United States Patent

(12) United States Patent
Lee et al.

(10) Patent No.: US 8,743,016 B2
(45) Date of Patent: Jun. 3, 2014

US008743016B2

(54) **ANTENNA WITH TAPERED ARRAY**

(75) Inventors: **Jae Seung Lee**, Ann Arbor, MI (US); **Paul Donald Schmalenberg**, Ann Arbor, MI (US); **Amin Rida**, Atlanta, GA (US); **Ronglin Li**, Norcross, GA (US); **Emmanouil M. Tentzeris**, Atlanta, GA (US)

(73) Assignees: **Toyota Motor Engineering & Manufacturing North America, Inc.**, Erlanger, KY (US); **Georgia Tech Research Corporation**, Atlanta, GA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 308 days.

(21) Appl. No.: **12/883,862**

(22) Filed: **Sep. 16, 2010**

(65) **Prior Publication Data**

US 2012/0068909 A1 Mar. 22, 2012

(51) **Int. Cl.**

H01Q 1/38 (2006.01)
H01Q 9/04 (2006.01)
H01Q 21/00 (2006.01)

(52) **U.S. Cl.**

USPC .... **343/893**; 343/700 MS

(58) **Field of Classification Search**

CPC H01Q 1/38; H01Q 9/0407; H01Q 9/0457; H01Q 9/0485; H01Q 9/0471; H01Q 3/26; H01Q 3/2605; H01Q 3/2664; H01Q 3/28; H01Q 21/0075; H01Q 21/22; H01Q 21/061; H01Q 21/065

USPC 343/842, 893

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,017,931	A *	5/1991	Carlyon	343/700 MS
5,287,116	A *	2/1994	Iwasaki et al.	343/700 MS
5,694,134	A *	12/1997	Barnes	343/700 MS
7,573,388	B2 *	8/2009	Khatri	340/572.7
2006/0044189	A1 *	3/2006	Livingston et al.	343/700 MS
2006/0097921	A1	5/2006	Luk et al.	
2006/0232490	A1	10/2006	Bisiules et al.	
2006/0284770	A1	12/2006	Jo et al.	
2007/0109201	A1	5/2007	Licul et al.	
2009/0027267	A1	1/2009	Carter et al.	
2009/0213024	A1	8/2009	Hsieh et al.	
2009/0274072	A1	11/2009	Knox	
2010/0056191	A1	3/2010	Eldering	

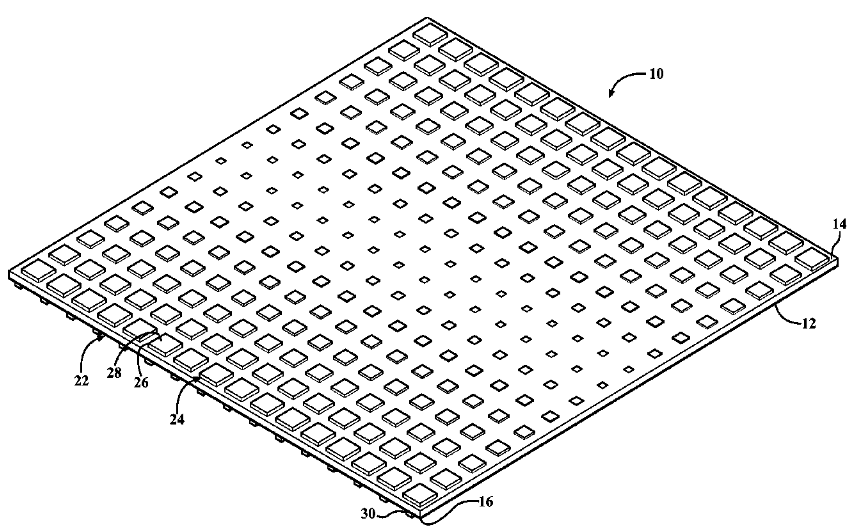
* cited by examiner

Primary Examiner — Hoang V Nguyen
Assistant Examiner — Patrick Holecek
(74) *Attorney, Agent, or Firm* — Gifford, Krass, Sprinkle, Anderson & Citkowski, P.C.

