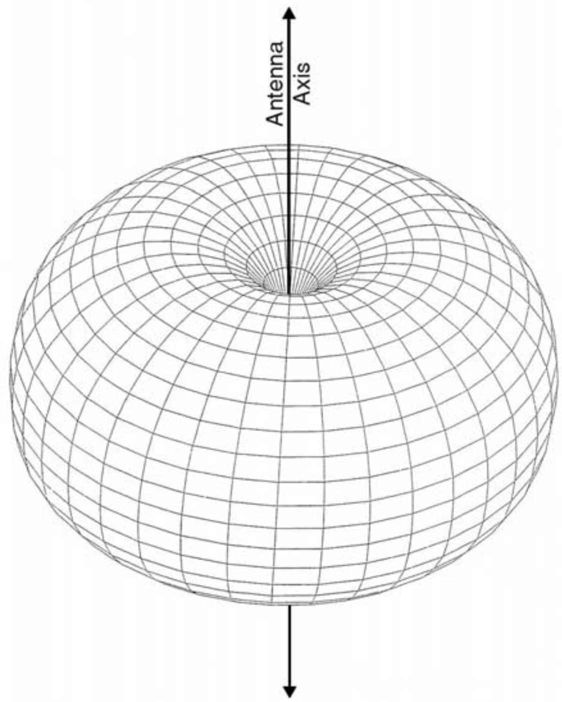
Analysis of RF Fields Associated with Operation of PG&E Automatic Meter Reading Systems



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Acknowledgment

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Summary

Four different automatic meter reading (AMR) systems were evaluated for their potential to produce radiofrequency (RF) fields in their vicinity and compliance with maximum permissible exposure (MPE) limits for the general public that have been established by the Federal Communications Commission (FCC). The systems included products from Cellnet Technologies, Inc., Distribution Control Systems, Inc., Hexagram, Inc., and Itron, Inc. In each case, low power RF signals are used to transmit meter reading data back to the utility network, eliminating the manual reading of meters in either residential or commercial environments. Typical equipment configurations include an internal transmitter inside the electric power meter that communicates with either a repeater or data collection unit located in the vicinity. In some cases, the repeater unit communicates bi-directionally with the meter unit and in others, the transmission from the meter is one-way to the repeater or data collection unit. The various transmitters used by these systems operate at power levels of 1-2 watts or less and most operate with very small duty cycles. The RF fields associated with operation of any of the products evaluated in this report, regardless of manufacturer, will comply by a wide margin with the FCC MPEs, commonly by several to many orders of magnitude below the allowable levels. The RF fields produced by these devices are comparable to or weaker than many of the RF fields found in our everyday living environment including, for example, radio and television broadcast signals, microwave oven leakage fields, and cellular telephone base station signals. The use of cellular telephones and walkie-talkies can result in RF fields that are typically much stronger than the fields that will usually be encountered by the public from use of the AMR technology studied in this report.

Introduction

Automatic meter reading (AMR) technology is being considered for implementation by the Pacific Gas & Electric Company (PG&E). AMR technology provides a cost effective approach to acquiring meter data from consumers since the technology can be adapted to the reading of electric, gas, and water meters. In practice, AMR works by transmitting meter data wirelessly such that it ends up at the utility company for processing, without an individual having to visit the meter site to manually record the reading. Several different approaches are used in AMR systems but the primary medium by which data are transmitted back to a central processing center is via the use of low power radiofrequency (RF) signals. Typically, a low power transmitting device is contained within an electric service meter and this transmitter sends digital messages from the meter to some form of data collection point that is within range of the transmitter.[1] Often, similar transmitter units may be attached to water and gas meters and these units wirelessly relay consumption data to the transceiver contained in the electric power meter for subsequent distribution to the relevant data collection point. The technology not only provides a highly efficient method for obtaining usage data from customers, but it also can provide up-to-the-minute information on consumption patterns since the meter reading devices can be adjusted to provide the desired data as frequently as needed. Typically, data is relayed from the meter to the data collection point on a daily or more often basis, substantially more frequently than the more common manual method of reading the meter, perhaps once per month.

Because all of these systems that are being considered for implementation by PG&E employ the use of RF energy in the form of low power signals being transmitted by the meters, and signals commonly produced by the data collection points, in response to the meter transmissions, it is relevant to address the issue of possible exposure of the general public to the signals. This report documents our analysis of the RF fields that could be produced by use of these systems, compares results of the strength of the signals to relevant human exposure limits, and contrasts them with other commonly encountered RF fields in our everyday environment.

Applicable RF Exposure Standards

Several guidelines or standards exist that recommend safe upper limits for human exposure to RF fields. These include limits developed by the Institute of Electrical and Electronics Engineers (IEEE, 1999), guideline published by the International Commission on Non-ionizing Radiation Protection (ICNIRP, 1998) and those promulgated by the Federal Communications Commission (FCC, 1997) relative to human exposure to RF fields[2]. Of these, the exposure guidelines of the FCC are most relevant to the evaluation of potential exposure because the AMR system equipment is regulated by the FCC. The FCC maximum permissible exposure (MPE) values are tabulated in Appendix A and are usually expressed in terms of the plane wave equivalent power density of the RF field or the strength of the electric and/or magnetic field components of the RF field. Power density is expressed as power per unit area and is most commonly given in units of milliwatts per square centimeter (mW/cm^2) or watts per square meter (W/m^2). Electric field strength is specified in units of volts per meter (V/m) or, sometimes, microvolts per meter (µV/m), or in decibels relative to a microvolt per meter (dBµV/m). The FCC exposure limits are, strictly, applied to FCC licensees such as operators of radio and television broadcast stations, two-way radio communications systems, cellular telephone base stations, etc.

Although most of the systems evaluated in this study operate in the "license free" band of 902-928 MHz (one system does not), and while these low power devices are not

[1] Repeaters or data collection units are distributed throughout an area to "service" the many individual meter transmitters, sometimes, several hundred units. These units are typically mounted on top of existing neighborhood power poles.
[2] Safe exposure limits are specified by the FCC in terms of Maximum Permissible Exposure (MPE) limits that vary with frequency. MPE limits for the general public include at safety factor of 50. See Appendix A for details on MPE limits for occupational/controlled exposures and general public/uncontrolled exposures.

directly affected by the FCC rules on human exposure, the FCC MPEs for the general public are well recognized by most RF operators and these exposure limits are among the most stringent of those that exist. Hence, we believe that it is relevant to use the FCC MPEs as bench marks for evaluating potential human exposure to the AMR systems discussed in this report. For purposes of this evaluation, the MPE values established for members of the general public have been applied.

Three of the AMR systems evaluated here make use of the license-free band of 902-928 MHz which is specified in Part 15 of the FCC rules while one operates within a licensed band in the 450-470 MHz range. This part of the rules specifies maximum power levels that may be used by transmitters operating in this band, and by the very nature of the license-free band which has associated with it a requirement that systems not cause interference with other licensed services, transmitter power is very low. Practically, Part 15 of the FCC rules limits transmitters operating in the license-free band, depending on their application, frequency band of operation, and modulation techniques, to an effective radiated power limit, or a maximum transmitter power and antenna gain limit. This has the effect of producing very low level RF fields.

Analysis of RF Fields

The intensities of RF fields (expressed as power density) that might be associated with operation of each of four different AMR systems were calculated using conventional field calculation methods but with the inclusion of a ground reflection factor as recommended by the FCC (1997). Power density was calculated for each system according to the following relationship:

$$S(W/m^2) = \frac{P_t \times G_{\max} \times \delta \times 2.56}{4\pi R^2} \qquad \text{Equation 1}$$

Where,

S is plane wave equivalent power density (W/m^2)

P_t is maximum transmitter output power (W)

G_{max} is the maximum possible antenna power gain (a dimensionless factor)

δ is the duty cycle of the transmitter

R is the radial distance between the transmitter and the point of interest (meters)

2.56 This factor accounts for possible ground reflections that could enhance the resultant field. Ground reflection could cause a maximum 1.6-fold increase of the field strength leading to an increase of $(1.6)^2$ or 2.56 in the power density since it is proportional to the square of field strength.

