'Shaken' *and* 'Stirred'

In *A View to a NAL* (AGL, February/March 2006 Vol. 3, No.1), Richard Strickland highlights a number of important factors that relate to the resulting quality of RF field measurements performed for assessing compliance with FCC regulations on human exposure. While Richard correctly points out the various sources of potential error that can creep in during the measurement process, my experience over the years supports the very significant impact that field perturbations by the operator can have on proper interpretation of results. This is especially the case at antenna sites with FM broadcasting present. In many cases, the extent to which the body perturbs (scatters and reflects) the field being measured can exceed, by far, all of the other uncertainties combined. Interestingly, it is this very fundamental interaction that most experts, let alone others, often do not understand or appreciate. And this lack of understanding can play a significant role in conclusions that are drawn about antenna site compliance.

A common example of what I am describing occurs when multiple "experts" reach different conclusions about RF field measurements taken at the very same place, often with the very same equipment. This can happen because the individuals performing the measurements do not recognize that the very RF fields they are measuring can be significantly changed from the so-called unperturbed condition. In practice, this means that as soon as the observer occupies the region wherein the field is to be measured, the field is no longer what it was in their absence. Further, simply depending on the orientation of the observer's body relative to the RF field measurement point, the indicated field value can be very different. In some cases, this difference can be the difference between compliance and noncompliance with FCC maximum permissible exposure (MPE) limits. Further, the result you get when measuring the field can be substantially influenced by your own physical size, let alone your orientation relative to the measurement point!

It is important to note that the MPE limits adopted by the FCC are based on a presumption of exposure to a plane electromagnetic wave that is uniform over the body dimensions. Of course, the real world of RF exposure is far from uniform. Presently, the FCC rules are in terms of determining the spatially averaged value of plane wave equivalent power density over the body. This spatial averaging technique tends to provide a value of the exposure field that more accurately relates to the whole body average specific absorption rate (SAR), the basic restriction of the regulations, than any single value of the field along the body axis.

The degree to which the presence of the observer can modify the field being measured depends on both frequency (i.e., how well the field interacts with the body), polarization of the fields, and body dimensions of the person performing the survey. Since the adult body resonance frequency is approximately 70-80 MHz, RF fields in the VHF band tend to interact more strongly with the body than other fields, much like the performance of a resonant dipole antenna. Secondly, when the polarization of the field is aligned with the principal body axis, generally vertical when performing measurements, the reflected and scattered fields will be more significant. For example, when performing measurements of FM broadcast band fields, especially when there is a significant vertical polarization component, one will observe more field-body interaction. So, how significant can this interaction be?

Measurements performed by myself on the roof of the World Trade Center (WTC) towers in New York in 1999 provide an interesting insight to this question. During one such study, broadband field measurements were made along the elevated walkway of the south tower approximately 300 feet adjacent to the broadcast antenna mast located on the north tower. At each measurement point, spatially averaged fields were measured from eight different directions spaced 45 degrees apart but, in each case, facing the measurement point. Each spatial average was acquired during an approximate 10-12 second vertical movement of the probe (a Narda Model B8742D) using the built-in spatial averaging feature of the meter (a Narda Model 8718). The purpose of the many measurements was to assess the impact of the measurement process itself on the resulting values.

