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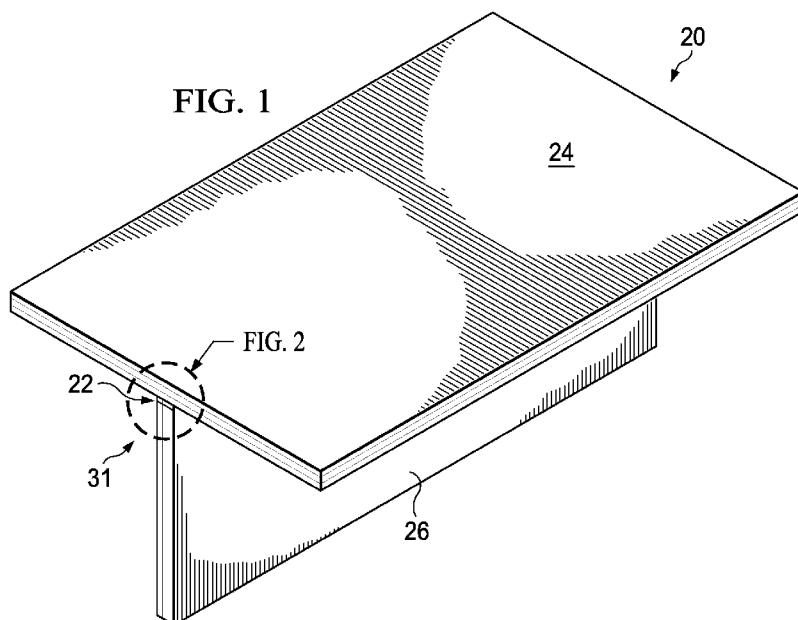
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(54) Title: COMPOSITE STRUCTURES HAVING BONDLINES WITH MATCHED ELECTRICAL CONDUCTIVITY



(57) Abstract: Two composite laminates are joined together by a bondline having portions exposed to the ambient environment. The bondline contains scrim having an electrical conductivity and impedance matched to that of the laminates in order to mitigate effects of lightning strikes.

**COMPOSITE STRUCTURES HAVING BONDLINES  
WITH MATCHED ELECTRICAL CONDUCTIVITY**

5

**BACKGROUND INFORMATION**

1. **Field:**

This disclosure generally relates to techniques for bonding composite structures, and deals more particularly with methods for mitigating the effects of lightning strikes at bondlines.

10

2. **Background:**

Fiber reinforced composite structures, such as, without limitation, carbon fiber reinforced plastics (CFRP) may be bonded together along a bondline using a structural adhesive. 15 The bondline may be strengthened and reinforced by introducing one or more layers of scrim into the adhesive.

In aircraft applications, areas of composite structures such as fuselage skins are sometimes repaired or reworked by 20 adhesively bonding composite repair patches to the structure. In order to reduce the effects of lightning strikes on the repair patch, it is necessary to provide a continuous electrical path between the repair patch and the structure to which it is bonded in order to dissipate electrical current flow.

25

In order to provide electrical continuity between a composite repair patch and the composite structure to which it is bonded, an electrically conductive scrim may be placed in the bondline. A problem arises, however, when portions of the 30 bondline are exposed to the ambient environment. A lightning strike may generate an undesirable electrical potential across the bondline. In order to avoid the effects of an undesirable electrical potential across the bondline, the exposed areas of the bondline are covered with an electrically insulating

sealant. Although sealants are effective, they increase the weight of the aircraft, and are both time-consuming and labor-intensive, adding to manufacturing costs.

5 Accordingly, there is a need for a method of joining composite structures along bondlines that mitigate the effects of lightning strikes, and reduce accompanying electrical potentials occurring across exposed bondlines. There is also a need for a method of bonding composite structures together which  
10 obviates the need for sealants to cover exposed portions of bondlines between the structures.

### **SUMMARY**

The disclosed methods provide composite structures joined together along bondlines that have electrical conductivities which are matched to the structures which they join. The use of bondlines having conductivities matched to those of the structures reduces an electrical potential across exposed portions of the bondline. The use of sealants to cover exposed portions of bondlines may be reduced or eliminated, thereby reducing aircraft weight and manufacturing costs.

According to one disclosed embodiment, a composite laminate structure is provided comprising first and second fiber reinforced plastic resin laminates each having an electrical impedance, and a structural bondline joining the first and second laminates together. The bondline has an electrical impedance substantially matching the electrical impedance of the first and second laminates. The fiber reinforcement in each of  
25 the first and second fiber reinforced plastic resin laminates are carbon fibers, and the bondline includes an adhesively impregnated scrim having an electrical impedance that substantially matches the electrical impedance of the first and second laminates. At least a portion of the bondline is exposed  
30

to an ambient environment. The first and second laminates and the bondline may form a T-joint. The first and second laminates may form part of a fuel tank having an open interior, and in which a portion of the bondline is exposed to the open interior 5 of the fuel tank. The bondline includes an adhesively impregnated scrim having an AC (alternating current) conductivity that substantially matches the AC conductivity of the first and second laminates.

10 According to another embodiment, a composite laminate structure is provided comprising a first carbon fiber reinforced plastic laminate having a first electrical impedance, and a second carbon fiber reinforced plastic laminate having a second electrical impedance substantially matching the first electrical 15 impedance. The laminate structure further includes an adhesive bondline between the first and second laminates. The adhesive bond includes an adhesive and a scrim having a third electrical impedance substantially matching the first and second electrical impedances. The first and second laminates may form part of a 20 fuel tank having an open interior adapted to store fuel, wherein a portion of the adhesive bondline is exposed to the open interior of the fuel tank. The first and second laminates and the adhesive bondline may form a T-joint. Each of the first, second and third electrical impedances include a resistive 25 component and a reactive component. The resistive components are substantially equal, and the reactive components are substantially equal. The scrim may be formed of carbon fibers. The first and second laminates and the bondline have substantially the same AC conductivity.

