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(54) **Multi-beam antenna**

(57) A multi-beam antenna, comprising at least one curved surface; at least one dielectric substrate; and a plurality of antenna feed elements on said dielectric substrate, wherein at least two of said plurality of antenna feed elements each comprise an end-fire antenna element adapted to launch electromagnetic waves in a direction substantially towards said at least one curved surface, and said direction for at least one said end-fire antenna element is different from said direction for at least another said end-fire antenna element.

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Description

TECHNICAL ART

[0001] The instant invention generally relates to a multi-beam antenna comprising an electromagnetic lens and a plurality of antenna feed elements.

BACKGROUND OF THE INVENTION

[0002] Known waveguide based antennas, while relatively efficient, are bulky and relatively expensive to manufacture. Known phased array antennas are relatively compact but are relatively inefficient. Known focal plane antennas are compact but offer a comparatively narrow field of view.

SUMMARY OF THE INVENTION

[0003] A multi-beam antenna comprises at least one electromagnetic lens, a dielectric substrate proximate thereto, and a plurality of antenna feed elements on the dielectric substrate. The at least one electromagnetic lens comprises a first side having a first contour at an intersection thereof with a reference surface. The dielectric substrate comprises a first edge having a second contour that is proximate to the first contour, wherein the first edge of the dielectric substrate is located on the reference surface and is proximate to the first side of one of the at least one electromagnetic lens. The plurality of antenna feed elements -- for example, end-fire antennas -- are located on the dielectric substrate proximate to and along the second contour of the first edge. The antenna feed elements are operatively coupled to associated feed signals, which may be multiplexed through a switching network to a corporate antenna feed port. The multi-beam antenna may further comprise at least one reflector, wherein the at least one electromagnetic lens is located between the dielectric substrate and the at least one reflector, and the at least one reflector is adapted to reflect electromagnetic energy generated by at least one of the plurality of antenna feed elements and propagated through the at least one electromagnetic lens.

[0004] These and other objects, features, and advantages of the instant invention will be more fully understood after reading the following detailed description of the preferred embodiment with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] In the accompanying drawings:

FIG. 1 illustrates a top view of a first embodiment of a multi-beam antenna comprising an electromagnetic lens;

FIG. 2 illustrates a side cross-section of the embodiment of **Fig. 1**;

FIG. 3 illustrates a side cross-section of the embodiment of **Fig. 1** incorporating a truncated electromagnetic lens;

FIG. 4 illustrates a side cross-section of an embodiment illustrating various locations of a dielectric substrate, relative to an electromagnetic lens;

FIG. 5 illustrates an embodiment wherein each antenna feed element is operatively coupled to a separate signal;

FIG. 6 illustrates an embodiment wherein the switching network is separately located from the dielectric substrate;

FIG. 7 illustrates a top view of a second embodiment of a multi-beam antenna, comprising a plurality electromagnetic lenses located proximate to one edge of a dielectric substrate;

FIG. 8 illustrates a top view of a third embodiment of a multi-beam antenna, comprising a plurality electromagnetic lenses located proximate to opposite edges of a dielectric substrate;

FIG. 9 illustrates a side view of the third embodiment illustrated in **Fig. 8**, further comprising a plurality of reflectors;

FIG. 10 illustrates a fourth embodiment of a multi-beam antenna, comprising an electromagnetic lens and a reflector; and

FIG. 11 illustrates a fifth embodiment of a multi-beam antenna.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

[0006] Referring to **Figs. 1** and **2**, a **multi-beam antenna 10, 10.1** comprises at least one **electromagnetic lens 12** and a plurality of **antenna feed elements 14** on **a dielectric substrate 16** proximate to a **first edge 18** thereof, wherein the plurality of **antenna feed elements 14** are adapted to radiate a respective plurality of **beams of electromagnetic energy 20** through the at least one **electromagnetic lens 12**.

[0007] The at least one **electromagnetic lens 12** has a **first side 22** having a **first contour 24** at an intersection of the **first side 22** with a **reference surface 26**, for example, a **plane 26.1**. The at least one **electromagnetic lens 12** acts to diffract the electromagnetic wave from the respective **antenna feed elements 14**, wherein different **antenna feed elements 14** at different locations and in different directions relative to the at least one **elec-**

tromagnetic lens 12 generate different associated **beams of electromagnetic energy 20.** The at least one **electromagnetic lens 12** has a **refractive index n** different from free space, for example, a **refractive index n** greater than one (1). For example, the at least one **electromagnetic lens** 12 may be constructed of a material such as Rexolite™, Teflon™, polyethylene, or polystyrene; or a plurality of different materials having different refractive indices, for example as in a Luneburg lens. In accordance with known principles of diffraction, the shape and size of the at least one **electromagnetic lens 12**, the **refractive index n** thereof, and the relative position of the **antenna feed elements 14** to the **electromagnetic lens 12** are adapted in accordance with the radiation patterns of the **antenna feed elements 14** to provide a desired pattern of radiation of the respective **beams of electromagnetic energy 20** exiting the **second side 28** of the at least one **electromagnetic lens 12**. Whereas the at least one **electromagnetic lens 12** is illustrated as a **spherical lens 12'** in **Figs. 1** and **2**, the at least one **electromagnetic lens 12** is not limited to any one particular design, and may, for example, comprise either a spherical lens, a Luneburg lens, a spherical shell lens, a hemispherical lens, an at least partially spherical lens, an at least partially spherical shell lens, a cylindrical lens, or a rotational lens. Moreover, one or more portions of the **electromagnetic lens 12** may be truncated for improved packaging, without significantly impacting the performance of the associated **multi-beam antenna 10, 10.1**. For example, **Fig. 3** illustrates an at least partially spherical **electromagnetic lens 12"** with opposing first 27 and **second 29 portions** removed therefrom.

[0008] The **first edge 18** of the **dielectric substrate 16** comprises a **second contour 30** that is proximate to the **first contour 24.** The **first edge 18** of the **dielectric substrate 16** is located on the **reference surface 26**, and is positioned proximate to the **first side 22** of one of the at least one **electromagnetic lens 12**. The **dielectric substrate 16** is located relative to the **electromagnetic lens 12** so as to provide for the diffraction by the at least one **electromagnetic lens 12** necessary to form the **beams of electromagnetic energy 20**. For the example of a **multi-beam antenna 10** comprising a planar **dielectric substrate 16** located on **reference surface 26** comprising a **plane 26.1**, in combination with an **electromagnetic lens 12** having a **center 32**, for example, a **spherical lens 12'**; the **plane 26.1** may be located substantially close to the **center 32** of the **electromagnetic lens 12** so as to provide for diffraction by at least a portion of the **electromagnetic lens 12**. Referring to **Fig. 4**, the **dielectric substrate 16** may also be displaced relative to the **center 32** of the **electromagnetic lens 12**, for example on one or the other side of the **center 32** as illustrated by **dielectric substrates 16' and 16"**, which are located on respective **reference surfaces 26' and 26"**.

