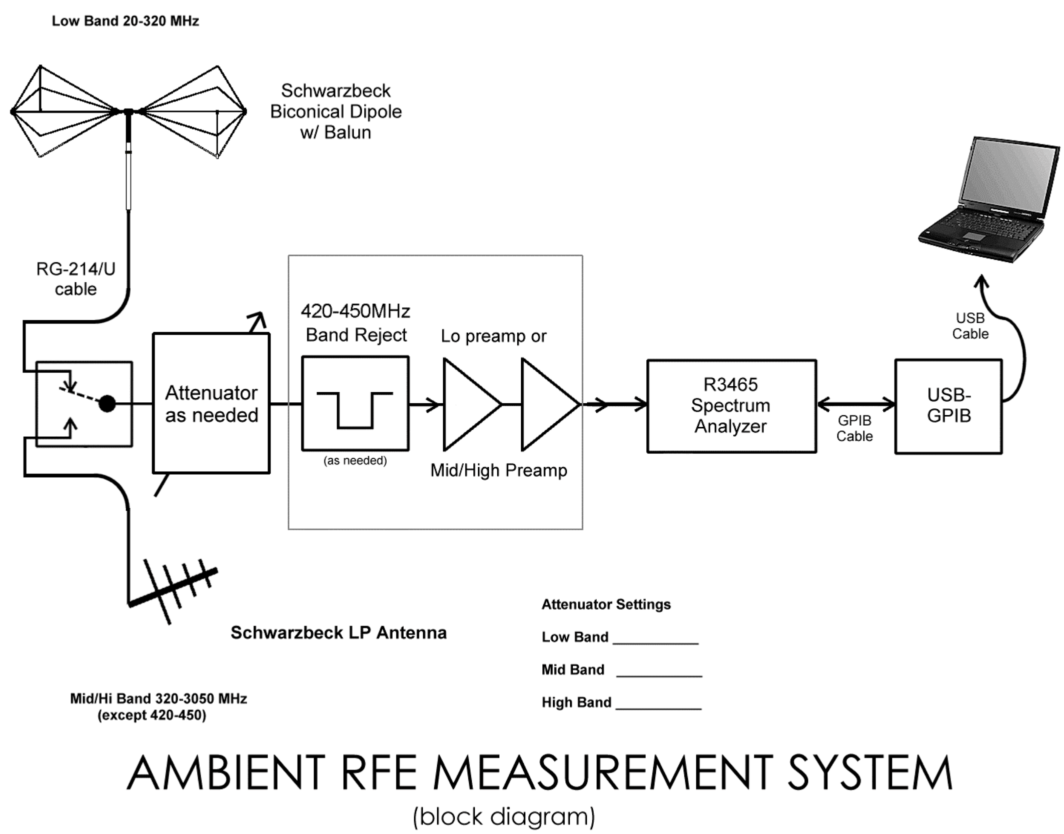
Section 4.2 of the Final Test Plan[3] contains a detailed discussion of the measurement rationale for the Ambient RFE test, and that discussion will not be repeated here. Instead, this section provides additional details on the actual test hardware and software that were not included in the Test Plan. To summarize the discussion in the Test Plan, the Advantest R3465 spectrum analyzer in conjunction with a low-noise preamplifier was used to measure the received signal level in 100 or 300 kHz wide bands (depending on frequency) from 30 to 3000 MHz. Multiple samples were taken in each frequency bin in order to determine peak and average levels via post-processing (described in detail in Section B5 below). The measured signal levels for each frequency bin, in dBm referenced to the preamplifier input, were transferred to a laptop computer where the unprocessed data were recorded in a series of data files. An ASCII text file format was utilized in the interest of simplicity. Furthermore, this choice of file format permits use of the largest variety of software tools for subsequent processing of the data by others. A description of the contents of these data files is provided below.

[3] Ref. 5, Sect. 4.2

B2.2 Equipment Configuration for Measuring the Average and Peak Ambient Power Density

This section provides additional details on the implementation of the instrumentation used to make the ambient power density measurements. At the time the Final Test Plan was prepared, Broadcast Signal Lab was still assembling the hardware and software. Although in concept the measurement system is not changed from that described in the test plan, there are some details in which it is different. The following paragraphs describe the components in the system block diagram as used in the field.

Figure B2-1 – Ambient Measurement Block Diagram



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B2.2.1 RF Spectrum Analyzer

The Advantest (Rhode and Schwarz) model R3465 spectrum analyzer was utilized to make all of the ambient measurements. Key parameters of this instrument are summarized in the following table[4].

Parameter	Value
Frequency range	9 kHz to 8.0 GHz
Phase noise	<-110dBc/Hz (100kHz offset)
Resolution Bandwidth	300Hz to 3 MHz, 5 MHz
Video Bandwidth	1 Hz to 3 MHz, 5 MHz
Sweep time	50 ms to 1000 sec
Measurement range	+30 dBm to indicated noise level
Reference level range (logarithmic)	-105 to +60 dBm
Input Attenuator range	0 to 70 dB (10 dB steps)
Average display noise level	<-115 dBm
1 dB gain compression (>10 MHz)	-5 dBm mixer input level
Frequency response (9 kHz to 3 GHz)	+/- 1.5 dB
Calibration signal accuracy	+/- 0.3 dB
IF gain error (15 to 35 deg C)	+/- 0.5 dB
Scale indication accuracy (15 to 35 deg C)	+/- 1.5 dB/80 dB
Input attenuator switching error	+/- 0.1 db per 10 dB step, 2.0 dB max.
Resolution bandwidth switching error	< +/- 0.3 dB
Operating temperature range	0 to 50 C

Table B2-1 – Spectrum Analyzer Specifications

The specific measurement parameters that were used for gathering the ambient data were not included in the Final Test Plan, because the hardware and software were not fully operational at the time that document was prepared. Considerable effort was devoted to optimizing those parameters to maximize the amount of ambient RFE data that could be captured in a reasonable amount of time. The specific parameters that were implemented in the test software are given below in Section B2.

In concept, the ambient measurement procedure does not differ from the procedure that would be used by a human operator manually using a spectrum analyzer to scan a specific frequency band for activity and then recording the resulting spectrum analyzer traces either digitally or on film. However, by performing these operations automatically under computer control, it is feasible to gather substantially more data in a given measurement interval, and to post-process the data from multiple frequency sweeps to aggregate the data into a "composite picture" of the ambient signals over a wide frequency span (here 30 to 3000 MHz), and over a long period of time (a couple of hours).

[4] Ref. 47

The skeptic may ask, "How do you know that you did not miss some signal in your measurements?" The answer is that BSL may have missed some highly transient signals, but those will not contribute significantly to the overall radio frequency exposure precisely because of their transient nature. Furthermore, extended periods of observation of the land mobile bands (where activity tends to be intermittent) convinced us that the BSL measurement protocol did not miss any significant contributors.

The width of the "frequency bins" (i.e., the spectrum analyzer resolution bandwidth) used in making measurements from 30 MHz to 950 MHz was 100 kHz, and measurements were made and recorded in 100 kHz steps within that frequency range, excepting the 420 to 450 MHz PAVE PAWS radar band. The PAVE PAWS frequency band was explicitly omitted in order to readily separate the ambient from the radar emissions.

The width of the "frequency bins" (i.e., the resolution bandwidth) used from 950 MHz to 3050 MHz were 300 kHz wide, and measurements were made in 300 kHz steps over that frequency range. This wider resolution bandwidth was chosen as a compromise to prevent the time required to make these "High band" measurements from taking a disproportionally large amount of time.

B2.2.230 to 300 MHz Antenna

Because the frequency range for the ambient measurements spans two decades, two one-decade-bandwidth calibrated antennas were used.

A broadband biconical dipole antenna, of the same design as that used for the PAVE PAWS measurements except being physically twice as large, was used for the ambient measurements from 30 to 300 MHz. Measurements were actually made from 20 to 320 MHz with this antenna, in the interest of simplifying the data collection software. The data taken from 20 to 30 MHz was not used in computing the final results. In order to approximate the full-hemisphere coverage of an isotropic antenna, it was necessary to make measurements in three mutually orthogonal orientations of the antenna. This process was described in the Final Test Plan[5].

B2.2.3300 to 3000 MHz Antenna

A broadband log-periodic dipole antenna was used for the ambient measurements from 0.3 to 3.0 GHz. In order to approximate the full-hemisphere coverage of an isotropic antenna, it was necessary to make measurements in nine orientations of the antenna. The antenna pattern of the particular log periodic antenna used is approximately 60 by 120 degrees, which implies that a total of nine antenna orientations is required to cover the entire 360 degree by 360 degree sphere.

[5] Ref. 5, Sect. 3.1.2.3

The antenna was placed in each of three orthogonal polarization axes to sample all arriving RF energy vectors. Because the LPDA is directional, it was rotated to three positions axially about each polarization axis to sample the entirety of an imaginary spherical surface surrounding the test fixture. The three polarization angles times the three axial rotations yields the nine antenna orientations required to obtain a power density value.

B2.2.4 Antenna Feedline

45 feet RG-214/U double-shielded coaxial cable was used to connect the antenna to the test equipment in all measurements. The attenuation of this cable was verified by BSL to be within the manufacturer's specification. The attenuation data were subsequently incorporated in the post processing of the data, using the formula presented in Appendix A above.

B2.2.5 Low-noise Preamplifiers

Two high-dynamic-range low-noise preamplifiers (one used for 30 to 300 MHz and one for 0.3 to 3.0 GHz) with noise figures of less than 6 dB were included in the test setup to establish the noise floor of the measuring equipment. The spectrum analyzer to that was used for these measurements has a specified noise floor of –145 dBm/Hz, or equivalently a noise figure of 29 dB (which is typical of the state of the art in spectrum analyzers).

The VHF preamplifier had a nominal gain of 39 dB over the band 30 to 300 MHz and the UHF preamplifier had a nominal gain of 33 dB over the frequency range 300 to 3000 MHz. Both amplifiers had noise figures of approximately 6 dB.

B2.2.6 Band Reject Filter

A concern at the time that the Final Test Plan was prepared was that (at one ambient measurement site) the PAVE PAWS radar signal might be capable of overloading the low-noise preamplifier. Therefore the equipment diagrams in the Final Test Plan document included a 420 to 450 MHz band-reject filter in the test setup[6]. This filter was not used in the field for a several reasons.

1) At no ambient measurement site was the PAVE PAWS signal sufficiently above the ambient to cause receiver overload.
2) The inclusion of a 420-450 MHz band reject filter would result in significant attenuation of ambient signals in the adjacent land mobile bands near 420 and 450 MHz, resulting in an unrealistic picture of 450 MHz land mobile activity in the Cape Cod region.

[6] Ref. 5, Sect. 4.1.2

3) The RF attenuator described in the following paragraph provided a substantially lower cost alternative to the band-reject filter for dealing with potential overload situations.

B2.2.7 Manual RF Attenuator

A precision RF attenuator (providing 0 to 69 dB attenuation in one dB steps) was included in the test setup to establish the over-all gain of the receiver. At many locations it was necessary to limit the gain of the preamplifier to avoid overload from strong local signals, particularly from FM broadcast stations. This attenuator provided a convenient way to establish the dynamic range of the ambient measurement setup in the field.

B2.3 Software Functional Description for Ambient RFE Data Collection

The following subsections describe the BSL-developed software that was used to control the test instruments and collect the data. The design objective for this software was to implement a data collection process that required a minimal amount of operator intervention, in an effort to maximize the amount of data captured and to minimize the opportunity for operator-induced errors.

Note that there are two programs described in the discussion that follows. The program Low Band BRFE is used for the frequency range 30 to 320 MHz, and the program Upper BRFE is for 320 MHz to 3000 MHz. In actuality, programs record BRFE data for the range 20 MHz to 3050 MHz, in order that there be the same number of frequency “bins” in each sub band measured. Early in the field test program, the functions contained in the program “Upper BRFE” were divided between two separate programs, one for 320-950 MHz and one for 950-3050 MHz. A detailed functional description of those two programs is not included here, since each is simply a subset of the functionality that is incorporated in Upper BRFE.

PROGRAM: Low Band BRFE

PURPOSE: To measure the strengths of all signals present between 20 MHz and 320 MHz using the Advantest Spectrum Analyzer (Model R3465).

OPERATOR INPUTS:

- Site description from predefined (pull down) list
- Actual site Latitude (dd-mm-ss.s) manually read from GPS Receiver
- Actual site Longitude (dd-mm-ss.s) manually read from GPS Receiver
- Spectrum analyzer reference level
- Preamp gain (including any attenuation manually inserted)
- Number of times to perform measurement cycle (default=4)
- Antenna being used (from pull down list or manual entry)

- Feedline description (from pull down list or manual entry
- Any comments desired to be included in data file

PROGRAM OPERATION:

- Open the data file, automatically assigning a unique name derived from the site designation and real-time clock
- Set:
  - Spectrum analyzer to known state (factory presets)
  - Spectrum analyzer sweep to 1001 points per curve
  - Spectrum analyzer sweep time to 2 seconds per sweep
  - Spectrum analyzer parameters to operator inputs
  - Point antenna to North for consistency – ask operator if antenna is pointed north

Data collection loop: (Operator specifies the number of times to perform)

- Point antenna to 240 degrees
  1. Set spectrum analyzer to:
     1.1. Center frequency of 70 MHz
     1.2. Span of 100 MHz
     1.3. Resolution Bandwidth of 100 KHz
  2. Ignore first two curves to allow instrument to settle
  3. Read 10 curves from the spectrum analyzer
     3.1. Compute for each 100 KHz between start and end frequencies:
        3.1.1. Minimum, maximum, average and median signal strengths
        3.1.2. Standard deviation
  4. Write data to disk file
  5. Set spectrum analyzer to:
     5.1. Center frequency of 170 MHz
     5.2. Span of 100 MHz
  6. Repeat steps 2. through 4.
  7. Set spectrum analyzer to:
     7.1. Center frequency of 270 MHz
     7.2. Span of 100 MHz
  8. Repeat steps 2. through 4.

- Point antenna to 0 degrees and repeat 1. through 8.
- Point antenna to 120 degrees and repeat 1. through 8.
- Return antenna to North
- Repeat all 9 measurements (three frequency bands and three antenna headings) as many times as specified by operator (the default 4 sets)
- Close data file
- Return to Windows Desktop

PROGRAM: Upper Band BRFE

PURPOSE: To measure the strengths of signals present between 320 MHz and 3050 MHz , skipping the frequencies between 420 MHz and 450 MHz using the Advantest Spectrum Analyzer (Model R3465).

OPERATOR INPUTS:

- Site description from predefined list
- Actual site Latitude from GPS Receiver
- Actual site Longitude from GPS Receiver
- Reference level
- Preamp gain
- Antenna being used
- Feedline description
- Any desired comments to be included in data file

PROGRAM OPERATION:

- Set:
  - Spectrum analyzer to known state (factory presets)
  - Spectrum analyzer sweep to 1001 points per curve
  - Spectrum analyzer sweep time to 2 seconds per sweep
  - Spectrum analyzer to operator inputs
  - Point antenna to North for consistency

Data collection loop:

- Point antenna to 240 degrees

9. Set spectrum analyzer to:
   9.1. Center frequency of 370 MHz
   9.2. Span of 100 MHz
   9.3. Resolution Bandwidth of 100 KHz
10. Ignore first two curves to allow instrument to settle
11. Read 10 curves from the spectrum analyzer
    11.1. Compute for each 100 KHz between start and end frequency:
        11.1.1. Minimum, maximum, average and median signal strengths
        11.1.2. Standard deviation
12. Write data to disk file
13. Set spectrum analyzer to:
    13.1. Center frequency of 500 MHz
    13.2. Span of 100 MHz
    13.3. Resolution Bandwidth of 100 KHz
14. Repeat 2. through 4.
15. Set spectrum analyzer to:
    15.1. Center frequency of 600 MHz

    15.2. Span of 100 MHz
    15.3. Resolution Bandwidth of 100 KHz
16. Repeat 2. through 4.
17. Set spectrum analyzer to:
    17.1. Center frequency of 700 MHz
    17.2. Span of 100 MHz
    17.3. Resolution Bandwidth of 100 KHz
18. Repeat 2. through 4.
19. Set spectrum analyzer to:
    19.1. Center frequency of 800 MHz
    19.2. Span of 100 MHz
    19.3. Resolution Bandwidth of 100 KHz
20. Repeat 2. through 4.
21. Set spectrum analyzer to:
    21.1. Center frequency of 900 MHz
    21.2. Span of 100 MHz
    21.3. Resolution Bandwidth of 100 KHz
22. Repeat 2. through 4.
23. Set spectrum analyzer to:
    23.1. Center frequency of 1100 MHz
    23.2. Span of 300 MHz
    23.3. Resolution Bandwidth of 300 KHz
24. Ignore first two curves to allow instrument to settle
25. Read 10 curves from the spectrum analyzer
    25.1. Compute for each 300 KHz between start and end frequency
        25.1.1. Minimum, maximum, average and median signal strengths
        25.1.2. Standard deviation
26. Write data to disk file
27. Set spectrum analyzer to:
    27.1. Center frequency of 1400 MHz
    27.2. Span of 300 MHz
    27.3. Resolution Bandwidth of 300 KHz
28. Repeat 16. through 18.
29. Set spectrum analyzer to:
    29.1. Center frequency of 1700 MHz
    29.2. Span of 300 MHz
    29.3. Resolution Bandwidth of 300 KHz
30. Repeat 16. through 18.
31. Set spectrum analyzer to:
    31.1. Center frequency of 2000 MHz
    31.2. Span of 300 MHz
    31.3. Resolution Bandwidth of 300 KHz
32. Repeat 16. through 18.
33. Set spectrum analyzer to:
    33.1. Center frequency of 2300 MHz
    33.2. Span of 300 MHz

33.3. Resolution Bandwidth of 300 KHz
34. Repeat 16. through 18.
35. Set spectrum analyzer to:
    35.1. Center frequency of 2600 MHz
    35.2. Span of 300 MHz
    35.3. Resolution Bandwidth of 300 KHz
36. Repeat 16. through 18.
37. Set spectrum analyzer to:
    37.1. Center frequency of 2900 MHz
    37.2. Span of 300 MHz
    37.3. Resolution Bandwidth of 300 KHz
38. Repeat 16. through 18.

- Point antenna to 0 degrees and repeat 1. through 30.
- Point antenna to 120 degrees and repeat 1. through 30.
- Return antenna to North
- Close data file
- Return to Windows Desktop

B2.4 System Operation for Ambient RFE Measurements

This section provides a narrative description in outline form of the operation of the BSL test equipment (described above) in the in the field.

B2.4.1 Equipment Setup

- Locate target test site using GPS coordinates and local maps.

- Survey the site to determine the best location for the measurement, considering proximity to overhead wires, traffic flow, emergency access, handicap access, etc.

- Change the test site location if necessary.

- Ensure that the vehicle is safely positioned away from traffic.

- When appropriate, place orange traffic cones in the roadway and have personnel wear an orange traffic vest when outside the vehicle.

- Determine that the total RF environment is compliant with occupational exposure standards by means of the Narda instrument to evaluate RF exposure potential (from 300 kHz to 50 GHz) and record the reading in percent of the occupational MPE limits.

[In no case was a proposed measurement site determined to be non-compliant with occupational MPE limits.]

- Set up the 30-300 MHz Schwarzbeck test antenna on the 30-foot fiberglass antenna mast, connect the coaxial cable to the input of the VHF preamplifier and connect antenna rotator cable to the control box.

B2.4.2 Equipment Operation - 30 to 320 MHz

- Set up the 30-300 MHz Schwarzbeck test antenna on the 30-foot fiberglass antenna mast, connect the coaxial cable to the input of the VHF preamplifier and connect antenna rotator cable to the control box.

- The operator turns on the test equipment.

- Connect the VHF preamplifier output to the spectrum analyzer.

- Take a series of manual scans of the 30 to 300 MHz region of the spectrum to determine the optimum settings for the input attenuator and spectrum analyzer reference level to minimize intermodulation products while maximizing the dynamic range of signals displayed.

- Note these settings for subsequent entry into the computer program.

- Check all other cable connections in the test equipment suite.

- Start the computer program Low Band BRFE .exe.

- From this point until the program terminates, the computer controls all equipment operation and all operator actions are at the direction of prompts on the computer screen.

- See the software functional description above for details.

– B2.4.3 Equipment Operation - 320 to 3050 MHz

- Take down the 30 to 300 MHz antenna and install the 300 to 3000 MHz log-periodic antenna on the 30-foot fiberglass mast.
- Note that three different orientations (“vertical,” “clockwise,” and “counterclockwise”) of this antenna are required in the course of the measurements, necessitating erecting the mast a total of three times.
- Connect the UHF preamplifier output to the spectrum analyzer input.
- Take a series of manual scans of the 30 to 300 MHz region of the spectrum to determine the optimum settings for the input attenuator and spectrum analyzer reference level to minimize intermodulation products while maximizing the dynamic range of the signals displayed.
- Note these settings for subsequent entry into the computer program.
- Check all other cable connections in the test equipment suite.
- Start the computer program Upper BRFE .exe.
- From this point until the program terminates, the computer controls all equipment operation and all operator actions are at the direction of prompts on the computer screen.
- See the software functional description above for details.

B2.4.4 Site Data Forms

- Take the following readings manually from the GPS receiver: Latitude, Longitude, Elevation, Bearing and distance to the PAWE PAWS, barometric pressure, and record on the site data form.
- Obtain temperature, dew point, and wind data (when available) from the National Weather Service broadcast on 162.550 MHz and record on the site data form.

- Provide a brief description of the test site location.

- Note the attenuator setting on the site data form.

- Make notes of any unusual circumstances with regard to the test equipment or site.

- Log any photographs taken.

[Site data forms were transcribed to a spreadsheet file PP site data transcription.xls]

B2.4.5 Site Photographs

At a minimum, at each site at least one photograph was made showing the test vehicle, antenna, and the local environment. At some sites, “snap shots” of the spectrum analyzer display were taken to show major contributors to the ambient RF environment.

B3 Measurement Uncertainty for the Ambient RFE Measurements

The following table provides a tabulation of the individual components of the measurement uncertainty contributed by the Advantest spectrum analyzer. All parameters in this table were obtained from the manufacturer’s specifications.

Advantest Spectrum Analyzer Measurement Uncertainty Budget			
	RSS Error	Power	RSS
Parameter	(dB)	ratio	component
Frequency response (9 kHz to 3 GHz)	1.5	1.41	0.1702
Calibration signal accuracy	0.3	1.07	0.0051
IF gain error (15 to 35 deg C)	0.5	1.12	0.0149
Scale indication accuracy (15 to 35 deg C)	1.5	1.41	0.1702
Input attenuator switching error (20 dB max)	0.2	1.05	0.0022
Resolution bandwidth switching error	0.3	1.07	0.0051
	RSS Uncertainty (ratio)		0.61
	RSS Uncertainty (dB)		2.06

Table B3-1 – Advantest Spectrum Analyzer Measurement Uncertainty Budget

The following table provides a tabulation of the individual components of the measurement uncertainty for the Ambient RFE measurements. The manufacturers' specifications were used for the spectrum analyzer and power sensor. Broadcast Signal Lab measured all other components.

Ambient RFE Measurement Uncertainty Budget				
Parameter	**Source**	**RSS Error (dB)**	**Power ratio**	**RSS component**
Spectrum Analyzer (30 MHz to 3000 MHz)	Specifications	2.06	1.61	0.37
Preamp gain	Measured	1.00	1.26	0.07
RF Attenuator	Measured	0.30	1.07	0.01
Feedline (45 ft RG-214/U)	Measured	0.10	1.02	0.00
Antenna (300-3000 MHz)	Specifications	1.00	1.26	0.07
		RSS Uncertainty (ratio)		0.71
		RSS Uncertainty (dB)		2.34

Table B3-2 – Ambient RFE Measurement Uncertainty Budget

In the Final Test Plan, it was predicted that the spectrum analyzer and antenna would contribute equally to the measurement uncertainty. In fact, the spectrum analyzer dominates the uncertainly. The predicted RSS uncertainty of 2.3 dB is slightly greater than the value of 2.0 dB specified in the Statement of Work, and the major contributor to that uncertainly is the spectrum analyzer. BSL maintains that the achieved measurement uncertainty represents the state of the art in broadband RF survey measurements, and that the achieved performance of the instrumentation achieves the overall objectives of the project.

B4 Post Processing the Ambient Data

B4.1 Reference to the Final Test Plan

Section 4.7 of the Final Test Plan[7] presented the format in which the summary ambient data would be presented in this Test Report. This section of the Final Test Report describes the means for reducing the ambient power density data for approximately 17,000 measurement frequencies for each ambient measurement site into an average weighted maximum permissible exposure (WMPE) value for each of the ten sites.

The functional description of the post-processing Visual Basic programs (Process xxx Ambient.vbp, where “xxx” denotes “Mid,” “High,” or “Upper”) given below provides a concise step-by-step description of the steps performed in post processing the data. The final output of this program is one text file containing the average power density for each frequency computed from one data file. Thus in this output file there are one pair of numbers (peak power density and average power density) for each measurement frequency. Additionally the program computes fractional maximum permissible exposure for each measurement frequency.

The final step in the data reduction is to import the data from this summary output file into a series of MS-Excel spreadsheets (described in Section B.4.3.2.2) in which the fractional MPE values from each frequency bin are added to produce a single peak and average weighted MPE number for that site. The weighted MPE numbers are presented in tables contained in the main body of this report.

Additionally, a series of 30 MS-Excel charts have been prepared to show a composite picture of the frequency occupancy for each of the ten sites. These graphs appear in Appendix L.

Before proceeding to the details of the post-processing programs, we shall describe the procedure used to compute the weighted maximum permissible exposure, which is central to the data reduction performed on the ambient data.

[7] Ref. 5, Sect. 4.7

B4.2 Computation of the Weighted Maximum Permissible Exposure

At any specific frequency f (in MHz), the Maximum Permissible Exposure for the general public (abbreviated here as MPE_{public}) is specified in IEEE Standard C95.1-1999[8] by the following relationships:

$$MPE_{public} = 200\ \mu W/cm^2 \quad \text{for } 30\text{ MHz} < f < 300\text{ MHz, and}$$

$$MPE_{public} = f/1.5\ \mu W/cm^2 \quad \text{for } 300\text{ MHz} < f < 3000\text{ MHz.}$$

For any value of power density S measured at a specific frequency f, the fractional MPE is obtained by dividing the measured power density S by the MPE:

$$\text{Fractional MPE} = S(\mu W/cm^2)/\ MPE_{public}$$

This Fractional MPE (expressed in decibels for convenience in dealing with the very small values which result) has been computed for each of the 10 ambient measurement sites. These results appear in the body of this Final Test Report.

For the Ambient Measurements, the Weighted Maximum Permissible Exposure (WMPE) for all significant emitters is obtained by adding the Fractional MPE of all of the separate emitters:

$$WMPE = \sum \text{Fractional MPE}$$

$$= \sum S(\mu W/cm^2)/\ MPE_{public}$$

where the summation is performed over all significant emitters.

Established RFE safety standards require that the Fractional MPE be less than unity (a ratio of 1.00 or equivalently 0 dB) for any single emitter. Similarly, the safety standards require that the WMPE be less than unity for a collection of emitters.

This computation has been performed for the ten ambient measurement sites. The summary results for each of the ten sites appear in the main body of this report.

B4.3 Data Reduction for Ambient RFE Measurements

The following paragraphs describe the means for reducing several million ambient data readings to peak and average values for a single antenna position at a single site.

[8] Ref. 8

B4.3.1 Low Band Ambient (30-320 MHz)

B4.3.1.1 Functional Description of the Visual Basic Post-Processing Software

PROGRAM: Process Low Ambient.vbp

PURPOSE: To convert the data taken by the program Low Band BRFE.exe to power density, find the peak and average values, and save converted data to disk.

OPERATOR INPUT: Select site to be converted from list of ambient measurement sites

PROGRAM OPERATION:

- Open text file "Ambient Data Directory.txt" and extract a list of the sites containing low band ambient data. Use to fill drop-down list for operator selection.
- Open text file "9106 Ant Factor.txt" and store array of antenna factors for use during data conversion.
- Open output file for summary data: "Ambient Low Band Summary.txt"
- Open input file for the site being processed: "Low0xx hh-mm-ss.txt"; xx denotes the site number
- Open output file for the site being processed: "Low0xx Power Density.txt" "; xx denotes the site number
- Read headers from input file and write to site output file.

DATA CONVERSION LOOP:

1. Read 1000 lines of data containing 16 columns of data. Each line contains frequency, 10 measured values plus the minimum, maximum, average, median and standard deviation for those ten measurements.
2. Store frequency into separate array.
3. Convert the 10 measured values for each frequency (20-119.9 MHz) to power density.
4. Skip over intermediate file headers.
5. Read 1000 lines of data for second frequency band (120-219.9 MHz) and convert to power density.
6. Skip over intermediate file headings.
7. Read 1001 lines of data for third frequency band (220-320 MHz) and convert to power density.
8. Repeat steps 1 through 7 for each antenna heading (240, 0 and 120 degrees.)
9. When all 3001 frequencies have been read, add together the power densities for each antenna heading to get the total power density for each frequency. (This is done separately for each of the ten measurements made at each frequency and antenna heading.)

10. Compute the average power density of all ten sets of measurements for each frequency.
11. Compute the maximum (peak) power density for each frequency.
12. Write the frequency, peak and average power density to the site output file.
13. Repeat steps 1 through 12 for each iteration (either two or four) of the above measurements.
14. Compute the average and peak of all the above sets of data.
15. Write frequency, peak and average to the summary file.
16. Ask operator if he wishes to process another site. If yes, repeat steps1 through 15 until all sites have been processed. If no, exit program.

B4.3.1.2 Description of the MS-Excel Workbook File "Ambient Low Band Summary 032704.xls"

Note: All ten Low Band ambient measurements are included as separate worksheets in this MS-Excel workbook, in contrast with the Mid Band and High Band measurements where a separate workbook exists for each site.

B4.3.1.2.1 Worksheet "Ambient Low Band Summary"

The data contained in this worksheet have been imported from the text file "Ambient Low Band Summary.txt" that was produced from the post-processing (in MS-Visual Basic) of the raw data contained in the 10 ambient RFE data files (one for each ambient site) covering the frequency range 20 to 320 MHz.

For each of the ten data files processed, this worksheet contains one peak and one average power density number (in microwatts per square centimeter) for each frequency and each site. The data are presented in frequency sequence.

In this worksheet, the post-processed data for the ten sites appear in sequence, with 3001 "frequency bins" for each site, spaced on 100 kHz centers from 20 MHz to 320 MHz.

Note that the Site_004 data appears after Site_010 in this file, because the Site_004 data only included two, rather than four, repetitions of the full frequency sweep. Therefore it required a slightly different processing algorithm.

There are three columns in the worksheet: 1) The frequency in MHz; 2) the peak power density obtained by searching all of the data taken at a given frequency and site for the largest value; and 3) the average power density obtained by averaging all the measurements made at that site and for that frequency.

The peak measurement is more likely to capture transient (such as land mobile) signals, while the average measurement is the number pertinent to determining Maximum Permissible Exposure.

B4.3.1.2.2 Worksheet “Site_001” through “Site_010”

The first three columns of these worksheets contain copies of the data from the worksheet “Ambient Low Band Summary,” broken out by site. The peak and average power densities are expressed in microwatts per square centimeter.

The fourth and fifth columns are the power density measurements, divided by the Maximum Permissible Exposure (200 microwatts per square centimeter over the frequency range of 30 to 300 MHz). We call this the “Fractional Maximum Permissible Exposure” since it represents the fraction of the MPE contributed by that particular frequency.

B4.3.1.2.3 Worksheet “Summary”

This worksheet is linked to the ten site worksheets “Site_001” through “Site_010” and summarizes the Weighted MPE computed for each of the ten sites.

In this summary sheet, the Weighted MPE (which is a fraction) is expressed logarithmically (in decibels) because the results span several orders of magnitude.

Additionally, the peak-to-average ratio is computed for each site to give an indication of the transient nature of the signals that comprise the total RFE power density for each site.

B4.3.2 Mid Band and High Band Ambient (320-420 and 450-3050 MHz)

B4.3.2.1 Functional Description of the Visual Basic Post-Processing Software

Note: The description provided here is a “generic” description of three different versions of essentially the same program that were used to post-process the 320 to 3050 MHz ambient data.

PROGRAMS: Process Mid Ambient.vbp, Process High Ambient.vbp and Process Upper Ambient.vbp
See below for the variations for High and Upper Ambient programs.

PURPOSE: To convert the data taken by the program Mid Band BRFE.exe to power density, find the peak and average and save converted data to disk.

OPERATOR INPUT: Select site to be converted from list of ambient measurement sites

PROGRAM OPERATION:

- Open text file "Ambient Data Directory.txt" and extract a list of the sites containing low band ambient data. Use to fill drop-down list for operator selection.
- Open text file "LPDA300-3000.txt" and store array of antenna factors for use during data conversion to power density
- Open input file for the site being processed: "Mid0xx hh-mm-ss.txt" "; xx denotes the site number
- Open output file for the site being processed: "Mid0xx Power Density.txt" "; xx denotes the site number
- Read headers from input file and write to site output file.

DATA CONVERSION LOOP:

17. Read 1000 lines of data containing 16 columns of data. Each line contains frequency, 10 measured values plus minimum, maximum, average, median and standard deviation for those ten measurements.
18. Store frequency into separate array.
19. Convert the 10 measured values for each frequency (320-419.9 MHz) to power density (no data was collected in the PAVE PAWS band 420-450 MHz).
20. Skip over intermediate file headers.
21. Read 1000 lines of data for second frequency band (450-549.9 MHz) and convert to power density.
22. Skip over intermediate file headings.
23. Read 1001 lines of data for third frequency band (550-649.9 MHz) and convert to power density.
24. Skip over intermediate file headings.
25. Read 1001 lines of data for third frequency band (650-749.9 MHz) and convert to power density.
26. Skip over intermediate file headings.
27. Read 1001 lines of data for third frequency band (750-849.9 MHz) and convert to power density.
28. Skip over intermediate file headings.
29. Read 1001 lines of data for third frequency band (850-950 MHz) and convert to power density.
30. Repeat steps 1 through 13 for each antenna heading and antenna position (240, 0 and 120 degrees, vertical, clockwise and counterclockwise.)
31. When all 6001 frequencies have been read, add together the power densities for each antenna heading and antenna position to get the total power density for each frequency. (This is done separately for each of the ten measurements made at each frequency and antenna heading and position.)
32. Compute the average power density of all ten sets of measurements for each frequency.
33. Compute the maximum (peak) power density for each frequency.
34. Write the frequency, peak and average power density to the site output file.

35. Compute the average and peak of all the above sets of data.
36. Write frequency, peak and average to the summary file.
37. Ask operator if he wishes to process another site. If yes, repeat steps1 through 15 until all sites have been processed. If no, exit program.

VARIATIONS ON THE BASIC PROGRAM:

For "Process High Ambient.vbp":

For High Band BRFE data, the program processes data taken by High Band BRFE and is run with the same steps as above except that there are seven frequency bands between 950 MHz and 3050 MHz with a total of 7001 frequencies measured. The input and output file names also reflect the band being processed.

For "Process Upper Ambient.vbp":

For Upper Band BRFE data, the programs Process Mid Ambient and Process High Ambient were combined into one program with 13 frequency bands between 320 MHz and 3050 MHz (excluding 420-450 MHz) with a total of 13001 frequencies measured. The input and output file names also reflect the band being processed.

B4.3.2.2 Description of the MS-Excel Workbook Files

Mid0xx Power Density.xls
High0xx Power Density.xls
Upper0xx Power Density.xls

Note: The designation "0xx" in the MS-Excel workbook file names refers to the site numbers for the ten ambient measurement sites.

B4.3.2.2.1 MS-Excel Worksheets

Each workbook includes either one or two worksheets containing ambient data that has been imported from the text files of the same name that were produced from the post-processing (in MS-Visual Basic) of the raw data contained in the 10 ambient RFE data files (one for each ambient measurement site) covering the frequency range 320 to 3050 MHz.

For each of the site data files processed, the corresponding worksheet contains one peak and one average power density number (expressed in both microwatts per square centimeter and dB referenced to one microwatt per square centimeter) for each frequency. Additionally, the worksheet contains the same data normalized by the Maximum Permissible Exposure for that frequency, as described above. These second two columns are labeled "Fractional MPE," representing the measured power density at a particular frequency normalized by the MPE for that frequency. The first Fractional

MPE column is a ratio, and the second column is the same number expressed in decibels. The data are presented in frequency sequence.

In this worksheet, the post-processed data for the ten sites appear in sequence, with 6001 “frequency bins” spaced on 100 kHz centers from 320 MHz to 950 MHz, skipping over the PAVE PAWS band of 420 to 450 MHz., and 7001 “frequency bins” spaced on 300 kHz centers from 950 MHz to 3050 MHz. The upper limit of these measurements was extended to 3050 MHz to permit having an equal number of frequencies in each sub-band measured. Had the measurements stopped at 3000 MHz, the upper-most sub band would have been 250 MHz wide, rather than 300 MHz.

The peak measurement of the ambient RFE is more likely to capture transient (such as land mobile) signals, while the average measurement of the ambient is the number pertinent to determining Maximum Permissible Exposure.

B4.3.2.2.2 MS-Excel Charts

These workbooks contain either one or two MS-Excel charts that plot the measured power density vs. frequency. For clarity in presentation, the results are expressed in decibels referred to 1 microwatt per square centimeter.

B4.3.2.2.3 Why There are Two Types of Workbooks for 300-3000 MHz

The ambient data collection software as originally written separated the measurements at 320-950 MHz and 950-3050 MHz into separate tasks to be performed in the field. It was determined once the measurement program got underway that time could be saved in the field by combining these data collection tasks into one program. Consequently, the later ambient measurements produced one raw data file covering the entire 320-3050 MHz spectrum, while for the earlier measurements, there are two data files (320 to 950 MHz and 950 MHz to 3050 MHz) covering the same frequency span.

It was simpler to maintain the two types of files in the post processing than to combine the separate data files from the earlier measurements (and run the risk of losing some data along the way).

APPENDIX C
The Propagation Modeling Task

C1 Method for Computing the Power Density

C1.1 Reference to the Final Test Plan

Section 5.1 of the Final Test Plan[1] contains a detailed discussion of the measurement rationale for the Drive Test, and that discussion will not be repeated here. To summarize that discussion, a spectrum analyzer operating in zero span mode is used as a fixed-tuned receiver to record the received signal power from a continuous-wave beacon transmitter located on top of the PAVE PAWS building. The test setup includes a WAAS-aided GPS receiver to provide position information in real time. Signal strength and position data is recorded on a computer while traversing a route that includes a major portion of the Cape Cod region. Later sections of this Appendix contain details of the equipment configuration, describe the equipment calibration, and calculate the estimated measurement accuracy. The results of the Drive Test measurements are presented in the body of this Final Test Report.

C1.2 Propagation Modeling

Sections 2.2.3, 2.2.4, 2.2.5, and 2.2.6 of the Final Test Plan provide an overview discussion of the propagation-modeling task, and that discussion will not be repeated here[2]. The three components of the modeling task are: 1) a model of the PAVE PAWS antenna pattern developed by the MITRE Corporation[3], 2) the Longley-Rice propagation model as implemented in the ComStudy software package[4], and 3) a terrain database which is also part of the ComStudy software[5]. These three tools were used to estimate the radio frequency exposure from the PAVE PAWS in each geographic Census Block Group on Cape Cod. The results of these predictions are presented in the body of this Final Test Report.

