United States Patent Application Publication	20250260168
Kind Code	A1
Publication Date	August 14, 2025
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ADDITIVELY MANUFACTURED ELECTROMAGNETICALLY COUPLED PATCH ANTENNA

Abstract

An antenna assembly includes a conductive ground plane, a lower layer of dielectric material above the ground plane, and an upper layer of dielectric material above the lower layer of dielectric material. In an example, at least one of the lower or upper layers of dielectric material comprise dielectric foam. The antenna assembly further includes a conductive feed line between at least a section of the lower layer of dielectric material and the upper layer of dielectric material, and a conductive patch above the upper layer of dielectric material. In an example, a dielectric constant of the lower layer of dielectric material is at least 25%, or at least 50% more, or at least 100% more, or at least 200% more, or at least 500% more than a dielectric constant of the upper layer of dielectric material.

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Appl. No.: **18/438921**

Filed: **February 12, 2024**

Publication Classification

Int. Cl.: **H01Q9/04** (20060101); **B33Y80/00** (20150101)

U.S. Cl.:

CPC **H01Q9/0421** (20130101); **B33Y80/00** (20141201); **H01Q9/045** (20130101);

Background/Summary

FIELD OF DISCLOSURE

[0001] The present disclosure relates to antennas, and more particularly, to electromagnetically coupled (EMC) patch antenna structures.

BACKGROUND

[0002] A patch antenna is a type of low profile antenna that can be mounted on a surface. It includes a sheet or "patch" of metal above a substrate that is deposited over a larger ground plane metal sheet. The metal patch provides a resonant transmission line, with its length corresponding to approximately one-half the wavelength of the resonant frequency. A patch antenna is often used at the radio frequency (RF) range, as such wavelengths are relatively short, which in turn allows the patches to be relatively small. There remain a number of non-trivial challenges with respect to designing and manufacturing patch antenna structures.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] FIGS. **1**A, **1**B, and **1**C illustrate various views of an electromagnetically coupled (EMC) patch antenna structure that includes a ground plane, one or more lower layers of dielectric material above the ground plane, one or more feed lines within the one or more lower layers of dielectric material, an upper layer of dielectric material above the one or more lower layers of dielectric material, and a radiating conductive patch above the upper layer of dielectric material, in accordance with an embodiment of the present disclosure.

[0004] FIG. **2**A illustrates a cross-sectional view of an EMC patch antenna structure having a single lower layer of dielectric material above a ground plane, one or more feed lines within the lower layer of dielectric material, an upper layer of dielectric material above the lower layer of dielectric material, and a radiating conductive patch above the upper layer of dielectric material, in accordance with an embodiment of the present disclosure.

[0005] FIG. **2**B illustrates a cross-sectional view of an EMC patch antenna structure having a lower layer of dielectric material above a ground plane, one or more feed lines above the lower layer of dielectric material, an upper layer of dielectric material above the lower layer of dielectric material, and a radiating conductive patch above the upper layer of dielectric material, in accordance with an embodiment of the present disclosure.

[0006] FIG. **2**C illustrates a cross-sectional view of an EMC patch antenna structure having a lower layer of dielectric material above a ground plane, one or more feed lines within the lower layer of dielectric material, an upper layer of dielectric material above the lower layer of dielectric material, a radiating conductive patch above the upper layer of dielectric material, and a top layer of dielectric material at least in part above the radiating conductive patch, in accordance with an embodiment of the present disclosure.

[0007] FIG. **3** illustrates a cross-sectional view of an EMC patch antenna structure having a direct current (DC) shorting structure between a ground plane and a radiating conductive patch above the ground plane, in accordance with an embodiment of the present disclosure.

[0008] FIG. **4** illustrates a flowchart depicting a method of forming an antenna assembly, in accordance with an embodiment of the present disclosure.

[0009] FIGS. **5**A, **5**B, **5**C, **5**D, **5**E, **5**F, **5**G**1**, and **5**G**2** collectively illustrate an antenna assembly in various stages of processing in accordance with the methodology of FIG. **4**, in accordance with an embodiment of the present disclosure.

[0010] FIG. **6** illustrates a flowchart depicting a method of forming an antenna assembly, in accordance with another embodiment of the present disclosure.

[0011] FIGS. **7**A, **7**B, **7**C, and **7**D collectively illustrate an antenna assembly in various stages of processing in accordance with the methodology of FIG. **6**, in accordance with an embodiment of the present disclosure.

[0012] Although the following detailed description will proceed with reference being made to illustrative examples, many alternatives, modifications, and variations thereof will be apparent in light of this disclosure.

DETAILED DESCRIPTION

[0013] Electromagnetically coupled (EMC) patch antenna assemblies are disclosed. An EMC patch antenna is configured for or otherwise capable of electromagnetic coupling between one or more feed line(s) and a patch that is radiating. In one embodiment, an antenna assembly includes a conductive ground plane, a lower layer of dielectric material above the ground plane, and an upper layer of dielectric material above the lower layer of dielectric material. In an example, at least one of the lower or upper layers of dielectric material comprise dielectric foam. The antenna assembly further includes a conductive feed line between at least a section of the lower layer of dielectric material and the upper layer of dielectric material, and a conductive patch above the upper layer of dielectric material. Because the patch can be electromagnetically excited via the feed line, there is no need for solder joints or other such physical connections attendant a probe-fed patch. Although such EMC patch antennas can be used for many applications, these EMC patch antennas may be particularly well-suited for applications in which the antenna structure may endure vibrations, such as in Global Positioning System (GPS) that is affixed or otherwise included in a vehicle or an airborne platform, or any other platform susceptible to vibration conditions that are problematic for solder-based feed connections.

[0014] Furthermore, one or more layers of dielectric material of the patch antenna may be manufactured using additive manufacturing processes, such as three-dimensional (3D) printing or a foaming process. Because of the nature of the additive manufacturing process, a height of such layer(s) of dielectric material may be fine-tuned, which in turn allows fine tuning of one or more antenna parameters (such as bandwidth, antenna gain, phase, and/or one or more other antenna parameters) of the patch antenna assembly. Also, the dielectric constants of the lower layer of dielectric and the upper layer of dielectric material can vary, from one example to the next. In some examples, a dielectric constant of the lower layer of dielectric material is at least 25%, or at least 50% more, or at least 100% more, or at least 200% more, or at least 500% more than a dielectric constant of the upper layer of dielectric material.

[0015] In another embodiment, a method of manufacturing an antenna assembly comprises additively forming a conductive ground plane, providing a lower layer of dielectric material above the ground plane, forming a feed line on the lower layer of dielectric material, providing an upper layer of dielectric material above the feed line, and forming a conductive patch above upper layer of dielectric material.

