THESIS

RADIO FREQUENCY FIELD STRENGTH FLUCTUATION DUE TO DIGITAL CONVERSION OF TELEVISION SIGNALS: A PILOT STUDY

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY P. BRIAN LANE ENTITLED “RADIO FREQUENCY FIELD STRENGTH FLUCTUATION DUE TO DIGITAL CONVERSION OF TELEVISION SIGNALS: A PILOT STUDY” BE ACCEPTED AS FULFILLING IN PART REQUIRMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

RADIO FREQUENCY (RF) FIELD STRENGTH FLUCTUATION DUE TO DIGITAL CONVERSION OF TELEVISION SIGNALS: A PILOT STUDY

All television stations in the United States ceased broadcasting on analog airwaves June 12, 2009 and now only broadcast in a digital format. Prior to June 12th, most stations broadcast in both analog and digital signals. The focus of this study was to determine whether this change in broadcasting affected exposures to radio frequency energies in the vicinity of Lookout Mountain in Golden, Colorado. The site, which is approximately 10 miles west of the Denver metropolitan area, is unique because there are homes located at and above the elevation of the transmitting towers with some homes located within 100 yards of the towers. There is public concern that the digital transition resulted in a significant increase in radio frequency exposure to homes. Measurements of radio frequency field strengths were taken during daylight hours at 21 locations where highest exposures were expected using an electromagnetic radiation meter. Measurements taken at the same locations before and after June 12, 2009 did not indicate a statistically significant change in radio frequency exposures and all measurements were below the Maximum Permissible Exposure (MPE) limit for the general public.

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List of Abbreviations

ANOVA	Analysis of variance
ANSI	American National Standards Institute
BDE	bond dissociation energy
BR	Basic restrictions
CARE	Canyon Area Residents for the Environment
COMAR	Committee on Man and Radiation
DNA	Deoxyribonucleic acid
DTV	Digital television
EMR	Electromagnetic Radiation
FCC	Federal Communication Commission
HSD	Honestly significant difference
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
LMPP	Lookout Mountain Pilot Project
MPE	Maximum Permissible Exposure
MSL	Mean sea level
MW	Mega Watt
NIR	Nonionizing radiation
ODC	Ornithine decarboxylase
OET	Office of Engineering and Technology
OSHA	Occupational Safety and Health Administration
RCAMSL	Radiation center above mean sea level
RF	Radio frequency
RFI	Radio frequency Interference
RFR	Radio frequency radiation
SAR	Specific absorption rate
SAS	Statistical Analysis System
UV	Ultraviolet
WBC	White blood cells

Chapter 1 - Introduction

Nonionizing Radiation Exposure

Over the past 40 years a dramatic increase in technological developments has resulted in communication applications that propagate electromagnetic fields. These applications cover the broadcasting gamut including AM, FM, and TV channels; cellular systems like wireless cell phones, commercial pagers and security systems; industrial applications such as radio frequency sealers, heaters, drying equipment and microwave ovens; and even medical applications such as magnetic resonance imaging.[2] These devices generally operate in the radio frequency range of the Electromagnetic Radiation (EMR) spectrum, (Fig. 1).

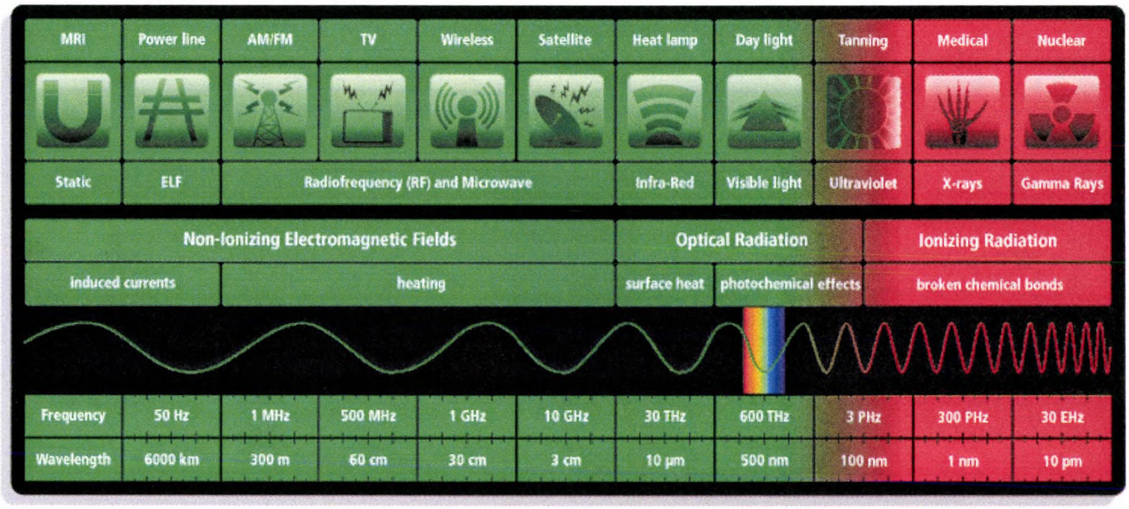


Figure 1: The Electromagnetic Spectrum, © GSM Association 1999 - 2009

Hypothesis

1. Total exposures originating from television and radio broadcasting towers on Lookout Mountain in Golden, Colorado before and after the digital conversion deadline (June 12, 2009) are not significantly different.

2. All television and radio broadcasting exposures originating from Lookout Mountain towers are below the minimum limit of 0.2 $mW \cdot cm^{-2}$, as established by the Institute of Electrical and Electronics Engineers (IEEE) C95.1-2005 standard.

Objective

1. Measure broadcasting exposure levels within 3.0 km of Lookout Mountain broadcasting towers during the period of February 2009 to January 2010.

2. Compare exposure levels before and after the digital conversion deadline (June 12, 2009).

The EMR spectrum is the range of all possible frequencies of electromagnetic radiation. EMR is a self-propagating electric and magnetic wave and is categorized by increasing frequency beginning with low frequency radio waves through high frequency gamma rays. Because frequency is inversely proportional to wavelength, high frequency photons, such as Ultraviolet, X-rays, and gamma rays, correspond to short wavelengths while low frequency photons, like radio waves correspond to long wavelengths.[3] According to the National Council on Radiation Protection and Measurement, wavelengths less than 100 nm are considered to be ionizing radiation while wavelengths greater than 100 nm are considered nonionizing radiation, (where 100 nm is approximately equivalent to 12 eV).[4] The International Commission on Non-Ionizing Radiation Protection (ICNIRP) defines nonionizing radiation (NIR) as "…all radiations and fields of the electromagnetic spectrum that do not normally have sufficient energy to produce ionization in matter; characterized by energy per photon less than about 12 eV…"[5] Nonionizing radiation begins with the lowest of radio frequencies and extends to the transition region located in the Ultraviolet (UV) region at approximately 100 nm, while ionizing radiation continues from approximately 100 nm region up to the highest frequencies corresponding to gamma rays (Fig. 1). When a photon of sufficient energy is incident upon biologic material it has the potential to either excite or ionize atoms. Excitation of atoms occurs when a photon transfers enough energy to an atom to cause a bound electron to move to a higher orbital, which results in localized heating. Ionizing radiation is distinguished by any particulate or electromagnetic radiation capable of ejecting orbital electrons resulting in the creation of ion pairs and the deposition of large amounts of energy. Each ionization event in air equates to approximately 33.7 eV (beta) or 35.5 eV (alpha) expended on average, which is much greater than the required energy to break strong chemical bonds.[6] The required energy to break a water bond is approximately 4.77 eV, which corresponds to a wavelength of 260 nm or 2.6×10^{-7} m (Appendix A). This wavelength is located in the UV region of the EMR spectrum.

Breaking a water bond is important; however a Deoxyribonucleic acid (DNA) double strand break is more significant since this could cause stochastic effects via direct initiation of cell death, mutagenesis, or malignant transformation.[7] "Stochastic effects occur by chance and primarily result in cancer and genetic effects."[8] A key in linking stochastic effects to EMR is the understanding of possible interactions as well as those that are not possible. To continue with our example consider the hydrogen bond, which is the weakest bond in DNA. "Hydrogen bonding is a special type of intermolecular attraction that exists between the hydrogen atom in a polar bond and an unshared electron pair on a nearby small electronegative ion or atom…"[9]. The required energy to break a hydrogen bond is approximately 4.53 eV, which correlates to a wavelength of 275 nm (Appendix A). The energy of a photon at 300 GHz, which is the upper end of the radio frequency region, is 0.0012 eV (Appendix A). This energy is approximately 3,700 times less than the minimum energy required to break a DNA bond. For example, it would take 3,700 photons of 0.0012 eV to almost simultaneously interact with the same atom to result in an ionization that could break a chemical bond within genetic material.[10] Thus, nonionizing radiation simply does not provide sufficient energy in individual photons to dissociate DNA bonds and initiate stochastic effects.

Biological Effects

Biological effects can be described in terms of effect alone (such as heating and perspiration from exercising) or actual harm (such as damaged skin from sunburns). Biological effects resulting from NIR exposures can be categorized into three broad groups – thermal, thermo-acoustic, and non-thermal effects.

Thermal Effects

A tremendous amount of research exists today documenting thermal effects of radio frequency radiation (RFR) in animal studies as well as human studies.[11-19]

According to the IEEE C95.1-2005 standard, thermal effects can be further divided into three frequency ranges which are presented in Table 1.

Table 1 - Thermal Effect Sub-groups[20]

Sub group	Frequency range	Outcomes	C95.1-2005 section
Electro-stimulatory effects	3 kHz to 5 MHz	Painful nerve impulses	C.1.1.2.k.1
Thermal effects	100 kHz to 3 GHz	Increase temperature	C.1.1.2.k.2
Skin heating effects	3 GHz to 300 GHz	Painful skin absorption	C.1.1.2.k.3

Electro-stimulatory effects are induced when electromagnetic fields, electric fields, or contact current in the frequency range of 3 kHz to 5 MHz is incident upon biologic tissue. "This excitation process of nerve and muscle is initiated by adequate depolarization of the cellular membrane from its resting potential..."[20] causing painful nerve impulses. The IEEE standard C95.1-2005 provides basic restrictions and maximum permissible exposure values to protect occupational workers and the general public from electro-stimulatory hazards. Protection values are expressed in units of volts per meter (V/m), amps per meter (A/m), and milliamps (mA) for different frequency ranges (within 3 kHz to 5 MHz) and for different parts of the body.

Thermal effects are the result of NIR exposure and subsequent tissue heating. This occurs when body's thermoregulatory system becomes overwhelmed and can no longer dissipate the additional heating. The mechanisms used by the human body to conserve and prevent overheating are evaporative heat loss via sweating and conductive heat loss by way of the circulatory system. Symptoms of exceeding thermoregulatory system limits are sweating and increased temperature, either whole body or localized.

The eyes and testes are of particular concern since these organs have very low blood circulation and are unable to conductively remove heat.[20] IEEE standard (C95.1-2005) provides protection limits based on a specific absorption rate (SAR) of 4 W/kg. SAR is a threshold limit of the electromagnetic energy that is absorbed in the body and is based on animal behavior studies. "The weight of evidence from animal studies supports the conclusion that teratogenic, reproductive, or developmental effects do not occur unless the radio frequency (RF) exposure is >4 W/kg and causes a significant temperature increase above the normal body temperature."[20] Based on these findings, protection limits for RFR exposures within a frequency range of 100 kHz up to 300 GHz are set at 0.4 W/kg for persons in a controlled environment and 0.08 W/kg for the general public. To put this into perspective, the resting metabolic rate, which is the amount of energy expended while at rest in a neutrally temperate environment, is approximately 1.25 W/kg for humans.[20] Thus, the SAR limit for the general public (0.08 W/kg) represents about 6.5 percent of the energy expended by humans at rest. The lower part of this frequency range overlaps the frequency range for electro-stimulatory effects. When operating in this transition region limits for both electo-stimulation and thermal heating must be met.

Skin heating occurs in the range of 3 GHz to 300 GHz and can result in painful skin absorption of incident power. The IEEE C95.1-2005 standard provides protection limits based on power density, which is given specified units of W/m^2 (Appendix F, Tables F.1 and F.2).

Thermo-acoustic Effects

The thermo-acoustic effect "…is a well established phenomenon and the RF induced sounds are similar to other common sounds, such as a click, buzz, hiss, knock, or chirp."[21] This phenomena is described by the thermo-acoustic expansion theory, sometimes referred to as thermo-elastic expansion, and is the accepted explanation by researchers and scientists.[21-27] This theory states that pulsed microwaves are absorbed in soft tissue within the head resulting in a "…thermo-elastic wave of acoustic pressure that travels by bone conduction to the inner ear. There, it activates the cochlear receptors via the same process involved for normal hearing."[28] This effect is not believed to be harmful; however, it has been used in developing exposure guidelines to pulsed radio frequency fields.[29-30]

Non-thermal Effects

Non-thermal effects are presumed biological effects resulting from chronic, low level exposures of nonionizing radiation that is absent of significant thermal heating. The major concern with non-thermal exposures is the body's inability to detect and provide a means of warning to a person, such as heating and sweating resulting from thermal effects. Currently, there is no known biologic process that results from non-thermal effects, but anxiety over the possibility of non-thermal effects still persists today. Non-thermal effects became a public concern in the United States shortly after Wertheimer and Leeper published the 1982 study titled "Adult Cancer Related to Electrical Wires Near the Home."[31] This study sparked vast concern in the association between childhood leukemia and low level magnetic fields as well as wire code classifications.[31] This study conducted comparison-wise statistical analysis in four different Colorado cities resulting in only one city being statistically significant (Denver, p-value = 0.11). A fifth comparison-wise analysis was conducted on the combined data from all four cities, which found no significance (p-value < 0.0001). Not surprisingly, the American Electric Power company, Technical Services Division, cited the following assumptions and confounding factors:[32]

1. Did not incorporate field measurements
2. Did not account for all confounding issues
3. Assumed high current capacity lines would produce high magnetic fields
4. The authors knew which studies reported children diagnosed with cancer before they assigned wire code classification to the children's residence
5. Failed to use control groups that are representative of the sample population

These assumptions and confounding issues degrade the already weak statistical power of the study. Additionally, two studies tried to replicate the Wertheimer and Leeper study and both studies concluded that no associations were found between childhood leukemia and wire codes.[33-34] In fact, the replication study conducted by Savitz (1998) included collecting field strength measurements inside the homes, but still found no association.

Since the Wertheimer and Leeper study, "…several thousand scientific papers, including over 600 studies…"[35] have drastically increased the database of scientific literature. Virtually all of these studies that have focused on biological effects of radio frequency radiation have some limitation – be it low statistical power, confounding issues, small sampling population or failure to utilize control groups.

In order to avoid these problems in the future, researchers should include logical, well thought out design parameters to ensure robust results. Epidemiological, case-control, cohort, or even a basic research study should incorporate parameters that will increase statistical power while diminishing confounding issues. Ideal studies will incorporate Hill's Criteria of Causation[36] which is summarized in Table 2.

Table 2 - Hill's Criteria of Causation[36]

Criteria	Description
Temporal Relationship	Exposure always precedes the outcome
Strength	Higher correlation provides a stronger association
Dose-Response	A dose-response relationship is present if strong evidence of a causal relationship exists. However, the absence of a dose-response relationship does not rule out a causal relationship
Consistency	If there is a casual relationship, then consistent results among different studies and different populations are expected
Plausibility	Accepted pathological processes must describe and association between the vector and disease

Since most of the available scientific literature is complex and highly variable it calls for professionals in the particular field of study to impute expert judgment and draw conclusions. "The most reliable reviews are carried out by panels of experts with a broad range of expertise and operating under well-defined procedures for selecting and evaluating data"[35] This type of review panel is routinely conducted by most standard-setting societies and organizations that develop international guidelines.

Accordingly, the IEEE C95.1-2005 standard presents an extensive literature review on radio frequency biological effects, which covers over 1,300 peer reviewed publications ranging from the 1950's up to 2005. No adverse health effects outside of thermal and electro-stimulation exposures were noted.[20] All other adverse health effects, including non-thermal effects, were either non-significant or the studies were plagued with confounding factors, weak statistical significance, and poor experimental designs. The conclusion of IEEE C95.1-2005 literature review is consistent with other expert groups and standard setting organizations presented in Table B.1 of Appendix B.

A search of scientific literature from 2005 to present, concerning exposure within a frequency range of 3 kHz to 300 GHz, yielded eight peer reviewed studies, which are summarized in Table B.2 of Appendix B. Out of these eight there are three literature reviews covering the following topics: RF induced genetic effects; RF effects on human systems (cardiovascular, reproductive, and immune systems); and RF effects on animals and humans as well as temporal trends in disease rates. All three literature reviews generally concluded that current evidence does not establish RFR as a health hazard.

The five other studies are research based studies that focused on proximity to broadcasting towers; human dosimetry in homes; RF exposures and human melatonin and biomarkers; comparison of calculated exposures verses measured exposures; and RF effects on in vitro mouse fibroblast.

The most relevant study to the current Lookout Mountain Pilot Project (LMPP) was conducted and published in 2006 by Burch et al.[37] This study, titled "Radio Frequency Nonionizing Radiation in a Community Exposed to Radio and Television Broadcasting" encompassed the same geographic area that the LMPP covers. The main objective of this the Burch study was to characterize spatial and temporal RFR exposure variations by collecting exterior and interior measurements at 576 homes. One exterior and five interior measurements were collected at each residence using an EMR-300 meter with a type 18 probe – the same probe LMPP used. Measurements were collected at the beginning and end of a 2.5-day collection period, weekly from September 2002 through December 2003. Subsequent spot measurements were collected eight to 29 months later. Exterior RF values ranged from non-detectible to 20.9 $\mu W/cm^2$ (0.021 mW/cm^2). This maximum value is 89.5 % lower than the minimum MPE limit (0.2 mW/cm^2). Spatial results indicated that “increasing proximity, elevation, and visibility were each associated with statistically significant increases in mean exterior and interior RF power densities ($p \leq 0.01$).”[38] This finding is generally expected based on RFR characteristics and the fact that the project area is mountainous terrain. The use of ESRI ArcInfo software (geographic information system) to determine line-of-sight visibility of broadcasting towers was unique. Temporal variations at 11 to 23 months later indicated an “increase by 15 ± 72% (25% did not change, 25% increased by > 100%).[37] The follow-up measurements resulted in an average absolute difference of 1.1 ± 1.9 $\mu W/cm^2$ (0.00110 mW/cm^2). However, even with temporal variation increases and based on the raw data, all RFR measurements were below the minimum MPE limit of 0.2 $mW{\cdot}cm^2$. In fact, the highest value (house exterior) was 0.0209 $\mu W{\cdot}cm^2$ (0.0000210 $mW{\cdot}cm^2$) which is well below the exposure limits.

Another relevant study to LMPP was conducted in 2005 by Reif et al.[39] This report, titled “Human Responses to Residential RF Exposure,” “examined the hypothesis that RF exposures are associated with reduced urinary melatonin metabolite excretion and alterations in immune parameters and other biomarkers in a population of 280 residents of Lookout Mountain in Golden Colorado.”[39] The objective of this study was to characterize residential RF and 60 Hz exposure effects on melatonin production; DNA damage and repair; and determine if ornithine decarboxylase (ODC), polymines, and immune markers are altered in any way. Most of the study comparisons were not statistically significant (p-values > 0.5). However, associations between melatonin and the total T cells indicated statistically significant (p-value = 0.04) higher levels of melatonin among individuals living in houses with exposures > 1.83 $\mu W/cm^2$ (0.00183 mW/cm^2) than any individual living in houses with exposures < 0.0500 $\mu W/cm^2$ (0.0000500 mW/cm^2). This study did not list specific measurement values so there was no way to compare exposure levels with current Maximum Permissible Exposure (MPE) limits. Seven out of eight immune markers showed non-significant increases between the two extremes of exposure. Associations between total melatonin excretion and immune markers indicated statistically significant higher levels of melatonin among individuals in houses with exposures $< 0.0500\ \mu W/cm^2$ ($0.0000500\ mW/cm^2$) than individuals living in houses with exposures $> 1.83\ \mu W/cm^2$ ($0.00183\ mW/cm^2$). Statistically significant immune markers and p-values were:

1. Total WBC (P-value = 0.02)
2. Helper T cells (P-value = 0.01)
3. Total lymphocytes, total T cells, and cytotoxic T cells (p-value ≤ 0.01)

Other studies have shown similar trends indicating impacts of RF exposure below MPE limits and many of these studies are included in the IEEE (C95.1-2005) literature review, which lead to the establishment of the current standards.[20,40-41] Whether or not there are subtle effects from exposures below the MPE has yet to be determined.

