Measuring RF Levels At Multi-signal Sites

The FCC's new rules concerning acceptable levels of RF emissions require new measurement techniques and RMS detection to ensure compliance in complex multitransmitter signal environments.

Anguish is a familiar response to FCC rulings, and industry concerns were in ample supply when the FCC issued its guidelines for human exposure to RF emissions back on Aug. 1, 1996. The release was first greeted with silence and then with a cacophony of comments ranging from general acceptance to disagreement with specific elements of the guidelines.

That is not surprising, considering the difficulty that today's multi-emitter transmission sites present to accurate RF emissions measurements. Multiple emitters dramatically complicate the measurement process, and it is quite easy to make measurements that appear accurate but are, in fact, quite the opposite. However, the shaped response probe, when used with an accurate RF radiation measuring instrument, provides true RMS detection and allows the operator to quickly determine compliance with FCC radiation exposure standards.

A COMPLEX SITUATION

The human body is a thermal entity that responds proportionally to RMS energy levels. The major human exposure standards used throughout the world, such as IEEE C95.1-1991 and National Council on Radiation Protection (NCRP) Report 86, are based on controlling the RMS level of exposure an individual receives. This level is averaged over the whole body during a period of time, typically six minutes. The FCC originally planned to adopt the IEEE standard but essentially adopted the NCRP standard instead.

The instruments used to make these measurements increasingly rely on digital circuitry, relegating the RF (analog) portion of the measurement only to the probe. Both in appearance and ease of use, these instruments are a vast improvement over their analog predecessors. However, it is easy to assume that because they display values in digits rather than with an analog meter, they are fundamentally more accurate.

In practice, the digital display portion of the instrument is the smallest contributor to measurement uncertainty. Performance of the probe, which is the signal gathering portion of the instrument, is the true determinant of overall accuracy. As a result, the probe is the most crucial part of an RF radiation measurement system, and its characteristics have more impact on data quality than any other element. The probe's importance becomes even more crucial when employed in dense signal environments.

The fact that data gathering must be conducted in the field at sites where there are other transmitting systems besides the one to be measured compounds measurement difficulties. The emitters may also operate at different frequencies, invoking more than one level of acceptable exposure as defined by today's frequency-dependent standards. The person making the measurement must accurately determine the contribution of the individual signals, total the energy from all emitters, and weigh the resulting information according to its relevance to the standard. If there are many emitters, this can take a long time.

The antennas for these systems are usually located within a stone's throw of each other. Without the ability to discriminate among signals, it is almost impossible to determine the radiation level of a specific emitter. In addition, diode detectors that have often been used for electric and magnetic field measurements in the broadcast industry have characteristics that make their accuracy questionable in these applications.

THE NEED FOR TRUE RMS DETECTION

The easiest way to design a probe to measure electric field intensity in the broadcast and communications bands below 3 GHz is to use simple diode detectors coupled to a dipole antenna. Most instrument manufacturers use three sets of detectors to build an isotropic, or omnidirectional, field probe. The measurement practices standard, IEEE C95.3 1991, requires that measurements be made independent of polarization, preferably with isotropic probes.

A peculiar characteristic of diode detectors used in isotropic probes is that they can become linear, or rather, stop functioning as an RMS detector, at high input levels as shown in Figure 1. Some manufacturers of RF radiation measurement systems use squaring circuits to compensate for the diode operating in the linear region.

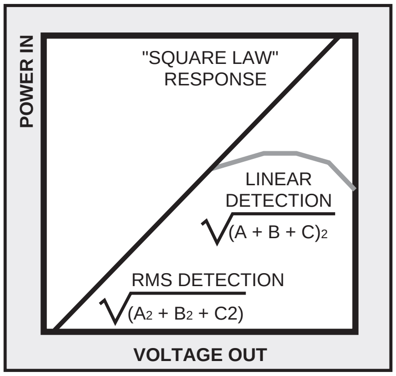


Figure 1. RMS vs. Linear Detection

This design approach can greatly overestimate actual field strength in multisignal environments. The greater the number of emitters, the greater the error. This error is typically 1 dB to 2 dB when there are two or three emitters; however, when many emitters are present (an increasingly common occurrence), these probes can indicate field strengths as much as 10 dB greater than are actually present. This is especially true when the signals are of the same magnitude.

