Technical E-Paper

BIDIRECTIONAL

antennas for *WiFi, IoT* and *Smart Road applications*.

9

Francesco Zaccarini Ph.D

In the era of ubiquitous wireless connectivity, bidirectional antennas can solve or optimize coverage of complex areas.

Although a bidirectional antenna system can be set up by installing two directional antennas in a *back-to-back configuration*, sometimes this solution does not provide optimal performance compared to a single, purpose-built antenna.

This technical report provides an overview of these antenna systems: how they are manufactured and what performance they can offer thanks to a specific design.

ElettroMagnetic Services SRL

1. Introduction.

A *bidirectional antenna* is a directional type radiating system that radiates through two main lobes or beams with antiparallel orientation.

Antennas of this type are recommended whenever there is a need to cover an area whose extension prevails in one dimension (longitudinal) compared to the other (transversal). In practice, it is possible to find numerous situations of this type, such as:

- Road and motorway sections, including viaducts and tunnels;
- Corridors of hotels and public buildings;
- Transit and connection areas in airport terminals;
- Areas of warehouse and logistics where forklifts or self-driving, unmanned forklifts are used.

The most intuitive solution for the implementation of an antenna system that radiates in two opposite directions is the one shown in the cover figure in there are two directional antennas (*Yagi-Uda type*) with radomes mounted on a pole in a *back-to-back configuration* and powered by a single coaxial cable through a -3dB power splitter.

Although this solution is adopted in most installations, as will be seen below, it is not always the optimal configuration in terms of both electrical performance and mechanical dimensions.

In fact, when very high coverage requirements and/or high frequencies are needed, such as in *WiFi highway connectivity* applications (*Smart Road applications*), the use of an integrated bidirectional antenna system is the optimal solution both in terms of performance and cost.

2. Types of bidirectional antennas.

From a design point of view, three different types of bidirectional antenna can be developed:

a) *Two separate antennas, installed in a back-to-back configuration and powered by an external splitter;*
b) *Two integrated radiating elements, i.e. mounted in a back-to-back configuration with some common parts and a single power point;*
c) *A single radiating element characterized by a bidirectional radiation pattern.*

To better clarify these three configurations, consider the examples below, in which a simple radiating element (consisting of a pair of parallel dipoles) has been used in the three different cases.

2.1. *Case a*: two separate antennas.

In this configuration (***Figure 2.1***) there are two identical antennas, each represented by a pair of parallel dipoles, mutually spaced of $\lambda/2$, positioned at a distance equal to 0.2 λ from a metal reflector with dimensions equal to λ .

Each of these antennas, considered on its own, is a typical panel with a gain of 10 dBi and a beamwidth of 60 ° in the H plane (***Figure 2.2***).

The panels are then installed in a *back-to-back configuration* and fed by two equal lengths of coaxial cable to a power splitter.

As already shown in the cover image, a practical installation of this type makes use of a mechanical support and pole mounting brackets for each antenna: consequently, the distance ***D*** between the antennas becomes a variable that is not defined a priori and that can reach significant dimensions compared to λ , especially when considering the higher frequency bands (3.6 GHz and 5.8 GHz).

Since, in fact, even two radiating elements mounted in a *back-to-back configuration become a composite antenna*, the radiation characteristics of the antenna system obtained depend on the distance ***D.***

Figure 2.3 shows this feature, with a series of radiation diagrams in the H plane, corresponding to different distances ***D*** between the antennas.

Although there are no large variations in the beam widths of the two main lobes, this parameter has a significant effect on the radiation in the other directions, which are just as important in many installations to ensure good coverage, like, for example, in the case of a stretch of motorway extending on both sides of the (central) point where the antenna is located.