[0009] The **dielectric substrate 16** is, for example, a material with low loss at an operating frequency, for example, Duroid™, a Teflon™ containing material, a ceramic material, or a composite material such as an epoxy/fiberglass composite. Moreover, in one embodiment, the **dielectric substrate 16** comprises a **dielectric 16.1** of a **circuit board 34**, for example, a **printed circuit board 34.1** comprising at least one **conductive layer 36** adhered to **dielectric substrate 16**, from which the **antenna feed elements 14** and other associated **circuit traces 38** are formed, for example, by subtractive technology, for example, chemical or ion etching, or stamping; or additive techniques, for example, deposition, bonding or lamination.

[0010] The plurality of **antenna feed elements 14** are located on the **dielectric substrate 16** along the **second contour 30** of the **first edge 18**, wherein each **antenna feed element 14** comprises a least one **conductor 40** operatively connected to the **dielectric substrate 16.** For example, at least one of the **antenna feed elements 14** comprises an **end-fire antenna element 14.1** adapted to launch or receive electromagnetic waves in a **direction 42** substantially towards or from the **first side 22** of the at least one **electromagnetic lens 12**, wherein different **end-fire antenna elements 14.1** are located at different locations along the **second contour 30** so as to launch or receive respective electromagnetic waves in different **directions 42**. An **end-fire antenna element 14.1** may, for example, comprise either a Yagi-Uda antenna, a coplanar horn antenna (also known as a tapered slot antenna), a Vivaldi antenna, a tapered dielectric rod, a slot antenna, a dipole antenna, or a helical antenna, each of which is capable of being formed on the **dielectric substrate 16**, for example, from a **printed circuit board 34.1**, for example, by subtractive technology, for example, chemical or ion etching, or stamping; or additive techniques, for example, deposition, bonding or lamination. Moreover, the **antenna feed elements 14** may be used for transmitting, receiving or both.

[0011] Referring to **Fig. 4**, the **direction 42** of the one or more **beams of electromagnetic energy 20** through the **electromagnetic lens 12, 12'** is responsive to the relative location of the **dielectric substrate 16, 16' or 16"** and the associated **reference surface 26, 26'** or **26"** relative to the **center 32** of the **electromagnetic lens 12**. For example, with the **dielectric substrate 16** substantially aligned with the **center 32, the directions 42** of the one or more **beams of electromagnetic energy 20** are nominally aligned with the **reference surface 26**. Alternately, with the **dielectric substrate 16'** above the **center 32** of the **electromagnetic lens 12, 12'**, the resulting one or more **beams of electromagnetic energy 20'** propagate in **directions 42'** below the **center 32**. Similarly, with the **dielectric substrate 16"** below the **center 32** of the **electromagnetic lens 12, 12',** the resulting one or more **beams of electromagnetic energy 20"** propagate in **directions 42"** above the **center 32**.

[0012] The **multi-beam antenna** 10 may further comprise at least one **transmission line 44** on the **dielectric substrate 16** operatively connected to a **feed port 46** of one of the plurality of **antenna feed elements 14** for feeding a signal to the associated **antenna feed element 14**. For example, the at least one **transmission line 44** may comprise either a stripline, a microstrip line, an inverted microstrip line, a slotline, an image line, an insulated image line, a tapped image line, a coplanar stripline, or a coplanar waveguide line formed on the **dielectric substrate 16**, for example, from a **printed circuit board 34.1**, for example, by subtractive technology, for example, chemical or ion etching, or stamping; or additive techniques, for example, deposition, bonding or lamination.

[0013] The **multi-beam antenna 10** may further comprise a **switching network 48** having at least one **input 50** and a plurality of **outputs 52**, wherein the at least one **input 50** is operatively connected -- for example, via at least one above described **transmission line 44** -- to a **corporate antenna feed port 54**, and each **output 52** of the plurality of **outputs 52** is connected -- for example, via at least one above described **transmission line 44** -- to a respective **feed port 46** of a different **antenna feed element 14** of the plurality of **antenna feed elements 14**. The **switching network 48** further comprises at least one **control port 56** for controlling which **outputs 52** are connected to the at least one **input 50** at a given time. The **switching network 48** may, for example, comprise either a plurality of micro-mechanical switches, PIN diode switches, transistor switches, or a combination thereof, and may, for example, be operatively connected to the **dielectric substrate 16**, for example, by surface mount to an associated **conductive layer 36** of a **printed circuit board 34.1.**

[0014] In operation, a **feed signal 58** applied to the **corporate antenna feed port 54** is either blocked -- for example, by an open circuit, by reflection or by absorption, -- or switched to the associated **feed port 46** of one or more **antenna feed elements 14**, via one or more associated **transmission lines 44**, by the **switching network 48**, responsive to a **control signal 60** applied to the **control port 56**. It should be understood that the **feed signal 58** may either comprise a single signal common to each **antenna feed element 14**, or a plurality of signals associated with different **antenna feed elements 14**. Each **antenna feed element 14** to which the **feed signal 58** is applied launches an associated electromagnetic wave into the **first side 22** of the associated **electromagnetic lens 12**, which is diffracted thereby to form an associated **beam of electromagnetic energy 20**. The associated **beams of electromagnetic energy 20** launched by different **antenna feed elements 14** propagate in different associated **directions 42**. The various **beams of electromagnetic energy 20** may be generated individually at different times so as to provided for a scanned **beam of electromagnetic energy 20.** Alternately, two or more **beams of electromagnetic energy 20** may be generated simultaneously. Moreover, different **antenna feed elements 14** may be driven by different frequencies that, for example, are either directly switched to the respective **antenna feed elements 14**, or switched via an associated **switching network 48** having a plurality of **inputs 50**, at least some of which are each connected to different **feed signals 58**.

