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(54) **Method and device for generating electromagnetic fields**

(57) A device is disclosed for generating an electromagnetic field (**E**, **H**) having the electrical field vector (**E**) or the magnetic field vector (**H**) concentrated around a target axis (z). The device includes an electromagnetic field source (16, 18; 21) for inducing a near-field configuration of the electromagnetic field having flux lines (F) of the electrical field vector (**E**) or the magnetic field vector

(**H**) that have components both parallel to the target axis (z) and orthogonal thereto (x, y). A suppressor element (22; 22'), such as e.g. a ferrite or a dielectric disc is coupled to the field source (16, 18; 21) for suppressing the components of the flux lines (F) of the electrical field vector (**E**) or the magnetic field vector (**H**) that extend orthogonal to the target axis (z).

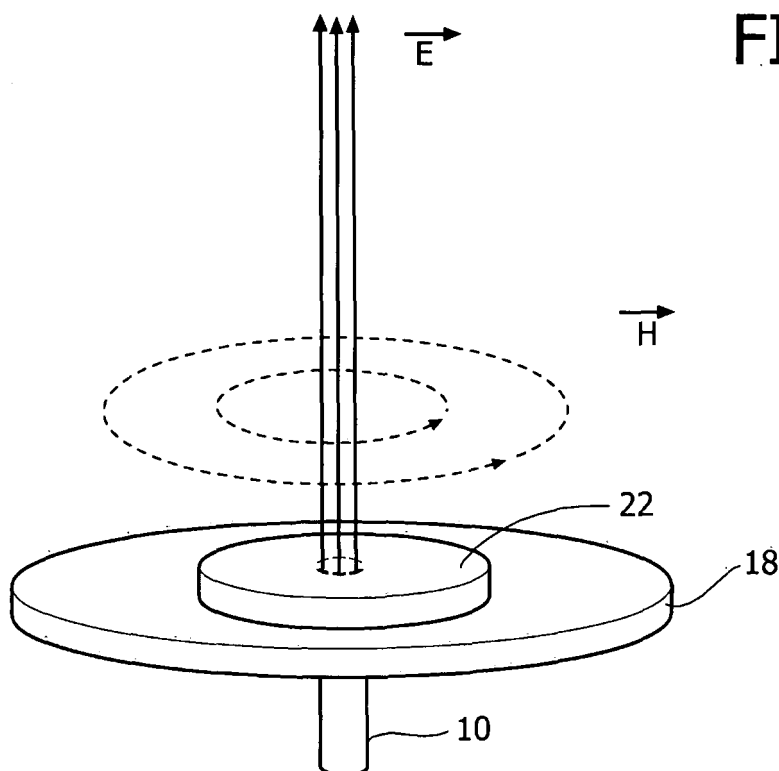


FIG. 3

Description

Field of the invention

[0001] The invention relates to techniques for generating electromagnetic fields.

[0002] The invention was developed with specific attention paid to its possible use in the medical field. However, reference to this possible field of application must in no way be construed in a limiting sense of the scope of the invention.

Description of the related art

[0003] Using electromagnetic fields for investigating the characteristics of a given medium or substance, for instance with the aim of locating very small inhomogeneities, is a well established approach in a number of domains ranging from material technology to the medical field as witnessed, e.g. by X-ray techniques. The scope of application of these investigation techniques involving the use of electromagnetic fields is continuously increasing as demonstrated i.a. by US-A-2002/0120189.

[0004] In general terms, the depth of penetration s - expressed in meters - of an electromagnetic wave into a medium (e.g. a body or substance) can be expressed as

$$s = \sqrt{\rho / (\pi f \mu)} \quad [\text{m}]$$

where:

- f is the frequency of the electromagnetic wave (Hz),
- ρ is the resistivity of the medium,
- μ is the magnetic permeability of the same medium, and
- $\sqrt{}$ denotes the square root operation.

[0005] For instance, the resistivity of a body tissue is about $5 \cdot 10^{-5}$ Ohm.meter.

[0006] This corresponds to a depth of penetration of about 18 centimetres at a frequency of 500 MHz, which would represent an acceptable value for a number of applications. The corresponding wavelength $\lambda = c/f$ (where c denotes the speed of light) at a frequency of 500 MHz is about 0.6 meters, which does not permit good focusing other than under quite specific circumstances (e.g. structures that for some reasons concentrate the electromagnetic field).

[0007] Much higher frequencies (for instance X-ray frequencies, to which much smaller wavelengths correspond) are thus currently used for high-resolution investigations.

[0008] A basic drawback associated with the use of such high frequencies lies in their high energetic contents. Such high-energy, ionizing electromagnetic fields may give rise to undesired negative effects for the per-

sons performing or subject to the investigation.

[0009] For that reason X-ray apparatus, e. g. as used in material technology investigation or quality control in industry, must be properly shielded for personnel safety while X-ray inspection is resorted to as seldom as possible in current medical practice.

[0010] This fact has rendered imaging techniques such as breast imaging techniques at microwave frequencies a promising field of investigation: see, e.g. E. C. Fear et al. "Enhancing Breast Tumor Detection with Near-Field Imaging" - IEEE Microwave Magazine, March 2002, pp. 48-56.