Although the results of ***Figure 2.3*** refer to a well-defined radiating element and the differences detected when ***D*** varies tend to be attenuated using a pair of higher-gain directional antennas, there is no doubt that it is not possible to

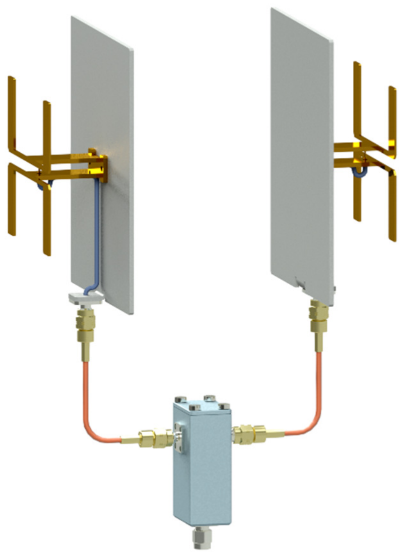


Figure 2.1
Case a: two separate antennas in *back-to-back* configuration.

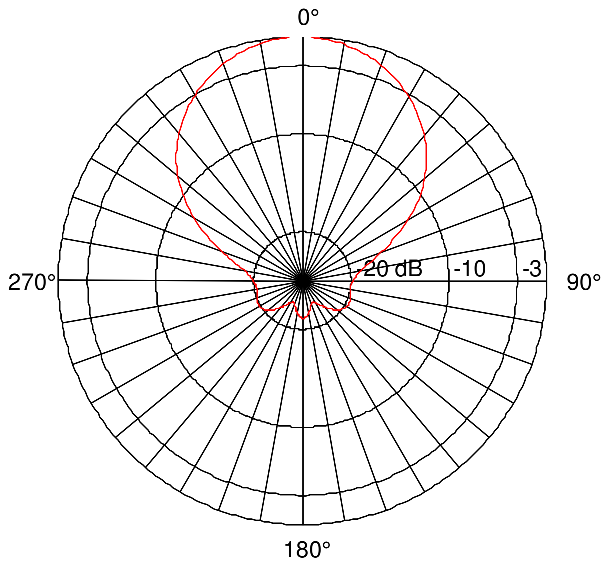


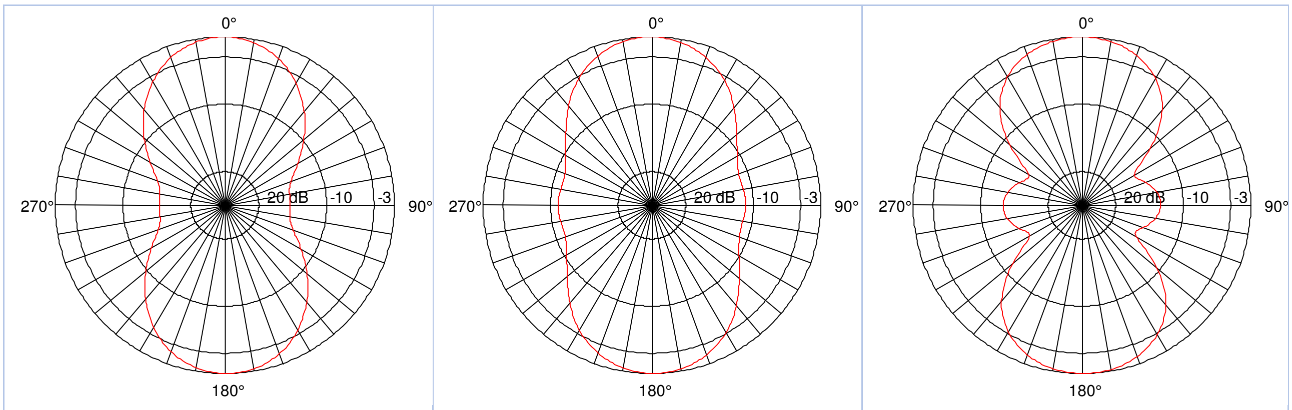
Figure 2.2
Radiation diagram in the H plane of a single directional antenna in *Figure 2.1*.

accurately characterize a bidirectional antenna system in the configuration of ***Figure 2.1*** since, in general, the distance ***D*** varies depending on the specific installation.

Furthermore, the losses introduced by the external distribution network were not taken into account in the gain calculation (the *directivity values* are shown at the bottom of the polar plots in ***Figure 2.3).***

Tolerances in the length of the connecting cables between the splitter and the individual antennas can also introduce phase and/or power unbalances which have the effect of altering the radiation patterns in ***Figure 2.3***, especially in the higher frequency bands, such as 5.8 GHz.