30 According to still another embodiment, a composite aircraft fuel tank is provided with lightning protection. The lightning protection comprises at least a first carbon fiber reinforced plastic laminate wall, at least a second carbon fiber reinforced

plastic laminate wall, and an adhesive bondline joining the first and second laminate walls, the adhesive bondline including an electrically conductive scrim having an electrical impedance substantially matching the electrical impedance of each of the 5 first and second laminate walls. At least a portion of the adhesive bondline is adapted to be exposed to fuel vapors within the fuel tank.

According to still another embodiment, a method of 10 providing lightning protection for a bond joint between two cured carbon fiber reinforced plastic laminates comprises installing scrim in the bond joint having an electrical impedance that substantially matches the electrical impedance each of the two carbon fiber reinforced plastic laminates. 15 Installing the scrim includes impregnating the scrim with an adhesive. The adhesive may be one of a film adhesive and a paste adhesive. The scrim may be formed of carbon fibers. The laminates and the scrim may possess substantially the same electrical conductivity. Installing the scrim in the bond joint 20 includes assembling the two laminates in a T-shaped configuration, and placing the scrim between an edge of one of the two laminates, and a face of the other of the two laminates.

According to a further embodiment, a method is provided of 25 reducing the electrical potential across an exposed bondline between two, carbon fiber reinforced plastic laminates. The method comprises determining the electrical conductivity of each of the two laminates, selecting a scrim having an electrical conductivity substantially matching the determined electrical 30 conductivity of each of the two laminates, installing the scrim and an adhesive between the two laminates, and curing the adhesive.

According to still further embodiment, a method is provided of fabricating a composite structure having an exposed bond protected against lightning strikes. The method comprises laying up first and second carbon fiber reinforced plastic pre-preg 5 laminates, curing the first and second pre-preg laminates, and joining the first and second cured laminates with a bond joint. Joining the first and second cured laminates with the bond joint may include selecting a scrim having an electrical impedance substantially matching the electrical impedance of each of the 10 first and second laminates, impregnating the scrim with a bonding adhesive, installing the impregnated scrim between the first and second laminates to form a bondline, and curing the adhesive.

15 **BRIEF DESCRIPTION OF THE DRAWINGS**

The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative embodiments, however, as well as a preferred mode of use, further objectives and advantages thereof, will 20 best be understood by reference to the following detailed description of an illustrative embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

25 Figure 1 is an illustration of a perspective view of a bonded composite structure having a bondline employing electrically conductive scrim according to the disclosed embodiments.

30 Figure 2 is an illustration of an end view of the area designated as Figure 2 in Figure 1.

Figure 3 is an illustration of a cross-sectional view of two laminate structures joined together by a lap joint employing the disclosed scrim.

5 Figure 4 is an illustration of a perspective view of the scrim along with two layers of adhesive used to form the bondline.

10 Figure 5 is an illustration of a graph showing electrical current flow resulting from a typical lightning strike.

Figure 6 is an illustration of a circuit diagram of an impedance.

15 Figure 7 is an illustration of a perspective view of an aircraft fuel tank, portions broken away to reveal the interior of the tank.

20 Figure 8 is an illustration of a flow diagram of a method of co-curing two composite pre-pregs along a bondline.

Figure 9 is an illustration of a flow diagram of a method of fabricating a bonded precured structure employing the disclosed scrim.

25 Figure 10 is an illustration of a flow diagram of aircraft production and service methodology.

30 Figure 11 is an illustration of a block diagram of an aircraft.

**DETAILED DESCRIPTION**

Referring first to Figures 1 and 2, a composite structure 20 comprises first and second composite pre-pregs 24, 26, which may be formed of by laying up pre-preg plies, such as a CFRP. In 5 this example, the first and second pre-pregs 24, 26 together are joined together along a bondline 22 between a face 29 of the first pre-preg 24 and an edge 27 of the second pre-preg 26, effectively forming a butt joint 31. The bondline 22 includes exposed portions 28, 30 at the ends of the bondline 22, which 10 are exposed to the surrounding ambient environment. As will be discussed below, the bondline 22 has an electrical conductivity  $\sigma_1$  and impedance  $Z_1$  that substantially match the electrical conductivity  $\sigma_2$  and impedance  $Z_2$  of each of the first and second pre-pregs 24, 26. This matching of the electrical conductivities 15  $\sigma_1$ ,  $\sigma_2$  and impedances  $Z_1$ ,  $Z_2$  reduces or eliminates build-up of an undesirable electrical potential or charge "V" (Figure 2) between the pre-pregs 24, 26 along the exposed portions 28, 30 of the bondline 22.

20 The disclosed bondline 22 may be employed to form other types of bonded joints between two laminate structures. For example, referring to Figure 3, the disclosed bondline 22 may be employed to form a lap joint 35 between first and second composite pre-pregs 24, 26. In this example, the bondline 22 25 also has exposed portions 28, 30 which need not be sealed as a result of the electrical conductivity  $\sigma_1$  and impedance  $Z_1$  of the bondline 22 being matched to the electrical conductivity  $\sigma_2$  and impedance  $Z_2$  of the first and second pre-pregs 24, 26.

30 Attention is now directed to Figure 4 which illustrates the components used to form the bondline 22. A scrim 32 is sandwiched between two layers 34, 36 of a suitable structural adhesive. The scrim 32 may be in any of the numerous configurations such as, without limitation, a mesh, knitted mat

or random fiber mat comprising intersecting strands of electrically conductive fibers. The conductive fibers have an AC conductivity  $\sigma_1$  and an impedance  $Z_1$  respectively matching the AC conductivity  $\sigma_2$  and impedance  $Z_2$  of the first and second pre-pregs 5 24, 26. The fibers may comprise a single material, or may comprise fibers of multiple types of materials which collectively have the required AC conductivity  $\sigma_1$  and impedance  $Z_1$  matched to the AC conductivity  $\sigma_2$  and impedance  $Z_2$  of the pre-pregs 24, 26. In the case of first and second pre-pregs 24, 26 10 comprising CFRPs, then the fibers of the scrim 32 may also be formed of carbon fibers similar or identical to those forming the carbon fiber reinforcement in the first and second pre-pregs 24, 26. While only a single layer of scrim 32 is illustrated in Figure 4, multiple layers of the scrim 32 may be employed in a 15 single bondline 22.