[0016] In yet another embodiment, another method of manufacturing an antenna assembly comprises additively manufacturing an element that includes (i) a ground plane, (ii) a patch above the ground plane, and (iii) a structure having a first end in contact with the ground plane and a second end in contact with the patch. In an example, additively manufacturing the element comprises printing the element using a three-dimensional (3D) printing process. The method further comprises providing a lower layer of dielectric material between the ground plane and the patch, forming a feed line on or within the lower layer of dielectric material, and providing an upper layer of dielectric material between the feed line and the patch. In an example, the upper layer of dielectric material is provided using a foaming process. In one example, the method further comprises removing at least a portion of the structure, such that a remnant of the structure, if any, is no longer in contact with the ground plane and/or the patch. In another example, the structure forms a direct current (DC) shorting structure between the ground plane and the patch. Numerous configurations and variations will be apparent in light of this disclosure.

[0017] General Overview

[0018] As mentioned herein above, there remain a number of non-trivial challenges with respect to designing and manufacturing patch antenna assemblies. For example, a probe-fed patch antenna uses a probe that is physically connected (e.g., via solder or conductive epoxy) to a radiating patch of the patch antenna assembly. The probe may be, for example, an elongated center conductor of a standard coaxial connector. The ground portion of the connector is soldered or otherwise conductively bonded to a ground plane, and the end of the probe (center conductor) is soldered or otherwise conductively bonded to the patch. However, these solder joints or physical conductive bonds are vulnerable to shock and other stresses, e.g., especially in applications that may endure vibrations during use. Additionally, it may be desirable to tune parameters of a patch antenna, which may often be cumbersome, e.g., due to difficulties in controlling or tuning dimensions of various components of the patch antenna.

[0019] Accordingly, techniques are described herein to form an electromagnetically coupled (EMC) patch antenna, which is configured for electromagnetic coupling between the feed line(s) and the patch. Thus, there is no solder joint between a given connector and the ground plane, and/or between the connector and the patch. Additionally, one or more layers of dielectric material of the patch antenna may be manufactured using additive manufacturing processes, such as a foaming process. Because of the nature of the additive manufacturing process, a height of such layer(s) of dielectric material may be fine-tuned, which in turn allows fine tuning of one or more antenna parameters (such as bandwidth, resonant frequency, antenna gain, phase, and/or other antenna parameters) of the patch antenna assembly. For instance, changing the height of the one or more layers of dielectric material affects the effective electrical length of the patch, which, in turn, affects the resonant frequency. In an example, increasing the height may lower the resonant frequency, while decreasing the height may increase the resonant frequency. Similarly, a thicker layer of dielectric material may provide a wider bandwidth, allowing the antenna to operate over a broader range of frequencies. This is because the thicker layer supports more modes of propagation. Thus, having control of the height of the one or more layers of dielectric material via additive manufacturing allows for tuning the antenna to a desired effective electrical length and resonance, while reasonably maintaining the radiation performance, such as gain and bandwidth. In one embodiment for the additively manufacturing the one or more layers of dielectric material, modeling and simulation tools are employed to determine the appropriate dielectric layer heights for the desired frequency response and properties such as the bandwidth, resonant frequency, gain, and phase. Once the modeling is completed, the one or more layers of dielectric material are additively manufactured in accordance with the specification.

[0020] In one embodiment, the antenna assembly comprises a conductive ground plane, which comprises at least partially electrically conductive material (e.g., comprises one or more metals and/or alloys thereof). In another example, the ground plane is at least partially non-conductive and at least partially plated with conductive material (e.g., a metal plating).

[0021] The antenna assembly further comprises one or more lower layers of dielectric material above the ground plane, and an upper layer of dielectric material above the one or more lower layers of dielectric material. For example, the lower layers of dielectric material comprise a first lower layer of dielectric material above the ground plane, and a second lower layer of dielectric material above the first lower layer of dielectric material. Any appropriate type of dielectric material may be used for the lower layers, such as foam, glass and/or ceramic material, composite laminate, epoxy, resin, and/or another appropriate dielectric or composite material (e.g., a composite material comprising woven fiberglass cloth and an epoxy resin binder, such as FR-4). In an example, the lower layers comprise dielectric foam material.

[0022] In an example, the lower layers of dielectric material may be additively manufactured above the ground plane, such as formed using a foaming process or another appropriate additive manufacturing process, as will be described below. Accordingly, in an example, a height of each of the lower layers of dielectric material may be controlled or fine-tuned, which allows to fine-tune associated antenna characteristics.

[0023] In one embodiment, one or more conductive feed lines are between the first and second lower layers of dielectric material. Thus, in an example, the conductive feed lines are within the lower layers of dielectric material. In an example, the antenna assembly includes two feed lines, e.g., to form a dual polarized antenna structure. However, in another example, a single feed line may be used instead, e.g., to form a single polarized antenna structure. In any case, current or other stimulus can be applied to the corresponding feed lines. In some cases the feed lines are driven by on-board circuitry (e.g., RF receiver circuitry). In other examples, the feed lines may be coupled to cabling or other conductive runs and circuitry that deliver the signals to excite the patch antenna.

[0024] In one embodiment, an upper layer of dielectric material is above the lower layers of the dielectric material. Any appropriate type of dielectric material may be used for the upper layer, such as an epoxy, foam, resin, and/or another appropriate dielectric composite material. In an example, the upper layer of dielectric material comprises dielectric foam material. In an example, the upper layer of dielectric material may be additively manufactured, such as formed using a foaming process. Accordingly, in an example, a height of the upper layer of dielectric material may be controlled or fine-tuned, which allows fine-tuning of associated antenna characteristics.

[0025] In an example, a dielectric constant of each of the lower layers of dielectric material is higher than a dielectric constant of the upper layer of dielectric material, e.g., by at least 1.25×, or at least 1.5×, or at least 2×, or at least 5×, or at least 10×. For example, the upper layer of dielectric material comprises a foam dielectric material, resulting in the dielectric constant of the upper layer of dielectric material being lower than the dielectric constant of the lower layers of dielectric material.

[0026] In one embodiment, the antenna assembly further comprises a conductive radiating patch above the upper layer of dielectric material. The patch comprises a conductive material (such as metal, for example, copper, and/or an alloy thereof), or a non-conductive material at least partially plated with a conductive material (e.g., a metal plating). The radiating patch is capable of being electromagnetically excited by the feed lines that are between the patch and the ground plane. Thus, the feed lines are electromagnetically coupled to the patch.

