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PLANER ANTENNA

Abstract

An antenna array with multiple testing antenna elements **14** that can test a device-under-test **12** in a practical way, thus allowing for a multitude of efficiencies (e.g. time saving, less errors, less mechanical components, etc.). At least a portion of each of the planer antenna elements **14** of an antenna array may be formed between an upper ground plane **16** and a lower ground plane **18**, which may enhance electromagnetic characteristics. In other configurations, defective ground structures {**22, 23**} may be formed in the upper ground plane **16** and/or a lower ground plane **18**, which may enhance electromagnetic characteristics. In some configurations, the defective ground structure {**22, 23**} may be formed above a pole portion **14**P of at least one planer antenna element **14**. In other configurations, the defective ground structure {**22, 23**} is formed between the pole portions **14**P of two adjacent planer antenna elements **14.**

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION [0001] This application is a continuation of International Application No. PCT/JP2023/007439 filed on Feb. 28, 2023, which claims priority to U.S. Application No. 63/432,705 filed on Dec. 15, 2022, the contents of which are hereby incorporated by reference in their entirety.

1. TECHNICAL FIELD
[0002] The present invention relates to a planer antenna.
2. RELATED ART
[0003] Consumer and industrial products that include electronic devices, inherently all emit some level of electromagnetic energy. This electromagnetic energy may be in the form of radio waves that are electromagnetic noise. Depending on the application of an electronic device, a certain level of electromagnetic noise may be tolerated. However, in some applications of electronic devices, electromagnetic noise above a certain amount may generate undesirable electromagnetic interference (EMI). Electromagnetic interference (EMI) can be undesirable because the EMI can compromise the operation of nearby electronic devices. Electromagnetic interference (EMI) can be undesirable because there are legal limits or industrial requirements to the amount of EMI that an electronic device can emit.
[0004] Prior to the completion of the manufacturing process, an electronic device may need to be tested in order to determine if the electronic device complies with all electromagnetic interference (EMI) requirements. During the testing of an electronic device, the electronic device can be referred to as a device-under-test. Some of these electromagnetic energy emissions are near-field (NF) electromagnetic interference (EMI) characteristics, such that the attributes of the device-under-test should be tested over the entire surface of the device-under-test. It may be unnecessarily time consuming or otherwise impractical for a testing device to include only one testing antenna element for near-field (NF) scanning or facilitating electromagnetic interference (EMI) analysis of the device-under-test, because a testing device with only a single testing antenna element must be moved over the surface of the device-under-test to take multiple readings during the testing process.
GENERAL DISCLOSURE
[0005] Some embodiments relate to an antenna array with multiple testing antenna elements that can test a device-under-test in a practical way that does not require any movement of the testing device over the surface of the device-under-test to take multiple readings, thus allowing for a multitude of efficiencies (e.g. time saving, less errors, less mechanical components, etc.). In some embodiments, at least a portion of each of the planer antenna elements of an antenna are formed between a first ground plane and a second ground plane, which may enhance electromagnetic characteristics. In other embodiments, defective ground structures are formed in the first ground plane and/or a second ground plane, which may enhance electromagnetic characteristics. In some embodiments, the defective ground structure is formed above a pole portion of a planer antenna element. In other embodiments, the defective ground structure is formed between the pole portions of two adjacent planer antenna elements.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. **1**A illustrates a testing device including an antenna array and a device-under-test, in accordance with embodiments.

[0007] FIG. **1**B illustrates a testing device including an antenna array and a device-under-test, in accordance with embodiments.

[0008] FIG. **2**A illustrates a planer antenna element between a first ground plane and a second ground plane, in accordance with embodiments.

[0009] FIG. **2**B illustrates a planer antenna element between a first ground plane and a second ground plane, in accordance with embodiments.

[0010] FIG. **2**C illustrates a planer antenna element between a first ground plane and a second ground plane, in accordance with embodiments.

[0011] FIG. **3**A illustrates a planer antenna element (without the substrate illustrated) between a first ground plane and a second ground plane, in accordance with embodiments.

[0012] FIG. **3**B illustrates a planer antenna element (without the substrate illustrated) between a first ground plane and a second ground plane, in accordance with embodiments.

[0013] FIG. **3**C illustrates a planer antenna element (without the substrate illustrated) between a first ground plane and a second ground plane, in accordance with embodiments.

[0014] FIG. **4**A illustrates a planer antenna element with only one ground plane, in accordance with embodiments.

[0015] FIG. **4**B illustrates a planer antenna element with only one ground plane, in accordance with embodiments.

[0016] FIG. **4**C illustrates a planer antenna element with only one ground plane, in accordance with embodiments.