While in many practical cases the use of two separate directional antennas, installed *back-to-back* and fed via an external splitter, is satisfactory, in applications where optimal coverage is required, it is advisable to opt for an optimized system, already designed to be bidirectional and with precisely defined radiation characteristics, as will be seen later in " *case b*" and " *case c*".



D = 0.25 λ (7.7 dBi) | *D* = 0.5 λ (6.8 dBi) | *D* = 0.75 λ (6.9 dBi)

D = 1.0 λ (6.9 dBi) | *D* = 2 λ (7.1 dBi) | *D* = 3.0 λ (7.2 dBi)

Figure 2.3

Radiation diagrams in plane H calculated at different distance values ***D*** between the two single antennas of *Figure 2.1*.

2.2. *Case b*: integrated radiant elements.

The second type of bidirectional antenna (***Figure 2.4***) entails the embedding of the two radiating elements on the opposite faces of a single reflector, i.e. of a metal plate with dimensions equal to λ. Compared to the previous case, there are two main advantages:

- the bidirectional antenna has precisely characterized radiation patterns, i.e. they can also be found in the operating position, since the degree of freedom represented by the distance ***D***, which depends on the particular installation, no longer exists;
- the radiating elements can be designed to have a single power point and a suitable input impedance, as shown in the figure, avoiding the use of splitters and external wiring.

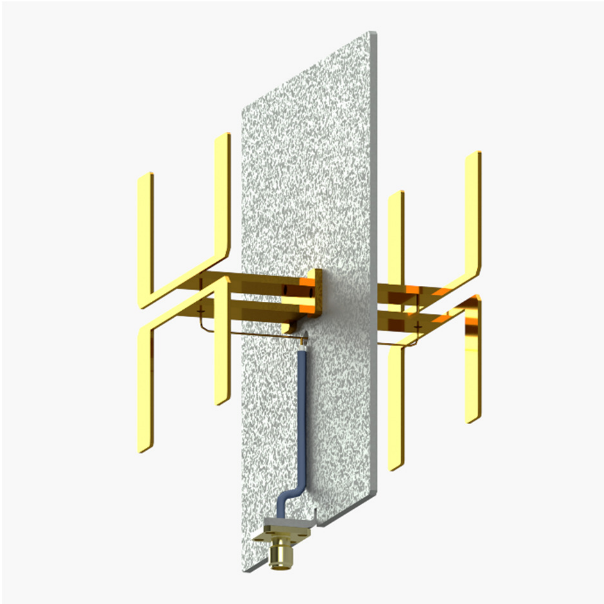


Figura 2.4
Case b: two integrated radiating elements

Figure 2.5 shows the radiation diagram, in the H plane, calculated for the integrated bidirectional system of ***Figure 2.4***: in this configuration, a directivity value of 7.0 dBi is obtained, again referring to both beams.

From a practical point of view, an antenna of this type is housed in a much more compact *radome* than in the previous case, and a so called jib mounting is used, which can be conveniently installed either on a mast (for example on the side of the road) and on a wall (e.g. in the middle of a corridor or tunnel, ***Figure 2.6***).

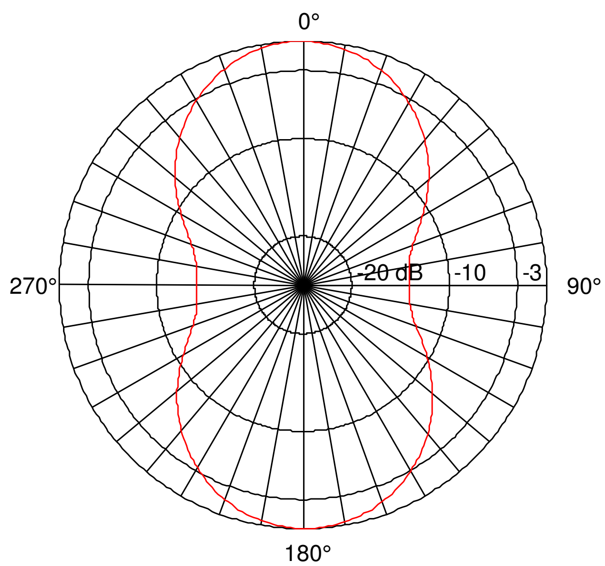


Figura 2.5
Radiation diagram in the H plane of the bidirectional antenna of *Figure 2.4.*

