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(54) THERMAL MULTI-LAYER INSULATION AND RADIO-FREQUENCY ABSORBER BLANKET

(57) Thermal multi-layer insulation (MLI) and radio-frequency (RF) absorber blanket comprising: an upper layer comprising a patterned frequency-selective structure (FSS) sheet tuned in function of the RF frequencies to be absorbed; one or more intermediate resistive layers for RF absorption; a lower RF ground layer. The upper layer may comprise a polymeric film, in particular a Kapton(tm), Mylar(tm) or Upilex(tm) film, and a patterned metallic coating in particular a vacuum deposited aluminium (VDA) coating. The upper layer may comprise a patterned polyimide film loaded with inorganic carbon, in particular Black Kapton(tm). Said patterned frequency-selective structure may be obtainable by metallic deposition and etching or cutting said pattern, in particular by laser etching or cutting. The patterned FSS sheet may have a pattern of unconnected square patches arranged in a grid.

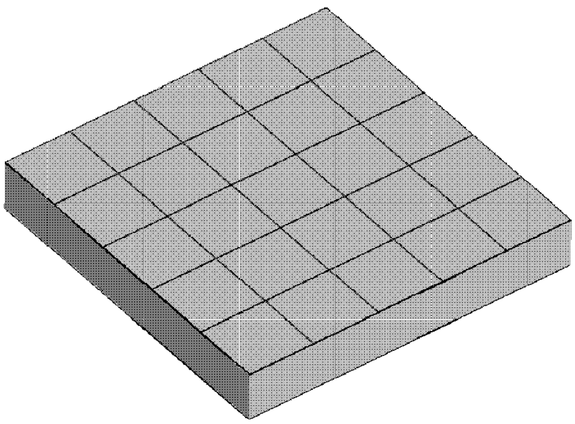

Fig. 1B

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Description

Technical field

[0001] The present disclosure relates to a multi-layer insulation (MLI) and radio-frequency (RF) absorber blanket having a frequency-selective structure (FSS) for blocking thermal radiation and managing electromagnetic interference (EMI), in particular for use in space (e.g. space telecommunications).

Background

[0002] MLI blankets are essential to the current space technology, and have been in use since the first days of space exploration. A prior art MLI is composed of metalized polymer layers, the purpose of which is to block radiation concentrated in the infrared (IR) and visible spectral ranges. However, the greatest shortcoming of these metalized layers is the strong reflection of the radio frequency (RF) and microwave (MW) signals. This issue is present in every satellite, though it is more prominent in telecommunication satellites, which combine many powerful MW transponders on a single platform, leading to EMI problems, and also influencing the radiation patterns of the antennas installed on the platform.

[0003] It is also known fact that MLI causes unwanted interference and even passive intermodulation (PIM) problems due to its high RF reflectivity in the specular direction. Usually, this is accounted for in the RF design of antenna payloads by representing the MLI as perfectly flat conducting ground plane. In fact, this is the standard practice in the industry. However, this is merely an approximation. In reality, the MLI is not a perfectly flat surface, i.e., due to its flexible nature wrinkles inherently are formed. This type of wrinkles is usual and sometimes even necessary in order to fit the MLI blankets on the structure. This wavy pattern however, causes diffuse reflection patterns that are difficult, if not impossible, to predict.

[0004] These facts are disclosed in order to illustrate the technical problem addressed by the present disclosure.

General Description

[0005] The present subject-matter relates to a RF absorber which built upon readily available and space qualified materials. This absorber proves to be capable of producing very low reflectivity values for very large bandwidths. Electrically speaking the final blanket assembly is a RF structure comprising "resonant cavities" in between several resistive layers. The resistive layers act so as to dissipate the energy "trapped" within the cavities. The more layers are added to the blanket stack, the higher the bandwidth that can be achieved.

[0006] Ka-band high frequencies make the design of radio frequency multi-layer insulation (RFMLI) even more challenging as we are dealing with smaller and smaller wavelengths, thus small dimensions. For lower frequency bands the construction effort are thus reduced and the accuracy improved.

[0007] Furthermore, it is valuable to provide MLI which is able to minimize RF reflectivity in multi-mission satellites where several antennas are foreseen with different transmit (TX) and receive (RX) frequencies.

[0008] Embodiments of said RF absorber are disclosed for Ka-band but that the disclosed absorber can be easily customized for other bands as for instance, for C/Ku-bands, Ku-band, or Ku/Ka-bands.

[0009] The disclosed MLI is able to manage such RF reflections, and minimize them to an insignificant level, with reflectivity simulation for TE/TM polarized waves for incidence angles up to 30° below -25 dB, for entire Ku/K/Ka-bands, validated by experimental tests with absorption below -20 dB for normal incidence for Ka-band (see Fig. 8A). The results are also validated for 30° incidence, even taking into account the thermal cycle (see fig. 8A'). The disclosed MLI can be easily tailored to Ku, K and Ka bands, with both narrow (see Fig. 8B) and wide band performances (see Figs. 8C and 8D), others frequencies are also possible and, other angles of incidence too, for example 45° or 60°.

[0010] The disclosed MLI is constructed using the available and space qualified materials typically used in standard MLI, therefore, the standard MLI properties, i.e., optical properties, thermal performance (was validated in TVAC at cycles up to 200 ºC during 80 h), grounding, attachment, venting and outgassing are also fulfilled as typical MLI.

[0011] The disclosed RFMLI is from a thermal and mechanical point of view, performing similarly to a typical MLI, thus also achieving its original purpose.

[0012] Finally, the disclosed blanket can be correctly tuned to specific requirements (frequencies, absorption level, incidence angle...) keeping its very low RF reflectivity.

[0013] It is disclosed a thermal multi-layer insulation (MLI) and radio-frequency (RF) absorber blanket comprising:

an upper layer comprising a patterned frequency-selective structure (FSS) coating whose capacitance is tuned in function of the RF frequency band to be absorbed;
one or more intermediate resistive layers for RF absorption;
a lower RF ground layer.

[0014] In an embodiment, the upper layer comprises a polymeric film and a patterned metallic coating, said patterned metallic coating being a frequency-selective structure.

[0015] In an embodiment, the polymeric film is polyimide film or polyester film, in particular a poly (4,4'-oxydiphenylene-pyromellitimide) or a poly (5,5'-Bi-2-benzofuran-1,1',3,3'-tetrone), or in particular a Kapton(tm) and Upilex(tm), or Mylar(tm) commercial film, respectively.

[0016] In an embodiment, the metallic coating is vacuum deposited aluminium (VDA) on a polymeric substrate, in particular the upper layer is Kapton(tm) with VDA, or Mylar (tm) with VDA, or on Upilex (tm) with VDA, or on other substrate.

[0017] In an embodiment, the upper layer comprises a patterned polyimide film loaded with inorganic carbon, which is said patterned frequency-selective structure.

[0018] In an embodiment, the upper layer comprises a patterned Black Kapton(tm) film as the frequency-selective structure and a polymeric film as a substrate of the Black Kapton(tm). Black Kapton(tm) is a carbon filled polyimide film made by DuPont, having high absorptance, high emittance and surface resistivity. Other similarly conductive materials may be used, alternatively.

[0019] In an embodiment, said patterned frequency-selective structure is obtainable by local tailored deposition or laying, followed by etching said pattern, in particular by laser etching.

[0020] In an embodiment, said patterned frequency-selective structure is obtainable by cutting said pattern, in particular by laser cutting.

[0021] In an embodiment, the patterned FSS sheet has a pattern of square, rectangular, hexagonal or circular patches arranged in a grid, in particular a pattern of unconnected patches arranged in a grid, further in particular a pattern of groups of in-group unconnected patches arranged in a grid.

[0022] In an embodiment, the one or more intermediate resistive layers for RF attenuation are 1 to 5.

[0023] In an embodiment, an intermediate resistive layer comprises a polyimide film loaded with inorganic carbon, in particular Black Kapton(tm).

[0024] In an embodiment, an intermediate resistive layer further comprises a spacer layer.

