This issue, *AGL* focuses on **site services**, particularly *monitoring, maintenance* and *construction*. Site construction safety is an ever-increasing concern as tower buildouts proliferate, so we present *(page 32)* the experienced views of **Winton W. Wilcox Jr.,** founder and president of ComTrain, Monroe, WI. Winton brings a detailed knowledge of tower climbing and teaching credentials together for the communications industry. He is an accredited junior-college instructor in both California and Wisconsin. A graduate of the Carolina School of Broadcasting and the University of Nevada–Reno, Winton holds a BS in managerial science with minors in math, history and philosophy. Before founding ComTrain, he served as division manager of Cable Data, vice president for Parallex and president of Broadcast Communication Systems. Winton is the author of *Tower Climbing Safety & Rescue* and numerous magazine articles featured in *Mobile Radio Technology, Electrical Contracting & Engineering News* and *Fire & Rescue*. He has also served as an expert witness for OSHA and has testified in numerous accident litigations.

Continuing with tower-erection safety, our contributors to "Law of Physics" *(page 29),* **David G. Sarvadi** and **Jeremy W. Brewer,** of the Washington-based law firm Keller and Heckman, address the ramifications of North Carolina labor regulations for our industry. **David** *(far left)* works with clients in the areas of occupational health and safety, and employment law. He is a member of the District of Columbia and Virginia Bars and holds a BS from Pennsylvania State University, an MS from the University of Pittsburgh Graduate School of Public Health and a JD from George Mason University. **Jeremy** *(near left)* also practices employment law and occupational safety and health law. He advises clients on workplace safety matters, including representing clients facing federal and state OSHA citations. Jeremy is a member of the Virginia State Bar, the District of Columbia Bar and the American Bar Association. He holds a BA from Denison University and a JD from American University's Washington College of Law.

Observations on how the FCC is handling implementation of the National Programmatic Agreement affecting siting on tribal lands come from **Connie Durcsak** of PCIA *(page 12; PCIA will host a seminar on the subject in March, see page 13).* Connie is the wireless infrastructure association's senior director of government and industry affairs. She directs the association's public-policy programs at the national, state and local levels. Connie also oversees PCIA's frequency coordination services. Before joining PCIA, Connie served as a principal consultant with PricewaterhouseCoopers. She holds a BA and a BEd from Acadia University and an MA in business from Marymount University.

The name is **Strickland—*Richard* Strickland.** We're having some good-natured fun with our "field agent" cover story this issue *(page 20)* to draw attention to one of Richard's pet peeves: RF field-level measurements have a significant amount of uncertainty, even when made by a skilled surveyor with the best instruments. Regulating sites on the basis of faulty survey techniques is not good for the industry, and it undermines confidence in the regulators. Richard's Long Island-based company, RF Safety Solutions, advises companies and government agencies on potential RF safety hazards and safe RF environments. His previous appearance in *AGL* was to discuss RF safety signage *(October/November 2005)*, and in the near future he'll tackle questions concerning personal protection equipment for working in RF fields.

Former editorial collaborators and industry experts round out this issue. Some may be new to you. "Klondike State"-based **Donald Koehler** discusses improving network operating center and monitoring operations *(page 38)*. Don has over 30 years' systems maintenance experience in communications equipment for RF-, satellite- and wireline-based environments. He also has supported field operations in overseas locations, such as Korea and the Komi Republic. Don served as a network operations manager for a major Alaskan telecommunications provider and is now involved in the computer-support industry. For borrowing advice, check out **Jarred Saba's** new "Capital Ideas" column *(page 18)*. For a case file on carrier collocation with public-safety agencies, see Massachussetts **Detective John P. Hebb's** siting story *(page 42)*. agl