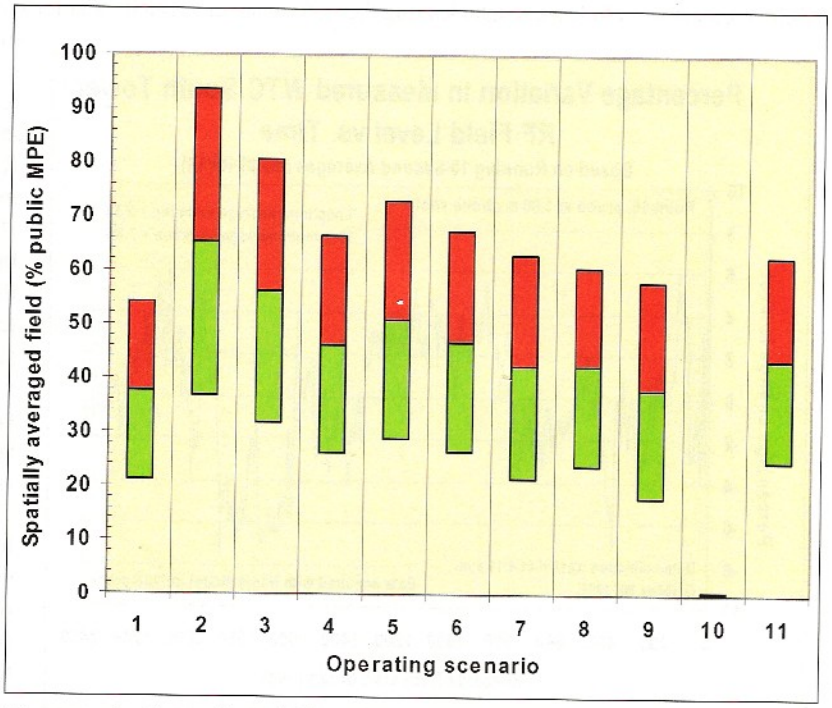
The spatially averaged values of fields were analyzed statistically by calculating the mean value of each set of eight measurements and the standard deviation of the values. Figure 1 illustrates representative data obtained at one of the many measurement points where the junction of the red and green bars represents the mean and the extents of the red and green bars represent one standard deviation of the measured values.

The different bars represent different operational scenarios used during the study to evaluate RF fields. For example, scenario 1 represented normal broadcast operations, scenario 2 represented the tower maintenance mode of operation, etc. As a point of interest, scenario 10 was the case of normal broadcasting but with all FM broadcast stations shut down. This illustrates the significant contribution of FM emissions to the total field at that particular point which included many TV station signals operating with very high effective radiated powers.

Figure 1 also points out some very interesting characteristics of the measured fields. Namely, the answer you get can depend largely on just how you stand to make the measurements. For scenario 2, as an example, the one sigma range of spatially averaged field is 36.8% to 93.6% of the FCC general public MPE with the best estimate of the unperturbed spatially averaged value being 65.2%. Put a different way, the percentage standard deviation in the eight measured values was ± 43.6%. For all of the measurements in the study, the measurements exhibited percentage standard deviations ranging from nominally 8% to 49%; the overall average of the deviations expressed as a percentage, based on over 1400 spatial averages acquired over the entire walkway, was 35%.

Additional insight to the variability associated with RF field measurements is evident from Table 1. This table illustrates the relatively wide dynamic range of spatially averaged values. It also provides information about the repeatability of the measurement process. In columns 2 and 3, the spatially averaged values are seen to range from 12.2% of the MPE when standing in one orientation to as much as 62.3% when standing in a different orientation. This is a factor of 5.1 times! Hence, it is easy to see why multiple "experts" could come to rather different conclusions if they do not adequately qualify their measurement data. The factor of 5 difference between spatially averaged values was when the same person using the same equipment was used in every measurement. With different people performing the measurements at different times with different equipment, the expectation would be for potentially even greater differences. Of course, generally, most persons performing field measurements will change their orientation, often times trying to find the greatest reading that they can. In other cases, individuals may work hard to find just the right orientation that results in a value that is the lowest. In either case, the approach is incorrect. Rather, the goal should be to obtain the best estimate of the unperturbed field and this is generally accomplished by taking multiple readings of spatial averages and calculating the grand average of all the spatially averaged values. By averaging all of the values, one is averaging out the perturbing influence of the body on the fields being measured. Performing the same measurements, as shown in columns 4 and 5, at the same location, spatially averaged values range from a low of 19.8% to a high of 63.7% of the MPE, a factor of 3.2 times in this case. These two sets of measurements yield a percentage difference of 10.7%, even though they were taken immediately sequentially in time.

