A method and system are provided for making a quantitative measurement of an electric field. A plurality of antennas separated from one another by known distances are arrayed in a region that extends in at least one dimension. A voltage difference between at least one selected pair of antennas is measured. Each voltage difference is divided by the known distance associated with the selected pair of antennas corresponding thereto to generate a resulting quantity. The plurality of resulting quantities defined over the region quantitatively describe an electric field therein.

28 Claims, 3 Drawing Sheets
### References Cited

**U.S. PATENT DOCUMENTS**

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Date</th>
<th>Inventor(s)</th>
<th>Class Code(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6,661,115 B2</td>
<td>12/2003</td>
<td>Lester</td>
<td>307/10.1</td>
</tr>
<tr>
<td>6,762,726 B2</td>
<td>7/2004</td>
<td>Alden</td>
<td>GOIR 29/0878</td>
</tr>
<tr>
<td>7,119,553 B2</td>
<td>10/2006</td>
<td>Yang et al.</td>
<td>343/703</td>
</tr>
<tr>
<td>7,330,032 B2</td>
<td>2/2008</td>
<td>Donnangelo</td>
<td>324/452</td>
</tr>
<tr>
<td>2006/0164094 A1</td>
<td>7/2006</td>
<td>Golder et al.</td>
<td>324/452</td>
</tr>
<tr>
<td>2007/0040545 A1</td>
<td>2/2007</td>
<td>Takiguchi</td>
<td>GO1S 11/06</td>
</tr>
<tr>
<td>2008/0246485 A1</td>
<td>10/2008</td>
<td>Hibbs et al.</td>
<td>324/76.11</td>
</tr>
<tr>
<td>2009/0295366 A1</td>
<td>12/2009</td>
<td>Cehelnik</td>
<td>324/76.11</td>
</tr>
<tr>
<td>2010/0259272 A1</td>
<td>10/2010</td>
<td>Care</td>
<td>324/457</td>
</tr>
<tr>
<td>2010/0271291 A1</td>
<td>10/2010</td>
<td>Care</td>
<td>345/58</td>
</tr>
<tr>
<td>2012/0013354 A1</td>
<td>1/2012</td>
<td>Bowler</td>
<td>GOIN 27/226</td>
</tr>
<tr>
<td>2012/0092019 A1</td>
<td>4/2012</td>
<td>Blum</td>
<td>324/457</td>
</tr>
</tbody>
</table>

**OTHER PUBLICATIONS**


* cited by examiner
FIG. 2

FIG. 3
ELECTRIC FIELD QUANTITATIVE MEASUREMENT SYSTEM AND METHOD

ORIGIN OF THE INVENTION

The invention was made by an employee of the United States Government and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to electric field measurement. More specifically, the invention is a method and system for making quantitative measurements of electric fields to include magnitude and direction thereof.

2. Description of the Related Art

Article and personnel inspection systems and methods range from labor-intensive and intrusive manual searches to mechanized systems that use non-intrusive x-ray or electromagnetic wave imaging to expose concealed articles, damage, etc. For example, most weapons detections systems rely on the concealed weapons having x-ray absorption greater than the concealing articles or the concealed weapon and having electrical conductivity large enough to be detectable by radiated electromagnetic waves. Articles that are outside the inspection capability of current inspection systems are not identified. Weapons such as ceramic knives or plastic guns (with little or no metal content) or disassembled distributed weapons are undetectable by current day non-intrusive inspection devices. These are low density system or systems that have been made from low density materials or made low density by distributing components through a larger volume.

In another example, the degraded electrical properties of insulation surrounding conduction wires is known to have caused fatal aircraft crashes. To date, there are no inspection systems capable of non-intrusive quantitative detection and characterization of insulation degradation. Current insulation integrity systems do not measure the dielectric properties of the insulation which must be known to determine the breakdown limits of the wire-insulator system.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a non-intrusive article and personnel inspection system.

Another object of the present invention is to provide a method and system that is readily adapted for use in a variety of applications to include security, surveillance, and inspection systems.

Other objects and advantages of the present invention will become more obvious hereinafter in the specification and drawings.