[0017] FIG. **5**A illustrates a planer antenna element between a first ground plane and a second ground plane, in accordance with embodiments.

[0018] FIG. **5**B illustrates a planer antenna element between a first ground plane and a second ground plane, in accordance with embodiments.

[0019] FIG. **5**C illustrates a planer antenna element between a first ground plane and a second ground plane, in accordance with embodiments.

[0020] FIG. **6**A illustrates a plurality of planer antenna elements in a one-dimensional array, in accordance with embodiments.

[0021] FIG. **6**B illustrates a plurality of planer antenna elements in a one-dimensional array, in accordance with embodiments.

[0022] FIG. **6**C illustrates a plurality of planer antenna elements in a one-dimensional array, in accordance with embodiments.

[0023] FIG. **7** illustrates a plurality of planer antenna elements in a two-dimensional array, in accordance with embodiments.

[0024] FIG. **8** illustrates a planer antenna element with a pointed tip, in accordance with embodiments.

[0025] FIG. **9** illustrates a planer antenna element with a curved shape, in accordance with embodiments.

[0026] FIG. **10** illustrates a planer antenna element with a rounded tip, in accordance with embodiments.

[0027] FIG. **11**A illustrates a defective ground structure in a ground plane above one or more planer antenna elements, in accordance with embodiments.

[0028] FIG. **11**B illustrates a defective ground structure in a ground plane above one or more planer antenna elements, in accordance with embodiments.

[0029] FIG. **12**A illustrates a defective ground structure in a ground plane between two planer antenna elements, in accordance with embodiments.

[0030] FIG. **12**B illustrates a defective ground structure in a ground plane between two planer antenna elements, in accordance with embodiments.
[0031] FIG. **12**C illustrates a defective ground structure in a ground plane between two planer antenna elements, in accordance with embodiments.
[0032] FIG. **13**A illustrates one or more defective ground structures in both an upper ground plane and a lower ground plane, in accordance with embodiments.
[0033] FIG. **13**B illustrates one or more defective ground structures in both an upper ground plane and a lower ground plane, in accordance with embodiments.
[0034] FIG. **14**A illustrates one or more defective ground structures in one of an upper ground plane or a lower ground plane, in accordance with embodiments.
[0035] FIG. **14**B illustrates one or more defective ground structures in one of an upper ground plane or a lower ground plane, in accordance with embodiments.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0036] Example FIGS. **1**A and **1**B illustrate a testing device **10** including an antenna array **14** and a device-under-test **12**, in accordance with embodiments. In embodiments, one or more planer antenna elements **14** are configured to detect electromagnetic propagation characteristics of a device-under-test **12**.
[0037] Embodiments relate to an antenna array **14** with multiple testing antenna elements that can test a device-under-test **12** in a practical way that does not require any movement of the testing device **10** over the surface of the device-under-test **12** to take multiple readings, thus allowing for a multitude of efficiencies (e.g. time saving, less errors, less mechanical components, etc.).
[0038] Example FIGS. **2**A, **2**B, and **2**C illustrate a planer antenna element **14** between a first ground plane **16** and a second ground plane **18**, in accordance with embodiments. FIG. **2**A illustrates a perspective view, FIG. **2**B illustrates a side view, and FIG. **2**C illustrated a top view.
[0039] In embodiments, a testing device **10** may include one or more planer antenna elements **14**, a first ground plane **16**, and a second ground plane **18**. For simplicity of explanation, FIGS. **2**A, **2**B, and **2**C illustrate only one antenna element **14**. In embodiments, at least a portion of the one or more antenna elements **14** are formed between the first ground plane **16** and the second ground plane **18**. In embodiments, the first ground plane **16** and the second ground plane **18** are conducting surfaces configured to reflect radio waves emitted from the at least one planer antenna element **14**. These reflections off of the first ground plane **16** and the second ground plane **18** may enhance the electromagnetic characteristics.
[0040] The one or more planer antenna elements **14** may be formed on a substrate **20**, in accordance with embodiments. For example, substrate **20** may be a Megtron-6 substrate. Example characteristics of substrate **20** may be a dielectric constant of 3.2, loss tangent of 0.004, and thickness of 300 micrometers. One of ordinary skill in the art would appreciate suitable characteristics of substrate **20**.
[0041] The one or more planer antenna element **14** is substantially insulated from the first ground plane **16** and the second ground plane **18**, in accordance with embodiments. In embodiments, planer antenna element **14** is insulated and/or isolated from either first ground plane **16** or second ground plane **18** by air. In other embodiments, insulation and/or isolation may be provided by an insulating material instead of air formed by spacing apart planer antenna element **14**, first ground plane, and second ground plane **16**.
[0042] In embodiments, the at least one planer antenna element **14** is formed on a first plane, the first ground plane **16** is formed on a second plane, and the second ground plane **18** is formed on a third plane. The first plane, the second plane, and the third plane are all substantially parallel planes. In general, the first ground plane **16**, second ground plane **18**, and planer antenna element **14** should be substantially parallel to facilitate ideal electromagnetic characteristics. Those skilled in the art will appreciate that a certain level of tolerance may be acceptable in the parallel attributes without significantly affecting the electromagnetic characteristics.

