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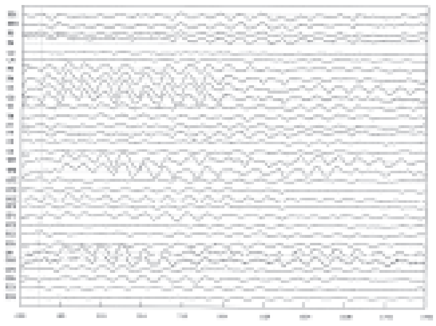
Technical EMV problems
during EEG examinations at additional

What is an EEG?

The so-called electroencephalogram in humans, in short EEG, is based on highly-sensitive measurements of potential differences at the head surface which are in a typical range of 10 to 300 µV. The potentials arise as the sum of the values of electrical activity of nerve cells located directly below the head surface, transducted by electrodes. The voltage differences between two electrodes at a time are determined via different switching schemes. The medical and diagnostical possibilities of the EEG arise from the multiple ways of positioning electrodes on the head, and from the paired difference measurements. During the spectral analysis often used in the application of this method, the curve representing the EEG time variation is usually transformed into frequency components in the range from a few tenths of Hz up to about 30 Hz. However, here we will not discuss in detail the issues of appropriate measurement periods or scanning frequency. Further details may be found instead in the book of Zschocke ("Klinische Elektroenzephalographie", Stephan Zschocke, Springer Verlag 1995).

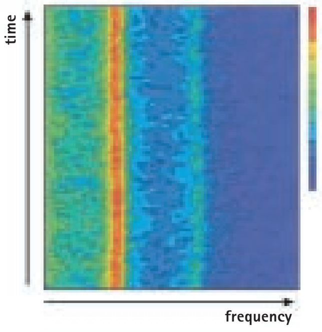
RF-field impact on the EEG and technical EMV

At present, there are quite a few publications available suggesting the existence of effects of weak, non-thermal radio-frequency fields on the EEG in humans. In this contribution we will not consider the different quality of these studies or the consistency of the results as compared to similar studies with contrary findings, nor will we consider their general view of possible health dangers caused by weak radio-frequency fields. Instead, we will concentrate on the question to what extent field conditions as a whole have to be controlled during these measurements both during radio-frequency exposure, and dur-



