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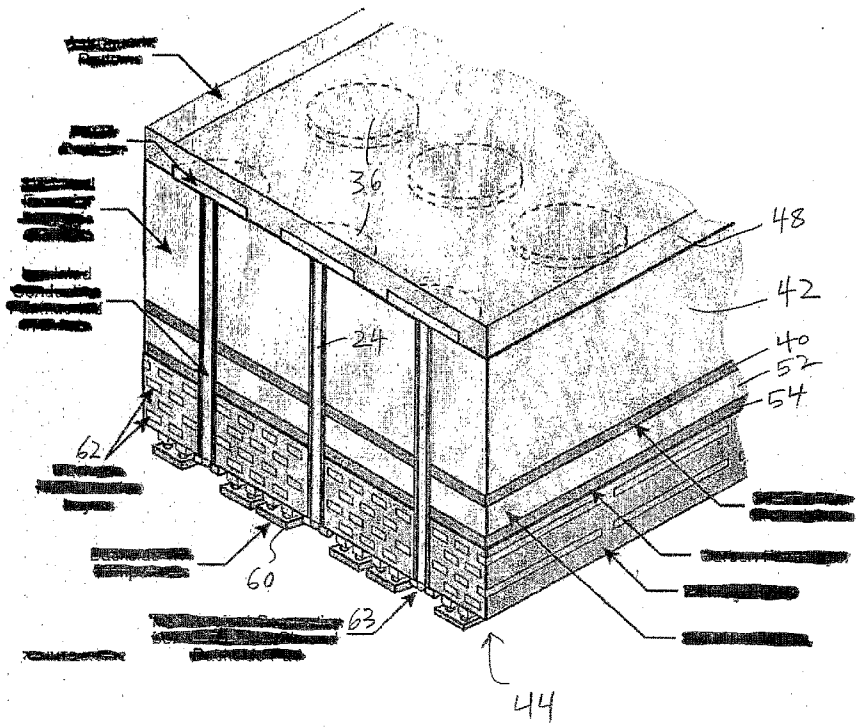
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(54) **Title:** ELECTROMECHANICAL STRUCTURE AND METHOD OF MAKING SAME



(57) **Abstract:** An electromechanical structure includes a core and a plurality of conductive pins through the core. The pins are configured to form a signal distribution network from a first side of the core to a second side of the core.

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ELECTROMECHANICAL STRUCTURE AND METHOD OF MAKING SAME

RELATED APPLICATIONS

This application claims the benefit of and priority to U.S. Provisional Application No. 60/704,089, filed July 29, 2005, which is hereby incorporated herein by reference.

FIELD OF THE INVENTION

This subject invention relates to a dual function composite system and electromechanical structures, and in one example, multilayer printed circuit boards which can replace conventional printed circuit boards.

BACKGROUND OF THE INVENTION

Composite technology offers a wide variety of advantages including a high strength to weight ratio. Thus, composite systems are now used in mobile platforms such as aircraft and spacecraft for a variety of structural components.

Those skilled in the art are also studying higher and more complex levels of system integration. In but one example, it would be useful to integrate antennas into composite aircraft wing panels or other aircraft structures such as a panel of a fuselage or a portion of a door, or to apply or attach antennas to an aircraft. Current design challenges include how to provide sufficient dielectric separation between the radiating antenna elements and the ground plane of the antenna. Plated through hole printed circuit board technology cannot be used in connection with such advanced systems due to the inability to form via structures in lightweight dielectric materials (e.g. open cell foams),

and/or the inability to form very high aspect ratio vias in dielectric materials. Also, it would be desirable to integrate the electrical bus extending between the antenna and this electronic subsystem into the aircraft structure. Otherwise, the weight savings provided by composite technology will suffer and the cost of using composite technology will be prohibitive.

SUMMARY OF THE INVENTION

It is therefore an object of this invention to provide composite systems with integrated electrical subsystems.

It is a further object of this invention to provide, in one embodiment, a notional antenna fully integrated with a composite aircraft wing panel.

It is a further object of this invention to provide such an integrated notional antenna which also includes a bus integrated with composite aircraft structural members.

It is a further object of this invention to provide, in composite structures, signal transmission pathways through the thickness of the composite and running in the plane of the composite.

It is a further object of this invention to provide a functional replacement for a plated through hole in a printed circuit board when materials and/or geometries prevent a plated through hole from being formed.

The subject invention results from the realization that, given a three dimensional composite system, electrical pathways in one direction can be established by inserting conductive pins to extend through the composite panel and an electrical pathway in the direction of the plane of the panel can be affected by integrating conductors into a ply of a composite component. The invention results from the further realization that when plated

through holes or vias in a printed circuit board are not possible, conductive pins may replace them as electrical pathways.

The subject invention, however, in other embodiments, need not achieve all these objectives and the claims hereof should not be limited to structures or methods capable of achieving these objectives.

This invention features an electromechanical structure including a core and a plurality of conductive pins through the core. The pins are configured to form a signal distribution network from a first side of the core to a second side of the core. In one embodiment, there is an array of radiating elements on the first side of the core each connected to one end of a pin, and a printed circuit board on a second side of the core electrically connected to the other ends of the pins forming a notional antenna subsystem. In one configuration, the electromechanical structure further includes a composite member which includes plies of fabric and resin impregnating the plies of fabric and at least one ply includes signal transmission elements integrated therewith and connected between the printed circuit board and electronics for the notional antenna system. The core may be a dielectric, and the dielectric core may be air. In such an example, the dielectric core will typically include a dielectric support mechanism which may be a dielectric honeycomb structure, or a dielectric truss structure for example. Such a dielectric truss structure may include a network of dielectric pins forming the truss structure. The dielectric core also may be a low density material, preferably foam, or the dielectric core may be a polymer. In one example, the structure includes a radome layer over the radiating elements, which may be made of astroquartz. In one preferred embodiment, a ground plane is disposed between the core and the printed circuit board, and the ground plane may be a composite layer including plies of conductive fibers

impregnated with a resin, and the fibers may be carbon. The structure may further include a structural layer between the ground plane and the printed circuit board, and the structural layer may include a foam sub-layer on a composite sub-layer. The composite sub-layer may include fibers impregnated with a resin, and the composite sub-layer fibers may be carbon. Typically, the ground plane includes holes therethrough for conductive pins. The conductive pins may be insulated and/or the holes may provide clearance between the conductive pins and the ground plane. Preferably, the pins are solid and made of a metal alloy, which may include copper. In another configuration, the pins include a composite core surrounded by metal coating. In a further configuration, the pins include a central conductor surrounded by a dielectric material surrounded by a coaxial shield conductor. In another variation the pins may be tubular, and in one configuration some pins may be configured to provide sidewall metallization around a cavity of radiating element.

The radiating elements may be printed on the core. The pins may be inserted through holes drilled in the core, or the pins may first be inserted through the holes formed in the dielectric core and the radiating elements then printed over the pins. The signal transmission elements are preferably wires which may be woven into the at least one ply of the composite member, and the wires may be insulated. In one example, the core is a solid composite component made of a number of plies of fabric impregnated with a resin.

This invention also features an electromechanical structure including a low density dielectric core, an array of radiating elements one side of the core, and a printed circuit board on an opposing side of the core. There are a plurality of conductive pins

through the core and insulated therefrom. The pins are configured to form a signal distribution network from the radiating elements to the printed circuit board.

This invention further features a method of fabricating an electromechanical structure, the method including inserting a plurality of conductive pins through a core and configuring the pins to form a signal distribution network from a first side of the core to a second side of the core. In one embodiment there is an array of radiating elements on the first side of the core each connected to one end of a pin and a printed circuit board on a second side of the core electrically connected to the other ends of the pins forming a notional antenna subsystem. In one configuration, the method further includes the addition of a composite member, which itself includes plies of fabric and resin impregnating the plies of fabric. At least one ply includes signal transmission elements integrated therewith and connected between the printed circuit board and electronics for the notional antenna system. The core is typically a dielectric, and it may be air, in which case the dielectric core will typically include a dielectric support mechanism. The dielectric support mechanism may be a dielectric honeycomb structure, or the dielectric support mechanism may be a dielectric truss structure, which may include a network of dielectric pins forming the truss structure. The dielectric core may be a low density material, preferably foam, or the dielectric core may be a honeycomb structure. In one example, the method further includes disposing a radome layer over the radiating elements, which may be made of astroquartz. A ground plane may be disposed between the core and the printed circuit board, in which the ground plane is a composite layer including plies of conductive fibers impregnated with a resin, and the fibers are carbon. The method may further include disposing a structural layer between the ground plane and the printed circuit board, and the structural layer may include a foam sub-layer on a

composite sub-layer. The composite sub-layer may include fibers impregnated with a resin, and the composite sub-layer fibers may be carbon. The method may further include drilling holes therethrough for the conductive pins, and the conductive pins may be insulated. The holes may also provide clearance between the conductive pins and the ground plane. Preferably, the pins are solid and made of a metal alloy which may include copper. In one variation, the pins include a composite core surrounded by metal coating. In another variation, the pins include a central conductor surrounded by a dielectric material surrounded by a coaxial shield conductor. The pins may be tubular, and in one variation, the pins may be configured to provide sidewall metallization around a cavity of a radiating element.

The method may further include printing the radiating elements on the core, and inserting the pins through holes drilled in the core. In one variation, the pins may be first inserted through the holes formed in the dielectric core and the radiating elements then printed over the pins. The signal transmission elements may be wires woven into the at least one ply of the composite member, and the wires may be insulated. Also, the core may be a solid composite component made of a number of plies of fabric impregnated with a resin.

This invention also features a method of fabricating an electromechanical structure, the method including inserting a plurality of conductive pins through a low density dielectric core and insulating the pins from the low density dielectric core and a ground plane. The method further includes disposing an array of radiating elements one side of the core, disposing a printed circuit board on an opposing side of the core, and configuring the pins to form a signal distribution network from the radiating elements to the printed circuit board.

This invention further features an electromechanical structure including a core, a plurality of conductive pins through the core, the pins configured to form a signal distribution network from a first side of the core to a printed circuit board on a second side of the core. In one preferred embodiment, there is a ground plane between the core and the printed circuit board, and the ground plane is a thin layer between the core and the printed circuit board. The thin layer may be copper, and the core is typically a dielectric core. In one example, there is an array of radiating elements on the first side of the core each connected to one end of a pin, and the printed circuit board is electrically connected to the other ends of the pins forming a notional antenna subsystem. The notional antenna subsystem may be configured to be affixed to an aircraft panel, in one example. The dielectric core may be air, and in such a case the dielectric core will typically include a dielectric support mechanism. The dielectric support mechanism may be a dielectric honeycomb structure, or the dielectric support mechanism may be a dielectric truss structure. The truss structure may include a network of dielectric pins forming the truss structure. The dielectric core may also be a low density material, preferably foam. The dielectric core may also be a polymer. There may be a radome layer over the radiating elements, and it may be made of astroquartz. The ground plane may include holes therethrough for the conductive pins. The conductive pins may be insulated, and/or the holes may provide clearance between the conductive pins and the ground plane. The pins may be solid and made of a metal alloy including copper or the pins may include a composite core surrounded by metal coating. In other examples, the pins include a central conductor surrounded by a dielectric material surrounded by a coaxial shield conductor, or the pins may be tubular. Also, some of the pins may be configured to provide sidewall metallization around a cavity of radiating element. Radiating elements

may be printed on the core and the pins inserted through holes drilled in the core, or the pins may be first inserted through the holes formed in the dielectric core and the radiating elements are then printed over the pins.

This invention also features a method of fabricating an electromechanical structure, the method including pre-drilling pilot holes in a dielectric core, pre-forming pilot holes in a ground plane, pre-drilling holes in a printed circuit board, and inserting a plurality of conductive pins through each of the printed circuit board, the ground plane, and the dielectric core to bond together the dielectric core, ground plane and printed circuit board.