[0043] In embodiments, the at least one planer antenna element **14** is at least one monopole antenna element. However, those skilled in the art may appreciate other types of antennas that may apply similar concepts as those described in the embodiments.
[0044] Example FIGS. **3**A, **3**B, and **3**C illustrate a planer antenna element **14** (without the substrate illustrated) between a first ground plane **16** and a second ground plane **18**, in accordance with embodiments. For the purposes of explanation, substrate **20** is not shown in FIGS. **3**A, **3**B, and **3**C, because substrate **20** is generally a mechanical support structure for planer antenna element **14** and may not be directly related to the intended electromagnetic propagation characteristics. As illustrated in FIG. **3**B, planer antenna element **14** is approximately halfway between first ground plane **16** and second ground plane **18**. However, in embodiments, planer antenna element **14** may not be halfway between first ground plane **16** and second ground plane **18**. As illustrated in FIG. **3**C, a portion of planer antenna element extends beyond the boundaries of the first ground plane **16** and the second ground plane **18** in a direction perpendicular to the first ground plane **16** and the second ground plane **18**, which affects the electromagnetic characteristics in an intentional manner.
[0045] Example FIGS. **4**A, **4**B, and **4**C illustrate a planer antenna element **14** with only one ground plane **16**, in accordance with embodiments. In some embodiments, planer antenna element **14** has only one ground plane **16**. All embodiments described herein may be modified to include only a single ground plane **16**, as both a first ground plane **16** and a second ground plane **18** are not necessary in every embodiment. In other words, even if an embodiment describes both a first ground plane **16** and a second ground plane **18**, there are other embodiments that include only a single ground plane **16**, even if two ground planes are shown, illustrated, or described.
[0046] Example FIGS. **5**A, **5**B, and **5**C illustrate a planer antenna element **14** between a first ground plane and a second ground plane, in accordance with embodiments. Example FIGS. **5**A, **5**B, and **5**C are similar to example FIGS. **2**A, **2**B, and **2**C, except that first ground plane **16** is shown as being transparent (dotted lines), so that planer antenna element **14** can be viewed without obstruction by first ground plane **16**.
[0047] Example FIGS. **6**A, **6**B, and **6**C illustrate a plurality of planer antenna elements {**14***a*, **14***b*, **14***c*} in a one-dimensional array, in accordance with embodiments. The one or more planer antenna elements **14** include a plurality of planer antenna elements {**14***a*, **14***b*, **14***c*}. The plurality of planer antenna elements {**14***a*, **14***b*, **14***c*} are formed in an array.
[0048] The array of planer antenna elements {**14***a*, **14***b*, **14***c*} is a one-dimensional array of planer antenna elements {**14***a*, **14***b*, **14***c*} which share substrate **20**. In embodiments, planer antenna elements {**14***a*, **14***b*, **14***c*} are spaced substantially evenly apart from each other. However, in other embodiments, planer antenna elements {**14***a*, **14***b*, **14***c*} may be spaced irregularly for either testing or electromagnetic characteristic purposes that are appreciated by those skilled in the art. Although only three planer antenna elements {**14***a*, **14***b*, **14***c*} are illustrated, any number of planer antenna elements **14** may be disposed in a one-dimensional array.
[0049] Example FIG. **7** illustrates plurality of planer antenna elements {**14***aa*, **14***ab*, **14***ac*, **14***ba*, **14***bb*, **14***bc*, **14***ca*, **14***cb*, **14***cc*} in a two-dimensional array, in accordance with embodiments. The array of planer antenna elements {**14***aa*, **14***ab*, **14***ac*, **14***ba*, **14***bb*, **14***bc*, **14***ca*, **14***cb*, **14***cc*} is a two-dimensional array of planer antenna elements **14**.
[0050] Embodiments relate to a first one-dimensional array of planer antenna elements including the plurality of planer antenna elements {**14***aa*, **14***ab*, **14***ac*}. Embodiments relate to a second one-dimensional array of planer antenna elements {**14***ba*, **14***bb*, **14***bc*} associated with a third ground plane **16***b* and a fourth ground plane **18***b*. Embodiments relate to a third one-dimensional array of planer antenna elements {**14***ca*, **14***cb*, **14***cc*} associated with a fifth ground plane **16***c* and a sixth ground plane **18***c*. Embodiments relate to a two-dimensional array of planer antenna elements including at least the first one dimensional array of planer antenna elements {**14***aa*, **14***ab*, **14***ac*} and the second one-dimensional array of planer antenna elements {**14***ba*, **14***bb*, **14***bc*}. In embodiments, any number of one-dimensional arrays of planer antenna elements may be used to

