RFR: FADS AND FALLACIES

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INTRODUCTION

There is a great deal of misinformation afloat regarding RF safety issues around broadcast and other communications transmission facilities.

- Various false and misleading claims have been made by some consultants about the regulatory environment in order to garner business
- Incorrect measurement techniques are promoted and taught by some self-styled experts
- Some quasi-legal judgments have been made that are based upon measurement accuracies that are unobtainable - with citations claiming 4-digit accuracy when the best that can be reasonable achieved is 2-digit
- The computational methodology used for FCC applications cannot show all situations where the MPE limits may be exceeded
- There is a lack of general awareness of the factors that can cause large human RF exposure measurement errors

We know that excessive exposure to radio frequency (RF) fields can cause undesirable effects, but the weight of scientific evidence is that low-level fields appear to be harmless. (The terms Radio Frequency Radiation (RFR), Non-Ionizing Electromagnetic Radiation (NIER), and Electro-Magnetic Fields (EMF) have been used interchangeably to describe exposure to RF fields.) In the United States the Federal Communications Commission, which licenses non-government users of the spectrum, has been given authority by the US Congress to regulate most exposure to RF fields.

This paper addresses some of the misinformation by starting with a review of the necessary background information on RF safety. For further review of the subject an extensive bibliography is provided at the end of this paper.

RFR and the issues of safety when working near RF sources have been getting an increasing amount of press. Although the FCC has not fined a large number of licensees, some of its most recent enforcement actions can be considered landmark cases. These precedent-setting cases include:

- The first action involving personal injury to a tower climber
- The first action involving multiple licensees that collectively generated enough energy on the ground to exceed the FCC's Maximum Permissible Exposure (MPE) limits for General Population/Uncontrolled exposure
- The FCC's recent issuance of a Notice of Apparent Liability for Forfeiture (NAL) to a television station with a proposed fine of $25,000 after establishing a $10,000 fine as the standard for RF radiation violations. A separate NAL involving another licensee at the same site has a proposed fine of $20,000

These examples illustrate the three main reasons why there is a need to understand the safety issues of RFR:

- Personal safety: minimize the risk to all personnel including employees, contractors, and visitors
- Regulatory compliance: comply with all FCC, OSHA, and local regulations
- Liability: minimize liability risk

BIOLOGY OF RF EXPOSURE

Among the general public there is a still a great deal of confusion between ionizing vs. non-ionizing radiation. Ionization is a process by which electrons are removed from atoms. This can physically change the makeup of a compound. RF radiation is non-ionizing, as contrasted to the radiation that is associated with nuclear energy, which is ionizing. Non-ionizing radiation has insufficient energy to remove electrons from the atomic orbit. Non-ionizing radiation does not cause biological effects from ionization. The ability of an electromagnetic field to produce ionization is directly related to frequency and the photonic energy of an electromagnetic field. With all things being equal, the higher the frequency, the higher the photonic energy. Ionizing radiation produces molecular changes that can lead to damage in biological tissue. Those categories of electromagnetic radiation with enough energy to cause ionization damage to biological material include X-ray and gamma radiation.

From the beginning of the use of RF it has been observed that RF radiation can cause body tissue to heat. Absorption of electromagnetic energy causes electrical currents to flow in the semi-conducting material of exposed human flesh. Significant heating can occur when the currents rise above a threshold level. Excessive heating can lead to damage in biological tissue.

Research began in the 1950s, and by the 1970s the concept of Specific Absorption Rate (SAR) had been developed to explain and quantify how the human body absorbs RF energy. SAR is measured in Watts per kilogram of body mass (W/kg). At its simplest, the SAR is essentially a function of how efficient the human body is as an antenna. The major factors are frequency, height, polarization versus body orientation, and whether or not the body is grounded. A “standard” man is defined as an individual that is 1.75 meters tall (about 5 feet, 9 inches) and is resonant at about 85 MHz, providing that he is not grounded. Thus, a standard man makes a great Channel 6 television antenna! The average woman, who is somewhat shorter, makes a great FM radio antenna!

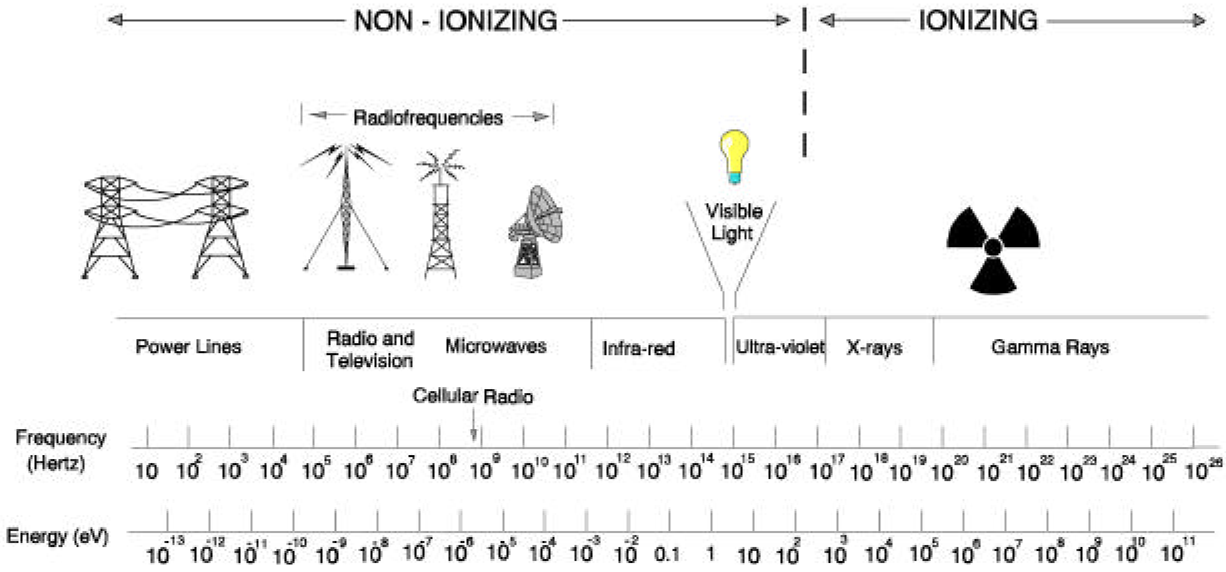
The other biological effects that are a concern and also have an impact on the standards and regulations are electro stimulation, shocks and burns. People who work around AM radio stations are usually quite familiar with this problem. Electro stimulation risks guide the standards below 100 kHz. SAR is the basis of all the major worldwide standards at higher frequency, but only up to the frequency at which surface absorption predominates and incident power density become the controlling factor.