[0025] In an embodiment, a spacer layer is a polymeric layer, in particular a Upilex(tm) foam layer, a Dacron(tm) mesh layer, Beta Cloth scrim layer, Glass Fabric scrim layer, Ceramic Fabric scrim layer or a Nomex(tm) scrim layer.

[0026] An embodiment comprises one or more adhesive layers between any said contiguous layers and/or sheets.

[0027] In an embodiment, an adhesive layer comprises transfer tape, in particular transfer tape 3M(tm) 9460 or 3M(tm) 966, or any other suitable adhesive, preferably space qualified when space applications are targeted.

[0028] In an embodiment, said ground layer is a typical MLI or the first layer of a typical MLI comprising a deposited metallic coating, in particular a vacuum deposited aluminium (VDA) coating.

[0029] An embodiment further comprises a topmost RF-transparent IR-filter comprising:

a first patterned FSS sheet;
an intermediate polymeric film which is substantially transparent to IR;
a second patterned FSS sheet;
wherein the first and second patterned FSS sheets have complementary patterns, in particular complementary checkerboard patterns of unconnected square patches;
in particular said polymeric film being a polyimide film or polyester film, or in particular a Kapton(tm), Mylar(tm) or Upilex(tm) film;
in particular said first and second patterned FSS sheets being patterned deposited metallic coatings, further in particular being a patterned vacuum deposited aluminium (VDA) coating, further in particular obtainable by laser etching.

Brief Description of the Drawings

[0030] The following figures provide preferred embodiments for illustrating the description and should not be seen as limiting the scope of invention.

Figure 1A: Schematic representation of a top view of an embodiment comprising the following layers: Kapton 25 μm layer with FSS on top vacuum deposited aluminium (VDA) coating, Black Kapton layer, spacer layer and ground layer.

Figure 1B: Schematic representation of a perspective view of the previous embodiment.

Figure 1C: Schematic representation of a lateral view of the previous embodiment.

Figure 2A: Schematic representation of a perspective view of an embodiment comprising the following layers: Kapton 25 μm layer with FSS on bottom vacuum deposited aluminium (VDA) coating, Black Kapton layer, spacer layer and ground layer.

Figure 2B: Schematic representation of a lateral view of the previous embodiment.

Figure 3A: Schematic representation of a lateral view of an embodiment comprising the following layers: FSS on Black Kapton layer, Kapton HN layer, spacer layer and ground layer.

Figure 3B: Schematic representation of a perspective view of the previous embodiment.

Figure 4A: Schematic representation of a lateral view of an embodiment comprising the following layers: FSS on Black Kapton layer, Kapton HN layer, spacer layer, FSS on Black Kapton layer, Kapton HN layer, spacer layer and ground layer.

Figure 4B: Schematic representation of a perspective view of the previous embodiment.

Figure 5A: Schematic representation of a lateral view of an embodiment comprising the following layers: Kapton 25 μm layer with FSS on VDA coating, spacer layer, Black Kapton layer, spacer layer, Black Kapton layer, spacer layer and ground layer.

Figure 5B: Schematic representation of a perspective view of the previous embodiment.

Figure 6A: Schematic representation of a lateral view of an embodiment comprising the following layers: Kapton 25 μm layer with FSS on VDA coating, spacer layer, Black Kapton layer, spacer layer, Black Kapton layer, spacer layer and ground layer.

Figure 6B: Schematic representation of a perspective view of the previous embodiment.

Figure 7A: Schematic representation of a perspective view of an embodiment of a RF transparent layer to be used as a IR filter.

Figure 7B: Schematic representation of a top view of the previous embodiment.

Figure 8: Illustration of experimental and numerical results.

Detailed Description

[0031] Absorbing layers of carbon-loaded films, in particular Black Kapton(tm), are well-proven materials and facilitate integration with the rest of the blanket (i.e., same manufacturing processes and techniques).

[0032] One of the main challenges of resonator architectures (for example, as adapted from Salisbury and Jaumann Screens) is the need to have a resistive material sheet. However, according to the present disclosure, it is indeed possible to manufacture functional resistive materials based on inorganic carbon rich compounds (graphite, Black Kapton(tm)), which, in turn, allows for the practical design of AMC absorbers. Such absorbers can have different architectures and configurations, but have in common focusing the maximum electric field near a frequency-selective structure (FSS) and using a lossy material to attenuate it. These RF absorption systems are made of the typical MLI materials, which means that it may be suited for application as a top-layer absorber. However, the top-layer absorber, due to its optical properties, might not be always the ideal inner-layer solution and even sometimes top-layer solution. In that case, an alternative solution is also disclosed.

[0033] Black Kapton(tm) provides reason that an absorbing, thin film, is an achievable reality. However, such a solution is expected to optionally need a somewhat thick layer (or multiple layers). It is possible to counteract this limitation through the implementation of frequency selective surfaces. These FSS act not only as RF filters per se, but also as focusing mechanisms that enhance the electric field on the lossy layers, thus maximizing absorption. This allows for less layers, thus reducing overall thickness. However, this may come at a cost in terms of complexity and optimization effort; moreover, numerical modelling indicates that the efficacy of this architecture is somewhat dependent on the angle of incidence and the relative position of the layers (which is somewhat a problem, taking into account the mechanical nature of the MLI). In a general manner, all the solutions based on absorption plus FSS are somewhat dependent on the grazing angle of the incoming wave, 90° being the best-case scenario (but it can be optimized to almost any other incidence angle). In these cases, polarization can also be taken into account when defining the geometric patterns. On a more positive note, FSS structures also provide a good degree of IR reflection.

[0034] Resistive capacitive FSS layers can be constructed using Black Kapton(tm), whereas the capacitive FSS can be constructed using Kapton 1-side VDA (opaque to IR). Furthermore, the layer spacing can be assumed to be vacuum for any material with unitary relative permittivity.

[0035] Ka-band high frequencies make the design of RFMLI even more challenging as we are dealing with smaller and smaller wavelengths, thus small dimensions. For lower frequency bands the construction effort are reduced and the accuracy improved.

[0036] One of the possible ways for realizing wideband RF absorbers is by using patterned metallic or resistive sheets often referred to as "Frequency Selective Surfaces" (FSS) placed in between (or embedded into) layers of dielectrics.

[0037] A structure can be formed by a number of FSS structures interspersed by dielectric (or, in general, magneto-dielectric) layers (the FSS formed by square patches at the top of the structure). The total thickness of the structure at the lowest operational frequency is a small fraction of the wavelength, while at its highest operational frequency it may be on the order of a wavelength or greater. The period of the FSS structures must be significantly smaller than their operation wavelengths.

[0038] Considering the FSS structures to be constructed from resistive materials and considering operational frequencies such that the thicknesses of the dielectric layers are small compared to the wavelength, the structure can be modelled as a chain connection of low-pass LRC filters, i.e. as a simple RLC ladder network.

[0039] The working principle behind such network is very simple and intuitive, i.e., the stages in this chain filter circuit are tuned in such a manner that the first stage (the outermost layer) passes through the signals with frequencies below f1 (highest frequency), the second stage does the same for frequencies up to f2 which is smaller than f1, the third stage passes the signals up to f3 < f2, etc. The waves with frequencies outside of the passband of a given stage are reflected. At the same time, the passing signals are absorbed in the resistive elements of the circuits they pass through.

[0040] In summary, the equivalent circuit is used as an RF absorber model to which optimization algorithm can be easily applied in order to achieve the desired frequency response, i.e., the desired RF absorptivity.

[0041] Once the equivalent circuit is optimized, the physical dimensions and properties for the FSS layers and dielectric spacers can be readily obtained. The final frequency response prediction for the RF absorber is then obtained by means of a 3D electromagnetic simulation.

[0042] The majority of materials considered for the absorber are readily available materials and most importantly they are space-qualified materials, which are usually used in the manufacturing of standard MLI blankets. Namely, the dielectric spacers which are composed by polyimide-based foams (or any other material RF transparent) and the resistive material, which is Black Kapton(tm).

[0043] According to the present disclosure, a wideband RF absorbing MLI blanket can in fact be constructed as a stack of patterned metallic or resistive sheets, i.e., Frequency Selective Surfaces placed in between (or embedded into) layers of dielectrics.

