US012394880B2

(12) United States Patent
Furlan

(10) **Patent No.: US 12,394,880 B2**
(45) **Date of Patent: *Aug. 19, 2025**

(54) **METHODS FOR FABRICATING AN ANTENNA AND A SHIELDED TRANSMISSION LINE**

(71) Applicant: **TAOGLAS GROUP HOLDINGS LIMITED**, Enniscorthy (IE)

(72) Inventor: **Vladimir Furlan**, Munich (DE)

(73) Assignee: **Taoglas Group Holdings Limited**, Enniscorthy (IE)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **18/742,085**

(22) Filed: **Jun. 13, 2024**

(65) **Prior Publication Data**

US 2024/0413516 A1 Dec. 12, 2024

Related U.S. Application Data

(63) Continuation of application No. 17/987,116, filed on Nov. 15, 2022, now Pat. No. 12,015,189, which is a

(Continued)

(51) **Int. Cl.**

H01Q 1/12 (2006.01)
H01P 3/08 (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***H01Q 1/1271*** (2013.01); ***H01P 3/085*** (2013.01); ***H01P 5/1007*** (2013.01); ***H01Q 1/12*** (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC H01Q 1/1271; H01Q 1/12; H01Q 1/2283; H01Q 1/243; H01Q 1/3233; H01Q 1/48;

(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,870,375 A	9/1989	Krueger, Jr. et al.
6,677,909 B2	1/2004	Sun et al.

(Continued)

FOREIGN PATENT DOCUMENTS

KR	101209620	12/2012
WO	2012079029	6/2012
WO	2016141177	9/2016

OTHER PUBLICATIONS

Mudegaonkar, et al. A microstrip-line-fed suspended square slot microstrip antenna for circular polarization operations, Communications on Applied Electronics 1(3) Feb. 2015.

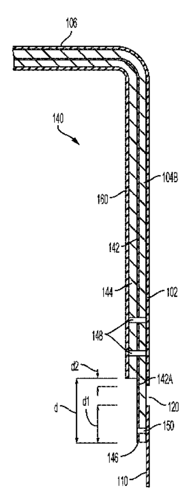
Primary Examiner — Hai V Tran

(74) *Attorney, Agent, or Firm* — Garson & Gutierrez, PC

(57) **ABSTRACT**

Disclosed is an antenna including a radiating element, a co-planar ground plane element and a transmission line extending across at least a portion of the radiating element and the ground plane element. The transmission line includes a dielectric layer having a portion of a first major surface adjacent to the ground plane and a second major surface opposite and separated from the first surface. A shield is formed on the second major surface. At least one via extends through the dielectric layer to connect the shield to the ground plane. A feed line extends longitudinally through the dielectric layer from a feed point at a proximal end of the transmission line towards a distal end of the transmission line, the feed line being shielded along a portion of its length extending across the ground plane element by the shield.

20 Claims, 10 Drawing Sheets



Related U.S. Application Data

continuation of application No. 17/164,097, filed on Feb. 1, 2021, now Pat. No. 11,509,036, which is a continuation of application No. 16/192,191, filed on Nov. 15, 2018, now Pat. No. 10,910,692.

(60) Provisional application No. 62/591,221, filed on Nov. 28, 2017.

(51) **Int. Cl.**

H01P 5/10	(2006.01)
H01Q 1/22	(2006.01)
H01Q 1/24	(2006.01)
H01Q 1/32	(2006.01)
H01Q 1/48	(2006.01)
H01Q 1/52	(2006.01)
H01Q 9/28	(2006.01)
H01Q 13/10	(2006.01)
H01Q 21/26	(2006.01)
H01Q 21/28	(2006.01)

(52) **U.S. Cl.**

CPC ***H01Q 1/2283*** (2013.01); ***H01Q 1/243*** (2013.01); ***H01Q 1/3233*** (2013.01); ***H01Q 1/48*** (2013.01); ***H01Q 1/52*** (2013.01); ***H01Q 1/526*** (2013.01); ***H01Q 9/285*** (2013.01); ***H01Q 13/10*** (2013.01); ***H01Q 21/26*** (2013.01); ***H01Q 21/28*** (2013.01)