This invention further features a method of fabricating an electromechanical structure, the method comprising pre-drilling pilot holes in a ground plane attached to a printed circuit board, bonding the ground plane and printed circuit board to a dielectric core, drilling holes through the printed circuit board and dielectric core coinciding with the pre-drilled pilot holes in the ground plane, and inserting a plurality of conductive pins through each of the printed circuit board, the ground plane, and the dielectric core.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages will occur to those skilled in the art from the following description of a preferred embodiment and the accompanying drawings, in which:

Fig. 1 is highly schematic three-dimensional view showing an example of a composite system with an integrated electrical subsystem in accordance with the subject invention;

Fig. 2 is a schematic three-dimensional top view of a fighter aircraft including a wing section with an integrated antenna array in accordance with the subject invention;

Fig. 3 is a schematic three-dimensional cutaway side view showing a portion of the wing of Fig. 2;

Fig. 4 is a schematic side cross-sectional view of the wing structure shown in Fig. 3;

Fig. 5 is a highly schematic three-dimensional view of one embodiment of a dielectric support mechanism for use with the subject invention;

Fig. 6A-6B are highly schematic views of another embodiment of a dielectric support mechanism for use with the subject invention;

Fig. 7 is a highly schematic representation showing how individual insulated wires can be woven with the fabric of a ply of a composite structure in accordance with the subject invention;

Fig. 8 is a schematic three-dimensional cut-away view showing one embodiment of a radar tile assembly for a notional antenna integrated as part of a panel of the wing structure of Fig. 3;

Fig. 9A is a schematic cross-sectional view of an example of one type of pin useful as a transmission element in accordance with the subject invention;

Fig. 10A is a schematic cross-sectional view showing another example of a transmission pin in accordance with the subject invention;

Fig. 11A is a schematic cross-sectional view of still another embodiment of a transmission pin in accordance with the subject invention;

Fig. 12A is a schematic cross-sectional view of yet another embodiment of a transmission pin in accordance with the subject invention;

Figs. 9B-12B are schematic views showing the pin examples of Figs. 9-12 insulated;

Fig. 13 is a schematic three-dimensional cut-away view showing another embodiment of a radar tile assembly for a notional antenna integrated as part of the top panel of the wing structure shown in Fig. 3;

Fig. 14 is a three-dimensional cut-away view of a multi-layer printed circuit board without plated through holes shown as part of another form of a notional antenna in accordance with the present invention;

Fig. 15 is a schematic three-dimensional front view showing one example how transmission or feed pins are inserted into a foam body in accordance with the subject invention;

Fig. 16 is a schematic three-dimensional front view showing one example how radiator patches are deposited on the foam body of Fig. 15 over the pins;

Fig. 17 is a schematic three-dimensional front view showing one example of fabrication of a multi-layer printed circuit board for power and signal re-distribution for the panel of the aircraft wing structure shown in Fig. 3;

Fig. 18 is a schematic three-dimensional front view showing one example how the flex circuit of Fig. 17 is bonded to the foam panel of Fig. 16 in accordance with the subject invention;

Fig. 19 is a schematic view of one example of a fabrication process in accordance with the present invention;

Figs. 20-24 are schematic views of another example of a fabrication process in accordance with the present invention;

Fig. 25 is a schematic three-dimensional side view of an electro-mechanical tile test structure in accordance with the subject invention;

Fig. 26 is a highly schematic three-dimensional front view of an example of the dual function composite and electrical system in accordance with the subject invention; and

Fig. 27 is a schematic top view of conductive pins configured in one example for sidewall metallization around a cavity of a radiating element in accordance with one embodiment of the subject invention.

DISCLOSURE OF THE PREFERRED EMBODIMENT

Aside from the preferred embodiment or embodiments disclosed below, this invention is capable of other embodiments and of being practiced or being carried out in various ways. Thus, it is to be understood that the invention is not limited in its application to the details of construction and the arrangements of components set forth in the following description or illustrated in the drawings. If only one embodiment is described herein, the claims hereof are not to be limited to that embodiment. Moreover, the claims hereof are not to be read restrictively unless there is clear and convincing evidence manifesting a certain exclusion, restriction, or disclaimer.

Fig. 1 illustrates a simplified view of a three-dimensional composite system 10 including composite members 12 and 14. Composite member 12 typically includes face sheets 16 and 18 separated by core 20. Face sheets 16 and 18 may be fabricated from plies of fabric impregnated with resin. Core 20 may be a lightweight cellular material, e.g. foam, or air. Composite member 14 includes numerous plies of fabric impregnated with resin.

One goal of the subject invention is to route signals from electronic subsystem A through composite system 10 to electronic subsystem B. Conductive pin 24 is shown extending through the thickness of composite member 12 to provide signal routing in one direction through the thickness of the composite member and wire 26 is shown integrated with the fabric of one ply of composite member 14 to provide signal routing in another direction mainly in the plane of composite member 14. By using multiple pins in composite member 12 and multiple wires integrated with one or more plies of the composite member 14, multiple electrical pathways and/or a bus can be established between subsystems A and B.

In accordance with the present invention, aircraft 32, Fig. 2 includes an integrated notional antenna electrically interconnected with an electronic subsystem within aircraft 32. The integrated notional antenna can be located on any portion of a mobile platform such as an aircraft, for example, on the panel of an airplane fuselage or portion of a door. As shown, the integrated notional antenna is included in wing portion or panel 30 of aircraft 32.

Wing portion 30 is shown in more detail in Figs. 3-4. Composite lower wing surface 34 includes an integrated array of radiating elements 36. Elements 36 may be rectangular, circular or elliptical with dimensions on the order of 0.1 inches by 0.1 inches up to several inches by several inches depending on the radar operating frequency. The separation between the centers of elements 36 can be or the order of 0.25 inches to several feet.

Integrated wires 26 may be included in any suitable structural member such as an aircraft fuselage, door, or portion of a wing. In one preferred configuration, composite spar 38 includes integrated wires 26 for connecting the antenna subsystem to its

associated electronics package and for providing support for the aircraft wing panel. As shown more clearly in Fig. 4, the notional antenna subsystem includes an array of radiating elements 36 separated from ground plane 40 by core 42 of low density or lightweight cellular material, or air, serving as a standoff dielectric. The dielectric may be any polymer, foam (open cell or closed cell), or in the case where core 42 is air, structural integrity is maintained by a dielectric support mechanism 11, Figs. 5 and 6A-6B. One embodiment of such a dielectric support mechanism 11 is honeycomb structure 13, Fig. 5, which may be made up of plastic, thermoplastic polymer, e.g., liquid crystal polymer or LCP, Kevlar, aramid, or other known materials. In another example, structural support can be provided by a dielectric support mechanism 11 including a network of dielectric pins 15 configured as truss structure 17, Figs. 6A-6B. One example of such a structure is discussed in U.S. Patent No. 6,291,049 which is incorporated herein by reference. Dielectric pins 15 are typically non-conductive material such as ceramic, glass, polymer or other known material. The size, number, and angles of dielectric pins 15 may be varied depending on a particular desired application.

In one preferred embodiment, the radiating elements 36, Fig. 4 are separated from ground plane 40 by dielectric open cell foam core 42 made of polyetherimide or polymethacrylimide with a thickness in the range between approximately several thousandths of an inch to several inches depending a particular application or design operating frequency. Conductive pins 24 extend through the core and each one is connected on one end to a radiating element 36. The other ends of the pins are electrically connected to printed circuit board 44 which is connected as shown at 46 to wires 26 integrated (e.g., woven, knitted or braided) with the fabric of one ply of composite spar 38. Cover or radome layer 48 is shown over radiating elements 36,

typically to decrease aerodynamic drawbacks and to protect radiating elements 36. Layer 48 is preferably made of astroquartz or glass, but may be made of any material which is effectively transparent at appropriate frequencies of radar operations. In the case of placement on an airplane wing, such material will typically possess load-bearing characteristics to withstand environmental stresses encountered along the wing of an aircraft. Typically, ground plane 40 is a composite structure including plies of conductive (e.g., carbon) fiber impregnated with a resin such as Cytec 977-3 or Hexel M73. Optional structural layer 50 includes structural foam sub-layer 52 and composite sub-layer 54.

Fig. 7 shows one internal ply of composite spar 38, Fig. 4 where insulated wires or cables 26 are interwoven, with fabric threads 56. In one example, spar 38 includes a textile impregnated with a resin. See also U.S. Patent No. 6,727,197 incorporated herein by this reference. Alternatively, wires 26 may be woven or knitted with fabric threads 56.

Fig. 8 shows in more detail multilayer printed circuit board 44 with back side transmit and receive components 60 and back side redistribution layers 62. Foam layer 42 forms a dielectric standoff. Sub-layer 52 in combination with ground plane 40, itself typically including carbon fibers, and carbon fiber composite sub-layer 54, provide mechanical strength and stiffness and provide a suitable load-bearing structure where lightweight, high structural strength and rigidity are important considerations. Similarly to core 42, sub-layer 52 may include a honeycomb structure, truss structure, or low density material, and like core 42, is preferably foam in one embodiment. Sub-layer 52 may have a thickness in the range of between approximately 0.25 inches and 2 inches, and sub-layer 54 together with ground plane 40 may have a thickness in the range of between approximately 0.06 inches and 0.10 inches. In one preferred embodiment, foam layer 42 is approximately 0.10 inches thick, sub-layer 52 is approximately 0.25 inches

thick, and sub-layer 54 together with ground plane 40 is approximately 0.10 inches thick. Pins 24 provide feeds to radiating elements 36 from a metallurgical connection with a backside pad as shown at 63. Such a high aspect ratio hybrid structure is not generally achievable with conventional printed circuit board manufacturing techniques.

In one example, pin 24, Fig. 9A may be solid metal alloy made of copper and beryllium and be between approximately .005 inches and .062 inches in diameter. There are typically 1-2 pins per radiating element.

In another embodiment, pin 24', Fig. 10A includes composite core 70 surrounded by metal coating 72 such as nickel/gold. In still another embodiment, coaxial pin 24", Fig. 11A includes central conductor 74 surrounded by dielectric 76 itself surrounded by a coaxial shield 78 made of conductive material to isolate central conductor 74 from any external electrical radiation. Alternatively, pin 24"', Fig. 12A is tubular and made of metal alloy such as copper and beryllium. In any configuration, pins 24-24"' may be insulated. Pilot holes drilled in circuit board 44, Fig. 8 enable small diameter pins to be inserted to minimize use of circuit board area for pin interconnects. The pilot holes can be undersized for a slight press fit with the individual pins. Although pins 24 are shown herein as extending vertically, this is not a necessary limitation of the invention, and pins 24 may be oriented at an angle as desired for a particular application. Also, although pins 24 are preferably electrical conductors, this is not a limitation of the invention. In one configuration, the pins may be optical fibers for connecting the systems.

In the embodiment of Fig. 8, ground plane 40 abuts pins 24, and therefore pins 24 in multilayer printed circuit board 44 are preferably insulated to prevent electrical contact with ground plane 40. In one example, pins 24 are isolated from the ground plane by

non-conductive insulating material 77. Insulation 77 may surround pin types 24, 24', 24", and 24"' as desired for a particular application as shown in Figs. 9B-12B. Insulation 77 may be polymer, glass, ceramic, Kevlar, fiberglass, or any other non-conductive material.

In another embodiment, multilayer printed circuit board 44, Fig. 13 does not include structural layer 50, Fig. 4, however, ground plane 40 including plies of carbon fiber impregnated with resin provides structural support. Since ground plane 40 abuts pins 24, insulated pins 24 are preferred.

In a further embodiment, ground plane 40', Fig. 14 of multilayer printed circuit board 44' forms a thin top layer over the printed circuit board 61 including backside redistribution layers 62. In one example, ground plane 40' is a copper metal layer typically between .0003 inches and .003 inches thick. Although minimal to no structural support is provided, due to its light and flexible nature, in one example multilayer printed circuit board 44' may serve as another type of notional antenna which can be affixed to an aircraft by attaching or hanging it rather than forming an integral portion of the aircraft structure. In a preferred configuration, ground plane 40' includes clearance holes 68 therethrough for conductive pins 24 so the pins do not contact the ground plane. In this case, pins 24 may be insulated or non-insulated as desired.

