Influence, Induction and their relative importance

Abstract

Influence and induction are the two domains imbedded in the general EM frame (as well as EM waves) that are both dynamical and can however be studied without referring to any propagation. It doesn't mean propagation doesn't occur, only that taking it into account is not relevant to get a clear picture and accurate predictions of the associated classes of phenomena.

About ranges

In order to obtain such particular behaviors we regroup under the names of Influence and Induction, two conditions must be fulfilled:

The first one is that the wavelengths of involved signals in the surrounding dielectric medium are much larger than devices sizes. In such situations it can be shown that the amount of energy radiated far away is much smaller than the amount of energy stored in a reversible manner inside or around the device like for capacitors or coils or exchanged between nearby devices as for the two coils of a transformer structure. This first condition can be called "non-radiative circumstance".

The second one is that we will only describe what happens in the vicinity of the devices, more accurately over distances that are much smaller than the wavelength involved in the surrounding media. This second condition can be called "near-field study".

As a result Influence and Induction can alternately be called, non-radiating near-field domains.

The second condition seems at first sight to be somehow redundant with the first one as we may expect according to the first condition that there is no far-field but it is not. The far-field still exist even if negligible amount of energy are concerned and cannot be described in the same formalism. This gets clearer when the conditions are explained in terms of lengths. To simplify we will consider that the system involves a sine wave behavior at a defined frequency. The first condition writes $L \ll \lambda$, where L is the size of the device or arrangements of devices and λ the wavelength in the surrounding medium. Whereas the second conditions write $x \ll \lambda$, where x represent the space around the device or arrangement of devices for which the model applies well. It results that there is no special constraints linking the domain size to the device size. Said otherwise, near means near compared to wavelength and not near compared to dipole size. It results that the distance relative to the source can be large if frequencies are small enough. For instance the effective near-field of a magnetar that is only a few km in diameter can cover distances of several light years, if no other nearby star or planets is involved and only average effects are considered. For effects linked to variations of the magnetic field occurring at a rate of one every second, the range will still be around thousand of kilometers. In both cases the relative distance (distance of perceptible effects compared to the size of the source is huge).

However for human made devices we will explain later why, at least in a reasonable future, the relative range for Influence and Induction devices may not get over a few tens (a practical range of little more than ten times the devices sizes).

A few words about taxonomy issues

They are many alternate ways that are used to define these domains. The dominant trend is to use the inappropriate expression quasi-static associated to electric or magnetic fields. It is also frequent to see the idea of a single quasi-static domain corresponding roughly to the classical electrical circuits frame.

The expression quasi-static is clearly defined in physics, it correspond to situations where the involved physical quantities varies with time but still follow equations that do not involve time. For instance the water pressure in the bottom of a container filled with some liquid at rest, follow the rule by $P=\rho gh$, where ρ is the liquid density, g the acceleration due to gravity forces at the container level (assumed constant for containers of reasonable sizes) and h is the total height of the liquid column. If some liquid is progressively added or removed, both P and h will depend on time but the preceding relation still applies and we may write: $P(t)=\rho gh(t)$, in this case we are in a quasi-hydrostatic regime. However if the liquid is falling in the vessel in large rates, one will have to take into account the momentum associated to the liquid input and it will lead to a new equation for pressure entering in the realm of hydrodynamics. For instance if you suddenly close a valve in a large water pipe crossed by some large water flow, you will observe a sudden rise of pressure that is called “hammer effect” and may lead to a destruction to either the valve or the pipe. This effect is correctly described in hydrodynamics by explicit time dependant equations.

It is very surprising that in the electromagnetic domain most books (if not all) still use the terms quasi-static in the exact EM counterpart (the flow of a current in a coil) keeping the term electrodynamics only for situations involving propagation and waves. It is exactly like if in fluid mechanics the turbulent flow of the water around the pillar of a bridge was conceived as quasi-static and only the small ripple at the surface of the water can be considered as dynamic. Stupid isn’t it? , yes but it is the sad state of things.