form a two-dimensional array of planer antenna elements. The different one-dimensional arrays may be positioned apart from each other so that the tips of the planer antenna elements {**14***aa*, **14***ab*, **14***ac*, **14***ba*, **14***bb*, **14***bc*, **14***ca*, **14***cb*, **14***cc*} have a uniform matrix spacing or an irregular spacing.

[0051] Example FIG. **8** illustrates a planer antenna element **14** with a pointed tip, in accordance with embodiments. In embodiments, each of the one or more planer antenna elements **14** includes a head portion **14**H and a pole portion **14**P contiguous with the head portion **14**H. In embodiments, the pole portion **14**P is in an area between the first ground plane **16** and the second ground plane **18**. In embodiments, the head portion **14**H is in an area that extends beyond a boundary of the first ground plane **16** and the second ground plane **18**. Also see FIGS. **2**C, **3**C, **4**C, **5**C, and **6**C, in accordance with embodiments. In embodiments, each of the at least one antenna element **14** includes a tail portion **14**T contiguous with the pole portion **14**P. The pole portion **14**P is between the tail portion **14**T and the head portion **14**H.

[0052] In embodiments, a width W.sub.T of the tail portion **14**T is smaller than a width W.sub.P of the pole portion **14**P. In embodiments, the width W.sub.T of the tail portion **14**T is approximately 500 micrometers. In embodiments, a length L.sub.T of the tail portion **14**T is between approximately 6,800 micrometers and 9,500 micrometers. In embodiments, the length L.sub.T of the tail portion **14**T is between approximately 8,900 micrometers and 9,100 micrometers.

[0053] In embodiments, a width W.sub.H of the head portion **14**H varies based on a distance from the pole portion **14**P. The width W.sub.H of the head portion **14**H has a maximum width at a point closest to the pole portion **14**P. The width W.sub.H of the head portion **14**H has a minimum width at a point furthest away from the pole portion **14**P.

[0054] Those skilled in the art appreciate other dimensions of planer antenna element **14** depending on the application and/or intended electromagnetic characteristics.

[0055] In embodiments, the head portion **14**H has an arrow shape, as illustrated in FIG. **8**. However, those skilled in the art appreciate that other shapes of the head portion **14**H may be implemented, in accordance with the embodiments.

[0056] In embodiments, head portion **14**H has a pointed tip. However, those skilled in the art appreciate that other shapes of the head portion **14**H may be implemented without a pointed tip. In some embodiments, a non-pointed tip may be implemented for intended electromagnetic characteristics. In other embodiments, a non-pointed tip may be implemented to facilitate practical and/or efficient manufacturing techniques of the planer antenna element **14**.

[0057] In embodiments, the point of the head portion **14**H furthest away from the tail portion **14**T is a tip. In embodiments, illustrated in FIG. **8**, the head portion **14**H has a substantially straight profile. However, in other embodiments, other profiles may be implemented, as appreciated by those skilled in the art.

[0058] Example FIG. **9** illustrates a planer antenna element **15** with a curved shape, in accordance with embodiments. In embodiments, the head portion **15**H has a curved profile for either electromagnetic propagation reasons or practical manufacturing reasons. In embodiments, the head portion **15**H has a substantially parabolic profile. In embodiments, the head portion **15**H has a substantially exponential varied profile. Embodiments relate to any profile of the head portion **15**H of planer antenna element **15**, as appreciated by those skilled in the art.

[0059] Example FIG. **10** illustrates a planer antenna element **17** with a rounded tip, in accordance with embodiments. As discussed above, embodiments where the head portion **17**H has a rounded tip may be because of intended electromagnetic characteristics and/or practical manufacturing technique reasons.

[0060] Example FIGS. **11**A and **11**B illustrate a defective ground structure {**22***a*, **22***b*, **22***c*} in a ground plane above one or more planer antenna elements {**14***a*, **14***b*, **14***c*}, in accordance with embodiments. In embodiments, the defective ground structure {**22***a*, **22***b*, **22***c*} is configured to minimize a return loss of the first planer antenna element {**14***a*, **14***b*, **14***c*}.