In accordance with the present invention, a method and system are provided for making a quantitative measurement of an electric field. A plurality of antennas separated from one another by known distances are arrayed in a region that extends in at least one dimension. A voltage difference between at least one selected pair of antennas is measured. A processor divides each voltage difference by the known distance associated with the selected pair of antennas corresponding thereto to thereby generate a resulting quantity. A plurality of resulting quantities are thereby defined over the region to quantitatively describe an electric field therein.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of a system for making quantitative measurements of an electric field in accordance with an embodiment of the present invention;

FIG. 2 is a schematic view of a selected antenna pair with each antenna having a dedicated voltage measurement device coupled thereto in accordance with an embodiment of the present invention;

FIG. 3 is a schematic view of a selected antenna pair and a single voltage measurement device that is coupled to one antenna at a time as controlled by a switching controller in accordance with another embodiment of the present invention;

FIG. 4 is a schematic view of a Junction Field Effect Transistor (JFET) coupled to each antenna of a selected antenna pair for the purpose of measuring voltage in accordance with an embodiment of the present invention;

FIG. 5 is a schematic view of a system for making quantitative measurements of an extrinsically-generated electric field that has been interrupted by an object in accordance with another embodiment of the present invention; and

FIG. 6 illustrates a two-dimensional array supported by a triboelectrically neutral structure in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings and more particularly to FIG. 1, a system for making quantitative measurements of an electric field is shown and is referenced generally by numeral 10. As will be explained further below, the quantitative measurements produced by system 10 provide information about both the magnitude and direction of the electric field at a variety of locations therein. System 10 can be configured for large scale or small scale applications to include security applications (e.g., personnel inspection at airports), surveillance applications (e.g., geographic area drive or fly over's), and inspections (e.g., package and/or luggage inspections, wire condition inspections, etc.).

System 10 includes an array of antennas 12 where the array can be comprised of individual physical antennas positioned at each of a plurality of known locations and distances from one another. Array 10 could also be realized in a virtual sense by moving a single antenna to each of the known array locations. However, movement of a single antenna 12 could generate a disturbance in an electric field that is to be measured. Accordingly, such disturbance would need to be accounted for when performing measurement calculations in accordance with the present invention. For sake of simplicity, the remainder of the description will assume that array 10 is formed using a plurality of physical antennas 12 maintained in a known spaced-apart relationship.

In the present invention, array 10 can occupy a three-dimensional space (e.g., in an x, y, z coordinate frame) as illustrated. However, the present invention is not so limited as array 10 could also exist in just two dimensions (e.g., the x-y plane), or even just a single dimension or row of antennas 12 (e.g., a row along the x coordinate). The amount of information about an electric field that is required for a particular application will typically dictate the number of dimensions defined by array 10.

Each of antennas 12 serves as an electric field sensor for its location in array 10. In accordance with the present invention,
the voltage difference between one or more selected pairs of
antennas 12 is measured or otherwise determined. For
similarity of illustration, a single pair of antennas 12 is coupled
to a voltage differencer 14. However, it is to be understood
that this capability is typically provided for multiple pairs of
antennas 12 in array 10. For example, each selected pair of
antennas could encompass two adjacent antennas.

Voltage differencer 14 is any device, circuit, etc., that can
collect voltages sensed by a selected pair of antennas 12 and
then form a difference (i.e., a voltage difference) between
the voltages so-collected. Each such collected voltage difference
is provided to a processor 16.

Processor 16 is any processing device, circuit, etc., that processes
each voltage difference by dividing it by the dis-
tance D between the antennas of the pair. The resulting quanti-
y is a “voltage per distance” quantity for the particular antenna
pair. Since the locations of antennas 12 are known, the
“voltage per distance” between the two known locations is a
vector quantity. This process is repeated for each selected
pair of antennas 12 in array 10. The resulting set of “voltage
per distance” quantities over the known antenna array loca-
tions describes the electric field in the region occupied by
array 10. Depending on the application, this information can be
further processed by processor 16, or could be provided to
some type of output device 18 for data “presentation” to a
user. For example, output device 18 could be capable of
producing a viewable image of the electric field data. In other
applications, output device 18 could be capable of producing a
tactile output felt by a user so that changes in an electric field
would be readily recognized and located. Output device 18
could also provide other and/or multiple types of outputs
without departing from the scope of the present invention.

