Study of Pulsed Character of Radiation Emitted by Wireless Telecommunication Systems

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Possible effects of electromagnetic fields on human health are a source of concern for a part of the public opinion. In particular, the "pulsed" character of RF radiated by wireless telecommunication systems to a level below the limit values as defined by radiation safety standards is sometimes presented as an additional risk factor. There is actually no scientific consensus regarding the criteria to distinguish pulsed from non-pulsed wave forms with no ambiguity. Indeed, signals radiated by wireless telecommunication systems show diversified wave forms which strongly depend on technical characteristics such as modulation, synchronization, multiple access and power control. In addition, multicarrier exposure gives rise to a RF field envelope which is different than for single carrier exposure. For example, if several signals of similar amplitude and different frequencies are present, the result of their summation features large amplitude variations (up to several dB). As a consequence, the analysis of several wireless telecommunication systems was carried out by considering single and multicarrier exposures in order to take into account cases of similar radiating sources on the same site.

1. INTRODUCTION

Possible effects of non-ionizing radiation on public health were a prolific source of studies for the last decades. Some of these effects are quite well known and described. They consist notably in induced currents flows effects from extremely low frequencies up to 10 MHz and local heating adverse reactions on living tissues or global thermal stress into the entire body from 100 kHz. These known effects have led to current sanitary recommendations in the radiofrequency spectrum range, with safety factors for occupational and public exposure [1][2][3]. Amongst still controversial issues, the waveform, related to modulation schemes, is often considered as an additional risk factor by the way of so-called “athermal effects”. In particular, this topic focuses on pulsed character of measured telecommunication signals. A first difficulty is that no consensual definition of pulsed waves has been proposed by standardization bodies (ETSI, ITU, CEPT, IEEE…), even if this character is commonly admitted for a given set of radio wave systems – e.g. pulse radar, which is used to measure an object position (distance and angular position) and speed. A second match is that despite suspected adverse reaction in weak pulsed electromagnetic fields, there is until now no accepted mechanism that could explain such effects. As a consequence, the relevance of the various parameters defining the shape of the measured signal is unknown. For instance, a pulse is characterized by its duration relative to the complete signal period, its shape (e.g. rectangular, triangular…), its rise time and its fall time. Given the wide signal diversity due to continuous technological evolutions, a first step is to analyze different existing signals and to compare their form in order to prepare future proposal of what could – or should not – be considered as pulsed.

2. MODULATION AND VARYING ENVELOPE

A single sinusoidal signal is the simplest form that can be radiated. However, it is known that no information such as voice, pictures and other data can be transmitted in this way. For this reason, the single-frequency signal – usually termed “carrier” – must be transformed in relation to the message to send. This process is called “modulation”.

There are three basic types of modulation according to the three physical parameters which characterize the carrier signal: amplitude modulation, frequency modulation and phase modulation. For each of these cases, the modulating signal represents the information to transmit.

a) Amplitude modulation

The amplitude modulation consists in varying the amplitude of the carrier according to the modulating signal. For this modulation, the envelope, which is defined as the curve representing the variations of the signal amplitude – that is its maximal value in time – then depicts the modulating signal.

When the modulating signal can take any value in a given range, the amplitude modulation is said to be analog. This is illustrated in Fig. 1. The AM (amplitude modulation) broadcasting is probably one of the oldest application of analog amplitude modulation, see Fig. 2.

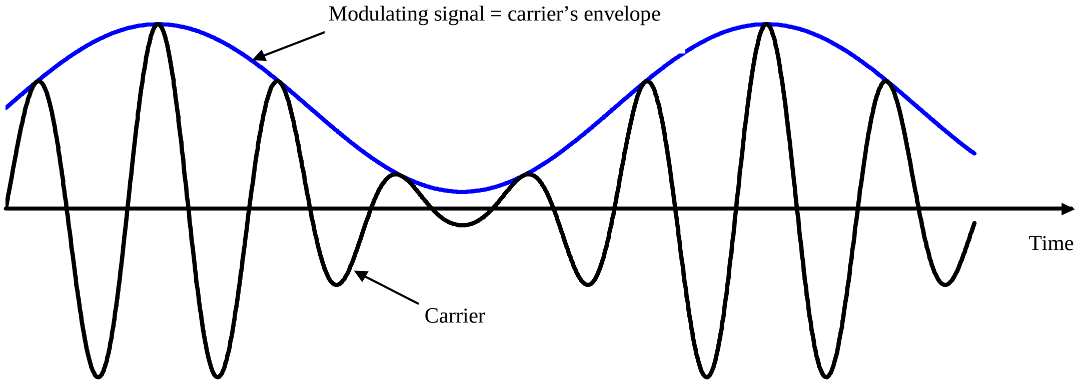

Figure 1. Analog amplitude modulation

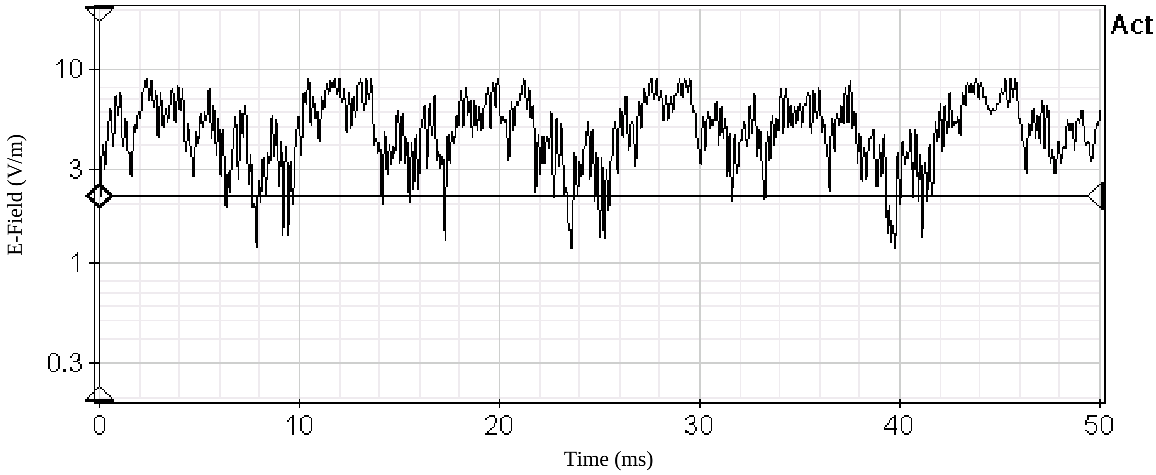

Figure 2. Measured envelope of an AM broadcasting carrier
(central carrier frequency: 620 kHz – frequency filter: 40 kHz – time resolution: 25 µs)

Conversely, if the amplitude of the modulating signal can only take discrete values, the modulation is said "digital" and the envelope features discrete variations. Fig. 3 represents a simple case of digital amplitude modulation, where the modulating signal has a rectangular shape which takes the "1" value when the carrier has to be emitted and the "0" value if not. This particular modulation, called "OOK" (on-off keying), is used by RFID (radiofrequency identification) systems. Let us note that the on and off sequences' duration is related to the value of the transmitted bits.

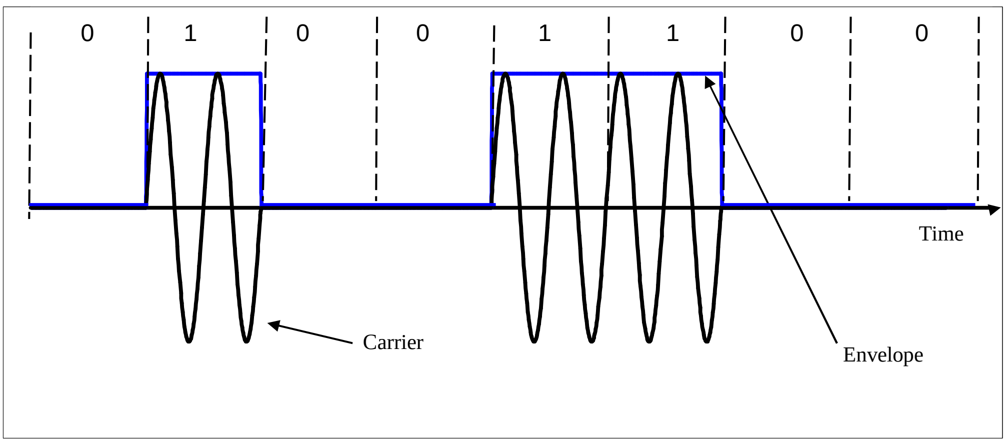

Figure 3. OOK modulation

b) Frequency modulation

Frequency modulation consists in varying the frequency of the carrier according to the modulating signal, as shown in Fig. 4 where T and f are respectively the instantaneous period and frequency. It is considered as analog if the carrier frequency can take any value in a given range. This modulation technique is used in FM (frequency modulation) broadcasting. Fig. 5 depicts the measured envelope of such a signal.

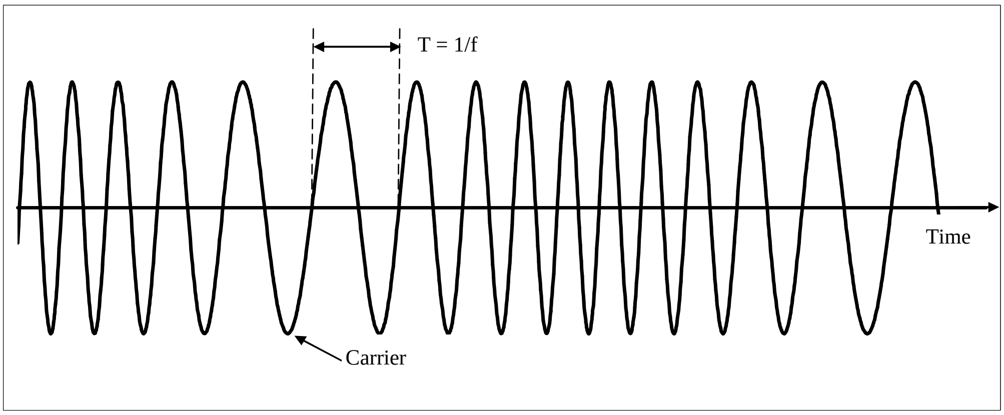

Figure 4. Analog frequency modulation

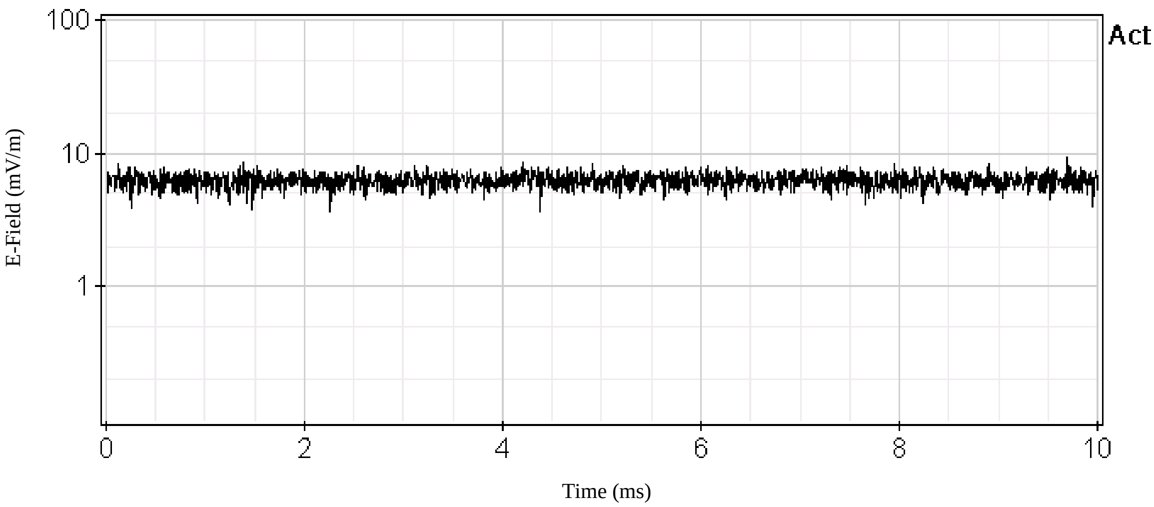

Figure 5. Measured envelope of a FM broadcasting carrier
(central carrier frequency: 90.5 MHz – frequency filter: 200 kHz – time resolution: 5 µs)

FSK (frequency-shift keying) is a particular case of digital frequency modulation, for which the frequency carrier can be equal to only two values, one corresponding to the binary 0 value, the other one to the 1 value.

Let us remark that frequency modulation does not affect the amplitude – thus the envelope neither – of the signal carrier, no matter it is analog or digital.

c) Phase modulation

Phase modulation consists in varying the carrier phase according to the modulating signal. As for frequency modulations, it is analog when the carrier phase takes any value in a given range; digital if it only takes some discrete values. A simple case of digital phase modulation is BPSK (binary phase-shift keying) for which the phase ϕ equals 0° or 180° related to the transmitted binary digit 0 or 1 respectively. Another example is QPSK (quadrature phase-shift keying) for which the phase vary amongst four discrete values in order to represent four 2-bit symbols. Both are illustrated in Fig. 6, including the reference signal (in blue with a lower amplitude scale) as a comparison.

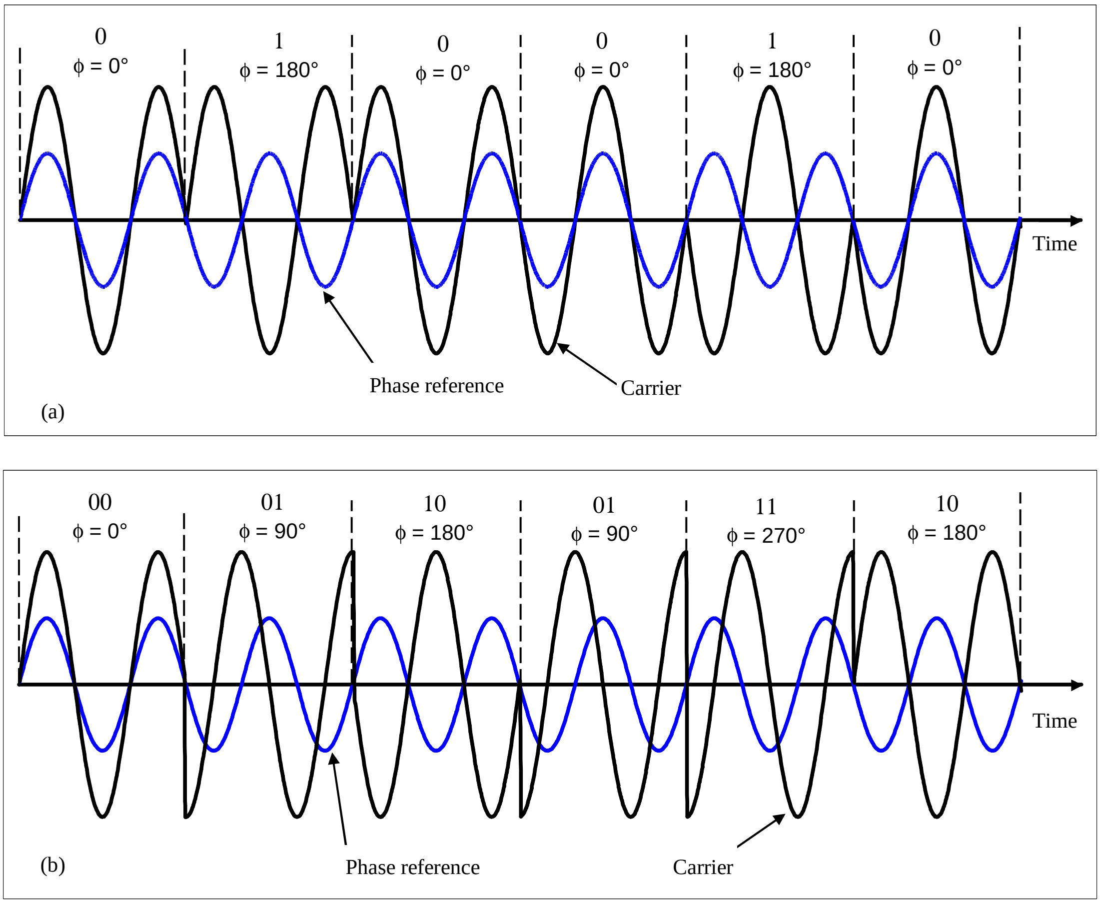

Figure 6. Phase modulation: reference carrier signal (blue), BPSK modulated signal (a) and QPSK modulated signal (b)

Like frequency modulation, phase modulation does not affect significantly the carrier envelope (in fact, there are very brief discontinuities the duration of which is comparable to the carrier period in most cases). However, many modulation schemes combine amplitude and phase modulations.

d) Synchronization and multiplexing

We have seen that amplitude modulation techniques impact the envelope of the radiated signal, the shape of this envelope being related to the message to transmit. However, this envelope may also be modified for synchronization and multiplexing purpose. Although these two functions affect the signal envelope in a similar way as “pure” amplitude modulation does, we shall use the expression “amplitude variations” instead of “modulation”. There is no indication that these two types of variations would affect the living tissues in a different way. This distinction is only introduced to avoid confusion between amplitude variations which are related to the carried message (what is termed “modulation”) and those which are due to other reasons.

