Technical E-Paper

Types and design of INTEGRATED ANTENNAS for wireless and IoT applications.

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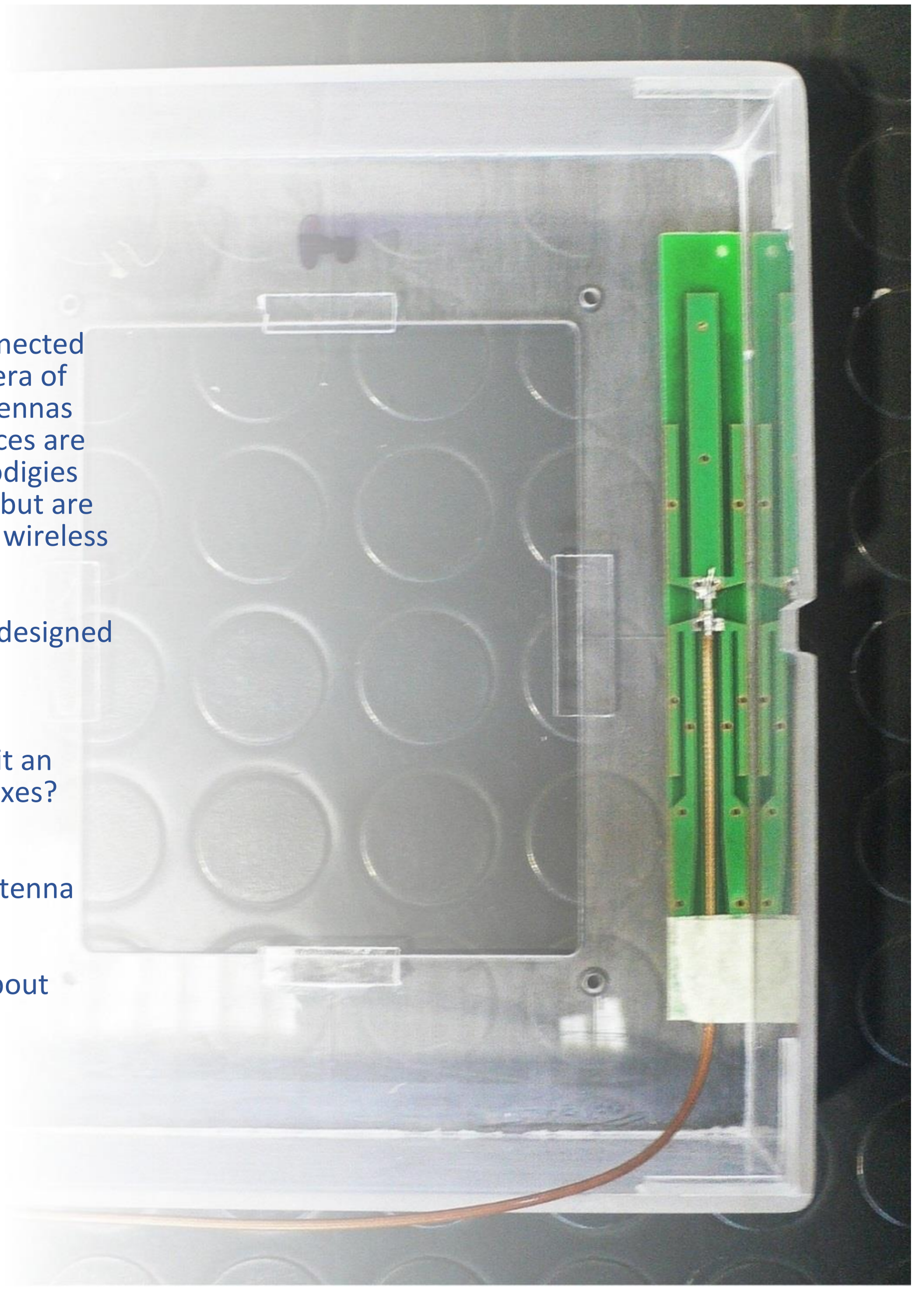

In this increasingly connected world, the contemporary era of the *Internet of Things*, antennas embedded into small devices are stunning technological prodigies that we don't even notice but are a fundamental part of any wireless system.

But how they are actually designed and built?

What are the integration techniques to shrink and fit an antenna into these tiny boxes?

What are the differences between an embedded antenna and a "traditional" one?

Here's a quick overview about the world of integrated antennas.

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1. Introduction.

Figure 1
The antenna of the first mobile phones.

In the last twenty-five years, the perceiving and consideration of the antenna has changed deeply, both to keep up with technology and to meet the increasingly stringent market requirements. In the early 1990s, no one cared about the *rubber duck antenna* stylus protruding from the first GSM cell phones (*Figure 1*), which was indeed considered by all, builders and users, as an indispensable technological constraint that could not be omitted at all.

