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(71) Applicant: **Elettronica S.p.A.**
00131 Roma (IT)

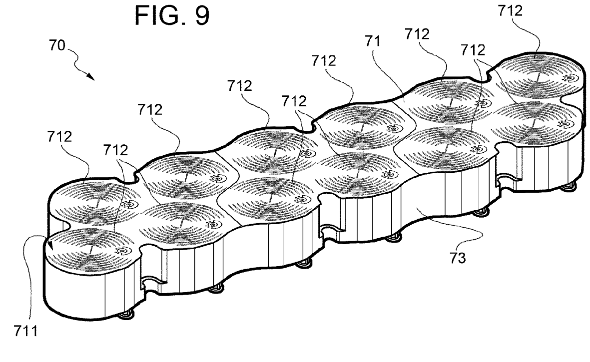
(72) Inventors:
- **Manna, Antonio**
81031 Aversa (IT)
- **Baldonero, Paolo**
00162 Roma (IT)

(74) Representative: **Boggio, Luigi et al**
Studio Torta S.p.A.
Via Viotti, 9
10121 Torino (IT)

(54) **Ultra-wide-band low-profile sinuous slot antenna array**

(57) Disclosed herein is an antenna system (70) for Electronic Counter Measures, comprising a flat antenna array (71;80) of three or more sinuous slot antennas (712; 81) arranged so as to form a triangular array lattice; wherein the flat antenna array (71;80) has a closed peripheral edge; wherein each sinuous slot antenna (712; 81) includes a respective feeding structure (41) arranged on a bottom surface (713) of the flat antenna array (71; 80); the antenna system (70) further comprising a hollow metallic structure (73), which includes: a base (732) having a closed peripheral edge; a closed side wall (733) rising from the closed peripheral edge of the base (732) up to a given height (H) where said closed side wall (733) ends with a closed top edge; and a hollow (731) defined by said base (732) and said closed side wall (733); wherein the hollow (731) is superiorly closed by the flat antenna array (71;80) whose closed peripheral edge is fixed on/to the closed top edge of the hollow metallic structure (73) and whose bottom surface (713) faces the hollow (731); the antenna system (70) further comprising a foam spacer (72) which fills the hollow (731) and keeps the sinuous slot antennas (712;81) spaced apart from the base (732) of the given height (H); wherein the given height (H) is equal to a quarter of a wavelength corresponding to a central operating frequency of the antenna array (71;80); wherein an absorbing sheet covers the base (732) on the bottom of the hollow (731), said absorbing sheet being designed to absorb surface currents on the base (732) on the bottom of the hollow (731); and wherein, for each sinuous slot antenna (712;81), the hollow metallic structure (73) further includes: a corresponding reflecting tapered element (734), which protrudes from the base (732) through the absorbing sheet and the foam spacer (72) into the hollow (731), is arranged below said sinuous slot antenna (712;81), and is designed to reflect back-radiation from said sinuous slot antenna (712;81); and a corresponding feeding turret (735), which protrude from the base (732) through the absorbing sheet and the foam spacer (72) into the hollow (731) up to the feeding structure (41) of said sinuous slot antenna (712;81), and which is coupled with the feeding structure (41) of said sinuous slot antenna (712;81).

FIG. 9



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Description

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates, in general, to a phased array with low-profile Ultra-Wide-Band (UWB) radiating elements for Electronic Counter Measure (ECM) applications, and, in particular, to a UWB low-profile sinuous slot antenna array for ECM applications.

BACKGROUND ART

[0002] As is known, ECM systems must cover an extremely wide band of the frequency spectrum (i.e., multiple octaves). Therefore, the electromagnetic sensors exploited in such systems must be designed to cover a frequency band of multiple octaves presenting very "flat" Radio Frequency (RF) performances in terms of gain, half-power beam-width and return loss level lower than 10 dB.

[0003] Furthermore, due to mechanical and environmental constraints, ECM systems, especially for avionic applications, require low-size, low-profile and mechanically-robust electromagnetic sensors.

[0004] In particular, electromagnetic sensors, in order to be exploitable in phased arrays for ECM applications, must meet the following requirements:

- UWB frequency spectrum coverage (i.e., typically 3:1);
- high efficiency (typically higher than 50%);
- wide angular coverage sector stable with frequency (typically $\pm 45°$ in both Elevation and Azimuth planes at central frequency of operation);
- integration in very dense array lattice in order to minimize the presence of undesired grating lobes;
- low-size and low-profile structure (i.e., thickness of radiating structure lower than $\lambda_0/4$ at minimum frequency of operation, where λ_0 denotes the wavelength corresponding to the minimum frequency of operation) in order to increase the system flush mount capability on avionic platforms giving the possibility to design conformal arrays integrated into the skin of the avionic platforms; and
- capability to receive instantaneously all the operating Horizontal, Vertical, and Left and Right Circular polarizations of electromagnetic field (i.e., the so-called "no blind" requirement).

[0005] In V. H. Rumsey, "Frequency independent antennas", 1957 IRE National Convention Record, pp 114-118, March 1957, frequency-independent antennas are described, which have unique RF performances, specifically gain flatness capability and pattern stability versus UWB operating frequency band (up to several octaves), that make such antennas good candidates for ECM phased arrays. Unfortunately, several drawbacks, such as feeding structure complexity and frequency scaled dimensions (i.e., the impossibility to populate "electrically-dense" array lattices), represent insurmountable obstacles to their use in ECM phased arrays.

[0006] Therefore, currently UWB end-fire radiating element structures, such as Tapered Slot Antennas (TSA), Vivaldi antennas, etc., are used to populate phased arrays for ECM applications instead of planar frequency-independent antennas.

[0007] In this connection, figures 1, 2 and 3 show, respectively, a perspective view, a side view and a top view of a three-dimensional (3D) Computer-Aided Design (CAD) model of an antenna array 10 of example based on Vivaldi radiating elements.

[0008] Vivaldi radiating elements presents the following two non-negligible drawbacks.

[0009] Firstly, Vivaldi radiating elements are not low-profile elements (in fact, the current flows in the plane of maximum radiation) and the total antenna height must be at least equal to half of the wavelength at the lowest operating frequency. Consequently Vivaldi elements cannot be used to populate conformal apertures.

[0010] Secondly, in order to satisfy the no blind polarization requirement, an additional item, i.e., a polarizer, must be used to rotate the radiated field. In this way it is possible to realize a no blind slant 45° polarization. On the other hand, inevitably the presence of the polarizer (and of its losses) lowers significantly the antenna efficiency. In this connection, figure 4 shows a perspective view of a 3D CAD model of a Vivaldi array 20 of example with polarizer for slant 45° polarization.

OBJECT AND SUMMARY OF THE INVENTION

[0011] The object of the present invention is therefore that of providing an antenna array which, in general, meets all the previously-listed ECM requirements and, thence, is exploitable in phased arrays for ECM applications, and, in particular, which merges the respective advantages of TSA antennas and frequency-independent antennas avoiding, at the same time, the respective drawbacks previously described.

[0012] This object is achieved by the present invention in that it relates to an antenna system, as defined in the appended claims.

[0013] In particular, the present invention relates to an antenna system for Electronic Counter Measures, which antenna system comprises a flat antenna array of three or more sinuous slot antennas arranged so as to form a triangular array lattice. The flat antenna array has a closed peripheral edge. Each sinuous slot antenna includes a respective feeding structure arranged on a bottom surface of the flat antenna array.

[0014] The antenna system according to the present invention further comprises a hollow metallic structure, which includes:

- a base having a closed peripheral edge;
- a closed side wall rising from the closed peripheral edge of the base up to a given height where said closed side wall ends with a closed top edge; and
- a hollow defined by said base and said closed side wall.

[0015] The hollow is superiorly closed by the flat antenna array whose closed peripheral edge is fixed on or to the closed top edge of the hollow metallic structure and whose bottom surface faces the hollow.

[0016] The antenna system according to the present invention further comprises a foam spacer which fills the hollow and keeps the sinuous slot antennas spaced apart from the base of the given height.

[0017] The given height is equal to a quarter of a wavelength corresponding to a central operating frequency of the antenna array.

[0018] The antenna system according to the present invention further comprises an absorbing sheet that covers the base on the bottom of the hollow, said absorbing sheet being designed to absorb surface currents on the base on the bottom of the hollow.