(57) **ABSTRACT**

An antenna with improved radiation efficiency is provided. The antenna includes an antenna array proximately coupled to a feed line. The antenna array includes a plurality of resonating lines. Each resonating line includes a plurality of axially aligned resonators. The resonators have a resonating surface. The resonating surfaces of the resonators at the ends of the resonating lines are larger than resonating surfaces of the resonators in the middle of the resonating lines. Power is supplied to each resonating ling through a feed line. Electrical field is uniformly distributed along the antenna array so as to improve the radiation efficiency of the antenna.

5 Claims, 3 Drawing Sheets



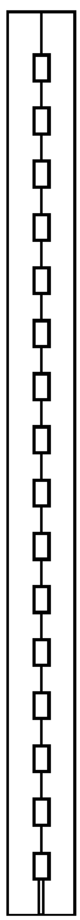


FIG. 1
Prior Art

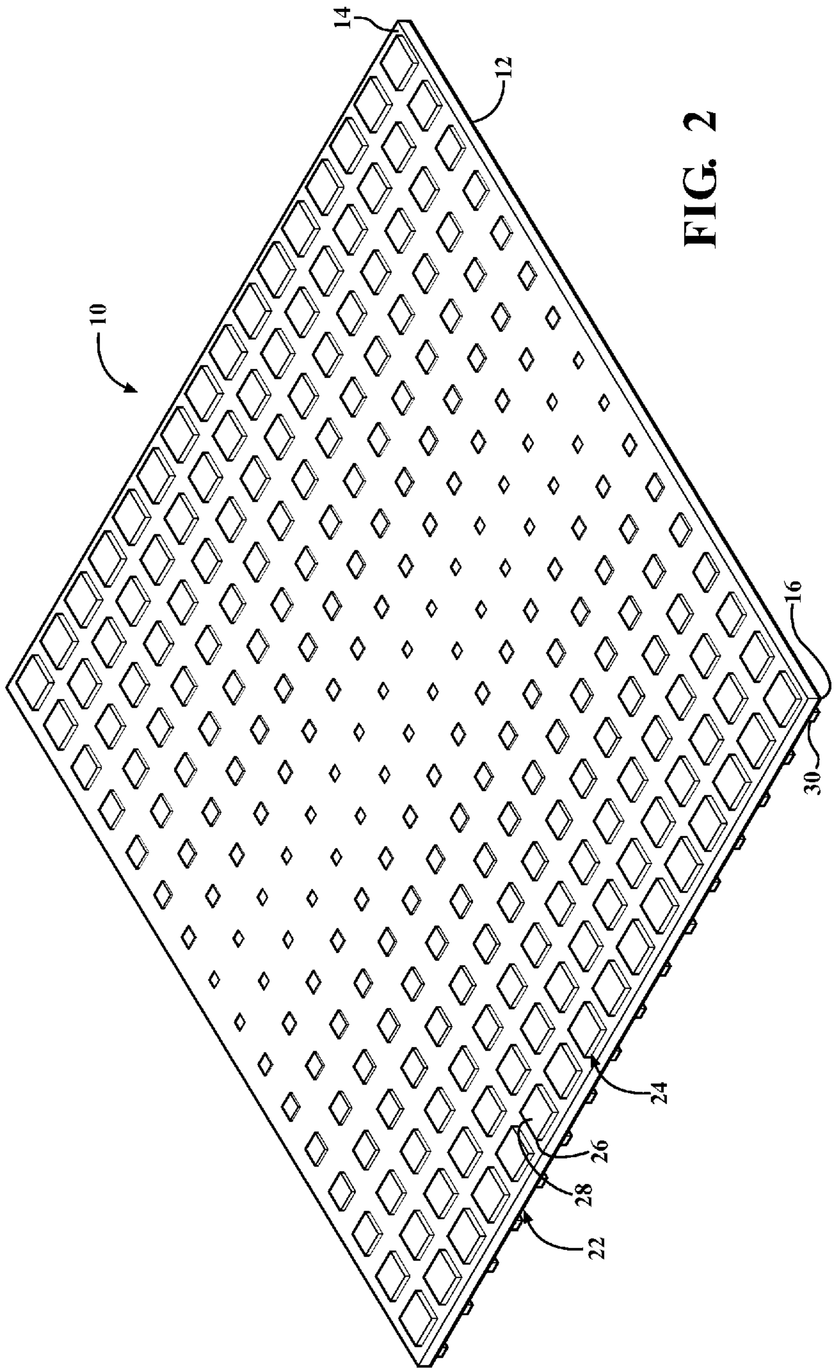


FIG. 2

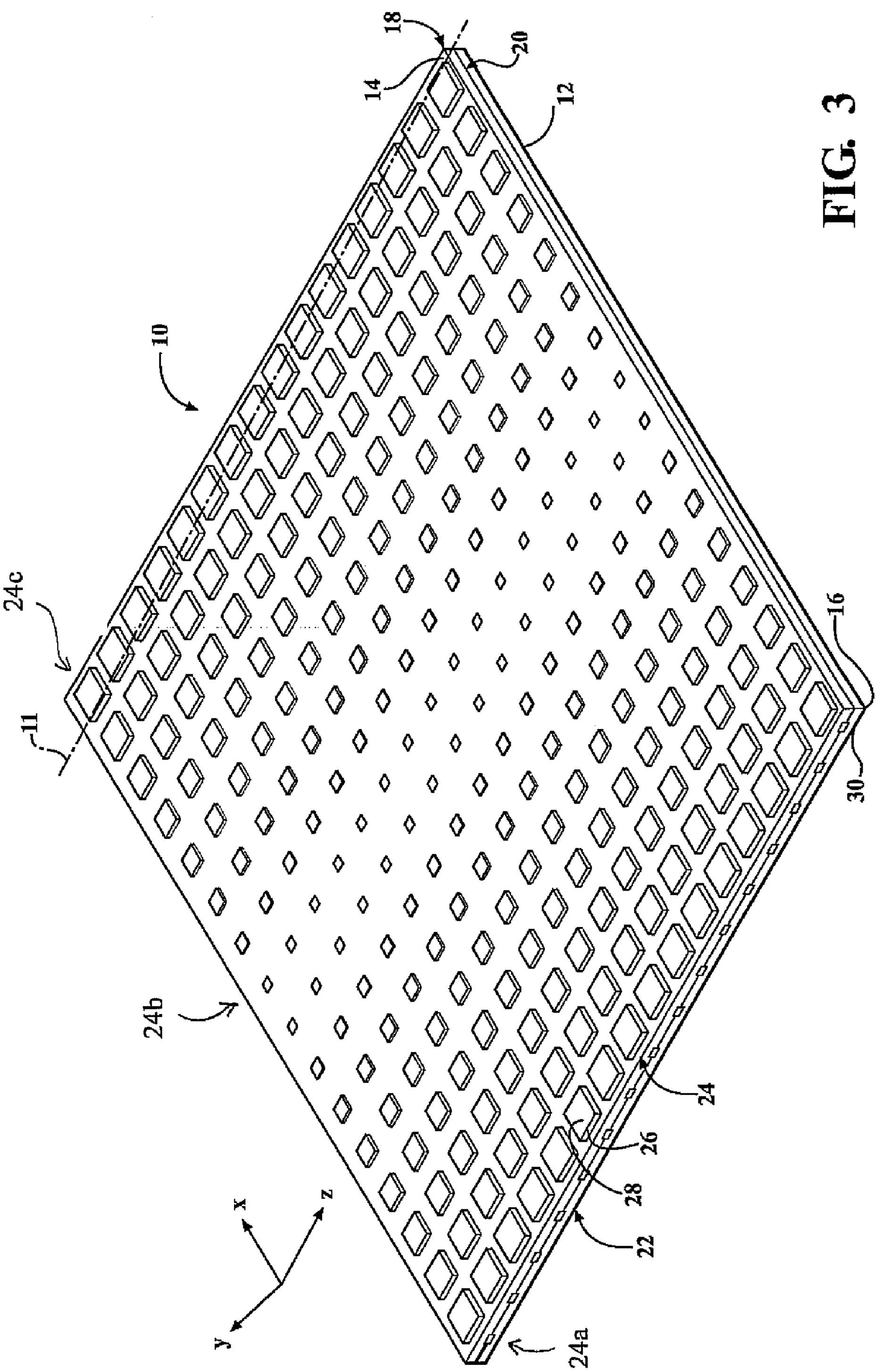
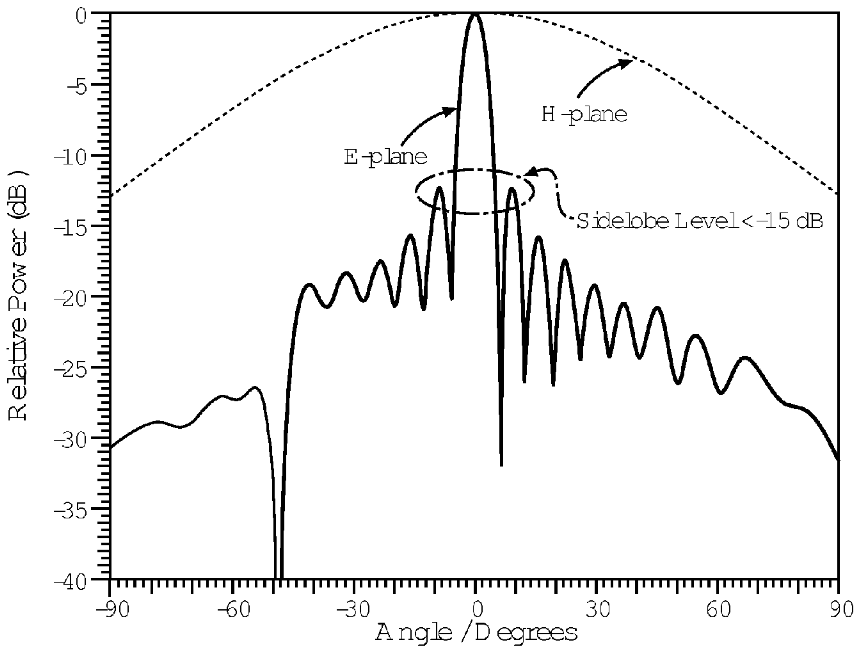