The last two columns show measurement data obtained when the author allowed his assistant, six inches shorter in height, to perform the series of eight spatial averages at the same location. In this case, the mean value was 27.7% compared to the means of 33.6% and 37.4% obtained by the author. The

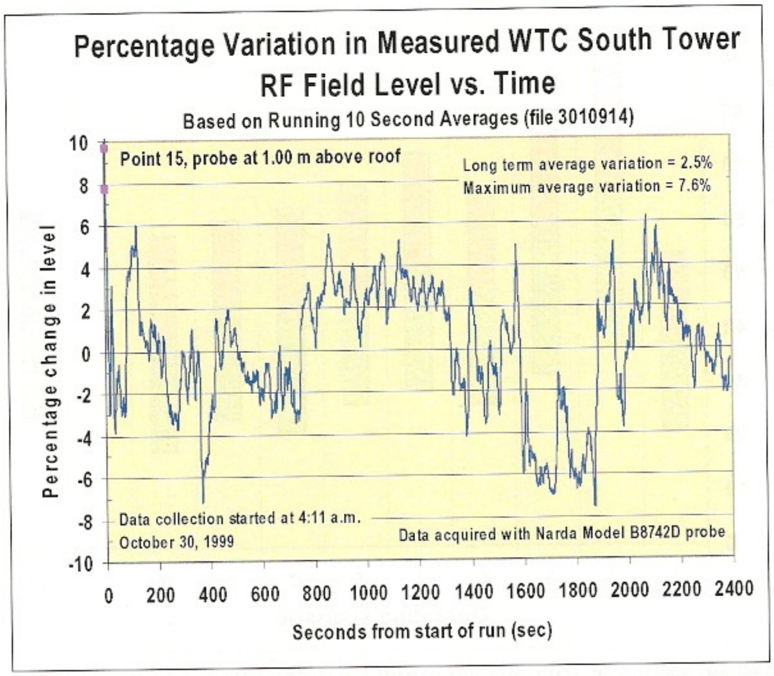


Measured values of spatially averaged RF fields relative to the FCC MPE for public exposure.

Table 1. Summary of repeated measurements by the author and an assistant at one location on the WTC south tower walkway.

Measurement trial	Author first time		Author second time		Assistant first time	
	Spatial average %MPE	Spatial maximum %MPE	Spatial average %MPE	Spatial maximum %MPE	Spatial average %MPE	Spatial maximum %MPE
1	62.3	136.0	63.7	90.6	43.5	53.4
2	44.3	99.7	57.9	73.9	33.7	39.5
3	30.0	64.1	44.6	58.2	28.5	38.2
4	13.2	23.6	32.1	46.7	15.5	19.1
5	12.2	26.3	22.3	39.4	17.0	30.3
6	23.8	45.5	19.8	26.0	20.5	39.5
7	35.8	67.8	26.8	32.7	29.0	47.4
8	47.3	100.0	32.3	47.0	34.0	47.8
Mean	**33.6**	**70.4**	**37.4**	**51.8**	**27.7**	**39.4**
Maximum/minimum ratio	5.1	5.8	3.2	3.5	2.8	2.8
Percentage standard deviation	51.7	55.9	43.6	41.7	34.6	27.6

assistant's result is different from the author's by 19.2% or 29.8%, depending on which measurement is taken for comparison. This finding points to the fact that when a high degree of exactness is required in RF field measurements at real world sites, the size of the individual can affect the recorded results, let alone differences in measurement technique or instrumentation.



Measured variation in composite RF field level during a 40 minute measurement session with field probe stationary.

No one can perfectly repeat field measurements taken at real world antenna sites. There will always be a degree of variability, even when trying to maintain precisely the same posture during the measurement process. Table 2 summarizes the results of performing eight successive measurements of the spatial average field at a single point while retaining, as close as possible, the very same orientation and body posture relative to the point.