C2 Conversion from Received Signal Power to Power Density

All field measurements made by BSL in the PAVE PAWS RFE study (PAVE PAWS, Ambient, and Drive Test) provided the value of the received signal power at the input to the receiver preamplifier. In other words, the standard interface for all measurements

[1] Ref. 5, Sect. 5.1
[2] Ref. 5, Sect. 2.2.3 ff
[3] Ref. 6 and personal communication from Arnold G. Kramer of MITRE Corporation, Bedford, MA
[4] Ref. 45
[5] Refs. 45 and 46

was at the junction of the antenna feedline and the receiver preamplifier. The data recorded in the data files was recorded in decibels referenced to one milliwatt (dBm) at the specified reference point.

On the other hand, exposure to radio frequency emissions at VHF (30 to 300 MHz) and UHF (300 to 3000 MHz) frequencies and beyond is measured as power density, that is, the power transmitted in an electromagnetic wave which traverses a specified area. In this report, all power density measurements are expressed in units of microwatts per square centimeter, or equivalently in decibels referenced to 1 microwatt per square centimeter. (Alternative units that are sometimes used in the literature are watts per square meter or milliwatts per square centimeter.)

The following discussion shows how these received power data are converted to power density. The drive test measurements and the Comstudy modeling of the drive test beacon were conducted in path loss terms, utilizing received dBm as the measurement units. The necessity to convert to power density occurs at the end of the drive test analysis where the output data must be transferred to the public health expert in units of power density to be related to MPE.

The fundamental relationship between power density *S* and electric field intensity *E* is

$$S(W/m^2) = E^2(V/m) / Z_0$$

where

$$Z_0 = 120\,\pi$$

$$= 377 \text{ ohms, the characteristic impedance of free space.}$$

BSL has chosen to report all power density numbers in decibels referenced to one microwatt per square centimeter. This was done 1) to be consistent with the units used in the 1979 PAVE PAWS *Environmental Impact Statement*, and 2) to use a logarithmic unit of measure to conveniently deal with numbers ranging over several orders of magnitude.

Therefore the above equation can be rewritten (in decibels) as follows:

$$S(dB\mu W/cm^2) = 10 \log [E^2(V/m) /1.2\pi]$$

$$= 20 \log E(V/m) - 10 \log (1.2\pi)$$

$$= E(dBV/m) - 5.76 \text{ dB}$$

and

$$E(dBV/m) = E(dB\mu V/m) - 120.0 \text{ dB}$$

$$= V_r(dB\mu V) + AF(dBV/m/V) + L_f(dB) - 120.0\ dB$$

where

V_r = the signal voltage at the receiver input,

AF = the antenna factor, and

L_f = the feedline loss.

$$E(dBV/m) = P_r(dBm) + 107.0\ dB + AF(dBV/m/V) + L_f(dB) - 120.0\ dB$$

$$= P_r(dBm) + AF(dBV/m/V) + L_f(dB) - 13.0\ dB$$

This relationship applies to both the peak and average measurements.

Therefore

$$S(dB\mu W/cm^2) = P_r(dBm) + AF(dBV/m/V) + L_f(dB) - 18.76\ dB$$

In summary, the conversion from received power in dBm to power density in microwatts per square centimeter is performed by means of the above equation: Add the received signal power in dBm, the antenna factor in dB(V/m/V), and the feedline loss in dB, and subtract 18.76 dB.

The antenna factor for the drive test antenna was computed to be 21.7 dB(V/m/V) at a frequency of 455 MHz, based on the manufacturer's specified gain of 0 dBd = 2.15 dBi.

The feedline loss was measured to be 1.0 dB at 455 MHz.

$$AF_{dB} = 20 \log f_{MHz} - 29.29 - G_{dBi}$$

$$= 20 \log 455 - 29.29 - 2.15$$

$$= 21.7\ dB$$

$$S(dB\mu W/cm^2) = P_r(dBm) + 21.7\ dB + 1.0 - 18.76\ dB$$

$$= P_r(dBm) + 3.9\ dB$$

This 3.9 dB figure is employed in the propagation modeling process to force the Comstudy software to output data in dBμW/cm^2 rather than its customary dBm. The gain of the antenna pattern is artificially increased by 3.9 dB to make this adjustment.

C3 The MITRE PAVE PAWS Antenna Model

Attachment C of the Statement of Work (SOW)[6] provides an antenna model developed by the MITRE Corporation, Bedford, MA that was specified to be used in the propagation modeling effort required by Section 3.1(d) of the SOW. The following is an expanded description of the MITRE model, including correction of one typographical error contained in the original description as provided to Broadcast Signal Lab in the SOW.

C3.1 Sine Space Coordinates

The MITRE antenna model utilizes "sine space" coordinates[7] u and v which map the physical space of the hemisphere in front of the antenna array (as specified by azimuth and elevation angles expressed in spherical coordinates) onto a unit circle. (The sine space coordinates are not defined for azimuths at the rear of the array.) One of the advantages of using sine space coordinates is that the antenna pattern in sine space is independent of the beam-pointing angle, facilitating the computation of the antenna pattern at any pointing angle.

If Az and El are the azimuth and elevation angles, respectively, of an arbitrary point in the far-field of the antenna relative to the projection on the horizontal plane of a vector normal to the array face, then the corresponding sine space coordinates u_{ff} and v_{ff} of the point specified by the angles Az and El are given by:

$$u_{ff} = \sin(Az)\cos(El)$$

$$v_{ff} = \sin(T)\cos(El)\cos(Az) - \cos(T)\sin(El)$$

where

T is the tilt angle of the array face from the vertical (T = 20 deg for PAVE PAWS).

Similarly if Az_0 and El_0 are the azimuth and elevation angles, respectively, of the beam steering coordinates relative to the normal to the array face, then the corresponding sine space coordinates u_0 and v_{0f} of that point are given by:

$$u_0 = \sin(Az_0)\cos(El_0)$$

$$v_0 = \sin(T)\cos(El_0)\cos(Az_0) - \cos(T)\sin(El_0)$$

[6] Ref. 6, Attachment C

[7] See for example Ref. 21, p. 2-19

The sine space coordinates for a point in the far field relative to the center of the beam are given by:

$$u = u_{ff} - u_0$$

$$v = v_{ff} - v_0$$

Observe that in sine space, the term

$$\sqrt{u^2 + v^2}$$

is the radial distance from the center of a unit circle to the point *(u,v)*.

We define the quantity *U* as

$$U = (\pi D/\lambda) \sqrt{u^2 + v^2}$$

Note that the quantity $(\pi D/\lambda)^2$ is the theoretical power gain (more precisely, the "directivity") of a uniformly illuminated circular aperture of diameter *D* referenced to the power gain of an isotropic radiator[8].

C3.2 Application to the PAVE PAWS Antenna

For the PAVE PAWS antenna,

$$D = 22.2\ m$$ and

$$\Lambda = 0.69\ m$$ at the band center frequency of 435 MHz.

Therefore

$$U = 101.173 \sqrt{u^2 + v^2}$$

When the antenna is steered away from boresight (*i.e.*, $u_0 \neq 0$, $v_0 \neq 0$), the antenna gain is reduced by a space factor, *SF*, given by

$$SF = (1 - (u_0^2 + v_0^2))^{1.15}$$

which accounts for the reduction in the gain of the array at angles off boresight. Factors contributing to this loss include the reduction in effective aperture off boresight and the impedance mismatch that occurs when the antenna is steered off boresight.

---

[8] See for example Ref. 21, p. 2-23

C3.3 Components of the Model

The MITRE mathematical model for the PAVE PAWS antenna pattern consists of four separate components, 1) the main beam, 2) the first sidelobe, 3) near-in higher order sidelobes, and 4) far-out higher order sidelobes. These equations for each of these four components are given below.

Main Beam

The field intensity (electric field E or magnetic field H) of the main beam is given by

$$E_{main\ beam} \sim [8\ J_2(U)\ /\ U^2 - 16\ J_3\ (U)\ /\ U^3]$$

First Sidelobe

The field intensity (electric field E or magnetic field H) of the first sidelobe is given by

$$E_{first\ sidelobe} \sim J_1(U)\ /\ U$$

In the above equations, $J_n(U)$ is the n_{th} order Bessel function of the first kind.

In computing the power gain of the main beam and first sidelobe, add the field intensity of the two components, including appropriate scaling factors particular to the PAVE PAWS antenna as given in the equation below. This equation as provided in the SOW omitted the square operation required to convert field intensity to power gain.

All of the gain equations that appear below are referenced to the PAVE PAWS boresight gain of +37.9 dBi[9]:

$$g_{boresight} = 10 \log (6200) = 37.9\ dBi.$$

$$g_{beam}(U) = \{\ 0.991782\ [8\ J_2(U)\ /\ U^2 - 16\ J_3\ (U)\ /\ U^3] + 0.0.0164363\ \ J_1(U)\ /\ U\ \}^2$$

Sidelobes

The power gain of the near-in higher order sidelobes is given by

$$g_{nearsl}(U) = 0.000106\ [\tanh(U+7.86) - \tanh(U-7.86)]$$

Whereas the main beam and first sidelobe patterns can be derived analytically, the expression for the higher-order sidelobe gain is an empirical approximation. The first term, given above, represents the sidelobes that arise from the random phase errors

[9] Ref. 1, Appendix A, Table A-1

between the 56 subarrays that comprise the PAVE PAWS antenna. Each of these 56 subarrays consists of 32 active antenna elements.

In addition to the sidelobes that arise from the subarray phase errors, there is a "filling in" of the nulls in the sidelobe structure that arise from the random errors in the 1792 individual active elements of the array[10]. The aggregate effect of this large number of very small errors is to create a "spatial white noise" which is modeled by a "floor" in the antenna gain pattern at approximately –46 dB with respect to the gain at the center of the main bean. The power gain of the far-out higher order sidelobes is modeled as

$$g_{farsl}(U) = 0.0000264$$

$$= -45.8\ dBi$$

Therefore the total power gain of the sidelobes is given by

$$g_{sl}(U) = 0.000106\ [\tanh(U+7.86) - \tanh(U-7.86)] + 0.0000264$$

The total array power gain pattern at any point in sine space referred to the gain at the center of the main beam is given by

$$g(U) = 1.4941 \text{ x } SF \text{ x } [g_{beam}(U) + g_{sl}(U)]$$

In the above equation, $g(U)$ is the ensemble average power gain of the antenna array, consisting of two terms $g_{beam}(U)$ and $g_{sl}(U)$. The first term $g_{beam}(U)$ represents the array pattern of the main beam and first sidelobe. The second term $g_{sl}(U)$ represents the average sidelobe level that results from imperfections in the array, including the non-ideal illumination and amplitude, phase, and position errors of the RF components.

C3.4 Evaluation of the Model Equations for Small Arguments

Note that the equations given above cannot be used in the form written above to evaluate the antenna gain on boresight (*i.e.,* for $U = 0$) because a division by zero would be required. However, the limiting values of the Bessel functions[11] for small arguments are such that all of the terms in the above equations remain finite as $U \rightarrow 0$.
Specifically, as $x \rightarrow 0$,

$$J_1(x)/x = 1/2$$

$$J_2(x)/x^2 = 1/4$$

$$J_3(x)/x^3 = 1/12$$

[10] See for example Ref. 21, Chap. 3; more detailed discussions appear in Refs. 22-27
[11] Ref. 28, Chapter on Bessel Functions

C3.5 Boresight Gain at Beam Center

The circularly polarized boresight gain of the PAVE PAWS array at beam center, referred to an isotropic radiator, is given by:

$$G_{boresight} = 10 \log (6200)$$

$$= +37.9 \text{ dBi}$$

C4 Drive Test Data Collection

C4.1 Reference to the Final Test Plan

Section 5.1ff of the Final Test Plan[12] contains a detailed discussion of the measurement rationale for the Drive Test, and that discussion will not be repeated here. To summarize that discussion, a low-gain omni directional antenna was mounted on the roof of a test vehicle in which were mounted a calibrated receiver tuned to the frequency of a continuous wave beacon, a Global Positioning System receiver, and a computer for recording signal strength data and geographic position. Further details on the equipment configuration appear below.

This section provides additional details on the implementation of the instrumentation used to make the Drive Test measurements. At the time the Final Test Plan was prepared, Broadcast Signal Lab was still assembling the hardware and software. Although in concept the measurement system is not changed from that described in the test plan, there are some details in which it is different. The following discussion describes the system as actually implemented and used in the field.

C4.2 Block Diagram

This section provides additional details on the implementation of the instrumentation used to make the ambient power density measurements. At the time the Final Test Plan was prepared, Broadcast Signal Lab was still assembling the hardware and software. Although in concept the measurement system is not changed from that described in the test plan, there are some details in which it is different. The following discussion describes the system as actually implemented and used in the field. The components in

[12] Ref. 5, Sect. 5.1

the block diagram are described in the following paragraphs. Figure C4-1 is a functional block diagram of the Drive Test setup.

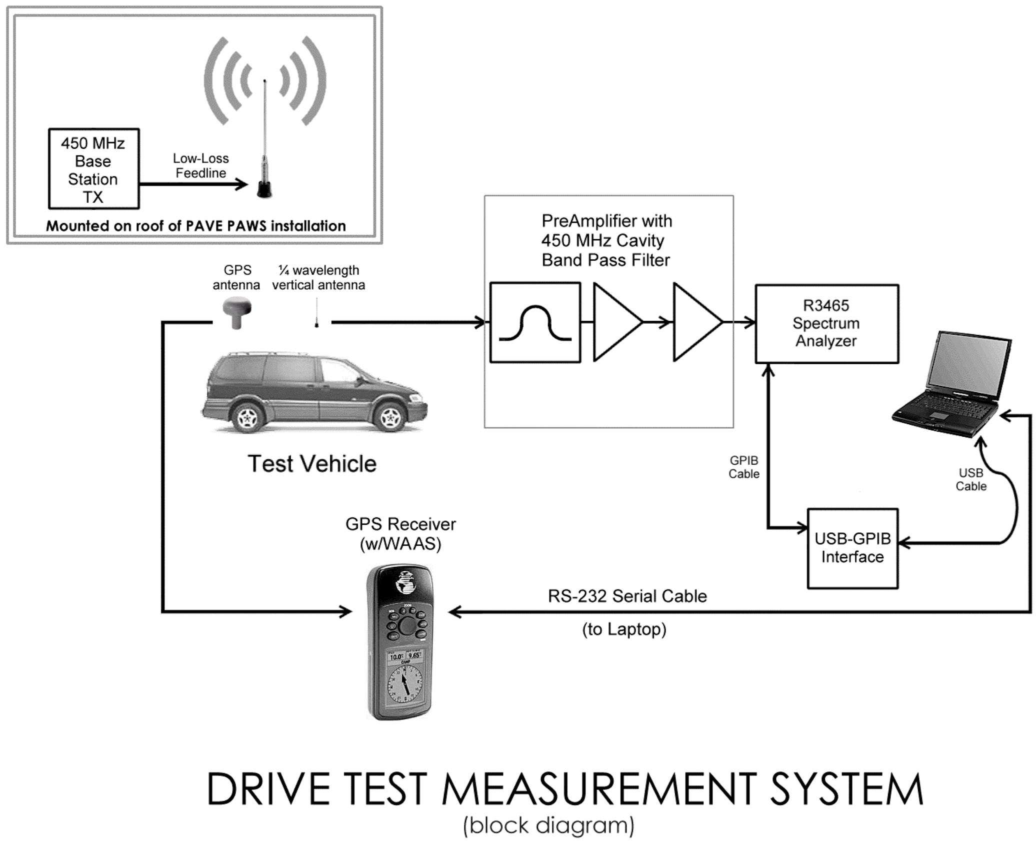


Figure C4-1 – Functional Block Diagram for Drive Test

C4.3 RF Spectrum Analyzer

The Advantest (Rhode and Schwarz) model R3465 spectrum analyzer was utilized to make the drive test signal strength measurements[13]. Key parameters of this instrument were summarized in the Appendix B and will not be repeated here.

The spectrum analyzer was utilized as a fixed-frequency superheterodyne receiver for the drive test. The dynamic range of this instrument approaches 100 dB. The analyzer display was used in “oscilloscope mode” to display the strength of the received signal in real time. The internal analog to digital converter provided 1000 samples of the displayed waveform for transfer to the attached computer for each time sweep of the display. The bandwidth of the “receiver” was determined by the resolution bandwidth of the spectrum analyzer.

[13] Ref. 47

C4.4 Antenna and Feedline

A commercial quarter-wavelength land mobile antenna, tuned to 455 MHz, was used as the drive test antenna. This antenna was mounted on a circular aluminum disk (3 feet in diameter) to provide a suitable ground plane. Among other things, the ground plane has the effect of decoupling the feedline from the field of the antenna so that the outer conductor of the coaxial cable does not become an "unintentional radiator."

The entire antenna assembly was attached to the roof rack on the test vehicle.

The free-space pattern and gain of a quarter-wave whip antenna (i.e., a "monopole") mounted on a ground plane is essentially the same as a dipole in "free-space." with the significant differences that the feedline of the monopole is decoupled from the radiated field and that the whip does not radiate below the horizon.

Therefore, the theoretical gain of the test antenna is 2.15 dBi. This results in an antenna factor for the drive test antenna of

$$
\begin{aligned}
AF(dBV/m/V) &= 20 \log f_{MHz} - 29.29\ dB - G_{dBi} \\
&= 53.16 - 29.29 - 2.15 \\
&= 21.7\ dBV/m/V
\end{aligned}
$$

8 Feet of RG-58/U coaxial cable, having a measured loss of 1.0 dB at a frequency of 455 MHz, was utilized as the antenna feedline.

C4.5 Low-noise Preamplifier

A high-dynamic-range low-noise preamplifier was included in the test setup to establish the noise floor of the measuring equipment. The spectrum analyzer to that was used for these measurements has a specified noise floor of –145 dBm/Hz, or equivalently a noise figure of 29 dB (which is typical of the state of the art in spectrum analyzers today). The preamplifier has a nominal gain of 39 dB at 455 MHz and a noise figure of approximately 6 dB.

C4.6 Cavity Band Pass Filter

A commercial quarter-wave cavity resonator was inserted between the antenna and preamplifier to provide rejection of out-of-band signals, since the preamplifier and spectrum analyzer both have very large bandwidths. This filter has an insertion loss of approximately 1 dB and a 3 dB bandwidth of approximately 1.5 MHz.

C5 Data Collection Software Functional Description

The following subsections describe the BSL-developed software that was used to control the test instruments and collect the data. The design objective for this software was to implement a data collection process that required a minimal amount of operator intervention, in an effort to maximize the amount of data captured and to minimize the opportunity for operator-induced errors.

PROGRAM: AdvDriveTest (Visual Basic)

PURPOSE: To measure the signal strength of a beacon mounted atop the Pave PAWS Radar while driving throughout Plymouth and Barnstable Counties. Data collected using an Advantest Spectrum Analyzer (Model R3465).

OPERATOR INPUT:

- Center Frequency
- Sweep Time
- Reference level
- Resolution band width
- Video band width
- Preamp gain

PROGRAM OPERATION:

- Set:
  - Spectrum analyzer to known condition (factory presets)
  - Spectrum analyzer to read 1001 points per sweep
  - Spectrum analyzer to operator inputs
  - Ignore first two sweeps to allow instrument to settle

DATA COLLECTION LOOP: (Runs until operator cancels operation)

- Read:
  - GPS Receiver
    - Date
    - Time
    - Latitude
    - Longitude
  - Spectrum analyzer trace

- Compute:
  - Minimum and maximum signal strength

  - Average signal strength
  - Median signal strength
  - Standard deviation

- Write data to disk after every 300 traces from the spectrum analyzer:
  - Date, Time
  - Latitude, Longitude
  - Minimum, maximum, average and median signal strength
  - Standard deviation

Termination:

- Write any remaining data to disk
- Close disk file

C6 Drive Test System Operation

This section provides a narrative description in outline form of the operation of the BSL test equipment (described above) in the in the field.

C6.1 Equipment Setup

Install the quarter-wave monopole antenna and its ground plane on the luggage rack on top of the test vehicle. Insure that everything is mechanically tight.

Connect the antenna to the coaxial cavity bandpass filter using the 8-foot length of RG-58/U coaxial cable. Connect the output of the cavity filter to the input of the VHF preamplifier (the frequency response of this amplifier is flat to 500 MHz and it has better dynamic range than the UHF preamplifier). Connect the output of the preamplifier to the Advantest spectrum analyzer.

Manually tune the spectrum analyzer to 455.925 MHz to verify that the beacon transmitter is operating. Measure the frequency of the beacon using the spectrum analyzer to insure that it is within a few hundred Hz of its nominal frequency.

Turn on the GPS receiver and connect it to the RS-232 to USB adapter designated "COM5."

Start the program "Adv Drive Test.exe" and provide all of the input data requested. Following a short delay while the spectrum analyzer is being configured by the software, signal strength data will be displayed on the computer screen. This data will update every few seconds.

Begin driving. No further operational intervention is required until it is desired to terminate the measurement.

C7 Drive Test Data Processing

Drive test data processing is discussed in detail in Appendix I.

C8 Accuracy of Power Density Predicted by the Propagation Model

The propagation model was tested against the drive test, and it is reasonable to infer the distribution of the distribution of the differences between the drive test measurements and the propagation model will reasonably reflect the differences that will exist between the propagation model and the actual radar emissions. Give the same location, terrain, land cover, and frequency band, the primary difference between a propagation model of the drive test beacon and one of the radar itself is the accuracy of the antenna models applied to the propagation model.

The radar emissions are varied in time and space, and the discussion in Appendix H explains the process of developing an average pattern for the ComStudy software to implement. Fortunately, the average emissions of the second sidelobe region of the radar antenna pattern appear to be dominant over the first sidelobe emissions when considering the emissions in the direction of the Cape Cod environment. This causes the exposure model to be reliant on the diffuse nature of the secondary sidelobe emissions. A small number of field measurements should be sufficient to provide a guide to the accuracy of the antenna model. The comparison between the predicted radar power density and the measured values is discussed in Section 4 of the Final Report.

In summary the propagation model tested quite well against the drive test measurements.

Table C8-1
Statistical Characteristics of Propagation Model vs Drive Test

Value	Result (dB)
Average variance	-1.6
Median	-2.9
Mode	0.0
Maximum	75.1
Minimum	-36.0
Std Dev	12.6

So, too, the PAVE PAWS computer estimated propagation based on the MITRE antenna model performed respectably, given the ore complex nature of the radar's emissions and the use of a small sample of 35 field measurements to check the results.

Table C8-2
Comparison of PAVE PAWS Propagation Estimate Against 35 Field Measurements

Radar Propagation/Antenna model departures from 35 field measurements	All 35 Sites	Excluding 4 Sites Behind Radar
Standard Deviation	8.5 dB	8.3
Median	7.0	5.9
Average	6.5	5.3

Meanwhile, the rear of the radar continues to present a modeling challenge. For this analysis, the rear of the radar antenna pattern was left at the value of the sidelobe levels. It could be run at a lower level to align it with the measurements taken at the rear of the radar. Alternatively, it could be run at nominally zero value to the rear of the radar, and a separate pattern could be created to model reflections off the large structures, such as the smokestack, and off passing aircraft.

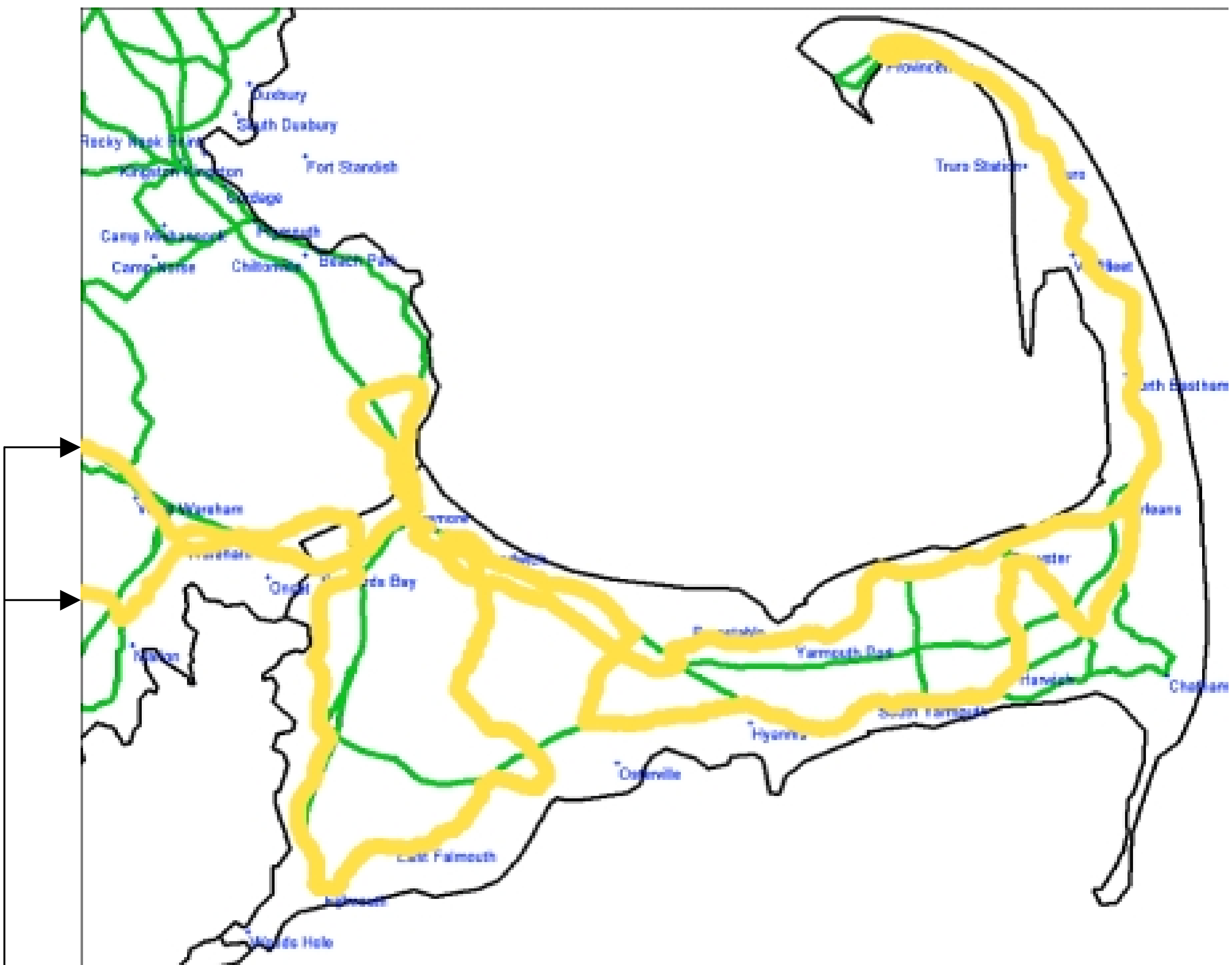
Finally, no peak antenna model was created because of the nature of the peak analysis. A peak-to-average ratio was developed and is discussed in the main report.

C8 The Measurement Route

C8.1 Reference to the Final Test Plan

Section 5.8 of the Final Test Plan[14] contains a detailed discussion of the rationale for the choice of the Drive Test Route. This discussion will not be repeated here. There were no deviations from the planned route, other than the overlaps and discontinuities where different measurement runs covered adjacent portions of the route.

C8.2 Drive Test Route



Route loops through Lakeville

[14] Ref. 5, Sect. 5.8

Route	Dir	Miles
Sagamore, MA		
MA 6a	W	1
US-6n	W	1
State 3	N	3
MA 3a to Vallersville, MA	N	4
Ship Pond Road to Long Pond Road	SE	4
Long Pond Road to Cedarville & Rt 3	W	2
US-6n to Buzzards Bay, MA	W	3
US-6 to Route 28 to Route 105	NW	20
Route 105 to US-6	S	21
US-6 to Bourne Bridge	E	12
Trowbridge Road to Shore Road to 28a to 151 to 28	S	7
State 28 to Falmouth, MA	E	6
State 28	E	12
Quinaquisset Avenue to Cotuit, MA	E	2
Main Street to Santuit, MA	NW	2
State 130 to Mashpee, MA	NW	4
State 130 to Forestdale, MA	NW	3
State 130	NW	5
State 130 to Sagamore, MA	NW	1
MA 6a to Sandwich, MA	E	2
MA 6a to East Sandwich, MA	E	3
Ma 6a to West Barnstable, MA	E	3
State 149 to Marstons Mills, MA	S	5
State 28 to West Harwich, MA	E	22
State 28	E	1
State 39 to Harwich, MA	N	1
State 124	N	6
State 137 to Brewster, MA	NW	<1
MA 6a	NE	6
US-6 to Provincetown, MA	E	29
Exit Provincetown via 6a, then US-6	W	27
MA 6a to Orleans, MA	SW	1
State 28 to South Orleans, MA	W	2
State 39	S	5
State 137 to East Harwich, MA	SE	<1
State 137 to Brewster, MA	NW	6
MA 6a to Dennis, MA	SW	6
Ma 6a to Yarmouth, MA	S	2
MA 6a	W	6
State 132	E	1
US-6	W	13
MA 6a to Sagamore, MA	E	1

NOTE: This table describes the entire route. However, portions of the route were driven at the convenience of the test crew. (The accumulated data is not in the same order as the route description.)

Broadcast Signal Lab

APPENDIX D
Equipment Calibration and Measurement Uncertainty

D1 Calibration Rationale and Reference to the Final Test Plan

Sections 3.3, 4.3, and 5.4 of the Final Test Plan contain a detailed discussion of the calibration rationale for the PAVE PAWS RFE Test, the Ambient RFE Measurements, and the Drive Test. That discussion will not be repeated here. This Appendix identifies the calibration reports for the instruments used, the results of calibration measurements made in BSL's laboratory, and a description of the method for computing the predicted overall measurement uncertainty.

D1.1 Calibration Reports

D1.1.2 Agilent E4416A Peak and Average RF Power Meter

The Agilent model E4416A was purchased new in October 2003 and was calibrated at the factory at the time of manufacture. The factory calibration report is on file.

D1.1.3 Agilent E9323A Peak and Average RF Power Sensor

The Agilent model E9328A was purchased new in October, 2003 and was calibrated at the factory at the time of manufacture. The factory calibration report is on file.

D1.1.4 Advantest R3465 Spectrum Analyzer

The Advantest model R3465A was returned to Advantest in December, 2003 for recalibration.. The factory calibration report is on file.

D1.1.5 Schwarzbeck BBA 9106 (30-300 MHz) Antenna

The Schwarzbeck model BBA 9106 antenna was purchased new in October, 2003 and was calibrated, together with its VHA9103 balun by the manufacturer. The factory calibration report is on file. Periodic recalibration of these passive antennas is not normally required.

D1.1.6 Schwarzbeck BBVK9138 (60-600 MHz) Antenna

The Schwarzbeck model BBVK9138 antenna was purchased new in October, 2003 and was calibrated, together with its VHA9103 balun by the manufacturer. The factory calibration report is on file. Periodic recalibration of these passive antennas is not normally required.

D1.1.7 Schwarzbeck USLP9143 (300-3000 MHz) Antenna

The Schwarzbeck model USLP9143 Logarithmic Periodic Broadband Antenna was purchased new in October, 2003 and was calibrated, together with its integrated balun by the manufacturer. The factory calibration report is on file. Periodic recalibration of these passive antennas is not normally required.

D1.2 BSL's Calibration Measurements

Broadcast Signal Lab performed calibration measurements of the various radio-frequency components (cables, preamplifiers, RF connectors, adapters, etc.) both before and after the field measurements. The first set of measurements, performed in early February, were of the individual components and are reported in Section D1.2.1 below. The second set of measurements, performed in April, were "end-to-end" measurements of the three measurement systems as described in Appendices A, B, and C respectively.

The equipment employed for the field measurements is listed in Table D-1, together with designation of when it was calibrated. The status of calibrations performed prior to the field measurements is designated in the "Pre-cal" column, and that performed following the measurements is designated in the "Post-cal" column of the table.

Table D-1 – Field Measurement Equipment

Item	Serial no.	Pre-cal.	Post-cal.
Agilent E4416A power meter	GB41292190	F	U
Agilent E9323A power sensor	US40411387	F	U
Schwarzbeck BBVK 9138 antenna with VHA 9103B balun assy.	N/A (ant. elements); 2218 (balun)	F	U
Schwarzbeck BBA 9106 antenna with VHA 9103B balun assy.	N/A (ant. elements); 2218 (balun)	F	U
Schwarzbeck USLP 9143 antenna	289	F	U

Advantest R3465 spectrum analyzer	8420196	F	I
Narda 8718-10 meter with cable	01648	F	U
Narda A8722D probe	06001	F	U
Radiometer chain	N/A	U	I
Drive test chain	N/A	U	I
VHF preamplifier	N/A	I	I
UHF preamplifier	N/A	I	I

F = Factory
I = In-house
U = Unnecessary due to stability of equipment

The equipment employed for in-house calibrations is listed in Table D-2.

Table D-2 – Calibration Equipment

Item	Serial no.	Traceable?
Agilent E4416A power meter	GB41292190	Yes
Agilent E9323A power sensor	US40411387	Yes
IFR COM-120B communications service monitor	500009549	Yes
Efratom MRT rubidium frequency standard	600	Yes
HP 8640B-option 323 rf signal generator	1624A0285	Yes

D1.2.1 Calibration of Individual RF Components, February 2004

Calibration equipment: Hewlett Packard 8640B-option 323 RF Signal Generator (S/N 1624A0285) and Agilent E4416A power meter (S/N GB1292190) with Agilent E9323A power sensor (S/N US40411387).

Output meter of HP8640B reads +0.8 dBm when the output is 0.00 dBm read on the Agilent power meter. The spec on the 8640B is +/- 1.5 dBm, so this is within specification. Amplitude flatness measurements of the 8640B determined that is was within the manufacturer's specifications for amplitude flatness vs frequency over the frequency range 30 MHz to 500 MHz..

Weinschel Variable Attenuator at 435 MHz – relative attenuation

Dial Setting	Measured Attenuation (relative to 0 dB setting)	Dial Setting	Measured Attenuation (relative to 0 dB setting)
00	0.00	30	29.50
01	0.81	31	30.32
02	1.85	32	31.36
03	2.92	33	32.42
04	3.84	34	33.34
05	4.84	35	34.34
06	5.89	36	35.38
07	6.84	37	36.33
08	7.85	38	37.35
09	8.84	39	38.33
10	9.78	40	39.38
11	10.58	41	40.18
12	11.62	42	41.23
13	12.69	43	42.30
14	13.60	44	43.21
15	14.61	45	44.20
16	15.65	46	45.27
17	16.59	47	46.22
18	17.60	48	47.21
19	18.58	49	48.19
20	19.67	50	49.51
21	20.48		
22	21.52		
23	22.60		
24	23.50		
25	24.50		
26	25.55		
27	26.50		
28	27.50		
29	28.49		

Note: For measurements made in the field using this attenuator, the attenuation settings used were typically less than 30 dB. The most commonly used settings were 0 and 10 dB attenuation.

Weinschel Variable Attenuator at 435 MHz – Absolute Attenuation

Setting	Attenuation
0	0.15
10	9.91
20	19.82
30	29.68
40	39.54
50	49.63
60	60.23

Various Coax Cable Attenuation Measurements

The attenuation of all RF cables measured at 435 MHz were recorded on tags affixed to the cables.

Radiometer preamplifier gain measurement, using HP8640B, Weinschel Attenuator, and Agilent E4416 power meter

Input signal level –39.38 dBm
Output signal level +0.66 dBm
Gain at 435 MHz 40.04 dB

Radiometer spectrum analyzer port (directional coupler) loss measurement average of two measurements –11.24 dB

Radiometer frequency response, referenced to the center frequency of 435 MHz

Frequency (MHz)	Relative output (referenced to 435 MHz)
415	-11.96
420	-1.93
425	-0.12
430	+0.08
435	0.00
440	-0.08
445	-0.38
450	-3.15

455	-15.77
460	-31.83
465	-44.73
470	Noise floor
475	Noise floor
480	Noise floor
485	Noise floor
490	Noise floor
495	Noise floor
500	Noise floor

Note: Only the attenuation on the high side of the passband was measured, to determine the response in the 450-470 MHz Land Mobile Band.

VHF Preamplifier Gain Measurement, using HP8640B, Weinschel Attenuator, and Agilent E4416A power meter

Measured at 435 MHz: 39.72 dB

VHF Preamplifier Gain Measurement vs. Frequency, using HP8640B, Weinschel Attenuator, and Agilent E4416A power meter

Frequency (MHz)	Gain	Frequency (MHz)	Gain
30	39.17	200	39.53
40	39.21	250	39.49
50	39.20	300	39.47
60	39.20	325	39.50
70	39.21	350	39.52
80	39.16	400	39.64
90	39.23	425	39.70
100	39.24	450	39.79
120	39.29	475	39.86
140	39.36	500	39.88
160	39.39		
180	39.52		
190	39.55		

The “nominal” gain value used for the 30 to 320 MHz Ambient measurements was 39 dB

Measurement of SMA (RG-142/U) coax cables at 435 MHz using HP8640B and Agilent E4416 power meter

Cable length	Attenuation at 435 MHz
82 cm	0.26 dB
47 cm	0.15 dB
37 cm	0.16 dB

Note: All attenuation measurements were made by the "substitution method" whereby the attenuation of the cable(s) from the signal source to the device under test does not need to be considered. The power meter was always connected directly to the device under test.

D1.2.2 End-to-End Calibration Measurements Performed April 2004

D.1.2.2.1 Measurement Procedure

Initially, the threshold of compression for each amplifier was determined, to ensure that calibration measurements would be performed at levels well below the threshold. All calibration measurements utilized the generator function of an IFR COM-120B communications service monitor as the RF source. Measurements of output levels were made using an Agilent E4416A power meter with E9323A sensor, in "average" mode. This instrument was also used to determine or verify input levels.

D.1.2.2.2 PAVE PAWS Radiometer Measurement System

The overall gain, averaged over the PAVE PAWS frequency band, was determined for the equipment chain used in measuring the radar emissions, from the antenna downlead through the radiometer unit. The latter unit embodies a directional coupler, switch, active bandpass filter, and an amplifier. The block diagram of this system is shown in Appendix A. The operating frequencies of the radar extend from 421.3 to 448.7 MHz. Accordingly, gain was measured at 0.5 MHz intervals from 421 through 449 MHz ("the band") and the results averaged. The chain included the variable attenuator and all cables actually employed in the field. The attenuator was set to its 10 dB position, a typical operating setting. Two runs were made and the results averaged. The IFR generator was checked and found to be flat within +/- 0.03 dB across the region of interest.