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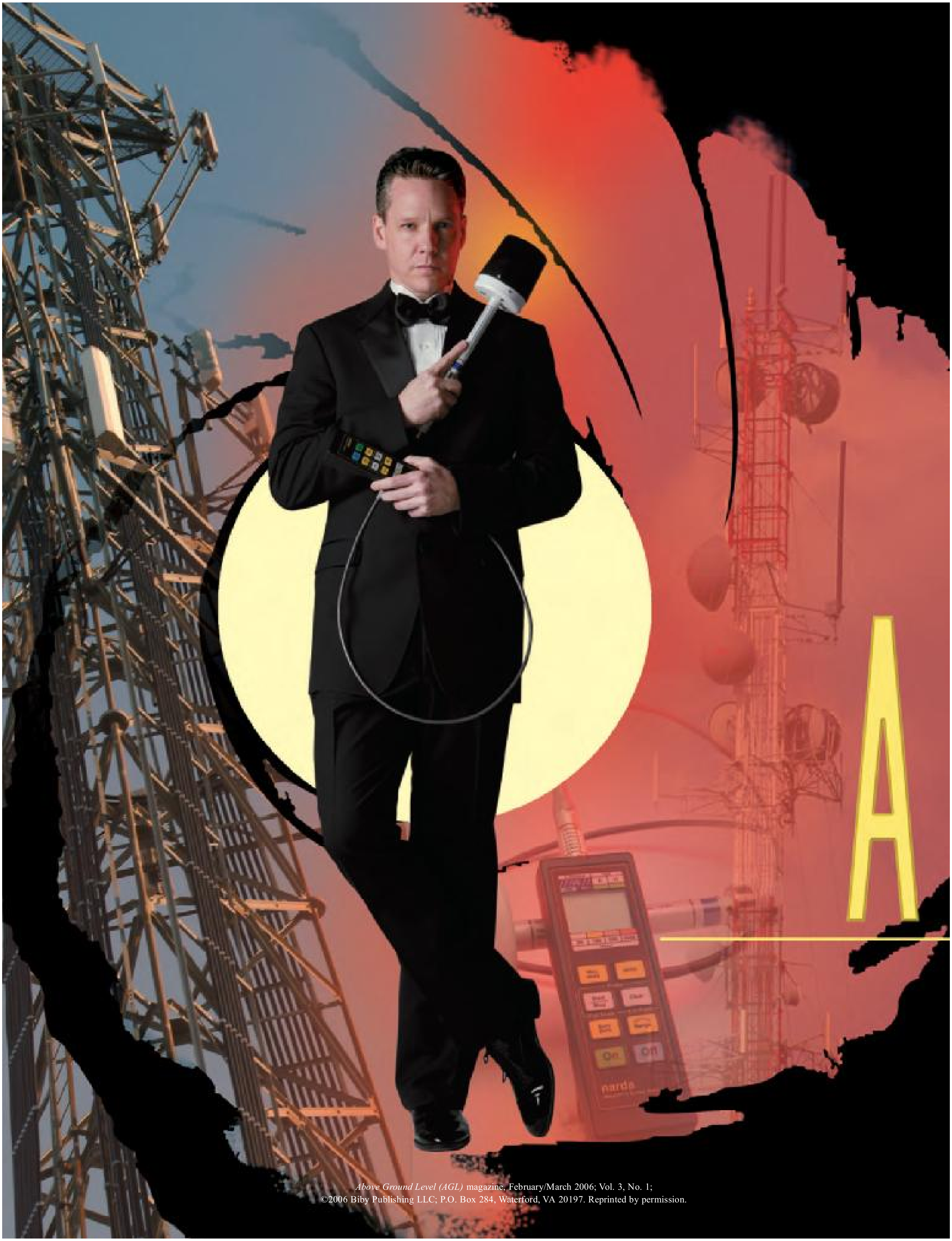

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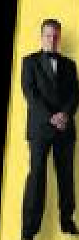
RF field surveying missions yield misleading results if proper equipment calibration and procedures are not followed. Even **government agents** with a ‘license to NAL’ make mistakes. Spatially averaged measurements provide a more reliable **reconnaissance** of the target.

VIEW TO A ‘NAL’



by Richard Strickland

Art and design by Scott Dolash; photography by Thomas Gibson;
RF test equipment courtesy of Narda Safety Test Solutions.