Research on the biological effects of electromagnetic fields has been conducted for more than 50 years. There is a misconception in the general public that this is a new field of research that has only begun in earnest with the advent of cellular telephones. This is not the case. This field has been seriously studied and those studies have been reviewed by several national and international scientific organizations.

The Bioelectromagnetics Society (BEMS) was established in 1978 as an independent organization of biological and physical scientists, physicians, and engineers interested in the interactions of non-ionizing radiation with biological systems. BEMS is an international society with 540 individual members from approximately 38 different countries and regions around the world, and has published hundreds of research papers that address the biologic effects of electromagnetic fields. These effects include both thermal and non-thermal effects on biological organisms and have covered a wide range of frequencies and power levels. The best summary of this research and its application to human exposure standards is found in Supplement 6 of the BEMS Journal (see bibliography).

SCIENCE OF STANDARDS

Worldwide standards organizations, both governmental and industrial, have reviewed the published science to determine acceptable human exposure limits. In the United Sates there are two organizations that have produced RF exposure standards. The government chartered National Council on Radiation Protection and Measurements (NCRP) produced RF exposure recommendations in



1986 in NCRP Report No. 86, "Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields." The non-profit professional Institute of Electrical and Electronic Engineers (IEEE) first produced a standard in 1988. The most recently updated version of this standard is IEEE Std C95.1, 2006 Edition, "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz" (IEEE C95.1-2006). The IEEE Standards Board (BD) approved this standard on 3 October 2005.

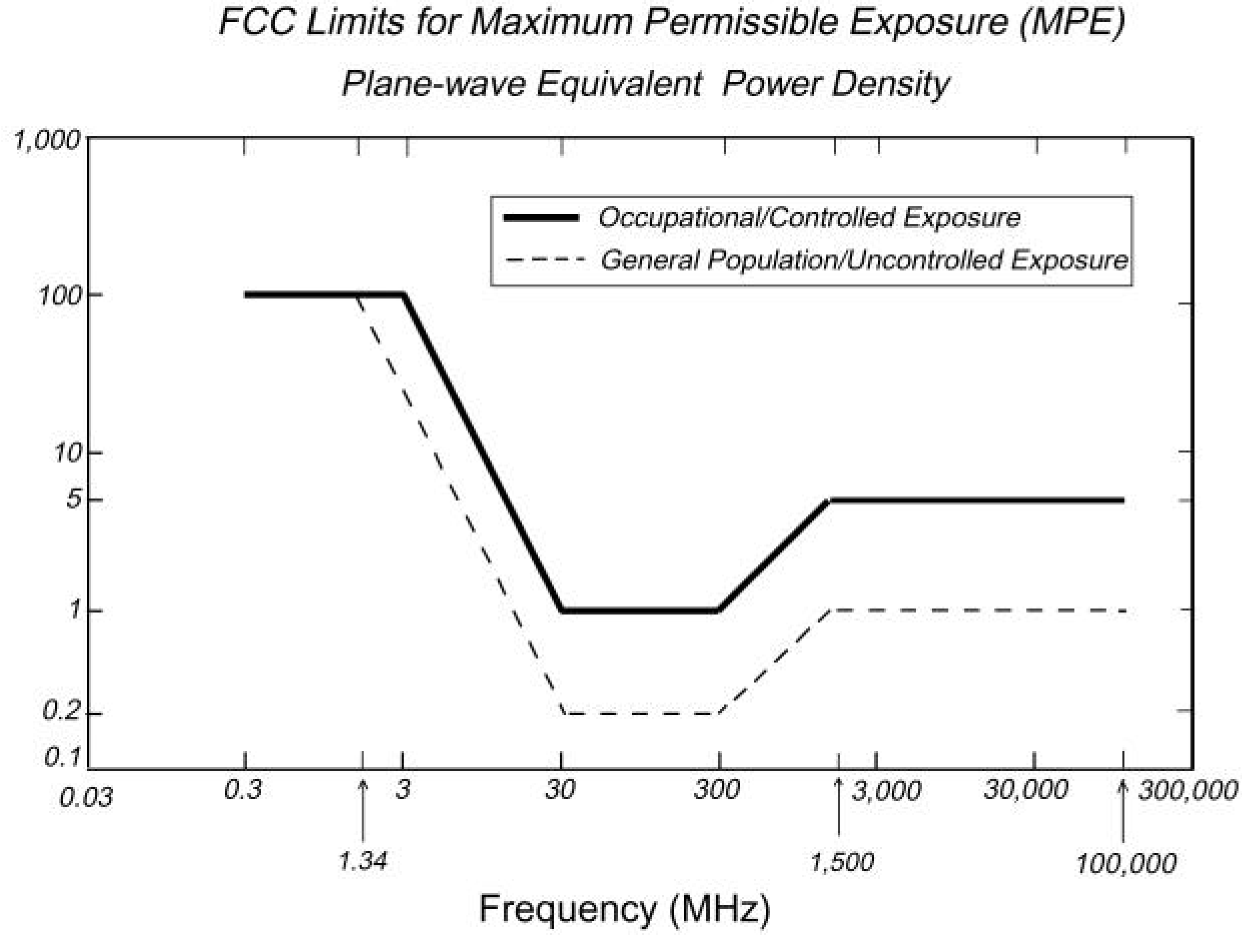
Internationally, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) produced "Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz)", 1998.