Results:

Nominal input level: - 40 dBm
Nominal output level in-band (“reference level”): - 14.5 dBm
Average overall gain, as measured: 25.5 dB

Average overall gain, normalized for “zero dB” setting of variable attenuator: 35.3 dB
Frequency response in band: reference level +0.5/-2.0 dB
Frequency response outside band: reference level - 3 dB at 418.7, 449.8 MHz, -10 dB at 415.2, 453.0 MHz
Noise level at output: - 50 dBm or lower

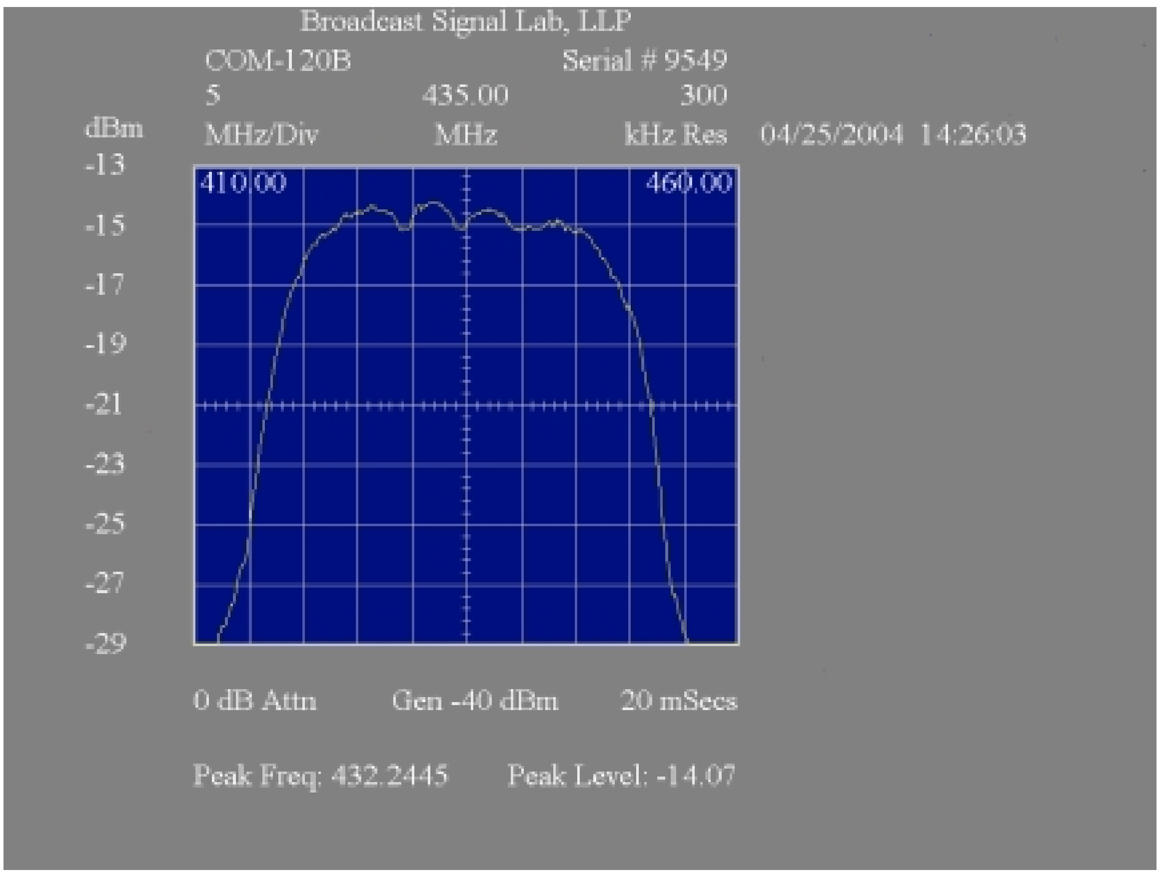


Figure D-1 Frequency Response of PAVE PAWS Radiometer

D1.2.2.3 Drive Test Measurements System

The equipment chain used for the drive test measurements consists of an antenna downlead and other interconnecting cables, a cavity bandpass filter tuned to the drive test beacon frequency of 455.925 MHz, and a preamplifier designated “VHF”. See the block diagram in Appendix C. This chain was checked at various frequencies in and adjacent to its passband.

Results:

Nominal input level: - 40 dBm
Nominal output level at beacon frequency: - 2.6 dBm
Overall gain at beacon frequency: 37.4 dB
Frequency response: - 3 dB at 454.4, 457.5 MHz, - 10 dB at 451.3, 460.3 MHz

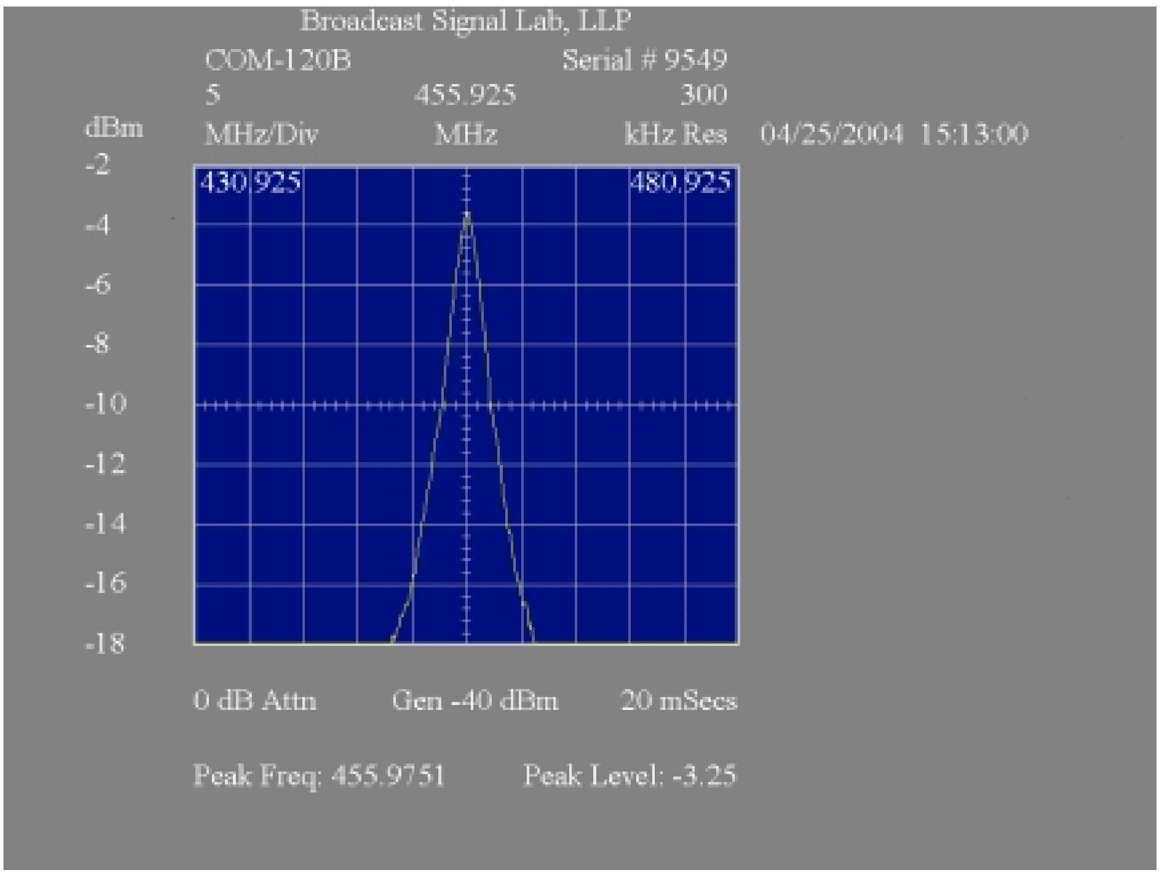


Figure D-2 Frequency Response of Drive Test Receiver

D1.2.2.4 Preamplifiers Used for Ambient Measurements

The “VHF” and “UHF” preamplifiers were also used in making the respective VHF and UHF ambient level measurements. Gain for these preamps was determined at several frequencies using the Agilent power meter and sensor to measure input and output levels. Several runs were made and the results averaged.

Results:

VHF preamplifier gain

Frequency (MHz)	Gain (dB)
30	38.3
100	38.5
200	38.8
300	39.1
435	39.7

Broadband noise level (at output): - 36 dBm

UHF preamplifier gain

Frequency (MHz)	Gain (dB)
300	33.4
400	33.1
500	32.7
600	32.8
800	32.6
1000	32.2

Broadband noise level (at output): - 42 dBm

D2 Accuracy of Measurements

D2.1 Method for Computing Measurement Uncertainty

The following is a brief summary of the procedure specified in the ANSI/NCSL Z540.2-1996 standard as it applies to the power density measurements performed in this study. This procedure was used to estimate the measurement uncertainties for both the PAVE PAWS and ambient measurements made by BSL.

1) Compile a list of the error components of the individual measurement uncertainties, expressed in dB. These are obtained from manufacturers' specifications or by measurement, as appropriate.

$$i^{th}\ \textit{Error Component (dB)} = 10 \log (1 + \Delta x_i/x_i)$$

2) Convert the individual error components to a power ratio:

$$\textit{Error Component} = 10\text{^}[\textit{Error Component(dB)} /10]$$

3) Subtract 1.000 from the *Error Component* to obtain the fractional error $(\Delta x_i/x_i)$

4) Square the fractional errors to get the root-sum-square (RSS) components $(\Delta x_i/x_i)^2$

5) Add all of the RSS components to obtain the sum of the squares:

$$SS = \Sigma (\Delta x_i/x_i)^2$$

6) Take the square root to get the RSS error

$$\textit{RSS Error} = [\Sigma (\Delta x_i/x_i)^2]^{0.5}$$

7) Add 1.000 to the RSS error and convert the result back dB to obtain the *RSS Error* in dB

$$\textit{RSS Error(dB)} = 10 \log (1 + \textit{RSS Error})$$

Appendix E
Contents of the Data Set

This Appendix contains a catalog of the contents of the data set included as a deliverable with this Final Test Report. Throughout the files there are readme.txt files describing the data structures (for data files only), naming conventions where appropriate, and the context of the information contained therein. Each file description is accompanied by the file path names.

E1 PAVE PAWS Data

E1.1 PAVE PAWS Field Measurement Raw Data

This file contains a transcription of the handwritten Site Data from the 50 PAVE PAWS sites and from the 10 ambient measurement sites.

File Name: PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\PP Site Data Transcription.xls

These text files contain all of the raw data recorded in the field for the 50 PAVE PAWS sites. In most cases, there are six data files per measurement site. The contents of the files are described in Appendix A.

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_01\

PP01 10-20-11 AM.txt	3/4/2004	10:40 AM	412,197
PP01 10-42-29 AM.txt	3/4/2004	10:55 AM	413,124
PP01 10-58-38 AM.txt	3/4/2004	11:11 AM	413,020
PP01 11-13-45 AM.txt	3/4/2004	11:26 AM	413,022
PP01 11-36-42 AM.txt	3/4/2004	11:49 AM	413,020
PP01 11-52-57 AM.txt	3/4/2004	12:07 PM	413,020

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_02\

PP02 4-22-30 PM.txt	3/4/2004	04:36 PM	413,036
PP02 4-37-58 PM.txt	3/4/2004	04:52 PM	413,035
PP02 4-53-41 PM.txt	3/4/2004	05:08 PM	413,035
PP02 5-09-16 PM.txt	3/4/2004	05:23 PM	413,035
PP02 5-25-18 PM.txt	3/4/2004	05:39 PM	413,036
PP02 5-44-43 PM.txt	3/4/2004	05:57 PM	413,098

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_03\

PP03 10-02-32 AM.txt	2/26/2004	10:14 AM	413,037
PP03 10-16-03 AM.txt	2/26/2004	10:28 AM	413,037
PP03 10-33-20 AM.txt	2/26/2004	10:45 AM	413,037
PP03 10-47-53 AM.txt	2/26/2004	11:00 AM	413,037
PP03 11-01-27 AM.txt	2/26/2004	11:13 AM	413,037
PP03 9-48-57 AM.txt	2/26/2004	10:01 AM	413,035

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_04\

PP04 1-00-11 PM.txt	2/26/2004	01:12 PM	413,032
PP04 1-15-20 PM.txt	2/26/2004	01:27 PM	413,033
PP04 11-53-16 AM.txt	2/26/2004	12:15 PM	413,136
PP04 12-17-06 PM.txt	2/26/2004	12:29 PM	413,033
PP04 12-30-52 PM.txt	2/26/2004	12:43 PM	413,035
PP04 12-44-29 PM.txt	2/26/2004	12:57 PM	413,035
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_05\			
PP05 1-15-18 PM.txt	3/1/2004	01:35 PM	413,102
PP05 1-36-47 PM.txt	3/1/2004	01:56 PM	413,024
PP05 2-00-30 PM.txt	3/1/2004	02:19 PM	413,024
PP05 2-21-09 PM.txt	3/1/2004	02:39 PM	413,025
PP05 2-40-51 PM.txt	3/1/2004	02:52 PM	413,027
PP05 3-09-51 PM.txt	3/1/2004	03:24 PM	413,030
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_06\			
PP06 10-42-23 AM.txt	3/1/2004	10:55 AM	413,031
PP06 11-16-16 AM.txt	3/1/2004	11:28 AM	413,025
PP06 11-33-50 AM.txt	3/1/2004	11:48 AM	413,025
PP06 11-49-16 AM.txt	3/1/2004	12:03 PM	413,025
PP06 12-04-57 PM.txt	3/1/2004	12:17 PM	413,037
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_07\			
PP07 11-01-24 AM.txt	3/1/2004	11:13 AM	413,034
PP07 2-43-35 PM.txt	2/24/2004	02:59 PM	413,087
PP07 3-00-13 PM.txt	2/24/2004	03:15 PM	413,037
PP07 3-16-19 PM.txt	2/24/2004	03:31 PM	413,031
PP07 3-32-44 PM.txt	2/24/2004	03:48 PM	413,030
PP07 3-49-23 PM.txt	2/24/2004	04:04 PM	413,031
PP07 4-07-39 PM.txt	2/24/2004	04:21 PM	413,048
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_08\			
PP08 10-23-05 AM.txt	2/28/2004	10:37 AM	413,109
PP08 10-45-59 AM.txt	2/28/2004	10:59 AM	413,030
PP08 11-00-37 AM.txt	2/28/2004	11:17 AM	413,067
PP08 11-18-21 AM.txt	2/28/2004	11:39 AM	413,032
PP08 11-42-00 AM.txt	2/28/2004	11:59 AM	413,032
PP08 12-03-03 PM.txt	2/28/2004	12:21 PM	413,045
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_09\			
PP09 1-00-08 PM.txt	2/24/2004	01:20 PM	413,026
PP09 11-09-02 AM.txt	2/24/2004	11:28 AM	413,107
PP09 11-31-19 AM.txt	2/24/2004	11:52 AM	413,049
PP09 11-54-16 AM.txt	2/24/2004	12:14 PM	413,024
PP09 12-16-36 PM.txt	2/24/2004	12:37 PM	413,029
PP09 12-39-14 PM.txt	2/24/2004	12:59 PM	413,025
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_10\			
PP10 2-55-24 PM.txt	2/27/2004	03:09 PM	413,093
PP10 3-11-00 PM.txt	2/27/2004	03:22 PM	413,026
PP10 3-25-33 PM.txt	2/27/2004	03:38 PM	413,024
PP10 3-49-37 PM.txt	2/27/2004	04:08 PM	413,065

PP10 4-10-33 PM.txt	2/27/2004	04:24 PM	413,026
PP10 4-31-59 PM.txt	2/27/2004	04:55 PM	413,042
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_11\			
PP11 10-47-25 AM.txt	3/3/2004	11:00 AM	413,077
PP11 11-01-24 AM.txt	3/3/2004	11:16 AM	413,035
PP11 11-19-34 AM.txt	3/3/2004	11:32 AM	413,036
PP11 11-48-29 AM.txt	3/3/2004	12:02 PM	413,033
PP11 12-04-22 PM.txt	3/3/2004	12:17 PM	413,124
PP11 12-22-29 PM.txt	3/3/2004	12:42 PM	413,043
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_12\			
PP12 10-12-09 AM.txt	2/23/2004	10:24 AM	413,038
PP12 10-25-35 AM.txt	2/23/2004	10:40 AM	413,038
PP12 10-42-00 AM.txt	2/23/2004	10:56 AM	413,037
PP12 10-58-06 AM.txt	2/23/2004	11:12 AM	413,039
PP12 11-17-12 AM.txt	2/23/2004	11:32 AM	413,056
PP12 9-56-04 AM.txt	2/23/2004	10:10 AM	413,074
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_13\			
PP13 1-09-50 PM.txt	2/20/2004	01:23 PM	413,051
PP13 12-23-40 PM.txt	2/20/2004	12:36 PM	413,098
PP13 12-38-07 PM.txt	2/20/2004	12:51 PM	413,059
PP13 12-52-48 PM.txt	2/20/2004	01:08 PM	413,049
PP13 1-25-27 PM.txt	2/20/2004	01:38 PM	413,049
PP13 1-44-59 PM.txt	2/20/2004	02:00 PM	413,051
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_14\			
PP14 3-52-56 PM.txt	2/20/2004	04:08 PM	413,190
PP14 4-12-33 PM.txt	2/20/2004	04:28 PM	413,033
PP14 4-30-17 PM.txt	2/20/2004	04:48 PM	413,028
PP14 5-00-03 PM.txt	2/20/2004	05:17 PM	413,029
PP14 5-19-22 PM.txt	2/20/2004	05:36 PM	413,029
PP14 5-39-56 PM.txt	2/20/2004	05:54 PM	413,048
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_15\			
PP15 3-58-57 PM.txt	2/10/2004	04:35 PM	660,632
(One file for this site)			
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_16\			
PP16 10-12-16 AM.txt	2/22/2004	10:32 AM	413,042
PP16 10-33-50 AM.txt	2/22/2004	10:53 AM	413,033
PP16 10-54-36 AM.txt	2/22/2004	11:17 AM	413,033
PP16 11-22-24 AM.txt	2/22/2004	11:42 AM	413,031
PP16 11-43-07 AM.txt	2/22/2004	12:01 PM	413,033
PP16 9-46-40 AM.txt	2/22/2004	10:09 AM	413,032
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_17\			
PP17 1-06-05 PM.txt	2/22/2004	01:23 PM	413,033
PP17 12-49-46 PM.txt	2/22/2004	01:04 PM	413,033
PP17 1-25-12 PM.txt	2/22/2004	01:39 PM	413,031
PP17 1-40-47 PM.txt	2/22/2004	01:55 PM	412,975
PP17 1-56-08 PM.txt	2/22/2004	02:09 PM	413,031

PP17 2-10-59 PM.txt	2/22/2004	02:24 PM	413,031
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_18\			
PP18 10-01-25 AM.txt	2/14/2004	10:18 AM	413,048
PP18 10-20-12 AM.txt	2/14/2004	10:35 AM	413,043
PP18 10-37-09 AM.txt	2/14/2004	10:53 AM	413,041
PP18 10-55-33 AM.txt	2/14/2004	11:10 AM	413,048
PP18 9-19-53 AM.txt	2/14/2004	09:36 AM	413,074
PP18 9-39-22 AM.txt	2/14/2004	09:55 AM	413,039
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_19\			
PP19 10-19-14 AM.txt	2/16/2004	10:37 AM	413,045
PP19 10-40-23 AM.txt	2/16/2004	10:55 AM	413,042
PP19 10-57-32 AM.txt	2/16/2004	11:12 AM	413,042
PP19 11-15-33 AM.txt	2/16/2004	11:30 AM	413,039
PP19 11-33-40 AM.txt	2/16/2004	11:48 AM	413,047
PP19 9-59-26 AM.txt	2/16/2004	10:16 AM	413,071
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_20\			
PP20 10-31-35 AM.txt	2/11/2004	11:01 AM	660,596
PP20 11-08-18 AM.txt	2/11/2004	11:38 AM	660,557
PP20 11-54-04 AM.txt	2/11/2004	12:11 PM	413,046
PP20 12-15-07 PM.txt	2/11/2004	12:32 PM	413,059
PP20 12-39-59 PM.txt	2/11/2004	12:57 PM	413,064
PP20 9-53-19 AM.txt	2/11/2004	10:25 AM	660,595
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_21\			
PP21 4-07-47 PM.txt	2/16/2004	04:28 PM	413,034
PP21 4-30-45 PM.txt	2/16/2004	04:46 PM	413,051
PP21 4-47-42 PM.txt	2/16/2004	05:02 PM	413,023
PP21 5-05-04 PM.txt	2/16/2004	05:20 PM	413,025
PP21 5-23-10 PM.txt	2/16/2004	05:37 PM	413,023
PP21 5-39-46 PM.txt	2/16/2004	05:55 PM	413,043
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_22\			
PP22 1-15-42 PM.txt	2/18/2004	01:30 PM	413,037
PP22 11-55-23 AM.txt	2/18/2004	12:16 PM	413,072
PP22 12-18-19 PM.txt	2/18/2004	12:35 PM	413,046
PP22 12-37-12 PM.txt	2/18/2004	12:53 PM	413,040
PP22 12-55-34 PM.txt	2/18/2004	01:14 PM	413,040
PP22 1-32-42 PM.txt	2/18/2004	01:47 PM	413,039
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_23\			
PP23 10-06-42 AM.txt	2/18/2004	10:26 AM	413,041
PP23 10-30-08 AM.txt	2/18/2004	10:50 AM	413,043
PP23 10-52-20 AM.txt	2/18/2004	11:12 AM	413,040
PP23 11-13-59 AM.txt	2/18/2004	11:33 AM	413,036
PP23 9-17-29 AM.txt	2/18/2004	09:37 AM	413,175
PP23 9-43-20 AM.txt	2/18/2004	10:04 AM	413,038
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_24\			
PP24 2-09-11 PM.txt	2/14/2004	02:25 PM	413,099
PP24 2-26-39 PM.txt	2/14/2004	02:42 PM	413,035

PP24 2-44-42 PM.txt	2/14/2004	03:00 PM	413,035
PP24 3-02-27 PM.txt	2/14/2004	03:17 PM	413,037
PP24 3-19-27 PM.txt	2/14/2004	03:35 PM	413,035
PP24 3-36-30 PM.txt	2/14/2004	03:52 PM	413,045

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_25\

PP25 10-11-07 AM.txt	2/13/2004	10:30 AM	413,037
PP25 10-35-08 AM.txt	2/13/2004	10:54 AM	413,069
PP25 10-58-35 AM.txt	2/13/2004	11:17 AM	413,065
PP25 11-20-16 AM.txt	2/13/2004	11:41 AM	413,045
PP25 9-23-54 AM.txt	2/13/2004	09:45 AM	413,094
PP25 9-47-25 AM.txt	2/13/2004	10:09 AM	413,045

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_26\

PP26 2-36-09 PM.txt	2/18/2004	02:54 PM	413,094
PP26 2-56-55 PM.txt	2/18/2004	03:13 PM	413,042
PP26 3-23-35 PM.txt	2/18/2004	03:39 PM	413,035
PP26 3-48-17 PM.txt	2/18/2004	04:03 PM	413,036
PP26 4-07-54 PM.txt	2/18/2004	04:23 PM	413,038
PP26 4-26-32 PM.txt	2/18/2004	04:43 PM	413,042

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_27\

PP27 1-02-46 PM.txt	2/13/2004	01:22 PM	413,033
PP27 12-33-28 PM.txt	2/13/2004	12:54 PM	413,125
PP27 1-25-40 PM.txt	2/13/2004	01:45 PM	413,029
PP27 1-47-30 PM.txt	2/13/2004	02:10 PM	413,033
PP27 2-12-30 PM.txt	2/13/2004	02:31 PM	413,051

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_28\

PP28 11-31-54 AM.txt	2/17/2004	11:44 AM	413,101
PP28 11-47-18 AM.txt	2/17/2004	11:59 AM	413,029
PP28 12-04-44 PM.txt	2/17/2004	12:17 PM	413,030
PP28 12-19-19 PM.txt	2/17/2004	12:33 PM	413,025
PP28 12-35-49 PM.txt	2/17/2004	12:48 PM	413,026
PP28 12-51-33 PM.txt	2/17/2004	01:04 PM	413,027

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_29\

PP29 2-35-35 PM.txt	2/12/2004	02:48 PM	413,040
PP29 2-54-36 PM.txt	2/12/2004	03:08 PM	413,079
PP29 3-12-58 PM.txt	2/12/2004	03:27 PM	413,039
PP29 9-02-45 AM.txt	2/19/2004	09:17 AM	413,119
PP29 9-20-38 AM.txt	2/19/2004	09:36 AM	413,037
PP29 9-39-58 AM.txt	2/19/2004	09:54 AM	413,043

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_30\

PP30 1-06-38 PM.txt	2/12/2004	01:19 PM	413,036
PP30 12-21-22 PM.txt	2/12/2004	12:34 PM	413,078
PP30 1-22-34 PM.txt	2/12/2004	01:35 PM	413,035
PP30 12-37-38 PM.txt	2/12/2004	12:50 PM	413,037
PP30 12-52-12 PM.txt	2/12/2004	01:04 PM	413,036
PP30 1-37-07 PM.txt	2/12/2004	01:50 PM	413,047

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_31\

PP31 10-04-29 AM.txt	2/21/2004	10:20 AM	413,078
PP31 10-42-24 AM.txt	2/21/2004	10:59 AM	413,088
PP31 11-03-34 AM.txt	2/21/2004	11:19 AM	413,041
PP31 11-23-38 AM.txt	2/21/2004	11:39 AM	413,044
PP31 11-42-41 AM.txt	2/21/2004	12:01 PM	413,040
PP31 12-05-34 PM.txt	2/21/2004	12:22 PM	413,049
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_32\			
PP32 10-19-14 AM.txt	2/29/2004	10:34 AM	413,044
PP32 10-35-28 AM.txt	2/29/2004	10:52 AM	413,044
PP32 10-53-48 AM.txt	2/29/2004	11:07 AM	413,044
PP32 11-08-52 AM.txt	2/29/2004	11:24 AM	413,044
PP32 11-25-44 AM.txt	2/29/2004	11:45 AM	413,044
PP32 11-46-09 AM.txt	2/29/2004	12:01 PM	413,044
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_33\			
PP33 1-12-51 PM.txt	2/29/2004	01:25 PM	413,034
PP33 12-44-53 PM.txt	2/29/2004	12:57 PM	413,038
PP33 12-58-57 PM.txt	2/29/2004	01:11 PM	413,036
PP33 1-26-43 PM.txt	2/29/2004	01:39 PM	413,036
PP33 1-40-12 PM.txt	2/29/2004	01:52 PM	413,035
PP33 1-59-20 PM.txt	2/29/2004	02:12 PM	413,035
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_34\			
PP34 3-00-55 PM.txt	2/22/2004	03:15 PM	413,036
PP34 3-16-28 PM.txt	2/22/2004	03:30 PM	413,038
PP34 3-31-53 PM.txt	2/22/2004	03:45 PM	413,038
PP34 3-47-22 PM.txt	2/22/2004	04:01 PM	413,038
PP34 4-02-38 PM.txt	2/22/2004	04:16 PM	413,039
PP34 4-18-09 PM.txt	2/22/2004	04:32 PM	413,039
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_35\			
PP35 10-04-28 AM.txt	2/20/2004	10:17 AM	413,039
PP35 10-22-43 AM.txt	2/20/2004	10:36 AM	413,041
PP35 10-37-50 AM.txt	2/20/2004	10:50 AM	413,040
PP35 9-14-28 AM.txt	2/20/2004	09:28 AM	413,159
PP35 9-29-52 AM.txt	2/20/2004	09:43 AM	413,038
PP35 9-45-40 AM.txt	2/20/2004	09:59 AM	413,038
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_36\			
PP36 3-31-02 PM.txt	2/21/2004	03:44 PM	413,046
PP36 3-47-32 PM.txt	2/21/2004	03:59 PM	413,038
PP36 4-01-35 PM.txt	2/21/2004	04:13 PM	413,038
PP36 4-15-46 PM.txt	2/21/2004	04:29 PM	413,037
PP36 4-30-56 PM.txt	2/21/2004	04:43 PM	413,042
PP36 4-46-06 PM.txt	2/21/2004	04:59 PM	413,038
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_37\			
PP37 3-45-22 PM.txt	2/23/2004	03:57 PM	413,051
PP37 3-58-49 PM.txt	2/23/2004	04:10 PM	413,031
PP37 4-11-48 PM.txt	2/23/2004	04:23 PM	413,035
PP37 4-25-30 PM.txt	2/23/2004	04:39 PM	413,031

PP37 4-40-17 PM.txt	2/23/2004	04:54 PM	413,031
PP37 4-55-59 PM.txt	2/23/2004	05:08 PM	413,031

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_38\

PP38 1-33-19 PM.txt	2/21/2004	01:46 PM	413,067
PP38 1-47-58 PM.txt	2/21/2004	02:01 PM	413,032
PP38 2-02-49 PM.txt	2/21/2004	02:15 PM	413,028
PP38 2-19-19 PM.txt	2/21/2004	02:32 PM	413,028
PP38 2-35-22 PM.txt	2/21/2004	02:47 PM	413,028
PP38 2-52-24 PM.txt	2/21/2004	03:04 PM	413,026

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_39\

PP39 11-06-35 AM.txt	2/19/2004	11:19 AM	413,175
PP39 11-21-03 AM.txt	2/19/2004	11:34 AM	413,051
PP39 11-36-53 AM.txt	2/19/2004	11:49 AM	413,053
PP39 12-14-43 PM.txt	2/19/2004	12:27 PM	413,049
PP39 12-37-39 PM.txt	2/19/2004	12:49 PM	413,049

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_40\

PP40 10-56-31 AM.txt	2/10/2004	11:36 AM	660,594
PP40 11-45-31 AM.txt	2/10/2004	12:42 PM	660,636
PP40 12-44-59 PM.txt	2/10/2004	01:23 PM	660,545
PP40 1-26-04 PM.txt	2/10/2004	01:59 PM	660,543
PP40 2-03-32 PM.txt	2/10/2004	02:32 PM	660,556
PP40 2-35-17 PM.txt	2/10/2004	03:07 PM	660,548

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_41\

PP41 1-11-52 PM.txt	2/16/2004	01:33 PM	413,046
PP41 12-48-42 PM.txt	2/16/2004	01:10 PM	413,096
PP41 1-35-59 PM.txt	2/16/2004	01:57 PM	413,037
PP41 2-01-38 PM.txt	2/16/2004	02:23 PM	413,038
PP14 2-25-21 PM.txt	2/16/2004	02:46 PM	413,031 *
PP41 2-48-45 PM.txt	2/16/2004	03:10 PM	413,056
PP41 3-13-03 PM.txt	2/16/2004	03:34 PM	413,037

* Data entry error transposed the site number for this file to site 14. When it did not appear in the proper folder during field measurements, it was assumed lost. Therefore, it was not used in analysis.

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_42\

PP42 1-11-21 PM.txt	2/14/2004	01:23 PM	413,050
PP42 11-55-34 AM.txt	2/14/2004	12:08 PM	413,074
PP42 12-11-24 PM.txt	2/14/2004	12:23 PM	413,045
PP42 12-26-47 PM.txt	2/14/2004	12:39 PM	413,044
PP42 12-41-32 PM.txt	2/14/2004	12:54 PM	413,052
PP42 12-56-42 PM.txt	2/14/2004	01:09 PM	413,044

PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_43\

PP43 2-59-52 PM.txt	2/29/2004	03:11 PM	413,030
PP43 3-13-42 PM.txt	2/29/2004	03:24 PM	413,029
PP43 3-29-30 PM.txt	2/29/2004	03:40 PM	413,029
PP43 3-41-54 PM.txt	2/29/2004	03:53 PM	413,030
PP43 3-53-57 PM.txt	2/29/2004	04:05 PM	413,030

PP43 4-05-57 PM.txt	2/29/2004	04:17 PM	413,030
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_44\			
PP44 10-02-20 AM.txt	2/12/2004	10:15 AM	413,039
PP44 10-16-36 AM.txt	2/12/2004	10:28 AM	413,034
PP44 10-31-38 AM.txt	2/12/2004	10:44 AM	413,034
PP44 10-47-23 AM.txt	2/12/2004	10:59 AM	413,035
PP44 11-01-31 AM.txt	2/12/2004	11:15 AM	413,053
PP44 9-47-13 AM.txt	2/12/2004	09:59 AM	413,056
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_45\			
PP45 2-32-44 PM.txt	2/17/2004	02:47 PM	413,090
PP45 2-50-25 PM.txt	2/17/2004	03:07 PM	413,033
PP45 3-09-35 PM.txt	2/17/2004	03:27 PM	413,031
PP45 3-47-06 PM.txt	2/17/2004	04:05 PM	413,077
PP45 4-07-11 PM.txt	2/17/2004	04:22 PM	413,037
PP45 4-30-29 PM.txt	2/17/2004	04:46 PM	413,092
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_46\			
PP46 1-14-06 PM.txt	3/5/2004	04:48 PM	413,046
PP46 12-30-42 PM.txt	3/5/2004	04:48 PM	413,085
PP46 12-44-14 PM.txt	3/5/2004	04:48 PM	413,049
PP46 12-58-13 PM.txt	3/5/2004	04:48 PM	413,041
PP46 1-29-23 PM.txt	3/5/2004	04:48 PM	413,046
PP46 1-43-25 PM.txt	3/5/2004	04:48 PM	413,046
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_47\			
PP47 3-10-34 PM.txt	2/11/2004	03:31 PM	413,080
PP47 3-33-57 PM.txt	2/11/2004	03:53 PM	413,043
PP47 3-56-21 PM.txt	2/11/2004	04:14 PM	413,044
PP47 4-17-32 PM.txt	2/11/2004	04:35 PM	413,037
PP47 4-37-44 PM.txt	2/11/2004	04:56 PM	413,038
PP47 4-58-18 PM.txt	2/11/2004	05:16 PM	413,047
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_48\			
PP48 10-01-41 AM.txt	3/5/2004	04:48 PM	413,061
PP48 10-16-02 AM.txt	3/5/2004	04:48 PM	413,061
PP48 10-34-35 AM.txt	3/5/2004	04:48 PM	413,050
PP48 10-51-37 AM.txt	3/5/2004	04:48 PM	413,042
PP48 9-25-45 AM.txt	3/5/2004	04:48 PM	413,129
PP48 9-44-48 AM.txt	3/5/2004	04:48 PM	413,069
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_49\			
PP49 2-56-06 PM.txt	3/5/2004	04:48 PM	413,080
PP49 3-11-21 PM.txt	3/5/2004	04:48 PM	413,194
PP49 3-26-00 PM.txt	3/5/2004	04:48 PM	413,038
PP49 3-45-06 PM.txt	3/5/2004	04:48 PM	413,036
PP49 3-59-15 PM.txt	3/5/2004	04:48 PM	413,036
PP49 4-12-37 PM.txt	3/5/2004	04:48 PM	413,045
PAVE PAWS Data\PAVE PAWS Field Measurement Raw Data\Site_50\			
PP50 2-11-48 PM.txt	2/19/2004	02:24 PM	413,103
PP50 2-26-31 PM.txt	2/19/2004	02:38 PM	413,040

PP50 2-41-52 PM.txt	2/19/2004	02:54 PM	413,040
PP50 2-57-34 PM.txt	2/19/2004	03:12 PM	413,034
PP50 3-24-01 PM.txt	2/19/2004	03:36 PM	413,035
PP50 3-38-54 PM.txt	2/19/2004	03:51 PM	413,045

E1.2 PAVE PAWS Photographs

All rig and site photographs for the 50 PAVE PAWS measurement sites are contained in this folder.

Folder Name: PAVE PAWS Rig and Spec Photos

All Spec An photographs for the 50 PAVE PAWS measurements are contained in this folder.

Folder Name: PAVE PAWS Spec An Photos

(Folder PAVE PAWS Photographs includes a readme.txt file detailing the contents of that folder.)

E1.3 PAVE PAWS Processed Data

As described in Appendix A, post-processing programs were written in Microsoft Visual Basic to perform the repetitive operations required to reduce the raw data recorded in the field to the desired outputs for the Final Test Report. These programs are contained in Visual Basic Programs\PavePaws.

This folder contains individual files for each of the approximately 300 measurement sequences, in which the raw data has been converted to peak and average power density. See the software functional description contained in Appendix A for the details on the creation of these intermediate files.