FIG. 3

FIG. 4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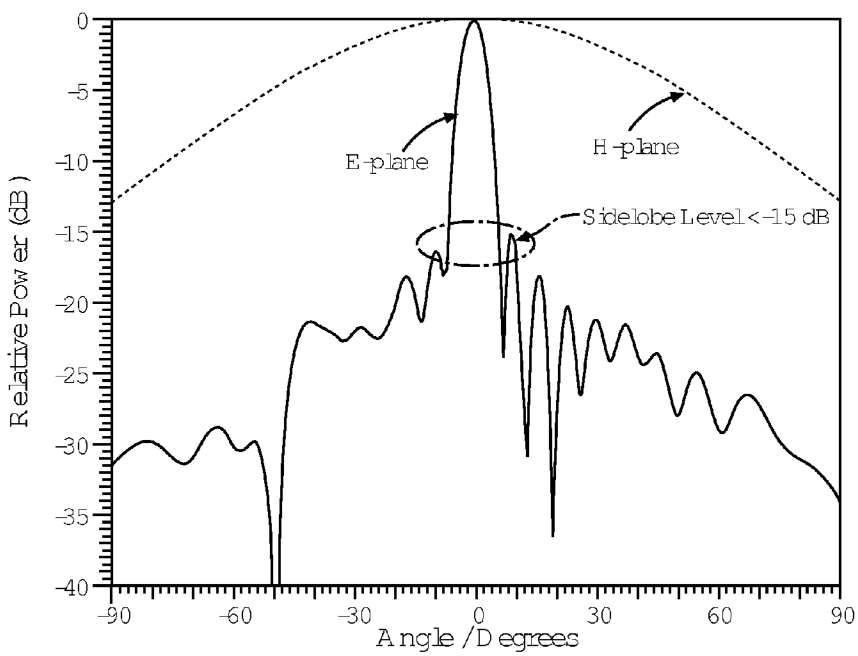
Angle /Degrees
E-plane
H-plane
Sidelobe Level<-15 dB

FIG. 5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Angle /Degrees
E-plane
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Sidelobe Level<-15 dB

ANTENNA WITH TAPERED ARRAY

FIELD OF THE INVENTION

The invention relates to an antenna configured to improve radiation efficiency.