We can even say that, in the early days of the radio-mobile, the antenna, in addition to the telephone, was a kind of flashy *status symbol* for the wealthy owners of the first big sized *TACS* devices.

Over the years, there has been a gradual size reduction of these portable terminals, together with an exponential increase in connectivity needs and as well as the allocated bands.

Today it would be totally unthinkable to put on the market a smartphone with an external, deployed antenna, although from a technical point of view it would allow a better operation of the phone in marginal coverage areas. In fact, in all those applications where the reliability of communication is the primary requirement (e.g. satellite phones, military equipment or more trivially... high-performance wireless routers), devices with external antennas, sometimes even with large dimensions, are still produced.

However, this is not the case of all the billions of daily use devices, connected to the internet over the air, as well as those particular applications in which a protruding antenna is actually not feasible for space reasons, visibility, mechanical stress, vandalism or barely for a design tendency due to marketing reasons.

The evolution of the electromagnetic modelling software has also allowed to deal with antenna configurations that are very different from the classic radiant structures (dipole, monopole, etc.) already known in literature, giving rise to more complex designs of embedded antennas.

Nowadays, when we all assume to be always connected to the web everywhere we are, the antenna itself has become something obvious and unknown, whose importance, unchanged since the dawn of telecommunications, is not adequately perceived, not only by ordinary people who use the smartphone, but sometimes also by those professionals who design and develop a wireless product and remain more "concentrated" in the definition of product’s bells and whistles, such as the software apps.

So, let's go into a little more detail, to find out what lies behind the scenes of everyday wireless device that, perhaps distractedly, we use and allows us to share all our life with the outside world.

2. Definition of *integrated antenna*.

So, let's see what's the mean of ***integrated antenna***.

*An antenna is named i**ntegrated** when it is inserted into a host device or apparatus and is therefore optimized so that it can function in such conditions, that is, taking into account the particular application for which the device or apparatus was developed.*

The antenna, inside the hosting device, must therefore be electrically and mechanically compatible with its electronics (circuits, components, batteries, wiring), with its mechanical structure (parts layout and casing) and with its actual application (installation criteria and operating conditions).

From an electromagnetic point of view, an integrated antenna cannot be considered as an independent element, since the *radiating system* actually consists of the antenna set and the hosting apparatus. In agree with this constraint, an embedded antenna must be properly designed, developed and characterized.

In addition, the actual compactness of most wireless and IoT products implies that the main antenna design limitation concerns the mechanical dimensions, respect to the wavelength λ, of the host apparatus.

As a result, an integrated antenna is always considered to be a *short antenna*, defined in the literature by the *Wheeler* formula:

$$\frac{2\pi}{\lambda} \cdot a < 1 \qquad [1]$$

where with ***a*** this is the maximum size of the antenna, which is to a first approximation the "*antenna + apparatus*" size.

3. But... what's the stuff that really radiates?

Any antenna consists of an assembly of one or more *radiating elements*, combined with other hardware parts or components needed to achieve a mechanical implementation of a real product with well-defined electrical performance. These other components can be both metal parts (reflector, brackets, supports, power lines, etc.) and details made from dielectric materials (insulators, radomes, etc.). The whole set can be defined as a *radiating system*, as the electrical characteristics of the antenna (both matching and radiation) depend not only on the radiating element but also on all this complex set which, in the so-called "normal" antennas, is designed to accomplish this unique aim.

Conversely, in the integrated antennas all components that are located near the radiating element are usually made for a purpose other than the optimization of the radiating system, since the whole apparatus generally provides other main functional purposes.

Let's see the field radiated by an integrated antenna from a far observation point. The radiation generated by the wireless device can be seen as produced by a distribution of equivalent surface currents that lie on a sphere of radius ***a***, where ***a*** is the minimum size that includes the whole "*apparatus + antenna*" set.

If we now consider to repeat the same observations by gradually reducing ***a*** to exclude the contributions to the radiation of all device's parts that fall outside the sphere, at some point you will find a sphere size a_{min} beyond which the observed far field will be substantially different from that of the largest sphere of radius ***a***. We could also simply say that the whole wireless device will no longer have acceptable performance.

So the question is, how big is the radius of sphere a_{min} ?

Certainly, in an integrated antenna the "minimum sphere" contains not only the radiating element, but also some other parts or conductors that effectively contribute to radiation, such as the ground layer of the PCB on which the radiating element is mounted, as well as the device circuitry.

So, for an integrated antenna, it's more important than ever not to confuse what we called the *radiating element* with the *radiating system*.

