Technical E-Paper

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Constraints and degrees of freedom in the design of Integrated Antennas

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Effective communication with the Customer who entrusts us with the development of a custom antenna is a fundamental aspect of our work.

Understanding, at the beginning of a project, the exact application of the system in which the antenna will be integrated, as well as how the wireless equipment operates, allows us to optimize the final result.

In particular, in this article we aim to raise awareness among interested readers about the constraints and degrees of freedom that determine the extent to which a device can be modified in order to maximize the efficiency of the antenna integrated within it, while avoiding “checkmate” situations in which it becomes impossible to identify an effective solution.

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1. Introduction.

We have written many times on the subject of “Integrated Antennas”: these are radiating elements that are installed inside a host device or item of equipment, enabling wireless connectivity over one or more frequency bands.

The operation of these antennas is heavily influenced by their operating environment; consequently, their development and optimization are closely dependent on the definition and sizing of the equipment in which they will be integrated.

Given a specific wireless device, whether already defined or still under development by the Customer, the development of a dedicated integrated antenna must necessarily comply with the design constraints of the equipment itself.

As a result, the antenna designer interprets these constraints by identifying, on a case-by-case basis, the available degrees of freedom, namely the possibility of modifying certain “boundary conditions” of the equipment in order to enable the antenna to operate at its best.

In this article, which has deliberately been written in a more discursive than strictly technical style, we share some considerations on this aspect, which is often underestimated within the multidisciplinary project teams that today develop complex wireless devices for innovative applications.

Measurements on an integrated antenna in a TPMS (Tyre Pressure Monitoring System) device for sports motorcycle tyres.

2. Constraints and degrees of freedom from a technical perspective.

The development of any antenna, whether traditional or integrated, cannot be separated from the application of the laws of electromagnetism. These laws impose intrinsic limits on any implementation, which an experienced designer is able to mitigate or at least identify, providing the Customer with suggestions regarding possible modifications to the equipment aimed at improving its wireless performance.

These possible modifications may conflict with design constraints, which may be technical, commercial, or organizational in nature, as we will see in the following section. The presence of mandatory constraints obviously reduces the degrees of freedom that the developer can rely on when optimizing the antenna.

From a technical perspective, the design constraints for an integrated antenna usually fall into one of the following categories:

- dimensional constraints;
- electrical constraints;
- constraints on materials and technologies;
- operational constraints.

Dimensional constraints.

Today, many wireless devices are extremely compact; consequently, the antenna must also necessarily be small in size. In this case, it is useful to distinguish between the radiating element, which may also be a ceramic chip component, and the ground plane: in principle, the latter should extend to approximately λ/4 in order to achieve the best radiation efficiency.

Dimensional constraints also include positioning constraints, related either to the antenna or to other main components within the equipment. This limitation often greatly reduces the degrees of freedom available for antenna optimization.

Electrical constraints.

Constraints on antenna performance are also almost always present, as the antenna must be able to achieve a certain level of EIRP (Effective Isotropic Radiated Power) or TRP (Total Radiated Power) for certification of the complete device.

These constraints are often not provided as formal specifications, but are inferred from preliminary field tests carried out using the equipment itself. They are often the main reason why the development of a dedicated integrated antenna becomes necessary.

Some applications require an antenna with a specific radiation pattern, for example a hemispherical pattern, as may be the case for a GPS antenna, a directional pattern for RFID applications, or isolation between two or more coexisting radiating elements, as in MIMO equipment.

Measurements on an integrated antenna in a device for measuring the heat consumption of a radiator.

Constraints on materials and technologies.

There are cases in which the integrated antenna must necessarily be placed inside housings or enclosures that are largely metallic, or moulded using dissipative plastics in order to comply with ATEX regulations for equipment intended for use in potentially explosive atmospheres. Another example is when the radiating element has to be embedded in resin or mounted close to large dielectric masses.

Technology-related constraints often concern the engineering process and series production of the equipment, where it may be necessary to ensure that the antenna can be assembled easily and repeatably.

Operational constraints.

Finally, there are constraints dictated by the way the wireless product will operate in its intended use, or arising from the way in which the device is installed and/or managed throughout its entire operational life.

