Non-radiating near-field

New technologies, old concepts

It is natural to start with a definition of the field we are going to explore: "**Wireless energy transfer at a distance without any material support. More precisely, the concerned technologies, although based on electric and magnetic fields do not involve a wave propagation model or the associated concept of photon**".
This first definition, proceeds by successive eliminations, it pinpoints that for the contemporary physicist this subject is conceptually blurred. This difficulty is however relatively new. If we come back more than a century ago, before the discovery of electromagnetic waves (EM in the following), physicists were equipped with proper classical tools to describe such situations in a fully satisfactory manner.
As we just suggested and will explain later to the interested reader, the discomfort that has followed the rising of quantum theories is linked, according to us, to the improper use of the interaction concept described as carried-out by energy particles seen as classical corpuscles; the photons.
Novices or pragmatic readers should be reassured, these new technologies, that intend to remove all the cumbersome wires that surround our everyday life, are much easily explained by classical concepts such as distant forces and continuous media than by quantum field theories. For instance, in the field literature someone often found improper expressions such as "emitter", "radiation", or "evanescent waves" but surprisingly a total ignorance of wave physics and quantum theories is more an advantage than a weakness to understand the underlying non-radiating near-field concepts.

The following didactical text is structured into a three level approach. It doesn't mean that the first level avoids important aspects and should be skipped by some readers, but only that the underlying physics is introduced in a straightforward manner without any mathematical developments or metaphysical issues.
The second level is also very practical; as a complement to the first level it introduces some basic mathematical material and penetrates a little deeper into physical concerns.
The dramatic side of the preceding introduction is headed for the audacious readers reaching the third level of this didactic training equipped with a solid scientific background. Apart finding the introduction of the formalism used to justify the main results and ideas previously introduced, these readers will be invited in this level to start a quasi-metaphysic thinking on the relevance of the fundamental pin-pointed particle concept founding the standard model of modern physics.

Let's now start this journey in the non-radiating wireless world by elementary considerations on the origin and meaning of used vocabulary.
From all the compact expressions to designate these rising technologies, the more consensual among specialists is "electromagnetic near-field" or simply "near-field". This expression is a pretty bad choice and is at least incomplete. Let's start by explaining this point.

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Near-field, what does it mean exactly?

The idea of relative proximity is easy to grasp, one has to compare the distance from the location of the observer to the size of the device that is considered. If this ratio is very small the observer is close-by the device and if it is large the observer is relatively far away from it, obviously in physics everything is relative!

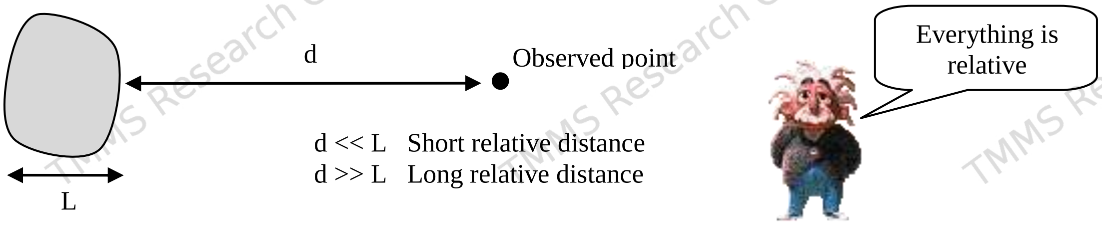

Fig 1: Concept of relative proximity

This idea enables mathematical simplifications when in practical situations we deal with areas that are either very close or very far from a given device under consideration, doing so approximations are made. Let's remind that the perfect physical description does not exist, all physical theory is by essence an approximate description of a larger more complex interconnected structure. The skill of the applied physicist is to find among existing tools and according to expected accuracy, the best approximation that fits the considered situation. On its side the theoretical physicist is expected to choose and define the elementary concepts that lead to the simplest intelligible model for our human typed mind to grasp the observed and measured facts[1]. The concept of geometric relative proximity is the first elementary concept that we encounter, it is a part of a larger family named by specialists as "dimensional analysis".

Unfortunately near-field concept is not usually directly linked to this idea of relative distance but more accurately to a comparison between the distance and the wavelength of the radiation originated from the object. Because the waves propagate at a constant speed it is possible to associate a specific length called wavelength for each frequency. It is then possible to compare the distance from the considered location to the wavelength. The EM far-field region corresponds to large relative values for the distance whereas the EM near-field region corresponds to small relative distance[2].

