

REINFORCED ANTENNA HOUSING

TECHNOLOGICAL FIELD

The present disclosure relates to radome structures, and specifically to radome structures configured to be reinforced with respect to small firearms and grenade shrapnel.

5 BACKGROUND

A radome is a structure configured to provide housing for one or more antennas or other electronic equipment. The radome structure generally provides protection to the electronic elements from environmental conditions while allowing transmission of electromagnetic radiation of one or more selected frequency ranges. Radomes are often
10 used in aerial platforms, mobile land platforms, maritime platforms and stationary platforms to provide protection of selected elements and allow certain level of communication through the radome. In addition to the above, in the example of aerial or mobile platforms, radomes are also generally designed to follow aerodynamic requirements while providing physical strength and stability that meet necessary
15 environmental conditions.

Typical conventional radome design is formed of one or more structural layers selected to provide strength and stability. The overall radome structure (either single or multi-layered) is generally designed to minimize attenuation of electromagnetic signals passing therethrough. In other words, a typical radome is designed to be generally
20 transparent to electromagnetic radiation in one or more radio frequency (RF) ranges or bandwidths.

In various scenarios, a radome structure may be configured to provide certain protection with respect to projectiles such as bullets, grenade shrapnel, and others. Various techniques are known for reinforcing radome structures including for example:
25 US 10,153,546 describes a composite radome wall structures (10) that exhibit both antiballistic and radar transparency properties and include an antiballistic internal

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solid, void-free core (12) and external antireflective (AR) surface layers (14-1, 14-2) which sandwich the core. The antiballistic core can be a compressed stack of angularly biased unidirectional polyethylene monolayers formed of tapes and/or fibers. Face sheets (16-1, 16-2) and/or one or more impedance matching layers (27, 28) may optionally be
5 positioned between the antiballistic core and one (or both) of the external AR layers so as to bond the core to the AR surface layer(s) and/or selectively tune the radome wall structure to the frequency of transmission and reception associated with the radar system.

US 9,385,423 describes a protective ballistic radome for a satellite antenna which can turn about an axis of rotation, has: a circular support in the form of a ring, having an
10 axis of revolution RR' to coincide with the axis of rotation, with the circular support having a lower base and an upper part in planes respectively parallel and perpendicular to the axis RR', an annular groove, having an axis of revolution that coincides with the axis RR', opening onto the upper part of the circular support, a set of n contiguous walls having upper ends and lower ends in planes that are respectively parallel and
15 perpendicular to the axis RR', the walls having their lower ends inserted into the annular groove of the circular support in order to form a ballistic wall in the form of a tube of circular section, having the same axis of revolution RR', about said satellite antenna.

WO 2019/121,404 relates to a process for producing a ballistic-resistant curved molded article said process comprising forming a stack of a plurality of composite sheets,
20 pressing the stack comprising the composite sheets at a temperature of between 80°C to 150°C and a pressure of between 10 and 400 bar for at least 5 minutes to obtain a curved molded article, cooling the compacted stack to a temperature below 80°C while maintaining the pressure above 10 bar, releasing the pressure from the cooled curved molded article; wherein the composite sheets comprise unidirectionally aligned high
25 tenacity polyethylene fibers and a matrix comprising a polyethylene resin being a homopolymer or copolymer of ethylene having a density of between 870 to 980 kg/m³ when measured according to ISO1183 and a melt flow index of between 0.5 and 50 g/10min when measured according to ASTM 1238B-13 at a temperature of 190°C and a weight of 21.6 kg.

30 US 8,599,095 describes a radome cover for an RF sensor has been provided. The radome cover comprises a first and a second ballistic layer, each ballistic layer having a ceramic layer. The two ballistic layers are sandwiched between at least two matching

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layers, and the matching layers are impedance matched to the ceramic layers. The radome cover provides ballistic protection for the RF sensor.

US 2017/008,251 A radome is provided and includes a first layer of low density polymer (LDPE) through which electromagnetic radiation is transmittable, a second layer
5 of LDPE foam through which the electromagnetic radiation, having passed through the first layer, is transmittable, a third layer of LDPE through which the electromagnetic radiation, having passed through the first and second layers, is transmittable and adhesive layers respectively interposed between the first and second layers and between the second and third layers.

10 US 10,693,223 describes a tri-band multiwall radome that includes a dense polymeric strike plate that is configured on the outside of the radome, a capture layer and a tuning layer. The polymeric strike plate is a tough polymer, such as a polycarbonate and breaks a bullet into fragments that are more easily captured by the capture layer. The capture layer includes a number of fabric sheets of highly oriented fibers, such as
15 polyethylene fibers, and a binder. The tuning layer may be a low-density foam that is configured inside of the capture layer and provided to reduce reflective losses and improve ballistic performance. A tri-band radome cover may have a dB loss over a wavelength of 8 to 40 kHz of no more than 1 dB. A tri-band radome cover may be formed in a dome shape.

20 GENERAL DESCRIPTION

There is a need in the art for a radome structure configuration providing reinforced enclosure. The present disclosure provides a radome structure configured to be reinforced with respect to projectiles such as bullets, grenade shrapnel, or others. The reinforced radome structure according to some embodiments of the present disclosure is configured
25 to maintain a structure of internal layers thereof, reduce risk of damage to electronic elements placed within the radome, and limit interference to transmission of electromagnetic radiation through the radome structure. Such interference in radiation transmission may be a result of layer separation generating additional reflective interfaces through the radome.

30 Certain radome configurations are known to provide resistance with respect to small firearm bullets (e.g., rifles, guns, handguns, grenade shrapnel, etc.). This resistance enhances durability of electronic elements positioned within or under the radome

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structure, and thus enhances efficiency of a vehicle or stationary system housing such electronic elements.

