

Anti-reflecting covering structure with a diffraction grating using resonant elements

The invention relates to the general field of the reflection of electromagnetic waves, particularly radio waves, and more particularly the field of preventing the effects of radio waves reflected by structures such as the facades of buildings on the space surrounding these structures. In particular, it concerns the effects of radio waves reflected by buildings located in airport zones on the proper operation of radio measurement systems.

In the context of the planning of airport zones, a major problem is that of determining the best way of siting the buildings required for the operation of the airport services, with the aim of minimizing the indirect effects of this siting on radio-sensitive areas. This is because these structures generally have large facades, which act as reflectors of the radio waves transmitted by the various transmission sources present in the vicinity of the airport zone or within this zone. In some cases, the reflection by the facade of a building of the radio transmission produced by a source which may or may not be distant from the building can prove extremely troublesome, insofar as the signal received by the facade is reflected toward an area where it will interfere with the radio transmissions taking place in this area. This is the case, in particular, if a building located in an area relatively close to a landing runway reflects toward the runway a radio transmission whose frequency band is located in the band occupied by transmissions of the landing system (ILS), particularly the band occupied by the "localizer" (providing radio alignment on the runway axis). This parasitic reflection, if strong enough, may affect the localizer signal and consequently disrupt the alignment of landing aircraft on the runway axis.

Because of the presence of numerous radio sources, notably the ILS antennas themselves, the problem of parasitic reflections from buildings is a major problem which is usually resolved by drawing up a siting plan including areas, notably those areas that are relatively close to the runways, where the location of any structure of significant size is prohibited. Taking into

consideration, notably, the concentration of urban development and the desire to locate airport zones relatively close to urban areas, it becomes increasingly necessary to maximize the level of occupation of airport zones in terms of surface area. It is therefore more urgent than ever to find a solution
5 to the problems of parasitic reflections of radio signals in sensitive directions.

According to the known prior art in this field, the facades of buildings which may accidentally give rise to parasitic reflections in sensitive directions may theoretically be equipped with patch structures, the purpose of which is
10 to create, together with the wall on which they are installed, a diffraction device for reflecting incident waves, transmitted by external electromagnetic sources, in a preferred direction, which avoids the creation of interference in a sensitive area. A structure of this type is generally composed of conductive elongate structural elements arranged so as to form ribs spaced apart from
15 each other. The ribs are generally tubular elements having a specified thickness such that a given value of phase shift is created between the wave directly reflected by the wall of the building and that reflected by the ribs. In this way, a diffraction grating of the Bragg grating type is formed, enabling the incident wave to be diffracted in a desired direction, according to the
20 phase shift created by the ribs of the diffraction device.

According to the wavelength λ whose reflection in a given direction is to be prevented, the ribs forming the covering have a given thickness h , which may be relatively large if the wave in question has a frequency of the
25 order of hundreds of megahertz. Because of their bulky nature, these elements are difficult to position on the surface of a facade, especially if the elements are installed after the construction of the building.

Furthermore, in order to ensure the correct diffraction of the incident wave, the facade exposed to the radiation whose effects are to be prevented
30 is, in most cases, preferably equipped with ribs having a length substantially equal to the height of the facade, or occupying a significant portion of the upper of the facade. The fixing of the structural elements on the facade in question therefore creates a heavy load on the facade, attempts being made to minimize this load by using hollow tube-shaped structural elements.

However, these elements are fragile objects, and suffer from the weakness of a lack of intrinsic rigidity.

Thus, the well-known types of prior art coverings use structural elements, the mounting of which on the facade to be equipped is relatively demanding in terms of their size, or more precisely their overall dimensions, and in terms of their weight, which is supported by the facade, and of the rigidity of the resulting structure.

One object of the invention is to propose an alternative structure to form a diffraction grating of the Bragg grating type. This structure is composed of tubular structural elements which, for the frequency band concerned, have an intrinsic rigidity greater than that of rectangular section elements, together with a substantially lesser thickness and width than those of elements forming the known structures.