[0015] Referring to **Fig. 5**, the **multi-beam antenna 10, 10.1** may be adapted so that the respective signals are associated with the respective **antenna feed elements 14** in a one-to-one relationship, thereby precluding the need for an associated **switching network 48**. For example, each **antenna feed element 14** can be operatively connected to an associated **signal 59** through an associated **processing element 61**. As one example, with the **multi-beam antenna 10, 10.1** configured as an imaging array, the respective **antenna feed elements 14** are used to receive electromagnetic energy, and the respective **processing elements 61** comprise detectors. As another example, with the **multi-beam antenna 10, 10.1** configured as a communication antenna, the respective **antenna feed elements 14** are used to both transmit and receive electromagnetic energy, and the respective **processing elements 61** comprise transmit/receive modules or transceivers.

[0016] Referring to **Fig. 6**, the **switching network 48**, if used, need not be collocated on a common **dielectric substrate 16**, but can be separately located, as, for example, may be useful for low frequency applications, for example, 1-20 GHz.

[0017] Referring to **Figs. 7, 8** and **9**, in accordance with a second aspect, a **multi-beam antenna 10'** comprises at least a **first 12.1** and a **second 12.2 electromagnetic lens**, each having a **first side 22.1, 22.2** with a corresponding **first contour 24.1, 24.2** at an intersection of the respective **first side 22.1, 22.2** with the **reference surface 26**. The **dielectric substrate 16** comprises at least a **second edge 62** comprising a **third contour 64** wherein the **second contour 30** is proximate to the **first contour 24.1** of the **first electromagnetic lens 12.1** and the **third contour 64** is proximate to the **first contour 24.2** of the **second electromagnetic lens 12.2**.

[0018] Referring to **Fig. 7**, in accordance with a second embodiment of the **multi-beam antenna 10.2**, the **second edge 62** is the same as the **first edge 18** and the **second 30** and **third 64 contours** are displaced from one another along the **first edge 18** of the **dielectric substrate 16**.

[0019] Referring to **Fig. 8**, in accordance with a third embodiment of the **multi-beam antenna 10.3**, the **second edge 62** is different from the **first edge 18**, and more particularly is opposite to the **first edge 18** of **the dielectric substrate 16.**

[0020] Referring to **Fig. 9**, in accordance with a third aspect, a **multi-beam antenna 10"** comprises at least one **reflector 66**, wherein the **reference surface 26** intersects the at least one **reflector 66** and one of the at least one **electromagnetic lens 12** is located between the **dielectric substrate 16** and the **reflector 66**. The at least one **reflector 66** is adapted to reflect electromagnetic energy propagated through the at least one **electromagnetic lens 12** after being generated by at least one of the plurality of **antenna feed elements 14.** A third embodiment of the **multi-beam antenna 10** comprises at least **first 66.1** and **second 66.2 reflectors** wherein the **first electromagnetic lens 12.1** is located between the **dielectric substrate 16 and the first reflector 66.1;** the **second electromagnetic lens 12.2** is located **between the dielectric substrate 16** and the **second reflector 66.2**, the **first reflector 66.1** is adapted to reflect electromagnetic energy propagated through the **first electromagnetic lens 12.1** after being generated by at least one of the plurality of **antenna feed elements 14** on the **second contour 30**, and the **second reflector 66.2** is adapted to reflect electromagnetic energy propagated through the **second electromagnetic lens 12.2** after being generated by at least one of the plurality of **antenna feed elements 14** on the **third contour 64.** For example, the **first 66.1** and **second 66.2 reflectors** may be oriented to direct the **beams of electromagnetic energy 20** from each side in a common nominal direction, as illustrated in **Fig. 9**. Referring to **Fig. 9**, the **multi-beam antenna 10"** as illustrated would provide for scanning in a direction normal to the plane of the illustration. If the **dielectric substrate 16** were rotated by **90** degrees with respect to the **reflectors 66.1, 66.2**, about an axis connecting the respective **electromagnetic lenses 12.1, 12.1**, then the **multi-beam antenna 10"** would provide for scanning in a direction parallel to the plane of the illustration.

[0021] Referring to **Fig. 10**, in accordance with the third aspect and a fourth embodiment, a **multi-beam antenna 10", 10.4** comprises an at least partially spherical **electromagnetic lens 12"'**, for example, a hemispherical electromagnetic lens, having a **curved surface 68** and a **boundary 70**, for example a **flat boundary 70.1**. The **multi-beam antenna 10", 10.4** further comprises a **reflector 66** proximate to the **boundary 70**, and a plurality of **antenna feed elements 14** on a **dielectric substrate 16** proximate to a **contoured edge 72** thereof, wherein each of the **antenna feed elements 14** is adapted to radiate a respective plurality of **beams of electromagnetic energy 20** into a **first sector 74** of the **electromagnetic lens 12"'**. The **electromagnetic lens 12'"** has a **first contour 24** at an intersection of the **first sector 74** with a **reference surface 26**, for example, a **plane 26.1**. The **contoured edge 72** has a **second contour 30** located on the **reference surface 26** that is proximate to the **first contour 24** of the **first sector 74.** The **multi-beam antenna 10", 10.4** further comprises a **switching network 48** and a plurality of **transmission lines 44** operatively connected to the **antenna feed elements 14** as described hereinabove for the other embodiments.

[0022] In operation, at least one **feed signal 58** applied to a **corporate antenna feed port 54** is either blocked, or switched to the associated **feed port 46** of one or more **antenna feed elements 14**, via one or more associated **transmission lines 44**, by the **switching network 48** responsive to a **control signal 60** applied to a **control port 56** of the **switching network 48**. Each **antenna feed element 14** to which the **feed signal 58** is applied launches an associated electromagnetic wave into the **first sector 74** of the associated **electromagnetic lens 12"'.** The electromagnetic wave propagates through -- and is diffracted by -- the **curved surface 68**, and is then reflected by the **reflector 66** proximate to the **boundary 70**, whereafter the reflected electromagnetic wave propagates through the **electromagnetic lens 12'"** and exits -- and is diffracted by -- a **second sector 76** as an associated **beam of electromagnetic energy 20**. With the **reflector 66** substantially normal to the **reference surface 26** -- as illustrated in **Fig. 10** -- the different **beams of electromagnetic energy 20** are directed by the associated **antenna feed elements 14** in different directions that are nominally substantially parallel to the **reference surface 26**.