Object and summary of the invention

[0011] Despite the notable success already achieved, providing a significant and consistent contrast between malignant and other breast tissues without having to resort e.g. to complex arrangements including a large number of transmit/receive antennas is still an open problem. In that respect, a general understanding in the art is that electromagnetic fields having moderate energy contents (e.g. nonionizing microwaves) could be advantageously used in detection techniques as considered in the foregoing if these fields could be produced in the form of electromagnetic fields having their electrical field vector or their magnetic field vector concentrated over a width of e.g. a few millimetres around a target or incidence axis. This would permit to use these fields to scan e.g. materials, tissues to locate, for instance, inhomogeneities therein with a high degree of resolution.

[0012] The object of the invention is thus to provide a solution for generating an electromagnetic with one out of the electrical field vector $\mathbf{E}$ and the magnetic field vector $\mathbf{H}$ concentrated around a target (or incidence) axis.

[0013] According to the present invention, that object is achieved by means of a method having the features set forth in the claims that follow. The invention also relates to a corresponding device.

[0014] The claims are an integral part of the disclosure of the invention provided herein.

[0015] In brief, a preferred embodiment of the arrangement described herein is a device for generating an electromagnetic field $\mathbf{E}$, $\mathbf{H}$ having the electrical field vector $\mathbf{E}$ or the magnetic field vector $\mathbf{H}$ concentrated around a target axis. The device includes an electromagnetic field source for inducing a near-field configuration of the electromagnetic field having flux lines of the electrical field vector $\mathbf{E}$ or the magnetic field vector $\mathbf{H}$ that have components both along the target axis and orthogonal thereto. A suppressor element is coupled to the field source in order to suppress the components of the flux lines of the electrical field vector $\mathbf{E}$ or the magnetic field vector $\mathbf{H}$ that extend orthogonal to the target axis, whereby the electrical field vector $\mathbf{E}$ or the magnetic field vector $\mathbf{H}$ is concentrated around the target axis.

[0016] As a result, the electrical field vector $\mathbf{E}$ or the magnetic field vector $\mathbf{H}$ is concentrated in a "spot" much

smaller than the associated wavelength.

Brief description of the annexed representations

[0017] The invention will now be described, by way of example only, by reference to the annexed figures of drawing, wherein:

- Figure 1 is a front view of an electromagnetic field generator as described herein;
- Figure 2 is a cross-sectional view along line II-II of figure 1;
- Figures 3 is a schematic representation of the behaviour of the electrical/magnetic field vectors as produced by the generator of figures 1 and 2;
- Figure 4 is a front view of an alternative embodiment of a generator as described herein;
- Figure 5 is a cross-sectional view along line V-V of figure 4,
- Figure 6 is a front view of a further alternative embodiment of a generator as described herein,
- Figure 7 is a cross-sectional view along line VII-VII of figure 6, and
- Figure 8 is a schematic representation of the behaviour of the electrical/magnetic field vectors as produced by the generator of figures 6 and 7.

In figure 2 reference G denotes an electromagnetic generator (i.e. an oscillator) with a frequency up to 3 GHz, typically 500MHz. Such generators are conventional in the area of telecommunications. Exemplary of such a generator is, for instance, the generator type 83630L produced by Agilent Technologies, Inc.

The electromagnetic field from the generator G is fed into a conventional coaxial cable 10 including a metal (e.g. copper) core 12, an insulating (e.g. Teflon) sheath 14 and an outer metal (e.g. copper) shield 10a.

In a manner that is conventional *per se*, the coaxial cable 10 is terminated, opposite to the generator G, with an (ir)radiation source (that is an "antenna") comprised of a metal disc 16, such as e.g. a copper disc mounted at the center of an insulating substrate 18 comprised e.g. of the material known as FR4. The metallic ground plane 10b of the substrate 18 is connected (e.g. soldered) to the outer shield 10a of the coaxial cable 10.

The metallic core 12 of the coaxial cable 10 extends through a central hole 20 of the substrate 18 to contact the metal disc 16.

The arrangement so far described (namely an arrangement

- not - including the element 22 to be described later) would generally induce in the space immediately surrounding the source or antenna 16, 18 - namely in "near-field" conditions
- flux lines F of the electrical field **E** extending along trajectories as schematically shown in broken lines

in figure 2.

[0018] Originally (i.e. in close proximity of the output end of the coaxial cable 10), these flux lines F would be aligned with a "target" or "incidence" axis z essentially corresponding to the common axis of the distal end of the coaxial cable 10 and the source 16, 18. Then, as the distance from the source 16, 18 increases, these flux lines F would gradually spread out as schematically shown in broken lines in figure 2 to include - at each point in space closely surrounding the target axis z:

- a component extending along the target axis z, and
- components extending orthogonal to the z axis, namely in the x, y directions.

[0019] In the arrangement shown in figure 1 and 2 the magnetic field vector **H** will have corresponding flux lines that lie in the x, y planes concentric and orthogonal to the z axis.

[0020] The element designated 22 in figures 2 and 3 is a disc of a ferromagnetic material such as ferrite with a diameter typically much larger than the disc 16 (e.g. 10 times). The ferrite disc 22 surrounds the disc 16 (with the exception of the side exposed to the coaxial cable 10, i.e. opposite the insulating substrate 18) with the purpose of suppressing the components of the flux lines F of the electrical field vector **E** that extend in the x, y directions, thereby maintaining only those components that are parallel to the axis of incidence z.