File Folder: PAVE PAWS Processed Data

PAVE PAWS Data\PAVE PAWS Processed Data\

Site_01-1	4/24/2004	06:53 PM	360,332
Site_01-2	4/24/2004	06:53 PM	394,858
Site_01-3	4/24/2004	06:53 PM	394,928
Site_01-4	4/24/2004	06:53 PM	394,865
Site_01-5	4/24/2004	06:53 PM	394,903
Site_01-6	4/24/2004	06:53 PM	394,831
Site_02-1	4/24/2004	06:53 PM	394,864
Site_02-2	4/24/2004	06:53 PM	394,809
Site_02-3	4/24/2004	06:53 PM	394,900
Site_02-4	4/24/2004	06:53 PM	394,775

Site_02-5	4/24/2004	06:53 PM	395,054
Site_02-6	4/24/2004	06:53 PM	395,156
Site_03-1	4/24/2004	06:53 PM	395,002
Site_03-2	4/24/2004	06:53 PM	395,059
Site_03-3	4/24/2004	06:53 PM	394,938
Site_03-4	4/24/2004	06:53 PM	394,934
Site_03-5	4/24/2004	06:53 PM	394,932
Site_03-6	4/24/2004	06:53 PM	395,007
Site_04-1	4/24/2004	06:53 PM	395,342
Site_04-2	4/24/2004	06:53 PM	394,102
Site_04-3	4/24/2004	06:53 PM	394,987
Site_04-4	4/24/2004	06:53 PM	395,095
Site_04-5	4/24/2004	06:53 PM	395,270
Site_04-6	4/24/2004	06:53 PM	395,017
Site_05-1	4/24/2004	06:53 PM	394,785
Site_05-2	4/24/2004	06:53 PM	394,507
Site_05-3	4/24/2004	06:53 PM	394,687
Site_05-4	4/24/2004	06:53 PM	394,787
Site_05-5	4/24/2004	06:53 PM	394,985
Site_05-6	4/24/2004	06:53 PM	394,994
Site_06-1	4/24/2004	06:53 PM	394,961
Site_06-2	4/24/2004	06:53 PM	394,907
Site_06-3	4/24/2004	06:53 PM	394,885
Site_06-4	4/24/2004	06:53 PM	394,910
Site_06-5	4/24/2004	06:53 PM	394,784
Site_06-6	4/24/2004	06:53 PM	394,951
Site_07-1	4/24/2004	06:54 PM	394,967
Site_07-2	4/24/2004	06:54 PM	394,896
Site_07-3	4/24/2004	06:54 PM	394,975
Site_07-4	4/24/2004	06:54 PM	395,086
Site_07-5	4/24/2004	06:54 PM	394,794
Site_07-6	4/24/2004	06:54 PM	394,952
Site_08-1	4/24/2004	06:54 PM	395,060
Site_08-2	4/24/2004	06:54 PM	394,977
Site_08-3	4/24/2004	06:54 PM	395,047
Site_08-4	4/24/2004	06:54 PM	394,936
Site_08-5	4/24/2004	06:54 PM	394,948
Site_08-6	4/24/2004	06:54 PM	394,958
Site_09-1	4/24/2004	06:54 PM	394,320
Site_09-2	4/24/2004	06:54 PM	394,154
Site_09-3	4/24/2004	06:54 PM	394,115
Site_09-4	4/24/2004	06:54 PM	394,171
Site_09-5	4/24/2004	06:54 PM	394,029
Site_09-6	4/24/2004	06:54 PM	394,256
Site_10-1	4/24/2004	06:54 PM	394,942
Site_10-2	4/24/2004	06:54 PM	394,801

Site_10-3	4/24/2004	06:54 PM	395,068
Site_10-4	4/24/2004	06:54 PM	394,998
Site_10-5	4/24/2004	06:54 PM	395,011
Site_10-6	4/24/2004	06:54 PM	395,164
Site_11-1	4/24/2004	06:54 PM	394,997
Site_11-2	4/24/2004	06:54 PM	394,972
Site_11-3	4/24/2004	06:54 PM	395,015
Site_11-4	4/24/2004	06:54 PM	395,034
Site_11-5	4/24/2004	06:54 PM	394,941
Site_11-6	4/24/2004	06:54 PM	395,053
Site_12-1	4/24/2004	06:54 PM	394,959
Site_12-2	4/24/2004	06:54 PM	394,885
Site_12-3	4/24/2004	06:54 PM	394,885
Site_12-4	4/24/2004	06:54 PM	394,807
Site_12-5	4/24/2004	06:54 PM	394,781
Site_12-6	4/24/2004	06:54 PM	394,944
Site_13-1	4/24/2004	06:54 PM	395,190
Site_13-2	4/24/2004	06:54 PM	394,973
Site_13-3	4/24/2004	06:54 PM	394,978
Site_13-4	4/24/2004	06:54 PM	394,998
Site_13-5	4/24/2004	06:54 PM	394,996
Site_13-6	4/24/2004	06:55 PM	395,107
Site_14-1	4/24/2004	06:55 PM	394,799
Site_14-2	4/24/2004	06:55 PM	395,022
Site_14-3	4/24/2004	06:55 PM	394,861
Site_14-4	4/24/2004	06:55 PM	394,686
Site_14-5	4/24/2004	06:55 PM	394,815
Site_14-6	4/24/2004	06:55 PM	394,734
Site_14-7	4/24/2004	06:55 PM	394,820
Site_15-1	4/24/2004	06:55 PM	387,760
Site_16-1	4/24/2004	06:55 PM	394,604
Site_16-2	4/24/2004	06:55 PM	394,780
Site_16-3	4/24/2004	06:55 PM	394,620
Site_16-4	4/24/2004	06:55 PM	394,712
Site_16-5	4/24/2004	06:55 PM	394,655
Site_16-6	4/24/2004	06:55 PM	394,699
Site_17-1	4/24/2004	06:55 PM	394,731
Site_17-2	4/24/2004	06:55 PM	395,169
Site_17-3	4/24/2004	06:55 PM	394,711
Site_17-4	4/24/2004	06:55 PM	388,026
Site_17-5	4/24/2004	06:55 PM	394,949
Site_17-6	4/24/2004	06:55 PM	394,949
Site_18-1	4/24/2004	06:55 PM	394,746
Site_18-2	4/24/2004	06:55 PM	394,675
Site_18-3	4/24/2004	06:55 PM	394,725
Site_18-4	4/24/2004	06:55 PM	394,698

Site_18-5	4/24/2004	06:55 PM	394,727
Site_18-6	4/24/2004	06:55 PM	394,807
Site_19-1	4/24/2004	06:55 PM	394,918
Site_19-2	4/24/2004	06:55 PM	394,749
Site_19-3	4/24/2004	06:55 PM	394,885
Site_19-4	4/24/2004	06:55 PM	394,716
Site_19-5	4/24/2004	06:55 PM	394,667
Site_19-6	4/24/2004	06:55 PM	394,944
Site_20-1	4/24/2004	06:55 PM	394,820
Site_20-2	4/24/2004	06:55 PM	394,812
Site_20-3	4/24/2004	06:55 PM	394,849
Site_20-4	4/24/2004	06:55 PM	394,973
Site_20-5	4/24/2004	06:55 PM	394,944
Site_20-6	4/24/2004	06:55 PM	394,920
Site_21-1	4/24/2004	06:55 PM	394,625
Site_21-2	4/24/2004	06:56 PM	394,696
Site_21-3	4/24/2004	06:56 PM	394,702
Site_21-4	4/24/2004	06:56 PM	394,466
Site_21-5	4/24/2004	06:56 PM	394,539
Site_21-6	4/24/2004	06:56 PM	394,502
Site_22-1	4/24/2004	06:56 PM	394,904
Site_22-2	4/24/2004	06:56 PM	394,772
Site_22-3	4/24/2004	06:56 PM	394,714
Site_22-4	4/24/2004	06:56 PM	394,721
Site_22-5	4/24/2004	06:56 PM	394,871
Site_22-6	4/24/2004	06:56 PM	394,681
Site_23-1	4/24/2004	06:56 PM	394,082
Site_23-2	4/24/2004	06:56 PM	394,239
Site_23-3	4/24/2004	06:56 PM	394,144
Site_23-4	4/24/2004	06:56 PM	394,290
Site_23-5	4/24/2004	06:56 PM	394,223
Site_23-6	4/24/2004	06:56 PM	394,443
Site_24-1	4/24/2004	06:56 PM	394,911
Site_24-2	4/24/2004	06:56 PM	394,730
Site_24-3	4/24/2004	06:56 PM	394,885
Site_24-4	4/24/2004	06:56 PM	394,672
Site_24-5	4/24/2004	06:56 PM	394,930
Site_24-6	4/24/2004	06:56 PM	394,855
Site_25-1	4/24/2004	06:56 PM	394,726
Site_25-2	4/24/2004	06:56 PM	394,777
Site_25-3	4/24/2004	06:56 PM	394,746
Site_25-4	4/24/2004	06:56 PM	394,737
Site_25-5	4/24/2004	06:56 PM	394,857
Site_25-6	4/24/2004	06:56 PM	394,651
Site_26-1	4/24/2004	06:56 PM	394,883
Site_26-2	4/24/2004	06:56 PM	394,880

Site_26-3	4/24/2004	06:56 PM	394,745
Site_26-4	4/24/2004	06:56 PM	394,756
Site_26-5	4/24/2004	06:56 PM	394,718
Site_26-6	4/24/2004	06:56 PM	394,848
Site_27-1	4/24/2004	06:56 PM	394,820
Site_27-2	4/24/2004	06:56 PM	394,729
Site_27-3	4/24/2004	06:56 PM	394,698
Site_27-4	4/24/2004	06:56 PM	394,651
Site_27-5	4/24/2004	06:56 PM	394,827
Site_28-1	4/24/2004	06:57 PM	394,960
Site_28-2	4/24/2004	06:57 PM	394,959
Site_28-3	4/24/2004	06:57 PM	394,977
Site_28-4	4/24/2004	06:57 PM	395,032
Site_28-5	4/24/2004	06:57 PM	395,126
Site_28-6	4/24/2004	06:57 PM	394,962
Site_29-1	4/24/2004	06:57 PM	395,015
Site_29-2	4/24/2004	06:57 PM	394,861
Site_29-3	4/24/2004	06:57 PM	394,863
Site_29-4	4/24/2004	06:57 PM	394,889
Site_29-5	4/24/2004	06:57 PM	394,818
Site_29-6	4/24/2004	06:57 PM	394,848
Site_30-1	4/24/2004	06:57 PM	395,008
Site_30-2	4/24/2004	06:57 PM	394,998
Site_30-3	4/24/2004	06:57 PM	395,058
Site_30-4	4/24/2004	06:57 PM	395,007
Site_30-5	4/24/2004	06:57 PM	395,081
Site_30-6	4/24/2004	06:57 PM	394,945
Site_31-1	4/24/2004	06:57 PM	395,048
Site_31-2	4/24/2004	06:57 PM	394,869
Site_31-3	4/24/2004	06:57 PM	395,035
Site_31-4	4/24/2004	06:57 PM	394,937
Site_31-5	4/24/2004	06:57 PM	395,003
Site_31-6	4/24/2004	06:57 PM	394,886
Site_32-1	4/24/2004	06:57 PM	394,795
Site_32-2	4/24/2004	06:57 PM	394,798
Site_32-3	4/24/2004	06:57 PM	394,932
Site_32-4	4/24/2004	06:57 PM	395,009
Site_32-5	4/24/2004	06:57 PM	394,925
Site_32-6	4/24/2004	06:57 PM	395,015
Site_33-1	4/24/2004	06:57 PM	394,972
Site_33-2	4/24/2004	06:57 PM	395,068
Site_33-3	4/24/2004	06:57 PM	395,073
Site_33-4	4/24/2004	06:57 PM	394,977
Site_33-5	4/24/2004	06:57 PM	395,054
Site_33-6	4/24/2004	06:57 PM	395,019
Site_34-1	4/24/2004	06:57 PM	394,762

Site_34-2	4/24/2004	06:57 PM	394,907
Site_34-3	4/24/2004	06:57 PM	394,804
Site_34-4	4/24/2004	06:57 PM	394,850
Site_34-5	4/24/2004	06:57 PM	394,981
Site_34-6	4/24/2004	06:58 PM	394,934
Site_35-1	4/24/2004	06:58 PM	395,215
Site_35-2	4/24/2004	06:58 PM	395,025
Site_35-3	4/24/2004	06:58 PM	394,944
Site_35-4	4/24/2004	06:58 PM	394,997
Site_35-5	4/24/2004	06:58 PM	395,046
Site_35-6	4/24/2004	06:58 PM	395,061
Site_36-1	4/24/2004	06:58 PM	395,058
Site_36-2	4/24/2004	06:58 PM	395,049
Site_36-3	4/24/2004	06:58 PM	394,987
Site_36-4	4/24/2004	06:58 PM	395,042
Site_36-5	4/24/2004	06:58 PM	394,994
Site_36-6	4/24/2004	06:58 PM	395,036
Site_37-1	4/24/2004	06:58 PM	395,106
Site_37-2	4/24/2004	06:58 PM	395,166
Site_37-3	4/24/2004	06:58 PM	395,207
Site_37-4	4/24/2004	06:58 PM	395,018
Site_37-5	4/24/2004	06:58 PM	395,011
Site_37-6	4/24/2004	06:58 PM	394,983
Site_38-1	4/24/2004	06:58 PM	395,059
Site_38-2	4/24/2004	06:58 PM	395,063
Site_38-3	4/24/2004	06:58 PM	395,100
Site_38-4	4/24/2004	06:58 PM	394,971
Site_38-5	4/24/2004	06:58 PM	395,207
Site_38-6	4/24/2004	06:58 PM	395,104
Site_39-1	4/24/2004	06:58 PM	395,194
Site_39-2	4/24/2004	06:58 PM	395,030
Site_39-3	4/24/2004	06:58 PM	394,970
Site_39-4	4/24/2004	06:58 PM	395,072
Site_39-5	4/24/2004	06:58 PM	395,214
Site_40-1	4/24/2004	06:58 PM	394,496
Site_40-2	4/24/2004	06:58 PM	394,389
Site_40-3	4/24/2004	06:58 PM	393,839
Site_40-4	4/24/2004	06:58 PM	394,338
Site_40-5	4/24/2004	06:58 PM	394,443
Site_40-6	4/24/2004	06:58 PM	393,741
Site_41-1	4/24/2004	06:58 PM	394,939
Site_41-2	4/24/2004	06:58 PM	394,845
Site_41-3	4/24/2004	06:58 PM	394,814
Site_41-4	4/24/2004	06:58 PM	394,788
Site_41-5	4/24/2004	06:58 PM	394,753
Site_41-6	4/24/2004	06:59 PM	394,882

Site_42-1	4/24/2004	06:59 PM	395,040
Site_42-2	4/24/2004	06:59 PM	395,088
Site_42-3	4/24/2004	06:59 PM	395,103
Site_42-4	4/24/2004	06:59 PM	394,945
Site_42-5	4/24/2004	06:59 PM	395,033
Site_42-6	4/24/2004	06:59 PM	395,094
Site_43-1	4/24/2004	06:59 PM	394,759
Site_43-2	4/24/2004	06:59 PM	394,357
Site_43-3	4/24/2004	06:59 PM	394,672
Site_43-4	4/24/2004	06:59 PM	394,871
Site_43-5	4/24/2004	06:59 PM	394,704
Site_43-6	4/24/2004	06:59 PM	394,487
Site_44-1	4/24/2004	06:59 PM	394,992
Site_44-2	4/24/2004	06:59 PM	394,988
Site_44-3	4/24/2004	06:59 PM	394,871
Site_44-4	4/24/2004	06:59 PM	395,000
Site_44-5	4/24/2004	06:59 PM	395,021
Site_44-6	4/24/2004	06:59 PM	395,079
Site_45-1	4/24/2004	06:59 PM	394,874
Site_45-2	4/24/2004	06:59 PM	394,942
Site_45-3	4/24/2004	06:59 PM	394,842
Site_45-4	4/24/2004	06:59 PM	394,971
Site_45-5	4/24/2004	06:59 PM	394,922
Site_45-6	4/24/2004	06:59 PM	395,114
Site_46-1	4/24/2004	06:59 PM	395,100
Site_46-2	4/24/2004	06:59 PM	394,889
Site_46-3	4/24/2004	06:59 PM	395,028
Site_46-4	4/24/2004	06:59 PM	395,025
Site_46-5	4/24/2004	06:59 PM	394,931
Site_46-6	4/24/2004	06:59 PM	394,986
Site_47-1	4/24/2004	06:59 PM	394,782
Site_47-2	4/24/2004	06:59 PM	394,713
Site_47-3	4/24/2004	06:59 PM	394,819
Site_47-4	4/24/2004	06:59 PM	394,774
Site_47-5	4/24/2004	06:59 PM	394,715
Site_47-6	4/24/2004	06:59 PM	394,782
Site_48-1	4/24/2004	06:59 PM	395,078
Site_48-2	4/24/2004	06:59 PM	394,982
Site_48-3	4/24/2004	06:59 PM	395,036
Site_48-4	4/24/2004	07:00 PM	395,126
Site_48-5	4/24/2004	07:00 PM	395,048
Site_48-6	4/24/2004	07:00 PM	394,969
Site_49-1	4/24/2004	07:00 PM	394,992
Site_49-2	4/24/2004	07:00 PM	395,173
Site_49-3	4/24/2004	07:00 PM	394,989
Site_49-4	4/24/2004	07:00 PM	394,991

Site_49-5	4/24/2004	07:00 PM	394,854
Site_49-6	4/24/2004	07:00 PM	394,909
Site_50-1	4/24/2004	07:00 PM	394,979
Site_50-2	4/24/2004	07:00 PM	395,073
Site_50-3	4/24/2004	07:00 PM	394,988
Site_50-4	4/24/2004	07:00 PM	395,025
Site_50-5	4/24/2004	07:00 PM	394,946
Site_50-6	4/24/2004	07:00 PM	395,084

The following MS-Excel file was used for further post processing and plotting of data for presentation in the final test report.

PAVE PAWS Data\PAVE PAWS Processed Data\PP Peaks and Aves.xls

E2 Ambient Data

E2.1 Ambient Field Measurement Raw Data

This file contains a transcription of the handwritten Site Data from the 50 PAVE PAWS sites and from the 10 ambient measurement sites.

File Name: Ambient Field Measurement Raw Data\PP Site Data Transcription.xls
(NOTE: this spreadsheet is a duplicate copy of the spreadsheet found in PAVE PAWS Data/PAVE PAWS Field Measurement Raw Data)

These text files contain all of the raw data recorded in the field for the 10 ambient measurement sites.

Ambient Data\Ambient Field Measurement Raw Data\Site_000\			
High000 11-03-49 AM.txt	2/9/2004	11:09 AM	829,006
Low000 11-17-44 AM.txt	2/9/2004	11:20 AM	352,595
Mid000 11-11-21 AM.txt	2/9/2004	11:15 AM	705,191
Ambient Data\Ambient Field Measurement Raw Data \Site_001\			
Low001 3-31-01 PM.txt	2/28/2004	04:00 PM	4,228,956
Upper001 1-44-25 PM.txt	2/28/2004	03:18 PM	13,926,669
Ambient Data\Ambient Field Measurement Raw Data \Site_002\			
High002 4-09-26 PM.txt	2/26/2004	04:55 PM	7,459,662
Low002 2-32-07 PM.txt	2/26/2004	02:59 PM	4,228,800
Mid002 3-23-32 PM.txt	2/26/2004	04:06 PM	6,345,277
Ambient Data\Ambient Field Measurement Raw Data \Site_003\			
Low003 12-57-35 PM.txt	3/4/2004	01:24 PM	4,229,110
Low003 1-29-30 PM.txt	3/4/2004	01:56 PM	4,229,037
Upper003 2-18-47 PM.txt	3/4/2004	02:22 PM	711,168
Upper003 2-29-25 PM.txt	3/4/2004	03:52 PM	13,926,643
Ambient Data\Ambient Field Measurement Raw Data \Site_004\			

Low004 4-41-18 PM.txt	3/3/2004	04:54 PM	2,114,650
Upper004 2-17-02 PM.txt	3/3/2004	02:53 PM	4,998,144
Upper004 2-58-05 PM.txt	3/3/2004	04:24 PM	13,926,922
Ambient Data\Ambient Field Measurement Raw Data \Site_005\			
Low005 11-25-22 AM.txt	2/27/2004	11:52 AM	4,228,996
Upper005 10-44-29 AM.txt	2/27/2004	10:56 AM	1,548,184
Upper005 12-07-39 PM.txt	2/27/2004	01:35 PM	13,926,675
Ambient Data\Ambient Field Measurement Raw Data \Site_006\			
High006 10-21-22 AM.txt	2/25/2004	10:22 AM	118,784
High006 10-25-04 AM.txt	2/25/2004	11:15 AM	7,459,549
Low006 12-38-55 PM.txt	2/25/2004	01:06 PM	4,228,365
Mid006 11-24-03 AM.txt	2/25/2004	12:10 PM	6,345,233
Ambient Data\Ambient Field Measurement Raw Data \Site_007\			
High007 1-57-15 PM.txt	2/23/2004	02:45 PM	7,459,770
Low007 12-09-08 PM.txt	2/23/2004	12:36 PM	4,228,999
Mid007 12-54-21 PM.txt	2/23/2004	01:53 PM	6,345,329
Ambient Data\Ambient Field Measurement Raw Data \Site_008\			
Low008 10-46-55 AM.txt	3/2/2004	11:19 AM	4,229,132
Upper008 11-34-58 AM.txt	3/2/2004	12:59 PM	13,927,000
Ambient Data\Ambient Field Measurement Raw Data \Site_009\			
Low009 2-52-36 PM.txt	3/2/2004	03:19 PM	4,229,040
Upper009 3-44-01 PM.txt	3/2/2004	05:06 PM	13,926,831
Ambient Data\Ambient Field Measurement Raw Data \Site_010\			
High010 4-06-18 PM.txt	2/25/2004	04:58 PM	7,459,681
Low010 2-24-39 PM.txt	2/25/2004	02:52 PM	4,229,032
Mid010 3-11-53 PM.txt	2/25/2004	04:01 PM	6,345,325

E2.2 Ambient Photographs

All rig and site photographs for the 10 Ambient measurement sites are contained in this folder.

Folder Name: Ambient Rig and Spec Photos

All Spec An photographs for the 10 Ambient measurements are contained in this folder.

Folder Name: Ambient Spec An Photos

(Folder Ambient Photographs includes a readme.txt file detailing the contents of that folder.)

E2.3 Ambient Processed Data

As described in Appendix B, post-processing programs were written in Microsoft Visual Basic to perform the repetitive operations required to reduce the raw data recorded in the field to the desired outputs for the Final Test Report These programs are contained in Visual Basic Programs\Background RFE

This file folder contains the text files listed below which contain all of the post-processed Ambient data. Appendix B contains a description of how these files were created. These files were used to prepare the composite spectrum scans and weighted MPE results presented in the test report. (*Note:* The dates shown in the list that follows are the dates that a backup copy of these files was made, not when the file was last modified.)

File Folder: Ambient Processed Data

Ambient Data\Ambient Processed Data\

Ambient Low Band Summary.txt	4/24/2004	03:10 PM	810,670
High002 Power Density.txt	4/24/2004	03:09 PM	581,776
High006 Power Density.txt	4/24/2004	03:09 PM	581,674
High007 Power Density.txt	4/24/2004	03:09 PM	581,773
High010 Power Density.txt	4/24/2004	03:09 PM	581,764
Low001 Power Density.txt	4/24/2004	03:09 PM	388,373
Low002 Power Density.txt	4/24/2004	03:09 PM	388,287
Low003 Power Density.txt	4/24/2004	03:09 PM	388,335
Low004 Power Density.txt	4/24/2004	03:09 PM	194,312
Low005 Power Density.txt	4/24/2004	03:09 PM	388,274
Low006 Power Density.txt	4/24/2004	03:09 PM	388,175
Low007 Power Density.txt	4/24/2004	03:09 PM	388,294
Low008 Power Density.txt	4/24/2004	03:09 PM	388,362
Low009 Power Density.txt	4/24/2004	03:09 PM	388,307
Low010 Power Density.txt	4/24/2004	03:09 PM	388,275
Mid002 Power Density.txt	4/24/2004	03:09 PM	486,672
Mid006 Power Density.txt	4/24/2004	03:09 PM	486,678
Mid007 Power Density.txt	4/24/2004	03:09 PM	486,671
Mid010 Power Density.txt	4/24/2004	03:09 PM	486,667
Upper001 Power Density.txt	4/24/2004	03:09 PM	1,079,701
Upper003 Power Density.txt	4/24/2004	03:09 PM	1,079,725
Upper004 Power Density.txt	4/24/2004	03:09 PM	1,079,808
Upper005 Power Density.txt	4/24/2004	03:09 PM	1,079,740
Upper008 Power Density.txt	4/24/2004	03:09 PM	1,079,846
Upper009 Power Density.txt	4/24/2004	03:09 PM	1,079,789

The following MS-Excel files were used for further post-processing and plotting of the data for presentation in the final test report.

Ambient Low Band Summary 032704.xls
Mid0xx Power Density.xls
High0xx Power Density.xls
Upper0xx Power Density.xls

Note: The designation "0xx" in the MS-Excel workbook file names refers to the site numbers for the ten ambient measurement sites. See Appendix B for further discussion on the contents of these workbook files.

E3 Drive Test Data

E3.1 Drive Test Raw Data

These text files contain all of the data recorded in the Drive Test. For a description of the contents of these files, see Appendix C.

The Drive Test *.txt files are found in the following file folder:

Folder Name: Drive Test Data\ Drive Test Raw Data \Original Drive Test Data

File Name: Drive Test xx-xx-xx XM.txt

These are the Drive Test data files. In the data file names xx-xx-xx XM represents the time-of-day stamp applied by the computer.

File Name: Drive Test Data\ Drive Test Raw Data \Drive Test Combined Data.xls

This MS-Excel workbook is a compilation of the data contained in the individual text files described above.

E3.2 Drive Test Beacon Photographs

This folder contains images relating to the installation of the Drive Test Beacon on the Pave Paws structure.

E3.3 Drive Test Processed Data

The files contained in this folder are the computer programs and transitional data files employed to convert the drive test data into a single value per 3-arc second cell.

File folder: Drive Test Data\ Drive Test Processed Data

This file contains the output of ComStudy's prediction of the drive test beacon

File: Drive Test Data\ Drive Test Processed Data \Beacon Matrix 57ERP dBm Matrix.rmx

This file is an MS-Excel workbook is the output of the drive test data consolidation process and a comparison with the data in the beacon matrix.

File: Drive Test Data\ Drive Test Processed Data \Drive Test Consolidated.xls

E4 Visual Basic Programs

File Folder: Visual Basic Programs

These are files of all Visual Basic programs used for the data collection and post processing portions of the project. (*Note:* The dates shown here are the dates that a backup copy of these files was made, rather than the date the file was last modified.)

Visual Basic Programs\Advantest\			
AdvBRFE.PDM	4/24/2004	03:10 PM	3,840
frmAdvDriveTest.frm	4/24/2004	03:10 PM	38,311
frmDataFile.frm	4/24/2004	03:10 PM	4,782
frmNewDriveTest.frm	4/24/2004	03:10 PM	39,085
New Drive Test.exe	4/24/2004	03:11 PM	77,824
New Drive Test.PDM	4/24/2004	03:11 PM	3,886
New Drive Test.vbp	4/24/2004	03:10 PM	1,040
New Drive Test.vbw	4/24/2004	03:10 PM	196
Visual Basic Programs\Advantest\New Drive Test\			
New Drive Test.CAB	4/24/2004	03:11 PM	1,511,841
setup.exe	4/24/2004	03:11 PM	139,776
SETUP.LST	4/24/2004	03:10 PM	3,804
Visual Basic Programs\Advantest\New Drive Test\Support\			
ASYCFILT.DLL	4/24/2004	03:10 PM	147,728
COMCAT.DLL	4/24/2004	03:10 PM	22,288
gpib-32.dll	4/24/2004	03:10 PM	229,376
MSCOMM32.OCX	4/24/2004	03:10 PM	103,744
MSVBVM60.DLL	4/24/2004	03:10 PM	1,388,544
New Drive Test.BAT	4/24/2004	03:10 PM	191
New Drive Test.exe	4/24/2004	03:10 PM	77,824
OLEAUT32.DLL	4/24/2004	03:10 PM	598,288
OLEPRO32.DLL	4/24/2004	03:10 PM	164,112
Project1.DDF	4/24/2004	03:10 PM	524
SETUP.EXE	4/24/2004	03:10 PM	139,776
Setup.Lst	4/24/2004	03:10 PM	3,804
SETUP1.EXE	4/24/2004	03:10 PM	249,856
ST6UNST.EXE	4/24/2004	03:10 PM	73,216
STDOLE2.TLB	4/24/2004	03:10 PM	17,920
VB6STKIT.DLL	4/24/2004	03:10 PM	101,888
Visual Basic Programs\Agilent Power Meter 031804\			
FRMPAV~2.log	4/24/2004	03:15 PM	84
frmPAVEPAWSNoiseRFE.frm	4/24/2004	03:15 PM	38,689

frmPAVEPAWSNoiseRFE.frx
4/24/2004 03:15 PM 1,978
PAVE PAWS NOISE-RFE.exe
4/24/2004 03:15 PM 73,728
PAVE PAWS NOISE-RFE.PDM
4/24/2004 03:15 PM 4,479
PAVE PAWS NOISE-RFE.vbp
4/24/2004 03:15 PM 1,069
PAVE PAWS NOISE-RFE.vbw
4/24/2004 03:15 PM 64

Visual Basic Programs\Agilent Power Meter 031804\PAVE PAWS RFE\

PAVE PAWS NOISE-RFE.CAB
4/24/2004 03:14 PM 1,510,897

setup.exe	4/24/2004	03:15 PM	139,776
SETUP.LST	4/24/2004	03:15 PM	3,824

Visual Basic Programs\Agilent Power Meter 031804\PAVE PAWS RFE\Support\

ASYCFILT.DLL	4/24/2004	03:15 PM	147,728
COMCAT.DLL	/24/2004	03:15 PM	22,288
gpib-32.dll	4/24/2004	03:15 PM	229,376
MSCOMM32.OCX	4/24/2004	03:15 PM	103,744
MSVBVM60.DLL	4/24/2004	03:15 PM	1,388,544
OLEAUT32.DLL	4/24/2004	03:15 PM	598,288
OLEPRO32.DLL	4/24/2004	03:15 PM	164,112
PAVE PAWS NOISE-RFE.BAT	4/24/2004	03:15 PM	191
PAVE PAWS NOISE-RFE.exe	4/24/2004	03:15 PM	73,728
Project1.DDF	4/24/2004	03:15 PM	534
SETUP.EXE	4/24/2004	03:15 PM	139,776
Setup.Lst	4/24/2004	03:15 PM	3,824
SETUP1.EXE	4/24/2004	03:15 PM	249,856
ST6UNST.EXE	4/24/2004	03:15 PM	73,216
STDOLE2.TLB	4/24/2004	03:15 PM	17,920
VB6STKIT.DLL	4/24/2004	03:15 PM	101,888

Visual Basic Programs\Background RFE\

frmHBAdvBRFE.frm	4/24/2004	03:11 PM	36,930
frmHBAdvBRFE.frx	4/24/2004	03:11 PM	439
frmHighBandProcessing.frm	4/24/2004	03:12 PM	14,153
frmLBAdvBRFE.frm	4/24/2004	03:11 PM	37,906
frmLBAdvBRFE.frx	4/24/2004	03:11 PM	444
frmLowAmbient.frm	4/24/2004	03:12 PM	13,389
frmMBAdvBRFE.frm	4/24/2004	03:11 PM	37,329
frmMBAdvBRFE.frx	4/24/2004	03:11 PM	439
frmMidAmbient.frm	4/24/2004	03:12 PM	13,934
frmUBAdvBRFE.frm	4/24/2004	03:12 PM	38,139
frmUBAdvBRFE.frx	4/24/2004	03:12 PM	439

frmUpperAmbient.frm	4/24/2004	03:12 PM	14,140
High Band BRFE.exe	4/24/2004	03:12 PM	65,536
High Band BRFE.PDM	4/24/2004	03:12 PM	3,931
High Band BRFE.vbp	4/24/2004	03:11 PM	996
High Band BRFE.vbw	4/24/2004	03:11 PM	131
Low Band BRFE.exe	4/24/2004	03:12 PM	65,536
Low Band BRFE.PDM	4/24/2004	03:11 PM	3,917
Low Band BRFE.vbp	4/24/2004	03:11 PM	995
Low Band BRFE.vbw	4/24/2004	03:11 PM	136
Mid Band BRFE.exe	4/24/2004	03:12 PM	65,536
Mid Band BRFE.PDM	4/24/2004	03:12 PM	3,917
Mid Band BRFE.vbp	4/24/2004	03:11 PM	995
Mid Band BRFE.vbw	4/24/2004	03:11 PM	136
Process High Band Ambient Data.vbp	4/24/2004	03:12 PM	662
Process High Band Ambient Data.vbw	4/24/2004	03:12 PM	66
Process Low Band Ambient Data.vbp	4/24/2004	03:12 PM	638
Process Low Band Ambient Data.vbw	4/24/2004	03:12 PM	58
Process Mid Band Ambient Data.vbp	4/24/2004	03:12 PM	638
Process Mid Band Ambient Data.vbw	4/24/2004	03:12 PM	58
Process Upper Band Ambient Data.vbp	4/24/2004	03:12 PM	644
Process Upper Band Ambient Data.vbw	4/24/2004	03:12 PM	60
Upper Band BRFE.exe	4/24/2004	03:12 PM	69,632
Upper Band BRFE.PDM	4/24/2004	03:12 PM	8,838
Upper Band BRFE.vbp	4/24/2004	03:12 PM	1,039
Upper Band BRFE.vbw	4/24/2004	03:12 PM	131

Visual Basic Programs\Background RFE\High Band BRFE\

High Band BRFE.CAB	4/24/2004	03:12 PM	1,507,915
setup.exe	4/24/2004	03:12 PM	139,776
SETUP.LST	4/24/2004	03:12 PM	3,805

Visual Basic Programs\Background RFE\High Band BRFE\Support\

ASYCFILT.DLL	4/24/2004	03:12 PM	147,728
COMCAT.DLL	4/24/2004	03:12 PM	22,288
gpib-32.dll	4/24/2004	03:12 PM	229,376
High Band BRFE.BAT	4/24/2004	03:12 PM	191
High Band BRFE.exe	4/24/2004	03:12 PM	65,536
MSCOMM32.OCX	4/24/2004	03:12 PM	103,744
MSVBVM60.DLL	4/24/2004	03:12 PM	1,388,544
OLEAUT32.DLL	4/24/2004	03:12 PM	598,288

OLEPRO32.DLL	4/24/2004	03:12 PM	164,112
Project1.DDF	4/24/2004	03:12 PM	524
SETUP.EXE	4/24/2004	03:12 PM	139,776
Setup.Lst	4/24/2004	03:12 PM	3,805
SETUP1.EXE	4/24/2004	03:12 PM	249,856
ST6UNST.EXE	4/24/2004	03:12 PM	73,216
STDOLE2.TLB	4/24/2004	03:12 PM	17,920
VB6STKIT.DLL	4/24/2004	03:12 PM	101,888
Visual Basic Programs\Background RFE\Low Band BRFE\			
Low Band BRFE.CAB	4/24/2004	03:11 PM	1,507,720
setup.exe	4/24/2004	03:11 PM	139,776
SETUP.LST	4/24/2004	03:11 PM	3,796
Visual Basic Programs\Background RFE\Low Band BRFE\Support\			
ASYCFILT.DLL	4/24/2004	03:11 PM	147,728
COMCAT.DLL	4/24/2004	03:11 PM	22,288
gpib-32.dll	4/24/2004	03:11 PM	229,376
Low Band BRFE.BAT	4/24/2004	03:11 PM	191
Low Band BRFE.exe	4/24/2004	03:11 PM	65,536
MSCOMM32.OCX	4/24/2004	03:11 PM	103,744
MSVBVM60.DLL	4/24/2004	03:11 PM	1,388,544
OLEAUT32.DLL	4/24/2004	03:11 PM	598,288
OLEPRO32.DLL	4/24/2004	03:11 PM	164,112
Project1.DDF	4/24/2004	03:11 PM	522
SETUP.EXE	4/24/2004	03:11 PM	139,776
Setup.Lst	4/24/2004	03:11 PM	3,796
SETUP1.EXE	4/24/2004	03:11 PM	249,856
ST6UNST.EXE	4/24/2004	03:11 PM	73,216
STDOLE2.TLB	4/24/2004	03:11 PM	17,920
VB6STKIT.DLL	4/24/2004	03:11 PM	101,888
Visual Basic Programs\Background RFE\Mid Band BRFE\			
Mid Band BRFE.CAB	4/24/2004	03:12 PM	1,507,903
setup.exe	4/24/2004	03:12 PM	139,776
SETUP.LST	4/24/2004	03:12 PM	3,796
Visual Basic Programs\Background RFE\Mid Band BRFE\Support\			
ASYCFILT.DLL	4/24/2004	03:11 PM	147,728
COMCAT.DLL	4/24/2004	03:11 PM	22,288
gpib-32.dll	4/24/2004	03:11 PM	229,376
Mid Band BRFE.BAT	4/24/2004	03:12 PM	191
Mid Band BRFE.exe	4/24/2004	03:11 PM	65,536
MSCOMM32.OCX	4/24/2004	03:11 PM	103,744
MSVBVM60.DLL	4/24/2004	03:11 PM	1,388,544
OLEAUT32.DLL	4/24/2004	03:11 PM	598,288
OLEPRO32.DLL	4/24/2004	03:11 PM	164,112
Project1.DDF	4/24/2004	03:11 PM	522
SETUP.EXE	4/24/2004	03:12 PM	139,776
Setup.Lst	4/24/2004	03:11 PM	3,796

SETUP1.EXE	4/24/2004	03:11 PM	249,856
ST6UNST.EXE	4/24/2004	03:11 PM	73,216
STDOLE2.TLB	4/24/2004	03:11 PM	17,920
VB6STKIT.DLL	4/24/2004	03:11 PM	101,888

Visual Basic Programs\Background RFE\Upper Band BRFE\

setup.exe	4/24/2004	03:12 PM	139,776
SETUP.LST	4/24/2004	03:12 PM	3,812
Upper Band BRFE.CAB	4/24/2004	03:12 PM	1,512,885

Visual Basic Programs\Background RFE\Upper Band BRFE\Support\

ASYCFILT.DLL	4/24/2004	03:12 PM	147,728
COMCAT.DLL	4/24/2004	03:12 PM	22,288
gpib-32.dll	4/24/2004	03:12 PM	229,376
MSCOMM32.OCX	4/24/2004	03:13 PM	103,744
MSVBVM60.DLL	4/24/2004	03:13 PM	1,385,744
OLEAUT32.DLL	4/24/2004	03:13 PM	598,288
OLEPRO32.DLL	4/24/2004	03:13 PM	164,112
Project1.DDF	4/24/2004	03:13 PM	526
SETUP.EXE	4/24/2004	03:13 PM	139,776
Setup.Lst	4/24/2004	03:13 PM	3,812
SETUP1.EXE	4/24/2004	03:13 PM	249,856
ST6UNST.EXE	4/24/2004	03:13 PM	73,216
STDOLE2.TLB	4/24/2004	03:13 PM	17,920
Upper Band BRFE.BAT	4/24/2004	03:13 PM	191
Upper Band BRFE.exe	4/24/2004	03:13 PM	69,632
VB6STKIT.DLL	4/24/2004	03:13 PM	101,888

Visual Basic Programs\PavePaws\

frmPPData.frm	4/24/2004	03:14 PM	10,328
frmPPData.frx	4/24/2004	03:14 PM	4
PP Data File Summary.frm	4/24/2004	03:14 PM	4,490
PP Data File Summary.vbp	4/24/2004	03:14 PM	643
PP Data File Summary.vbw	4/24/2004	03:14 PM	56
Process PP Data.vbp	4/24/2004	03:14 PM	626
Process PP Data.vbw	4/24/2004	03:14 PM	53

Visual Basic Programs\Standard Code\

Wait Routine.bas	4/24/2004	03:13 PM	967

E5 Documents

E5.1 Final Test Plan

This is a copy of the final test plan document (8 January 2004) in Adobe PDF format.

Documents\Final Test Plan\Final Test Plan.pdf 1/09/2004 04:34:40 PM 4.30Mbyte

This is the slide presentation of the Draft Final Test Plan.

Documents\Final Test Plan\Pave Paws Final Test Plan.ppt

E5.2 Final Test Report

This is a copy of the Final Test Report document (08 June 2004) in Adobe PDF format.

Documents\Final Test Report\ Final Test Report.pdf

This is the written response to the comments received during the comment period for the Draft Final Report.

Documents\Final Test Report\ Response to Comments June 3.pdf

This is the slide presentation of the Draft Final Report.

Documents\Final Test Report\ Pave Paws DFR.ppt.

E6 Exposure Model

E6.1 Antenna Pattern Data

This MS-Excel workbook parses the long-range surveillance patterns for deriving the weighting of the beam pointing angles.

Exposure Model\ Antenna Pattern\ LRS_Patterns 040402.xls

This MS-Excel workbook computes the weighted average antenna pattern for one face and derives a two-face model.

Exposure Model\ Antenna Pattern\ Avg pattern calcs linear dual.xls

This file contains the dual face average antenna pattern derived from the MS-Excel workbook Avg pattern calcs linear dual.xls and formatted for use with ComStudy.

Exposure Model\ Antenna Pattern\ PAVE PAWS Avg Pattern Comstudy.pt2

E6.2 Exposure Estimation

This file contains the ComStudy prediction of the PAVE PAWS radar's average emissions in the environment. The .rmx suffix is the ComStudy file suffix. However, the file is simply a text file formatted to ComStudy's specificiations.

Exposure Model\ Exposure Estimation\PAVE PAWS Average Exposure Matrix.rmx

This bitmap file presents the PAVE PAWS Average Public Exposure for the entire Cape Cod area.

Exposure Model\ Exposure Estimation\Average Exposure full area.bmp

This bitmap file presents the PAVE PAWS Average Public Exposure for the portion of the Cape Cod region nearest to the radar site.

Exposure Model\ Exposure Estimation\ Average Exposure zoom.bmp

Rev 1.0
6/8/04

Appendix F
Broadband RFE Survey

F1 Broadband Survey

A component of the field survey protocol established by Broadcast Signal Lab involved the measurement of the total RFE energy at each site. Broadcast Signal Lab performs such measurements as a matter of course in its field work.

The instrument employed is a NARDA 8718 metering unit and a model 8722 probe. The system is capable of sensing radio frequencies from 300 kHz to 50 GHz, covering nearly the entire radio spectrum, at least that which sees the most active and ubiquitous use. Because it is a broadband instrument, it has limited sensitivity and will not respond to low exposure levels. With respect to the public exposure limits, the instrument is sensitive to a combined RFE level from all intercepted sources when they are in total greater than one and one half percent of the limit.

At nearly all of the 60 field measurement sites the instrument was turned on, zeroed, and employed to sample the ambient RFE. At no site was there a reading above the sensitivity of the instrument. While this does not give any specific numerical data on the total combined RFE at a site, it does confirm that all sites measured were compliant by a substantial margin with state and federal human exposure criteria simultaneously for all emissions.