Calculations were performed for distances from 1 foot to 100 feet from each transmitting device. Electric meter transmitters were assumed to be 5 ft above the ground and pole-mounted collection or repeater units were assumed to be 30 ft above ground.

AMR Systems Evaluated

A total of four different AMR systems were included in the analysis. These systems are summarized in Table 1. Company information is provided in Appendix B.

Table 1. Summary of AMR system technical information used in analysis of RF fields

	Subsystem	Frequency (MHz)	Transmitter power (mW)	Antenna gain (dBi)	Duty cycle
Cellnet	Meter to repeater	902-928	100	-1	0.01
	Repeater to meter	902-928	1000	6	0.01
	Repeater to network	902-928	1000	6	0.05
DCSI[1]	EMTr & RMTr	902-928	6.3	2.15	0.00044
	ORION	902-928	1	2	0.00044
Hexagram	Meter to DCU	450-470	820 EIRP[2]	2	0.00000925
	DCU to network	450-470	2000	5	0.0001
Itron	Meter to repeater	902-928	100	2	0.0293
	Repeater to network	902-928	900	2.1	0.13

[1] This system communicates meter data from associated gas, water, and electric meters to the utility network via carrier current technology rather than RF signals.
[2] EIRP = effective isotropic radiated power (see glossary).

It should be noted that a wide range of alternative equipment is available from the above suppliers that can be configured in a number of ways to provide for automatic meter reading. The systems evaluated here consist of those units for which technical information was provided to PG&E and may not include the entire range of all possible products available from a particular company. Furthermore, in some instances, when transmitter units with different power levels were available from a given supplier, the analysis of RF fields was accomplished for the unit that would result in the greatest RF fields near the system.

Analysis Results

The RF field level (as a power density) has been calculated due to operation of the various AMR systems. Since these devices use very low levels of antenna power, the resultant power density is very tiny, especially in comparison to the allowable MPE exposure limits for the general public. The analysis reveals that the extremely weak RF fields produced are orders of magnitude less than the FCC MPE values. To display such small numbers relative to the exposure limits, the power density is displayed in two commonly used formats of RF field vs. distance. In the first presentation format, the RF field is expressed in decibels (dB) referenced to MPE using the following relationship: power density in decibels (dB) = 10 Log (RF Level/MPE). Therefore, the decibels are compared to the MPE limit; for example, a value of 0 dB means an RF power density (RF field) value equal to the MPE. A value of -10 dB means the AMR device produces an RF field that is one-tenth of the MPE, -20 dB is 1/100 of the MPE, -30 db is 1/1000 of the MPE, and so forth. The results are also provided as power density in units of microwatts per square centimeter ($\mu W/cm^2$). Calculated values of power density vs. distance are given in Figures 1 and 2 for the Cellnet system. It is clear from Figure 1 that the greatest RF field is at the closest distance from a meter equipped with the Cellnet meter transmitter unit where the field is 35 dB below (-35 dB) the MPE (0.00029 of the MPE) and decreases with distance from the meter.

Similar graphs are provided for the DCSI, Hexagram, and Itron systems in Figures 3-8. Each of these graphs illustrate the extremely weak signals that are produced in the immediate vicinity of the various AMR systems, ranging from approximately 31 to 58 dB below the applicable public MPE values (0.000794 to 0.00000158 of the permissible exposure limits).

Comparison to Standards and Common RF Fields

Table 2 summarizes the results for distances where people may approach close to the equipment. The levels would be much less for distances farther away. These results demonstrate that even close to the AMR units, public exposure is far less than one-percent of safe exposure limits for the general public.

Table 2. Summary of AMR system RF field levels- microwatts/cm^2

	Subsystem	RF Level- 1 ft $\mu W/cm^2$	RF Level- 3 ft $\mu W/cm^2$	Maximum Permissible Exposure (MPE)- $\mu W/cm^2$
Cellnet	Meter to repeater	0.174	0.0193	601
	Repeater to meter	0.0140	0.0138	
	Repeater to network	0.0700	0.0692	
DCSI	EMTr & RMTr	0.000997	0.000111	601
	ORION	0.000152	0.0000169	
Hexagram	Meter to DCU	0.00166	0.000185	300
	DCU to network	0.000221	0.000219	
Itron	Meter to repeater	0.485	0.0539	601
	Repeater to network	0.0664	0.0656	

The weak RF fields associated with operation of the different AMR systems evaluated may also be put in perspective, for example, by comparing them to commonly found RF fields in our everyday environment due to radio and television broadcast stations. In an EPA study, environmental field measurements across the United States showed that most people, most of the time, are exposed to very weak RF fields from broadcast stations (Tell and Mantiply, 1980). In that study, the median RF field exposure of the public was determined to be approximately 0.005 $\mu W/cm^2$. The same study estimated that 1% of the public in metropolitan areas was exposed to RF fields exceeding 1 $\mu W/cm^2$. Compared to the applicable exposure limits that are relevant to these measured field levels, the median and 1 percentile figures correspond to about -46 dB and -23 dB below the MPE values. These data on common public exposure to ambient broadcast signals fall within or even above the calculated values for RF fields associated with operation of the various AMR systems studied.

A common appliance found in most homes is the microwave oven. All microwave ovens leak small amounts of RF energy during their normal operation. Figure 9 illustrates a measurement of electric field strength at a distance of 3 meters from a microwave oven. These data were reported by Gawthrop et al. (1994) and show a maximum field strength of 1.972 V/m or an equivalent power density of 1.03 $\mu W/cm^2$. This power density represents 0.10% of the public MPE at the microwave oven frequency of 2.45 GHz. Power density S is related to electric field strength E by the relationship:

$$S = \frac{E^2}{377} \qquad \text{Equation 2}$$

where,
S is plane wave equivalent power density (W/m^2)
E is electric field strength (V/m)
377 is the impedance of free space (ohms).

Mantiply et al. (1999) summarized a large amount of field measurement data showing field strengths of various RF field sources across the frequency spectrum. Their summary is illustrated graphically in Figure 10, taken from their report. This figure demonstrates the wide variety of common RF sources on our everyday environment.

Typically, the strongest RF fields in general urban environments are those from domestic broadcasting services, including AM and FM radio and VHF and UHF television. RF exposures at frequencies comparable to the proposed AMR systems include walkie-talkies operating in the family radio service (FRS) band (462.5625-467.7125 MHz) with up to 500 mW of radiated power; general mobile radio service (GMRS) band (462-467 MHz) with up to 1,000-5,000 mW of radiated power, and cellular phones with up to about 600 mW of radiated power. The following Table 3 gives a general comparison of some typical power density levels for common sources with the proposed AMR system components (Tell 2002).

Table 3. Comparison of AMR fields with common RF sources.

RF Source	Power Density- µW/cm^2
Cellnet AMR System @ 3 ft:	0.01 – 0.07
DCSI AMR System @ 3 ft:	0.00001 – 0.0001
Hexagram AMR System @ 3 ft:	0.0002
Itron AMR System @ 3 ft:	0.05 – 0.07
Installed Microwave Oven- FDA Allowable	5,000
Wireless Local Area Network @ 2 ft	13
Cell Phones @ head	1,000 – 3,000
Walkie-Talkies @ head	500 – 10,000

Interference

Interference due to operation of the various AMR systems is unlikely to occur. This is because all units use very low power and operate in radio frequency bands reserved for devices of this type. In addition, the FCC requires that unlicesened low-power RF devices must not create interference and users of such equipment must resolve any interference problems or cease operation. According to the FCC (47CFR Part 15): "The operator of a radio frequency device shall be required to cease operating the device upon notification by a Commission representative that the device is causing harmful interference. Operation shall not resume until the condition causing the harmful interference has been corrected."

Conclusions

Four different automatic meter reading (AMR) systems were evaluated for their potential to produce radiofrequency (RF) fields in their vicinity and compliance with maximum permissible exposure (MPE) limits for the general public that have been established by the Federal Communications Commission (FCC). All four systems use very low power radio equipment and produce RF fields far below exposure standards for the public. The RF fields close to the AMR devices are typically far less than 1% of the RF exposure standards and much less than other typical RF sources such as walkie-talkies and cellular telephones. Interference due to operation of the various AMR systems is unlikely to occur because all units use very low power and operate in radio frequency bands reserved by the FCC for devices of this type.