Each of the adhesive layers 34, 36 may comprise an adhesive resin film or an adhesive resin paste which adheres to the CFRP plies of the pre-pregs 24, 26. The scrim 32 may be embedded into 20 and adhere to each of the adhesive layers 34, 36, as by pressing the scrim 32 into the adhesive layers 34, 36. Other techniques for integrating bonding adhesive with the scrim 32 may be possible, including impregnating the scrim 32 with the adhesive. The scrim 32 is configured to provide continuous electrical 25 conductivity throughout the bondline 22 and may also serve as a binding matrix.

As previously mentioned, the scrim 32 possesses an AC conductivity  $\sigma_1$  and an impedance  $Z_1$  that substantially match the 30 electrical conductivity  $\sigma_2$  and impedance  $Z_2$  of each of the composite pre-pregs joined by the bondline 22. Electrical conductivity  $\sigma$  is a measure of the material's ability to conduct electric current. In the case of a lightning strike causing electrical current to flow through the pre-pregs 24, 26, and

through the bondline 22, the current flow is typically not constant, but varies, similar to an alternating current (AC). For example, Figure 5 is a graph showing electrical current flow 37 over time 39, produced by a typical lightning strike. During 5 an initial time period "A", the current flow begins with a sharp spike 43 at the initial lightning attachment 41, then decays slowly during time period "B", may be somewhat constant during time period "C", and then quickly increases during time period "D", forming another sharp spike 45 immediately before 10 detachment at 47. Accordingly, the pre-pregs 24, 26, and the scrim 32 each have respective AC conductivities  $\sigma_1$ ,  $\sigma_2$  and respective impedances  $Z_1$ ,  $Z_2$  (Figures 2 and 3).

Figure 6 is a circuit diagram representing the components 15 of each of the impedances  $Z_1$ ,  $Z_2$ . The impedance  $Z$  is the sum of a resistive component  $R_x$  and a reactive component  $X$ , thus,  $Z = R_x + X$ . The reactive component  $X$ , or "reactance", includes inductance  $L$  and capacitance  $C$ , and represents the opposition of the scrim 32, viewed as a circuit, to a change of electric 20 current or voltage caused by the lightning strike. Because the AC conductivity  $\sigma_1$  and the impedance  $Z_1$  of the scrim 32, and thus of the bondline 22, are respectively matched to those of the first and second pre-pregs 24, 26, the current flow through the pre-pregs 24, 26 passes unimpeded through the bondline 22, 25 rather "seeing" a discontinuity in the bondline 22 which may results in the build-up of an undesirable electrical potential or charge "V" (Figure 2) across the bondline 22 in the area of the exposed portions 28, 30.

30 The bondline 22 described above having a "matched" electrical conductivity  $\sigma_1$  and a "matched" impedance  $Z_1$  may be used in a wide variety of composite laminate structures to mitigate the effects electrical current flows due to lightning strikes. For example, the disclosed bondline 22 may be employed

in a composite aircraft fuel tank 42 shown in Figure 7. The fuel tank 42 includes a composite laminate top 44, bottom 46 and sides 48, 50 forming an internal volume 55. The fuel tank 42 may further include internal ribs 52 as well as a baffle walls 54, 5 each of which are bonded along its top and bottom edges to the top and bottom walls 44, 46 respectively, by a T-joint and bondline 22 similar to that shown in Figures 1 and 2 which use the scrim 32 shown in Figure 4. The disclosed bondline 22 may also be employed to bond the repair patches (not shown) to 10 underlying composite structures, such as CFRP laminate skins.

Attention is now directed to Figure 8 which illustrates the overall steps of a method of reducing the buildup of an electrical potential or charge across a bond line 22 in the area 15 of exposed portions 28, 30 of the bondline 22 between two pre-pregs 24, 26 subjected to the effects of lightning strikes. At step 56, the electrical conductivities  $\sigma_2$  of each of the two pre-pregs 24, 26 are determined. Next at 58, scrim used in the bondline 22 is selected which has an electrical conductivity  $\sigma_1$  20 substantially matching the electrical conductivity  $\sigma_2$  of each of the two pre-pregs 24, 26. At step 60, the scrim 32 along with the adhesive is installed between the pre-pregs 24, 26, following which the pre-pregs 24, 26 and the pre-pregs and the adhesive are co-cured at step 62.

25  
Figure 9 broadly illustrates the steps of a method of fabricating a CFRP laminate structure 20 having bondlines 22 provided with lightning protection. At step 64, first and second CFRP pre-pregs 24, 26 are laid up, and formed to shape, as 30 required. At step 66, each of the first and second CFRP pre-pregs 24, 26 are cured to form laminates. At step 68 a scrim 32 is selected having an electrical impedance  $Z_1$  substantially matching the electrical impedance  $Z_2$  of the first and second pre-preg laminates 24, 26. At 70, the scrim 32 is impregnated or

otherwise integrated into a suitable bonding adhesive. At step 72, the impregnated scrim is installed between surfaces of the first and second pre-preg laminates 24, 26 to form a bondline 22 which may include exposed portions 28, 30. Finally, at 74, the 5 adhesive is cured.

Embodiments of the disclosure may find use in a variety of potential applications, particularly in the transportation industry, including for example, aerospace, marine, automotive 10 applications and other application where autoclave curing of composite parts may be used. Thus, referring now to Figures 10 and 11, embodiments of the disclosure may be used in the context of an aircraft manufacturing and service method 76 as shown in Figure 10 and an aircraft 78 as shown in Figure 11. Aircraft 15 applications of the disclosed embodiments may include, for example, without limitation, fabrication of composite laminate assemblies and subassemblies requiring bonded joints that require protection against the effects of lightning strikes on an aircraft. During pre-production, exemplary method 76 may 20 include specification and design 80 of the aircraft 78 and material procurement 82. During production, component and subassembly manufacturing 84 and system integration 86 of the aircraft 78 takes place. Thereafter, the aircraft 78 may go 25 through certification and delivery 88 in order to be placed in service 90. While in service by a customer, the aircraft 78 is scheduled for routine maintenance and service 92, which may also include modification, reconfiguration, refurbishment, and so on.