All of these groups set out to determine an acceptable level of RF exposure that would not cause any harm. The make-up of these groups typically includes members from a broad range of scientific fields, backgrounds, and points of view. These standards and guidelines represent a consensus of the broad expertise of those committee members and were based on a review of thousands of research reports in the scientific literature on human exposure to electromagnetic fields. All of the research documents were reviewed for engineering, biological, and statistical validity. From this, an exposure threshold was identified for unfavorable biological effects in humans. Allowable exposure was based on frequency effects of the body as a receiving antenna. It is important to observe that there are no verified reports of injury to humans or adverse effects on the health of humans who have been exposed to electromagnetic fields below the exposure limits of any of these standards.

REGULATORY REQUIREMENTS

Federal Communications Commission

In the Telecommunications Act of 1996, the U.S. Congress required the FCC to "prescribe and make effective rules regarding the environmental effects of radio frequency emission." This was a reaction to various local governments developing a hodgepodge of exposure standards—some based on science and others on politics. The FCC based its guidelines on the IEEE and NCRP standards. These were reviewed and modified for the FCC rules. The FCC regulation



discussion can be found in FCC Docket 93-62.

The FCC Regulations provide for two sets of Maximum Permissible Exposure (MPE) limits, one for Occupational/Controlled exposure and one for General Population/Uncontrolled (i.e. public) exposure. Public limits (uncontrolled environments) apply to "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" [those shown by the standards]. Occupational limits (controlled environments) apply to "exposure that may be incurred by persons who are aware of the potential for exposure as a concomitant of employment, exposure of other cognizant individuals, or exposure that is the incidental result of passage through areas where analysis shows the exposure levels may be above those (allowed for Uncontrolled Environments) but do not exceed the values" for Controlled Environments. The FCC does not, however, allow the use of time averaging to demonstrate compliance with the public MPE.

The MPE limits are frequency dependent, with the greatest restrictions occurring in the human resonance region, in which humans RF energy at the greatest rate, from 30 MHz to 300 MHz. The public limits are only one fifth of the occupational limits for all frequencies above 3 MHz.

As part of an RF safety program, qualified workers are allowed to enter controlled areas. Qualified workers, per the FCC Regulations, are those who are fully aware and able to exercise control. Fully aware workers have received both written and verbal instruction in the area of RF safety and are able to exercise control over their exposure, by using appropriate equipment such as RF personal monitors and RF protective garments. Thus, all the various tradespeople who might visit a rooftop RF environment—HVAC, elevator repair, window washer, building maintenance, and even some electronics types—would rarely be classified as fully aware and able to exercise control. If they have not been made fully aware of their potential RF exposure and able to exercise control of their exposure, then they cannot enter a controlled environment.

For this reason it is very difficult to control an entire roof, but fairly simple to control a tower. This distinction is important because it influences the types and locations of signs that should be used. There is an expectation that a company will have a program in place to manage these hazards. This means that there is a need for a written policy, and workers must receive some form of RF safety information or training.

Occupational Safety and Health Administration

RF exposure is also an issue for the Occupational Safety and Health Administration (OSHA), just like any other potential work-place hazard. To further complicate the situation, 23 states have their own Occupational Safety and Health standards and administer all of these regulations at the state level. All state standards are required to be as strict as the federal standards and most states use the federal standard as a starting point. Some states, however, have more restrictive standards than the federal OSHA, so it is prudent to research state and local requirements before accepting advice from an out-of-state safety consultant for any safety plans intended to fulfill any perceived OSHA requirements.

Federal OSHA does have an RF standard (albeit an obsolete one) in their regulations, and under its General Duty clause it uses scientifically based consensus standards. OSHA is on record as accepting either the FCC regulations or the IEEE standard. There are no specific useful OSHA rules on the subject of non-ionizing radiation, and OSHA does not mandate specific training requirements for workers who may be exposed to RF. There is some general language about training. However, training is only necessary if there are workers that will work in areas of RF exposure above the FCC public exposure limits. It is acceptable to have a policy of limiting contractors or other workers at a site to exposure levels below the FCC public exposure limit. In general, OSHA encourages organizations to develop and implement an RFR safety program.

Where there have been injuries, OSHA has issued violations under the General Duty Clause, Section 5(a)(1) of the Occupational Safety and Health Act, which requires the employer to provide a safe and healthful work place. Additional citations have been issued for failure to perform a hazard assessment to determine the necessary hazard avoidance or personal protective equipment requirements.

The obsolete OSHA exposure standard 29 CFR 1910.97, recommends exposure be limited to RF fields no higher than a power density limit of 10 mW/cm² from 10 MHz to 100 GHz. This exposure limit is twice as high as the highest FCC limit for occupational exposure and 50 times as high as the lowest FCC limit for public exposure. When two federal rules are in conflict the more stringent rule applies. Therefore the FCC guidelines have precedence over the OSHA guidelines. OSHA rules also specify the look of an RF warning sign, but this sign standard has become obsolete. The OSHA RF exposure standards are outdated and incomplete. All of the OSHA general safety requirements may or may not apply depending on the size of the company, and other listed exemptions.