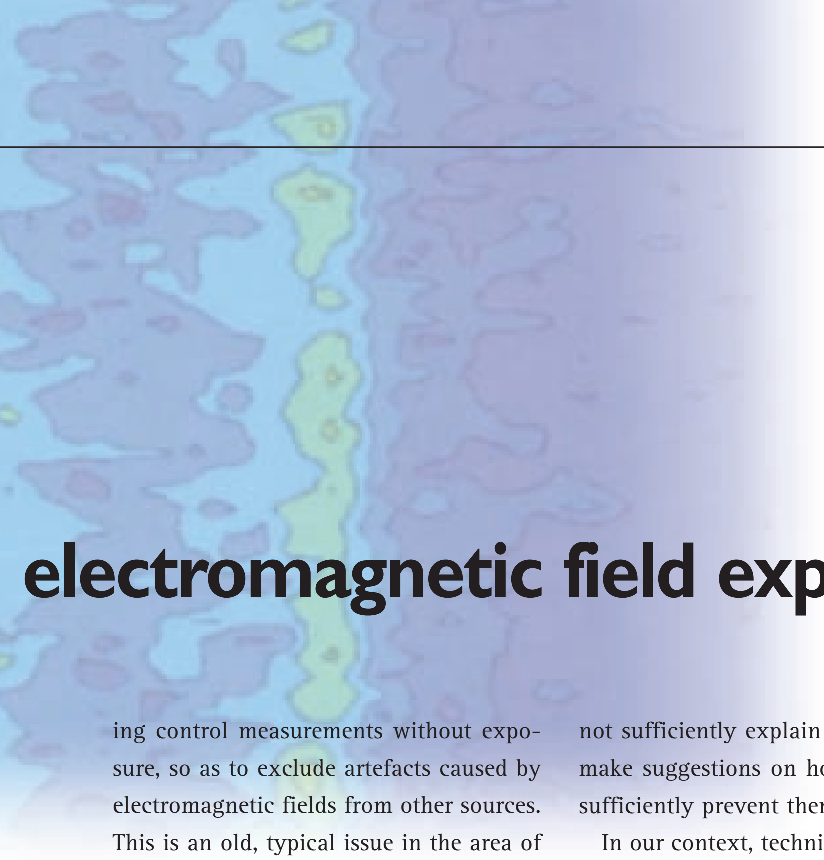
EEG original recording frequency ranges

delta waves 0.5 - 3.5 Hz
theta waves 3.5 - 7.5 Hz
alpha waves 7.5 - 12.5 Hz
beta waves 12.5 - 30 Hz



EEG power/frequency/time diagram (spectral analysis)

During the tests of Gehlen et al. (Bio-cerebral effects at low-frequency-pulsed radio-frequency fields, Edition Wissenschaft 12/1996) the original EEG signals were presented as a three-dimensional diagram. Time is shown on the y-axis, frequency on the x-axis; calculated power values are shown in dB as a third dimension in colour.



electromagnetic field exposure

ing control measurements without exposure, so as to exclude artefacts caused by electromagnetic fields from other sources. This is an old, typical issue in the area of technical EMC which has led to a series of standardisation measures, technical construction specifications and regulations for EEG devices and measurement procedures. The aim is to ensure that EMC-induced artefacts in "daily-life" EEG occur as seldom as possible, and can be excluded or taken into consideration by following the correct procedures in the performance of the measurement and the subsequent interpretation of data. Above all, the knowledge and experience of staff are crucial for identifying typical artefacts.

This issue is of special relevance, when additional electromagnetic fields are intentionally produced – not only in the RF range – during EEG recordings in order to investigate potential biological RF field effects in participants. Medical experience shows in practice that the existing procedures and solutions for the control of unwanted signals are totally unable to deal with the 50-Hz "hum" or its harmonics. Electronic instruments are often placed in the near or immediate vicinity of EEG test sites, either as part of RF exposure set-ups or as control or monitoring units. The same is true for connecting cables, in which unexpected compensation currents may occur. As a consequence, new artefacts, which are often difficult to detect, may develop.

The publications available to the author on EEG effects caused by RF radiation do not sufficiently explain these artefacts or make suggestions on how to foresee and sufficiently prevent them.

In our context, technical EMC problems caused by direct coupling of radio-frequency field energy in EEG electrodes and devices play a minor role. Such effects naturally can also occur. However, with careful procedures, they are mostly easily recognisable and controllable. Here, we discuss the actual variations of EEG difference signals not caused by neuro-physiological processes, but rather by other external effects.