[0061] In embodiments, the defective ground structure {**22***a*, **22***b*, **22***c*} is at least one slot in at least one of the first ground plane **16** or the second ground plane **18**. In other words, in embodiments, the defective ground structure {**22***a*, **22***b*, **22***c*} is the removal or prevention of formation of a portion of the first ground plane **16** during a manufacturing process.
[0062] In embodiments, the at least one planer antenna element {**14***a*, **14***b*, **14***c*} includes a first planer antenna element **14** and the defective ground structure **22** that overlaps the pole portion **14**P of the first planer antenna element **14** in a direction perpendicular to at least one of the first ground plane **16** or the second ground plane **18**. Although planer antenna element **14** is illustrated as an example, other embodiments can implement other shapes (e.g. planer antenna element **15**, planer antenna element **17**, etc.).
[0063] In embodiments, the at least one slot of the defective ground structure **22** is a single slot. However, in other embodiments, the defective ground structure **22** may be multiple slots.
[0064] In embodiments, the at least one slot of the defective ground structure **22** has an I-shape. However, in other embodiments, the defective ground structure **22** may have another shape appreciated by those skilled in the art. In embodiments, the longest dimension of the I-shape is parallel to a boundary between the head portion **14**H and the pole portion **14**P and a shortest dimension of the I-shape is perpendicular to the boundary between the head portion **14**H and the pole portion **14**P.
[0065] In embodiments, there is only ground plane **16** and ground plane **18** is non-existent. In embodiments, an apparatus includes at least one planer antenna element {**14***a*, **14***b*, **14***c*} and a single ground plane **16**. The single ground plane **16** has a defective ground structure {**22***a*, **22***b*, **22***c*}. The defective ground structure {**22***a*, **22***b*, **22***c*} is at least one slot in the single ground plane **16**. In embodiments, the at least one planer antenna element {**14***a*, **14***b*, **14***c*} includes a first planer antenna element **14** and the defective ground structure overlaps **22** the pole portion **14**P of the first planer antenna element **14** in a direction perpendicular to the single ground plane **16**.
[0066] Example FIGS. **12**A, **12**B, and **12**C illustrate a defective ground structure {**23***d*, **23***e*} {**23***aa*, **23***ab*, **23***ac*, **23***ba*, **23***bb*, **23***bc*, **23***ca*, **23***cb*, **23***cc*} in a ground plane **16** between two planer antenna elements {**14***a*, **14***b*} or {**14***b*, **14***c*}, in accordance with embodiments. In embodiments, the defective ground structure {**23***d*, **23***e*} {**23***aa*, **23***ab*, **23***ac*, **23***ba*, **23***bb*, **23***bc*, **23***ca*, **23***cb*, **23***cc*} is configured to minimize a return loss of the first planer antenna element {**14***a*, **14***b*, **14***c*}. In embodiments, the defective ground structure {**23***d*, **23***e*} {**23***aa*, **23***ab*, **23***ac*, **23***ba*, **23***bb*, **23***bc*, **23***ca*, **23***cb*, **23***cc*} is configured to minimize coupling between the first planer antenna element **14***a* and the second planer antenna element **14***b* or between the second planer antenna element **24***b* and the third planer antenna element **24***c*.
[0067] In embodiments, the defective ground structure {**23***d*, **23***e*} or {**23***aa*, **23***ab*, **23***ac*, **23***ba*, **23***bb*, **23***bc*, **23***ca*, **23***cb*, **23***cc*} is at least one slot in at least one of the first ground plane **16** or the second ground plane **18**. In some embodiments, the defective ground structure {**23***d*, **23***e*} or {**23***aa*, **23***ab*, **23***ac*, **23***ba*, **23***bb*, **23***bc*, **23***ca*, **23***cb*, **23***cc*} is at least one slot in only one of the first ground plane **16** or the second ground plane **18**.
[0068] In embodiments, the defective ground structure {**23***d*, **23***e*} or {**23***aa*, **23***ab*, **23***ac*, **23***ba*, **23***bb*, **23***bc*, **23***ca*, **23***cb*, **23***cc*} is in an area of at least one of the first ground plane **16** or the second ground plane **18** that does not overlap the pole portion {**14***p*, **15***p*, **17***p*} in a direction perpendicular to at least one of the first ground plane **16** or the second ground plane **18**.
[0069] In embodiments, there is only ground plane **16** and ground plane **18** is non-existent. In other words, some embodiments include two ground planes and some embodiments include only a single ground plane.
[0070] In embodiments, the at least one planer antenna element **14** includes a first planer antenna element **14***a* adjacent to a second planer antenna element **14***b*. The first planer antenna element **14***a* and the second planer antenna element **14***b* both at least partially overlap at least one of the first ground plane **16** or the second ground plane **18** in the direction perpendicular to at least one of the