Local Government

In the Telecommunications Act of 1996, the U.S. Congress required the FCC to "prescribe and make effective rules regarding the environmental effects of radio frequency emission." Included in this Act was a prohibition against state and local government from regulation of wireless facilities (typically cellular telephone base stations) based on the "environmental effect of RF emissions." Broadcasters are not a "Wireless Facility" under the definitions of this Act. Some local governments have regulated broadcasters' emissions of RF fields, setting emissions limits lower than the FCC guidelines and demanding additional measurements and reporting.

COMPLIANCE WITH REGULATIONS

Licensees have responsibilities and liabilities in several situations.

- As a licensee, regardless of where the emitter is located and whether it is your own property or a shared site
- As an employer
- As a company that hires contractors
- As a company that has visitors

In terms of compliance, licensees must:

- Comply with FCC Regulations for public areas
- Comply with FCC Regulations regarding employees and contractors
- Comply with OSHA Regulations regarding employees

In practice, doing the things described in the following paragraphs should satisfy all of these needs in a way that both makes sense and does not cost a fortune.

Achieving Compliance

To achieve compliance with regulations, minimize liability, and prevent overexposure, use this simple checklist as a guide.

- Determine the location of potential hazards
- Quantify the magnitude of RF fields on the ground and in other areas that are easily accessible
- Establish rules for access to areas where RF fields may exceed applicable MPEs
- Restrict access to towers and other areas with significant RF field levels
- Install appropriate RF safety signs and physical barriers
- Train your workers
- Document all of the above

Analysis of RF Sites

There are several ways to determine the magnitude of RF fields. These include calculations and measurements. The FCC has a list of categorically exempt facility types based on service, power level, and antenna location. While <u>all licensees</u> must comply with the RF exposure rules, there are some facilities that in their typical configuration are unlikely to produce fields that exceed the FCC guidelines. This is not the case with broadcast stations. All broadcast stations must certify that they do not produce RF fields that exceed the FCC guidelines in publicly accessible areas.

Calculating RF fields at ground levels at simple sites with a small number of antennas is a relatively straightforward process. Calculations using the FCC's methods are conservative, and if everything is clearly below the public MPE limits, you should be fine. There are a number of commercially available computer programs to model complex sites. The FCC has the program FM Model available on its web site for calculating the fields around FM sites. In FCC Bulletin OET-65 the FCC engineers have provided the information needed to model most RF emitters.

One noted exception for FM and TV sites is conducted fields in the tower guy wires. We have made measurements at a number of sites where the measured fields are much lower than the fields predicted by FM Model, except at locations around the guy wire anchors. This problem occurs when guy wires pass through the antenna aperture and produce fields in excess of the FCC MPE in the direct area around the guy wire anchors.

Other electromagnetic modeling programs such as moment method programs can also be used to calculate exposure. This is useful for calculating exposure in unusual situations that are not covered in OET-65. We have found this useful in sizing the fencing around complex AM sites. A few hours of calculations can save thousands of dollars in fencing.

Measurements

Measurements are typically used at complex sites and sites where calculations indicate there may be a problem. However, measurements have their own set of challenges and are not always that easy to make correctly. There is an old adage in engineering: "No one believes theory except the one that developed the theory. Everyone believes measurements except the one who made them." This is often the case when it comes to RF field level measurements. It can be difficult to obtain believable measurements at complex multi-user sites. Making measurements correctly is very important. Overly conservative measurements and excessively restrictive safety plans are a waste of resources and do not serve workers' or the employers' best interests. Hazard warning should be reserved for situations where there is a genuine hazard.

RF field level measurements will always have a significant amount of uncertainty, even when a skilled surveyor using the best available instruments makes the measurements. Measurement uncertainty has three major components:

- Measurement uncertainty due to the instrumentation
- Perturbation of the field by the surveyor
- Time and spatial variations in the field

Some of the common measurement problems that can occur with even the best equipment are false readings due to 60 Hz pickup, zero drift, and static pickup. Measurements below 30 MHz, and especially below 10 MHz, are particularly challenging and require special techniques due to the interaction of the survey equipment, the surveyor's body, and the electric field. Anyone who has ever made electric field strength measurements around an AM station knows how difficult it can be to get good results. Sometimes these measurement errors do not cause a problem. For example, we often see weak fields reported on the ground close to a tall broadcast tower when the reality is that the fields are below the measurement threshold of the instrument—the surveyor is simply reading zero drift. On the other hand, we have seen reports that state a rooftop environment is not in compliance when the field levels are actually negligible. In these cases the surveyor was getting false readings from the electric fields of a nearby 60 Hz distribution or transmission line or static from something like a nylon windbreaker.

The methods and techniques that are used to make measurements should vary with the situation. Remember, the goal is to determine whether there are any potential safety issues and whether a site or an area is in compliance with applicable regulations such as the FCC's. We suggest the following method.

Check large areas on the ground or roof by moving the probe about in three dimensions looking for peak field readings. If none of the readings exceeds 25% of the MPE limit for General Population/Uncontrolled exposure, make a couple of spatially averaged measurements and document accordingly. A report might state that the spatially averaged field levels in this area range from 15 to 25% of the MPE limit. Do not get carried away with trying to determine whether the number is 17% or 19.5%. First, no one really cares. Second, this implies a level of precision that is not possible to achieve. Each report should state an assessment of the field levels, but it is important that a section that discusses measurement uncertainty of the instrument also be included. In reality, measurement uncertainly is often driven more by the techniques used and the variable nature of the fields than by the instrumentation.

When spatial peaks exceeding the MPE limit are found, more care should be given in evaluating the fields in that particular area. We suggest making a minimum of four spatially averaged measurements. This normally means not only using spatial averaging as a function of height, but also taking into consideration the impact of body position on measurements.