Sometimes, decisions regarding the architecture of the communication system or of the equipment itself impose constraints on the antenna and lead to non-optimal choices.

The design constraints that may affect the development of an integrated antenna are often provided by the Customer, who, at a very advanced stage in the development of their wireless device, turns to us with a product that has already been fully defined, including the antenna. Unfortunately, however, the antenna does not perform satisfactorily.

In these situations, which it is no exaggeration to describe as emergencies, we operate, where possible, by relying on a limited number of degrees of freedom; in other words, by respecting all the constraints already implemented in the product itself, even though this does not in fact represent the optimal solution to the problem.

Measurement of the effect of the dielectric on an integrated antenna.

The situation is different when we are involved at an early stage of the project, when it is still possible to modify certain mechanical solutions of the equipment in order to allow the integration of a more efficient antenna, or one with a less problematic engineering process. In this case, of course, a greater number of degrees of freedom can be relied upon when defining the integrated antenna.

That said, it is natural to ask what can be done if, in order to create a high-performance antenna integrated into a specific wireless device, one additional degree of freedom is needed beyond those currently available: for example, the possibility of moving certain components away from the radiating element, or placing the antenna in a position different from the one initially allocated by the Customer.

The constraint on the equipment that we would like to reduce or remove in order to maximize antenna performance is not always technical in nature, but is often commercial or organizational.

3. Commercial and organizational constraints.

In a complex, multidisciplinary project, to what extent is it possible to take a step back and make a change to the product under development?

Very often, project corrections that would allow a tangible improvement in the quality of the finished product, even when technically simple to implement, encounter resistance of another kind, which we could define as commercial and organizational in nature.

Commercial constraints.

It often happens that the constraints imposed on a given wireless device are dictated by commercial assessments or requirements: for example, the need to create a product with an attractive design, or the need to keep somewhat risky promises made to the end Customer in order to secure the order and stand out from competitors. The reasoning, whether right or wrong, becomes: "let's get the order first… the rest will be dealt with later or… someone else will take care of it."

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In other cases, the purpose for which the product is being developed, as well as its actual application, may be lost sight of, leading to the introduction of constraints in the form of technical refinements that are not functionally necessary and that, in the future, will almost certainly result in problems and weak points in the finished product.

Commercial constraints also include confidentiality constraints, which can sometimes prove to be a serious handicap in the development of a custom antenna. If the exact application of the wireless device or system is not known, it is not possible to assess whether the achievable antenna performance will be sufficient for the intended purpose.

Sometimes, a real impasse can arise when a highly "confidential" Customer, who is understandably not particularly knowledgeable in electromagnetism, makes incorrect assessments that may jeopardize the final result.

Although professional confidentiality is guaranteed by default, in such cases it is advisable to reassure the Customer through a preliminary NDA, so that a full and independent evaluation of the project can be carried out, highlighting any limitations of a technology that, later on, in the event of problems, could otherwise be attributed to the antenna.

Organizational constraints.

In an integrated antenna project, constraints introduced by project management are often present and, in most cases, can be resolved only at the cost of significant losses in time and efficiency.

In some medium-sized and large companies, a complex project is rightly carried out in parallel by highly competent working groups, each specialized in its own discipline, but communicating horizontally with one another through "interfaces" that do not have sufficient technical and technological expertise.

In such cases, working back through the process in order to make a late-stage modification to the product undoubtedly becomes difficult to implement.

In the writer's opinion, in certain environments the belief has taken hold that the management of a company, or more simply of a project, is not required to have either specific technical expertise or specific product knowledge, reducing project coordination to the mere management of information flows whose actual importance is not fully understood.

Since this particular subject falls outside the scope of this article, we leave any further considerations to the reader, based on their own professional experience.

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4. The importance of communication.

A supplier specialized in the development of custom antennas certainly cannot ease or eliminate all the constraints of a project it is asked to carry out. However, it is essential that it be able to optimize the result of its design activity based on the information provided by the Customer.

It should be remembered, in fact, that for the Customer, the added value of an antenna designed ad hoc for a specific item of equipment or application must be greater than the cost incurred for the project.

