EXPOSURE TO ELECTROMAGNETIC FIELDS GENERATED BY POWER LINES CARRYING SMART METERING RF SIGNALS

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ABSTRACT

The paper presents the results of the measurements of the electric and magnetic fields produced by electricity distribution networks carrying G3-PLC smart metering signals in the CENELEC-A and FCC-2 frequency bands.

These results show that the electromagnetic exposure is, in all cases, well below the limits of European Council recommendation 1999/519/EC for the general public.

INTRODUCTION

The E.M. fields generated by smart metering have become the focus of public health concerns. Various communication solutions are used to retrieve the meter data. Some of them use wireless links such as VHF radio, WLAN or public mobile communication networks. This paper concerns a solution based on Power Line Carrier (PLC) technology which uses the electricity distribution network (EDN) for transmission to concentrators installed in MV/LV transformer stations. The PLC signals generate, around the cables in which they circulate, electric and magnetic fields at the same frequencies. As their intensities depend obviously on distances between the conductors constituting the cable, the field has been measured around an overhead bundle preassembled cable BAXB (in short “BAXB cable”) and an overhead non-insulated line (in short “non-insulated line”).

PLC FOR SMART METERING

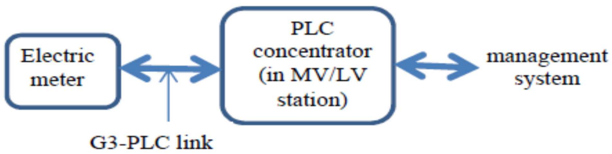


Fig. 1: transmission link between an electric meter and a concentrator

Fig. 1 shows the principle of the solution analysed in this paper. The communication between the customer’s electric meter and a concentrator uses low power RF signals transmitted through the EDN. There are various PLC standards. This paper deals with the G3-PLC standard which uses frequency bands between 5 and 150 kHz (termed “CENELEC band”) or between 150 and 500 kHz (termed “FCC band”). These two bands are divided into several sub bands. The results presented in this papers where obtained with meters transmitting in the CENELEC-A (from ≅ 36 kHz to ≅ 91 kHz) and FCC-2 (from ≅ 150 kHz to ≅ 478 kHz).

The communication between the concentrators and the management system of the EDN uses other supports e.g. optical fibres, mobile communication network, etc.

According to manufacturers’ specifications, the theoretical data throughput ranges between 4 and 45 kbits/s for the meters working in the CENELEC-A bands. In the FCC-2 band (which is about 6 times wider), it ranges between 20 and 229 kbits/s. The meter daily transmission time cannot be determined precisely as it depends on parameters set by the EDN operator (e.g. the number of readings). Moreover, some meters can relay the messages sent by other meters located upstream in the EDN. Some estimates indicate however that it would range, in most cases, between a few seconds to a few tens of seconds for a “normal” meter. For a meter acting as a repeater, it would range between a few minutes and a few tens of minutes.

HEALTH EFFECTS OF E.M. FIELDS IN THE 5 TO 500 kHz FREQUENCY BAND

The potential effects on health of the different types of electromagnetic fields are studied for more than 40 years. We shall focus here below on proven effects of electric and magnetic fields in the range between 5 to 500 kHz which are used for PLC transmission. According to the health authorities [1],[2],[3], it is admitted that, in the above mentioned frequency band:

- the electric and magnetic fields may induce electric currents in the human body which may induce nerve excitation above a certain level. At higher exposure levels, induced currents in head and trunk have effects on the central nervous system;
- the energy absorption of E.M. fields above 100 kHz may produce a temperature increase of the human body which could result in overheating in high exposure situations.

The exposure limits have been set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [1],[2],[3] to prevent nerve excitation due to the induced currents and any adverse effect which would be due to temperature increase in the body. These limits are termed “basic restrictions” and “reference levels”. Some of the basic restrictions are internal quantities which cannot be measured directly. Conversely, the reference levels are expressed in quantities such as external electric or magnetic field strength which can be measured directly. Respect of the reference level will ensure respect of the relevant basic restriction. If the measured value exceeds the reference level, it does not necessarily follow that the basic restriction will be exceeded. The limits recommended by the ICNIRP in 1998 [1] were adopted in the European "Council recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields" here after termed "Rec. 1999/519/CE". Table 1 summarizes the reference levels in the 5 to 500 kHz band according to Rec. 1999/519/CE. We note that the reference level for the magnetic field decreases with the frequency between 150 and 500 kHz and the results of the measurement will be compared with the lowest limit (1.5 A/m). Table 1 limits are applicable to permanent[1] all body exposures.