An important observation from Table 2 is that the measurement of spatially averaged field values, in this case, contained an inherent variability of about 5%. These results illustrate why one must use care when declaring the significance of a field measurement used to indicate compliance or noncompliance with the FCC RF rules on exposure. If the results of a field measurement reported to exceed the MPE do not exceed the MPE by at least the measurement repeatability, they should be considered suspect. More desirable is the inclusion of measurement data that support some statistical claim as to the repeatability and stability of the various measurements so that the reader of the report can draw a clear conclusion on the interpretation of the results. Too many times, RF survey reports do not include such data, leaving the statements in the report without technical support other than the word of the author. The simple inclusion of the results of making a series of, say, 10 repeated measures of the spatially averaged field at some reference point at the site, along with the mean and standard deviation of the values, goes a long way toward qualifying your data.

Table 2. Assessment of repeatability of RF field spatial average measurements. All measurements taken with the same body orientation relative to the measurement point.

Measurement trial	Spatial average percent of MPE	Spatial maximum percent of MPE
1	65.6	95.8
2	64.0	91.0
3	58.7	81.3
4	59.6	78.9
5	60.2	87.7
6	57.4	80.8
7	58.6	84.1
8	58.4	84.7
Overall average	60.3	85.5
Maximum/minimum ratio	1.1	1.1
Percentage standard deviation	4.8	6.7

A final word is in order addressing the issue of temporal variability of the RF fields being measured during typical RF surveys. In most cases that I am aware of, rarely does the author of an RF survey report provide any information about the stability of the RF fields being measured. Such variations only add to the challenge of arriving at solid measurement results. If FM broadcasting is the only source of RF at a site, this becomes much less of an issue. However, if analog TV broadcasting is present, there will be an inherent temporal variation in the signal levels due to the video programming of various stations. Pulling again from my past experiences at the World Trade Center, Figure 2 illustrates the variation in combined RF fields (FM plus TV broadcast) at a point on the walkway of the south tower.

The data in Figure 2 were acquired by positioning a broadband field probe on a dielectric (non-conductive) stand at 1 meter above the walkway and recording meter readings at a rate of 1 per second for a continuous session lasting 40 minutes. This represented a total of 2400 readings. The data were transferred to a computer and analyzed by calculating the running 10-second average of all the data points, exclusive of the first and last minutes since the operator had to remove himself from the measurement area and this presence caused field disturbance seen by the probe. Figure 2 shows that the long term, 10-second average was only about 2.5% but the maximum 10-second average deviated from the long-term average by about 7.6%. These values were determined by comparing each 10-second average to the mean of all the data for the observation period (exclusive of the first and last minutes). The significance of these data is that your resulting field measurement, when analog TV signals are present, will be influenced by the time variability in the composite RF field, independent of any other factors such as field perturbations discussed above. When the field can vary by 7-8% during the typical time it takes to make a spatial average measurement, this becomes another factor in why performing highly accurate measurements, for example when compliance at a site is on the line, can be problematic.

In summary, the above data help support the contention of Strickland that when it comes to making close calls on compliance, great care is needed to be sure that you have adequately examined all of the relevant factors that can influence your final interpretation. Beyond instrumentation characteristics, be on the lookout for how much you screw up the field you are measuring and keep in mind the possibility that the fields are varying in time. As they say, the devil is in the details.

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A successful mission

It is satisfying to see an article appear in the technical press that is based upon the experience common to practitioners in the field of RF exposure surveys. There is a great deal of misunderstanding regarding the art of making RF exposure measurements. Richard Stricklands vast knowledge of the measurement technology sheds a great deal of light upon this obscure area. Having been a witness to some of the measurement circumstances that he describes I can only say "Amen, Brother" and hope that, as knowledge spreads, good measurement practice will overcome some of the ignorant claims and shoddy measurement practice I have been employed to correct over the years.