[0027] In one embodiment, the antenna assembly includes a direct current (DC) shorting structure (e.g., a shorting pin) between a ground plane and the patch above the ground plane. In an example, the shorting structure comprises conductive material, e.g., similar to the conductive material of the ground plane and/or the patch. In an example, the conductive shorting structure affects, such as improves, bandwidth of the antenna assembly. In an example and as will be described below (e.g., see FIGS. **6**-**7**D), the patch, the shorting structure, and/or the ground plane may be manufactured using an additive manufacturing process, such as a 3D printing process. For example, the ground plane, the shorting structure, and/or the patch may be manufactured using a same material deposition process. In such an example, there may not be an interface (such as a seam) between the shorting structure and the patch, and/or between the shorting structure and the ground plane, e.g., due to formation of these components using a same deposition process.

[0028] Various example techniques for forming the antenna assembly are described herein below. In one example method of forming the antenna assembly (e.g., as described with respect to FIGS. **4**-**5**G**2** below), the ground plane is formed, followed by formation of a first lower layer of dielectric material above the ground plane. The feed lines are formed above the first lower layer of dielectric material, and then the second lower layer of dielectric material is formed above the first lower layer of dielectric material and the feed lines. In an example, one or more of the first and second lower layers of dielectric material may be additively formed, e.g., using a foaming process. Subsequently the upper layer of dielectric material is formed above the lower layers of dielectric material, e.g., using a foaming process. The patch is finally formed above the upper layer of dielectric material.

[0029] In another example method of forming the antenna assembly (e.g., as described with respect to FIGS. **6**-**7**D below), an element comprising the ground plane, the patch, one or more structures is formed using an additive manufacturing process, such as a 3D printing process. The one or more structures support the patch above the ground plane. One such example structure may be sacrificial in nature and may later be removed (such as the structure **702** of FIGS. **7**A-**7**C). Another such example structure may form the shorting structure or shorting pin between the patch and the ground plane, and may not be removed later (such as the shorting structure **304** of FIGS. **7**A-**7**D). In an example, the element is a continuous, monolithic, and conductive element. The element being a monolithic and continuous element implies that any section of the element is conjoined (e.g., physically joined) with any other section of the element via one or more intervening sections. Thus, the element is a single integral conductive element that has been additively manufactured.

[0030] In an example, additively manufacturing the element may include using any appropriate additive manufacturing techniques to form the element. For example, additively manufacturing the element may include printing the element using a 3D printer. Additive manufacturing, such as 3D printing, uses computer-aided-design (CAD) software and/or 3D object scanners to direct hardware to deposit material, layer upon layer, in precise geometric shapes. As its name implies, additive manufacturing adds material to create an object. Thus, additive manufacturing involves a computer controlled process that creates 3D objects, such as the element, by depositing materials, usually in layers.

[0031] Subsequent to forming the monolithic element, one or more lower layers of dielectric material are provided above the ground plane (e.g., using an additive manufacturing technique or another appropriate technique), and one or more feed lines are formed within or on the lower layer(s) of dielectric material, as also described above. Subsequently, an upper layer of dielectric material above the one or more feed lines is provided (e.g., see FIG. **7**C), such as using a foaming process.

[0032] Note that the upper layer of dielectric material now can support the patch above the ground plane. Accordingly, the structures of the monolithic element, which were previously used to support the patch above the ground plane, may optionally be removed (e.g., unless the structures are used as shorting structures in the antenna assembly), e.g., using an appropriate machining or drilling technique. Numerous configurations and variations will be apparent in light of this disclosure.

[0033] Materials that are “compositionally different” or “compositionally distinct” as used herein refers to two materials that have different chemical compositions. This compositional difference may be, for instance, by virtue of an element that is in one material but not the other (e.g., copper is compositionally different than an alloy of copper), or by way of one material having all the same elements as a second material but at least one of those elements is intentionally provided at a different concentration in one material relative to the other material (e.g., two copper alloys each having copper and tin, but with different percentages of copper, are also compositionally different). If two materials are elementally different, then one of the materials has an element that is not in the other material (e.g., pure copper is elementally different than an alloy of copper).

[0034] It should be readily understood that the meaning of “above” and “over” in the present disclosure should be interpreted in the broadest manner such that “above” and “over” not only mean “directly on” something but also include the meaning of over something with an intermediate feature or a layer therebetween. As will be appreciated, the use of terms like “above” “below” “beneath” “upper” “lower” “top” and “bottom” are used to facilitate discussion and are not intended to implicate a rigid structure or fixed orientation; rather such terms merely indicate spatial relationships when the structure is in a given orientation.

Architecture

[0035] FIG. **1**A illustrates a perspective view, FIG. **1**B illustrates a cross-sectional view, and FIG. **1**C illustrates an exploded view of an electromagnetically coupled (EMC) patch antenna structure **100** (also referred to herein as an antenna structure **100**, or simply as a structure **100**), wherein the patch antenna structure **100** comprises a ground plane **116**, one or more lower layers **112***a*, **112***b* of dielectric material above the ground plane **116**, one or more feed lines **120***a*, **120***b* within the one or more lower layers **112***a*, **112***b* of dielectric material, an upper layer **108** of dielectric material above the one or more lower layers **112***a*, **112***b* of dielectric material, and a radiating conductive patch **104** above the upper layer **108** of dielectric material, in accordance with an embodiment of the present disclosure. As will be described below, the structure **100** (e.g., at least some of the components of the structure **100**) may be additively manufactured, and hence, the structure **100** is also referred to as an additively manufactured electromagnetically coupled patch antenna structure **100**.
[0036] Referring to FIGS. **1**A-**1**C, the structure **100** comprises a conductive ground plane **116**. For example, the ground plane **116** comprises material is at least partially electrically conductive (e.g., comprises one or more metals and/or alloys thereof). In another example, the material of the ground plane **116** is at least partially non-conductive and at least partially plated with another conductive material (e.g., a metal plating). In an example, the ground plane **116** comprises an appropriate metal such as copper, and/or an alloy thereof.
[0037] The structure **100** comprises one or more lower layers **112***a*, **112***b* of dielectric material above the ground plane **116**, and an upper layer **108** of dielectric material above the one or more lower layers **112***a*, **112***b* of dielectric material. For example, the lower layers of dielectric material comprise two such lower layers **112***a*, **112***b* of dielectric material. In such an example, the lower layers **112***a*, **112***b* of dielectric material may be compositionally and/or elementally the same, although they may be different in another example.
[0038] Any appropriate type of dielectric material may be used for the lower layers **112***a*, **112***b*, such as an appropriate dielectric material used in printed circuit boards (PCBs), a composite material comprising woven fiberglass cloth and an epoxy resin binder, glass and/or ceramic material, composite laminate, foam, epoxy, resin, and/or another appropriate dielectric material. In an example, the lower layers **112***a*, **112***b* comprise dielectric foam material.
[0039] In one embodiment, one or more conductive feed lines **120***a*, **120***b* are between the lower layer **112***a* and the lower layer **112***b*. Thus, in an example, the conductive feed lines **120***a*, **120***b* are embedded within the lower layers **112***a*, **112***b*.
[0040] In the perspective view of FIG. **1**A, the feed lines **120***a*, **120***b* would not be visible (e.g., as being covered by the layers **108** and **112***b*), and hence, are illustrated in dotted lines in this figure. The feed lines **120***a*, **120***b* are visible in FIGS. **1**B and **1**C.
[0041] The feed lines **120***a*, **120***b* comprise conductive material, such as one or more metals and/or alloys thereof. The two feed lines **120***a*, **120***b* are used to form a dual polarized antenna structure **100**. However, a single feed line may be used instead, e.g., to form a single polarized antenna structure.
[0042] As illustrated in FIG. **1**B, at least a section of the feed line **120***a* may be below (e.g., vertically below) the patch **104**, and similarly, at least a section of the feed line **120***b* may be below (e.g., vertically below) the patch **104**. For example, a vertical imaginary line, which is orthogonal to a plane of the patch **104** and the ground plane **116**, passes through the patch **104** and the feed line **120***a*. Similarly, another vertical imaginary line, which is orthogonal to a plane of the patch **104** and the ground plane **116**, passes through the patch **104** and the feed line **120***b*. However, in another example, no section of the feed lines **120***a* and/or **120***b* may be below (e.g., vertically below) the patch **104**.
[0043] Although not illustrated, an end of the feed line **120***a* (such as a left end of the feed line **120***a* in the orientation of FIG. **1**B) may be in electrical connection with a cable connector, which supplies current to the feed line **120***a*. Similarly, although not illustrated, an end of the feed line **120***b* (such as a right end of the feed line **120***b* in the orientation of FIG. **1**B) may be in electrical