The most interesting of the five research studies conduct since 2005 was the in vitro study conducted by Lee et al. (2008).[42] The objective of this study was "…to determine whether RFR exposure affects cell cycle distribution, cellular invasion, or migration.[42] NIH3T3 mouse fibroblasts and shams (control groups) were exposed to 849 MHz at two specific absorption rates (SAR) of 2 W/kg and 10 W/kg. These exposures were applied to two different time regimens of 1 hour and 1 hour per day for three days. No statistically significant differences were found between the sham exposed and mouse fibroblast exposed cells. Additionally, an identical experiment was conducted using gamma radiation at 0.2 and 10 Gy. This experiment resulted in statistically significant alterations in cellular motility and invasiveness. The author concluded with "...results show that 849 MHz RF radiation exposure exerts no detectable effects on cell cycle distribution, cellular migration, or invasion at average SAR values of 2 or 10 W/kg."[42]

This study is important on several levels. First, the frequency of 849 MHz is centered in the cellular telephone range of (824 MHz to 894 MHz). Secondly, the SAR's chosen for this study (2 and 10 W/kg) resulted in no adverse affects at the cellular level. This is significant because the IEEE (C95.1-2005) standard for the general public is set at 1/50th of the thermal threshold effect SAR (4 W/kg).[20]

Chapter 2 – Measurement Uncertainties and Assumptions

Lookout Mountain Pilot Project (LMPP) measurements were made with a Wandel and Goltermann EMR-300 field strength meter in conjunction with a type 18 broadband probe. This probe was calibrated to a National Institute of Standards and Technology approved traceable source. The measurements obtained from this instrument indicate total field strengths produced by all sources in its operating band, including broadcast radio, TV, WIFI, and cellular sources. Uncertainty related to electromagnetic field measurements with an isotropic probe are: absolute error, frequency response, linearity, isotropic deviation, thermal response and modulation.[43] These errors of uncertainty (Table 3) are thoroughly covered in Karabetsos (2005)[43] research paper titled "Uncertainty Estimation in Electromagnetic Field Measurements for Assessing Compliance with Safety Limits."

Table 3 – Typical Sources of Uncertainty for Electromagnetic Fields

Uncertainty	Type	Value
Absolute error (it includes calibration accuracy error)	1	±1 dB
Frequency response error	1	0.82 dB
Linearity error	1	0.82 dB
Isotropic deviation error	1	0.71 dB
Thermal response error	2	±1 dB
GSM Modulation error	2	< 10%
1. Estimation by Calibration 2. Estimation by manufacturer data sheet		

The major assumption made for the LMPP was exposures from FM radio resulted in the largest percentages among all radio frequency sources. This assumption is based, in part, on the 1998 study by the FCC[44], which helped focus the hypotheses on testing for trends before and after the digital conversion. Another assumption was that all measurements were collected in the far field range from the broadcasting towers. For measurements collected within close proximity to the towers the assumption was that the broadcasting signal overshot the collection point location leaving it outside of the near field zone. If measurements were to be collected within the near field zone then the electric and magnetic fields would have to be measured separately. Also, for measurements collected in the near field there is a high probability that the technicians body will react like an antenna, which could greatly affect the measured power densities. Based on this information, during collection of data set nine at locations seven and nine power density readings were taken while physically holding the meter and probe and then duplicated remotely via a laptop computer. This comparison resulted in non significant differences in measurements. Thus, the technicians' body didn't significantly impact the measurements.

Chapter 3 - Material and Methods

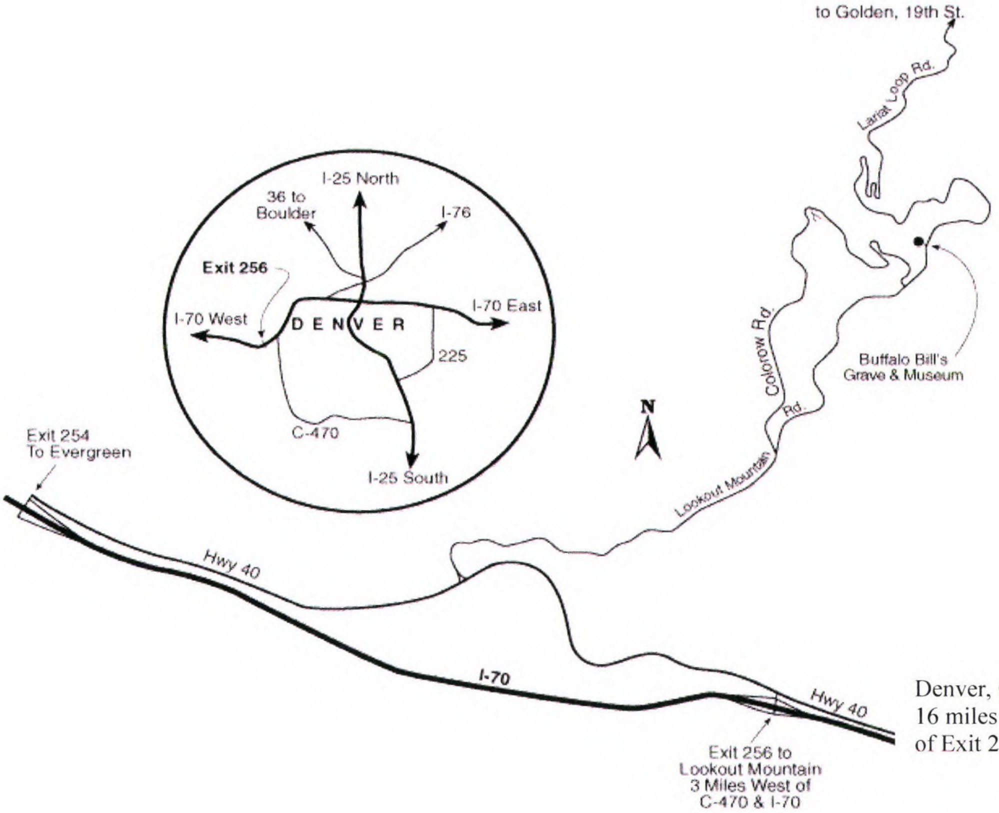
Site selection

Based on a preliminary survey of more than 100 field strength measurements at potential sampling locations from Cody Park and Spruce road to the west; I-70 and Mt. Evans Vista to the south and natural topography to the north and east, 21 locations (Fig 4 and 5) were selected based on field strength measurements greater than 0.000100 $mW \cdot cm^{-2}$, topography, and proximity to antenna locations (Fig. 5 and Table 4). This selection criterion was designed to determine the peak field strength measurements and reduce the probability of underestimating these field strength measurements. The 21 locations are approximately 16 miles due west of Denver and are bounded by Paradise Hills to the south, Go A Quah Street to the west, and natural topography to the north and east (Fig. 5 and Table 5). This project location is unique since there are homes located at and above the elevation of the television and FM towers (Fig. 5 and Table 4) with some homes located within several hundred yards of the towers. The largest of the three groupings of broadcasting towers is presented in Figures 2 and 3. Latitudes, longitudes, and elevations above mean sea level (MSL) were determined using a Garmin 60CSx Global Positioning System (Appendix C). The 21 study locations were between 2,182 m and 2,338 m above MSL. The radiation center above mean sea level (RCAMSL) for all study television and radio broadcasting stations are located between 2,384 m and 2,248 m above MSL. Thus, 13 of the 21 locations are potentially within the broadcasting stations main beam. Currently, there are seven digital television stations licensed to broadcast a total of 4.90 MW of radiated power and nine FM radio stations licensed to broadcast a total of 0.576 MW (576.7 kW) of radiated power (Fig. 5 and Table 4). The City of

Golden requested measurements in November 2009 of six additional locations within Golden city limits. These locations are numbered 22 through 27 (Table 5). These additional locations are well below 1,890 m MSL with a median value of 0.000370 mW·cm^2 and a range of 0.000100 mW·cm^2 to 0.00670 mW·cm^2 and are not included in the statistical analysis.

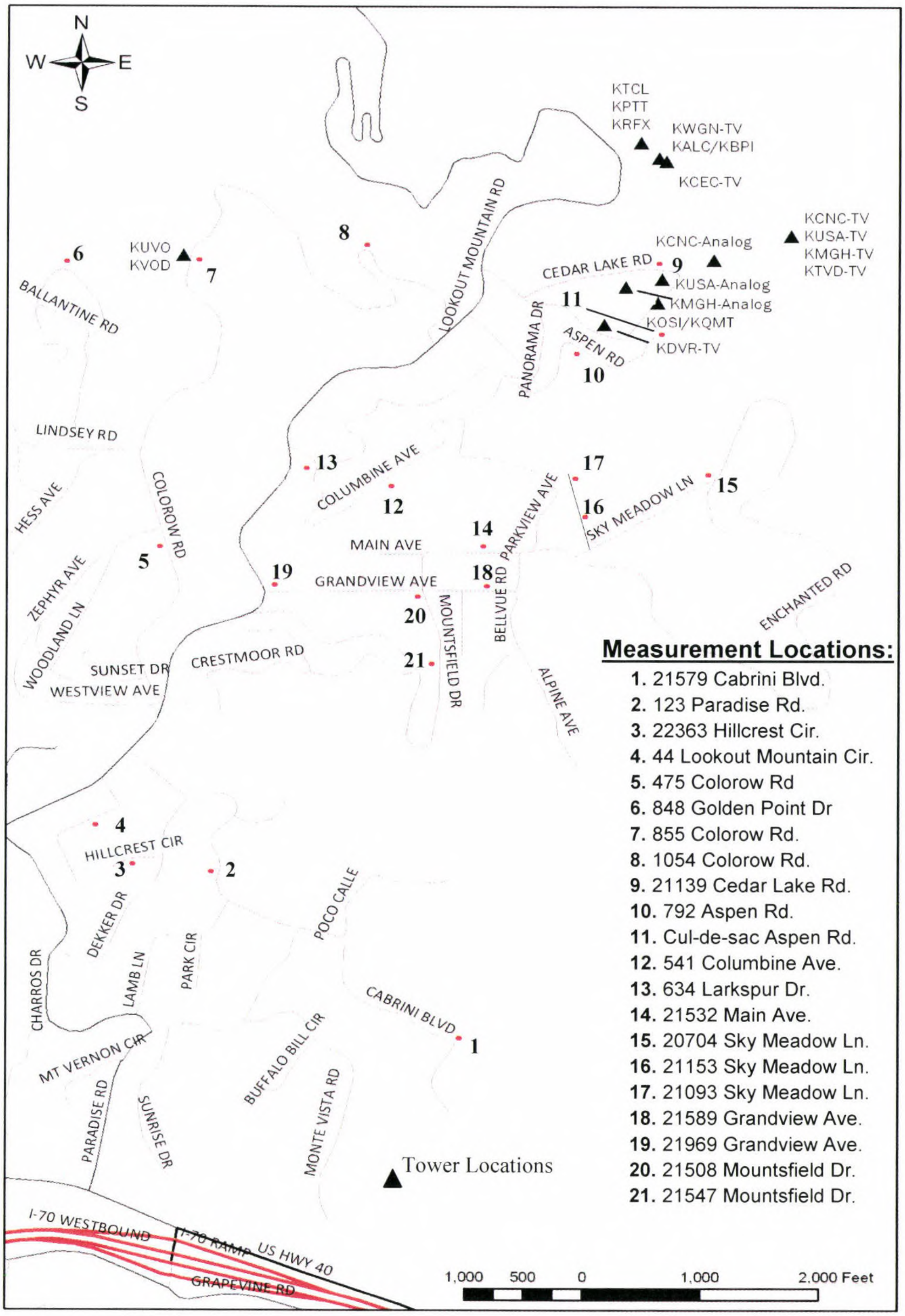
Figure 2 - Radio and TV Broadcasting Towers on Lookout Mountain

Figure 3 - Radio and TV Broadcasting Towers on Lookout Mountain



Denver, CO
16 miles SE
of Exit 256

Figure 4 - Lookout Mountain Vicinity Map
Downloaded from www.co.jefferson.co.us on 20 March 2010



Measurement Locations:

1. 21579 Cabrini Blvd.
2. 123 Paradise Rd.
3. 22363 Hillcrest Cir.
4. 44 Lookout Mountain Cir.
5. 475 Colorow Rd
6. 848 Golden Point Dr
7. 855 Colorow Rd.
8. 1054 Colorow Rd.
9. 21139 Cedar Lake Rd.
10. 792 Aspen Rd.
11. Cul-de-sac Aspen Rd.
12. 541 Columbine Ave.
13. 634 Larkspur Dr.
14. 21532 Main Ave.
15. 20704 Sky Meadow Ln.
16. 21153 Sky Meadow Ln.
17. 21093 Sky Meadow Ln.
18. 21589 Grandview Ave.
19. 21969 Grandview Ave.
20. 21508 Mountsfield Dr.
21. 21547 Mountsfield Dr.

Figure 5 - Lookout Mountain Location Map (provided by Jefferson County, Colorado) showing broadcasting tower locations and measurement locations.

Table 4 - TV and Radio Broadcasting Stations in Vicinity of Lookout Mountain.

Call sign	Freq. MHz / Channel	Lat[1]	Long[2]	ERP[3] (kW)	Max HAAT[4] (m)	HAAT[5] (m)	RCAGL[6] (m)	RCAMSL[7] (m)
Television Broadcasting Stations								
KWGN-TV	590 / 34	39.73278	105.2356	1000	648	336	122	2341
KCNC-TV	596 / 35	39.73083	105.2317	1000	694	374	215	2384
KMGH-TV	174 / 7	39.73083	105.2317	48	678	359	199	2368
KUSA	186 / 9	39.73072	105.2316	45	672	352.4	192	2362
KTVD	500 / 19	39.73083	105.2317	1000	694	374	215	2384
KDVR	578 / 32	39.72917	105.2367	1000	651	317	105	2347
KCEC	692 / 51	39.73278	105.2356	900	556	232.5	39	2248.8
Radio Broadcasting Stations								
KVOD	88.1	39.67167	105.2181	1.2	N/A	321	7	2348
KUVO	89.3	39.67361	105.2169	22.5	N/A	342	28	2363
KTCL	93.3	39.73306	105.2361	71	N/A	346	49	2256
KPTT	95.7	39.73306	105.2361	71	N/A	346	49	2256
KQMT	99.5	39.72917	105.2361	74	N/A	495	40	2262
KOSI	101.1	39.72917	105.235	74	N/A	495	40	2262
KRFX	103.5	39.73306	105.2361	71	N/A	346	49	2256
KALC	105.9	39.73278	105.2356	96	N/A	524	73	2292
KBPI	106.7	39.73278	105.2356	96	N/A	524	73	2292

1. Latitude
2. Longitude
3. Effective radiated power
4. Maximum height above average terrain
5. Height above average terrain
6. Radiation center above average ground level
7. Radiation center above average mean sea level

Table 5 - Selected RF Measurement Locations in Vicinity of Lookout Mountain

Location	Road Name	LAT	LONG
1	Cabrini Blvd, Golden, CO 80401-9406	39.71013	105.24252
2	Paradise Rd, Golden, CO 80401-8836	39.71461	105.25008
3	Hillcrest Cir, Golden, CO 80401-9423	39.71461	105.25210
4	Lookout Mountain Cir, Golden, CO 80401	39.71537	105.25236
5	Colorow Rd, Golden, CO 80401-9554	39.72231	105.25116
6	Golden Point Dr, Golden, CO 80401-9501	39.72992	105.25383
7	Colorow Rd, Golden, Colorado 80401	39.72916	105.25083
8	Colorow Rd, Golden, CO 80401-9510	39.72893	105.24303
9	Cedar Lake Rd, Golden, CO 80401-9493	39.72839	105.23838
10	Aspen Rd, Golden, CO 80401-9439	39.72770	105.23856
11	Aspen Rd, Colorado 80401	39.72730	105.23565
12	Columbine Ave, Golden, CO 80401-8842	39.72479	105.24439
13	Larkspur Dr, Golden, CO 80401	39.72511	105.24636
14	Main Ave, Golden, CO 80401-9429	39.72210	105.24158
15	Sky Meadow Ln, Golden, CO 80401-8811	39.72292	105.23305
16	Sky Meadow Ln, Golden, CO 80401-8807	39.72379	105.23764
17	Sky Meadow Ln, Golden, CO 80401-8826	39.72457	105.23788
18	Grandview Ave, Golden, CO 80401-9421	39.72162	105.24186
19	Grandview Ave, Golden, CO 80401-8816	39.72206	105.24727
20	Mountsfield Dr, Golden, CO 80401-9432	39.72116	105.24283
21	Mountsfield Dr, Golden, CO 80401-9431	39.7201	105.2429
22	Crawford St. - Shelton Elementary	39.7228	105.2153
23	Blue Jay Dr	39.7261	105.2197
24	Mourning Dove Lane	39.7275	105.2203
25	Shelton Rd	39.7314	105.2211
26	Infinity Cir	39.7408	105.2219
27	Bonvue Dr	39.7400	105.2317

Equipment

RF measurements were collected with a broadband, isotropic electric field type 18 probe (Wandel & Goltermann, model 2244/90.72), which can detect radio frequency fields (analog and digital) in the frequency range of 100 kHz to 3 GHz (Fig. 6, 7 and Appendix C). This range includes most typical frequencies in telecommunication applications and all significant broadcasting frequencies in vicinity of Lookout Mountain including digital television signals.

Figure 6 – Wandel & Goiltermann EMR-300 Meter

Figure 7 – EMR-300 Meter with Type 18 Isotropic Probe

The probe received a two year calibration certificate on January 19, 2009 by Liberty Labs, Inc, (Appendix D). This probe was used in conjunction with an EMR-300 broadband RF survey meter (Wandel & Goltermann, model 300). See Appendix C for probe and meter specifications. The EMR-300 (measurement range 0.00001 to 27 $mW\cdot cm^{-2}$) automatically re-zeroes itself at six minute intervals and has the ability to store 1,500 time-stamped measurements. Instantaneous isotropic measurements were collected at each of the 27 locations presented in Table 5 between February 2009 and January 2010 (Table 6). In addition, the EMR meter and probe was used to collect spatially averaged measurements for sampling event nine. This data was used to validate the statistical analysis.

Data Collection and Management

Peak isotropic measurements were collected between 10:00 AM and 2:00 PM at the 27 locations listed in Table 5. These measurements are considered peak isotropic measurements, as they are spot measurements and not spatial averaged measurements.

Table 6 - Data Collection Periods

Sampling Event	Date collected
1	10 Feb 09
2	8 April 09
3	14 May 09
4	1 July 09
5	7 Aug 09
6	15 Sep 09
7	24 Nov 09
8	16 Dec 09
9	15 Jan 10

For all locations and all sampling dates, peak exposure measurements was obtained by holding the probe approximately 2.0 m above ground level and orienting the probe towards the nearest group of broadcasting towers. Tower locations were determined by either visual means or by map and tower latitudes and longitudes. Additional exposures were measured at other probe positions, but for the 15 Jan 2010 measurements, an additional, systematic set of exposure measurements were collected at five different probe positions (Table 7 and Fig 8 - 12). Front high and front low probe positions were taken facing the antennas while the other probe positions (left high, left low, and right high) were taken perpendicular to the antennas. The left low and front low measurements were taken approximately 1.0 m above ground level. All other measurements were taken at 2.0 m above ground level. Spatially averaged measurements were collected for data set nine only, in addition to peak measurements for validation purposes. A distance of 10 m was maintained between measurement location and potential reflectors, such as vehicles. All measurements were stored in the EMR meter and uploaded to an Excel spreadsheet.