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Mantiply, E. D., K. R. Pohl, S. W. Poppell, J. A. Murphy (1997): Summary of Measured Radiofrequency Electric and Magnetic Fields (10 kHz to 30 GHz) in the General and Work Environment. *Bioelectromagnetics* 18:563-577.

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Tell, R.A. (2002): An overview of common sources of environmental levels of radio frequency fields. EPRI Technical Report 1005496, Palo Alto, CA.

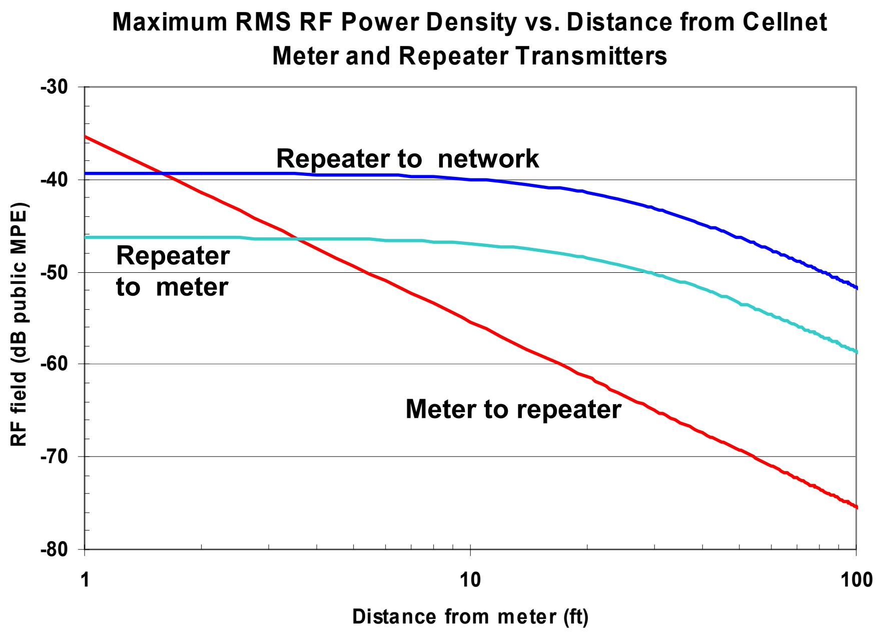


Figure 1. RMS RF field for the Cellnet meter and repeater modules vs. distance expressed as decibels relative to the FCC MPE value. 0 dB is equal to the MPE.

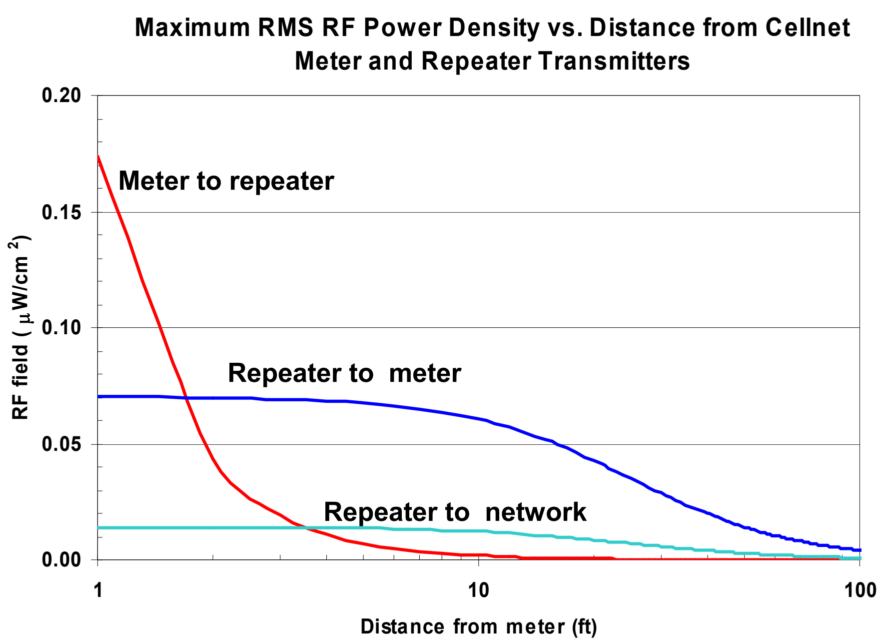


Figure 2. RMS RF field for the Cellnet meter and repeater modules vs. distance expressed as power density in microwatts per square centimeter (μW/cm^2). The public MPE is equal to 601 μW/cm^2 for the Cellnet frequency.

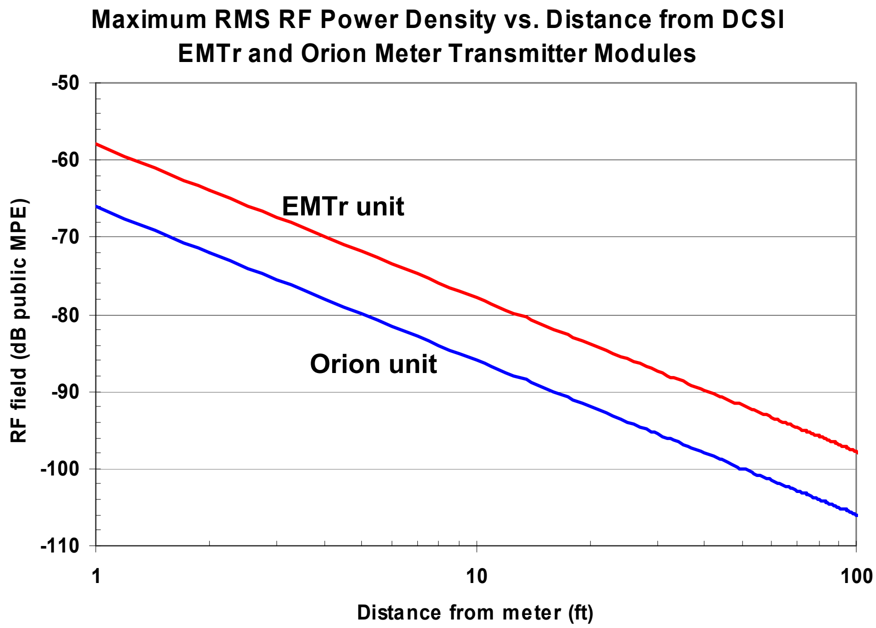


Figure 3. RMS RF field for the DCSI EMTr and Orion meter transmitter modules vs. distance expressed as decibels relative to the FCC MPE value. 0 dB is equal to the MPE.

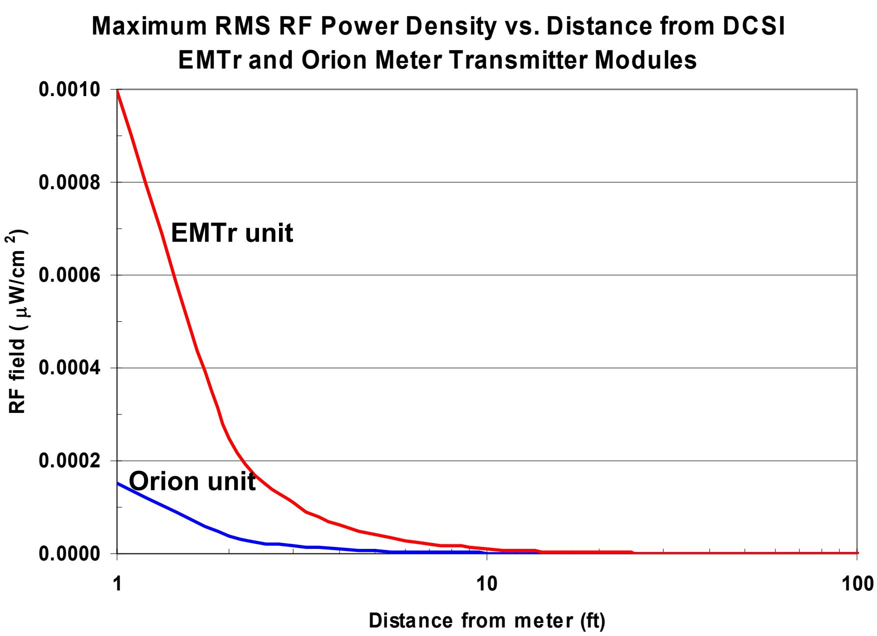


Figure 4. RMS RF field for the DCSI EMTr and Orion meter transmitter modules vs. distance expressed as power density in microwatts per square centimeter ($\mu W/cm^2$). The public MPE is equal to 601 $\mu W/cm^2$ for the DCSI frequency.