A major issue with conventional reinforced radome structures relate to deformation of the reinforced layers in response to absorption of impact energy. As indicated above, various reinforced radome structures utilize a reinforced layer configured to maintain layer integrity and continuity in response to impact by a bullet, shrapnel, or other projectiles, and to stop the bullet or other projectiles from passing through the layer. As a result of such impact, the reinforced layer may deform due to the absorbed energy, and cause deformation and separation of layers of the radome structure affecting radiation transmission through the radome.

The present disclosure provides a radome structure comprising at least one reinforced (hardened) layer and at least one deformation absorbing layer, configured for absorbing deformations caused by impact of a projectile in the reinforced layer. The deformation absorbing layer may be configured of foam or other selected soft material. In some embodiments, the deformation absorbing may be configured as a cavity, or an arrangement of cavities, in the radome structure, having air or gas defining a space within the radome structure. The cavity may be maintained by a frame comprising rods and/or walls maintaining structure of the radome, while defining one or more cavities therewithin.

In some embodiments, the deformation absorbing layer may be formed of an arrangement of two or more layers comprising a brittle layer formed of deformable material such as foam, and a cavity layer defined by a frame formed of rods and/or walls maintaining one or more air-filled cavities.

The deformation absorbing layer may be configured to absorb deformations locally and thus to prevent separation between the layers. Generally, in response to impact by a bullet or other projectiles, the reinforced/hardened layer absorbs the impact and deforms into the deformation absorbing layer. Generally, the reinforced layer may be configured for stopping an incoming bullet or projectile, while it may be configured to avoid breaking of the bullet/projectile, thereby reducing radome area affected by the bullet/projectile. The deformation absorbing layer may be of a selected thickness, e.g., 0.2-2cm, or 0.8-1.5 cm or 0.8 cm or more, sufficient to absorb the deformation of the reinforced layer and prevent layer separation and propagation of the deformation through layers of the radome structure. In this connection, the term 'foam' when used herein in

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respect to the deformation absorbing layer should be understood broadly as relating to any material having plastic characteristics, and capable of collapsing locally in response to local pressure applied thereon. Typical materials that may be used for the deformation absorbing layer include for example plastic foam, polymethacrylimide (PMI) based structural foam such as Rohacell, Polyurethane foam, Polystyrene foam, Epoxy foam, Melamine foam, and other foam-like materials as described herein below.

Further, in some embodiments, the deformation absorbing layer may be formed as a cavity within the radome structure. The cavity may hold air or other gas and may be sealed or allow gas flow with the surrounding. As a result of gas presence in the deformation absorbing layer, when configured as a cavity, the dielectric coefficient of this layer may be very low and effectively similar to air dielectric coefficient. Thus, introducing a low dielectric coefficient within the layers of the radome may improve radiation transmission properties, at least within certain frequency bands. Further, the cavity-based deformation absorbing layer eliminates expansion of deformations caused by the absorbed kinetic energy of the bullet/projectile and provides for space to maintain deformations of the reinforced layer.

Further, in some embodiments, the radome structure may comprise at least one dielectric matching/adjustment layer configured to tune a dielectric profile of the radome to allow improved transmission of one or more selected frequency ranges. The dielectric matching layer may be placed prior to the reinforced layer, between the reinforced layer and the deformation absorbing layer, or in two or more locations between layers of the radome. According to some embodiments where the dielectric matching layer is located between the reinforced layer and the deformation absorbing layer, the dielectric matching layer may be etched in a selected pattern, providing effective structural discontinuity of the dielectric matching layer. The etching pattern may be formed of relatively thin etching lines that do not affect transmission of electromagnetic radiation and provides controlled breaking patterns. The etching pattern provides that deformation of the reinforced layer, due to projectile impact therein, causes breaking of the dielectric matching layer along the etched lines. This results in local discontinuity preventing the deformation from affecting radiation transmission through large regions of the radome. Accordingly, projectile or bullet impact may result in local discontinuity and disruption, while layer separation that affects transmission through regions of the radome structure is avoided.

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Additionally, according to some embodiments of the present disclosure, the radome structure may comprise one or more additional layers such as internal and/or external skin layers, one or more additional dielectric matching layers positioned externally to the reinforced/hardened layer and/or internally to the deformation absorbing layer, and/or one or more adhesive layers. The skin layer may be used to enable coatings of the radome structure, and to provide certain additional environmental protection. Additionally, and specifically in embodiments utilizing a cavity as a part of the deformation absorbing layer, the skin layer may also take part in improving electrical performance and transmission of the radome structure. In some embodiments, the internal and/or external skin layers may be formed of any one of fiberglass, Quartz, Teflon, ceramic, ultem (polyetherimide), divynycell, HDPE (high density polyethylene), or other suitable materials. Dielectric matching layers may be used to enhance radome transmission with respect to selected one or more frequency ranges and reduce reflection loss. The dielectric matching layer may provide an effective dielectric profile through the radome to provide selected transmission properties. In some embodiments, adhesive layers may be used to bond the different layers together and strengthen the radome structure.

Thus, according to a broad aspect, the present disclosure provides a radome structure comprising one or more layers comprising at least one reinforced layer and at least one deformation absorbing layer positioned internally with respect to enclosed space of the radome structure to absorb deformation of the reinforced layer caused by projectile impact, wherein said at least one deformation absorbing layer has predetermined thickness selected to absorb deformations caused by projectile impact within the reinforced layer, and wherein said reinforced layer is formed of a tough ductile material selected to deform upon impact by the projectile.

According to some embodiments, the at least one deformation absorbing layer comprises at least one cavity within the radome structure, said at least one cavity forms a layer within the radome structure.

According to some embodiments, the at least one deformation absorbing layer is defined by a cavity within the radome structure.

According to some embodiments, the at least one deformation absorbing layer comprises a frame formed of rods and/or walls defining one or more cavities filled with air or gas.

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According to some embodiments, the at least one deformation absorbing layer comprises at least one layer of brittle or foam-like material.

According to some embodiments, the at least one deformation absorbing layer comprises at least one layer of brittle or foam-like material and at least one cavity layer.