A typical illustration is the signal radiated by GSM (Global System for Mobile Communications) base stations, which use TDMA (time division multiple access) to allow simultaneous communications with several mobile phones with only one carrier: each GSM carrier is divided into 8 “time slots”, the duration of which is equal to 577 µs. Each time slot is allocated to one communication. A perfect synchronization of mobile phone and base station allows successive time slots separation. With most base stations, the time slot includes a 547.6-µs long transmission sequence followed by a 29.4-µs long “zero-emission” one (even if one may assume that the 29.4-µs long “zero-emission” sequence is used to allow mobile and base station synchronization, we shall see later that such synchronization may be achieved in a different way). Fig. 7 shows a measured envelope of a BCCH (Broadcast Control Channel) signal. Although the GSM standard uses GMSK (Gaussian minimum shift keying) which is a constant-envelope modulation (the amplitude is not influenced by the message to transmit), the envelope of its carrier features periodic drops.

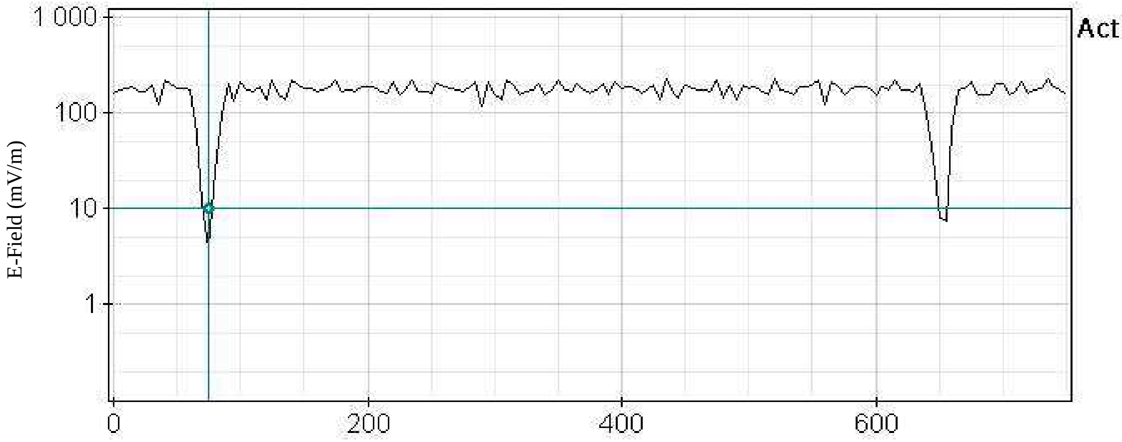

Figure 7. Measured envelope of a GSM base station BCCH carrier
(central frequency: 949.4 MHz – frequency filter: 200 kHz – time resolution: 5 µs)

Some systems use a technique called "time-division duplex" (TDD) where the same frequency is used alternatively for transmission and reception. Their respective durations can depend on the volume of data to be transmitted in each direction. Although this technique is available with some third generation networks, it is not presently used in Belgium where the UMTS (Universal Mobile Telecommunications System) network operates FDD (frequency-division duplexing) mode where two different frequency bands allow simultaneous two-way transmission. Other systems using TDD are for instance DECT (Digital Enhanced Cordless Telecommunications), Bluetooth, WLAN (Wireless Local Area Network, also called "Wi-Fi" in most countries) and WiMAX (Worldwide Interoperability for Microwaves Access).

Another example of envelope variations for synchronization purpose is the analog television signal, see Fig. 8; this shows amplitude variations at 15,625 Hz which allow lines synchronization. The variations between two pulses are due to amplitude modulation which represents the luminance and the chrominance of each pixel. Moreover, Fig. 9 reveals synchronization pulses for frames at a frequency of 50 Hz. Let us note that the signal comes back to a non-null value after these peaks.

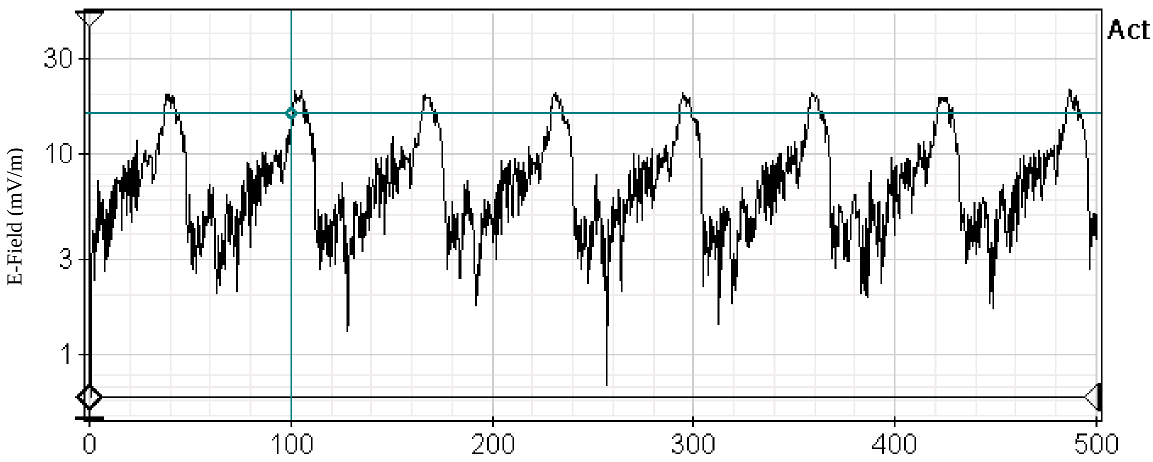

Figure 8. Measured envelope of an analog television signal
(central frequency: 783.25 MHz – frequency filter: 3.2 MHz – time resolution: 312.5 ns)

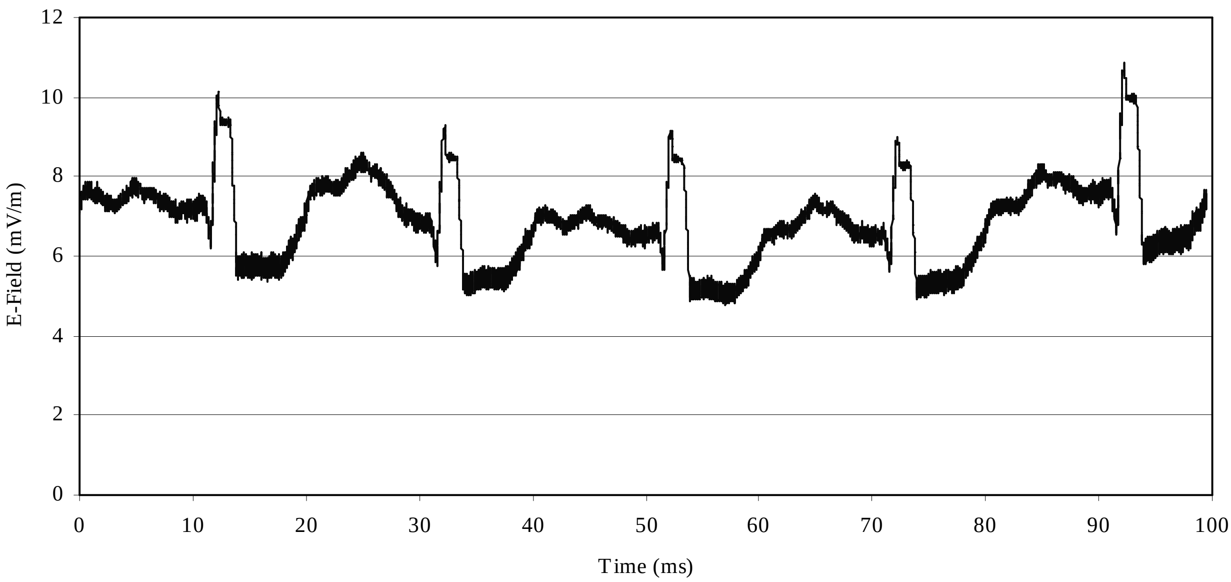

Figure 9. Measured mean envelope of an analog television signal
(central frequency: 783.25 MHz – frequency filter: 10 MHz – time resolution: 504 ns)

3. MULTIPLE-CARRIER EXPOSURE

We previously focused on signal envelopes corresponding to single-carrier transmission, which actually does not account for most cases: on the one hand, a single transmitter can radiate several carriers; on the other hand, several carriers from different transmitters may be present at the same place. As a consequence, we need to take into account every component of the spectrum close to significant in general. Given that interferences between components emitted from far frequency ranges are quite negligible and that summing signals using different modulation techniques results in attenuating, smoothing rapid variations, we will from now on focus on analyzing the resulting envelope of different emitted actual signals of the same type. That is, similar envelope variations (due to modulation, TDMA, TDD or synchronization) for carriers in a same frequency range, with comparable measured electromagnetic field intensities.

Summing several radiofrequency signals can produce resulting envelopes that are very different from the single-carrier case. A good illustration is the FM broadcasting signal. As we know, summing two sine waves whose frequencies are close to each other results in a beat phenomenon: for instance, two carriers at 99 MHz and 101 MHz with the same amplitude produce a new carrier at 100 MHz (mean value of both frequencies), but with an amplitude varying at a 1-MHz rate (that is, half the difference between both frequencies). Actual FM broadcasting transmitter may give rise to a much more complex situation because there are often more than two carriers radiated from the same antenna site. Fig. 10 shows the frequency spectrum of some FM carriers around 100 MHz. The highest peaks come from sources located close to the measurement site; the weakest have been produced by emitters located further. The envelope resulting from the summation of all these FM carriers is depicted on Fig. 11 which points large amplitude variations with a maximum to minimum ratio reaching 20, which can be considered as an extinction (dividing the electromagnetic field by 20 corresponds to dividing the power density by 400). This must be compared with Fig. 5 whose envelope depicts quasi-constant amplitude. From this point, it is clear that several components with constant, similar amplitude produce a cumulated electromagnetic field that strongly varies in time. The fact that several similar carriers may be present at the same place at comparable levels should be taken into account when the pulsed character of radiofrequency waves is analyzed.

The multiple interruptions are due to the fact that summing carriers of different – but close – frequencies together causes a slow shift of a component peaks. This is shown in Fig. 12 which depicts three sinusoids with close frequencies. At some instants, the result of the summation is rather high (e.g. at time t_1); later the summation drops to a nearly null value (e.g. at time t_2 and t_3). Let us note that the interruptions that could be regarded as extinctions in Fig. 11 do not exceed a few hundred times the period of a carrier (about 50 ns which is the time resolution). In comparison, interruption duration for GSM standard reaches almost 30,000 times the carrier period (29.4 µs × 949.4 MHz ≅ 28,000). Let us insist on the fact that this can occur when the different components are emitted at quite close frequencies and with similar amplitudes: for instance, when two radiation sources produce a field of 1 V/m and 0.1 V/m respectively, the second one has only a negligible effect on the cumulated field amplitude because it is one hundred times (10^2) weaker than the first one.

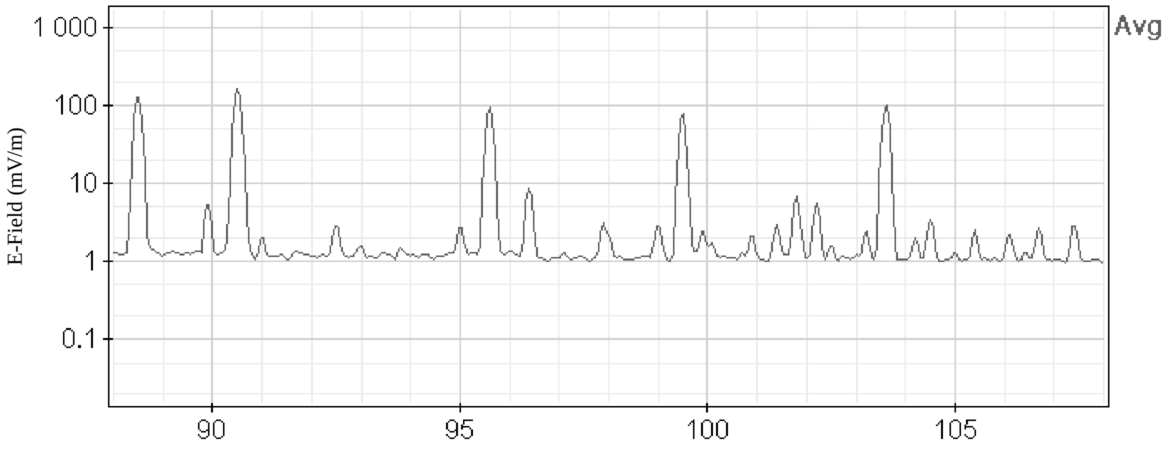

Figure 10. Measured spectrum within the FM broadcasting band (frequency filter: 100 kHz)

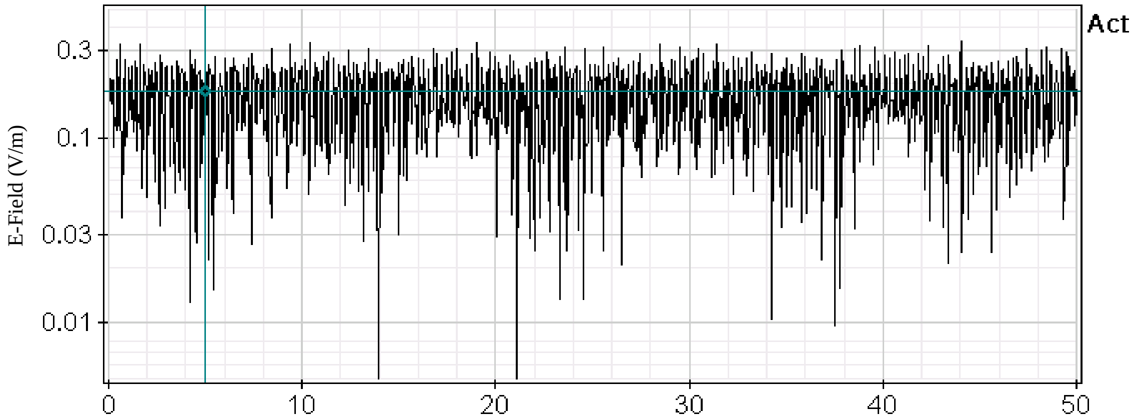

Figure 11. Measured envelope of cumulated radiation from more than one FM broadcasting emitter (central frequency: 98 MHz – frequency filter: 20 MHz – time resolution: 50 ns)

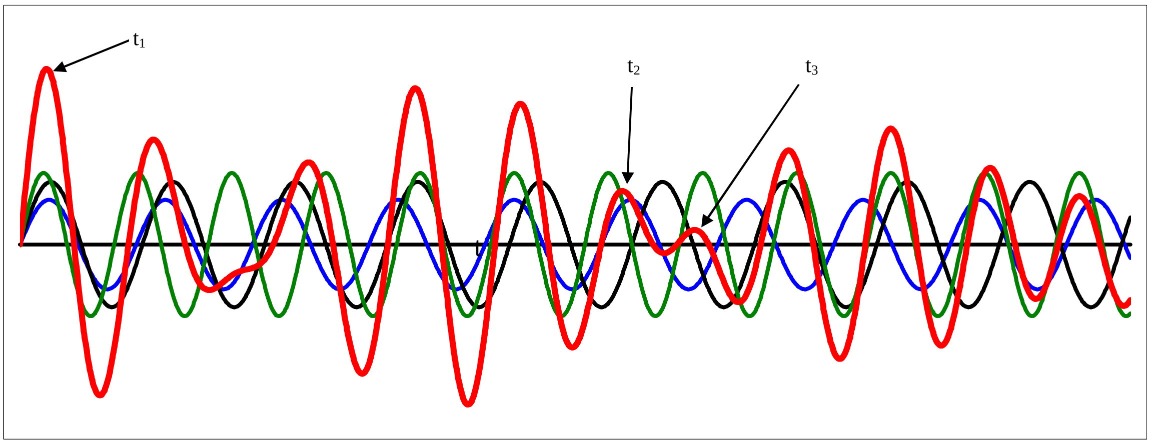

Figure 12. Measured envelope of cumulated radiation (red) of three components with close frequencies

Typical cases of exposure to several carriers occur in the vicinity of mobile phone base stations. It is either due to the fact that one single antenna radiates several carriers or because there are several antennas on the same site or at places where carriers from several antenna sites are received at nearly the same level. The result of such a summation is illustrated by the example in Fig. 13 which highlights amplitude variations due to the traffic channels and with the periodic extinctions every 577 µs.