For this purpose, the invention proposes a diffraction device for covering a facade of a building, or any other reflecting wall, exposed to the electromagnetic radiation transmitted by a distant source, the device including a plurality of tubular resonant elements, positioned in a periodic manner and in a substantially parallel way on the facade of the building so as to form a diffraction grating. Each resonant element forms an LC resonator configured to re-radiate a wave corresponding to the incident wave subjected to a phase shift. These resonant elements are arranged on the wall in such a way that the incident wave is diffracted in a preferred direction. The resonant elements are also oriented in a direction substantially perpendicular to the plane defined by the propagation vectors of the incident and reflected waves.

According to a specific embodiment of the device, the spacing pitch of the different conductive elements is determined as a function of the wavelength λ and the angle of incidence θ so as to create a diffraction grating of the Bragg grating type, producing a phase shift of the incident wave such that the latter is diffracted in a preferred direction.

According to the invention, if the electromagnetic transmission source is distant, the spacing between the different conductive elements is constant along the wall.

According to the invention, if the electromagnetic transmission source is nearby, the spacing between the different conductive elements is a function of the local angle of incidence of the electromagnetic wave.

5 According to the invention, each resonant element is composed of a tube of conductive material whose wall, which defines an inner cavity, has a longitudinal opening. The dimensions and geometry of the cavity defined by the wall, as well as the width of the longitudinal opening formed in this wall, are defined so that the element acts, in electromagnetic terms, as an LC
10 resonator with a resonance frequency F_0 and a bandwidth ΔF_0 .

Additionally, according to the invention, each resonant element is preferably configured so as to have overall dimensions which can be inscribed within a parallelepipedal volume of given dimensions taking
15 mechanical stresses into account.

According to the invention, the resonant elements forming the device may have cross sections of various polygonal shapes which are all inscribed in a rectangle, the resonant elements having specific values of capacitance
20 or inductance according to the chosen cross section.

In a specific embodiment, the wall of a resonant element has the shape, in cross section, of a rectangle, one length of which has a discontinuity limited by two segments substantially perpendicular to said
25 length, whose ends are directed toward the inside of the perimeter.

Additionally, according to the invention, each resonant element may be configured so as to form a plurality of adjoining tubular cavities.

30 In a specific embodiment, each resonant element is itself formed by a plurality of juxtaposed resonant elements, whose lateral walls are in electrical contact.

In a specific embodiment, the inner volume of the resonant elements is
35 empty.

Alternatively, in another embodiment, the cavity defined by the wall of the resonant element is filled with a dielectric material chosen so as to reinforce the rigidity of the element.

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According to a variant of this embodiment, the cavity defined by the wall of the resonant element is filled with two superimposed layers of dielectric material, a conductive strip being placed in the cavity, at the interface between the two layers, facing the longitudinal slit formed along the wall.

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Alternatively, in another embodiment, the cavity defined by the wall of the resonant element is filled with a nonconducting ferromagnetic material chosen so as to increase the bandwidth ΔF_0 and reduce the frequency F_0 of the resonant cavity.

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Alternatively, in another embodiment, the cavity defined by the wall of the resonant element is filled with a dielectric material having a high permittivity ϵ , chosen so as to reduce the frequency F_0 of the resonant cavity.

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The characteristics and advantages of the invention will be made more clearly evident by the following description which is based on the appended drawings, which show:

- in Figure 1, a schematic representation of the whole of the device according to the invention;

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- in Figure 2, an equivalent diagram of the operation of a structural element forming the device according to the invention;

- in Figures 3 to 8, illustrations of different variant embodiments of the device according to the invention;

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- in Figure 9, an illustration highlighting the advantageous nature of the device according to the invention in terms of size;

- in Figure 10, a curve illustrating the advantages gained by the use of the device according to the invention.