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A View to a 'NAL'

RF field measurements are taken to reveal any potential safety threats and whether a site, or an area, complies with applicable regulations. People often ask me, "Is it easy to measure RF fields?" The difficulty, or complexity, of the task depends on *what* is being measured, the *level* of precision required, the survey *equipment* being used, and the knowledge and skills of the *person* making the measurements.

I have taught technicians to check for leaks in waveguide transmission lines and taught industrial hygienists and maintenance workers—with no electronics background—to check for leaks around semiconductor processing equipment. In both cases, the task is relatively simple: find the leak and get it fixed. No great precision is needed. On the other hand, I have looked at results from surveys at sites where I have worked and known immediately that the surveyor misinterpreted what he saw.

Equipment briefing from 'Q Branch'

My friend Edward E. Aslan (principal engineer at Narda Microwave and an IEEE Fellow) once wrote a scholarly paper on measurement artifacts. Because Aslan holds more than 90 percent of the worldwide patents for the design of RF survey instruments, he knows what he is talking about. I took much of what I learned from Aslan and taught a course for professional engineers, through the National Association of Broadcasters, that explained some of the odd survey results that many of them had seen and could not explain. These measurement artifacts are a combination of equipment-design issues and interactions between the RF field, the instrument and the surveyor.

RF field-level measurements always have uncertainty, even when made by a skilled surveyor using the best available instrument. 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 common measurement problems encountered even with the best equipment are false readings caused by 60 Hz pickup, zero drift and static pickup. Measurements below 30 MHz (and especially below 10 MHz), are particularly challenging. They require special techniques to compensate for the interaction of the survey equipment, the surveyor's body and the electrical field. Anyone who has ever made measurements around an AM station knows how difficult it can be to get good results.

Sometimes, these measurement errors don't pose a problem. For example, I often see modest 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, I have seen reports that a rooftop environment was not in compliance, yet actual field levels were negligible. The surveyor was getting false readings from 60 Hz pickup or static from something like a nylon windbreaker. Of course, if you are inspecting for the FCC and you make such mistakes, it can cause problems.

Obtaining reliable intelligence

The methods and techniques used to make measurements should vary with the situation. I first check large areas on the ground or roof by moving the probe position in the three spatial dimensions, looking for peak field readings. If none exceeds 25 percent of the FCC's maximum permissible exposure (MPE) limit for general population/uncontrolled exposure, I make a couple of spatially averaged measurements and document them accordingly.

My report might state that the spatially averaged field levels in this area ranged from 15 to 25 percent of the MPE limit. I don't get carried away trying to determine whether the averaged level is 17 percent or 19.5 percent. First, no one really *cares*. Second, to do so implies a level of precision that is impossible to achieve. Each of my reports states my assessment of the field levels but also includes an advisory section that discusses measurement uncertainty of the instrument. (Actually, measurement uncertainly is more often a function of the techniques used and the variable nature of the fields than of the capabilities of the instrument.)

When you do find spatial peaks that exceed the MPE limit, you have to be more careful in evaluating the fields in that particular area. I make a minimum of three spatially averaged measurements. If all three measurements vary no more than 10 percent, and none shows field levels that exceed the limit, I average the three. If I see more than about a 10 percent variation among the three readings, I keep making measurements until I am satisfied that I have obtained consistent, repeatable readings.

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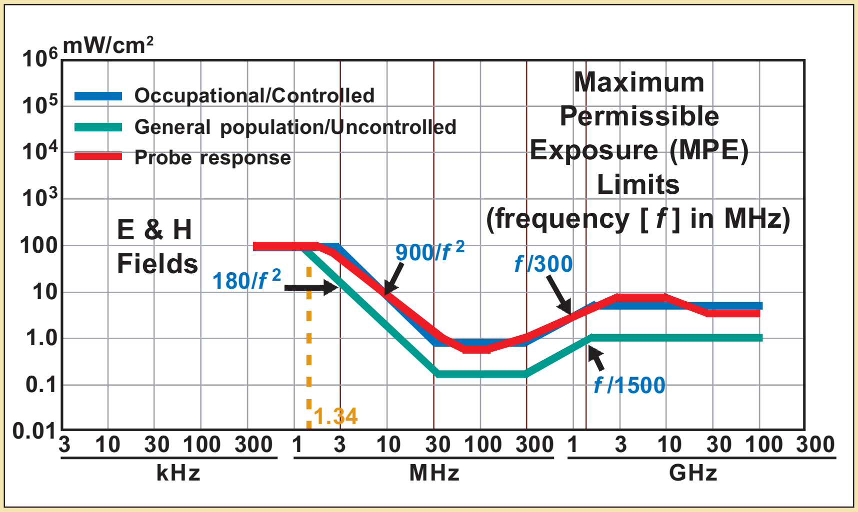
If the readings indicate that the area has levels that exceed the MPE limit by a small amount, and classifying the area in this way would affect operations, I try to further refine the measurement. For example, if I initially got a reading of 110 percent in a small area that nonqualified personnel frequent, I would take the time to see if more precise techniques might yield a number below 100 percent. This normally means not only using spatial averaging as a function of height but also taking into consideration the effect of body position on measurements.