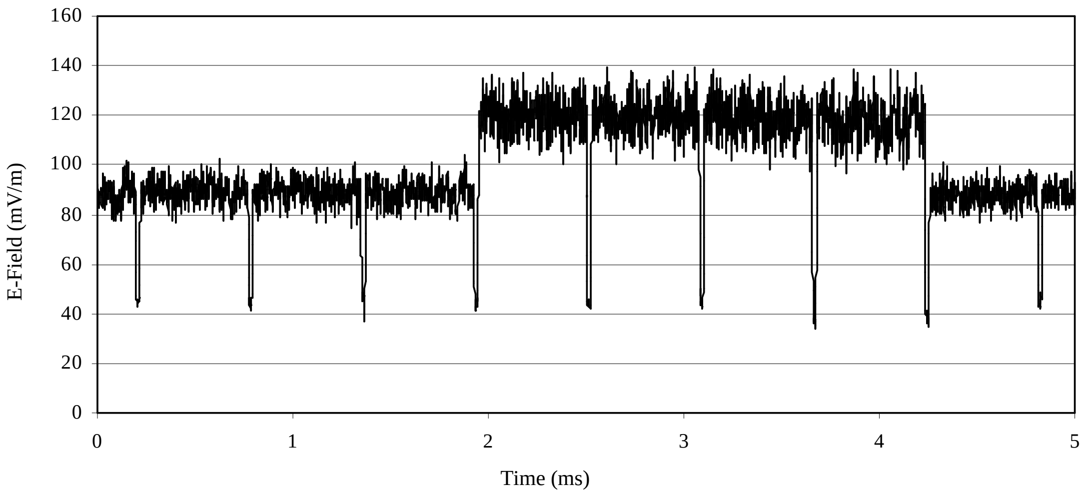

Figure 13. Measured mean envelope of a cumulated GSM signal emitted by several base stations (central frequency: 940 MHz – frequency filter: 32 MHz – time resolution: 1375 ns)

4. MEASUREMENTS AND ANALYZES

a) Method and equipment

A persistent difficulty when classifying telecommunication signals according to their hypothetical adverse effects is that there is presently no accepted mechanism that could link the pulsed character of a low-intensity radiofrequency field to such effects. Moreover, no clear definition of a "pulsed" wave exists. In addition, some signals are considered as pulsed even if their amplitude features slow and periodic variations. In such cases, the Fourier analysis reveals some low frequency components that the living tissues could maybe demodulate in some way even if the field is weak in comparison to the level required to produce thermal effects.

From then, a first step is to analyze and compare the envelope of usual signals radiated by some telecommunication systems in order to help for classifying them into the "pulsed" or the "not pulsed" category as a next step. In particular, let us remind that some analog signals may have a rapidly varying envelope and that some digital modulations do not feature amplitude variations.

Because the situations of simultaneous exposure to several carriers are frequent (e.g. from mobile phone base stations, FM broadcasting antennas…), the envelope of the cumulated field must be considered when it is relevant. Given that summing fields radiated in the same frequency band but with different envelope shapes tends to smooth the strongest variations of amplitude and because of the wide diversity of existing situations, this paper will focus on signals of the same type in a the same frequency range. Moreover, let us remind that a measured cumulated electromagnetic field in a given frequency band is mainly influenced by the one with the highest intensity, so that we have to sum fields with similar amplitudes to get reliable results.

Unfortunately, the scientific and technical literature does not always provide useful information regarding the carrier envelope pattern, especially when complex modulation and multiplexing techniques are used. Performing envelope detection records of the studied signals is in general more efficient, especially when exposure to several carriers is considered.

Measurements were carried out with the equipments listed here below:

- a field meter NARDA SRM 3006 which is similar to a spectrum analyzer;
- one triaxial antenna for measuring the electric component of electromagnetic field from 27 to 3000 MHz;
- one triaxial antenna for measuring the electric component of electromagnetic field from 400 to 6000 MHz;
- a loop-antenna sensitive to the magnetic component between 9 kHz and 80 MHz.

The spectrum analyzer has been used in "Spectrum Analysis" mode to determine the carriers present in a given frequency range. The "Scope" mode performs signal envelope detection and recording. For a given duration, it displays the amplitude variations of the sum of all the frequency components within a chosen frequency band (called the frequency filter). The filter bandwidth must be large enough in order that all the considered carriers are taken into account. Let us mention that in order to get the best time resolution in Scope mode, envelope detections have been carried out with only one axis of triaxial antennas active.

If the sweeping time is less than 16,000 times the time resolution, the device shows the curve obtained during a measurement (“Act” is then written on the figure’s right side) and the figure caption mentions “Measured envelope...”

If the sweeping time is greater than 16,000 times the time resolution, the device gives the maximum, the minimum and the mean values. The figure caption then says: “Measured mean envelope...”

All measurements concern operating devices in normal conditions, so that transient signals radiated when switching on and off have not been taken into account.

b) Frequency modulation broadcasting

As mentioned above, radio emission due to a FM broadcasting source does not cause notably varying amplitude, see Fig. 5. Conversely, the amplitude of the summed electromagnetic field reveals important, irregular and very short (a few times the signal period) variations of amplitude, see Fig. 11.

c) Amplitude mdulation broadcasting

According to Fig. 2, measured envelope of AM broadcasting often depicts reductions of about 15 dB due to the analog modulation within about 100 µs, that is a few hundred times the carrier period which is 621 kHz.

d) Analog television

Fig. 8 and Fig. 9 depict the envelope of a signal recorded in Brussels, Belgium. They show rapid variations in amplitude especially due to synchronization pulses. For instance, Fig. 8 reveals a signal drop of about 16.5 dB. Let us note that analog television signal is generally admitted as pulsed [4]. Because there was only one analog television emitter left in this part of the country, it was not worth measuring other components in the same frequency band.

e) Digital Audio Broadcasting

Measurement of a DAB (Digital Audio Broadcasting) signal has been carried out in Brussels. The results are shown in Fig. 14. As described in ETSI standards, the signal is interrupted every 96 ms during 2.543 ms for synchronization purposes.

DAB+ is an upgrade of DAB which uses improved audio data compressing. T-DMB permits to transmit video. The DAB, DAB+ and T-DMB systems differ from coding but radiation is similar.

Let us remark that there is generally only one carrier radiated at a given place, so that there is no worth measuring the cumulated field of several DAB emitters.

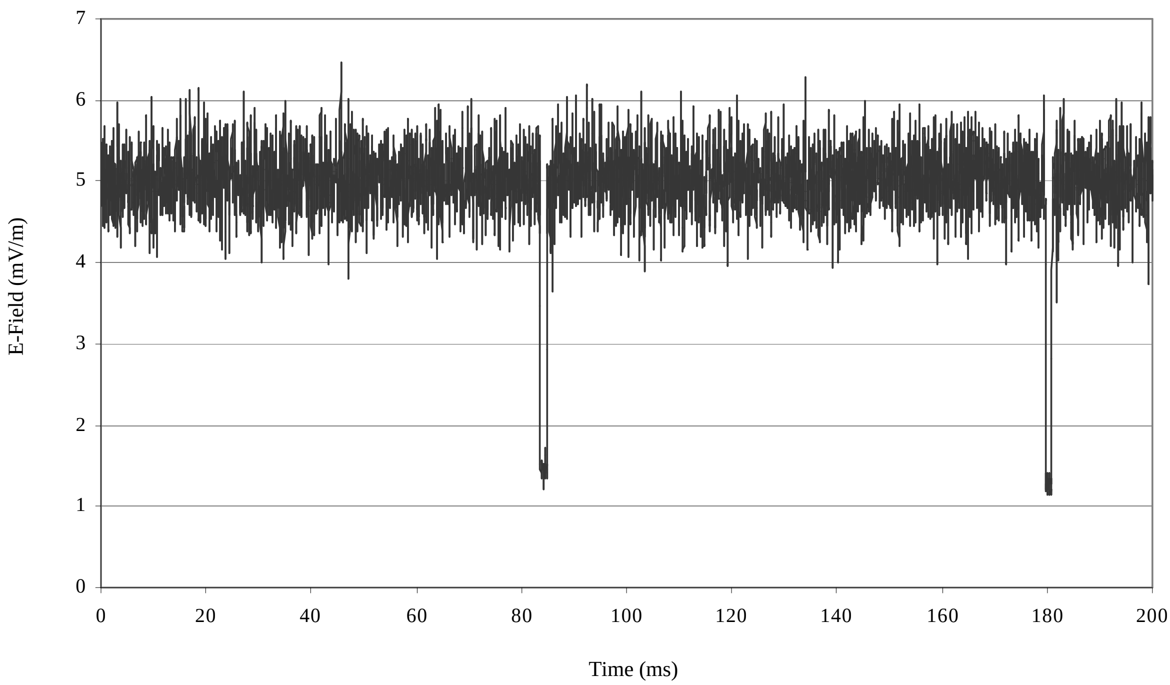

Figure 14. Measured mean envelope of a DAB signal
(central frequency: 226 MHz – frequency filter: 1 MHz – time resolution: 52 µs)

f) Digital Video Broadcasting - Terrestrial

The envelope of the radiated DVB-T (Digital Video Broadcasting – Terrestrial) signal has been measured at different time scales, see Fig. 15 and 16.

This shape is due to the use of OFDM (orthogonal frequency-division multiplexing) which consists in transmitting a set of orthogonal sub-carrier signals with frequencies close to each other. This results in irregular and very short variations (a few hundreds times the carrier's period) similar to the multi-carrier cumulated FM broadcasting envelope, see Fig. 11.

It is noticeable that several DVB-T carriers can be present in the same place. However, the resulting cumulated field is expected to show approximately the same envelope variations as discussed above.

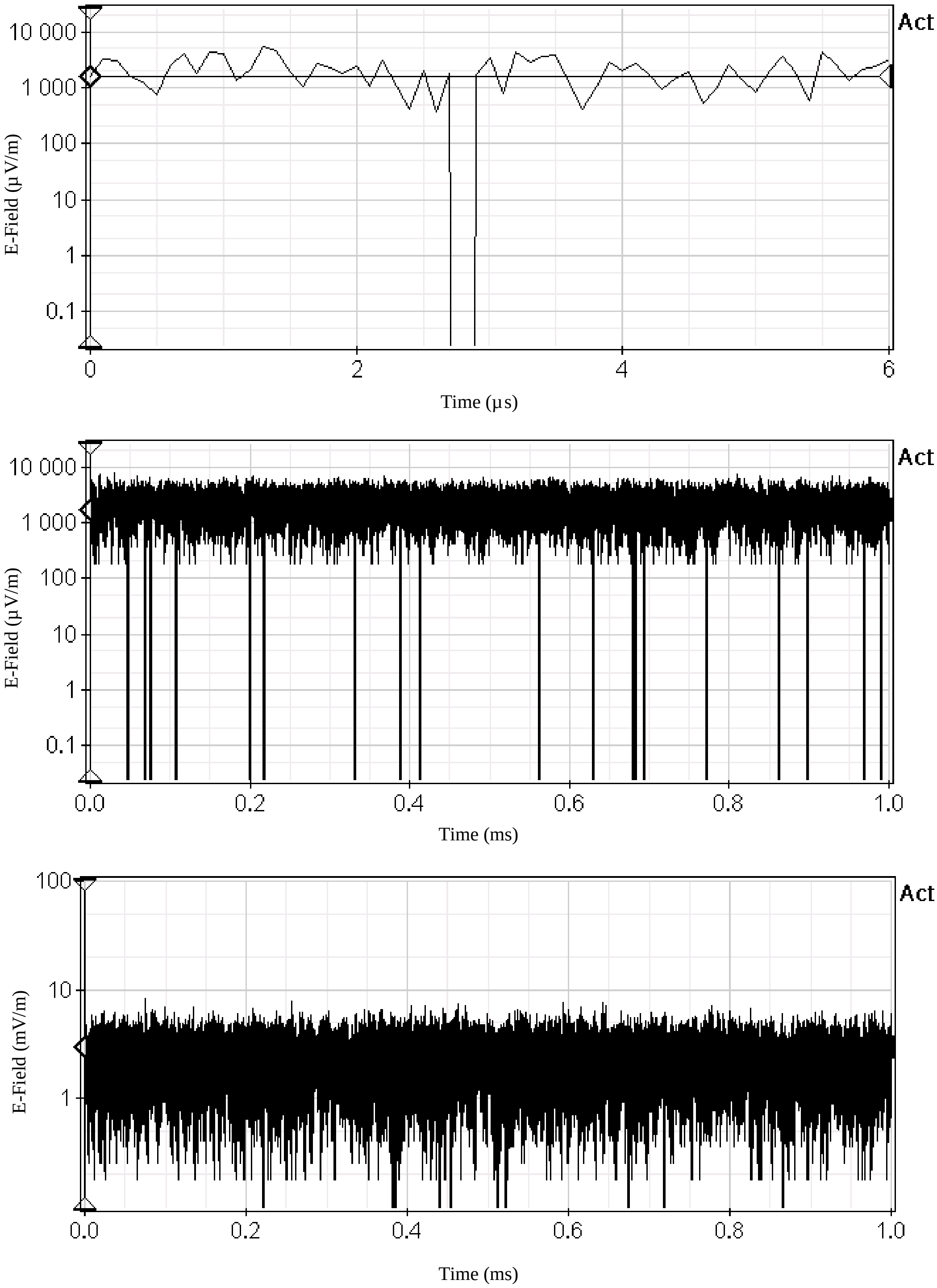

Figure 15. Measured envelope of a DVB-T signal
(central frequency: 650 MHz – frequency filter: 10 MHz – time resolution: 100 ns)