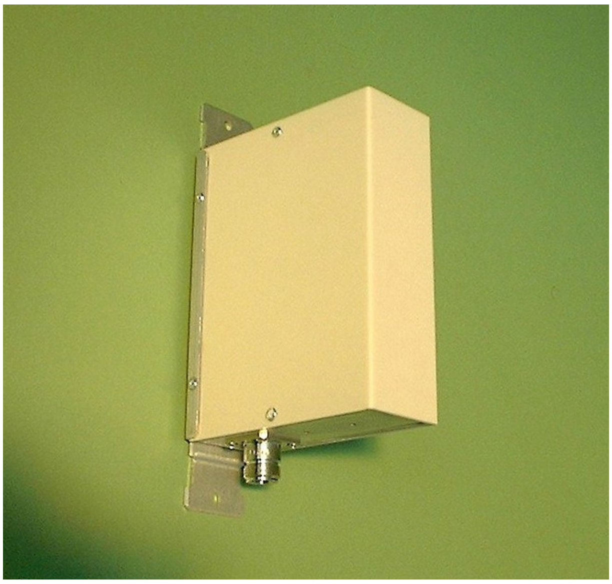


Figura 2.6
Bidirectional 5.6 GHz wall-mounted antenna *(mod. BP6VWM, ElettroMagnetic Services)*

2.3. *Case c*: single bidirectional radiating element.

The third and final type of bidirectional antenna, shown in ***Figure 2.7***, consists of a single radiating element which provides the desired radiation characteristics on its own.

In this example, reference is made to a printed circuit board (PCB) antenna, consisting of the two parallel dipoles seen above, spaced $\lambda/2$ and powered in phase, which radiate in the two antiparallel broadside directions, i.e. perpendicular to the PCB plane.

This configuration presents, in the H plane, the radiation diagram shown in ***Figure 2.8***: in this case, the simulation provides a directivity value of 5.8 dBi.

There is no doubt that, from a construction and mechanical point of view, an antenna of this type has considerable advantages both in terms of thickness and construction simplicity, since there are essentially no parts to assemble except for the antenna feed, which in this example is an SMA-f with direct soldering on the PCB, at the microstrip feed point.

Comparing the radiation characteristics of this antenna with the previously described bidirectional system (***Figure 2.4***), in this case a lower directivity value is obtained (5.8 dBi compared to 7.0 dBi). Without going into the reason for this difference, due to the presence of the reflector (image plane) in the "*case b*" antenna, it is sufficient here to keep in mind that, for the same gain, the size of the PCB ("*case c*") is greater than the size of the metal reflector in the previous case (*"case b")*.

Finally, as with the design of any other antenna, it is indispensable to correctly assess the losses introduced by the feed line (and the distribution network), which in "*case b*" and "*case c*" is single rather than double (in fact in "*case* a", of course, there are two feed/matching networks, one for each antenna).

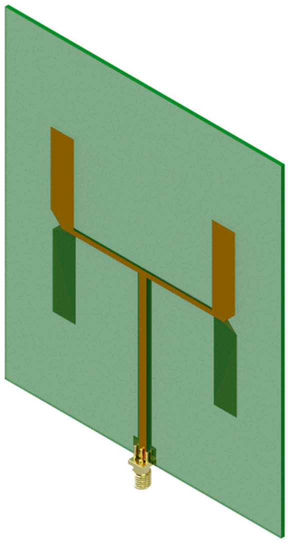


Figure 2.7
Case c: single bidirectional radiating element.