Figures 1 and 2 show the general structure of the device according to the invention. As shown in Figure 1, the covering according to the invention takes the form of an arrangement of parallel elongate structural elements 12 whose length depends on the dimensions of the wall 11 to be covered.

5 The structural elements 12 are arranged on the wall 11 so as to form a diffraction grating having a pitch d . According to the invention, the spacing pitch d of the different conductive elements is conventionally determined as a function of the wavelength λ and the angle of incidence θ so as to create a diffraction grating, producing a phase shift of the incident wave such that the
10 latter is diffracted in a preferred direction. Depending on whether or not the source of the radio transmission received by the wall is considered to be a distant source, the pitch d is a constant pitch, as in Figure 1, or a pitch varying as a function of the local angle of incidence of the electromagnetic wave.

15 The structural elements 12 are also arranged on the wall 11 so as to be oriented in a direction substantially perpendicular to the plane defined by the propagation vectors of the incident and reflected waves. Thus, in the specific case of a building facade, the structural elements are positioned vertically.

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According to the invention, each structural element 12 is a conductive element in the form of a hollow cylinder or tube, of polygonal shape, having a flat face 15 by which it is fixed to the wall 11, the wall of the tube being provided, on the opposite face 13, with a longitudinal slit 14 having a given
25 width e . The structural elements 12 are made from a conductive material, such that they form L-C (i.e. inductance-capacitance) circuits with distributed constant L and C . The inductance L is formed by the wall of the tube itself and is a function of the area delimited by the wall of the tube, while the capacitance C is formed by the slit 14 and by the cavity 21.

30 The dimensions of the wall of the tube are also determined in such a way that the values of the inductance L and the capacitance C make it possible to form an equivalent resonant circuit having a resonance frequency F_0 and a bandwidth ΔF_0 defined in a known way by the following relations:

$$F_0 \propto \frac{1}{\sqrt{L \cdot C}} \quad [1]$$

and

$$\Delta F_0 \propto \sqrt{\frac{L}{C}} \quad [2]$$

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In terms of operation, each resonant element is configured or designed in such a way that, when it is illuminated by an incident radio wave, it produces a radio wave having the same frequency but subjected to a given phase shift, so that the combination of the waves reflected by the different structural elements 12 and the waves directly reflected by the portions of the wall 11 located between these structural elements forms a wave diffracted in the desired direction.

The device according to the invention therefore acts as a conventional diffraction grating of the Bragg grating type, having simply conducting structural elements. In terms of dimensions, however, the structural elements constituting the device can be used to form a covering which is advantageously easier to install on a wall, particularly on a wall of a building.

This is because, unlike the dimensions of the conductive elements forming a conventional diffraction grating, the dimensions of the resonant elements which form the device according to the invention are not directly a function of the path difference to be created between the waves reflected by the wall 11 itself and those reflected by the structural elements to obtain the desired diffraction, but are affected by the values of capacitance and inductance to be obtained.

Consequently, for the same result, that is to say for the same phase shift between the waves reflected by the wall 11 itself and those reflected by the structural elements, the dimensions of the resonant element are substantially smaller than those of a simple conductive element.

Figure 9 illustrates this structural advantage by showing the respective dimensions of the structural elements forming two diffraction gratings intended to control the wave reflected by a wall illuminated at an incidence of approximately 25° by a radio wave having a frequency of about a hundred megahertz transmitted by a distant source, that is to say a source located at

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a distance from the wall such that the wave received by the facade 10 of the building is a plane wave (Fraunhofer zone). In both cases, gratings formed by structural elements with a rectangular cross section are considered. The first grating 91 is a conventional grating formed by simple conductive elements, whereas the second grating 92 is a device according to the invention, formed by resonant elements 12. As may be seen in the figure, the same result, namely the production of a phase shifted wave, is achieved with dimensions of a resonant element 12 very substantially smaller than those of a simple conductive element.