[0019] For each sinuous slot antenna, the hollow metallic structure further includes:

- a corresponding reflecting tapered element, which protrudes from the base through the absorbing sheet and the foam spacer into the hollow, is arranged below said sinuous slot antenna, and is designed to reflect back-radiation from said sinuous slot antenna; and
- a corresponding feeding turret, which protrude from the base through the absorbing sheet and the foam spacer into the hollow up to the feeding structure of said sinuous slot antenna, and which is coupled with the feeding structure of said sinuous slot antenna.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] For a better understanding of the present invention, preferred embodiments, which are intended purely by way of example and are not to be construed as limiting, will now be described with reference to the attached drawings (all not to scale), wherein:

- Figures 1, 2 and 3 show, respectively, a perspective view, a side view and a top view of an antenna array based on Vivaldi radiating elements;
- Figure 4 shows a Vivaldi array with polarizer for slant 45° polarization;
- Figure 5 schematically illustrates the geometry of a single sinuous arm of a known planar sinuous antenna;
- Figure 6 schematically shows a sinuous slot structure of a known sinuous slot antenna;
- Figures 7a and 7b show, at two different detail levels, a feeding structure for the sinuous slot structure shown in Figure 6;
- Figures 8a and 8b show, respectively, a known sinuous slot antenna based on the sinuous slot structure and the feeding structure shown in Figures 6, 7a and 7b, and a 90° RF transition structure of said known sinuous slot antenna;
- Figure 9 shows a perspective view of an antenna system according to a first preferred embodiment of the present invention;
- Figure 10 shows an exploded view of the antenna system of Figure 9;
- Figures 11a and 11b show, respectively, a top surface and a bottom surface of a component of the antenna system of Figures 9 and 10;
- Figure 12 shows lattice distances of antenna elements of the antenna system of Figures 9 and 10;
- Figure 13 shows a perspective view of another component of the antenna system of Figures 9 and 10;
- Figure 14 shows a modular antenna array based on the antenna system of Figures 9 and 10;
- Figure 15 shows a sinuous slot antenna array of an antenna system according to a second preferred embodiment of the present invention; and

- Figures 16 and 17 show, respectively, average gain of a single element and scan losses of the antenna system according to the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

[0021] The following discussion is presented to enable a person skilled in the art to make and use the invention. Various modifications to the embodiments will be readily apparent to those skilled in the art, without departing from the scope of the present invention as claimed. Thus, the present invention is not intended to be limited to the embodiments shown and described, but is to be accorded the widest scope consistent with the principles and features disclosed herein and defined in the appended claims.

[0022] In particular, in the following the present invention, that concerns an antenna system for ECM applications, will be described by making explicit reference to RF transmission without this implying any loss of generality. In fact, the antenna system according to present invention, even if its operation will be described with explicit reference to transmission, can operate, without the need of modifications, also as a receiving system according to the well-known reciprocity principle.

[0023] The present invention stems from Applicant's idea of exploiting, as radiating elements of a phased array for ECM applications, sinuous slot antennas.

[0024] As is known (in this connection reference may, for example, be made to United States Patent US 4,658,262), a sinuous antenna comprises an array of N identical sinuous arms (with N>1), for example N sinuous metal strips, which lie on a common surface, extend outwardly from a common point and are arranged symmetrically on the common surface at intervals of 360°/N about a central axis containing the common point. In other words, the array of N identical sinuous arms has a rotational symmetry with respect to (i.e., around) the central axis such that a rotation of 360°/N degrees about said central axis leaves the overall sinuous structure unchanged. The sinuous arms have widths which increase with distance from the common point. Conveniently, the common surface can be planar or conical or pyramidal.

[0025] More in detail, each antenna arm comprises P cells of bends and curves, wherein said cells are scaled in size one with respect to another and are numbered from 1 to P, where 1 is the outermost cell that is the largest one, and P is the innermost cell that is the smallest one. The outside and inside radii of the generic pth cell (with $1 \le p \le P$), measured from the common point, are respectively denoted as R_p and R_{p+1} and are related by a first design parameter τ_p, which is a positive number lower than 1 and defines the ratio between the inside radius R_{p+1} and the outside radius R_p, i.e., it results that $\tau_p=R_{p+1}/R_p$.

[0026] In order for the geometry of a sinuous arm to be better understood, figure 5 schematically illustrates the geometric structure of a single sinuous arm of a planar sinuous antenna with respect to a two-dimensional (2D) reference system of polar coordinates r and ϕ centred on a point C that is the common point from which the N sinuous arms of the planar sinuous antenna extend.

[0027] In particular, with reference to figure 5, the equation for the curve of the pth cell is given by:

$$\phi = (-1)^p \alpha_p \sin\left(\frac{180\ln(r/R_p)}{\tau_p}\right),$$

with $R_{p+1} \le r \le R_p$ and where α_p denotes a second design parameter, which is a positive number and defines the angular width of the pth cell.

[0028] If α_p and τ_p are constant for all the cells, namely if they are independent of p, the curve is a log-periodic function of the logarithm of the radius r and, thence, satisfies the log-periodic principle; otherwise, namely if α_p and τ_p are not independent of p, the curve can be referred to as a quasi-log-periodic curve.

[0029] The sinuous arm is then generated considering a third design parameter δ that denotes a certain number of degrees defining the swing of the sinuous curve to create an arm:

$$\phi = (-1)^p \alpha_p \sin\left(\frac{180\ln(r/R_p)}{\tau_p}\right) \pm \delta ,$$

with, again, $R_{p+1} \le r \le R_p$.

[0030] It is important to highlight that the bandwidth of the sinuous antenna depends mainly on the physical size of the sinuous curve. In particular, the external maximum radius R_1 and the internal minimum radius R_P are strictly related to, respectively, the lowest operating frequency f_{low} and the highest operating frequency f_{high} so that it results that:

$$R_1 \approx \frac{\lambda_{low}/4}{\alpha_1+\delta} \quad \text{and} \quad R_P \approx \frac{\lambda_{high}/4}{\alpha_P+\delta},$$

where λ_{low} and λ_{high} denote, respectively, the wavelength associated with the lowest operating frequency f_{low} and the wavelength associated with the highest operating frequency f_{high}.

[0031] For a sinuous antenna in slot version, i.e., with N sinuous slots in place of the N sinuous arms, the basic sinuous design rules previously described are still valid.

[0032] As previously said, the present invention relates to the use, in order to realize a phased arrays for ECM applications, of a sinuous slot antenna array, i.e., an array of sinuous slot antennas.

[0033] In particular, an antenna system for ECM phased arrays according to a preferred embodiment of the present invention, comprises a sinuous slot antenna array based on a sinuous slot antenna which is presented and described in A. Manna, P. Baldonero, F. Trotta, "Novel UWB Low-Profile Sinuous Slot Antenna", Proceedings of 5th European Conference on Antennas and Propagation (EUCAP), Rome, 11-15 April 2011, and which is a "quasi" frequency-independent antenna, has all the advantages of frequency-independent antennas, and has also a unique extremely-simple feeding structure.

[0034] In this connection, reference is made to figure 6 which shows the sinuous slot structure (indicated as a whole by 30) proposed in *"Novel UWB Low-Profile Sinuous Slot Antenna".*

[0035] In particular, the sinuous slot structure 30 is designed to operate in 6-18 GHz frequency band and comprises:

- two sinuous slots (i.e., N=2) 31 and 32, each of which can be obtained by rotating the other sinuous slot of 180° around a central point O from which the radii of the cells are measured; and
- a straight feeding slot 33 that connects the smallest cells "P" (i.e., the innermost cells) of the sinuous slots 31 and 32 and is centered with respect to the central point O (i.e., the central point O is substantially median with respect to the straight feeding slot 33).

[0036] In detail, the sinuous slot structure 30 is based on the following parameters:

- R_1 = 12 mm;
- R_P = 1.5 mm;
- α = 50°;
- δ = 10°; and
- sixteen cells per arm (i.e., P=16).

[0037] For the sinuous slot structure 30 a linear growth of the sinuous slots 31 and 32 has been chosen in order to guarantee a constant cell width similarly to an Archimedean spiral.

[0038] More in detail, the sinuous slot antenna described in the afore-mentioned paper is realized by:

- providing a thin disc-shaped dielectric element having a front planar surface and a back planar surface, wherein both said surfaces are metalized, i.e., covered by metallizations;
- cutting the sinuous slot structure 30 in the front planar surface of the disc-shaped dielectric element so that the straight feeding slot 33 is centered with respect to the centre of the disc-shaped dielectric element (said centre being, thence, median with respect to said straight feeding slot 33); and
- making on the back planar surface of the disc-shaped dielectric element a feeding structure for feeding the sinuous slot structure 30 through the straight feeding slot 33, wherein making the feeding structure includes removing the metallization (s) from the areas of the back planar surface not occupied by said feeding structure so as to expose the underlying dielectric.

[0039] Conveniently, the disc-shaped dielectric element may be, for example, obtained from a Rogers RT/duroid® 5880 laminate with a thickness of 0.254 mm.

[0040] From figure 6 it is possible to note that the sinuous slot structure 30 does not exploit all the area available on the front and back surfaces of the dielectric element. Such strategy seems to be disadvantageous due to the lower total length of the external cells that consequently resonate at higher minimum frequency. In reality such choice hides a very attractive advantage, namely the possibility of exploiting the free metallic part of the front planar surface of the disc-shaped dielectric element as a ground plane for a microstrip printed on the back planar surface of the disc-shaped dielectric element. In this way it is possible to feed the sinuous slots 31 and 32 by means of a microstrip ending with a UWB fan-shaped open stub that causes the RF signal to flow into the straight feeding slot 33 and, then, into the sinuous slots 31 and 32.

[0041] In order for the feeding structure of the sinuous slot structure 30 to be better understood, reference is made to figures 7a and 7b, wherein the figure 7a shows the back planar surface (indicated by 40) of the disc-shaped dielectric element and the figure 7b is a zoomed view of a central region of said back planar surface 40 extending around a central point O' thereof (in figures 7a and 7b the disc-shaped dielectric element is not shown for the sake of illustration clarity).