Table 1: Reference levels between 5 and 500 kHz

PLC Bands	Electric field (V/m)	Magnetic field (A/m)
CENELEC (5 - 150 kHz)	87	5
FCC (150 – 500 kHz)	87	730/f(kHz) (4.9 A/m at 150 kHz 1.5 A/m at 500 kHz)

E.M. FIELDS DUE TO PLC - DISCUSSION

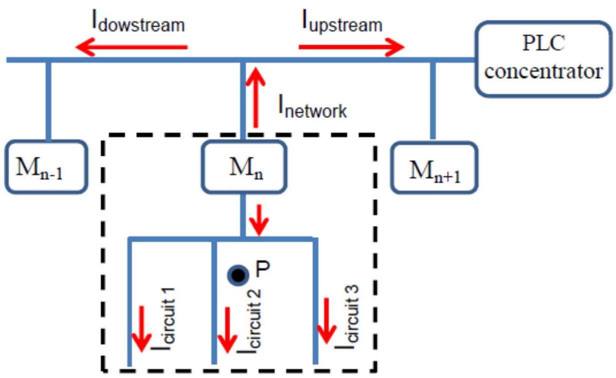


Fig. 2: PLC currents generated by a smart meter

Fig. 2 unifilar diagram depicts a part of an EDN where three adjacent houses are equipped with smart meters identified by the symbol M_{n-1}, M_n and M_{n+1}. The red arrows show PLC currents energy transfer in the different circuits connected to meter M_n and in the EDN. The current $I_{upstream}$ circulates in the direction of the PLC concentrator while $I_{downstream}$ circulates in the opposite direction. At any point P, the magnetic field is the vectors addition of the ones produced by the PLC currents in the different circuits shown in Fig. 2 and also the PLC currents in the electric circuits of the neighbour buildings. If we consider a point at a distance d from two parallel conductors separated by a distance e, it is known, from Ampere's law, that the magnetic field at this point is proportional to the current in the conductors, to the distance e and inversely proportional to d². Consequently, the shorter distance from the conductors which carry the highest currents, the stronger magnetic field. The PLC generator (which is a part of the meter) is equivalent to a voltage source connected to several impedances in parallel as shown in Fig. 3. The impedances of the EDN (corresponding to $Z_{upstream}$ and $Z_{downstream}$) are obviously very low as they correspond to all the loads (connected in parallel) and which are fed by the MV/LV transformer station. Consequently, it is at short distance of the cables carrying the $I_{network}$, $I_{upstream}$ and $I_{downstream}$ currents that the magnetic field is the highest.

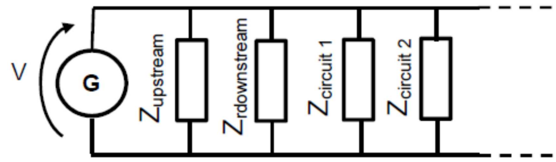


Fig. 3: PLC generator and loads equivalent circuit

E.M. FIELDS MEASUREMENT

Meters used and measurement equipment

A SAGEMCOM meter (model CX1000-6) conforming to the G3-PLC standards was used for the measurements in the CENELEC-A band. Regarding the FCC band, no meter was commercially available when the measurements were carried out. However, some modems G3-PLC working in the FCC-2 band were available and a MAXIM INTEGRATED modem (model G3-PLC MAC/PHY Powerline Transceiver MAX2992EVKIT) has been used for the measurements in this band.

The E.M. fields have been measured with:

- a "Selective Radiation Meter" NARDA model SRM-3006 – frequency range : from 9 kHz to 6 GHz;
- for the magnetic fields, a probe "Three-Axis-Antenna, H Field" NARDA model P/N 3581/02 - frequency range : from 9 kHz to 250 MHz;
- for the electric fields, a probe "Single-Axis-Antenna, E Field" NARDA model BN 3531/04 - frequency range : from 9 kHz to 300 MHz.

The "Selective Radiation Meter" NARDA SRM-3006 provides the resultant of the magnetic given by:

$$H_{res} = \sqrt{H_x^2 + H_y^2 + H_z^2}$$

where H_x, H_y, H_z are the components respectively parallel to the x, y and z axis.

Measurement configuration

Fig. 4 unifilar diagram represents the configuration in which the fields have been measured. An 8-m long cable (or non-insulated line) under test (CUT) was strung between two concrete posts at 2 m above the ground. The meter was connected at the end A of the CUT. The end B was connected, through another BAXB cable, to the electrical installation of the building where the measurements were performed and to a MV/LV

1 An exposure is considered as permanent if its duration exceeds 6 minutes.

transformer. The end B of the CUT was also connected through a switch SW to an 8.4 kW load (i.e. ≅ 17.3 Ω on each phase). This configuration guarantees that the intensity of the PLC current in the CUT corresponds to a real situation.