[0023] Referring to **Fig. 11**, in accordance with a fourth aspect and a fifth embodiment, a **multi-beam antenna 10"', 10.5** comprises an **electromagnetic lens 12** and plurality of **dielectric substrates 16**, each comprising a set of **antenna feed elements 14** and operating in accordance with the description hereinabove. Each set of **antenna feed elements 14** generates (or is capable of generating) an associated set of **beams of electromagnetic energy 20.1, 20.2 and 20.3**, each having associated **directions 42.1, 42.2 and 42.3,** responsive to the associated **feed 58** and **control 60 signals.** The associated **feed 58** and **control 60 signals** are either directly applied to the associated **switch network 48** of the respective sets of **antenna feed elements 14,** or are applied thereto through a **second switch network 78** have associated **feed 80** and **control 82 ports**, each comprising at least one associated signal. Accordingly, the **multi-beam antenna 10"', 10.4** provides for transmitting or receiving one or more beams of electromagnetic energy over a three-dimensional space.

[0024] The multi-beam antenna 10 provides for a relatively wide field-of-view, and is suitable for a variety of applications, including but not limited to automotive radar, point-to-point communications systems and point-to-multi-point communication systems, over a wide range of frequencies for which the **antenna feed elements 14** may be designed to radiate, for example, 1 to **200 GHz.** Moreover, the **multi-beam antenna 10** may be configured for either mono-static or bi-static operation.

[0025] While specific embodiments have been described in detail in the foregoing detailed description and illustrated in the accompanying drawings, those with ordinary skill in the art will appreciate that various modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be illustrative only and not limiting as to the scope of the invention, which is to be given the full breadth of the appended claims and any and all equivalents thereof.

[0026] The following are claims of the parent application 00980567.2 **as filed:**

1. A multi-beam antenna, comprising,

a. at least one electromagnetic lens, wherein said at least one electromagnetic lens has a first side comprising a first contour at an intersection with a reference surface;

b. a dielectric substrate, wherein said dielectric substrate comprises a first edge comprising a second contour proximate to said first contour, said first edge of said dielectric substrate is located on said reference surface, and said first edge is proximate to said first side of one of said at least one electromagnetic lens; and

c. a plurality of antenna feed elements on said dielectric substrate along said second contour of said first edge.

2. A multi-beam antenna as recited in claim 1, wherein said reference surface is a plane.

3. A multi-beam antenna as recited in claim 2, wherein said plane is substantially close to a center of said electromagnetic lens for said electromagnetic lens having a center.

4. A multi-beam antenna as recited in claim 1, wherein said at least one electromagnetic lens is selected from a spherical lens, a Luneburg lens, a spherical shell lens, a hemispherical lens, an at least partially spherical lens, an at least partially spherical shell lens, a cylindrical lens, and a rotational lens.

5. A multi-beam antenna as recited in claim 1, wherein said dielectric substrate comprises a dielectric of a printed circuit board.

6. A multi-beam antenna as recited in claim 1, wherein each said antenna feed element comprises a least one conductor operatively connected to said dielectric substrate.

7. A multi-beam antenna as recited in claim 1, wherein at least one said antenna feed element comprises an end-fire antenna element adapted to launch electromagnetic waves in a direction substantially towards said first side of said at least one electromagnetic lens, and said direction for at least one said end-fire antenna element is different from said direction for at least another said end-fire antenna element.

8. A multi-beam antenna as recited in claim 7, wherein said end-fire antenna is selected from a Yagi-Uda antenna, a coplanar horn antenna, a Vivaldi antenna, a tapered dielectric rod, a slot antenna, a dipole antenna, and a helical antenna.

9. A multi-beam antenna as recited in claim 1, further comprising at least one transmission line on said dielectric substrate, wherein at least one said at least one transmission line is operatively connected to a feed port of one of said plurality of antenna feed elements.

10. A multi-beam antenna as recited in claim 9, wherein said transmission line is selected from a stripline, a microstrip line, an inverted microstrip line, a slotline, an image line, an insulated image line, a tapped image line, a coplanar stripline, and a coplanar waveguide line.

11. A multi-beam antenna as recited in claim 1, further comprising a switching network having an input and a plurality of outputs, said input is operatively connected to a corporate antenna feed port, and each output of said plurality of outputs is connected to a different antenna feed element of said plurality of antenna feed elements.

12. A multi-beam antenna as recited in claim 9, further comprising a switching network having an input and a plurality of outputs, said input is operatively connected to a corporate antenna feed port, and each output of said plurality of outputs is connected to a different antenna feed element of said plurality of antenna feed elements via said at least one transmission line.

13. A multi-beam antenna as recited in claim 11, wherein said switching network is operatively connected to said dielectric substrate.

14. A multi-beam antenna as recited in claim 1, wherein said at least one electromagnetic lens comprises at least a first and a second electromagnetic lens, each of said first and second electromagnetic lenses has a first side, each said first side has a corresponding first contour at an intersection of said first side with said reference surface, said dielectric substrate comprises at least a second edge, said second edge comprises a third contour, said second contour is proximate to said first contour of said first electromagnetic lens, said third contour is proximate to said first contour of said second electromagnetic lens, further comprising at least one antenna feed element on said dielectric substrate along said third contour of said second edge.

15. A multi-beam antenna as recited in claim 14, wherein said second edge is the same as said first

edge and said second and third contours are displaced from one another along

16. A multi-beam antenna as recited in claim 14, wherein said second edge is different from said first edge.

17. A multi-beam antenna as recited in claim 14, wherein said second edge is opposite to said first edge.

18. A multi-beam antenna as recited in claim 1, further comprising at least one reflector, wherein said reference surface intersects said at least one reflector, one of said at least one electromagnetic lens is located between said dielectric substrate and said reflector, and said at least one reflector is adapted to reflect electromagnetic energy propagated through said at least one electromagnetic lens after being generated by at least one of said plurality of antenna feed elements.

19. A multi-beam antenna as recited in claim 17, further comprising at least first and second reflectors wherein said reference surface intersects said at least first and second reflectors, said first electromagnetic lens is located between said dielectric substrate and said first reflector, said second electromagnetic lens is located between said dielectric substrate and said second reflector, said first reflector is adapted to reflect electromagnetic energy propagated through said first electromagnetic lens after being generated by at least one of said plurality of antenna feed elements on said second contour, and said second reflector is adapted to reflect electromagnetic energy propagated through said second electromagnetic lens after being generated by said at least one antenna feed element on said third contour.