The above-described functions of voltage differencer 14
can be realized in a variety of ways that do not depart from the
scope of the present invention. For example, as illustrated in
FIG. 2, each antenna 12 could have a dedicated voltage mea-
suring device 20 coupled thereto. The voltages measured by
two of devices 20 associated with a selected pair of antennas
12 could be provided directly to processor 16 on dedicated lines
that can also indicate telemetry frequencies if devices 20
and processor 16 were configured for wireless data transmis-
sion/reception.

In the embodiment shown in FIG. 3, a single voltage mea-
suring device 30 and switching controller 32 are used to
collect voltages from all selected pairs of antennas 12 in array
10. As would be understood in the art, switching controller 32
couples a selected pair of antennas 12 to device 30 for a
voltage difference measurement, uncouples device 30 there-
from, and then couples another selected pair of antennas 12
to device 30. This process is typically repeated in some sequen-
tial pattern to collect the voltage differences for the entire
array of antennas.

As mentioned above, the present invention can be realized
on a variety of size scales. The antennas can range from
complex aircraft-mounted antennas to simple wires or even
carbon nanotubes. Likewise, the voltage measurement and/or
differentiating devices can range from complex systems to
simple circuits. By way of example, a simple small-scale
arrangement of antennas and dedicated voltage measuring
device is illustrated in FIG. 4. For simplicity of illustration,
only a pair of antennas and their associated voltage measuring
devices are shown. However, it is to be understood that this
basic structure can be repeated to form a one, two, or three-
dimensional antenna array. Each antenna 12 is coupled to a
gate “G” of a Junction Field Effect Transistor (JFET) 40. For
a small scale arrangement using JFET 40, antenna 12 would
typically be a simple wire or line of carbon nanotubes.
of the present invention. Antennas 12 could be mounted on or encased within support structure 60. Support structure 60 and/or antennas 12 could also be reconfigurable based upon feedback control. That is, the electric field being “observed” by antennas 12 could be used as a feedback control parameter to reconfigure or reposition structure 60 and/or antennas 12.

The advantages of the present invention are numerous. Electric fields are quantitatively measured/determined in a non-intrusive fashion. The basic concepts presented herein are applicable to a wide variety of security, surveillance and inspection applications. The invention can be scaled in size to meet the needs of various installation scenarios. Since even non-electrically conductive objects can cause a detectable disturbance in an electric field, the present invention provides the basis for a new form of object detection and localization.

Although the invention has been described relative to a specific embodiment thereof, there are numerous variations and modifications that will be readily apparent to those skilled in the art in light of the above teachings. For example, a filter(s) could be coupled between an antenna and its voltage measuring device in order to filter out unwanted background or environmental noise. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced other than as specifically described.

What is claimed is as new and desired to be secured by Letters Patent of the United States is:

1. A system for making a quantitative measurement of an original true, non-distorted electric field, including static and quasi-static electric fields, independent of the time of measurement, the system comprising:
   - an object;
   - a plurality of antennas separated from one another by known distances, said plurality of antennas arrayed in a region that extends in at least one dimension;
   - means coupled to said plurality of antennas for measuring a voltage difference between at least one selected pair of antennas from said plurality of antennas; and
   - a processor coupled to said means for measuring, said processor dividing each said voltage difference by one of said known distances associated with said selected pair of antennas corresponding thereto to thereby generate a resulting quantity with a plurality of resulting quantities being thereby defined over said region to quantitatively describe an electric, electrostatic, quasi-electrostatic field therein,

   wherein said system quantitatively describes said electric field when said object is electrically conductive, and said system quantitatively describes said electric, electrostatic, and quasi-electrostatic field when said object is electrically non-conductive, and wherein the system makes a quantitative measurement of an original true, non-distorted electric field, including static an quasi-static electric fields independent of the time of measurement.

2. A system as in claim 1, wherein said means for measuring comprises a dedicated voltage measurement device coupled to each of said plurality of antennas.

3. A system as in claim 1, wherein said means for measuring comprises:
   - a common voltage measurement device; and
   - a controller for successively coupling and uncoupling each said selected pair of antennas to said common voltage measurement device in a sequenced and patterned fashion.

4. A system as in claim 1, further comprising an electric field generator for generating a reference electric field in proximity to said plurality of antennas.