5 According to some embodiments, the reinforced layer is formed of a tough ductile material selected to deform upon impact and spread the force on a selected area for stopping and maintaining the projectile intact.

According to some embodiments, the radome structure may further comprise a dielectric matching layer positioned between said reinforced layer and said brittle layer,
10 said dielectric matching layer being etched in a selected pattern to form local discontinuity in response to deformation of the reinforced layer caused by projectile impact thereon.

According to some embodiments, a dielectric coefficient of said intermediate dielectric matching layer is between dielectric coefficient of said reinforced layer and dielectric coefficient of said deformation absorbing layer.

15 According to some embodiments, dielectric coefficient of said dielectric matching layer may be between dielectric coefficient of said reinforced layer and dielectric coefficient of said deformation absorbing layer. In some embodiments, the intermediate dielectric matching layer may provide a selected dielectric coefficient profile. In some embodiments, said intermediate dielectric matching layer has a varying dielectric
20 coefficient, varying with respect to thickness of the layer.

According to some embodiments, the radome structure may comprise a dielectric matching layer positioned externally with respect to said reinforced layer.

According to some embodiments, the radome structure may further comprise an internal continuous skin layer.

25 According to some embodiments, the radome structure may further comprise an external continuous skin layer coated with a selected paint scheme.

According to some embodiments, the radome structure may further comprise one or more adhesive layers between layers of said radome structure.

According to some embodiments, the reinforced layer is formed of woven high-
30 density Polyethylene (HDPE).

According to some embodiments, the reinforced layer is formed of high-modulus Polyethylene (HMPE).

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According to some embodiments, the reinforced layer is formed of ultra-high molecular weight Polyethylene (UHMWPE).

According to some embodiments, the reinforced layer is formed of Aramid fibers (Kevlar).

5 According to some embodiments, the reinforced layer is formed of one or more materials and comprises one or more of: woven high- density polyethylene (HDPE), high-modulus polyethylene, (HMPE), ultrahigh molecular weight polyethylene (UHMWPE), and/or Aramid fibers (Kevlar).

10 According to some embodiments, the deformation absorbing layer has thickness in a range between 0.2 cm and 2 cm.

According to some embodiments, the deformation absorbing layer has thickness in a range between 0.8 cm and 1.5 cm.

According to some embodiments, the deformation absorbing layer has thickness 0.8 centimeter or more.

15 According to some embodiments, the dielectric coefficient of said reinforced layer is greater than dielectric coefficient of said deformation absorbing layer.

According to some embodiments, the dielectric coefficient of said reinforced layer is lower than dielectric coefficient of said deformation absorbing layer.

20 According to some embodiments, the radome structure may further comprise one or more sensors located within layers of the radome, said one or more sensors being configured to generate sensing data indicative of structural condition of the radome. According to some embodiments, the one or more sensors being configured to generate output data indicative of location and/or size of impact to said radome structure.

25 According to some embodiments, the one or more sensors may be configured to generate output data indicative of location and/or size of impact to said radome structure.

30 According to some embodiments, total thickness of the radome structure may be selected to allow transmission of a selected wavelength range within a selected angular range. For example, for normal incidence, total thickness may be selected to be an integer multiple of half wavelength of a selected frequency. In some embodiments, the selected frequency may be in HF to UHF bands having wavelengths between 30 cm and 100 m; in some embodiments, the selected frequency may be in L-band having wavelengths between 15 and 30 cm; in some embodiments the selected frequency may be in S-band having wavelengths between 7.5 cm and 15 cm; in some embodiments the selected

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frequency may be in C-band having wavelength between 3.75 and 7.5 cm; in some embodiments the selected frequencies may be in X-band having wavelengths between 2.5 cm and 3.8 cm; in some embodiments the selected frequencies may be in Ku-band having wavelengths between 1.67 cm and 2.5 cm; in some embodiments the selected frequency
5 may be in K-band having wavelengths between 1.1 cm and 1.7 cm; and in some embodiments the selected frequency may be in Ka-band having wavelengths between 0.75 cm and 1.1 cm.

In this connection it should be understood that wavelength and frequency of electromagnetic radiation are directly related in accordance with the relation $\lambda = c/f$ in
10 free space and $\lambda = c/nf$ in a dielectric material where n is the refractive index and f is the respective frequency.

According to one other broad aspect, the present disclosure provides a vehicle comprising one or more antenna units and one or more radome structures placed over said one or more antenna units, said one or more radome structure comprise at least a region
15 of reinforced radome structure being reinforced with respect to bullet impact, said at least a region of reinforced radome structure comprise one or more layers comprising at least one reinforced layer and at least one deformation absorbing layer positioned internally with respect to enclosed space of the radome structure, wherein said at least one deformation absorbing layer has predetermined thickness selected to absorb deformations
20 caused by projectile impact within the reinforced layer, and wherein said reinforced layer is formed of a tough ductile material selected to deform upon impact by the projectile.

According to some embodiments, the one or more radome structure may be configured in accordance with any of the embodiments described herein.

According to yet another broad aspect, the present disclosure provides a method for
25 forming a reinforced radome, the method comprising:

- (a) providing at least one reinforced layer having a selected dielectric coefficient with respect to a selected frequency range;
 - (b) providing at least one deformation absorbing layer having selected thickness being attached to said reinforced layer internally with respect to said radome
30 structure;
- wherein said at least one reinforced layer is formed of a tough ductile material selected to deform upon impact by the projectile.

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According to some embodiments, providing a deformation absorbing layer comprises providing a frame capable of maintaining an air-filled cavity located internally of the reinforced layer with respect to volume enclosed by the radome structure, said air-filled cavity is configured to provide volume for maintaining deformations of said reinforced layer when stopping a high-speed object.

According to some embodiments, providing a deformation absorbing layer comprises providing a frame capable of maintaining an air-filled cavity and providing a layer of brittle or foam-like material selected to deform in response to deformation of the at least one reinforced layer.