[0044] A possible application could be the Gregorian type antenna, since the RF performance of the antenna is somewhat degraded by the use of standard MLI blankets due to their high RF reflectivity. It is one of the main objectives of this RF absorber blanket to mitigate these RF issues, whilst still maintaining the same properties of the standard MLI, i.e., thermal and optical properties as well as electrical grounding properties. In addition, due to its characteristics, it can also be used to mitigate for instance Passive Intermodulation (PIM).

[0045] Additionally, and because it represents the outermost layers of the overall MLI blanket, the RF absorber must also be capable of handle with the infrared (IR) energy, i.e., it must behave as an IR filter/shield. Finally, the overall blanket must fulfil standard grounding requirements.

[0046] Ka-band was selected to be the operational frequency band for the RF absorbing MLI to be constructed as an embodiment. This is due to the ever-growing interest on this frequency band for satellite communications. In addition, the possible application, STANT antenna, has also previously undergone testing in this frequency band, hence, providing a good base for comparison, and consequently avoiding further testing/measurements. The main RF specifications for an embodiment of the RF absorbing blanket are: Frequency band: 19 to 30 GHz; Return loss higher than 20 dB; Incidence angles up to 60º. The multi-layer FSS structure according to the disclosure has indeed the potential to easily cover the Ka-band with RF reflection values well below -20 dB. Ka-band is being widely spread among telecom satellites.

[0047] The manufacturing of the FSS structures (which can be done by laser etching or metallic deposition) is a relatively complex procedure. Notice that, the fact that by targeting a considerable smaller frequency band means that the frequency specifications are more easily attainable with simpler structures.

[0048] In light of these reasons and to keep the laser etching of FSS structures to a minimum so as to speed up and reduce the complexity of the manufacturing process, a thinner and simpler absorber embodiment has been designed. We refer to this absorber as the "AMC absorber", because its working principle is based on that of an Artificial Magnetic Conductor, i.e., AMC, composed by a single metallic FSS (aluminum) structure, a resistive layer (Black Kapton) and a dielectric spacer, which can be considered to be equivalent to vacuum. The equivalent circuit for this kind of absorber is given by fig. 9.

[0049] The metallic FSS can be constructed by etching the aluminum coating of a polymeric sheet. Due to the very small aluminum thickness, this metallic FSS construction is considerably faster than that of resistive FSS (Black Kapton) needed for the wideband concept discussed before.

[0050] It remains to be said that this concept inherently solves the IR problem, i.e., the outermost metallic layer (the metallic FSS) acts as an IR shield. This is because the FSS is composed by an array of relatively large aluminum squares with very small spacing in between, resulting in a practically opaque layer to the infrared spectrum.

[0051] So as to maintain the manufacturing simplicity of the absorber concept as well as its inherent IR shielding capabilities but in order to increase the absorber's bandwidth, there is another absorber, which is electrically more intricate, but still maintains the manufacturability simplicity of the previous absorber.

[0052] Starting with the previous absorber and adding layers of dielectric spacer alternated with resistive sheets so as to create "resonant cavities" as a means to increase the absorber bandwidth. For the frequency specifications at hand, adding three dielectric layers (e.g. polyimide based foam) interleaved by two resistive sheets (e.g. Black Kapton) was the ideal combination. The relatively large frequency band nature shown, makes this absorber very suitable as it covers the entire operational frequency spectrum.

[0053] The dielectric spacers may consist on polyimide based foams, the resistive sheets can be standard Black Kapton foils and the metallic FSS that sits on top of the absorber can be constructed by laser etching of the aluminum deposited on a polymeric foil.

[0054] It remains to be said that the layup also contemplates several adhesive layers. The main purpose of these layers is to enable a tight fitting of the remaining layers that compose the absorber, hence avoiding "air gaps" on the layers interface. Please note that, improved assembling methods without using the adhesive layers are also possible so as to mitigate the effect of the air gaps. The impact of the adhesive layers on the RF performance of the absorber can be easily taken into account. However, the impact of the adhesive layers on frequency response is minimum and the performance of the RF absorber with adhesive layers is still well within the specifications.

[0055] The RFMLI performance was tested for different angles of incidence, namely normal, 5º, 10º, 20º, 30º, 40º, 45º, 50º and 60º for TE polarized waves and for TM polarized waves. The absorber reflection response is still very acceptable for incidence up to 30º as the reflection coefficient is below -20 dB. On the other hand, and as expected, due to high incidence angle, the reflection response is not so good for 60º, nevertheless a significant absorption level is still verified for the entire frequency band. However, an alternative embodiment may be tuned to have the same reflection coefficient (below -20 dB) at 60° incidence or almost any other angle.

[0056] The disclosed absorbers work by transforming RF Power into heat. This power exchange occurs on the resistive sheets located in between the dielectric layers. One of the primary functions of a standard MLI blanket is to control/deal with temperature gradients, thus, it is of utmost importance to analyze how much heat is generated within the RF absorber so that the remaining MLI blanket can be designed accordingly. One way of accomplish this is by identifying the percentage of RF power dissipated by the different resistive sheets within the RF absorber. The outermost resistive sheet dissipates the most RF power within the operational frequency band, hence, this becomes the most critical sheet, as it is the one that generates more heat. In other words, it is of extreme importance amount relative power absorbed by each resistive sheet, i.e., the amount of heat that is going to be generated (depending on the incident power absolute value) within the absorber due to incident RF power. The generated heat data is thus usable to the synthesis of a standard MLI that sits below the disclosed RF absorbers.

[0057] One of the main advantages of the absorber described is the fact that the outmost layer of the absorber can be a metallic FSS, which by itself acts as a natural IR filter/shield. As discussed before, the metallic FSS structure consists on a metallic pattern etched on aluminum. The FSS pattern considered within the scope of this work is that of a simple array of metallic rectangles. This choice was motivated due to the symmetry of the square array structure and mainly because cause this type of pattern has a capacitive behaviour (equivalent circuit capacitor) which can be predicted analytically. The FSS structure is completely defined by its period and by the spacing between the rectangles, i.e., the gap. As expected (parallel plate capacitor) the FSS capacitance increases by decreasing the gap between the rectangles. Also the capacitance is higher when considering larger period values (for the same gap). On the other hand, the effective capacitance is practically independent of frequency (e.g. considering a gap of 30 μm). As for the FSS performance as an IR shield, we intuitively see that the smaller the gap, the better IR shield the FSS shall be. In fact we have that the percentage of area covered by the metallic squares on the FSS is given by:

$$A = \left(1 - \frac{gap}{period}\right)^2 .$$

[0058] From the equation we also conclude that larger periods (relatively to the gap) FSS structures also result in better IR shields. Hence, based on the previous equation we conclude that a compromise between the gap and the period dimensions can be achieved so as to maximize the overall performance of the structure.

[0059] Typically, and due to the static charge accumulation on its surface, standard MLI blankets are usually featured with grounding pads which are connected to the frame of the spacecraft by grounding cables so as to discharge the static charges. The top layer of standard MLI blankets is usually composed by a continuous sheet of aluminum, which facilitates the flow of charges. On the present case however, we face a possible grounding issue as the top layer of the absorber is a surface of metallic squares which are not electrically connected with each other. In order to tackle with this grounding problem, the inclusion of a grounding mesh on the FSS pattern can be used. The grounding mesh period can be large enough so it does not interfere with the operation of the FSS structure. This can in principle be accomplished by ensuring that the grounding mesh period is relatively larger than the longest wavelength on the FSS operational frequency band. Furthermore, in order to comply with the standard grounding requirements the grounding path must provide a low DC resistance.

[0060] The prime cause for Passive Intermodulation (PIM) is the junction of dissimilar materials. It is mostly generated when different metals come together and it is usually caused by rust corrosion and oxidation. As far as standard MLI is concerned, the most problematic area for PIM generation seems to be the grounding rivet connection. Regarding the MLI blanket with the RF absorption structure and based on the sources of PIM that are referred above, it seems that the standard MLI PIM reduction measures should be considered for the RF absorber proposed on this document.