Accordingly, the subject invention provides composite systems with integrated electrical subsystems, in one example notional antennas, and in various embodiments, further provides an improved alternative to plated through holes where material types or other parameters such as high aspect ratio prohibit the use of conventional boards.

In one embodiment, fabrication begins by inserting feed pins 24 in foam panel 42, Fig. 15. The pins can be inserted manually with or without pilot holes drilled in foam panel 42, inserted using an ultrasonic horn, and/or inserted using numerical control

processes. Next, radiator elements 36 are direct metal deposited on foam panel 42, Fig. 16. A protective layer (not shown) such as LCP, epoxy glass, or the like or a bonding film or layer or metamaterials may be used to bond the elements 36 to panel 42. The radiator elements make metallurgical contact with the pins 24 previously inserted in foam panel 42. Alternatively, a direct printing technique can be used to create a radiator element pattern, or patched radiator elements could be formed on a flex circuit film bonded to foam panel 42.

Next, the multilayer printed circuit board is fabricated as shown in Fig. 17 to include copper ground plane 40, clearance holes 68, power and distribution circuitry as shown at 90 all on a multilayer flex circuit board. The multilayer flex circuit board may include a flexible substrate such as polyimide, LCP, or foam. This multilayer printed circuit board provides power and signal redistribution and backside component attachment for MMICs and the like, and one example of the resultant multi-layer printed circuit board is board 44', Fig. 14, where pins 24 are uninsulated.

Thus, this flex circuit is bonded to the foam panel as shown in Fig. 18. Solder reflow techniques are used to electrically interconnect the radiator feeds provided by pins 24 to the flex circuit. The solder is reflowed to complete the metallurgical connection of the pad to pin on the back side. In one variation, a conductive polymer such as conductive epoxy could be used in place of solder.

In another embodiment, fabrication begins by pre-drilling pilot holes 71, Fig. 19 in foam core 42 and pre-drilling pilot holes 73 in printed circuit board 61 which typically includes redistribution portion 62. Pilot holes 75 are formed in ground plane 40 and sub-layers 52 and 54 typically by using an ultrasonic horn using known ultrasonic techniques. Next, feed pins 24 are inserted through printed circuit board 61, sub-layers 52 and 54,

ground plane 40, and core 42 from backside 67, thus bonding the various layers together and forming an electromechanical structure, i.e. a multi-layer printed circuit board, and in one example, the resultant multi-layer circuit board may be board 44, Fig. 8, after inclusion of metallurgical elements, antenna elements, and the like as desired for a particular application.

A further embodiment is shown in Figs. 21-24, where fabrication begins by pre-drilling pilot holes 80, Fig. 21 in ground plane 40 which is a thin top layer over printed circuit board 61 including redistribution portion 62. Next, foam core 42 is attached to ground plane 40 and printed circuit board 61 and ground plane 40 are drilled, Fig. 22, and pins 24 are then inserted through each of the printed circuit board 61, the ground plane 40, and the foam core 42, Fig. 23. Next, metallurgical connections 63, Fig. 24 can be formed as shown, and antenna elements 36 may be direct deposited or printed on core 42 as discussed above. In each variation, the resulting electromechanical structure is capable of being used in place of printed circuit boards with plated through holes for particular desired applications as discussed above.

Fig. 25 shows one electromechanical test tile structure 100 manufactured in accordance with this invention where electrical pathways are formed between path 102 on each face plate 104a and 104b on foam core 106. In this way, as shown in Fig. 26, a wide variety of electrical interconnections could be formed to provide signal transmission between point 110 on face sheet 104a to point 112 through core 106 (e.g., a foam or air core) via transversely extending pins 24a and 24b. Conventional plated through hole technology cannot be used with most foam core composites and thus pins 24 provide a suitable replacement to provide pathways through the structure. And then, to provide electrical pathways in the planar direction of a composite structure, conductors are

integrated with the fabric of at least one ply thereof, e.g., conductor 26 interwoven with the fabric of a ply of composite face sheet 104a. More than one ply may include conductive wires woven, knitted, or braided with the fabric thereof, and the internal or external plies could be chosen as desired to include pathways through the structure. Pins can be inserted through the thickness of a core, as discussed above and in U.S. Patent No. 6,291,049 which is incorporated herein by this reference, to reinforce the structure, to prevent delamination of the individual plies with respect to each other, and to provide electrical pathways through the structure. In such an example, foam core 106, Fig. 25 could be eliminated and there would simply be a number of composite fabric plies between face plate 104a and face plate 104b. Thus, aircraft wing notational antenna subsystem referred to in Figs. 2-24 above are but only a few examples of the wide variety of uses of the innovative technology of the subject invention. Other uses include, but are not limited to, thermal conductivity and management, where pins serve as thermal shunts to transfer heat, or pins 24 may be inserted through the thickness of the composite structure to provide sidewall metallization around the cavity of a radiating element 36, as shown in Fig. 27.

Although specific features of the invention are shown in some drawings and not in others, this is for convenience only as each feature may be combined with any or all of the other features in accordance with the invention. The words "including", "comprising", "having", and "with" as used herein are to be interpreted broadly and comprehensively and are not limited to any physical interconnection. Moreover, any embodiments disclosed in the subject application are not to be taken as the only possible embodiments. Other embodiments will occur to those skilled in the art and are within the following claims.

In addition, any amendment presented during the prosecution of the patent application for this patent is not a disclaimer of any claim element presented in the application as filed: those skilled in the art cannot reasonably be expected to draft a claim that would literally encompass all possible equivalents, many equivalents will be unforeseeable at the time of the amendment and are beyond a fair interpretation of what is to be surrendered (if anything), the rationale underlying the amendment may bear no more than a tangential relation to many equivalents, and/or there are many other reasons the applicant can not be expected to describe certain insubstantial substitutes for any claim element amended.

What is claimed is:

CLAIMS

1. An electromechanical structure comprising:

a core;

a plurality of conductive pins through the core;

the pins configured to form a signal distribution network from a first side of the core to a second side of the core.

2. The structure of claim 1 in which there is an array of radiating elements on the first side of the core each connected to one end of a pin and a printed circuit board on a second side of the core electrically connected to the other ends of the pins forming a notional antenna subsystem.

3. The structure of claim 2 further including a composite member comprising:

plies of fabric,

resin impregnating the plies of fabric,

at least one ply including signal transmission elements integrated therewith and connected between the printed circuit board and electronics for the notional antenna system.

4. The structure of claim 3 in which said core is a dielectric.

5. The structure of claim 4 in which the dielectric core is air.

6. The structure of claim 5 in which the dielectric core includes a dielectric support mechanism.

7. The structure of claim 6 in which the dielectric support mechanism is a dielectric honeycomb structure.

8. The structure of claim 6 in which the dielectric support mechanism is a dielectric truss structure.

9. The structure of claim 8 in which the truss structure includes a network of dielectric pins forming the truss structure.

10. The structure of claim 4 in which the dielectric core is a low density material.

11. The structure of claim 4 in which the dielectric core is foam.

12. The structure of claim 4 in which the dielectric core is a polymer.

13. The structure of claim 4 further including a radome layer over the radiating elements.

14. The structure of claim 13 in which the radome layer is made of astroquartz.

15. The structure of claim 2 further including a ground plane between the core and the printed circuit board.

16. The structure of claim 15 in which the ground plane is a composite layer including plies of conductive fibers impregnated with a resin.

17. The structure of claim 16 in which the fibers are carbon.

18. The structure of claim 15 further including a structural layer between the ground plane and the printed circuit board.

19. The structure of claim 18 in which the structural layer includes a foam sub-layer on a composite sub-layer.

20. The structure of claim 19 in which the composite sub-layer includes fibers impregnated with a resin.

21. The structure of claim 20 in which the composite sub-layer fibers are carbon.

22. The structure of claim 15 in which the ground plane includes holes therethrough for the conductive pins.

23. The structure of claim 22 in which the conductive pins are insulated.

24. The structure of claim 22 in which the holes provide clearance between the conductive pins and the ground plane.

25. The structure of claim 1 in which the pins are solid and made of a metal alloy.

26. The structure of claim 25 in which the metal alloy includes copper.

27. The structure of claim 1 in which the pins include a composite core surrounded by metal coating.

28. The structure of claim 1 in which the pins include a central conductor surrounded by a dielectric material surrounded by a coaxial shield conductor.

29. The structure of claim 1 in which the pins are tubular.

30. The structure of claim 1 in which the pins are configured to provide sidewall metallization around a cavity of radiating element.

31. The structure of claim 2 in which the radiating elements are printed on the core.

32. The structure of claim 2 in which the pins are inserted through holes drilled in the core.

33. The structure of claim 30 in which the pins are first inserted through the holes formed in the dielectric core and the radiating elements are then printed over the pins.

34. The structure of claim 3 in which the signal transmission elements are wires woven into the at least one ply of the composite member.

35. The structure of claim 34 in which said wires are insulated.

36. The structure of claim 1 in which the core is a solid composite component made of a number of plies of fabric impregnated with a resin.

37. An electromechanical structure comprising:

a low density dielectric core;

an array of radiating elements one side of the core;

a printed circuit board on an opposing side of the core; and

a plurality of conductive pins through the core and insulated therefrom, the pins configured to form a signal distribution network from the radiating elements to the printed circuit board.

38. A method of fabricating an electromechanical structure, the method comprising:

inserting a plurality of conductive pins through a core; and

configuring the pins to form a signal distribution network from a first side of the core to a second side of the core.

39. The method of claim 38 in which there is an array of radiating elements on the first side of the core each connected to one end of a pin and a printed circuit board on a second side of the core electrically connected to the other ends of the pins forming a notional antenna subsystem.

40. The method of claim 39 further including a composite member comprising:

plies of fabric,

resin impregnating the plies of fabric,

at least one ply including signal transmission elements integrated therewith and connected between the printed circuit board and electronics for the notional antenna system.

41. The method of claim 39 in which said core is a dielectric.

42. The method of claim 41 in which the dielectric core is air.

43. The method of claim 42 in which the dielectric core includes a dielectric support mechanism.

44. The method of claim 43 in which the dielectric support mechanism is a dielectric honeycomb structure.

45. The method of claim 43 in which the dielectric support mechanism is a dielectric truss structure.

46. The method of claim 45 in which the truss structure includes a network of dielectric pins forming the truss structure.

47. The method of claim 41 in which the dielectric core is a low density material.

48. The method of claim 41 in which the dielectric core is foam.

49. The method of claim 41 in which the dielectric core is a honeycomb structure.

50. The method of claim 39 further including disposing a radome layer over the radiating elements.

51. The method of claim 50 in which the radome layer is made of astroquartz.

52. The method of claim 39 further including disposing a ground plane between the core and the printed circuit board.

53. The method of claim 52 in which the ground plane is a composite layer including plies of conductive fibers impregnated with a resin.

54. The method of claim 53 in which the fibers are carbon.

55. The method of claim 52 further including disposing a structural layer between the ground plane and the printed circuit board.

56. The method of claim 55 in which the structural layer includes a foam sub-layer on a composite sub-layer.

57. The method of claim 56 in which the composite sub-layer includes fibers impregnated with a resin.

58. The method of claim 57 in which the composite sub-layer fibers are carbon.

59. The method of claim 52 in which the ground plane includes holes therethrough for the conductive pins.

60. The method of claim 59 in which the conductive pins are insulated.

61. The method of claim 59 in which the holes provide clearance between the conductive pins and the ground plane.

62. The method of claim 38 in which the pins are solid and made of a metal alloy.

63. The method of claim 62 in which the metal alloy includes copper.

64. The method of claim 38 in which the pins include a composite core surrounded by metal coating.

65. The method of claim 38 in which the pins include a central conductor surrounded by a composite dielectric material surrounded by a shield.

66. The method of claim 38 in which the pins are tubular.

67. The method of claim 38 in which the pins are configured to provide sidewall metallization around a cavity of a radiating element.