Table 7 - Instrument Positions and Collection Order for Data Set Nine

Order collected	**Probe Position**
1	Front high
2	Front low
3	Left high
4	Left low
5	Right high

Figure 8 – Front High Instrument Position

Figure 9 – Front Low Instrument Position

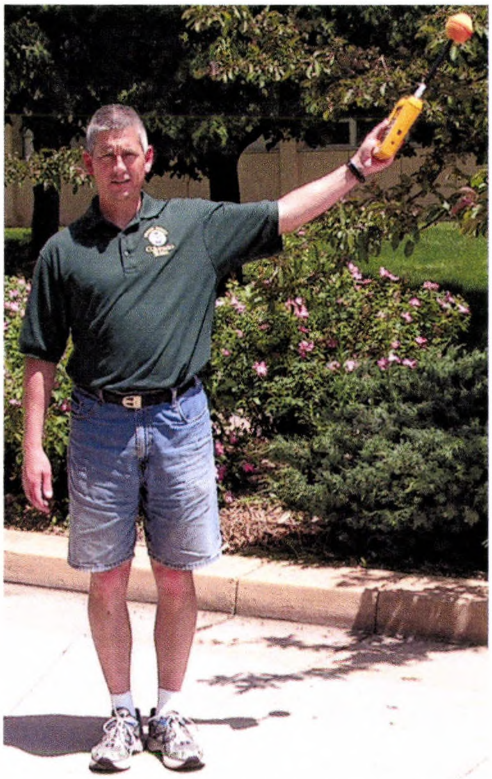


Figure 10 – Left Low Instrument Position

Figure 11 – Left Low Instrument Position

Figure 12 – Right High Instrument Position

Chapter 3 - Statistical Analysis

Statistical analyses were conducted using the Statistical Analysis System (SAS) software version 9.2. For each analysis, the type I error rate was set at 5%. Thus, 5% of the time the statistical test will result in a significant finding when no relationship exists in the population. Conversely, 95% of the time the statistical test will result in a significant finding when a relationship exists in the population. This 95% confidence interval is generally accepted in academia and research. First, an analysis of variance (ANOVA) was used to determine if the exposure measurement means across locations and times were likely to be equal, indicating all measurements are from the same sample population. Second, Tukey's HSD (Honestly Significant Difference) test was used to determine which means are significantly different from one another when the ANOVA test resulted in a significant finding. Tukey's HSD method is a multiple comparison procedure that simultaneously compares all possible mean measurements to every other mean measurement and identifies where the difference between two means are greater than the standard error, which results in grouping mean measurements that are not significantly different. Finally, an *apriori* linear combination of means, also called a contrast, was used to compare total exposure measurements leading up to the digital conversion deadline (June 12th, 2009) with the total exposure measurements collected after the conversion deadline. The contrast was used to ascertain if a trend across time exists or if all measurements across time are not significantly different. A uniform method of reporting was utilized for all box and whisker plots, as shown in figure 13.

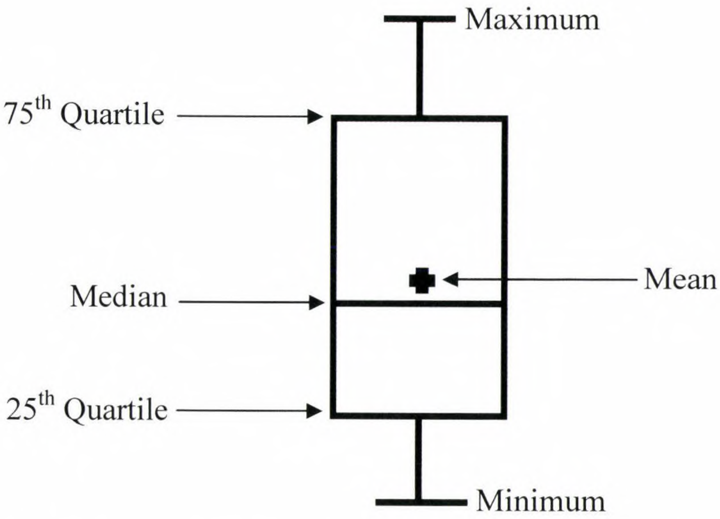


Figure 13 – Box and Whisker Plot Legend for Figures 15, 17, 18, 20 and 22.

Chapter 4 - Results

A total of 956 measurements were made across 27 locations at nine different times from February 2009 through January 2010. The median exposure for the 956 measurements is 0.00304 mW·cm^{-2} and ranged from 0.000100 mW·cm^{-2} up to 0.249 mW·cm^{-2}. The instantaneous maximum value of 0.249 mW·cm^{-2} was measured on July 1st 2009 at location seven. No other values measured were greater than the minimum MPE limit of 0.2 mW·cm^{-2}. The next highest value was 0.130 mW·cm^{-2} measured on May 9th 2009 at the same location. Calculated MPE limits for each broadcasting station are presented in Table 8.

Table 8 - Calculated MPE Limits for the General Public

Call sign	Freq. (MHz) / Channel	Calc. MPE* (mW/cm^2)
Television Broadcasting Stations		
KWGN-TV	590 / 34	0.300
KCNC-TV	596 / 35	0.300
KMGH-TV	174 / 7	0.200
KUSA	186 / 9	0.200
KTVD	500 / 19	0.250
KDVR	578 / 32	0.290
KCEC	692 / 51	0.350
Radio Broadcasting Stations		
KVOD	88.1	0.310
KUVO	89.3	0.290
KTCL	93.3	0.250
KPTT	95.7	0.230
KQMT	99.5	0.200
KOSI	101.1	0.200
KRFX	103.5	0.200
KALC	105.9	0.200
KBPI	106.7	0.200

* Maximum Permissible Exposures calculated based on Table 9 of Std. C95.1-2005. (Appendix E)

Comparison of Exposure Rates among Instrument Positions

For the January 15, 2010 data an analysis of variance (ANOVA) was conducted to determine if the front high instrument position, which was the very first measurement collected at all locations across the nine sampling times, resulted in the highest exposure rates. This was done to validate a method of only using the front high measurements across all locations and all sampling times. Because exposure rates differed among instrument positions, the front high measurements for each location in January 15, 2010 data were normalized to 1.0, and all other measurements at other positions were normalized as well. Figure 14 indicates that 79 of the 84 measurements collected at instrument positions two through five, were less than the normalized front high value of 1.0. This result provides a 95 percent confidence level that the front high instrument position results in the highest measurements across all probe positions. In addition, the five measurements that were greater than instrument position one were distributed across the nine sampling times and not all at one location (Fig. 14).

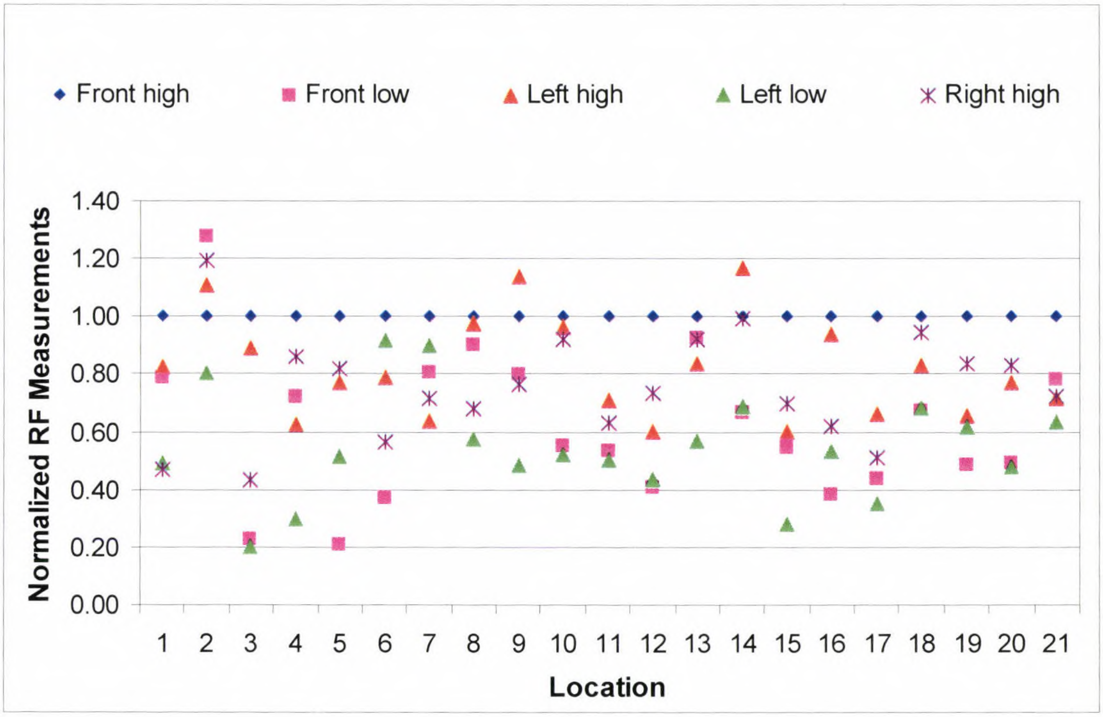


Figure 14 – Normalized (relative to sampling event nine) instrument position measurements

An ANOVA indicated there was a significant difference between instrument positions two through five (p-value < 0.0001). The front high instrument position was not included in the ANOVA test since the normalized measurements are not statistically different. The box and whisker plot (Fig. 15) and Tukey's HSD test (Table 9) indicated positions 3 and 5 have significantly smaller values than positions 2 and 4.

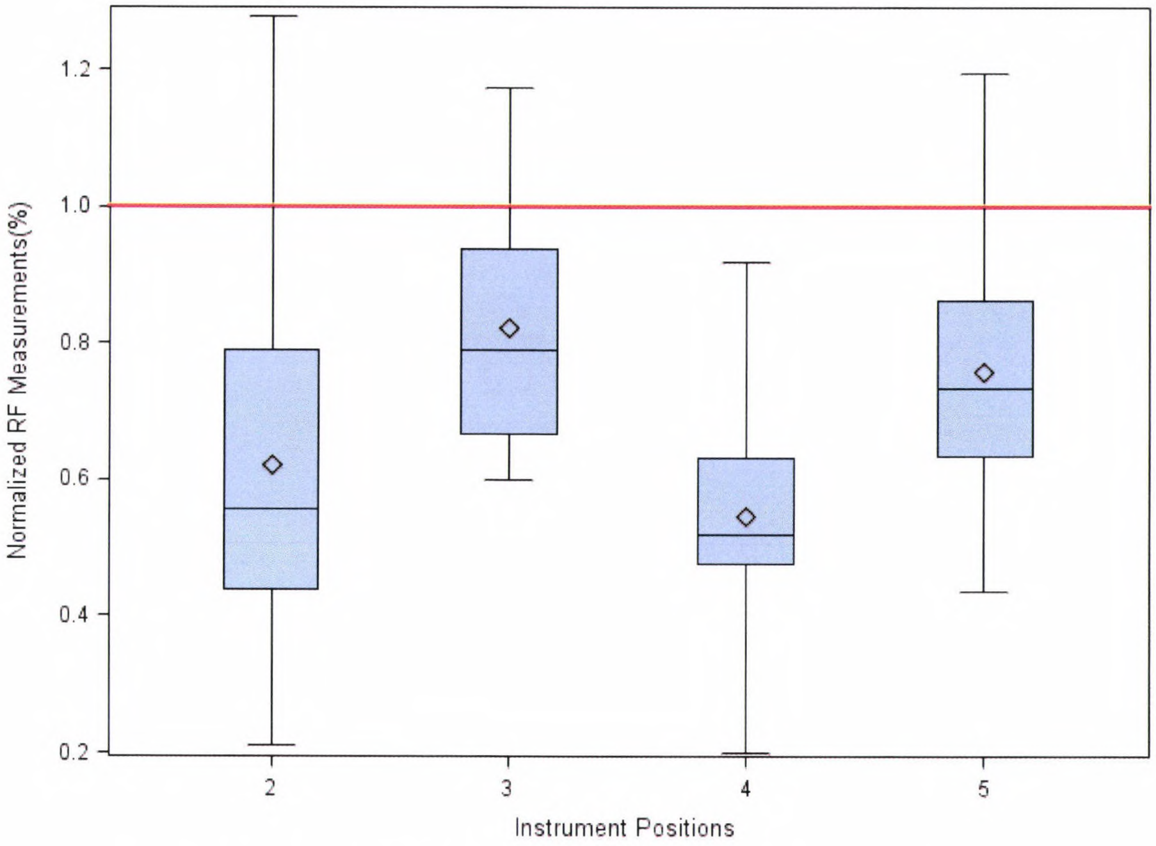


Figure 15 – Box and Whisker plot of normalized instrument positions. See figure 13 for legend.

Table 9 - Tukey's HSD Test for Instrument Positions

Tukey's Grouping		**Instrument Positions**	**Mean**	**N**
A		3	0.821	21
A				
A		5	0.757	21
	B	2	0.621	21
	B			
	B	4	0.545	21

Tests for normality (Table 10 and Fig. 16) indicated that the normalized instrument position measurements were not significantly different from a normal distribution. Therefore, front high measurements resulted in the highest values across all instrument positions, and the exclusive use of the front high measurements in an analysis of variance across all sampling events will not result in an underestimate of radio frequency exposures.

Table 10 - Tests for Normality (Gaussian) of the Normalized Sampling Event Nine

Test	Statistic	p Value
Shapiro-Wilk[1]	W = 0.988	0.651
Kolmogorov-Smirnov[2]	D = 0.0789	0.150
Cramer-von Mises[3]	W-Sq = 0.0615	0.250
Anderson-Darling[4]	A-Sq = 0.350	0.250

Note: SAS generates four tests for normality as a part of the Proc Univariate output. Data is statistically significant when the p-value is less than or equal to a significance level of 0.05, (95% confidence level).

1. **Shapiro-Wilk test:** based on the linearity of the Q—Q plot
2. **Kolmogorov-Smirnov test:** based on the maximum absolute difference between the cumulative distribution function (CDF) of the data and the theoretical normal distribution
3. **Cramer-von Mises test:** average square difference between the CDF of the data and the theoretical normal distribution.
4. **Anderson-Darling test:** Very similar to the Cramer-von Mises test, but the tails are weighted more heavily.

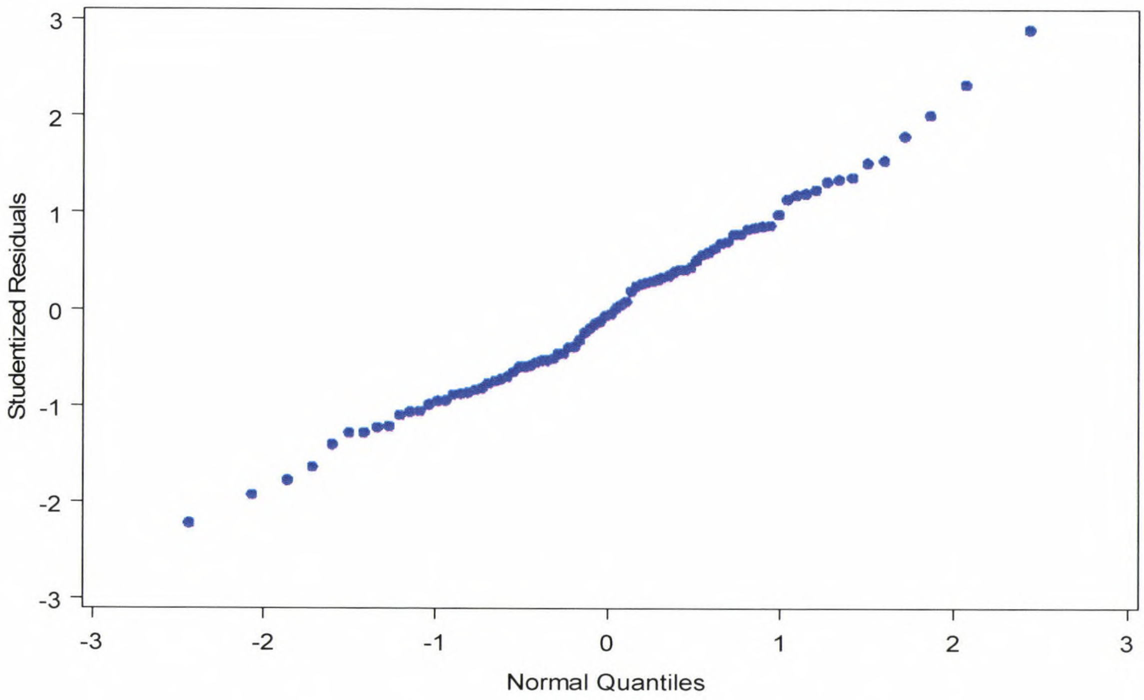


Figure 16 – QQ plot of normalized Sampling Event Nine

Additionally, spatial averaged measurements were collected for sampling event nine and a comparison of the instantaneous verses the spatially averaged measurements indicated that the instantaneous measurements resulted in higher values at all 21 locations. Comparing the instantaneous measurements to the minimum MPE limit is more restrictive and ensured measurements were not underestimated (Appendix D).

Temporal Trends of Front High Measurements (mW/cm^2)

A two-way ANOVA indicated no significant variation in front high measurements across time (p-value = 0.0868), but significant variation across locations exist (p-values < 0.0001). Box and whisker plots for front high measurements across time and location are presented in Figures 17 and 18.

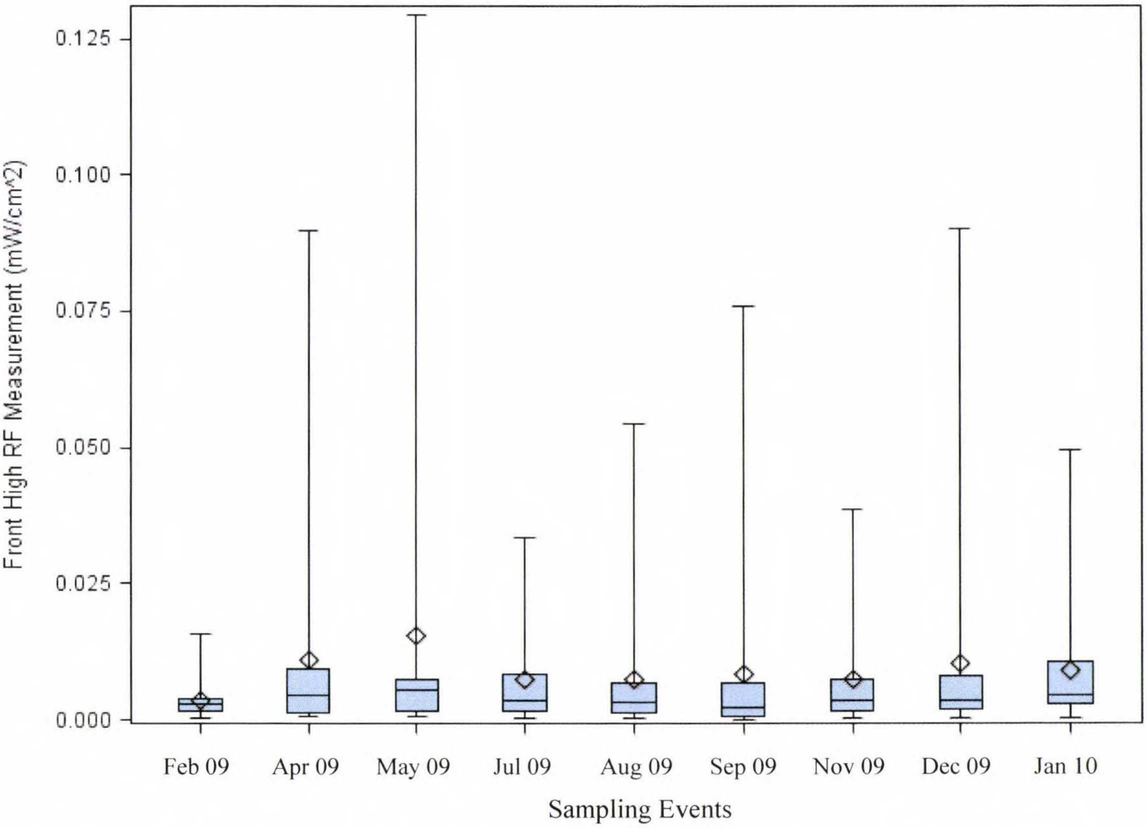


Figure 17 - Box and Whisker plot of All Measurements (mW·cm^{-2}) across Time

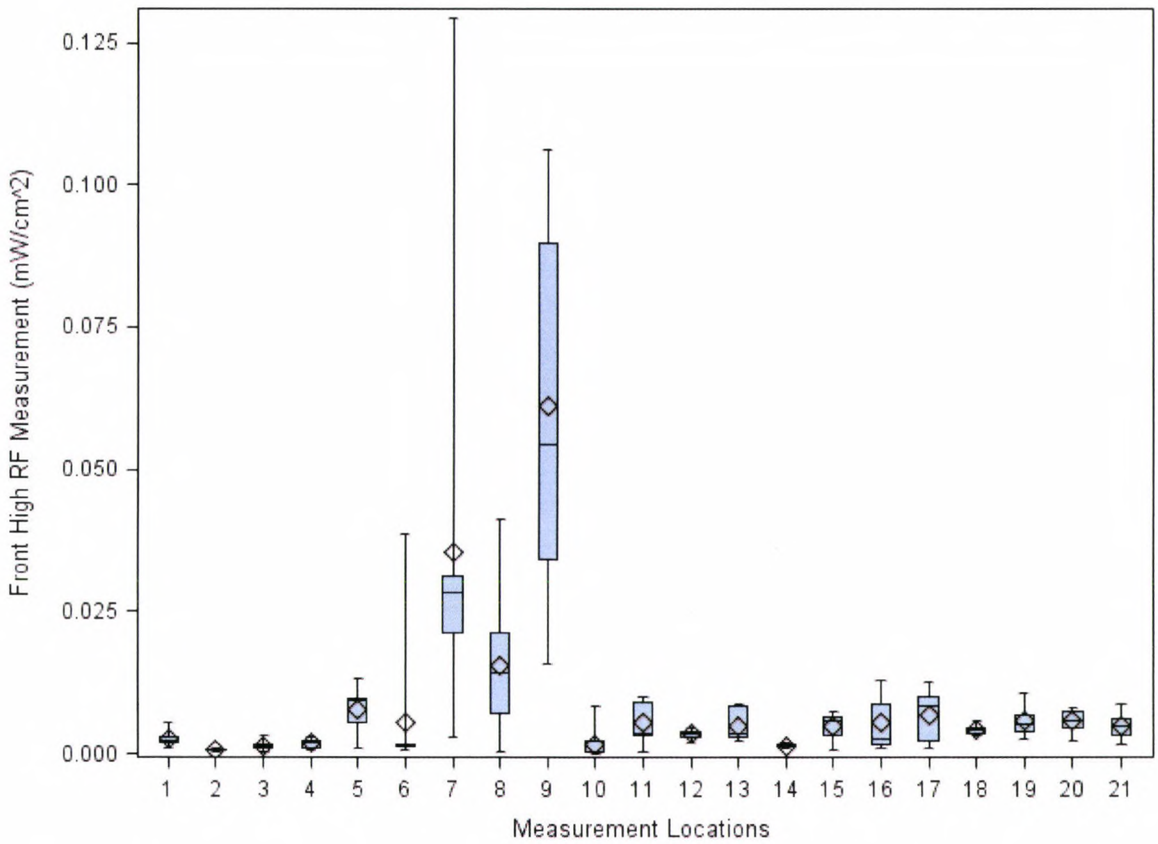


Figure 18 - Box and Whisker plot of All Measurements ($mW \cdot cm^{-2}$) across Location