(58) **Field of Classification Search**

CPC H01Q 1/52; H01Q 1/526; H01Q 9/285; H01Q 13/10; H01Q 21/26; H01Q 21/28; H01Q 13/085; H01P 3/085; H01P 5/1007

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,963,312	B2	11/2005	Schuneman et al.	
7,271,779	B2	9/2007	Hertel	
8,362,958	B2	1/2013	Lin et al.	
8,427,373	B2	4/2013	Jiang et al.	
9,166,300	B2	10/2015	Taura	
9,257,747	B2	2/2016	Flores-Cuadras	
9,391,372	B2	7/2016	Hwang et al.	
9,472,855	B2	10/2016	Toyao et al.	
9,653,807	B2	5/2017	Binzer et al.	
9,660,350	B2	5/2017	Lo Hine Tong et al.	
2005/0200557	A1	9/2005	Tanaka et al.	
2008/0167073	A1*	7/2008	Hobson	H01Q 13/10 455/557
2011/0221652	A1	9/2011	Li et al.	
2011/0273360	A1*	11/2011	Campero	H01Q 5/307 343/893
2012/0068896	A1	3/2012	White et al.	
2012/0127050	A1	5/2012	Song et al.	
2013/0099981	A1	4/2013	Vortmeier et al.	
2013/0257664	A1	10/2013	Kagaya et al.	
2013/0321212	A1	12/2013	O'Shea et al.	
2014/0060921	A1	3/2014	Reul et al.	
2014/0111393	A1	4/2014	Tong et al.	
2015/0091763	A1	4/2015	Tong et al.	
2015/0364823	A1	12/2015	Hashimoto et al.	
2016/0134021	A1	5/2016	Helander et al.	
2017/0279177	A1	9/2017	Oguri et al.	