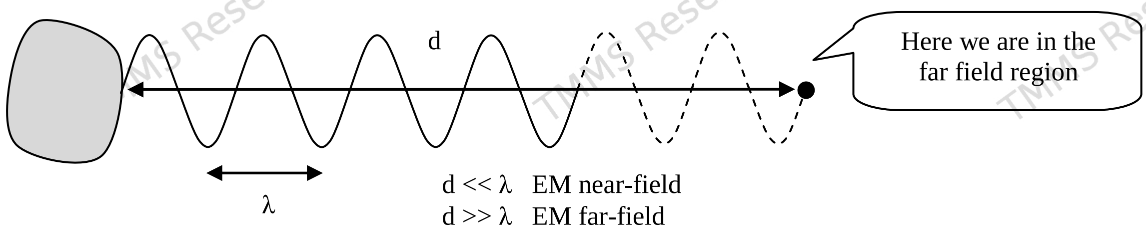

Fig 2: Concept of EM proximity

[1] This search for the simplest explanations is known as the « Ockham's Razor Principle ».
[2] According to the size and the geometry of the radiating object it is possible to distinguish other intermediate areas such as the Fraunhofer transition region for cornet antennas.

The two previous concepts, the geometric proximity and the EM proximity could be combined. It is then possible to be close to an object while being in its far EM field (if the wavelength is much smaller than the object size) or far from the object while still being in its EM near-field (if the wavelength is much larger than the object size).

This double proximity concept is sometimes confusing, because if no explicitly set it is not possible to know if proximity refers to the object size or to wavelength. But it is above all insufficient to characterize an important physical property of practical devices: their ability to radiate energy far away. The two previous concepts are in fact no use, taken individually, to specify if a given device stores energy in the vicinity of its electrodes as it is the case for a capacitor or radiates the largest part of the involved energy far away as it is the case for a mobile phone. To specify if the device is of the first or second kind one has to consider the third possible comparison for distances, the ratio of the size of the object compared to the wavelength.

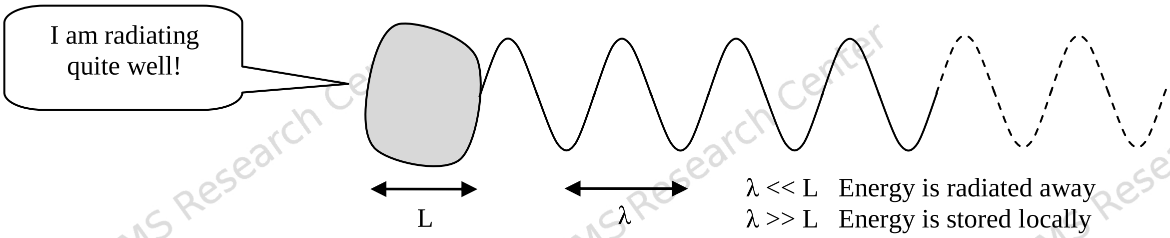

Fig 3: Mainly radiating or weakly radiating devices

This last ratio does not involve the distance from the device. Some devices are essentially radiating ones if their sizes are similar or larger than the involved wavelengths whereas other store energy in their vicinity without any appreciable losses if their dimensions are much smaller than the involved wavelengths.

When someone considers a non-radiating near-field, it means that he considers the EM near-field region (a distance from the device small compared to the wavelength) of a weakly radiating device (a device with a small size compared to the wavelength).

In the limiting ideal cases of static electric or magnetic fields, for instance if one considers a capacitor or a permanent magnet, the near-field area is infinite and the energy radiated far away is zero.

<u>And then?</u>

For weakly radiating devices, the largest part of the involved energy stays stored in the EM near-field area. If two similar devices are placed in their respective near-field regions, they may exchange some energy with large transfer efficiency without involving any radiations. It is for instance the case when someone manipulates permanent magnets to move objects at short distances. More generally it is also the case for devices involving interactions between

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slowly rotating dipoles (that is to say nearly all existing electrical generators). It is also the case for some solid-state devices (where the rotating field is obtained without any mechanical mobile parts) such as transformers or more generally coupled coils (provide the coils remain coupled in their non-radiating near-field domains).
For interested readers, we will describe in details in the part dedicated to wirelessly coupled circuit the mostly ignored case of coupled oscillating electrical dipoles.
The devices involved in this work will all belongs to the solid-state subset of electrical engineering machines.