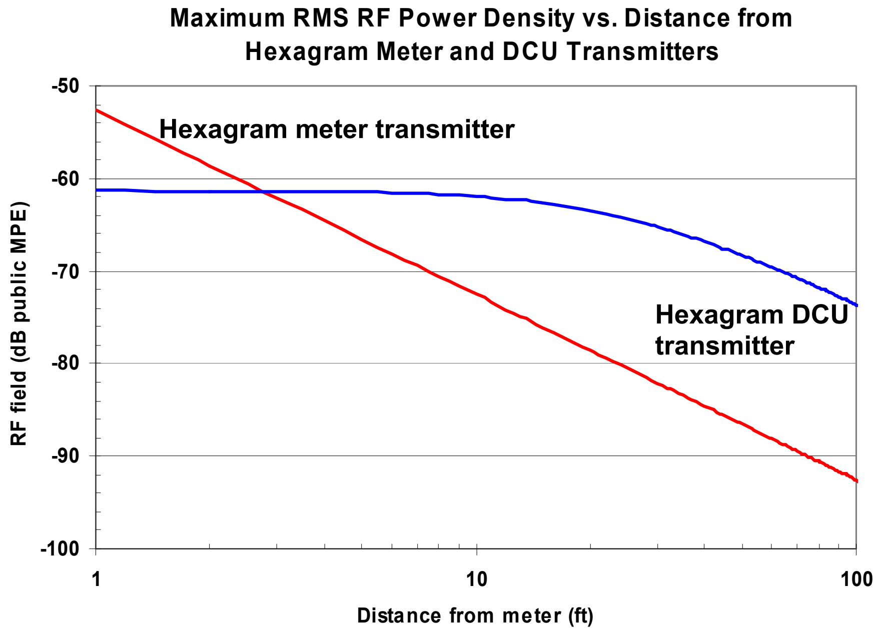


Figure 5. RMS RF field for the Hexagram meter and DCU transmitters vs. distance expressed as decibels relative to the FCC MPE value. 0 dB is equal to the MPE.

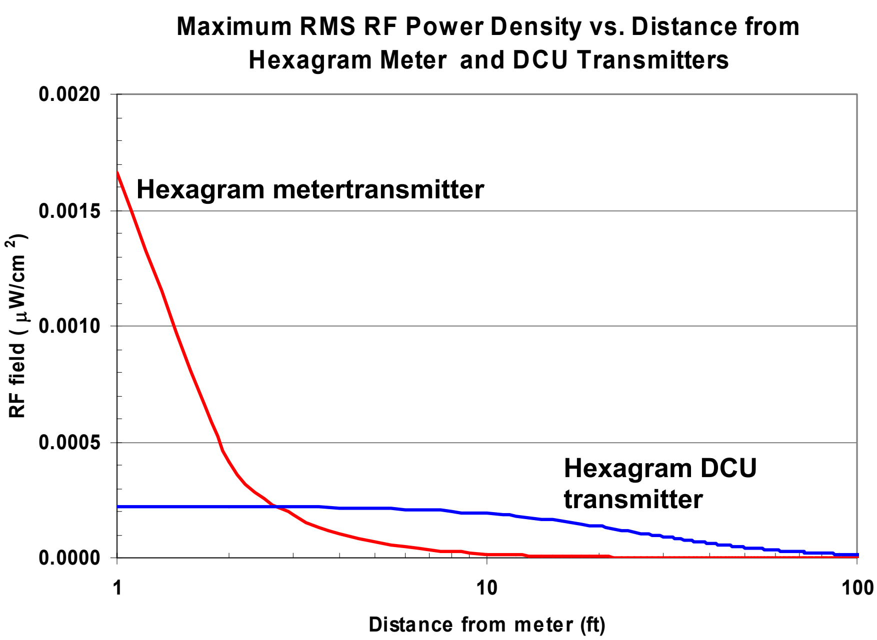


Figure 6. RMS RF field for the Hexagram meter and DCU transmitters vs. distance expressed as power density in microwatts per square centimeter ($\mu W/cm^2$). The public MPE is equal to 300 $\mu W/cm^2$ for the Hexagram frequency.

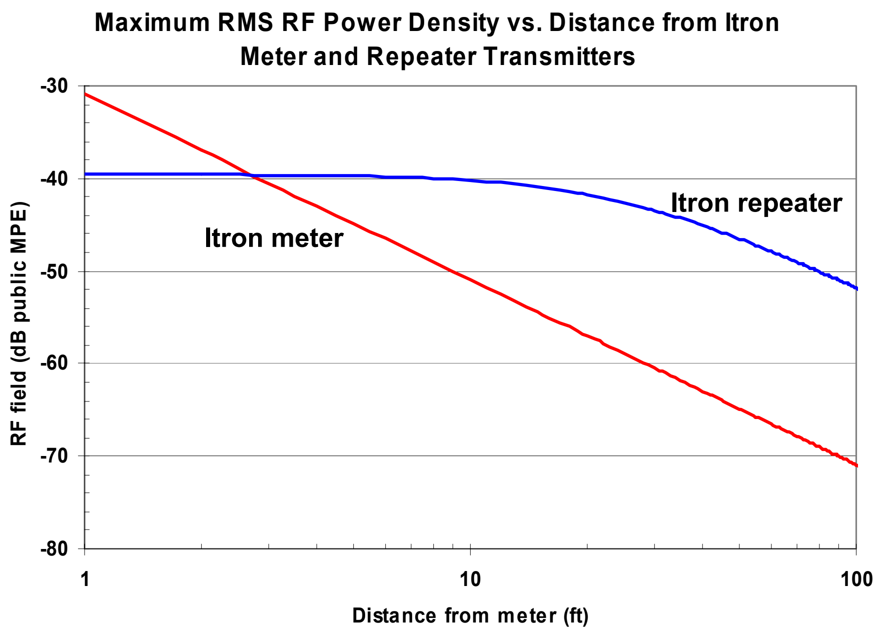


Figure 7. RMS RF field for the Itron meter and repeater transmitter vs. distance expressed as decibels relative to the FCC MPE value. 0 dB is equal to the MPE.

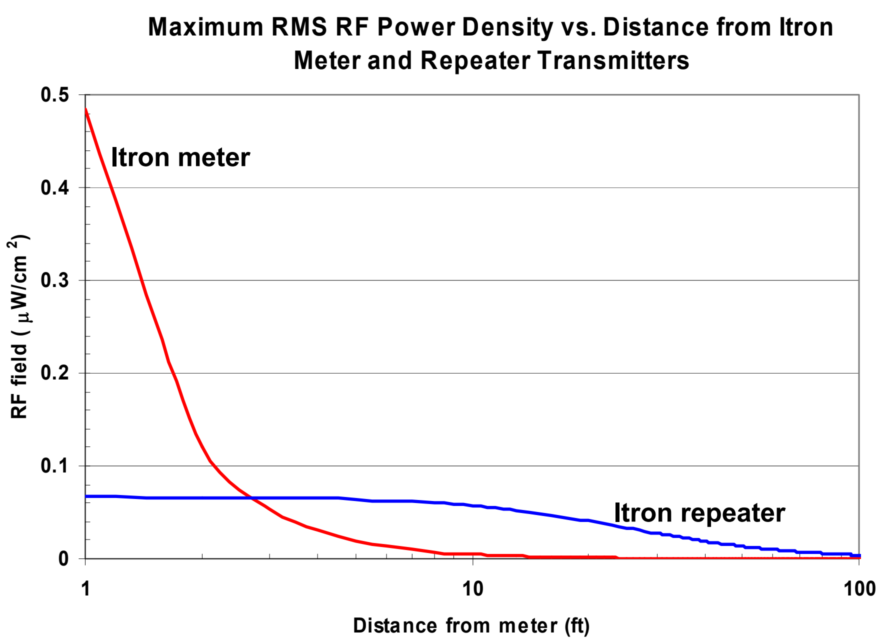


Figure 8. RMS RF field for the Itron meter module and repeater transmitter vs. distance expressed as power density in microwatts per square centimeter ($\mu W/cm^2$). The public MPE is equal to 601 $\mu W/cm^2$ for the Itron frequency.