When you start an embedded antenna design activity, it is therefore necessary to develop a radiating system and not just insert, somewhere inside the apparatus or on its PCB, a radiating element. This also means that, considering the two respective spheres, it always applies:

$$a_{radiating\ system} > a_{radiating\ element} \quad [2]$$

Although it may seem like an obvious observation, this is a basic concept for anyone approaching the world of integrated antennas: it's incorrect to think that a tiny ceramic chip antenna, that extends for a small fraction of wavelength, will provide appreciable performance as a stand alone element, with no properly sized nearby conductors that support most of the radiation currents.

4. Integrated antenna types.

Figure 2-A, *2-B* and *2-C* show a schematic drawing of a RF device PCB, on which we assume that the whole electronic hardware of the device itself is embedded on the same board of the *RF chip*, here shown as a dark grey coloured squared box.

Often the RF chip consists of a real data modem that incorporates both the communication protocol and the actual *radio transceiver.*
Depending on the way the device has been conceived, there are essentially three families of integrated antennas, described as follows.

***Built-in antenna on PCB** (Figure 2-A):*

Here the antenna is embedded on the same board as the other electronics, and it is directly fed by a short length of *50Ω* microstrip transmission line that connects the printed radiating element to the RF input/output pin of the radio module. If a matching network is needed, some SMD lumped elements are inserted somewhere in the microstrip to achieve the correct impedance at the operating frequency.

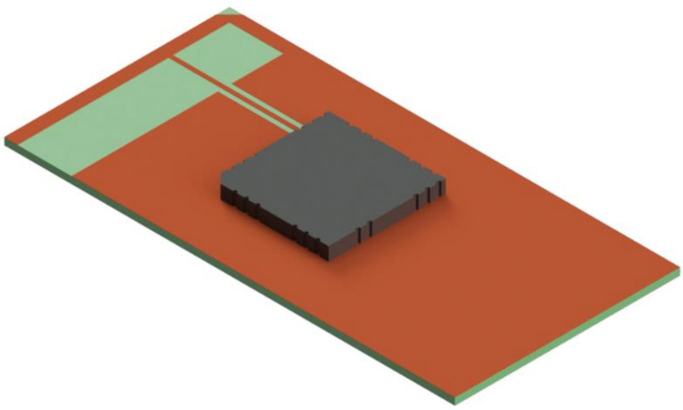

Figure 2-A
Built-in radiating element on PCB.

In this picture, the antenna is an *IFA* (*Inverted F Antenna*), made on an edge portion of the circuit board and uses the same *gnd layer* of the PCB as a ground plane.

PCB mounted antenna *(Figure 2-B):*

In this case, the radiating element is mounted onto the PCB, generally welded as with a typical SMD or lumped component. On the board, one or more solder pads for antenna placement are provided, such as for the feed point that connects to the *RF chip* also with a short length of microstrip line.

In the example shown, the antenna is still an *IFA* element, but here it is etched from a thin brass sheet, even so still uses the PCB ground layer to work properly. In this category, you can include all the *SMD chip antennas*, as well as the integrated antennas of modern smartphones, which often use structural elements of the mobile phone as true radiating elements (e.g. the metal frame). Again, at the feed point on the microstrip, a matching network with SMD lumped elements is often adopted.

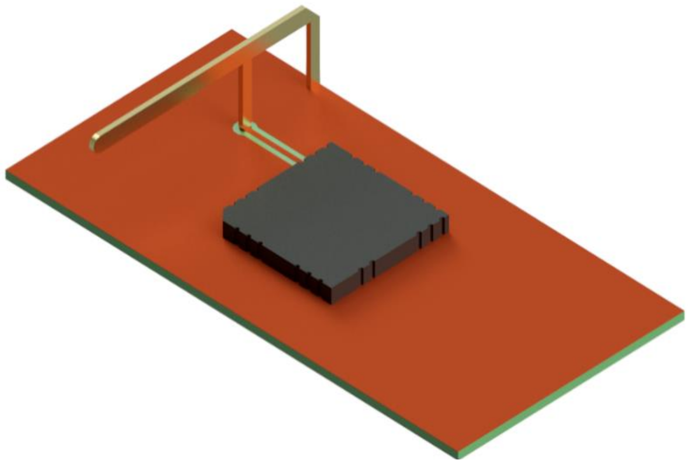

Figure 2-B
Radiating element welded on PCB.

Separate antenna *(Figure 2-C)*:

Here the antenna is totally apart from the PCB and connected to the RF chip on the board by a short coaxial cable provided by a miniaturized connector, usually a *U.FL* or *MMCX* type plug. On the circuit board, at the proper port of the *RF chip*, a mating SMD coaxial socket is mounted.

The antenna, already adapted *50Ω* of the characteristic impedance of the cable, is located inside the casing and can be symmetrical/balanced or can take advantage of a ground plane that is external to the PCB.