[0061] Initially, an RF absorber blanket was designed by running an optimization algorithm for all the relevant parameters on the equivalent circuit, so as to achieve minimal reflectivity. The preliminary tests for this absorber however, did not produce acceptable results. On the other hand, the theoretical (equivalent circuit) results were in fairly good agreement with those of the 3D electromagnetic simulations indicating that the problem was on the electric properties considered for the several materials constituting the blanket, which are the same for both the theoretical and 3D simulation models. In light of these conclusions it was clear that further characterization for the materials, more specifically the Black Kapton material, was needed in order to accurately model the RFMLI for synthesis design of said absorbers. The actual values of permittivity for the Black Kapton are many times higher than those initially considered. Hence, the equivalent circuit model must be modified accordingly. Due to its high permittivity, the Black Kapton film cannot be considered as a simple resistor within the equivalent circuit. With such high permittivity values, and for the considered operational frequency band, we must also contemplate the electrical length for these resistive films, i.e., we must account the electromagnetic propagation of the RF waves through the Black Kapton films. Notice that the adhesive layers may now be taken into consideration within the equivalent circuit in order to obtain the best possible agreement between the equivalent circuit results and those from the 3D electromagnetic model. A shunt resistor is not suited to model the Black Kapton. Instead, it is modelled as a lossy medium with complex propagation constant given by

$$\gamma = \alpha + j\beta = j\omega\sqrt{\mu\epsilon}\sqrt{1 - j\frac{\sigma}{\omega\epsilon}}$$

[0062] where α and β are the attenuation and propagation constants respectively, and ε and σ are the permittivity and conductivity values. The Black Kapton medium characteristic impedance is given by

$$\eta = \frac{j\omega\mu}{\gamma}$$

[0063] where γ is the complex propagation constant referred above. From the values of complex propagation constant and complex medium impedance, an admittance matrix can be created and introduced in the equivalent circuit.

[0064] In order to more accurately design the FSS structure that sits on top of the RF absorber, some improvements have also been made to the FSS synthesis process. It was assumed that the metallic patch array was surrounded solely by two different mediums, i.e., vacuum on one side and foam material on the other side. This assumption was made in order to simplify the calculations performed to obtain the capacitance. However, the metallic FSS is actually constructed by etching the aluminum out from a thin aluminum deposit on a Kapton substrate, hence, there is always a layer of Kapton on one of the sides of the FSS. In a more realistic scenario, i.e., including the Kapton layer and where we have also incorporated the adhesive layer, the electric field due to the gaps between the FSS squares extends beyond the Kapton and adhesive layers. The electric field extends to these adjacent layers, consequently, the total capacitance for the FSS structure will be different. In fact, because these extra layers have relatively high permittivity, we shall see that the capacitance values for the FSS, when placed on top of these layers, shall be higher than what was previously considered.

[0065] **Figure 1** illustrates an embodiment comprising the following layers: FSS on top VDA coating of Kapton 25 μm layer, Black Kapton layer, spacer layer and ground layer.

[0066] **Figure 2** illustrates an embodiment comprising the following layers: FSS on bottom VDA coating of Kapton 25 μm layer, Kapton 25 μm layer, Black Kapton layer, spacer layer and ground layer. This embodiment is very similar to the previous embodiment, except for the optical properties of the top layer are thus correspondingly altered.

[0067] **Figure 3** illustrates an embodiment comprising the following layers: FSS on Black Kapton layer, Kapton layer, spacer layer and ground layer. The FSS is obtained from the Black Kapton layer itself and including a support layer which is Kapton layer. Additionally, a top RF transparent layer for obtaining specific optical properties can be added.

[0068] **Figure 4** illustrates an embodiment comprising the following layers: FSS on Black Kapton layer, Kapton layer, spacer layer, FSS on Black Kapton layer, Kapton layer, spacer layer and ground layer. The FSS is obtained from the Black Kapton layer itself and including a support layer which is Kapton layer. This embodiment is very similar to the previous embodiment except for a repetition of the FSS of the Black Kapton and spacer layers. Depending on the number of layers, this configuration can be considered a broadband configuration. Additionally, a top RF transparent layer for obtaining specific optical properties can be added.

[0069] **Figure 5** illustrates an embodiment comprising the following layers: FSS on top VDA coating of Kapton 25 μm layer, spacer layer, Black Kapton layer, spacer layer, Black Kapton layer, spacer layer and ground layer. This is a wideband structure which may comprise additional layers.

[0070] **Figure 6** illustrates an embodiment comprising the following layers: FSS on bottom VDA coating of Kapton 25 μm layer, spacer layer, Black Kapton layer, spacer layer, Black Kapton layer, spacer layer and ground layer. This embodiment is very similar to the previous embodiment except the optical properties of the top layer are thus correspondingly altered. This is a wideband structure which may comprise additional layers.

[0071] **Figure 7** illustrates an embodiment of a RF transparent layer to be used as an IR filter top layer. It comprises two complementary FSS layers obtained from VDA. It is necessary a substrate for the VDA, for example a Kapton layer. This embodiment is designed such that it does not interfere with the layers below and is thus 'RF transparent'.

[0072] **Figure 8** illustrates experimental results of RF absorption for (A) Ka-band, (B) for Ku-band, (C) for C/Ku-Bands, (D) RF absorption for Ku/Ka-bands.

[0073] **Figure 9** illustrate equivalent circuit of embodiment according to the present disclosure.

[0074] The term "comprising" whenever used in this document is intended to indicate the presence of stated features, integers, steps, components, but not to preclude the presence or addition of one or more other features, integers, steps, components or groups thereof. The disclosure should not be seen in any way restricted to the embodiments described and a person with ordinary skill in the art will foresee many possibilities to modifications thereof.

[0075] The above described embodiments are combinable. The following claims further set out particular embodiments of the disclosure.

Claims

1. Thermal multi-layer insulation (MLI) and radio-frequency (RF) absorber blanket comprising:

an upper layer comprising a patterned frequency-selective structure (FSS) coating whose capacitance is tuned in function of the RF frequency band to be absorbed;
one or more intermediate resistive layers for RF absorption; a lower RF ground layer.

2. Thermal MLI and RF absorber blanket according to claim 1, wherein the upper layer comprises a polymeric film and a patterned metallic coating, said patterned metallic coating being the frequency-selective structure.

3. Thermal MLI and RF absorber blanket according to claim 2, wherein the polymeric film is polyimide film or polyester film, in particular a poly (4,4'-oxydiphenylene-pyromellitimide) or a poly (5,5'-Bi-2-benzofuran-1,1',3,3'-tetrone), or in particular a Kapton(tm) and Upilex(tm), or Mylar (tm) commercial film, respectively.

4. Thermal MLI and RF absorber blanket according to any of the claims 2-3, wherein the metallic coating is vacuum deposited aluminium (VDA), in particular the upper layer is Kapton(tm) with VDA.

5. Thermal MLI and RF absorber blanket according to claim 1, wherein the upper layer comprises a patterned polyimide film loaded with inorganic carbon, which is said patterned frequency-selective structure.

6. Thermal MLI and RF absorber blanket according to the previous claim, wherein the upper layer comprises a polymeric film and a patterned Black Kapton(tm) film, said patterned Black Kapton(tm) film being the frequency-selective structure.

7. Thermal MLI and RF absorber blanket according to any of the previous claims, wherein said patterned frequency-selective structure is obtainable by etching said pattern, in particular by laser etching.

8. Thermal MLI and RF absorber blanket according any of the claims 1-7, wherein said patterned frequency-selective structure is obtainable by cutting said pattern, in particular by laser cutting.

9. Thermal MLI and RF absorber blanket according to any of the previous claims, wherein the patterned FSS sheet has a pattern of square, rectangular, hexagonal, or circular patches arranged in a grid, in particular in a pattern of groups of unconnected patches arranged in a grid.

10. Thermal MLI and RF absorber blanket according to any of the previous claims, wherein the one or more intermediate resistive layers for RF attenuation are 1 to 5.