Claims

1. A multi-beam antenna, comprising:

a. at least one curved surface;
b. at least one dielectric substrate; and
c. a plurality of antenna feed elements on said dielectric substrate, wherein at least two of said plurality of antenna feed elements each comprise an end-fire antenna element adapted to launch electromagnetic waves in a direction substantially towards said at least one curved surface, and said direction for at least one said end-fire antenna element is different from said direction for at least another said end-fire antenna element.

2. A multi-beam antenna as recited in claim 1, wherein at least one of said at least one curved surface is substantially circular in a first cross section along an intersection with a reference surface parallel to said dielectric substrate along said plurality of antenna feed elements.

3. A multi-beam antenna as recited in claim 1, wherein at least one of said at least one curved surface is substantially spherical.

4. A multi-beam antenna as recited in claim 1, wherein at least one of said at least one curved surface is substantially refractive of at least some of said electromagnetic waves.

5. A multi-beam antenna as recited in claim 1, wherein at least one of said at least one curved surface is substantially diffractive of at least some of said electromagnetic waves.

6. A multi-beam antenna as recited in claim 1, wherein at least one of said at least one curved surface is dielectric.

7. A multi-beam antenna as recited in claim 1, wherein at least one of said at least one curved surface is a surface of an electromagnetic lens.

8. A multi-beam antenna as recited in claim 1, wherein said direction of at least one said end-fire antenna element is substantially aligned with a radius of curvature of said at least one curved surface.

9. A multi-beam antenna as recited in claim 8, wherein said direction of at least one said end-fire antenna element is substantially co-incident with said radius of curvature of said at least one curved surface.

10. A multi-beam antenna as recited in claim 1, wherein each said antenna feed element comprises a least one conductor operatively connected to said dielectric substrate.

11. A multi-beam antenna as recited in claim 9, wherein said dielectric substrate comprises a dielectric of a printed circuit.

12. A multi-beam antenna as recited in claim 1, wherein said at least one dielectric substrate is substantially planar.

13. A multi-beam antenna as recited in claim 1, wherein said end-fire antenna is selected from a Yagi-Uda antenna, a coplanar horn antenna, a Vivaldi antenna, a tapered dielectric rod, a slot antenna, a dipole antenna, and a helical antenna.

14. A multi-beam antenna as recited in claim 1, further comprising at least one transmission line on said dielectric substrate, wherein at least one said at least one transmission line is operatively connected to a feed port of one of said plurality of antenna feed elements.

15. A multi-beam antenna as recited in claim 14, wherein said transmission line is selected from a stripline, a microstrip line, an inverted microstrip line, a slotline, an image line, an insulated image line, a tapped image line, a coplanar stripline, and a coplanar waveguide line.

16. A multi-beam antenna as recited in claim 1, further comprising a switching network having an input and a plurality of outputs, said input is operatively connected to a corporate antenna feed port, and each output of said plurality of outputs is connected to a different antenna feed element of said plurality of antenna feed elements.

17. A multi-beam antenna as recited in claim 14, further comprising a switching network having an input and a plurality of outputs, said input is operatively connected to a corporate antenna feed port, and each output of said plurality of outputs is connected to a different antenna feed element of said plurality of antenna feed elements via said at least one transmission line.

18. A multi-beam antenna as recited in claim 16, wherein said switching network is operatively connected to said dielectric substrate.

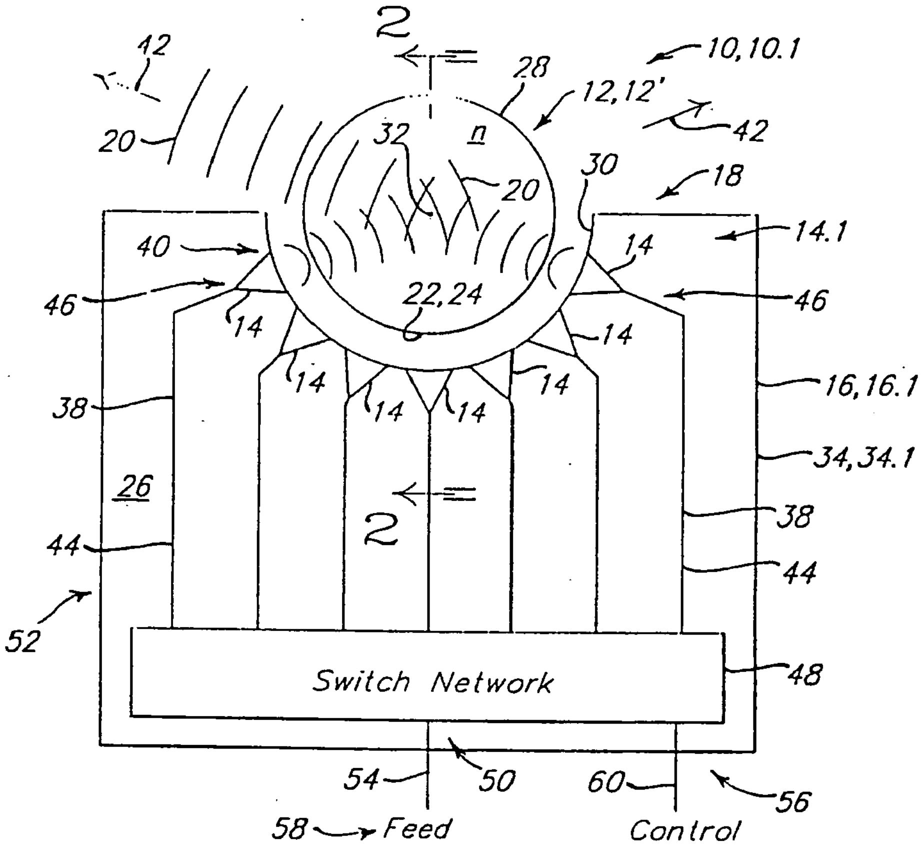
2
2
42
20
32
n
28
12,12'
10,10.1
42
30
20
18
14.1
40
14
46
46
22,24
14
14
14
14
14
14
38
16,16.1
34,34.1
26
38
44
44
52
Switch Network
48
54
50
60
56
58
Feed
Control

FIG. 1.