Each of the processes of method 76 may be performed or 30 carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include without limitation any number of aircraft manufacturers and major-system subcontractors; a third party may include without limitation any

number of vendors, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

5 As shown in Figure 11, the aircraft 78 produced by exemplary method 76 may include an airframe 94 with a plurality of systems 96 and an interior 98. Examples of high-level systems 96 include one or more of a propulsion system 100, an electrical system 102, a hydraulic system 104, and an 10 environmental system 106. Any number of other systems may be included. Although an aerospace example is shown, the principles of the disclosure may be applied to other industries, such as the marine and automotive industries.

15 Systems and methods embodied herein may be employed during any one or more of the stages of the production and service method 76. For example, components or subassemblies corresponding to production process 84 may be fabricated or manufactured in a manner similar to components or subassemblies 20 produced while the aircraft 96 is in service. Also, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during the production stages 84 and 86, for example, by substantially expediting assembly of or reducing the cost of an aircraft 78. Similarly, one or more of apparatus 25 embodiments, method embodiments, or a combination thereof may be utilized while the aircraft 78 is in service, for example and without limitation, to maintenance and service 92.

30 The description of the different illustrative embodiments has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different illustrative embodiments may provide

different advantages as compared to other illustrative embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of 5 ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

**CLAIMS:**

What is claimed is:

- 5 1. A composite laminate structure, comprising:  
first and second fiber reinforced plastic resin laminates  
each having an electrical impedance; and  
a structural bondline joining the first and second  
laminates together, the bondline having an electrical impedance  
10 substantially matching the electrical impedance of the first and  
second laminates.
2. The composite laminate structure of claim 1, wherein:  
the fiber reinforcement in each of the first and second  
15 fiber reinforced plastic resin laminates are carbon fibers, and  
the structural bondline includes an adhesively impregnated  
scrim having an electrical impedance that substantially matches  
the electrical impedance of the first and second laminates.
- 20 3. The composite laminate structure of either Claim 1 or claim  
2, wherein at least a portion of the structural bondline is  
exposed to an ambient environment.
- 25 4. The composite laminate structure of any preceding Claim,  
wherein the first and second laminates and the structural  
bondline form a T-joint.
5. The composite laminate structure of any preceding Claim,  
wherein:  
30 the first and second laminates form part of a fuel tank  
having an open interior, and  
a portion of the structural bondline is exposed to the open  
interior of the fuel tank.

6. The composite laminate structure of any preceding Claim, wherein the structural bondline includes an adhesively impregnated scrim having an AC conductivity that substantially matches the AC conductivity of the first and second laminates.

5

7. A composite laminate structure, comprising:

a first carbon fiber reinforced plastic laminate having a first electrical impedance;

10 a second carbon fiber reinforced plastic laminate having a second electrical impedance substantially matching the first electrical impedance; and

15 an adhesive bondline between the first and second laminates, the adhesive bond including an adhesive and a scrim having a third electrical impedance substantially matching the first and second electrical impedances.

8. The composite laminate structure of claim 7, wherein:

the first and second laminates form part of a fuel tank having an open interior adapted to store fuel, and

20 a portion of the adhesive bondline is exposed to the open interior of the fuel tank.

25 9. The composite laminate structure of either claim 7 or claim 8, wherein the first and second laminates and the adhesive bondline form a T-joint.

10. The composite laminate structure of any of claims 7 to 9, wherein:

30 each of the first, second and third electrical impedances include a resistive component and a reactive component, the resistive components are substantially equal, and the reactive components are substantially equal.

11. The composite laminate structure of any of claims 7 to 10, wherein the scrim is formed of carbon fibers.

12. The composite laminate structure of any of claims 7 to 11,  
5 wherein the first and second laminates and the bondline have substantially the same AC conductivity.

13. A composite aircraft fuel tank having lightning protection, comprising:

10 at least a first carbon fiber reinforced plastic laminate wall;

at least a second carbon fiber reinforced plastic laminate wall;

15 an adhesive bondline joining the first and second laminate walls, the adhesive bondline including an electrically conductive scrim having an electrical impedance substantially matching the electrical impedance of each of the first and second laminate walls.

20 14. The composite aircraft fuel tank of claim 13, wherein at least a portion of the adhesive bondline is adapted to be exposed to fuel vapors within the fuel tank.

15. A method of providing lightning protection of for a bond  
25 joint between two cured carbon fiber reinforced plastic laminates, comprising:

installing scrim in the bond joint having an electrical impedance that substantially matches the electrical impedance each of the two carbon fiber reinforced plastic laminates.

30 16. The method of claim 15, wherein installing the scrim includes impregnating the scrim with an adhesive.

17. The method of claim 16, wherein the adhesive is one of a film adhesive and a paste adhesive.

18. The method of claim any of claims 15 to 17 wherein the 5 scrim is formed of carbon fibers.

19. The method of any of claims 15 to 18, wherein the laminates and the scrim possess substantially the same electrical conductivity.

10

20. The method of claim 16, wherein installing the scrim in the bond joint includes:

assembling the two laminates in a T-shaped configuration, and

15 placing the scrim between an edge of one of the two laminates, and a face of the other of the two laminates.

21. An aircraft fuel tank having a exposed bond joint produced by the method of claim 15.

20

22. A method of reducing the electrical potential across an exposed bondline between two carbon fiber reinforced plastic laminates, comprising:

25 determining the electrical conductivity of each of the two laminates;

selecting a scrim having an electrical conductivity substantially matching the determined electrical conductivity of each of the two laminates;

30 installing the scrim and an adhesive between the two laminates;

curing the adhesive.

