SUSCEPTIBILITY OF A DIGITAL TURBINE CONTROL SYSTEM TO IEEE 802.11 COMPLIANT EMISSIONS

Clinton E. Carter, B.S.N.E., P.E.

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APPROVED:

Perry R. McNeill, Major Professor
Albert Grubbs, Committee Member
Roman Stemprok, Committee Member
Stephen Ellis, TXU Comanche Peak, Industry Representative
Sandra L. Terrell, Interim Dean of the Robert B. Toulouse School of Graduate Studies

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Within the nuclear industry, there have been numerous instances of radio transmissions interfering with sensitive plant equipment. Instances documented vary from minor instrument fluctuations to major plant transients including reactor trips. With the nuclear power industry moving toward digital technologies for control and reactor protection systems, concern exists regarding their potential susceptibility to contemporary wireless telecommunications technologies.

This study evaluates the susceptibility of Comanche Peak's planned turbine controls upgrade to IEEE 802.11 compliant wireless radio emissions. The study includes a review of previous research, industry emissions standards, and technical overview of the various IEEE 802.11 protocols and details the testing methodology utilized to evaluate the digital control system.

The results of this study concluded that the subject digital control system was unaffected by IEEE 802.11 compliant emissions even when the transmitter was in direct contact with sensitive components.

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF ILLUSTRATIONS

Figure Page

CHAPTER 1

INTRODUCTION

With the nuclear power industry moving toward digital technologies for control and reactor protection systems, concern exists within the nuclear community regarding whether the emissions from higher frequency contemporary wireless telecommunications and mobile computing technologies could interfere with digital systems [1]. The purpose of this research is to evaluate the susceptibility of a planned digital turbine controls upgrade at the Comanche Peak Steam Electric Station to IEEE 802.11 compliant wireless radio emissions.

The Comanche Peak Steam Electric Station is a nuclear generation facility owned and operated by TXU Energy. Comanche Peak is a dual unit facility located eighty-five miles southwest of Dallas, Texas. Each unit is a Westinghouse four-loop pressurized water reactor (PWR) design. The station has been in commercial operation for approximately twelve years. As a consequence of equipment aging and obsolescence concerns, Comanche Peak is in the midst of upgrading analog station controls and communication systems with contemporary digital technologies.

Project Saturn is an initiative presently underway at Comanche Peak to replace the main turbine control and protection systems of both units with digital controls. The first phase of Project Saturn will be implemented on Unit 2 during the fall refueling outage of 2003. The first phase will replace the analog control circuitry of the main turbine control with digital controls.

There have been numerous instances of radio transmissions interfering with sensitive plant equipment within the nuclear industry [2]. Instances documented vary from minor instrument fluctuations to major plant transients including reactor trips. Most of the experiences documented to date have involved portable radio devices operating in lower frequency bands.

Purpose of the Study

The purpose of this research is to determine the susceptibility of the planned digital turbine controls upgrade at the Comanche Peak Steam Electric Station to the Institute of Electrical and Electronics Engineers (IEEE) IEEE 802.11a, b and g radio emissions.

Statement of the Problem

Within the nuclear industry, there have been numerous instances of radio transmissions interfering with sensitive plant equipment. Instances documented vary from minor instrument fluctuations to major plant transients including reactor trips. With the nuclear power industry moving toward digital technologies for control and reactor protection systems, concern exists regarding their potential susceptibility to contemporary wireless telecommunications technologies.

Current guidelines may be too restrictive when considering higher frequency and lower power telecommunications technologies [3]. This situation limits operational flexibility by the unnecessary establishment and size of exclusion zones in a power plant [4].

Significance of the Study

An upgrade to Comanche Peak's telecommunications infrastructure is underway in parallel with plant controls upgrades [5]. The Integrated Communications Network (ICN) will eventually provide for voice, data and video communications at Comanche Peak. A key aspect of the ICN will be the ability to establish a wireless connection with the network thus enabling mobile computing applications, enhanced equipment monitoring and improved workforce productivity. The wireless components of the network are based on standards established by the Institute of Electrical and Electronics Engineers (IEEE).

Aging and obsolescence of analog control systems is an issue throughout the nuclear industry. The accepted strategy employed throughout the industry is to replace antiquated equipment with state of the art digital systems. The potential for interference from external sources must be thoroughly understood as digital components become more prevalent in nuclear plants.

Research Question

The focus of the research documented in this thesis is to address the following question: Do the various protocols under the IEEE 802.11 standard affect a typical digital control system in a nuclear power application?

> Null: The protocols within IEEE 802.11 have no noticeable effect on the output of the digital control system evaluated.
>
> $H_0 : \mu_{bkgd} = \mu_{802.11b} = \mu_{802.11a} = \mu_{802.11g}$
>
> Alternative: The protocols within the IEEE 802.11 standard have a noticeable effect on the digital control system evaluated.
>
> $H_1 : \mu_{bkgd} \neq \mu_{802.11b} \neq \mu_{802.11a} \neq \mu_{802.11g}$

Assumptions

1. All test equipment did not drift from calibration tolerances during experimentation.
2. Temperature and humidity were constant throughout the experimentation.
3. Background radio emissions were constant throughout experimentation.
4. Contributions from background emissions were negligible.

Limitations

Research performed was limited to those frequencies and protocols as described within the IEEE 802.11standard. All experimentation was conducted in a laboratory environment, away from the physical nuclear plant. Background emission levels within the laboratory were measured but could not be eliminated as the control system could not be isolated due to its size and simulation set-up complexity. Experimentation performed was limited to a single digital control system. Therefore, the results of this experiment should not be construed as to apply generically to other control systems.

CHAPTER 2

REVIEW OF LITERATURE

Principals of Electromagnetic Interference.

Radio signals are electromagnetic waves with both electrical and magnetic properties [13]. The magnetic and electrical fields of a radio wave are perpendicular to one another and oscillate as they propagate from their source. To describe radio signal propagation, it is convenient to consider the transmitter, or antenna, as a point source radiating isotropically. The radio wave can be viewed as a spherical emission radiating ever outward from its point of origin. The power density at any distance along the spherical wavefront is given by the equation [7]:

$$P_a = P_{rad} / 4\pi R^2 \quad (1)$$

Where: P_{rad} = total radiated power (watts)

R = radius of the spherical wave (meters).

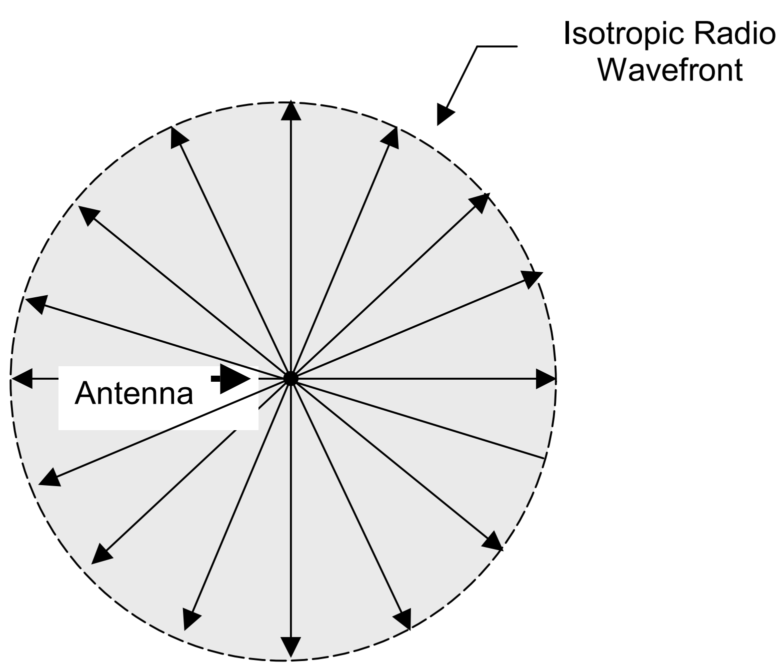

Fig. 1. Isotropic Propagation of a Point Source Radio Wave

Power density is reduced as waves propagate. Attenuation is a result of radio wave spherical spreading as it radiates outward. Wave attenuation between any two points can be defined by the following equation [7] [8]:

$$\lambda_{atten} = 10\log(P1\backslash P2) \text{ (dB)} \qquad (2)$$

Where: P1 = power density at point 1 (watts\m^2)

P2 = power density at point 2 (watts\m^2).

Radiation coupling is a mechanism where electric or magnetic field strengths of a propagating wave impart energy on components they encounter. The region close to the source is known as the near, or induction, field. This field is the region of most concern. The region farther away is known as the far, or radiation, field. The transition region between the near and far fields is where the observation point is distance r equal to the wavelength λ divided by 2π:

$$r = (\lambda/2\pi). \qquad (3)$$

Field wave impedance varies with distance and is dependent on whether the field is electric or magnetic. Wave impedance in the far field, ($r>\lambda/2\pi$) is equal to the characteristic impedance of the medium through which the field is propagating (e.g., 377Ω in air and free space) [9]. Both the electric and magnetic field strengths fall off as 1/r in the far field, i.e., in inverse proportion to distance. Propagation of wave impedance in the near field is determined by characteristics of the source and distance from the source. If the source impedance is high in the near field compared to free space, the electric and magnetic field strengths attenuate at rates $1/r^3$ and $1/r^2$, respectively. If the source impedance is low in comparison, the rates of attenuation are reversed: the electric field strength will fall off at a rate of $1/r^2$ and the magnetic field strength at a rate of $1/r^3$. The transition between far and near fields for the IEEE 802.11 protocols are calculated in Appendix C.

EPRI Methodology

The Electric Power Research Institute in April, 1996 published Technical Report TR-102323, *Guidelines for Electromagnetic Interference Testing of Power Plant Equipment* [3]. The purpose of the report was to provide guidance to ensure electromagnetic compatibility of safety-related digital equipment in nuclear plants. Revisions to the document were published in 1997 and 2000. TR-102323 has become the defacto standard within the industry to implement the regulatory requirements prescribed by the Nuclear Regulatory Commission in Reg. Guide 1.180 *Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation and Control Systems* [10]. The document details the process for identifying emission sources in nuclear power plants, recommends susceptibility and emissions standards and details design and layout practices for minimizing susceptibility to electromagnetic interference. Recommended limiting practices to bound and control equipment emissions for new EMI/RFI sources introduced into the plant environment are of particular interest. These limiting practices are a set of design conditions that should be satisfied to ensure new equipment emissions remain below designated susceptibility limits. Equipment can be installed without concern for affecting other plant equipment for equipment emissions determined to be below these limits. If on the other hand, emissions are determined to be above recommended limits, additional engineering analyses and site surveys are prescribed before the equipment could be installed in the plant. The practices as outlined in the report, apply to all new safety-related plant modifications that include analog, digital and hybrid systems and components. The guidelines are further extended to non-safety related systems whose operation can affect safety-related systems or components and those deemed important for power production.