According to some embodiments, providing at least one reinforced layer comprises providing at least one reinforced layer formed of a tough ductile material selected to deform upon impact and spread the force on a selected area for stopping and maintaining the projectile intact.

According to some embodiments, the method may further comprise, providing an intermediate dielectric matching layer externally to said reinforced layer.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to better understand the subject matter that is disclosed herein and to exemplify how it may be carried out in practice, embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Figs. 1A and 1B schematically illustrate a portion of a reinforced radome structure according to some embodiments of the present disclosure, **Fig. 1A** exemplifies layer structure and **Fig. 1B** exemplifies layer structure after stopping of a bullet by the radome;

Figs. 2A to 2E illustrate a portion of a reinforced radome structure according to some embodiments of the present disclosure utilizing a dielectric matching layer, **Fig. 2A** exemplifies layer structure and **Fig. 2B** exemplifies layer structure after stopping of a bullet by the radome, **Figs. 2C, 2D and 2E** exemplify possible etching patterns of the intermediate dielectric matching layer;

Fig. 3 exemplifies layer structure of a portion of a radome structure according to some embodiments of the present disclosure and illustrating adhesive layers between the radome layers;

Figs. 4A and 4B show front and back sides of a conventional radome after impact by bullets illustrating partial penetration due to impact energy;

Fig. 5 is a block diagram exemplifying a method for forming a reinforced radome according to some embodiments of the present disclosure;

Fig. 6 exemplifies a radome structure including one or more sensors embedded within the structure according to some embodiments of the present disclosure; and

Figs. 7A to 7D exemplify an additional configuration of a radome structure according to some embodiments of the present disclosure, **Fig. 7A** exemplify the radome structure utilizing an air pocket region, **Fig. 7B** exemplify the radome structure utilizing an additional dielectric layer, **Fig 7C** and **7D** exemplify two optional frames for maintaining an air pocket according to some embodiments of the present disclosure.

15 DETAILED DESCRIPTION OF EMBODIMENTS

As indicated above, the present disclosure provides a radome structure having selected layer structure and configured to be reinforced with respect to bullets or projectiles of certain energy and/or velocity range. The radome structure is configured to allow transmission of electromagnetic radiation of one or more selected frequency ranges, with selected minimal attenuation level and phase distortion, while being reinforced to stop various bullets or shrapnel. Generally, variations in structure of the radome may affect attenuation of signals and/or may cause phase or other distortions, which may affect transmission and/or reception of signals through the radome. The radome structure of the present disclosure is designed to absorb local deformation, preventing separation between the radome layers, and reduce the effect of such deformation on transmission of radiation therethrough.

Reference is made to **Figs. 1A and 1B** exemplifying schematic layer configuration of a radome structure according to some embodiments of the present disclosure. **Figs. 1A and 1B** exemplify a radome structure **100** having a reinforced layer **120** and a deformation absorbing layer **140**. In some embodiments, the deformation absorbing layer **140** has a dielectric coefficient greater than that of the reinforced layer **120**. In some embodiments, the radome structure **100** may include one or more internal

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and/or external dielectric matching layers (not specifically shown) providing selected dielectric profile through the radome. In some other embodiments, the deformation absorbing layer **140** has a dielectric coefficient lower than the dielectric coefficient of the reinforced layer **120**. The radome structure **100** is generally configured with selected

5 spatial shape to encompass (fully or partially) a volume where one or more electronic devices **50** such as antenna may be located. More specifically, the radome **100** is generally configured to provide certain protection from environmental conditions to the electronic devices **50** located under or within the radome **100**. Additionally, the radome **100** may also include internal and/or external skin layers **110** and **180**, formed of continuous

10 materials and configured to prevent moisture, dirt, oils from entering between the radome layers and/or into the enclosed volume within the radome. Additionally layers **110** and/or **180** may be used to cover the radome providing further protection layer. Such additional layers may for example provide rain erosion protection, anti-static coatings, and/or provide paint layer of selected color pattern to provide desired visibility and/or

15 camouflage. In some embodiments, the internal and/or external skin layers **110** and **180** may be formed of one or more materials selected from Fiberglass, Quartz, Teflon, Ceramic, Ultem, Divinycell, HDPE (high density polyethylene), or other suitable materials.

In some embodiments, the reinforced layer **120** and the deformation absorbing

20 layer **140** may be isotropic. In some embodiments, the reinforced layer **120** may be isotropic and the deformation absorbing layer **140** may be anisotropic. In some embodiments, the reinforced layer **120** may be anisotropic, and the deformation absorbing layer **140** may be isotropic. In some embodiments the reinforced and deformation absorbing layers may be anisotropic.

25 The reinforced layer **120** may be formed of a woven polymer material having sufficient strength to contain a penetrating projectile. More specifically, the reinforced layer **120** may be configured in accordance with one or more selected armor standards selected from body armor standards: VPAM armor standards PM1 to PM6, TR armor standards SK L, SK 1 to SK 3, HOSDB standards HG1/A, HG1 to HG3, RF1, RF2 and

30 SG3, GOST armor standards class 1 to 6 including class 2A, and 5A, and BR1 to BR4, NIJ armor standards type I, type II and IIA, type III and IIIA, US military standards soft armor, SAPI, ISAPI (not including armor piercing bullets), and ESAPI (not including

armor piercing bullets), GA141 standard GA 1 to GA 6, or any other selected armor standard.

Generally, upon stopping a bullet or other projectiles **200**, the reinforced layer **120** may deform in response to absorbed energy and momentum of the bullet or projectile **200**. Deformation of the reinforced layer **120** in reinforced radomes formed in accordance with previously published reinforced radome designs may cause deformation of the radome structure and separation between layers as exemplified below in **Figs. 4A and B**. The present disclosure utilizes a deformation absorbing layer **140** positioned internally to the reinforced layer **120** with respect to location of one or more antenna units **50** located within the radome **100**. The deformation absorbing layer **140** provides for containing deformations of the reinforced layer **120** and prevents such deformation from affecting external surfaces (e.g., external layers **110** or **180**) of the radome **100**. Further, the use of deformation absorbing layer **140** provides for locally containing inner layer deformation in case of impact, and eliminate, or at least significantly reduce layer separation within the radome **100**, thereby maintaining radome transmission properties of selected frequency range. Thus, the deformation absorbing layer **140** is positioned and configured to absorb deformation of the reinforced layer **120** and maintain general structure of the radome.