connection with another cable connector, which supplies current to the feed line **120***b*.

[0044] In an example, the lower layers **112***a*, **112***b* of dielectric material may be additively manufactured above the ground plane **116**, such as formed using a foaming process or another appropriate additive manufacturing process, as will be described below. In an example, additively manufacturing the lower layers **112***a*, **112***b* facilitates in controlling or fine tuning vertical Z-axis heights of the lower layers **112***a*, **112***b*. For example, as illustrated in FIG. **1**B, the vertical Z-axis heights of the lower layers **112***a*, **112***b* are h**2***a* and h**2***b*, respectively, such that a combined vertical Z-axis height of the lower layers **112***a*, **112***b* is h**2**. The heights h**2***a*, h**2***b*, and/or h**2** may be used to tune one or more antenna characteristics (such as bandwidth, antenna gain, phase, and/or one or more other antenna characteristics). Additively manufacturing the lower layers **112***a*, **112***b* facilitates in fine tuning the heights h**2***a*, h**2***b*, and/or h**2**, thereby facilitates controlling associated antenna characteristics.

[0045] The upper layer **108** of dielectric material is above the lower layer **112***b* of the dielectric material. Any appropriate type of dielectric material may be used for the upper layer **108**, such as an epoxy, foam, resin, and/or another appropriate dielectric composite material. In an example, the upper layer **108** comprise dielectric foam material. In an example, the upper layer **108** of dielectric material may be additively manufactured, such as formed using a foaming process above the lower layers **112***a*, **112***b*. In an example, additively manufacturing the upper layer **108** facilitates in controlling or fine tuning vertical Z-axis height of the upper layer **108**. For example, as illustrated in FIG. **1**B, the vertical Z-axis height of the upper layer **108** is h**1**. The height h**1** (e.g., along with the heights h**2***a*, h**2***b*, and/or h**2**) may be used to tune antenna characteristics (such as bandwidth, antenna gain, phase, and/or one or more other antenna characteristics). Additively manufacturing the upper layer **108** facilitates in fine tuning the height h**1**, thereby facilitates in controlling associated antenna characteristics. In some examples, heights h**2***a*, h**2***b*, h**1** of one or more of the layers **112***a*, **112***b*, **108** of dielectric material may influence the bandwidth of the patch antenna structure **100** and/or the resonant frequency of the antenna. For instance, changing the heights h**2***a*, h**2***b*, h**1** of the one or more layers of dielectric material affects the effective electrical length of the patch **104**, which, in turn, affects the resonant frequency of the patch antenna structure **100**. The heights h**2***a*, h**2***b*, h**1** of the one or more layers **112***a*, **112***b*, **108** of dielectric material may also influence the bandwidth of the patch antenna structure **100**. In an example, increasing one or more of the heights h**2***a*, h**2***b*, h**1** may lower the resonant frequency, while decreasing one or more of the heights h**2***a*, h**2***b*, h**1** may increase the resonant frequency. Similarly, a thicker layer of dielectric material supports more modes of propagation and therefore may provide a wider bandwidth, allowing the antenna to operate over a broader range of frequencies. Thus, having control of the height of the one or more layers **112***a*, **112***b*, **108** of dielectric material via additive manufacturing allows for tuning the patch antenna structure **100** to a desired resonance, while reasonably maintaining the radiation performance, such as gain and bandwidth. In one embodiment for the additively manufacturing the one or more layers **112***a*, **112***b*, and/or **108** of dielectric material, modeling and simulation tools are employed to determine the appropriate heights of the layers **112***a*, **112***b*, and/or **108** for the desired frequency response and properties such as the bandwidth, resonant frequency, gain, and phase. Once the modeling is completed, the one or more layers of dielectric material are additively manufactured in accordance with the specification.

[0046] In an example, a dielectric constant of the lower layers **112***a* and/or **112***b* of dielectric material is higher than a dielectric constant of the upper layer **108** of dielectric material, e.g., by at least 1.25×, or at least 1.5×, or at least 2×, or at least 5×, or at least 10×, where the suffix “x” denotes multiplication (e.g., 1.25× implies that the dielectric constant of a lower layer of dielectric material is higher than the dielectric constant of the upper layer of dielectric material by 1.25 times or 25%). For example, the upper layer **108** of dielectric material comprises a foam dielectric material, resulting in the dielectric constant of the upper layer **108** of dielectric material being lower than the dielectric constant of the lower layers **112***a* and/or **112***b* of dielectric material.