This dimensional characteristic provides two advantages. The first advantage is ergonomic, and consists in the fact that, when mounted on a wall, the diffraction device according to the invention appears less prominent and less masking, so that, if the wall is a facade with windows, the exterior light penetrates into the building more easily. The second advantage is mechanical, and consists in the fact that, since the resonant elements have smaller dimensions, the problem of their intrinsic rigidity and their possible deformation under the effect of their own weight is less acute when they are mounted on the wall 11 to be covered.

The following text describes different variant embodiments of the resonant elements forming the device according to the invention, in which the structural elements have cross sections of various shapes. These different variant embodiments are described here with the aim of demonstrating that, for given overall dimensions, it is possible to produce resonant elements having different resonance frequencies F_0 and bandwidths ΔF_0 .

To provide a clear demonstration of the comparative advantages of the different variants, the structural elements considered here are those whose cross sections form quadrilaterals which can be inscribed the same rectangle having a given length w and width h . It should be noted that the variant embodiments described below do not in any way limit the form, purpose or scope of the invention.

According to a first simple variant embodiment, each tube has, as shown in Figure 2, a rectangular cross section with two rectilinear opposing longer sides 23 and 25, having a length w , corresponding respectively to the

inner face 15 and the outer face 13, and two shorter sides 26, with a length of h, corresponding to the lateral faces 16. The side 13 also has a discontinuity 24 corresponding to the slit 14. In this variant embodiment, the value of the inductance L is notably determined by the area defined by the wall of the tube. Regarding the value of the capacitance C, this is determined by the width of the slit 14 which corresponds, in the cross-sectional view, to the discontinuity 24, and by the dimensions of the inner space delimited by the wall of the element (see illustration 2-b).

According to a second variant embodiment, each resonant element has a cross section such as that shown in Figure 3, in which the wall of the element 12 has, along the slit 14, corresponding to the discontinuity 24 in the cross section, two edges curved inward at 90° and facing each other, represented by two segments of identical length 31 and 32. These two edges have lengths defined in such a way as to increase the value of the capacitance C with respect to that of the preceding variant, and to make this capacitance C less dependent on the size of the cavity (plane capacitor).

According to a third variant embodiment, shown in Figure 4, the resonant elements 12 that are used have, in section, a rectangular cross section, one of the lengths of which has a discontinuity 24 corresponding to the slit 14. However, the cavity 17, defined by the wall of the resonant element 11, accommodates an inner extension 41, fixed to the face of the wall 15 opposite the wall 13 including the slit 14, and forming a rib 41 projecting inside the cavity.

In this variant embodiment, this rib 41 has, in cross section, a "T" shape, the bar of which is parallel to the lengths 23 and 25 of the rectangle representing the section of the element. It is configured and arranged within the cavity in such a way that the bar of the "T" is placed facing the discontinuity 24, at a distance defined as a function of the expected resonance frequency F_0 and bandwidth ΔF_0 . This configuration advantageously enables the value of the capacitance C to be increased substantially without any substantial modification of the value of the inductance L.

According to a fourth variant embodiment, shown in Figure 5, the cavity of the resonant elements 12 that are used does not simply contain ambient air, but is filled with a dielectric material 51 which, in this case, essentially serves to reinforce the mechanical rigidity of the element. This
5 variant is particularly advantageous if the element used is very long relative to the dimensions of the wall to be covered.

It should be noted that, in this variant embodiment, the material accommodated in the cavity may also have diverse electromagnetic properties. Thus, by using a material having a high permittivity ϵ_r , it is
10 possible to increase the value of the capacitance C, without changing the dimensions of the cavity or the shape of the wall. Conversely, by using a material having a high permeability μ_r , the value of the inductance L can be increased without making any other changes.

It should also be noted that this variant embodiment may be
15 associated with all the preceding variants. It may, in particular, include the positioning in the material of a longitudinal strip 52 arranged so as to face the slit 14. This produces a radiating element which is very similar in its design to the element of the fourth variant embodiment described above.