* cited by examiner

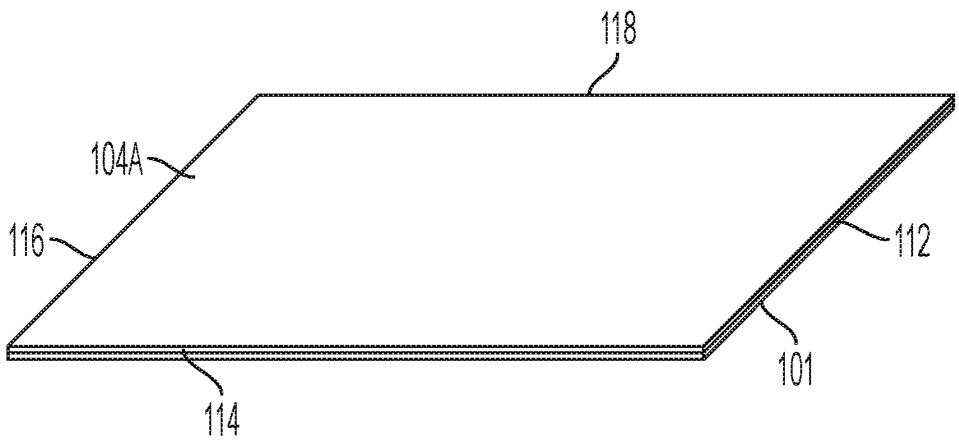


FIG. 1A

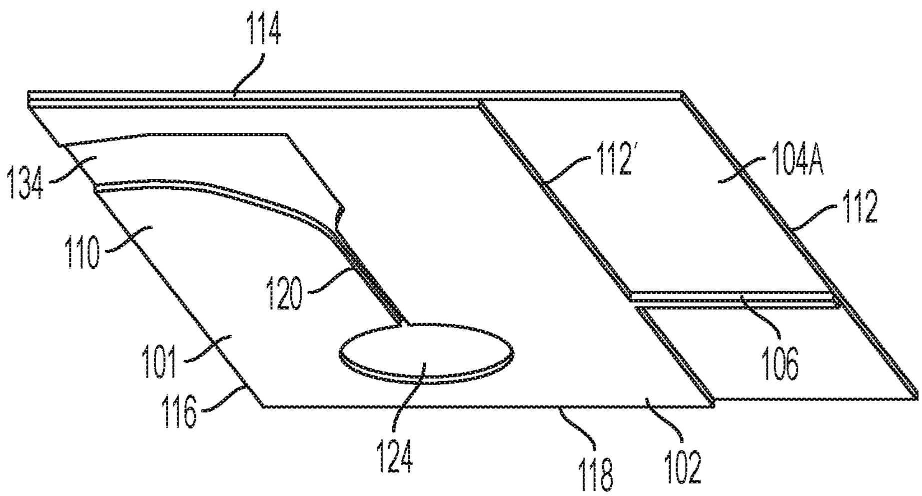


FIG. 1B

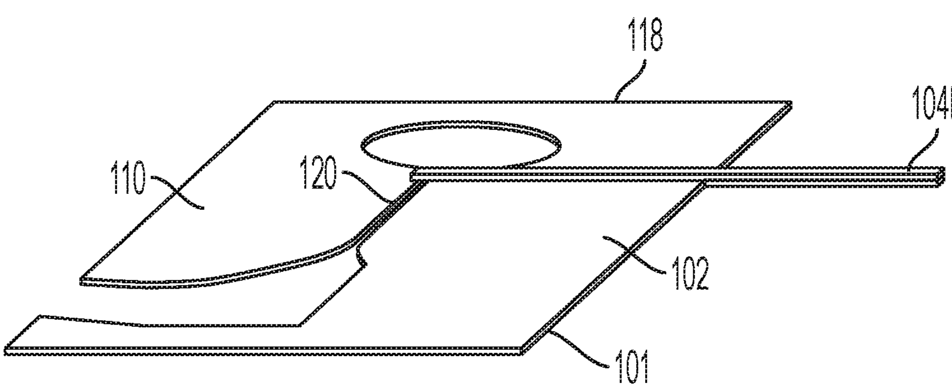