[0047] The structure **100** comprises a conductive radiating patch **104** above the upper layer **108** of dielectric material. The patch **104** comprises a conductive material (such as metal, for example, copper, and/or an alloy thereof), or a non-conductive material least partially plated with a conductive material (e.g., a metal plating). The radiating patch **104** is excited by the feed lines **120***a*, **120***b* that are between the patch **104** and the ground plane **116**. The feed lines **120***a*, **120***b* are electromagnetically coupled to the radiating patch **104**. As used herein, a radiating patch refers to a patch that is capable of radiating and not necessarily a patch that is actively radiating (e.g., a radiating patch may not be radiating when not in use). Likewise, an electromagnetically coupled (EMC) patch antenna structure as used herein refers to a patch antenna structure that is capable of electromagnetic coupling and not necessarily a patch antenna structure that is actively electromagnetically coupled (e.g., an EMC patch antenna may not be electromagnetically coupled when not in use). Given the electromagnetic coupling, there is no need for any solder joints between feed lines **120***a*, **120***b* and patch **104**. Such a solder-free coupling at the feed line/patch interface is advantageous, as described above.
[0048] In FIGS. **1**A-**1**C, the two lower layers **112***a*, **112***b* of dielectric material are distinct, e.g., manufactured at different times in the process flow, and/or are compositionally or elementally different. However, in another example, the two lower layers **112***a*, **112***b* of dielectric material may be replaced by a single lower layer **112** of dielectric material, which embeds the feed lines **120***a*, **120***b*, as illustrated in FIG. **2**A. For example, FIG. **2**A illustrates a cross-sectional view of an EMC patch antenna structure **200***a* (also referred to herein as an antenna structure **200***a*, or simply as a structure **200***a*) having a single lower layer **112** of dielectric material above a ground plane **116**, one or more feed lines **120***a*, **120***b* within the lower layer **112** of dielectric material, an upper layer **108** of dielectric material above the lower layer **112** of dielectric material, and a radiating conductive patch **104** above the upper layer **108** of dielectric material, in accordance with an embodiment of the present disclosure. Like elements in FIGS. **1**A-**1**C and **2**A are labelled using the same labels. The antenna structure **200***a* of FIG. **2**A will be apparent, based on the above description of the antenna structure **100** of FIG. **1**A-**1**C.
[0049] In FIGS. **1**A-**1**C, the feed lines **120***a*, **120***b* are embedded within the two lower layers **112***a*, **112***b* of dielectric material. However, in another example, the feed lines **120***a*, **120***b* may be above the lower layers **112***a*, **112***b* of dielectric material. For example, FIG. **2**B illustrates a cross-sectional view of an EMC patch antenna structure **200***b* (also referred to herein as an antenna structure **200***b*, or simply as a structure **200***b*) having a lower layer **112** of dielectric material above a ground plane **116**, one or more feed lines **120***a*, **120***b* above the lower layer **112** of dielectric material, an upper layer **108** of dielectric material above the lower layer **112** of dielectric material, and a radiating conductive patch **104** above the upper layer **108** of dielectric material, in accordance with an embodiment of the present disclosure. Like elements in FIGS. **1**A-**1**C and **2**B are labelled using the same labels. The antenna structure **200***b* of FIG. **2**B will be apparent, based on the above description of the antenna structure **100** of FIG. **1**A-**1**C.
[0050] FIG. **2**C illustrates a cross-sectional view of an EMC patch antenna structure **200***c* (also referred to herein as an antenna structure **200***c*, or simply as a structure **200***c*) having a lower layer **112** of dielectric material above a ground plane **116**, one or more feed lines **120***a*, **120***b* within the lower layer **112** of dielectric material, an upper layer **108** of dielectric material above the lower layer **112** of dielectric material, a radiating conductive patch **104** above the upper layer **108** of dielectric material, and a top layer **220** of dielectric material at least in part above the radiating conductive patch **104**, in accordance with an embodiment of the present disclosure. Thus, the layer **220** of dielectric material acts as a superstrate dielectric material that is around and/or above the patch **104**, in an example. Like elements in FIGS. **1**A-**1**C and **2**C are labelled using the same labels.
[0051] The antenna structure **200***c* of FIG. **2**C will be apparent, based on the above description of the antenna structure **100** of FIG. **1**A-**1**C.
[0052] FIG. **3** illustrates a cross-sectional view of an EMC patch antenna structure **300** (also

referred to herein as an antenna structure **300**, or simply as a structure **300**) having a direct current (DC) shorting structure **304** between a ground plane **116** and a radiating conductive patch **104** above the ground plane **116**, in accordance with an embodiment of the present disclosure. Like elements in FIGS. **1**A-**1**C and **3** are labelled using the same labels.

[0053] In an example, the shorting structure **304** comprises conductive material, e.g., similar to the conductive material of the ground plane **116** and/or the patch **104**. In an example, the conductive shorting structure **304** affects, such as improves, bandwidth of the antenna structure **300**.

[0054] In an example and as will be described below (e.g., see FIGS. **6-7**D), the patch **104**, the shorting structure **304**, and/or the ground plane **116** may be manufactured using an additive manufacturing process, such as a 3D printing process. For example, the ground plane **116**, the shorting structure **304**, and/or the patch **104** may be manufactured using a same material deposition process. In an example, the ground plane **112**, the shorting structure **426**, and the patch **104** may comprise elementally and/or compositionally the same material. In such an example, there may not be an interface (such as a seam) between the shorting structure **304** and the patch **104**, and/or between the shorting structure **304** and the ground plane **116**, e.g., due to formation of these components using a same deposition process. For example, the ground plane **116**, the shorting structure **304**, and the patch **104** may comprise a continuous and monolithic body of conductive material, such as a metal and/or an alloy thereof. The antenna structure **300** of FIG. **3** will be apparent, based on the above description of the antenna structure **100** of FIG. **1**A-**1**C.

Method of Manufacturing

[0055] FIG. **4** illustrate a flowchart depicting a method **400** of forming an example antenna assembly (such as any of the antenna structures described above), in accordance with an embodiment of the present disclosure. FIGS. **5**A, **5**B, **5**C, **5**D, **5**E, **5**F, **5**G**1**, and **5**G**2** collectively illustrate an example antenna assembly **500** in various stages of processing in accordance with the methodology **400** of FIG. **4**, in accordance with an embodiment of the present disclosure. FIGS. **4** and **5**A-**5**G**2** will be discussed in unison.

[0056] Referring to the method **400** of FIG. **4**, at **404**, a conductive ground plane is formed, such as formed using an additive manufacturing process. FIG. **5**A illustrates the ground plane **116**. In an example, an appropriate additive manufacturing process, such as a 3D printing process, may be employed. The ground plane **116** comprises material that is at least partially electrically conductive (e.g., comprises one or more metals and/or alloys thereof). In another example, the material of the ground plane **116** is at least partially non-conductive and at least partially plated with another conductive material (e.g., a metal plating). In an example, the ground plane **116** comprises an appropriate metal such as copper, and/or an alloy thereof.