The implication of such gross errors is significant:

The cost of correcting the phantom problem can be high.

Implementing operational limits is at the least undesirable, and at worst unacceptable.

. It is possible to believe that a given transmitter is out of compliance when it is not

It is essential, therefore, that the measurement system have the ability to make true RMS measurements. Narda probes use a patented technique in which the diode detectors are always kept in the square law region without the use of squaring circuits. This design is referred to as compensated diode detection.

FREQUENCY-DEPENDENT STANDARDS

An accurate RMS measurement of the total emissions level, with all emitters operating at maximum power, provides an accurate quantitative value but may not yield the answer to the most important question: whether the level is compliant with a given exposure standard. This problem occurs because maximum permissible exposure (MPE) limits in the major standards vary by 20 dB over the communications bands as shown in Figure 2.

If the measured value is below the most restrictive level, which normally occurs in the 30 MHz to 300 MHz band, a true RMS measurement from a conventional “flat response” probe will provide all the required information; however, if the measured value is greater than this limit, the site or area may still be compliant, depending on the relative contributions from signals outside this human resonance region. It depends on how much energy is contributed by each emitter.

For example, a site with AM, FM, and UHF pager signals simultaneously broadcast may produce a level of 5 mW/cm^2 in the instrument. Assuming a relatively small portion of the energy is from the FM antenna, and most of the energy is contributed by the AM antenna, then the overall value of 5 mW/cm^2 may still be in compliance, even though the limit for 30 MHz to 300 MHz is typically only 1 mW/cm^2.

This effect is demonstrated by comparing the signal levels shown in Figures 2 and 3. In each figure, a total power of 5 mW/cm^2 was measured, but Figure 2 shows a level of 71% of the standard, while Figure 3 shows 169% percent of the standard.

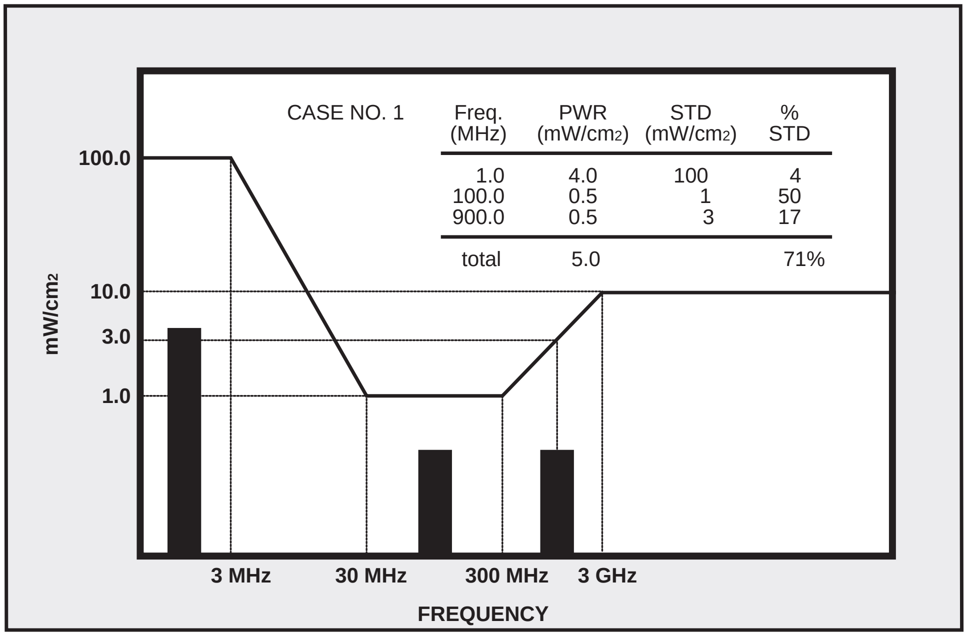
But how can the portion of the energy produced by each emitter be determined? Traditionally, there have been two solutions to this problem. The first is to turn off all of the emitters except one and make measurements of each emitter; however, cost constrictions have forced engineers to abandon Sunday night maintenance sessions conducted when traffic is light, so selectively turning off emitters becomes less of an option. In addition, today’s competitive communications marketplace makes complete emitter shutdowns intolerable at any time.