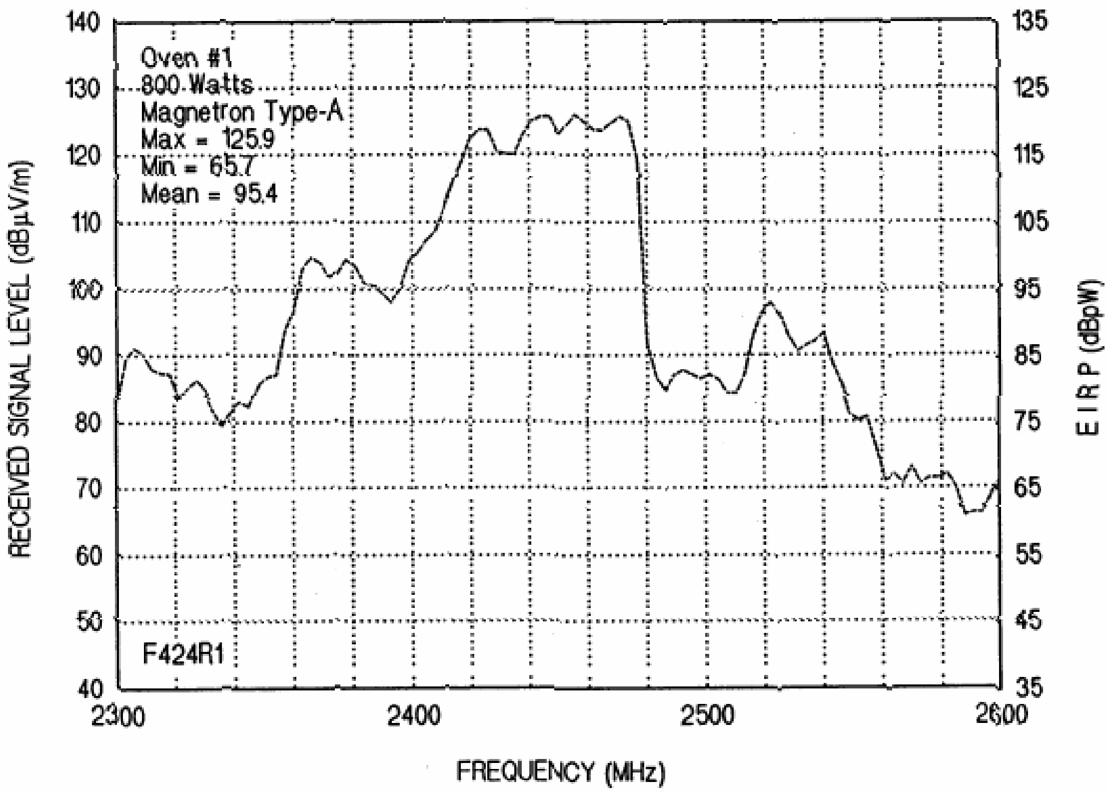
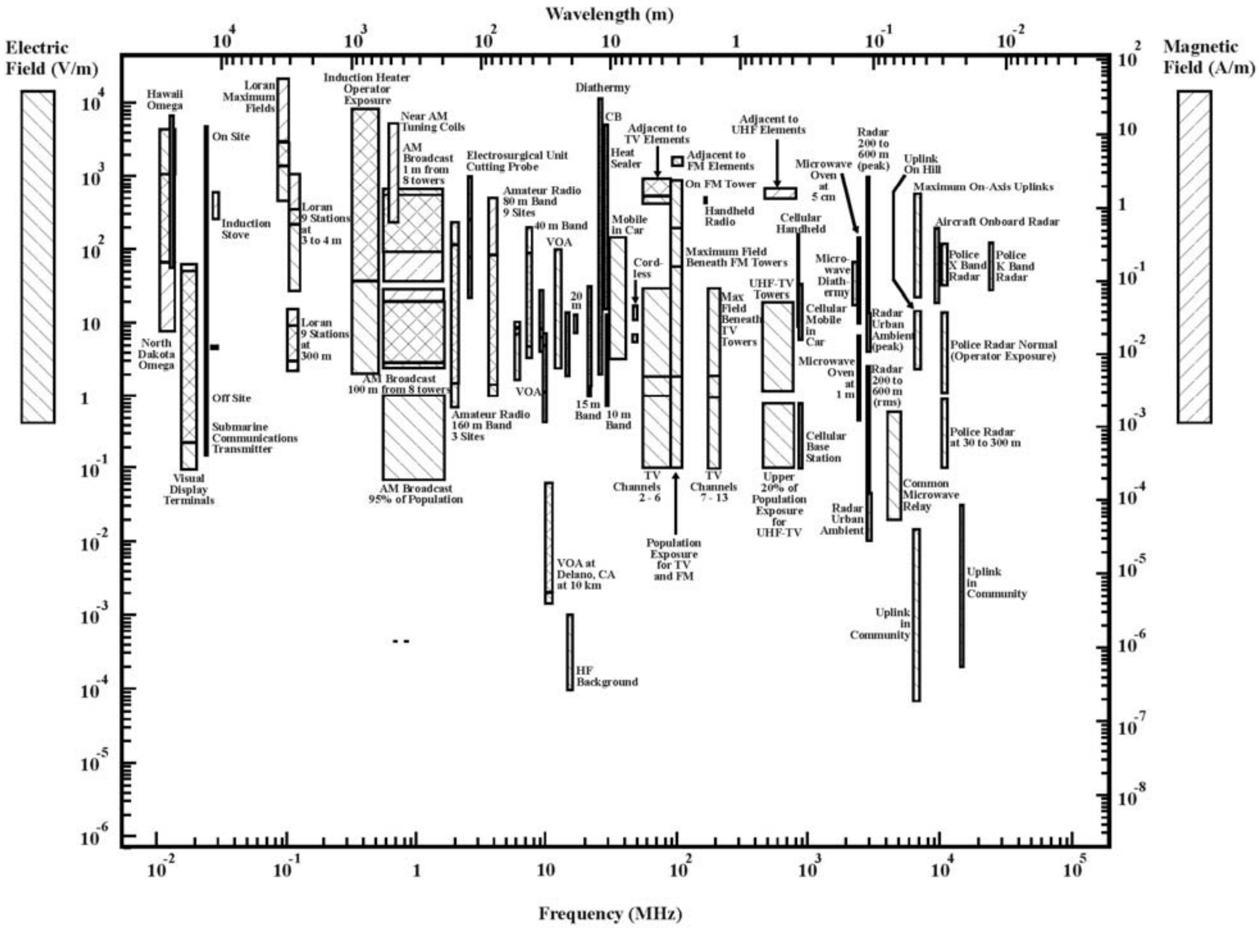


Figure 9. Peak electric field strength at 3 meters vs. frequency plot of microwave oven signals from NTIA report (Gawthrop et. al, 1994). The maximum signal strength measured in this example was equivalent to 1.972 V/m or 1.03 μW/cm^2.