Distinguishing friend from foe

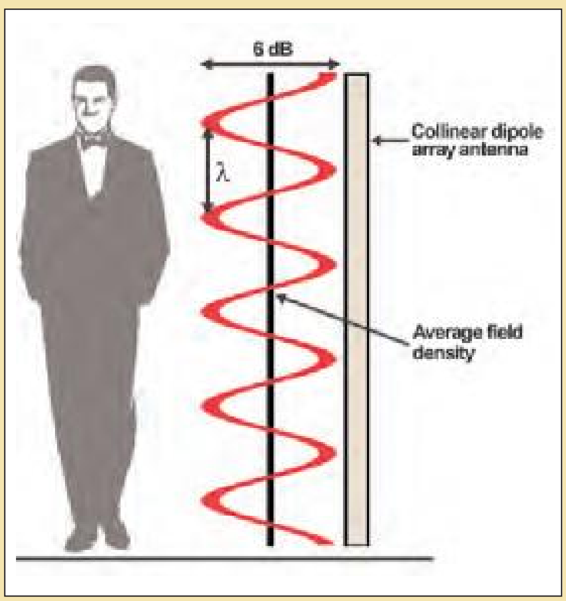
Virtually all RF safety measurements are made with broadband instruments—a probe and a meter. The accuracy of a survey instrument is almost entirely determined by the accuracy of the probe. Most probe specifications are expressed in decibels (dB). A parameter that has a 1.0 dB tolerance means the value could be off by 26 percent. By contrast, even a simple meter should be accurate to within five percent.

Frequency deviation is the most important characteristic that contributes to measurement uncertainty, but it is not the only one to consider. FCC regulations, and all major worldwide standards, have exposure limits that vary as a function of frequency. The growth of wireless services and the deployment of digital television have 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 at the point of detection varies over 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. *(See graph at left.)*



The red line shows the typical frequency response of a Narda 8700 series shaped frequency-response probe, compared to the 1997 FCC regulations. Note that the greatest deviations from the FCC MPE limits occur at the transition points. The design of the tuning circuits causes the response to 'round' at these points. These probes include calibration frequencies at or near each of the transition points.



Standards for human exposure to RF radiation specify MPE levels averaged over the whole body. Collinear dipole antenna arrays commonly used in wireless communications have multiple lobes close to the antenna. Field strength typically varies by 6 dB along the length of an array. Therefore, the measured value depends not only on the distance from the antenna but also on the height above ground level.

Calibrating your sights for action

As previously mentioned, the major component of measurement uncertainty for a probe is normally its frequency deviation. The Narda Safety Test Solutions Model A8742D probe I use is calibrated at 14 frequencies to guarantee that the frequency deviation—error vs. frequency—is a maximum of ±2 dB. Other characteristics, such as ellipse ratio and isotropic response, are less significant than frequency deviation but they cannot be ignored. *A good rule of thumb when making measurements in multisignal 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. These probes are tested at multiple frequencies and have a guaranteed maximum deviation of ±2 dB over their entire frequency band. 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: 100 MHz.

If measurements are made where there is only a single emitter or where all emitter frequencies are close to each other, as in the case of a site with only cellular 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.