TR-102323 establishes administrative controls to protect sensitive plant equipment from portable transceivers such as cell phones and two-way radios. These administrative controls are in the form of exclusion zones. The size of the exclusion zone is dependent on the effective radiated power and antenna gain of the emitter. The size of an exclusion zone also depends on the allowable electric field emission levels designated in the area of the installed equipment. An 8 dB difference should be maintained between the susceptibility operating envelope and the allowed emissions level. TR-102323 specifies the maximum allowed emission level of any transmitter to be 4 V/m to satisfy the 8 dB margin. The minimum distance of an exclusion zone, in meters, is calculated by:

$$d = (30PG)^{0.5} / E \qquad (4)$$

Where: P = the effective radiated power of the EMI/RFI emitter {watts}

G = the gain of the antenna

E = the allowable electric field strength of the emitter at the point of installation {volts/meter}.

The above calculation is considered to provide a conservative margin to prevent equipment interference. One calculates the minimum exclusion distance using the EPRI methodology by solving equation (4) given a specified radiated power level, antenna gain and assigning an electric field strength of 4 volts/meter. The resultant transceiver exclusion distance provides assurance that at least an 8 dB margin is maintained between transceiver emissions and recommended equipment susceptibility levels.

Previous Research

The earliest research into nuclear plant equipment interference potential from IEEE 802.11 emissions performed at Comanche Peak was in the spring of 2000 [11]. Researchers evaluated the effects of 802.11 and 802.11b emissions on known sensitive plant equipment in order to identify any possible interference issues. All testing was performed in a laboratory environment away from the actual plant. The training laboratory provided the capability to energize and evaluate analog equipment identical to that currently installed in the plant. Components evaluated were those available at the plant's training facility. These included components from the following plant systems: Rod Control System, Nuclear Instrumentation System, Solid State Protection System, Digital Rod Position Indication System, 7300 process control and protection equipment and various plant instrumentation. Most of the components tested did not react to the 802.11 emissions, however, the study did reveal some interference issues associated with two pressure transmitters. The Rosemount transmitter was exposed to an 802.11b signal at a power of 100 mW. At a distance of one inch from the exposed sensing element, the transmitter output was deflected +/- 3 mV DC. No deflection of the output was observed on contact when the sensing element cover was replaced. The second transmitter was a Barton model 763. A one milliamp deflection was noted at 4 inches from the device with the cover off. Similar to the Rosemount transmitter, no deflection was noted when the cover was in place.

Another study was conducted in the fall of 2001 at Wyle Laboratories [12] [13]. The Wyle experiment was designed to evaluate electromagnetic interference effects of high frequency wireless communications systems. Wyle's report documents the results of testing performed on two nuclear plant devices. The first device was a Rosemount Model

3051CA1A22AA1AA0131 pressure transmitter and the second was a Powers Process Controls Model 535 Process Controller. The test subjected these devices to IEEE 802.11 and IEEE 802.11b radio signals in addition to other high frequency emissions. The Wyle study included a Siemens Model 240 direct sequence cordless telephone, a Siemens model 4010 frequency hopping cordless telephone and a 3COM IEEE 802.11b LAN card communication with a 3COM wireless gateway. The study concluded that the subject devices were immune to IEEE 802.11 signals at emission levels up to the testing limit of 100 volts/meter. The study did note that the Rosemount transmitter was susceptible to interference when the cover was removed.

Characterization of IEEE 802.11 Radio Signals

There are four major protocols within the IEEE 802.11 Standard. Each protocol along with key attributes is listed in Table 1 below [14] [15].

Table 1.
IEEE 802.11 Protocols - Key Attributes

Technology	Frequency Band	Power Output	Modulation	Data Rate	Transmission Protocol
802.11	902-928 MHz	500 mW	GFSK	1 Mbps	FHSS
	2.4-2.4834 GHz	500 mW	GFSK	2 Mbps	FHSS
802.11b	2412.-2.462 GHz	100 mW	DPSK	1 Mbps	DSSS
		100 mW	DQPSK	2 Mbps	DSSS
		100 mW	CCK	5.5 Mbps	DSSS
		100 mW	CCK	11 Mbps	DSSS
802.11a	5.15-5.35 GHz	100 mW	BPSK	9 Mbps	OFDM
		100 mW	QPSK	18 Mbps	OFDM
		100 mW	16-QAM	36 Mbps	OFDM
		100 mW	64-QAM	54 Mbps	OFDM
802.11g	2.400-2.4836	100 mW	16-QAM	36 Mbps	OFDM
		100 mW	64-QAM	54 Mbps	OFDM
		100 mW	PBCC	22 Mbps	OFDM

The original protocol was a frequency hopping spread spectrum technology (FHSS) which was ratified in 1997 by the IEEE 802.11 Committee. Referred to as simply IEEE 802.11, this technology operates over two frequency bands: 902-928 MHz and 2.4-2.4835 GHz. The available bandwidth is sub-divided into 79 channels. The signal hops from one channel to another as it is transmitted based on a predetermined hopping pattern. The maximum throughput of an 802.11 FHSS signal is 2 Mbps. The maximum power emission from an 802.11 compliant device is 500 mW.

The 802.11 FHSS held the dominant share of the wireless market in 2001 [16]. Today, the trend is away from this original form of wireless networking technology in favor of the higher throughput associated with IEEE 802.11 b, g and a. For this reason, 802.11 FHSS was not included in the scope of testing as a part of this research. Table 1 summarizes IEEE 802.11 key attributes.

The most prevalent wireless LAN networking technology, according to Wi-Fi Planet, a web service dedicated to the advancement of IEEE 802.11 business and technology, is IEEE 802.11b [17]. IEEE 802.11b is a direct sequence spread spectrum technology operating over a frequency range of 2.412-2.462 GHz. Maximum power output of IEEE 802.11 compliant devices is 100 mW. IEEE 802.11b spreads the carrier signal energy across a 30 MHz spectrum. This approach tends to improve signal resilience to interference on a single frequency. A number of modulation schemes are used by the protocol depending on the data transfer rate. Data rates available under the 802.11b standard are 11, 5.5, 2 and 1 Mbps. The first two listed utilize Complimentary Code Keying (CCK) modulation, which is a form of Quadrature Phase-Shift Keying (QPSK) [14]. The 2 Mbps data transfer rate utilizes Differential Quadrature Phase-Shift Keying (DQPSK). The 1 Mbps data transfer rate utilizes Differential Binary Phase-Shift Keying (DBPSK). The modulation scheme utilized by the transmitting device is determined by the signal strength of the link to another transceiver. Table 1 summarizes IEEE 802.11b key attributes.

IEEE 802.11a is growing in popularity and is expected to eventually replace 802.11b as the leading wireless LAN technology. This change is due to improved data throughput of 54 Mbps over 802.11b's 11 Mbps. This standard operates over a frequency range of 5.15-5.35 GHz with a maximum allowed output of 100 mW for commercial LAN networking devices. IEEE 802.11a utilizes Orthogonal Frequency Division Multiplexing (OFDM) technology to spread the data across 52 carriers. Carriers are spaced apart at precise intervals of 312.5 kHz. This procedure provides the orthogonality to allow the receiver to efficiently reassemble the transmitted signal without undue corruption from other potentially interfering frequencies. Spreading the spectrum across a number of carriers also makes the signal less sensitive to multipath interference. Modulation schemes and corresponding data transfer rates vary similarly to 802.11b based on the signal strength between associated transceivers. Data transfer rates are 54, 36, 18 and 9 Mbps. Modulation schemes are 64-QAM, 16-QAM, QPSK and BPSK respectively. Table 1 summarizes IEEE 802.11a key attributes.

IEEE 802.11g is not a ratified standard. However, commercial products are available that utilized earlier drafts of the standard as a guideline. IEEE 802.11g has gained popularity as it is both backwards compatible with IEEE 802.11b and forward compatible with IEEE 802.11a. IEEE 802.11g supports data throughput up to 54 Mbps. 802.11g utilizes the same modulation schemes at higher data rates as does 802.11a. At 22 Mbps, 802.11g utilizes Packet Binary Convolutional Coding (PBCC). IEEE 802.11g key attributes are summarized in Table 1.

CHAPTER 3

METHODOLOGY

Research Design

The research method employed was experimental. The overall approach to the experimentation was to energize the digital turbine control system and establish simulated conditions equivalent to 100 % power, steady state conditions. Figure 2 provides an overview of the digital control system as it appeared during experimentation within Comanche Peak's digital laboratory.

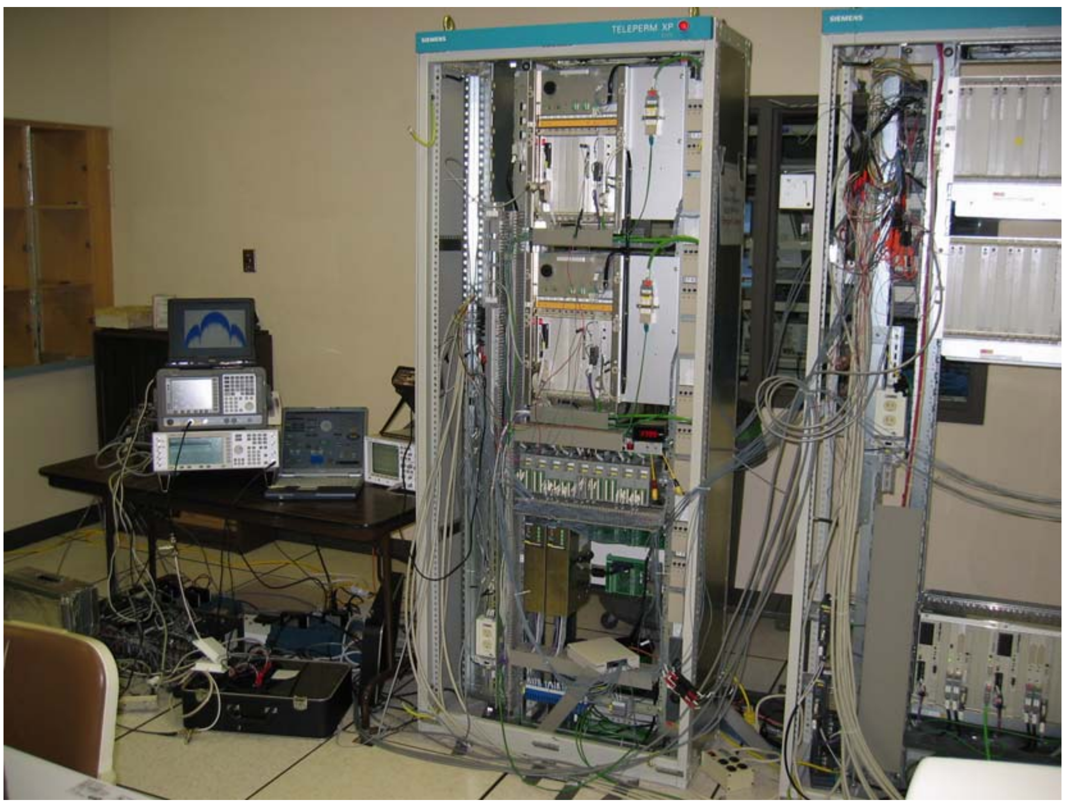

Fig. 2. Overview of Digital Controls Lab

A close up of the control system cabinet as viewed from the front appears in Figure 3.

