# NATIONAL AND INTERNATIONAL STANDARDS ON THE MEASUREMENT OF ELECTROMAGNETIC FIELDS AND STATE-OF-THE-ART MEASUREMENT INSTRUMENTS

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## INTRODUCTION

Exposure levels for non-ionizing radiation have been introduced world-wide on a technical basis. An ever growing number of countries tend to fix exposure levels on a political basis. These activities require measurement standards for both low-frequency and high-frequency measurement procedures and instruments. This standardization process has been started on different national bases but is not yet finished at an international level. I.e. in the low-frequency range, there are as yet no standardized measurement techniques in existence around the world. The result is that a large number of low-frequency devices are available commercially, but results from the different devices are not comparable. Moreover, there is no other branch of measurement technology where, in specifying technical data, so much information is either concealed or misrepresented. This is hardly acceptable in a field with major safety implications, as is the case with measurement of electromagnetic fields and waves.

## GERMANY: VDE

When it stipulated its limits, the VDE also defined the necessary measurement techniques in DIN VDE 0848 (1). The VDE is thus an exception within Europe. These measurement techniques described in this standard are particularly valuable for the high-frequency range. However, precise specifications are lacking, along with requirements for test equipment. The standard leaves the choice of measurement technique to the person making the measurement, even though all errors and the influence of the frequency spectrum must be taken into account when determining the field strength values. The limit between high frequency and low frequency was set at 30kHz. For the low-frequency range, the norm is restricted to rudimentary guidelines for designing the test setup. Important is the restriction for the magnetic field probe, which is required to be a induction coil with an area of $0{,}01m^2$.

## EUROPE: EBU

At the European level, the EBU (European Broadcasting Union) has standardized measurement techniques, but they are tailored very specifically to the needs of the broadcasting industry (5). The effects of the various modulation techniques on the measurement results are documented in great detail.

## INTERNATIONAL: IEC

In the eyes of the experts, the current situation is unacceptable: Limits have been stipulated, yet the measurement problem is left to the whims of the free market. The measurement techniques valid in Europe, particularly for verifying the limits of the two CENELEC norms (3, 4), were delegated to the IEC (International Electrotechnical Commission). IEC created two working groups with the aim of defining the test and measurement standards immediately under tight time constraints. The voting drafts of these papers are expected to circulate at the end of 1996. Both standards are focused to measurement procedures and measurement equipment with specific regard to human exposure. For the frequency range 100 kHz to 1 GHz, there is a draft dealing with radio communications (10). However, this standard has only limited use in industrial applications.

## AUSTRALIA

In Australia, a newly revised version of the standard for measurement of high-frequency fields is now available in draft form (9). The original versions were highly practical documents, and the new standard is a continuation of this trend towards detailed description of test and measurement techniques. One new and innovative feature is the long-awaited description of a spatial averaging technique for avoiding excessive influence of RF hot spots and better recording of the whole-body exposure. Measurements are required at five points of a square (corners and center) having an edge-length of 300mm; the average of the five measured values is then displayed.

## SWITZERLAND

The Swiss Federal Bureau for the Environment, Forests and Landscape (Bundesamt für Umwelt, Wald und Landschaft) has issued a recommendation with limits based on the IRPA values, including a detailed study of measurement of high-frequency fields (2). Here, the focus areas are error estimation in measurement and calibration, and investigation of measurement uncertainties. Radar signals are given special treatment. For low-frequency field measurements, the corresponding recommendation is not yet available.

## USA

In the USA, the third revised version of the standard on measurement of high-frequency fields is now available (8). The fourth version is expected at the end of 1996. This standard will be used around the world as part of the standardization process at the national level, even if it is modified in each case. There is detailed coverage of three main areas: general test-related issues, instrumentation and actual measurements. In the fourth version, the section on instrumentation will most likely be revised since major technological advances have been made since the last version was published in 1991. A corresponding standard on the measurement of low-frequency electrical and magnetic fields is in preparation (7).

## CONSEQUENCES FOR THE MEASURING DEVICES AND MEASUREMENT PROCEDURES.

It is a basic fact that the complexity of determining limits entails unusual problems for test equipment as well as for test personnel. One the one hand, the instruments must be simple to operate. However, the results must be precise, traceable and reproducible. Except for highly trained personnel in scientific and technical fields, the person making the measurements is generally uninformed about the theoretical and practical aspects of electromagnetic fields. In recent years, this problem has become more acute as the national and international limits recommendations have made their way into industry. This also explains the introduction of innovative measurement techniques for high-frequency as well as low-frequency applications (6). Due to space constraints, all of the requirements for field measuring devices cannot be considered here; this is a task for the IEC working groups. However, we will look at some of the most innovative advances in measurement technology over the past five years:

## LOW FREQUENCY, ELF

3D-E-field measurement: When measuring electrical fields under high-voltage lines, the older one-dimensional technique was sufficient since it was possible to compute the field pattern in advance. However, the current standards of the VDE and Cenelec require measurement of the resultant field strength, regardless of application. Especially in industrial environments (switching fields, transformer stations, induction heating devices), the field pattern is a function of the installation and also varies over time, meaning that three-dimensional measurements are required. A setup of a state-of-the-art measurement device is shown in Figure 1 (12).