According to a fifth variant embodiment, shown in Figure 6, a slit 61 is
20 formed on one of the lateral faces 16 of the resonator, the assembly being held in place by an appropriate dielectric mechanical structure, which is omitted from the figure for the sake of clarity. An element 62 having high self-inductance is also placed within the cavity 17, and is connected electrically by each of its ends 63 and 64 to the two edges 65 and 66 of the slit 61. Thus
25 the inductance of the circuit LC is increased, resulting in a decrease in its resonance frequency F_0 and an increase in its bandwidth ΔF_0 .

In terms of construction, the element 62 may consist of a single assembly extending over the whole length of the cavity 17, or, as shown in Figure 6, may consist of a plurality of elements arranged in sequence with
30 each other, each element being connected by its ends to the edges of the slit 61.

According to a sixth variant embodiment, shown in Figure 7, each resonant element has a slit 61 formed on one of the lateral faces 16 of the
35 resonator, together with separate inductances 71, which are preferably

distributed over the whole length of the slit and each of which has its terminals connected to the two edges 65 and 66 of the slit 61. As in the previous case, this arrangement increases the inductance of the circuit LC, resulting in a decrease in its resonance frequency f_0 and an increase in its bandwidth Δf_0 . Additionally, and optionally, each resonant element may have separate capacitive elements 72 which are fitted, preferably, along the whole of the slit 14, and which have their terminals connected to the edges of this slit.

According to a seventh variant embodiment, shown in Figure 8, each resonant element making up the device according to the invention consists of two or more elementary resonant elements 11 as described above. Each elementary resonant element is configured so as to have a given resonance frequency F_0 and a given bandwidth ΔF_0 , F_0 and ΔF_0 generally being the same for all the associated resonant elements.

This arrangement of adjacent resonant elements tuned to the same frequency F_0 has the notable advantage of increasing the power re-radiated by the resonant element, given that, in a known way, the value of the re-radiated power depends mainly on the dimensions (particularly the width w) of the face of the resonant element that includes the slit 14. Thus, by juxtaposing two or more elementary resonant elements, the power retransmitted by the device is substantially increased, without any notable change in the operating parameters of the resonant circuit itself.

In a simple embodiment, shown in Figure 8, the composite elements formed in this way may be made from a single tubular structure 81 with a rectangular cross section, the inner cavity of which is separated into elementary cavities 82 by intermediate partitions 83, each elementary cavity 82 being provided with a longitudinal slit represented by the discontinuities 84 in the sectional view of Figure 7.

Thus, as may be gathered from the embodiments described in the preceding text, the device according to the invention proposes, for the construction of the covering of a wall subjected to a radio transmission whose reflection in a given direction is to be avoided, a solution which is an advantageous alternative, in terms of both installation and operation, to the

use of diffraction gratings with simple conductive structural elements according to the prior art.

Figure 10 shows, in a single frame of reference (angle of observation and equivalent surface of the wall), the radar equivalent surface curves for a wall formed by the facade of a building, relating to three states, namely a first state (curve 101) corresponding to a bare wall, a second state (curve 102) corresponding to a wall covered with a diffraction grating according to the prior art, and a third state (curve 103) corresponding to a wall covered with the device according to the invention. As can be seen in the figure, although it is less effective than the prior art devices (curve 102), the device according to the invention enables the equivalent surface of the wall to be reduced to a very considerable degree. It therefore enables the level of nuisance caused by the reflection of undesired radio waves to be reduced to a sufficient extent, while advantageously having much smaller overall dimensions than those of the prior art devices, making this device, in particular, less bulky and easier to install.