[0042] As shown in figures 7a and 7b, on the back planar surface 40 a feeding structure 41 is realized, which includes a feeding line 42 in the form a straight strip that:

- radially extends from the central point O' in a median position with respect to the straight feeding slot 33 (namely the central point O' is median with respect to the straight feeding slot 33);
- is perpendicular to the straight feeding slot 33;
- has a predefined width W_m parallelly to the straight feeding slot 33; and
- ends, at the central point O', with a fan-shaped

open stub 43.

[0043] In particular, the straight feeding line 42 and the fan-shaped open stub 43 extend from opposite sides of the straight feeding slot 33 and have one and the same axis of symmetry that is perpendicular to the straight feeding slot 33 and passes through the central point O'.

[0044] As previously said, in the making of the feeding line 42 and of the fan-shaped open stub 43, the metallization (s) in the areas of the back planar surface 40 not occupied by said feeding line 42 and by said fan-shaped open stub 43 is/are removed so as to expose the underlying dielectric. In other words, after the making of the feeding line 42 and of the fan-shaped open stub 43, on the back planar surface 40 of the disc-shaped dielectric element only the metallization (s) defining said feeding line 42 and said fan-shaped open stub 43 are present, while the dielectric is exposed in the rest of said back planar surface 40.

[0045] Conveniently, in order to minimise reflection due to mismatch between the feeding structure 41 and the sinuous slot structure 30, the width W_m of the feeding line 42 and the radius R_F and the angular size θ_F of the fan-shaped open stub 43 (measured, respectively, from the central point O', and with respect to the axis of symmetry or to the straight feeding slot 33) can be optimised to achieve a return loss lower than -15 dB in the 6-18 GHz frequency band.

[0046] Since, the sinuous slot structure 30 has a bidirectional radiation pattern, namely, in use, it radiates forward and backward, a proper metallic back cavity is needed. For a 3:1 frequency band it is possible to easily exploit the back-radiation by means of a metallic cavity spaced apart from the the top planar surface of about $\lambda_0/4$ at central frequency of operation (where λ_0 denotes the wavelength corresponding to the central frequency of operation). Furthermore the cavity is designed also to properly feed the feeding structure 41 and, thence, the sinuous slot structure 30 by means of a RF transition structure.

[0047] In order for the RF transition structure to be better understood, reference is made to figures 8a and 8b, wherein the figure 8a is a perspective view of the overall sinuous slot antenna (indicated as a whole by 50) proposed in *"Novel UWB Low-Profile Sinuous Slot Antenna"* and the figure 8b is a zoomed perspective view only of a 90° RF transition structure (indicated as a whole by 60) employed in said sinuous slot antenna 50.

[0048] In particular, the 90° RF transition structure 60 comprises a GPO® connector (exploited due to small size of the antenna 50). In detail, the pin of the GPO® connector bead is soldered on the the top planar surface (indicated by 51) of the sinuous slot antenna 50. Thus, by means of metallic via hole, the RF signal travels through the feeding line 42 up to the straight feeding slot 33.

[0049] The sinuous slot antenna proposed in *"Novel UWB Low-Profile Sinuous Slot Antenna"* presents excellent RF performances in terms of gain at boresight, half-power beam-width and return loss level.

[0050] As far as the present invention is concerned, figures 9 and 10 show respectively:

- a perspective view of a 3D CAD model of an antenna system (in both figures 9 and 10 indicated as a whole by 70) according to a first preferred embodiment of the present invention; and
- an exploded view of the antenna system 70.

[0051] The antenna system 70 is designed to cover a 3:1 frequency band directly in slant 45° polarization (without the need of a polarizer), specifically it is designed to operate in 6-18 GHz frequency band thereby being a UWB antenna system.

[0052] As shown in figures 9 and 10, the antenna system 70 includes:

- a sinuous slot antenna array 71;
- a foam spacer 72; and
- a hollow metallic structure 73.

[0053] In particular, the hollow metallic structure 73 has a hollow 731 which is superiorly closed, i.e., stopped, by the sinuous slot antenna array 71 and the foam spacer 72 fills said hollow 731.
[0054] In detail, the sinuous slot antenna array 71 includes:

- a dielectric sheet having a top surface 711, a bottom surface and a closed peripheral edge, wherein the top surface 711 is metalized; and
- twelve sinuous slot antennas 712 made, i.e., formed, in the dielectric sheet, specifically each in a respective portion of the dielectric sheet, and arranged so as to form a triangular array lattice with two rows of six elements.

[0055] It is important to highlight the fact the number of the sinuous slot antennas can be different from twelve. Indeed, it can be equal to, or higher than, three so as to allow a triangular mesh arrangement of the sinuous slot antennas.
[0056] Preferably, each of the sinuous slot antennas 712 includes the sinuous slot structure 30 and the feeding structure 41 proposed in *"Novel UWB Low-Profile Sinuous Slot Antenna"* and previously described. But, differently from *"Novel UWB Low-Profile Sinuous Slot Antenna",* in the antenna system 70 the twelve sinuous slot antennas 712 are printed on one and the same dielectric sheet and, thence, the antenna system 70 is designed so as to take into account and properly manage the mutual coupling between the sinuous slot antennas 712.
[0057] In this connection, figures 11a and 11b show respectively:

- the top surface 711 of the dielectric sheet where the twelve sinuous slot structures 30 of the twelve sinuous slot antennas 712 are printed; and
- the bottom surface (indicated by 713) of the dielectric sheet where the twelve feeding structures 41 of the twelve sinuous slot antennas 712 are printed.

[0058] As previously described, each feeding structure 41 includes the straight feeding line 42 ending, at a first end, with the fan-shaped open stub 43 and, at a second end, with an end portion designed for 90° RF transition coupling.
[0059] Furthermore, in order to minimize the presence of grating lobes, a triangular array lattice has been chosen. In this connection, figure 12 shows the lattice distances selected as a good tradeoff between single element allotted area (i.e., the wider is the area, the lower is the operating minimum frequency) and the presence of grating lobes. In particular, as shown in figure 12, adjacent sinuous slot antennas 712 arranged along one and the same row are spaced apart (in particular the centers of said adjacent sinuous slot antennas 712 are spaced apart) of $d_{Az} = 3/2\ \lambda_{min}$, and the rows are placed side by side not aligned so as to form the triangular array lattice and are spaced apart (in particular the axes containing the centers of the respective sinuous slot antennas 712) are spaced apart of $d_{El} = 7/6\ \lambda_{min}$, where λ_{min} denotes the wavelength corresponding to the lowest operating frequency at which the antenna system 70 is designed to operate, i.e., to transmit and receive.
[0060] With the presented lattice the sinuous slot antenna array 71 covers a frequency band wider than one octave (i.e., 3:1).
[0061] Again with reference to figures 9 and 10, the sinuous slot antenna array 71 is arranged so as to superiorly close, i.e., stop, the hollow 731 of the hollow metallic structure 73 and so that the bottom surface 713 of the dielectric sheet faces said hollow 731. The foam spacer 72 (for example ROHACELL® 71HF) is inserted in the hollow 731 to guarantee the correct distance between the sinuous slot antenna array 71 and the bottom of the hollow 731.
[0062] Moreover, figure 13 shows a perspective view of the hollow metallic structure 73, which includes:

- a base 732 that has a closed peripheral edge and has a size and a shape substantially corresponding to the size and the shape of the sinuous slot antenna array 71, in particular of the dielectric sheet;
- a closed side wall 733 rising, i.e., upwardly extending, from the closed peripheral edge of the base 732 up to a given height H where said closed side wall 733 ends with a closed top edge corresponding to the closed peripheral edge of the dielectric sheet;
- the hollow 731 defined by said base 732 and said closed side wall 733;
- reflecting tapered elements 734 which protrude from the base 732 through the foam spacer 72 into the hollow 731, are shaped substantially like domes or circular cones or truncated circular cones, and are arranged, each, in a respective position corresponding to the position of a corresponding sinuous slot antenna 712 on the dielectric sheet thereby forming, all together, a triangular array lattice corresponding to the triangular array lattice formed by the twelve sinuous slot antennas 712; and
- feeding turrets 735 which protrude from the base 732 through the foam spacer 72 into the hollow 731 up to the given

height H, which are arranged, each, in a respective position corresponding to the position of the end portion of the feeding line 42 of a corresponding sinuous slot antenna 712 on the bottom surface 713 of the dielectric sheet, and which end at the given height H, each, with a respective connection portion designed to form with the end portion of the feeding line 42 of the corresponding sinuous slot antenna 712 a 90° RF transition coupling based on a metallic via hole propagation of the RF signals between said respective connection portion and said end portion of the feeding line 42.

[0063] Furthermore, an absorbing sheet of an absorbing material covers the base 732 on the bottom of the hollow 731, wherein the reflecting tapered elements 734 and the feeding turrets 735 protrude from the base 732 into the hollow 731 through the absorbing sheet and the foam spacer 72.

[0064] Again with reference to figure 9, in the antenna system 70 the closed peripheral edge of the dielectric sheet of the sinuous slot antenna array 71 is fixed, for example glued, on or to the closed top edge of the closed side wall 733 of the hollow metallic structure 73 so as to close, i.e., stop, the hollow 731 and so that the bottom surface 713 of the dielectric sheet faces said hollow 731.

[0065] Conveniently, the base 732, the closed side wall 733 and the reflecting tapered elements 734 are made integrally in one piece of a metallic material.