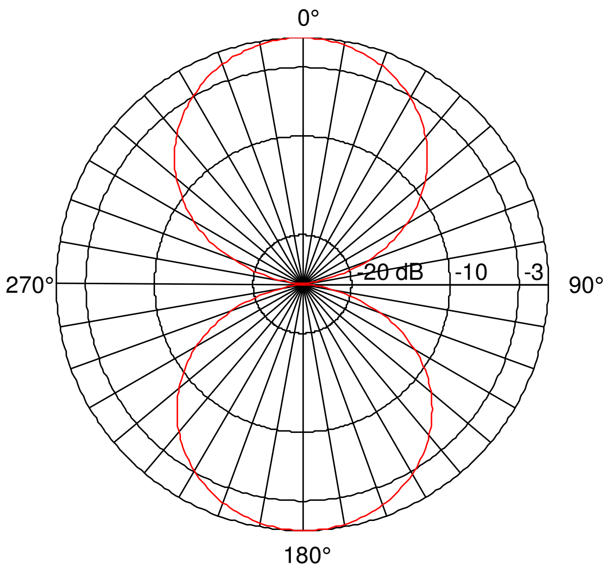


Figure 2.8
Radiation diagram in the H plane of the bidirectonal antenna in *Figure 2.7*.

3. Bidirectional arrays.

In the previous paragraph, the three basic types of bidirectional antennas were described, taking as an example a radiating element of small size (respect to λ) and with a low gain.

If there is a need to increase the gain of the antenna system, or to synthesize radiation patterns with specific characteristics, it is possible to build composite bidirectional antennas (*bidirectional arrays*) using several simple radiating elements, suitably arranged and fed.

If, in "*case a*", this means using two separate directing arrays, e.g. two panels or a pair of *Yagis*, in "*case b*" and "*case c*", arrays of bidirectional radiating elements are designed and installed.

In this way, it is possible to include precise radiation characteristics in the antenna that are the same for both beams, such as *downtilt* or *squint,* as well as zero compensation in the radiation patterns in the vertical and/or horizontal plane.

Examples of bidirectional arrays for the 2.4 GHz band are shown in ***Figure 3.1***, where the two antennas in the picture (for vertical and horizontal polarisations respectively) belong to the type described in "*case b*", i.e. with radiating elements (here *circular patches*) integrated on both sides of a single ground plane. The latter has been realised by metallising a low-loss dielectric laminate, on which the microstrip power supply and matching network has also been integrated. This network also implements a *downtilt* and a *squint*, in azimuth and elevation respectively.

With these arrays of 2×3 circular patches on each side, connected to the distribution network through a single feed point (directly at 50Ω input impedance), gain values of about 11dBi are obtained on each beam, as well as very precise characteristics of the radiation lobes, consisting of a *squint* of 15° in the horizontal plane and a *downtilt of* 4°÷5° in the vertical plane. Finally, it is important to compensate the zeros of the

Figure 3.1
Bidirectional arrays, with V and H polarisation respectively, for the 2.4 GHz band (*ElettroMagnetic Services*).

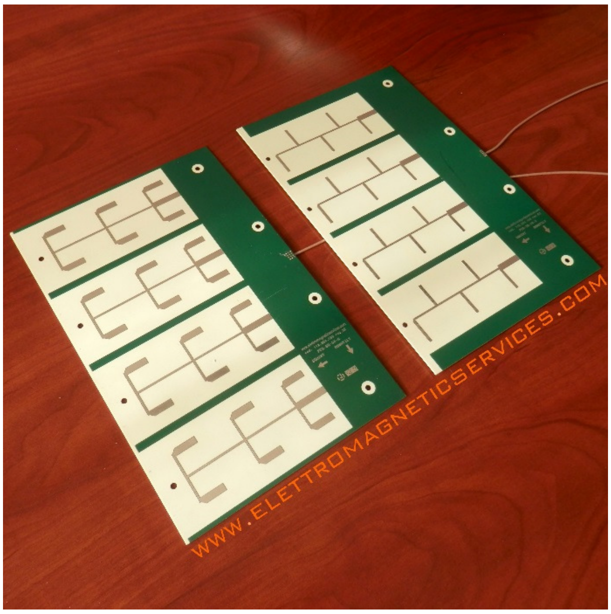


Figure 3.2
Bidirectional arrays, with V and H polarisation respectively, for the 5.8 GHz band (*ElettroMagnetic Services*).

radiation diagram in the zenith plane. As an example, the corresponding radiation diagrams for the antenna in vertical polarisation are shown in ***Figure 3.3***.