68. The method of claim 39 further including printing the radiating elements on the core.

69. The method of claim 39 further including inserting the pins through holes drilled in the core.

70. The method of claim 69 in which the pins are first inserted through the holes formed in the dielectric core and the radiating elements are then printed over the pins.

71. The method of claim 40 in which the signal transmission elements are wires woven into the at least one ply of the composite member.

72. The method of claim 71 in which said wires are insulated.

73. The method of claim 38 in which the core is a solid composite component made of a number of plies of fabric impregnated with a resin.

74. A method of fabricating an electromechanical structure, the method comprising:

inserting a plurality of conductive pins through a low density dielectric core;

insulating the pins from the low density dielectric core and a ground plane;

disposing an array of radiating elements one side of the core;

disposing a printed circuit board on an opposing side of the core; and

configuring the pins to form a signal distribution network from the radiating elements to the printed circuit board.

75. An electromechanical structure comprising:

a core;

a plurality of conductive pins through the core;

the pins configured to form a signal distribution network from a first side of the core to a printed circuit board on a second side of the core.

76. The structure of claim 75 further including a ground plane between the core and the printed circuit board.

77. The structure of claim 76 in which the ground plane is a thin layer between the core and the printed circuit board.

78. The structure of claim 77 in which the thin layer is copper.

79. The structure of claim 77 in which the core is a dielectric core.

80. The structure of claim 79 in which there is an array of radiating elements on the first side of the core each connected to one end of a pin.

81. The structure of claim 80 in which the printed circuit board is electrically connected to the other ends of the pins forming a notional antenna subsystem.

82. The structure of claim 81 in which the notional antenna subsystem is configured to be affixed to an aircraft panel.

83. The structure of claim 81 in which the dielectric core is air.

84. The structure of claim 83 in which the dielectric core includes a dielectric support mechanism.

85. The structure of claim 84 in which the dielectric support mechanism is a dielectric honeycomb structure.

86. The structure of claim 84 in which the dielectric support mechanism is a dielectric truss structure.

87. The structure of claim 86 in which the truss structure includes a network of dielectric pins forming the truss structure.

88. The structure of claim 81 in which the dielectric core is a low density material.

89. The structure of claim 81 in which the dielectric core is foam.

90. The structure of claim 81 in which the dielectric core is a polymer.

91. The structure of claim 81 further including a radome layer over the radiating elements.

92. The structure of claim 91 in which the radome layer is made of astroquartz.

93. The structure of claim 77 in which the ground plane includes holes therethrough for the conductive pins.

94. The structure of claim 77 in which the conductive pins are insulated.

95. The structure of claim 93 in which the holes provide clearance between the conductive pins and the ground plane.

96. The structure of claim 75 in which the pins are solid and made of a metal alloy.

97. The structure of claim 96 in which the metal alloy includes copper.

98. The structure of claim 75 in which the pins include a composite core surrounded by metal coating.

99. The structure of claim 75 in which the pins include a central conductor surrounded by a dielectric material surrounded by a coaxial shield conductor.

100. The structure of claim 75 in which the pins are tubular.

101. The structure of claim 75 in which the pins are configured to provide sidewall metallization around a cavity of radiating element.

102. The structure of claim 81 in which the radiating elements are printed on the core.

103. The structure of claim 81 in which the pins are inserted through holes drilled in the core.

104. The structure of claim 103 in which the pins are first inserted through the holes formed in the dielectric core and the radiating elements are then printed over the pins.

105. A method of fabricating an electromechanical structure, the method comprising:

pre-drilling pilot holes in a dielectric core;

pre-forming pilot holes in a ground plane;

pre-drilling holes in a printed circuit board; and

inserting a plurality of conductive pins through each of the printed circuit board, the ground plane, and the dielectric core to bond together the dielectric core, ground plane and printed circuit board.

106. A method of fabricating an electromechanical structure, the method comprising:

pre-drilling pilot holes in a ground plane attached to a printed circuit board;

bonding the ground plane and printed circuit board to a dielectric core;

drilling holes through the printed circuit board and dielectric core coinciding with the pre-drilled pilot holes in the ground plane; and

inserting a plurality of conductive pins through each of the printed circuit board, the ground plane, and the dielectric core.

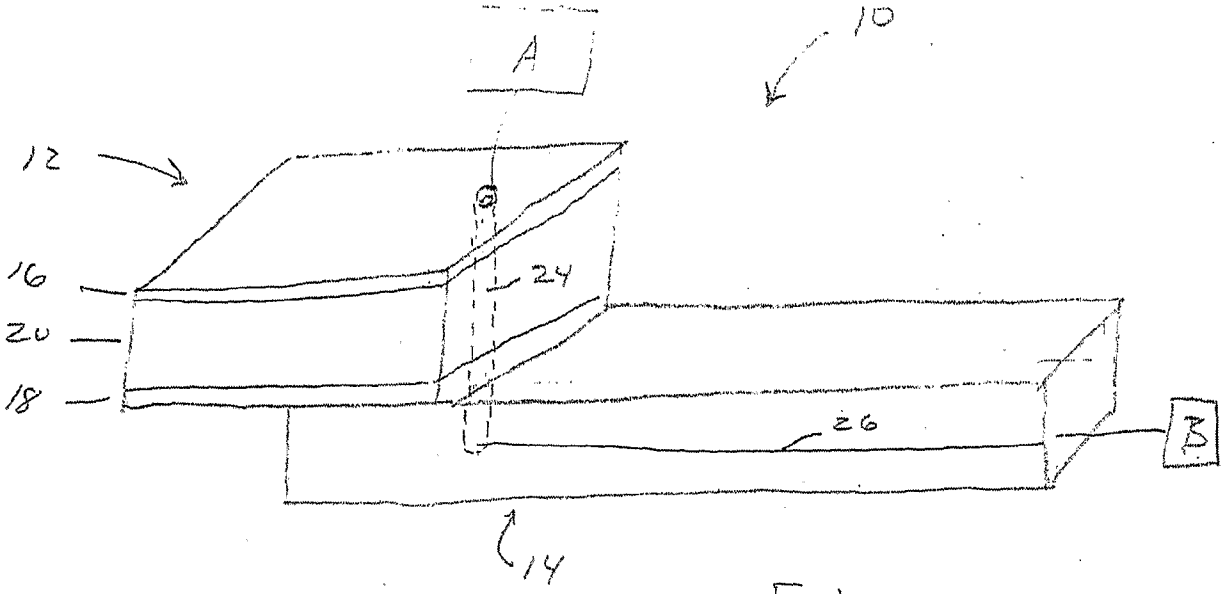


Fig 1

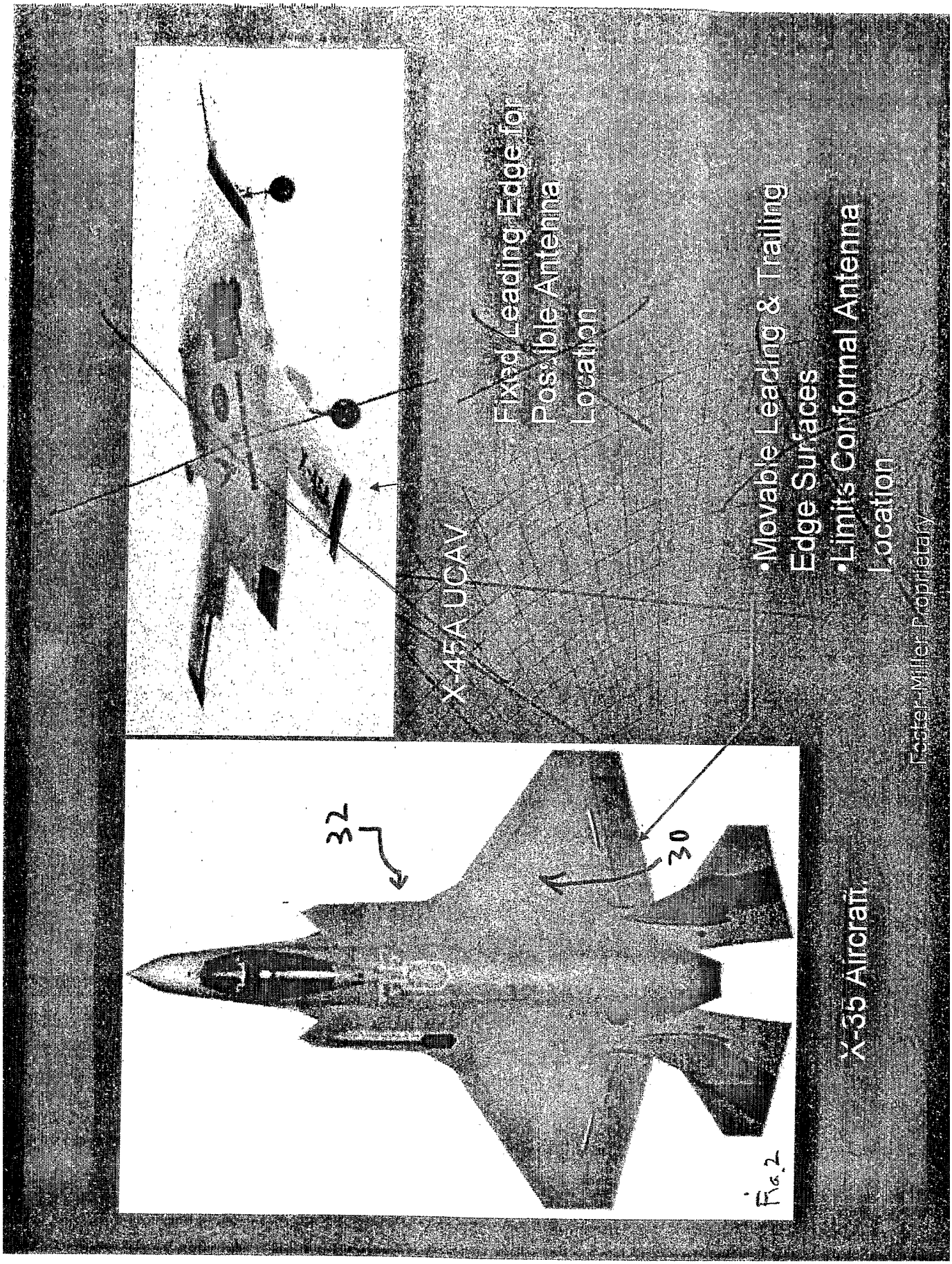

X-45A UCAV
Fixed Leading Edge for Possible Antenna Location
•Movable Leading & Trailing Edge Surfaces
•Limits Conformal Antenna Location
X-35 Aircraft
32
30
Lockheed Martin Proprietary

