During the last 20 years the general public has become increasingly concerned about potentially adverse health effects due to exposure to electromagnetic fields at extremely low frequencies (ELF).

As far as we presently know, the evidenced biological effects in both *vitro* and *vivo* lab experiments cannot be univocally interpreted, since the large number of studies so far provide different results and appear closely related to a certain experimental method, to the biological target and to the employed exposure characteristics.

Because of the difficult interpretation of studies based on laboratory experiments, the World Health Organization (through IARC - International Agency Research on Cancer), issued a monographs in October 2001 reporting the results of an analysis over a large number of literature works, where the ELF magnetic fields are classified according to the evidence of carcinogenicity, on the sole basis of epidemiological studies. Such fields have been classified, as *possible carcinogens*, a category defining an agent with a limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenity in experimental animals.

On the basis of this classification and of the studies supporting it, The WHO comes to the conclusion that, in a population exposed to average levels of magnetic field over 0.3-0.4 $\mu$T, the probability for children of contracting leukemia is increased by up to a twofold, compared with a population exposed to lower levels.

The WHO recommendation is that EMS levels are kept low, but commensurate with good quality operation of EMF technology through voluntary cost effective precautionary measures. Growing public concern about this risk has led several national bodies, and even regional ones in Italy, to set prudentially restrictive limitations on permitted exposure levels, even introducing concepts such as “attention levels” and “quality goals” for the magnetic field component.

Such cautionary approach requires greater accuracy in evaluating the electromagnetic pollution, especially when it comes to the determination of the sources and their impact on the territory.

While the electric field generated by high – voltage power lines is constant in time, since it is related to the line voltage, the magnetic field varies in time as the current flowing in the line conductors. Since the exposure levels for the population can vary much in space (depending on the power – line configuration) and in time, so - called “simplified” methods have been employed in order to quantify such levels within the epidemiological studies.

In order to analyse the variability in time, the most complete method, especially for pre – existent exposures, consists in the calculation of the magnetic field value in the interested area, based on the electric companies recorded data. The usefulness of theoretical evaluations consists in their being independent from the degree of line utilisation when the measuring surveys are carried through.

On the basis of information about the current flowing through the line in a given time – interval, it is therefore possible to elaborate a more complete evaluation, that takes into account the temporal variation of the magnetic field levels.

The process of modelling the source, in order to calculate the generated magnetic field, introduces some approximation respect to real conditions: analysing quantitatively and qualitatively such approximation related problematics, and the related possibility of affecting the results is the purpose of this work.

The magnetic field generated by power lines is calculated by the Ampère-Laplace – law, according to which the field $B$, generated by a linear conductor describing a curve $\Gamma$ (catenary) can be determined in a generic point in space $P$ with the expression:

$$\vec{B} = \mu_0 \int_{\Gamma} I \frac{dl \times \vec{r}}{4\pi r^3}$$  \hspace{1cm} (1)

Where $I$ is the current flowing in the dl element of the conductor, $r$ is the distance between dl and the point $P$ and $\mu_0$ is the magnetic permeability in free space.

A simpler way of modelling, requiring fewer input data and less calculation, is the one that approximates the conductors to rectilinear cables of infinite length. In this case, the expression (1) is reduced to:

$$B = \mu_0 \frac{I}{4\pi r}$$  \hspace{1cm} (2)

Many softwares that implements the two models have been compared analysing results and versatility. The chosen software has been validated against experimental data, obtained from a
A campaign of monitoring surveys lead in the Turin urban area. From the obtained results we can deduce that “catenary models” can be compared with experimental data, with a very good approximation in the greater part of the analysed cases. This model is however useful in the case of the underground lines, because conductors can be considered as horizontal wires of infinite length introducing an acceptable approximation.

**Figure 1_A)** Magnetic field map obtained composing longitudinal and cross-sectional profiles recorded during the measures on analysed span **B)** Theoretical evaluation of magnetic field in the same span

The analysed “Catenary models” are ineffective in complex multiple lines configuration. To solve the problem, it's however possible to join a single measure in a point along a chosen axis with the theoretical evaluation executed for every single line, in the same point, in order to calculate the value of total magnetic field.

So, when more independent lines exist, the value of magnetic field is given from a phasorial sum of the components of single lines, calculated considering single load angles and mutual phase - difference between voltages.