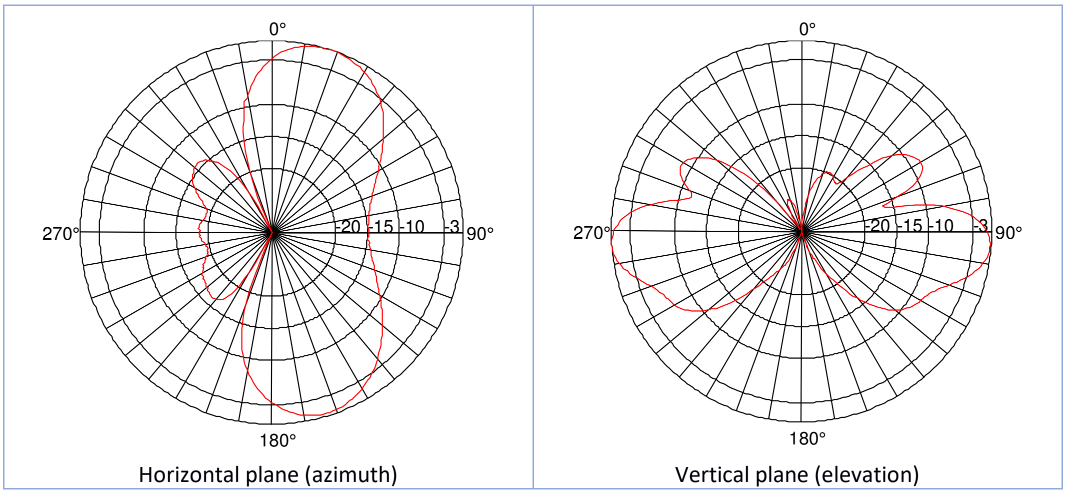


Figure 3.3
Radiation diagrams of the 2.4 GHz antenna in vertical polarization in ***Figure 3.1***, measured in the two main floors.

A second example of bidirectional arrays, this time with a coplanar dipole configuration, i.e. belonging to the type described in *"case c"* of the previous paragraph, is shown in ***Figure 3.2***, where the two antennas are photographed for the respective H and V polarisations. In this case, a gain of about 13 dBi was obtained, always introducing a *squint* and a *downtilt* in the corresponding radiation diagrams (***Figure 3.4***), also characterized by compensation of zeros in the vertical plane.

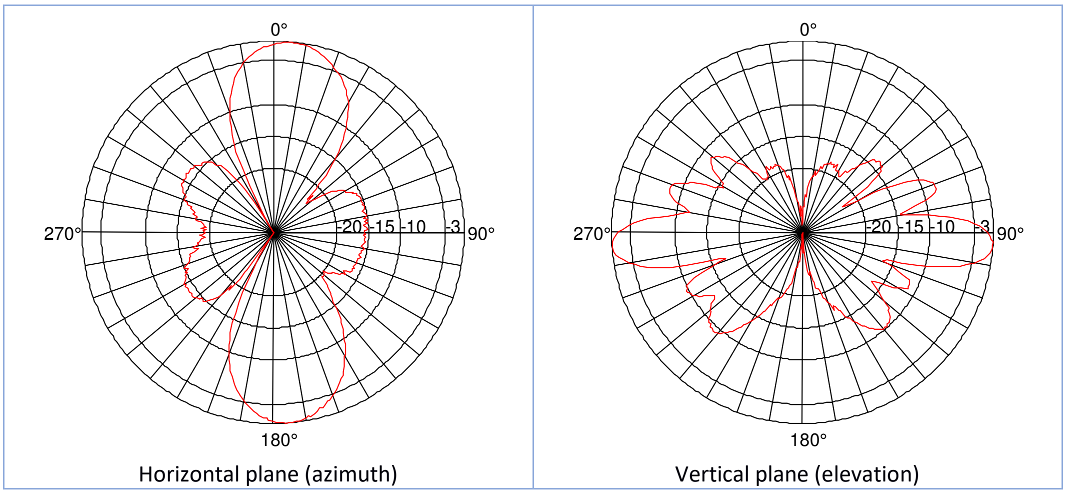


Figure 3.4
Radiation diagrams of the 5.8 GHz antenna in vertical polarization in ***Figure 3.2***, measured in the two main floors.