FIG. 1C

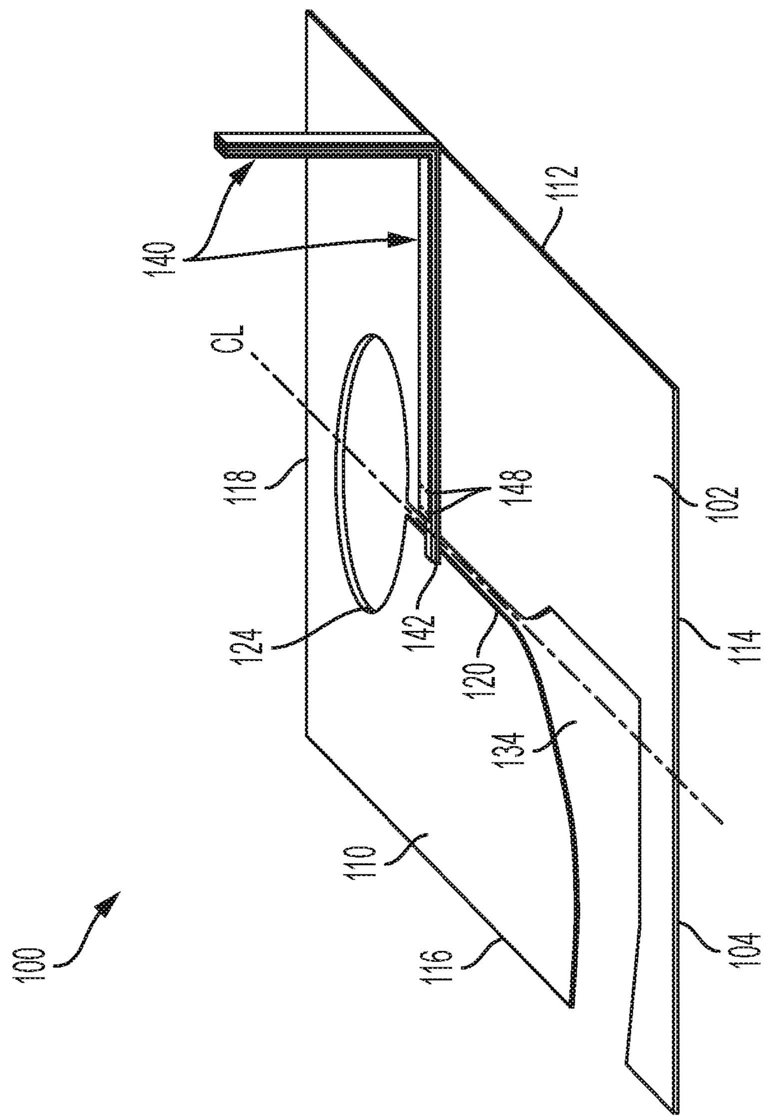


FIG. 2

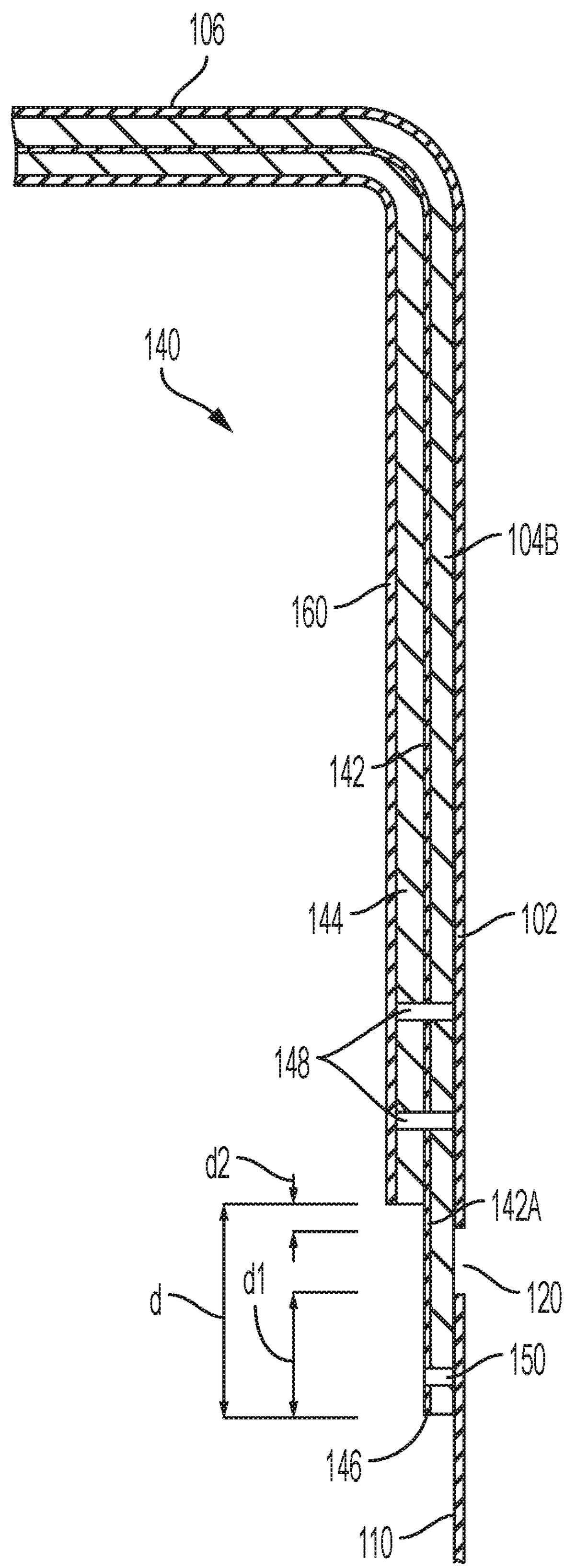


FIG. 3

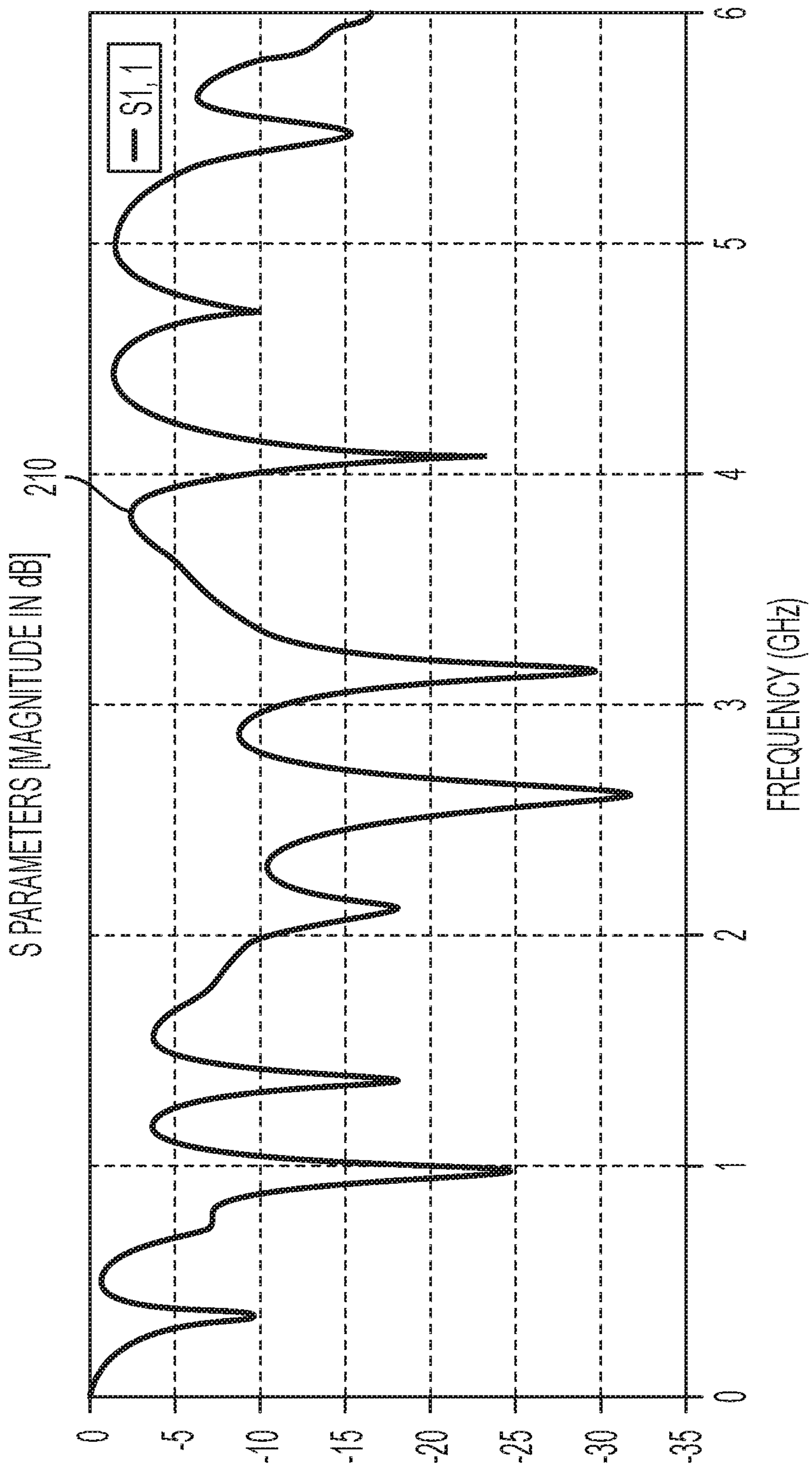