BACKGROUND OF THE INVENTION

Current radar systems operating at the microwave range include an antenna. The antenna includes an array of resonating elements mounted onto a substrate. The antenna array includes a plurality of resonating lines. Each resonating line includes a plurality of axially aligned resonators. Power is supplied to each resonating line through a feed line.

In certain embodiments, the feed line is proximately coupled to each of the resonating lines. The feed lines are mounted on the substrate and are generally disposed beneath the resonating lines. Electricity is supplied along the feed lines, actuating the resonators so as to receive echoes from a transmitting antenna. However, a concentration of electrical field forms along the mid portion of the antenna array, as shown in FIG. **1**. This concentration affects the radiation efficiency of the antenna, and may generate a side lobe (as shown in FIG. **4**) which may affect the accuracy of the antenna.

Accordingly, it remains desirable to have an antenna having an array proximately coupled to the feed line which reduces the concentration of electrical field along the mid portion of the antenna array.

SUMMARY OF THE INVENTION

According to one aspect of the invention, an antenna for use in an automobile is provided. The antenna includes an array proximately coupled to a feed line. The antenna array includes a plurality of resonating lines. Each resonating line includes a plurality of axially aligned resonators. Power is supplied to each resonating line through the feed line. The resonators have a resonating surface. The resonating surfaces of the resonators at the ends of the resonating lines are larger than resonating surfaces of the resonators in the middle of the resonating lines.

BRIEF DESCRIPTION OF THE DRAWINGS

Advantages of the present invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. **1** is an illustration of a prior art antenna;

FIG. **2** is an illustrative view an antenna of the present invention;

FIG. **3** is a perspective view of an antenna having two layers;

FIG. **4** is a diagram showing the processed echos from a prior art antenna; and

FIG. **5** is a diagram showing the processed echos from an antenna of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

With reference first to FIG. **2**, an antenna **10** having a uniform distribution of an electrical field is shown. The uniform distribution of electrical field improves the radiation efficiency of the antenna **10** and reduces the size of side lobes.

The antenna **10** includes a substrate **12** formed of a dielectric material. The substrate **12** includes a first surface **14** opposite a second surface **16**. The substrate **12** may be formed as a single layer as shown in FIG. **2**. Alternatively, the substrate **12** may be formed of multiple layers **18**, **20** of dielectric material, as shown in FIG. **3**. The substrate **12** has a predetermined thickness configured to optimize the radiation efficiency of the antenna **10**.

An antenna array **22** is disposed on the first surface **14** of the substrate **12**. The antenna array **22** has a plurality of resonating lines **24**, and each resonating line **24** has a plurality of resonators **26** axially aligned to each other. Each of the plurality of resonating lines **24** includes a first resonating end **24***a* spaced apart from a second resonating end **24***c*, and a center resonating portion **24***b* disposed between the first and second resonating ends **24***a*, **24***c*. Each of the plurality of resonators **26** has a resonating surface **28**. The resonating surfaces **28** of the resonators **26** at the first and second resonating ends **24***a*, **24***c* of the resonating line **24** are larger than the resonating surfaces **28** of the resonators **26** in the center resonating portion **24***b* the resonating line **24**. Thus the resonators **26** are tapered from the ends of the resonating line **24** to the middle of the resonating line **24**.

A plurality of feed lines **30** provides power to the antenna **10**. More specifically, each feed line **30** is proximately coupled to a resonating line **24** in the antenna array **22**. The feed line **30** is formed of an electrical conductive material such as copper, gold or the like. The feed line **30** has a predetermined width that is configured to generate a desired impedance at each of the resonators **26**. The feed lines **30** are spaced apart from the resonating lines **24**. Each feed line **30** is axially aligned with and generally directly below a corresponding resonating line **24**.

With reference again to FIG. **2** and now to FIG. **3**, the operation of the antenna **10** is provided. The antenna array **22** is mounted on the first surface **14** of the substrate **12**. The antenna array **22** includes sixteen resonating lines **24**. Each of the resonating lines **24** includes sixteen resonators **26**. The resonators **26** are spaced equally apart from each other along each resonating line **24**. The surface area of the resonators **26** at the end of each resonating line **24** is larger than the surface are of the resonators **26** in the middle of the resonating line **24**.