[0066] Preferably, each of the connection portions of the feeding turrets 735 includes the 90° RF transition structure 60 with the GPO® connector proposed in *"Novel UWB Low-Profile Sinuous Slot Antenna"* and previously described.

[0067] As shown in figures 10 and 13, the hollow metallic structure 73 has no internal metallic walls protruding into the hollow 731 and thus a particular attention has been paid in the design of such an item.

[0068] Furthermore, the presence and the shape of the reflecting tapered elements 734 have a twofold aim:

- reflect efficiently the antenna back radiation to achieve an unidirectional array pattern; and
- avoid the presence of internal spurious resonances.

[0069] Moreover, the absorbing sheet is arranged on the bottom of the hollow 731 in order to, in use, absorb surface currents thereon (i.e., on the bottom of the hollow 731, namely on the base 732) and avoid destructive back radiations.

[0070] Conveniently, the given height H of the closed side wall 733 and of the feeding turrets 735 is equal to $\lambda_0/4$, where λ_0 denotes the wavelength at the central operating frequency f_0 at which the antenna system 70 is designed to operate, i.e., to transmit and receive. The foam spacer 72 fills the hollow 731 so as to keep the sinuous slot antenna array 71 and the bottom of the hollow 731 spaced apart of the given height H. This given height H, which, thence, is substantially the height of the overall antenna system 70, causes said antenna system 70 to have a low profile.

[0071] Conveniently, the sinuous slot antenna array 71, the foam spacer 72 and the hollow metallic structure 73 are glued together by means of structural adhesive (for example Araldite AV138) to guarantee structural robustness.

[0072] A further important feature of the antenna system 70 is the shape, in particular the side profile, of said antenna system 70. In fact, the side profile of the base 732, of the closed side wall 733 and of the sinuous slot antenna array 71 is substantially sinusoidal so as to allow two or more antenna systems 70 to be placed side by side to form a modular structure. In this connection, figure 14 shows a modular array of twenty-four sinuous slot elements realized using two "twelve-sinuous-slot-elements arrays", in particular two antenna systems 70 in which no changes in inter-distances between elements and no modifications of the mechanics (i.e., of the hollow metallic structure 73) have been introduced.

[0073] Furthermore, a second preferred embodiment of the present invention relates to an antenna system which differs from the antenna system 70 according to the first preferred embodiment only in the sinuous slot antenna array.

[0074] In particular, according to said second preferred embodiment of the present invention, the sinuous slot structures of sinuous slot antennas arranged along one and the same row are connected.

[0075] In this connection, figure 15 shows a sinuous slot antenna array 80 of an antenna system according to the second preferred embodiment of the present invention, said sinuous slot antenna array 80 comprising two rows of six sinuous slot antennas 81 each having a respective sinuous slot structure 82 with two sinuous slots (similar to the sinuous slot structure 30 previously described).

[0076] As shown in figure 15, the sinuous slot structure 82 of each sinuous slot antenna 81 having two adjacent sinuous slot antennas 81 along one and the same row has:

- the largest and outermost cell (i.e., the cell "1") of one of its two sinuous slots connected to the largest and outermost cell of a sinuous slot of one of the two adjacent sinuous slot antennas 81; and
- the largest and outermost cell (i.e., the cell "1") of the other of its two sinuous slots connected to the largest and outermost cell of a sinuous slot of the other of the two adjacent sinuous slot antennas 81.

[0077] In this way, each single sinuous slot antenna 81 is loaded with the surrounding ones, the total electrical length of the antenna grows significantly and, thence, the minimum operating frequency lowers.

[0078] In figure 16 the average gain of single element of the antenna system 70 at boresight versus frequency is shown. In particular, the graph shown in figure 16 has been calculated measuring all twelve elements pattern once at time with the other elements loaded to 50 Ohm. Then, by means of post-processing, the element average gain at boresight has been obtained.

[0079] Moreover, in figure 17 the scan losses of the antenna system 70 at four particular steering points versus frequency are shown. The scan points are respectively (Az, El) = (30°,0°), (45°,0°), (0°, 30°) and (0°, 45°). The curves shown in figure 17 represent the "losses" of array gain at the previously listed steering points compared to boresight.

[0080] The advantages of the present invention are clear from the foregoing. In particular, it is worth highlighting the fact that the present invention can be advantageously exploited to make phased arrays which fully meet ECM requirements, namely which present all the following features:

- UWB frequency spectrum coverage (i.e., 3:1);
- high efficiency;
- wide angular coverage sector stable with frequency;
- integration in very dense array lattice thereby minimizing the presence of undesired grating lobes;
- low-size and low-profile structure thereby increasing the system flush mount capability on avionic platforms giving the possibility to design conformal arrays integrated into the skin of the avionic platforms; and
- capability to receive instantaneously all the operating Horizontal, Vertical, and Left and Right Circular polarizations.

[0081] Finally, it is clear that numerous modifications and variants can be made to the present invention, all falling within the scope of the invention, as defined in the appended claims.

Claims

1. An antenna system (70) for Electronic Counter Measures, comprising a flat antenna array (71;80) of three or more sinuous slot antennas (712;81) arranged so as to form a triangular array lattice; wherein the flat antenna array (71; 80) has a closed peripheral edge; wherein each sinuous slot antenna (712;81) includes a respective feeding structure (41) arranged on a bottom surface (713) of the flat antenna array (71;80);
the antenna system (70) further comprising a hollow metallic structure (73), which includes:

- a base (732) having a closed peripheral edge;
- a closed side wall (733) rising from the closed peripheral edge of the base (732) up to a given height (H) where said closed side wall (733) ends with a closed top edge; and
- a hollow (731) defined by said base (732) and said closed side wall (733);

wherein the hollow (731) is superiorly closed by the flat antenna array (71;80) whose closed peripheral edge is fixed on/to the closed top edge of the hollow metallic structure (73) and whose bottom surface (713) faces the hollow (731);
the antenna system (70) further comprising a foam spacer (72) which fills the hollow (731) and keeps the sinuous slot antennas (712;81) spaced apart from the base (732) of the given height (H);
wherein the given height (H) is equal to a quarter of a wavelength corresponding to a central operating frequency of the antenna array (71;80);
wherein an absorbing sheet covers the base (732) on the bottom of the hollow (731), said absorbing sheet being designed to absorb surface currents on the base (732) on the bottom of the hollow (731);
and wherein, for each sinuous slot antenna (712;81), the hollow metallic structure (73) further includes:

- a corresponding reflecting tapered element (734), which protrudes from the base (732) through the absorbing sheet and the foam spacer (72) into the hollow (731), is arranged below said sinuous slot antenna (712;81), and is designed to reflect back-radiation from said sinuous slot antenna (712;81); and
- a corresponding feeding turret (735), which protrude from the base (732) through the absorbing sheet and the foam spacer (72) into the hollow (731) up to the feeding structure (41) of said sinuous slot antenna (712;81), and which is coupled with the feeding structure (41) of said sinuous slot antenna (712;81).

2. The antenna system of claim 1, wherein the triangular array lattice comprises two or more rows of sinuous slot antennas (712;81);
wherein adjacent sinuous slot antennas (712;81) in one and the same row are spaced apart of a first distance equal to three halves of a wavelength corresponding to the lowest operating frequency of the antenna array (71;80);
and wherein adjacent rows are spaced apart of a second distance equal to seven sixths of the wavelength corre-

sponding to the lowest operating frequency of the antenna array (71;80).

3. The antenna system according to claim 1 or 2, wherein the flat antenna array (71;80) includes a dielectric sheet having a top surface (711) and a bottom surface (713);
wherein the top surface (711) of the dielectric sheet is metalized;;
wherein each sinuous slot antenna (712;81) is made in a respective portion of the dielectric sheet;
and wherein the feeding structures (41) of the sinuous slot antennas (712;81) are formed on the bottom surface (713) of the dielectric sheet.

4. The antenna system according to any preceding claim, wherein the feeding structure (41) of each sinuous slot antenna (712;81) includes an end portion designed for 90° Radio Frequency transition;
and wherein each feeding turret (735) includes a connection portion, which is designed for 90° Radio Frequency transition and which is coupled with the end portion of the feeding structure (41) of the corresponding sinuous slot antenna (712;81).

5. The antenna system according to any preceding claim, wherein each sinuous slot antenna (712) includes a respective sinuous slot structure (30); and wherein the sinuous slot structures (30) of different sinuous slot antennas (712) are not connected.

6. The antenna system according to any claim 1-4, wherein each sinuous slot antenna (81) includes a respective sinuous slot structure (82);
wherein the triangular array lattice comprises two or more rows of sinuous slot antennas (81);
and wherein the sinuous slot structures (82) of the sinuous slot antennas (81) in one and the same row are connected.

7. The antenna system of claim 6, wherein the sinuous slot structure (82) of each sinuous slot antenna (81) includes two sinuous slots;
and wherein the sinuous slot structure (82) of each sinuous slot antenna (81) adjacent to two sinuous slot antennas (81) in one and the same row has:

- the outermost cell of one of its two sinuous slots connected to the outermost cell of a sinuous slot of one of the two adjacent sinuous slot antennas (81); and
- the outermost cell of the other of its two sinuous slots connected to the outermost cell of a sinuous slot of the other of the two adjacent sinuous slot antennas (81).