first ground plane **16** or the second ground plane **18**. The defective ground structure **23***d* is between the first planer antenna element **14***a* and the second planer antenna element **14***b*. The defective ground structure **23***d* does not overlap either the first planer antenna element **14***a* or the second planer antenna element **14***b* in the direction perpendicular to at least one of the first ground plane or the second ground plane. Likewise, in embodiments, defective ground structure **23***e* is between second planer antenna element **14***b* and third planer antenna element **14***c*.

[0071] In embodiments, the at least one slot {**23***aa*, **23***ab*, **23***ac*, **23***ba*, **23***bb*, **23***bc*, **23***ca*, **23***cb*, **23***cc*} is a matrix of slots. In embodiments, each slot of the matrix of slots {**23***aa*, **23***ab*, **23***ac*, **23***ba*, **23***bb*, **23***bc*, **23***ca*, **23***cb*, **23***cc*} has a square shape with a gap on one edge of the square shape. In embodiments, an orientation of the gap on one edge of the square shape is different for at least two slots of the matrix of slots {**23***aa*, **23***ab*, **23***ac*, **23***ba*, **23***bb*, **23***bc*, **23***ca*, **23***cb*, **23***cc}*.

[0072] In embodiments, the matrix of slots comprises a plurality of rows of slots {**23***aa*, **23***ab*, **23***ac*, **23***ba*, **23***bb*, **23***bc*, **23***ca*, **23***cb*, **23***cc*}. Each of the plurality of rows of slots are parallel to both the first planer antenna element **14***a* and the second planer antenna element **14***b*. The orientation of the gap on one edge of the square shape of each slot {**23***aa*, **23***ab*, **23***ac*} {**23***ba*, **23***bb*, **23***bc*} {**23***ca*, **23***cb*, **23***cc*} in a same row of slots is the same. The plurality of rows of slots comprises a first row of slots adjacent to a second row of slots. The orientation of the gap on one edge of the square shape of each slot in the first row of slots is different than the orientation of the gap on one edge of the square shape of each slot in the second row of slots. In other embodiments, there may be other patterns of variations in the orientations of the gaps, as appreciated by those skilled in the art.

[0073] In embodiments, the one edge of the square shape on which there is the gap is an edge that is perpendicular to both the first planer antenna element **14***a* and the second planer antenna element **14***b*. In embodiments, the matrix of slots may be at the edge of the boundary of the first ground plane **16**, while in other embodiments the matrix of slots may be spaced away from the edge of the boundary of the first ground plane **16**.

[0074] In embodiments, there is only ground plane **16** and ground plane **18** is non-existent. In embodiments, an apparatus may include at least one planer antenna element {**14***a*, **14***b*, **14***c*} and a single ground plane **16**. The single ground plane **16** may have a defective ground structure {**23***d*, **23***e*} {**23***aa*, **23***ab*, **23***ac*, **23***ba*, **23***bb*, **23***bc*, **23***ca*, **23***cb*, **23***cc*}. The defective ground structure {**23***d*, **23***e*} {**23***aa*, **23***ab*, **23***ac*, **23***ba*, **23***bb*, **23***bc*, **23***ca*, **23***cb*, **23***cc*} is at least one slot in the single ground plane **16**. In embodiments, the at least one planer antenna element {**14***a*, **14***b*, **14***c*} includes a first planer antenna element **14***a* adjacent to a second planer antenna element **14***b*. The first planer antenna element **14***a* and the second planer antenna element **14***b* both at least partially overlap the ground plane in the direction perpendicular to the ground plane. The defective ground structure {**23***d*, **23***e*} {**23***aa*, **23***ab*, **23***ac*, **23***ba*, **23***bb*, **23***bc*, **23***ca*, **23***cb*, **23***cc*} is between the first planer antenna element and the second planer antenna element. The defective ground structure {**23***d*, **23***e*} {**23***aa*, **23***ab*, **23***ac*, **23***ba*, **23***bb*, **23***bc*, **23***ca*, **23***cb*, **23***cc*} does not overlap either the first planer antenna element **14***a* or the second planer antenna element **14***b* in the direction perpendicular to the ground plane.