The feed line **30** is proximately coupled to each of the resonating lines **24**. As shown in FIG. **3**, the feed lines **30** are disposed on the second surface **16** of the substrate **12**. However, it is anticipated that the feed lines **30** may be sandwiched between a first and second layer **18**, **20** of dielectric material as shown in FIG. **3**.

Electricity is supplied to each feed line **30**, actuating the individual resonators **26**. The electricity creates a magnetic inductance which excites the resonators **26**. As each resonator **26** is excited, an electrical field is generated. The strength of the electrical field is dependent upon the amount of electricity supplied along the feed line **30** and the size of the resonating surfaces **28** of the resonators **26**.

The electrical field accumulates along the middle of the antenna array **22** due to the excitement of adjacent resonators **26**. Since there is a large concentration of resonators **26** in the middle of the antenna array **22**, a larger concentration of electrical field is found in the middle of the antenna array **22**. As known in proximately coupled arrays **22** of the prior art, the concentration of electrical field reduces the radiation efficiency of the resonators **26**.

The present invention overcomes this problem by reducing the magnitude of the electrical field generated by each of the resonators **26** in the middle of the antenna array **22**. This is done by having the resonating surface **28** of the resonators **26** in the middle of the antenna array **22** smaller than the resonating surface **28** of the resonators **26** at the ends of the resonating lines **24**.

The electrical field in the middle of the antenna array **22** is still accumulated. However, since the electrical field generated by the resonators **26** in the middle of the array **24** is smaller, the concentration of the electrical field in the middle may be configured to be the same as the electrical field generated at the ends of the resonating lines **24**. Thus, the electrical field is generally uniform along each of the resonating lines **24**. The uniform electrical field along the antenna array **22** improves the radiation efficiency of the antenna **10** relative to prior art antennas.

With reference now to FIG. **5**, a chart is provided. The chart provides experimental data. The data shows the reduction in side lobes relative to a proximately coupled non-tapered antenna array **22** having the same number of resonators **26**, operating at the same frequency, as shown in FIG. **4**. Specifically, the tapered antenna array **22** antenna **10** of the present invention has side lobes less than fifteen dB, whereas the antenna of the prior art has side lobes greater than fifteen dB.

The invention has been described in an illustrative manner. It is therefore to be understood that the terminology used is intended to be in the nature of the words of description rather than limitation. Many modifications and variations of the invention are possible in light of the above teachings. For example, the antenna **10** may include thirty-two resonating lines **24**, each having thirty-two resonators **26**. Thus within the scope of the appended claims the invention may be practiced other than as specifically described.

The invention claimed is:

1. An antenna configured to generate a uniform distribution of an electrical field, the antenna comprising:

a substrate formed from a dielectric material, the substrate having a first surface opposite a second surface;

a plurality of feed lines, each of the plurality of feed lines extending along an axis from a first end of the substrate to a second end of the substrate; and

an antenna array disposed on the first surface of the substrate, the antenna array proximately coupled to the feed line, the antenna array having a plurality of resonating lines, each of the plurality of resonating lines having a first resonating end spaced apart from a second resonating end, and a center resonating portion disposed between the first and second resonating ends, each resonating lines having a plurality of resonators axially aligned and each of the resonating lines is aligned along the axis of a corresponding feed line in the plurality of the feed lines, each of the plurality of resonators having a resonating surface, the resonating surfaces are larger at the first and second resonating ends than the resonating surfaces in the center resonating portion of the resonating line so as to produce a smaller electric field in the center of the substrate resulting in a generally uniform electric field throughout the substrate and along the respective feed lines.

2. The antenna as set forth in claim **1**, wherein the substrate includes a first layer and a second layer, the feed line disposed between the first and second layer of the substrate.

3. The antenna set forth in claim **1**, wherein the plurality of resonators is spaced equally apart from each other.

4. The antenna as set forth in claim **1**, wherein the area of the resonating surfaces of the resonators becomes smaller as the resonators are disposed further away from respective ends of the resonating lines.

5. The antenna as set forth in claim **1**, wherein each of the resonators of each of the plurality of resonating lines are disposed along a common axis with an adjacent resonator of an adjacent resonating line.

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