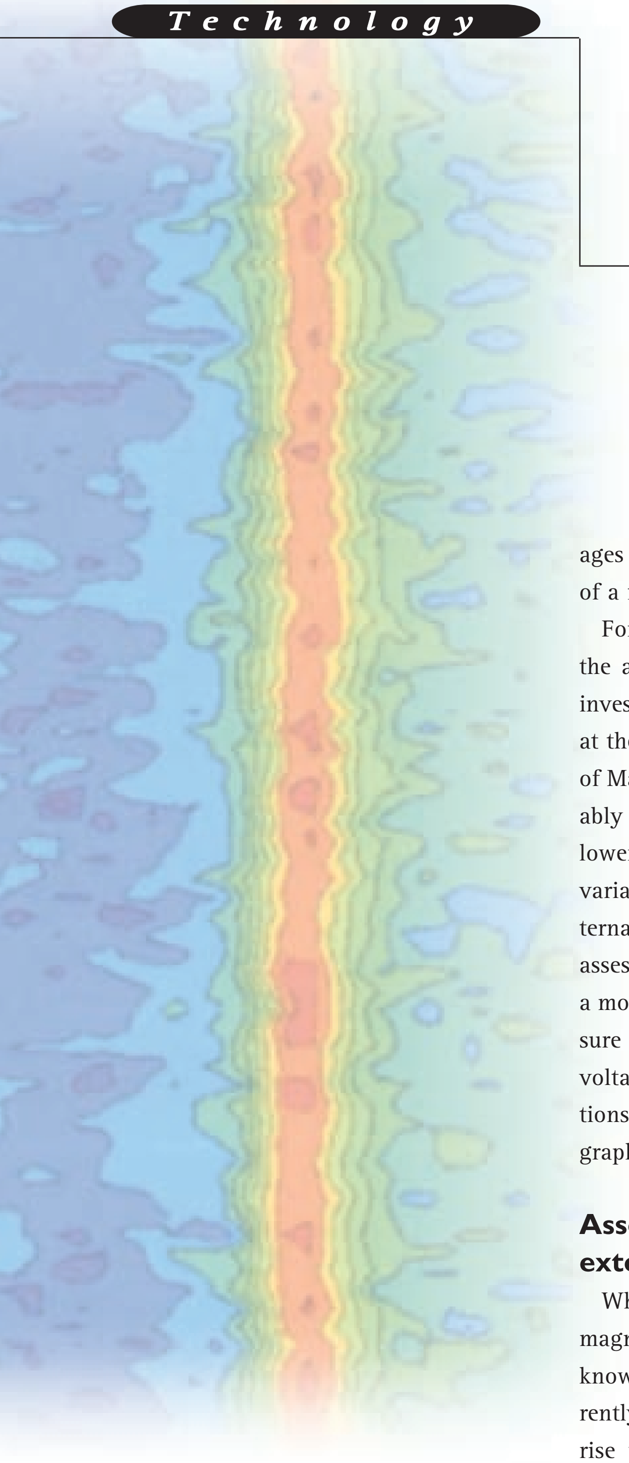
Plausible mechanisms of EEG effects

In the following, we will by example deal with two (in the view of the author) highly-plausible mechanisms of the falsification of results caused by external static and/or low-frequency magnetic fields:

a) The two electrode conductors used for a given measurement, each together with all potential conducting channels in the head, form induction loops. When there is a magnetic flux alteration within these loops caused by external alternating fields, an additional artificial voltage develops at the difference input port of the EEG evaluation device. As well, static magnetic fields can lead to flux alterations within the loop caused by slight or rapid body movements.

b) In the artery system of the body, the heartbeat produces pulselike travelling waves in both blood pressure and blood flow velocity. These result in slight body movements (see a) as well as Hall voltages in the artery cross-section, since an external static or low-frequency magnetic field together with the ion velocity in the blood produces a cross-direction Lorentz force. All these artefacts produced by heartbeat are known in connection with combined EEG and Magnetic Resonance Imaging (so-called pulse artefact, see e.g. "Methodological Issues in EEG-correlated Funtional MRI Experiments," L. Lemieux et al., Int. Journal of Bioelectromagnetism, IJBEM 1999, 1(1) pp. 87-95). The consequences are an alteration of the potential distribution at the head surface. which is modulated by the fundamental component of the wave variation in theblood flow velocity, and its harmonics. Though this phenomenon in a broader sense could be interpreted as a biological effect, it is not connected with an altered activity of the nervous system and therefore has to be seen as an EEG artefact.

For the first effect described in a), the available literature gives limit values for external field strengths below which interference effects can definitely be neglected. In view of the small potential differences which are the "true" EEG, these low external-field limit values otherwise unknown in technical EMC are not surprising. According to DIN VDE 0107 (VDE 0107): 1994-10, the 50-Hz flux density at the EEG measurement site, for example, is not to exceed an effective value of 70 nT (!); obviously, the assessment is based upon the maximum tolerable interference volt-



ages in the range of 1 µV for loop planes of a few hundred cm².

For the effect b), to the knowledge of the author, to date there is no thorough investigation yet available; the data gained at the extremely high static flux densities of Magnetic Resonance Imaging are probably not simply portable to the case of lower flux densities with different time variations. It is important to note that internal calculations show that realistically-assessed flux densities in the near field of a mobile phone under experimental exposure conditions can lead to interference voltages exceeding 1 µV. These calculations are explained in the following paragraph.