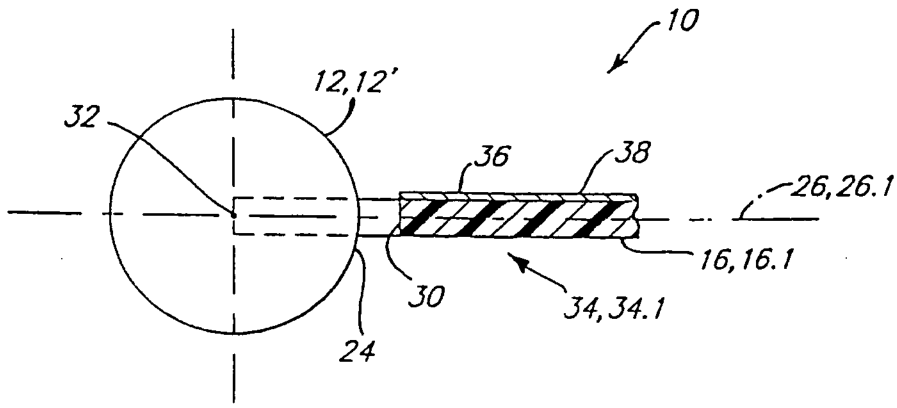
10
12,12'
32
36
38
26,26.1
16,16.1
30
34,34.1
24

FIG. 2.

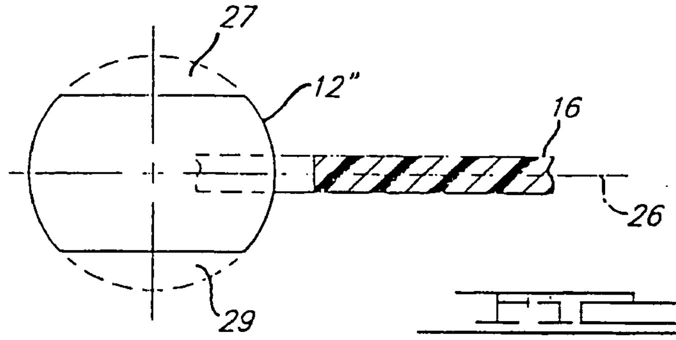

FIG. 3.

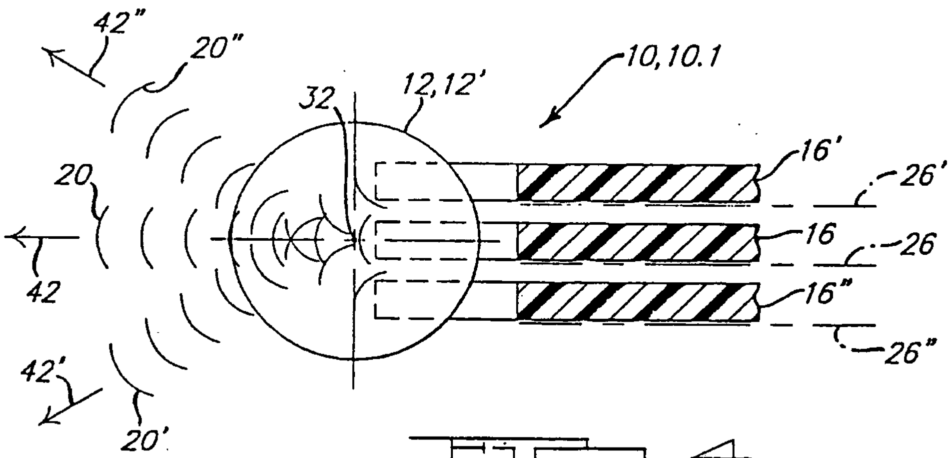

FIG. 4.

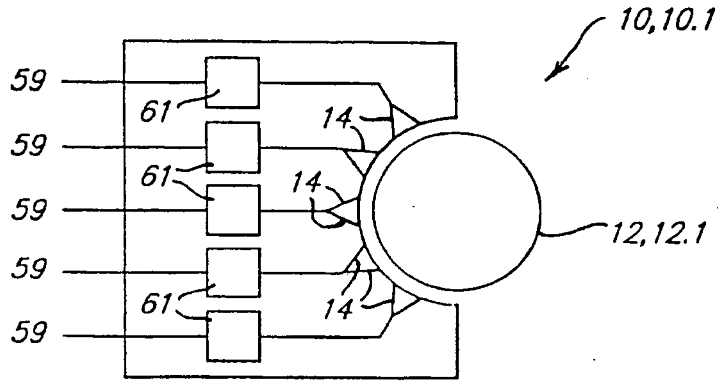

FIG. 5.

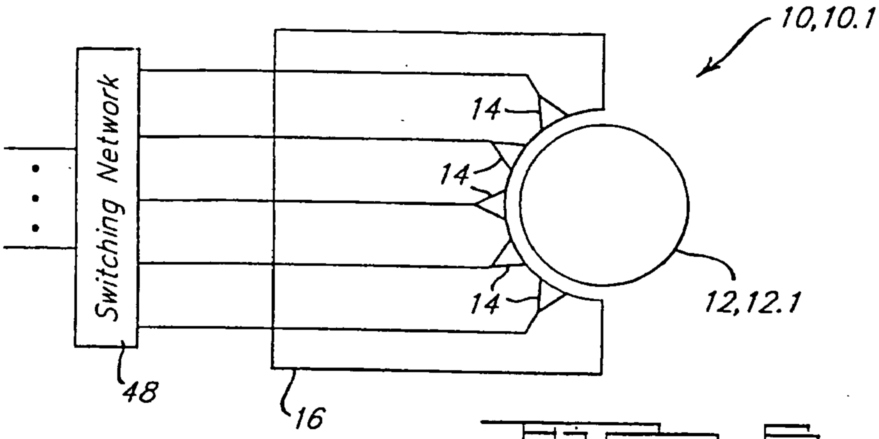
10,10.1
14
14
14
12,12.1
Switching Network
48
16

FIG. 6.

