Radio-frequency radiation: poor

Concern about exposure to RF radiation means that its measurement must be taken seriously. But Hugo Bibby argues that guidelines, calibration and technical expertise are not up to standard.

Last year the UK's Independent Expert Group on Mobile Phones (IEGMP) brought the issue of radio-frequency (RF) radiation safety under the spotlight. Established to examine the effects of mobile phones, base stations and transmitters on health, the group published its findings in a report that made recommendations for both the telecommunications industry and the UK government.

The report (entitled "Mobile Phones and Health", also known as the Stewart Report after William Stewart, chairman of the IEGMP) raised the issue of what may or may not be a safe level of radiation, and recommended that the UK adopt the guidelines issued by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), as opposed to those issued by the UK-based National Radiological Protection Board (NRPB).

What the Stewart Report failed to do (as did many other documents before it) was provide recommendations about how RF safety measurements should actually be made.

Both ICNIRP and NRPB guidelines list the maximum permissible exposure levels for human safety in terms of field strength, induced current and, ultimately, energy absorption. For the majority of telecoms applications, the field strength measurement is the most relevant. The permissible exposure levels are frequency dependent. For example, for very high frequencies ICNIRP quotes an "occupational" level of 10 W/m^2 (61 V/m), while above 2 GHz the level is 50 W/m^2 (137 V/m). Exposure levels for the general public are a stringent one-fifth of these levels.

Measuring up for safety

Apart from mathematical modelling, anyone wishing to prove compliance with the guidelines has two choices – to use either narrow-band or broadband measurement techniques. The first option employs a relatively narrow-band antenna and a spectrum analyser. Although necessary for measuring very low field strengths at the μV/m level, this technique is time consuming, expensive and complicated. As a result, the standard method of measurement employs broadband equipment.

Broadband survey equipment, which normally consists of a meter and probe, is often misused and misunderstood. The meter is usually digital and has a variety of software features. Its main function is to respond to an analogue input from the probe, which does the measuring. The probe contains a detector which uses diode, thermocouple or loop technology. The accuracy of the measurement depends on the technology used.

It is vital to understand the equipment because measurement errors can be large – typically 25–100%, and in worst-case conditions a massive 1000%. The reasons for this are threefold: limitations of measurement equipment; poor measurement techniques; and confusion regarding the safety guidelines themselves.

Confusion about guidelines frequently arises because the documents from ICNIRP and NRPB are scientific in content and difficult to understand. The meaning of terms such as time averaging, spatial averaging, specific absorption rate and magnetic flux density is often not clear. But the main issue is that ICNIRP and NRPB provide little information about how to actually take measurements.

In the US, safety guidelines on human exposure are provided by the Federal Communications Commission and by the American National Standards Institute and Institute of Electrical and Electronics Engineers (ANSI/IEEE). The radiation limits suggested by these bodies are similar to those of ICNIRP and the NRPB respectively.

Hugo Bibby of UK equipment supplier Link Microtek p

Unlike European agencies, the US organizations provide information about the equipment that should be used. The existing IEEE Standard C95.3-1991 document (a new draft is under way) attempts to ensure that measurements are reasonably accurate and that the equipment is understood. This does not guarantee that every measurement is correct or that surveyors are even aware of the documents. But it does provide a common point of reference.

Unfortunately, no equivalent documents are readily available in Europe. Here, the lack of information means that measurements may be carried out incorrectly and with entirely inap-

r guidance skews survey results

tek puts a Narda radio-frequency radiation meter and probe through their paces.

propriate survey equipment.

The biggest culprit in terms of equipment error is the diode detector, which is the most commonly used broadband RF radiation-monitoring device. An unfortunate characteristic of the diode detectors used in field probes is that, for a given power level, they become linear, or rather stop functioning as a root-mean-square (RMS) detector with the desired square-law response (see figure overleaf). Some manufacturers use "squaring" circuits to compensate for the operation of the diode in this region. The downside of this approach is that it can greatly overestimate the actual field strength in multiple-signal environments, including many telecoms sites. The greater the number of RF emitters, the greater the error. For two or three emitters the error is typically 1–2 dB, and overestimation can be as much as 10 dB at a busy site.

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To make matters worse, diode detectors can also underestimate the level of some signals by 10 dB or more. For example, diode detectors are often used for pulsed-signal measurements such as radar, where the very high peak fields may drive diodes into saturation. Even if this does not happen, the detector may overestimate true field strength as it changes from an RMS to a peak-detecting device.

Video resistance provides compensation

Despite these problems, there are solutions to the limitations of diode detectors. Narda Microwave, US, manufactures a range of diode probes that contain patented compensation circuitry, which is based on the video resistance of the diode. Video resistance is the impedance to the RF-rectified DC output signal. This changes dramatically when the diode moves from square-law detection mode to linear detection mode.

The diode can operate effectively outside of its square-law region if the change in video resistance is taken into account using compensation circuitry that simply maintains the video resistance. The disadvantages of this approach are that it limits the dynamic measurement range to about 30 dB and reduces the diode's output voltage, necessitating an amplifier mounted in the probe-handle to increase the signal voltage. However, including such an amplifier introduces an added benefit: its high impedance limits cable modulation, which is the presence of unwanted signals induced in the cable that connects the meter and probe.