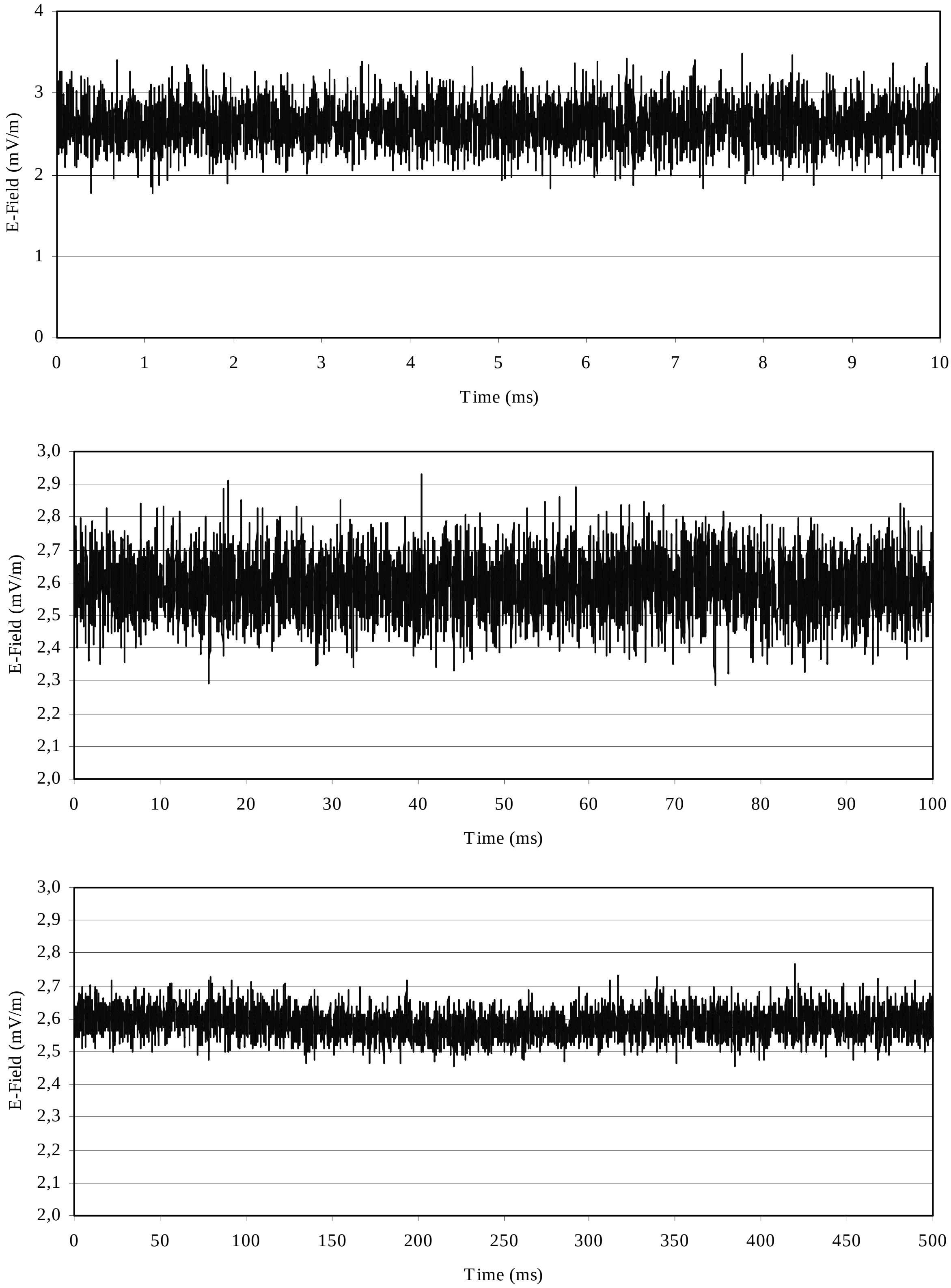

Figure 16. Measured mean envelope of a DVB-T signal
(central frequency: 650 MHz – frequency filter: 10 MHz – time resolution: (a) 2.8 µs; (b) 25.2 µs; (c) 125.2 µs)

g) GSM base stations and 2G mobile phones

Base stations for mobile telephony “2G” can transmit within two frequency bands: between 925 MHz and 960 MHz (GSM) and between 1805 MHz and 1880 MHz (DCS, Digital Cellular System).The frequency of the carriers is the only difference between the two standards. Fig. 7 and 17 illustrate this point at the frequency of the control channel BCCH: both standards use TDMA to share the communication time between the simultaneous users. The transmission is stopped every 547.6 µs during 29.4 µs in the end of each time slot.

Moreover, the amplitude at “traffic carrier” is not constant due to the power control mechanism which does not affect the BCCH carrier. In addition, the transmission is stopped during the “unused” time slots. As a consequence, Fig. 18 and Fig. 19 show intermittent, but regular interruptions of emission.

The HSCSD (High-Speed Circuit-Switched Data), GPRS (General Packet Radio Service) and EDGE (Enhanced Data rate for GSM Evolution) standards have been developed to increase the data rate to a level similar to UMTS (3G). These standards are put together in the so-called “2.5G” systems and are related to the electronic components before the antenna, with no change in the measured envelope.

Let us remark that cumulated field measurements within the whole either GSM or DCS 1800 band show that the envelope still highlights regular interruptions even in the realistic case of several antennas from different operators.

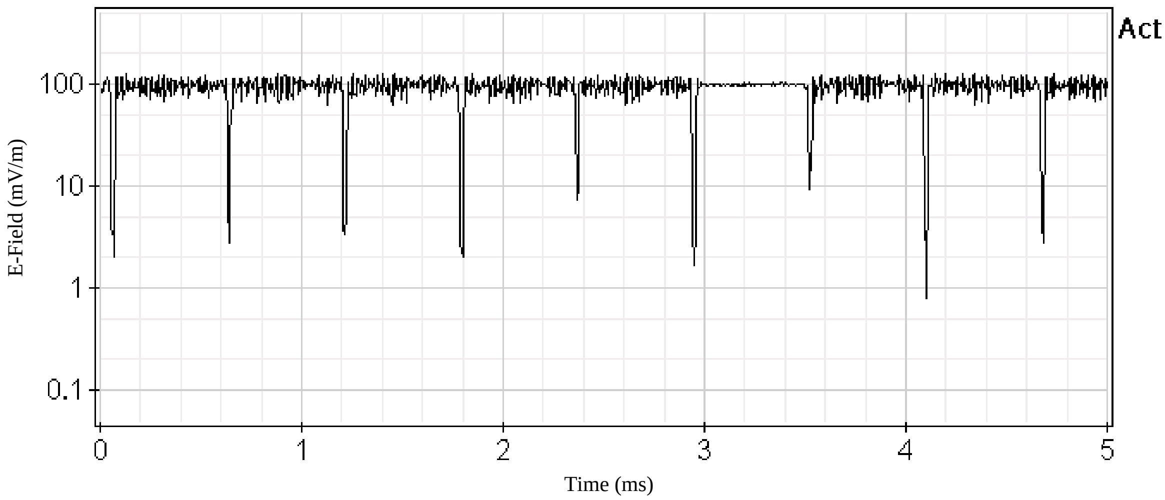

Figure 17. Measured envelope of a DCS base station BCCH carrier
(central frequency: 1826.8 MHz – frequency filter: 200 kHz – time resolution: 5 µs)

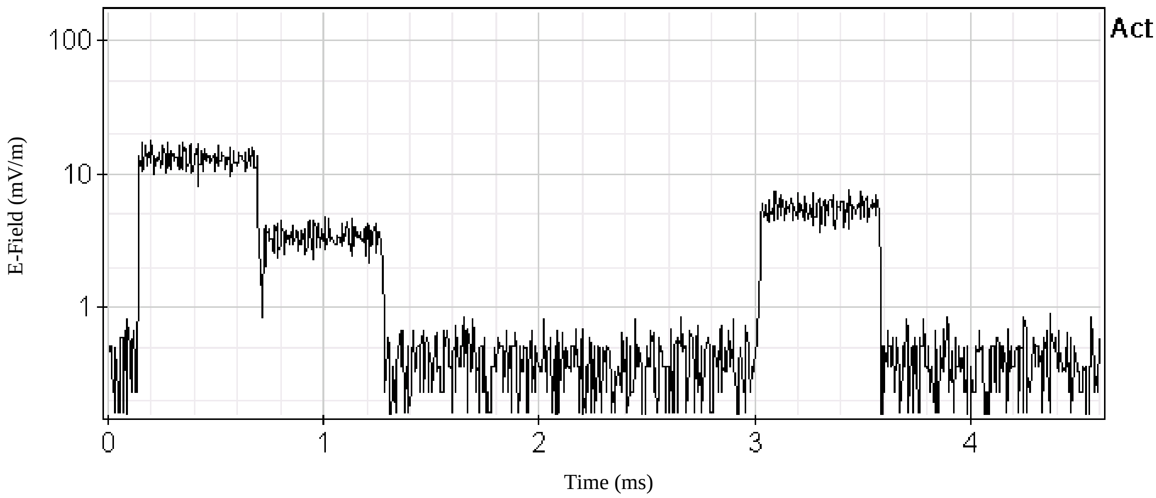

Figure 18. Measured envelope of a GSM base station carrier alocated to a traffic channel
(central frequency: 948.6 MHz – frequency filter: 200 kHz – time resolution: 5 µs)

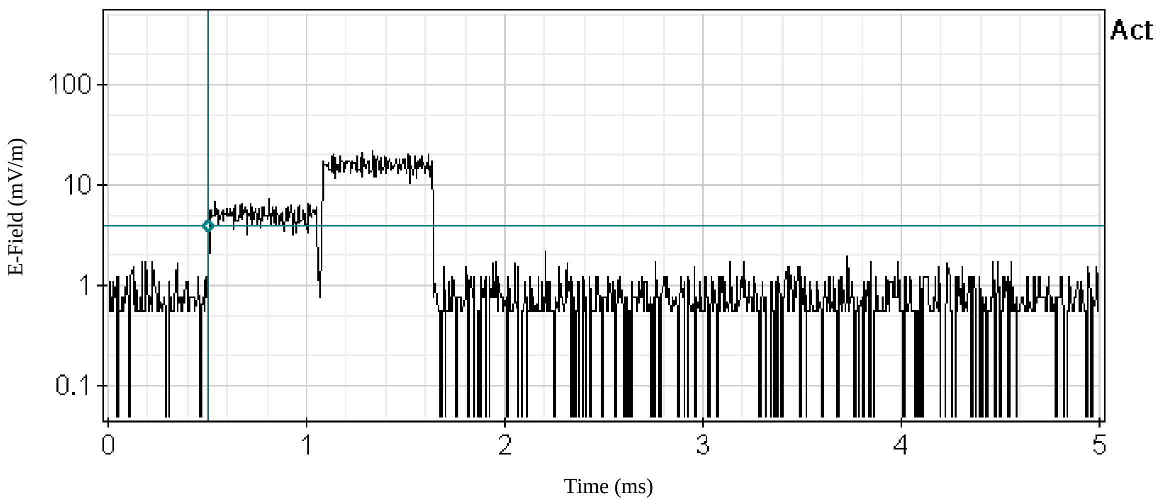

Figure 19. Measured envelope of a DCS base station carrier alocated to a traffic channel
(central frequency: 1813.8 MHz – frequency filter: 200 kHz – time resolution: 5 µs)

Fig. 20 highlights the use of TDMA by the mobile phone (2G): while the GMSK modulation scheme does not imply amplitude variations by itself, a mobile phone transmits only a part of the time, that is 547.6 µs every 4.615 ms, i.e. at a repetition rate of 216.7 Hz.

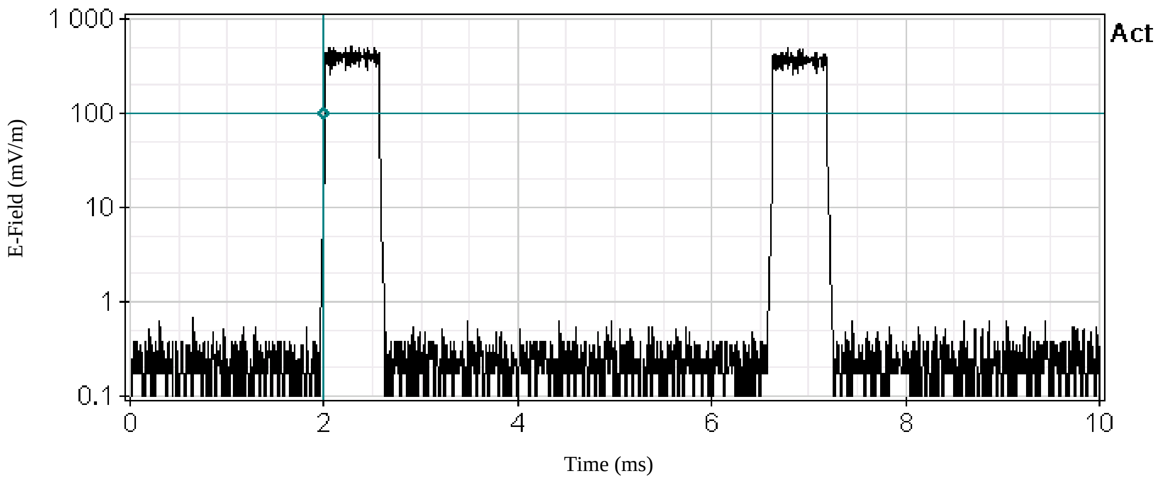

Figure 20. Measured envelope of a GSM (2G) signal
(central frequency: 886.8 MHz – frequency filter: 200 kHz – time resolution: 5 µs)

h) GSM-R network

The GSM-R network operates for railways companies and its physical layer characteristics are very similar to the GSM (2G) ones, including the use of TDMA techniques. However, the measurements that have been carried out in Belgium do not feature any interruption of the carrier signal as illustrated in Fig. 21. This shows that it is possible to use TDMA with uninterrupted transmission, provided that the synchronization of successive time slots is controlled by another process.

Conversely, measurements of GSM-R signals radiated from Germany that were carried out in Hergenrath, Belgium, show that the German GSM-R network uses TDMA by stopping the transmission every 547.6 µs during 29.4 µs as shown in Fig. 22.