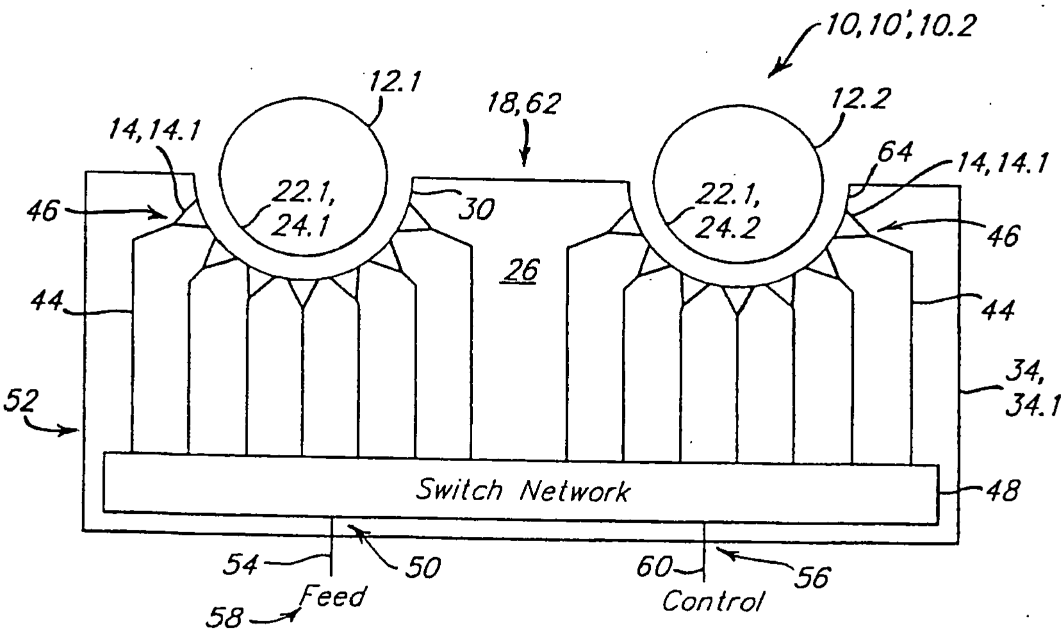
10,10',10.2
12.1
18,62
12.2
14,14.1
64
14,14.1
46
22.1,
24.1
30
22.1,
24.2
46
26
44
44
34,
34.1
52
Switch Network
48
54
50
60
56
Feed
Control
58

FIG. 7.

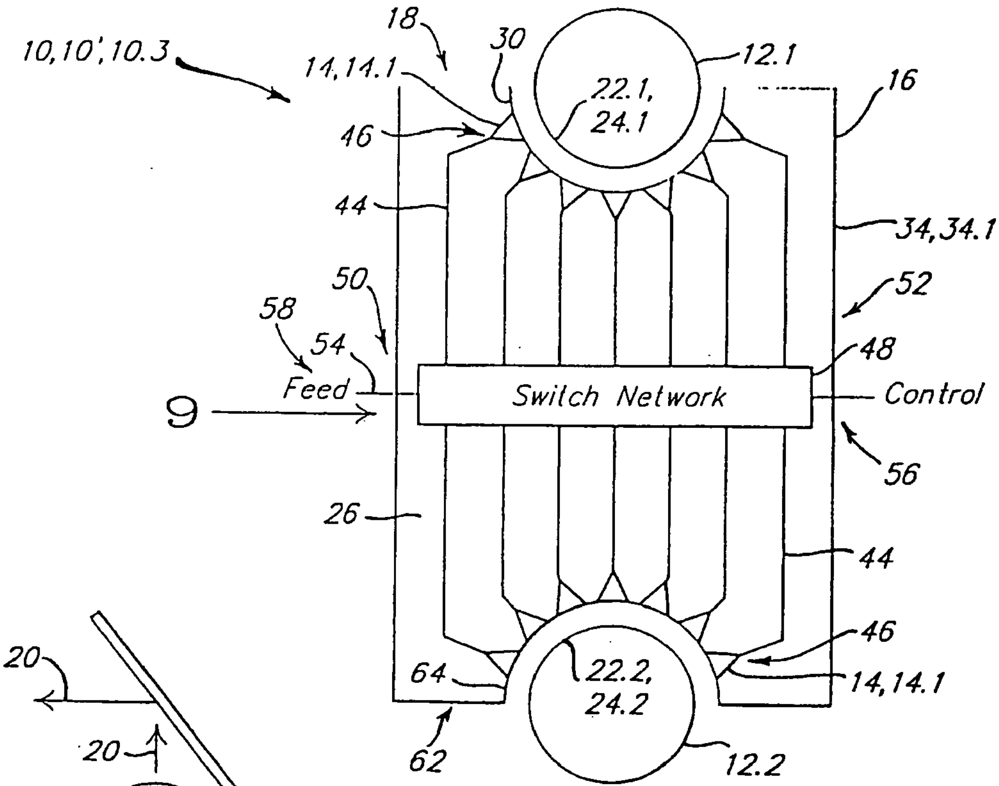
10,10',10.3
18
30
14,14.1
12.1
22.1,
24.1
16
46
44
34,34.1
50
52
58
54
48
Feed
Switch Network
Control
9
56
26
44
46
64
22.2,
24.2
14,14.1
62
12.2

FIG. 8.

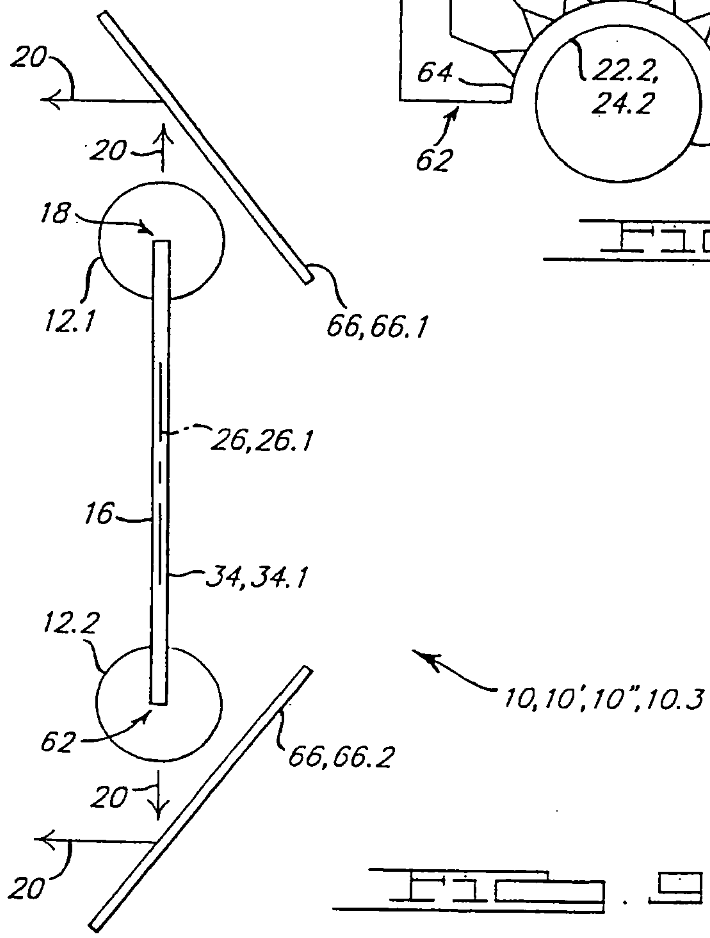
20
20
18
12.1
66,66.1
26,26.1
16
34,34.1
12.2
10,10',10'',10.3
62
66,66.2
20
20

FIG. 9.