[0075] Example FIGS. **13**A and **13**B illustrate one or more defective ground structures {**22***aa*, **22***ab*, **22***ac*, **22***ba*, **22***bb*, **22***bc*} or {**22***a*, **22***b*, **22***c*, **22***d*, **22***d*} in both an upper ground plane **16** and a lower ground plane **18**, in accordance with embodiments. In embodiments, the defective ground structure {**22***aa*, **22***ab*, **22***ac*, **22***ba*, **22***bb*, **22***bc*} or {**22***a*, **22***b*, **22***c*, **22***d*, **22***d*} is at least one slot in at least one of the first ground plane **16** or the second ground plane **18**.

[0076] In embodiments, as illustrated in FIG. **13**A, at least one of the first ground plane **16** or the second ground plane **18** has a defective ground structure {**22***aa*, **22***ab*, **22***ac*, **22***ba*, **22***bb*, **22***bc*} or {**22***a*, **22***b*, **22***c*, **22***d*, **22***d*}. In embodiments, as illustrated in FIG. **13**B, the defective ground structure {**22***aa*, **22***ab*, **22***ac*, **22***ba*, **22***bb*, **22***bc*} or {**22***a*, **22***b*, **22***c*, **22***d*, **22***d*} is in both the first ground plane **16** and the second ground plane **18**.

[0077] Example FIGS. **14**A and **14**B illustrate one or more defective ground structures {**22***aa*, **22***ab*, **22***ac*} or {**22***a*, **22***b*} in only one of an upper ground plane **16** or a lower ground plane **18**, in accordance with embodiments.
[0078] In embodiments, the defective ground structure {**22***aa*, **22***ab*, **22***ac*} or {**22***a*, **22***b*} is at least one slot in at least one of the first ground plane **16** or the second ground plane **18**. Although FIGS. **14**A and **14**B illustrate defective ground structures {**22***aa*, **22***ab*, **22***ac*} or {**22***a*, **22***b*} in only first ground plane **16** with no defective ground structures in the second ground plane **18**, embodiments relate to defective ground structure in second ground plane **18** and no defective ground structure in the first ground plane **16**.
[0079] It will be obvious and apparent to those skilled in the art that various modifications and variations can be made in the embodiments disclosed. This, it is intended that the disclosed embodiments cover the obvious and apparent modifications and variations, provided that they are within the scope of the appended claims and their equivalents.

Claims

1. An apparatus comprising: at least one planer antenna element; a first ground plane; and a second ground plane, wherein at least a portion of the at least one planer antenna element is formed between the first ground plane and the second ground plane.
2. The apparatus of claim 1, wherein: the at least one planer antenna element comprises a plurality of planer antenna elements; and the plurality of planer antenna elements are formed in an array.
3. The apparatus of claim 1, wherein the at least one planer antenna element is configured to detect electromagnetic characteristics of a device-under-test.
4. The apparatus of claim 1, wherein the at least one planer antenna element is at least partially insulated from the first ground plane and the second ground plane.
5. The apparatus of claim 2, wherein the array of planer antenna elements is a one-dimensional array of planer antenna elements.
6. The apparatus of claim 2, wherein the array of planer antenna elements is a two-dimensional array of planer antenna elements.
7. The apparatus of claim 2, comprising: a first one-dimensional array of planer antenna elements comprising the plurality of planer antenna elements; a second one-dimensional array of planer antenna elements associated with a third ground plane and a fourth ground plane; and a two-dimensional array of planer antenna elements comprising the first one dimensional array of planer antenna elements and the second one-dimensional array of planer antenna elements.
8. The apparatus of claim 1, wherein the at least one planer antenna element is formed on a first plane; the first ground plane is formed on a second plane; and the second ground plane is formed on a third plane; wherein the first plane, the second plane, and the third plane are all substantially parallel planes.
9. The apparatus of claim 1, wherein the at least one planer antenna element is at least one monopole antenna element.
10. The apparatus of claim 1, wherein the first ground plane and the second ground plane are conducting surfaces configured to reflect radio waves emitted from the at least one planer antenna element.
11. The apparatus of claim 1, wherein each of the at least one antenna element comprises: a head portion; and a pole portion contiguous with the head portion.
12. The apparatus of claim 11, wherein: the pole portion is in an area between the first ground plane and the second ground plane; and the head portion is in an area that extends beyond a boundary of the first ground plane and the second ground plane.
13. The apparatus of claim 11, wherein at least one of the first ground plane or the second ground plane has a defective ground structure.