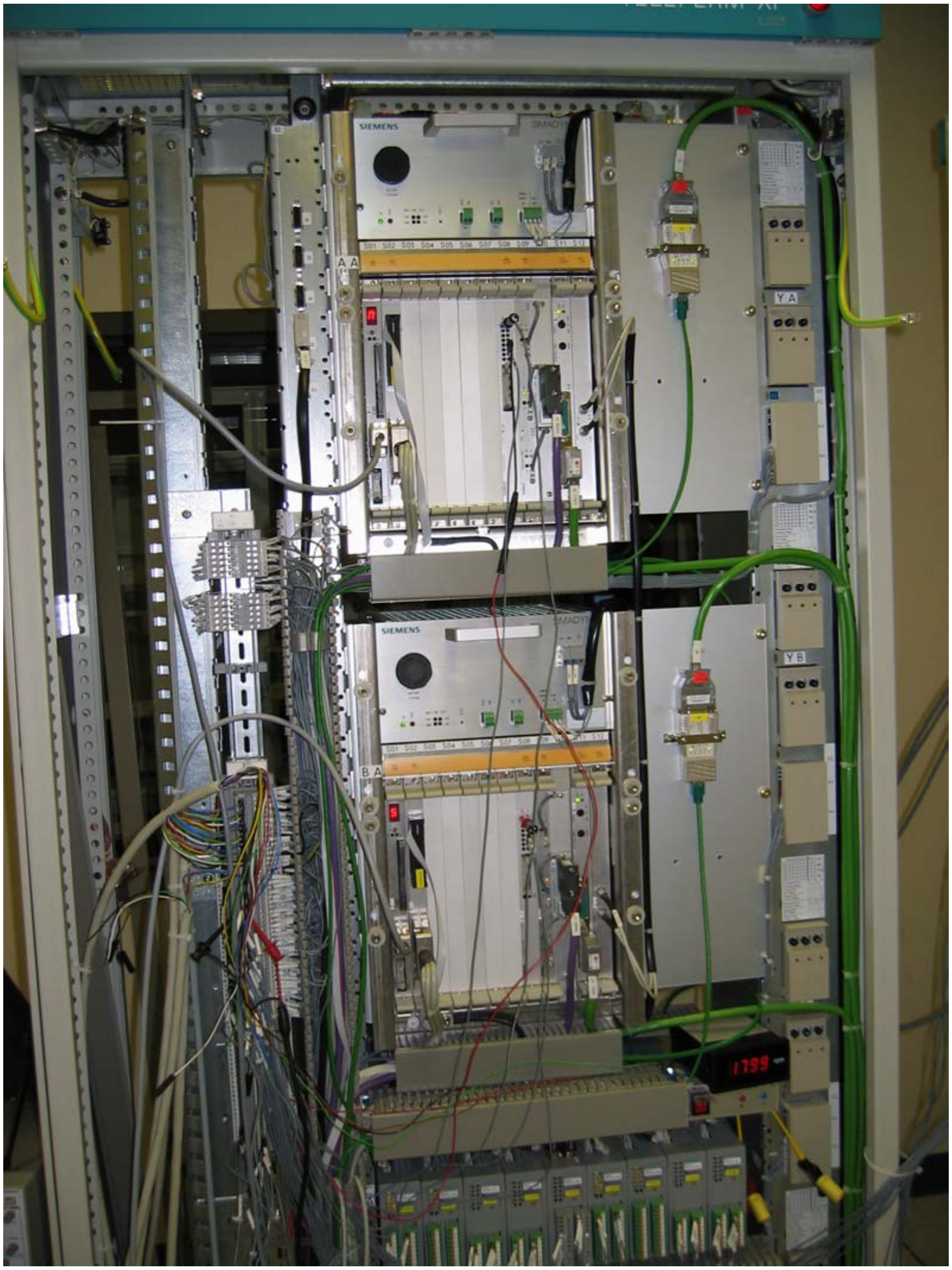

Fig. 3. Front View of Siemens Digital Control System

The control system cabinet, internal components and wiring were exposed to IEEE 802.11a, b and g compliant radio signals once initial conditions were established. The signals represented various frequencies and modulation schemes within the standard. Control system output was monitored for any variance when subjected to these radio signals from various distances including direct contact with internal equipment. Signal transmission began in the far field and moved inward at approximately one inch per second through the near field up to direct contact. If any control system output displacement was noted, the approach was to measure the distance at which the interference was first observable along with the signal strength at the same distance. The degree of interference would be measured as the transmitter was moved in one inch increments until contact with the target. Figure 4 illustrates the basic setup.

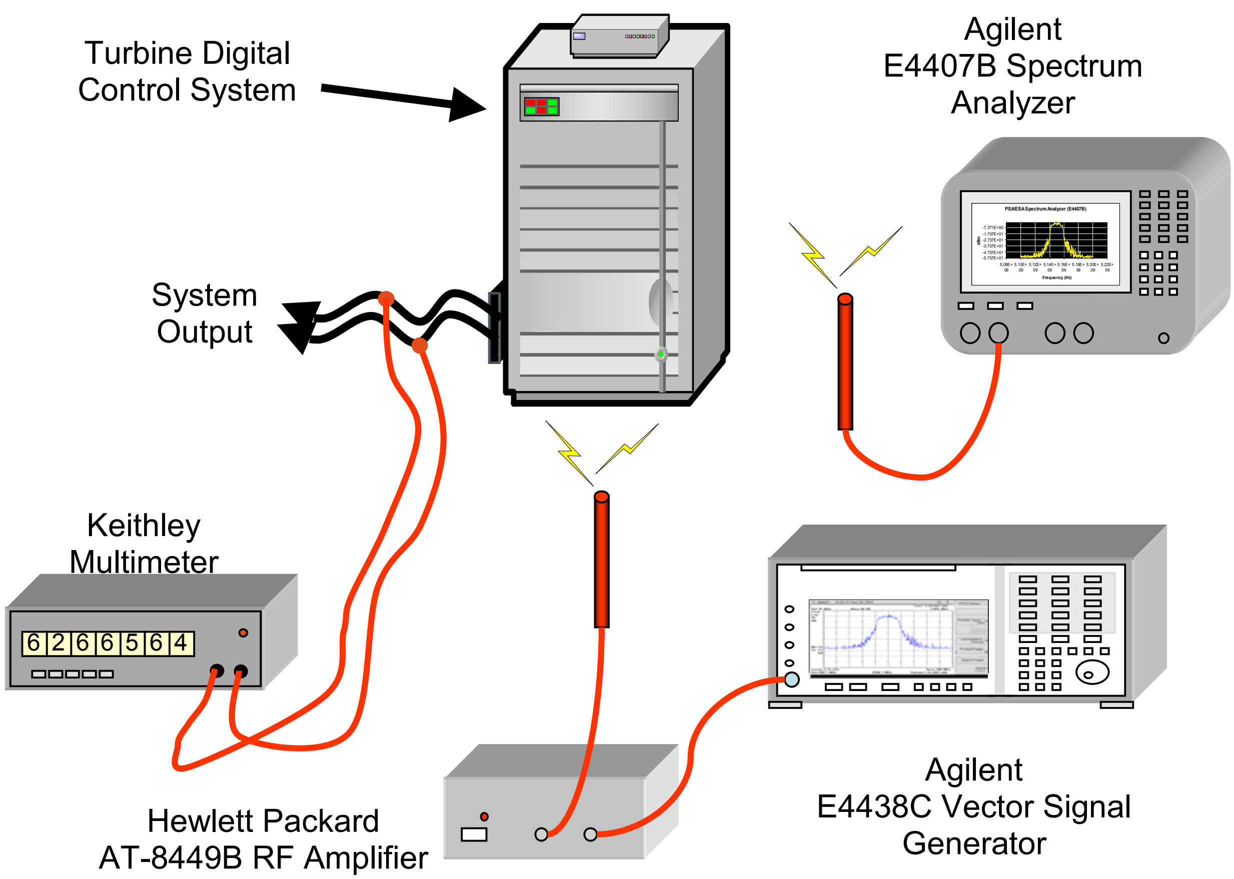

Fig. 4. Experimental Configuration for EMI Evaluation

Frequency and signal strength, and various modulation schemes would be evaluated if interference was indicated at a given distance,. This would provide indication as to whether the interference was strictly power and frequency dependent or is the signal spreading and modulation contributing to the issue. For example, if the research concluded that DBPSK modulation of an IEEE 802.11b signal caused interference, firmware enhancements could be recommended to eliminate this particular modulation technique from networking equipment to be deployed in the power plant. Frequency, power and distance recommendations could be made for providing exclusion distances from sensitive plant equipment should interference be observed. Control system output data was still recorded and evaluated at contact if no interference was indicated.

Dr. Robert L. Getty was consulted to determine an appropriate methodology for evaluate the data collected, the number of samples for each treatment and the appropriate significance level to be assigned. Dr. Getty recommended a single factor ANOVA statistical analysis was to evaluate the means of various treatments in contrast to control system output in the absence of 802.11 signals.

The test parameters for each signal evaluated are listed in Table 2 below.