In this regard, it is essential to exchange information with the Customer in order to gain a thorough understanding of their needs and expectations, both at the beginning of the project and during its operational phase.

The main means through which it is possible to "communicate" with the Customer are the following.

a) Meeting or video call after the first contact.

A very useful tool is the availability of an initial meeting with the Customer, covered by an NDA if required, in response to their first contact. On this occasion, it is often already possible to obtain a detailed description of the Customer's needs and to estimate the possible critical issues of an integrated antenna that must comply with the project constraints.

These meetings are often requested by the Customer at a preliminary stage of product development, when advice on where and/or how to integrate an antenna within the equipment can prove valuable at the start of the device's mechanical and electronic design.

Timely communication of this kind is, for both parties, a sound investment in the successful outcome of the project.

Already after this first meeting, which involves neither commitment nor obligation, it is possible to provide an initial assessment. This may even lead to the conclusion that the development of a custom integrated antenna is not necessary, as off-the-shelf antennas can be used, or, in the most extreme cases, that a custom integrated antenna would not bring any improvement to the equipment's performance, because the project is too constrained and has reached a "checkmate" condition.

b) Technical-commercial proposal.

The information exchanged under point a) is useful for preparing the technical and commercial proposal, in order to formalize the possible collaboration for the development of the custom antenna. From a technical perspective, this document allows the Customer to verify whether the information provided and the requests made have been correctly understood and interpreted, and, from a commercial perspective, whether this development activity meets their expectations.

c) Detailed technical proposal.

Upon request, a more detailed technical analysis of the proposal can be carried out, highlighting both the critical aspects that the project may present and the type of solutions that can be implemented.

d) Preliminary measurements.

If an antenna has already been included in the product, or if field tests have been carried out with provisional prototypes that have led to unsatisfactory performance, an initial characterization of the wireless equipment is performed in order to evaluate the electrical specifications of the antenna already in use, under its actual operating conditions.

This allows both the Customer and the antenna developer to have a reference point from which to estimate the advantages that can be obtained with an ad hoc antenna.

e) Feasibility study.

In more complex cases, or when requested by the Customer, the development activity begins with a feasibility study aimed at defining the path for the subsequent operational phase of the project. In this phase, several solutions are generally examined, and it is possible to assess whether the degrees of freedom allowed by the structure integrating the antenna are sufficient to guarantee the desired performance, or whether it is necessary to modify or remove constraints imposed by the equipment.

Any continuation of the activity into the operational phases of the project is, of course, based on the outcomes of this initial phase.

Preliminary measurements on a pre-existing integrated antenna, in order to determine reference specifications against which improvements can be made.

Although Guglielmo Marconi certainly would not have needed any help in designing an antenna, communication with the Customer is a fundamental aspect of any custom antenna project, all the more so when the antenna is integrated into a device.

5. Conclusions.

In this article on integrated antennas, we have discussed the constraints or, using a complementary term, the degrees of freedom of a project, distinguishing them from the so-called technical specifications, which represent the starting point for any development activity.

Indeed, although specifications can be considered design constraints, constraints are not always due to the technical aspects of a specific product. They are often caused by other factors whose analysis, carried out in close collaboration with the Customer, makes it possible to obtain the best result from the development activity.

It is important to inform the Customer of the existence of any critical issues that could lead to a reduction in antenna performance, so that any choices or modifications, whether having a greater or lesser impact on the equipment hardware, can be discussed jointly.

The design of custom integrated antennas requires a careful preliminary evaluation, to be carried out on a case-by-case basis, since each implementation has its own specific characteristics and critical issues.

An open and collaborative exchange of information with the Customer, who usually handles the design of the entire wireless equipment, is a very important aspect of this type of activity.

For this reason, it is essential to establish communication procedures with the Customer that allow both parties to work on the joint development of the equipment and the antenna.

All the information and experiences presented in this article are the result of the design, development, and production of custom professional antennas carried out by ***ElettroMagnetic Services Srl*** *according to the* ***AntennaCustomizer*** *method.*

For questions, clarifications, or further information on this or other topics related to professional antennas, please contact ***bollini@elettromagneticservices.com****.*

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