The second solution involves making measurements with narrowband instruments, and while effective, this solution takes a long time to perform. Every emitter must be measured at every location, and directional antennas must often be used, so at every location three measurements must be made at all frequencies of interest and then summed. Even then, measurement uncertainty can be as high as 6 dB. As a result, this technique is rarely used.

SHAPED PROBES

The introduction of shaped frequency response probes reduces the chance for error in making RF radiation measurements in multisignal environments, and simplifies the measurement procedure.

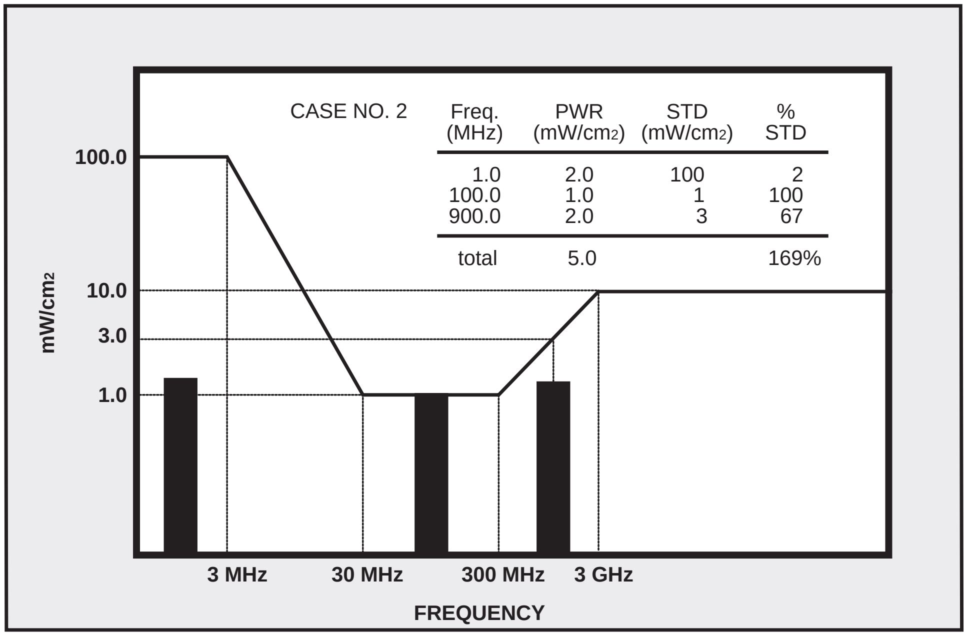
All probes are defined by whether they measure the electric or magnetic field, their frequency range, their power measurement rating, and whether their frequency response curve is flat or shaped. A shaped probe is a sensor with a frequency response curve that is “shaped” to mimic the requirements of a major standard, such as IEEE C95.1-1991 or NCRP Report 86. In contrast, a conventional probe is designed to have a flat frequency response throughout a broad operating range to ensure that its response is the same at all frequencies.



CASE NO. 1

Freq. (MHz)	PWR (mW/cm^2)	STD (mW/cm^2)	% STD
1.0	4.0	100	4
100.0	0.5	1	50
900.0	0.5	3	17
total	5.0		71%

Figure 2.
In this example, three emitters combined to have a total field strength of 5 mW/cm^2 which equals 71% of the standard.



CASE NO. 2

Freq. (MHz)	PWR (mW/cm^2)	STD (mW/cm^2)	% STD
1.0	2.0	100	2
100.0	1.0	1	100
900.0	2.0	3	67
total	5.0		169%

Figure 3.
This example shows the same three emitters as in Figure 2 with the same total field strength. However, this energy distribution results in 169% of the standard.

In the shaped probe shown in Photo 1, the energy of all the signals is weighted in accordance with the requirements of the standard, and the results are displayed as a percent of standard. The only considerations when using a shaped probe are ensuring that all systems at the site are operating at or near maximum power and that the probe is shaped to the correct standard.