Measurement Tools

These days most measurements of human RF exposure are made using instruments manufactured by either Holaday (ETS-Lindgren) or NARDA (some industrial and military users have other instrumentation). A major concern for making measurements at a multiple user antenna farm is the instrument response to multiple fields on different frequencies. What is needed is a true RMS response. If the diode detector is used in the square law portion of its operating characteristic, a reasonably accurate summation of the multiple (composite) fields will result. If not, large measurement errors can occur. The multiple frequency measurement problem is discussed in the appendix of the old Holaday instruments instruction manual.

Linear detection squares the signals after adding. If there are two signals of roughly equal intensity, E_1 and E_2, the desired summation is $(E_1)^2 + (E_2)^2$. The result obtained by squaring the signals after addition is $(E_1)^2 + 2(E_1)(E_2) + (E_2)^2$. The $2(E_1)(E_2)$ term results in a measurement error and can grow quite large as the number of signals increases. For this reason the most accurate measurements of RF fields using diode detection are provided by use of probes that utilize square law detection. Diode probe errors are also discussed in "Multiple-Source, Multiple Frequency Error of an Electric Field Meter" (Randa and Kanda).

At medium frequencies used for AM, the measurement problem is lead pickup. The cable connecting the probe to the meter will become a good antenna when it is aligned with the electric field. In many cases the readings will become totally unreliable because the probe and meter are at different electrical potentials and the instrument functions as a voltmeter. This effect can be overcome somewhat by holding the probe in the horizontal plane, and coiling up the cable when making electric field measurements around AM towers. Having the probe directly attached to the meter without using the cable at all will also help. Touching the metal meter case should also be avoided.

So-called “conformal” or “shaped” probes can be a great help when measurements are conducted at antenna farms where there are multiple antennas at multiple frequencies (i.e. FM and TV). These probes give a response in percent of the appropriate standard of the total field of all sources. One word of caution about shaped probes: Make sure that the probe conforms to the standard that you are using. For example shaped probes for magnetic fields that follow the IEEE C95.1 standard will give indications in the AM band 1/100 of the FCC MPE limits (1% meter indication is equal to 100% of the FCC MPE). This is due to the fact that the C95.1 limit for magnetic fields in the one megahertz region is 16 amperes per meter while the FCC limit is about 1.6 amperes per meter. The percent of standard indications of conformal meters is always derived from the equivalent power density or square of the field strength.

The frequencies of all emitters in the area to be measured must be ascertained before measurements are conducted. Many probes have spurious responses outside of the measurement range specified by the manufacturer.

Measurements in rain or snow are not recommended unless the meter and probe are kept dry. Abrupt temperature changes can induce large measurement errors when moving between environments with differing ambient temperatures unless you allow time for the instrument to acclimate to the new temperature.

Measurement Techniques

The accuracy of human exposure RF field measurements is affected by more than just errors associated with the instruments used to perform the measurements. Human electromagnetic exposure standards define the limits to such exposure in terms of plane wave equivalent power density (uniform field exposure). There is no practical way to assess, a priori, what the perturbed field exposure would be. Experiments have shown that in a mixed field (i.e. both FM and television) exposure situation, the influence of a two-meter person can cause the measured exposure to vary from 50% to 190% of the FCC MPE limits. At a site with a single FM antenna, the cumulative error resulting from the presence of two persons of differing height has been estimated to be about 25% of the measured power density.

Further, the human body absorbs much more of the energy of a field that is aligned with the long axis of the body. In practical terms this means that the vertically polarized field has a much greater impact on the energy absorbed by a person than does the horizontally polarized field. In the case of the detailed measurements performed on the single FM station, the power density from the vertically polarized field within about three meters of the antenna tower was 1% of the total isotropic measured power density. The horizontal power density was, on the other hand, 90% of the total isotropic power density. In addition, the body will only absorb about 10% of the horizontal plane power density.

Because the body interacts more strongly with RF fields polarized with the long axis of the body, it is common for significantly more field perturbation to occur for vertically polarized fields. Hence, the uncertainty associated with site measurements where the vertically polarized component predominates will be greater that when horizontal polarization is predominate.

The take-home message of the above is that people walking around the base of an FM tower only face a fraction of the exposure hazard that isotropic measurements may indicate.

Radio and Television Broadcast Antennas

The RF field levels from a TV or FM broadcast antenna are normally quite low at ground level and increase as a function of elevation above the ground with the maximum level occurring at an elevation of 8/4 above the ground due to phase addition of the incident and ground reflected fields. For FM stations, this means that the peak fields are roughly 2½ feet above the ground. The field intensity then drops off as the elevation is increased. The ratio of field strength from peak to null is typically 8:1 or greater.

Multiple signal environments, typical of many broadcast antenna farms, are far more complicated because of various wavelengths and the interactions that take place between fields near ground level. TV and radio are time varying signals and the field levels of NTSC TV signals can vary a great deal depending on what is being broadcast. Field levels in these environments vary dramatically in all three dimensions and as a function of time. Even spatially averaged measurements will not be totally repeatable.

Field levels also vary due to the interaction of the surveyor's body with the field. Even with these variables, spatially averaged measurements will be far more accurate and repeatable than making measurements based on looking for spatial peaks.

Spatially Averaged Measurements

All modern RF protection standards require that measurements of potentially hazardous RF exposure environments be made by spatially averaging the measurements. The standards are based upon whole body average exposure, and spatial averaging approximates this condition. The interpretations working group of IEEE C95.1-1991 issued an interpretation recommending spatial averaging some years ago.

Measurements should not be made too close to re-radiating objects as such fields do not accurately represent the potential human exposure. Contact current measurements, while not required by the FCC, are a better measure of potential exposure. In some cases guy wires associated with even relatively low power FM antennas can radiate fields exceeding the FCC public MPE limits.