11. Thermal MLI and RF absorber blanket according to any of the previous claims, wherein an intermediate resistive layer comprises a polyimide film loaded with inorganic carbon, in particular Black Kapton(tm), in particular wherein an intermediate resistive layer further comprises a spacer layer, in particular a spacer layer being a polymeric layer, in particular a Upilex(tm) foam layer, a Dacron(tm) mesh layer, Beta Cloth scrim layer, Glass Fabric scrim layer, Ceramic Fabric scrim layer or a Nomex(tm) scrim layer.

12. Thermal MLI and RF absorber blanket according to any of the previous claims comprising one or more adhesive layers between any said contiguous layers and/or sheets, in particular an adhesive layer comprises transfer tape, in particular transfer tape 3M(tm) 9460 or 3M(tm) 966.

13. Thermal MLI and RF absorber blanket according to any of the previous claims wherein said ground layer is a MLI or the first layer of a MLI comprising a deposited metallic coating, in particular a vacuum deposited aluminium (VDA) coating.

14. Thermal MLI and RF absorber blanket according to any of the previous claims, further comprising a topmost RF-transparent IR-filter comprising:

a first patterned FSS sheet;
an intermediate polymeric film which is substantially transparent to IR;
a second patterned FSS sheet;
wherein the first and second patterned FSS sheets have complementary patterns.

15. Thermal MLI and RF absorber blanket according to the previous claim, wherein the first and second patterned FSS sheets have complementary checkerboard patterns, in particular complementary checkerboard patterns of unconnected square patches, further in particular wherein said intermediate polymeric film is a polyimide film or polyester film, or in particular a Kapton (tm), Mylar (tm) or Upilex (tm) film; and said first and second patterned FSS sheets are patterned deposited metallic coatings, further in particular being patterned vacuum deposited aluminium (VDA) coatings, further in particular obtainable by laser etching.