A miss is as good as a mile

Spatial averaging is an important technique that reduces the amount of measurement uncertainty when assessing an RF environment. This technique is important for both wireless and broadcast systems.

Most wireless systems antennas are collinear dipole arrays. These antennas are made up of a series of radiating elements that are normally spaced one wavelength apart. A common measurement requirement is to determine the strength of the RF fields on a rooftop near one or more of these antennas. Even if there is only a single antenna to consider, and its output power is held constant, it is possible to obtain field-level measurements that vary by as much as 6 dB above exactly the same point on a rooftop. *(See the diagram on page 24.)* This is because there is roughly a 6 dB, or 4:1, ratio between each peak and null of the electric field. Because the radiating elements are spaced one wavelength apart, the vertical distance between peak and null is only half a wavelength. If an "X" is marked on the roof, and two measurements are made directly above that point, a difference of about six inches in height can yield readings that vary by as much as 6 dB at cellular and paging frequencies. At PCS frequencies, the vertical distance between peak and null is about three inches. This variance can occur when both measurements are in line with the antenna and is independent of a partial-body-exposure scenario. In contrast, spatially averaged measurements will be far more consistent.

A difference of about six inches in height can yield readings that vary by as much as 6 dB.

Knowing the lay of the land

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 ground level, with the maximum level occurring at an elevation of one quarter-wavelength above ground level. For FM stations, this means that the peak fields are roughly 2½ feet above the ground. The field intensity then drops off as elevation increases. The ratio of field strength, from peak to null, is typically 8:1 or greater.

Multisignal environments, typical of the many broadcast antenna farms, are far

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more complicated because of various wavelengths and the interactions that take place between fields near ground level. *Field levels in these environments vary dramatically in all three dimensions and as functions 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.*

Double-O accuracy/'double trouble'

The FCC stepped up enforcement of its RF radiation regulations about four years ago. Unfortunately, the agency has been making measurements with instrumentation that typically overestimates field levels by about 2:1 and has also been using an inaccurate, indefensible deferential approach to determine compliance at antenna farms.

The FCC purchased several sets of survey equipment and trained its inspectors in Denver in the spring of 2003. Shortly thereafter, I surveyed a small broadcast site on a mountaintop outside of Denver. This was a simple site, with one high-power TV station antenna and two low-power station antennas on a single tower. On arrival, I told the chief engineer that I was going to start on the high side of the site outside of the enclosure, as I thought that was where we might find the highest field levels. He then told me that the FCC had been there a few days earlier and that they had found a "hot spot" in exactly that area. I then made several spatially averaged measurements in the area and found an average field level of only 55 to 60 percent of the public MPE limit.

I checked with the FCC to determine *why* they were going to require the high-power station to lower its power (until some RF safety "NOTICE" signs were installed), and found that they had measured field levels of about 120 percent. This bothered me—why should our two sets of readings vary by *a factor of two* at such a simple site? The FCC even confirmed that virtually all the energy was from the high-power station by making the station shut down. I had my probe personally checked by Narda's Ed Aslan, and was assured that my equipment was accurate to within about three percent at that station's frequency.

About four months later, I did a survey at the big antenna farm on Mt. Wilson, outside of Los Angeles. One of the workers showed me the spray-painted spot on the ground that the FCC had recently marked as having the "highest field levels on the mountain." *[This inspection was discussed in "What You Should Know About MPE," in the June/July 2005 issue of AGL—Editor.]* I made a couple of quick checks in this small area and measured only about 80 to 90 percent of the public MPE limit. I didn't do more, as I was there for other reasons.

About a month later, the FCC issued a *Notice of Apparent Liability for Forfeiture (NAL)* to three FM stations and one TV station for jointly exceeding the public limit in this area, an area justifiably deemed public since access was not restricted. The *NAL* stated that the field

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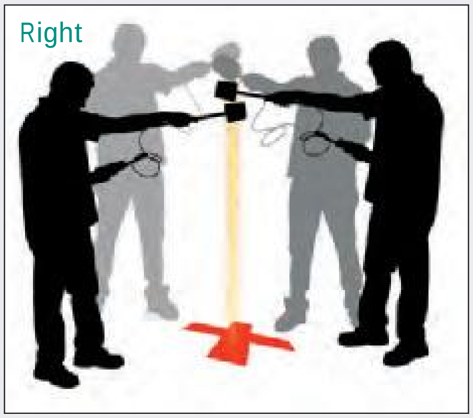
Proper Surveillance Techniques

The FCC approves and encourages spatially averaged measurements, but it 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 rate of speed, you get an average over the height of a person. A typical logging rate is 32 data points per second. A typical 10-second spatial average will be based on more than 300 measurements.