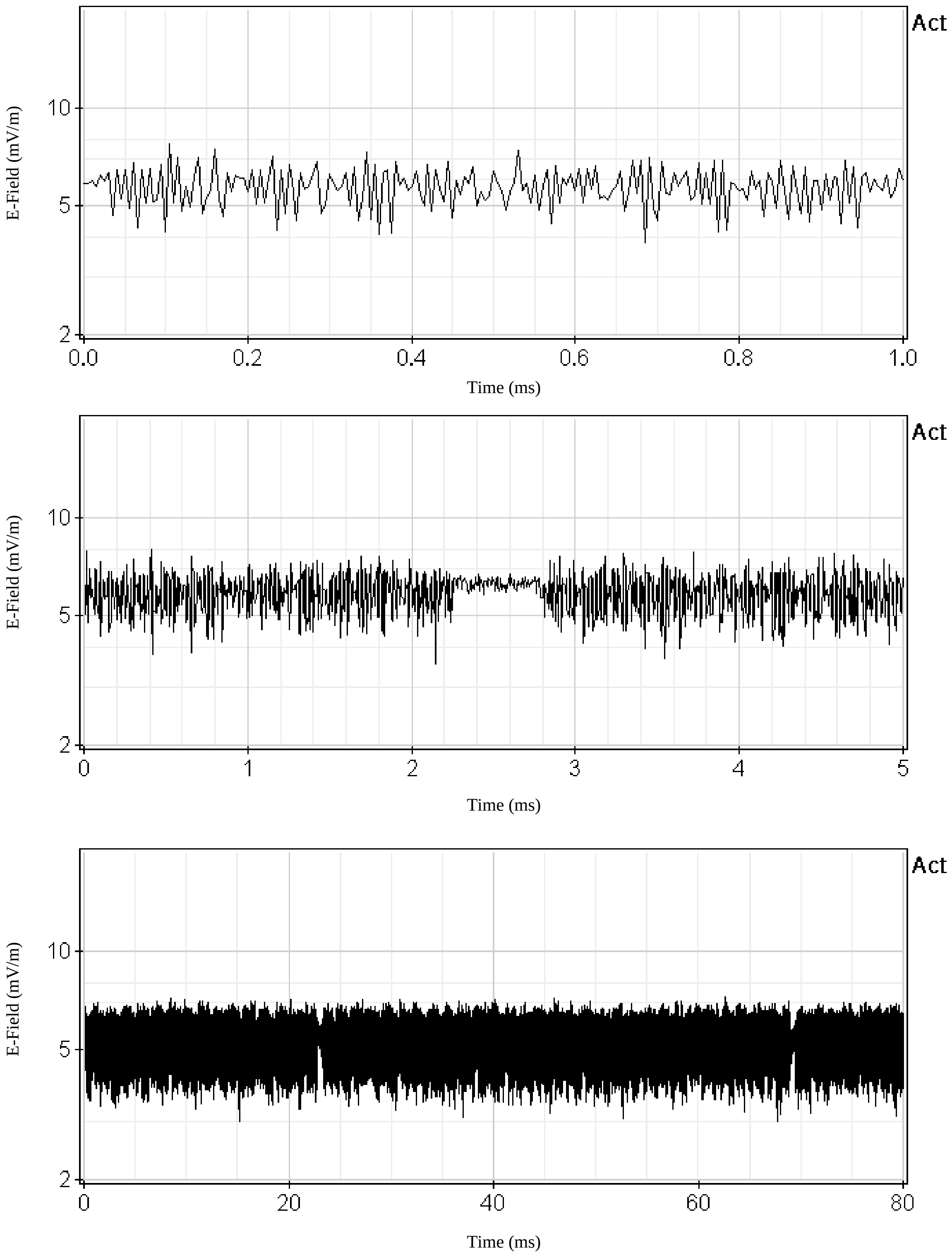

Figure 21. Measured envelope of a GSM-R base station BCCH carrier
(Belgium – central frequency: 923.6 MHz – frequency filter: 200 kHz – time resolution: 5 μs)

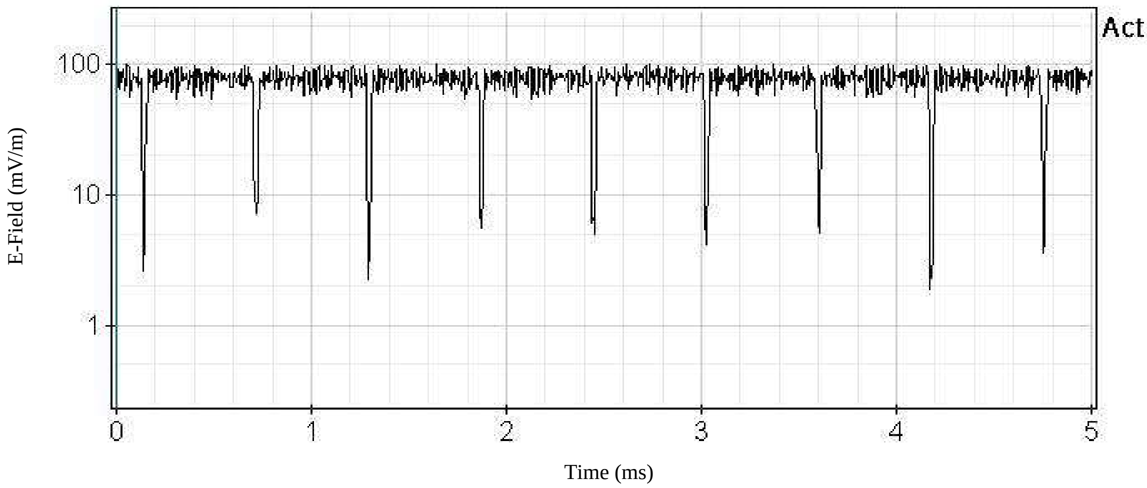

Figure 22. Measured envelope of a GSM-R base station BCCH carrier
(Germany – central frequency: 921.4 MHz – frequency filter: 200 kHz – time resolution: 5 µs)

i) Terrestrial Trunked Radio network

TETRA is a digital radio communication system mostly used by emergency services. Like the GSM standard, it uses the time-division multiple access techniques, with noticeable difference such as the time slot duration (14.2 ms instead of 577 µs) and the number of time slots per frame (4 instead of 8).

It has been pointed that time-division multiple access produces periodic interruptions of the radio transmission in some cases (e.g. GSM) but not necessarily (see GSM-R section).

Fig. 23 and 24 show a TETRA signal's envelope at a MCCH (Multidestination Control Channel) frequency which is a control channel that plays the same role than BCCH in GSM standards. The periodic interruptions do not correspond to the duration of a time slot: the base station actually ceases emitting during less than 6 ms every 4.08 s in order to preserve amplifiers linearity. These interruptions are ensured by the BLCH (Base station Linearization Channel).

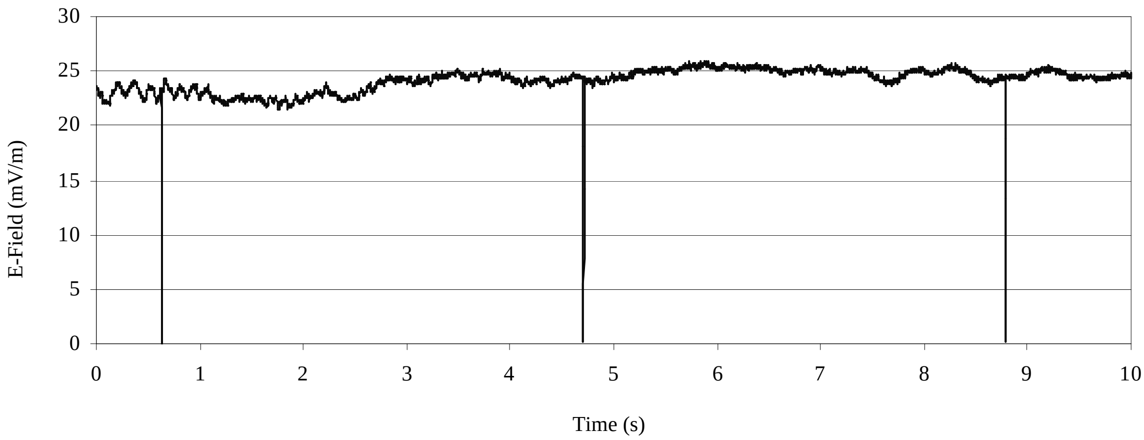

Figure 23. Measured mean envelope of a TETRA signal, MCCH carrier
(central frequency: 390.86 MHz – frequency filter: 50 kHz – time resolution: 2.56 ms)

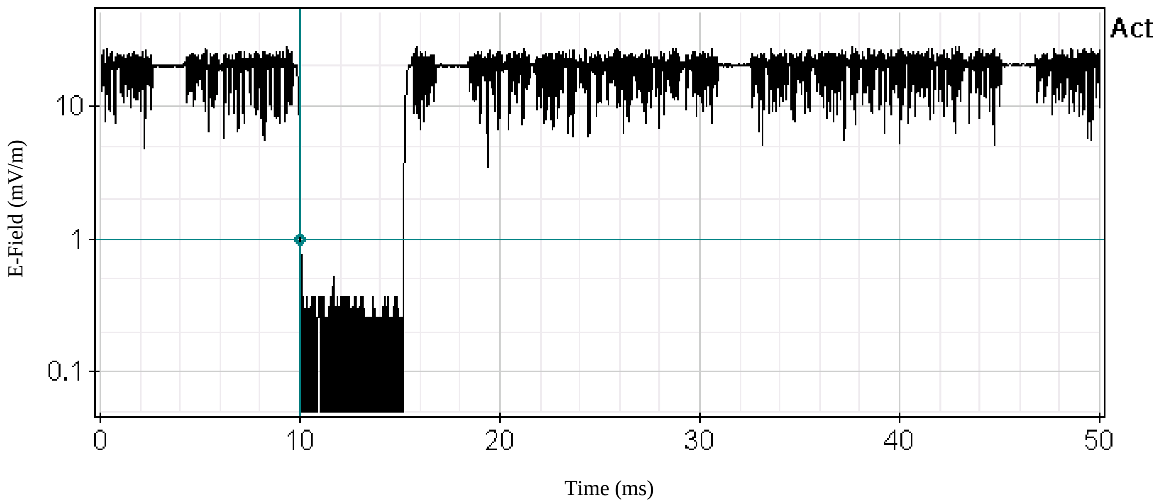

Figure 24. Measured envelope of a TETRA signal, MCCH carrier
(central frequency: 390.86 MHz – frequency filter: 50 kHz – time resolution: 20 µs)

The same signal has been measured in order to take into account the traffic channels and the other MCCH carriers on the same site. Fig. 25 shows no deep difference with the narrow-band measurement except that the amplitude does not return to zero due to the measurement bandwidth. It is noticeable that the field produced by other sites is negligible due to the generally little density of TETRA antennas.

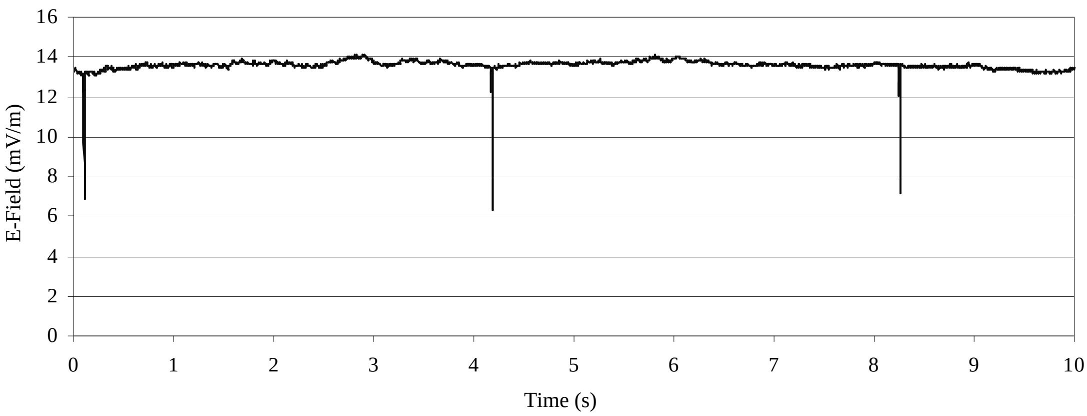

Figure 25. Measured mean envelope of a TETRA signal, MCCH carrier
(central frequency: 393 MHz – frequency filter: 6.4 MHz – time resolution: 5 ms)

Besides, let us note that the TETRA mobile phones only transmit during a time slot to four (instead of one to eight for GSM), so that the signal's envelope is similar to Fig. 20.

j) Universal Mobile Telecommunications System network

As mentioned in §2.d, UMTS has been designed to operate by two main modes which are time-division duplex and frequency-division multiplexing. We know that TDD systems allocate the communication time by switching between transmission and reception so that the method produces transmission interruptions.

UMTS-FDD is quite different because the base station and the mobile phone transmit in distinct frequency ranges, (between 2110 MHz and 2170 MHz from the base station to the mobile phone and between 1900 MHz to 1980 MHz from the mobile phone to the base station). All the communications through a given operator network can simultaneously use the same frequency because the identification is achieved by the code. This is the so-called CDMA (code division multiple access) method. Because traffic and control channels lay over each other, a 5-MHz bandwidth may contain several carriers. This is taken into account in the figure captions for UMTS signals' envelope below: Fig. 26 to 31 represent the envelope of UMTS-FDD radiation in a 5-MHz band, with brief interruptions often not longer than a point of the curve. Given the time resolution of Fig. 26 and the approximate frequency of 2 GHz, the fall duration is not more than 400 times the carriers' period of 0.5 ns. This is approximately the same ratio as for FM cumulated field envelope in Fig. 11.

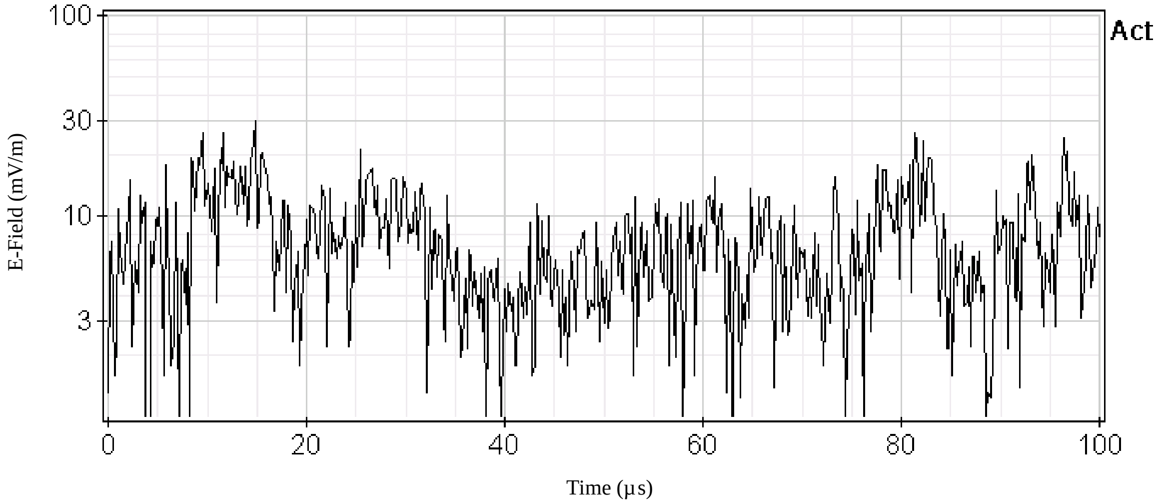

Figure 26. Measured envelope in a 5-MHz band allocated to UMTS-FDD
(central frequency: 2162 MHz – frequency filter: 5 MHz – time resolution: 200 ns)

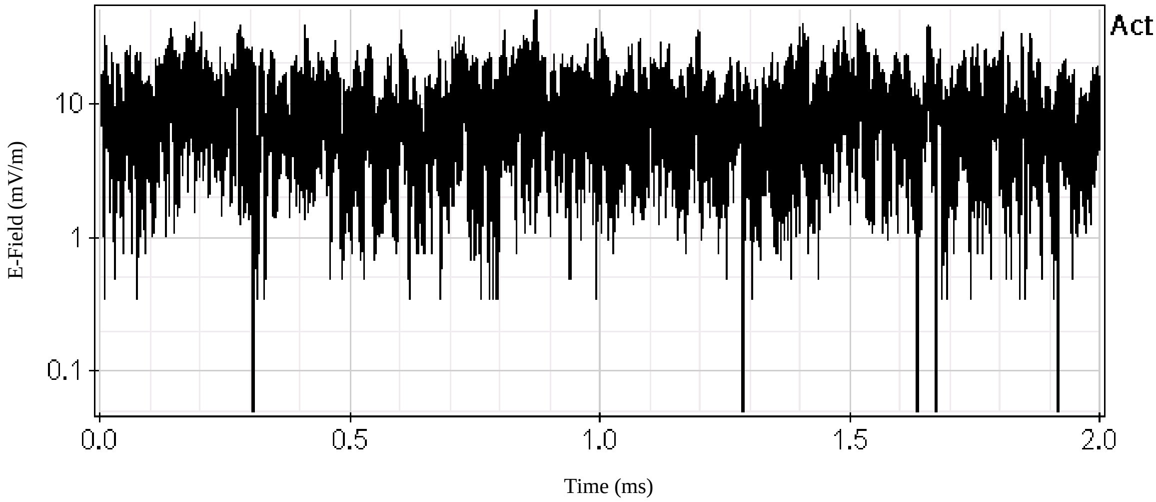

Figure 27. Measured envelope in a 5-MHz band allocated to UMTS-FDD
(central frequency: 2112.6 MHz – frequency filter: 5 MHz – time resolution: 200 ns)