23. A method of fabricating a composite structure having an exposed bond protected against lightning strikes, comprising:

laying up first and second carbon fiber reinforced plastic pre-preg laminates;

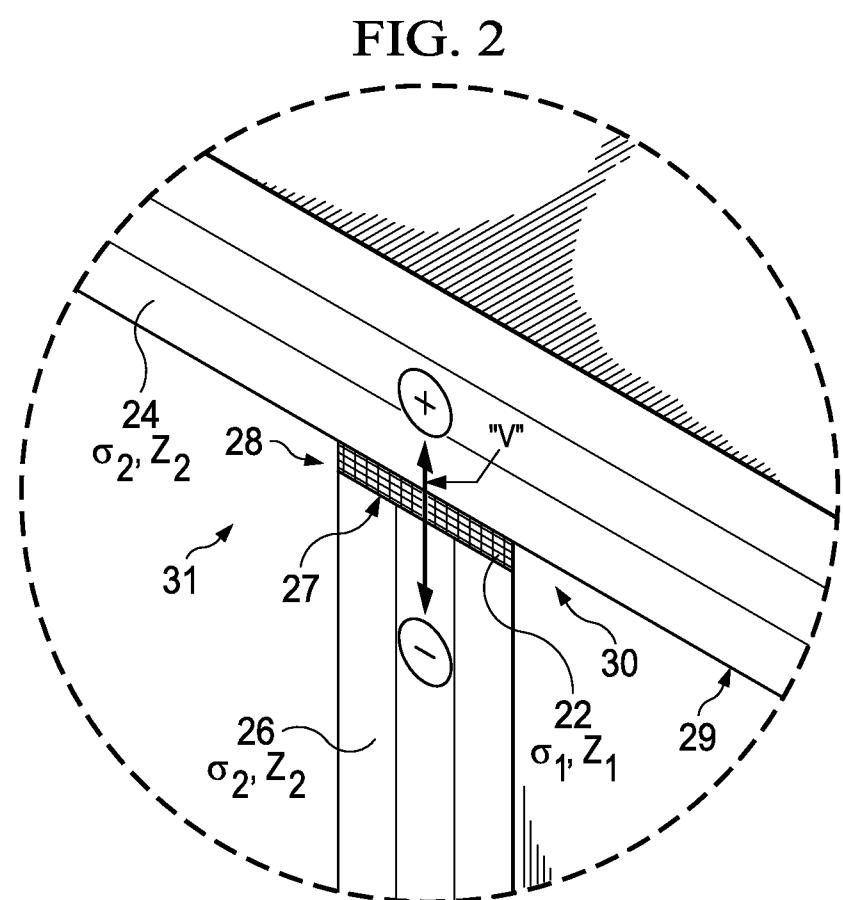
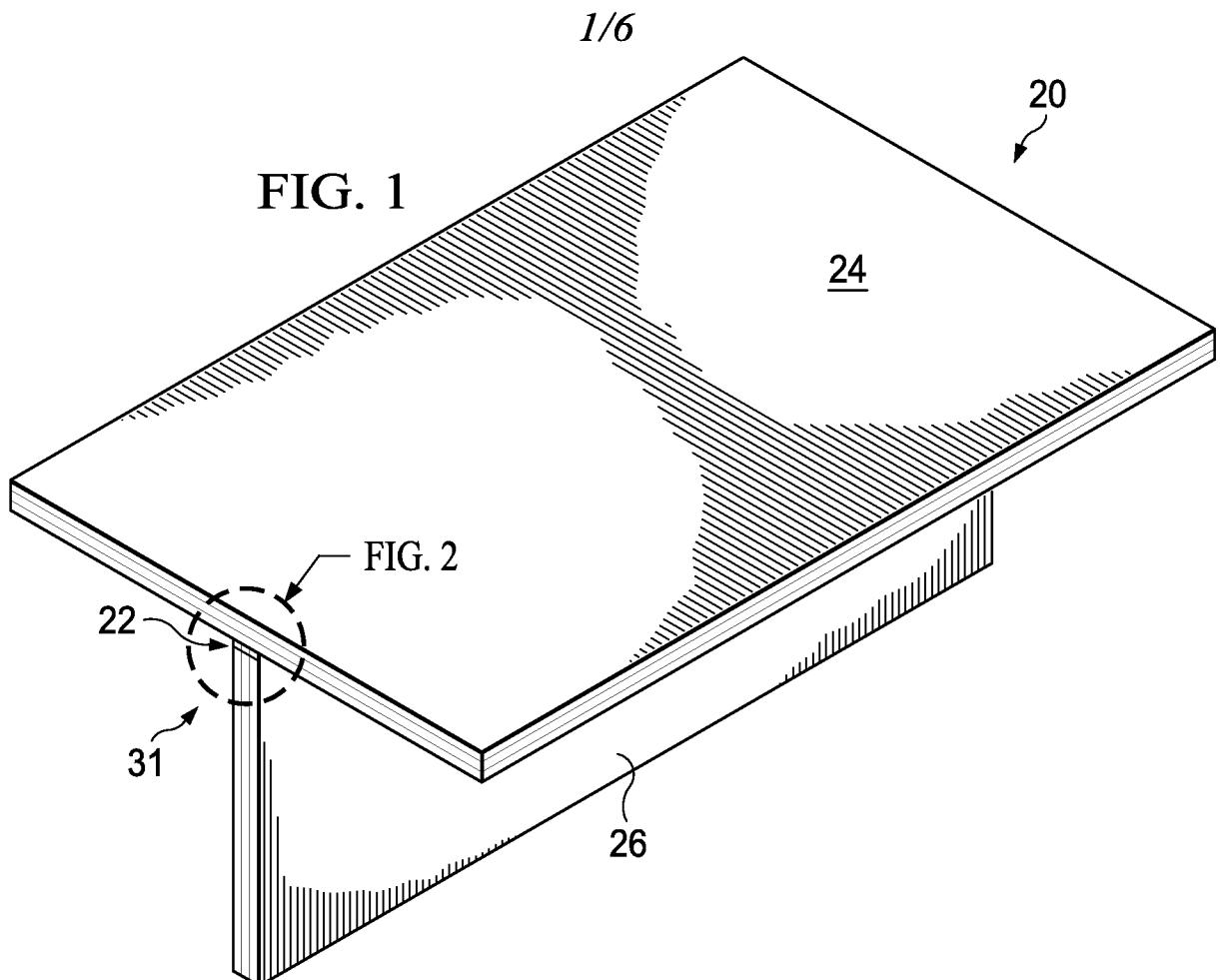
curing the first and second pre-preg laminates;

joining the first and second cured laminates with a bond 5 joint, including-

selecting a scrim having an electrical impedance substantially matching the electrical impedance of each of the first and second laminates,

impregnating the scrim with a bonding adhesive,

10 installing the impregnated scrim between the first and second laminates to form a bondline, and curing the adhesive.