Appendix G
Computing the Effective Radius of the Earth from Surface Meteorological Data

The *radio refractive index* of air, n, is a function of atmospheric pressure, temperature, and humidity[1]. Near the surface of the earth and for VHF/UHF frequencies, n is approximately 1.0003. Since for air n never exceeds unity by more than a few parts in 10,000, it is convenient to consider climatic variations of n in terms of the *radio refractivity* N defined as

$$N = (n - 1) \times 10^6$$

The radio refractivity, N, is computed from the following equation:

$$N = 77.6\, P/T + 3.73 \times 10^5\, e/T^2$$

where

P = Atmospheric pressure in millibars (or equivalently in hPa, hectopascals)

e = Partial pressure of H_2O in millibars

T = Absolute temperature (Kelvin)

$= T(^\circ C) + 273.15$

The *partial pressure* $e(T)$ of H_2O at temperature T is equal to the *saturation vapor pressure* $e_s(T_d)$, where T_d is the dew point. The procedure is to 1) determine the dew point, 2) look up in a table[2] the saturation vapor pressure of water for that temperature, and 3) insert the value into the formula above.

Alternatively, the following approximation[3] can be used to compute the saturation vapor pressure of water:

$$e_s(T(^\circ C)) = 6.11 \times 10^{[\,7.5\, T(^\circ C) / (T(^\circ C) + 237.3)]}$$

where $e_s(T)$ is in millibars.

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[1] Refs. 43 (Chap. 12) and 52 (Chap. 1)
[2] Ref. 54
[3] Ref. 55

For example, consider a dry, fair weather day in February (typical of the weather encountered by the BSL field measurement team) when

T = 35 deg F = 274.8 K

T_d = 10 deg F = 260.9 K, and

P = 30.0 in-Hg = 1016 mbar.

Then

$$
\begin{aligned}
N &= 77.6\ P/T + 3.73 \times 10^5\ e/T^2 \\
&= 77.6 \times 1016 / 274.8 + 3.73 \times 10^5 \times 2.40 / (274.8)^2 \\
&= 286.9 + 11.9 \\
&= 298.8
\end{aligned}
$$

The effective earth's radius is then computed from

$$
\begin{aligned}
K &= [1 - 0.04665 \exp (0.005577\ N)]^{-1} \\
&= 1.328 \\
&\approx 1.333 \text{ (the customary nominal value)}
\end{aligned}
$$

Appendix H
Average Antenna Pattern Derivation

H1 Overview

An antenna radiation pattern model of the phased array radar was supplied to Broadcast Signal Lab by MITRE Corporation. Broadcast Signal Lab evaluated the structure of the model and presents an analysis in Appendix C3. The model was employed to convert the instantaneous antenna pattern for each beam into an average antenna radiation pattern for insertion into the propagation model.

H2 Rationale

The antenna radiation pattern produces a gain figure for any azimuth/elevation combination at any of the specified beam pointing angles. The primary source of energy in the environment from the radar is the Long Range Surveillance "fence" (LRS). This search function operates at approximately 3 degrees above the horizontal, spanning the 120-degree azimuth sweep of each of the two radar arrays. The LRS fence is the primary source of environmental emissions for several reasons:

1. The search requires the longest pulse durations (compared to the short range surveillance pulses) to obtain greater signal-to-noise echoes from very distant objects. LRS pulses are 5 to 8 millliseconds in duration, totaling 4.16 seconds per 41.04-second sweep. (Table 1) Short range surveillance (SRS) pulses are 0.9 milliseconds in duration, totaling 0.6 seconds per 41.04-second sweep. The addition of SRS power to the LRS power increases the total power emitted by 0.6 dB.
2. The LRS search is conducted at the lowest elevations employed by the radar beams, thereby contributing the energy of the sidelobes closest to the beams into the environment. The closer (i.e. lower order) sidelobes are more powerful than the higher order sidelobes. Tracking pulses, by contrast, are on the average emitted at significantly higher elevations, impressing their higher order sidelobes into the environment.
3. The consistent, repetitive nature of the LRS search assures a monotony of emissions into the environment over time. Tracking pulses, by contrast, are intermittent, infrequent and irregular in their utilization.

The LRS fence is swept at a 41.04-second interval (the rate can be doubled in times of need). Other resources, such as short-range surveillance and tracking, are interleaved during the 41-second cycle.

Table 1 summarizes the pulse duration computations for LRS and SRS. The SRS sweep has a negligible impact on the total average emission of the radar. The SRS emissions are not included in subsequent computations.

Table 1 Comparison of Long and Short Range Surveillance Power

	LRS	SRS
Pulse duration	5 ms 8 ms	0.9 ms
Beam Clusters	154 116 = 270	240
Beams per cluster	3 2	3
Individual beams	462 232	720
Beams x duration	2310 1856 = 4166	648
Power ratio SRS/LRS		-8.1 dB
Addition of SRS increases total power by only 0.6 dB	(4166 + 648)/ 4166 = 0.64 dB	

H3 Computation

To compute an average antenna pattern, the LRS emissions in the 120 beam positions per array were evaluated. There are 60 undithered beam positions in the LRS fence, and 60 dithered positions. These two sets of positions are alternated during the LRS search activity. While the positions of the dithered and undithered beams are only approximately ½ degree apart at the most, both sets of beams were combined in the pattern calculations.

To compute the average antenna pattern a five-dimensional matrix must be evaluated. The dimensions are: 1) the elevation of each point of interest, 2) the azimuth of each point of interest, 3) the gain on the radial to each point of interest, 4) computed for the antenna pattern of each of the 120 beam pointing angles, 5) weighted by the amount of time the radar emits energy at each beam pointing angle. The latter dimension (5) is computed from two facts, the number of times a beam is used during one sweep and the duration of the pulses emitted each time that beam is used.

H3.1 Exposure Window

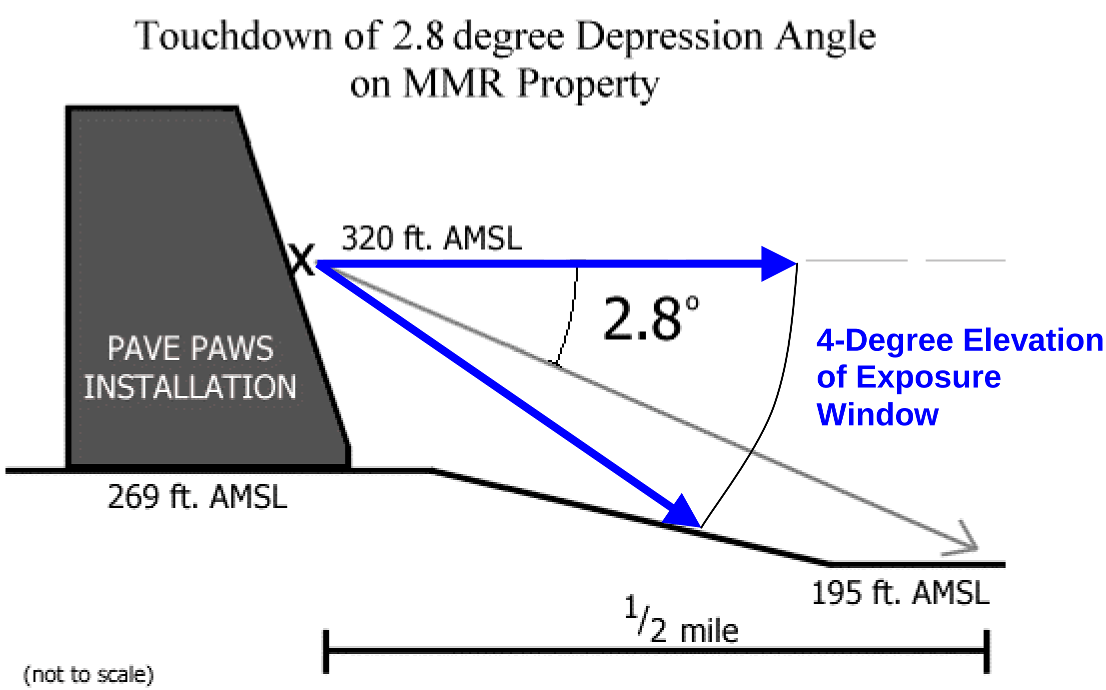
Dimensions 1) and 2), the azimuths and elevations of interest, were established with the creation of an Exposure Window.

The Exposure Window was created to focus the computations on only that region of the radar antenna pattern that would direct energy into the environment. This minimized the computational burden. The Exposure Window is the region with respect to the radar through which radar emissions would propagate toward occupied space. A range of elevations from horizontal (0 degrees) to 4 degrees below horizontal (-4 degrees) was selected. Most emissions to Cape Cod occur within the 0 to –1-degree portion of the window, but the 4-degree figure was selected to ensure no emissions toward closer locations would be overlooked. A 2.8-degree figure was estimated in the Final Test Plan based on the fact that the lay of the terrain and the distance to the perimeter of the military reservation limit the depth of the depression angle to which the public would be exposed. This antenna pattern is not optimized for evaluating emissions on the

Massachusetts Military Reservation near the radar facility, and particularly not for near-field estimations.

The width of the Exposure Window is the full 180 degrees of each array face on the radar. Combined, the azimuth and elevation of the Exposure Window form a spherical section, like that of the peel of an orange slice, onto which the radar emissions are averaged and mapped.

Figure 1 Exposure Window Elevation



Graphic from Final Test Plan, adapted for four-degree window

The Exposure Window was divided into discrete sampling points every ¼-degree, from 0 through –4 degrees (inclusive) and –90 through +90 degrees (inclusive) azimuth. The gain values of the array were computed for each of these points. 120 computations of the gain values were conducted to represent the emissions of each beam pointing angle in the LRS fence.

H3.2 Beam Pointing Angles

The MITRE model was employed to obtain the gain figures of the pattern for each beam pointing angle. The beam pointing angles are defined and consist of two groups—dithered and undithered angles. The following table lists the angles employed.

Table 2 Beam Pointing Angles

Commanded Beam Positions	Beam No.	U Sine Space Coordinate	V Sine Space Coordinate	Az Deg	El deg
		Undithered Beams			
	1	-0.86484	0.12158	-60.000	3.001
*	2	-0.83383	0.12158	-56.707	4.009
	3	-0.81625	0.14761	-54.822	2.999
*	4	-0.78519	0.14761	-51.902	3.841
	5	-0.76407	0.17078	-49.917	2.998
*	6	-0.73294	0.17078	-47.263	3.712
	7	-0.70933	0.19128	-45.260	2.997
*	8	-0.67810	0.19128	-42.801	3.610
	9	-0.64686	0.19128	-40.434	4.171
	10	-0.62821	0.21637	-38.981	2.997
*	11	-0.59698	0.21637	-36.733	3.491
	12	-0.56574	0.21637	-34.547	3.946
	13	-0.54278	0.23755	-32.924	2.998
*	14	-0.51154	0.23755	-30.826	3.394
	15	-0.48031	0.23755	-28.773	3.758
	16	-0.45439	0.25497	-27.066	3.000
*	17	-0.42316	0.25497	-25.079	3.312
	18	-0.39192	0.25497	-23.122	3.597
	19	-0.36396	0.26889	-21.374	2.999
*	20	-0.33273	0.26889	-19.467	3.237
	21	-0.30149	0.26889	-17.580	3.451
	22	-0.27211	0.27945	-15.812	3.000
*	23	-0.24088	0.27945	-13.960	3.170
	24	-0.20964	0.27945	-12.122	3.318
	25	-0.17930	0.28683	-10.343	3.000
*	26	-0.14807	0.28683	-8.528	3.106
	27	-0.11683	0.28683	-6.720	3.192
	28	-0.08589	0.29111	-4.934	3.000
*	29	-0.05466	0.29111	-3.138	3.045
	30	-0.02343	0.29111	-1.344	3.070
	31	0.02343	0.29111	1.344	3.070
*	32	0.05466	0.29111	3.138	3.045
	33	0.08589	0.29111	4.934	3.000
	34	0.11683	0.28683	6.720	3.192
*	35	0.14807	0.28683	8.528	3.106
	36	0.17930	0.28683	10.343	3.000

Commanded Beam Positions	Beam No.	U Sine Space Coordinate	V Sine Space Coordinate	Az Deg	El deg
	37	0.20964	0.27945	12.122	3.318
*	38	0.24088	0.27945	13.960	3.170
	39	0.27211	0.27945	15.812	3.000
	40	0.30149	0.26889	17.580	3.451
*	41	0.33273	0.26889	19.467	3.237
	42	0.36396	0.26889	21.374	2.999
	43	0.39192	0.25497	23.122	3.597
*	44	0.42316	0.25497	25.079	3.312
	45	0.45439	0.25497	27.066	3.000
	46	0.48031	0.23755	28.773	3.758
*	47	0.51154	0.23755	30.826	3.394
	48	0.54278	0.23755	32.924	2.998
	49	0.56574	0.21637	34.547	3.946
*	50	0.59698	0.21637	36.733	3.491
	51	0.62821	0.21637	38.981	2.997
	52	0.64686	0.19128	40.434	4.171
*	53	0.67810	0.19128	42.801	3.610
	54	0.70933	0.19128	45.260	2.997
	55	0.73294	0.17072	47.274	3.713
*	56	0.76407	0.17072	49.918	3.00l
	57	0.78519	0.14755	51.907	3.843
*	58	0.81625	0.14755	54.823	3.003
	59	0.83383	0.12158	56.707	4.009
*	60	0.86484	0.12158	60.000	3.001
		Dithered Beams			
	61	-0.84921	0.12158	-58.301	3.526
	62	-0.81821	0.12158	-55.156	4.470
*	63	-0.80063	0.14761	-53.328	3.434
	64	-0.76956	0.14761	-50.503	4.231
*	65	-0.74844	0.17078	-48.567	3.365
	66	-0.71732	0.17078	-45.981	4.046
*	67	-0.69371	0.19128	-44.017	3.311
	68	-0.66248	0.19128	-41.607	3.897
*	69	-0.63125	0.19128	-39.283	4.435
	70	-0.61259	0.21637	-37.849	3.250
	71	-0.58136	0.21637	-35.633	3.724
*	72	-0.55013	0.21637	-33.476	4.160
	73	-0.52715	0.23755	-31.869	3.200
	74	-0.49591	0.23755	-29.794	3.580

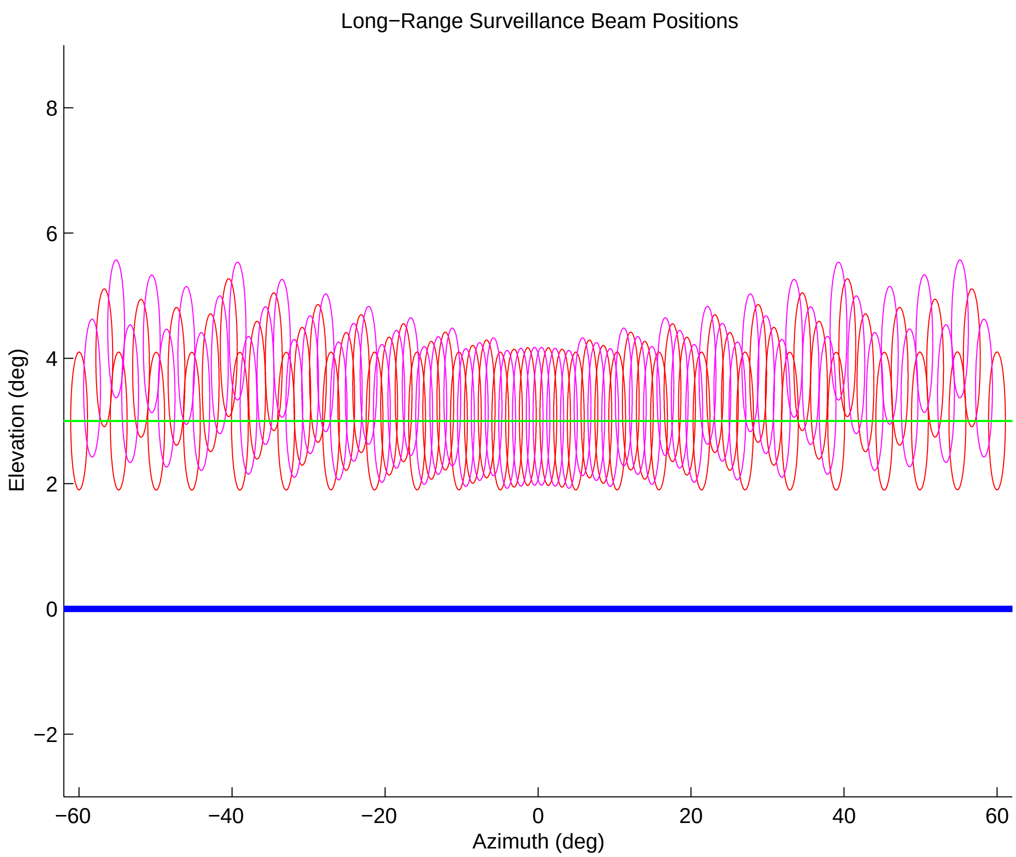
Commanded Beam Positions	Beam No.	U Sine Space Coordinate	V Sine Space Coordinate	Az Deg	El deg
*	75	-0.46468	0.23755	-27.760	3.929
	76	-0.43876	0.25497	-26.067	3.160
	77	-0.40753	0.25497	-24.096	3.458
*	78	-0.37630	0.25497	-22.154	3.730
	79	-0.34834	0.26889	-20.418	3.121
	80	-0.31711	0.26889	-18.521	3.347
*	81	-0.28587	0.26889	-16.644	3.549
	82	-0.25648	0.27945	-14.883	3.088
	83	-0.22525	0.27945	-13.039	3.247
*	84	-0.19402	0.27945	-11.207	3.384
	85	-0.16368	0.28683	-9.434	3.055
	86	-0.13245	0.28683	-7.623	3.151
*	87	-0.10122	0.28683	-5.819	3.227
	88	-0.07027	0.29111	-4.035	3.025
	89	-0.03903	0.29111	-2.240	3.060
*	90	-0.00780	0.29111	-0.448	3.075
	91	0.00780	0.29111	0.448	3.075
	92	0.03903	0.29111	2.240	3.060
*	93	0.07027	0.29111	4.035	3.025
	94	0.10122	0.28683	5.819	3.227
	95	0.13245	0.28683	7.623	3.151
*	96	0.16368	0.28683	9.434	3.055
	97	0.19402	0.27945	11.207	3.384
	98	0.22525	0.27945	13.039	3.247
*	99	0.25648	0.27945	14.883	3.088
	100	0.28587	0.26889	16.644	3.549
	101	0.31711	0.26889	18.521	3.347
*	102	0.34834	0.25889	20.418	3.121
	103	0.37630	0.25497	22.154	3.730
	104	0.40753	0.25497	24.096	3.458
*	105	0.43876	0.25497	26.067	3.160
	106	0.46468	0.23755	27.760	3.929
	107	0.49591	0.23755	29.794	3.580
*	108	0.52715	0.23755	31.869	3.200
	109	0.55013	0.21637	33.476	4.160
	110	0.58136	0.21637	35.633	3.724
*	111	0.61259	0.21637	37.849	3.250
	112	0.63125	0.19128	39.283	4.435
	113	0.66248	0.19128	41.607	3.897

Commanded Beam Positions	Beam No.	U Sine Space Coordinate	V Sine Space Coordinate	Az Deg	El deg
*	114	0.69371	0.19128	44.017	3.311
	115	0.71732	0.17072	45.982	4.049
	116	0.74844	0.17072	48.568	3.369
*	117	0.76956	0.14755	50.504	4.235
	118	0.80063	0.14755	53.329	3.438
*	119	0.81821	0.12158	55.156	4.470
	120	0.84921	0.12158	58.301	3.526

Figure 2

H3.3 Time-Weighting

A weighting scheme was developed to address the amount of time each beam pointing angle is emitting energy. There are two factors in this process, pulse duration, and beam angle repetition.



H3.3.1 Pulse Duration

The radar compensates for reduced efficiency at the extreme ends of its sweep. It does so by emitting longer pulses (8 ms) than in the rest of the radar sweep (5 ms). Pulses are transmitted in doublets (pairs) at the extreme ends of the sweeps and in triplets in the rest of the sweep. (The doublets are emitted in the last 6 degrees at each end of the sweep) This yields either 15 milliseconds of triplets or 16 milliseconds of doublets during one resource interval, depending on the orientation of the beam. It would have simplified the computation to assume all LRS resources were, say, 15.5 ms in duration, however, the individual pulses in a doublet or triplet are emitted in slightly different beam pointing angles. This requires the computation of each pulse for each beam pointing angle to be most accurate.

H3.3.2 Beam Reuse

In addition to the variation in pulse duration, the radar emphasizes the extreme edges of the radar face by returning to the edges of the faces to emit beams more often than at the center. This emphasis occurs at approximately the last 15 degrees of each end of the sweep.

A table of the Long Range Surveillance Scan Sequence was provided by MITRE. It was employed to weight each beam pointing angle (designated by Beam Number) for its duration of use.

Table 3 Long Range Surveillance Scan Sequence

Doublets			Triplets																Doublets					
2	4	6	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	53	56	58	60(3)	Beams/Scan(1)	Clusters(2)	Time (sec)
1/0																					1/0			
1	1	1	1	1	1	1	1							1	1	1	1	1	1	1	1	42	16	2.4320
2	2								1			1								2	2	14	6	0.9120
1		2	2					1					1					2	2		1	20	8	1.2160
2	1			2	2	2				1	1				2	2	2			1	2	32	12	1.8240
1	2		3				2							2				3		2	1	20	8	1.2160
2		1		3					2			2					3		1		2	20	8	1.2160
1			1		3	3		2					2		3	3		1			1	28	10	1.5200
2	1	2								2	2								2	1	2	18	8	1.2160
1	2		2	1			3							3			1	2		2	1	26	10	1.5200
2			3		1				3			3				1		3			2	18 correction: 22 (BSL)	8	1.2160
1	1	1		2		1		3					3		1		2		1	1	1	30	12	1.8240
2	2		1				1			3	3			1				1		2	2	26	10	1.5200
1		2			2											2			2		1	14	6	0.9120
2	1		2	3		2		1	1			1	1		2		3	2		1	2	38	14	2.1280
1	2																			2	1	8	4	0.6080
2		1	3	1	3		2			1	1			2		3	1	3	1		2	38	14	2.1280
1			1			3									3			1			1	16	6	0.9120
2	1	2			2			2	2			2	2			2			2	1	2	30	12	1.8240
1	2		2	2													2	2		2	1	20	8	1.2160
2							3			2	2			3							2	16	6	0.9120
1	1	1	3	3	1	1									1	1	3	3	1	1	1	36	14	2.1230
2	2							3	3			3	3							2	2	20	8	1.2160
1		2	1	1			1							1			1	1	2		1	26	10	1.5200
2					2	2				3	3				2	2					2	22	8	1.2160
1	1		2					1					1					2		1	1	20	8	1.2160
2	2	1	3	2					1			1					2	3	1	2	2	30	12	1.3240
1					3	3	2							2	3	3					1	22	8	1.2160
2	1	-2	1	3						1	1						3	1	2	1	2	30	12	1.8240
1								2					2								1	10	4	0.6080
29	17	12	16	12	10	9	8	8	7	7	7	7	8	8	9	10	12	16	12	17	29	690	270	41.0400

Provided by MITRE

An Excel spreadsheet called LRS Patterns.XLS contains the weighting computations.

H3.3.3 Weighting Process

The weighting process follows this sequence:

Select a Beam Number, B.

Select a position within the Exposure Window, (Observer, V)

Compute the antenna pattern for B and obtain the antenna gain, G, in the direction of V.

Determine whether B is in a doublet or triplet region. Assign the pulse duration, PD, value 8 or 5 ms to this combination of B and V.

Examine the LRS Scan Sequence and determine how many times this B is employed during the full sweep (Hits, H).

Multiply the G by the PD time by the number of hits per sweep, H to obtain the weighted gain for this particular B and V combination.

$$G \times PD \times H = WG_{B,V}$$

Reiterate this computation for all values of B with respect to the same Observer, V.

For B= 1-120, sum all values of $WG_{B,V}$.

This result is the observer weighted sum, WS_V.

Compute the weighted sum, WS_V, for each position V within the Exposure Window.

Each weighted sum must now be normalized to the total duration of pulses from the LRS sweep. From the Long Range Surveillance Scan Sequence table, count the total number of 8 ms pulses and 5 ms pulses and multiply each number by the 8 or 5 ms duration. Add these two subtotals to obtain a total LRS emission duration, TD. Divide the weighted sum for each observer position, WS_V by TD to obtain a weighted average,

$$WS_V / TD = WA_V$$

The weighted average, for each observer azimuth/elevation point in the exposure window is the ratio of the observer emission to the power of the main beam.

H3.3.4 Duty Cycle Compensation

One step remains to normalize the antenna pattern for average exposure purposes—the radar duty cycle. Because the radar is not continuous duty, the average antenna pattern WA_V overstates the average power of the emissions because it is based on the gain of the antenna and the ratio of the pulse times at each beam position to the total pulse time. The average duty cycle of the LRS fence is 4166 ms of pulse energy per 41.04-second sweep.

$$\frac{4166}{41{,}040} = 0.1015 \text{ duty factor, i.e. } -9.93 \text{ dB}$$

An additional 9.93 dB is deducted from the antenna pattern to adjust for the duty factor.

H4 Data

The MITRE antenna model formula is described in Appendix C3. This algorithm was entered into Mathcad. A four-dimensional array was produced in Mathcad containing azimuth and elevation of each point in the Exposure Window as two of the dimensions. The third dimension is the set of 120 beam pointing angles weighted for share of time used, and the fourth dimension is the result—the computed antenna gain levels in the Exposure Window of the radar.

To facilitate processing, output from Mathcad was taken in the form of 17 arrays (mathematical arrays, not antenna arrays), one for each elevation angle in the exposure window (0 to –4 degrees in ¼-degree increments). Each of these Iso-Elevation Arrays (IEA) contains 120 columns of data by 721 rows. Each row represents one ¼-degree sample of azimuth, for a total of 181 degrees in the 721 rows. Each column contains the data for one beam pointing angle, totaling 120 columns.

The IEA's were imported to a spreadsheet (Avg pattern calcs linear.xls), where they occupy worksheets numbered 0-16 representing each of the 17 elevation angles of interest. The data in each worksheet were combined to produce an average antenna pattern for the elevation represented by each worksheet. This was accomplished by adding the data horizontally in each of the 120 rows. Thus, each of the 17 worksheets contains a single 721-data-point column containing weighted antenna gain values for the full azimuth of the radar at the elevation angle represented by the worksheet. This column was copied from each worksheet into a single worksheet on the same spreadsheet document; that worksheet is called "sums".

"Sums" contains, therefore, an array of average antenna gain values for each elevation and each azimuth within the Exposure Window. This is the antenna pattern employed in the propagation model of PAVE PAWS emissions.

An additional step was performed in the last worksheet of the spreadsheet document, "Sums formatted". This worksheet is employed to format the output data for transfer to the propagation modeling software. Where the data in "sums" are arranged in a matrix, they are installed in a single column in "Sums formatted" to produce a vector text file for importation into Comstudy.

In "Sums formatted" An adjustment of 37.9 dB is added to change the reference of the antenna pattern from the gain of the main beam to isotropic gain. A further adjustment of 3.9 dB is added to force Comstudy to produce a result in dBμW/cm^2 rather than dBm. (this calculation is derived in Appendix C2). Finally, 2.15 dB are subtracted to normalize the antenna pattern to Effective Radiated Power (ERP) rather than Effective Isotropic Radiated Power (EIRP) because Comstudy expects the antenna pattern to be the former.

Power gain is then converted to field gain by taking the square root of the power gain value. Then multiplication and rounding is performed to remove decimal places and to conform to the propagation software antenna model format. Azimuth, elevation and text columns were inserted into the worksheet to complete the formatting. The resulting columns were exported to a text editor for final finishing and conversion to the desired antenna pattern data file for Comstudy.

H5 Summary Data on Antenna Pattern

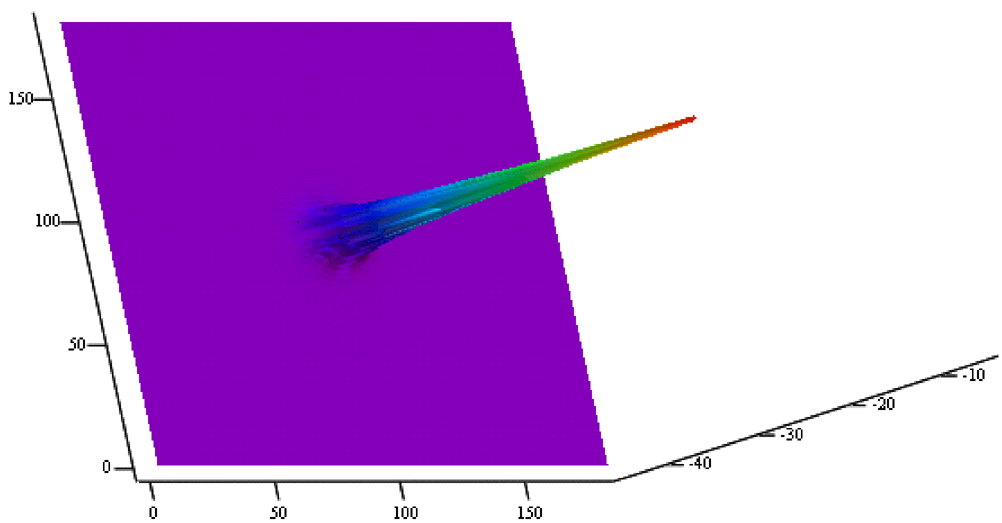
To demonstrate the execution of the MITRE antenna model as written to Mathcad appears on its face to be correct, sample outputs in the form of flat graphics of the pattern were produced. Below is a pattern plot of the full 180-degree azimuth by 180-degree elevation pattern of the MITRE model with the main beam at 3 degrees elevation and centered in azimuth on the array face. (The plot is a flat projection of radial coordinates, so it lacks the curvature of the actual pattern)

The MITRE pattern depicts the sidelobe energy as a nearly flat noise-like region outside the first sidelobe and closer secondary sidelobes.

For a better view of the fine structure of the beam lobes, Figure 4 is an expanded display showing a narrower range of azimuth and elevation values.

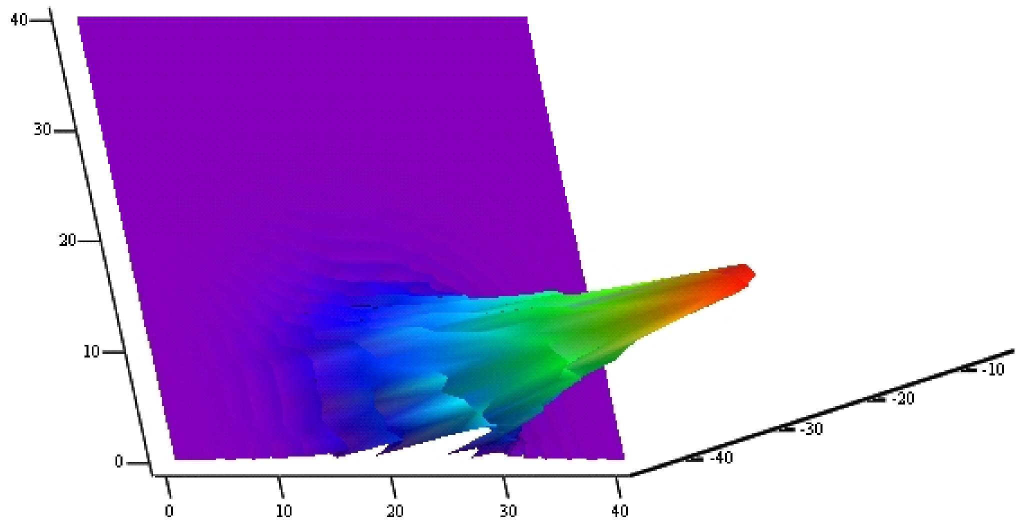
Figure 3 Full Face Pattern

3-degree beam elevation off face center



X and Y axes in degrees. Z axis in dB relative to main beam power.
(Image tilt is artificial to simulate radar face orientation)
90 elevation corresponds to zero true elevation

Figure 4 Close-up of Beam



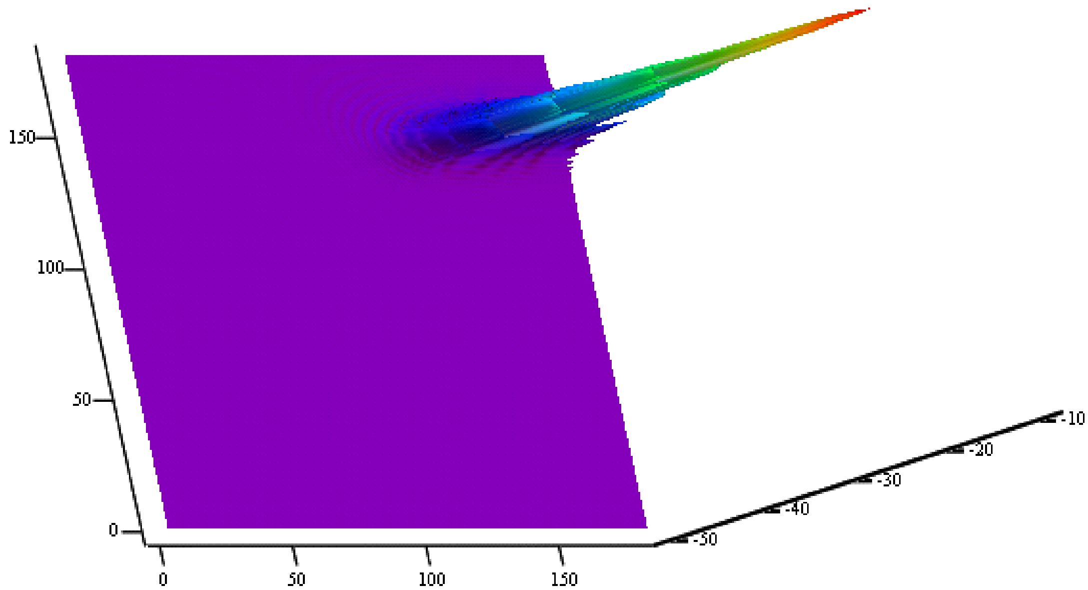
3-3-3-

3-degree beam elevation, azimuth off face center
Span is 40 degrees. 0 elevation corresponds to zero true elevation.

Testing our implementation of the MITRE model, other beam pointing angles were plotted. Below, Figure 4 plots an extreme beam pointing angle, 60 degrees in both azimuth and elevation from the face normal and from horizontal, respectively. The azimuth and elevation of the adjusted beam correspond with the input criteria. Also, notice how the base of the beam becomes ellipsoidal (that is, it "flattens out") when it is steered significantly off the radar bore. These characteristics confirm that the fundamentals of both the MITRE model and Broadcast Signal Lab's implementation are not obviously flawed.

Figure 5 Full Face Pattern

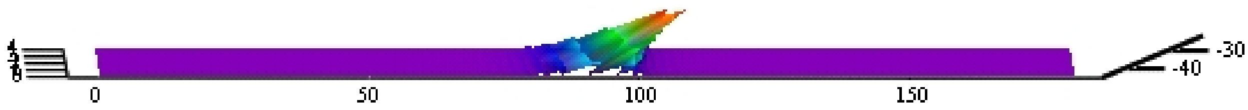
Beam at 60 degrees azimuth and elevation



90 on the Y axis represents horizontal

Finally, for reassurance that our method of sampling the 4-degree high, 180-degree wide Exposure Window was executed correctly, plots of the window with sample beams were run. Figure 5 below shows the Exposure Window with a beam at 3 degrees above horizontal and centered laterally on the face. Note how the very edge of the low order sidelobes are visible in the center of the plot, but the full power of the main beam is above the region depicted. This is characteristic of all of the Exposure Window patterns generated for the 120 LRS beam pointing angles.

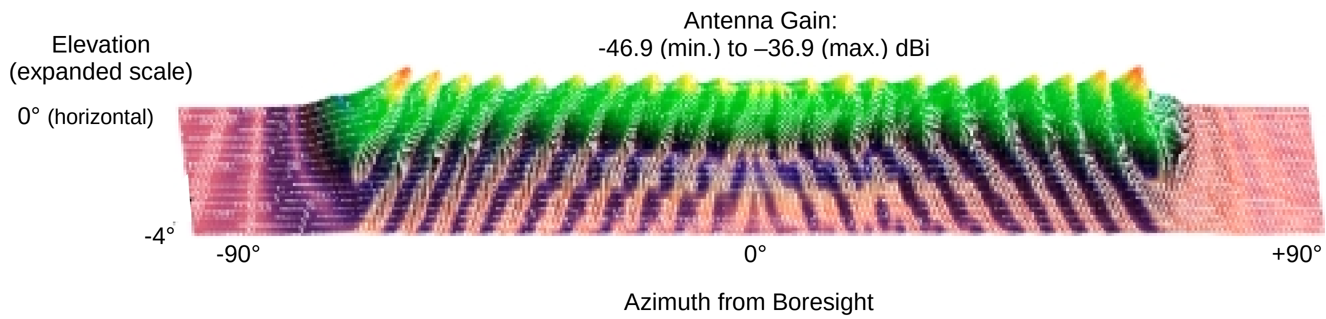
Figure 6 Exposure Window with Edge of Primary Sidelobes



Beam at azimuth center, 3 degree elevation
Window at 0 to –4 degrees elevation (true), -90 to +90 degrees azimuth (relative)

Finally, a plot of the average antenna pattern was produced.

Figure 7 PAVE PAWS Average Antenna Pattern in Exposure Window



H5.1 Summary Statistics

The characteristics of the average antenna pattern are as follows:

Table 4 Average Antenna Pattern Exposure Window Characteristics

	Full Window, from 0 to –4 degrees elevation	Partial Window, from 0 to –1 degrees elevation	Partial Window, from –1.25 to –4 degrees elevation
MAX dBi	-36.9	-36.9	-40.7
MIN dBi	-46.9	-46.9	-46.9
AVG dBi	-43.2	-40.7	-45.0

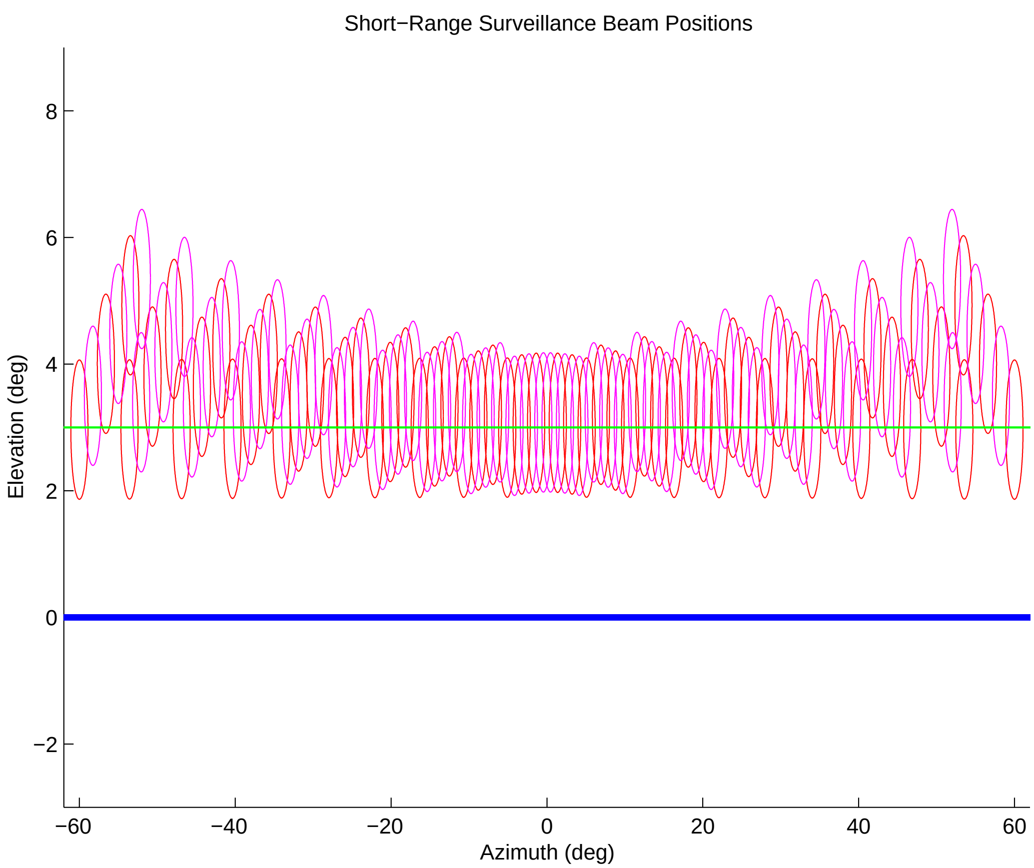
As can be inferred from the Table 4 and Figure 7, the roving of the beam and its elevation above the horizontal contribute to a fairly constant average emission level throughout the Exposure Window. There are about ten deciBels difference between the highest and lowest average levels.