The more nonuniform the field levels are, the greater the variance that can be expected. The fields at multiple-emitter broadcast sites can vary dramatically in intensity over a distance of a few inches *in any direction*. It often requires at least five spatially averaged measurements in the same location to have the confidence that a reasonably accurate measurement has been made. It is not just a matter of averaging the spatially averaged measurements. Experience teaches the surveyor to know which measurements should be *ignored*.



Assuming that the surveyor does not move his or her feet, the averages can vary because of a nonuniform 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 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 actual fields and of additional energy reflecting off the surveyor's own body.

One highly regarded expert in the field who has made thousands of spatially averaged measurements believes that it is difficult to repeat the same measurement to within five percent, even when the greatest care is taken. This assumes that:

- the surveyor does not move and attempts to measure the exact same spot.
- nothing changes in the fields that are being measured.

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

If a series of spatially averaged measurements made with the surveyor in one position indicates that the field levels are close to the MPE limit, then it is necessary to take additional measurements to average out the effects of the surveyor's body on the measurements. The best way to do this is to perform four or five spatially averaged measurements while standing in one position, and then repeat the procedure in a minimum of three other 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 erroneously 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).

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level in this area of noncompliance measured “160.5 percent” of the public MPE limit. Imagine that: *four-digit* measurement accuracy. It was also about *double* what I had measured. The FCC claimed that one FM station had field levels of about 80 percent of the MPE limit; the other three stations had field levels between 10 and 12 percent. The other 18 stations partially illuminating the spot were deemed to have field levels below 10 percent. The *NAL* claimed that the FCC used 10 percent, rather than the 5 percent specified in its regulations, to allow for measurement uncertainty.

I did some digging and checked into the instrumentation that the inspectors were using. Yes, the FCC had paid to get multiple-frequency calibration performed on their Type 25 probes. But unfortunately, the survey sets did not have the frequency deviation *centered,* as with the equipment that I use. A review of the calibration data clearly shows that all the FCC instrumentation reads 3–4 dB *high* throughout the broadcast band—i.e., at least *double.*

The other big problem is the FCC inspectors’ methodology. They did make numerous spatially averaged measurements to arrive at the “160.5 percent” average. But to determine which stations were significant contributors, while minimizing downtime, they used a fundamentally flawed technique. They made two spatially averaged measurements with each station powered down, one at a time. They determined each station’s contribution by subtracting the average of these two readings from the baseline of 160.5 percent. Although this method is fine for the FM station that was contributing about half the energy, it is virtually useless when trying to quantify the small contributions of the other stations.

In essence, the FCC determined each station’s contribution by subtracting a large, imprecise number from another large, imprecise number to calculate a small number.

At a site like Mt. Wilson, the next measurement could easily vary by 10 percent *without shutting any station off.* Calculations were made for one of the stations cited at Mt. Wilson using the FCC-recommended formula. These calculations are normally accepted by the FCC because they are conservative—calculating the field levels at two meters above the ground. This calculation showed field levels of about *one quarter* of what the FCC cited.

‘License renewed—or revoked?

As late as December 2005, FCC inspectors were using the same bizarre method at a big antenna farm in Boise, Idaho where there are more than 30 stations contributing to the field.

Where does it stop?

Accurately measuring RF fields depends on methodology, equipment calibration and a skills base. Without a proper combination of these factors, misinterpretations will defeat the purposes of establishing RF safety and ensuring regulatory compliance. agl

Strickland is president of RF Safety Solutions, South Setauket, NY. His email address is: RStrick@RFSafetySolutions.com.

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