[0057] The method **400** proceeds from **404** to **408**. At **408**, one or more lower layers of dielectric material are provided above the ground plane, and one or more feed lines are formed within or on one or more of the lower layer(s) of dielectric material, e.g., as illustrated in FIGS. **5**B, **5**C, and **5**D. For example, in FIG. **5**B, a first lower layer **112***a* of dielectric material is provided above the ground plane **116**. In FIG. **5**C, feed lines **120***a* and **120***b* are formed on the first lower layer **112***a* of dielectric material. In FIG. **5**D, a second lower layer **112***b* of dielectric material is formed on the first lower layer **112***a* of dielectric material and the feed lines **120***a*, **120***b*, such that the feed lines **120***a*, **120***b* are sandwiched between the first and second lower layers **112***a* and **112***b*.

[0058] In an example, the first and second lower layers **112***a* and **112***b* may be additively formed. For example, the lower layers **112***a*, **112***b* comprising dielectric foam may be provided above the ground plane **116** using any appropriate foaming technique. Merely as an example, during the foaming process, a mixture of an activator and a foaming portion may be deposited above the ground plane **116**, and then the foaming mixture may be cured at an appropriate temperature, such that rigid foam forms from the activator and the foaming portion. In another example, a foaming gel or solution may be applied above the ground plane **116** and then cured, such that rigid foam forms above the ground plane **116**. In yet another example, a foaming power (e.g., comprising microspheres including resins or another appropriate material) is applied and then cured at an appropriate temperature, such that the foaming power transforms to the rigid dielectric foam of the layers **112***a*, **112***b*. Any appropriate foaming process can be used, and the selection of the foaming process and/or the selection of an appropriate type of foam may be implementation specific. In an example, between the foaming processes to form the lower layers **112***a* and **112***b*, the feed lines **120***a*, **120***b* may be formed above the lower layer **112***b*. In an example, any appropriate deposition technique (such as a 3D printing process, or another appropriate metal deposition process) may be employed to form the feed lines **120***a*, **120***b*.

[0059] In another example, the first and second lower layers **112***a* and **112***b* may not be dielectric foam material, such as may comprise a PCB dielectric material, a laminate, an epoxy, a resin, and/or another appropriate non-foam dielectric material. In some such examples, the lower layers **112***a* and **112***b* may be pre-formed, and then attached (e.g., using adhesive) to the ground plane **116**.

[0060] The method **400** proceeds from **408** to **412**. At **412**, an upper layer of dielectric material is provided above the one or more feed lines. For example, FIG. **5**E illustrates the upper layer **108** of dielectric material above the feed lines **120***a*, **120***b*, and also above the lower layer **112***b* of dielectric material.

[0061] In an example, the upper layer **108** of dielectric material may be additively formed, such as using a foaming process. Examples of various foaming process have been described above.

[0062] In an example, a dielectric constant of the lower layers **112***a* and/or **112***b* of dielectric material is higher than a dielectric constant of the upper layer **108** of dielectric material, e.g., by at least 1.25×, or at least 1.5×, or at least 2×, or at least 5×, or at least 10×. For example, the upper layer **108** of dielectric material comprises a foam dielectric material having relatively lower dielectric constant, resulting in the dielectric constant of the upper layer **108** of dielectric material being lower than the dielectric constant of the lower layers **112***a* and/or **112***b* of dielectric material.

[0063] Forming one or more of the lower layers **112***a*, **112***b*, and the upper layer **108** of dielectric material using additive manufacturing processes facilitates in fine tuning a height of the corresponding layer of dielectric material, e.g., as described above with respect to FIG. **1**B. This in turn allows to fine tune or control one or more parameters of the resultant antenna, in an example, as also described above with respect to FIG. **1**B. In one embodiment for the additively manufacturing the one or more layers **112***a*, **112***b*, and/or **108** of dielectric material, prior to manufacturing these layers, modeling and simulation tools are employed to determine the appropriate heights of the layers **112***a*, **112***b*, and/or **108** for the desired frequency response and properties such as the bandwidth, resonant frequency, gain, and phase. Once the modeling is completed, the one or more layers **112***a*, **112***b*, and/or **108** of dielectric material are additively manufactured in accordance with the specification. Because additive manufacturing processes facilitates in fine tuning a height of the corresponding layer of dielectric material, the heights of layers **112***a*, **112***b*, and/or **108** may be fine tuned in accordance with the target heights determined during the modeling and simulation.

[0064] Optionally (and although not illustrated in FIG. **4**), subsequent to process **412** (or any time during the method **400**), a shorting structure **305** may be formed within the structure **500**, as illustrated in FIG. **5**F. For example, opening may be formed (or may be pre-formed) within the layers **112***a*, **112***b*, **108** of the dielectric material, and conductive material (such as metal or alloy thereof) may be deposited or inserted within the opening, to form the shorting structure **304**.

[0065] The method **400** proceeds from **412** to **416**. At **416**, a conductive patch is formed above upper layer of dielectric material, e.g., as illustrated in FIGS. **5**G**1** and **5**G**2**. For example, FIG. **5**G**1** is the structure **500** without the shorting structure **304** (e.g., is formed from the structure of FIG. **5**E). On the other hand, FIG. **5**G**2** is the structure **500** with the shorting structure **304** (e.g., is formed from the structure of FIG. **5**F). The conductive patch **104** may be formed using any appropriate deposition technique, such as an additive metal or an alloy deposition process, and may include 3D printing, metal ink printing, or simply attaching a pre-formed patch **104** to the layer **108** using an adhesive.

[0066] Note that the processes in method **400** are shown in a particular order for ease of description. However, one or more of the processes may be performed in a different order or may not be performed at all (and thus be optional), in accordance with some embodiments. Numerous variations on method **400** and the techniques described herein will be apparent in light of this disclosure.

[0067] FIG. **6** illustrate a flowchart depicting another method **600** of forming an example antenna assembly (such as any of the antenna structures described above), in accordance with an embodiment of the present disclosure. FIGS. **7**A, **7**B, **7**C, and **7**D collectively illustrate an example antenna assembly **700** in various stages of processing in accordance with the methodology **600** of FIG. **6**, in accordance with an embodiment of the present disclosure. FIGS. **6** and **7**A-**7**D will be discussed in unison.

[0068] At **604** of the method **600**, a continuous, monolithic, and conductive element **701** is additively manufactured, where the element **701** includes (i) a ground plane **116**, (ii) a patch **104** above the ground plane **116**, and (iii) one or more structures **702**, **304**, each structure having a first end in contact with the ground plane and a second end in contact with the patch. Examples of the structures includes the shorting structure **304**, and one or more other structures **702** that support the patch **104** above the ground plane **116**. Thus, the antenna structure **700** can include the structures **702** and/or the shorting structure **304**. Note that at this point, the layers dielectric material has not yet been applied. Accordingly, the patch **104** is supported above the ground plane **116** by the structures **702** and/or **304**.