More specifically, **Fig. 1A** illustrates a portion of the radome structure **100** intact and illustrates a projectile or bullet **200** propagating towards the radome **100**. **Fig. 1B** illustrates the radome structure **100** after impact by the projectile **200**, exemplifying deformation **250** of the reinforced layer **120** propagating into the deformation absorbing layer, while being absorbed thereby. As described above, the reinforced layer **120** can stop the projectile **200** and absorb its energy by deformation to a certain level. The deformation of the reinforced layer **120** penetrates into the deformation absorbing layer **140**, which collapses locally to contain the local deformation.

Generally, the reinforced layer **120** may be formed of high-density material designed for absorbing kinetic energy of incoming bullets or projectiles. The reinforced layer may be made of tough ductile material selected to deform upon impact and spread the force on a selected area for slowing and stopping the bullet without breaking it. The reinforced layer may for example be formed of one or more of woven high-density Polyethylene (HDPE), high-modulus Polyethylene, (HMPE), ultra-high molecular weight Polyethylene (UHMWPE), Polyurethane, Aramid fibers (Kevlar), Polycarbonate,

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ceramic materials. In this connection, it should be noted that the use of tough ductile material for the reinforced layer provides for stopping incoming bullets or other projectiles, while generally to maintain the incoming bullet/projectile intact. Certain bullets may be configured to break upon impact, and such bullets may break when hitting
5 the reinforced layer 120 of the radome according to the present disclosure, however, a typical solid structured bullet, which is not specifically designed for breaking is maintained intact.

The deformation absorbing layer **140** may be formed of a brittle or foam-like material selected from: plastic foam, Polymethacrylimide (PMI) based structural foam
10 such as Rohacell, Polyurethane foam, Polystyrene foam, Epoxy foam, Melamine foam, and other foam-like materials. The material composition of the deformation absorbing layer **140** is selected to support collapse thereof into the layer in response to pressure applied thereon. Further, the deformation absorbing layer **140** is configured with sufficient thickness for absorbing deformation within the layer and preventing
15 propagation of the deformation through the deformation absorbing layer **140** toward the internal side of the structure. Thickness of the deformation absorbing layer **140** may be selected in accordance with armor level desire from the radome structure. For example, for NIJ level III, the deformation absorbing layer may be of thickness of 0.8 cm to 1.5 cm. Radome structures formed for lower energy absorbing standards may utilize a
20 deformation absorbing layer of thickness of 0.2 cm to 2 cm. In some embodiments, as indicated above, the deformation absorbing layer **140** may have a dielectric coefficient greater than the dielectric coefficient of the reinforced layer **120**. Generally, material selection and density of the deformation absorbing layer **140** may be selected to provide a dielectric profile of the radome structure **100** allowing transmission of electromagnetic
25 radiation of selected frequency ranges. Generally, in some embodiments, the deformation absorbing layer **140** may be formed of a brittle or foam-like material, while having a plurality of holes or cavities therewithin. In some embodiments as described further below, the brittle or foam-like material may be a first or second layer of the deformation absorbing layer, combined with a cavity layer defined by a frame maintaining one or more
30 cavities.

To provide efficient transmission of radiation to and from the one or more antenna units **50**, the radome structure **100** of the present disclosure may have selected dielectric properties. As indicated above, the reinforced layer **120** and the deformation absorbing

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layer **140** may have selected dielectric coefficients to provide selected transmission properties. Further, in some embodiments, the radome structure may include an intermediate dielectric matching/adjustment layer providing selected dielectric constant profile through the structure. In this regard reference is made to **Figs. 2A and 2B** illustrating a portion of radome structure **100** including a dielectric matching layer **130** located between the reinforced layer **120** and the deformation absorbing layer **140**. **Fig. 2A** illustrates a section of the radome structure **100**, and **Fig. 2B** illustrates the radome section **100** after impact by a bullet **200**. Generally, in some embodiments, the radome structure **100** may include internal and/or external dielectric matching layers in addition to an intermediate dielectric matching layer.

As described above, the radome structure **100** includes a reinforced layer **120** and a deformation absorbing layer **140** configured for absorbing deformation caused by impact from projectiles, such as bullet **200**. The radome structure of **Figs. 2A and 2B** further includes an intermediate dielectric matching layer **130** located between the reinforced layer **120** and the deformation absorbing layer **140**. According to some embodiments of the present disclosure, the intermediate dielectric matching layer **130** is etched in a selected pattern allowing the layer to form a plurality of local discontinuities along the layer **130**, in response to deformation of the reinforced layer **120**. More specifically, etching of the dielectric matching layer **130** provides that in case of an impact, the layer breaks at location of the impact, limiting the deformation to the impact location. Accordingly, when intact, the dielectric matching layer **130** provides selected dielectric profile of the radome **100** along surface thereof. This is while, in response to impact by a projectile, e.g., bullet **200**, the reinforced layer **120** may deform into the dielectric matching layer **130** causing the layer **130** to break locally, thus avoiding radome layer separation, and allowing the deformation to proceed into and deformation absorbing layer **140**. The deformation absorbing layer **140** is formed of foam, or any other soft material capable of collapsing in response to pressure applied thereon, configured to absorb the deformation and prevent it from propagating toward internal surface of the radome structure **100**. Additionally, the radome structure **100** may include internal and external layers **110** and **180** providing protection from humidity, allowing coating of the radome, etc. The radome structure **100** may also include adhesive layers **150** located between the layers of the structure to attach the different layers of the radome structure into a single structure.