[0021] As described in the foregoing, when no suppression of the components in the x, y directions is performed, the electrical field vector **E** in the space surrounding the target axis z is generally angled to the z axis in that it exhibits, in addition to a component along the z axis, also components in the x, y directions.

[0022] Figure 3 schematically represents the effect deriving from the presence of the suppressor element 22. Specifically, figure 3 illustrates the typical behaviour (i.e. orientation) of the electrical field vector **E** up to a distance d of the order of 10cm from the source 16, 18 when the arrangement of figures 1 and 2 is supplemented with the suppressor ferrite disc 22.

[0023] When the ferrite element 22 is present, the electrical field vector **E** is substantially aligned with the z-axis since its components in the x, y directions are suppressed. The element 22 will thus concentrate the electrical field vector **E** around the target axis z in that the modulus of the electrical field vector **E** will have a maximum value in correspondence with the target axis z and a value gradually decreasing with the distance from the target axis z due to the suppression of the components in the x, y directions.

[0024] For instance, the modulus of the vector **E** will be, at a radial distance of 10 mm from the z axis, 20dB lower than the modulus in correspondence with the z axis (i.e. x=y=0). The magnetic field vector **H** will have corresponding flux lines that lie in the x, y planes concentric

and orthogonal to the z axis (see figure 3).

[0025] Those of skill in the art will otherwise appreciate that the representation of figure 3 corresponds to an ideal behaviour. In fact, the suppressive effect of the ferrite element 22 will not be absolute, so that residues of the components in the x, y directions will cause the electrical field vector **E** to be slightly diverging with respect to the target axis z, while having a dominant component aligned with that axis.

[0026] The concentration effect just described can be further increased by superposing to the element 22 a layer 22a (see figure 2) of a resistive material which further enhances the suppression effect of the x, y components.

[0027] A dielectric lens 22b can be arranged in the space facing the source 16, 18 to perform a focusing action on the (already concentrated) electric field **E**.

[0028] Figures 4 and 5 illustrate an alternative embodiment of the generator described with reference to figures 1 and 2.

[0029] In the embodiment of Figures 4 and 5, the generator G is again connected to a source comprised of a metallic pad 16 mounted on an insulating substrate 18. In the embodiment of Figures 4 and 5, the source 16, 18 is fed with the electromagnetic field generated by the generator G via a so-called strip line 24.

[0030] The strip line 24 includes a metallic strip-like core 12a extending between metallic ground planes 12b. Again, a ferrite disc 22 is mounted on the metal pad 16 to suppress the components of the electrical field in the x, y plane thus leading to a result substantially similar to that shown in figure 3.

[0031] The arrangements shown in the drawings lend themselves to adjustment both in structural terms (diameter of the pad 16, thickness thereof, and so on, shape and size of the ferrite 22) as well as regard the features of the "suppressor" material here exemplified in the form of a ferrite.

[0032] Reference to a ferrite is dictated by the prompt availability of such material in different versions with different characteristics (losses, dielectric constant).

[0033] However, alternative suppressor materials can be easily devised e.g. in the form of garnets having the desired properties (e.g. relative magnetic permeability μ_r in the range e.g. 100-1000).

[0034] Ferrites and garnets of the types mentioned in the foregoing are currently available from companies such as TCI Ceramics (USA) or Trans Tech (USA).

[0035] Alternative arrangements to those described in the foregoing may be devised to induce a substantially dual (i.e. complementary) near-field configuration of flux lines for the vectors **E** and **H**, namely the magnetic field vector **H** having flux lines that are originally parallel to the z axis and then open out to include components in the x, y directions, with the flux lines for the electrical field vector **E** lying in the x, y planes concentric and orthogonal to the z axis.

[0036] For instance figures 6 to 8 illustrate the gener-

ator G again feeding a strip line 24 including a metallic strip-like core 12a extending between metallic ground planes 12b.

[0037] A spiral coil 21 extends over the upper surface of the insulating substrate 18 to connect a distal extension of the core 12a and an extension of the upper ground plane 12b of the strip line 24.

[0038] The arrangement so far described (namely an arrangement - not - including the suppressor element 22' to be described later) would generally induce in the space immediately surrounding the spiral coil or antenna 21 - namely in "near-field" conditions - flux lines F of the magnetic field **H**, extending along trajectories as schematically shown in broken lines in figure 7.

[0039] Originally (i.e. in correspondence of the plane of the coil 21) these flux lines F would be aligned with the target axis z orthogonal to the plane of the support 18, i.e. orthogonal to the plane of the spiral coil or antenna 21. Then, as the distance from the upper plane of the spiral coil or antenna 21 increases, these flux lines F would gradually spread out as schematically shown in broken lines in figure 7 to close around the coil or antenna 21 and thus include - at each point in space closely surrounding the target axis z:

- a component extending along the target axis z, and
- components extending orthogonal to the z axis, namely in the x, y directions.

[0040] In the arrangement shown in figures 6 to 8 the electrical field vector **E** will have corresponding flux lines that lie in the x, y planes concentric and orthogonal to the z axis.

[0041] In essential duality with figure 3, figure 8 shows the effect of placing a suppressor element 22' of a dielectric material surrounding the spiral coil or antenna 21.