The calculated power[45] for front high measurements across time was 55 percent indicating a reduced ability to detect mean differences among the 21 measurements across the nine sampling events. Large error bars in Figure 17 suggest measurements are not from a normal distribution. In fact, the lognormal histogram plots (Fig. 19) indicate measurements are from a lognormal distribution, which is representative of radio frequency waves located in the far field range. Radio frequencies waves in the far field range behave according to the inverse square law and measurements are recorded as power density with units of $mW \cdot cm^{-2}$. Spatial variation across location (Fig. 18) is expected and is easily understood when proximity and elevation of the data collection locations are considered in relation to the broadcasting towers.

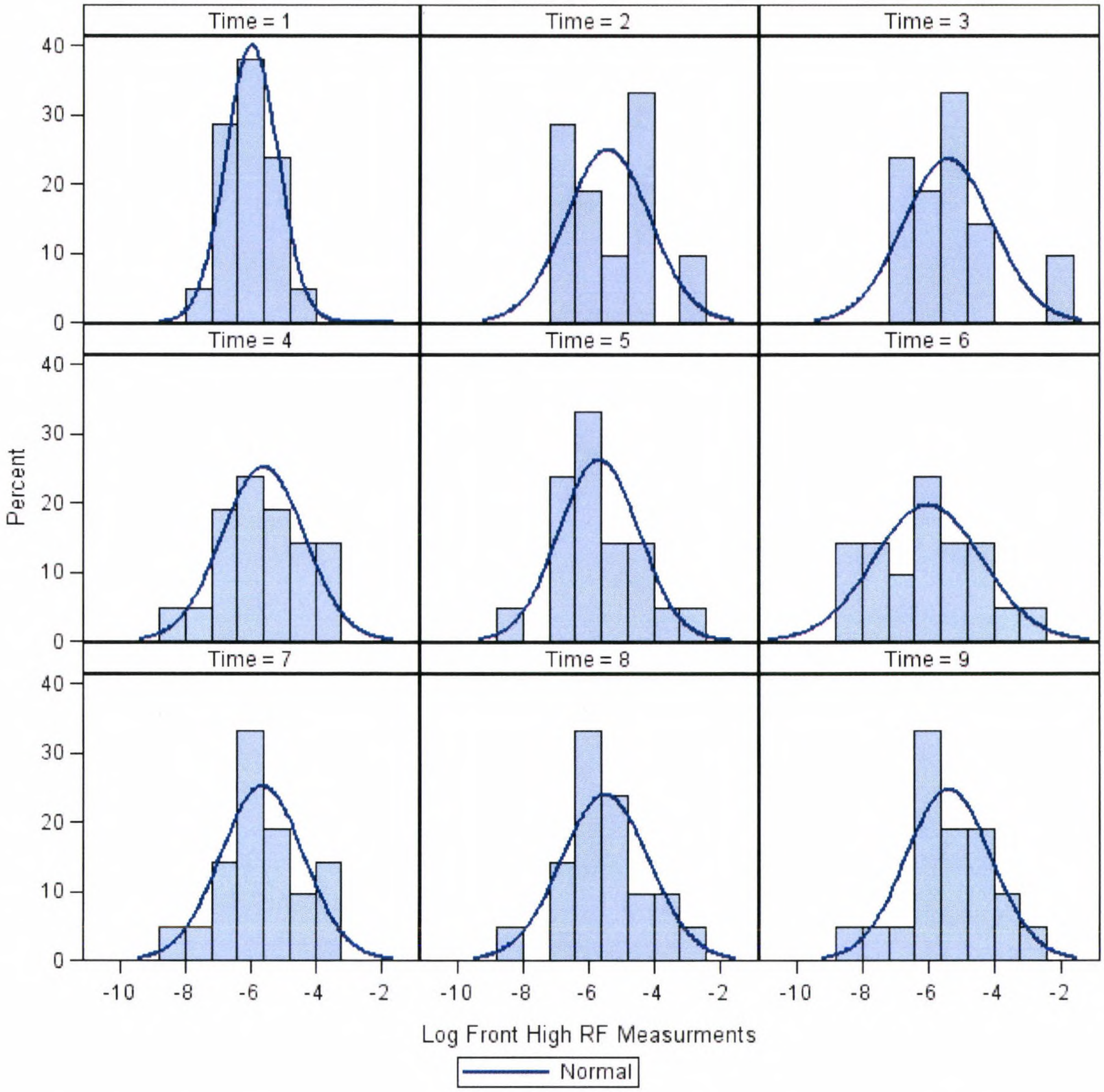


Figure 19 - Log-Normal Histogram for Front High Measurements (mW $\cdot$cm^{-2}) across Time

Tukey's HSD test (Table 11) indicates two groupings, but with the exception of group A at time three (mean = 0.0153 mW$\cdot$cm^{-2}) and group B at time one (mean = 0.00349 mW$\cdot$cm^{-2}), the other seven means are not significantly different. Thus, Tukey's HSD test reveals no continuous trend over time. An *apriori* linear combination comparison of those data sets collected before the digital conversion deadline (63 measurements) and the data sets following the deadline (126 measurements) indicated no significant difference in means (difference = 0.00155 mW·cm^{-2}; t (test statistic) = 0.90; and p-value = 0.370).

Table 11 - Tukey's HSD for Sampling Event One through Nine across Time

Tukey's Grouping		Sampling Time	Date	Mean	N
	A	3	May-09	0.0153	21
	A				
B	A	2	April-09	0.0109	21
B	A				
B	A	8	Dec-09	0.0103	21
B	A				
B	A	9	Jan-10	0.00914	21
B	A				
B	A	6	Sep-09	0.00852	21
B	A				
B	A	7	Nov-09	0.00752	21
B	A				
B	A	5	Aug-09	0.00736	21
B	A				
B	A	4	Jul-09	0.00728	21
B					
B		1	Feb-09	0.00349	21

This linear combination tested the hypothesis that exposures before and after the conversion deadline of June 12th 2009 did not differ significantly. The calculated power[45] for the linear combination comparison was 97 percent at one standard deviation and 99 percent at two standard deviations.

Temporal Trends of Normalized Front High Measurements

Because the large variation across location (Fig. 18) could mask or obscure variations across time (Fig. 17), the measurements for each location were normalized to a value of 1.0 by dividing by the maximum values observed at each location across all sampling events. This normalizing procedure diminished variation across location and thereby increased the ability of the statistical test to detect mean differences in variation across the nine sampling events. Thus, a two-way ANOVA for the normalized front high measurements indicated significant variation across time (p-value = 0.0052) and across location (p-value < 0.0001). Box and whisker plot for measurements across times is presented in Figure 20.

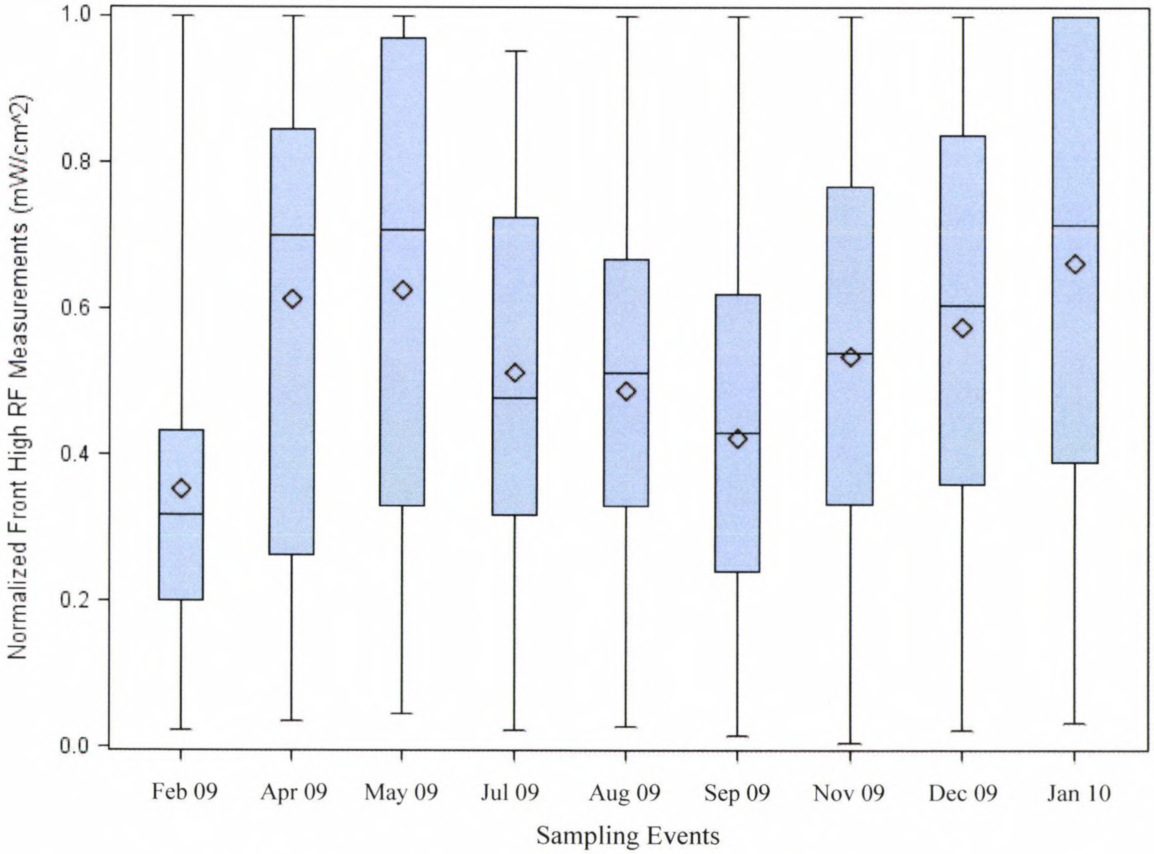


Figure 20 - Box and Whisker plot of Normalized Measurements (mW·cm^{-2}) across Time

Tukey's HSD test revealed two groupings (Table 12), but there was no temporal trend as demonstrated by an *apriori* linear combination of normalized means of those data sets collected before the digital conversion deadline (June 12th, 2009) and the data sets following the deadline (difference = 0.00293 $\text{mW} \cdot \text{cm}^{-2}$; t (test statistic) = 0.07; and p-value = 0.944).

Table 12 - Tukey's HSD for All Normalized Data across Time

Tukey Grouping		Sampling Time	Date	Mean	N
	A	9	Jan-10	0.662	21
	A				
	A	3	May-09	0.624	21
	A				
B	A	2	Apr-09	0.613	21
B	A				
B	A	8	Dec-09	0.576	21
B	A				
B	A	7	Nov-09	0.535	21
B	A				
B	A	4	Jul-09	0.513	21
B	A				
B	A	5	Aug-09	0.489	21
B	A				
B	A	6	Sep-09	0.424	21
B					
B		1	Feb-09	0.353	21

Chapter 5 - Discussion

The main objective of this research project was to determine if the Lookout Mountain radio frequency exposures showed a trend over time and, if so, was this trend due to the DTV conversion. While there are some statistical differences in Radio frequency measurements across time, no trends were observed from the *apriori* linear combination test for either the measured means or the normalized means. This lack of change is not surprising given the 1998 FCC study results, which showed that FM radio stations are responsible for approximately 95 percent of the field strength exposures at Lookout Mountain while the balance was attributed to television broadcasting stations.[44]

A frequency analyzer was considered for this project in order to distinguish exposures rate percentages by frequency. This type of analysis would provide total exposure percentages on Lookout Mountain as well as assign percentages to each broadcasting antenna. However, while this data might be informative it is not within the project scope not to mention the prohibitive cost of a spectrum analyzer. Additionally, due to the controversy surrounding the close proximity of broadcasting towers to residential areas and the past legal actions taken by the CARE (Canyon Area Residents for the Environment) action group it was decided to avoid identification of specific RF sources.

Only one of the 956 measurements collected exceeded the lowest MPE limit of 0.2 $mW \cdot cm^{-2}$ for frequency range of 100 MHz to 400 MHz (Appendix F, Table F.2). This measurement (0.249 $mW \cdot cm^{-2}$) was one of six measurements collected on July 1, 2009 at location seven. The 0.249 $mW \cdot cm^{-2}$ measurement was taken at 11:49:06. The previous measurement of 0.126 $mW \cdot cm^{-2}$ was taken at 11:48:26 and the subsequent measurement of 0.02 $mW \cdot cm^{-2}$ was taken at 11:50:06. Thus, the 0.248 $mW \cdot cm^{-2}$ exposure was for $\leq$ 1.67 minute duration, which did not exceed the averaging time of 30 minutes for the general public or 6 minutes for the occupational worker.

Lookout Mountain Exposure Data from Others

The Lake Cedar Group, owners of several television broadcasting antennas on top of Lookout Mountain, retained Mr. Musselman as a private consultant in 2008 to set up a RF Monitoring Program.[46] Mr. Randall Musselman, Mr. Myron Oliner (private consultant), and Mr. Russ Clark (Jefferson County representative) met in July of 2008 to determine appropriate sites that should be included in this monitoring program. Thirteen sites were selected based on significant radio frequency levels past measurements; historical continuity, and locations of high public interest (Fig. 21).[46]

Five spatial average measurements where collected on a monthly basis at the 13 locations. These spatial average measurements' were collected using a zigzag pattern covering the area of a six-foot tall adult body. The highest and lowest measurements were discarded and the average of the three remaining measurements was reported as the spatially averaged percentage of the general publics MPE limit. This report did not mention the instrument make and model.

Mr. Musselman's data covered a period from July 2008 to October 2008 and January 2009 to June 2009. A two-way ANOVA of Mr. Musselman's data indicated that variation across time is not significant (p-value = 0.793), but that a significant variation exists across locations (p-value < 0.0001). A box and whisker plot across time (Fig. 22) and Tukey's HSD test (Table 13) indicated means are not significantly different. Most importantly, the average means of Mr. Musselman's data are located below the 40th percentile of the MPE with some individual values at the 80th percentile, which is represented by the error bars (Fig. 22). Thus, all reported measurements were below the MPE limit for the general public.

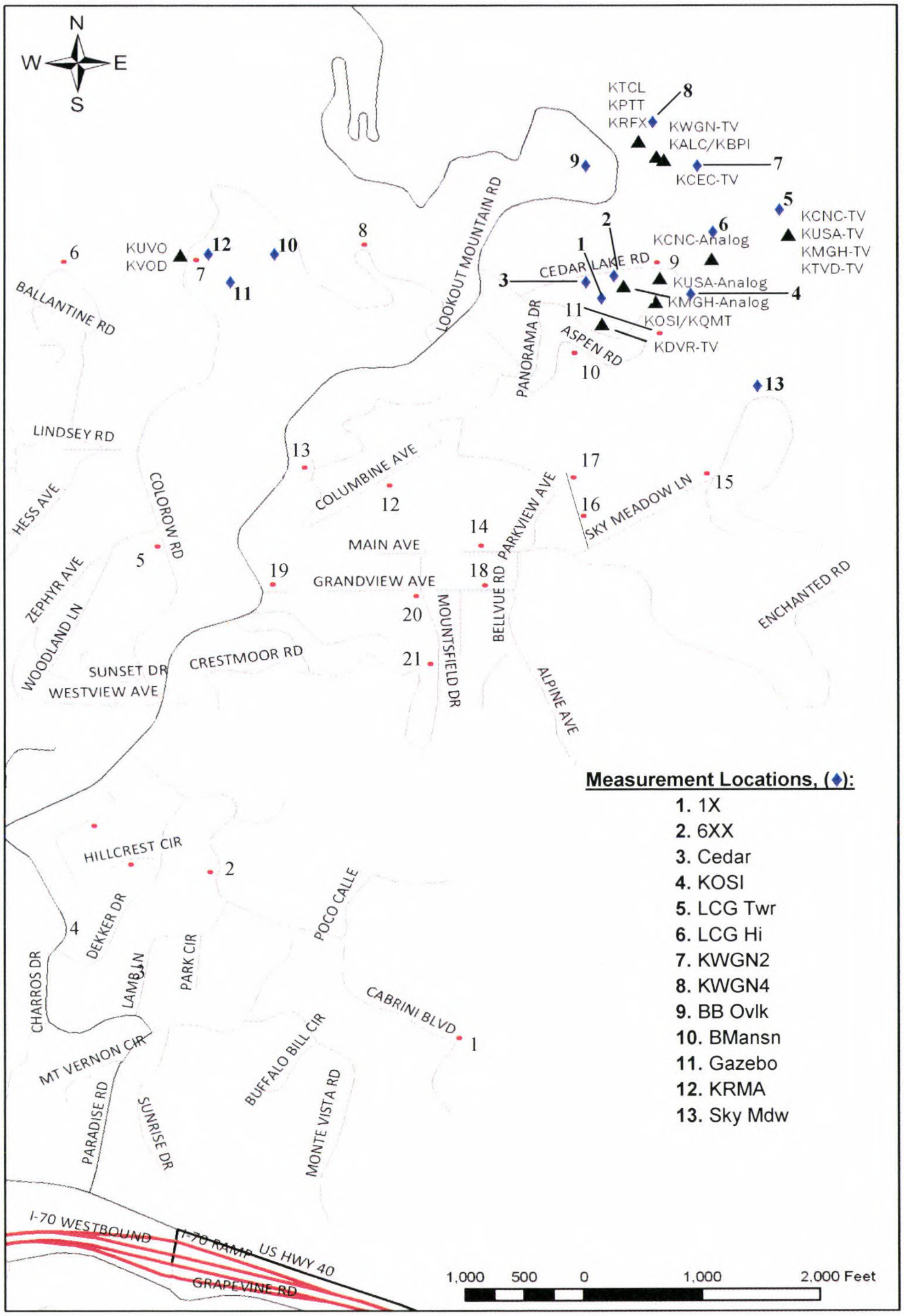


Figure 21 – Mr. Musselman's Location Map Showing Broadcasting Tower Locations and Measurement Locations