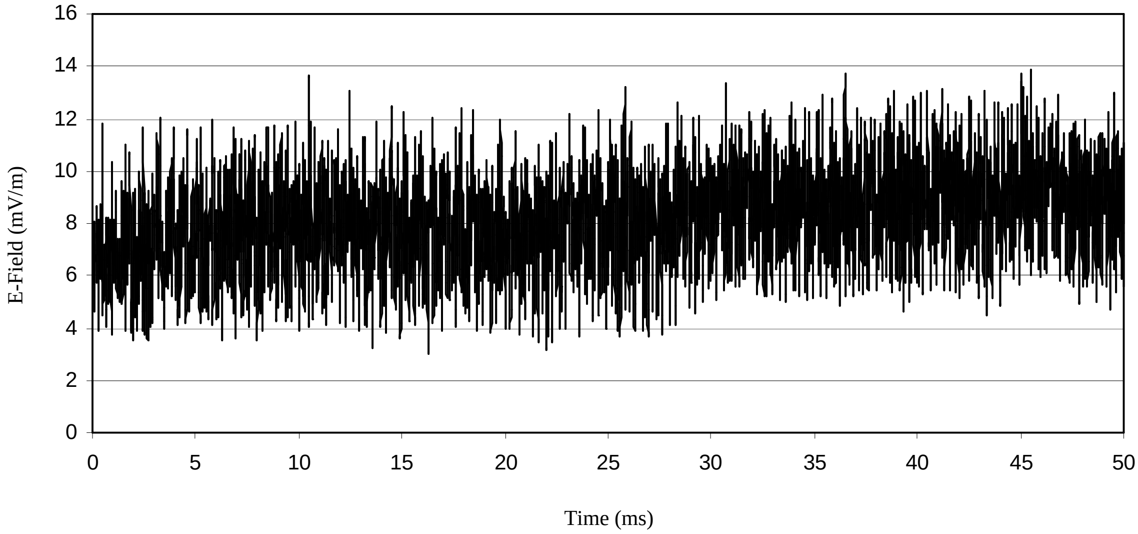

Figure 28. Measured mean envelope in a 5-MHz band allocated to UMTS-FDD
(central frequency: 2162 MHz – frequency filter: 5 MHz – time resolution: 200 ns)

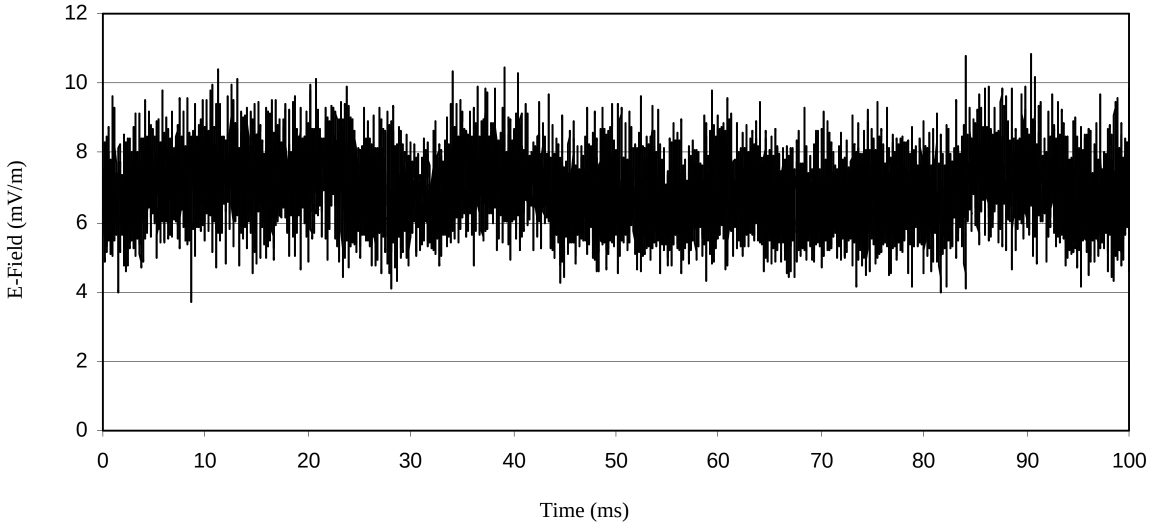

Figure 29. Measured mean envelope in a 5-MHz band allocated to UMTS-FDD
(central frequency: 2162 MHz – frequency filter: 5 MHz – time resolution: 25.6 µs)

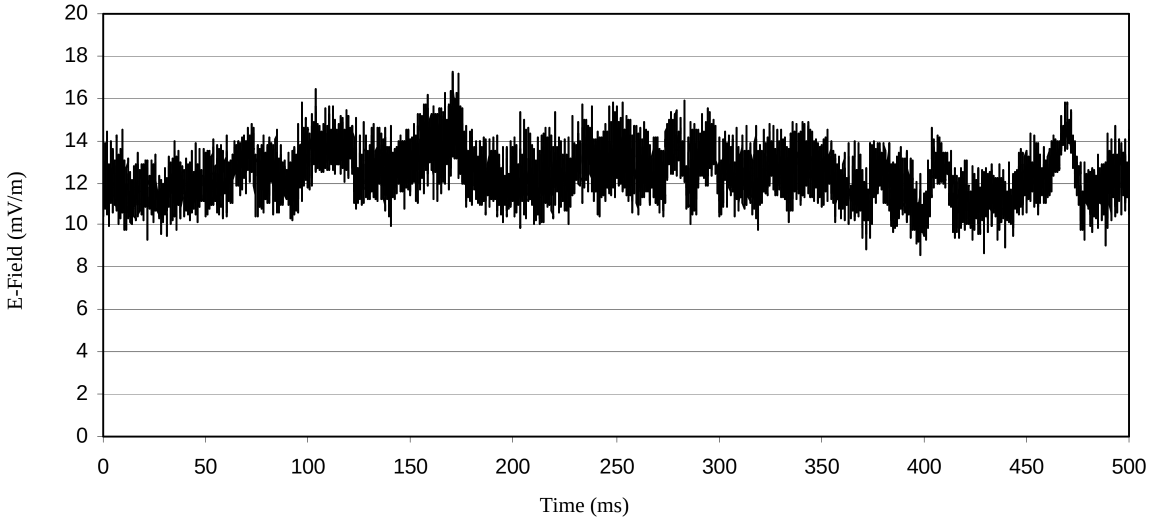

Figure 30. Measured mean envelope in a 5-MHz band allocated to UMTS-FDD
(central frequency: 2112.6 MHz – frequency filter: 5 MHz – time resolution: 125.6 µs)

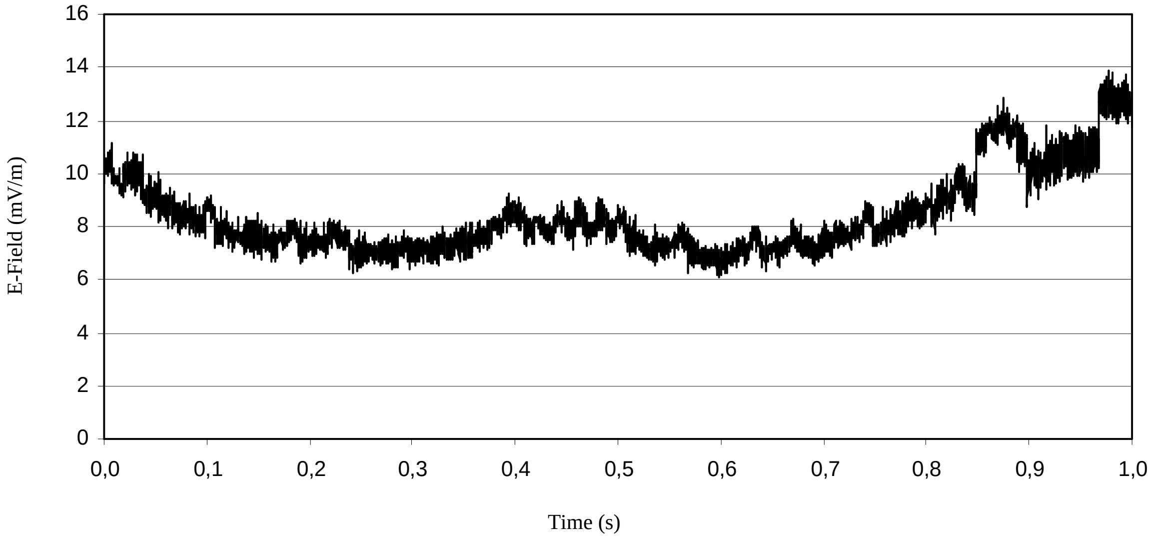

Figure 31. Measured mean envelope in a 5-MHz band allocated to UMTS-FDD
(central frequency: 2112.6 MHz – frequency filter: 5 MHz – time resolution: 250.4 µs)

Fig. 32 shows UMTS-FDD signals when all the traffic channels are inactive. The apparent periodic variations of the envelope are due to fact that the ten first percents of every time slot of the control channel are repeated at a constant rate, as mentioned in [5].

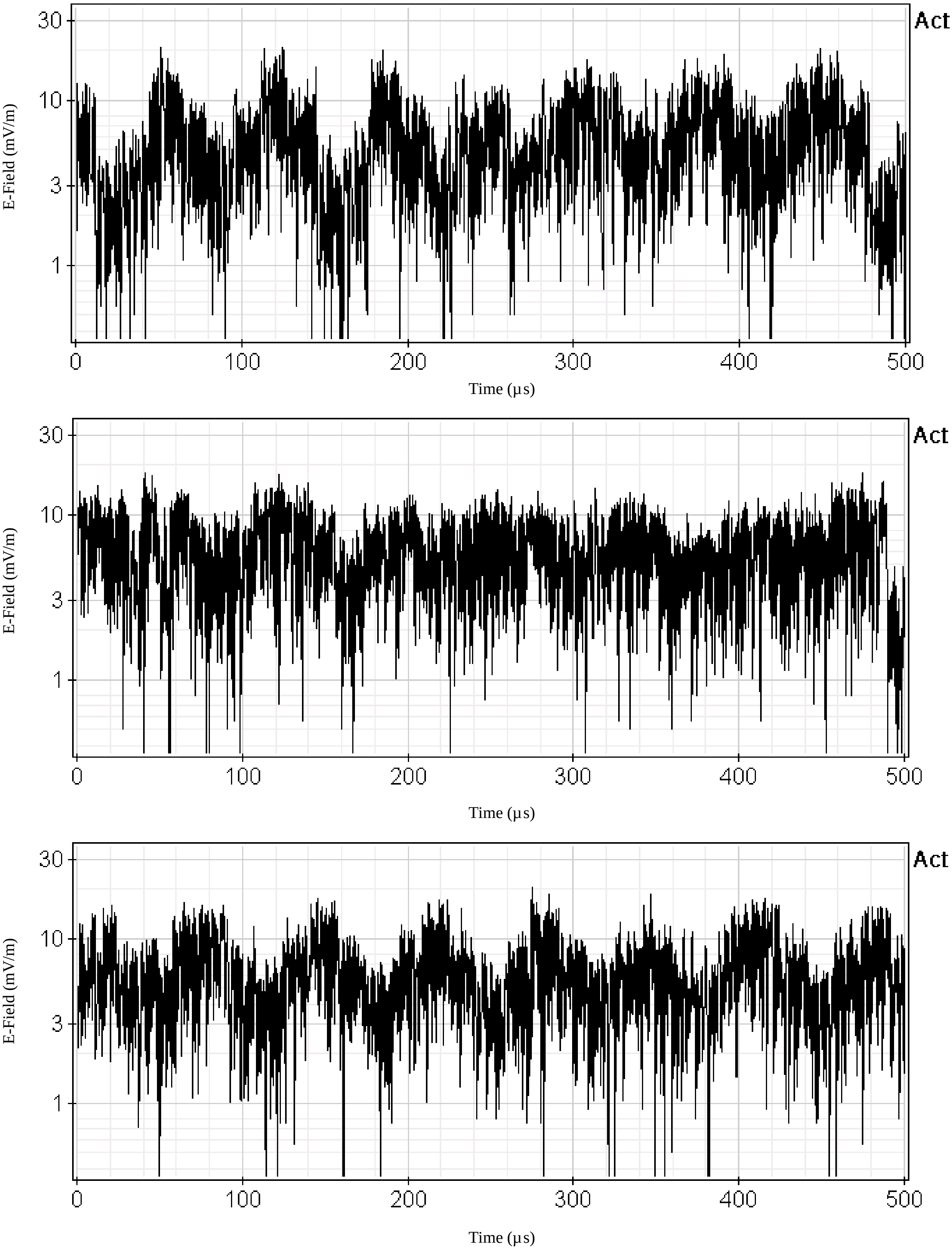

Figure 32. Measured envelope in a 5-MHz band allocated to UMTS-FDD with no traffic
(central frequency: 2162.2 MHz – frequency filter: 5 MHz – time resolution: 200 ns)

UMTS HSDPA, also called “3.5G”, “3G+” or “turbo 3G” is a standard that upgrades the downloading data rate by changing of modulation according to the needs and the quality of the signal, from QPSK to 16QAM and 64QAM. 16QAM and 64QAM schemes induce amplitude variations that do not appear in Fig. 33, probably because the 5-MHz bandwidth contains several carriers that vary differently, covering the amplitude variations. Measurements during longer times show occasional and irregular changes in the envelope, see Fig. 34. These HSDPA measurements were taken when significant traffic was generated.

It is noticeable that only the HSPDA signals were recorded in Fig. 33 and 34 despite that UMTS-FDD signals are generally emitted simultaneously (from the same 5-MHz band or from a close another one). However, cumulated field’s envelope is expected to depict the same noisy aspect.