Jim Hatfield
Hatfield & Dawson

'On the Industry's Special Service'

Hats off to AGL magazine for your consistently excellent coverage of RF safety issues. As an RF PPE supplier, we're often surprised at the lack of coverage afforded by many publications on this important aspect of antenna site safety. Despite the issuance of FCC OET Bulletin 65 over eight years ago, RF compliance topics are still routinely pushed aside in favor of traditional industry issues such as fall protection.

A perfect example of your benefit to readers is Richard Strickland's fine article on RF measurements (Feb/Mar). He addresses precisely what field personnel and site managers need to know, and presents comprehensive information with a real world perspective that folks in the field can quickly and safely utilize in their work and planning.

Keep up the good work, AGL; you've fast become a must read for the industry.

Sincerely,
Steve Hofstatter
UniTech Services Group
Charlotte, NC

'Timely' and 'intuitive'

AGL has the most timely information for tower owners, renters and wireless installers. Since your magazine's inception, we have been amazed how the authors of the AGL magazine's articles answer the questions we and our bankers are asking about this industry, potential, financing, growth and speculation. You cannot imagine how much effect your intuitive news has on our tower service and tower ownership/rental decisions. We feel as though we should owe you for what we would have otherwise have paid several consultants to ascertain this seemingly inside trend information. Thanks again for your informative help and keep us on your mailing list, we bank on it.

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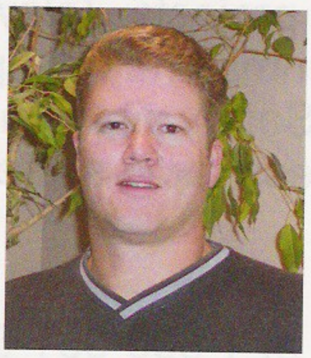
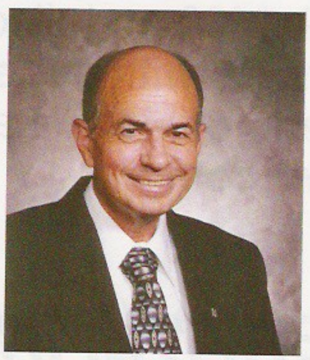
Before we get into this issue of *AGL,* there are some "closing-overs" left to discuss about last issue's lead feature, "A View to a NAL," by Richard Strickland. We direct your attention to our expanded Letters section, beginning on page 56, where several industry RF specialists weigh in supporting Richards's conclusions and expanding on his points about RF exposure measurements. Correspondent **Ric Tell,** of Richard Tell Associates (pictured at right), offers a detailed continuance of that topic. Ric has been involved with the topic of RF hazards for more than 35 years, in the public sector for EPA and in the private sector as an RF consultant. He chairs the Risk Evaluation Working Group of Subcommittee 4, which is revising the IEEE standard for RF exposure.

As noted on our cover, several articles this issue relate to grounding and lightning protection for sites as well as backup power. **George M. Kauffman, P.E.,** focuses on coaxial lightning protection beginning on page 42. Vice president of engineering for NexTek, Westford, MA, for the past five years, George has overseen development of new lightning-arrestor and dc power-conditioning products. He has a BS in mechanical engineering and an MS in engineering management from the University of Massachusetts—Amherst.



The ins-and-outs of single-point grounding are discussed by **William O'Keefe** of PolyPhaser, Minden, NV, beginning on page 46. Don't let the fact that Wil is the marketing manager for PolyPhaser fool you. He has a range of professional experience in RF communications and industrial electronics gained as an RF communications specialist in the Air Force and as a motion-control engineer. Wil received his BS in business and is an MBA candidate at the University of Nevada, Reno.



We never tire of pointing out contributions from **Harold Kinley** because he is a joy to know and he's in-the-know. Hal served for many years managing the communications systems and sites for the South Carolina Forestry Commission, and he now serves as an radio communications consultant based in Spartanburg, SC. On page 18, he concludes his two-part discussion of antenna arrays with a description of phasing principles.