The FCC approves and encourages spatially averaged measurements, but does not define how they should be made. The most common method uses a timing function in the instrument. When the probe is moved vertically at a uniform speed, the result can represent the average over the height of a person. A typical logging rate is 32 data points per second. A typical 10-second spatial average will, then, be based on more than 300 measurements.

The greater the nonuniformity of the field, the greater the variance that can be expected in field measurements. The fields at complex broadcast sites can vary dramatically in intensity over a distance of a few inches in any direction. It often requires more than four spatially averaged measurements in the same location to have the confidence that a reasonably accurate measurement has been made. And it is not just a matter of averaging the spatially averaged measurements. Experience teaches the surveyor to know which measurements should be repeated.

Assuming that the surveyor does not move his or her feet, the averages can vary because of a non-uniform rate of speed and/or because the probe is moved over a slightly different area. If field levels are highest at head height, a slight delay in stopping the measurement adds a disproportionate amount of energy from the highest field area to the average. Similarly, if the highest field levels are near the ground, a slight delay in starting to move the probe after pushing the start button can have similar results. Of course, the field levels often change between measurements, causing even more deviation.

If the surveyor moves his or her body and attempts to make spatial averages over the same point on the ground, one often sees very large differences in readings due to the influence of the surveyor's body on the measurements. In some cases, the body can block the energy from reaching the area being measured. In other cases, the probe may detect energy that is a combination of the incident fields and fields reflecting off of the surveyor's body.

One highly regarded expert in the field who has made thousands of spatially averaged measurements believes that it is very difficult to repeat the same measurement to within 5% even when the greatest care is taken.

Realistically, if a series of spatially averaged measurements are within 10% of the mean, the surveyor is being very careful.

If a spatially averaged measurement indicates that the field levels are close to the MPE limit, then it is necessary to make additional measurements to average out the effects of the surveyor's body on the measurements. The best way to do this is to perform spatially averaged measurements at one measurement point while standing at four positions. It is critical to make sure that all measurements are always made with the probe positioned over the same point on the ground. Although this concept may seem obvious, at least one organization has been teaching people to stand in one position and to simply rotate their body. Of course, this results in a series of measurements that are made over different points in a circle that is about six to eight feet in diameter (depending on the length of the surveyor's arm and the length of the probe).

Time Averaged Measurements

The FCC does not accept the use of time averaging for demonstrating compliance with the public MPE. For occupational exposure the areas where the exposure exceeds the MPE limits can be marked and signs installed indicating maximum time for a worker to remain in such areas. The time average is a running one-tenth hour average such that the average exposure for any six-minute period of time cannot exceed the MPE limit.

Measurement Uncertainty and Accuracy

Uncertainty and Equipment Design

Virtually all RF safety measurements are made with broadband instruments comprised of a probe and a meter. The accuracy of a survey instrument is almost entirely driven by the accuracy of the probe. Most probe specifications are expressed in dB. A parameter that has a 1.0 dB tolerance means the value could be off by 26% in terms of equivalent power density. In contrast, even a simple meter should be accurate to within 5%.

Probe frequency response is the most important instrument parameter that contributes to measurement uncertainty, but it is not the only parameter that should be considered. The FCC regulations and all of the major worldwide standards have exposure limits that vary as a function of frequency. The growth of wireless services and deployment of digital television have both led to a growing number of sites that have multiple emitters operating at frequencies with different MPE limits. This has led to the use of shaped-frequency response probes as the primary tools used for surveys of wireless and broadcast sites.

Shaped-frequency response probes are designed so that sensitivity varies over their frequency range. The goal is to match a standard, such as the FCC regulations, as closely as possible. NARDA Microwave holds the patent on this technology, which is similar to a filter. It is impossible to make the sensitivity match the MPE limits exactly. The greatest errors tend to occur at the transition points where the MPE limit changes from a constant to a slope or vice versa. In the FCC regulations for occupational/controlled exposure, these transition points occur at 3 MHz, 30 MHz, 300 MHz, and 1,500 MHz.

Defining Accuracy

The major component of measurement uncertainty for a probe is normally its accuracy as a function of frequency. The NARDA Safety Test Solutions Model A8742D probe is calibrated at 14 different frequencies with a specification that the frequency response error does not exceed ±2 dB. Other parameters, such as ellipse ratio and isotropic response, are less significant than frequency deviation, but cannot be ignored. A good rule of thumb when making measurements in multi-signal environments with this type of equipment is to assume an uncertainty of ±3 dB.

The ±3 dB figure for measurement uncertainty is only applicable for the NARDA 8700 series shaped-frequency response probes. The other brand of shaped-frequency response probes is also supplied by NARDA Safety Solutions. The Type 25 FCC-shaped probe is used with the EMR series of meters. This probe does not have a guaranteed maximum frequency response error. Most of these probes have been sold with only a single-calibration frequency at 100 MHz.

If measurements are made where there is only a single emitter or where all emitter frequencies are very close to each other, as is the case at a site with only one service, a correction factor can be used to reduce the amount of measurement uncertainty. This normally reduces overall measurement uncertainty from the instrumentation to about ±1 dB. The use of correction factors is less accurate when one attempts to interpolate between two calibration frequencies near the transition regions of the probe.

Measured Compliance and Site Characterization

Enforcement of FCC RF radiation regulations began about four years ago. However, we have serious reservations about both the instrumentation and the techniques used for certain measurements in complex situations.

There are at least two instances where the instrumentation used to determine compliance appears to have been calibrated so that it reads inaccurately high. In at least two other cases, multiple frequency contributions were “sorted out” by powering down individual stations which were small contributors and subtracting one large imprecise number from large imprecise number to get a small number, whose inaccuracy was therefore much larger than its magnitude. This is a basic numerical analysis error, in violation of the methods taught in applied mathematics classes.