[0069] In an example, the element **701** is a monolithic and continuous structure. The element **701** being a monolithic and continuous structure implies that any section of the element **701** is conjoined (e.g., physically joined) with any other section of the element **701** via one or more intervening sections. Thus, the element **701** is a single integral element that has been additively manufactured.

[0070] In an example, additively manufacturing the element **701** may include using any appropriate additive manufacturing techniques to form the element **701**. For example, additively manufacturing the element **701** may include printing the element **701** using a 3D printer. Additive manufacturing, such as 3D printing, uses computer-aided-design (CAD) software and/or 3D object scanners to direct hardware to deposit material, layer upon layer, in precise geometric shapes. As its name implies, additive manufacturing adds material to create an object. Thus, additive manufacturing involves a computer controlled process that creates 3D objects, such as the element **701**, by depositing materials, usually in layers.

[0071] The method **600** proceeds from **604** to **608**. At **608**, one or more lower layers of dielectric material are provided above the ground plane, and one or more feed lines are formed within or on one or more of the lower layer(s) of dielectric material, as illustrated in FIG. **7**B. In an example, process **608** is similar to the process **408** of the method **400** described above.

[0072] The method **600** proceeds from **608** to **612**. At **612**, an upper layer **108** of dielectric material above the one or more feed lines is provided, as illustrated in FIG. **7**C. In an example, process **612** is similar to the process **412** of the method **400** described above. Subsequent to the formation of the upper layer **108** of dielectric material, now the upper layer **108** of dielectric material can at least in part support the patch **104**.

[0073] The method **600** proceeds from **612** to **616**. At **616**, at least a portion of the one or more structures are removed, e.g., as illustrated in FIG. **7**D. For example, the one or more structures included the shorting structure **304** and the structure **702**. As illustrated in FIG. **7**D, the structure **702** is at least in part removed, e.g., such that remnant of the structure **702**, if any, is no longer in contact with the ground plane **116** and/or the patch **104**. In an example, the structure **702** may be machined or drilled away.

[0074] In an example, the process **616** may be optionally omitted. For example, if the structure **701** comprises the shorting structure **304** (and not the structure **702**), then the shorting structure **304** need not be removed at process **616**.

[0075] Note that the processes in method **600** are shown in a particular order for ease of description. However, one or more of the processes may be performed in a different order or may not be performed at all (and thus be optional), in accordance with some embodiments. Numerous variations on method **600** and the techniques described herein will be apparent in light of this disclosure.

Further Example Examples

[0076] The following pertain to further examples, from which numerous permutations and configurations will be apparent.

[0077] Example 1. An antenna assembly comprising: a conductive ground plane; a lower layer of dielectric material above the conductive ground plane; an upper layer of dielectric material above the lower layer of dielectric material, wherein at least one of the lower or upper layers of dielectric material comprise dielectric foam; a conductive feed line between at least a section of the lower layer of dielectric material and the upper layer of dielectric material; and a conductive patch above the upper layer of dielectric material, wherein the conductive patch is configured for electromagnetic coupling with the conductive feed line.

[0078] Example 2. The antenna assembly of example 1, wherein a dielectric constant of the lower layer of dielectric material is at least 25% more than a dielectric constant of the upper layer of dielectric material.

[0079] Example 3. The antenna assembly of any one of examples 1-2, wherein the upper layers of dielectric material comprise dielectric foam.

[0080] Example 4. The antenna assembly of any one of examples 1-3, wherein the lower layer of dielectric material is a first lower layer of dielectric material, and wherein the antenna assembly further comprises: a second lower layer of dielectric material above the first lower layer of dielectric material, such that the conductive feed line is between the first and second lower layers of dielectric material, and the upper layer of dielectric material is above the second lower layer of dielectric material.

[0081] Example 5. The antenna assembly of example 4, wherein dielectric constants of each of the first and second lower layers of dielectric material are at least 25% more than a dielectric constant of the upper layer of dielectric material.

[0082] Example 6. The antenna assembly of any one of examples 1-5, further comprising a shorting structure between the conductive ground plane and the conductive patch, wherein the shorting structure is monolithic and continuous with each of the conductive ground plane and the conductive patch.

[0083] Example 7. The antenna assembly of any one of examples 1-6, wherein the conductive feed line is a first conductive feed line, and wherein the antenna assembly further comprises: a second conductive feed line between at least another section of the lower layer of dielectric material and the upper layer of dielectric material.

[0084] Example 8. The antenna assembly of any one of examples 1-7, wherein the conductive feed line is within the lower layer of dielectric material.

[0085] Example 8a. The antenna assembly of any one of examples 1-8, wherein coupling from the conductive patch to the conductive feed line is free of physical connection.

[0086] Example 8b. The antenna assembly of any one of examples 1-8a, wherein coupling from the conductive patch to the conductive feed line is free of solder joints.

[0087] Example 8c. The antenna assembly of any one of examples 1-8b, wherein coupling from the conductive patch to the conductive feed line is free of conductive bonds.

[0088] Example 9. A method of manufacturing an antenna assembly, the method comprising: additively forming a conductive ground plane; providing a lower layer of dielectric material above the conductive ground plane; forming a conductive feed line on the lower layer of dielectric material; providing an upper layer of dielectric material above the conductive feed line; and forming a conductive patch above upper layer of dielectric material.

[0089] Example 10. The method of example 9, wherein providing the upper layer of dielectric material above the conductive feed line comprises: additively forming the upper layer of dielectric material above the conductive feed line.

[0090] Example 11. The method of any one of examples 9-10, wherein providing the upper layer of dielectric material above the conductive feed line comprises: providing the upper layer of dielectric material using a foaming process.

[0091] Example 12. The method of any one of examples 9-11, wherein the lower layer of dielectric material is a first lower layer of dielectric material, and wherein the method further comprises: forming a second lower layer of dielectric material above the conductive feed line, such that the conductive feed line is sandwiched between the first and second lower layers of dielectric material.

[0092] Example 13. The method of example 12, wherein dielectric constants of each of the first and second lower layers of dielectric material are at least 25% more than a dielectric constant of the upper layer of dielectric material.

[0093] Example 14. The method of any one of examples 9-13, wherein providing the lower layer of dielectric material above the conductive ground plane comprises: additively forming the lower layer of dielectric material above the conductive ground plane.