The value of mutual phase - difference between the two lines can be obtained with experimental measure. In order to calculate the total magnetic field from two lines in different load situations, it is possible to execute the single theoretical valuations and correct them for such angle.

After verifying the good approximation of theoretical valuation in most cases, the possibility of getting a likely evaluation of public’s exposure from theoretical data has been considered, trough an analysis of:

- a) trend and spatial variability of magnetic field value in bands of distance from the lines (with 10m bandwidth for aerial lines and of 5m bandwidth for the underground lines),
- b) differences between successive spans of the same line
- c) temporal variability of emissions.

In figure 2 we find the result of an analysis in bands of distance for a considered span. Magnetic field values have been calculated, through a theoretical evaluation, using average and maximum annual currents. It can be noticed as exposition extrapolation, through evaluation in bands of distance from the lines, is not very significant; so, even if magnetic field tends to decrease with distance, variability within a single band reaches 100%, causing strong spatial differences.

As result we obtain strong difference of longitudinal value between the points situated in correspondence of the minimum vertical clearance and the points situated in correspondence of the pylons.

This spatial difference between the values depends substantially from cables geometry: height, pylons' types, span length and sag (from which the vertex of the catenary depends).

In this context therefore, appears fundamental to consider the possible causes of variation of these parameters. In particular, sag parameter changes in function of the load (current increases cables temperature, due to Joule effect) and environmental factors, as ambient temperature (that can also be much different from Every Day Stress conditions, TEDS=15°) and possible mechanical overloads.

Through a lengthening balance equation, it's possible to calculate the correct sag parameter in
known situations of internal and external temperature and mechanical overloads. In figure 3 we can find the result of an analysis in bands of distance for two successive spans of a line; through this analysis, I studied the possibility to extrapolate obtained results of a single span into the remaining part of line. Magnetic field values have been calculated, through theoretical evaluation, using average and maximum annual currents. In the diagram we can observe that the two successive spans differ also of 100% in the levels of exposure in some bands. In this context it’s difficult to extrapolate obtained results from a single span to all the line. Instead, it’s possible to extend results in a point to the rest of the line for underground lines. In this cables configuration, in fact, the cross-sectional of magnetic field profile depends only from the depth (usually 1.5 m) and from cables laying, knowing therefore the line tracing and the depth, the magnetic field value can be gained in every point of the line.

![Figure 2](image1.png)  
**Figure 2** _magnetic field levels analysis in bands of distance calculated, through a theoretical evaluation, using average and maximum annual currents_

Analysing, finally, temporal variability, in figure 4 we can find the comparison between spot measurements and the values calculated with annual average and 24 hours median current for some of the considered points.

![Figure 3](image2.png)  
**Figure 3** _magnetic field levels analysis in bands of distance for two successive spans of a line_

The study is complicated, in fact we observe a mean variation one of approximately 40% between the measure spot and the two statistical levels, and a similar variation between the annual average and the median one on 24 hours.

![Figure 4](image3.png)  
**Figure 4** _Magnetic field from spot measures and calculated from annual average current and median on the 24 hours for some of considered points._
From all obtained results, it's possible to assert that the theoretical valuation of magnetic field generated by power lines is the most complete instrument in order to estimate population exposure, especially in retrospective studies (case-control studies); but there are methodological and intrinsic limits that do not allow an easy data interpretation. First of all there are strong spatial differences (cross-sectional distance from the line being equal), emphasized by the sag parameter variation with boundary conditions (the effect of the cables lowering is stronger by the minimum vertical clearance). We also need to study every span singularly, because also successive span of the same line can be a very different. The study is then particularly complex about temporal trend, in fact we observe a mean variation one of approximately 40% between the measure spot and the annual average and the 24 hours median, and a similar variation between the annual average and the median one on 24 hours.

The calculation turns out even more difficult in the case in which more independent lines insist in the same zone, especially if cables are not parallel or if they are intercrossed. The used method turns out effective, but spans analysis in correspondence of the point in which the cables are intersected resulted particularly problematic, probably owing to methodological errors in measures, especially in the geographical positioning of the point and the tracings of the lines. Therefore we have to consider all these factors if we are analyzing a zone of remarkable dimensions, in which many sources exist, from a macrocopic point of view.

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