4. Applications of bidirectional antennas.

As mentioned at the start, bidirectional antennas are widely used in the *WiFi* and *IoT* sectors, where there is a growing need to make installations in complex locations or environments in an efficient, discreet and cost-effective manner.

While in *WiFi* it is desirable to be able to cover a given area using the smallest possible number of *access points*, in the world of *IOT* where *client* devices with their integrated antennas are increasingly miniaturised, coverage must be improved by optimising the antennas on the *concentrator* side.

There will therefore be a growing need for antennas designed for specific applications, limiting the use of standard models to less critical and more conventional installations.

This is the case, for example, of *WiFi* connectivity that must be guaranteed on the motorways of the near future, i.e. the *Smart Road* application, where specially designed bidirectional antennas play a key role in optimising the efficiency of the network.

An example of this is shown in **Figure 4.1** and **Figure 4.2**, where the distribution of power density, in *dBm/m*^{2}, on a section of motorway, is shown in plan view.

In both cases, the antenna (or antennas) is located at the bottom left, at the coordinates (0.-5 metres) on the graph and at a height of 6 meters above the road surface. The coverage refers to a 500-meters stretch of motorway carriageway, and only the right-hand half is shown in the graph, since obviously the left-hand half is mirrored with respect to *X=0*.

In **Figure 4.1,** two separate antennas are used in *back-to-back* configuration, and shadow areas are highlighted (in blue), which are not easy to define a priori as they depend on how the two directional antennas are mounted (see *paragraph 2.1*).

The lowest value of power density obtained, in the area shown, is approximately *-105 dBm/m*^{2}.

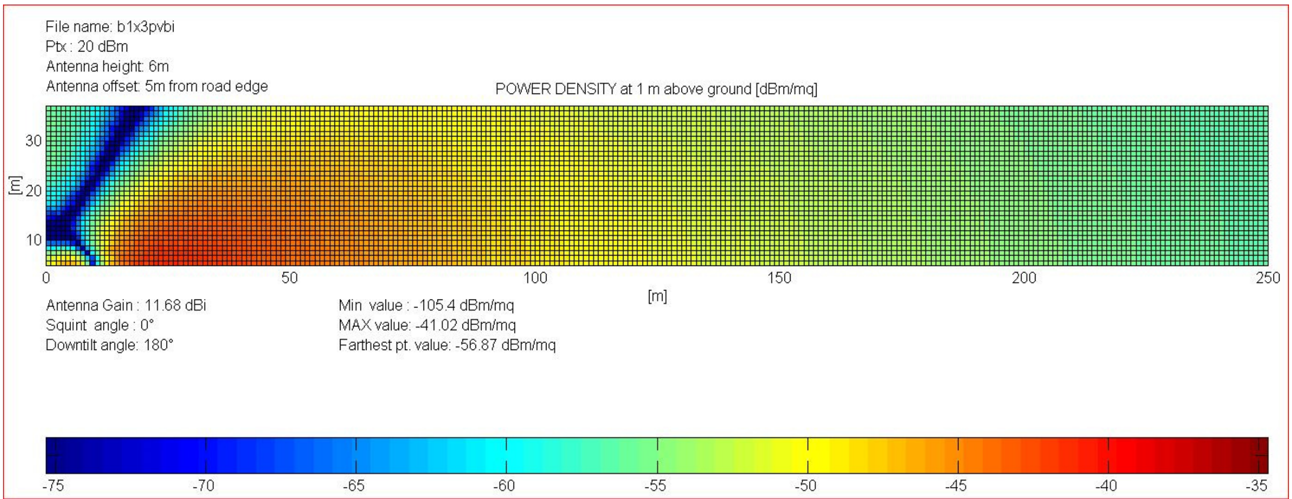


Figure 4.1

Example of coverage (radiated power density) of a motorway section using two separate antennas, wired in a *back-to-back configuration* using a power splitter.

Figure 4.2 shows the same area, but this time covered with a tailor-made bidirectional antenna, i.e. with a radiation pattern designed so as not to have deep holes or minima. This is possible because the bidirectional antenna can be designed as a single integrated radiating system (see *paragraphs 2.2 and 2.3*).

With this optimised solution, the worst-case power density value calculated is approximately *-62 dBm/m²*, and this without having to resort to a very complex configuration of radiating elements.