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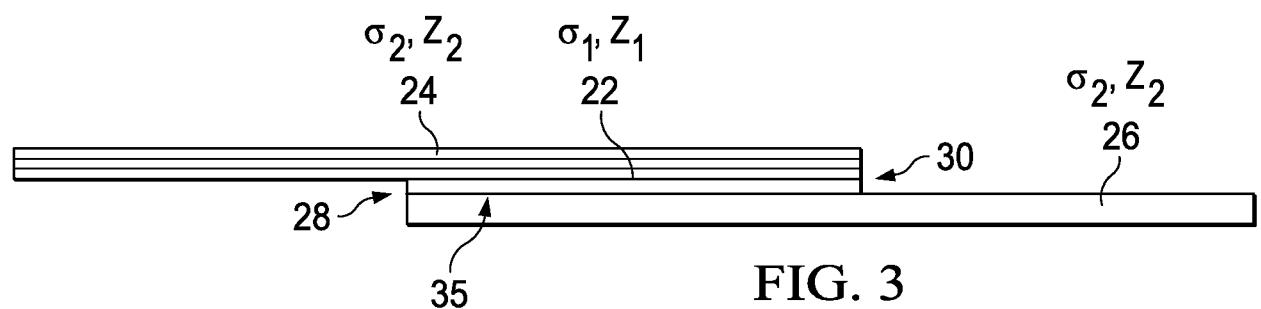


FIG. 3

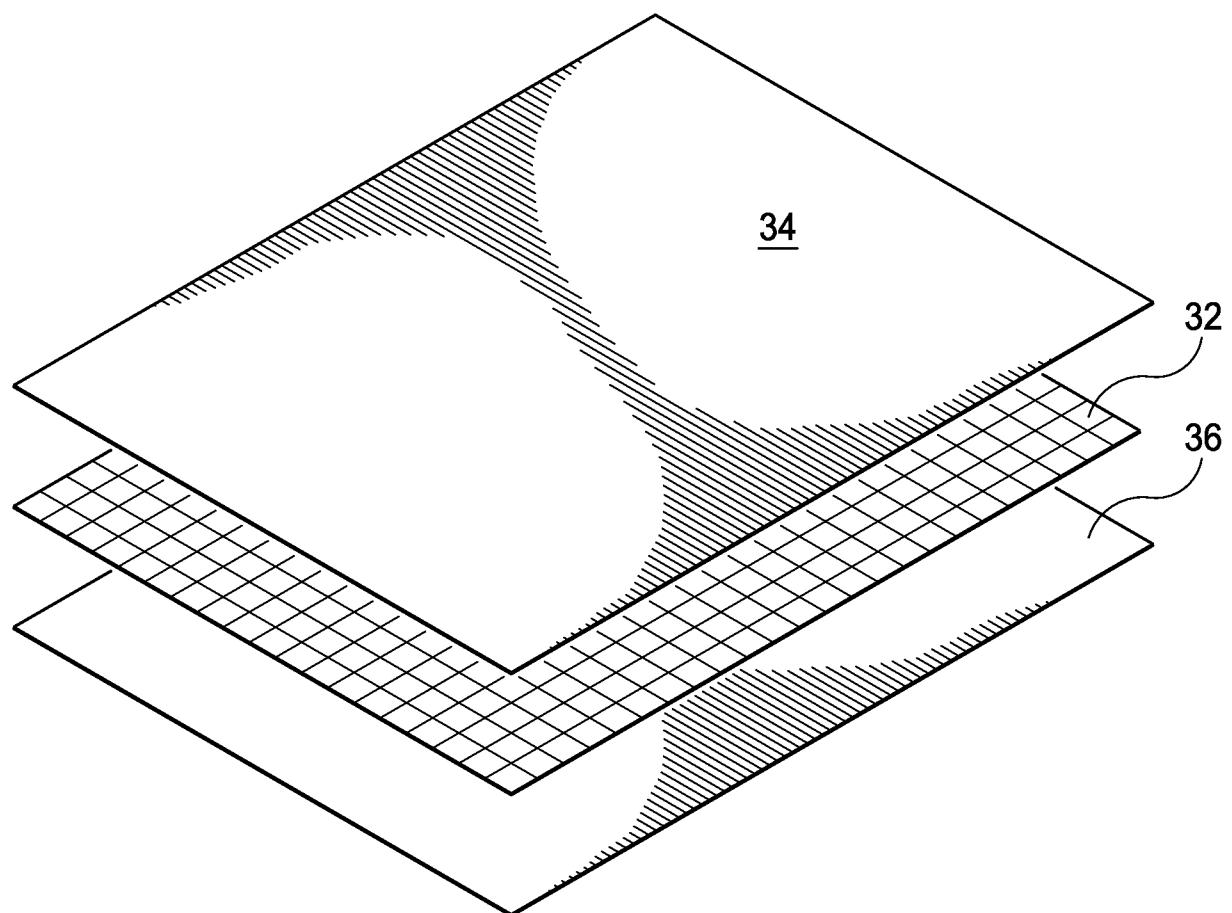
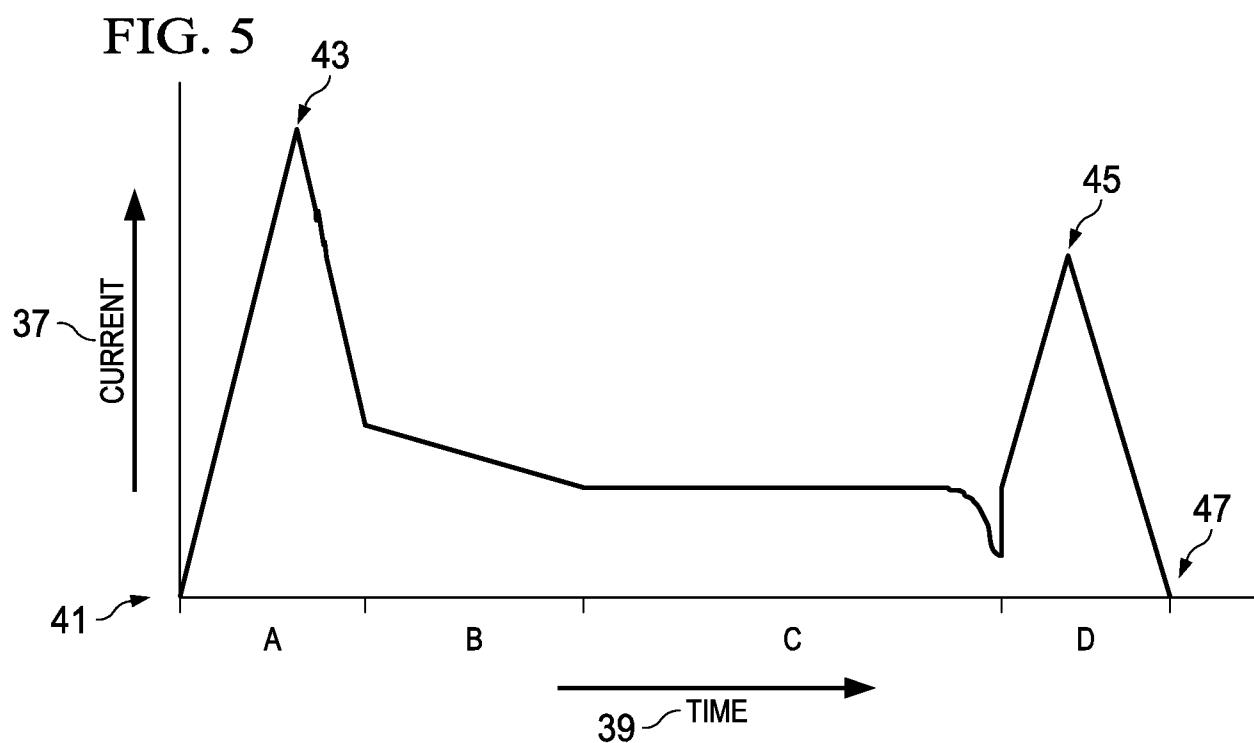
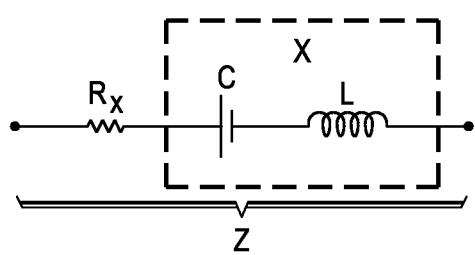