In general, if a probe specification lists a dynamic range greater than 30 dB, at some point it will operate outside of its square-law region. For a typical telecoms environment this can result in an error of more than 70% (depending on the field strength and frequency of the measured signals).

An example of the effectiveness of video compensation was shown in a recent field test in which two signals were generated at 900 MHz and 910 MHz with equal levels that varied (see table overleaf). Comparing the measurements taken by a Narda 8761D device and another manufacturer's common-diode sensor probe that did not have compensation circuitry, it is clear that inserting the series resistance has a profound effect on accuracy.

Thermocouple-based probes have an inherent square-law detection characteristic, so they do not suffer from the problems associated with diode-based probes. However, thermocouple detectors operate at a minimum frequency of about 300 MHz. It is therefore sensible to use a thermocouple detector if measurements are required above this frequency.

Some users of broadband equipment are reluctant to accept that these issues are real and affect everyday measurements. Instead, they believe that diode-detection limitations are confined to theoretical scenarios created in the laboratory, and that all is well in the field because diode probes are calibrated by accredited test houses and sold by reputable companies.

Sadly this is far from the truth, because calibration conditions may not represent real-world measurement situations at all. There is no national or international standard that decrees how probes should be calibrated, so the onus falls upon the manufacturer's calibration instructions and the technical ability of any given calibration house. Usual calibration conditions are a uniform continuous-wave (CW) signal at moderate power levels and an ambient temperature of about 20 °C. Such conditions do not test the ability of the device to accurately assess multiple or pulsed signals, nor do they take into account the fact that diode detectors are sensitive to temperature – requiring a typical temperature compensation of 0.05 dB per degree.

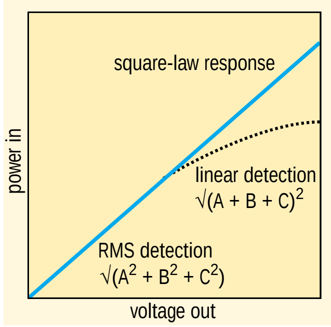
In addition, no standards apply to equipment specifications. Consequently, manufacturers may hide some important specifications or provide information only at optimum conditions – for example, test procedures performed in a laboratory environment with a CW signal at a fixed frequency.

Frequency sensitivity is the biggest cause of measurement error, contributing up to ±2.5 dB. Although calibration largely removes this error, some manufacturers quote prices for equipment that has not been fully calibrated to make it more attractive. Isotropicity, linearity and temperature sensitivity also need to be considered, and may generate a total measurement error of more than 4 dB.

Comparing diode detector accuracy

Signal level	*Total*	*Uncompensated-diode reading*	*Error (%)*	*Compensated-diode reading*	*Error (%)*
1000	2000	3350	+68	2280	+14
500	1000	1660	+66	1110	+11
250	500	870	+74	510	+2
50	100	156	+56	100	0
5	10	12.2	+22	10	0

Source: R Johnson, E Aslan and J A Leonowich *Technology of E & H Field Sensors for Measurement of Pulsed Radio Frequency Electromagnetic Fields* Erice, Sicily, Nov 1999.



Response of a diode detector showing the transition from RMS to linear mode.

The benefits of doing it right

When these points are raised, often the response is: "So what? We don't need a high level of accuracy." However, accuracy is important. For example, organizations whose employees regularly work in RF fields should have accurate records of exposure levels. Unfortunately, overexposures do occur, and in the worst case it would be difficult to defend against legal action without a record of accurate measurements.

The location of equipment, antennas and access routes must be planned according to maximum permissible exposure levels, therefore the overestimation of field strengths can also be a costly business. Indeed, with exposure limits being lowered, such errors could become even more costly. Ultimately, accuracy is important when measurements are being used to determine compliance or non-compliance with human-safety guidelines.

As well as the limitations associated with equipment, inaccuracies may also arise from poor technique or use of the wrong device. Pressure from the public and the media has created a growing market for RF safety measurements. However, many people taking measurements do not have sufficient knowledge or training to carry out surveys competently. Training can eliminate most problems, but unless manufacturers specify their equipment in an appropriate way, it is always possible that the wrong device will be used.

An uncompensated diode probe is sufficient for low-power, single-frequency measurements. In all other cases (including high power levels, pulsed and multiple signals) a thermocouple or compensated-diode probe is essential.

Beyond selecting a suitable probe, the surveyor has other important decisions to make. These begin with obvious system-related issues such as power level. The surveyor must then decide what parameter needs to be measured: electric field, magnetic field or power density, for example. Another important issue is to decide which units of measurement are appropriate: V/m, A/m, W/m^2 or mW/cm^2. The surveyor must make other key decisions, including whether to perform a spatially or time-averaged measurement.

The main factor that determines which parameters to measure is whether a near-field measurement is required. Simply put, the near field can be thought of as the area relatively close to the RF source – typically within a few metres. However, this distance is a function of both the wavelength and the type of antenna. Inside the near-field boundary, it is necessary to measure both the electric and the magnetic field.

It is essential that the regulatory bodies consider both the quality of field-strength monitoring equipment and the standardization of measurement methods. If these issues are not addressed, the industry will be in the curious situation of having documents such as the Stewart Report recommending safe levels, while the surveyors and equipment used to assess compliance may not be up to the job.

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