S PARAMETERS [MAGNITUDE IN dB]
S1,1
210
FREQUENCY (GHz)
0
-5
-10
-15
-20
-25
-30
-35
0
1
2
3
4
5
6

FIG. 4

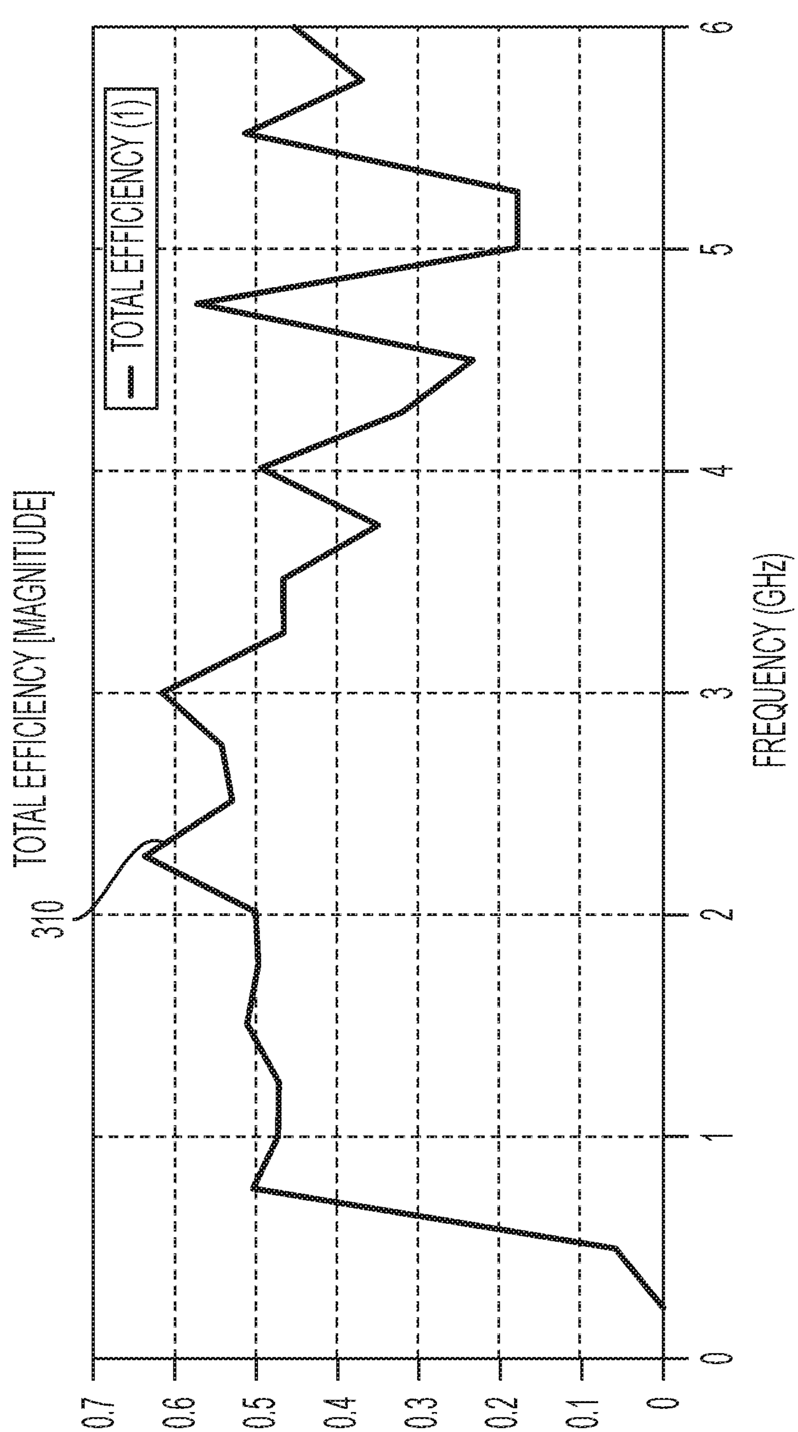

TOTAL EFFICIENCY [MAGNITUDE]
FREQUENCY (GHz)
TOTAL EFFICIENCY (1)
310
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
1
2
3
4
5
6