Table 2.
IEEE 802.11 Test Parameters

IEEE Standard	Frequency Band (GHz)	Tested Freq. (GHz)	Min. Power Output (MW)	Modulation	Data Rates (Mbps)	Physical Layer	Device	Signal Studio File Name
802.11b	2412.-2.462	2.412	100	DPSK	1	DSSS	E4438C	B2412DBPSK
802.11b	2412.-2.462	2.412	100	DQPSK	2	DSSS	E4438C	B2412DQPSK
802.11b	2412.-2.462	2.412	100	CCK	5.5	DSSS	E4438C	B2412CCK
802.11b	2412.-2.462	2.412	100	CCK	11	DSSS	E4438C	B2412CCK11
802.11b	2412.-2.462	2.427	100	DPSK	1	DSSS	E4438C	B2427DBPSK
802.11b	2412.-2.462	2.427	100	DQPSK	2	DSSS	E4438C	B2427DQPSK
802.11b	2412.-2.462	2.427	100	CCK	5.5	DSSS	E4438C	B2427CCK
802.11b	2412.-2.462	2.427	100	CCK	11	DSSS	E4438C	B2427CCK11
802.11b	2412.-2.462	2.447	100	DPSK	1	DSSS	E4438C	B2447DBPSK
802.11b	2412.-2.462	2.447	100	DQPSK	2	DSSS	E4438C	B2447DQPSK
802.11b	2412.-2.462	2.447	100	CCK	5.5	DSSS	E4438C	B2447CCK
802.11b	2412.-2.462	2.447	100	CCK	11	DSSS	E4438C	B2447CCK11
802.11b	2412.-2.462	2.462	100	DPSK	1	DSSS	E4438C	B2462DBPSK
802.11b	2412.-2.462	2.462	100	DQPSK	2	DSSS	E4438C	B2462DQPSK
802.11b	2412.-2.462	2.462	100	CCK	5.5	DSSS	E4438C	B2462CCK
802.11b	2412.-2.462	2.462	100	CCK	11	DSSS	E4438C	B2462CCK11
802.11a	5.150-5.350	5.15	100	BPSK	9	OFDM	E4438C	A515BPSK
802.11a	5.150-5.350	5.2	100	QPSK	18	OFDM	E4438C	A52QPSK18
802.11a	5.150-5.350	5.25	100	16-QAM	36	OFDM	E4438C	A5216QAM36
802.11a	2.400-2.4835	5.35	100	64-QAM	54	OFDM	E4438C	A53564QAM54
802.11g	2.400-2.4835	2.462	100	16-QAM	36	OFDM	E4438C	G246216QAM
802.11g	2.400-2.4835	2.462	100	64-QAM	54	OFDM	E4438C	G246264QAM
802.11g	2.400-2.4835	2.462	100	PBCC	22	OFDM	E4438C	G2462PBCC

The test procedure utilized during experimentation may be found in Appendix A.

Test Equipment and Software

The details of the desired experimentation were reviewed with Raul Sierra, of Agilent Technologies. Mr. Sierra, an engineering consultant, recommended and approved the experimentation design including: software, equipment and system integration [18]. All IEEE 802.11 compliant test signals were constructed using the Agilent Signal Studio for 802.11 WLAN, revision A.01.44 [14]. This software package allows the user to construct IEEE 802.11a, b and g compliant personalities incorporating the various modulation schemes available within the standards. A Dell Latitude laptop computer running Microsoft Windows 98 was used to run the software and store all output data from the experiment. The signals were downloaded to an Agilent E4438C ESG Vector Signal Generator over an Agilent 82357A USB/GPIB Interface Cable. The calibration certificate for the E4438C as well as all other calibration certificates, may be found in Appendix F. The signal generator was configured using E4438C Option 417 which is a software upgrade package specifically designed for IEEE 802.11 signal generation and waveform modulation. The E4438C design limit required an in line amplifier to be utilized in order to achieve a 100 mW output signal. A Hewlett Packard Model 8449B preamplifier was employed to acquire the desired output power. Figure 5 provides an overview of the test equipment utilized:

Fig. 5. View of Test Equipment Set-up

IEEE 802.11b and g radio signals produced by the signal generator were broadcast over a Hyperlink Technologies Model HG2409P 8 dBi antenna. This antenna was designed for a frequency range of 2.4 to 2.5 MHz. IEEE 802.11a radio signals were broadcast over a Hyperlink Technologies Model HG5308P 8 dBi antenna. For the higher frequencies of the IEEE 802.11a standard, a Hyperlink Technologies Model HG5308P 8 dBi antenna was utilized. The antenna data sheets may be found in Appendix G. The antennas were connected to the E4438C signal generator over a standard RG 58 C/U cable using standard type-N and BNC connectors. The cables were assembled according to the manufacturer's specifications. The cable assemblies contributed to a loss of 0.5 dBm as measured over a direct connection to the spectrum analyzer.

Digital control system output was measured using a Keithley 197 Autoranging Microvolt DMM multimeter. The device was calibrated in accordance with TXU Comanche Peak procedures with a calibration due date of 8/28/03 as represented by the affixed calibration sticker observed during testing.

Signal strength was measured and recorded using an Agilent Technologies E4407B ESA E Series Spectrum Analyzer to document actual signal strength associated with any deflection in control system output. The calibration certificate may be found in Appendix F. Antennas connected to the spectrum analyzer were the same as those previously discussed above utilizing the same cabling scheme.

CHAPTER 4

ANALYSIS AND RESULTS

The methodology of data analysis as described in this section was specified by Dr. Robert Getty, Assistant Professor of Management Science at the University of North Texas. Three sets of digital control system output data were collected. Each set included 25 data points. A single factor Analysis of Variance (ANOVA) statistical analysis was performed to verify output stability [19].

Table 3.
Results of ANOVA Analysis of Control System Output – Background Conditions

ANOVA	Alpha = 0.01					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.26666E-05	2	4.13333E-05	0.288595504	0.750177915	4.912692475
Within Groups	0.010312	72	0.000143222			
Total	0.010394667	74				

For a significance level of 0.01, the probability value was calculated to be 0.75 which provided indication of very stable background conditions. Each treatment was measured at one inch from the front of the system's internal central processing unit. Twenty-five data points were recorded for each of the 23 treatments. An ANOVA analysis was performed that included all experimental treatments as well as the three original background measurements discussed above. The results appear in Table 4.

Table 4.
Results of ANOVA Analysis of Control System Output Subjected to IEEE 802.11 Signals

ANOVA	Alpha = 0.01					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.005432962	25	0.000217318	1.549578705	0.043516358	1.802924032
Within Groups	0.087512	624	0.000140244			
Total	0.092944962	649				

The probability value was calculated to be 0.0435 with a significance level of 0.01 which indicates with 99% confidence that the results fail to reject the null hypothesis:

$$H_0 : \mu_{bkgd} = \mu_{802.11b} = \mu_{802.11a} = \mu_{802.11g.}$$

It was therefore concluded with 99% confidence based on the results of statistical analysis that the subject turbine control system was unaffected by IEEE 802.11 emissions.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research was to evaluate the susceptibility of the planned digital turbine controls upgrade at the Comanche Peak Steam Electric Station to IEEE 802.11a, b and g radio emissions.

Conclusion

The results of statistical analysis failed to disprove the null hypothesis. It is concluded with 99% confidence, based on statistical analysis that this experimentation failed to disprove the null hypothesis. The system was subjected to radio transmissions from far and near fields, on contact with key components and exposed cabling and throughout the cabinet internals. It is concluded that Comanche Peak's digital control system was unaffected by IEEE 802.11 compliant radio emissions during experimentation.

Recommendation

1. The Electric Power Research Institute (EPRI) should consider performing similar testing on digital control systems being deployed in the nuclear industry to more fully characterize susceptibility to high frequency radio emissions.

APPENDIX A

TEST PROCEDURE 802.11

Test Procedure 802.11

Test Date: 07/19/2003

1) Set-up the Agilent Vector Signal Generator, Model E4407B as follows:

    a) Enable WLAN Option 417.

    b) Center Frequency = Frequency being tested.

    c) Attenuation in Auto.

    d) Signal Tracking and CF step to manual.

    e) Adjust resultant output to ~20 dB as measured over cable connection to the E4407B spectrum analyzer through the HP 8449B preamplifier.

    E4438C Signal Generator Output: 13.0 dB

    E4407B Spectrum Analyzer Reading: 19.5 dB

2) Connect antennas to instrument cabling. Optimize input measurement. Measure and record background radio emissions on the Agilent ESA Series Spectrum Analyzer, Model E4407B. Save as an Excel file. File Name: Bkgrnd mmddyy and save to laptop.

3) Measure and record representative 802.11 a, g and b signal strengths at 1 meter and 1 inch from target.

    a) 802.11a: -28.4 dB @ 1 meter

    b) 802.11a: -7.2 dB @ 1 inch

    c) 802.11g: -7.3 dB @ 1 meter

    d) 802.11g: 13.4 dB @ 1 inch

    e) 802.11b: -8.2 dB @ 1 meter

    f) 802.11b 13.5 dB @ 1 inch

4) Set up the digital turbine control system at 100% steady state operation.

Turbine Power: 1190 (MWe)   Turbine Speed: 1800 RPM   Time @ Steady State: 18 Hours

4) Connect the Keithley197 Autoranging Microvolt DMM multimeter to the digital control system output. Record Device Number and Calibration due date.

   Device ID: IC1623   Calibration Due Date: 08/22/03

5) Record digital control system output (mA) on the data sheet. Collect 3 sets of data consisting of 25 readings approximately 10 seconds apart and record as background output, Treatments 24, 25 and 26.

6) Verify output stability by evaluating performing ANOVA statistical analysis on 3 background treatments with an Alpha of 0.01.

SUMMARY Alpha = 0.01				
Groups	*Count*	*Sum*	*Average*	*Variance*
Bkgnd 25	25	1534.35	61.374	0.000183333
Bkgnd 25	25	1534.34	61.3736	0.000157333
Bkgnd 25	25	1534.29	61.3716	8.9E-05

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.26666E-05	2	4.13333E-05	0.288595504	0.750177915	4.912692475
Within Groups	0.010312	72	0.000143222			
Total	0.010394667	74				

7) Input test signals into the E4438C as indicated on Table 2.0.

8) Measure 802.11 a, g and b signal strength at 1 meter and 1 inch from target. Save in file: 1Meter80211x and 1Inch80211x where x is a, b or g, as appropriate.

9) Vary distance from target in incremental distances until deflection beyond the normal output fluctuation band is observed or contact with the target. Begin at the calculated transition boundary between far field and near field. If deflection is noted, move out into

the far field until deflection is no longer observed. See Appendix C for Far Field to Near Field transition calculations.

Near Field Transition 2.5 GHz: __8 (7.83) inches__

Near Field Transition 5.2 GHz: __4 (3.61) inches__

10) Record distance where deflection is observed and measure signal strength at target.
11) Move in at incremental units (inches) until contact recording deflection collecting 10 measurements at each point and record.
12) If no output deflection is noted, then measure output with transmitter at 1 inch from control system processor and record on form.
13) Identify any affected components on data sheet.
14) Testing complete. Secure equipment.