H6 Short Range Surveillance

The short range surveillance sweep was discussed briefly in Section H2 above. Figure 8 is a visual representation of the beam pointing angles of the SRS sweep. Comparison with the LRS sweep pattern, Figure 2, shows more similarity than difference in the patterns. This supports the conclusions of H2 regarding the limited contribution of the SRS to the environmental emissions.

Figure 8 SRS Beam Positions

Supplied by MITRE



Broadcast Signal Lab

Appendix I
Drive Test Data Consolidation Procedure

I1 Introduction

The drive test obtained several thousand data points of field-measurements on approximately 250 miles of roads on and near Cape Cod. The signal under test is a continuous wave beacon installed on top of the PAVE PAWS structure. The drive test data points (DT) are referenced to GPS-measured coordinates. These data are to be compared to a computer estimation of the propagation simulating the same signal source. The propagation simulation (PS) data points are computed for a matrix calculated at three second intervals of latitude and longitude (cells approximately 200 to 300 feet on each side). Each computed data point is associated with the center of a three-second cell.

The objective of the drive test is to obtain a field characterization of the variance of the propagation simulation. A consolidation procedure is necessary to associate each DT measurement with a corresponding PS cell.

The analysis was carried out with FoxBASE, a derivative of Ashton-Tate dBase. A single module was written in Perl to accomplish a task that would be awkward in FoxBASE.

The overall procedure consisted of a series of modules that were run sequentially along with the Perl script and a few manual FoxBASE steps. The code was developed in this manner so that each module could be written and tested individually and so that the interim data files would not have to be recreated. Files created in this process are included in the data files supplied with this report.

If desired, the modules can be easily combined into a single overall FoxBASE procedure. FoxBASE provides work areas to hold the database files and their indices. In order, to facilitate the combination, a consistent assignment of files was implemented in all modules.

Work area	File
1 (a)	drv_trm
2 (b)	bm_db
3 (c)	temporarary database
4 (d)	drv_cons

The following sections describe the procedure in the order of execution.

I2 Trim Original Drive Test

The original Drive Test Data was provided in an Excel file, which contained raw as well as corrected data. Excel was used to remove the unwanted columns such as the date, time, N and W associated with the coordinates, and unused columns.

The fields remaining were:

Latitude
Longitude
Min
Max
Avg
Median
SD
Corrected Min
Corrected Max
Corrected Avg
Corrected Median

I3 Importation of Drive Test data into FoxBASE

The spreadsheet was saved as a tab-delimited text file. A text editor was used to change the tabs into commas. The resulting file was imported into a FoxBASE file called drv_trm.dbf. where the latitude and longitude are in fields called lat_minut and long_minut respectively.

I4 Conversion of Drive Test Latitude and Longitude to Decimal Degrees (convmin.prg)

The original coordinates were expressed as degrees and minutes. This step converted them into decimal degrees

Two new columns were added to drv_trm.dbf, called lat and long, to hold the converted values.

The module **convmin.prg** performs the conversion, changing lat_minut (in the form ddmm.mmmm) to lat (in the form dd.dddddd.) Likewise, it converts long_minut into long.

I5 Generating the Beacon Vector file (matrix2vector.pl)

The original Beacon PS data was in a Matrix File format with measurements reported in dBm. A vector format is more convenient for FoxBASE since it can handle millions of records but is limited in the number of fields per record. Therefore, a Perl script, called **matrix2vector.pl** was written to convert the Matrix data into Vector form. The program operated using the follow procedure:

1. Read line 1 containing the longitudes. Store them in an array
2. For each of the subsequent lines:

- read the first field which is the latitude
- read each subsequent field for the DB value
- for each DB value write a line consisting of the latitude, the corresponding longitude and the value, all comma delimited.

The resulting file, bm.txt, was checked at the beginning and end of the first data row, the beginning and end of the second, and the beginning and end of the last.

Bm.txt was imported into FoxBASE and called bm_db.dbf and spot-checked. It contained approximately 4 times the number of records as the original vector file. This value is consistent with a double density in both axes.

I6 Assign Test Drive records to Beacon Cells (find_cell)

The drv_trm.dbf, the drive test database, was expanded by adding two new columns, cell_lat and cell_long to store the coordinates of the beacon cell in which every record resides.

The module **find_cel.prg** was written to perform the Beacon PS cell assignment. For latitude, it performed the following steps:

1. Indexed the drv_trm.dbf by lat and then used that index. This sorted the records by increasing latitude

2. Indexed the bm_db (beacon data) by lat and then used that index. This effectively sorted records by increasing latitude

3. For each drv_trm record, starting with the lowest latitude, each bm_db record was examined. The records were skipped while:

   drv_trim.lat > bm_db.lat + 1.5/3600

   In other words, the bm_db records with latitudes less than the target were skipped. The next bm_db record had the lowest latitude that is greater than the drv_tm value. This was the corresponding cell.

   The factor of 1.5/3600 is an offset that places the cell boundary 1.5 seconds, half the cell width above the latitude of the cell center.

4. Each drv_trm cell_lat field was updated with the latitude of the bm_db record thus selected.

A similar procedure was carried out for the longitude.

I7 Consolidate Drive Test Data (consol.prg)

A module, **consol.prg,** was written which consolidated the drive test data into a new database called drv_cons.dbf. Each record in drv_cons represents all of the drv_trm data assigned to the same cell.

The program uses the following steps:

1. The drv_trm database was indexed by a composite index composed of cell_lat and cell_long.

2. To find all DT samples that belong to the same PS cells, each drv_trm record was processed, starting at the lowest coordinate combination. Its cell coordinates were stored. The significant data from all records whose cell latitude and longitude match these values were stored in a temporary database. The temporary database then contained all of the records belonging to one cell.

3. The number of temporary records was counted. A “center” index was generated by:
   center = int(count/2 +1)

4. The temporary database was indexed by the med (median) power value. This index was used to sort the temporary database. A presumptive min was set at -9999 and presumptive max at +9999

5. The temporary database was scanned. For each record:

   - If the min field was less than the presumptive min, the presumptive min was replaced
   - If the max field was greater than the presumptive max, the presumptive max was replaced
   - The sum of the avg fields was calculated
   - The sum of the squares of the SD fields was calculated
   - When the record count equaled the center, the median field was stored
   - When the record count equaled the center +1, the median field was again stored

6. A new record in the drv_cons.dbf was created with the following characteristics:

   - The lat and long field were the cell_lat and cell_long
   - The no_reading field was the number of temporary records
   - The min field was the presumptive min
   - The max filed was the presumptive max
   - The avg field was the sum of the avg field divided by the no_readings

- If the no_readings was odd, the med field was the center median field. If the no_readings was even, the med field was the average of the center reading and the center+1 reading
- The SD field was square-root of the sum of the squares

I8 Append Beacon Data to Consolidated Drive (ap_bm.prg)

This module appended the Beacon PS power (dB) value for each cell to the drv_cons.dbf record for the corresponding cell. It used the following procedure:

1. The bm_db was indexed with a combination reflecting its latitude and longitude coordinates.

2. For each record in drv_cons, a corresponding coordinate value was calculated

3. A "seek" was executed to locate the corresponding bm_db record with this index.

4. To double-check that the correct bm_db record was retrieved, its coordinates were compared to the drv_cons values. An error would be set, and processing stopped, should an error be detected.

5. The bm_db field of the drv_cons.dbf was updated with the db field of the beacon database.

   The variance field was updated with the med – bm_db

I9 Final output

The drv_cons.dbf was stored in comma delimited text form. This file was imported into Excel. Within Excel, column titles were added and the spreadsheet was sorted by latitude. This output file is named Drive Test Consolidated.xls.

Broadcast Signal Lab

Appendix J
50 PAVE PAWS Measurement Sites Identification

Each of the following pages contains details about one of the fifty PAVE PAWS measurement sites.

Path Profiles

Each site page has a path profile from the center of elevation of the radar antenna arrays to the height above ground of the measurement taken at each site. These profiles take into account the curvature of the earth with respect to radio waves, resulting in bowed horizontal axis lines, particularly on the profiles of sites that are more distant from the radar installation. Since the radio horizon is determined by a combination of earth curvature and atmospheric conditions, a typical curvature factor, “k,” is employed for illustration. That factor is 4/3. See Appendix G for more discussion of the k factor.

Those sites with a radio line of sight path from radar to receiving antenna have two lines linking the two locations. The solid red line is the line of sight path from the radar, on the left, to the receiver, on the right. The blue elliptical line represents the Fresnel clearance, selected to be at 0.6 times the first Fresnel zone. This is a commonly employed Fresnel factor to illustrate the potential of the terrain to interfere with the arriving signal. If the blue Fresnel curve intersects land (or water) then a Fresnel loss figure is computed and its value is reported in the legend.

On paths where there are one or more points of terrain obstruction, a third line is shown. It is a red dotted line that starts at the radar, follows line of sight to the first obstruction, diffracts around the obstruction to either the next obstruction or the destination. Each obstruction is topped with a black square indicating the point of diffraction where the line bends over the obstruction. The computer analyzes these obstructions and estimates the path losses due to diffraction, reporting the diffraction loss figure in the legend.

Legend

Whether or not a particular site has Fresnel or diffraction loss figures described above, each path will have a base loss. This is the path loss predicted for the distance between the source and the destination. The base loss is also presented in the legend. The legend also contains information about the site coordinates, site elevation, and distance and bearing from the radar.

Picture and Map

Each site page also contains a photograph of the position of the test antenna on the site with landmarks sufficient to return and repeat measurements. Some sites do not have photographs due to inclement weather. All sites have a description to support the photograph. The descriptions are contained in the table below. The topographic map indicates each site with a blue diamond and numerals.

PAVE PAWS Measurement Site Locations

Visited	Zone #	Avg dBMPE	Site #	Site Name	Town	Latitude			Longitude			Site AMSL	Distance from Radar (mi)	Bearing from Radar (deg)	Note
4-Mar-04	3	**-68.1**	1	Pilgrim Monument site	Provincetown	42	3	9.7	70	11	25.1	49	27.38	41	NE corner of monument parking lot.
4-Mar-04	3	**-74.9**	2	Snows Field, Snowfield Rd	Truro	42	0	3.9	70	3	33.4	131	30.06	55	Parking lot drive in front of field house
26-Feb-04	3	**-83.5**	3	CCNS HQ	Welfleet	41	54	15.1	69	58	45.2	42	30.69	70	
26-Feb-04	3	**-86.9**	4	Nauset Light Parking	Eastham	41	51	32.4	69	57	9.6	49	31.11	77	
1-Mar-04	1	**-66.0**	5	Rock Harbor parking	Orleans	41	47	58.9	70	0	32.5	13	27.5	83	North west end of parking lot at Rock Harbor
1-Mar-04	1	**-70.0**	6	Great Hill	Chatham	41	41	40.9	69	58	35.8	98	29.3	98	Intersection of Horizon Drive and Horizon Circle, near water towers
24-Feb-04	1	**-73.4**	7	Keith Lane circle	Brewster	41	45	7.5	70	4	54.1	108	23.6	90	End of Circle at Keith Lane
28-Feb-04	1	**-88.3**	8	Cemetery, Harwich Ctr	Harwich	41	41	22.6	70	4	49.8	42	24.1	101	Location rear of Island Pond Cemetery - west of graves of Atlas, Lure, Wilson & Wormington
24-Feb-04	1	**-48.8**	9	Scargo Hill	Dennis	41	44	22.1	70	10	50.3	65	18.5	93	Antenna placed on Scargo Tower: 8' antenna mast on 22.5' tower deck for 30' height
27-Feb-04	1	**-80.5**	10	Woodside Cemetery, Yarmouthport, off Summer Street	Yarmouth	41	42	1.2	70	14	49.6	65	15.5	104	Near E. Dexter Payne grave stone at center of cemetery.
3-Mar-04	1	**-77.1**	11	Main St Centerville	Barnstable	41	38	48.9	70	20	52.6	62	12.3	127	Facing Barnstable Day Care Center
23-Feb-04	2	**-66.4**	12	Athletic field Rt 130, north of	Mashpee	41	39	16.1	70	29	42.9	108	7.17	162	Rear parking lot between ball fields

Visited	Zone #	Avg dBMPE	Site #	Site Name	Town	Latitude			Longitude			Site AMSL	Distance from Radar (mi)	Bearing from Radar (deg)	Note
20-Feb-04	2	**-81.2**	13	Ashumet Rd Davisville Rd E Falmouth school	Falmouth	41	34	33.2	70	33	38.4	36	12.3	185	Halfway down parking lot south of school - in parking row adjacent to athletic field
20-Feb-04	4	**-62.6**	14	Mashnee Island Grill	Bourne	41	43	5.6	70	38	4.7	6	5.58	244	North end of parking lot at Mashpee Island Grill
10-Feb-04	3	**-39.2**	15	Shawme Crowell State Park	Sandwich	41	45	46.7	70	31	31.7	167	0.95	46	Driveway of campsites C32-36 painted with 'C32 - 36' on pavement
22-Feb-04	1	-55.7	16	Cardinal Rd Circle	Sandwich	41	44	0.2	70	29	27.1	252	2.8	119	Antennas on pavement at crux of circle
22-Feb-04	1	-74.5	17	Rt 130 @ Cotuit Rd	Sandwich	41	42	48.3	70	29	23.2	173	3.71	138	Parking lot of retail complex south of intersection of Rt 130 and Cotuit Rd. - (South End) - facing rear of tavern and post office
14-Feb-04	1	-63.4	18	Mt Hope Cemetery Rt 6A	Sandwich	41	45	8.8	70	29	6.3	22	2.75	92.39	Rear of cemetery near Hamblin Monument
16-Feb-04	1	-61.1	19	Jarves Rd @ Factory St	Sandwich	41	45	38.3	70	29	30.9	13	2.45	78.33	Grassy lot of intersection of Jarves and Factory Streets
11-Feb-04	1	-66.9	20	Sandwich Public Library	Sandwich	41	45	28.3	70	29	54.8	9	2.07	81	Antenna located in picnic area / play area
16-Feb-04	1	-50.5	21	Holder Ln Circle	Sandwich	41	44	29.7	70	29	25.6	134	2.59	108	Rig placed on island at circle on Holder Lane across from #10
18-Feb-04	3	-61.8	22	Scusset Beach Parking 1	Sandwich	41	46	38.3	70	29	56.4	9	2.63	50	Site near canal in shadow of canal electric power plant
18-Feb-04	3	-47.6	23	Scusset Beach Parking 2	Sandwich	41	46	44.7	70	30	4.8	9	2.62	47	Unobstructed site in parking lot, in second row of facing east end of bath houses
14-Feb-04	3	-71.6	24	Sagamore athletic field	Bourne	41	46	25.9	70	32	23.9	13	1.44	357	Parking lot - west side of athletic field; in space between bleachers, restroom, and tennis

Visited	Zone #	Avg dBMPE	Site #	Site Name	Town	Latitude	Longitude	Site AMSL	Distance from Radar (mi)	Bearing from Radar (deg)	Note
											court
13-Feb-04	3	-56.5	25	Church Lane @ Cape Pine Rd	Bourne	41 47 3.9	70 32 45.2	85	2.21	350	Play area west of apartments, behind dumpster at junction of Scotch Pine and White Pine between rear parking and basketball court - across from side of unit #18
18-Feb-04	3	-60.8	26	Sagamore School, Williston Rd	Bourne	41 46 44.5	70 31 54.4	68	1.83	11	Located in school parking lot adjacent to Williston Rd., across from #33
13-Feb-04	5	-55.7	27	Brigantine Passage Dr	Bourne	41 46 41	70 33 3.6	137	1.85	339	Location in circle approx. 20 ft. from hydrant by driveway of house #8
17-Feb-04	5	-85.5	28	Little Sandy Pond Rd	Plymouth	41 47 55	70 35 41.8	104	4.3	317	on side walk beside Little Sandy Pod Rd nr crest of hill
19-Feb-04	6	-74.3	29	Rt 6E Canal overlook	Bourne	41 45 46.3	70 34 21.6	124	1.9	291	Location - sidewalk about 100 ft NE of overlook info sign
12-Feb-04			29	Rt 6E Canal overlook	Bourne	41 45 46.6	70 34 21.5	124	1.9	290	Antenna in parking lot adjacent to tree - slightly farther south of initial visit on 2/12
12-Feb-04	6	-84.4	30	Cypress St @ Rt 6 Bypass	Bourne	41 45 8.8	70 36 7	32	3.28	269	Bay community church Parking lot overlooking Rt. 6 bypass
21-Feb-04	4	-74.3	31	Monument Beach, Tower Circle	Bourne	41 43 2.1	70 36 21.5	75	4.29	235	On street circle, between houses #14 and #15
29-Feb-04	4	-76.7	32	Wings Neck Road @ Harbor Drive	Bourne	41 41 33.9	70 38 14.7	6	6.6	331	Wings Neck Road - Just south of intersection with Harbor Drive, beside Telco Terminal Box, north of driveway to house #211. Harbor Drive is marked "Private Colony"
29-Feb-04	2	-86.3	33	Cataumet Club, Scraggy Neck	Bourne	41 39 56.8	70 37 12	32	7.36	215	Intersection of Scraggy Neck Road and Squeteague Harbor

Visited	Zone #	Avg dBMPE	Site #	Site Name	Town	Latitude			Longitude			Site AMSL	Distance from Radar (mi)	Bearing from Radar (deg)	Note
				Rd											Road - open area facing Cataumet Club tennis court.
22-Feb-04	2	-70.6	34	Carolyn Cir Forestdale	Sandwich	41	40	33.4	70	30	55.4	127	5.46	167	Antenna on level clearing in Carolyn Circle's circle.
20-Feb-04	2	-84.5	35	Barnstable County Fairgrounds	Falmouth	41	37	4.9	70	32	1.6	78	9.34	179	Parking lot east of Fairgrounds Buildings
21-Feb-04	2	-93.7	36	Falmouth HS, Brickkiln Rd	Falmouth	41	35	30.6	70	36	25.3	52	11.7	198	Parking lot north of Falmouth High School
23-Feb-04	2	-88.6	37	Mashpee Senior Center	Mashpee	41	37	26.8	70	29	18.7	29	9.28	164	North side of parking lot at Mashpee Senior Center
21-Feb-04	2	-91.5	38	N Falmouth School	Falmouth	41	38	17	70	37	18.7	26	9.05	208	In front of school building on northeast side
19-Feb-04	1	-91.8	39	Marstons Mills School, 2095 Main St	Barnstable	41	39	10.2	70	24	38.6	62	9.55	136	
10-Feb-04	3	-48.7	40	Shawme Crowell State Park	Sandwich	41	45	46.2	70	31	31.7	167	0.95	46	Same as 15
16-Feb-04	3	-67.0	41	Burbank St and Main (Rt 130)	Sandwich	41	45	40.9	70	30	56.1	72	1.31	64	On pavement at Burbank Street side of island at Main Street (Rt. 130)
14-Feb-04	1	-90.5	42	Old County Rd, Near State Hatchery	Sandwich	41	43	45.3	70	25	58.7	42	5.68	107	Site on old pavement adjacent to Old County Road, directly from State Hatchery Drive / gate
29-Feb-04	6	-102.9	43	Assawompset School	Lakeville	41	50	50.9	70	56	46.3	98	22.05	287	In basketball court at rear of school
12-Feb-04	6	-91.2	44	Onset School, Union Ave	Wareham	41	44	35.6	70	39	34.7	32	6.3	264	Southern end of parking lot at CW Bishop Ave. and Union Ave. across from #4 CW Bishop Ave.
17-Feb-04	3	-65.7	45	Ellisville Rd @ Inge's Way	Plymouth	41	49	44.3	70	32	44.8	127	5.27	356	Intersection Ellisville Rd and Inge's Way (The O'Connor

Visited	Zone #	Avg dBMPE	Site #	Site Name	Town	Latitude			Longitude			Site AMSL	Distance from Radar (mi)	Bearing from Radar (deg)	Note
															house #30 is at that intersection)
5-Mar-04	3	-87.6	46	October Lane circle, Cedar Bushes	Plymouth	41	53	54.7	70	33	45.6	16	10.1	353	
11-Feb-04	3	-58.1	47	Freezer Road @ Tupper Road	Sandwich	41	46	6.2	70	30	22.3	16	1.97	58	Lawn between sign and shop of Cape Cod Aqua Center. Weather radio went off air.
5-Mar-04	2	-84.9	48	Stone School Circle, Otis AFB	Bourne (MMR)	41	39	22.7	70	34	31.3	98	6.96	196	West end parking lot
5-Mar-04	5	-70.4	49	Post 'n Rail Av Cedarville	Plymouth	41	48	30.5	70	33	42.3	59	4.02	343	
19-Feb-04	1	-91.1	50	Barnstable HS, rear	Barnstable	41	39	19.7	70	19	25.6	65	13	121	

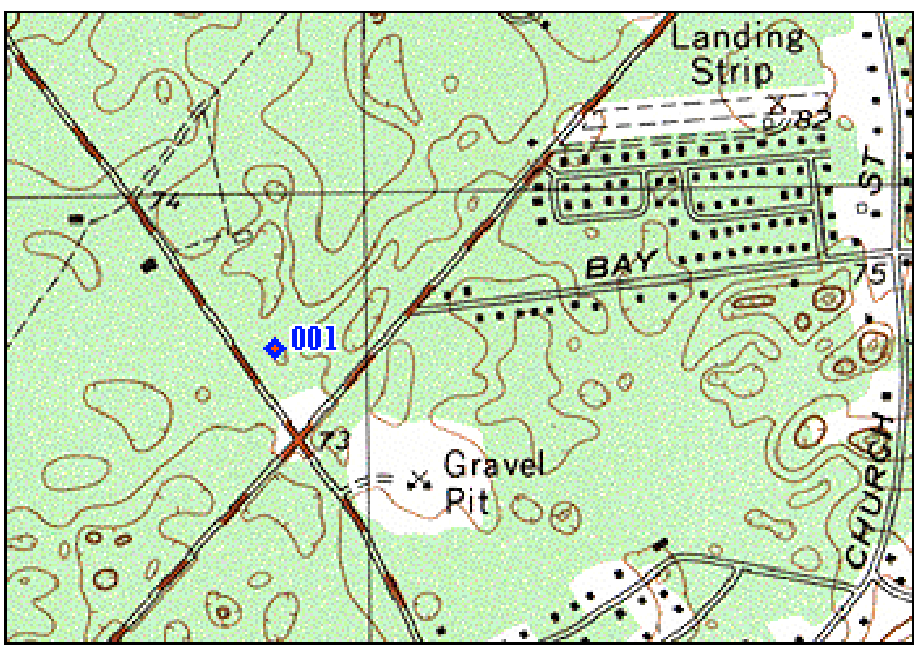
APPENDIX K
Ambient Site ID

K1 The Ambient RFE Photos of Site Rigging & Topographical Maps of Measurement Sites

K1.1 Listing of ambient measurement site locations and dates visited.

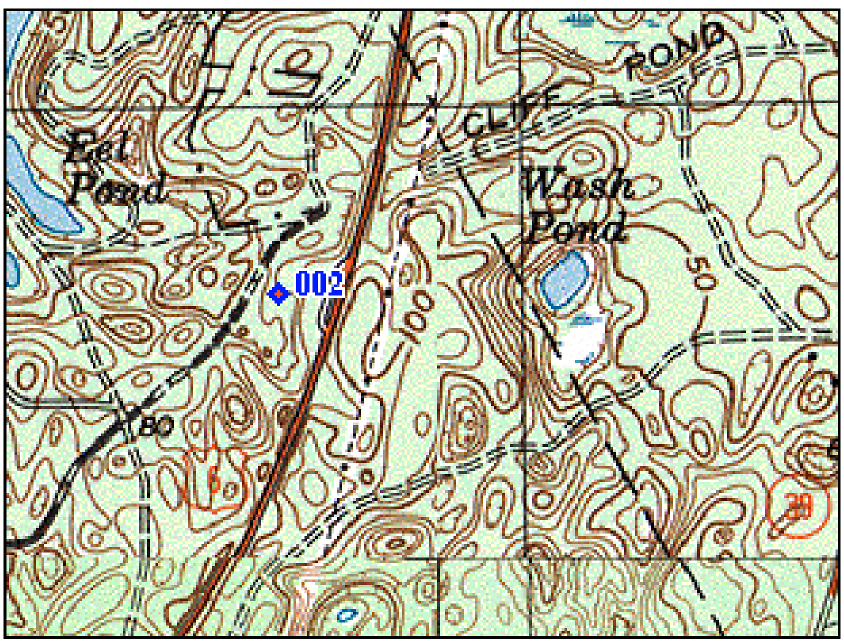
Site 1	Rt.137 @ Rt.39	Harwich	Feb.28, 2004
Site 2	Rt.6 Westbound rest area	Orleans	Feb.26, 2004
Site 3	Old North Cemetery & Rt.6	Truro	Mar.04, 2004
Site 4	Baker School on Rt.28	West Dennis	Mar.03, 2004
Site 5	Whites Path	Yarmouth	Feb 27, 2004
Site 6	Barnstable Commuter Lot, Exit 6	Barnstable	Feb.25, 2004
Site 7	Athletic Field off Rt.130, north of Ashumet Rd.	Mashpee	Feb.23, 2004
Site 8	Jones Rd. School	Falmouth	Mar.02, 2004
Site 9	Rt.28 near Otis Rotary	Bourne	Mar.02, 2004
Site 10	Barnstable County Court	Barnstable	Feb.25, 2004

Ambient
Site #001 Rt. 137 @ Rt. 39, Harwich



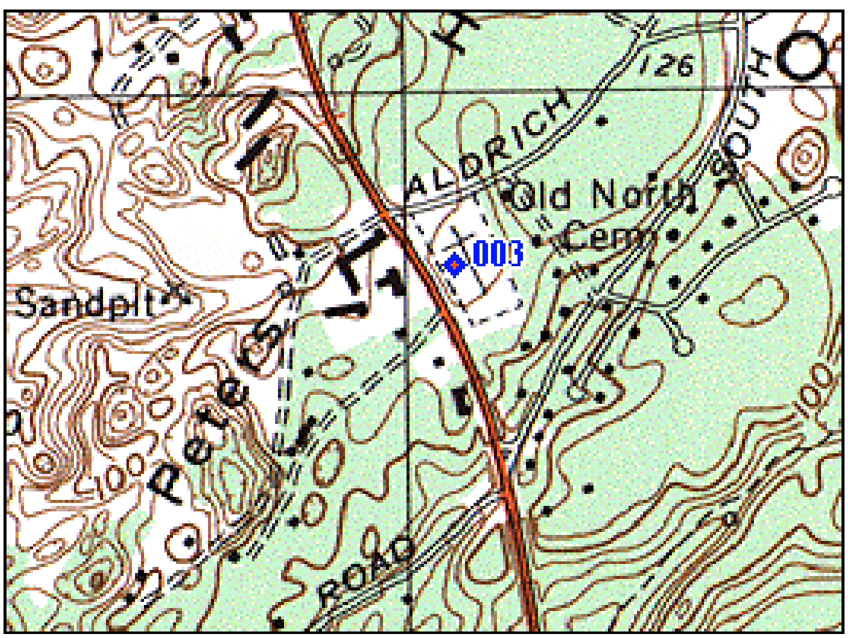
Map created with TOPO!® ©2003 National Geographic (www.nationalgeographic.com/topo)

Ambient
Site #002 Rt. 6 Westbound Rest Area, Orleans



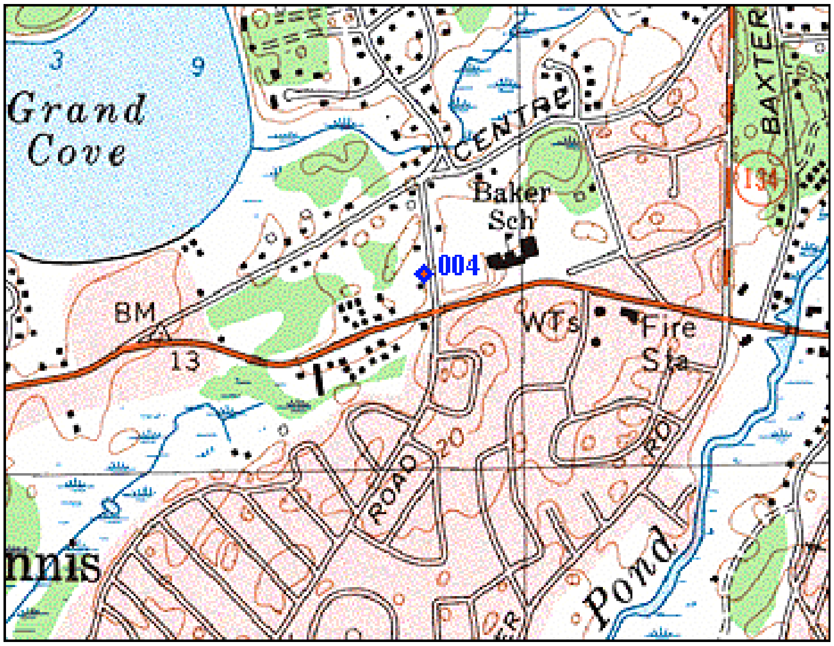
Map created with TOPO!® ©2003 National Geographic (www.nationalgeographic.com/topo)

Ambient
Site #003 Old North Cemetery & Rt.6, Truro



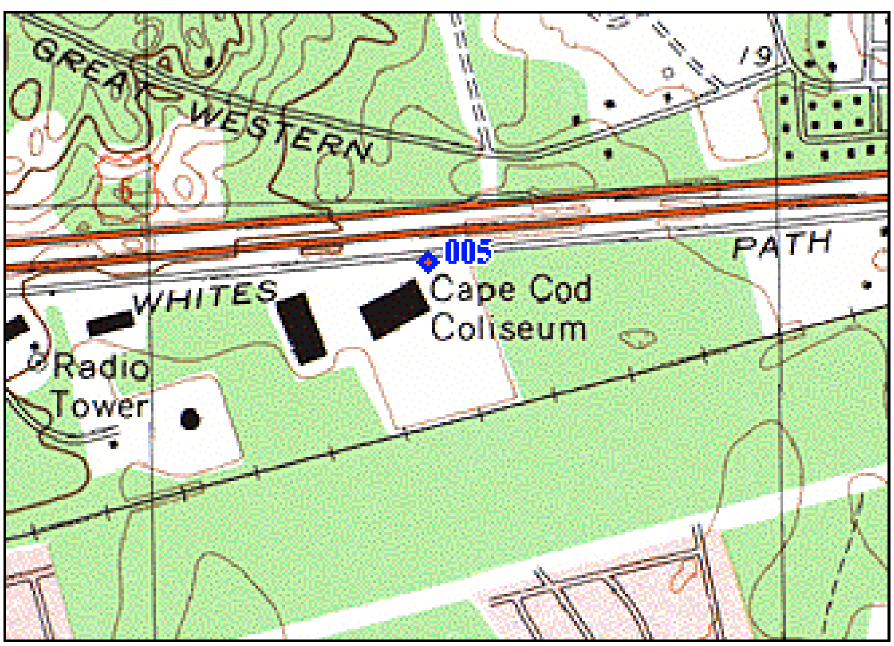
Map created with TOPO!® ©2003 National Geographic (www.nationalgeographic.com/topo)

Ambient
Site #004 Baker School on Rt. 28, West Dennis



Map created with TOPO!® ©2003 National Geographic (www.nationalgeographic.com/topo)

Ambient
Site #005 Whites Path, Yarmouth



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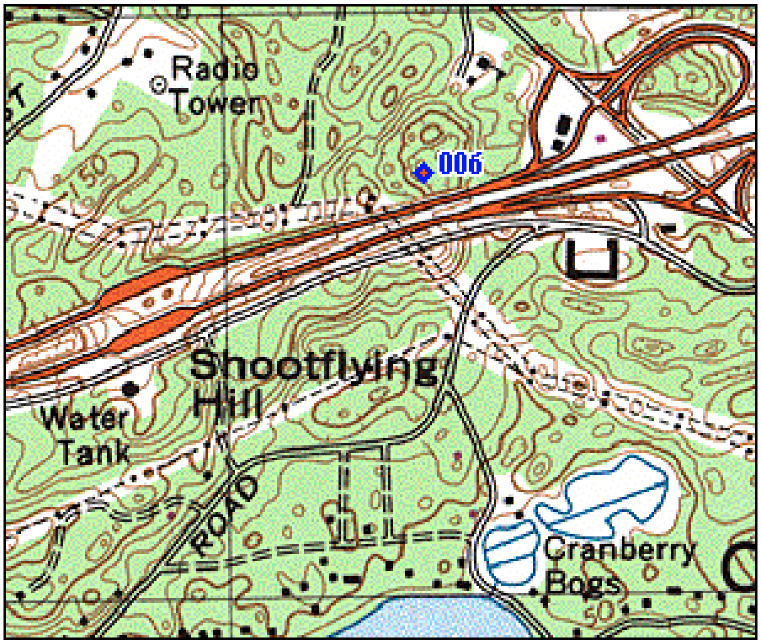
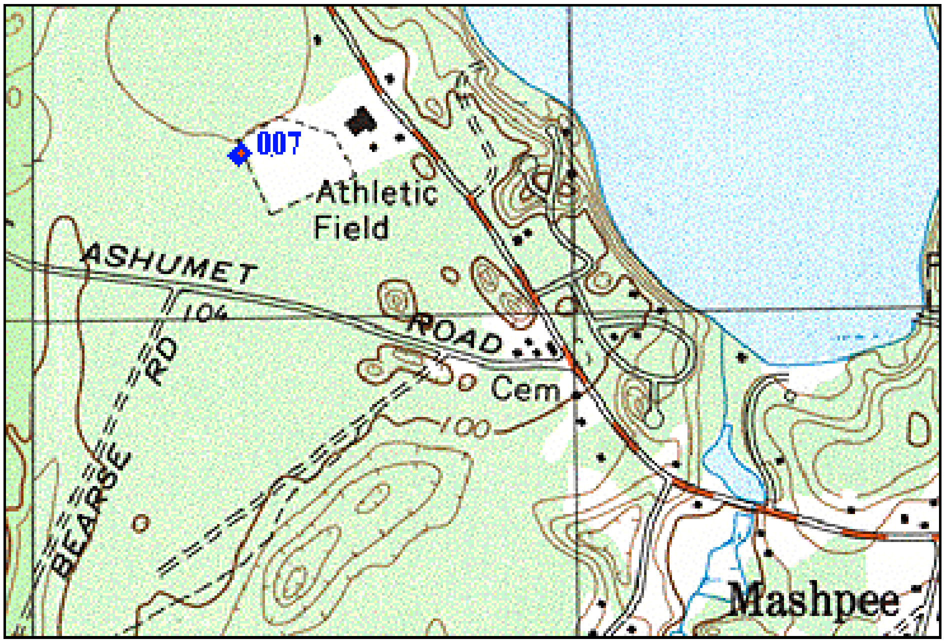
Ambient
Site #006 Barnstable Commuter Lot, Exit 6, Barnstable



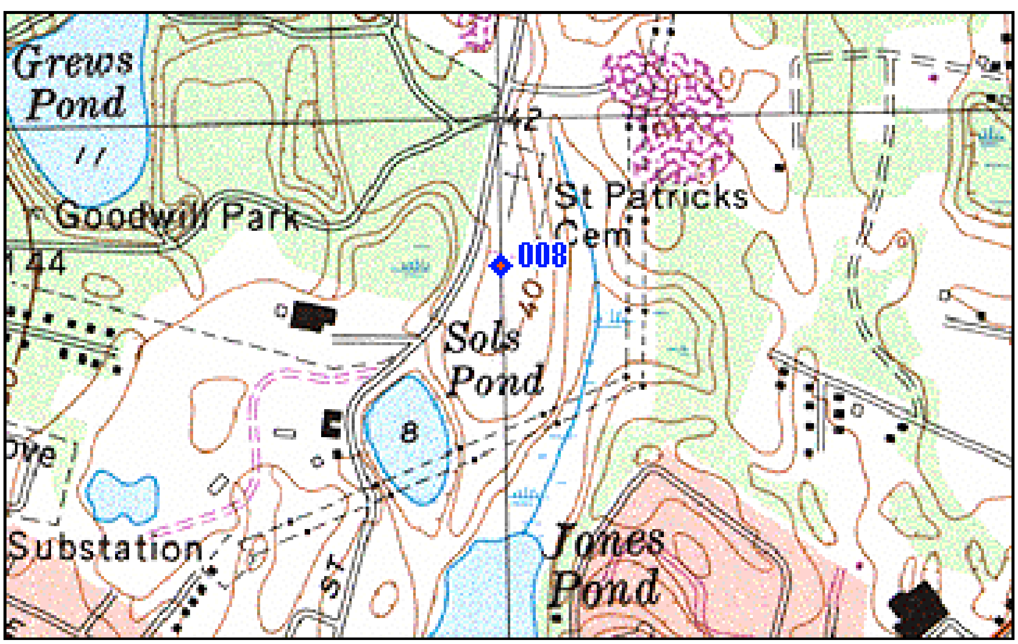
Map created with TOPO!® ©2003 National Geographic (www.nationalgeographic.com/topo)

Ambient
Site #007 Athletic Field/Rt.130, N of Ashumet Rd, Mashpee



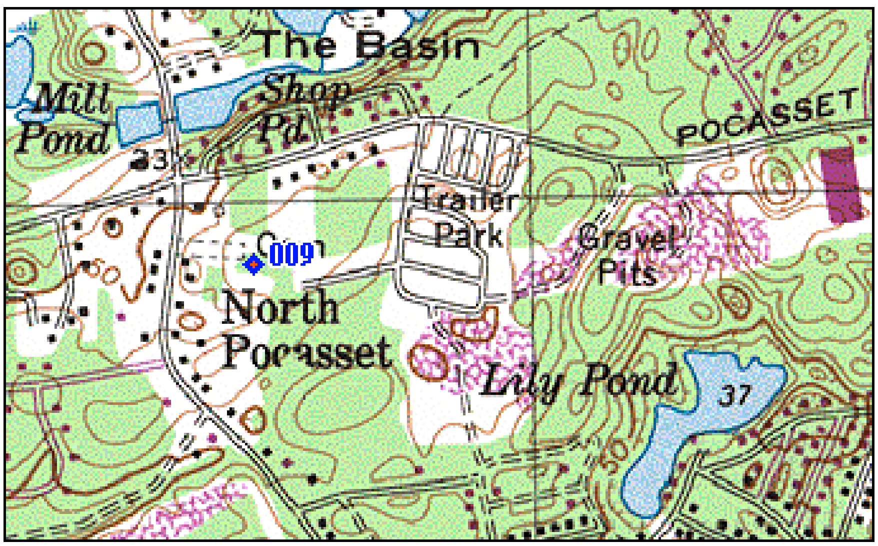
Map created with TOPO!® ©2003 National Geographic (www.nationalgeographic.com/topo)