FIG. 5

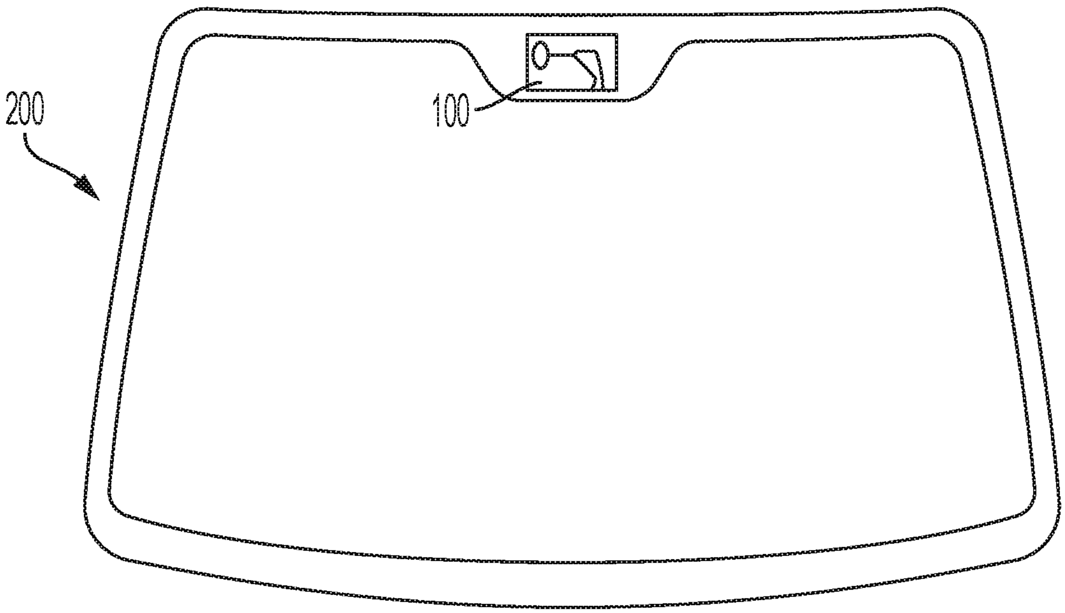


FIG. 6A

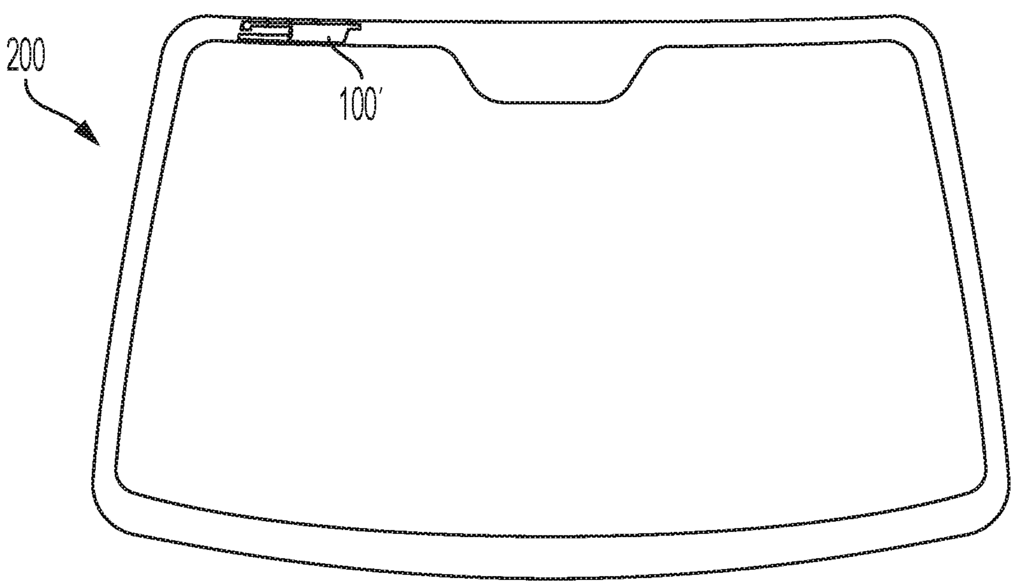


FIG. 6B

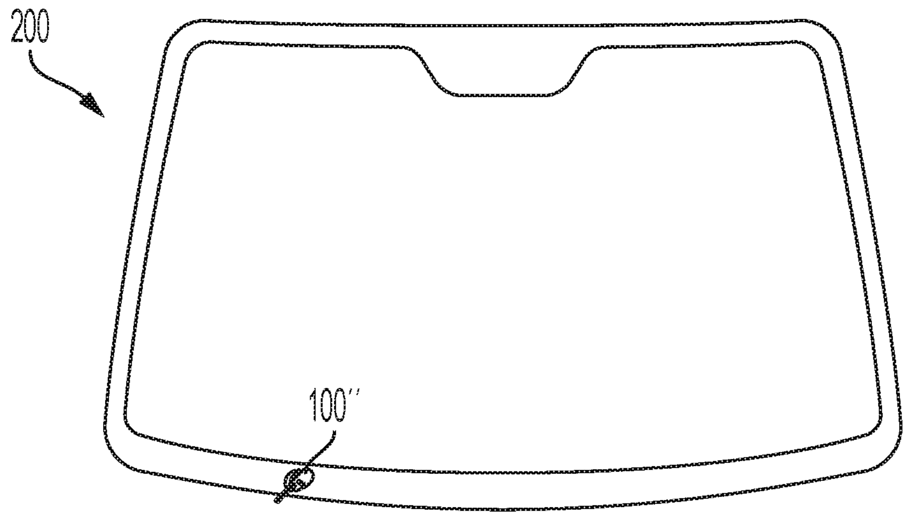


FIG. 6C

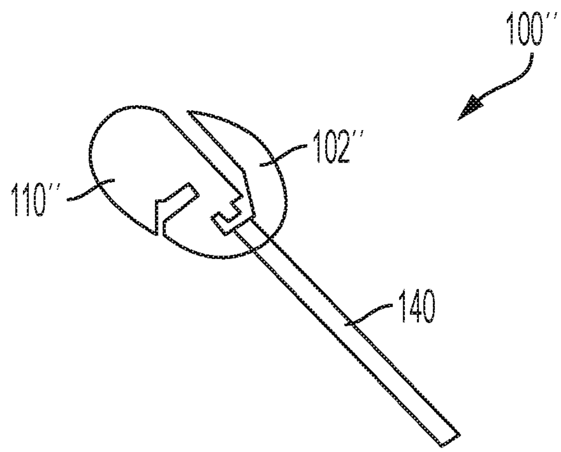