[0042] In fact, when no suppression of the components in the x, y directions is performed, the magnetic field vector **H** in the space surrounding the target axis z would be generally angled to the z axis in that would exhibit, in addition to a component along the z axis, also components in the x, y directions (see the approximately circular trajectories F in figure 7).

[0043] Conversely, when the dielectric suppressor element 22' is present, the components in the x, y directions are suppressed (figure 8) and the magnetic field vector **H** is substantially aligned with the z-axis.

[0044] Again, the element 22' will concentrate the magnetic field vector **H** in that the modulus of that vector will have a maximum value in correspondence with the target axis z and a value gradually decreasing with the distance from that axis due to the suppression of the components in the x, y directions.

[0045] The suppression effect just described in respect of the components of the flux lines in the x, y directions can be achieved by using a dielectric materials having high dielectric constants ($\epsilon_r = 38, 80$).

[0046] Again, dielectric materials of the types men-

tioned in the foregoing are currently available with companies such as TCI Ceramics (USA) or Trans Tech (USA).

[0047] Those of skill in the art will again appreciate that the representation of figure 8 corresponds to an ideal behaviour. In fact, the suppressive effect of the dielectric element 22' will not be absolute, so that residues of the components in the x, y directions will cause the magnetic field vector **H** to be slightly diverging with respect to the z axis, while having a dominant component aligned with the z axis.

[0048] The power generated by the generator G will depend on the envisaged application of the radiation. Experiments carried out so far by the applicant indicates that power levels in the range between a few milliwatts and a few watts are adapted to cover most applications as envisaged at present in the medical field.

[0049] While the coaxial cable 10/strip-line 24 can be notionally of any length, lengths in the range of a few mm to a few meters are typically adopted within the framework of the present invention. These values represent a reasonable compromise between the need of minimizing losses and attenuation along the cable 10 and the need of at least partly remotizing and/or rendering freely displaceable with respect to the generator G the electromagnetic field source 16, 18 fed via the cable 10.

[0050] The arrangement described herein lends itself to realising multi-beam arrangements including a plurality of sources 16, 18, 21 having associated suppressor elements 22, 22'. Those multi-beam arrangements are adopted to be operated as phased arrays to "steer" the resulting (electrical or magnetic) field in a general scanning movement of the target area.

[0051] Of course, without prejudice to the underlying principle of the invention, the details and embodiments may vary, even significantly, with respect to what has been described and illustrated, without departing from the scope of the invention as defined by the annexed claims.

Claims

1. A method of generating an electromagnetic field (**E**, **H**) having one out of the electrical field vector (**E**) and the magnetic field vector (**H**) concentrated around a target axis (z), the method including the steps of:

- inducing a near-field configuration of said electromagnetic field having flux lines (F) of said one out of said electrical field vector (**E**) and said magnetic field vector (**H**), wherein said flux lines (F) have components both parallel to said target axis (z) and orthogonal thereto (x, y), and
- subjecting said near-field configuration to suppression of said components of said flux lines (F) of said one out of said electrical field vector

(**E**) and said magnetic field vector (**H**) extending orthogonal to said target axis (z), whereby said one out of said electrical field vector (**E**) and said magnetic field vector (**H**) is concentrated around said target axis (z).

2. The method of claim 1, **characterized in that** it includes the steps of:

- inducing a near-field configuration of said electromagnetic field wherein said electrical field vector (**E**) has flux lines (F) with components both parallel to said target axis (z) and orthogonal thereto (x, y), and
- subjecting said near-field configuration to suppression of said components of said flux lines (F) of said electrical field vector (**E**) extending orthogonal to said target (z), whereby said electrical field vector (**E**) is concentrated around said target axis (z).

3. The method of claim 2, **characterized in that** it includes the step of subjecting said near-field configuration to suppression of said components of said flux lines (F) of said electrical field vector (**E**) extending orthogonal to said target axis (z) by using a ferromagnetic material (22), preferably a material having a relative magnetic permeability in the range of 100-1000.

4. The method of claim 3, **characterized in that** it includes the step of selecting said ferromagnetic material out of ferrite and garnet.

5. The method of claim 1, **characterized in that** it includes the steps of:

- inducing a near-field configuration of said electromagnetic field wherein said magnetic field vector (**H**) has flux lines (F) with components both parallel to said target axis (z) and orthogonal thereto (x, y), and
- subjecting said near-field configuration to suppression of said components of said flux lines (F) of said magnetic field vector (**H**) extending orthogonal to said target axis (z), whereby said magnetic field vector (**H**) is concentrated around said target axis (z).

6. The method of claim 5, **characterized in that** it includes the step of subjecting said near-field configuration to suppression of said components of said flux lines (F) of said magnetic field vector (**H**) extending orthogonal to said target axis (z) by using a dielectric material (22').

7. The method of claim 6, **characterized in that** it includes the step of selecting as said dielectric material

a dielectric material having a dielectric constant in the range 32-80.

8. The method of any of the preceding claims, **characterized in that** it includes the step of generating said electromagnetic field (**E**, **H**) with a frequency in the range up to 3 GHz, preferably a few hundreds MHz.