Fig. 2

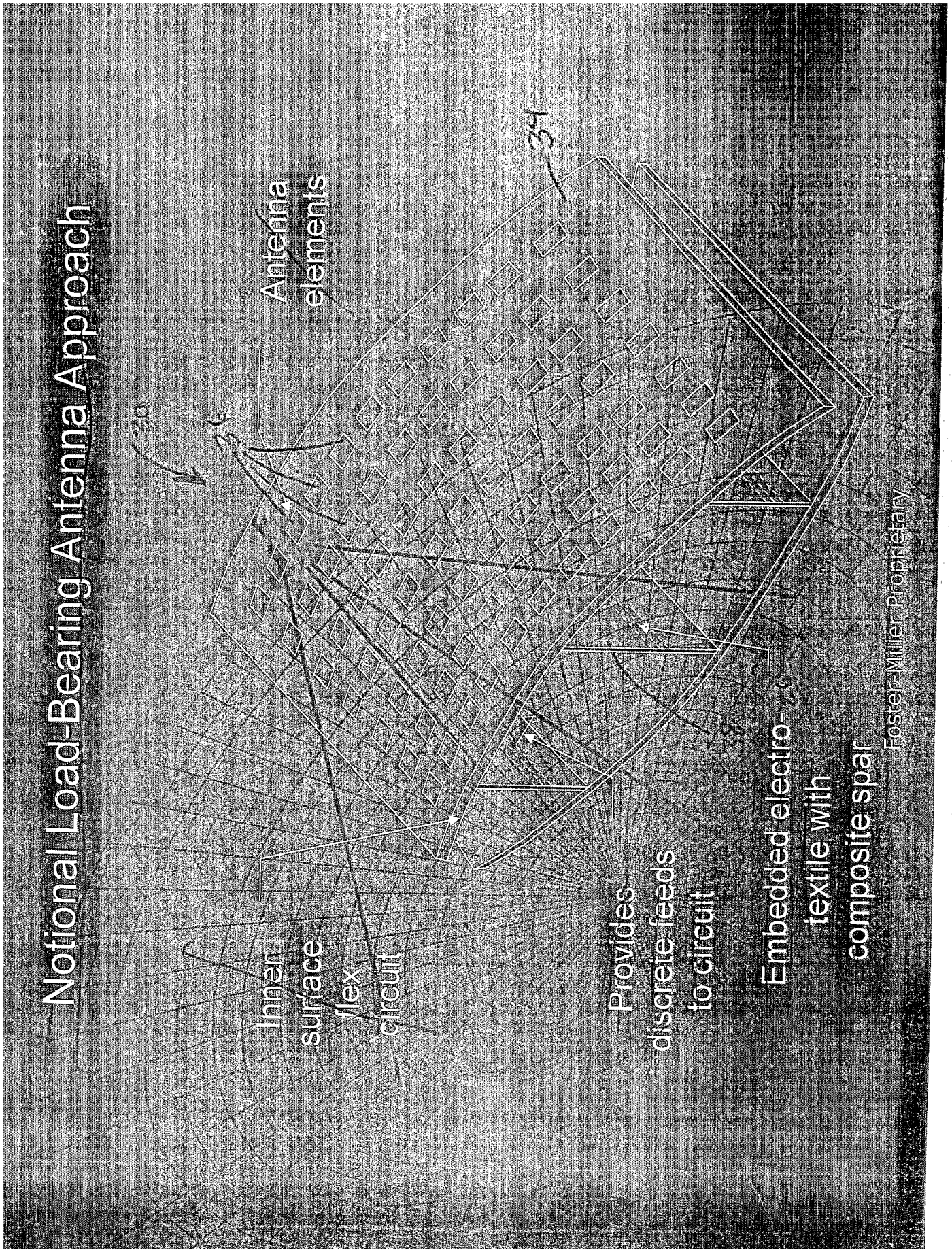

Notional Load-Bearing Antenna Approach
Antenna elements
Inner surface flex circuit
Provides discrete feeds to circuit
Embedded electro-textile with composite spar
Foster-Miller Proprietary

Fig 3

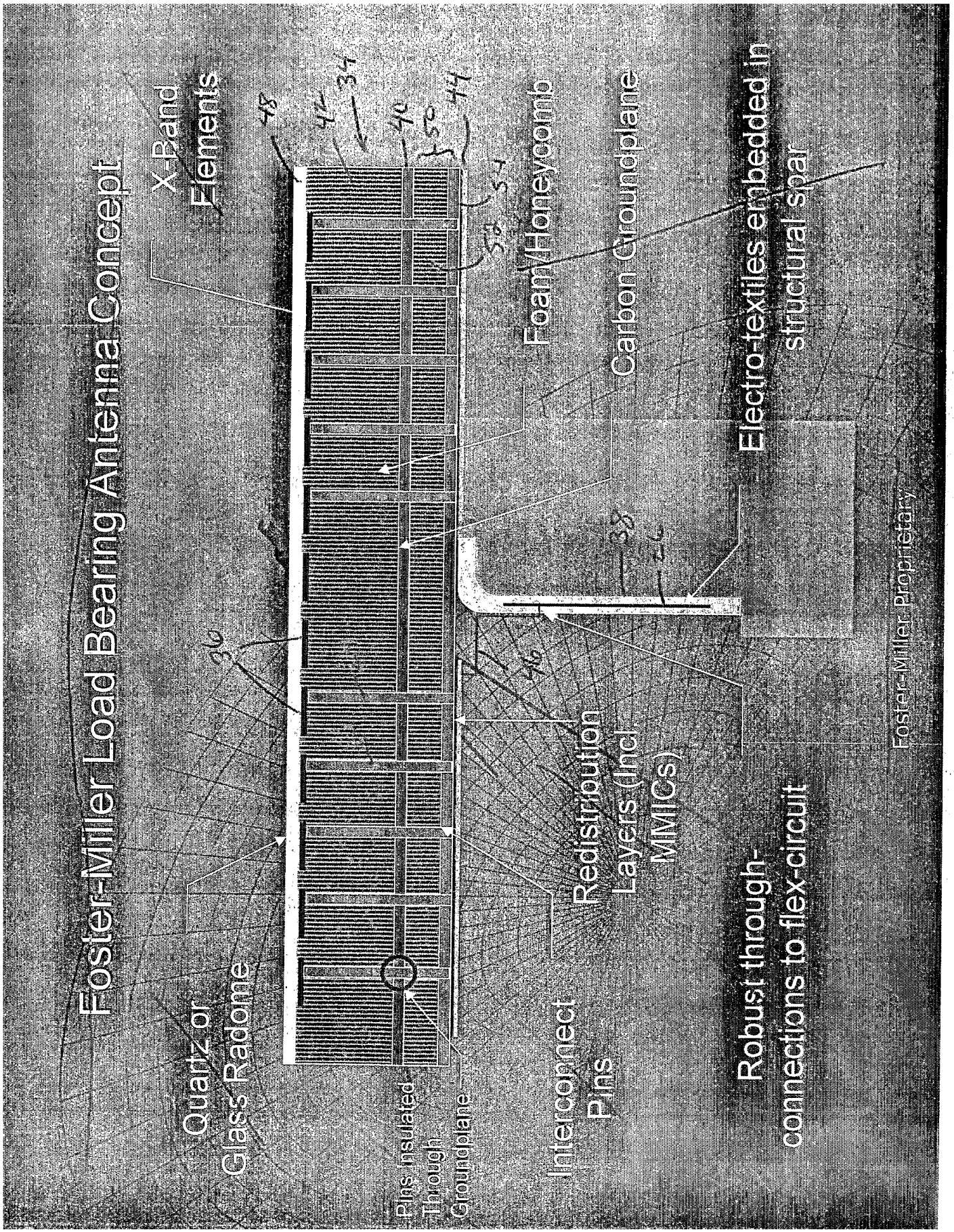

Foster-Miller Load Bearing Antenna Concept
X-Band Elements
Quartz or Glass Radome
Pins Insulated Through Groundplane
Interconnect Pins
Redistribution Layers (Incl MMICs)
Foam/Honeycomb
Carbon Groundplane
Electro-textiles embedded in structural spar
Robust through-connections to flex-circuit
Foster-Miller Proprietary