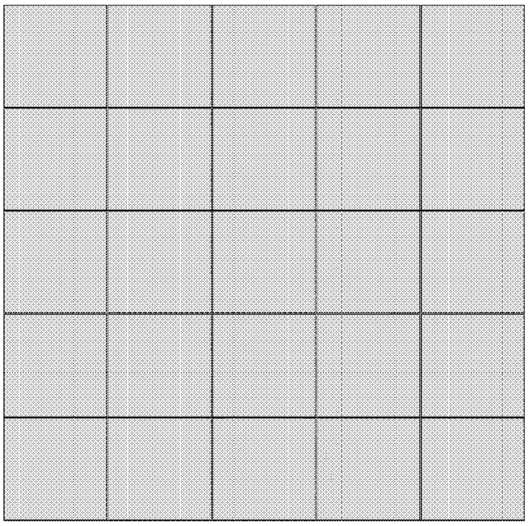


Fig. 1A

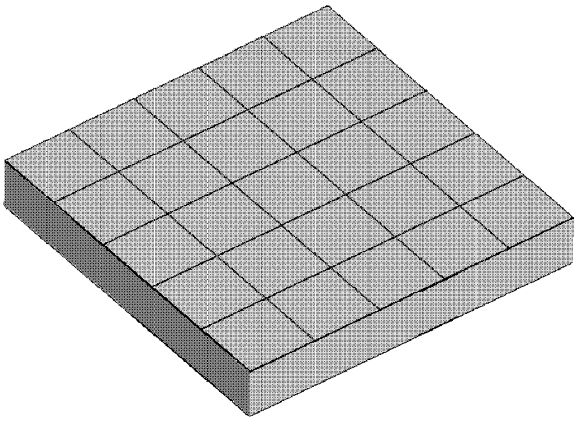


Fig. 1B

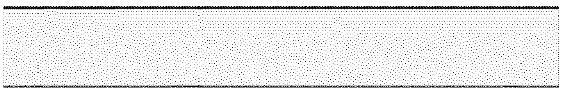


Fig. 1C

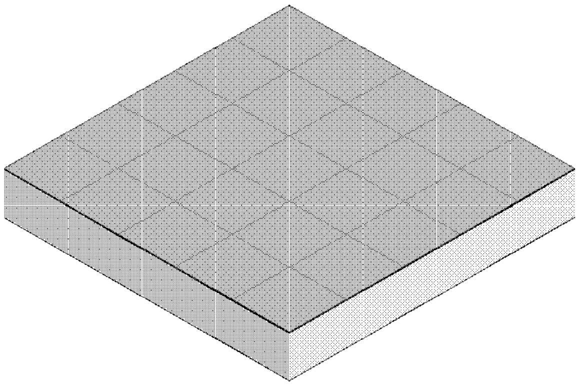


Fig. 2A

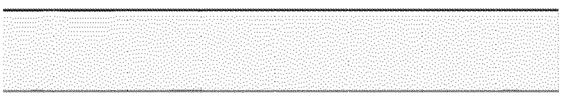


Fig. 2B

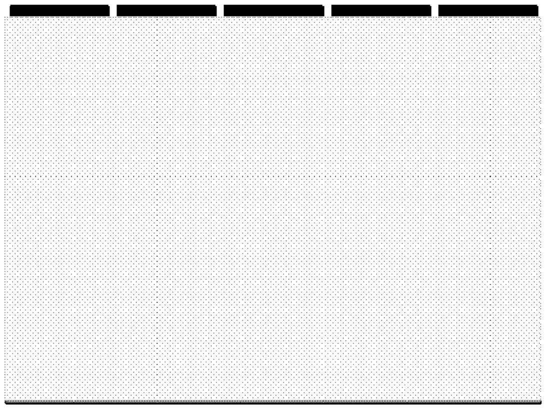


Fig. 3A

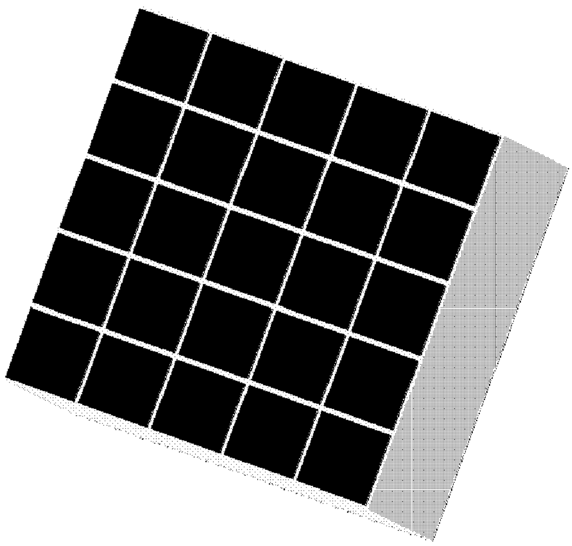


Fig. 3B

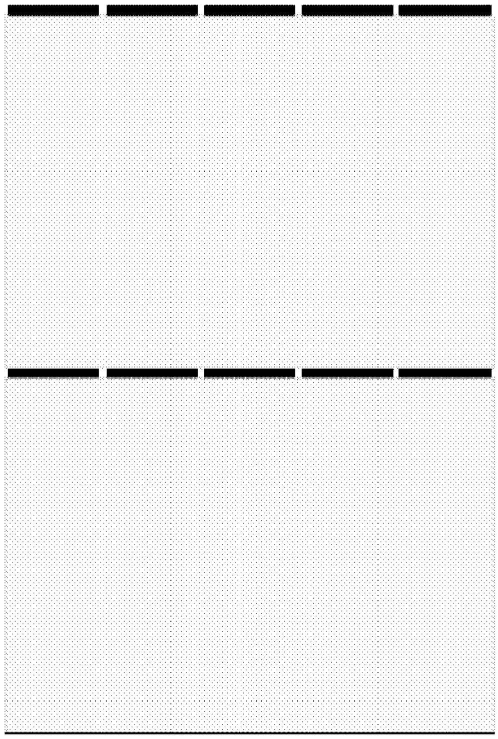


Fig. 4A

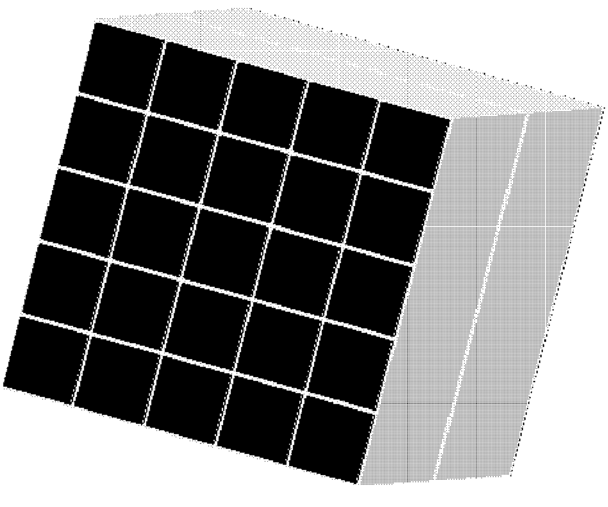


Fig. 4B

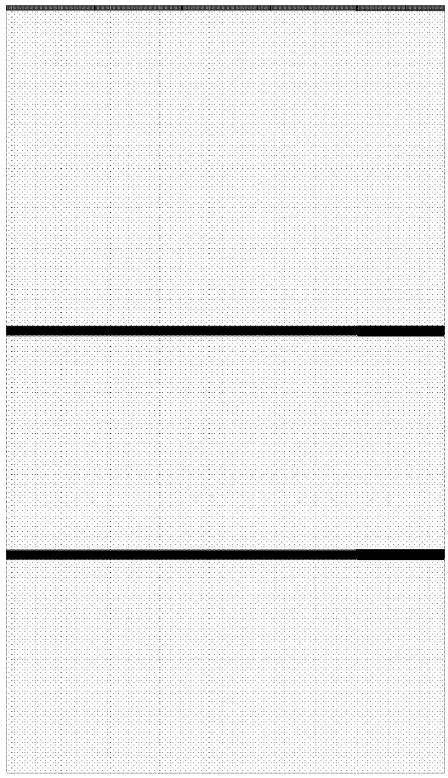


Fig. 5A

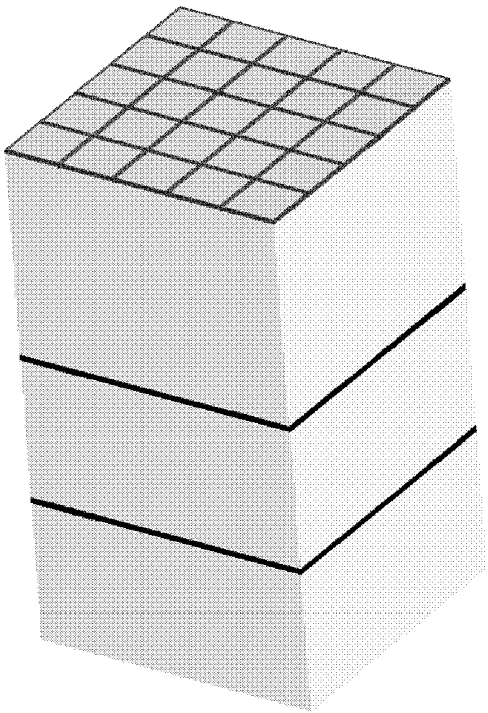


Fig. 5B

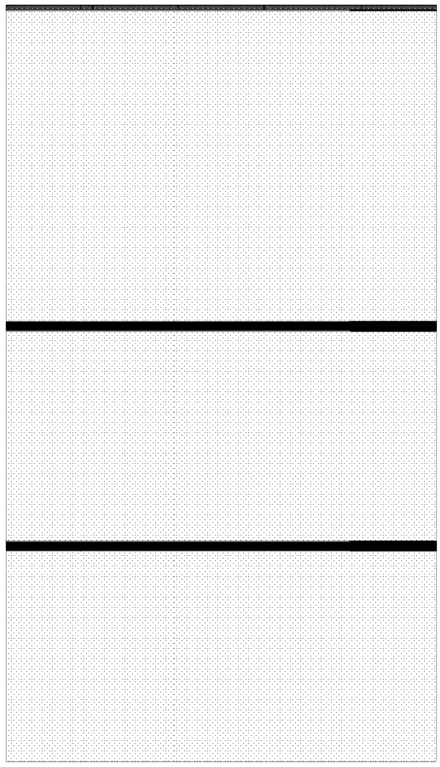


Fig. 6A

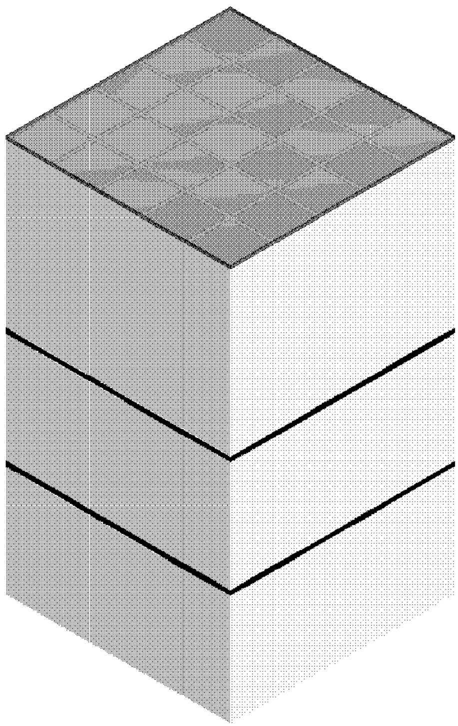


Fig. 6B

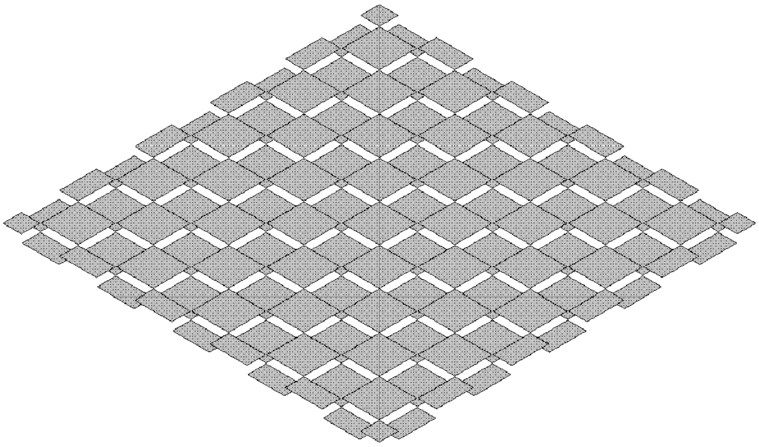