It doesn’t mean that EM engineers do not understand what they are doing, only that there is a misleading vocabulary usage. However this inappropriate state of things also induces dogmatic attitudes; for instance many young fellows try to understand dynamic near-field properties only in terms of propagation and waves and guess what, it is exactly what the Wikipedia present entry quasistatic approximation does in contradiction with the other entry quasistatic process. Some volunteers to start the cleansing process?

A second worrying mistake was to call the Induction domain Electromagnetic induction. As we have seen in “A short story of the birth of electromagnetism”, there is not one but two dynamic coupling terms one involving the variation of the electromagnetic field to produce some electric field, that can be called “magneto-electric induction” and the other one, much more difficult to observe, where a variable electric field induces a magnetic field. This last one can logically be called “electro-magnetic induction” as the discoverer of the effect Faradays himself call it (see for instance here). Guess what; again the wrong choice prevails nowadays, in part for historic reasons that we will explain below.

Mathematical models

Vocabulary issues exist and according to Nicolas Boileau Despréaux ’s quote “*Whatever is well conceived is clearly said, and the words to say it flow with ease.*”, they surely reveal some conceptual issues.

Happily these difficulties are removed in the mathematical formalism. In this frame, Influence relates to situations where the dynamic magnetic coupling term is negligible and the dynamic electrical coupling term has to be taken into account, reversely Induction relates to the dual situations where the electrical coupling term is negligible and only the dynamic magnetic coupling term has to be taken into account.

In both situations no propagation is allowed, the speed of light is even not present in the specific sets of equations. Reversely both sets of equations can be derived by increasing the speed of light toward infinity and keeping only the remaining terms[1].

In RF engineers' point of view we may say that Influence and Induction situations correspond to field impedances that are respectively much higher or much smaller than the vacuum impedance. As device impedances do not match wave impedance, little energy can be carried away by propagation.

Possible applications

An interesting starting point is to consider that non-radiating near field applications are similar to non-compressible fluid mechanics applications such as: flows in pipes, fans, wind turbine and more generally propulsion, pumps and energy conversion devices. Similarly we may consider that the EM wave's domain corresponds only to acoustics.

The first practical idea is that it is as unrealistic to describe Influence and Induction through waves as it is to explain how a plane is flying only using acoustics. The second practical idea that emerges clearly from this comparison is that electromagnetic no-radiating applications are probably well underdeveloped compared to radiating ones.

The underdevelopment seems particularly true for Influence application and can be partly explained by historical choices. Surprisingly both Influence and Induction where well known well before Maxwell work and even well before the electrification of the world started. In the following chapter we explain how EM perception has been modified throughout the various industrialization steps.

How influence has been somehow left apart in the industrial history of EM

Well before the Maxwell unification of electromagnetism in a coherent mathematical frame and the discovery of EM Waves, electric light bulbs of different type (incandescent, luminescent) were already present in most houses and company. In these obscure (a way to speak) non wireless times two forms of interactions where known to produce effects on distant electrical circuits, the action of an electric field and the one of a magnetic field. However the second one was already omnipresent as a tool to produce electrical energy from mechanical sources (rotating

[1] Such a technical approach was first used by Le Bellac & Levy- Leblond in 1973 and leads to what they called the two Galilean limits of EM (for a recent review see here). We think that best conceptual choice is to understand Influence and Induction as "incompressible" limits of some "virtual" EM fluid. Note that the interested reader may also find many articles dealing with similarities between EM and fluid mechanics.

induction machines) and to transform in order to transport it over large distances (induction transformers).

To understand why Influence was left apart we have to travel further back in the past. In the eighteen century, when Coulomb was born, electricity was well known because of its electrostatic aspects and used as a way to entertain the noble society. Many influence machines where built to produce the high-voltages involved (although the concept of voltage was far from being formulated) and even the first capacitor the Leyden Jar has been discovered.