Another problem is the definition of a “remote area not likely to be visited by the public.” Such sites should be fenced if possible, but where fencing is not “feasible,” the FCC’s own directives do not absolutely require it.

WHAT THE MEASUREMENTS CAN TELL US

Despite the difficulty of measurements, they can tell us a lot. According to the FCC, measurements remain the ultimate test of a site’s compliance with the exposure guideline. Measurements carried out beyond two decimal places suggest an accuracy of measurement that is not possible with the instrumentation and the methods available. The purpose of measurements is to place the site in one of the following categories.

- Below the public MPE limits

- Above the public MPE limits but below the controlled MPE limits
- Above the occupational (Controlled) MPE limits but at a level where a time limit exposure is acceptable (e.g. 200% of the controlled MPE gives a exposure time limit of three minutes)
- Above the range of the meter

HAZARD REDUCTION

The goal of all of these regulations is to prevent the exposure to any person unaware of their potential exposure to RF fields that exceed the public MPE. All energized AM tower bases are required to be fenced. In populated areas, all areas that exceed the public MPE must have a physical barrier to limit access. In many situations the most practical way to control exposure is to fence the site.

This is not always practical. The FCC recognized this is OET 65:

> *Restricting access is usually the simplest means of controlling exposure to areas where high RF levels may be present. Methods of doing this include fencing and posting such areas or locking out unauthorized persons in areas, such as rooftop locations, where this is practical. There may be situations where RF levels may exceed the MPE limits for the general public in remote areas, such as mountain tops, that could conceivably be accessible but are not likely to be visited by the public. In such cases, common sense should dictate how compliance is to be achieved. If the area of concern is properly marked by appropriate warning signs, fencing or the erection of other permanent barriers may not be necessary.*

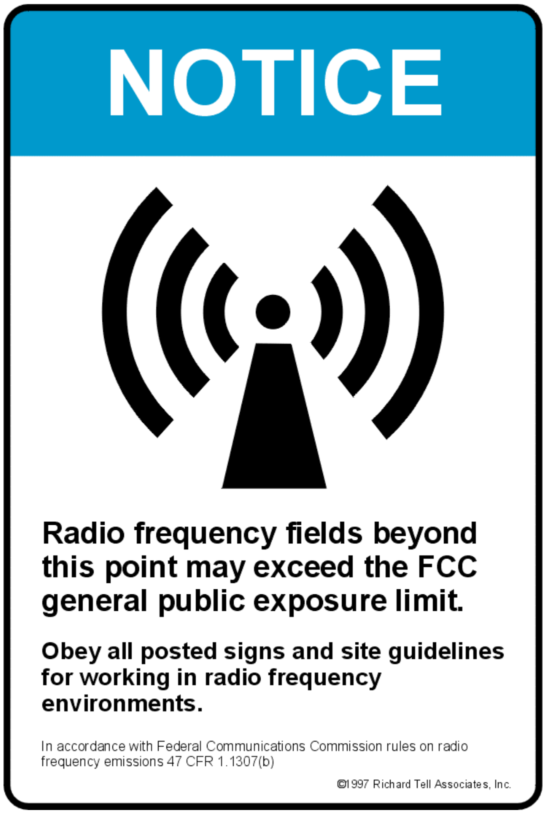
Fences are wholly impractical in areas where the snow depth destroys the fabric on fences due to the freezing of large chunks of snow and ice on the fence fabric. Experience has shown that fencing at sites like this lasts, at best, only two seasons. While fencing a remote mountain top site can be done, it represents a great deal of cost and requires continued maintenance. Signs remain the only practical method of access control at these types of locations.

There is an expectation that a larger company will have a program in place to manage these hazards. This means that there is a need for a written safety policy, a training program, and task-specific procedures. There are no regulatory mandated requirements regarding training certification, class time, or frequency of training. The training program should be commensurate with the exposure hazards encountered in the workplace and should be repeated as necessary to keep all workers informed of the hazards.

Co-operation among all users at a multi-user site is very important. Site management must work with users to coordinate work in hazardous areas. If there are areas at the site where the exposure is in excess of the FCC public guidelines, the site must have a site-specific safety plan. It is also important for all users to speak with one voice as to the status of the site. We know of sites where some of the users classify it as a public site and other users classify it as a controlled site.

SIGNS

Installing the correct RF safety signs is an important aspect of achieving compliance, reducing liability exposure, and reducing risk to personnel. At first glance it seems to be simple. Just install a few signs around the site and everybody will be fine. Unfortunately, this appears to be the prevailing attitude at many of the broadcast and wireless sites that we visit to conduct RF safety surveys.



The purpose of RF safety signs is to communicate useful information. If you install the wrong sign or even the correct sign in the wrong location, the message will be wrong. In addition, if you install signs and do not control access in accordance with the information contained on the sign, you have inadvertently communicated something else—that the signs are meaningless.

We have observed warning signs at many low power antenna installations, usually wireless telecommunications antenna sites, that are categorically excluded from conducting a routine FCC environmental assessment. In many cases, these signs are misleading to the public and contribute to the prevailing “urban myth” that cell sites (cellular telephone base stations) are somehow hazardous to the health of the general public. This excess of caution results from an unwillingness to determine if there is an actual FCC compliance issue.

The three most common signs that we use relate to RF field levels. The message panel of these NOTICE, CAUTION, and WARNING signs all start with “Beyond this point: Radio frequency fields at this site…” with the remainder of each message declaring a different field level. It is important to know and understand the differences:

NOTICE …may exceed the FCC general public exposure limit.