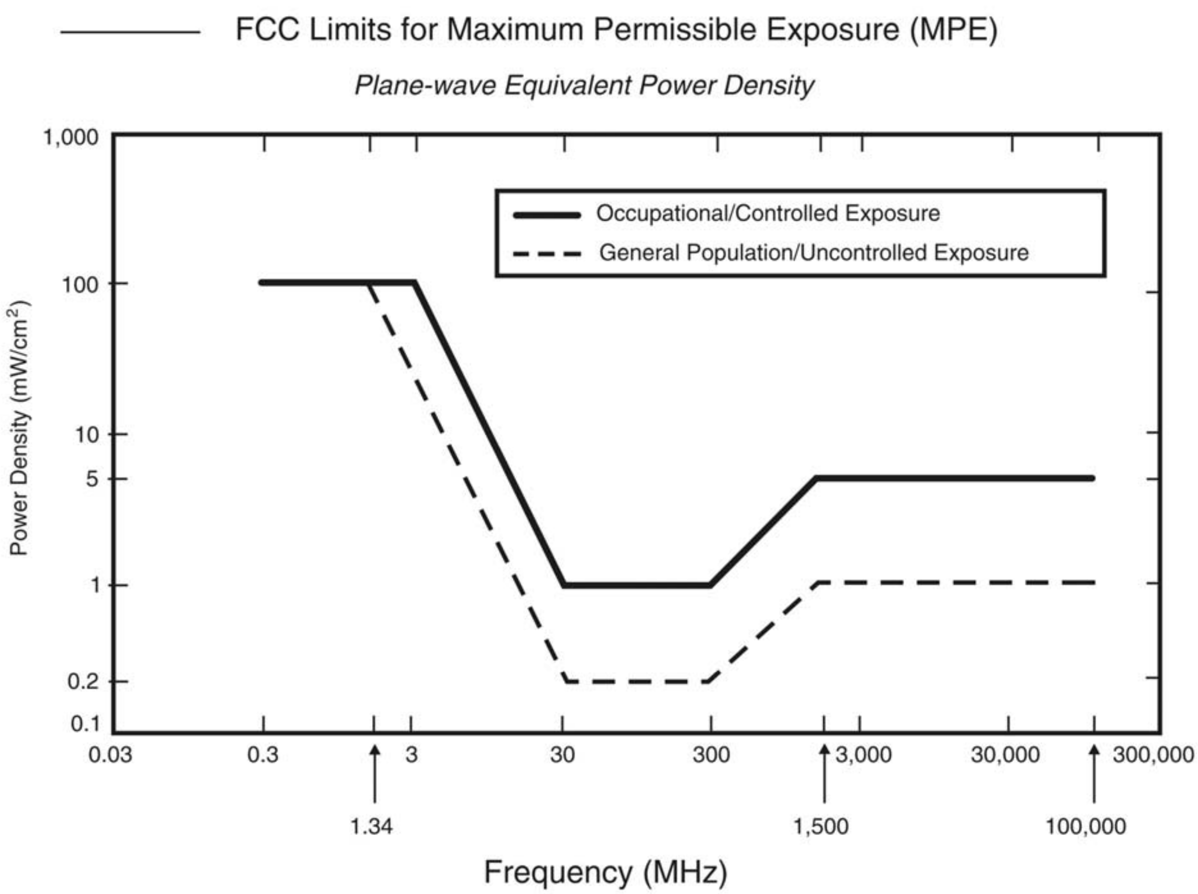
Summary of Measured Radio Frequency Levels in the General and Work Environment (U.S. EPA - 1997)

Figure 10. Summary of RF levels in the general and work environment (from Mantiply, et al., 1997). The RF field levels for the various AMR subsystems evaluated in this report range from 0.006 to 1.3 V/m at 1-3 ft. (Note: calculated AMR electric field in V/m is equal to the square root of $[(\mu W/cm^2/100)(377)]$).

APPENDIX A - LIMITS FOR MAXIMUM PERMISSIBLE EXPOSURE (MPE)
Adopted by the Federal Communications Commission
(Reference = Table 1. Title 47 CFR)

The United States Federal Communications Commission (FCC) first adopted guidelines to be used for human exposure to RF emissions in 1985. The FCC revised and updated their guidelines August 1, 1996, as a result of a rule-making proceeding initiated in 1993. The FCC Office of Engineering and Technology issued a new Evaluating Compliance document OET-Bulletin 65 in August 1997. The new guidelines incorporate limits for maximum permissible exposure (MPE) in terms of electric and magnetic field strength and power density for transmitters operating between 300 kHz And 100 GHz. The FCC carefully considered a large number of comments submitted in its rule-making proceedings, particularly those from the U. S. Environmental Protection Agency (EPA), the Food and Drug Administration (FDA) and other federal health and safety agencies. The guidelines were "based substantially on the recommendations of those agencies, and it is the Commission's belief that they represent a consensus view of the federal agencies responsible for matters relating to public safety and health."

The FCC RF exposure limits are presented below in graphic and tabular formats for occupational (controlled) and the public or general population (uncontrolled) exposures.



(A) Limits for Occupational/Controlled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\lvert E\rvert^2$, $\lvert H\rvert^2$ or S (minutes)
0.3-3.0	614	1.63	(100)*	6
3.0-30	1842/f	4.89/f	$(900/f^2)$*	6
30-300	61.4	0.163	1.0	6
300-1500	--	--	f/300	6
1500-100,000	--	--	5	6

(B) Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\lvert E\rvert^2$, $\lvert H\rvert^2$ or S (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	$(180/f^2)$*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

f = frequency in MHz *Plane-wave equivalent power density

NOTE 1: ***Occupational/controlled*** limits apply in situations in which persons are exposed as a consequence of their employment provided those persons are fully aware of the potential for exposure and can exercise control over their exposure. Limits for occupational/controlled exposure also apply in situations when an individual is transient through a location where occupational/controlled limits apply provided he or she is made aware of the potential for exposure.

NOTE 2: ***General population/uncontrolled*** exposures apply in situations in which the general public may be exposed, or in which persons that are exposed as a consequence of their employment may not be fully aware of the potential for exposure or can not exercise control over their exposure.

NOTE 3: The FCC does not permit use of time averaging to demonstrate compliance with the general public/uncontrolled MPE limits.

Appendix B

Company Information for AMR Systems Included in Analysis

Cellnet Technologies, Inc.
30000 Mill Creek Avenue
Suite 100
Alpharetta, GA 30022
Phone: 678-258-1550

Distribution Control Systems, Inc.
945 Hornet Drive
Hazelwood, MO 63042
Phone: 314-895-6400

Hexagram, Inc.
23905 Mercantile Road
Cleveland, OH 44122
Phone: 216-464-1057

ITRON
2818 N. Sullivan Road
Spokane, WA 99216
Phone: 509-924-9900

Appendix C

Glossary of Terms

ANSI- American National Standards Institute, issued first standard for protection against intense microwave exposure in 1966.

antenna- A device designed to efficiently convert conducted electrical energy into radiating electromagnetic waves in free space (or vice versa).

attenuation- The phenomenon by which the amplitude of an RF signal is reduced as it moves from one point in a system to another. It is often given in decibels.

averaging Time (T_{avg})- The appropriate time period over which exposure is averaged for purposes of determining compliance with the maximum permissible exposure (MPE). For exposure durations less than the averaging time, the maximum permissible exposure, MPE', in any time interval, is found from:

$$MPE' = MPE\left(\frac{T_{avg}}{T_{exp}}\right)$$

where T_{exp} is the exposure duration in that interval expressed in the same units as T_{avg}. T_{exp} is limited by restriction on peak power density.

bandwidth- A measure of the frequency range occupied by an electromagnetic signal. It is equal to the difference between the upper frequency and the lower frequency, usually expressed in Hertz.

carrier current- A term used to include the use of electric power lines for communication of voice or data signals by imposing a radiofrequency signal on the 60-Hz voltage waveform. The data signals are "received" at some distant point by a receiver connected to the power line, not by use of an antenna to detect a radiated RF fields.

continuous exposure- Exposure for durations exceeding the corresponding averaging time (usually 6 minutes for occupational exposure and 30 minutes for the general public). Exposure for less than the averaging time is called short-term exposure.

controlled environment- Controlled environments are locations where there is exposure which may be incurred by persons who are aware of the potential for exposure associated with employment, by other cognizant persons or as the incidental result of transient passage through areas where analysis shows the exposure levels are below some standard level for this environment but above the level for uncontrolled environments.

controlled exposure- a term applied by the FCC to occupational human exposures to radio frequency fields when persons are exposed as a consequence of their employment and in which those persons who are exposed have been made fully aware of the potential for exposure and can exercise control over their exposure.

dBi- decibel referenced to an isotropic antenna- a theoretical antenna which transmits (or receives) electromagnetic energy uniformly in all directions (i.e. there is no preferential direction).