5. A system as in claim 1, wherein said means for measuring comprises:
   - a Junction Field Effect Transistor (JFET) coupled to each of said plurality of antennas, each said JFET having a gate, a source and a drain with said gate only coupled to a corresponding one of said plurality of antennas; and
   - a voltage supply providing a voltage across said source and said drain of each said JFET.

6. A system as in claim 1, wherein each of said plurality of antennas comprises a plurality of carbon nanotubes.

7. A system as in claim 1, further comprising an imaging device coupled to said processor for producing an image of said electric field using said plurality of resulting quantities.

8. A system as in claim 1, further comprising a tactile feedback system coupled to said processor for producing a tactile output using said plurality of resulting quantities.

9. A system as in claim 1, further comprising a triboelectrically neutral material supporting said plurality of antennas.

10. A system as in claim 9, wherein said triboelectrically neutral material is flexible.

11. A system for making a quantitative measurement of an original true, non-distorted electric field, including static and quasi-static electric fields, independent of the time measurement, the system comprising:
   - an array of antennas;
   - a plurality of Junction Field Effect Transistors (JFET), a respective JFET connected to a respective antenna in said array, each said JFET having a gate directly coupled only to said respective antenna, each said JFET further having a source and a drain associated therewith;
   - a voltage supply coupled across said source and said drain of each said JFET;
   - means coupled to said antennas for measuring a voltage difference between selected pairs of said antennas; and
   - a processor coupled to said means for measuring, said processor dividing each said voltage difference by a distance between one of said selected pairs of said antennas associated therewith to thereby generate a resulting quantity with a plurality of resulting quantities being thereby defined over said array to quantitatively describe an electric, electrostatic, and quasi-static electrostatic field encompassing said array, wherein the system makes a quantitative measurement of an original true, non-distorted electric field, including static and quasi-static electric fields, independent of the time measurement.

12. A system as in claim 11, wherein said means for measuring comprises a dedicated voltage measurement device coupled to each of said antennas.

13. A system as in claim 11, wherein said means for measuring comprises a common voltage measurement device; and

14. A system as in claim 11, further comprising an electric field generator for generating a reference electric field in proximity to said array.

15. A system as in claim 11, wherein each of said antennas comprises a plurality of carbon nanotubes.

16. A system as in claim 11, further comprising an imaging device coupled to said processor for producing an image of said electric field using said plurality of resulting quantities.

17. A system as in claim 11, further comprising a tactile feedback system coupled to said processor for producing a tactile output using said plurality of resulting quantities.
18. A system as in claim 11, further comprising a triboelectrically neutral material supporting said array of antennas.

19. A system as in claim 18, wherein said triboelectrically neutral material is flexible.

20. A method of making a quantitative measurement of an original true, non-distorted, electric field including static and quasi-static electric field, independent of the time of measurement, comprising the steps of:
   providing an object;
   using at least one antenna to sense voltage differences between known locations in a region that extends in at least one dimension; and
   dividing each of said voltage differences by a distance between two of said known locations associated therewith to thereby generate a resulting quantity. With a plurality of resulting quantities being thereby defined over said region to quantitatively describe an electric, electrostatic, and quasi-electrostatic field therein, wherein said electric, electrostatic and quasi-electrostatic field is quantitatively described when said object is electrically conductive, and said electric, electrostatic and quasi-electrostatic field is quantitatively described when said object is electrically non-conductive, wherein the system makes a quantitative measurement of an original, non-distorted electric field, including static and quasi-static electric fields, independent of the time measurement.

21. A method according to claim 20, wherein said step of using includes the step of moving a single antenna to each of said known locations.

22. A method according to claim 20, wherein said step of using includes the step of positioning a plurality of antennas in a spaced apart fashion in said region.

23. A method according to claim 20, further comprising the step of generating a reference electric field in proximity to said at least one antenna.

24. A method according to claim 20, further comprising the step of producing an image of said electric field using said plurality of resulting quantities.

25. A method according to claim 20, further comprising the step of producing a tactile output using said plurality of resulting quantities.

26. A method according to claim 20, further comprising the step of supporting each said antenna with a triboelectrically neutral material.

27. A method according to claim 26, wherein said step of supporting includes the step of encasing each said antenna with a triboelectrically neutral material.

28. A system as in claim 11, further including an object, and said system quantitatively describes said electric field when said object is electrically conductive, and said system quantitatively describes said electric field when said object is electrically non-conductive.

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