Fig. 7A

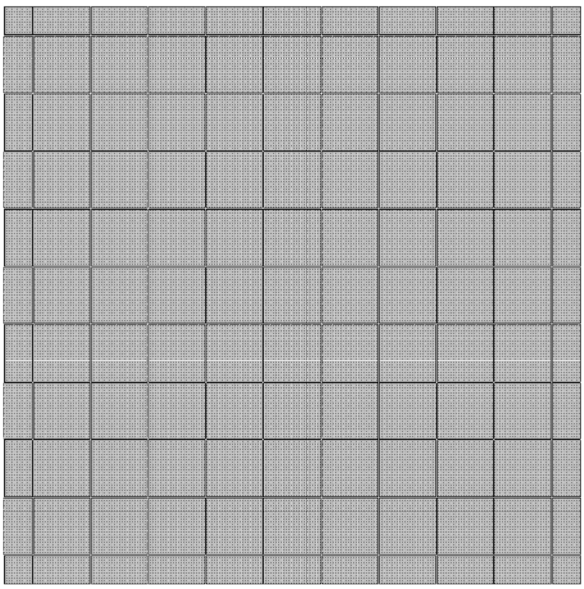
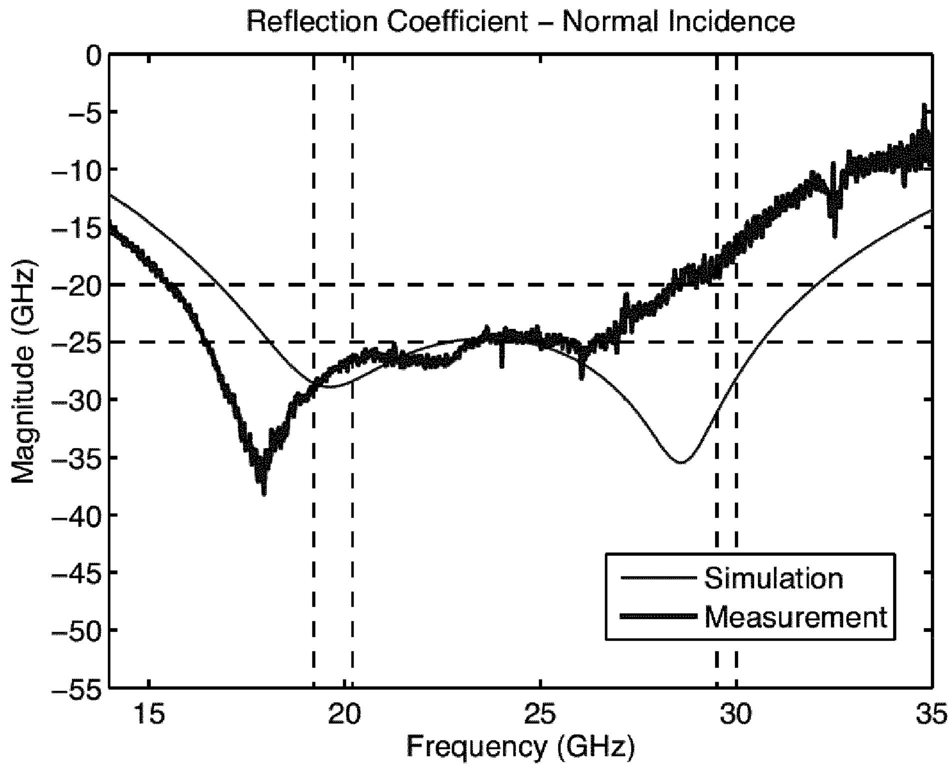
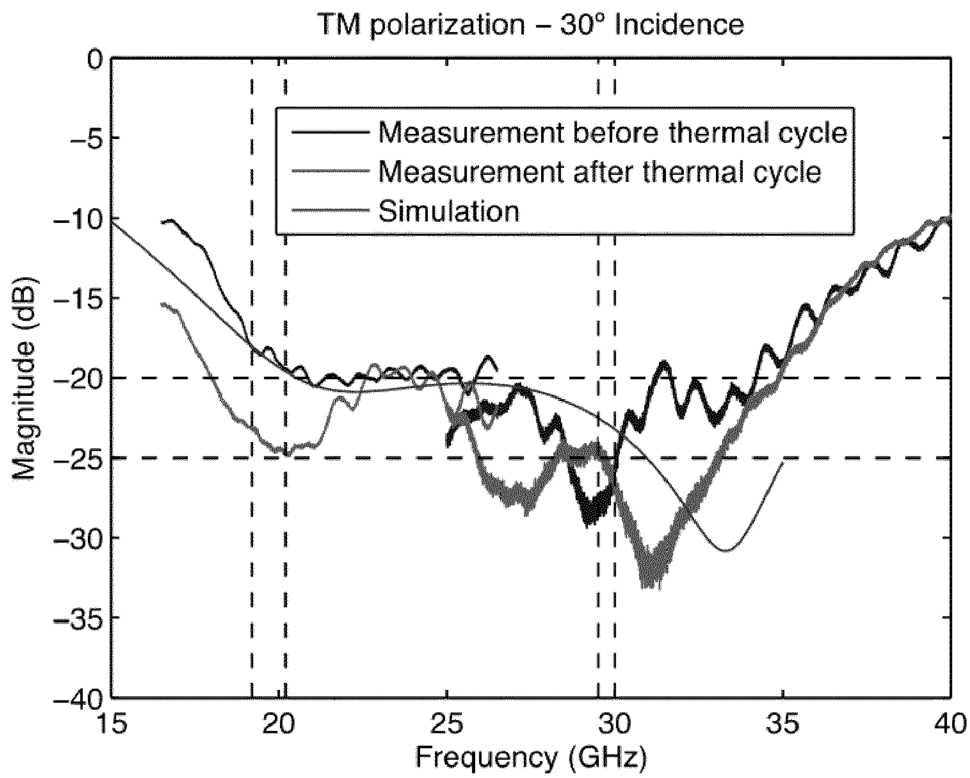


Fig. 7B



Reflection Coefficient – Normal Incidence
0
–5
–10
–15
–20
–25
–30
–35
–40
–45
–50
–55
Magnitude (GHz)
15
20
25
30
35
Frequency (GHz)
Simulation
Measurement

Fig. 8A



TM polarization – 30° Incidence
0
–5
–10
–15
–20
–25
–30
–35
–40
Magnitude (dB)
15
20
25
30
35
40
Frequency (GHz)
Measurement before thermal cycle
Measurement after thermal cycle
Simulation

Fig. 8A’

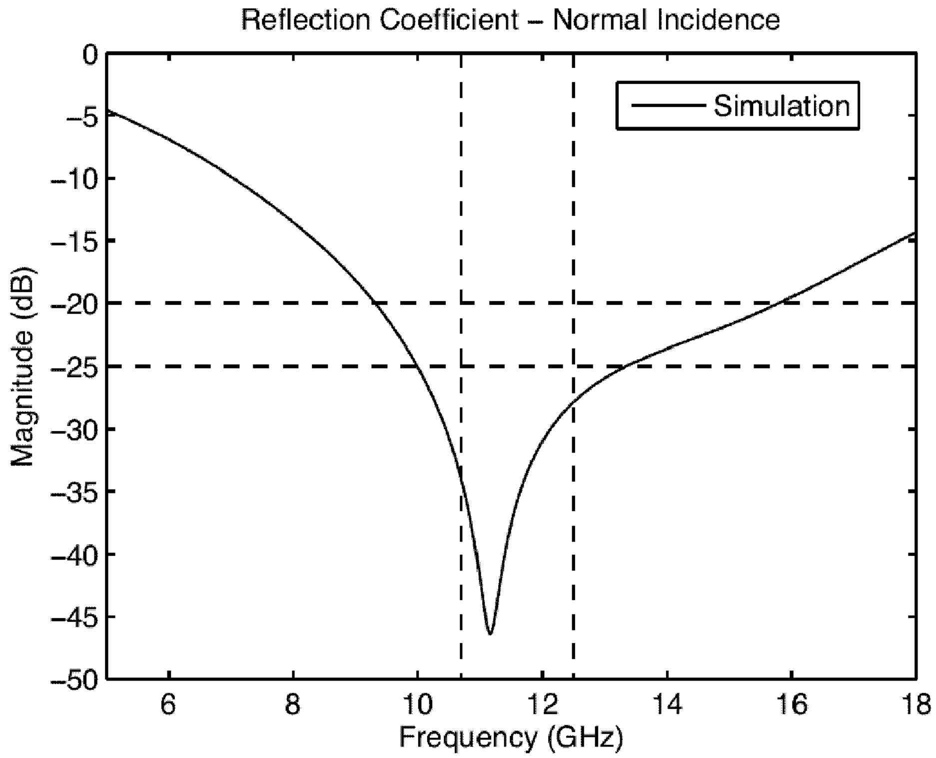

Reflection Coefficient – Normal Incidence
Simulation
Magnitude (dB)
0
−5
−10
−15
−20
−25
−30
−35
−40
−45
−50
6
8
10
12
14
16
18
Frequency (GHz)