decibel (dB)- a dimensionless quantity used to logarithmically compare some value to a reference level. For power levels (watts or watts/m^2), it would be ten times the logarithm (to the base ten) of the given power level divided by a reference power level. For quantities like volts or volts per meter, a decibel is twenty times the logarithm (to the base ten) of the ratio of a level to a reference level.

duty cycle- a measured of the percentage or fraction of time that an RF device is in operation. A duty cycle of 1.0, or 100%, corresponds to continuous operation. Also called duty factor. A duty cycle of 0.01 or 1% corresponds to a transmitter operating on aveage only 1% of the time.

effective isotropic radiated power (EIRP)- the apparent transmitted power from an isotropic antenna (i.e. a theoretical antenna that transmits uniformly in all possible directions as an expanding sphere).

effective radiated power (ERP)- the apparent transmitted power from an antenna, taking into account the effect of the antenna to concentrate the power in a given direction rather than emitting it in all directions, expressed in watts (W), and typically referenced to a half-wave dipole type of antenna.

electric field strength- a field vector (E) describing the force that electrical charges have on other electrical charges, often related to voltage differences, measured in volts per meter (V/m).

electromagnetic field- a composition of both an electric field and a magnetic field that are related in a fixed way that can convey electromagnetic energy. Antennas produce electromagnetic fields when they are used to transmit signals.

electromagnetic spectrum- the range of frequencies associated with electromagnetic fields. The spectrum ranges from extremely low frequencies beginning at zero hertz to the highest frequencies corresponding to cosmic radiation from space.

EPA- Environmental Protection Agency.

exposure- exposure occurs whenever a person is subjected to electric, magnetic or electromagnetic fields or to contact currents other than those originating from physiological processes in the body and other natural phenomena.

far field- the far field is a term used to denote the region far from an antenna compared to the wavelength corresponding to the frequency of operation. It is a distance from an antenna beyond which the transmitted power densities decrease inversely with the square of the distance.

Federal Communications Commission (FCC)- the Federal Communications Commission (FCC) is an independent agency of the US Federal Government and is directly responsible to Congress. The FCC was established by the Communications Act of 1934 and is charged with regulating interstate and international communications by radio, television, wire, satellite, and cable. The FCC also allocates bands of frequencies for non-government communications services (the NTIA allocates government frequencies). The guidelines for human exposure to radio frequency electromagnetic fields as set by the FCC are contained in the Office of Engineering and Technology (OET) Bulletin 65, Edition 97-01 (August 1997). Additional information is contained in OET Bulletin 65 Supplement A (radio and television broadcast stations), Supplement B (amateur radio stations), and Supplement C (mobile and portable devices).

free space impedance- an expression of the apparent degree to which free space impedes the flow of electromagnetic energy express in ohms and equal to the ratio of the strength of the electric and magnetic fields (the impedance of free space is equal to 377 ohms).

gain, antenna- a measure of the ability of an antenna to concentrate the power delivered to it from a transmitter into a directional beam of energy. A search light exhibits a large gain since it can concentrate light energy into a very narrow beam while not radiating very much light in other directions. It is common for cellular antennas to exhibit gains of 10 dB or more in the elevation plane, i.e., concentrate the power delivered to the antenna from the transmitter by a factor of 10 times in the direction of the main beam giving rise to an effective radiated power greater than the actual transmitter output power. In other directions, for example, behind the antenna, the antenna will greatly decrease the emitted signals. Gain is often referenced to an isotropic antenna (given as dBi).

gigahertz (GHz)- one billion hertz.

hertz- the unit for expressing frequency, one Hertz (Hz) equals one cycle per second.

IEEE- Institute of Electrical and Electronics Engineers.

ISM- Industrial, Scientific, and Medical. There are various ISM frequency bands designated by the FCC for equipment or appliances designed to generate and use RF energy for industrial, scientific or medical purposes.

isotropic antenna- a theoretical antenna which transmits (or receives) electromagnetic energy uniformly in all directions (i.e. there is no preferential direction). The radiated wavefront is assumed to be an expanding sphere.

“license free”- a phrase meaning that an RF transmitter is operated at such low power and within an authorized frequency band that no formal license to operate is required by the FCC. There are restrictions placed on these devices, however, such as they shall not produce interference and/or may not create RF fields exceeding particular field strengths.

magnetic field strength- a field vector (H) that is equal to the magnetic flux density divided by the permeability of the medium. Magnetic field strength is expressed in units of amperes per meter (A/m).

maximum permissible exposure (MPE)- the rms and peak electric and magnetic field strength, their squares, or the plane wave equivalent power densities associated with these fields and the induced and contact currents to which a person may be exposed without harmful effect and with an acceptable safety factor.

megahertz (MHz)- one million hertz.

microwatts- one-millonth of a watt, a microwatt (μW) or 10^{-6} watts.

microwatt per square centimeter ($\mu W/cm^2$)- a measure of the power density flowing through an area of space, one millionth of a watt passing through a square centimeter.

microwave- an electromagnetic wave at super high frequencies, typically above 300 MHz, the wavelength of which is very short (micro).

milliwatt per square centimeter (mW/cm^2)- a measure of the power density flowing through an area of space, one thousandth of a watt passing through a square centimeter. One milliwatt per square centimeter is equal to 1,000 microwatts per square centimeter.

modulation- refers to the variation of either the frequency or amplitude of an electromagnetic field for purposes of conveying information such as voice, data or video programming.

near field- a region very near antennas in which the relationship between the electric and magnetic fields is complex and not fixed as in the far field, and in which the power density does not necessarily decrease inversely with the square of the distance. This region is sometimes defined as closer than about one-sixth of the wavelength. In the near field region the electric and magnetic fields can be determined, independently of each other, from the free-charge distribution and the free-current distribution respectively. The spatial variability of the near field can be large. The near field predominately contains reactive energy that enters space but returns to the antenna (this is different from energy that is radiated away from the antenna and propagates through space).

omnidirectional antenna- an antenna that emits a signal of essentially constant strength in all directions, in contrast to a directional antenna.

picowatts- picowatts or pW (10^{-12} watts).

plane wave- wave with parallel planar (flat) surfaces of constant phase (See also Spherical wave). Note: The cover of this report shows an idealized spherical wave that expands outward- in an appropriate region that this spherical wave can be considered as a plane (flat) wave.

plane wave equivalent power density- the power density associated with an electromagnetic wave propagated in free space in which the front of the wave is flat (plane). Meters used for measuring power density are often calibrated in terms of the plane wave equivalent power density.

polarization- the orientation of the electric field component of an electromagnetic field relative to the earth's surface. Vertical polarization refers to the condition in which the electric field component is vertical, or perpendicular, with respect to the ground, horizontal polarization refers to the condition in which the electric field component is parallel to the ground.

power density- power density (S, sometimes called the Poynting vector) is the power per unit area normal to the direction of propagation, usually expressed in units of watts per square meter (W/m^2) or, for convenience, milliwatts per square centimeter (mw/cm^2) or microwatts per square centimeter ($\mu w/cm^2$). For plane waves, power density, electric field strength, E, and magnetic field strength, H. are related by the impedance of free space, i.e. 120π (377) ohms. In particular, $S = E^2/120\pi = 120\pi H^2$ (Where E and H are expressed in units of V/m and A/m, respectively, S is in units of $W/m^{2)}$. Although many RF survey instruments indicate power density units, the actual quantities measured are E or E^2 or H or H^2.

Poynting vector- a field vector quantity equal to the vector product (cross product) of the electric field and magnetic field of an electromagnetic wave. The Poynting vector (S, also called power density) is equal to E X H, with units of W/m^2.

radiating field- the components of the total electromagnetic field produced by an antenna that contains all of the energy propagated away from the antenna. In the radiation field, both the electric and magnetic fields are codependent with an intensity that varies inversely with distance from the source.

radiation pattern- a description of the spatial distribution of RF energy emitted from an antenna. Two radiation patterns are required to completely describe the transmitting performance of an antenna, one for the azimuth plane and another for the elevation plane.

radio frequency (RF)- although the RF spectrum is formally defined in terms of frequency as extending from 0 to 3000 GHz, the frequency range of interest is 3 kHz to 300 GHz.

radio spectrum- the portion of the electromagnetic spectrum with wavelengths above the infrared region in which coherent waves can be generated and modulated to convey information- generally about 3 kHz to 300 GHz.

reflection- an electromagnetic wave (the “reflected” wave) caused by a change in the electrical properties of the environment in which an “incident” wave is propagating. This wave usually travels in a different direction than the incident wave. Generally, the larger and more abrupt the change in the electrical properties of the environment, the larger the reflected wave

RF - radiofrequency.

root-mean-square (RMS)- the effective value of, or the value associated with joule heating, of a periodic electromagnetic wave. The RMS value of a wave is obtained by taking the square root of the mean of the squared value of the wave.