Even if in this latter example the antenna is mounted as a stand-alone part, its operating behaviour is strongly affected by all the nearby hardware, so it is considered an integrated antenna as well.

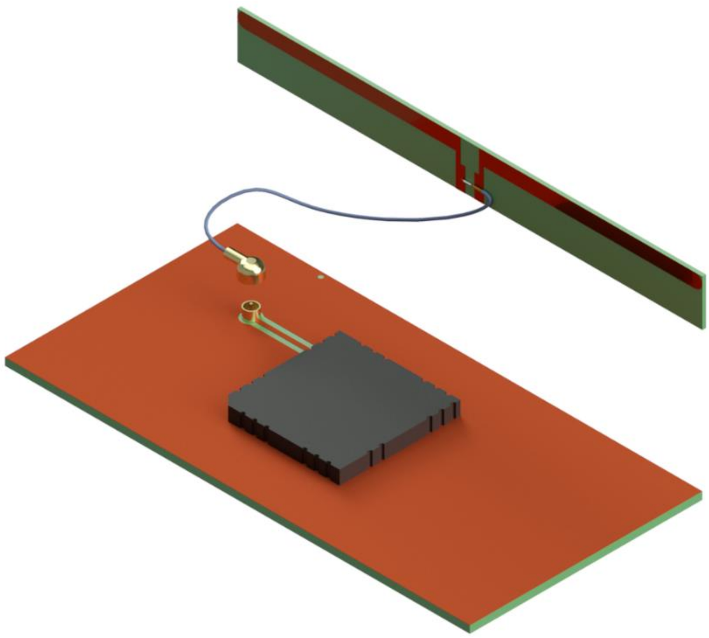

Figure 2-C
The radiating element is separated from the PCB.

5. Integrated trade antennas or custom-designed antennas?

Let us now start from *paragraph 2*, where it has essentially been said that a single radiating element (and its size) is not enough to obtain an efficient integrated antenna. In most of the actual wireless devices, mechanical dimensions are the major constraint in the design of a high-performance integrated antenna, and this limit becomes the main challenge of any designer.

Several tiny integrated antennas (i.e. *radiating elements*) are available on the market as standard products, featuring very small footprints so they can be mounted on a PCB like any other SMD component, and often these items are offered as a plug-and-play device.

However, when adopting these antennas for your own designs, it is important to bear in mind that their declared electrical specifications refer only to a specific *radiating system* cleverly defined by their manufacturer, consisting of the actual radiating element mounted on an *evaluation board*, expressly designed to maximize antenna performance. The *evaluation board* is characterized by a rather generous size compared to the SMD radiating element, typically of the order of $\lambda/4$.

It is therefore clear how crucial it becomes to verify early how much the size of the *evaluation board* gets closer to the actual room that's available in the device you're going to develop. If these dimensions fairly different, we are faced with two possible scenarios: first, the performance of the apparatus does not meet the expectations and therefore there is a concrete risk of not guaranteeing the expected functionality and/or not passing the certification tests; secondly, the size of the entire apparatus must be revised so that the antenna has the right space to perform properly.

It is therefore useful to have an alternative solution, which allows us to get the expected performance without having to alter the shape and size of the entire device. This possibility is given to us by the design of a *custom integrated antenna*. In addition, if this activity is carried out at the same time as the development of the other parts of the apparatus, it can be taken into account also *other specifications* that should not be underestimated, such as the production cost of the antenna and the simplification of its integration into the device, to foresee of the next assembly phase.

It is therefore advisable, at least during the preliminary evaluation phase, to always consider the cost-benefit ratio of such development activity.

Last but not least, let us not forget that relying on an external supplier for the sourcing of a particular component always entails a certain amount of risk, related to a possible discontinuation of that chip antenna availability, which is obviously excluded with a customized antenna that becomes an exclusive part and resource of the Customer, as well as the whole apparatus that contains it.

If you choose, for your project, to adopt a chip radiating element that is already available from a given supplier, it is important to know how the antenna manufacturer is available to evaluate the electrical performance of his own product mounted on the particular *board* you are developing and if he can provide you adequate support and advice to optimize his chip antenna on your particular design.

6. Conclusions.

In this document we reviewed the main aspects of integrated antennas.

In an integrated antenna, electrical characteristics do not depend on the *radiating element* but from all the so-called boundary conditions introduced by all the host apparatus hardware: the whole object become a *radiating system* that must be as efficient as possible, in agree with all the existing mechanical constraints.

In most cases, any project that requires the integration of an antenna represents a particular electromagnetic problem, regardless of the type of radiating element that is chosen.

To achieve an optimized radiating system on your embedded wireless device, it is important to keep a certain number of degrees of freedom in order to develop the best possible antenna for your own application.

For any needs and/or question feel free to contact us at

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