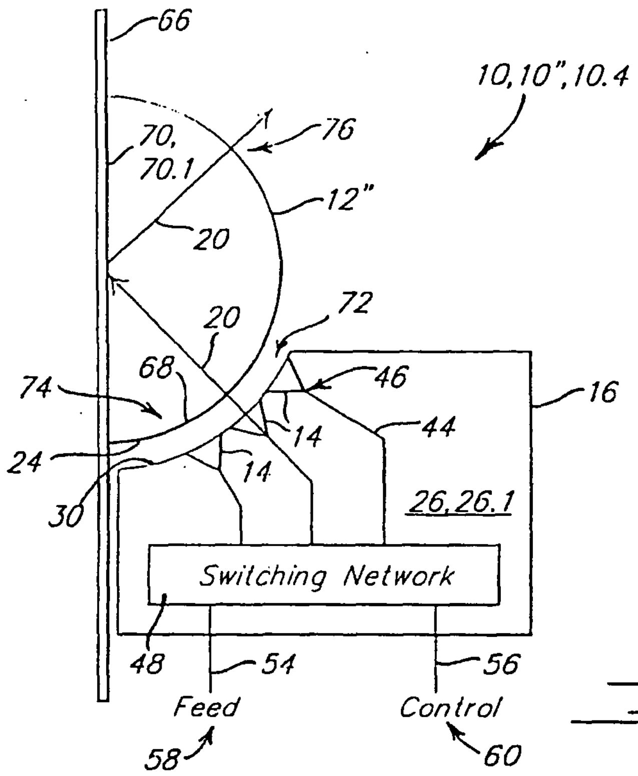
66
10,10",10.4
70,
70.1
76
12"
20
20
72
68
46
74
16
14
44
24
14
26,26.1
30
Switching Network
48
54
56
Feed
Control
58
60

FIG. 10.

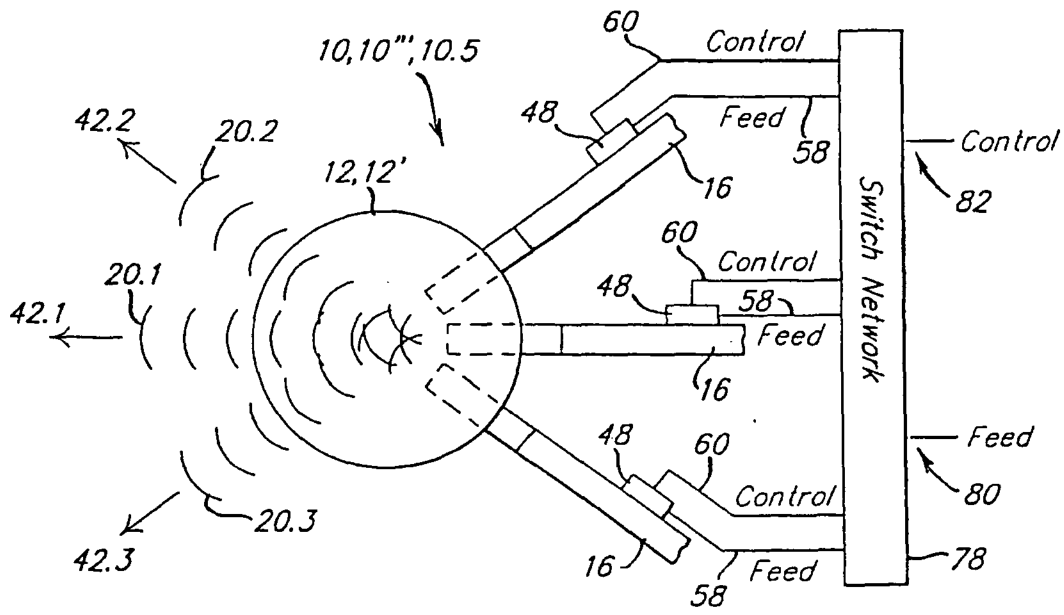
60
Control
10,10"',10.5
48
Feed
42.2
20.2
58
Control
12,12'
16
82
60
Switch Network
20.1
Control
48
58
42.1
Feed
16
48
60
Feed
80
Control
20.3
42.3
16
58
Feed
78

FIG. 11.

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EUROPEAN SEARCH REPORT

Application Number
EP 06 02 4287

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 0 427 470 B1 (RAYTHEON CO [US]) 25 September 1996 (1996-09-25) * figure 1 * * column 3, lines 35-44 * * column 5, lines 11-13 * * column 4, line 39 - column 5, line 30 *	1-18	INV. H01Q25/00 H01Q13/08
Y	WO 92/13373 A (THOMSON CONSUMER ELECTRONICS) 6 August 1992 (1992-08-06) * abstract; figures 1-3 * * page 1, lines 19-22 * * page 2, lines 1-3,22-28 * * page 5, lines 16-30 *	1,6-18	
Y	US 5 583 511 A (HULDERMAN GARRY N) 10 December 1996 (1996-12-10) * abstract; figure 2 * * column 1, lines 5-50 * * column 3, lines 8-65 *	1,6-18	

TECHNICAL FIELDS SEARCHED (IPC)

H01Q

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	5 February 2007	CORDEIRO, J

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05-02-2007

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0427470 B1	25-09-1996	DE 69028680 D1	31-10-1996
		DE 69028680 T2	15-05-1997
		EP 0427470 A2	15-05-1991
		US 5099253 A	24-03-1992
WO 9213373 A	06-08-1992	AU 1162992 A	27-08-1992
		CN 1064177 A	02-09-1992
		DE 69212807 D1	19-09-1996
		DE 69212807 T2	30-01-1997
		ES 2090604 T3	16-10-1996
		JP 6504659 T	26-05-1994
		MX 9200323 A1	01-09-1992
		NZ 241412 A	26-07-1994
		RU 2067342 C1	27-09-1996
		TR 27907 A	11-10-1995
		ZA 9200539 A	23-09-1993
US 5583511 A	10-12-1996	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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Patent documents cited in the description

- WO 00980567 A **[0026]**