8. The antenna system according to any preceding claim, wherein the flat antenna array (71;80) is a planar or conformal antenna array.

9. A modular antenna system comprising several antenna systems (70) as claimed in any preceding claim;
wherein the antenna systems (70) are placed side by side thereby forming a modular antenna structure.

10. The modular antenna system of claim 9, wherein the side profile of each antenna system (70) is sinusoidal.

11. A phased array system for Electronic Counter Measures, comprising the antenna system (70) claimed in any claim 1-8 or the modular antenna system claimed in claim 9 or 10.

12. An Electronic Counter Measure system comprising the antenna system (70) claimed in any claim 1-8 or the modular antenna system claimed in claim 9 or 10.

FIG. 1

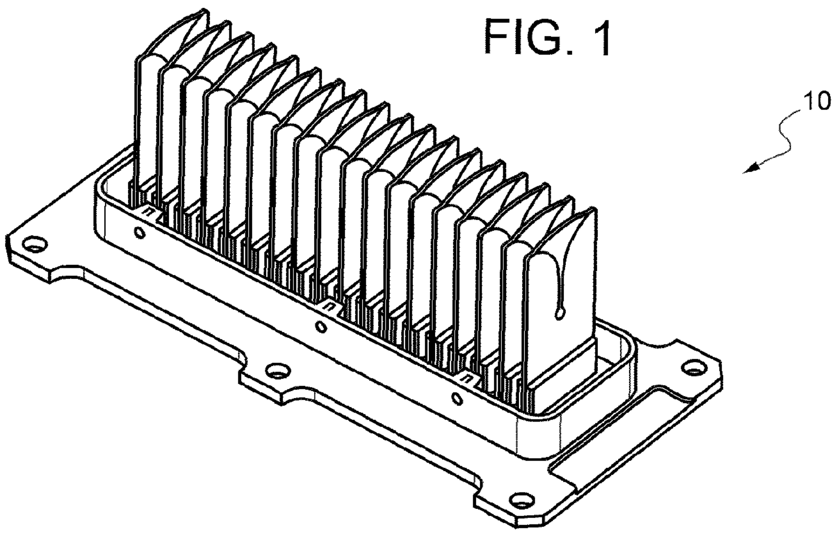


FIG. 2

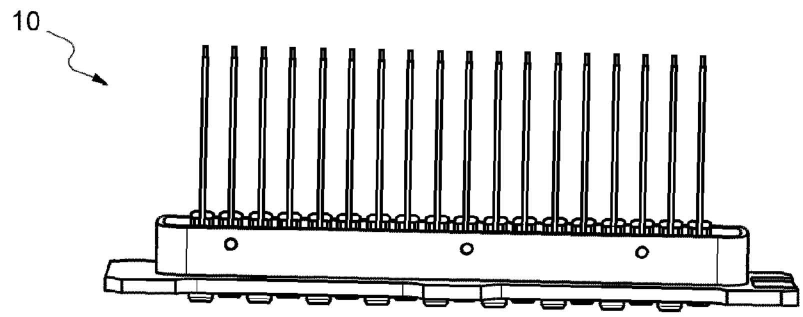


FIG. 3

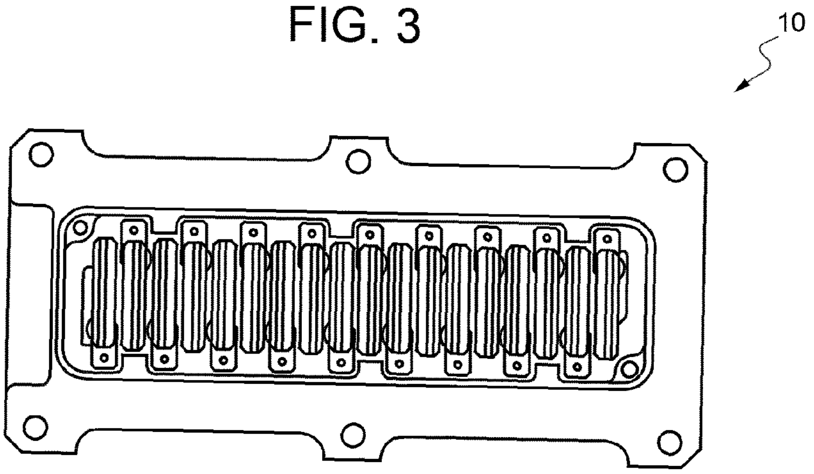


FIG. 4

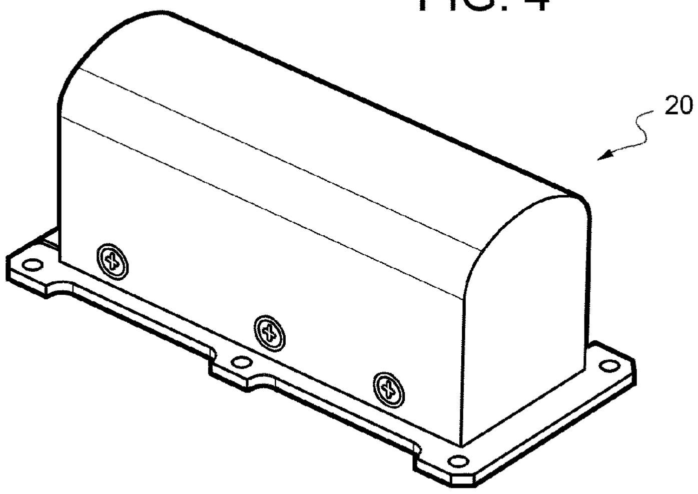


FIG. 5

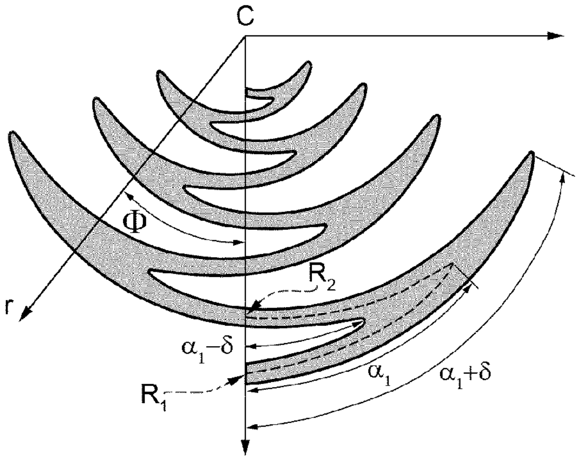


FIG. 6

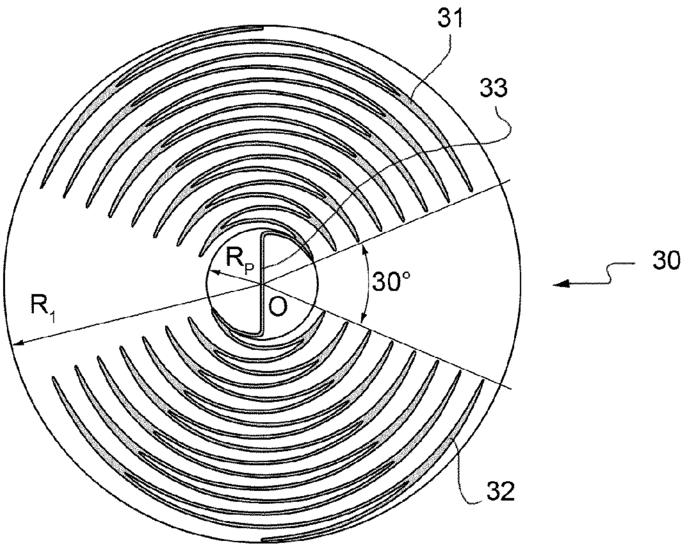


FIG. 7a

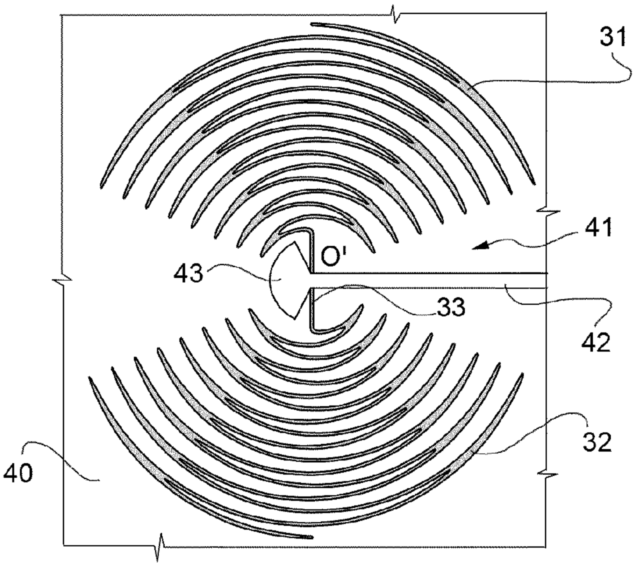


FIG. 7b

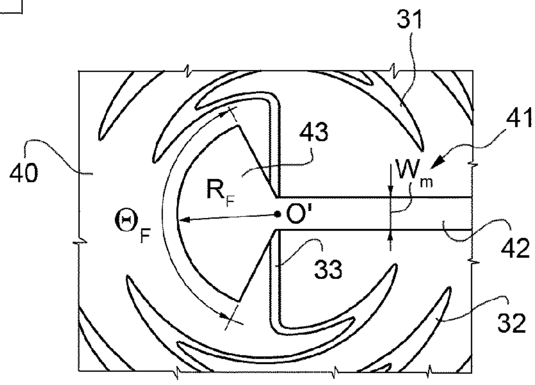


FIG. 8a