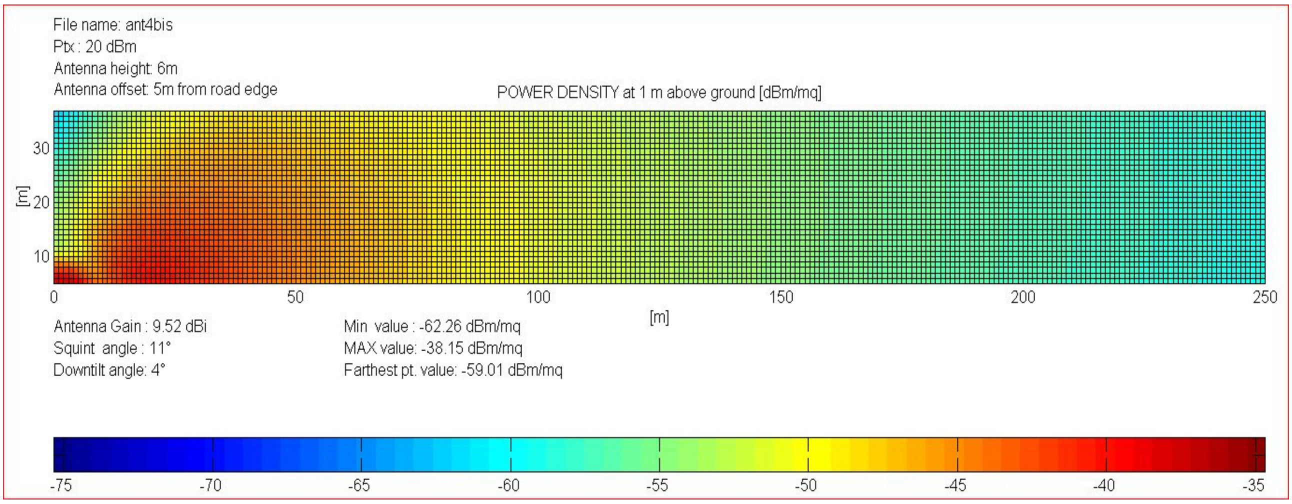


Figure 4.2
Example of coverage (radiated power density) of a motorway section by means of a tailor-made bidirectional antenna.

In indoor applications, such as airport terminals, hotels or railway stations, bidirectional antennas can also be used profitably because they can be concealed more easily, for example in signage or advertising boards, making them more discreet and less prone to vandalism.

As shown in **Figures 4.1** and **4.2**, even in the warehouses or forecourts of companies dealing with logistics, the advantages of using bidirectional antennas are certainly more of a technical than an aesthetic nature, since it is possible to minimise or eliminate shadow areas.

In fact, these wireless networks are usually defined and installed using traditional antennas (e.g. omnidirectional or sector), often mounted in less than optimal conditions (e.g. close to a reinforced concrete wall) for which it is not possible to make any prediction about their radiative behaviour under operating conditions.

5. Conclusions.

In this technical report we have attempted to provide an overview of *bidirectional* antennas, highlighting the fact that it is possible to construct tailor-made antenna systems for applications requiring good coverage of specific areas.

In fact, although in principle a bidirectional antenna can be obtained by coupling two traditional directional antennas in a *back-to-back* configuration, the use of integrated antenna systems makes it possible to create antennas optimised for the type of installation and coverage required.

The three types of integrated antennas that can be designed and built have been described in this in-depth study, trying to show the differences and special features of each one in a simplified manner.

There are also examples of bidirectional antennas in the 2.4 GHz and 5.8 GHz bands that have been developed and manufactured to meet specific and stringent coverage requirements.

In *WiFi, IoT* and *Smart Road applications,* bidirectional antennas will find an increasing number of applications, including in integrated and compact systems containing both the equipment and a number of antennas operating on different frequency bands with *MIMO* technology in space and/or polarisation diversity values.

To submit your question or for any clarification or information, write to
sales@elettromagneticservices.com

Thank you for taking the time to read this article.

If you want to read more, find the complete list here:

https://www.elettromagneticservices.com/news

ElettroMagnetic Services SRL

Broadcast your excellence!