14. The apparatus of claim 13, wherein the defective ground structure is configured to minimize a return loss of the first planer antenna element.
15. The apparatus of claim 13, wherein the defective ground structure is at least one slot in at least one of the first ground plane or the second ground plane.
16. The apparatus of claim 15, wherein: the at least one planer antenna element comprises a first planer antenna element; and the defective ground structure overlaps the pole portion of the first planer antenna element in a direction perpendicular to at least one of the first ground plane or the second ground plane.
17. The apparatus of claim 16, wherein the at least one slot of the defective ground structure has an I-shape.
18. The apparatus of claim 17, wherein the at least one slot is a single slot.
19. The apparatus of claim 17, wherein: a longest dimension of the I-shape is parallel to a boundary between the head portion and the pole portion; and a shortest dimension of the I-shape is perpendicular to the boundary between the head portion and the pole portion.
20. The apparatus of claim 15, wherein the defective ground structure is in an area of at least one of the first ground plane or the second ground plane that does not overlap the pole portion in a direction perpendicular to at least one of the first ground plane or the second ground plane.
21. The apparatus of claim 20, wherein: the at least one planer antenna element comprises a first planer antenna element adjacent to a second planer antenna element; the first planer antenna element and the second planer antenna element both at least partially overlap at least one of the first ground plane or the second ground plane in the direction perpendicular to at least one of the first ground plane or the second ground plane; the defective ground structure is between the first planer antenna element and the second planer antenna element; and the defective ground structure does not overlap either the first planer antenna element or the second planer antenna element in the direction perpendicular to at least one of the first ground plane or the second ground plane.
22. The apparatus of claim 21, wherein the defective ground structure is configured to minimize coupling between the first planer antenna element and the second planer antenna element.
23. The apparatus of claim 21, wherein the at least one slot comprises a matrix of slots.
24. The apparatus of claim 23, wherein each slot of the matrix of slots has a square shape with a gap on one edge of the square shape.
25. The apparatus of claim 24, wherein an orientation of the gap on one edge of the square shape is different for at least two slots of the matrix of slots.
26. The apparatus of claim 25, wherein: the matrix of slots comprises a plurality of rows of slots; each of the plurality of rows of slots are parallel to both the first planer antenna element and the second planer antenna element; the orientation of the gap on one edge of the square shape of each slot in a same row of slots is the same; the plurality of rows of slots comprises a first row of slots adjacent to a second row of slots; and the orientation of the gap on one edge of the square shape of each slot in the first row of slots is different than the orientation of the gap on one edge of the square shape of each slot in the second row of slots.
27. The apparatus of claim 24, wherein the one edge of the square shape on which there is the gap is an edge that is perpendicular to both the first planer antenna element and the second planer antenna element.
28. The apparatus of claim 13, wherein the defective ground structure is in both the first ground plane and the second ground plane.
29. The apparatus of claim 13, wherein the defective ground structure is in only one of the first ground plane or the second ground plane.
30. The apparatus of claim 11, wherein each of the at least one antenna element comprises: a tail portion contiguous with the pole portion, wherein the pole portion is between the tail portion and the head portion.
31. The apparatus of claim 30, wherein a width of the tail portion is smaller than a width of the pole

portion.
32. The apparatus of claim 30, wherein the width of the tail portion is approximately 500 micrometers.
33. The apparatus of claim 30, wherein a length of the tail portion is between approximately 6,800 micrometers and 9,500 micrometers.
34. The apparatus of claim 33, wherein the length of the tail portion is between approximately 8,900 micrometers and 9,100 micrometers.
35. The apparatus of claim 11, wherein: a width of the head portion varies based on a distance from the pole portion; the width of the head portion has a maximum width at a point closest to the pole portion; and the width of the head portion has a minimum width at a point furthest away from the pole portion.
36. The apparatus of claim 35, wherein the head portion has an arrow shape.
37. The apparatus of claim 35, wherein the head portion has at least one of: a substantially straight profile; a curved profile; a substantially parabolic profile; and an substantially exponential varied profile.
38. The apparatus of claim 35, wherein the point furthest away from the tail portion is a tip.
39. The apparatus of claim 38, wherein the tip is a rounded tip.
40. An apparatus comprising: at least one planer antenna element; and a ground plane, wherein the ground plane has a defective ground structure, and wherein the defective ground structure is at least one slot in the ground plane.
41. The apparatus of claim 40, wherein: the at least one planer antenna element comprises a first planer antenna element; and the defective ground structure overlaps the pole portion of the first planer antenna element in a direction perpendicular to the ground plane.
42. The apparatus of claim 40, wherein: the at least one planer antenna element comprises a first planer antenna element adjacent to a second planer antenna element; the first planer antenna element and the second planer antenna element both at least partially overlap the ground plane in the direction perpendicular to the ground plane; the defective ground structure is between the first planer antenna element and the second planer antenna element; and the defective ground structure does not overlap either the first planer antenna element or the second planer antenna element in the direction perpendicular to the ground plane.