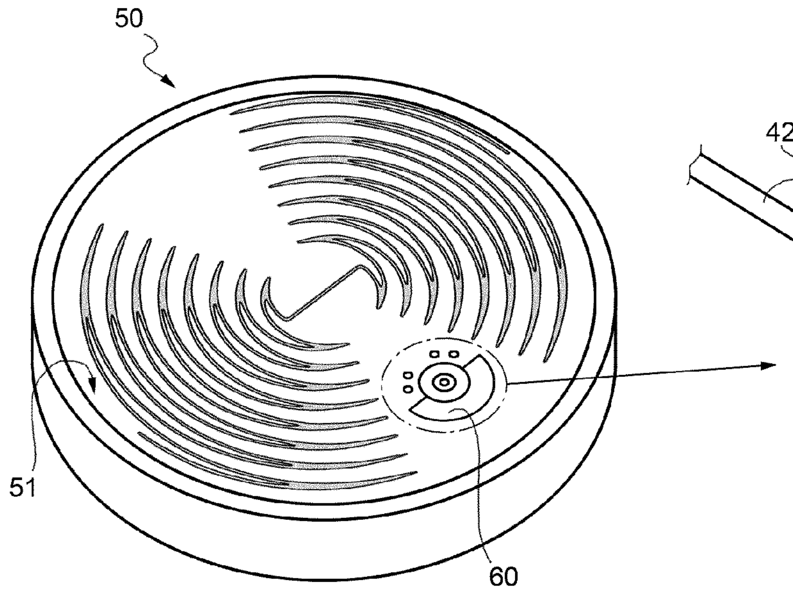


FIG. 8b

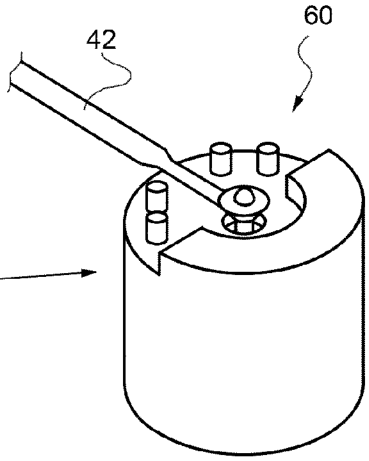


FIG. 9

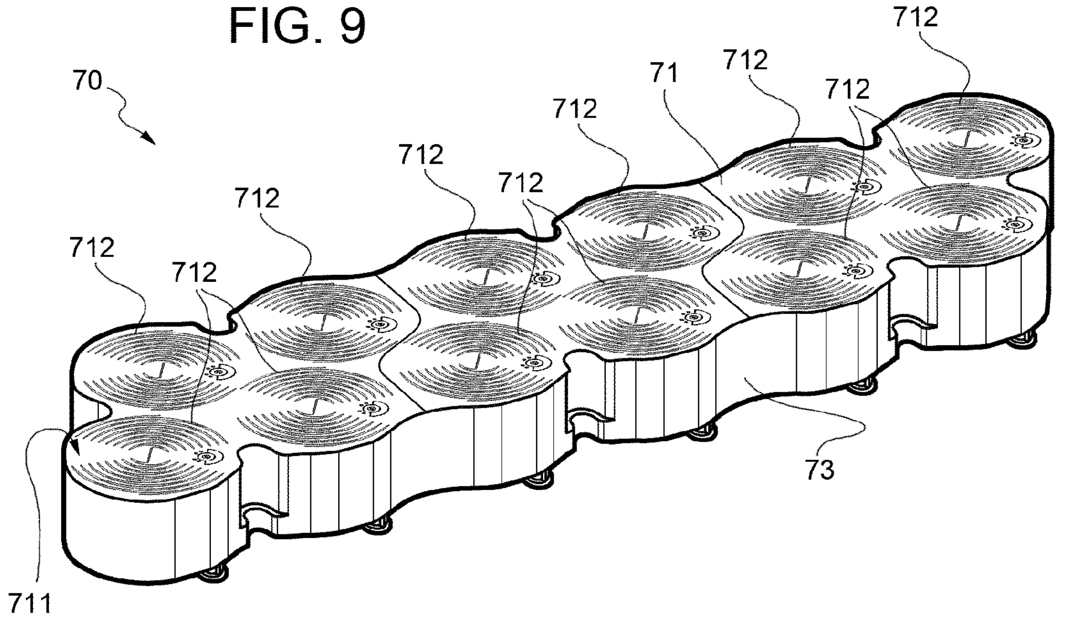

70
712
712
71
712
712
712
712
712
712
712
712
73
711

FIG. 10

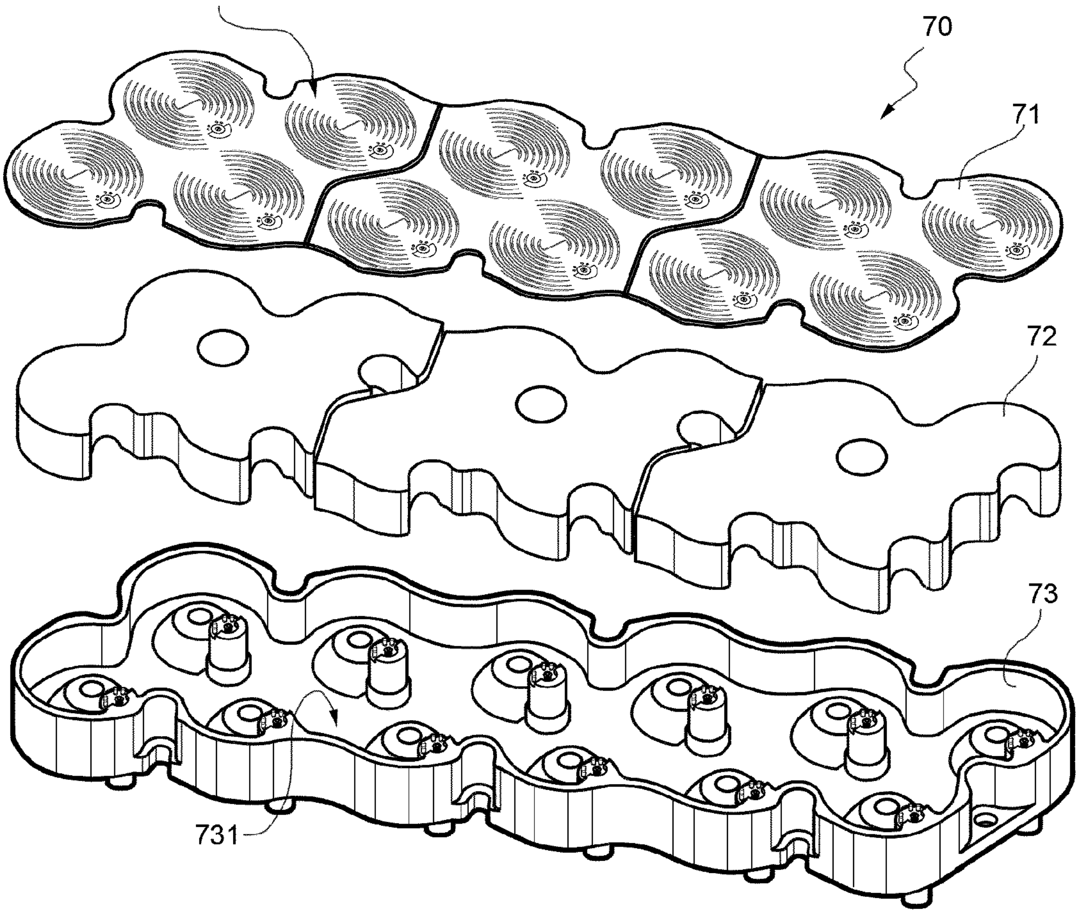

711
70
71
72
73
731

FIG. 11a

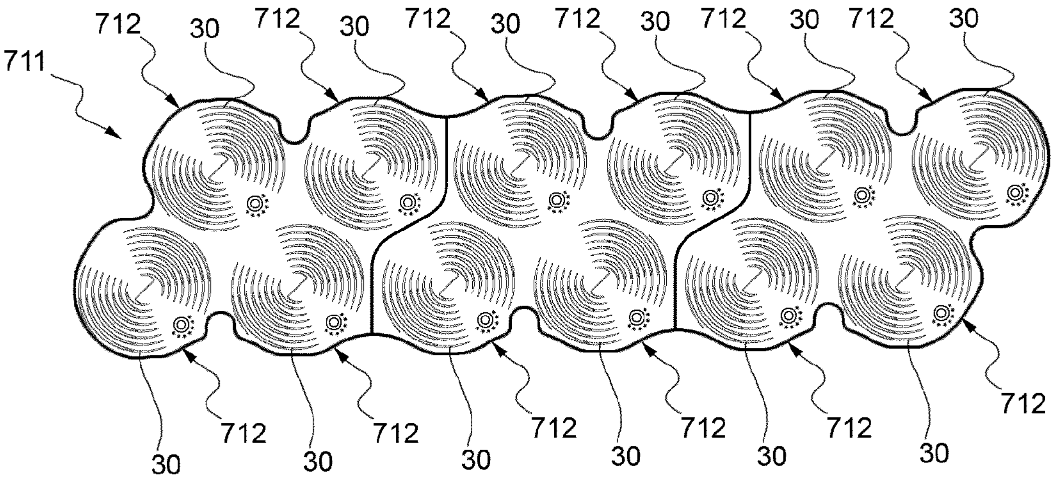


FIG. 11b

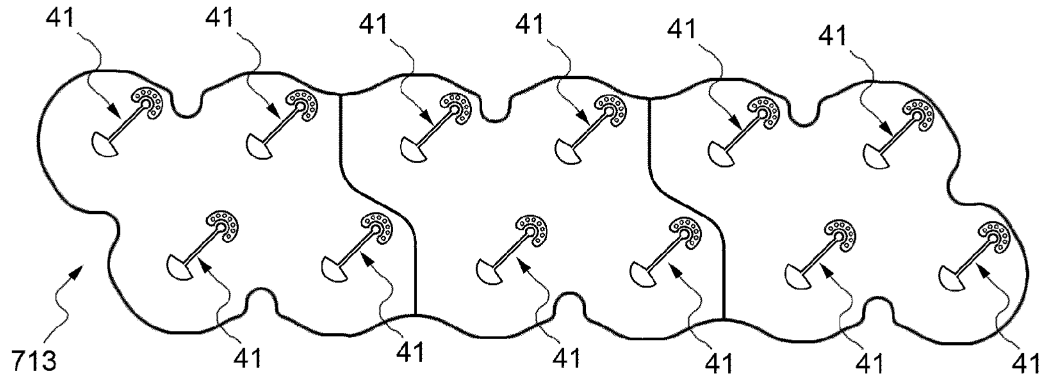


FIG. 12

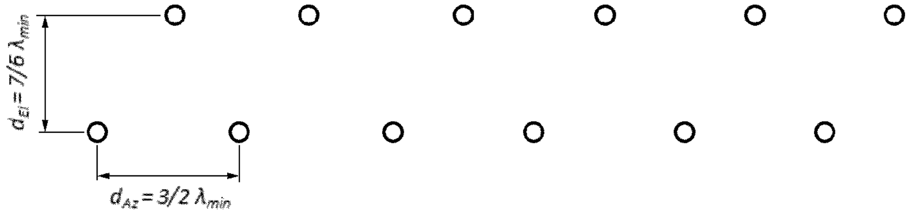


FIG. 13

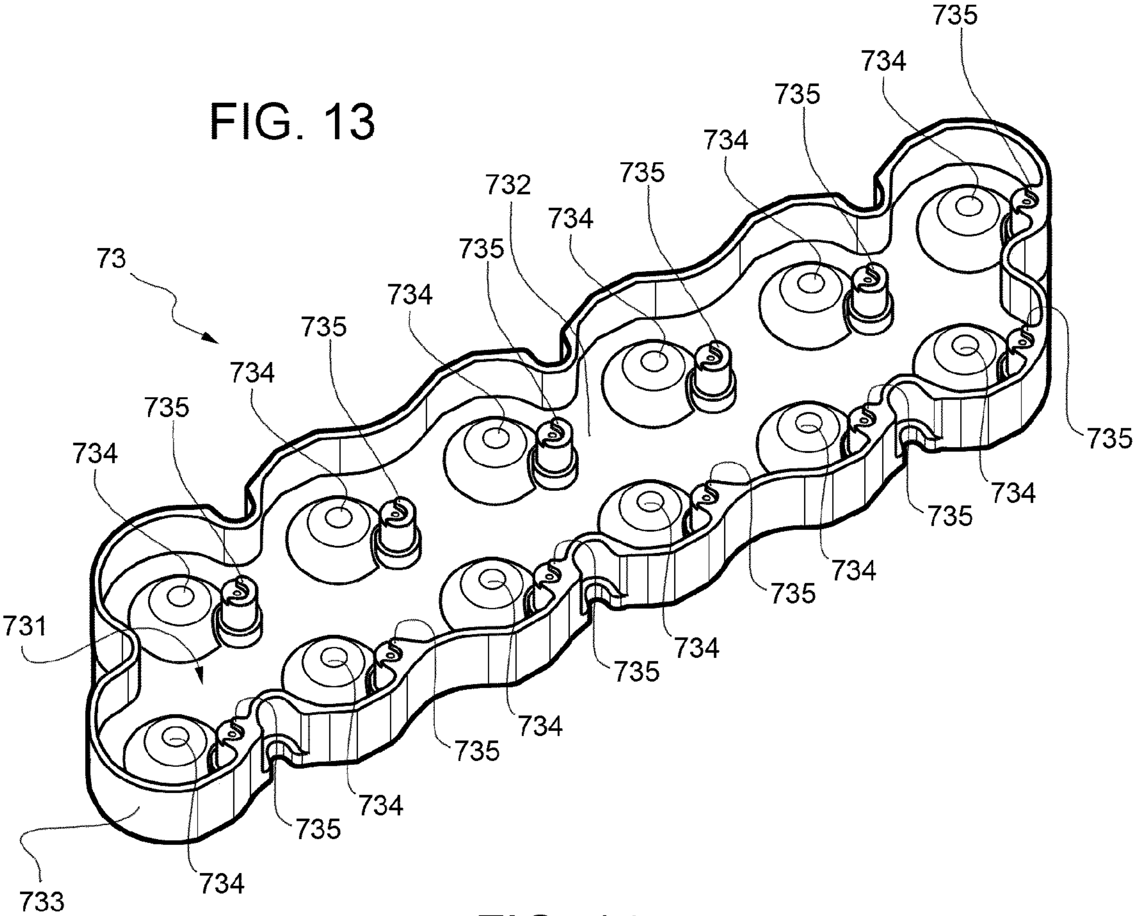

735
734
735
734
735
732
734
735
73
734
735
734
735
734
735
735
734
731
735
734
735
734
735
735
734
735
734
735
734
733
734