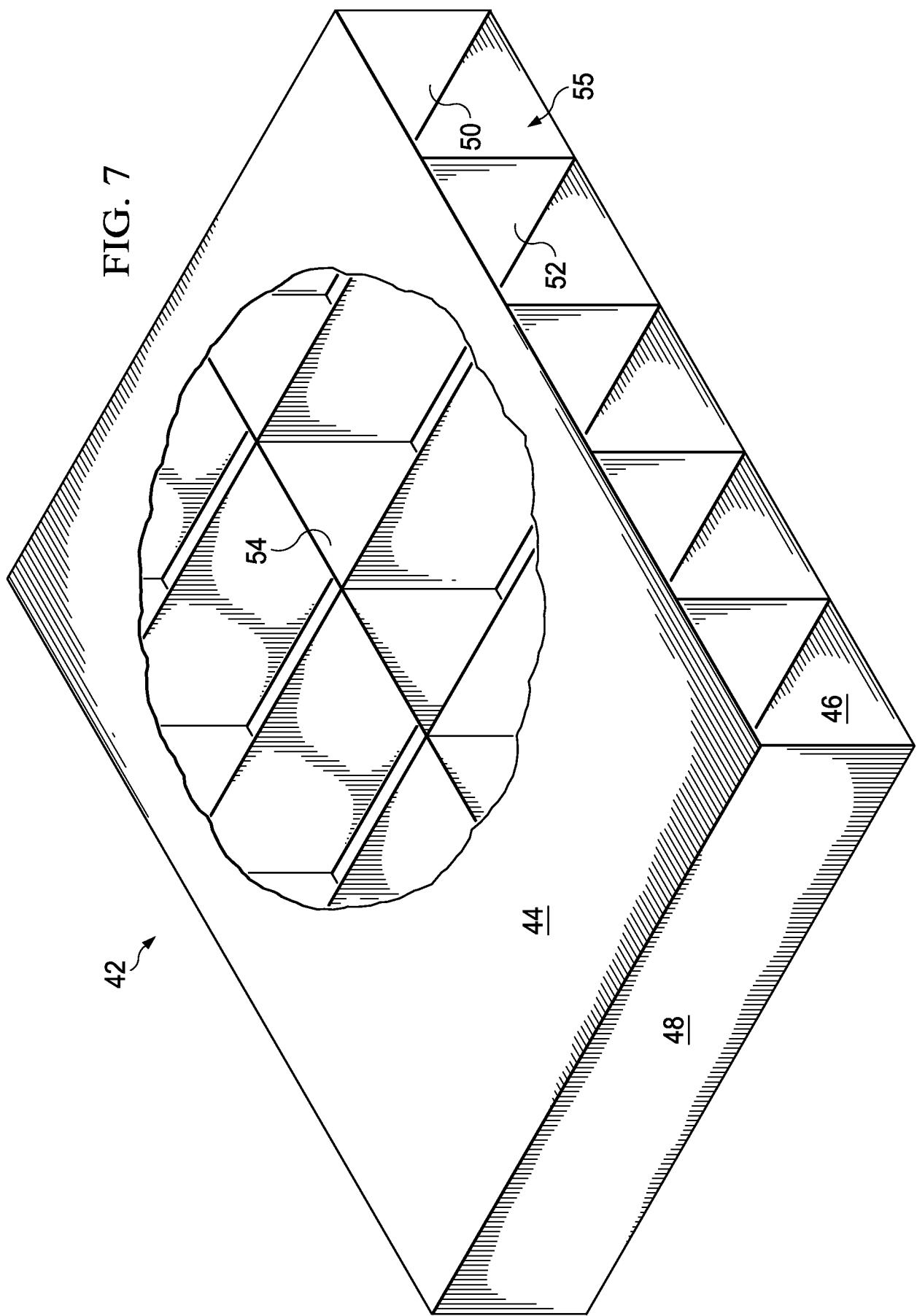
FIG. 4

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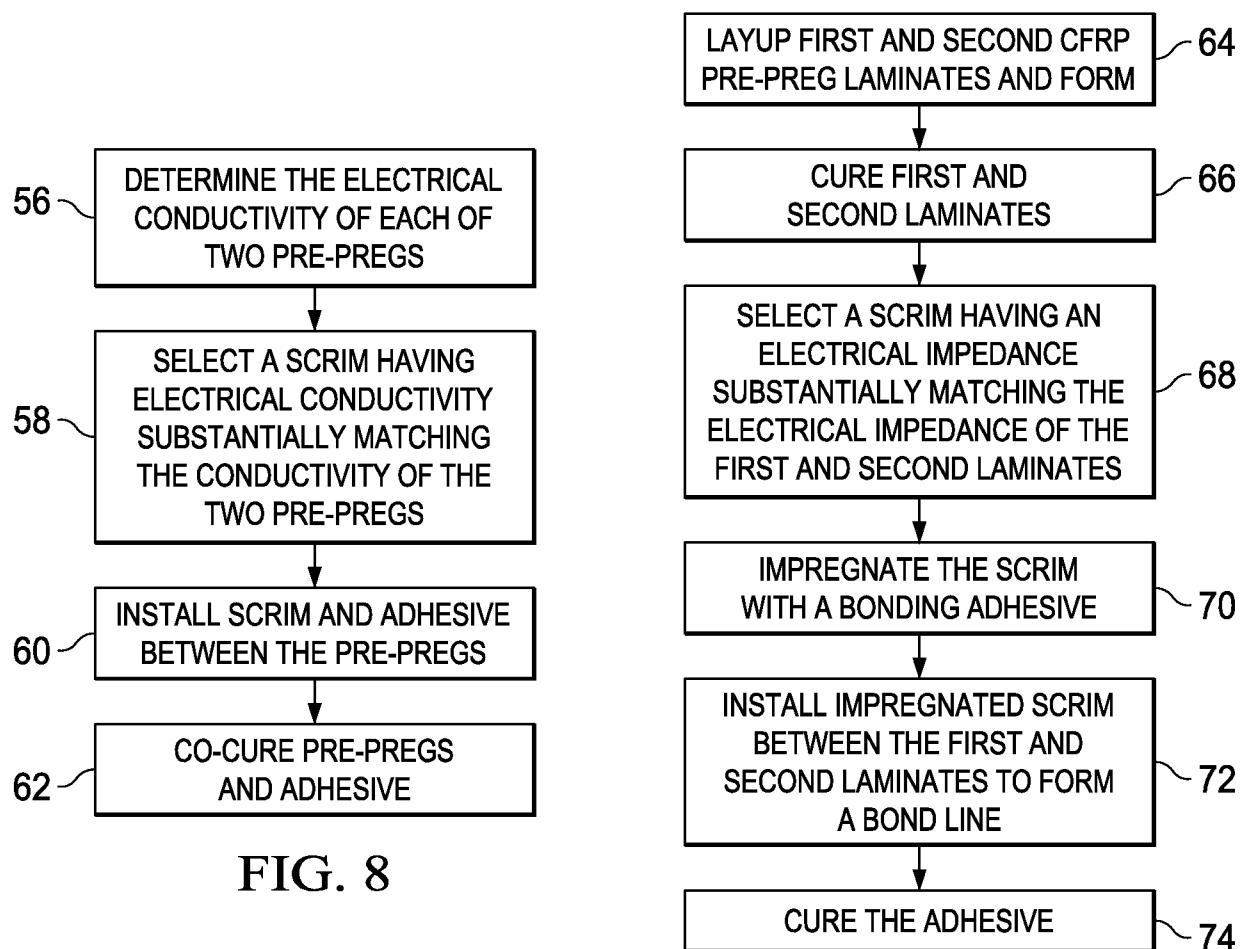
**FIG. 6**