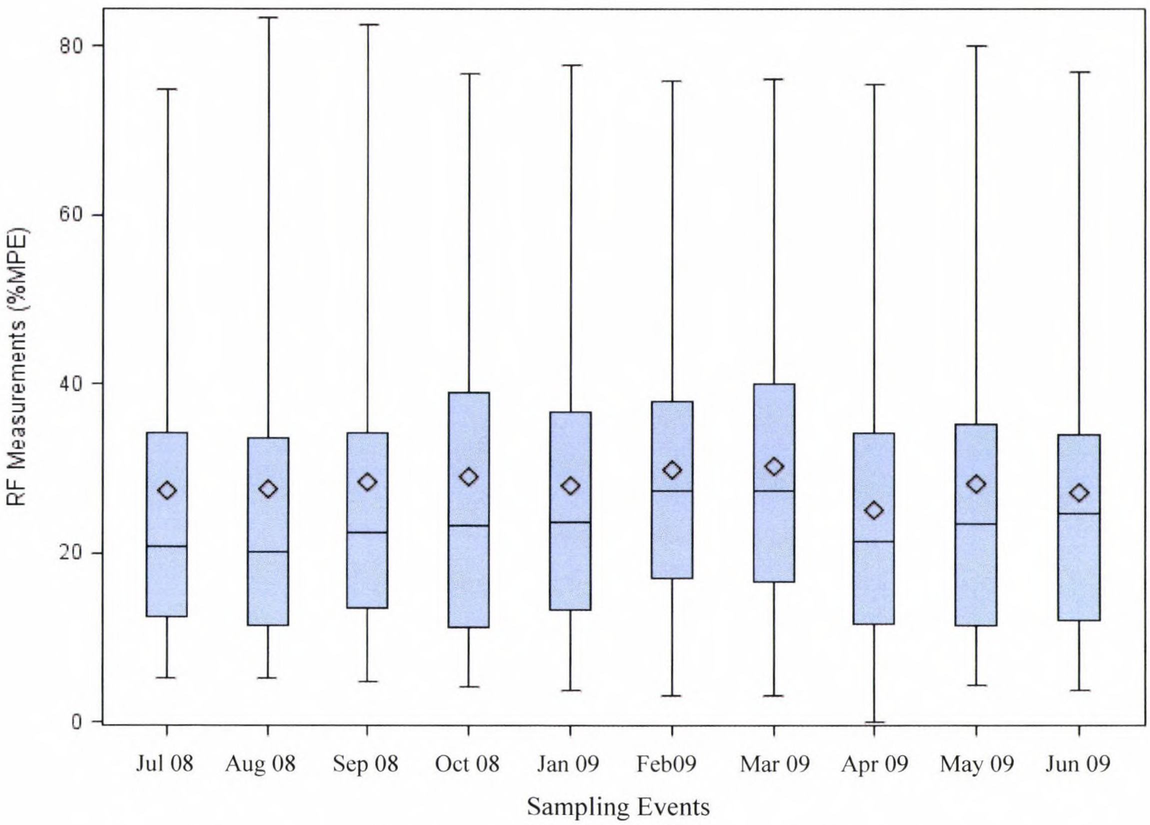


Figure 22 - Box and Whisker plot of Mr. Musselman's Data across Time

Table 13 - Tukey's HSD Test for Mr. Musselman's Data across Time

Tukey's Grouping	Time	Average Mean % MPE	N
A	Mar 2009	30.3	5
A			
A	Feb 2009	29.9	5
A			
A	Oct 2008	29.1	5
A			
A	Sept 2008	28.5	5
A			
A	May 2009	28.3	5
A			
A	Jan 2009	28.1	5
A			
A	Aug 2008	27.5	5
A			
A	July 2008	27.5	5
A			
A	June 2009	27.2	5
A			
A	April 2009	25.1	5

Other TV and Radio Broadcasting Studies

There are two other recent studies that utilize antenna technical data to determine potential exposures based on calculated theoretical power densities. The first study was conducted by Bakhashwain in 2006 near the Damam Coast Radio Station located in Saudia Arabia, which compared measured and calculated power densities.[47] The calculated power densities were based on assumed technical specifications of an omni-directional short dipole antenna and a high gain log periodic antenna with calculated antenna gains. The author concluded that theoretical calculations confirmed the measured reading and that both calculated and theoretical power densities are well below the IEEE standards[47] However, it is not clear how the author arrived at this conclusion since the data was not clearly presented.

The second study was conducted by Sirav and Seyhan in 2009 near 64 different TV and radio transmitters, which are located near residential neighborhoods in Turkey.[48] The authors calculated theoretical power densities based on technical data received from 31 of the 64 transmitters. The power densities were calculated by using the Federal Communication Commission (FCC) method, which is published in the Office of Engineering and Technology (OET) 65 report[49]. The authors concluded that the radiation exposures may be up to four times higher than the permitted standards of Turkey and ICNIRP.[48]

Both of these studies have very limited statistical power based on the fact that neither study accounted for confounding errors, assumptions, and reflective properties from objects and natural topography. The later study utilized the FCC's method, which calculates worst case exposures originating from omni-directional, dipoles, and directional arrays antennas.[50] The OET 65 report suggests using a relative field factor, which is based on the antenna's vertical radiation pattern. This modification factor should give more accurate results.

Theoretical exposure levels were not calculated for the Lookout Mountain Pilot project because antenna technical specifications, including vertical radiation patterns, were not available. Also, theoretical equations are based on flat terrain and minimum reflection. Calculating exposure values in the vicinity of Lookout Mountain would almost certainly result in values that are not representative of actual conditions, not to mention above the general public MPE limits.

Chapter 6 - Conclusion

Project Summary

The Lookout Mountain pilot project measured radio frequency radiation originating from television and radio broadcasting antennas near Golden, Colorado. Peak isotropic measurements were collected at 21 locations throughout residential areas contiguous to three groups of broadcasting antennas. A total of 956 measurements were collected between February 10th 2009 and January 15th 2010.

The main objectives of this study was to measure radio frequency exposure levels within 3.0 km of Lookout Mountain during the period of February 2009 and January 2010; identify potential trends of exposure levels before and after the conversion deadline; and to evaluate compliance with the maximum permissible exposure limits for the general public.

Project Conclusion

Based on the statistical analysis, with an *apriori* linear combination p-value = 0.9441, the radio frequency exposure measurements before and after digital conversion were not statistically different. Also, the statistical analysis did not indicate any type of trends in exposure measurements across time. Finally, 955 measurements out of 956 were below the minimum MPE limits for the general public. It is important to note that even though the one measurement 0.249 $mW \cdot cm^{-2}$ exceeded the MPE limit of 0.200 $mW \cdot cm^{-2}$ for frequency ranges 100 MHz to 400 MHz it did not exceed the limits for frequency ranges of 30 MHz to 93 MHz or 400 MHz to 2000 MHz.

Recommendations

Based on the culmination of this study and past Lookout Mountain studies, for a total of 17 studies over the past 27 years, it is suggested not to pursue future studies of this kind as long as antenna position and antenna effective radiated power do not change. However, continued Radio Frequency Monitoring Programs by the broadcasters through third-party consultants, in which status reports are provided to Jefferson County and made available to the general public, are recommended.

Future Regulatory Limits

There is a lack of scientific literature on how radio frequency radiation can impact medical implant devices. These devices cover the gamut from pacemakers to hearing aids to magnetic shunts. The Committee on Man and Radiation (COMAR) Technical Information Statement regarding Radiofrequency Interference (RFI) with Medical Devices provides a good summary of the current information on RFI problems.[51] The COMAR report recommends that users of medical implant devices and the manufacturer of the device work together to ensure safe operation. COMAR also recommends administrative controls that include educational training for the user and their employer. The bottom line is that some of these devices are very sensitive to electromagnetic fields and currently very little is known about how RFI affects medical devices.

If new MPE limits are ever promulgated to include protection of medical implanted devices, then the data contained in this project could be used to validate current exposure levels.

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Appendix A – Required Energy to Break Chemical Bonds

An example calculation of the energy required to break water bonds can be made. A water bond is used for this example since 68% of the human body, by weight, is water. In order to perform this calculation the bond dissociation energy (BDE), the energy required to break up a chemical bond into its constituents, must be determined. This BDE for water is approximately 463 kJ/mol.[9] The energy per bond is found by dividing the bond energy by Avogadro's number (6.022×10^{23} atoms per mol).

$$E_{bond} = \frac{\text{dissociation energy}}{\text{Avogadro's Number}} = \frac{463{,}000\,\frac{\text{J}}{\text{mol}}}{6.022\times10^{23}\,\frac{\text{bonds}}{\text{mol}}} = 7.69\times10^{-19}\,\frac{\text{J}}{\text{bond}}$$

$$E_{bond} = \frac{7.64\times10^{-19}\,\frac{\text{J}}{\text{bond}}}{1.6\times10^{-19}\,\frac{\text{eV}}{\text{J}}} = 4.775\ \text{eV}$$

The photon wavelength corresponding to this energy is given by:

$$\lambda = \frac{h\cdot c}{E_{bond}} = \frac{(6.626\times10^{-34}\,\text{J}\cdot\text{s})\cdot(3\times10^{8}\,\frac{\text{m}}{\text{s}})}{7.69\times10^{-19}\,\text{J}} = (2.58\times10^{-7}\,\text{m})\cdot\frac{1\text{nm}}{10^{-9}\,\text{m}} \approx 260\ \text{nm}$$

Where: λ = wavelength, m
h = Plank's constant, J-s
c = Speed of light, m/s

The minimum required energy to break a hydrogen bond (BDE = 436 kJ/mol)[9] can be calculated in the same manner. The energy per bond is given by:

$$E_{bond} = \frac{436{,}000 \frac{\text{J}}{\text{mol}}}{6.022 \times 10^{23} \frac{\text{bonds}}{\text{mol}}} = 7.24 \times 10^{-19} \frac{\text{J}}{\text{bond}}$$

$$E_{bond} = \frac{7.24 \times 10^{-19} \frac{\text{J}}{\text{bond}}}{1.6 \times 10^{-19} \frac{\text{eV}}{\text{J}}} = 4.53\text{eV}$$

The photon wavelength corresponding to this energy is given by:

$$\lambda = \frac{\text{h} \cdot \text{c}}{E_{bond}} = \frac{(6.626 \times 10^{-34}\,\text{J} \cdot \text{s}) \cdot (3 \times 10^{8} \frac{\text{m}}{\text{s}})}{7.24 \times 10^{-19}\,\text{J}} = (2.75 \times 10^{-7}\,\text{m}) \cdot \frac{1\text{nm}}{10^{-9}\,\text{m}} \approx 275\text{nm}$$

The photon energy that corresponds to the upper end of the RF region, 300 GHz can also be determined. The photon wavelength corresponding to 300 GHz frequency is:

$$\lambda = \frac{c}{f} = \frac{3 \times 10^{8} \frac{\text{m}}{\text{s}}}{300\ \text{GHz} \cdot 10^{9} \frac{\text{Hz}}{\text{GHz}}} = 0.001\ \text{m}$$

The energy of a 300 GHz photon is given by:

$$E = \frac{\text{h} \cdot \text{c}}{\lambda} = \frac{(6.626 \times 10^{-34}\,\text{J} \cdot \text{s}) \cdot (3 \times 10^{8} \frac{\text{m}}{\text{s}})}{0.001\ \text{m} \cdot 1.69 \times 10^{-19} \frac{\text{J}}{\text{eV}}} = 0.0012\ \text{eV}$$

Appendix B – Conclusions from Health Agencies and Expert Panels Regarding Electromagnetic Exposures

Table B. 1 - Conclusions from Health Agencies and Expert Panels[35]

Health Agencies and Expert Panels - Comments on Health Effects from Electromagnetic Exposure	
Agency or Panel	Statement
UK Independent Expert Group on Mobile Phones	"The balance of evidence to date suggests that exposures to RF radiation below NRPB and ICNIRP guidelines do not cause adverse health effects to the general population"[52]
World Health Organization	"Despite extensive research, to date there is no evidence to conclude that exposure to low level electromagnetic fields is harmful to human health."[53]
Health Council of the Netherlands	"The Committee concludes that the scientific information concerning non-thermal effects discussed in this report provides no reason to apply the precautionary principle and lower the SAR limits for partial body exposure."[54]
U.S. Department of Health and Human Services, Centers for Disease Prevention and Control	"In the last 10 years, hundreds of new research studies have been done to more directly study possible effects of cell phone use. Although some studies have raised concerns, the scientific research, when taken together, does not indicate a significant association between cell phone use and health effects."[55]
German Research Center	"In summary, the overall balance of evidence from epidemiological occupational studies does not indicate that RF radiation affects the risk of cancer in people."[56] Also, …"the hypothesis that EMF from mobile phone communication has a harmful effect is not substantiated."[56]
Health Canada	"Health Canada has conducted its own research to determine whether RF energy could cause damage to DNA or changes to certain genes. The exposure levels used in these studies included those that were well above the limits specified in Health Canada's RF exposure guidelines. Based on Health Canada's research, no effects from RF exposure were seen."[57]

New Zealand Ministry of Health	“There is no known mechanism which could explain this association, and hence there is considerable doubt over whether it is indicative of a cause and effect relationship.”[58] “Evidence of links between exposures and adult cancers are, at most, very weak, and generally inconsistent. There is no good laboratory evidence suggesting an effect of ELF fields on the development of cancer.”[58]
Ireland Expert Group	“RF fields normally found in our environment do not produce any significant heating. While non-thermal mechanisms of action have been observed, none have been found to have any health consequence.”[59]
States of Jersey, Minister for Economic Development	Regarding potential health effects from mobile phone antennas, “…it is equally clear that there is no scientific evidence to show that an actual risk exists.”[60]
Ministry of Internal Affairs & Communications, Japan	“The Committee concludes that no clear evidence is found of the effects of radio waves on the human body at intensity levels lower than those specified in the RRPG (Radio Radiation Protection Guidelines).”[61]
UK Mobile Telecommunications and Health Research Program	“Overall, the Stewart Committee concluded that the balance of evidence indicated that there was no general risk to the health of people living near base stations on the basis that exposures were expected to be small fractions of internationally accepted guideline values.”[62] However, “…compelling evidence from both experimental studies and epidemiological research that using a mobile phone while driving impairs performance and increases the risk of an accident.”[62]
World Health Organization	“Concerning radio frequency fields, the balance of evidence to date suggests that exposure to low level RF fields (such as those emitted by mobile phones and their base stations) does not cause adverse health effects.”[63] “However, the epidemiological evidence is weakened by methodological problems, such as potential selection bias. In addition, there are no accepted biophysical mechanisms that would suggest that low-level exposures are involved in cancer development. Thus, if there were any effects from exposures to these low-level fields, it would have to be through a biological mechanism that is as yet unknown. Additionally, animal studies have been largely negative. Thus, on balance, the evidence related to childhood leukemia is not strong enough to be considered causal.”[64]

Australian Radiation Protection and Nuclear Safety Agency	"At low levels of exposure to RF EME (ie field intensities lower than those that would produce measurable heating), the evidence for production of harmful biological effects are ambiguous and unproven. Although there have been studies reporting a range of biological effects at low levels, there has been no indication that such effects might constitute a human health hazard, even with regard to long-term exposure."[65]
UK Position Statement	"In summary, the absence of robust new evidence of harmful effects of EMFs in the past two years is reassuring and is consistent with findings over the past decade."[66]
U.S. Food and Drug Administration	"The scientific evidence does not show a danger to any users of cell phones from RF exposure, including children and teenagers."[67]
U.S. National Cancer Institute	"Incidence data from the Surveillance, Epidemiology and End Results (SEER) program of the National Cancer Institute showed no increase between 1987 and 2005 in the age-adjusted incidence of brain or other nervous system cancers despite the dramatic increase in use of cellular telephones."[68]
U.S. Federal Communications Commission	"There is no scientific evidence that proves that wireless phone usage can lead to cancer or a variety of other problems, including headaches, dizziness or memory loss."[69] "At relatively low levels of exposure to RF radiation, i.e., field intensities lower than those that would produce significant and measurable heating, the evidence for production of harmful biological effects is ambiguous and unproven."[70]

Table B. 2 – Literature Review of RFR (3 kHz to 300 GHz) from 2005 to 2009

Type of Study	Yr	No. of Cases	Description	Outcome	p-value / OR / 95% CI	Reference
Lit. review	05	> 60 studies	Review focused on genetic effects of radio frequency radiation	RFR fields are not capable of inducing genetic effects and do not enhance chemical or physical mutagens/ carcinogens		Verschaev[71]
Research	06	280 residence	Proximity to RF towers and exposure	Overall, no difference in mean residential RF levels. However, after 1 to 2yr follow up, 25% exterior and 38% interior remained unchanged. There was a weak positive correlation between elevation and distance (r=0.12) and % of transmitters visible (r=0.15), and a negative correlation between distance and % of visible transmitters (-0.55).		Burch[38]
Lit. review	06	Over 132 studies ranging from 1997 to 2006	RF radiation (3 KHz to 300) exposure to cardiovascular, reproductive, and immune system. Also looked at subjective effects.	Concluded: there is only weak evidence for a relationship between RFE and any endpoint studied…thus providing at present no sufficient foundation for establishing RFE as a health hazard.		Jauchem[72]
Lit. review	07	Endpoints: cancer, non-cancer, neurologic, and behavioral	Studies reviewed: cellular, animal, cell phone, temporal trends in disease rates, and proximity	These studies have provided little support for adverse health effects arising from RF exposure at levels below current international standards. Moreover, radio and television broadcast waves have exposed populations to RF for > 50 years with little evidence of deleterious health consequences.		Valberg[73]
Research	08	Mouse fibroblast	Mouse fibroblast exposed to 849 MHz RF radiation at SAR values of 2 and 10 W/kg for 1 hour per day for 3 days	No statistically significant differences between: 1. sham exposed and radiation exposed cells. 2. Changes in motility and invasiveness. 849 MHz radiation exposure exerts no detectable effects on cell cycle distribution, cellular migration, or invasion at SAR values of 2 and 10 W/kg		Lee[42]

Research	09	166 volunteers between April 2007 and February 2008	Measured RF exposure of individuals over two separate weeks	Mean weekly exposure to all RF-EMF sources was 0.13 microW/m^2 (0.0013 mW/cm^2) ranging from 0.000014 mW/cm^2 to 0.000881 mW/cm^2	Frei[74]
Research	09	1,959 cases and 5,848 controls	Validation study to demonstrate wave propagation modeling for calculating RF exposure is a good exposure metric for large scale epidemiology studies	Odds ratio ranged from 1.3 to 1.6 with a sensitivity of 76.6% and a specificity of 97.4%. Study found that calculated RF exposures are better exposure metric than distance alone when there's more than one transmitter	Schmiedel[75]
Research	06	280 residence	Proximity to RF towers and exposure	Overall, no difference in mean residential RF levels. However, after 1 to 2yr follow up, 25% exterior and 38% interior remained unchanged. There was a weak positive correlation between elevation and distance (r=0.12) and % of transmitters visible (r=0.15), and a negative correlation between distance and % of visible transmitters (-0.55).	Reif[39]

Appendix C – Equipment Specifications

Table C. 1 - Narda EMR-300 Specifications[76]

Display Specification	Display Type:	4½ Digit LCD
	Display Refresh Rate:	400 msec., typical
	Resolution:	0.01 V/m, (2.65×10^{-8} mW·cm^{-2}) 0.0001 A/m, (3.75×10^{-7} mW·cm^{-2})
	Settling Time	1 sec. (0 to 90% of measured value)
Warning Circuits (Red LED's in the keypad)	Visible:	ON/OFF and variable threshold
	Audible:	Piezoelectric, tone varies with measured value
Measurement Functions	Units:	V/m, A/m, mW/cm^2, W/m^2,% of limit value
	Results Displayed:	Current result or maximum value
	Averaging:	Current result or variable from 4 sec. to 15 min.
Calibration Data	One calibration factor settable per probe	
Self Tests	Auto. self-test: converter, battery, supply voltages, memory and zero adjustment	
	Period zero adjustment and battery check during operation	
	All tests can be performed during exposure to the field	
Interfaces	Fiber optic, serial interface for results transfer, remote control and calibration.	
Additional Functions	Storage of up to 1500 values, real-time clock. and spatial averaging	
Power Supply	Batteries	
Operating Time	8 hours	
Operating Temperature	0 to +50°C	