Fig 4

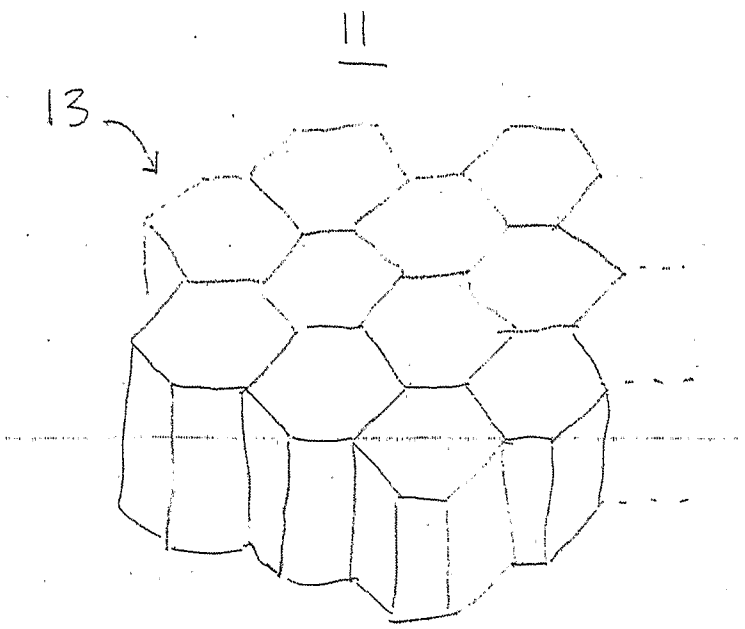


Fig. 5

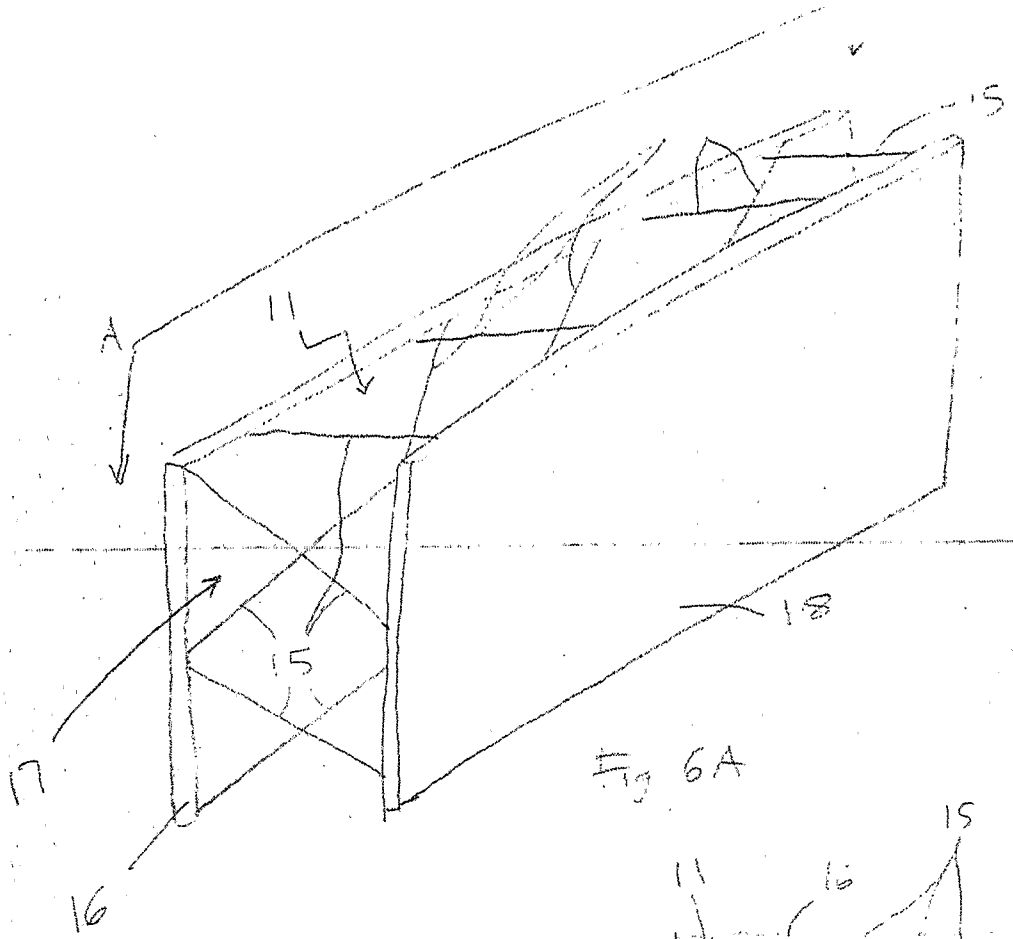


Fig 6A

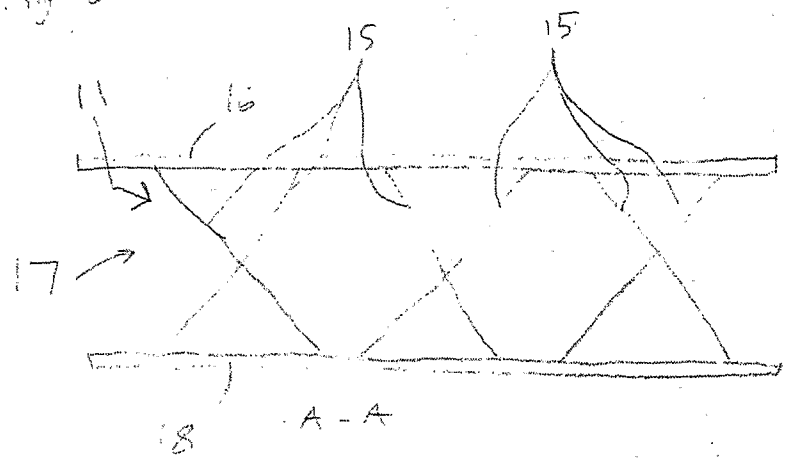


Fig 6B

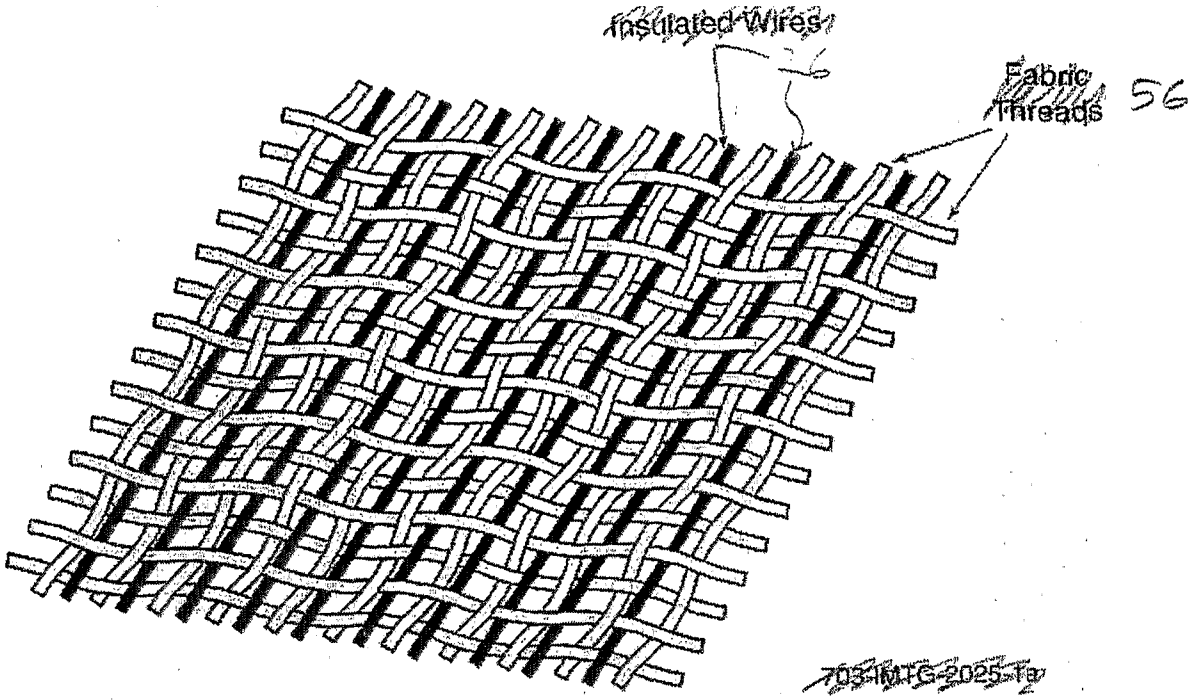


Fig. 7

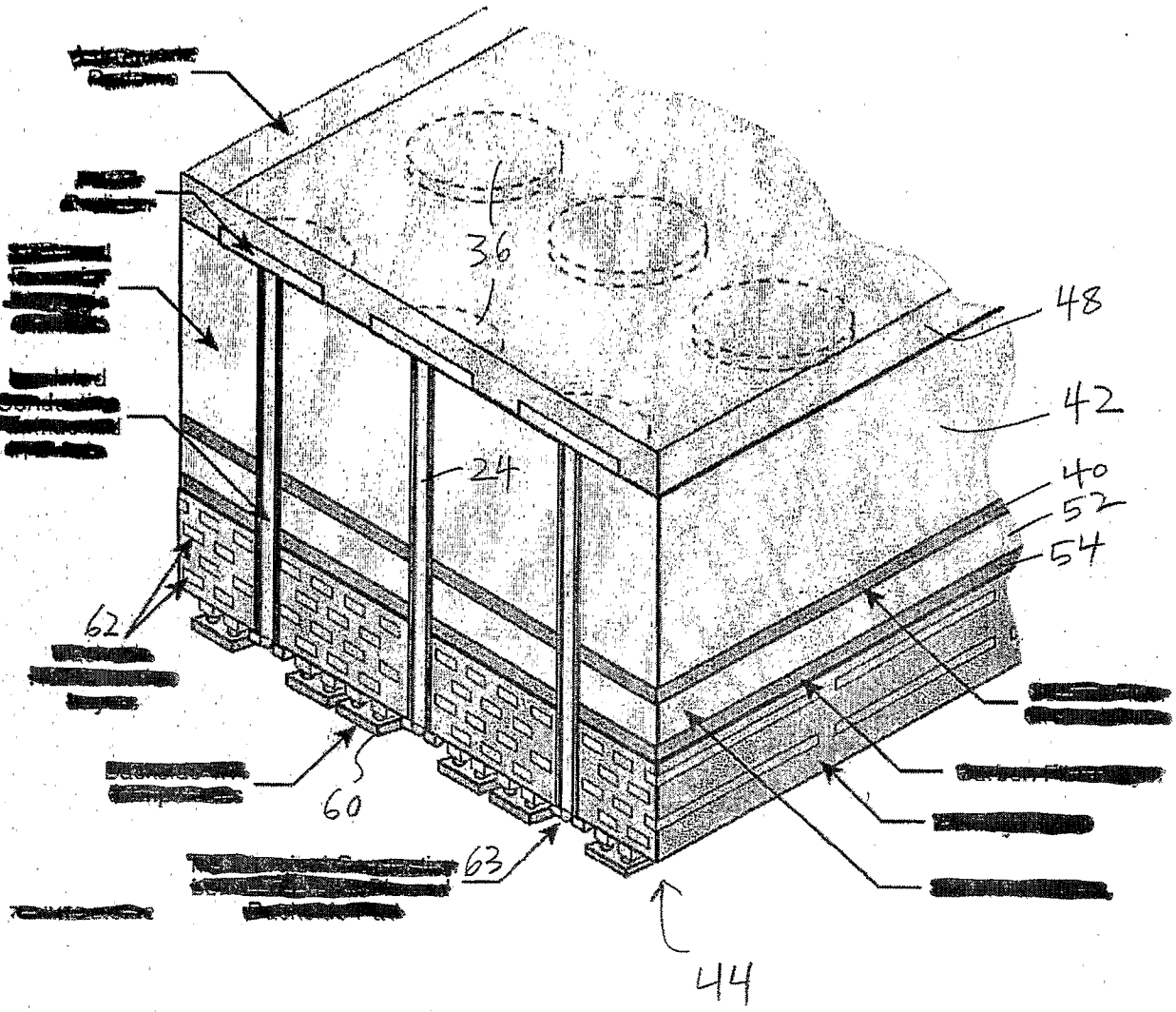
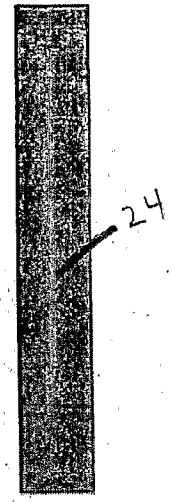
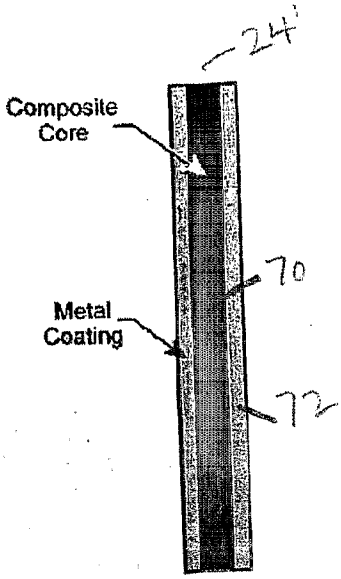