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FIG. 7

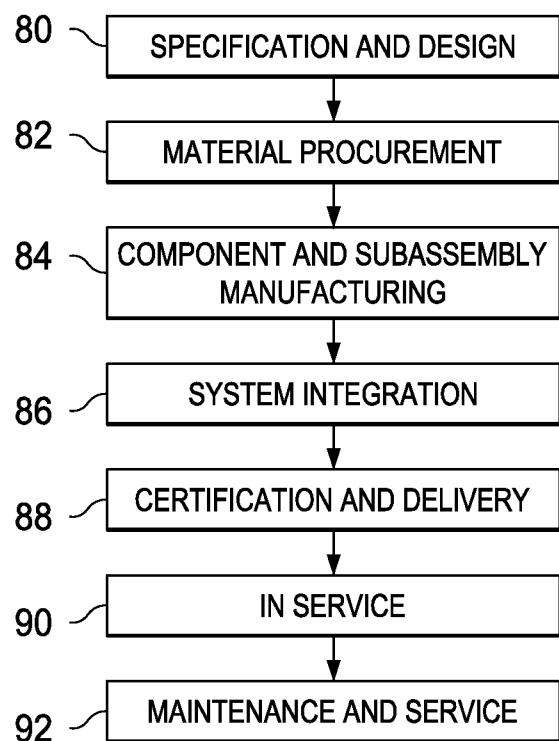


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FIG. 10 76



78 FIG. 11