Data Sheet 1 Digital Control System Output Data

Test Date: 07/19/2003

Data	IEEE 802.11b 2.412 GHz Treatments			
	1	2	3	4
	B2412DBPSK	B2412DQPSK	B2412CCK	B2412CCK11
1	61.38	61.38	61.36	61.36
2	61.39	61.37	61.36	61.39
3	61.37	61.37	61.39	61.38
4	61.35	61.37	61.37	61.38
5	61.38	61.38	61.38	61.36
6	61.37	61.35	61.37	61.37
7	61.35	61.37	61.37	61.37
8	61.36	61.38	61.37	61.37
9	61.37	61.38	61.38	61.38
10	61.37	61.37	61.37	61.39
11	61.37	61.38	61.36	61.39
12	61.39	61.39	61.37	61.38
13	61.37	61.38	61.37	61.37
14	61.37	61.38	61.38	61.36
15	61.36	61.37	61.38	61.36
16	61.35	61.37	61.37	61.38
17	61.36	61.38	61.38	61.38
18	61.35	61.37	61.38	61.38
19	61.37	61.37	61.38	61.39
20	61.36	61.36	61.37	61.38
21	61.37	61.39	61.35	61.36
22	61.38	61.36	61.37	61.37
23	61.37	61.37	61.37	61.38
24	61.36	61.39	61.37	61.39
25	61.37	61.39	61.38	61.38

Data Sheet 2 Digital Control System Output Data

Test Date: 07/19/2003

Data	IEEE 802.11b 2.427 GHz Treatments			
	5	6	7	8
	B2427DBPSK	B2427DQPSK	B2427CCK	B2427CCK11
1	61.38	61.37	61.39	61.38
2	61.37	61.37	61.39	61.35
3	61.38	61.38	61.39	61.36
4	61.37	61.39	61.36	61.36
5	61.38	61.37	61.37	61.38
6	61.36	61.37	61.37	61.37
7	61.39	61.36	61.37	61.38
8	61.39	61.37	61.37	61.39
9	61.36	61.37	61.37	61.39
10	61.37	61.36	61.36	61.39
11	61.35	61.37	61.39	61.37
12	61.36	61.39	61.38	61.37
13	61.36	61.38	61.38	61.38
14	61.36	61.38	61.37	61.37
15	61.36	61.35	61.37	61.35
16	61.37	61.37	61.37	61.36
17	61.36	61.37	61.37	61.36
18	61.36	61.36	61.37	61.37
19	61.38	61.37	61.38	61.36
20	61.37	61.37	61.39	61.36
21	61.37	61.38	61.38	61.37
22	61.37	61.39	61.37	61.39
23	61.39	61.38	61.37	61.39
24	61.37	61.39	61.37	61.39
25	61.38	61.38	61.36	61.38

Data Sheet 3 Digital Control System Output Data

Test Date: 07/19/2003

Data	802.11b 2.447 GHz Treatments			
	9	10	11	12
	B2447DBPSK	B2447DQPSK	B2447CCK	B2447CCK11
1	61.37	61.35	61.38	61.39
2	61.36	61.36	61.37	61.38
3	61.38	61.39	61.38	61.37
4	61.37	61.36	61.39	61.37
5	61.36	61.38	61.39	61.36
6	61.37	61.38	61.39	61.37
7	61.38	61.36	61.37	61.38
8	61.39	61.37	61.32	61.36
9	61.39	61.35	61.36	61.37
10	61.38	61.35	61.38	61.37
11	61.37	61.36	61.37	61.36
12	61.36	61.38	61.35	61.36
13	61.37	61.33	61.37	61.37
14	61.36	61.34	61.36	61.36
15	61.35	61.35	61.36	61.37
16	61.37	61.36	61.38	61.39
17	61.36	61.37	61.37	61.3
18	61.36	61.37	61.37	61.39
19	61.34	61.36	61.36	61.37
20	61.38	61.39	61.38	61.37
21	61.38	61.34	61.39	61.36
22	61.39	61.38	61.38	61.36
23	61.38	61.37	61.38	61.37
24	61.36	61.37	61.36	61.37
25	61.35	61.37	61.35	61.38

Data Sheet 4 Digital Control System Output Data

Test Date: 07/19/2003

Data	IEEE 802.11b 2.462 GHz Treatments			
	13	14	15	16
	B2462DBPSK	B2462DQPSK	B2462CCK	B2462CCK11
1	61.39	61.38	61.39	61.37
2	61.38	61.37	61.39	61.38
3	61.37	61.38	61.38	61.38
4	61.36	61.38	61.37	61.38
5	61.37	61.37	61.36	61.37
6	61.37	61.37	61.37	61.36
7	61.37	61.36	61.37	61.36
8	61.38	61.37	61.38	61.36
9	61.37	61.36	61.38	61.35
10	61.38	61.35	61.37	61.37
11	61.37	61.35	61.38	61.37
12	61.39	61.37	61.37	61.39
13	61.38	61.36	61.38	61.38
14	61.39	61.38	61.37	61.39
15	61.39	61.35	61.36	61.38
16	61.37	61.37	61.37	61.37
17	61.37	61.38	61.38	61.36
18	61.38	61.38	61.35	61.37
19	61.38	61.38	61.36	61.36
20	61.38	61.39	61.37	61.37
21	61.37	61.37	61.37	61.38
22	61.37	61.37	61.37	61.37
23	61.38	61.36	61.39	61.37
24	61.38	61.36	61.38	61.37
25	61.39	61.37	61.37	61.39

Data Sheet 5 Digital Control System Output Data

Test Date: 07/19/2003

Data	IEEE 802.11a Treatments			
	17	18	19	20
	A515BPSK	A52QPSK18	A5216QAM36	A53564QAM54
1	61.38	61.37	61.37	61.36
2	61.38	61.36	61.38	61.36
3	61.38	61.38	61.36	61.37
4	61.38	61.36	61.36	61.37
5	61.39	61.36	61.38	61.37
6	61.38	61.38	61.38	61.37
7	61.38	61.36	61.38	61.36
8	61.36	61.36	61.38	61.39
9	61.36	61.37	61.36	61.38
10	61.35	61.38	61.37	61.38
11	61.37	61.39	61.36	61.38
12	61.38	61.39	61.36	61.37
13	61.38	61.37	61.38	61.39
14	61.36	61.37	61.3	61.36
15	61.35	61.37	61.38	61.37
16	61.38	61.37	61.37	61.37
17	61.39	61.39	61.38	61.37
18	61.38	61.36	61.38	61.38
19	61.38	61.37	61.36	61.36
20	61.38	61.37	61.38	61.36
21	61.37	61.38	61.36	61.37
22	61.38	61.37	61.37	61.38
23	61.36	61.38	61.37	61.38
24	61.37	61.38	61.38	61.38
25	61.37	61.36	61.39	61.39

Data Sheet 6 Digital Control System Output Data

Test Date: 07/19/2003

Data	IEEE 802.11g Treatments			
	21	22	23	Not Used
	G246216QAM	G246264QAM	G2462PBCC	
1	61.375	61.37	61.37	
2	61.37	61.37	61.37	
3	61.38	61.38	61.36	
4	61.36	61.38	61.36	
5	61.38	61.38	61.35	
6	61.38	61.38	61.37	
7	61.36	61.37	61.37	
8	61.38	61.39	61.36	
9	61.35	61.35	61.38	
10	61.36	61.36	61.36	
11	61.39	61.37	61.36	
12	61.38	61.37	61.37	
13	61.39	61.36	61.36	
14	61.38	61.36	61.35	
15	61.37	61.36	61.37	
16	61.37	61.36	61.37	
17	61.36	61.37	61.38	
18	61.37	61.38	61.38	
19	61.35	61.39	61.38	
20	61.37	61.39	61.38	
21	61.38	61.38	61.36	
22	61.36	61.38	61.37	
23	61.37	61.36	61.36	
24	61.37	61.36	61.37	
25	61.37	61.36	61.39	

Data Sheet 7 Digital Control System Output Data

Test Date: 07/19/2003

Data	Background Treatments			
	24	25	26	Not Used
	Background 1	Background 2	Background 3	
1	61.36	61.39	61.37	
2	61.37	61.38	61.37	
3	61.35	61.37	61.37	
4	61.36	61.38	61.38	
5	61.37	61.36	61.38	
6	61.38	61.38	61.38	
7	61.39	61.35	61.37	
8	61.35	61.39	61.36	
9	61.36	61.38	61.36	
10	61.37	61.37	61.37	
11	61.38	61.36	61.36	
12	61.38	61.37	61.36	
13	61.36	61.38	61.38	
14	61.37	61.39	61.38	
15	61.38	61.37	61.36	
16	61.37	61.36	61.39	
17	61.38	61.35	61.37	
18	61.38	61.38	61.37	
19	61.41	61.36	61.36	
20	61.37	61.37	61.37	
21	61.38	61.36	61.38	
22	61.39	61.39	61.39	
23	61.38	61.38	61.38	
24	61.39	61.38	61.37	
25	61.37	61.39	61.36	

APPENDIX B

IEEE 802.11 WAVEFORMS

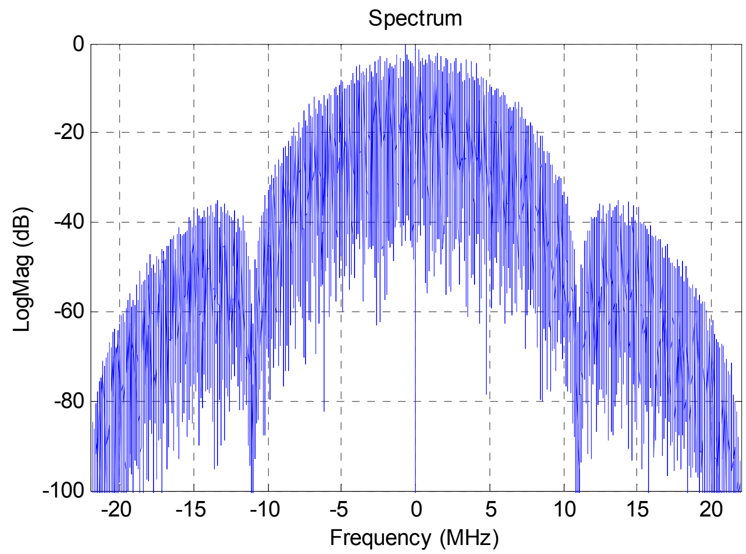

Fig. B1. IEEE 802.11b DPPSK Modulation (1 Mbps Data Rate)