Assessment of the effects of external fields

What would be the cause of unwanted magnetic fluxes? In technical EMC, it is a known fact that electronic equipment currently on the market nearly always gives rise to a broad time-varying frequency spectrum because of the use of switching network components and generally fast regulation functions in power circuits. This development in most cases is enhanced by the demand for high-performance and/or small-device formats. When connecting or networking different systems, sometimes considerable magnetic fields can develop due to large loops which can be ignored as long as they do not lead to EMC interference coupling. As the exceptionally-low interference levels required for EEG measurements are required in almost no other situation, such measurements have to be carried out very carefully.In devices which operate continuously, there occur significantly-large time-varying fields at short or long time-scales (thermal effects on sample rates, etc) as well.

When an EEG measurement site is in the presence of electrical or electronic exposure, measurement, or monitoring equipment, the fields at the head – the site of the electrode conductors – arising from such equipment must be as exactly known as possible during the entire duration of the measurement. Only after doing this, can the neuronal activity of the head itself be regarded as the sole source for EEG variations.

We will demonstrate this by an example: when holding a mobile phone to the head in the normal telephoning position, we know that in addition to the RF signal, considerable spatial- and time-varying magnetic flux densities in the low-frequency range can affect the EEG measurement. A GSM cell phone of 2 W transmit power and 3 V supply voltage needs in the transmit mode a current of about 1 to 2 A, which alternates at a frequency of 217 Hz. Depending on the internal regulation and filter functions, the layout of supply lines, and so on, a direct field component and alternating field components at different frequencies occur which can be very strong in the vicinity of the mobile phone. Without being statistically representative, our laboratory actually measured magnetic near-fields in the range of 100 nT up to above 10 µT between 5 and 500 Hz at a few randomly-selected mobile phones. This is easily to be understood: A wire of 2 A current strength at a distance of 2 cm has a flux density of 20 µT, and a wire loop of 4 cm in diameter and 4

A current as much as 125 µT at the loop centre. The supply lines within a mobile telephone cannot always be laid out close together as so to ensure a reduction in the field at positions external to the telephone.

If the cell phone is replaced by antennas placed at a slightly greater distance from the head, with separate RF feeding and amplification, a similar result is obtained. The greater distance does not *per se* ensure that there will be no effects on the EEG. Even sham-exposure measurements, or measurements at switched-off RF but switched-on electronics (stand-by), should be checked applying the above-mentioned criteria. In particular, possible compensation currents in cable connections, which are passed around corners or set in loops, can even at a distance of several meters still cause interference-relevant flux densities in EEG measurements.

Possible solutions

How can the effects of such external fields on the EEG be identified? The 50-Hz "hum" can be avoided mainly by

putting the EEG workstation in an electromagnetically-quiet environment without the need for further electrotechnical isolation. Of particular interest here are "only" the little-known cases where an inadequately-performed potential compensation has prevented the use of entire hospital wings for EEG measurements. It is recommended (in practice carried out mostly as spasmodic random checks) to simultaneously perform a measurement using a "blind electrode," i.e. an induction loop in the vicinity of the head without skin contact, in order to directly identify externally-induced voltages caused by external time-varying flux densities. However, to obtain a consistent conclusion, these must be verified three-dimensionally, i.e. in three orthogonal loops. However, the above mentioned case b) possibly might not be satisfactorily elucidated by this means, since a Hall voltage is not an induction voltage, and so the direct or very low-frequency alternating fields relevant to interference with this can not be measured by an induction loop. Therefore, we have to emphasize that this case is in need of still deeper analysis and – as a fundamentally-required basis – an examination of the entire magnetic field situation.

As a summary, it is required to comprehensively examine the overall magnetic field situation in the environment of the head during the whole EEG measurement period both at RF exposure and at sham exposure, in order to be able to definitely exclude false conclusions on EEG alterations which actually arise from RF exposure. To this end, only those flux measurement devices are of use which are sufficiently sensitive and which cover the entire frequency range of relevance. Further, it must be ensured that field conditions at the head as far as possible remain unaltered. On-line monitoring should not itself produce an additional magnetic field, as is possible, for example, with compensation measurement devices.

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