Ambient
Site #008 Jones Rd. School, Falmouth



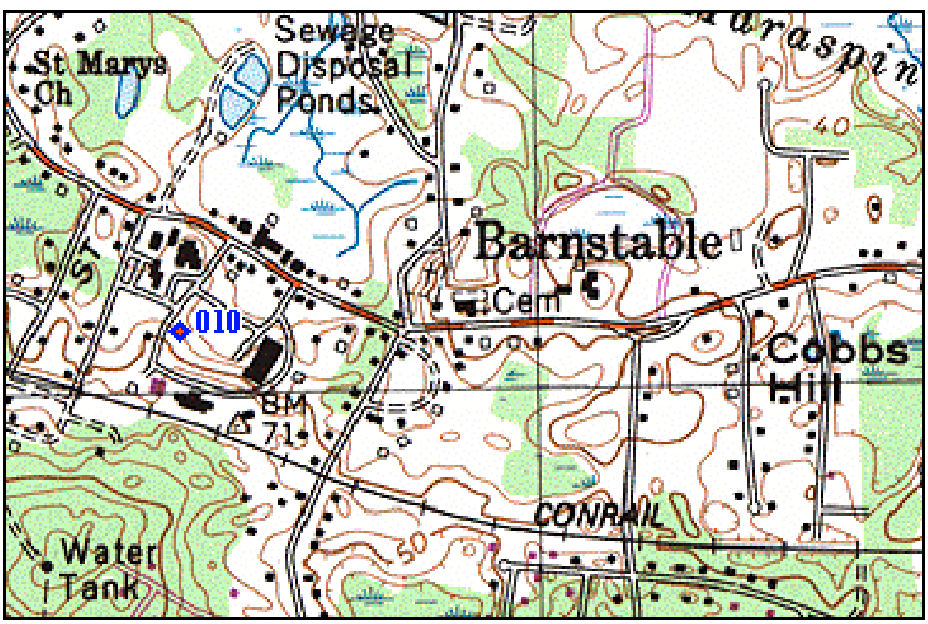
Map created with TOPO!® ©2003 National Geographic (www.nationalgeographic.com/topo)

Ambient
Site #009 Rt.28, Near Otis Rotary, Bourne



Map created with TOPO!® ©2003 National Geographic (www.nationalgeographic.com/topo)

Ambient
Site #010 Barnstable County Court, Barnstable



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Appendix L

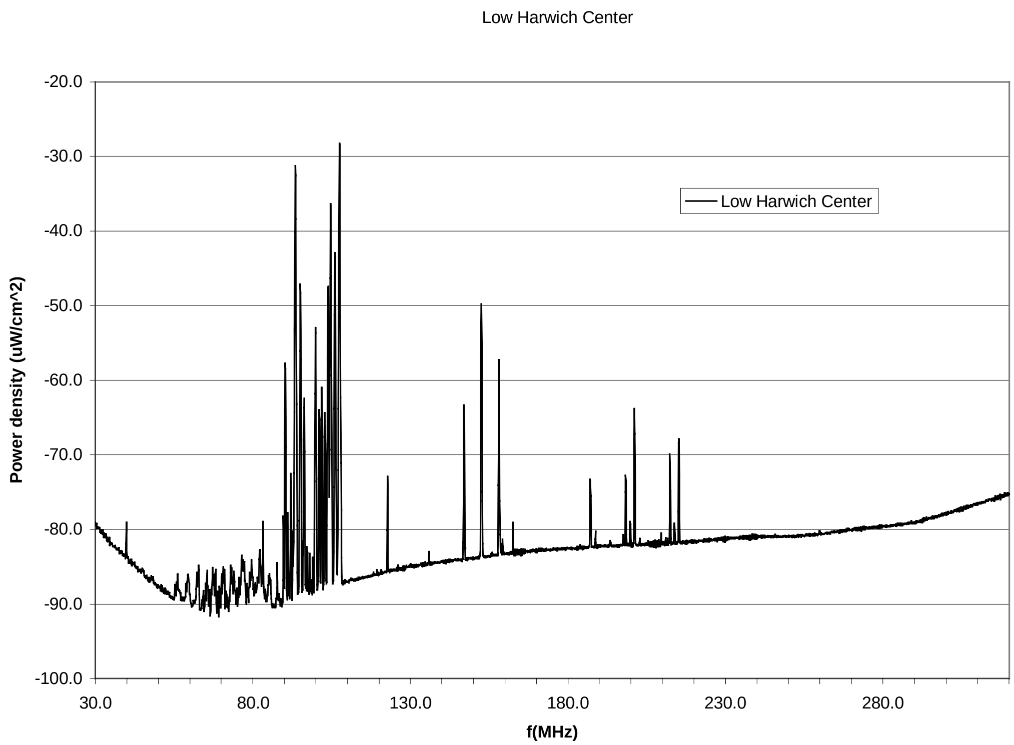
Ambient RFE Plots for all 10 Sites

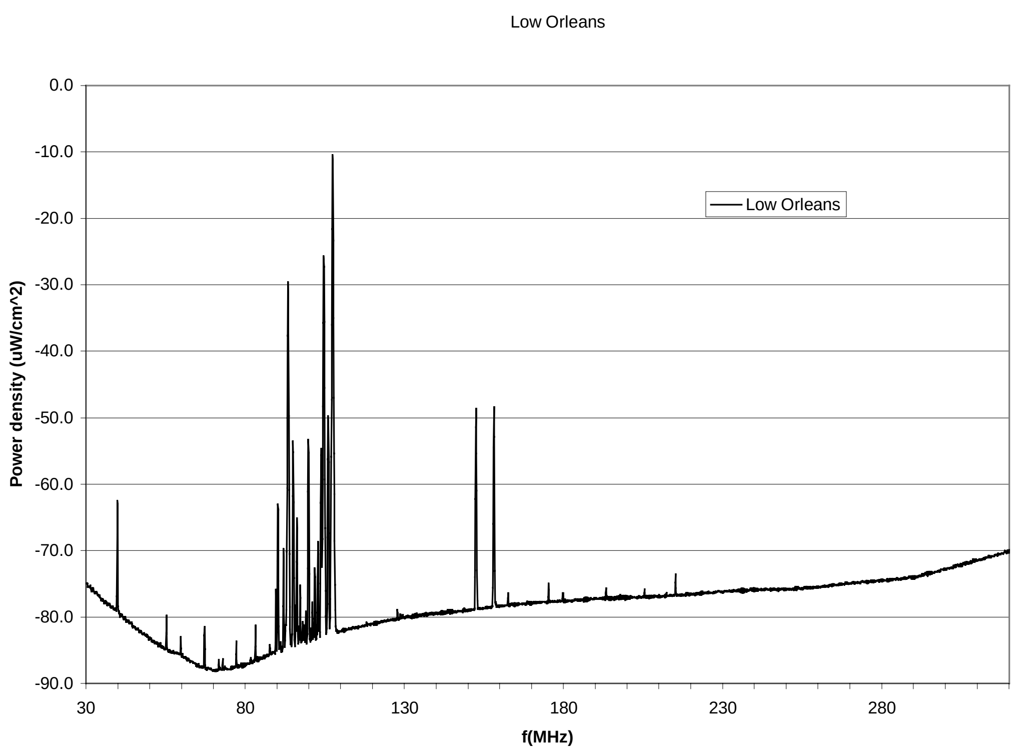
30 to 320 MHz “Lo Band”

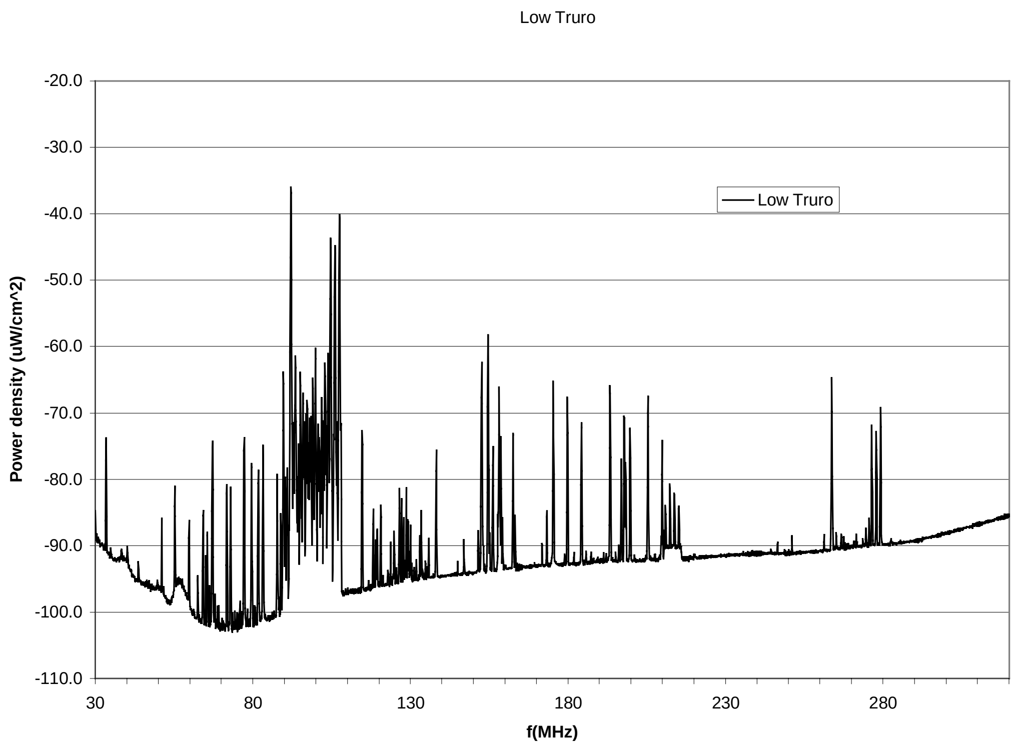
320 to 950 MHz- “Mid Band

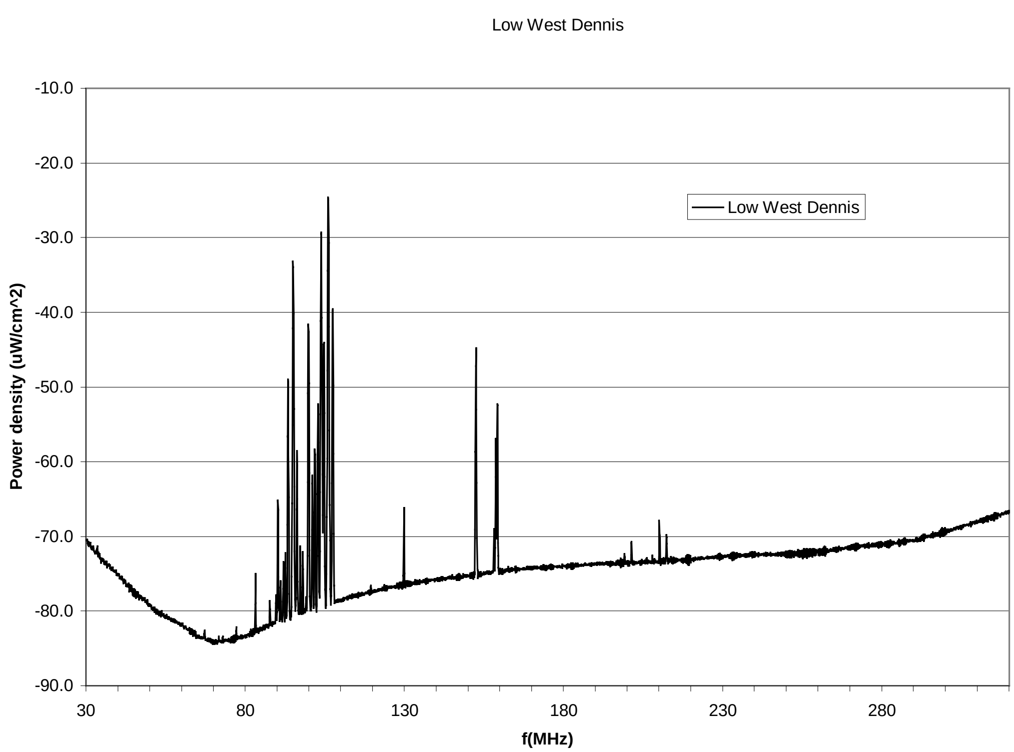
950 MHz to 3050 MHz- “Hi Band”

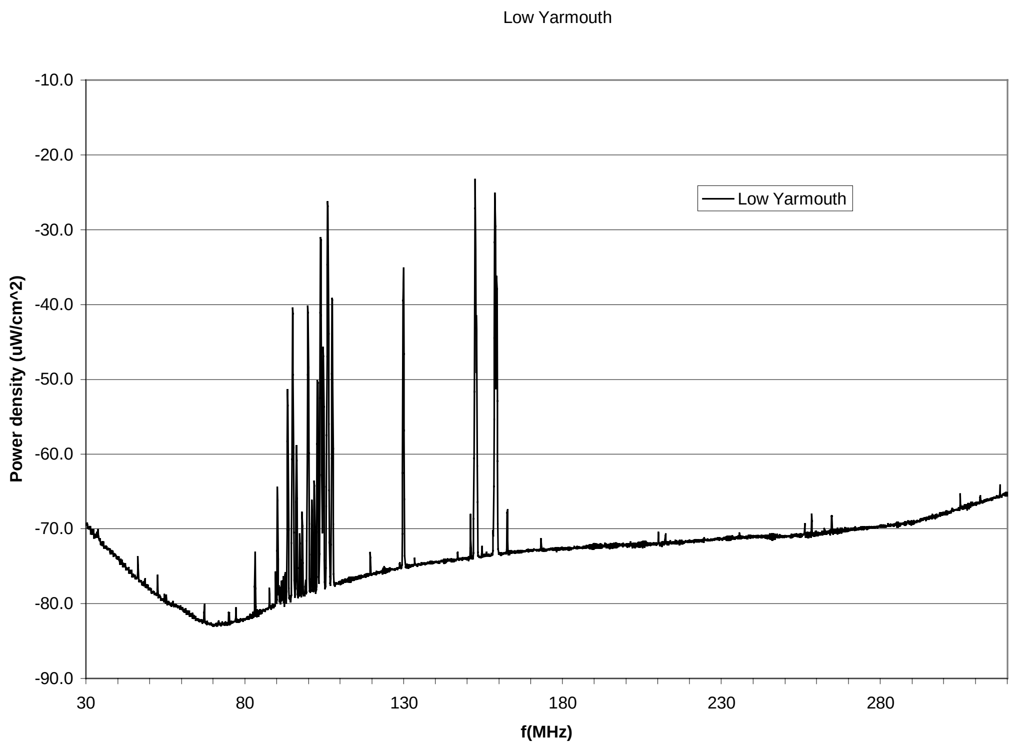
The Ambient RFE Plots are produced from the Excel spreadsheet data files contained in the Ambient Data file folder in the accompanying data set. These plots are presented in $dBuW/cm^2$.

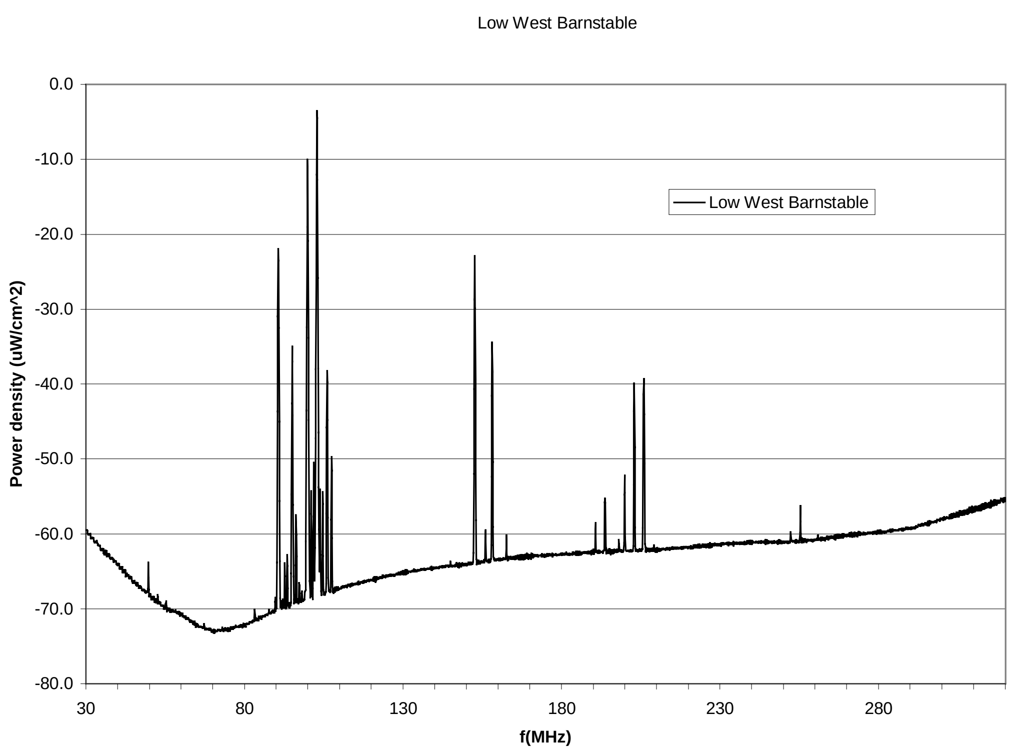

Low Harwich Center
Low Harwich Center
Power density (uW/cm^2)
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
30.0
80.0
130.0
180.0
230.0
280.0
f(MHz)

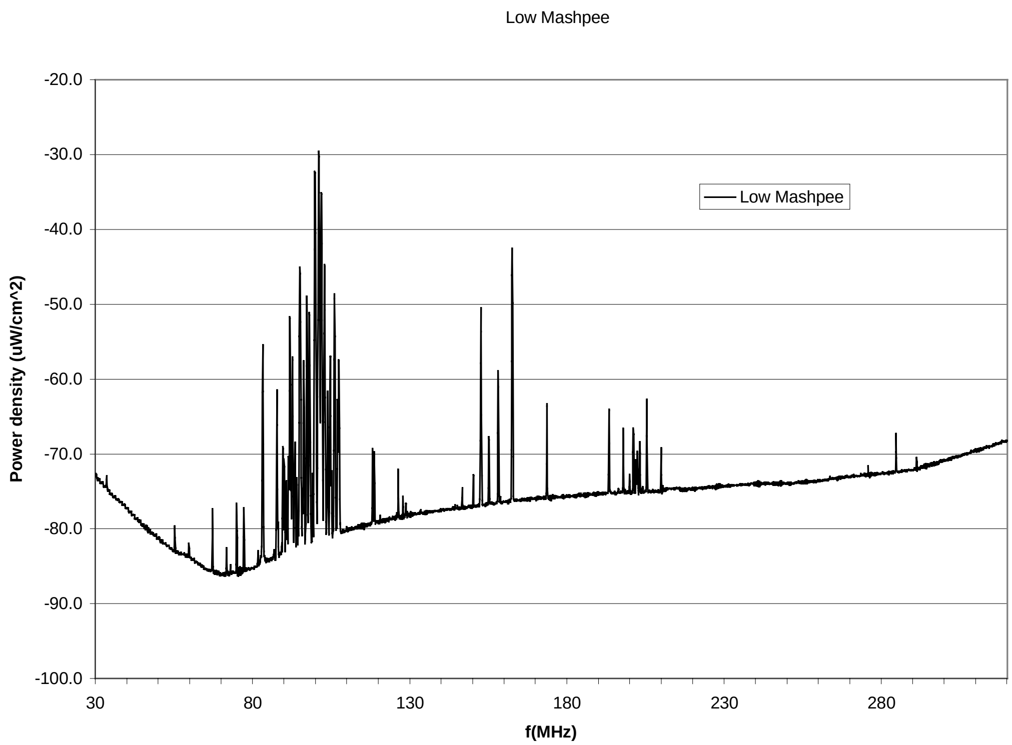

Low Orleans
Low Orleans
Power density (uW/cm^2)
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
30
80
130
180
230
280
f(MHz)

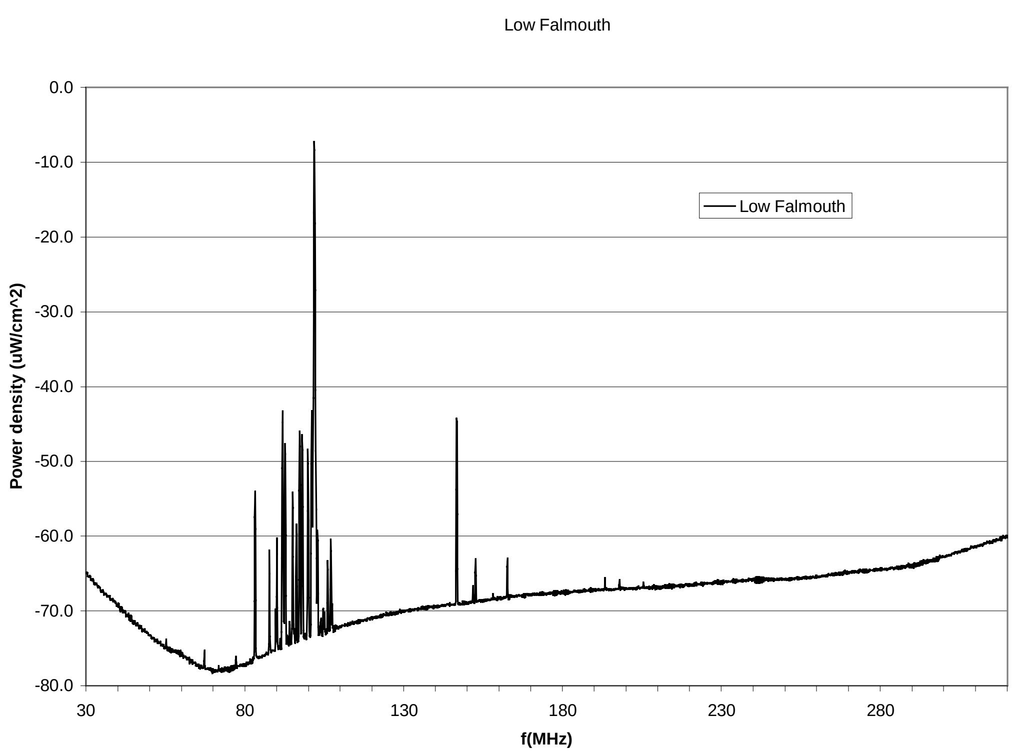

Low Truro
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
-110.0
Power density (uW/cm^2)
30
80
130
180
230
280
f(MHz)
Low Truro

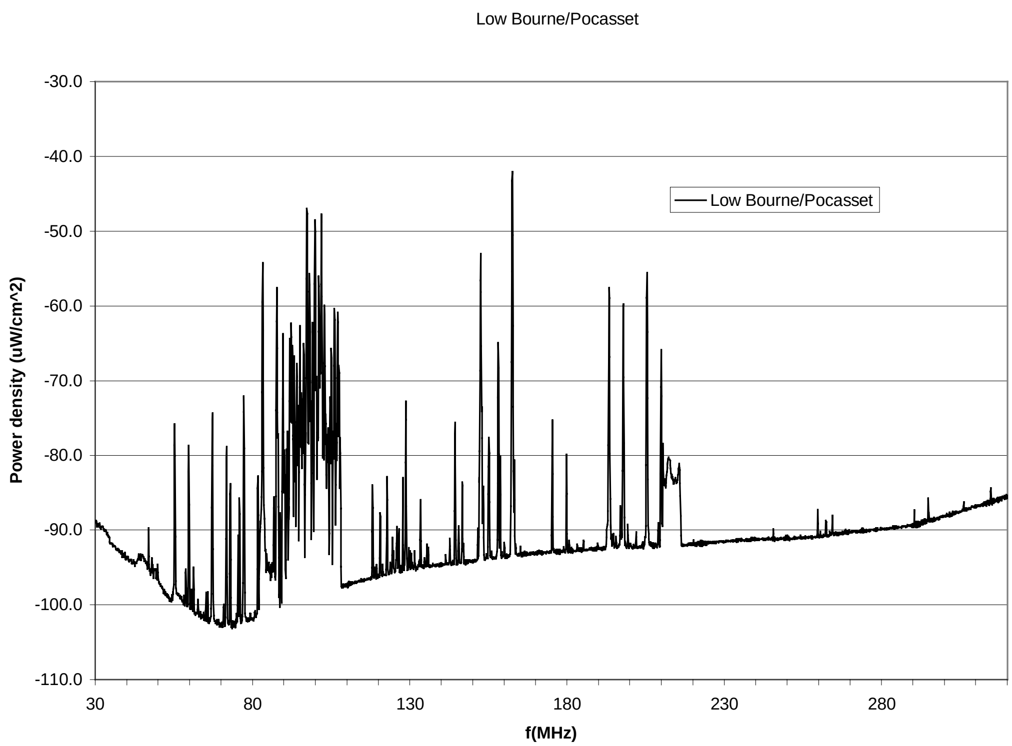

Low West Dennis
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
Power density (uW/cm^2)
30
80
130
180
230
280
f(MHz)
Low West Dennis

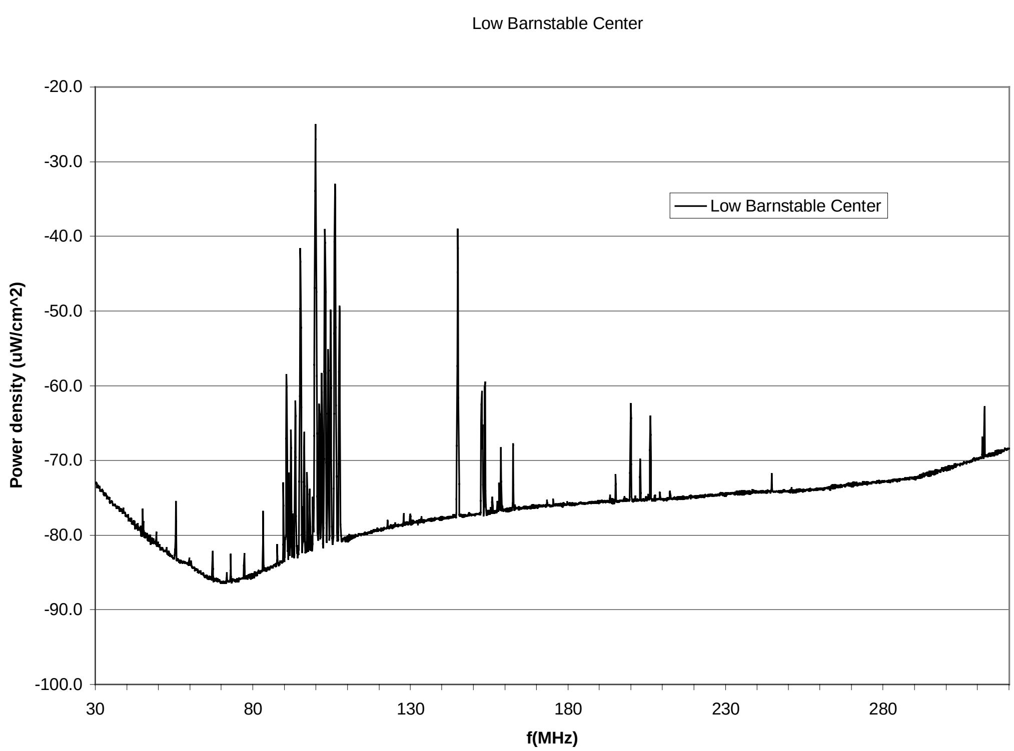

Low Yarmouth
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
Power density (uW/cm^2)
Low Yarmouth
30
80
130
180
230
280
f(MHz)

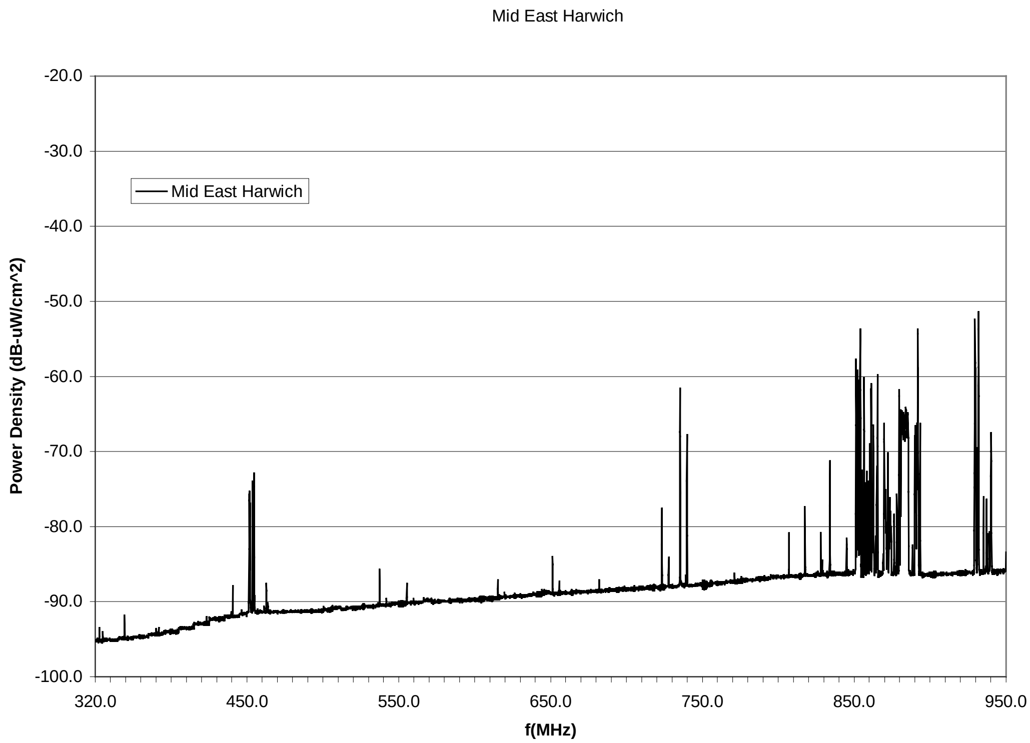

Low West Barnstable
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
Power density (uW/cm^2)
Low West Barnstable
30
80
130
180
230
280
f(MHz)


Low Mashpee
Low Mashpee
Power density (uW/cm^2)
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
30
80
130
180
230
280
f(MHz)


Low Falmouth
Low Falmouth
Power density (uW/cm^2)
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
30
80
130
180
230
280
f(MHz)


Low Bourne/Pocasset
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
-110.0
Power density (uW/cm^2)
Low Bourne/Pocasset
30
80
130
180
230
280
f(MHz)


Low Barnstable Center
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
Power density (uW/cm^2)
Low Barnstable Center
30
80
130
180
230
280
f(MHz)


Mid East Harwich
Mid East Harwich
Power Density (dB-uW/cm^2)
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
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-90.0
-100.0
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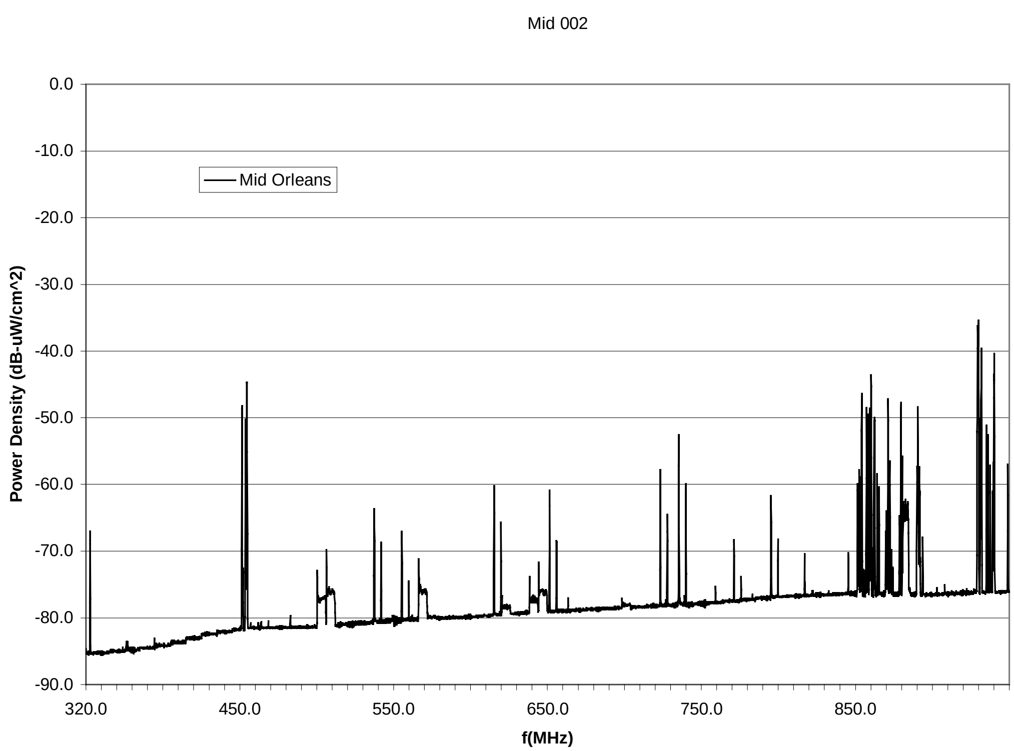
550.0
650.0
750.0
850.0
950.0
f(MHz)


Mid 002
Mid Orleans
Power Density (dB-uW/cm^2)
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
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550.0
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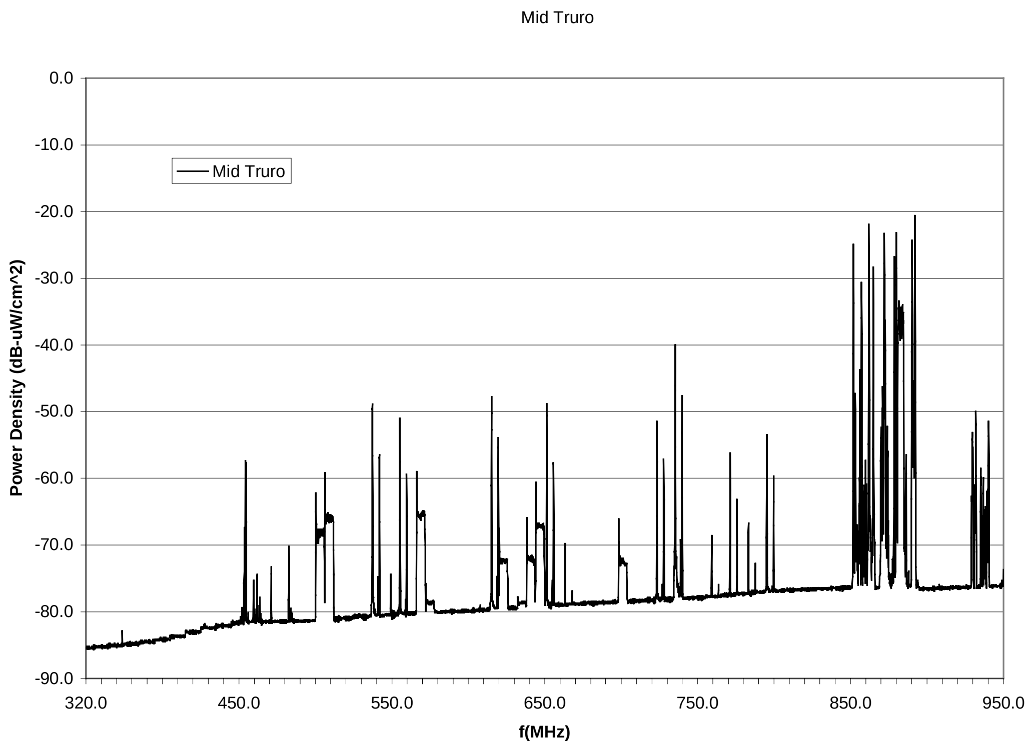
750.0
850.0
f(MHz)