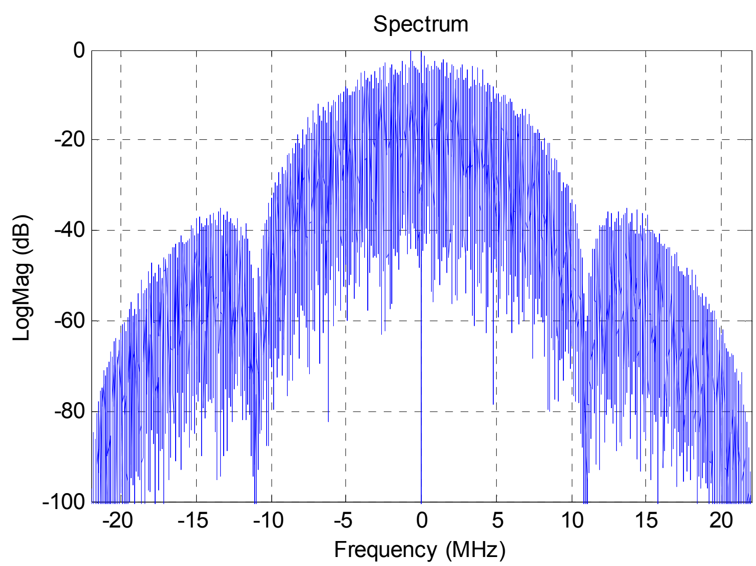

Fig. B2. IEEE 802.11b DQPSK Modulation (2 Mbps Data Rate)

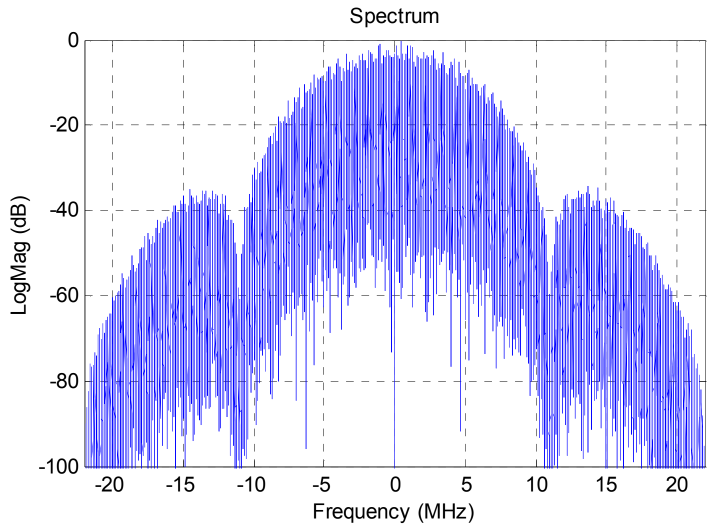

Fig. B3. IEEE 802.11b CCK Modulation (5.5 Mbps)

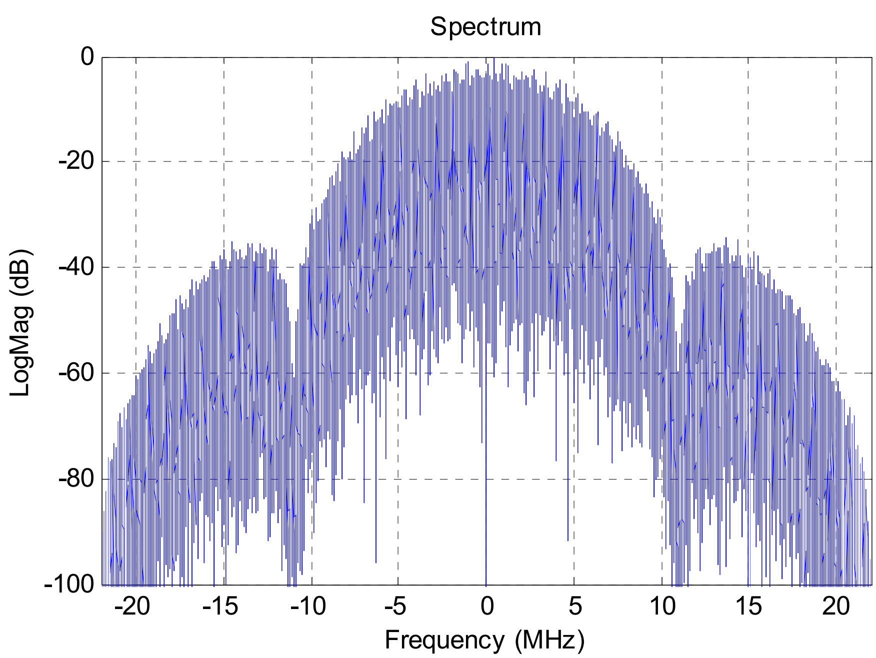

Fig. B4. IEEE 802.11b CCK Modulation (11 Mbps Data Rate)

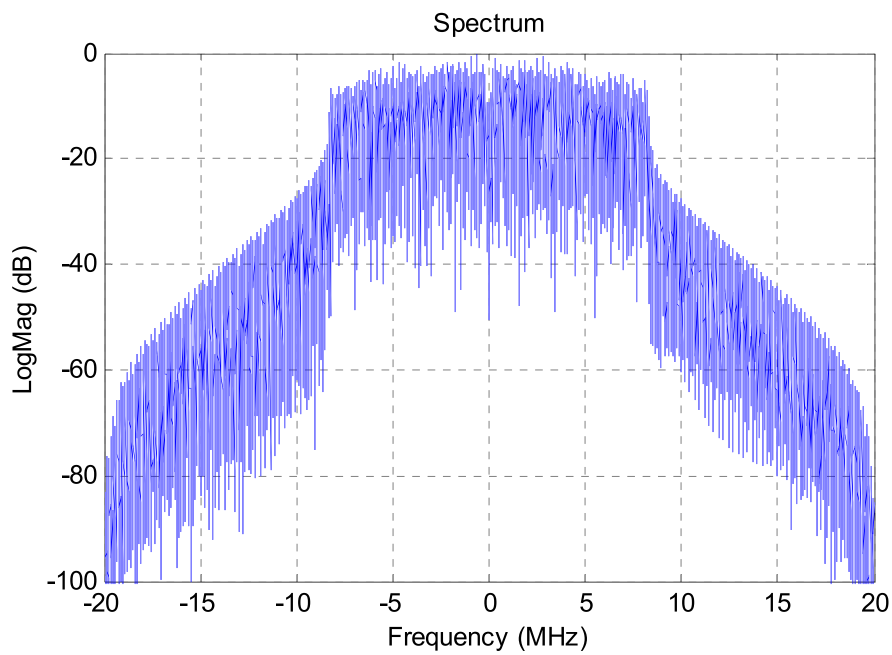

Fig. B5. IEEE 802.11a BPSK Modulation (9 Mbps Data Rate)

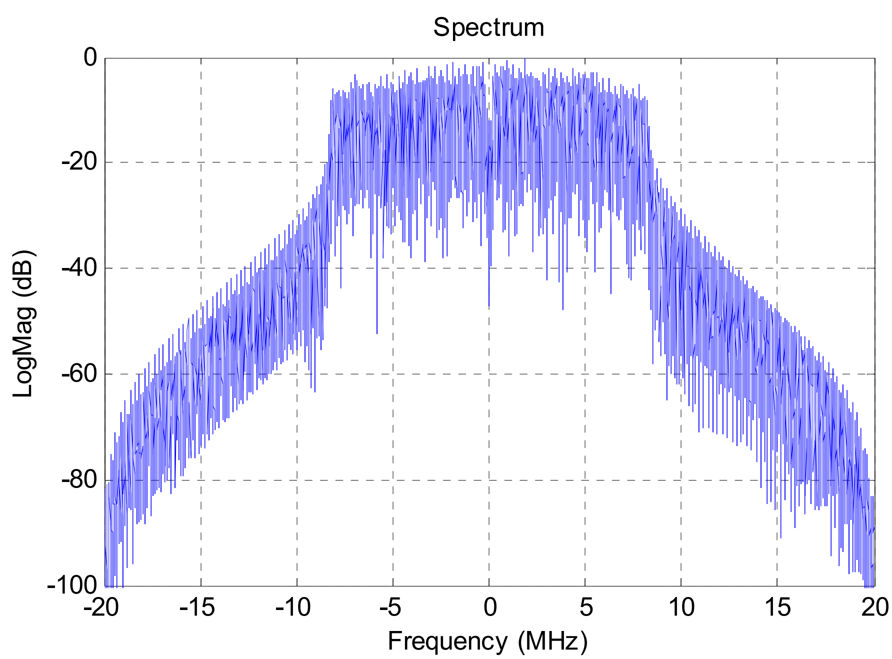

Fig. B6. IEEE 802.11A QPSK Modulation (18 Mbps Data Rate)

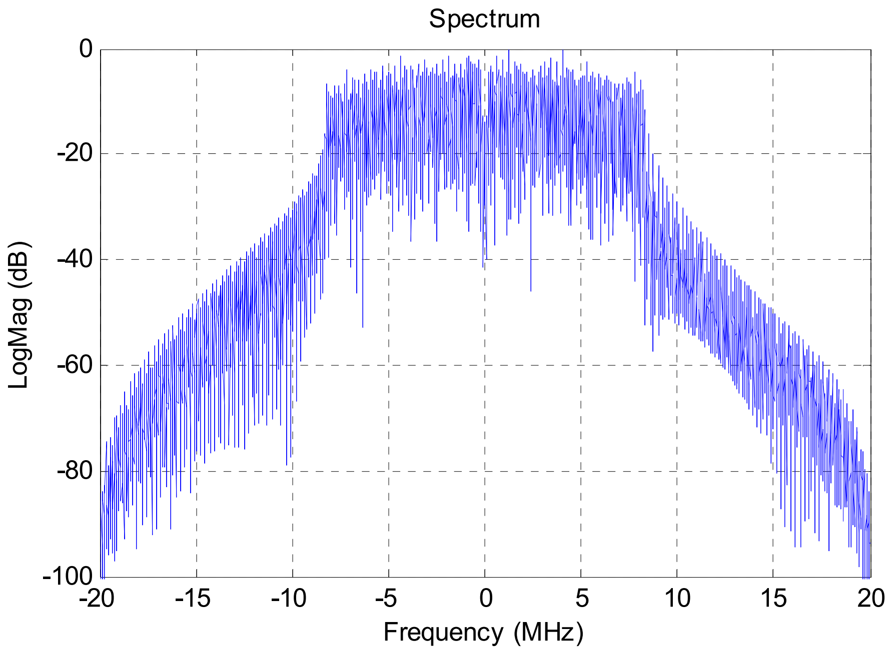

Fig. B7. IEEE 802.11a 16-QAM Modulation (36 Mbps)