Etching pattern of the dielectric matching layer **130** may provide full penetration of the layer **130**, providing a layer formed of a plurality of separated regions of selected dimensions. Alternatively, the etching may be partial, providing a pattern of lines along the dielectric matching layer **130**. The etching pattern of layer **130** provides weakness regions along the layer **130** allowing breaking of the layer in response to projectile impact. **Figs. 2C to 2E** exemplify three possible etching patterns for etching of the intermediate dielectric matching layer **130**. As exemplified in the figures, the etching may preferably include etching along at least two axes, forming an arrangement of a plurality of separable regions along the layer **130**. For example, the etching may provide hexagonal arrangement of region, rectangular arrangement, parallelogram arrangement or any other selected arrangement of separable regions along the intermediate dielectric matching layer **130**. This configuration provides that impact absorption by the reinforced layer **120** of the radome structure **100** results in deformation of the reinforced layer **120** into the intermediate dielectric matching layer **130**, causes braking of the intermediate dielectric matching layer along the etching lines, and containing the deformation while eliminating, or at least significantly reducing propagation of the deformation along the layer.

Reference is further made to **Fig. 3** showing another exemplary illustration of a portion of radome structure **100** according to some embodiments of the present disclosure. As shown in **Fig. 3**, the radome structure includes a reinforced layer **120** and a deformation absorbing layer **140** as described above. The radome structure may also include a dielectric matching layer **130** having a selected etching pattern to allow local breaking in response to impact of selected force. Further, as indicated above, the radome structure **100** may include internal and external layers **110** and **180** providing protection from humidity, allowing coating of the radome, etc., and adhesive layers **150** located between the layers of the structure to attach the different layers of the radome structure into a single structure. Further, as also indicated above, the radome structure may include internal and/or external impedance matching layers, not specifically shown. It should be noted that internal and/or external impedance matching layers may or may not be etched with a selected pattern and may or may not take part in stopping of bullets, shrapnel, or any other object impinging on the radome structure.

The layer configuration of the radome structure of the present disclosure provides protection with respect to projectiles of certain impact energy, while preventing distributed effect on radiation transmission through the structure. Reference is made to

Figs. 4A and 4B exemplifying layer separation in reinforced radome structure formed in accordance with conventional techniques, after impact by typical small firearm bullets. **Fig. 4A** shows impact points on front side of the radome (bullet impact direction) and **Fig. 4B** shows back side of the radome. As shown by regions **SR** in **Fig. 4B**, impact energy in a conventional reinforced radome may cause separation of layers. Layer separation may reduce radome strength and stability, making the radome structure less durable. In addition, layer separation may generate additional anti matching conditions throughout the inner radome layers. As a result, transmission of radiation through the radome may be reduced within large regions around impact positions.

Differently, from the impact in **Figs. 4A and 4B**, a radome structure according to the present disclosure utilizes a deformation absorbing layer positioned internally with respect to the reinforced layer. As described above, the structure of the radome according to the present disclosure is configured to absorb impact energy and limit deformation propagation through the structure, absorbing the deformation within the deformation absorbing layer. This limits the regions affected by deformation to small and local regions, allowing reduction of interruption of transmission of radiation through the radome around the local points of impact. Thus, enabling the radome to operate up to a predetermined impact density.

According to some exemplary embodiments, the radome structure **100** of the present disclosure may include a layer arrangement selected from the following list:

- a. Reinforced layer **120**, deformation absorbing layer **140**;
- b. Skin layer, reinforced layer **120**, deformation absorbing layer **140**;
- c. Reinforced layer **120**, deformation absorbing layer **140**, skin layer;
- d. Skin layer, reinforced layer **120**, deformation absorbing layer **140**, skin layer;
- e. Reinforced layer **120**, etched dielectric matching layer **130**, deformation absorbing layer **140**;
- f. Skin layer, reinforced layer **120**, etched dielectric matching layer **130**, deformation absorbing layer **140**;
- g. Reinforced layer **120**, etched dielectric matching layer **130**, deformation absorbing layer **140**, skin layer;
- h. Skin layer, reinforced layer **120**, etched dielectric matching layer **130**, deformation absorbing layer **140**, skin layer;

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- i. Skin layer, dielectric matching layer **130**, reinforced layer **120** deformation absorbing layer **140**, skin layer;
- j. dielectric matching layer **130**, reinforced layer **120** deformation absorbing layer **140**, skin layer;

5 Additionally, the radome structure **100** may include one or more dielectric matching layers located externally to the reinforced layer **120** and/or internally to the deformation absorbing layer **140**. Further additionally, the radome **100** structure may include one or more adhesive layers located between selected layers of the radome **100** to attach the radome layers together.

10 Reference is now made to **Fig. 5** exemplifying a block diagram illustrating actions to forming a reinforced radome according to some embodiments of the present disclosure. As shown, forming of the radome comprises providing a reinforced layer having selected thickness and dielectric properties **5010** to provide selected stopping criteria, and allowing transmission of radiation of selected frequency ranges. Additionally, the method
15 comprises providing a deformation absorbing layer, having selected thickness and dielectric coefficient profile **5020**. Generally forming the radome comprises attaching said deformation absorbing layer to the reinforced layer internally with respect to radome structure **5052** or attaching the reinforced layer to the deformation absorbing layer externally with respect to the radome structure **5054**. In some embodiments, the method
20 may further comprise providing an intermediate dielectric adjustment/matching layer **5030** and placing said intermediate dielectric matching layer between the deformation absorbing layer and said reinforced layer. Further, the method may comprise applying a selected etching pattern on the intermediate dielectric matching layer **5040**. Exemplary etching patterns are illustrated in **Figs. 2C to 2E** above. The etching pattern includes an
25 arrangement of lines where thickness or strength of the intermediate dielectric matching layer is reduced, to enable the layer to brake in response to deformation of the reinforced layer and form local discontinuity in the dielectric layer.