Mid Truro
Mid Truro
Power Density (dB-uW/cm^2)
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
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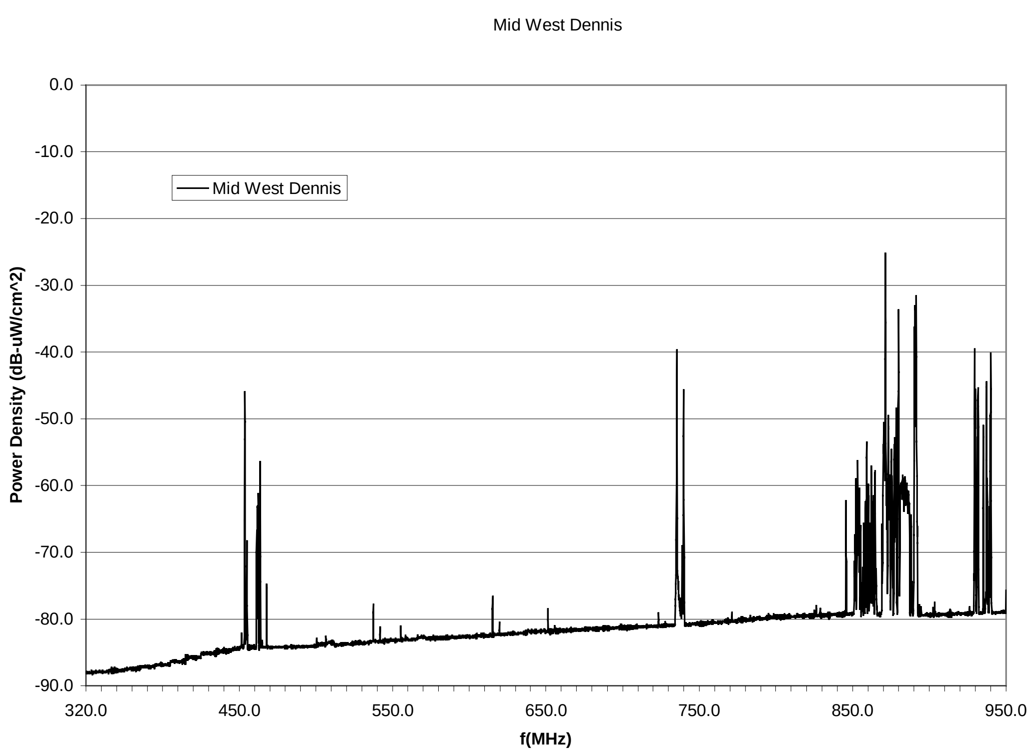
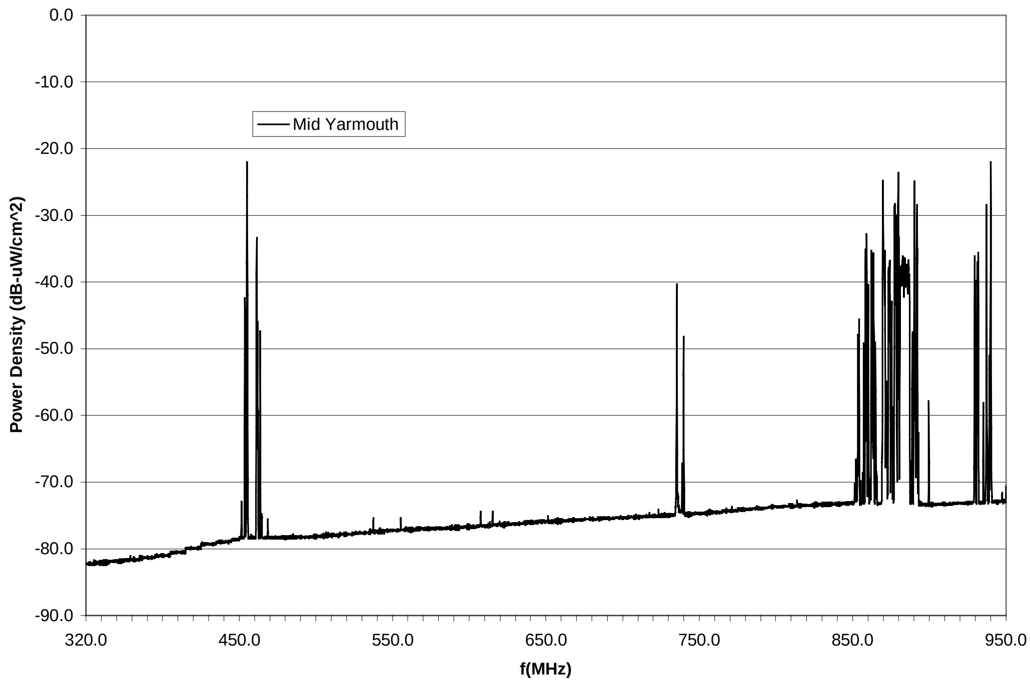
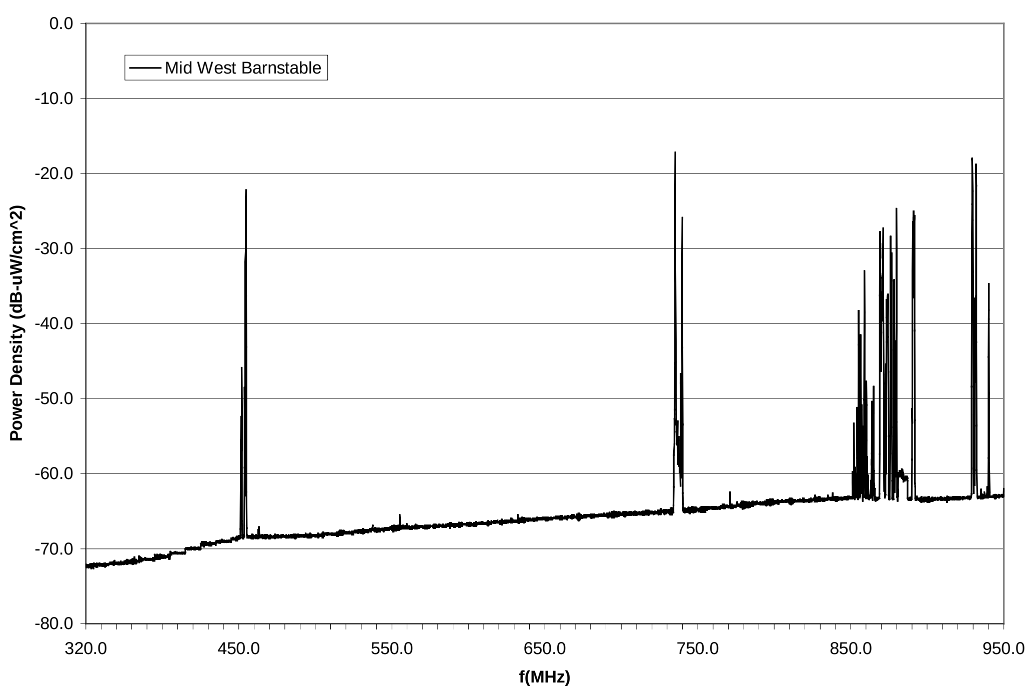
750.0
850.0
950.0
f(MHz)

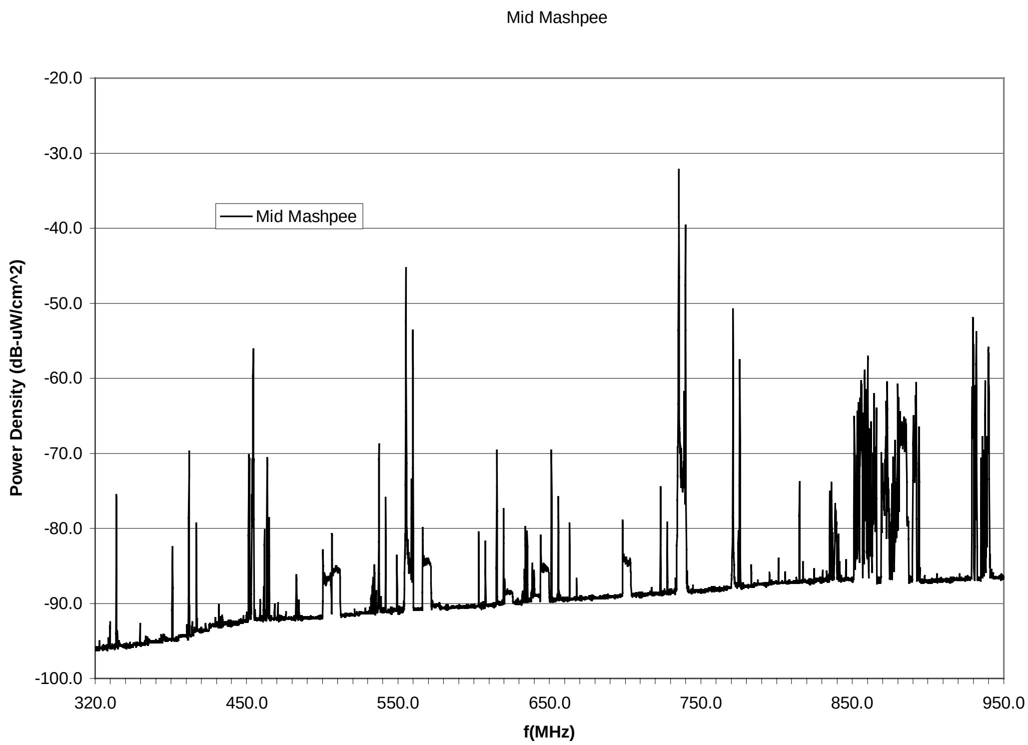

Mid West Dennis
Mid West Dennis
Power Density (dB-uW/cm^2)
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
320.0
450.0
550.0
650.0
750.0
850.0
950.0
f(MHz)

Mid Yarmouth



Mid West Barnstable





Mid Mashpee
Mid Mashpee
Power Density (dB-uW/cm^2)
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
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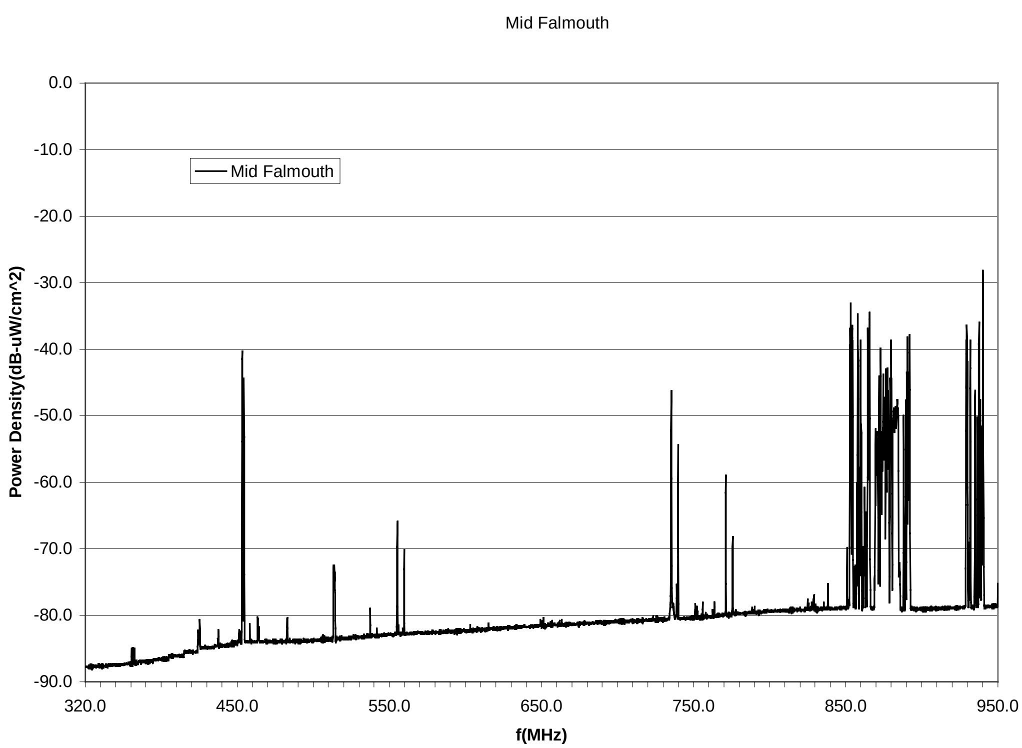
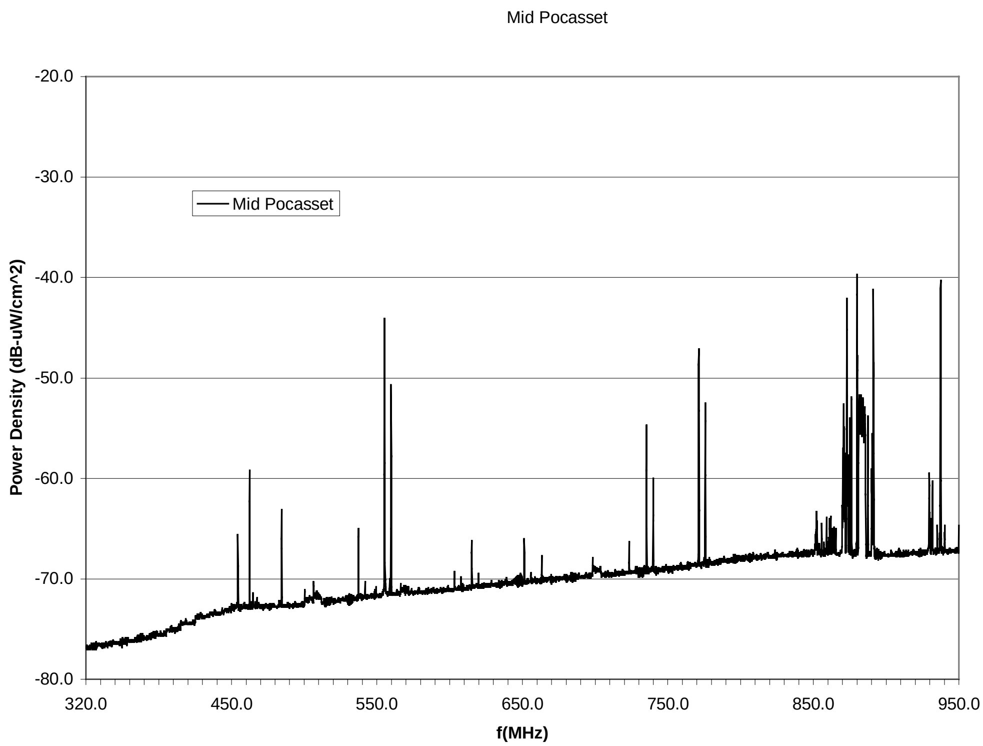
750.0
850.0
950.0
f(MHz)



Mid Falmouth
Mid Falmouth
Power Density(dB-uW/cm^2)
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
320.0
450.0
550.0
650.0
750.0
850.0
950.0
f(MHz)


Mid Pocasset
Mid Pocasset
Power Density (dB-uW/cm^2)
-20.0
-30.0
-40.0
-50.0
-60.0
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-80.0
320.0
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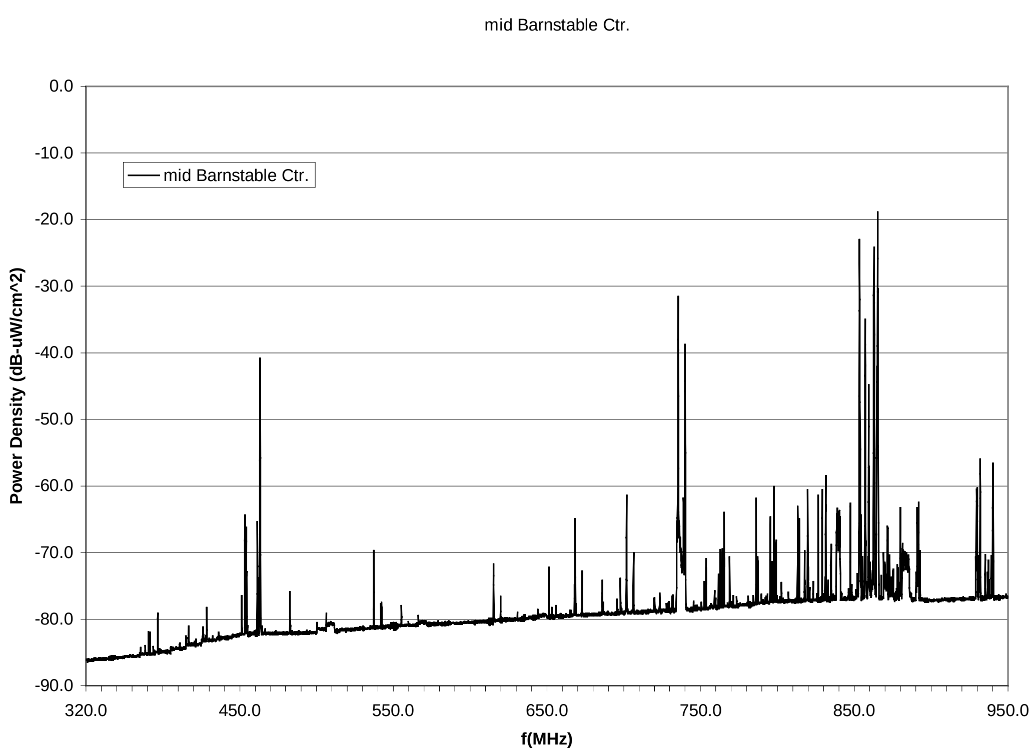
550.0
650.0
750.0
850.0
950.0
f(MHz)


mid Barnstable Ctr.
mid Barnstable Ctr.
Power Density (dB-uW/cm^2)
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
320.0
450.0
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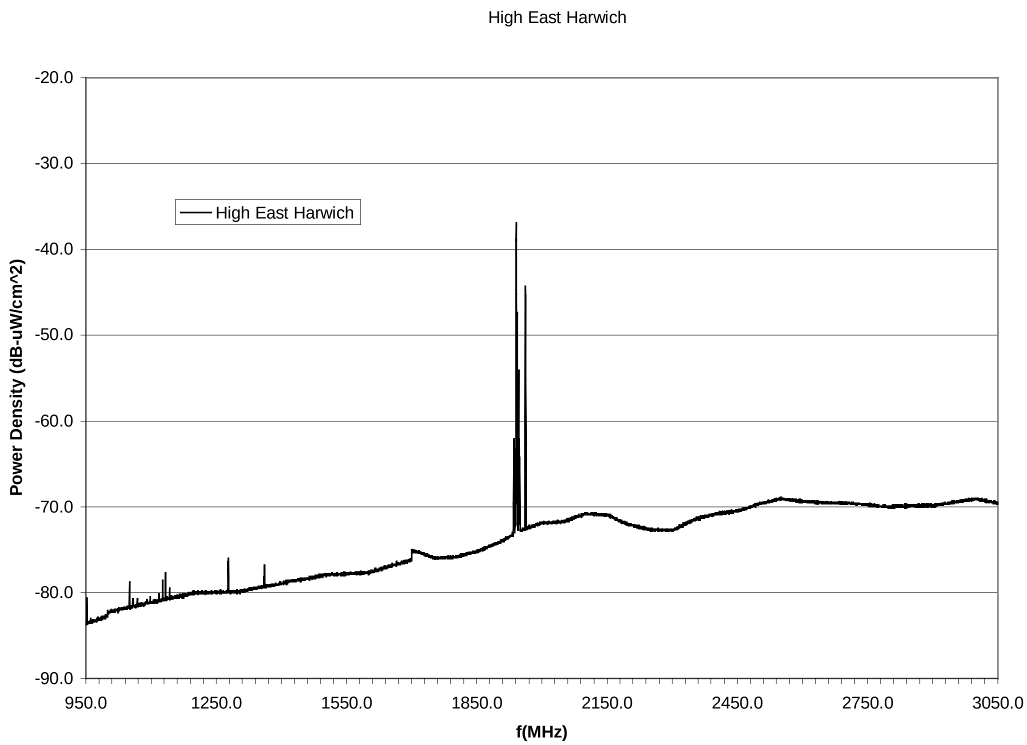
850.0
950.0
f(MHz)


High East Harwich
High East Harwich
Power Density (dB-uW/cm^2)
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
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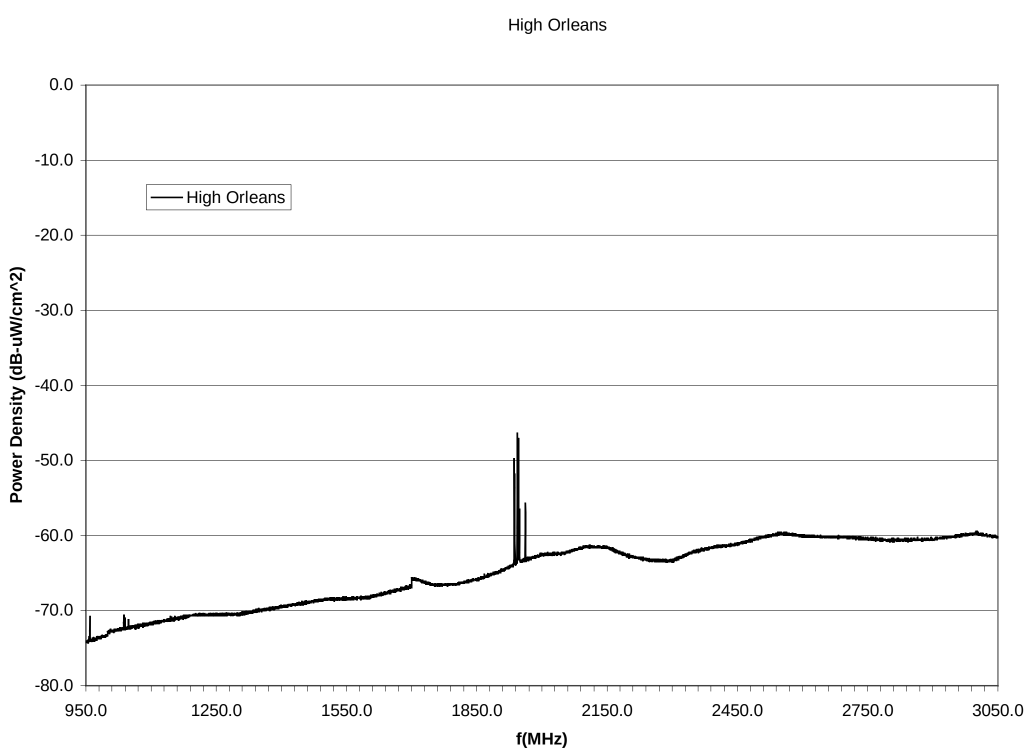
2450.0
2750.0
3050.0
f(MHz)


High Orleans
High Orleans
Power Density (dB-uW/cm^2)
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
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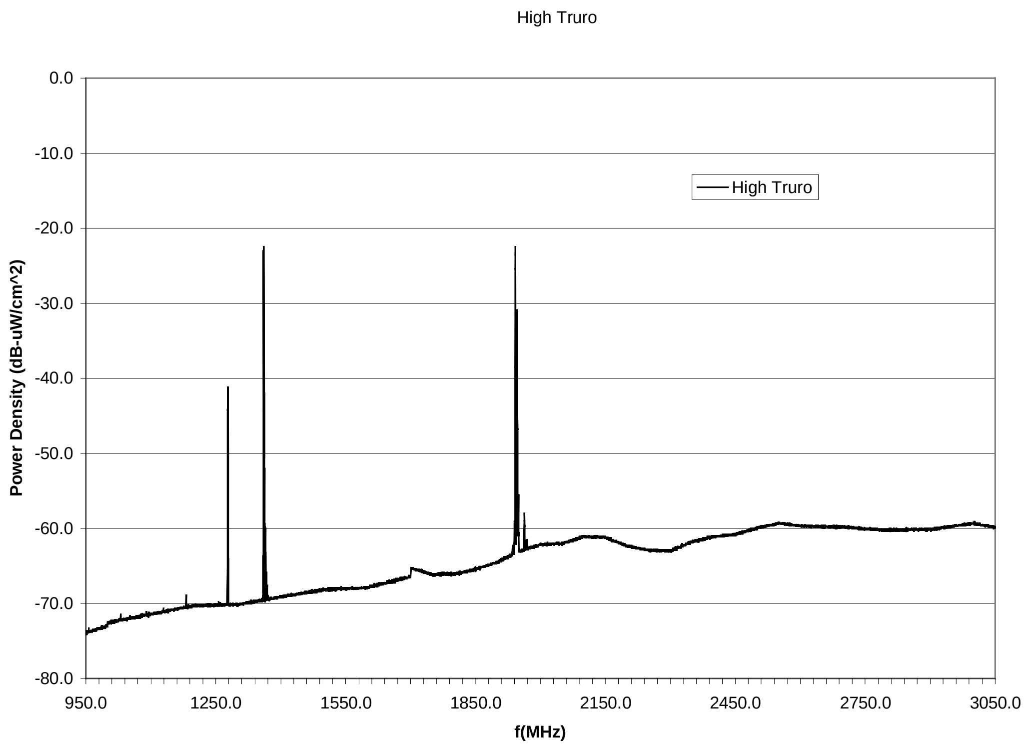
3050.0
f(MHz)


High Truro
High Truro
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
Power Density (dB-uW/cm^2)
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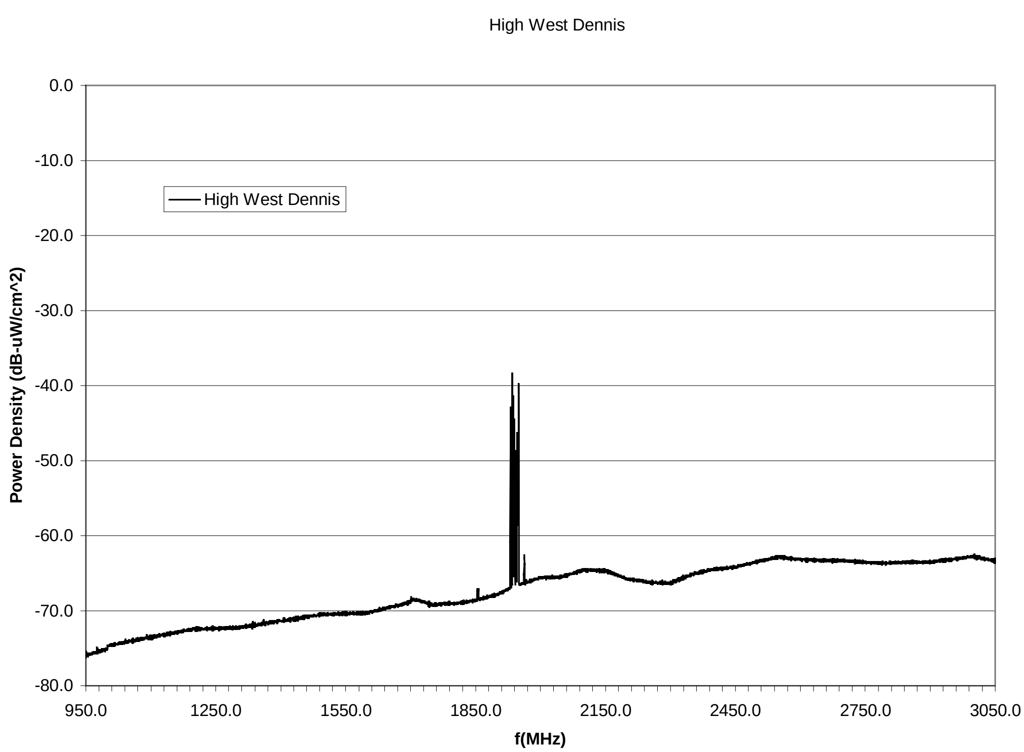
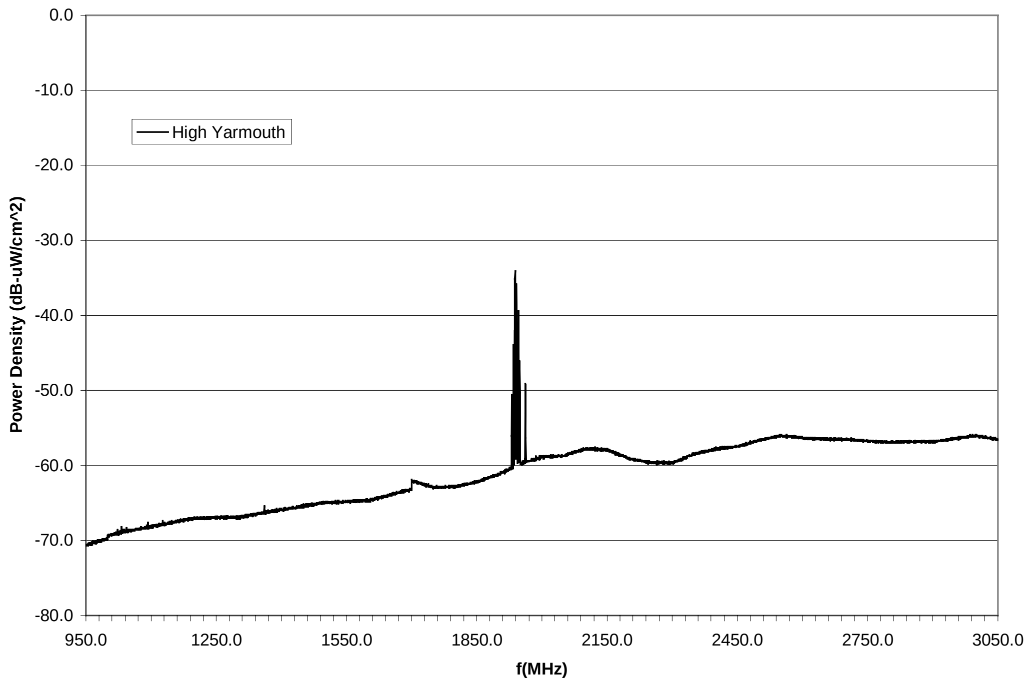
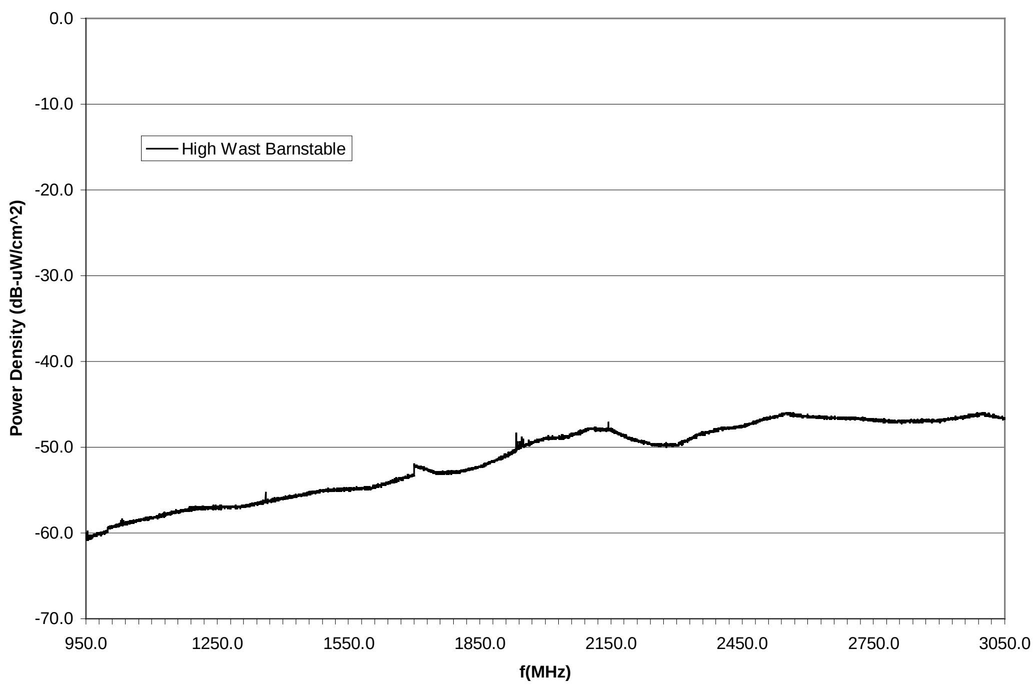
3050.0
f(MHz)

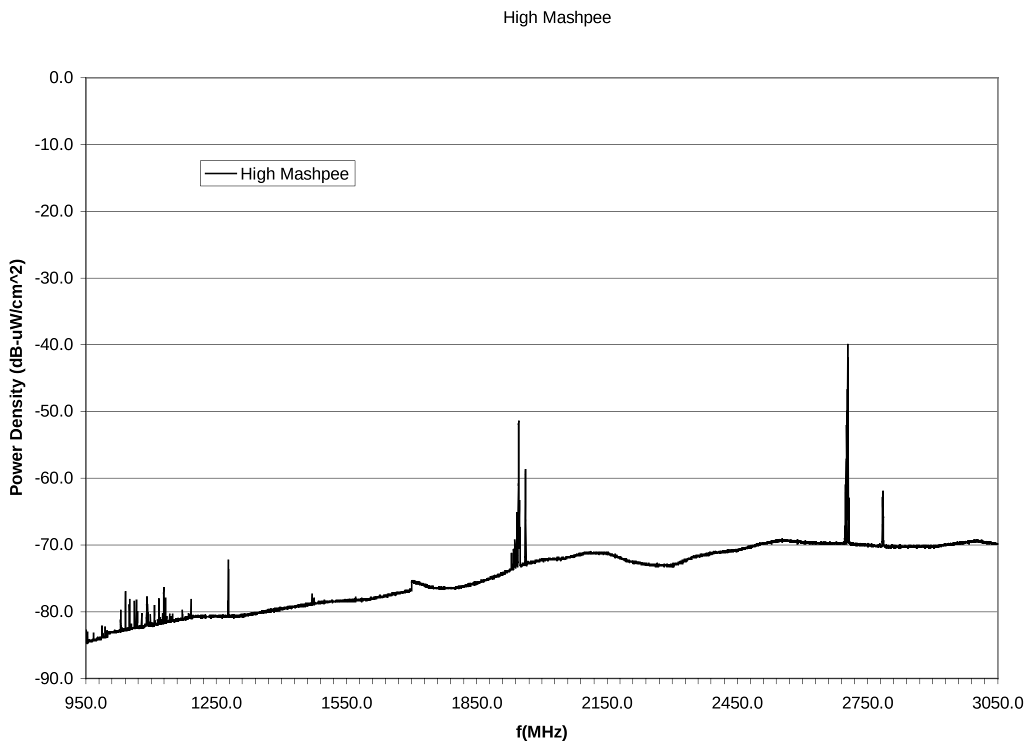

High West Dennis
High West Dennis
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
Power Density (dB-uW/cm^2)
950.0
1250.0
1550.0
1850.0
2150.0
2450.0
2750.0
3050.0
f(MHz)

High Yarmouth



High Wast Barnstable




High Mashpee
High Mashpee
Power Density (dB-uW/cm^2)
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
950.0
1250.0
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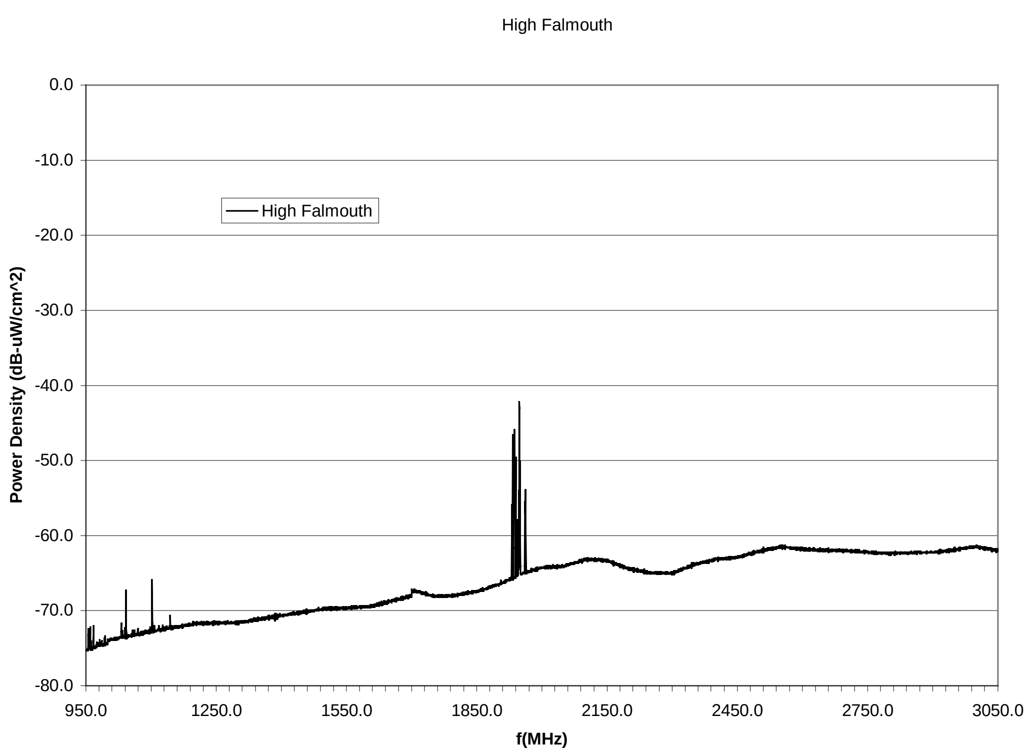
3050.0
f(MHz)


High Falmouth
High Falmouth
Power Density (dB-uW/cm^2)
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
950.0
1250.0
1550.0
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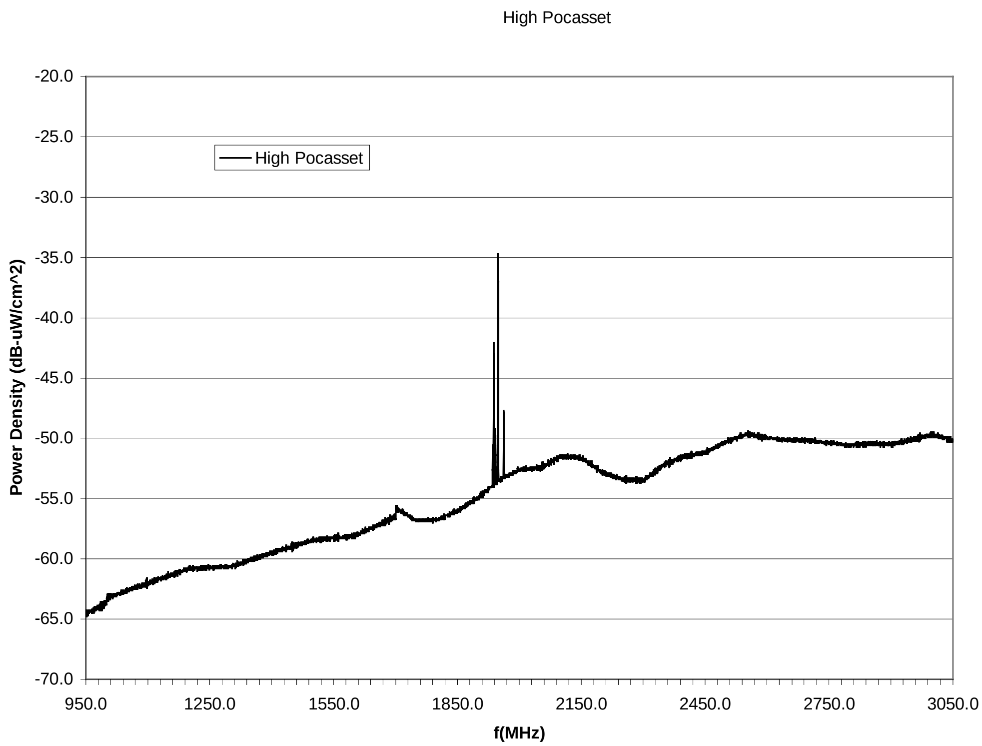
2450.0
2750.0
3050.0
f(MHz)


High Pocasset
High Pocasset
Power Density (dB-uW/cm^2)
-20.0
-25.0
-30.0
-35.0
-40.0
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-50.0
-55.0
-60.0
-65.0
-70.0
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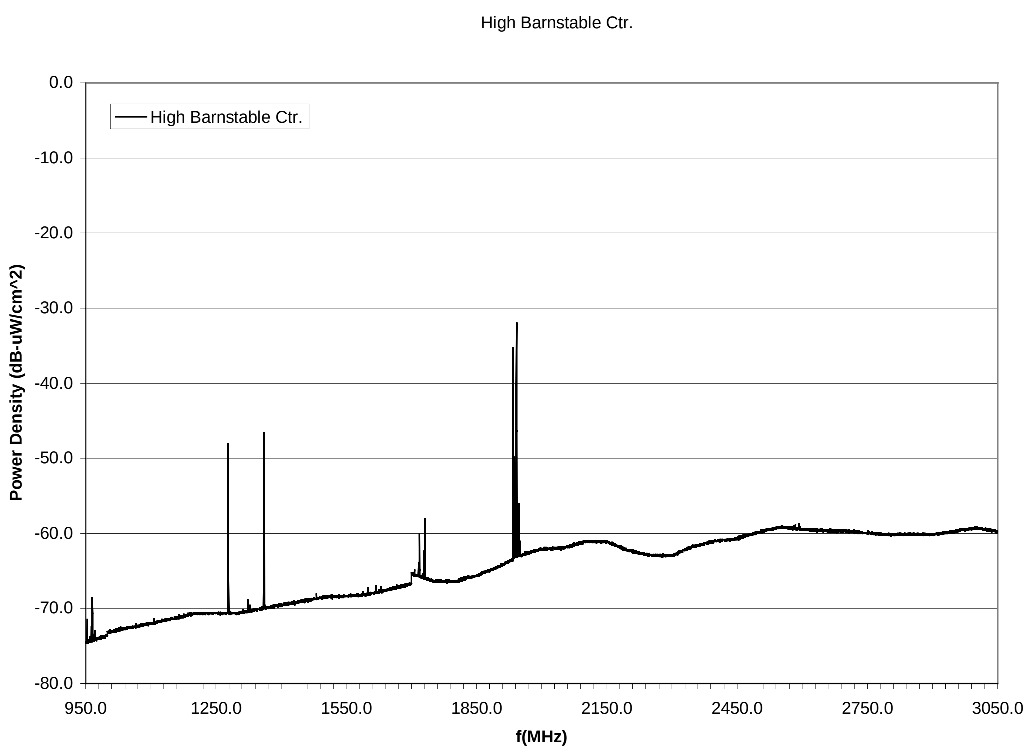
3050.0
f(MHz)


High Barnstable Ctr.
High Barnstable Ctr.
Power Density (dB-uW/cm^2)
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
950.0
1250.0
1550.0
1850.0
2150.0
2450.0
2750.0
3050.0
f(MHz)

Appendix M
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