The choice of an appropriate vocabulary

Near field devices exchange energy in a very different manner than far-field applications do. It seems vise, to avoid confusions and get rid of long definitions proceeding by elimination as done previously, to choose an appropriate enlighten and precise vocabulary. In order to define the two domains of applications for non-radiating near-field we propose to use "**magnetic induction**" for systems based on the use of a non-radiating near-field dominated by its magnetic component and "**electric influence**" for systems based on a non-radiating near-field dominated by its electric component[1]. We will sometime use the name "**Induction**" to designate the magnetic induction application field and by "**Influence**" the electric influence application field. We will try to avoid the use of the though current expression "quasi-static", because analysis will demonstrate that such systems are fundamentally dynamics by nature[2]. Besides it seems appropriate to keep, whenever possible, historical expressions of the electrical engineering field such as: "electromotive force", "generator dipole", "electromotive dipole". When dealing with coils coupled in a non-radiading manner, even if this is done through relatively large distances, we will use expressions such as "primary or secondary" coils and not "emitter and receiver" or "antennas" as it is too often the case in present texts, showing the increasing presence of the all wavelike dogma.

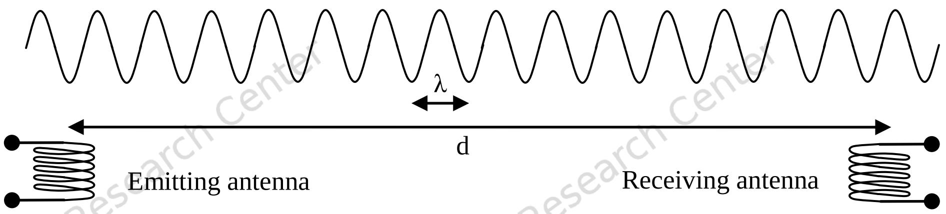

Fig 4 : Example of a radiating situation and appropriate vocabulary use

[1] In some countries such as in the United-States the expression "electric induction" is more current thant the one of "electrical influence" however this is confusing and do not correspond to historical facts.
[2] The only possibility is to give to the "quasi-static" expression the meaning "non-radiating" which is not its etymological meaning.

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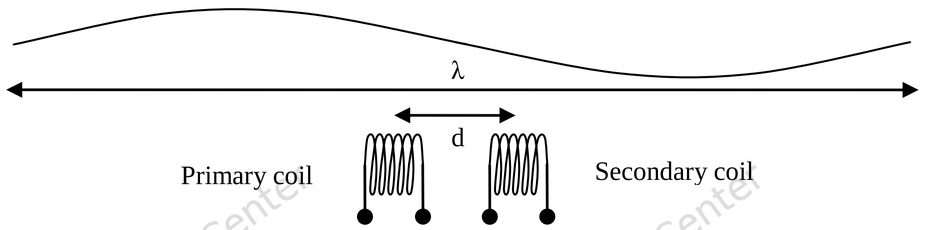

Fig 4 : Example of a non-radiating near-field situation and appropriate vocabulary use

To conclude this introduction to the field, let's give some order of magnitude of practical values. For a 1 MHz frequency (Nearly all recent devices use frequencies below this value) the wavelength is 300m. Then human sized devices separated by distances in the meter range are well inside the non-radiating near-field domain.

<u>To summarize</u>

The proximity concept involved in the near-field expression is not sufficient to describe the behavior of EM devices. One has to add another concept, the idea of total radiated energy and of potential energy that remains stored in the device vicinity in a way that still remains mysterious in these days.
Since the unquestionable success of quantum electrodynamic theory (QED) it is widely believed that all EM energy exchanges are done through simple exchanges of photons. This is formally true and we will not try to deny in the following indisputable results confirmed by extremely precise experimental agreements. However we will fight a raising dogmatic wavelike interpretation and propose some clearer physical explanations.
QED involves in fact various photons, only the far field corresponds to real photons that can be detected and measured individually. For the near-field the situation is far more complex.
Even more surprising, the near-field can take two totally uncoupled forms often called improperly quasi-electrostatics and quasi-magnetostatics. We will respectively designate these two forms by the expressions "**electrical influence**" and "**magnetic induction**" or shortly by the names "**Influence**" & "**Induction**". These domains, even if they take some modern technologic forms, can be described and modeled using old tools, concepts and vocabulary that where elaborated during the emergence of electrical machines, and then long before the discovery of EM waves.

The reader that does not wish to pursue some more in the fundamental domain is kindly requested to choose an application domain and to follow the proposed didactic approach.

Level 2 proposes some more food for thought starting from the classical concept of distant forces and calling attention to the quasi-mechanic near-field character leading to a proposal of a new conceptual frame.

In the level 3 we develop the EM unification idea but in an opposite way. We show that a fundamental non trivial qualitative and quantitative rupture exists in the classical Maxwell's equations frame and that this situation remains in the QED frame. This bifurcation is proposed as a way to formalize the conceptual distinction that we have made between near-field and far-field.