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An attempt to assess the question from a biophysical point of view

High frequency electromagnetic fields are subjected to low-frequency modulation so that they can transmit information. With modern mobile radio applications, these modulations range from several Hertz (Hz) to several Kilohertz (kHz): In GSM (Global System for Mobile Communications) mobile telephony these frequencies include 217 Hz amongst others, while TETRA (Terrestrial Trunked Radio) mobile equipment (for authorities and security agencies employs a 17.65 Hz modulation. Biological processes run on timescales that extend from the nanosecond range (ns = 10^{-9} s) up to periods of years, though some also have time constants similar to the pulse duration of mobile telephony system modulations. Many of these processes, including ones in the brain (keyword: EEG, "electroencephalogram") are also connected with the generation of low-frequency electrical and magnetic sources. Is it thus implausible to expect mobile telephony modulations to have an influence on biological systems?

Unfortunately (or perhaps fortunately) things are not quite as simple as that. Let us first look at the different types of modulation that exist (Fig. 1). With **amplitude modulation (AM),** the strength (amplitude) of the high-frequency, sinusoidal carrier signal is varied with the pulse of the low-frequency signal, i.e. the low-frequency source that contains the information to be transmitted is combined with the high-frequency source. One special case of modulation is **pulse modulation (PM)**. Here, the high-frequency source is repeatedly switched on and off, leading to a rectangular signal. **Frequency modulation (FM)** is marked by the fact that the amplitude of the source remains constant or only varies a little, while the frequency

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tance of pulsed signals?

changes to a greater or lesser extent, depending on the low-frequency signal modulated upon it. The last basic type of modulation to be mentioned is **phase modulation or PM** (also known as “continuous phase frequency shift keying“ or often just “phase shift keying“ – **PSK**). Put simply, the high-frequency wave train for modulation is continued, displaced by 90°, 180° or 270° at particular points. The concrete modulations of present-day communication systems are mostly a mixture of several of these basic modulation forms.

What effect do such fields have on the biological system? First, let us ignore modulation and look at the pure high-frequency signal, a periodic, sinusoidal oscillation between electrically and magnetically positive and negative values. It operates by exercising forces on the charges that are present in the body, the movements of which attempt to follow the development of the field and so begin oscillating. The charges may be ions, though they can also be dipoles (such as water) or multipoles (like proteins, for instance.) The higher the frequency, the smaller the amplitude of oscillation, as the particles can no longer follow the development of the field due to their inertia. So they just “vibrate“ around their centre points. In the process, the particles “rub“ against neighbouring molecules, giving rise to heat, the main mechanism of the field-particle interaction, particularly in the MHz and GHz ranges being looked at here. Let us now concentrate on low-frequency modulation. In order for this to be effective in the body, it has to be decoupled from the high-frequency signal. Only when it has been demodulated is it “visible“ to the body. There are a number of possible ways that demodulation of this kind can take place.

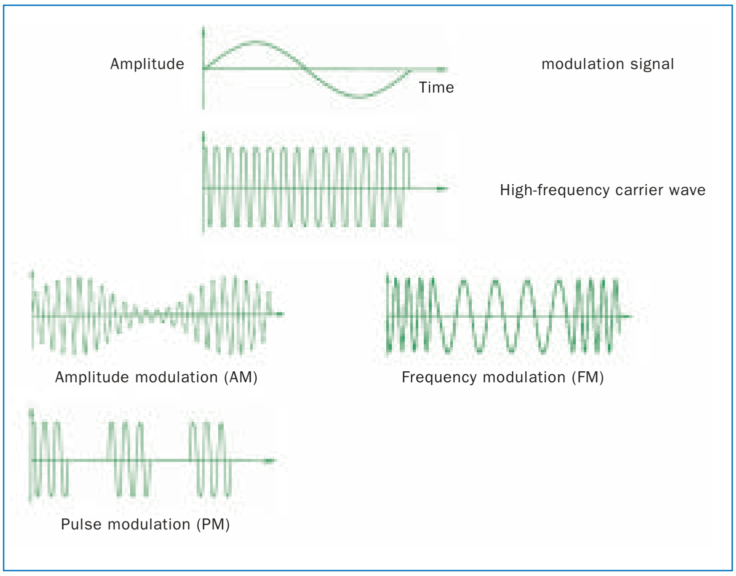

Fig. 1 The fundamental types of modulation

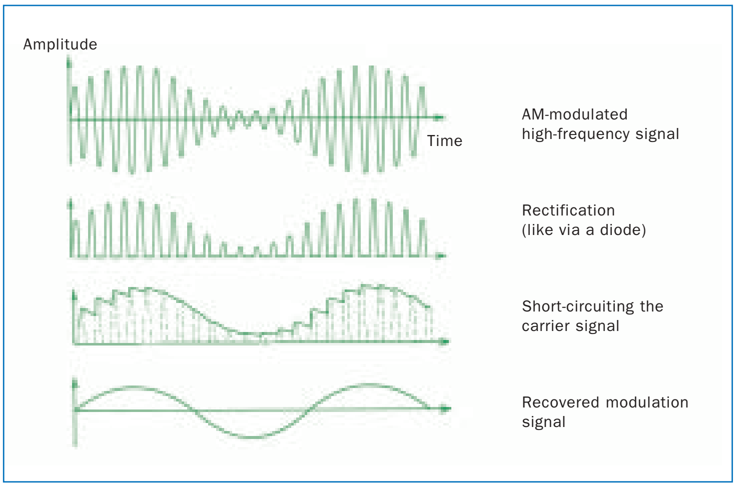

Fig. 2 Electrical demodulation with amplitude modulation as an example (AM)

Let us look first at:

- **Electrical demodulation.** This means that an electrical signal modulated at high-frequency recovers its original form in frequency and amplitude. For this, a non-linear element is necessary, which means that the output signal does not act proportionately to the input signal. In our case of electrical demodulation, the modulated signal is rectified, i.e. from a particular threshold voltage on, only the positive or negative half-wave can pass through. In electronics, a diode is normally used for this purpose. By means of subordinate capacitors and resistors (so-called "RC modules") the high frequency carrier signal is short-circuited and the low frequency modulation signal (Fig. 2) produced. In biology the cell membrane is known as a non-linear element and it also possesses the characteristics of an RC module – it is only lacking the particular diode characteristics that could effect rectification. Although there are ideas about this, these do not apply for the frequency range being observed: Jiri Silny, in his summary of the action mechanisms of pulsed radio waves, [2004] described the selective transport of ions through membrane channels because of the attractive or repulsive effect of a positive or negative half-wave on a type of ion, which leads to an excess charge of these ions in the cell after a certain time and thus to independent excitation: a rectification effect similar to that achieved by a diode. However, as the time needed for the ions to pass through the membrane is 10^{-3} to 10^{-6} seconds though the duration of a half-wave in the mobile telephone range is only approx. 10^{-8} to 10^{-10}, this mechanism is viewed as being too lethargic or inertial and thus regarded as being unlikely to apply for the observed frequency range. A purely mathematical examination of the membrane as a rectifier under modulated high frequency influence was recently presented by Iftekhar Ahmed at a workshop in Zurich [Ahmed and Excell 2005, see also the report on the COST 281 Workshop in FGF Newsletter No. 1/ 2005: Haberland 2005]. The authors also discovered an analytic solution to the problem. However there has so far not been any evidence that their assumptions are based on any biological reality. Thus, on present knowledge, a direct electrical demodulation is seen as impossible, so that the low frequency modulation does not exert any direct effects on the low frequency fields and currents in the body.
- **Thermal demodulation** is based on the mode of action of high frequency fields as they create heat in the body by exciting particle vibrations. If the field is pulse modulated for instance, the body will only be warmed up during the pulse. The situation becomes interesting when the amplitude of the pulses is high in relation to their (temporal) mean, in other words if the pulse length is very short in comparison to the temporal pulse spacing (low duty cycle). The field strengths during pulses can be many times higher than the mean field strength (without the mean field strength itself reaching the limit). The result is a brief period of heating. However, this occurs to greater or lesser extents as a result of the different but characteristic dielectric properties of the various parts of the body (water will heat up more quickly than bones, for instance.) The accompanying expansion due to heat can lead to regular thermo-elastic waves in the body, which correlate with the pulse duration. This phenomenon is seen as the cause of the frequently cited "microwave hearing". Radar and UWB (ultra-wideband) are applications that generate such pulses. These effects are taken into consideration in the exposure limits recommended by the ICNIRP, the International Commission on Non-Ionizing Radiation Protection (see [SSK 1999]): Special regulations apply for pulse modulations that achieve at least 32 times the mean field strength or at least 1000 times the mean power-flux density. These acoustic effects are not possible with mobile radio communication devices: the maximum measured field strength of mobile phones (the duty cycle for the GSM standard is 1:8) varies in the approx. 10 to 100 V/m range, and the pulse length with GSM is 577µs. Microwave hearing has only been observed with field strengths of at least around 2 kV/m and at pulse lengths smaller then 30µs.

- A type of **mechanical demodulation** operates by means of the fact that biological membranes are **polarised by electrical fields.** If the pulsed high frequency fields have sufficient field strengths, forces are induced during the duration of the pulse so that, for instance, pores are formed the in the cell membranes – the so-called "electrical breakdown". As the field strengths needed for this effect are in the kV/m to MV/m range and thus exceed normal exposure limits, this type of demodulation is not subjected to further treatment.

There are a number of other ideas about possible demodulation in biological systems, also believed to be effective below the limits. However, it has so far not been possible to prove their existence. Reference should be made at this point to an article by Kenneth Foster and Michael Repacholi [Foster and Repacholi 2004].

One thing that is subject to particular controversy continues to be the influence of modulated high frequency fields on calcium ions. In the 1970s and '80s, a number of working groups, using slightly differently designed experiments, measured increased calcium efflux from brain tissue – in particular with fields modulated at 16 Hz (close to the modulation frequency of TETRA hand-operated devices). Newer approaches, aimed at repeating these investigations with improved methods (though with different carrier frequencies) have been unable to detect any (demodulation) effect. Attempts have been made to explain how these fields could be demodulated, mostly related to resonance phenomena affecting receptor binding sites and channels of membranes. However, they failed because the fact that such phenomena are disturbed by thermal noise and energy loss due to the surrounding medium was not taken into consideration.

Summary

Summarising, it can be said that demodulation mechanisms do exist in biological systems – though their known effects are covered by applicable exposure limits. Nevertheless a number of studies report on modulation specific biological effects even below the limits. However, in most cases these have not yet been replicated – good outlines are provided by Rainer Meyer and the findings of this year's COST 281 Workshop on the subject of modulation, which was held in Zurich [Meyer 1998, Meyer 2003, Haberland 2005]. Is there a previously unknown demodulation mechanism or are the studies mentioned subject to error? A number of current research projects are looking into this question. These include the German mobile telephony research programme, the mechanism section of which is also concerned with possible demodulations (see [Gimsa et al. 2003]), and the British "Mobile Telecommunications and Health Research" programme, which (among other things) is looking at specific effects of the TETRA system. A conclusive answer to the question of possible modulation-specific effects below valid exposure limits is still to be provided.

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