A typical shaped probe has a full-scale range of “300% of standard.” In IEEE C95.1-1991, this means the probe can measure three times the MPE that the standard allows in controlled environments. As a result, it requires 300 mW/cm^2 from an AM radio station (where the standard allows 100 mW/cm^2) to generate the full 1 Vdc output from the probe (all Narda 8700 Series probes deliver 1 Vdc output to the meter under full-scale conditions). In contrast, it takes only 3 mW/cm^2 at VHF television or FM radio frequencies to generate the same output. The shaped probes are calibrated at several frequencies in the same manner as flat response probes.

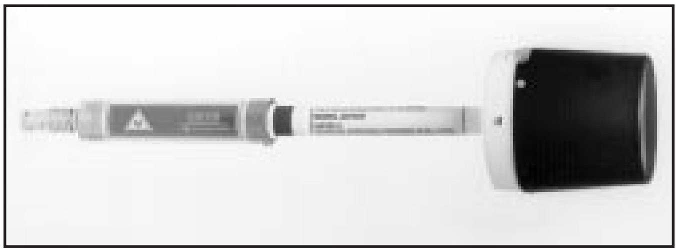


Photo 1. A shaped probe is physically identical to a standard isotropic probe. The difference between the two lies in the shaped probe's frequency response curve, which is "shaped" to mimic the requirements of a major standard.

MEASUREMENT UNCERTAINTY

Several factors contribute to measurement uncertainty. The first is frequency response, which is typically ±1 dB to ±2 dB (±25% to ±55%). Every probe has a certain amount of frequency response deviation, which is the amount of deviation from the correct measured value that a probe yields at various frequencies.

The smaller the deviation, the greater the accuracy. In a flat response probe, the amount of frequency response deviation is compared to the ideal (a straight line), where a shaped probe is evaluated by how far it deviates from the standard it is designed to mimic. A certain amount of frequency deviation is unavoidable, so it is important to calibrate the instrument at as many frequencies as possible.

Frequency response errors can be minimized by using a correction factor. Correction factors cannot be universally employed. They can be used when there is only one emitter being surveyed, when there are multiple emitters operating at the same frequency (encountered when measuring industrial equipment) and when there are multiple emitters operating at frequencies close to each other in the spectrum (assuming the nearest calibration frequencies have similar correction factors).

When the frequencies of the emitters are diverse, however, there is no way to determine the distribution of energy from the various emitters. So a correction factor should not be used because it could compound the error.

Ellipse ratio is the ratio of readings that occur when the probe is rotated around the axis of its handle, and is typically ±0.75 dB. Narda probes are calibrated in this manner, by rotating the probe about its axis and using the mean value for the correction factor. The correction factors are included on the handle of the probe.

Calibration uncertainty adds another 0.5 dB, and the meter itself varies no more than 3%. Isotropic response is the error that occurs when the probe is pointed in different directions and includes the ellipse ratio and some additional uncertainties. The isotropic response is generally no greater than the ellipse ratio, as long as the probe is pointed toward the source. A good rule of thumb is that the total uncertainty is no greater than ±3 dB, without the use of factors (the worst case).

With a shaped probe, which has a frequency response of ±2 dB, an indication of less than 50% of standard is certain to be compliant, while an indication of greater than 200% is certain to be out of compliance. In actual practice, the areas that fall into this window of uncertainty are quite small. In the worst case, narrowband measurement techniques can be employed to resolve the problem if these narrow areas are deemed operationally important. A good method of mapping the area where compliance is guaranteed is to set the meter to alarm at 50% of standard and quickly map the area. In this manner, the resultant plot can be used to determine compliance.

SUMMARY

The density of systems operating from a single tower or rooftop location is increasing every year. This complex signal environment makes it extremely difficult to accurately determine whether the radiation present at the overall site is in compliance with standards such as IEEE C95.1-1991 and NCRP Report 86, in which MPE limits vary with frequency.

Probes with shaped frequency response curves, along with RMS detection, make compliance with FCC guidelines more accurate in complex multisignal measurement environments. Together with a well-administered RF radiation safety program, they allow regulatory compliance to be confidently demonstrated.