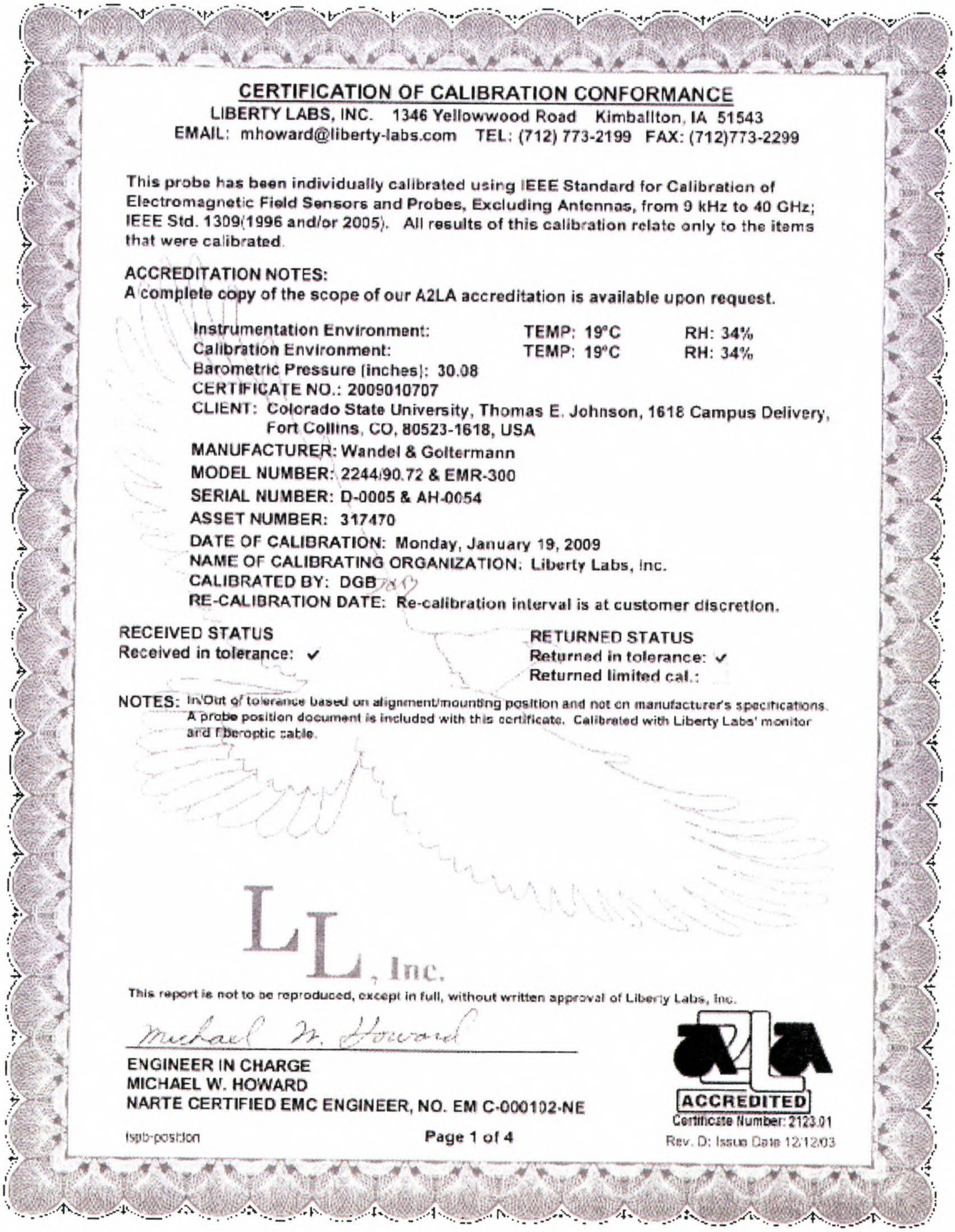
Table C. 2 - Narda EMR-300 Type 18 Probe Specifications[76]

Sensor type	Electric field (E)
Frequency range	100 kHz to 3 GHz
Directional characteristics	Isotropic, three-dimensional
Temperature range	0 to 50°C
Measurement range	0.2 to 320 V/m, (0.00001 to 27 mW·cm-2)
Dynamic range	64 dB typ.
Absolute error at 27.5 V/m and 27.12 MHz	+/- 1.0 dB
Linearity at 27.12 MHz For 1.2 to 200 V/m For 200 to 320 V/m	 +/- .5 dB +/- .7 dB
Frequency response at 27.12 MHz 80 kHz 300 kHz to 1.2 GHz 1.2 GHz to 2.5 GHz 3 GHz	 -3 dB +/- 1 dB +/- 1.5 dB +/- 3 dB
Probe isotropic deviation freq. > 1 MHz	+/- 0.5 dB
Probe and EMR 300 unit	+/- 1.0 dB
Overload CW Pulsed	800 V/m, (175 mW·cm-2) 8000 V/m, (17.5 mW·cm-2)
H field suppression	> 20 dB
Temperature response, 0 to 50°C	+0.2 / -1.5 dB, (+/- 0.025 dB/K)
Sensor type	Electric field (E)

Table C. 3 - Garmin GPS 60CSx Specifications

Receiver: 12 channel SiRFstar III™ high-sensitivity GPS receiver (WAAS-enabled) continously tracks and uses up to 12 satellites to compute and update your position	
Acquisition times:	Warm: < 1 sec Cold: <38 sec AutoLocate™: <45
Update rate:	1/second, continuous
GPS accuracy:	Position: <10 meters, typical Velocity: .05 meter/sec steady state
DGPS (WAAS) accuracy:	Position: <5 meters, typical Velocity: .05 meter/sec steady state
Protocol messages:	NMEA 0183 output protocol
Antenna:	Built-in quad helix receiving antenna, with external antenna connection (MCX)
Electronic Compass Accuracy:	+/- 2 degrees with proper calibration (typical); +/- 5 degrees extreme northern and southern latitudes
Altimeter Resolution:	1 ft
Altimeter Range	-2,000 to 30,000 feet

Appendix D – Certification of Calibration



CERTIFICATION OF CALIBRATION CONFORMANCE

LIBERTY LABS, INC. 1346 Yellowwood Road Kimballton, IA 51543
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This probe has been individually calibrated using IEEE Standard for Calibration of Electromagnetic Field Sensors and Probes, Excluding Antennas, from 9 kHz to 40 GHz; IEEE Std. 1309(1996 and/or 2005). All results of this calibration relate only to the items that were calibrated.

ACCREDITATION NOTES:
A complete copy of the scope of our A2LA accreditation is available upon request.

Instrumentation Environment:	TEMP: 19°C	RH: 34%
Calibration Environment:	TEMP: 19°C	RH: 34%

Barometric Pressure (inches): 30.08
CERTIFICATE NO.: 2009010707
CLIENT: Colorado State University, Thomas E. Johnson, 1618 Campus Delivery, Fort Collins, CO, 80523-1618, USA
MANUFACTURER: Wandel & Goltermann
MODEL NUMBER: 2244/90.72 & EMR-300
SERIAL NUMBER: D-0005 & AH-0054
ASSET NUMBER: 317470
DATE OF CALIBRATION: Monday, January 19, 2009
NAME OF CALIBRATING ORGANIZATION: Liberty Labs, Inc.
CALIBRATED BY: DGB
RE-CALIBRATION DATE: Re-calibration interval is at customer discretion.

RECEIVED STATUS
Received in tolerance: ✓

RETURNED STATUS
Returned in tolerance: ✓
Returned limited cal.:

NOTES: In/Out of tolerance based on alignment/mounting position and not on manufacturer's specifications. A probe position document is included with this certificate. Calibrated with Liberty Labs' monitor and fiberoptic cable.

LL, Inc.

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Michael W. Howard

ENGINEER IN CHARGE
MICHAEL W. HOWARD
NARTE CERTIFIED EMC ENGINEER, NO. EM C-000102-NE

ACCREDITED
Certificate Number: 2123.01

lspb-position
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Rev. D: Issue Date 12/12/03

Appendix E – Sampling Event Nine

Table E. 1 – Comparison of Measurements Collected on January 15th 2010

Location	Spatial Avg. (mW/cm^2)	Peak Avg. (mW/cm^2)	Peak Max. (mW/cm^2)
1	0.00174	0.00252	0.00352
2	0.000360	0.000390	0.000460
3	0.000290	0.00182	0.00330
4	0.00152	0.00208	0.00297
5	0.00489	0.00872	0.0132
6	0.000960	0.000980	0.00134
7	0.000760	0.0229	0.0282
8	0.0124	0.0176	0.0213
9	0.0174	0.0416	0.0566
10	0.000180	0.000210	0.000270
11	0.00320	0.00599	0.00886
12	0.00169	0.00287	0.00451
13	0.00166	0.00294	0.00345
14	0.00197	0.00167	0.00217
15	0.00237	0.00409	0.00655
16	0.000820	0.00124	0.00179
17	0.00526	0.00746	0.0126
18	0.00243	0.00294	0.00355
19	0.00222	0.00764	0.0106
20	0.00477	0.00571	0.00800
21	0.00268	0.00479	0.00620

The IEEE C95.1-2005 standard states that the MPE "…corresponds to the spatially averaged plane wave equivalent power density or the spatially averaged values of the squares of electric and magnetic field strengths."[20] However, a comparison of the spatially averaged and peak values collected on January 15, 2010 (Table E.1) indicates that the peak values are higher than the spatially averaged values and consequently results in a more conservative comparison with the MPE limits.

Appendix F - Standards and Regulatory Organizations

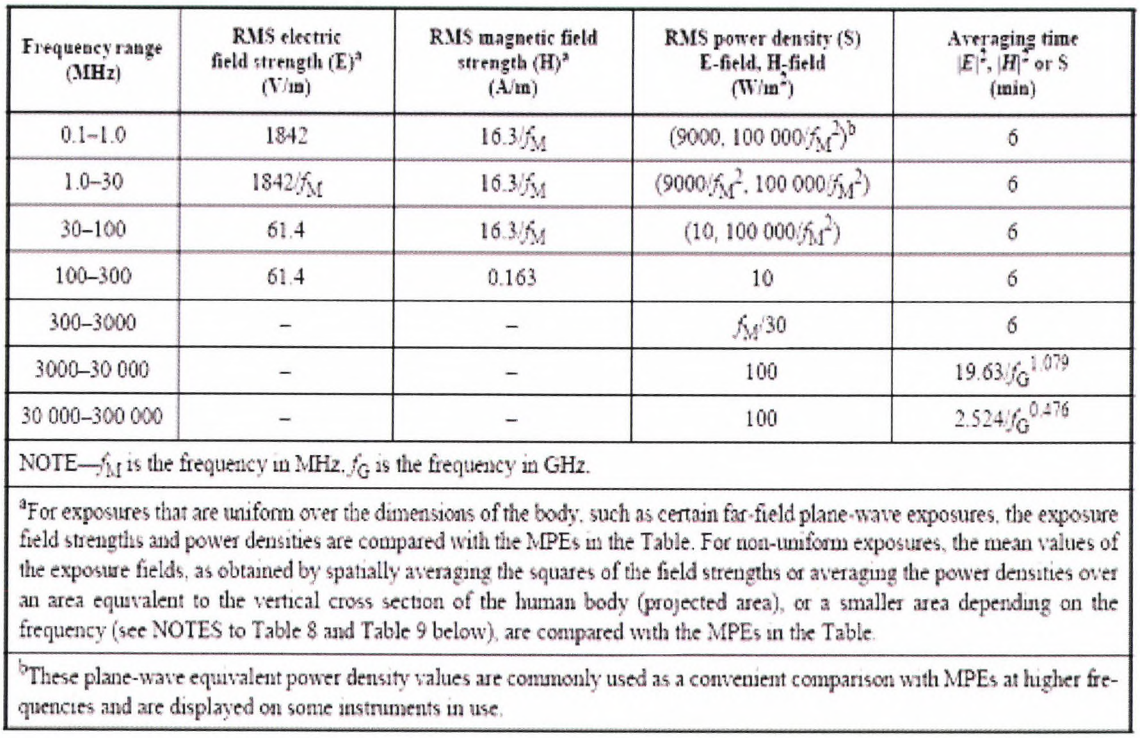
IEEE C95.1-2005 Standard

The study of EMR began with the advent of radar and the onset of WWII. Anecdotal reports of male sterility and opacity in the eyes began surfacing among military radar technicians, which lead to a concerted effort to understand the interactions of RF energy and to establish exposure limit.[77] Prior to WWII, microwaves were not of sufficient power to cause harmful effects.[78] The first studies on effects of EMR were conducted for medical applications, but "between the early 1940s and 1960, research on the biological effects of microwave radiation slowly shifted from its medical context and the search for benefits to a military-industrial context and the search for hazards."[78] One of the first studies on biological effects of EMR in the United States began shortly after the development and implementation of radar during the early stages of World War II. Lieutenant Commander L. Eugene Daily conducted a study after allegations of deleterious effects among radar technician began surfacing. This study, published in 1943, reported no clinical evidence to support the allegations. The study concluded radar is not a health hazard.[72,79] However, this conclusion soon changed with two independent studies. The first study conducted by Louis Daily in 1948 reported cataract formation in dog eyes and the second study, conducted by H.M. Hines in the same year, reported "...lenticular opacities in rabbits and dogs and testicular degeneration in rats."[78] These experiments and the multitude of experiments that followed were designed to test high-dose, short-duration thermal threshold exposures from microwave energies. These early experiments resulted in establishing arbitrary exposure limits ranging from 1 W/m^2 up to 1000 W/m^2. But, by the late 1950's these values "...began to converge to a value of 100

W/ m^2."[30] This exposure limit was based on a thermal threshold model that controlled for the creation of lenticular opacities. In 1960, the Institute of Radio Engineers, known today as the Institute of Electrical and Electronics Engineers (IEEE), established the first standard setting committee (Committee C95). The idea behind Committee C95 was to develop safety standards for radio frequency and microwave exposures from an open consensus process.[30] This first standard was published in 1966 with revisions published in 1974 (ANSI, 1974) and 1982 (ANSI, 1982). These standards recommended exposure limits of 100 W/m^2 for continuous wave and 10 $W \cdot h \cdot m^{-2}$ for short-term exposures based on a thermal time constant of 0.1. Up to this point standards were based on thermal effects only, but by the early 1980's speculation of biological effects that occur below thermal threshold levels began appearing in scientific literature. The 1982 revision evaluated thermal reports carefully and established a main objective to protect humans from all biological effects caused by thermal or non-thermal interaction mechanisms.[77] This revision incorporated studies and experimental research from the scientific literature that covered areas such as immunology, teratology, blood-brain barrier, cataracts, genetics, hematology, and cardiovascular studies. In addition, this revision incorporated a specific absorption rate (SAR) for frequencies between 100 kHz to 6 GHz. SAR is a measure of the electromagnetic energy that is absorbed in the body and it is recorded in units of W/kg. The 1982 standard was a one tier system so it applied to both the occupational worker and the general public. The standard was amended again in 1999 (C95.1) to integrate protection against electrical stimulation below thermal thresholds; change short term exposure averaging times to prevent skin burns, and more importantly establish a two tier system that delineates controlled and uncontrolled environments. The current standard, C95.1- 2005, is far more exhaustive than the earlier standards. 132 members representing academia, laboratories, Department of Defense, independent consultants, 23 countries and the general public approved this standard. The current C95.1-2005 standard is subdivided into two sets of exposure limits. Both sets of limits provide exposure protection from electric, magnetic, and electromagnetic fields as well as induced and contact currents. The first set of exposure limits provides protection from electro-stimulation originating from a frequency range of 3 kHz to 5 MHz while the second set provides protection from thermal heating originating from a frequency range of 100 kHz to 300GHz. Within the transition region both sets of rules must be applied. These limits are expressed in maximum permissible exposure (MPE) limits for external fields, induced current, and contact currents while internal fields and SAR are expressed in terms of basic restrictions (BR).

FCC LIMITS FOR MAXIMUM PERMISSIBLE EXPOSURE (MPE)

Table F. 1 – A. Limits for Occupational and Controlled Exposure[50]



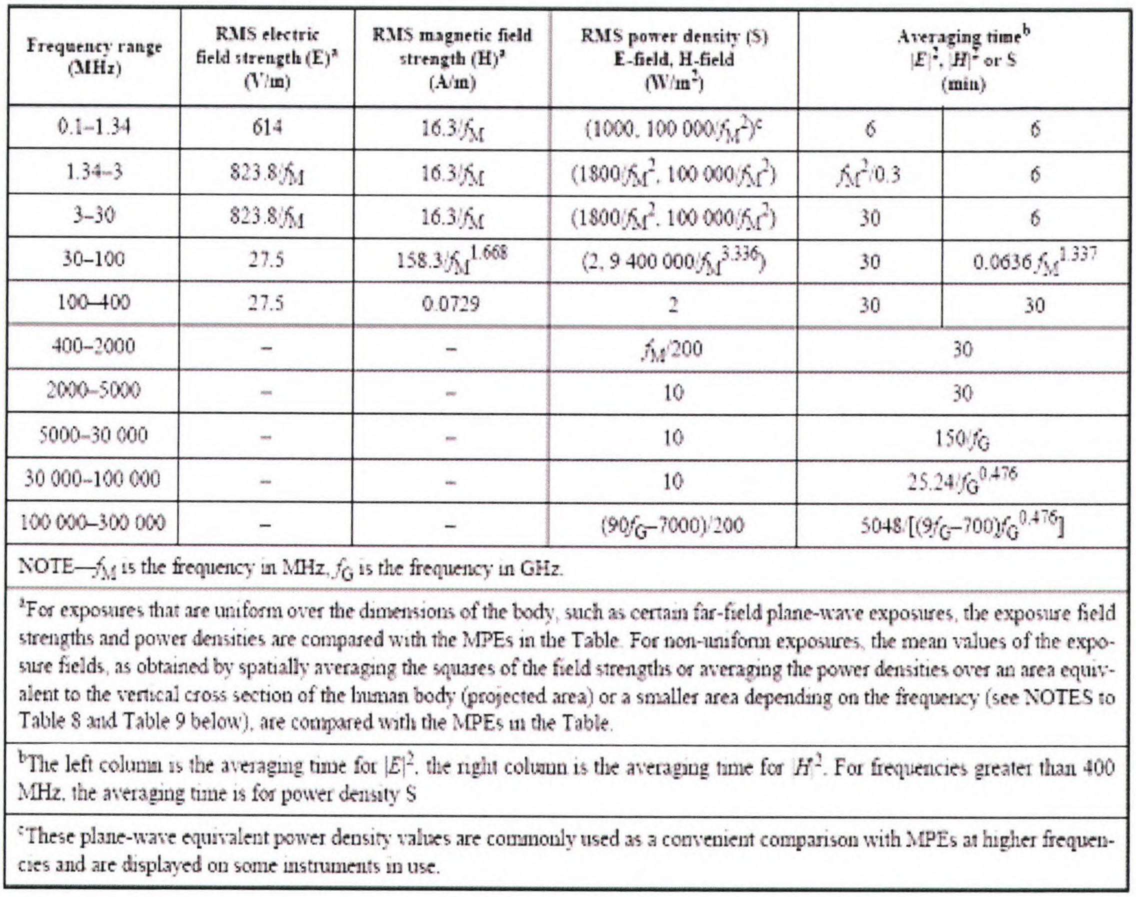
Frequency range (MHz)	RMS electric field strength (E)[a] (V/m)	RMS magnetic field strength (H)[a] (A/m)	RMS power density (S) E-field, H-field (W/m^2)	Averaging time $\|E\|^2$, $\|H\|^2$ or S (min)
0.1–1.0	1842	$16.3/f_M$	$(9000, 100\,000/f_M^2)$[b]	6
1.0–30	$1842/f_M$	$16.3/f_M$	$(9000/f_M^2, 100\,000/f_M^2)$	6
30–100	61.4	$16.3/f_M$	$(10, 100\,000/f_M^2)$	6
100–300	61.4	0.163	10	6
300–3000	–	–	$f_M/30$	6
3000–30 000	–	–	100	$19.63/f_G^{1.079}$
30 000–300 000	–	–	100	$2.524/f_G^{0.476}$

NOTE—f_M is the frequency in MHz, f_G is the frequency in GHz.