 Additionally, in some embodiments, the method may further include providing and/or applying one or more additional layers **5060** to the radome structure. The
30 additional layers may include internal and/or external dielectric matching layers, skin layers, and/or one or more adhesive layers located between the radome layers as described above.

The radome layers may be formed by various techniques including e.g., molding, three-dimensional printing, applying pre-prepared constructions, composite materials techniques, etc.

Additionally, in some embodiments of the present disclosure, the radome structure
5 **100** may include one or more sensors positioned within the radome. Reference is made to **Fig. 6** illustrating a radome structure as shown in **Fig. 1A** and including sensors **210** and **220**. Sensors **210** and **220** may be pressure sensors, optical fiber sensors, ultra-sound sensors, acoustic sensors or any other sensor that may provide output data on radome shape, stress, curvature, and indicate any variation in radome shape. The one or more
10 sensors **210** and **220** may be configured to periodically transmit sensing data to an external control unit and/or to provide an operator with data on radome impact, size and location of the impact, and enable the operator or control unit to determine condition of the radome following such impact.

Further, reference is made to **Figs. 7A** to **7D** exemplifying an additional
15 configuration of the radome structure **100** according to some embodiments of the present disclosure. **Fig. 7A** exemplifies a radome structure utilizing a cavity-based deformation absorbing layer, **Fig. 7B** exemplifies a radome structure that further utilizes a dielectric matching layer located externally with respect to the reinforced layer, **Figs. 7C** and **7D** exemplify frame structures that may be used for maintaining the cavity deformation
20 absorbing layer.

As illustrated in **Fig. 7A**, the radome structure **100** may be formed utilizing a reinforced layer **120** followed by a cavity **140** defining the deformation absorbing layer. The radome structure also utilizes an internal skin **180**, which may also act as a boundary of the cavity layer **140**, and may further utilize external **110** skin providing surface for
25 paint and/or environmental protection. In some embodiments, the radome structure **100** may utilize a combination of two or more layers including a brittle or foam-like layer as exemplified above with reference to **Figs. 1A** to **1B** and **2A** to **2B**, and an additional layer defined by a frame of rods or walls maintaining one or more cavities **140**.

Fig. 7B illustrates an additional configuration of the radome structure **100**,
30 utilizing a dielectric adjustment layer **130**, which is located externally of the reinforced layer **110**. In such configuration, the external skin layer **110** may be a layer of paint on top of the dielectric adjustment layer **130**, or used as a skin layer.

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An incoming bullet or projectile may penetrate through the skin layer **110** (when used), the dielectric adjustment layer **130** (when used), and may then stopped by the reinforced layer **120**. The reinforced layer **120** may be configured to stop the bullet, while preferably avoid breaking thereof, to reduce number of interfering elements within the radome, and maintain locality of the impact. As a result of the bullet kinetic energy, stopping of the bullet may cause deformation of the reinforced layer **120**. Similarly to the illustration of **Fig. 1B**, the deformation in the reinforced layer **120** may extend into deformation absorbing layer **140**. Since deformation absorbing layer **140** is effectively a cavity within the radome structure **100**, deformation of the reinforced layer does not go beyond the impact location.

Exemplary frame structures **142** suitable for use to maintain cavity region within the deformation absorbing layer **140** according to some embodiments of the present disclosure, are illustrated in **Figs. 7C** and **7D**. **Fig. 7C** illustrated a frame formed of rods generating one or more box shaped elements defining the cavity of layer **140**. **Fig. 7D** illustrates a frame formed of a plurality of walls extending in parallel to general direction of radiation propagating through the radome structure **100**. The frame **142** maintains cavity region **144** holding air or other gasses between an inner wall of the reinforced layer **120** and an inner skin layer **180** of the radome structure. It should be understood that although frame **142** is illustrated in **Figs. 7C** and **7D** as having cubical or rectangular structure, the present disclosure is not limited to such rectangular or cubical structure, and various other frame geometries may be used. For example, frame **142** may be formed of a plurality of walls or rods defining a hexagonal, triangular or any other geometry of the frame **142**. Further, frame geometry may vary along surface of the radome structure in accordance with various design parameters including, e.g., general shape and curvature of the radome structure. The frame **142** may be configured of a plurality of walls or rods configured to maintain the layer structure, while maintaining one or more cavities between them. For example, the frame **142** may be formed as a honeycomb-type frame defining a plurality of separated air/gas filled cavities, forming together the deformation absorbing layer **140**.

Generally, the use of cavity-based deformation absorbing layer **140** provides a distance between deformation of the reinforced layer **120** and the antenna **50**, while maintaining the antenna **50** in close proximity to the radome structure **100**. More specifically, the antenna **50** may face the first (innermost) skin layer **180**, and may be

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placed in direct contact with inner skin layer **180**, or at a selected distance therefrom. This is while the deformation absorbing layer **140** distances any deformation of the reinforced layer **120** from the antenna **50**.

The inventors simulated transmission of a radome structure as exemplified in **Fig. 5 7B**, demonstrating transmission in a range between -0.2dB and -0.9dB for radiation for S-band, X-band and Ku-band radiation having various angles with respect to the normal of the radome structure.

Thus, the present disclosure provides a protected antenna housing, or radome structure, configured to contain impact energy and resulting deformation into a
10 deformation absorbing layer thus preventing propagation of the deformation through the structure. The radome structure is configured to maintain locality of deformation and prevent separation of layers in response to impact of projectiles and/or bullets.

It is to be noted that the various features described in the various embodiments can be combined according to all possible technical combinations.

15 It is to be understood that the invention is not limited in its application to the details set forth in the description contained herein or illustrated in the drawings. The invention is capable of other embodiments and of being practiced and carried out in various ways. Hence, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting.
20 As such, those skilled in the art will appreciate that the conception upon which this disclosure is based can readily be utilized as a basis for designing other structures, methods, and systems for carrying out the several purposes of the presently disclosed subject matter.