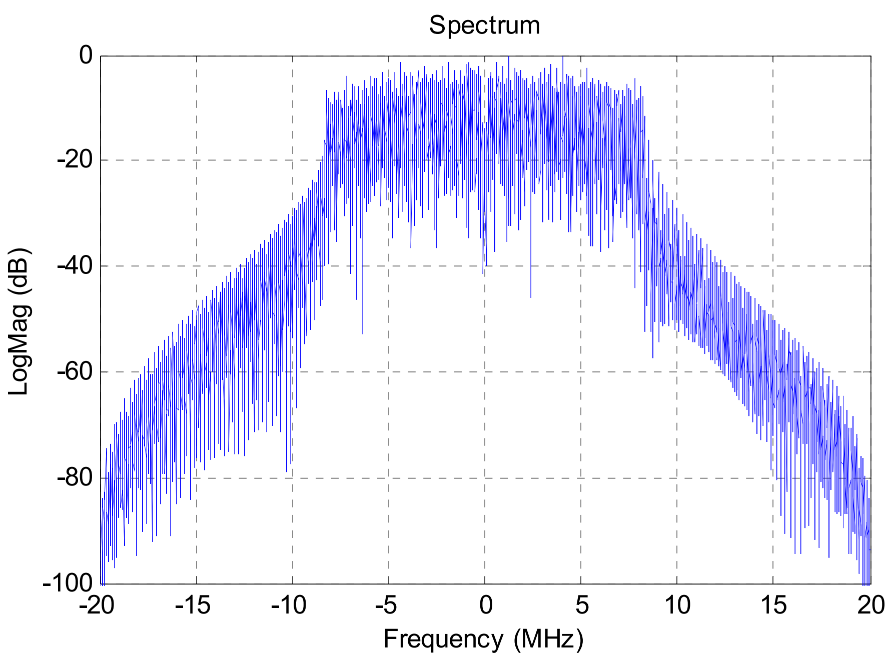

Fig. B8. IEEE 802.11a 64-QAM Modulation (54 Mbps Data Rate)

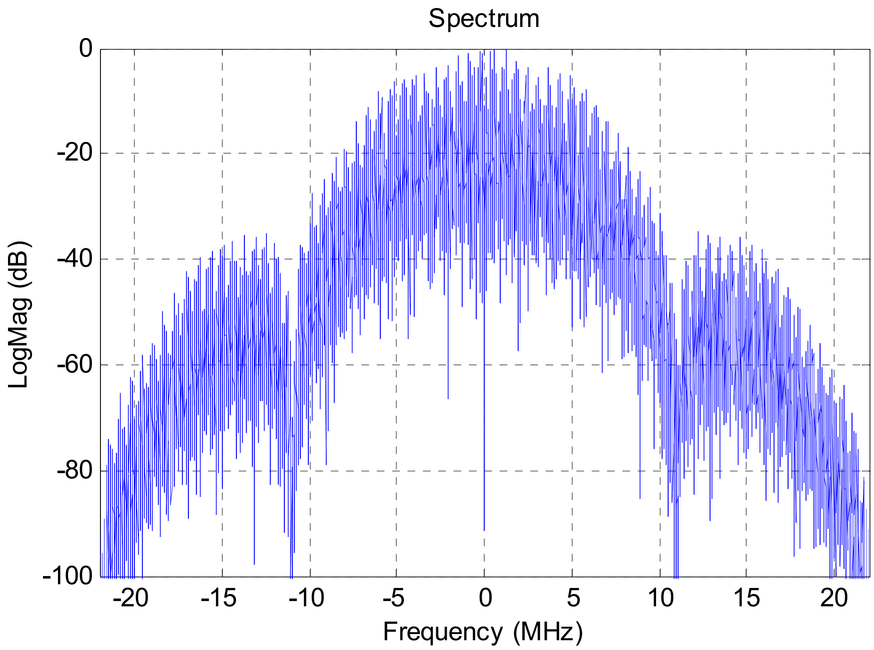

Fig. B9. IEEE 802.11g PBCC Modulation (22 Mbps)

APPENDIX C

CALCULATION OF FAR FIELD / NEAR FIELD TRANSITION

Calculation of Far Field / Near Field Transition

The transition region between the near and far fields is where the observation point is around a distance r equal to the wavelength λ divided by 2π [14]:

$$r = (\lambda/2\pi) \text{ (meters)} \tag{5}$$

Where: λ = Wavelength (meters).

To determine r for any given frequency *f*, the following procedure may be used:

$$T = 1/f \tag{6}$$

Where: T = Period of One Wavelength (seconds)

F = Frequency (Hertz or cycles per second).

Multiplying the period by the speed of light yields the wavelength λ and substituting into (5) yields:

$$r = (\lambda/2\pi) = (Tc/2\pi)$$

$$= (1/f)c/2\pi)(3.28 \text{ ft/meter})(12 \text{ inches/ft})$$

Where: c = 3.0 E+8 meters/sec.

The following table lists the results of the above calculations for the frequencies evaluated:

Table 5.
Far / Near Field Transition Distances for IEEE 802.11 Frequencies

IEEE Standard	Tested Frequency *f* (GHz)	Near Field Transition r (inches)
802.11b	2.412	7.8
802.11b	2.427	7.7
802.11b	2.447	7.68
802.11b	2.462	7.63
802.11a	5.15	3.65
802.11a	5.2	3.61
802.11a	5.25	3.6
802.11a	5.35	3.51
802.11g	2.462	7.63

APPENDIX D

CALCULATION OF EPRI RECOMMENDED EXCLUSION DISTANCES

Calculation of EPRI Recommended Exclusion Distance

Utilizing the guidance provided in EPRI TR102323 [8], the minimum distance of an exclusion zone, in meters, is calculated by:

$$d = (30PG)^{0.5} / E \qquad (7)$$

Where: P = the effective radiated power of the EMI/RFI emitter {watts}

G = the gain of the antenna

E = the allowable electric field strength of the emitter at the point of installation = 4 volts/meter.

IEEE 802.11 emissions are limited to 100 mW under the standard. As a degree of conservatism and to overcome attenuation losses in test cabling, the 100 mW emission was broadcast using an 8 dBi antenna. Using equation 1 above, the EPRI recommended distances are as follows:

For unity gain:

$$d = [(30)(100E\text{-}3)(1)]^{0.5} / 4 = 0.43 \text{ meters or } 1.42 \text{ feet}$$

For 8 dBi gain:

$$d_{(8dBi)} = [(30)(100E\text{-}3)(8)]^{0.5} / 4 = 1.22 \text{ meters or } 4.02 \text{ feet}$$

APPENDIX E

ANOVA ANALYSIS OF EXPERIMENTAL DATA

ANOVA Analysis Tables

A single factor ANOVA analysis was performed for the 26 treatments as listed in the data sheets in APPENDIX A. Each treatment represented the turbine control system output and was comprised of 25 data points collected approximately 10 seconds apart. An Excel 2002 Data Analysis ANOVA software option was utilized to generate the following output data based on a significance level of 0.01

Table 6.

ANOVA Mean Variance Summary

ANOVA: Single Factor Alpha = 0.01 SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
B2412DBPSK	25	1534.19	61.3676	0.000127333
B2412DQPSK	25	1534.37	61.3748	0.000101
B2412CCK	25	1534.3	61.372	7.5E-05
B2412CCK11	25	1534.4	61.376	0.000108333
B2427DBPSK	25	1534.26	61.3704	0.000120667
B2427DQPSK	25	1534.34	61.3736	0.000107333
B2427CCK	25	1534.36	61.3744	9.23333E-05
B2427CCK11	25	1534.32	61.3728	0.000171
B2447DBPSK	25	1534.23	61.3692	0.000174333
B2447DQPSK	25	1534.09	61.3636	0.000240667
B2447CCK	25	1534.26	61.3704	0.000254
B2447CCK11	25	1534.2	61.368	0.000291667
B2462DBPSK	25	1534.43	61.3772	7.1E-05
B2462DQPSK	25	1534.23	61.3692	0.000116
B2462CCK	25	1534.33	61.3732	9.76667E-05
B2412CCK11	25	1534.3	61.372	0.000108333
A515BPSK	25	1534.34	61.3736	0.000124
A52QPSK18	25	1534.3	61.372	0.0001
A5216QAM36	25	1534.24	61.3696	0.000295667
A53565QAM54	25	1534.32	61.3728	9.6E-05
G246216QAM	25	1534.275	61.371	0.000116667
G246264QAM	25	1534.28	61.3712	0.000127667
G2462PBCC	25	1534.2	61.368	1E-04
Bkgnd 24	25	1534.35	61.374	0.000183333
Bkgnd 25	25	1534.34	61.3736	0.000157333
Bkgdn 26	25	1534.29	61.3716	8.9E-05

Table 7.

ANOVA Analysis Results

ANOVA	Alpha = 0.01					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.005432962	25	0.000217318	1.549578705	0.043516358	1.802924032
Within Groups	0.087512	624	0.000140244			
Total	0.092944962	649				

Based on the probability as represented by the P-value of 0.0435 being greater than the significance value of 0.01 used in the calculation, it is concluded with 99% confidence that the means of the 26 treatments are equal.

APPENDIX F

EQUIPMENT CALIBRATION CERTIFICATES

Electro Rent Corporation

ISO 9002 REGISTERED COMPANY — ANSI-RAB QMS ACCREDITED

Certificate Of Calibration

Mfg Model No: AT-E4438C/506/2/5/40{1/UNJ
Description: 250kHz-6GHz Vector Signal Generator/Internal Baseband 32MB/6GB Hard

Report Number: WDC.692863
Serial Number: MY42080480
Technician: JUANRAMIREZ Calib
Date: 09/25/02

Asset Number: 1132096G
Temperature: 72.0F
Humidity: 50.0%
Calib Due: 09/25/04

Proc. Used: VENDOR CAL

Cond. Before: WITHIN MFR SPECS

Cond. After: IN TOL NO ADJ

Calib Facility:
AGILENT TECHNOLOGIES
MOUNTAIN VIEW, CA
Customer Name:
TXU ELECTRIC
f.."DALLAS, **TX 752210020**

CALIBRATION STANDARDS USED

MFG/MODEL NO.	ASSET NO.	DUE DATE	MFG/MODEL NO.	ASSET NO.	DUE DATE

Calibration Remarks:

THE EQUIPMENT LISTED ABOVE MEETS OR EXCEEDS PUBLISHED SPECIFICATIoNS AND HAS BEEN CALIBRATED USING MEASUREMENT STANDARDS WHOSE ACCURACIES ARE TRACEABLE TO THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY. OTHER NATIONAL STANDARDS, OR OTHERWISE VERIFIED USING INDUSTRY ACCEPTED METHODS. ELECTRO RENT CORPORATION'S MEASUREMENT STANDARDS CALIBRATION SYSTEM IS COMPLIANT WITH ANSI/NCSL Z540-1-1994 AND ISO 10012-1. THIS CERTIFICATION SHALL NOT BE REPRODUCED IN FULL, WITHOUT THE WRITTEN APPROVAL OF ELECTRO RENT CORPORATION .