[a] For exposures that are uniform over the dimensions of the body, such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the MPEs in the Table. For non-uniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body (projected area), or a smaller area depending on the frequency (see NOTES to Table 8 and Table 9 below), are compared with the MPEs in the Table.

[b] These plane-wave equivalent power density values are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

Table F.2 - B. Limits for General Population and Uncontrolled Exposure[50]



Frequency range (MHz)	RMS electric field strength (E)[a] (V/m)	RMS magnetic field strength (H)[a] (A/m)	RMS power density (S) E-field, H-field (W/m^2)	Averaging time[b] $\lvert E\rvert^2$, $\lvert H\rvert^2$ or S (min)	
0.1–1.34	614	$16.3/f_M$	$(1000, 100\,000/f_M^2)$[c]	6	6
1.34–3	$823.8/f_M$	$16.3/f_M$	$(1800/f_M^2, 100\,000/f_M^2)$	$f_M^2/0.3$	6
3–30	$823.8/f_M$	$16.3/f_M$	$(1800/f_M^2, 100\,000/f_M^2)$	30	6
30–100	27.5	$158.3/f_M^{1.668}$	$(2, 9\,400\,000/f_M^{3.336})$	30	$0.0636 f_M^{1.337}$
100–400	27.5	0.0729	2	30	30
400–2000	–	–	$f_M/200$	30	
2000–5000	–	–	10	30	
5000–30 000	–	–	10	$150/f_G$	
30 000–100 000	–	–	10	$25.24/f_G^{0.476}$	
100 000–300 000	–	–	$(90f_G-7000)/200$	$5048/[(9f_G-700)f_G^{0.476}]$	

NOTE—f_M is the frequency in MHz, f_G is the frequency in GHz.

[a] For exposures that are uniform over the dimensions of the body, such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the MPEs in the Table. For non-uniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body (projected area) or a smaller area depending on the frequency (see NOTES to Table 8 and Table 9 below), are compared with the MPEs in the Table.

[b] The left column is the averaging time for $\lvert E\rvert^2$, the right column is the averaging time for $\lvert H\rvert^2$. For frequencies greater than 400 MHz, the averaging time is for power density S

[c] These plane-wave equivalent power density values are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

ICNIRP Guidelines

The Eighth International Congress of the International Radiation Protection Association established the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in May 1982. "The functions of the Commission are to investigate the hazards that may be associated with the different forms of NIR, develop international guidelines on NIR exposure limits, and deal with all aspects of NIR protection."[5] This guideline is mainly used in European countries, but is gaining international acceptance. The ICNIRP guide provides a two tier system – "the higher tier is referred to as Occupational while the more restrictive tier is referred to as general population."[80]

FCC OET Bulletin 65

The Federal Communication Commission (FCC) established the Office of Engineering & Technology (OET) Bulletin 65 in August 1997 to limit human exposure to radio frequency radiation originating from transmitting facilities. This standard draws from the 1986 NCRP Report 86 (paragraph "D") for its field limits and incorporates portions of the 1991 IEEE standard (paragraph "C").[80] The FCC has coordinated consensus from other government agencies, including National Institute for Occupational Safety and Heath and the Food Drug Administration.[81]

OSHA 29 CFR 1910.97

OSHA provides non-enforceable nonionizing radiation guidelines for workers in normal environmental conditions covering frequency range of 10 MHz to 100 GHz. Within this frequency range OSHA recommends a maximum power density of 10 mW/cm^2 averaged over a 6 minute period. Excursions above the limit are allowed as long as the 6 minute average is within the limits. This limit applies to both partial body and whole body irradiation. Even though OSHA's limits are non-enforceable some states have nonionizing programs similar to OSHA's guideline, but may be more restrictive to the point of enforcement.

Appendix G - Conversion to Digital Broadcasting

Broadcasting in the United States essentially began in 1906 when Reginald Fessenden aired a Christmas musical via radio. This broadcasting was mostly heard by wireless operators aboard ships since they had appropriate receivers.[82-83] However, over the next several years interest in broadcasting became increasingly popular due to people like Charles Herrold, Frank Conrad and Earle Terry who began broadcasting music on a regular basis.[84] Following WWI other pioneers in radio began broadcasting music over the airwaves and by the late 1920's the National Broadcasting Company and Columbia Broadcasting System became dominant radio networks. The 1950's was a turning point for the radio dominant media. Television broadcasting began replacing radio with programs like Truth or Consequences, baseball games, and evening news.[84] Television programming popularity with the American people grew exponentially and with it more and more broadcasting stations went on air. Today, according to the Federal Communication Commission, there are over 9,000 television stations and many more radio stations on the air. In addition to television and radio stations there are other applications that use the radiofrequency bandwidth, such as, microwaves, satellite, telephone, emergency radios, and radar and navigation stations. While the spectrum "can not be exhausted, it can support a finite number of unique RF signals without overlap and interference for communication purposes in any given geographic region."[4] Spectrum allocation inefficiencies and the ever growing scarcity of the spectrum has lead the FCC to take action.[85] In 1987 the Federal Communication Commission established a blue ribbon Advisory Committee on Advanced Television Service for the express purpose of recommending a broadcast standard.[86]

U.S. President George Bush signed into law legislation that mandated U.S. broadcasters cease analog television signals on February 17, 2009 and begin broadcasting in an all digital format. Anticipating this transition, in 1996, the U.S. Congress authorized an additional channel to each television station so that they could start a digital channel while maintaining the analog channels.[87] According to the Federal Communication Commission website, the transition will free up bandwidth that could then be used for emergency communications (police and fire departments); some of spectrum could be auctioned off to wireless companies providing advanced wireless services; and it would allow broadcasters to multicast - providing several digital channels at the same time.[87] However, as the deadline was nearing there was great political opposition to delay the DTV transition deadline. On, 26 January 2009 the U.S. Senate voted to postpone the transition to June 12, 2009.[87-88] "Since June 13, 2009, all full-power U.S. TV stations have been transmitting in digital only."[87]

Appendix H – Summary of NIR Studies on Lookout Mountain, Colorado

Table H. 1 - Summary of Past RFR Studies in Vicinity of Lookout Mountain

Year	Description	Outcome	Reference
1983 & 1984	Interference of electronic devices and health concerns	RF levels less than ANSI Protection guide of 1000 μWcm^{-2}	Tell[89]
1986	FCC comprehensive study	One location exceeded FCC 1000 μWcm^{-2} (10,000 μWcm^{-2})and several other locations exceeded the non regulatory 200 μWcm^{-2}	Tell[89]
1996	Jefferson County retained consultants to provide a general ambient RF field assessment	Four locations where peak measurements exceeds FCC/ANSI uncontrolled area 200 μWcm^{-2} standard, but none of the spatially average values exceed the standard	Tell[90]
1998	FCC survey for continuous general public exposure	Several locations near towers exceeded FCC/ANSI 200 μWcm^{-2} std. FCC provided mitigating actions	Ulcek[44]
1998	Broadcasting stations retained consultants to measure RF levels	All public accessible locations comply with FCC guidelines. However, 4 locations exceed non regulatory ANSI peak limits. Suggested mitigation actions	Hammett[91]
1999	Broadcasting stations retained consultants to provide an analysis of RF levels due to proposed joint DTV tower	Utilized a computer model and determined all public accessible locations will be below uncontrolled limit	Hammett[92]
1999	Jefferson County retained consultant to calculate anticipated NIR due to joint DTV tower	Calculate power densities well below FCC limit of 200 μWcm^{-2}	Hart[93]

2001	Jefferson County retained consultant to compare alternative antenna sites	Considered 4 locations. Concluded that Eldorado Mt., Lookout Mt. and Mount Morrison locations could provide proper coverage	Hart[94]
2004	Lake Cedar Group retains a consultant to conduct monthly measurements	Spatially averaged measurements were collected at 17 locations near Lookout Mt. towers. No readings exceeded the standard (Jan - Dec 2004)	Oliner[95]
2005	Study examined RF effects on melatonin and other biomarkers	Reported an increase overnight melatonin excretion. Increase in Tcells per mL (P=.09) Increase lymphocytes (P=.05). Higher concen. Of lymphocytes, T-cells, and natural killer cells when there's an increase in melatonin excretion. RF appeared to be assoc. with decrease in ODC. No assoc. between RF and any other polymines	Reif[39]
2006	Study quantified RF exposure to 280 residents in and outside of their home	Spatial and temporal factors contribute to RF exposure. GPS/GIS tech. can improve exposure assessment and reduce misclassifications. RF spot meas. are correlated over time (exterior r=0.99, p<.001) and (interior: r=.97, p<.001) Increasing proximity, elev, and visibility are assoc. with significant RF exposure (p<0.01)	Burch[38]
2007	Lake Cedar Group conducts monthly measurements	Spatially averaged measurements were collected at 17 locations near Lookout Mt. towers. No readings exceeded the standard. (Jan - Dec 2007)	Oliner[96]
2008	Lake Cedar Group retains a consultant to conduct monthly measurements	Spatially averaged measurements were collected at 17 locations near Lookout Mt. towers. No readings exceeded the standard. (Jan - Dec 2008)	Oliner[97]
2008	Lake Cedar Group retains a consultant to conduct monthly measurements	Spatially averaged measurements were collected at 13 locations near Lookout Mt. towers. No readings exceeded the standard. (July – Oct 2008)	Musselman[46]
2009	Lake Cedar Group retains a consultant to conduct monthly measurements	Spatially averaged measurements were collected at 13 locations near Lookout Mt. towers. No readings exceeded the standard. (Jan. – June 2009).	Musselman[98]

Appendix I - SAS Code

Residual Instrument Position Measurements

```
data RF;
input Loc Pos ratio;
lr = log(ratio);
if Pos = 1 then delete;
cards;
loc     pos     ratio
1       1       1
1       2       0.789772727
1       3       0.826704545
1       4       0.485795455
1       5       0.471590909
2       1       1
2       2       1.277777778
2       3       1.111111111
2       4       0.805555556
2       5       1.194444444
3       1       1
3       2       0.23030303
3       3       0.893939394
3       4       0.2
3       5       0.436363636
4       1       1
4       2       0.723905724
4       3       0.626262626
4       4       0.292929293
4       5       0.861952862
5       1       1
5       2       0.209885932
5       3       0.770342205
5       4       0.515589354
5       5       0.819771863
6       1       1
6       2       0.373134328
6       3       0.791044776
6       4       0.917910448
6       5       0.567164179
7       1       1
7       2       0.807515066
7       3       0.638071606
7       4       0.900389933
7       5       0.718894009
8       1       1
8       2       0.90657277
8       3       0.979342723
8       4       0.570892019
8       5       0.679812207
9       1       1
9       2       0.804036327
9       3       1.142280525
9       4       0.482542886
9       5       0.768314834
```

10	1	1
10	2	0.555555556
10	3	0.962962963
10	4	0.518518519
10	5	0.925925926
11	1	1
11	2	0.536117381
11	3	0.70993228
11	4	0.498871332
11	5	0.633182844
12	1	1
12	2	0.407982262
12	3	0.600886918
12	4	0.436807095
12	5	0.733924612
13	1	1
13	2	0.930434783
13	3	0.837681159
13	4	0.568115942
13	5	0.92173913
14	1	1
14	2	0.67027027
14	3	1.172972973
14	4	0.686486486
14	5	0.994594595
15	1	1
15	2	0.546564885
15	3	0.603053435
15	4	0.27480916
15	5	0.697709924
16	1	1
16	2	0.38547486
16	3	0.938547486
16	4	0.530726257
16	5	0.620111732
17	1	1
17	2	0.437549722
17	3	0.666666667
17	4	0.351630867
17	5	0.509944312
18	1	1
18	2	0.676056338
18	3	0.830985915
18	4	0.681690141
18	5	0.949295775
19	1	1
19	2	0.489622642
19	3	0.655660377
19	4	0.616037736
19	5	0.840566038
20	1	1
20	2	0.497493734
20	3	0.770676692
20	4	0.476190476
20	5	0.830827068
21	1	1
21	2	0.785483871

```
21      3       0.720967742
21      4       0.630645161
21      5       0.724193548
;
proc sort; by pos;
/*
proc means n mean median std min max;
by pos;
var ratio;
run;  */
proc boxplot;
      plot ratio*pos;
run;
proc sort; by Loc; run;
proc boxplot;
      plot ratio*Loc;
run;
proc glm alpha=0.05;
class pos Loc;
model ratio=pos Loc;
means pos / lsd clm; * CI's for means;
means pos / tukey; * The default is the "lines" output;
means pos / tukey cldiff; * Forces the cl output;
/*lsmeans Day /pdiff cl; * Gives p-values for comparisons; */
output out=out1 student=s1 predicted=p1;
run;
proc plot data=out1;
plot s1*p1/hpos=40 vpos=25;
proc gplot;
plot s1*p1;
label s1='Studentized Residuals'
symbol1 v=dot;

proc univariate normal;
var s1;
qqplot;
proc npar1way data=RF wilcoxon;
class pos;
var ratio;
exact wilcoxon /n=1000; run;
```

Front High Exposures Across Time and Location

```
data RF;
input Loc Time Meas;
cards;
1       1       0.00109
1       2       0.00139
1       3       0.00543
1       4       0.00222
1       5       0.00294
1       6       0.00233
1       7       0.00293
1       8       0.00196
1       9       0.00352
```

2	1	0.00041
2	2	0.00078
2	3	0.00084
2	4	0.00052
2	5	0.00095
2	6	0.00059
2	7	0.0006
2	8	0.00076
2	9	0.00036
3	1	0.00112
3	2	0.00111
3	3	0.00109
3	4	0.0015
3	5	0.00136
3	6	0.00028
3	7	0.0014
3	8	0.00186
3	9	0.0033
4	1	0.0009
4	2	0.0024
4	3	0.0021
4	4	0.00202
4	5	0.00102
4	6	0.00074
4	7	0.00188
4	8	0.00288
4	9	0.00297
5	1	0.0031
5	2	0.00922
5	3	0.00545
5	4	0.00955
5	5	0.00972
5	6	0.00976
5	7	0.00106
5	8	0.00821
5	9	0.01315
6	1	0.00165
6	2	0.00133
6	3	0.00171
6	4	0.00166
6	5	0.00114
6	6	0.00056
6	7	0.03869
6	8	0.00185
6	9	0.00134
7	1	0.00309
7	2	0.01531
7	3	0.12936
7	4	0.0301
7	5	0.02645
7	6	0.03112
7	7	0.02133
7	8	0.03269
7	9	0.02821
8	1	0.00709
8	2	0.04133
8	3	0.0113

8	4	0.01864
8	5	0.0031
8	6	0.01415
8	7	0.00022
8	8	0.02204
8	9	0.0213
9	1	0.01578
9	2	0.08972
9	3	0.10609
9	4	0.03358
9	5	0.05444
9	6	0.0758
9	7	0.03404
9	8	0.09
9	9	0.04955
10	1	0.00299
10	2	0.00222
10	3	0.0008
10	4	0.0002
10	5	0.00024
10	6	0.00019
10	7	0.00842
10	8	0.0002
10	9	0.00027
11	1	0.00324
11	2	0.01
11	3	0.00249
11	4	0.00945
11	5	0.0036
11	6	0.00022
11	7	0.00347
11	8	0.00911
11	9	0.00886
12	1	0.00374
12	2	0.00296
12	3	0.00329
12	4	0.00362
12	5	0.00248
12	6	0.00209
12	7	0.00368
12	8	0.00461
12	9	0.00451
13	1	0.00282
13	2	0.00886
13	3	0.00859
13	4	0.00845
13	5	0.00293
13	6	0.00215
13	7	0.00295
13	8	0.00365
13	9	0.00345
14	1	0.00148
14	2	0.00115
14	3	0.0012
14	4	0.00123
14	5	0.00131
14	6	0.001

14	7	0.00179
14	8	0.00155
14	9	0.00185
15	1	0.00223
15	2	0.00083
15	3	0.00731
15	4	0.00594
15	5	0.00673
15	6	0.0064
15	7	0.00335
15	8	0.00443
15	9	0.00655
16	1	0.00261
16	2	0.00868
16	3	0.00163
16	4	0.00618
16	5	0.012
16	6	0.01292
16	7	0.001
16	8	0.00142
16	9	0.00179
17	1	0.00423
17	2	0.00233
17	3	0.01249
17	4	0.00118
17	5	0.0084
17	6	0.00107
17	7	0.0087
17	8	0.00994
17	9	0.01257
18	1	0.00595
18	2	0.00457
18	3	0.00544
18	4	0.00428
18	5	0.00362
18	6	0.00361
18	7	0.00456
18	8	0.00325
18	9	0.00355
19	1	0.00462
19	2	0.00996
19	3	0.00404
19	4	0.00331
19	5	0.00503
19	6	0.00274
19	7	0.00602
19	8	0.0068
19	9	0.0106
20	1	0.00356
20	2	0.00598
20	3	0.00593
20	4	0.00608
20	5	0.00215
20	6	0.00456
20	7	0.00728
20	8	0.00757
20	9	0.00798

```
21      1       0.00157
21      2       0.00866
21      3       0.00538
21      4       0.00317
21      5       0.00495
21      6       0.00672
21      7       0.00444
21      8       0.00237
21      9       0.0062
;
proc sort; by Time;
proc sgplot;
      vbox meas/category=time extreme;
      label meas='Measurement' time='Time Period';
run;

proc sgpanel;
 panelby time/columns=3 ;
 colaxis  logbase=e type=log;
 histogram meas/;
density meas / type=normal;run;

proc sgpanel;
 panelby time/columns=3 ;
 *colaxis  logbase=e;
 histogram logmeas/;
density logmeas / type=normal;
label logmeas='Log Front High RF Measurements';
run;

proc sort; by Loc; run;
proc sgplot;
      vbox meas/category=loc extreme;
      label meas='Measurement' loc='Location';
run;
proc glm alpha=0.05;
class Time Loc;
model Meas=Time Loc;
means Time / lsd clm; * CI's for means;
means Time / tukey; * The default is the "lines" output;
means Time / tukey cldiff; * Forces the cl output;

means Loc / lsd clm; * CI's for means;
means Loc / tukey; * The default is the "lines" output;
means Loc / tukey cldiff; * Forces the cl output;

/*lsmeans Day /pdiff cl; * Gives p-values for comparisons; */
output out=out1 student=s1 predicted=p1;
contrast  'HD?' Time -0.333333  -0.333333 -0.333333 0.1666666 0.166666
0.1666666 0.166666 0.1666666 0.1666666;
estimate  'HD?' Time -0.333333  -0.333333 -0.333333 0.1666666 0.166666
0.1666666 0.166666 0.1666666 0.1666666;
run;
proc plot data=out1;
plot s1*p1/hpos=40 vpos=25;
proc gplot;
plot s1*p1;
```

```
symbol1 v=dot;
proc univariate normal;
var s1;
qqplot;
proc npar1way data=RF wilcoxon;
class Time;
var Meas;
exact wilcoxon /n=1000; run;
```

Front High Normalized Exposures Across Time and Location

```
data RF;
input Loc Time ratio;
cards;
loc     pos     ratio
1       1       0.200736648
1       2       0.255985267
1       3       1
1       4       0.408839779
1       5       0.541436464
1       6       0.429097606
1       7       0.539594843
1       8       0.360957643
1       9       0.64825046
2       1       0.431578947
2       2       0.821052632
2       3       0.884210526
2       4       0.547368421
2       5       1
2       6       0.621052632
2       7       0.631578947
2       8       0.8
2       9       0.378947368
3       1       0.339393939
3       2       0.336363636
3       3       0.33030303
3       4       0.454545455
3       5       0.412121212
3       6       0.084848485
3       7       0.424242424
3       8       0.563636364
3       9       1
4       1       0.303030303
4       2       0.808080808
4       3       0.707070707
4       4       0.68013468
4       5       0.343434343
4       6       0.249158249
4       7       0.632996633
4       8       0.96969697
4       9       1
5       1       0.235741445
5       2       0.701140684
5       3       0.414448669
5       4       0.726235741
```