9. A device for generating an electromagnetic field (**E**, **H**) having one out of the electrical field vector (**E**) and the magnetic field vector (**H**) concentrated around a target axis (z), the device including:

- an electromagnetic field source (16, 18; 21) for inducing a near-field configuration of said electromagnetic field having flux lines (F) of said one out of said electrical field vector (**E**) and said magnetic field vector (**H**), wherein said flux lines (F) have components both parallel to said target axis (z) and orthogonal thereto (x, y), and
- a suppressor element (22, 22') coupled to said electromagnetic field source (16, 18; 21) for suppressing in said near-field configuration the components of said flux lines (F) of said one out of said electrical field vector (**E**) and said magnetic field vector (**H**) extending orthogonal to said target axis whereby said device generates said one out of said electrical field vector (**E**) and said magnetic field vector (**H**) concentrated around said target axis (z).

10. The device of claim 9, **characterized in that** it includes:

- said electromagnetic field source (16, 18) for inducing a near-field configuration of said electromagnetic field wherein said electrical field vector (**E**) has flux lines (F) with components both parallel to said target axis (z) and orthogonal thereto (x, y), and
- said suppressor element (22) coupled to said electromagnetic field source (16, 18) for suppressing in said near-field configuration the components of said flux lines (F) of said electrical field vector (**E**) extending orthogonal to said target axis (z), whereby said device generates said electrical field vector (**E**) concentrated around said target axis (z).

11. The device of claim 10, **characterized in that** said suppressor element (22) is comprised of a ferromagnetic material, preferably a material having a relative magnetic permeability in the range 100-1000.

12. The device of claim 11, **characterized in that** said suppressor element (22) is comprised of a material selected out of ferrite and garnet.

13. The device of any of claims 10 to 12, **characterized in that** it includes a layer (22a) of a resistive material associated with said suppressor element (22) to further suppress said flux lines (F) of said electrical field vector (**E**) extending orthogonal to said target axis (z).

14. The device of any of claims 10 to 13, **characterized in that** it includes a dielectric lens (22b) to focus said electrical field vector (**E**) concentrated around said target axis (z).

15. The device of claim 9, **characterized in that** it includes:

- said electromagnetic field source (21) for inducing a near-field configuration of said electromagnetic field wherein said magnetic field vector (**H**) has flux lines (F) with components both parallel to said target axis (z) and orthogonal thereto (x, y), and
- said suppressor element (22') coupled to said electromagnetic field source (21) for suppressing in said near-field configuration the components of said flux lines (F) of said magnetic field vector (**H**) extending orthogonal to said target axis (z), whereby said device generates said magnetic field vector (**H**) concentrated around said target axis (z).

16. The device of claim 15, **characterized in that** said suppressor element (22') is comprised of a dielectric material.

17. The device of claim 16, **characterized in that** said suppressor element (22') is comprised of a dielectric material having a dielectric constant in the range 38-80.

18. The device of any of the preceding claims 9 to 17, **characterized in that** it includes an electromagnetic field generator (G) for feeding said electromagnetic field source (16, 18; 21), wherein said electromagnetic field generator (G) is operable for generating said electromagnetic field (**E**, **H**) with a frequency in the range between up to 3 GHz, preferably a few hundreds MHz.

19. The device of claim 9, **characterized in that** said electromagnetic field source (16, 18) includes an irradiating member (16; 21) and **in that** said suppressor element (22; 22') at least partly surrounds said irradiating member (16; 21).

20. The device of claim 19, **characterized in that** said irradiating member (16; 21) is arranged over an insulating substrate (18) and **in that** said suppressor element (22; 22') surrounds said irradiating member

(16; 21) opposite said insulating substrate (18).

21. The device of claim 15, **characterised in that** said electromagnetic field source includes an irradiating coil (21). 5
22. The device of claim 21, **characterised in that** said irradiating coil is a spiral coil (21) arranged over an insulating substrate (18). 10
23. The device of any of the preceding claims 9 to 22, **characterized in that** said electromagnetic field source (16, 18) is fed via a coaxial cable (10).
24. The device of any of the preceding claims 9 to 22, **characterized in that** said electromagnetic field source (16, 18) is fed via a strip line (24). 15