So why a century later, all this was considered as some kind of obsolete stuff ? And even worse, how the electro-magnetic induction was associated to the wrong domain?

They are two main reasons according to us. But first you have to remember that we are in times that are very far from the Maxwell enlightenments. The idea of charge was there but the vitreous electricity and resinous electricity were not yet discovered. To some extent also the idea of voltage/electric field was there but not clearly explained. The idea of electric current was not in the air or in a totally nebulous way. Progressively the idea of electric currents emerged especially after the invention of the first battery by Alessandro Volta. Rapidly, electrochemical generator became more convenient to handle than the electrostatic machines. So, well before understanding electricity rules people get used to manipulate low voltages and high currents. Then the first reason of the inversion is that people where more comfortable with low impedance circuits that they found less expensive to realize, safer and more reliable than the original high impedance stuff. Moreover the new possible high current investigations opened many new fields of investigations.

The second reason that prevents the domain to be reopened later on is even clearer: the maximum practical effects of observed electric forces in usual conditions where much smaller than their magnetic counterpart. Electric force was only able to raise hair on the head or to attract some small paper sheet whereas electromagnets were soon able to carry heavy loads.

In standard air conditions, the maximum electrostatic energy density before electrical breakdown occurs is given by: ED= where the breakdown field is around 30kV/cm leading to a practical maximum value for the energy density of about 40J/m3. The largest magnetic field than can be produced with no cooling or the use of superconductor materials is around 1T leading to an energy density in the air outside the coil of MD= = 400.000J/m3 then ten thousand times more !

It is clear that for quasi-static applications Influence cannot compete with Induction, so no mystery if totays electrostatic forces are only present in some low power systems such as dust cleaner ink propulsion and no more. However history is sometimes surprising and it may well be that Influence comes back as a leading technology in power systems in the near future.

Why the situation could be reversed once more

Influence machines existed in many types in the past (for instance as electrostatic generators or motors). We have explained that such devices were not able to compete with induction because the energy density level allowed in air and corresponding forces where much smaller.

In terms of mechanics the power of a force is given by P=**F**.**v** , the idea is that a small force can give a large power if it is acting at high speeds. For alternating currents a similar rule applies, for the same transferred energy the power involved will be proportional to the frequency. The reason why the transformer sizes were dramatically reduced in recent years is because their working frequencies were increased from 50-60Hz to about 1Mhz in present times. Said otherwise if a system involves only 1mJ of transferred energy at each alternation, it leads to a power capability of 100mW at 50Hz but it rises up to 2kW at 1MHz. The result is that at high-frequencies the power abilities are no more limited by maximum power density but by losses. And capacitor usually leads to much lower losses than coils. Lest give a practical exemple, here in KanTan Labs we have capacitors that you can hold in a hand (dimensions are a few cm only) that are able to handle reactive power level above 10kVA with a total dissipation of about a few watt, coils able to handle such power levels will be hundred times bigger.

A second point that leads to a large advantage for capacitive power systems is that ferrites core cannot be used to handle reactive magnetic power above 1MHz, whereas many dielectric materials can work at much larger frequencies.

To summarize

The two non-radiative near-field domains that we prefer to call Influence and Induction correspond to special circumstances where the concept of propagation is irrelevant to describe accurately the observed phenomena. Practically they correspond to a generalization of capacitive and inductive coupling that arise in the circuit frame.

Mathematically it corresponds to situations where in the Maxwell equations' frame one dynamic coupling term exist but the other one is so weak that it can be neglected, or where both terms exist with similar levels but are uncoupled either because they occupy different regions of space or because of some other geometrical considerations.

Alternatively they can be seen as non-relativistic EM cases that are very similar to the dynamics of incompressible fluids. Influence and induction are complementary to the propagation domain in the same manner than flows dynamics are complementary to acoustics in fluid dynamics. If influence could not match with induction in the low frequency domain, the situation is totally reversed in the high-frequency domain where Influence systems can handle both higher-frequencies and higher power-levels.