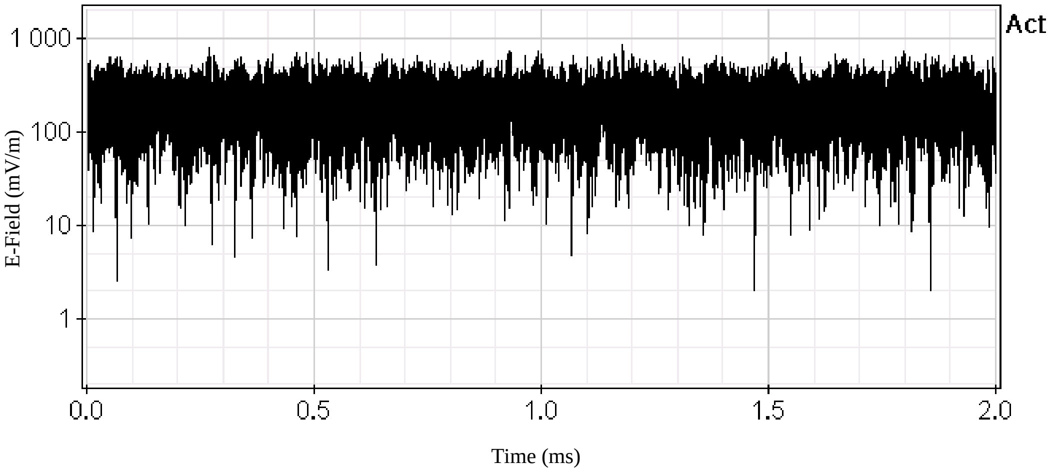

Figure 33. Measured envelope in a 5-MHz band allocated to UMTS HSDPA
(central frequency: 2166.2 MHz – frequency filter: 5 MHz – time resolution: 200 ns)

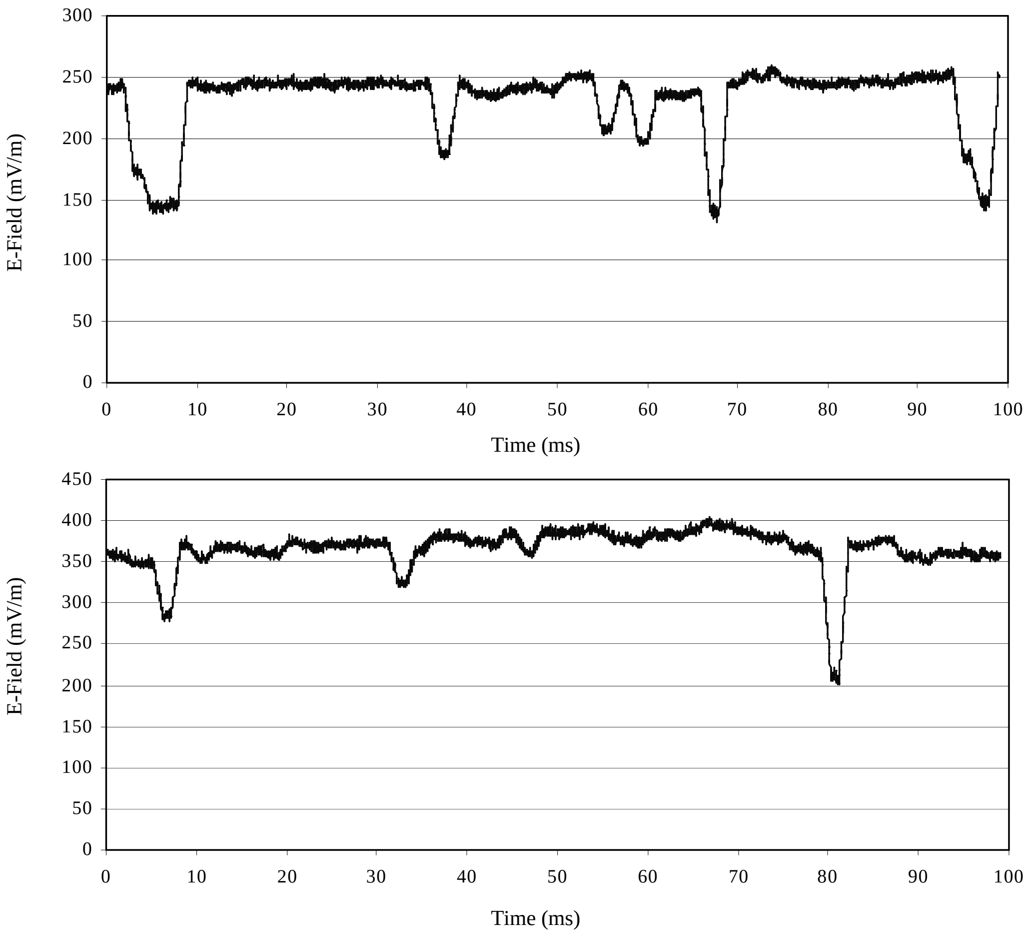

Figure 34. Measured mean envelope in a 5-MHz band allocated to UMTS-FDD with no traffic
(central frequency: 2166.2 MHz – frequency filter: 5 MHz – time resolution: 1024 µs)

The UMTS can be deployed in several frequency bands, for instance in the GSM band. As mentioned in § 4, the sum of the fields radiated by two different technologies, for instance GSM and UMTS both emitted at 900 MHz from nearby sources, should show a signals' envelope with noisy variations from UMTS, periodic decreases in the amplitude due to TDMA and increases due to traffic channels from GSM.

The envelope of 3G mobile phones radiation was recorded during a communication. Some results are presented in Fig. 35.

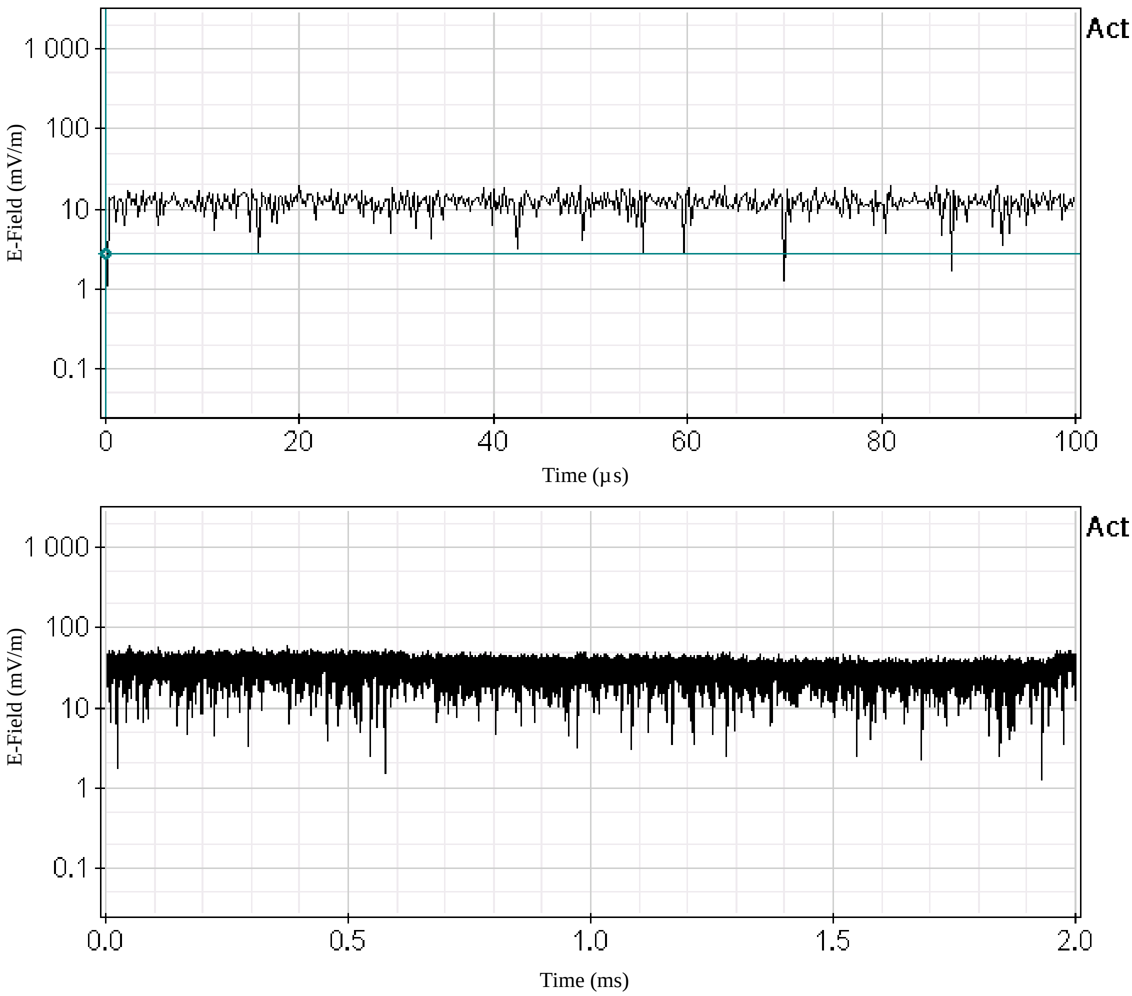

Figure 35. Measured envelope in a 5-MHz band allocated to UMTS-FDD mobile phones
(central frequency: 1922.5 MHz – frequency filter: 5 MHz – time resolution: 200 ns)

k) Long Term Evolution network

LTE technology is a mobile phone standard currently in deployment. It is also called "4G" or "LTE Advanced". This system can use different frequency bands and the channel bandwidth can be adapted to the needs. Fig 36 represents a LTE carrier's envelope emitted by a testing "3.9G compatible" base station – that is, not yet 4G according to the LTE network standards, but having the same radiation pattern – which is located at Heverlee, Belgium. This shows recurrent, rapid variations that look like pulses in the absence of data transfer. These pulses depict the control channels radiated alone. When downloading data, the envelope looks like Fig.37.

Because LTE had not been deployed while preparing this paper, it was not possible to measure a cumulated field resulting from summing LTE and other networks' signals, for instance in the DCS 1800 frequency band. However, the existing interruptions will likely stay measurable but attenuated, while the variations during a "continuous transmission" could be more important.

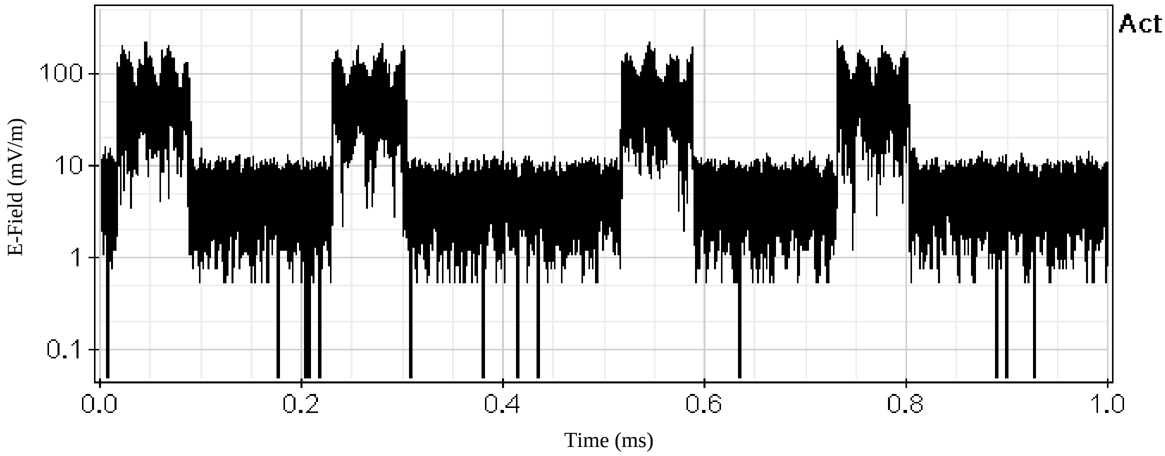

Figure 36. Measured envelope of the signal emitted by a LTE base station with no traffic (central frequency: 1815 MHz – frequency filter: 10 MHz – time resolution: 100 ns)

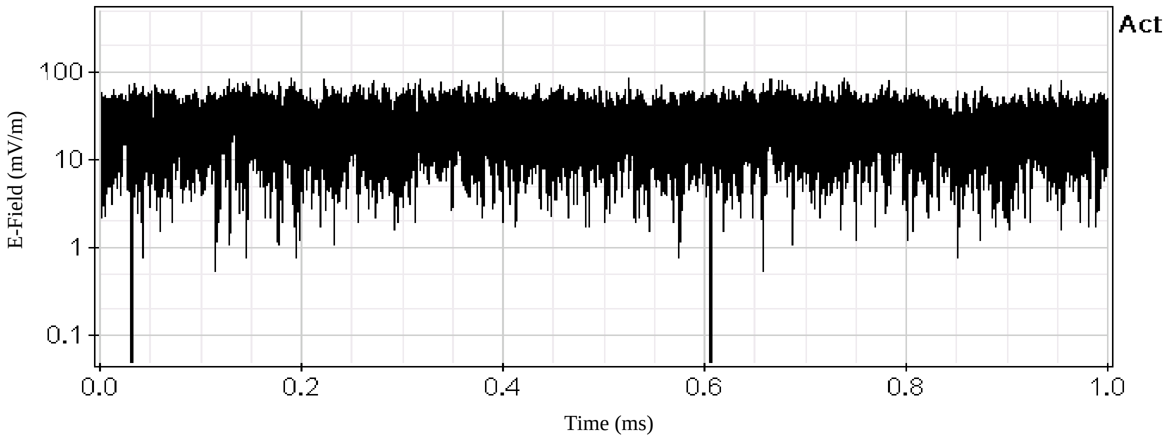

Figure 37. Measured envelope of the signal emitted by a LTE base station when downloading (central frequency: 1815 MHz – frequency filter: 10 MHz – time resolution: 100 ns)

l) WLAN networks

A wireless local area network (also called “Wi-Fi” in most countries) allows connecting digital devices (e.g. computers, personal digital assistants…) to each other. They communicate by a set of protocols referenced by the so-called IEEE 802.11 standards. The current version (802.11n) makes possible separate or simultaneous use of two frequency bands, one around 2.4 GHz and the other one at about 5.5 GHz.

As mentioned in § 2, Wi-Fi protocol use time division duplex to share packaged information. Fig. 38 and 39 depict pulse structures, the duration of which depends on the amount of data being downloaded.

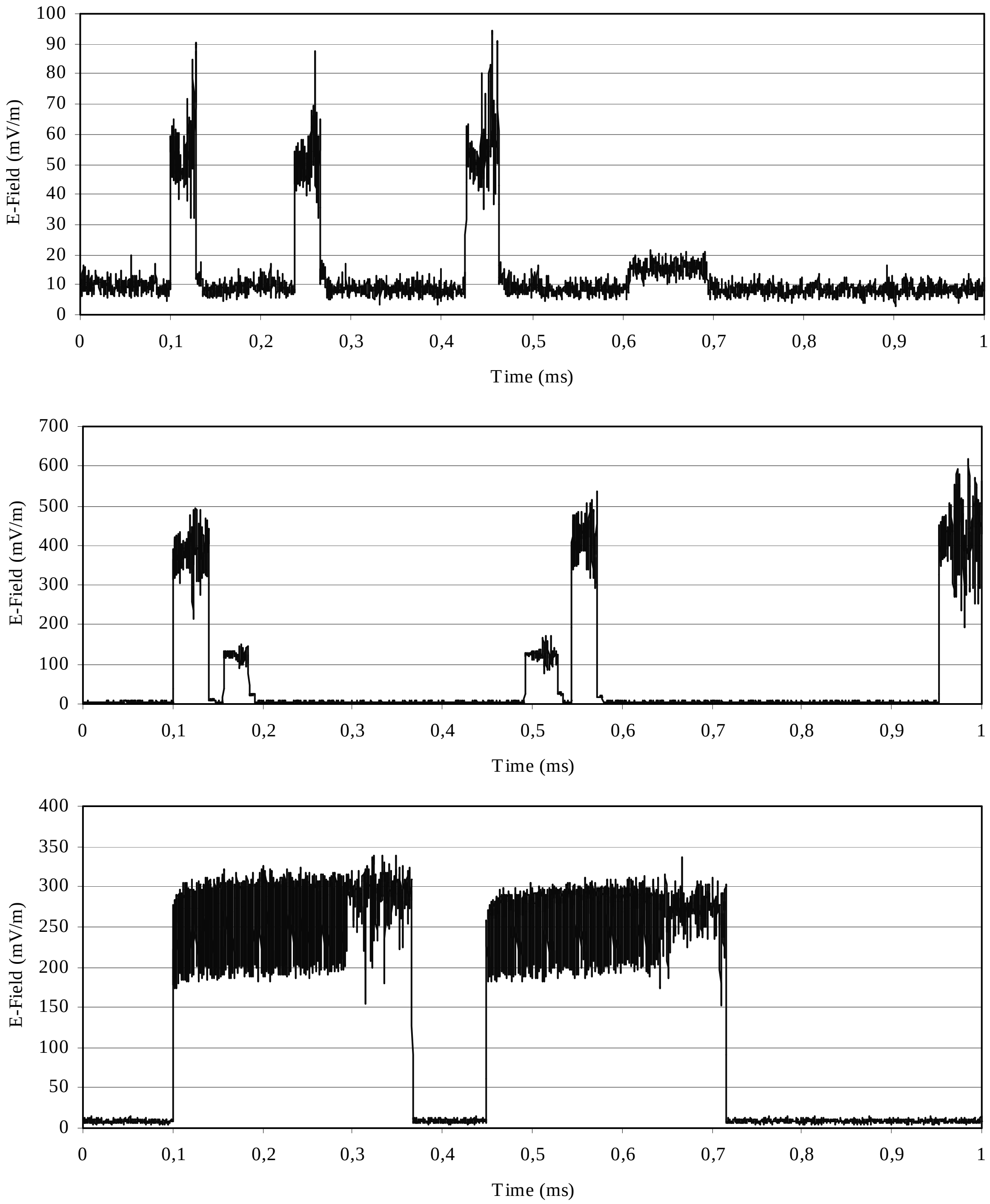

Figure 38. Measured mean envelope of the signal emitted by a WLAN station when downloading (central frequency: 2437 MHz – frequency filter: 20 MHz – time resolution: 400 ns)