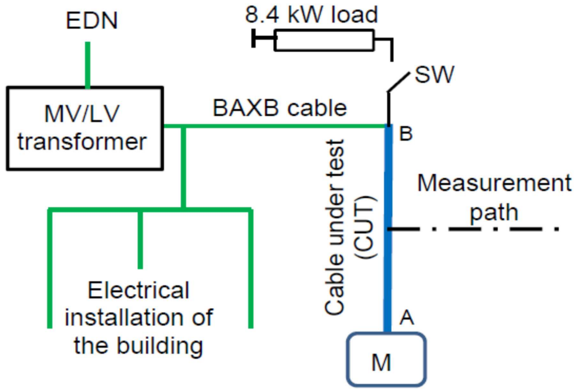


Fig. 4: E.M. field measurement configuration

The magnetic field due to PLC current has been measured along a path perpendicular to the CUT and at the same height, i.e. 2m above the ground. The field was first measured with the probe against the CUT and then every 10 cm up to a distance of 1 m. Then it was measured every 50 cm until the measured signal drops below the background noise level.

The electric field in the PLC frequency was negligible in the vicinity of the BAXB cable. It has only been measured in the vicinity of a non-insulated cable.

Measurement results

Overhead bundle preassembled cable BAXB

Fig. 5 shows the decrease of the magnetic field versus distance in the vicinity of a BAXB cable carrying PLC currents in the CENELEC-A and FCC-2 bands.

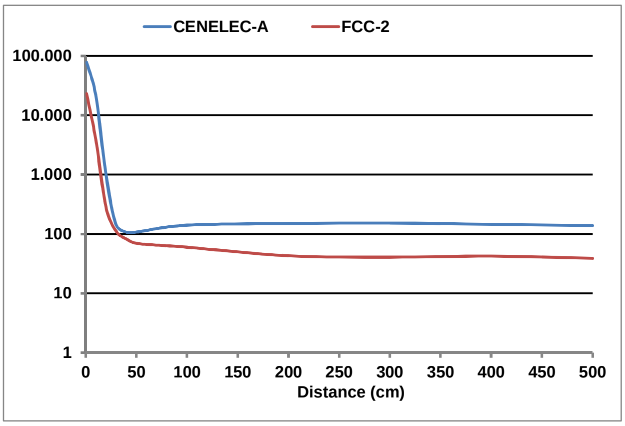


Fig. 5: BAXB cable - Magnetic field (in µA/m) versus distance

The distance is measured between the centre of the probe and the cable axis. At 50 cm, the magnetic field is of 100 µA/m order in both bands.

Table 2 compares the magnetic field at several distances with the Rec. 1999/519/CE of table 1 converted in µA/m. The measured magnetic field is clearly much lower, even against the cable.

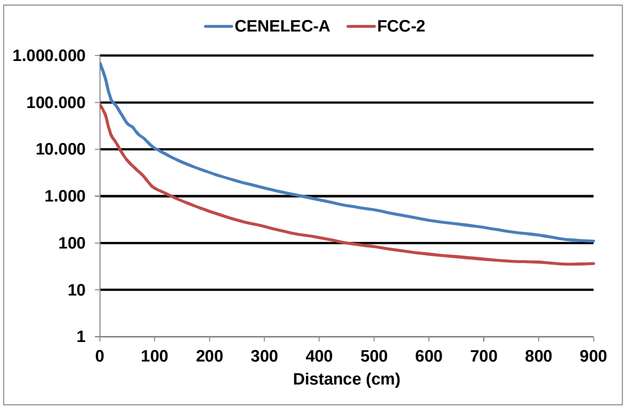
Table 2: BAXB cable - Magnetic field versus distance

Distance	CENELEC-A	FCC-2
Ref. Lev. Rec. 1999/519/CE	5 000 000 µA/m	1 500 000 µA/m
Probe against cable	≅ 77 000 µA/m	≅ 23 000 µA/m
10 cm	≅ 22 000 µA/m	≅ 3900 µA/m
100 cm	**≅ 100 µA/m**	**≅ 100 µA/m**

Overhead non-insulated line

The non-insulated line consisted in four conductors; two of them separated by a 34 cm distance and strung at the same height were carrying the PLC current. Fig. 6 shows the results with the 8.4 kW load connected. The distance is measured between the centre of the probe and one of the conductors carrying PLC currents.

Fig. 6: Non-insulated line - Magnetic field (in µA/m) versus distance



As with the BAXB cable, the magnetic field is several times higher in the CENELEC-A band and decreases slower than with the BAXB cable. At CENELEC-A and FCC-2 frequencies, it drops below 100 µA/m at a distance of about 4.5 and 9 m respectively.

