Practical RF & Microwave Rad Haz Safety Monitoring
The Truth Behind Radiation Measurements

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Stewart Report
Recent publication of the IEGMP (Independent Expert Group on Mobile Phones) 'Stewart Report' has again put the matter of RF radiation safety under the spotlight. The report makes a number of recommendations for the telecommunications industry as well as Government. The report quite rightly raises the issue of what may, or may not, be a 'safe' level of radiation. It recommends that the UK adopts the safety guidelines issued by the International Commission on Non Ionising Radiation Protection (ICNIRP) as opposed to the current UK safety guidelines, issued by the National Radiological Protection Board (NRPB).

However, what the report fails to do, as have many other documents before, is to lay down any kind of advice or recommendation on how RF safety measurements should actually be made. Both ICNIRP & NRPB guidelines list the maximum permissible exposure levels for human safety in terms of field strength, induced current and ultimately energy absorption (SAR). For the majority of 'real world' telecommunications situations, measurements of field strengths are generally undertaken. The permissible exposure levels are frequency dependant e.g. for VHF frequencies ICNIRP quote an 'occupational' level of 10 W/m^2 (61V/m) whilst above 2GHz the level is $50W/m^2$ (137V/m). For general public the exposure levels are more stringent at one fifth of these levels.

Equipment – broadband Vs narrow band
Aside from mathematical modeling anyone wishing to prove compliance with the guidelines has two main choices, either to use 'narrow band' or 'broadband' techniques. The narrow band option entails the use of a relatively narrow band antenna and a spectrum analyser. Although this enables measurement of very low field strengths (uV/m etc.) the downside of the technique is that it is very time consuming, expensive, cumbersome and technically challenging. For example the antennas employed are often directional, and do not provide the isotropic response desirable for safety surveys. This means three sets of readings, x,y & z polarisations, are required at each measurement point.

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Because of this, the more standard and practical measurement technique adopted for human safety is to use broadband equipment. It should be noted that broadband equipment can measure down to as little as 0.5V/m, well within the ICNIRP Occupational and General Public guidelines. Given this capability it should be asked in many situations exactly what a 'narrow band' survey does accomplish. Broadband survey equipment is also relatively simple to operate and much more compact, often consisting of only a meter and probe combination. However, it should still be noted that even this equipment is often misused and misunderstood.

The meter, although usually digital with a variety of software features, is designed to respond to an analogue input from the probe. The probe houses the detector, the key element in the monitoring system. A variety of detectors can be used, (e.g. diode, thermocouple or loop) and it is the technology that is used in these detectors that provides the basis for an accurate measurement.

The need for measurement guidelines

Without some understanding of the measurement equipment, measurement errors can be large, typically 25% to 100% and under worst case conditions a massive 1000%. The reasons for this are threefold, confusion with the safety guidelines themselves, limitations of measurement equipment and lastly poor measurement technique.

Because documents from both NRPB and ICNIRP are very scientific in content it makes them difficult to understand, not only for the general public but also for health and safety professionals and engineers alike. There is often confusion with terms such as time and spatial averaging, Specific Absorption Rate, Magnetic Flux density etc. The main issue, however, is that NRPB and ICNIRP provide little information on how to make measurements.

In the U.S., the case is somewhat different. There are not only safety guidelines on human exposure from the Federal Communications Commission (FCC) and ANSI/IEEE (similar to ICNIRP and NRPB levels respectively) but there is also official documentation on what equipment should be used from both bodies. The IEEE C95.3 1991 (a new draft is underway) document drives a number of issues home to ensure reasonable measurement accuracy and understanding of the measurement equipment. This certainly does not guarantee that every measurement in the U.S. is taken correctly or indeed that surveyors are even aware of the documents, but it does at least provide a common point of reference. There are no well-known equivalent documents available in Europe, but there certainly should be.

Unfortunately in Europe, the lack of information on measurement technique and measurement equipment leads to a situation, where measurements may be being carried out incorrectly and with entirely inappropriate survey equipment.

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Detector errors

An area of great concern is the common use of the diode detector for broadband RF radiation monitoring. An unfortunate characteristic of diode detectors is that they are inherently non-linear. When used in field probes they can stop functioning as an RMS detector. At this point they no longer give an output for 'power in' in the desired square law response. Some manufacturers use 'squaring' circuits to compensate for the diode operating in this region. The downside of this approach is that it can greatly overestimate the actual field strength in multiple signal environments (most shared telecommunication broadcast sites), the greater the number of emitters, the greater the error. The error is typically 1 to 2 dB for two or three emitters and can be as much as a 10dB over estimation at a busy site.

Even worse, diode based probes can hugely underestimate the level of some signals by 10 dB or more. Time and time again diode-based probes are used for pulsed signal measurements such as radar where the high peak fields generated drive diodes into saturation giving rise to large errors (under reading).

Diode detectors are also, highly temperature sensitive – typically 0.05dB per degree. This is yet another source of error. The detectors must have temperature compensation circuitry.