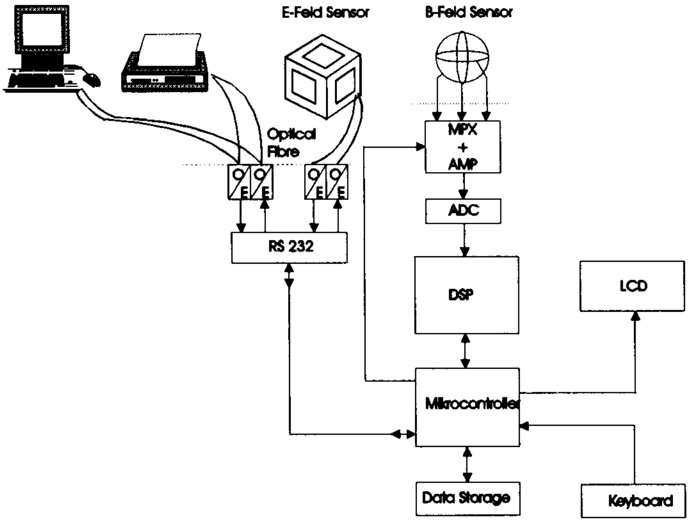


Figure 1 Setup of the EFA-3 measurement system for isotropic B- and E-field measurements

Tuneable filters: E-field and H-field measuring device must also allow selective recording of the field components since the international and national limits recommendations are all highly frequency dependent. Broadband equipment cannot handle this measurement when the frequency of the emitter is unknown and the existence of multiple signals cannot be excluded as a possibility. One example is an induction heating system, which simultaneously radiates 50/60 Hz fields with all their harmonics as well as heating frequencies in the 25 kHz range. Newer measuring devices are equipped with filter functions for handling such situations.

## RF & MICROWAVE

Wide frequency ranges: Extremely broadband probes, primarily for applications in ISM areas and in telecommunications (AM & FM radio, GSM, TV) have been developed with frequency ranges from 100 kHz to 3 GHz and a negligible frequency response. Figure 2 shows the typical frequency response curve.

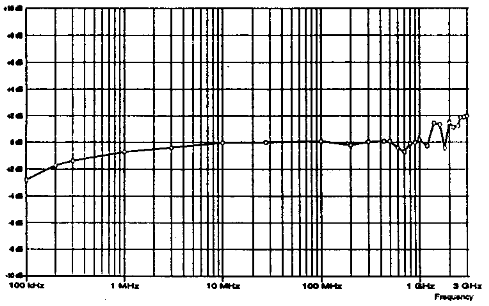


Figure 2 Typical Frequency Response of EMR-30 100 kHz to 3 GHz

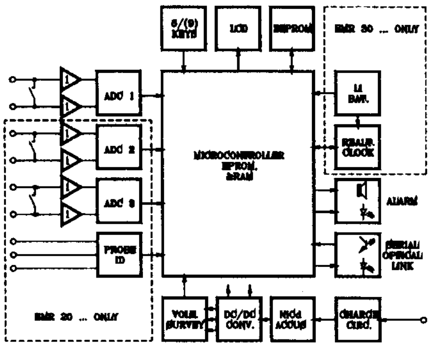


Figure 3 Triaxial digital axis processing for RF & Microwave measurements

Triaxial evaluation: Today, using trichannel digital evaluation of the individual axes of an isotropic sensor, it is easy to cover a dynamic range of 60 dB with a single probe (11). All of the limits stipulated in national and international standards can be covered without resorting to exchangeable probes with their associated calibration problems. Figure 3 illustrates the modular design of a triaxial digital system.

No auto-zero: Elimination of the need for an "auto-zero" function is another advance. Due to their extremely high-impedance input stages, field meters require continuing offset alignment. In the past, it was necessary to locate a field-free space for this procedure, thereby providing a typical trap for untrained personnel. Newer devices automatically perform this alignment even under field exposure.

## CONCLUSION

This paper describes the international activities and policies for standardizing the measurement equipment for electromagnetic fields. Activities of the various countries, mainly Germany (VDE), USA (IEEE), Europe (IEC) and Australia (AS/NZS) as well as others are covered. Based on these reports requirements for measurement equipment are discussed and new designs for instruments especially developed for the measurement of electromagnetic fields with particular regard to human exposure are presented.

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