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FIG. 1

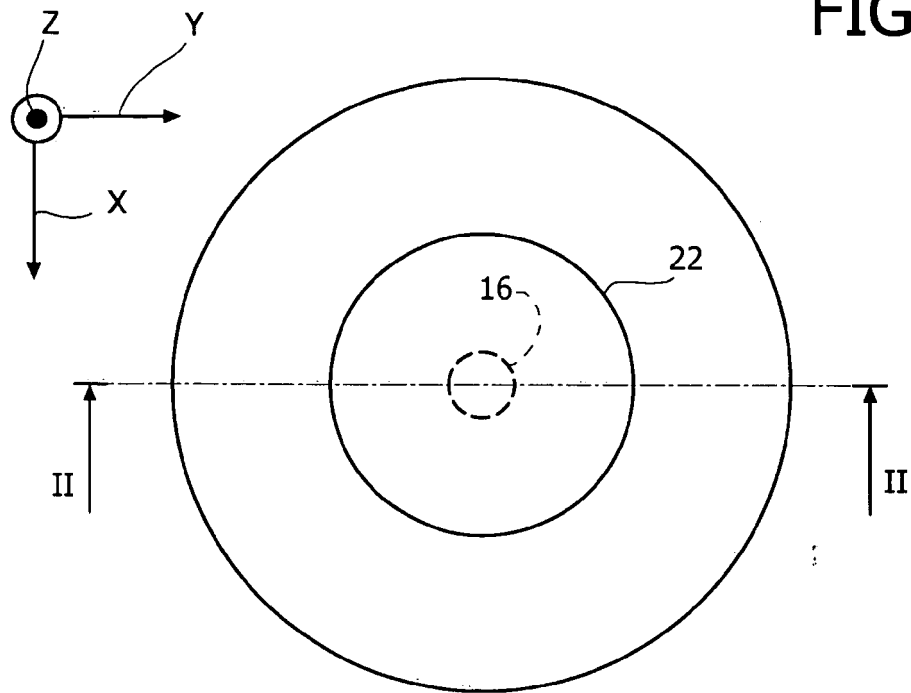
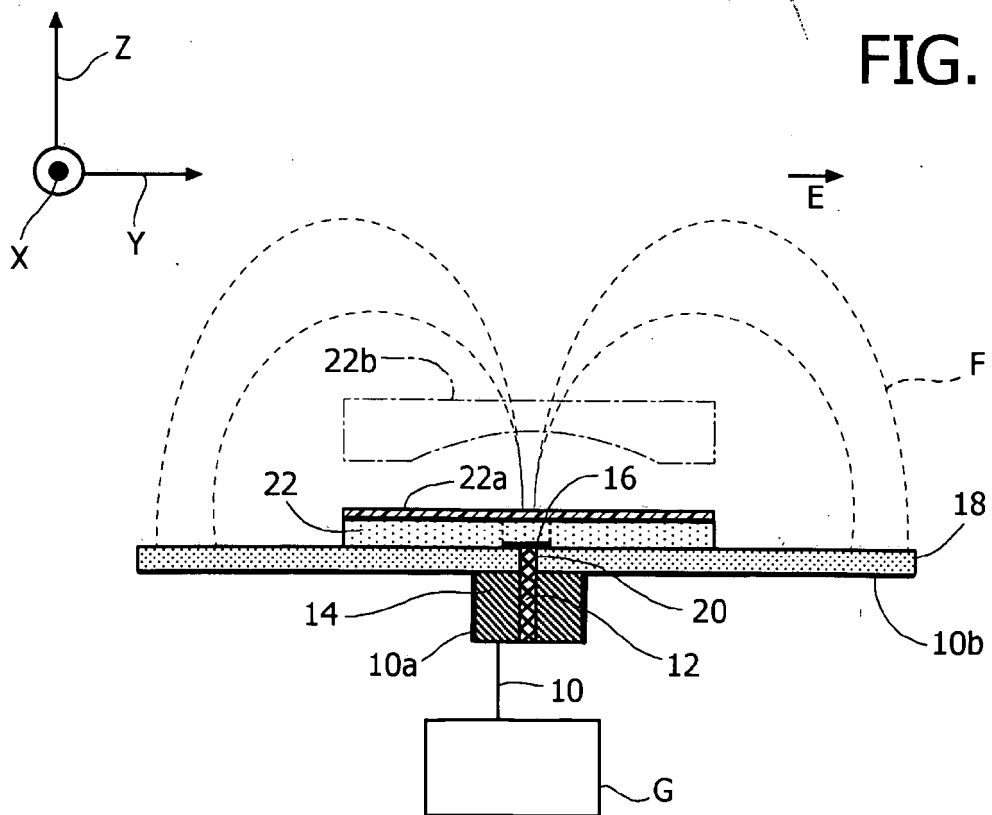