Those skilled in the art will readily appreciate that various modifications and
25 changes can be applied to the embodiments of the invention as hereinbefore described without departing from its scope, defined in and by the appended claims.

CLAIMS:

1. A radome structure comprising one or more layers comprising at least one reinforced layer and at least one deformation absorbing layer positioned internally with respect to enclosed space of the radome structure to absorb deformation of the reinforced layer caused by projectile impact, wherein said at least one deformation absorbing layer has predetermined thickness selected to absorb deformations caused by projectile impact within the reinforced layer, and wherein said reinforced layer is formed of a tough ductile material selected to deform upon impact by the projectile.
2. The radome structure of claim 1, wherein said at least one deformation absorbing layer comprises at least one cavity within the radome structure, said at least one cavity forms a layer within the radome structure.
3. The radome structure of claim 1 or 2, wherein said at least one deformation absorbing layer is defined by a cavity within the radome structure.
4. The radome structure of claim 2 or 3, wherein said at least one deformation absorbing layer comprises a frame formed of rods and/or walls defining one or more cavities filled with air or gas.
5. The radome structure of any one of claims 1 to 4, wherein said at least one deformation absorbing layer comprises at least one layer of brittle or foam-like material.
6. The radome structure of claim 5, wherein said at least one deformation absorbing layer comprises at least one layer of brittle or foam-like material and at least one cavity layer.
7. The radome structure of any one of claims 1 to 6, wherein said reinforced layer is formed of a tough ductile material selected to deform upon impact and spread the force on a selected area for stopping and maintaining the projectile intact.
8. The radome structure of any one of claims 1 to 7, further comprising a dielectric matching layer positioned between said reinforced layer and said brittle layer, said dielectric matching layer being etched in a selected pattern to form local discontinuity in response to deformation of the reinforced layer caused by projectile impact thereon.
9. The radome structure of claim 8, wherein dielectric coefficient of said intermediate dielectric matching layer is between dielectric coefficient of said reinforced layer and dielectric coefficient of said deformation absorbing layer.
10. The radome structure of any one of claims 1 to 7, further comprising a dielectric matching layer positioned externally with respect to said reinforced layer.

11. The radome structure of any one of claims 1 to 10, further comprising an internal continuous skin layer.
12. The radome structure of any one of claims 1 to 11, further comprising an external continuous skin layer coated with a selected paint scheme.
- 5 13. The radome structure of any one of claims 1 to 12, further comprising one or more adhesive layers between layers of said radome structure.
14. The radome structure of any one of claims 1 to 13, wherein said reinforced layer is formed of woven high-density Polyethylene (HDPE).
- 15 15. The radome structure of any one of claims 1 to 13, wherein said reinforced layer is formed of high-modulus Polyethylene (HMPE).
16. The radome structure of any one of claims 1 to 13, wherein said reinforced layer is formed of ultra-high molecular weight Polyethylene (UHMWPE).
17. The radome structure of any one of claims 1 to 13, wherein said reinforced layer is formed of Aramid fibers (Kevlar).
- 15 18. The radome structure of any one of claims 1 to 17, wherein said deformation absorbing layer has thickness in a range between 0.2 cm and 2 cm.
19. The radome structure of any one of claims 1 to 17, wherein said deformation absorbing layer has thickness in a range between 0.8 cm and 1.5 cm.
- 20 20. The radome structure of any one of claims 1 to 17, wherein said deformation absorbing layer has thickness 0.8 centimeter or more.
21. The radome structure of any one of claims 1 to 20, wherein dielectric coefficient of said reinforced layer is greater than dielectric coefficient of said deformation absorbing layer.
22. The radome structure of any one of claims 1 to 20, wherein dielectric coefficient of said reinforced layer is lower than dielectric coefficient of said deformation absorbing layer.
- 25 23. The radome structure of any one of claims 1 to 22 further comprising one or more sensors located within layers of the radome, said one or more sensors being configured to generate sensing data indicative of structural condition of the radome.
- 30 24. The radome structure of claim 23, wherein said one or more sensors being configured to generate output data indicative of location and/or size of impact to said radome structure.

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25. A vehicle comprising one or more antenna units and one or more radome structures placed over said one or more antenna units, said one or more radome structure comprise at least a region of reinforced radome structure being reinforced with respect to bullet impact, said at least a region of reinforced radome structure comprise one or more
5 layers comprising at least one reinforced layer and at least one deformation absorbing layer positioned internally with respect to enclosed space of the radome structure, wherein said at least one deformation absorbing layer has predetermined thickness selected to absorb deformations caused by projectile impact within the reinforced layer, and wherein said reinforced layer is formed of a tough ductile material selected to deform upon impact
10 by the projectile.

26. A method for forming a reinforced radome, the method comprising:

- (a) providing at least one reinforced layer having a selected dielectric coefficient with respect to a selected frequency range;
- (b) providing at least one deformation absorbing layer having selected thickness
15 being attached to said reinforced layer internally with respect to said radome structure;
wherein said at least one reinforced layer is formed of a tough ductile material selected to deform upon impact by the projectile.

27. The method of claim 26, wherein said providing a deformation absorbing layer
20 comprises providing a frame capable of maintaining an air-filled cavity located internally of the reinforced layer with respect to volume enclosed by the radome structure, said air-filled cavity is configured to provide volume for maintaining deformations of said reinforced layer when stopping a high-speed object.

28. The method of claim 26 or 27, wherein said providing a deformation absorbing
25 layer comprises providing a frame capable of maintaining an air-filled cavity and providing a layer of brittle or foam-like material selected to deform in response to deformation of the at least one reinforced layer.

29. The method of any one of claims 26 to 28, wherein said providing at least one reinforced layer comprises providing at least one reinforced layer formed of a tough
30 ductile material selected to deform upon impact and spread the force on a selected area for stopping and maintaining the projectile intact.

30. The method of any one of claims 26 to 29, further comprising, providing an intermediate dielectric matching layer externally to said reinforced layer.