Safety factor- additional safety is incorporated into MPE limits by the use of a safety factor (SF). A safe level exposure is divided by the safety factor to yield the allowable exposure limits or maximum permissible exposure (MPE). The FCC uses a SF of 5 for occupational and 50 for public exposure limits. This means the MPE for the general public is 50 times less than a level determined to be safe.

specific absorption rate (SAR)- the time derivative of the incremental energy absorbed by (dissipated in) an incremental mass contained in a volume) of a given density. SAR is expressed in units of watts per kilogram (or milliwatts per gram, mW/g). Guidelines for human exposure to radio frequency fields are based on SAR thresholds where adverse biological effects may occur. When the human body is exposed to a radio frequency field, the SAR experienced is proportional to the squared value of the electric field strength induced in the body.

spherical wave- a wave with concentric spherical surfaces of constant phase. Far from its source a spherical wave expands to approximate a flat surface or plane wave over discrete areas. Note: the cover of this report shows an idealized spherical wave generated by a rod antenna.

uncontrolled environment- uncontrolled environments are locations where there is the exposure of individuals who have no knowledge or control of their exposure. The exposures may occur in living quarters or workplaces where there are no expectations that the exposure levels may exceed some standard level limits for this environment

uncontrolled exposure- a term applied by the FCC to human exposures to radio frequency fields when the general public is exposed or in which persons who are exposed as a consequence of their employment may not be made fully aware of the potential for exposure or cannot exercise control over their exposure. Members of the general public always fall under this category when exposure is not employment-related.

Appendix D

Units

Watt = 10^3 **milliwatt (mW)**
Watt = 10^6 **microwatt (µW)**
Watt = 10^{12} **picowatt (pW)**

milliwatt = 10^{-3} watt
microwatt = 10^{-6} watt
picowatt = 10^{-12} watt

watt per square meter (W/m^2) = 10^{-1} mW/cm^2 = 10^2 $\mu W/cm^2$ = 10^8 pW/cm^2

milliwatt per square centimeter (mW/cm^2) = 10^3 $\mu W/cm^2$ = 10^9 pW/cm^2 = 10 W/m^2

microwatt per square centimeter ($\mu W/cm^2$) = 10^{-3} mW/cm^2 = 10^6 pW/cm^2 = 10^{-2} W/m^2

picowatt per square centimeter (pW/cm^2) = 10^{-9} mW/cm^2 = 10^{-6} $\mu W/cm^2$ = 10^{-8} W/m^2

RF Field (power density) in decibels with reference to MPE

power density in decibels (dB) = 10 Log (RF Level/MPE)

Decibels (referenced to MPE)	RF Field as Percent of MPE Level
0	100 %
-10	10 %
-20	1 %
-30	0.1 %
-40	0.001 %

Appendix E

FCC Frequency Allocations

A summary of the FCC Frequency Allocations (based on the Oct '93 Code of Federal Regulations - 47 CFR 2.106) in the general region of the frequency bands of the four proposed AMR systems considered by PG&E, namely 450-470 MHz and 902-928 MHz.

450 - 460 MHz: FM @ 25 kHz steps (450-455 base, 455-460 mobile)

450.050 - 450.925 Auxiliary Broadcasting
451.025 - 452.025 Industry
452.050 - 452.500 Taxi / Industry / Transport
452.525 - 452.600 Automobile Emergency
452.625 - 452.950 Transportation - Trucks / Railroad
452.975 - 453.000 Relay Press
453.025 - 453.975 Local Govt / Public Safety
454.025 - 454.650 Mobile Telephone
454.675 - 454.975 Mobile Telephone Air (ground)
455.050 - 455.925 Auxiliary Broadcasting
456.025 - 457.025 Industry
457.050 - 457.500 Taxi / Industry / Transport
457.525 - 457.600 {Maritime - shipboard repeater (mobiles @ 467.xxx)
{Business - low power
457.625 - 457.950 Transportation - Trucks / Railroad
457.975 - 458.000 Relay Press
458.025 - 458.975 Public Safety / Local Govt
459.025 - 459.650 Mobile Telephone
459.675 - 459.975 Mobile Telephone Air (airborne)

460 - 470 MHz: FM @ 25 kHz steps (460-465 base, 465-470 mobile)

460.025 - 460.550 Police / Public Safety
460.575 - 460.625 Fire
460.650 - 460.875 Business - Airport use
460.900 - 461.000 Business - Central Alarms
461.025 - 462.175 Business
462.200 - 462.525 Manufacturers / Industry
462.550 - 462.725 GMRS (12.5 kHz steps)
462.750 - 462.925 Business (paging)
462.950 - 463.175 MED (Ambulance/Hospital)
463.200 - 465.000 Business
465.025 - 465.550 Police / Public Safety
465.575 - 465.625 Fire
465.650 - 465.875 Business - Airport use
465.900 - 466.000 Business - Central Alarms
466.025 - 467.175 Business
467.200 - 467.525 Manufacturers / Industry

467.550 - 467.725 GMRS   (25 kHz steps)
467.750 - 467.925 {Business (2w, telemetry)
467.750 - 467.825 {Maritime - shipboard (rptr at 457.xxx)
467.950 - 468.175 MED (Ambulance/Hospital)
468.200 - 469.975 Business

470 - 806 MHz: 6 MHz per channel, wide FM audio
470.000 - 512.000 {Broadcast TV, chs 14-20
{Large Metro Public Safety   (25 kHz steps - FM)
512.000 - 806.000 Broadcast TV, Chs 21-69

806 - 896 MHz: FM @ 25 kHz steps (mobile 806-851, base 851-896)
806.0125- 809.7375 General - conventional
809.7625- 810.9875 General - single channels
811.0125- 815.9875 General - trunked
816.0125- 820.9875 SMR - trunked
821.0125- 823.9875 Public Safety - trunked   (12.5 kHz steps)
824.040 - 834.360 Cellular Telephone   (30 kHz steps)
834.390 - 835.620 Cellular Telephone (data)   (30 kHz steps)
835.650 - 848.970 Cellular Telephone   (30 kHz steps)
849.000 - 851.000 Aircraft Telephone   (6 kHz steps - AM)
851.0125- 854.7375 General - conventional
854.7625- 855.9875 General - single channels
856.0125- 860.9875 General - trunked
861.0125- 865.9875 SMR - trunked
866.0125- 868.9875 Public Safety - trunked   (12.5 kHz steps)
869.040 - 879.360 Cellular Telephone   (30 kHz steps)
879.390 - 880.620 Cellular Telephone (data)   (30 kHz steps)
880.650 - 893.970 Cellular Telephone   (30 kHz steps)
894.000 - 896.000 Aircraft Telephone   (6 kHz steps - AM)

896 - 1300 MHz:
896.000 - 901.000 SMR/Business/Industry - mobile (12.5 kHz steps)
901.000 - 902.000 Personal Communications Services
902.000 - 928.000 Amateur (33cm)/ various secondary (ISM and license free)
928.000 - 929.000 Domestic public radio, wide area paging
929.000 - 930.000 paging
930.000 - 931.000 Personal Communications Services - base
931.000 - 935.000 Domestic public radio, common carrier paging, Govt. private
935.000 - 940.000 SMR/Business/Industry - base (12.5 kHz steps)
940.000 - 941.000 Personal Communications Services - base
941.000 - 960.000 Govt private, private microwave, common carrier, paging
960.000 -1215.000 Aeronautical navigation
1215.000 -1240.000 US Govt - Radiolocation / Space
1240.000 -1300.000 Amateur (23cm)