ELEcrRO RENT AUTHORIZED CORPORATION
SIGNATURE

.1 d **k.k'** **TITLE**

"22 ***J14-J1*** } "s ~ **-D~;E. .~ 7~ ::::/**

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Certificate Of Calibration

Mfg Model No: AT-E4407B/1DR/304/A4{H
Description: 9kHz-26.SGHz Spectrum Analyzer/Narrow Resolution Bandwidths/Bluetooth Premium Bundle/GPIB and

Report Number: SCC.681492
Serial Number: US41443108
Technician: ERODRIGUEZ Calib
Date: 07/22/02

Asset Number: 1221866H
Temperature: 70.0F
Humidity: 50.0%
Calib Due: 07/22/03

Proc. Used: VENDOR CAL
Cond. Before: WITHIN MFR SPECS
Cond. After: IN TOL NO ADJ

Calib Facility:
AGILENT TECHNOLOGIES
ENGLEWOOD, CO Customer Name:
TXU ELECTRIC
DALLAS; TX 752210020

CALIBRATION STANDARDS USED

MFG/MODEL NO.	ASSET NO.	DUEcDATE	MFG/MODEL NO.	ASSET NO. DUE DATE

Calibration Remarks:

THE EQUIPMENT LISTED ABOVE MEETS OR EXCEEDS PUBLISHED SPECIFfCATIONS AND HAS BEEN CALIBRATED USING MEASUREMENT STANDARDS WHOSE ACCURACIES ARE TRACEABLE TO THE NATIONAL INSTITUTE OF srrANDARDS AND TECHNOLOGY, OTHER NATIONAL STANDARDS. OR OTHERWISE VERIFIED USING INDUSTRY ACCEPTED METHODS. ELECTRO RENT CORPORATION'S MEASUREMENT STANDARDS CALIBRATION SYSTEM IS COMPLIANT WITH ANSI/NCSL Z540-1-1994 AND ISO 10012-1. THIS CERTIFICATION SHALL NOT BE REPRODUCED IN FULL, WITHOUT THE WRITTEN APPROVAL OF ELECTRO RENT CORPORATION .

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ELEcrRO RENT CORPORATION
AUTHORIZED SIGNATURE

TITLE

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www.hvDerlinktech.com .1201 Clint Moore Road. Boca Raton FL 33487

Electro Rent Corporation

NQA ISO 9002 REGISTERED COMPANY — ANSI-RAB QMS ACCREDITED

Certificate Of Calibration

Mfg Model No: AT-8449B
Description: lGHz-26.5GHz RF Amplifier

Report Number: WDC.716728
Serial Number: 3008A01111
Technician: GNOTZ
Calib Date: 04/22/03

Asset Number: 1212382A
Temperature: 70.0F
Humidity: 35.0%
Calib Due: 04/22/05

~"~.~ -~~~ **Proc. Used: MFR PROCEDURE** ~~

Calib Facility: ELECTRO RENT CORPORATION (WDC)
15385 OXNARD ST
VAN NUYS, CA 91411

Cond. Before: WITHIN MFR SPECS

Cond. After: IN TOL NO ADJ

Customer Name:
TXU ELECTRIC
DALLAS, TX 752210020

CALIBRATION STANDARDS USED

MFG/MODEL NO. , ASSET NO. DUE DATE WEI-74-30-12 474992B 09/04/03 AT-85025E 231871G 11/11/03 AT-8757D 238879F 10/10/03 MTQ-HD12487 1126752E 10/11/03

MFG/MODEL NO. ASSET NO. AT-11664E 456184E AT-83650B 1092422A AT-346C 238728G

DUE DATE
08/30/03
07/30/04
04/13/04

Calibration Remarks:

THE EQUIPMENT LISTED ABOVE MEETS OR EXCEEDS PUBLISHED SPECIFICATIONS AND HAS BEEN CALIBRATED USING MEASUREMENT STANDARDS WHOSE ACCURACIES ARE TRACEABLE TO THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, OTHER NATIONAL STANDARDS, OR OTHERWISE VERIFIED USING INDUSTRY ACCEPTED METHODS. ELECTRO RENT CORPORATION'S MEASUREMENT STANDARDS CALIBRATION SYSTEM IS COMPLIANT WITH ANSI/NCSL Z540-1-1994 AND ISO 10012-1. THIS CERTIFICATION SHALL NOT BE REPRODUCED IN FULL, WITHOUT THE WRITTEN APPROVAL OF ELECTRO RENT CORPORATION .

ELECTRO RENT CORPORATION
AUTHORIZED SIGNATURE

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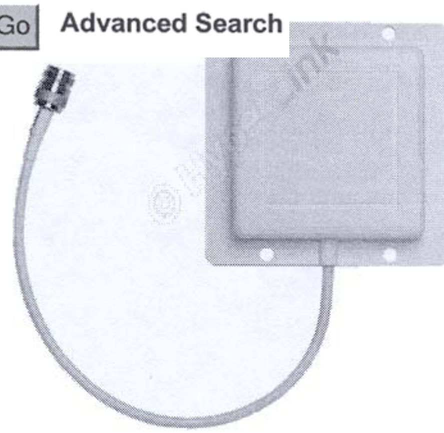
APPENDIX G

ANTENNA DATA SHEETS

HyperGain@ HG2409P
2.4 GHz 8 dBi Flat Patch Antenna

Search: Go Advanced Search



This very compact flat patch antenna provides 8 dBi gain with very broad coverage. It is suitable for both indoor and outdoor applications in the 2.4 GHz ISM band. This antenna's construction features sealed internal elements and an aesthetic UV-stable white plastic radome. Can be wall or ceiling mounted, as well as mast-mounted using U-bolts.

Electrical Specifications

Frequency	2400-2500 MHz
Gain	8dBi
Horizontal Beam Width Vertical	75 degrees 65
Beam Width Impedance	degrees 50
VSWR	Ohm
	< 1.5:1 avg.

This antenna features a 12 inch coax lead that can be terminated with any of the connectors listed in the table or drop-down menu below.
Specify the desired connector by choosing the appropriate part number.

The following standard connectors are available from stock:

Part Number	Sale Price
HG5308P-NF	$49.95

Mechanical Specifications

Weight	0.4 Ibs. (.18 Kg)
Dimensions	**4.5** x **4.5** x **.9 inches 114** x **114** x **23 mm**
Radome Material	UV-inhibited Polymer
Mounting Polarization	**Four ~ in. (6.3 mm) Holes**
Wind Survival	Horizontal or Vertical
	>150 MPH (241 KPH)

This antenna is also available with the any of the following connectors by special order at a nominal additional charge of $5.00. If you do not see your connector listed please QQ-O1as;t our sales department.

Available Connectors

This antenna is supplied with a 12" pigtail with any of the connectors listed in the tables below. Specify the desired connector by choosing the appropriate part number.

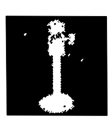
Standard Connectors

The following standard connectors are available from stock:

Connector Type !	Part Number
IN **Female**	HG2409P-NF
IN **Male**	HG2409P-NM

Mounting Options

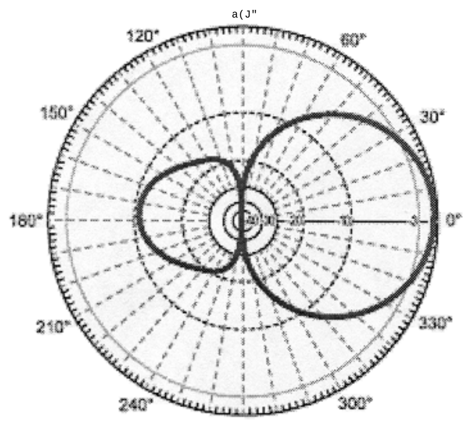
Hyperlink's patch antennas offer several unique mounting options. They can be mounted flat against a wall, or to a mast using a pair of 2 inch U-bolts. The antennas also accept most tilt-and-swivel security camera brackets equipped with standard 1/4-20 threads.

Description	Part Number	Sale Price	Buy Now
 **Small Metal Tilt-and-swivel Mounting Bracket** for indoor wall mounting. Includes wall-mounting hardware.	~ PMTO2	**$9.95** ~;i	
 Morli..m PI..~ti,.. Tilt-..nrl-~\Ali"ol	I-I~Y-	tQ Q~ ~~1,	

e-mail: sales@.hvDerlinktech.com .tel: 561-995-2256. fax: 561-995-2432 web: www.hvDerlinktech.com .1201 Clint Moore Road. Boca Raton FL 33487

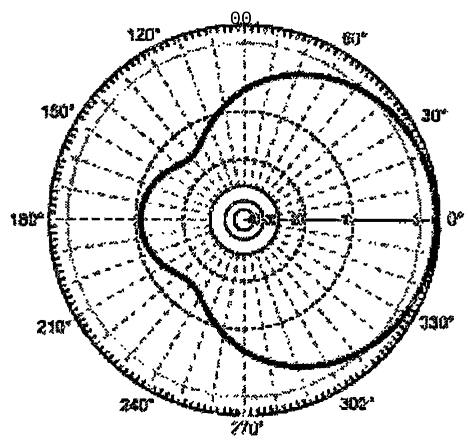
Weight	~ 0.4 lbs.
Dimensions	4.5" x 4.5" x 1"
Radome Material	UV-inhibited Polymer
Mounting	Four ¼" Holes
Polarization	Horizontal and Vertical
Wind Survival	>150 MPH

Antenna Patterns



no.

Vertical



HorizontaJ

Electrical Specifications

Frequency I **Gain** I **Horizontal Beam Width**	5150- 5350 MHz
	8dBi
	75 degrees
~ertical Beam Width	60 degrees
Impedance	50 Ohm
VSWR	< 1.5:1 avg.

Mechanical Specifications

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Guaranteed Quality

All HyperGain@ antennas are tested and backed by Hyperlink's Limited Warranty.

Need help selecting the right antenna for your application? Contact HyperLink Technologies' friendly technical support staff for assistance.

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