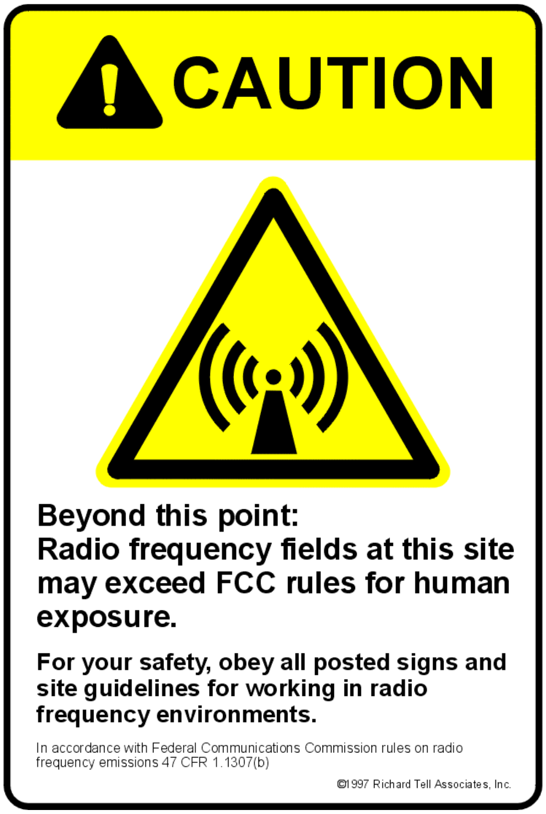
CAUTION …may exceed FCC rules for human exposure.

WARNING …exceeds FCC rules for human exposure.

Perhaps the sign that we recommend most often is one that we refer to as a “Tower CAUTION” sign. The message panel on this sign states “On this tower: Radio frequency fields near some antennas may exceed FCC rules for human exposure.” Other commonly used RF safety signs warn of the burn hazard from touching a hot AM tower or hot guy wires.

The NOTICE sign described above states that the field levels in areas beyond the sign may exceed the public limits, while the CAUTION sign states that the field levels may exceed the limits for human exposure. The limits for human exposure refer to the FCC’s MPE limits for Occupational/Controlled exposure. The WARNING sign states that the field levels exceed the limits for human exposure.

Used correctly, the blue NOTICE signs should identify all areas where the RF field levels may exceed the public limits, but are below the human or occupational limits. Officially, only qualified workers should be allowed past this point, although this is a gray area. Many treat the NOTICE sign as a pre-warning.



A yellow CAUTION sign is meant to identify an area that has RF field levels that generally exceed the public limits with a few isolated hot spots that exceed the human or occupational limits. Only qualified workers—workers who are fully aware and able to exercise control—should be allowed to enter these areas.

Used correctly, an orange WARNING sign identifies areas where the RF field levels definitely exceed the human or occupational limits. One should never enter such areas without shutting systems off and/or reducing power, and having equipment such as an RF personal monitor to verify that the field levels have been reduced below the human exposure limits.

AM radio sites present two potential dangers and are a sore spot with FCC inspectors. AM sites should have both RF field level signs and DANGER signs that warn of the serious potential for RF burns should one contact the tower or feed line.

SAFETY PLANS AND DOCUMENTATION

The FCC requires an RF Safety Plan for sites that have RF exposure that exceeds the public MPE. In its simplest form, a safety plan must cover the following items:

- Contact information for all licensees at the site
- Hazard identification (e.g., location of areas that exceed the Controlled MPE)
- Hazard training information (what to shut off, what personal protection equipment to use, where not to go, etc.)
- Sign-in logs for visitors

Safety plans may be quite involved at complex sites where there are auxiliary and main antennas.

For license renewal, the FCC wants to have certification from all licensees that they meet the RFR rules. This is a checklist and certification that does not require any documentation to be filed with the FCC. By this point in time all licensees should have given this subject some consideration. Licensees should have in their files some proof that they have considered this subject. The worksheets in Form 303 are sufficient to show this. For complex sites or sites that exceed the public MPE, a measurement report or site safety plan is also sufficient to demonstrate that the licensee has controls for RFR. The IEEE has published a Recommended Practice for RF Safety Programs - C95.7-2006 that was approved 22 September 2005.

WARNING

Beyond this point:
Radio frequency fields at this site exceed the FCC rules for human exposure.

Failure to obey all posted signs and site guidelines for working in radio frequency environments could result in serious injury.

In accordance with Federal Communications Commission rules on radio frequency emissions 47 CFR 1.1307(b)

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CONCLUSION

While protection from excessive RF fields is an important consideration, we have to keep ourselves grounded in the underlying physics of the problem. Excessive and inept applications of these rules do not serve the licensee or protect the general public. Enforcement actions should be at the places where there is a clear disregard for the rules and not at sites where there are only perceived marginal infractions subject to measurement errors.

All site users need to speak with one voice as to the RF exposure conditions at the site. The FCC cannot have two different stories as to whether the site is publicly accessible or a controlled site. Some recent enforcement actions have been a result of one licensee who thought the site was classified as a public site calling in the FCC Enforcement Bureau on another set of licensees who had represented the site as a controlled environment. Better site management and communications could have saved a great deal of ill will, time, and money.

Excessively conservative measurement does not serve the licensees or protect the general public. We are aware of practitioners in this field that use peak measurement and refuse to use spatial averaging despite the clear direction from the FCC and IEEE on this subject. This is bad engineering practice and it does not serve the client to have them spend $100,000 on a fence on a remote mountain top when $10,000 will meet the need.

To overcome common myths about the human RF exposure environment and how to handle it, a careful study of the source documents is recommended. Herein we have attempted an overview of these materials. The FCC, IEEE International Committee on Electromagnetic Safety (ICES) and NCRP documentation is very informative on these issues.

There are many voices in the wilderness on this subject. It is always best to get answers from those closest to the sources of the science and regulation regarding exposure to RF energy, and avoid those who would rather make money by scaring you than solving your real problems.

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