FIG. 2



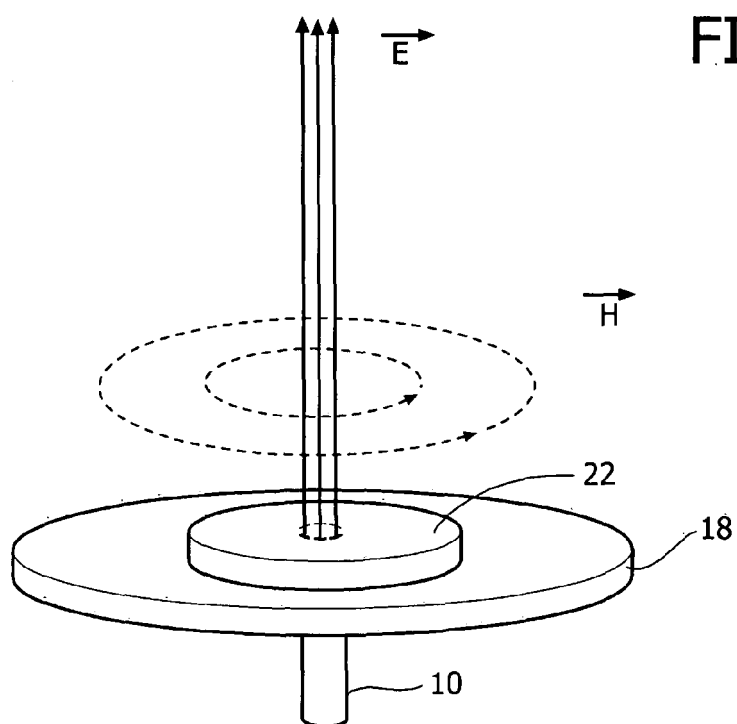


FIG. 3

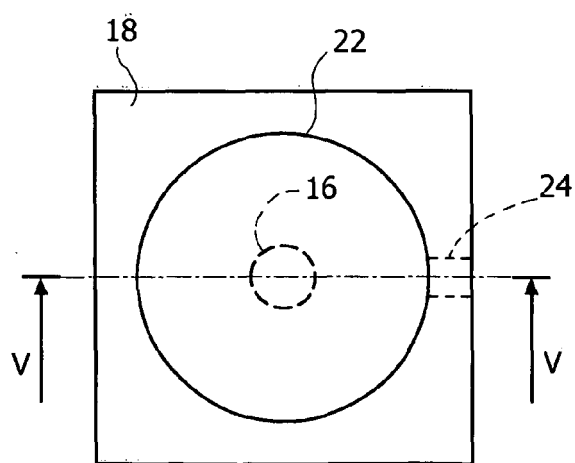


FIG. 4

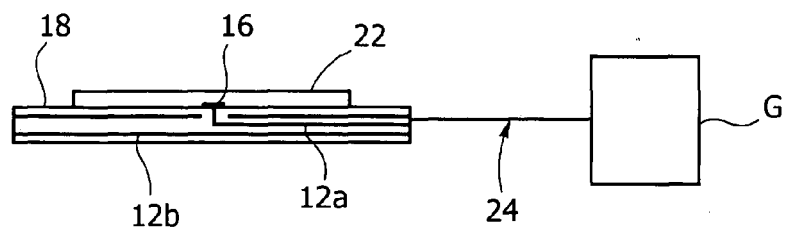


FIG. 5

FIG. 6

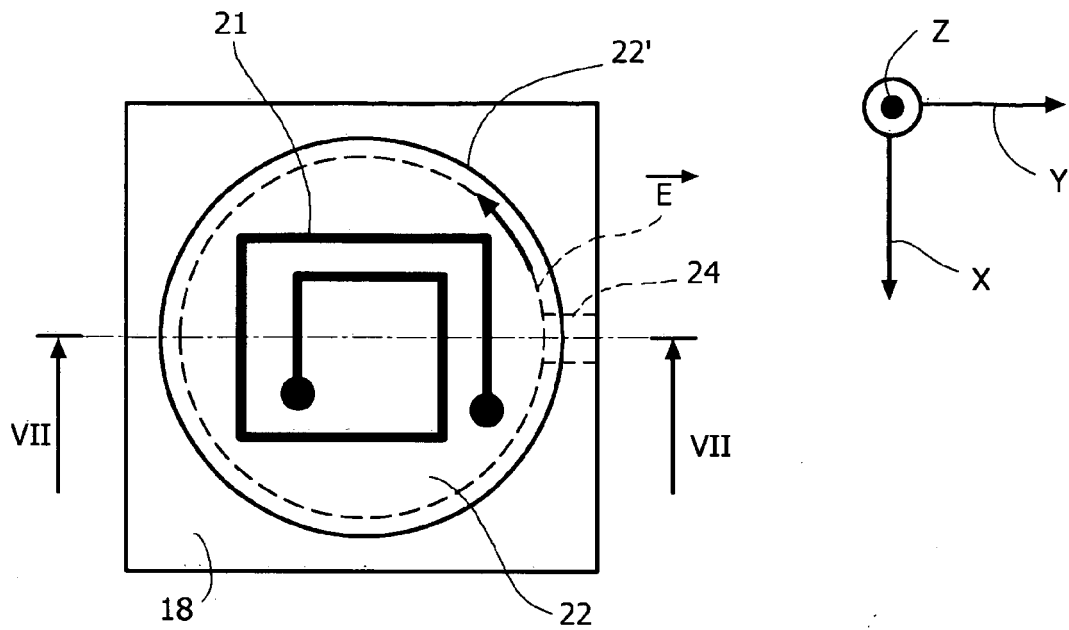


FIG. 7

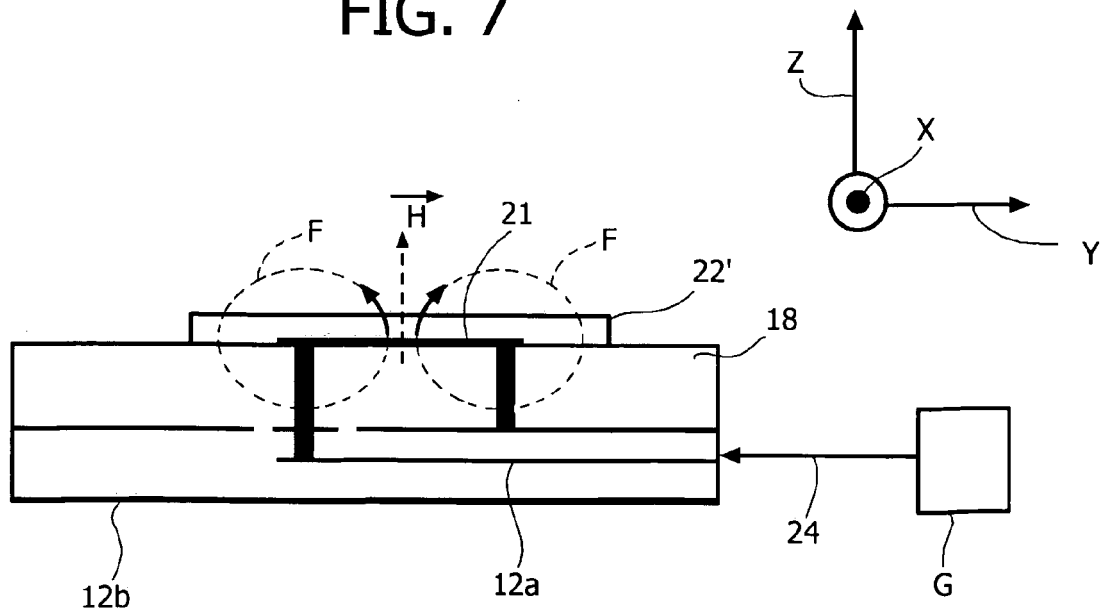
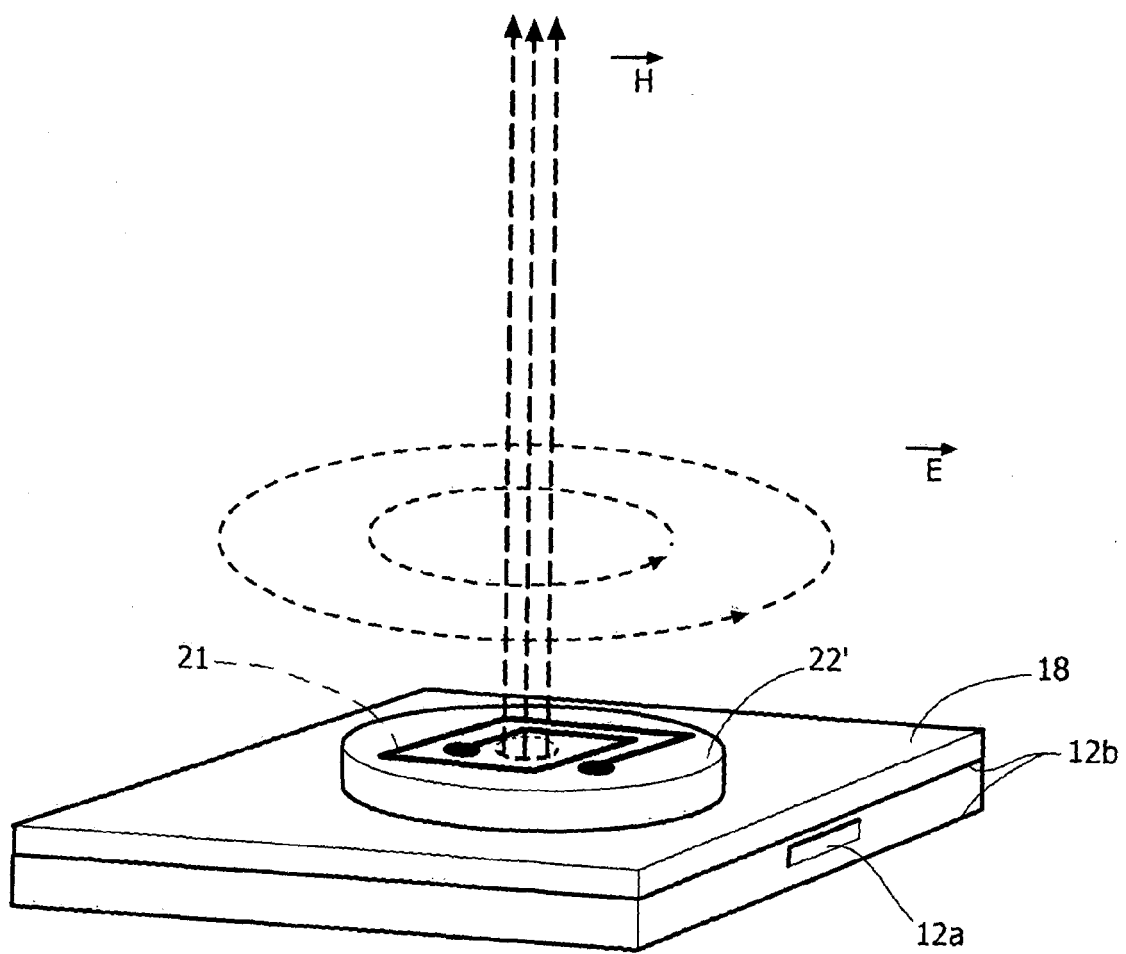


FIG. 8





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 06 42 5221

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 0 755 092 A (DYNEX SEMICONDUCTOR LIMITED; PLESSEY SEMICONDUCTORS LIMITED) 22 January 1997 (1997-01-22) * abstract; figures 1-4 * * column 2, line 15 - column 4, line 26 * -----	1-24	INV. H01Q19/09 H01Q1/40 H01Q3/44 H01Q9/04 H01Q9/27
A	US 2004/164907 A1 (KILLEN WILLIAM D ET AL) 26 August 2004 (2004-08-26) * abstract; figures 1-3 * * paragraphs [0055] - [0050] * -----	1-24	
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 24 August 2006	Examiner Unterberger, M
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 06 42 5221

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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