There are solutions to the limitations of diode detectors. Narda Microwave manufactures a range of diode probes with patented compensation circuitry. This centers around the video resistance of the diode. Video resistance of a diode is the impedance to the RF rectified DC output signal. There is a major change in video resistance when the diode's detection changes from square law to linear detection. When this change is not accounted for, the diode can operate outside of its square law region. The compensation circuitry simply maintains the video resistance. The disadvantages of this approach are that it limits the dynamic measurement range to about 30dB and reduces the diode's output voltage necessitating a probe handle mounted amplifier to increase the signal voltage. The high impedance of the amplifier does give a benefit in that it limits cable modulation (cable modulation is essentially unwanted signals induced in the cable which is used to connect the meter and probe) from sources such as overhead power lines. To summarise if a probe specification lists a dynamic range of greater than 30dB, at some point it will operate outside of it's square law region. For a typical telecoms environment (depending on the field strength and frequency) of the measured signal(s) this can result in error of anything up to 70%. (Ref 3).

Thermocouple detection

The more robust solution for measurement of RF fields is to employ probes using thermocouple detectors as they have inherent square law detection characteristic so do not suffer from the problems associated with diode based probes. However, thermocouple detectors are limited to a minimum frequency

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of operation of about 300MHz. If measurements are only required above this frequency it is sensible to use a thermocouple based probe.

Measurements in the 'real world'

There is reluctance by some users of broadband equipment to accept that these issues are real and that they can affect every day measurements, thinking instead that diode detection limitations are confined to theoretical scenarios created in the laboratory. After all, diode probes are calibrated by accredited test houses and sold by reputable companies so everything must be OK. This is far from the truth, as calibration conditions do not represent 'real world' measurement situations. There is no national or international standard that decrees how probes should be calibrated for 'real world' use. The onus falls upon the manufacturers calibration instructions and the respective technical ability of any given calibration house. Usual calibration conditions are a uniform CW signal at moderate power levels and at ambient temperature. Obviously, this does not test the device's ability to accurately assess the fields in normal everyday environments (multiple signals, time varying or pulsed conditions).

In terms of equipment specifications there are no 'standards' that need apply. Consequently manufacturers may hide some important specifications or provide information but only at optimum conditions i.e. a laboratory environment with a CW signal at a fixed frequency. Frequency sensitivity is the biggest cause of measurement error contributing up to +/- 2.5dB (calibration largely removes this but some manufactures quote equipment without a full calibration to make the sale price look more attractive). Isotropicity, linearity, temperature sensitivity all need to be considered and may give a total measurement error of over 4dB.

Why is accuracy important?

Often when these points are raised, the attitude is so what? We don't need a high level of accuracy, but ***accuracy is important*** particularly, if the maximum permissible exposure levels are reduced further still. Some companies are already considering using the general public levels for their employees, in this relatively low-level environment there is no room for large measurement inaccuracy. Any employer, whose employees regularly work in RF fields, should have accurate records of exposure levels. Unfortunately over-exposures do occur and in the worst case defending any legal action without a record of accurate measurements is obviously very difficult.

Incorrect determination of field strengths can be very costly as it directly affects the location of equipment, antennas, access routes and siting of restricted areas. With maximum permissible exposure levels being lowered this can only get more costly. Ultimately it is common sense, accuracy must be important when measurements are being used to determine compliance (or not) with ***human safety*** guidelines.

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Using the correct equipment

As well as limitations in measurement equipment there is also the issue of poor measurement technique or using the wrong equipment. Because of public and media pressure on the telecommunications sector there is a growing market for RF safety measurements. Many people taking measurements do not have sufficient background knowledge or training to competently undertake surveys or even decide what is required. Expensive narrow band surveys are often employed when a simple broadband survey is more than adequate.

Understanding the situation

In practical situations the potential 'surveyor' is faced with a number of questions, starting with obvious system questions like power level, then leading on to what needs to be measured? Electric (E) field, Magnetic (H) field, Power density? What are the appropriate units of measurement i.e. V/m, A/m, W/m², m W/cm², does it need to be a spatially or time averaged measurement etc.

The main factor that determines what needs to be measured is whether or not it is a 'near field' measurement. In non-technical terms the near field can be thought of as an area relatively close to the RF source, typically a distance of a few metres at most (this distance is a function of both the wavelength and the type of antenna). Inside the near field boundary it is considered necessary to measure both the Electric (E) and the Magnetic (H) field. The units of measurement can be V/m, A/m, or W/m².

There are other issues that form good measurement technique, centered mainly on having sufficient knowledge of the equipment being used. Training can eliminate most common problems but there is always the risk that unless manufacturers specify their equipment in an appropriate way it is always possible that the wrong equipment will be used.

The current dilemma

Regulatory bodies need to pay some attention to field strength monitoring equipment and the standardisation of measurement methods. CENELEC is currently attempting to produce some guidelines but this work is only just underway. Indeed there is little point in re-inventing the wheel as the IEEE C95.3 document is comprehensive but very few people in industry are aware of it's existence as ICNIRP and NRPB documents do not reference it. Until we have European guidelines or widespread adoption of the IEEE C95.3 we will be in the curious situation of having documents such as the Stewart Report recommending 'safe' levels, and that safety surveys should be carried out but having measurement equipment used to demonstrate compliance that may be inadequate and the 'surveyors' ignorant of the survey equipment limitations. If a low power single frequency measurement is all that is required then in itself this is acceptable. However, for any other scenario – 'real world' (high power levels, pulsed, multiple signals) there could be problems.

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