FIG. 14

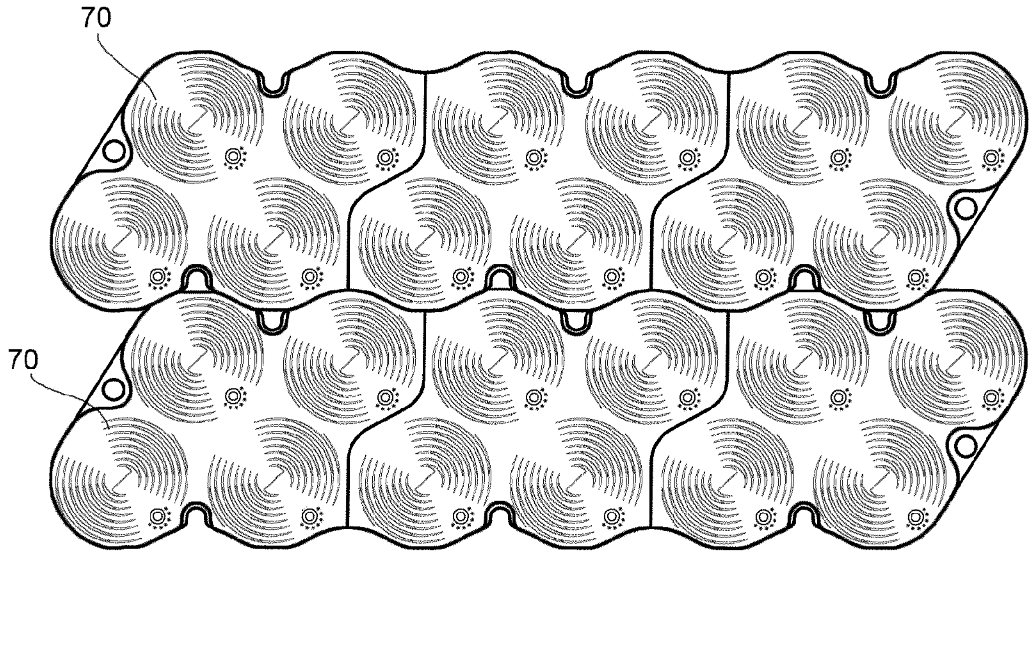

70
70

FIG. 15

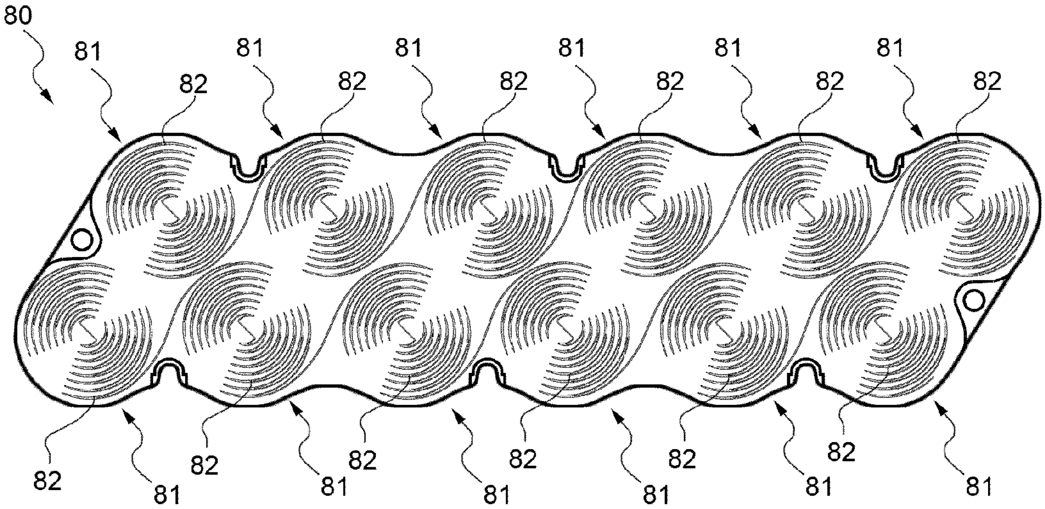

80
81
82

FIG. 16

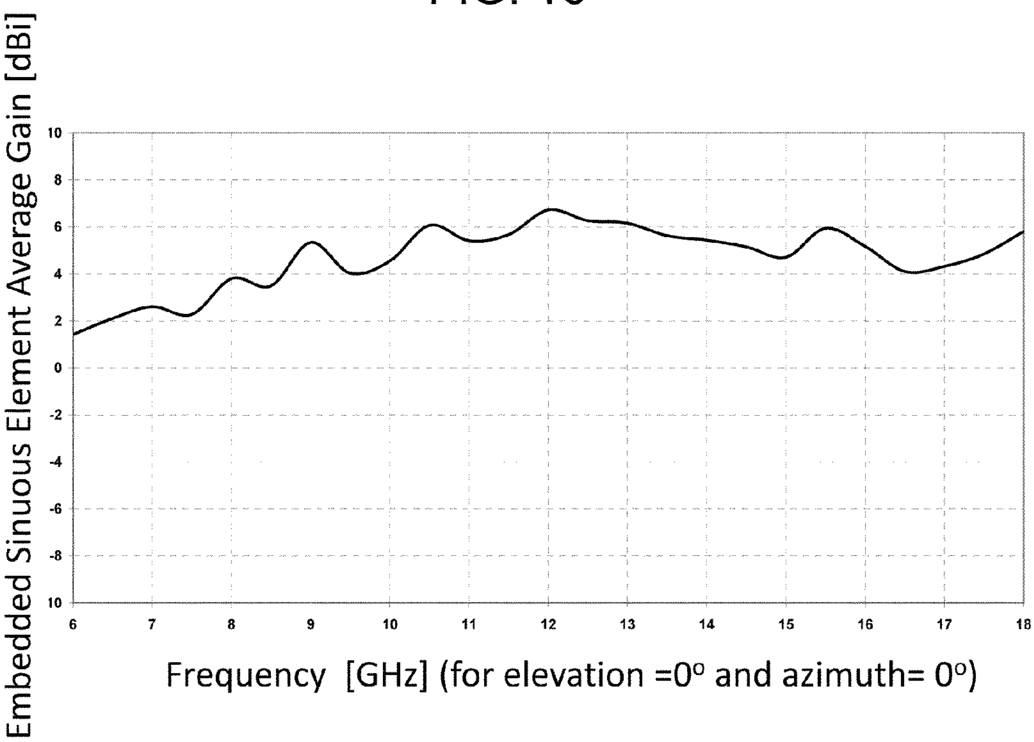
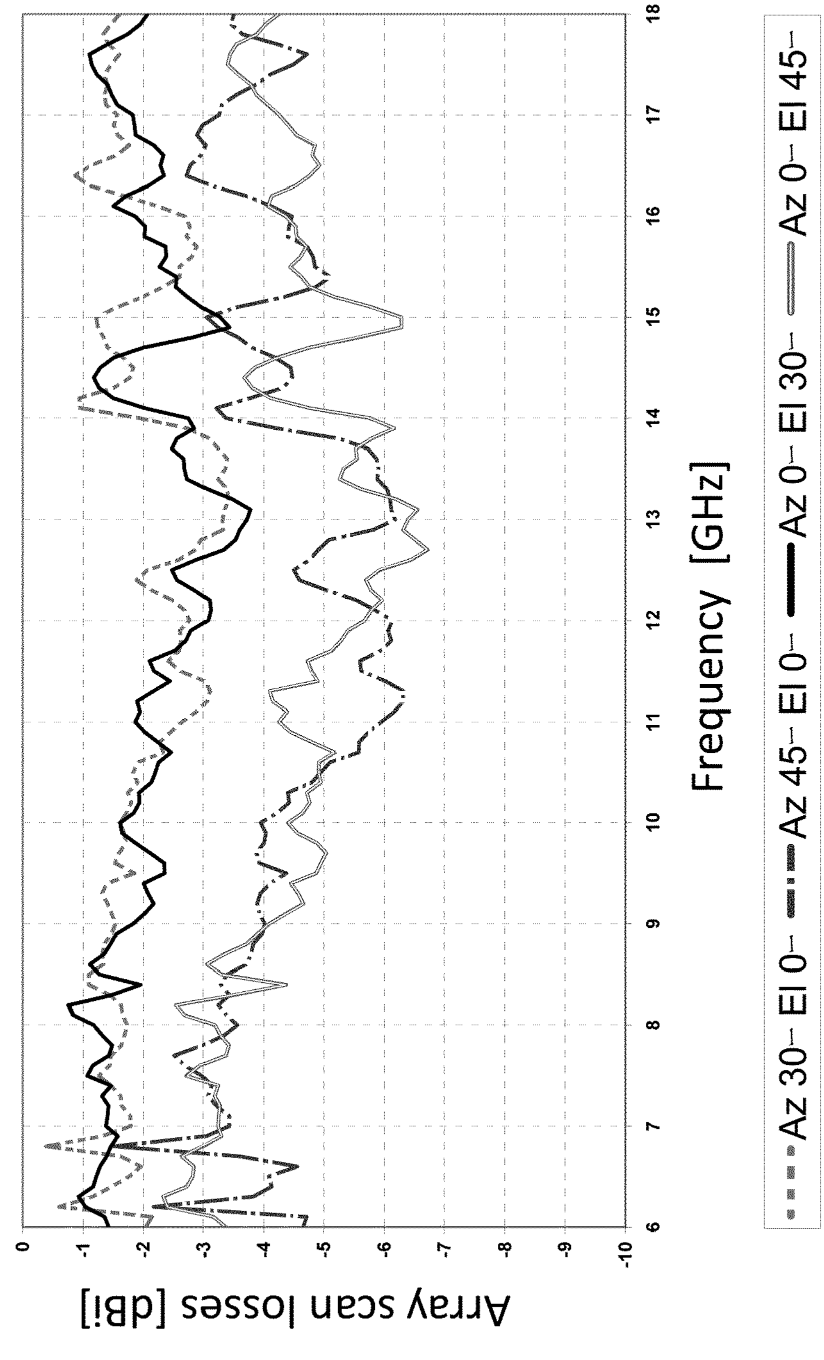

Embedded Sinuous Element Average Gain [dBi]
10
8
6
4
2
0
-2
-4
-6
-8
10
6
7
8
9
10
11
12
13
14
15
16
17
18
Frequency [GHz] (for elevation =0° and azimuth= 0°)

FIG. 17


Array scan losses [dBi]
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
6
7
8
9
10
11
12
13
14
15
16
17
18
Frequency [GHz]
Az 30-- El 0--
Az 45-- El 0--
Az 0-- El 0--
Az 0-- El 30--
Az 0-- El 45--

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EUROPEAN SEARCH REPORT

Application Number
EP 13 15 5549

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	MANNA A ET AL: "Novel UWB low-profile sinuous slot antenna", ANTENNAS AND PROPAGATION (EUCAP), PROCEEDINGS OF THE 5TH EUROPEAN CONFERENCE ON, IEEE, 11 April 2011 (2011-04-11), pages 783-786, XP031878266, ISBN: 978-1-4577-0250-1 * pages 784-785; figures 1,3,5 * -----	1-12	INV. H01Q9/27 H01Q11/10 H01Q13/10 H01Q21/06
A	US 2011/133986 A1 (BELLION ANTHONY [FR] ET AL) 9 June 2011 (2011-06-09) * abstract; figures 1,5 * * paragraphs [0031] - [0037] * -----	1-12	
A	US 6 219 006 B1 (RUDISH RONALD M [US]) 17 April 2001 (2001-04-17) * figures 1,2 * * column 3, lines 38-67 * * column 5, line 15 - column 7, line 12 * -----	1-12	
A	EP 0 198 578 A1 (HAMEL RAYMOND HORACE DU) 22 October 1986 (1986-10-22) * abstract; figures 1-5 * * page 9, line 9 - page 10, line 2 * -----	1-12	TECHNICAL FIELDS SEARCHED (IPC): H01Q

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	2 May 2013	Unterberger, Michael

CATEGORY OF CITED DOCUMENTS

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02-05-2013

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- **V. H. RUMSEY.** Frequency independent antennas. *IRE National Convention Record,* March 1957, 114-118 **[0005]**
- **A. MANNA ; P. BALDONERO ; F. TROTTA.** Novel UWB Low-Profile Sinuous Slot Antenna. *Proceedings of 5th European Conference on Antennas and Propagation,* 11 April 2011 **[0033]**