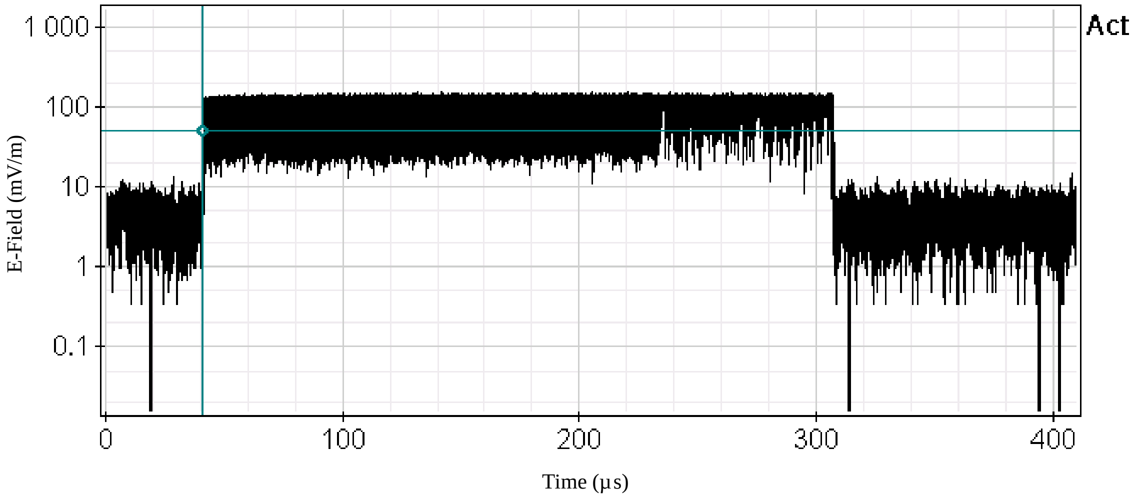

Figure 39. Measured envelope of the signal emitted by a WLAN station when downloading (central frequency: 2437 MHz – frequency filter: 20 MHz – time resolution: 50 ns)

m) WiMAX network

WiMAX is another standard that provides Internet access, allows high data rate transfers and covers longer distances than wireless local area networks with the help of elevated antennas. The authorized frequency range is quite large: between 2 GHz and 66 GHz. WiMAX standard uses time division duplex as WLAN does. Fig. 40 depicts pulse forms when traffic channels are activated, with a constant duration of emission. On the other hand, Fig. 41 illustrates that no signal is radiated in the absence of traffic.

A WLAN produces a relatively weak electromagnetic field that is stronger near the source and rapidly decreases with the distance from the source. For this reason and given that mobile phones cause more intense local exposure to electromagnetic fields in different frequency bands, we can reasonably afford that the WLAN radiation is dominant near the source and negligible further in most existing situations, what makes unnecessary the measurement of cumulated fields from all the possible present sources.

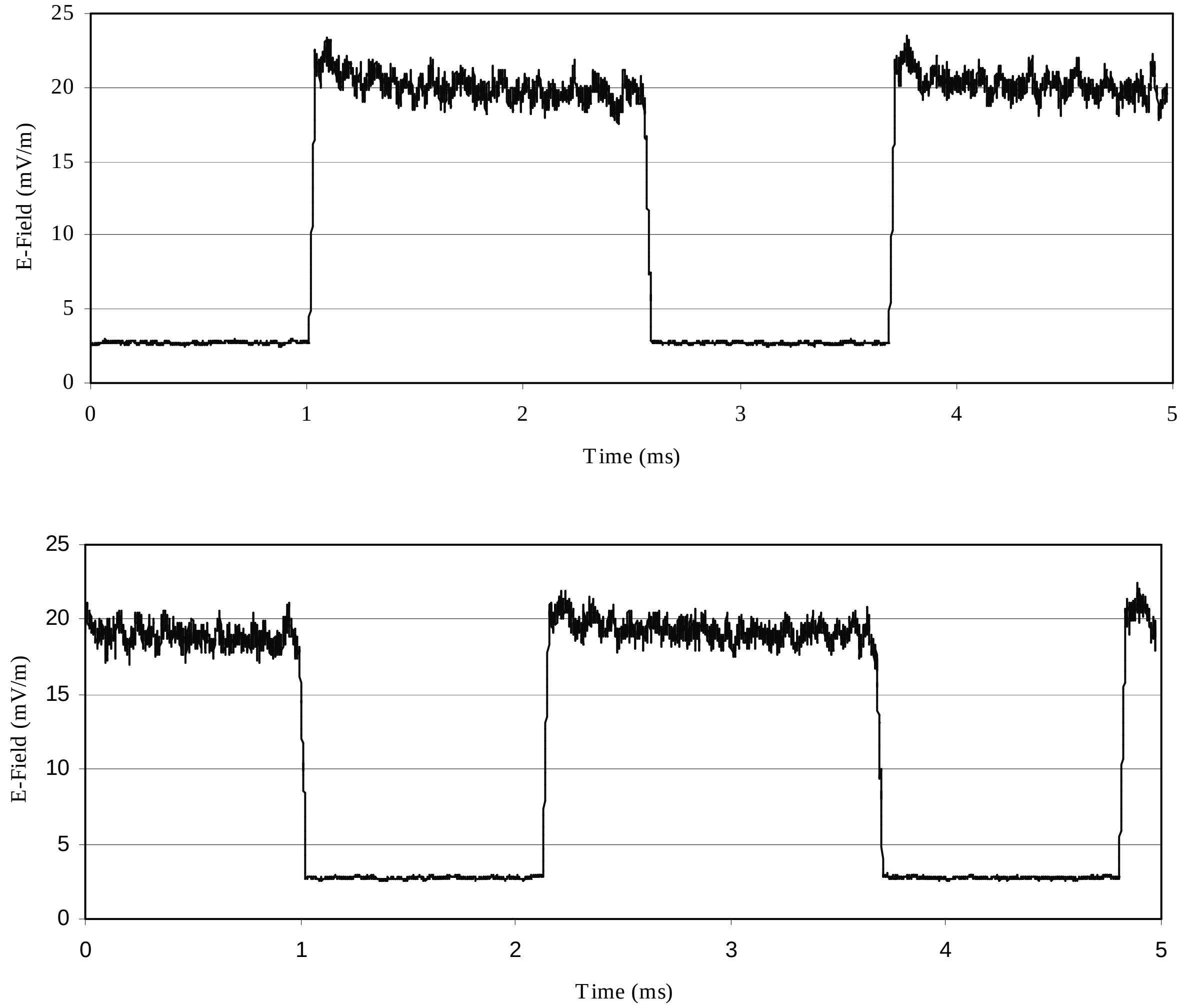

Figure 40. Measured mean envelope of a carrier radiated by a WiMAX base station
(central frequency: 3.58 GHz – frequency filter: 20 MHz – time resolution: 28 µs)

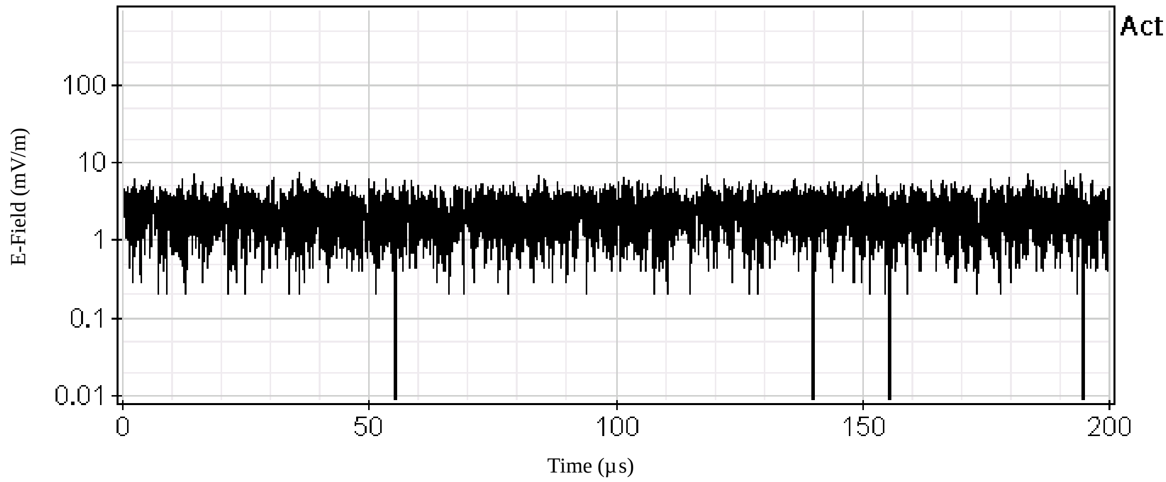

Figure 41. Measured mean envelope of a carrier radiated by a WiMAX base station when no traffic
(central frequency: 3.58 GHz – frequency filter: 20 MHz – time resolution: 50 ns)

5. SYNTHESIS AND CONCLUSIONS

Radiation produced by the studied telecommunication systems shows generally important amplitude variations in time. This is true for many radio systems based on digital transmission and even for less recent techniques such as AM broadcasting which uses analog transmission techniques. Moreover, FM broadcasting of which every carrier's amplitude is constant undergoes important variations when we consider the cumulated electromagnetic field produced by several transmitters. Summing several components of similar amplitudes and slightly different frequencies may result in strong, irregular variations of the envelope.

Setting a boundary between signals for which the amplitude varies quickly in time and pulsed radiation is quite complex because some analog signals' envelope such as analog television's signal are generally considered as pulsed because they feature amplitude variations that look like non-rectangular pulses. Besides, given that no definition of a pulsed signal has been consensually fixed and because no active mechanism could connect adverse, non-thermal effects to some distinctive parameters defining the pulsed wave form (rising and falling times, interruptions' duration, periodicity and so on), there is no reason to state that a non-rectangular fall in intensity back to a value different from zero is expected to be more or less risky than an exposure to rectangular pulses falling down to a null value. Actually, a definition of a pulsed wave must consider the complexity and the diversity of existing and future radio transmission systems.

It is known that the human body is generally exposed to several radiations of the same type. For instance, a GSM base station currently transmits several carriers simultaneously. As is seems very unlikely that the living tissues would be able to dissociate these components, the sum of all the radiations that could be present at one place should be taken into account. For this reason, the measurements were carried out by focusing on existing exposure conditions when it was possible. The analyzed results are presented in table I below.

TABLE I. SYNTHESIS OF THE RESULTS

Radiation sources	**Amplitude variations of the measured signals**		
	Order of magnitude	***Duration in carriers' period (T)***	***Causes***
Analog television broadcasting antenna	15 dB – 20 dB	50 Hz: 1,300,000 T 15,625 Hz: 7800 T	Synchronization
DAB antenna	Interruptions	575,000 T	Synchronization
AM broadcasting antennas	> 15 dB	10 T – 100 T	Modulation
DVB-T antennas	> 20 dB	100 T – 1000 T	Modulation
UMTS-FDD and UMTS HSDPA base stations	> 20 dB	400 T	Modulation, cumulated field, power control
FM broadcasting antennas	> 26 dB	1 T – 10 T	Cumulated field
2G (GSM and DCS) base stations	Interruptions	900 MHz: 27,000 T 1800 MHz: 55,000 T	TDMA
GSM-R base stations	< 10 dB or interruptions[a]	5000 T or 27,000 T	TDMA
TETRA base stations	Interruptions	2,340,000 T	Break in the transmission
LTE base stations	Interruptions or 20 dB	126,000 T	Inactive channels when no traffic
WLAN antennas	Interruptions	No transmission if no traffic	TDD
WiMAX base station	Interruptions	No transmission if no traffic	TDD

a. Amplitude variations of the cumulated field into the GSM-R frequency range

b. In. Belgium, TDMA for GSM-R is controlled with no interruptions

If only the shape and the magnitude of the amplitude variations are taken into account, it comes from the different results that:

- Several systems that are different by the frequency range, the modulation schemes and the transmission mode can present similar types of varying envelope. For instance, FM broadcasting, which uses an analog modulation which generates a constant envelope, can be compared with digital video broadcasting and UMTS-FDD if several carriers are simultaneously considered which corresponds to actual conditions.
- Conversely, very similar standards can undergo quite different envelope shapes: GSM-R and TETRA are direct descendants of the GSM networks but the study of their amplitude variations showed that TDMA can be ensured with no interruption of the transmission in some situations.

- It is not right that every digital mode system presents transmission interruptions: conversely, “pure” digital frequency and phase modulations do not affect the amplitude which is in fact more often influenced by techniques that do not depend on the message to transmit.
- We showed that analog signals can vary as much as digital ones. In particularly, let us recall that pulse radar systems are very good examples of analog pulsed transmission.

Which mechanisms could be active in aimed non-thermal, adverse effects is not clear until now. Discussions include the way that the living tissues and the human body could react to non-ionizing radiation, in particular, which parameter characterizing the waveform could be the most influent. One hypothesis concerns the possible ability of the living tissues to demodulate a signal, resulting in the importance to study some low, even extremely low frequency modulated components. The other more “global” point of view refers only to a cumulated influence of all the components because the human body could possibly not be able to discriminate within the spectrum of the signal, so that the effects of the envelope shape (e.g. pulsed variations of the amplitude) would need to be defined.

ACKNOWLEDGMENT

Measurements of UMTS HSDPA signals were carried out inside the company Mobistar’s place of business in order to generate significant traffic.
Because LTE was not deployed in Belgium at the time of writing this paper, the measured signals were emitted by a test base station with the assistance of the company Belgacom-Proximus.
Measurements of GSM-R envelopes in Hergenrath (at the border between Germany and Begium) were taken in the presence of B Holding’s representatives. The aim was to compare characteristics of the GSM-R network of these two countries.

REFERENCES

[1] International Commission on Non-Ionizing Radiation Protection, “Guidelines for limitig exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz),” Health Physics vol. 74/4, pp. 494-522, April 1998.

[2] “Directive 2004/40/CE du Parlement européen et du Conseil du 29 avril 2004 concernant les prescriptions minimales de sécurité et de santé relatives à l’exposition des travailleurs aux risques dus aux agents physiques (champs électromagnétiques) (dix-huitième directive particulière au sens de l’article 16, paragraphe 1, de la directive 89/391/CEE),” JO, L 159, p.1, April 2004.

[3] “Recommandation du Conseil du 12 juillet 1999 relative à la limitation de l’exposition du public aux champs électromagnétiques (de 0 Hz à 300 GHz (1999/519/CE),” JO, L 199, pp.59-70, July 1999.

[4] J.-M. Aran, J.-C. Bolomey, P. Buser, R. de Seze, M. Hours, I. Lagroye, and B. Veyret, “Rapport à l’Agence Française de Sécurité Sanitaire Environnementale: téléphonie mobile et santé,” AFSSE, pp. 18-19, March 2003.

[5] M. H. Virnich, “Wann ist Hochfrequenzstrahlung gepulst? Untersuchung von Pulseffekten im Zeit- und im Frequenzbereich,” EMV-Tagung des VDB, Stuttgart, March 2006.