5	5	0.739163498
5	6	0.742205323
5	7	0.080608365
5	8	0.624334601
5	9	1
6	1	0.042646679
6	2	0.034375808
6	3	0.044197467
6	4	0.042905143
6	5	0.029464978
6	6	0.014474024
6	7	1
6	8	0.047815973
6	9	0.034634272
7	1	0.023886827
7	2	0.118351886
7	3	1
7	4	0.232683983
7	5	0.204468151
7	6	0.240568955
7	7	0.164888683
7	8	0.252705628
7	9	0.218073593
8	1	0.171546092
8	2	1
8	3	0.273409146
8	4	0.451004113
8	5	0.075006049
8	6	0.34236632
8	7	0.00532301
8	8	0.533268812
8	9	0.515364142
9	1	0.148741634
9	2	0.84569705
9	3	1
9	4	0.316523706
9	5	0.513149213
9	6	0.714487699
9	7	0.320859647
9	8	0.848336318
9	9	0.467056273
10	1	0.355106888
10	2	0.263657957
10	3	0.095011876
10	4	0.023752969
10	5	0.028503563
10	6	0.022565321
10	7	1
10	8	0.023752969
10	9	0.032066508
11	1	0.324
11	2	1
11	3	0.249
11	4	0.945
11	5	0.36
11	6	0.022
11	7	0.347

11	8	0.911
11	9	0.886
12	1	0.811279826
12	2	0.64208243
12	3	0.713665944
12	4	0.785249458
12	5	0.537960954
12	6	0.453362256
12	7	0.798264642
12	8	1
12	9	0.978308026
13	1	0.318284424
13	2	1
13	3	0.969525959
13	4	0.953724605
13	5	0.330699774
13	6	0.242663657
13	7	0.332957111
13	8	0.411963883
13	9	0.389390519
14	1	0.8
14	2	0.621621622
14	3	0.648648649
14	4	0.664864865
14	5	0.708108108
14	6	0.540540541
14	7	0.967567568
14	8	0.837837838
14	9	1
15	1	0.30506156
15	2	0.113543092
15	3	1
15	4	0.812585499
15	5	0.920656635
15	6	0.875512996
15	7	0.458276334
15	8	0.606019152
15	9	0.896032832
16	1	0.202012384
16	2	0.671826625
16	3	0.126160991
16	4	0.478328173
16	5	0.92879257
16	6	1
16	7	0.077399381
16	8	0.109907121
16	9	0.138544892
17	1	0.336515513
17	2	0.185361973
17	3	0.99363564
17	4	0.093874304
17	5	0.668257757
17	6	0.085123309
17	7	0.692124105
17	8	0.790771679
17	9	1
18	1	1

```
18      2       0.768067227
18      3       0.914285714
18      4       0.719327731
18      5       0.608403361
18      6       0.606722689
18      7       0.766386555
18      8       0.546218487
18      9       0.596638655
19      1       0.435849057
19      2       0.939622642
19      3       0.381132075
19      4       0.312264151
19      5       0.474528302
19      6       0.258490566
19      7       0.567924528
19      8       0.641509434
19      9       1
20      1       0.446115288
20      2       0.749373434
20      3       0.743107769
20      4       0.761904762
20      5       0.269423559
20      6       0.571428571
20      7       0.912280702
20      8       0.948621554
20      9       1
21      1       0.181293303
21      2       1
21      3       0.621247113
21      4       0.366050808
21      5       0.571593533
21      6       0.775981524
21      7       0.512702079
21      8       0.273672055
21      9       0.715935335
;
proc sort; by Time;
proc sgplot;
      vbox Ratio/category=time extreme;
      label Ratio='RF Values' time='Time Period';
run;
proc sort; by Loc; run;
proc sgplot;
      vbox ratio/category=loc extreme;
      label ratio='RF Values' loc='Location';
run;
proc glm alpha=0.05;
class Time Loc;
model ratio=Time Loc;
means Time / lsd clm; * CI's for means;
means Time / tukey; * The default is the "lines" output;
means Time / tukey cldiff; * Forces the cl output;

means Loc / lsd clm; * CI's for means;
means Loc / tukey; * The default is the "lines" output;
means Loc / tukey cldiff; * Forces the cl output;
```

```
output out=out1 student=s1 predicted=p1;
contrast  'HD?' Time -0.333333  -0.333333 -0.333333 0.1666666 0.166666
0.1666666 0.166666 0.1666666 0.1666666;
estimate  'HD?' Time -0.333333  -0.333333 -0.333333 0.1666666 0.166666
0.1666666 0.166666 0.1666666 0.1666666;

run;
proc plot data=out1;
plot s1*p1/hpos=40 vpos=25;
proc gplot;
plot s1*p1;
symbol1 v=dot;
proc univariate normal;
var s1;
qqplot;
proc npar1way data=RF wilcoxon;
class Time;
var ratio;
exact wilcoxon /n=1000; run;
```

Mr. Musselman's Data % MPE across Time

```
data RF;
input Time Loc reading;
cards;
1      1      20.424
1      2      28.226
1      3      18.142
1      4      10.982
1      5      12.438
1      6      48.89
1      7      21.074
1      8      5.166
1      9      34.29
1      10     74.9
2      1      20.04
2      2      29.82
2      3      11.516
2      4      11.986
2      5      11.2
2      6      48.316
2      7      20.118
2      8      5.264
2      9      33.63
2      10     83.366
3      1      20.688
3      2      28.486
3      3      15.456
3      4      10.754
3      5      13.41
3      6      50.77
3      7      23.97
3      8      4.762
3      9      34.216
3      10     82.624
```

4	1	23.368
4	2	32.816
4	3	17.328
4	4	11.14
4	5	10.08
4	6	52.816
4	7	23.164
4	8	4.094
4	9	38.98
4	10	76.702
5	1	20.08
5	2	23.93
5	3	13.20
5	4	11.95
5	5	3.69
5	6	42.21
5	7	23.22
5	8	28.00
5	9	36.76
5	10	77.75
6	1	22.45
6	2	38.00
6	3	17.12
6	4	10.26
6	5	3.14
6	6	40.76
6	7	23.66
6	8	31.16
6	9	36.98
6	10	75.96
7	1	21.40
7	2	37.78
7	3	16.66
7	4	12.18
7	5	3.03
7	6	40.04
7	7	25.01
7	8	29.66
7	9	40.65
7	10	76.18
8	1	19.51
8	2	0.000
8	3	12.03
8	4	11.64
8	5	2.83
8	6	45.61
8	7	23.15
8	8	26.61
8	9	34.31
8	10	75.52
9	1	19.33
9	2	34.01
9	3	10.91
9	4	11.35
9	5	4.33
9	6	40.98
9	7	20.71

```
9     8     26.15
9     9     35.33
9     10    80.08
10    1     18.27
10    2     34.02
10    3     9.93
10    4     12.04
10    5     3.71
10    6     36.64
10    7     21.49
10    8     27.72
10    9     31.35
10    10    76.99
;
proc sort; by Time; run;
proc sgplot;
    vbox reading/category=time extreme legendlabel="% MPE";
      label reading = 'Reading' time='Time Period';
run;
proc glm alpha=0.05;
class Loc Time;
model reading=Loc Time;
means Time / lsd clm; * CI's for means;
means Time / tukey; * The default is the "lines" output;
means Time / tukey cldiff; * Forces the cl output;
output out=out1 student=s1 predicted=p1;
run;
proc plot data=out1;
plot s1*p1/hpos=40 vpos=25;
proc gplot;
plot s1*p1;
symbol1 v=dot;
proc univariate normal;
var s1;
qqplot;
proc npar1way data=RF wilcoxon;
class Loc;
var reading;
exact wilcoxon /n=1000; run;
```

Appendix J – Raw Data

Table J.1 - Field Strength Measurements, (mW·cm^{-2})

Loc	Instantaneous									Spat Avg.
	Data 1 Feb 09	Data 2 April 09	Data 3 May 09	Data 4 July 09	Data 5 Aug 09	Data 6 Sep 09	Data 7 Nov 09	Data 8 Nov 09	Data 9 Jan 10	Data 9 Jan 10
1	0.0011	0.0014	0.0054	0.0022	0.0029	0.0023	0.0029	0.0020	0.0035	0.0012
	0.0026	0.0013	0.0048	0.0025	0.0010	0.0018	0.0017	0.0018	0.0028	0.0022
	0.0015	0.0013		0.0026	0.0027	0.0030	0.0015	0.0027	0.0029	
	0.0025	0.0047				0.0031	0.0031	0.0021	0.0017	
						0.0026	0.0017	0.0015	0.0017	
2	0.0004	0.0008	0.0008	0.0005	0.0010	0.0006	0.0006	0.0008	0.0004	0.0004
	0.0005	0.0008	0.0009	0.0004	0.0009	0.0006	0.0007	0.0006	0.0005	0.0004
				0.0005	0.0013	0.0006	0.0004	0.0005	0.0004	
						0.0005	0.0005	0.0006	0.0003	
						0.0004	0.0007	0.0006	0.0004	
3	0.0011	0.0011	0.0011	0.0015	0.0014	0.0003	0.0014	0.0019	0.0033	0.0003
	0.0019	0.0012	0.0012	0.0013	0.0017	0.0004	0.0013	0.0009	0.0008	0.0003
	0.0012	0.0014	0.0015	0.0013	0.0017	0.0002	0.0009	0.0016	0.0030	
	0.0020					0.0002	0.0020	0.0008	0.0007	
	0.0021					0.0002	0.0012	0.0009	0.0014	
4	0.0009	0.0024	0.0021	0.0020	0.0010	0.0007	0.0019	0.0029	0.0030	0.0015
	0.0008	0.0029	0.0022	0.0025	0.0009	0.0007	0.0017	0.0028	0.0022	0.0016
			0.0022	0.0026	0.0012	0.0011	0.0014	0.0017	0.0019	
				0.0025		0.0006	0.0013	0.0012	0.0009	
						0.0007	0.0013	0.0028	0.0026	
5	0.0031	0.0092	0.0055	0.0096	0.0097	0.0098	0.0011	0.0082	0.0132	0.0049
	0.0059	0.0089	0.0055	0.0090	0.0116	0.0103	0.0013	0.0062	0.0028	0.0049
	0.0056		0.0093	0.0098	0.0107	0.0080	0.0013	0.0082	0.0101	
			0.0110	0.0108		0.0094	0.0013	0.0074	0.0068	
			0.0110	0.0108		0.0087	0.0014	0.0089	0.0108	
						0.0083				
6	0.0017	0.0013	0.0017	0.0017	0.0011	0.0006	0.0387	0.0019	0.0013	0.0010
	0.0018	0.0016	0.0017	0.0017	0.0008	0.0006	0.0202	0.0016	0.0005	0.0009
	0.0021	0.0027		0.0017	0.0009	0.0010	0.0090	0.0010	0.0011	
	0.0022			0.0019		0.0009	0.0280	0.0010	0.0012	
				0.0017		0.0010	0.0287	0.0017	0.0008	
7	0.0031	0.0153	0.1294	0.0301	0.0265	0.0311	0.0213	0.0327	0.0282	0.0008
	0.0081	0.0153	0.1300	0.0317	0.0691	0.0466	0.0231	0.0282	0.0228	0.0008
	0.0078			0.0611	0.0815	0.0388	0.0175	0.0220	0.0180	

	0.0085			0.1255	0.0728	0.0732	0.0165	0.0184	0.0254	
	0.0104			0.2477		0.0811	0.0165	0.0166	0.0203	
				0.0200						
8	0.0071	0.0413	0.0113	0.0186	0.0031	0.0142	0.0002	0.0220	0.0213	0.0128
	0.0084	0.0423	0.0120	0.0199	0.0033	0.0151	0.0003	0.0156	0.0193	0.0120
	0.0076			0.0222	0.0032	0.0150	0.0004	0.0142	0.0209	
	0.0054			0.0220		0.0140	0.0002	0.0091	0.0122	
	0.0097					0.0203	0.0002	0.0164	0.0145	
	0.0108									
	0.0082									
9	0.0158	0.0897	0.1061	0.0336	0.0544	0.0758	0.0340	0.0900	0.0496	0.0172
	0.0374	0.0880	0.1031	0.0344	0.0610	0.0801	0.0248	0.0607	0.0398	0.0177
	0.0528	0.0836		0.0985	0.0634	0.0446	0.0211	0.0964	0.0566	
	0.0299			0.0727		0.0248	0.0715	0.0550	0.0239	
	0.0600					0.0500	0.0895	0.0829	0.0381	
							0.0819			
							0.0670			
10	0.0030	0.0022	0.0008	0.0002	0.0002	0.0002	0.0084	0.0002	0.0003	0.0002
	0.0035	0.0051	0.0005	0.0002	0.0002	0.0003	0.0072	0.0002	0.0002	0.0002
	0.0019	0.0054		0.0002	0.0002	0.0003	0.0068	0.0002	0.0003	
	0.0047			0.0002		0.0002	0.0103	0.0002	0.0001	
	0.0038					0.0002	0.0122	0.0002	0.0003	
	0.0400									
11	0.0032		0.0025	0.0095	0.0036	0.0002	0.0035	0.0091	0.0089	0.0046
	0.0030	0.0100	0.0029	0.0091	0.0065	0.0058	0.0029	0.0101	0.0048	0.0018
	0.0028			0.0086	0.0092	0.0061	0.0021	0.0059	0.0063	
	0.0033			0.0087	0.0056	0.0058	0.0030	0.0116	0.0044	
	0.0064					0.0057	0.0041	0.0050	0.0056	
	0.0130					0.0045				
	0.0034					0.0076				
12	0.0037	0.0030	0.0033	0.0036	0.0025	0.0021	0.0037	0.0046	0.0045	0.0017
	0.0042	0.0027	0.0033	0.0031	0.0022	0.0021	0.0028	0.0024	0.0018	
	0.0056			0.0031	0.0030	0.0013	0.0013	0.0039	0.0027	
				0.0031	0.0024	0.0011	0.0018	0.0015	0.0020	
					0.0023	0.0032	0.0040	0.0033	0.0033	
					0.0024					
					0.0027					
					0.0027					
					0.0033					
					0.0032					
13	0.0028	0.0089	0.0086	0.0085	0.0029	0.0022	0.0030	0.0037	0.0035	0.0017
	0.0038	0.0089	0.0089	0.0079	0.0021	0.0023	0.0016	0.0022	0.0032	
	0.0049		0.0093	0.0088	0.0020	0.0020	0.0027	0.0032	0.0029	

	0.0051		0.0091	0.0089	0.0031	0.0019	0.0026	0.0023	0.0020	
					0.0031	0.0024	0.0038	0.0020	0.0032	
14	0.0015	0.0012	0.0012	0.0012	0.0013	0.0010	0.0018	0.0016	0.0019	0.0019
	0.0014	0.0011	0.0013	0.0015	0.0014	0.0011	0.0022	0.0015	0.0012	0.0021
				0.0016	0.0014	0.0010	0.0017	0.0012	0.0022	
				0.0016	0.0024	0.0009	0.0015	0.0009	0.0013	
					0.0021	0.0009	0.0018	0.0016	0.0018	
					0.0017					
15	0.0022	0.0008	0.0073	0.0059	0.0067	0.0064	0.0034	0.0044	0.0066	0.0024
	0.0034	0.0008	0.0076	0.0062	0.0036	0.0055	0.0031	0.0029	0.0036	
	0.0026			0.0057	0.0038	0.0023	0.0029	0.0032	0.0040	
	0.0041			0.0062	0.0030	0.0055	0.0047	0.0015	0.0018	
					0.0062	0.0068	0.0045	0.0046	0.0046	
					0.0068					
					0.0064					
					0.0065					
16	0.0026	0.0087	0.0016	0.0062	0.0120	0.0129	0.0010	0.0014	0.0018	0.0008
	0.0042	0.0084	0.0015	0.0085	0.0009	0.0130	0.0010	0.0007	0.0007	
	0.0035			0.0152	0.0011	0.0131	0.0006	0.0013	0.0017	
	0.0034			0.0125	0.0010	0.0061	0.0007	0.0008	0.0010	
	0.0038					0.0106	0.0010	0.0010	0.0011	
17	0.0042	0.0023	0.0125	0.0012	0.0084	0.0011	0.0087	0.0099	0.0126	0.0052
	0.0042	0.0025	0.0113	0.0015	0.0080	0.0006	0.0120	0.0050	0.0055	0.0053
	0.0063	0.0025		0.0017	0.0077	0.0007	0.0095	0.0071	0.0084	
	0.0032				0.0025	0.0011	0.0086	0.0034	0.0044	
	0.0049				0.0076	0.0010	0.0125	0.0073	0.0064	
	0.0074									
18	0.0060	0.0046	0.0054	0.0043	0.0036	0.0036	0.0046	0.0033	0.0036	0.0021
	0.0048	0.0089	0.0058	0.0044	0.0029	0.0021	0.0030	0.0030	0.0024	0.0028
			0.0055	0.0045	0.0020	0.0024	0.0026	0.0032	0.0030	
				0.0044	0.0031	0.0038	0.0023	0.0037	0.0024	
					0.0017	0.0037	0.0027	0.0030	0.0034	
					0.0039	0.0036				
					0.0037					
					0.0040					
19	0.0046	0.0100	0.0040	0.0033	0.0050	0.0027	0.0060	0.0068	0.0106	0.0023
	0.0061	0.0091	0.0040	0.0045	0.0031	0.0029	0.0045	0.0044	0.0052	0.0022
	0.0066		0.0035	0.0050	0.0060	0.0030	0.0030	0.0059	0.0070	
					0.0057	0.0030	0.0059	0.0035	0.0065	
					0.0050	0.0028	0.0055	0.0048	0.0089	
20	0.0036	0.0060	0.0059	0.0061	0.0022	0.0046	0.0073	0.0076	0.0080	0.0047
	0.0030	0.0056	0.0061	0.0049	0.0066	0.0035	0.0058	0.0038	0.0040	0.0048

	0.0048		0.0068	0.0061	0.0033	0.0047	0.0024	0.0040	0.0062	
	0.0061		0.0070	0.0063	0.0015	0.0067	0.0079	0.0035	0.0038	
					0.0033	0.0068	0.0038	0.0074	0.0066	
					0.0028	0.0069				
					0.0031	0.0066				
21	0.0016	0.0087	0.0054	0.0032	0.0050	0.0067	0.0044	0.0024	0.0062	0.0027
	0.0031	0.0089	0.0054	0.0047	0.0045	0.0067	0.0043	0.0017	0.0049	
	0.0037			0.0050	0.0055	0.0065	0.0027	0.0022	0.0045	
	0.0038			0.0049	0.0022	0.0064	0.0024	0.0011	0.0039	
					0.0050	0.0066	0.0046	0.0014	0.0045	
					0.0050					
					0.0066					
22						0.0067	0.0006	0.0003	0.0004	
						0.0067	0.0003	0.0005	0.0005	
						0.0065	0.0001	0.0003	0.0003	
						0.0064	0.0003	0.0002	0.0002	
						0.0066	0.0003	0.0003	0.0003	
23						0.0067	0.0002	0.0003	0.0003	
						0.0067	0.0002	0.0002	0.0003	
						0.0065	0.0002	0.0003	0.0003	
						0.0064	0.0001	0.0002	0.0002	
						0.0066	0.0002	0.0002	0.0002	
24						0.0067	0.0002	0.0003	0.0002	
						0.0067	0.0002	0.0002	0.0002	
						0.0065	0.0002	0.0002	0.0003	
						0.0064	0.0002	0.0001	0.0002	
						0.0066	0.0002	0.0002	0.0002	
25						0.0067	0.0003	0.0003	0.0003	
						0.0067	0.0003	0.0002	0.0003	
						0.0065	0.0002	0.0003	0.0004	
						0.0064	0.0004	0.0003	0.0003	
						0.0066	0.0003	0.0003	0.0003	
26						0.0067	0.0006	0.0005	0.0006	
						0.0067	0.0005	0.0005	0.0007	
						0.0065	0.0006	0.0005	0.0006	
						0.0064	0.0004	0.0004	0.0007	
						0.0066	0.0005	0.0004	0.0005	
27						0.0067	0.0005	0.0008	0.0005	
						0.0067	0.0004	0.0007	0.0003	
						0.0065	0.0004	0.0007	0.0006	
						0.0064	0.0005	0.0005	0.0003	
						0.0066	0.0003	0.0007	0.0004	