CLAIMS

1 - A diffraction device for fitting to a facade (11) of a building, exposed to an electromagnetic radiation transmitted by a source located at a distance from said building, said diffraction device having a plurality of tubular resonant elements (12) positioned on said facade of said building, characterized in that :

- the resonant elements (12) of said plurality of resonant elements are positioned vertically (page 6 lines 17-19) in a substantially parallel way on the facade (11) of said building, so as to form a diffraction grating,
- each resonant element (12) has a form of a hollow cylinder of a conductive material, and a wall of said hollow cylinder, defining an inner cavity (17), has a longitudinal slit (14) having a given width e (page 6 lines 21-25),
- the dimensions and geometry of the cavity (17) defined by the wall, as well as the width of the longitudinal slit (14) formed in this wall, form an inductance-capacitance (LC) circuit having a resonance frequency (F_0) and a bandwidth (ΔF_0) (page 6 lines 30_33, claim 5) to re-radiate a wave corresponding to an incident wave.

2 - The device as claimed in claim 1, characterized in that a spacing pitch d of the conductive elements (12) of the diffraction grating is determined as a function of the wavelength λ and the angle of incidence θ to diffract the incident wave in a preferred direction.

3 - The device as claimed in either of claims 1 and 2, characterized in that, if the electromagnetic transmission source is distant, the spacing d between the different conductive elements (12) is constant.

4 - The device as claimed in either of claims 1 and 2, characterized in that, if the electromagnetic transmission source is nearby, the spacing d between the different conductive elements is a function of the local angle of incidence of the electromagnetic wave.

5 - The device as claimed in one of preceding claims, characterized in that the wall of a resonant element (12) has, in cross section, a rectangular shape.

5 6 - The device as claimed in claim 5, characterized in that the cavity (17) defined by the wall of a resonant element (12) accommodates an inner extension (51) fixed to the inner face of said wall and forming a rib having a "T" shape in cross section, the bar of which is parallel to the lengths of the rectangle, the rib (51) being configured and arranged within the cavity (17) in such a way that the bar of the "T" is placed facing the opening (24) present in one of the lengths of the rectangle, at a distance defined as a function of the frequency F_0 and the bandwidth ΔF_0 .

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7 - The device as claimed in claim 5, characterized in that the slit (24) of a resonant element (12) is limited by two segments (31, 32) substantially perpendicular to the wall, ends of said two segments being directed toward the inside of the rectangle.

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8 - The device as claimed in claim 5, characterized in that a resonant element (12) comprises a slit (61) on a lateral face (16) of the wall of the resonator element and comprises at least one self-inductance element (62) inside the cavity (17), ends (63, 64) of said self-inductance element being respectively connected electrically to edges (65, 66) of said slit (61).

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9 - The device as claimed in claim 5, characterized in that a resonant element (12) comprises a slit (61) on a lateral face (16) of the wall of the resonator element and comprises inductances (71), distributed over a length of said slit (61), terminals of each inductance being connected to edges (65, 66) of the slit (61).

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10 - The device as claimed in claim 9, characterized in that a resonant element (12) comprises capacitive elements (72) fitted along the slit (14) with their terminals connected to edges of said slit (14).

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11 - The device as claimed in claim 5, characterized in that at least two resonant elements (12) are adjacent.

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12 - The device according to any of the preceding claims, characterized in that the cavities (17) defined by the walls of the resonant elements are filled with a dielectric material (51) chosen so as to reinforce the rigidity of the elements.

5 13 - The device according to any of the preceding claims, characterized in that the cavities (17) defined by the walls of the resonant elements (12) are filled with two superimposed layers of a dielectric material chosen so as to reinforce the rigidity of the elements, a conductive strip (52) being placed in each cavity (17) at the interface between the two layers, facing the longitudinal slit (14) formed along
10 the wall.

14 - The device according to any of the preceding claims, characterized in that the cavities (17) defined by the walls of the resonant elements (12) are filled with a nonconducting ferromagnetic material chosen so as to increase the bandwidth ΔF_0 and reduce the resonance frequency F_0 of said resonant elements.
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15 - The device according to any of the preceding claims, characterized in that the cavities (17) defined by the walls of the resonant elements (12) are filled with a dielectric material having a high permittivity ϵ , chosen so as to reduce the resonance frequency F_0 of said resonant elements.
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16 - A facade (11) of a building comprising a diffraction device in accordance with one of the preceding claims.