Fig 8



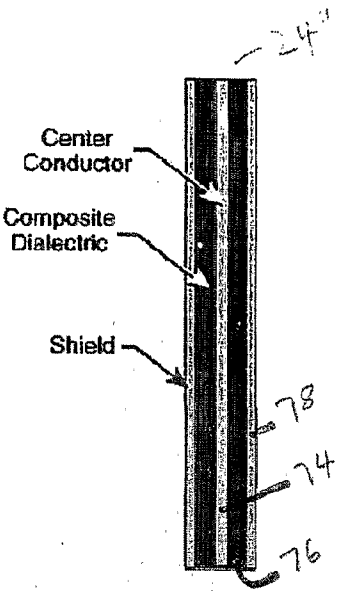
Metal Alloy

Fig 9A



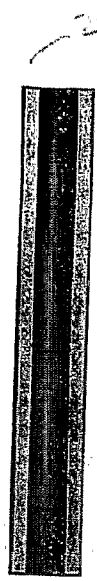
Coated Composite

Fig 10A



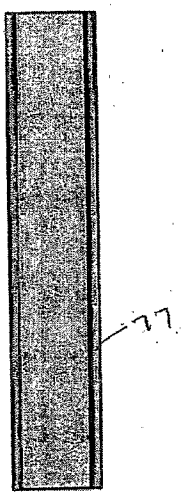
Coaxial Conductor

Fig 11A



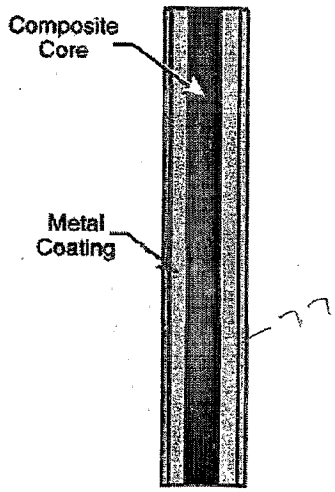
Tube

Fig 12A



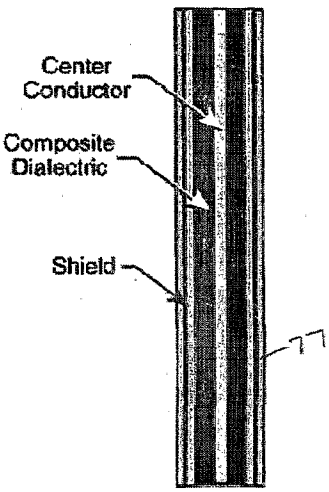
nsulated Metal Alloy

Fig. 9B



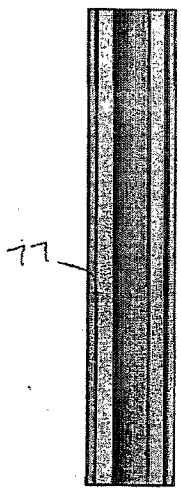
Insulated Coated Composite

Fig. 10B



Insulated Coaxial Conductor

Fig. 11B



Insulated Tube

Fig. 12B

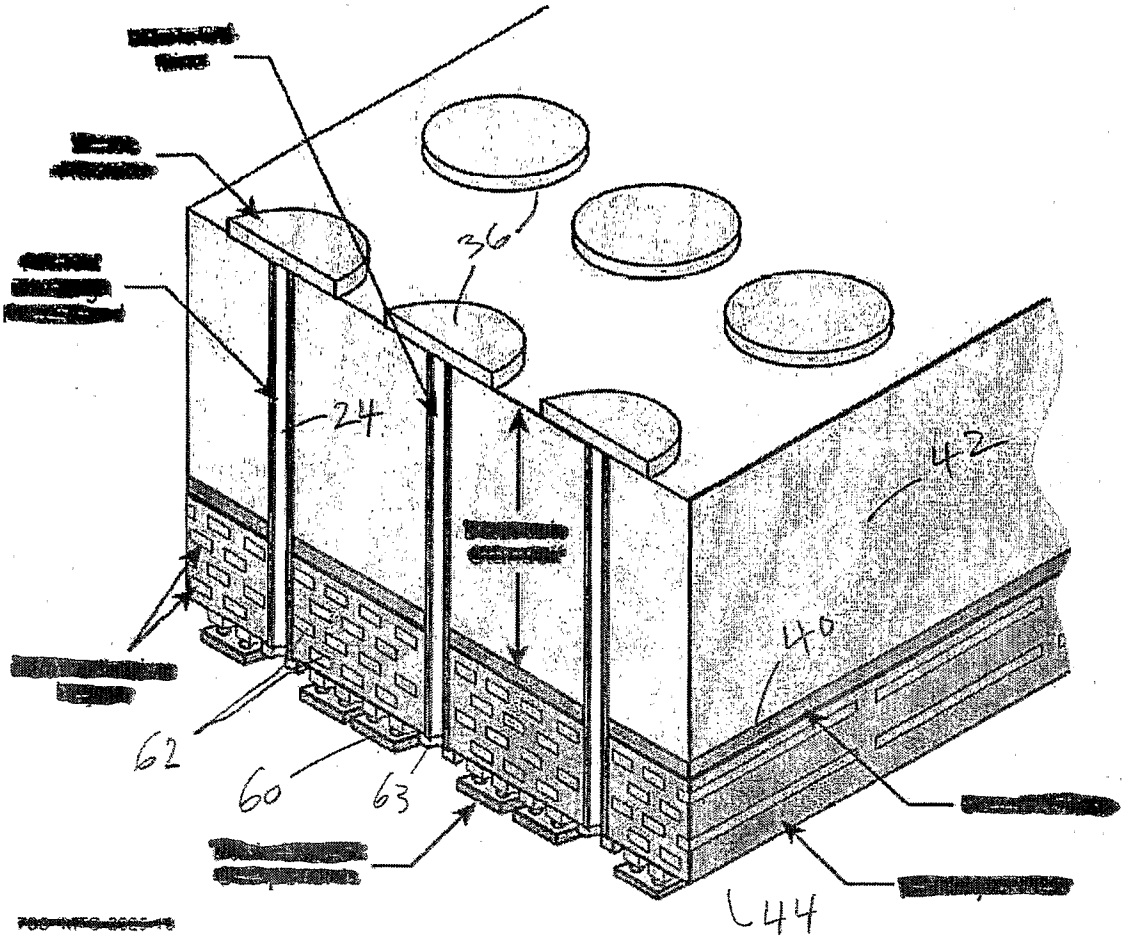


Fig 13

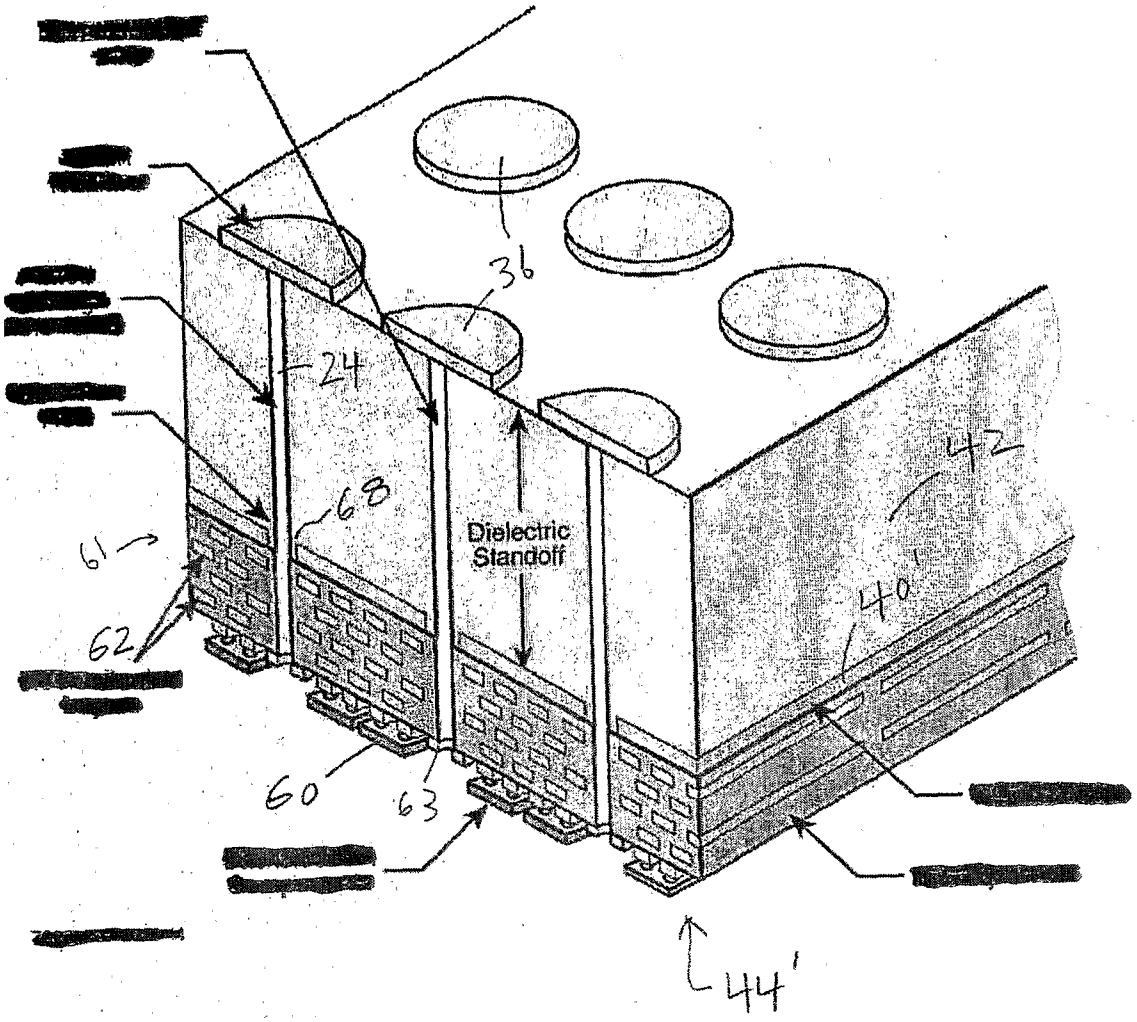
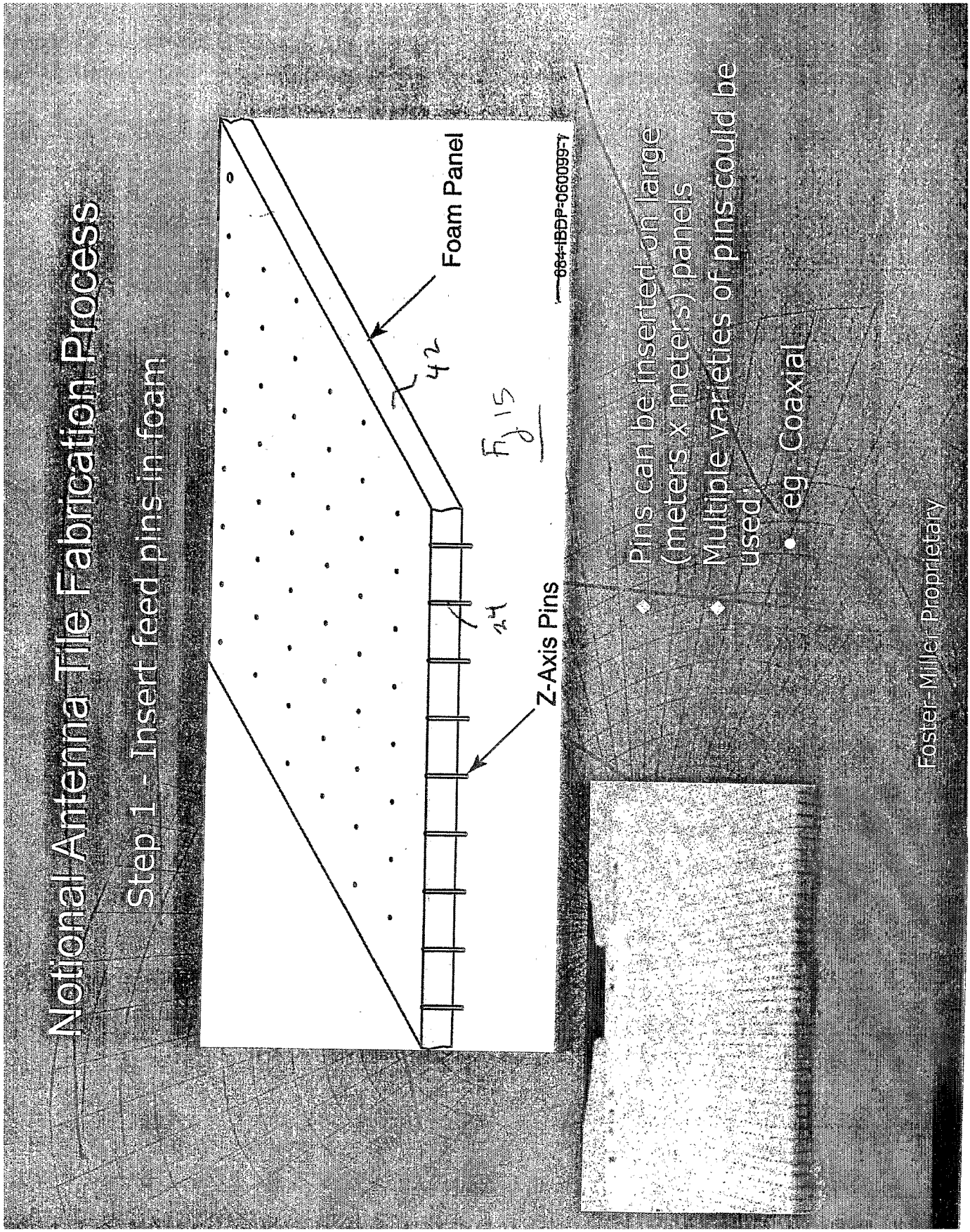
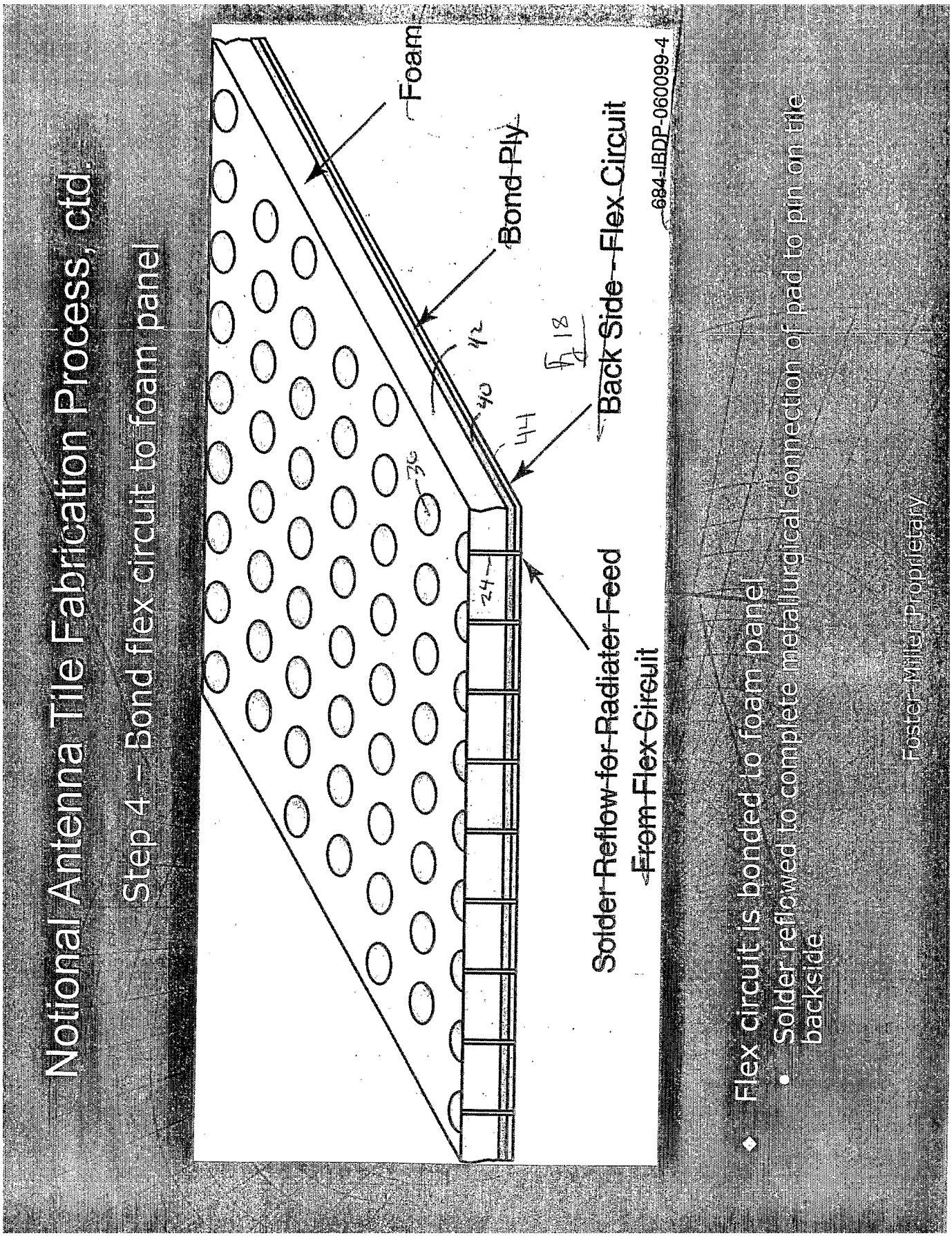