Table 3: Non-insulated cable - Magnetic field

Distance	CENELEC-A	FCC-2
Ref. Lev. Rec. 1999/519/CE	5 000 000 µA/m	1 500 000 µA/m
Against cable	≅ 680 000 µA/m	≅ 87 000 µA/m
10 cm	≅ 330 000 µA/m	≅ 56 000 µA/m
100 cm	≅ 10 500 µA/m	≅ 1,500 µA/m
200 cm	**≅ 3200 µA/m**	**≅ 480 µA/m**

Table 3 compares the magnetic field at several distances with the Rec. 1999/519/CE of table 1 converted in µA/m. As with the BAXB cable, the measured magnetic field is clearly lower, even against the cable.

The electric field was also measured between the two conductors carrying the PLC current. It was equal to 3.5

and 2.5 V/m respectively at the CENELEC-A and FCC-2 frequencies. At 50 cm below the two conductors, the electric field was lower than 0.5 V/m in both bands. All these results are negligible with respect to the 87 V/m level of the Rec. 1999/519/CE.

Comparison with other sources at same frequencies

All maximum values in tables 2 and 3 (measured against the CUT) are well below the lower limits (5 and 1.5 A/m) mentioned in table 1. However it is known that some pressure groups consider that the exposure limits of the Rec. 1999/519/CE do not provide a sufficient level of protection, in particular in the cases of long term exposure. Of course this controversy is not the subject of this paper but some comparisons with other sources of electric and magnetic fields should be quite reassuring.

Except for the persons performing work on the EDN and considering the usual thickness of the walls of buildings, it seems unlikely that people could be within a 1 m distance from a BAXB cable during a long period. The magnetic field at 1 m is printed in bold in table 2.

In the case of non-insulated lines, they are in principle laid further away from the wall to avoid touching them. Consequently, a minimum realistic distance of 2 m can be assumed when long duration exposure is considered. The magnetic field at 2 m is printed in bold in table 3.

The human exposure to E.M. fields in the frequency range allocated to PLC is not recent. Indeed, frequencies in same band or close to it are used for telecommunications since the first half of the 20th century. This is for example the case of maritime and aeronautical radio navigation systems and broadcast radio in LW (from 150 to 300 kHz) and MW (from 525 to 1605 kHz). There are, all other the world, thousands of radio emitters the power of which exceeds 1 MW. One example is the RTL AM radio broadcast emitter located in Beidweiler at about 10 km at the North-East of the city of Luxembourg. It radiates a power of 1500 kW at 234 kHz. Its broadcasts can be received in a large part of the neighboring countries (Belgium, France and Germany). The magnetic field produced by this emitter has been measured, at various distances, in Luxembourg and Belgium. The results are summarized in table 4.

Table 4: RTL emitter magnetic field at 234 kHz

Distances from emitter and locations	**Magnetic field** (µA/m)
at 2 km, near Beidweiler	≅ 9000
at ≅ 10 km, city of Luxembourg	1600 to 4500
at ≅ 50 km, North of Luxembourg	≅ 200
at ≅ 50 km, South of Belgium	≅ 1000
at ≅ 100 km, South of Belgium	≅ 100

Similar measurements were made around the RTBF AM radio broadcast emitter (621 kHz) located in Wavre at about 15 km at the South-East of Brussels.

Table 4: RTBF emitter magnetic field at 621 kHz

Distances from emitter and locations	**Magnetic field** (µA/m)
at 5 km, Wavre	≅ 1400
at ≅ 11 km, Louvain-la-Neuve	≅ 1100
at ≅ 18 km, Waterloo	≅ 650
at ≅ 35 km, Namur	≅ 150

Domestic induction heating cookers are another example of strong magnetic field source, generally at a frequency between 20 and 60 kHz, i.e. very close to the CENELEC-A band. A magnetic field ≅ 100 mA/m has been measured at 40 cm of a 3 kW cooker working at 40 kHz.

CONCLUSIONS

Even against an overhead bundle preassembled cable BAXB and a non-insulated line carrying G3-PLC smart meter signals, the magnetic field produced is well below the lower limits (5 and 1.5 A/m in the CENELEC-A and FCC-2 bands respectively) of the European Council recommendation 1999/519/CE.

At 1 m of a BAXB cable, the magnetic field is of the same order of the one measured at 100 km from the RTL AM radio broadcast emitter.

At 2 m of an overhead non-insulated line, the measured magnetic field is higher than with BAXB cable but still negligible in comparison with the reference levels of the European Council recommendation.

Acknowledgements

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