[0094] Example 15. The method of any one of examples 9-14, wherein the conductive feed line is a first conductive feed line, and wherein the method further comprises: forming a second conductive feed line on the lower layer of dielectric material.

[0095] Example 16. A method of manufacturing an antenna assembly, the method comprising: additively manufacturing an element that includes (i) a ground plane, (ii) a patch above the ground plane, and (iii) a structure having a first end in contact with the ground plane and a second end in contact with the patch, such that the structure is monolithic and continuous within the ground plane and the patch; providing a lower layer of dielectric material between the ground plane and the patch; forming a feed line on or within the lower layer of dielectric material; and providing an upper layer of dielectric material between the feed line and the patch.

[0096] Example 17. The method of example 16, further comprising: removing at least a portion of the structure, such that a remnant of the structure, if any, is no longer in contact with the ground plane and/or the patch.

[0097] Example 18. The method of any one of examples 16-17, wherein the structure forms a direct current (DC) shorting structure between the ground plane and the patch.

[0098] Example 19. The method of any one of examples 16-18, wherein providing the upper layer of dielectric material comprises: providing the upper layer of dielectric material using a foaming process.

[0099] Example 20. The method of any one of examples 16-19, wherein additively manufacturing the element comprises printing the element using a three-dimensional (3D) printing process.

[0100] Numerous specific details have been set forth herein to provide a thorough understanding of the examples. It will be understood, however, that other examples may be practiced without these specific details, or otherwise with a different set of details. It will be further appreciated that the specific structural and functional details disclosed herein are representative of examples and are not necessarily intended to limit the scope of the present disclosure. In addition, although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described herein. Rather, the specific features and acts described herein are disclosed as example forms of implementing the claims. Furthermore, examples described herein may include other elements and components not specifically described, such as electrical connections, signal transmitters and receivers, processors, or other suitable components for operation of the antenna system **100**.

[0101] The terms and expressions which have been employed herein are used as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions, of excluding any equivalents of the features shown and described (or portions thereof), and it is recognized that various modifications are possible within the scope of the claims. Accordingly, the claims are intended to cover all such equivalents. Various features, aspects, and examples have been described herein. The features, aspects, and examples are susceptible to combination with one another as well as to variation and modification, as will be appreciated in light of this disclosure. The present disclosure should, therefore, be considered to encompass such combinations, variations, and modifications. It is intended that the scope of the present disclosure be limited not by this detailed description, but rather by the claims appended hereto. Future filed applications claiming priority to this application may claim the disclosed subject matter in a different manner and may generally include any set of one or more elements as variously disclosed or otherwise demonstrated herein.

Claims

1. An antenna assembly comprising: a conductive ground plane; a lower layer of dielectric material above the conductive ground plane; an upper layer of dielectric material above the lower layer of dielectric material, wherein at least one of the lower or upper layers of dielectric material comprise dielectric foam; a conductive feed line between at least a section of the lower layer of dielectric material and the upper layer of dielectric material; and a conductive patch above the upper layer of dielectric material, wherein the conductive patch is configured for electromagnetic coupling with the conductive feed line.

2. The antenna assembly of claim 1, wherein a dielectric constant of the lower layer of dielectric material is at least 25% more than a dielectric constant of the upper layer of dielectric material.

3. The antenna assembly of claim 1, wherein the upper layer of dielectric material comprise dielectric foam.

4. The antenna assembly of claim 1, wherein the lower layer of dielectric material is a first lower layer of dielectric material, and wherein the antenna assembly further comprises: a second lower layer of dielectric material above the first lower layer of dielectric material, such that the conductive feed line is between the first and second lower layers of dielectric material, and the upper layer of dielectric material is above the second lower layer of dielectric material.

5. The antenna assembly of claim 4, wherein dielectric constants of each of the first and second lower layers of dielectric material are at least 25% more than a dielectric constant of the upper layer of dielectric material.

6. The antenna assembly of claim 1, further comprising a shorting structure between the conductive ground plane and the conductive patch, wherein the shorting structure is monolithic and continuous with each of the conductive ground plane and the conductive patch.

7. The antenna assembly of claim 1, wherein the conductive feed line is a first conductive feed line, and wherein the antenna assembly further comprises: a second conductive feed line between at least another section of the lower layer of dielectric material and the upper layer of dielectric material.

8. The antenna assembly of claim 1, wherein the conductive feed line is within the lower layer of dielectric material.

9. A method of manufacturing an antenna assembly, the method comprising: additively forming a conductive ground plane; providing a lower layer of dielectric material above the conductive ground plane; forming a conductive feed line on the lower layer of dielectric material; providing an upper layer of dielectric material above the conductive feed line; and forming a conductive patch above upper layer of dielectric material.

10. The method of claim 9, wherein providing the upper layer of dielectric material above the conductive feed line comprises: additively forming the upper layer of dielectric material above the conductive feed line.
11. The method of claim 9, wherein providing the upper layer of dielectric material above the conductive feed line comprises: providing the upper layer of dielectric material using a foaming process.
12. The method of claim 9, wherein the lower layer of dielectric material is a first lower layer of dielectric material, and wherein the method further comprises: forming a second lower layer of dielectric material above the conductive feed line, such that the conductive feed line is sandwiched between the first and second lower layers of dielectric material.
13. The method of claim 12, wherein dielectric constants of each of the first and second lower layers of dielectric material are at least 25% more than a dielectric constant of the upper layer of dielectric material.
14. The method of claim 9, wherein providing the lower layer of dielectric material above the conductive ground plane comprises: additively forming the lower layer of dielectric material above the conductive ground plane.
15. The method of claim 9, wherein the conductive feed line is a first conductive feed line, and wherein the method further comprises: forming a second conductive feed line on the lower layer of dielectric material.
16. A method of manufacturing an antenna assembly, the method comprising: additively manufacturing an element that includes (i) a ground plane, (ii) a patch above the ground plane, and (iii) a structure having a first end in contact with the ground plane and a second end in contact with the patch, such that the structure is monolithic and continuous within the ground plane and the patch; providing a lower layer of dielectric material between the ground plane and the patch; forming a feed line on or within the lower layer of dielectric material; and providing an upper layer of dielectric material between the feed line and the patch.
17. The method of claim 16, further comprising: removing at least a portion of the structure, such that a remnant of the structure, if any, is no longer in contact with the ground plane and/or the patch.
18. The method of claim 16, wherein the structure forms a direct current (DC) shorting structure between the ground plane and the patch.
19. The method of claim 16, wherein providing the upper layer of dielectric material comprises: providing the upper layer of dielectric material using a foaming process.
20. The method of claim 16, wherein additively manufacturing the element comprises printing the element using a three-dimensional (3D) printing process.