Fig. 14


Notional Antenna Tile Fabrication Process
Step 1 - Insert feed pins in foam
Foam Panel
42
Fig 15
24
Z-Axis Pins
884-IBDP-060099-7
Pins can be inserted on large (meters x meters) panels
Multiple varieties of pins could be used eg. Coaxial
Foster-Miller Proprietary

Notional Antenna Tile Fabrication Process, ctd.
Step 2 – Print radiator elements
Direct Metal Printed (QMP) Radiator Patches
684-IBDP-060099-2
42
24
Fig 16
Radiator elements are printed on surface of foam and make metallurgical contact with inserted pins
Alternatively, could bond flex circuit with etched radiator elements
Foster-Miller Proprietary

Notional Antenna Tile Fabrication Process, cfd.
Step 3 – Fabricate multilayer PCB
Multilayer Flex Circuit Board
Power and Data Distribution
90
Clearance Holes
Copper Ground Plate
40
42
Fig 17
Fabricate multilayer PCB for power and signal redistribution and backside component attach (MMICs, etc.)
Foster-Miller Proprietary


Notional Antenna Tile Fabrication Process, ctd.
Step 4 – Bond flex circuit to foam panel
Foam
Bond Ply
Back Side – Flex Circuit
Solder Reflow for Radiater Feed From Flex Circuit
684-IBDP-060099-4
Flex circuit is bonded to foam panel
Solder reflowed to complete metallurgical connection of pad to pin on tile backside
Foster-Miller Proprietary

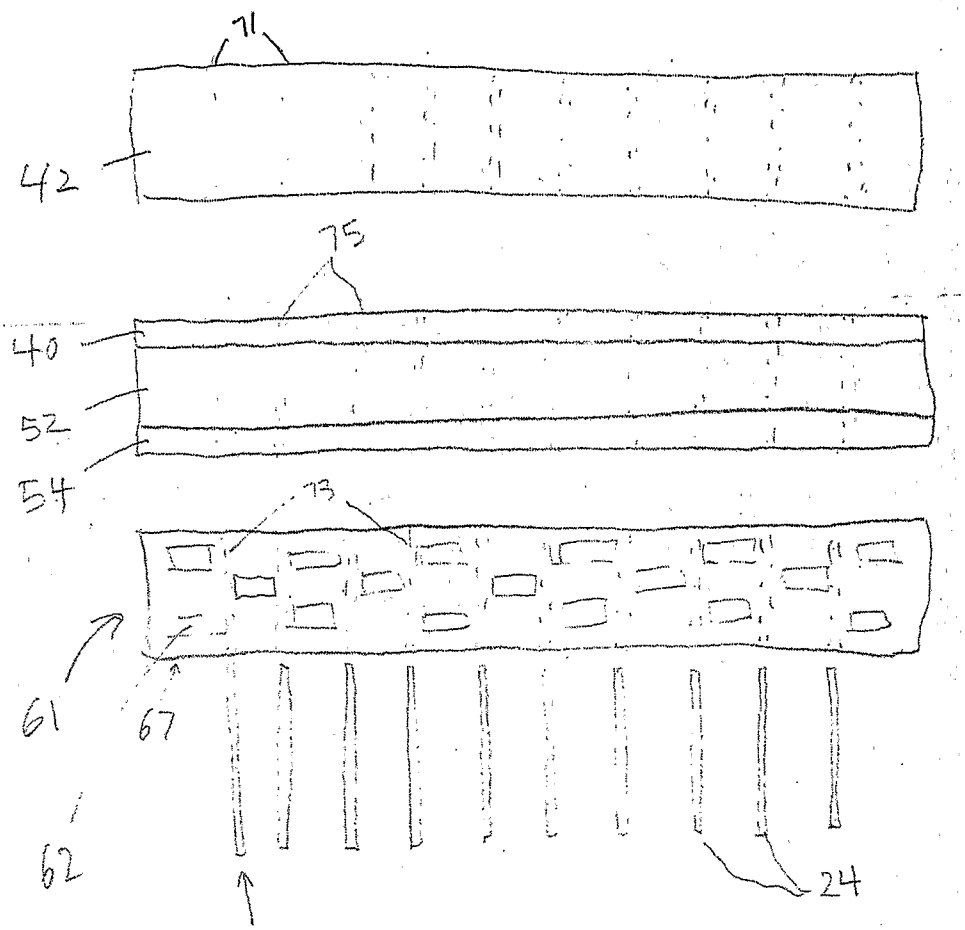


Fig. 19

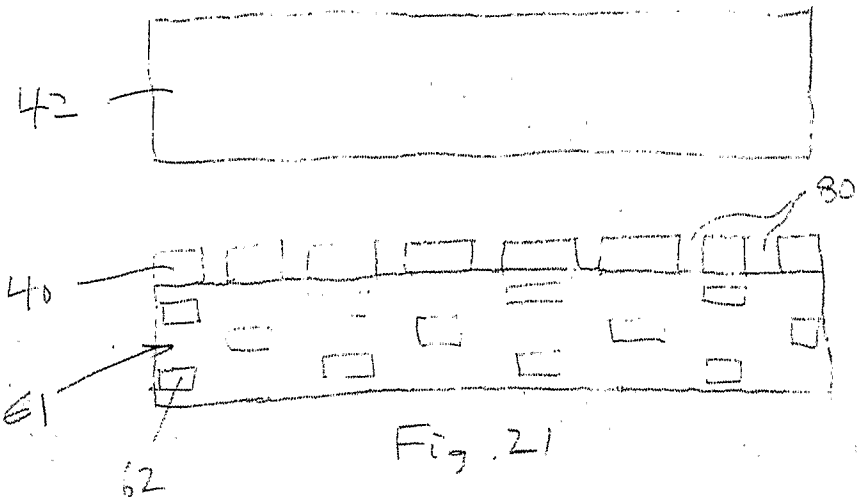


Fig. 21

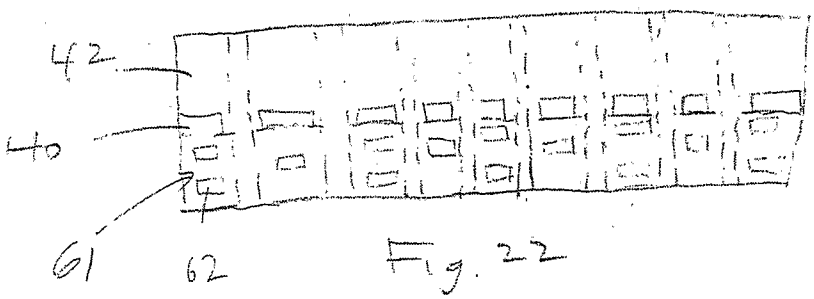


Fig. 22



Fig 23

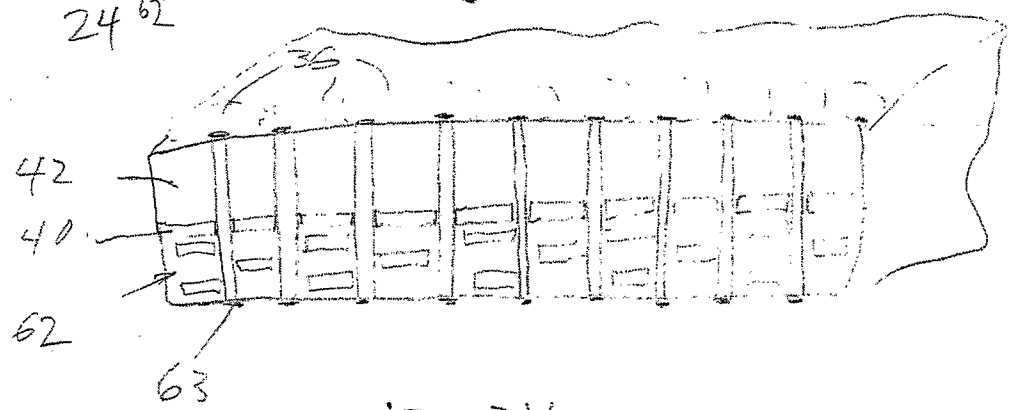


Fig 24

Notional Antenna Tile Fabrication Process, cont.
Electromechanical Tile Test Structures
Foster-Miller Proprietary

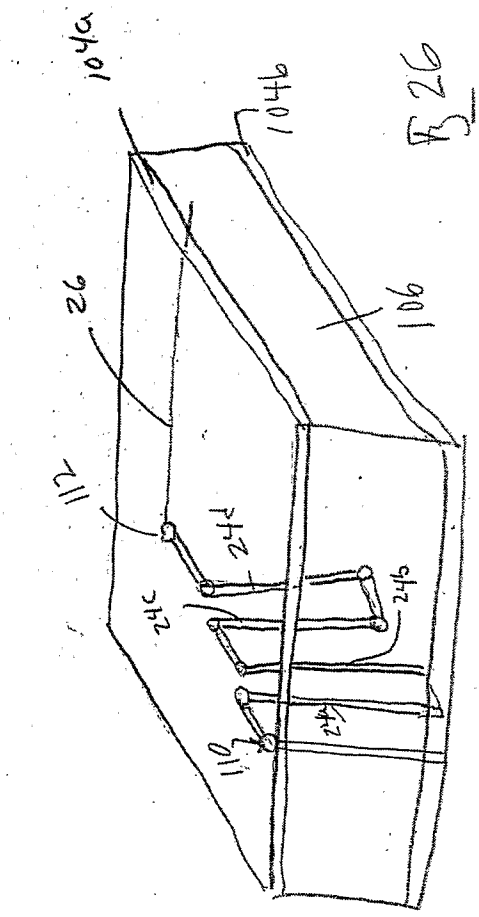


FIG 26

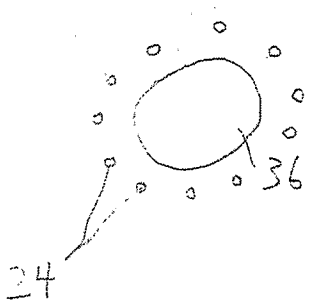


Fig. 27