Fig. 8B

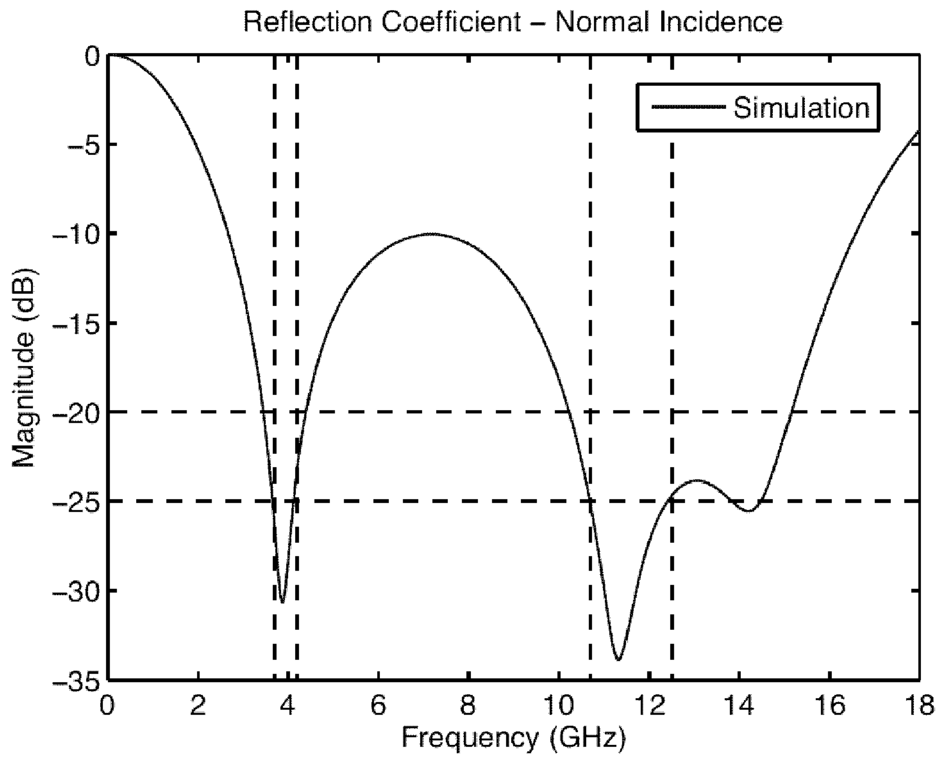

Reflection Coefficient – Normal Incidence
Simulation
Magnitude (dB)
0
−5
−10
−15
−20
−25
−30
−35
0
2
4
6
8
10
12
14
16
18
Frequency (GHz)

Fig. 8C

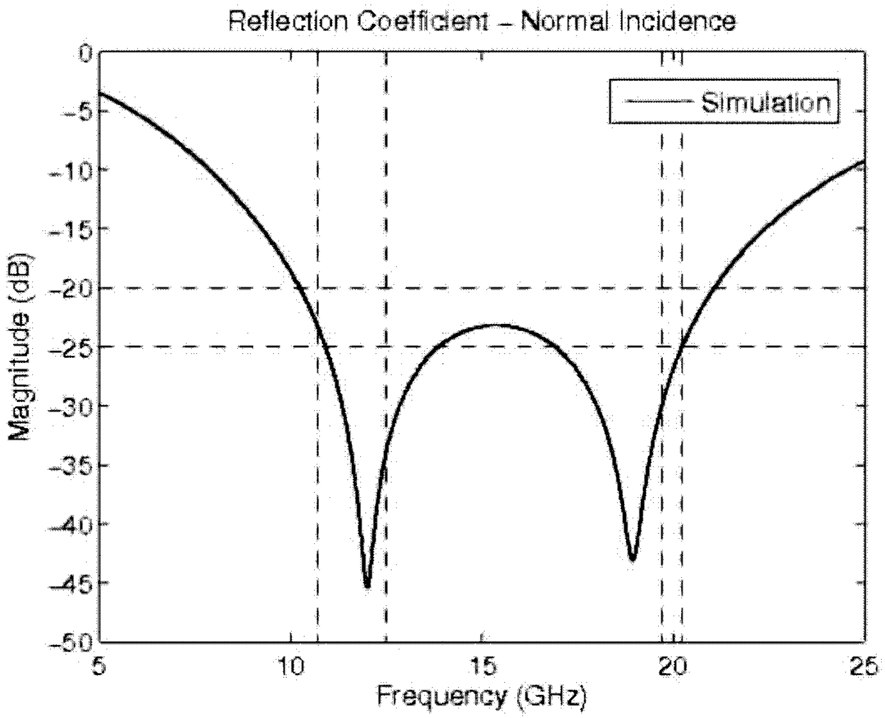

Reflection Coefficient – Normal Incidence
Simulation
Magnitude (dB)
Frequency (GHz)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
5
10
15
20
25

Fig. 8D

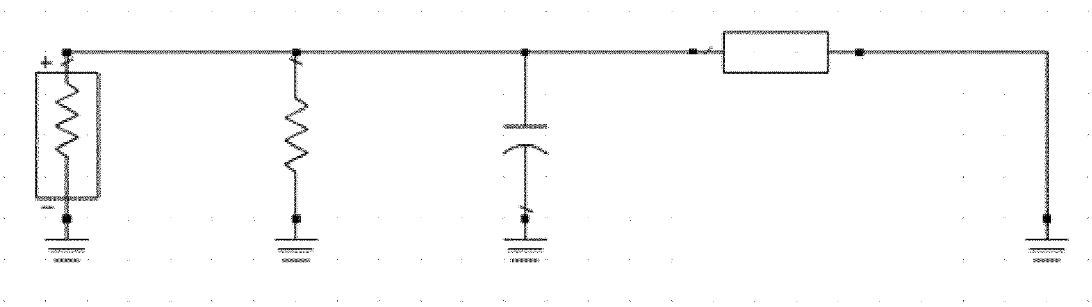


Fig. 9

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EUROPEAN SEARCH REPORT

Application Number
EP 17 15 6431

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y A	Chandrika Sudhendra ET AL: "An Ultra Wide Band Radar Absorber Based on Square Patch Resistive FSS", Proc. 7th annual Antenna Test and Measurement Society International Conference-ATMS 2014, 6 February 2014 (2014-02-06), pages 1-5, XP055399140, Chennai, India Retrieved from the Internet: URL:https://atmsindia.org/tech_papers/2014/20_FULL PAPER_An Ultra Wide Band Radar Absorber Based on Square Patch Resistive FSS.docx [retrieved on 2017-08-16] * sections II. and III.; figures 1(a), 1(b), 2-6; table 1 *	1-13 14 15	INV. H01Q17/00 H01Q15/00
X A	SUDHENDRA CHANDRIKA ET AL: "A novel ultra wide band Radar Absorber based on hexagonal resistive patch FSS", 2013 IEEE APPLIED ELECTROMAGNETICS CONFERENCE (AEMC), IEEE, 18 December 2013 (2013-12-18), pages 1-2, XP032737454, DOI: 10.1109/AEMC.2013.7045118 [retrieved on 2015-02-18] * sections I.-III.; figures 1, 2(b), 4, 5(a); table 1 *	1-13 14,15	TECHNICAL FIELDS SEARCHED (IPC) H01Q

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	18 August 2017	Blech, Marcel

3

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A	US 5 598 989 A (ROSS BARRY S [US] ET AL) 4 February 1997 (1997-02-04) * column 2, line 3 - column 3, line 64; figures 2-5 * ----- -/--	1-13	

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
The Hague	18 August 2017	Blech, Marcel

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Application Number
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DOCUMENTS CONSIDERED TO BE RELEVANT			
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T	K. KEMPA: "Percolation effects in the checkerboard Babinet series of metamaterial structures", PHYSICA STATUS SOLIDI. RAPID RESEARCH LETTERS, vol. 4, no. 8-9, 2 July 2010 (2010-07-02), pages 218-220, XP055399396, DE ISSN: 1862-6254, DOI: 10.1002/pssr.201004266 * sections 2-5; figures 1, 2 * -----	15	TECHNICAL FIELDS SEARCHED (IPC)
T	YOSUKE NAKATA ET AL: "Plane-wave scattering by self-complementary metasurfaces in terms of electromagnetic duality and Babinet's principle", PHYSICAL REVIEW. B, CONDENSED MATTER AND MATERIALS PHYSICS, vol. 88, no. 20, 22 November 2013 (2013-11-22), XP055399376, US ISSN: 1098-0121, DOI: 10.1103/PhysRevB.88.205138 * section V.; page 5 - page 7; figures 3, 4 * -----	15	

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
The Hague	18 August 2017	Blech, Marcel

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18-08-2017

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