FIG. 6D

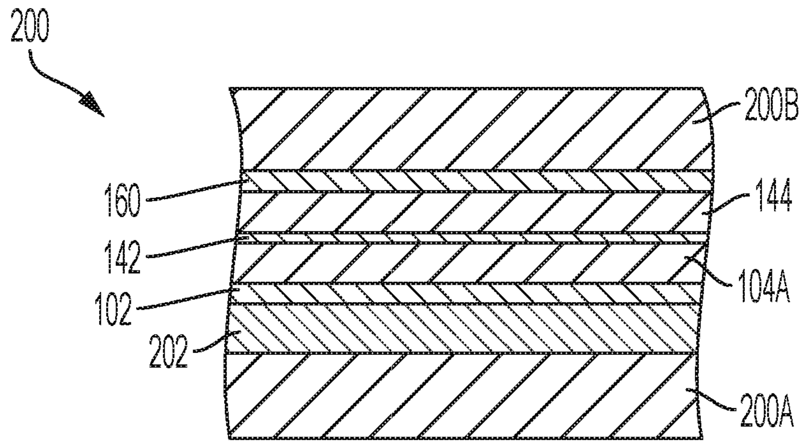

200
200B
160
144
142
104A
102
202
200A

FIG. 7

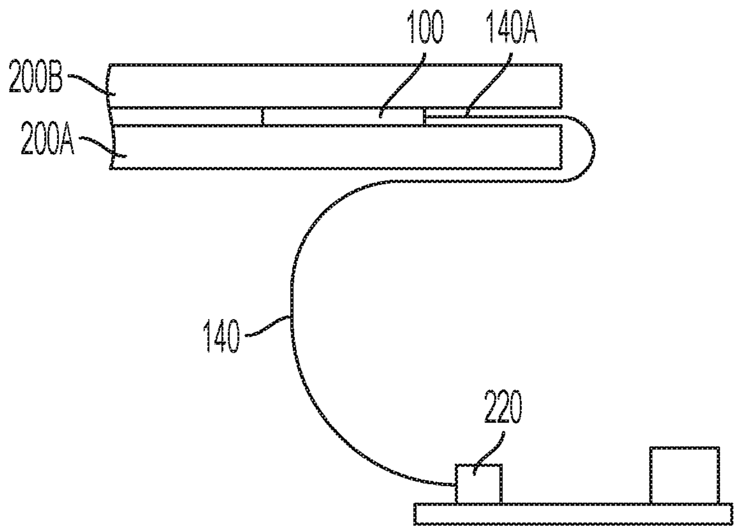

100
140A
200B
200A
140
220

FIG. 8

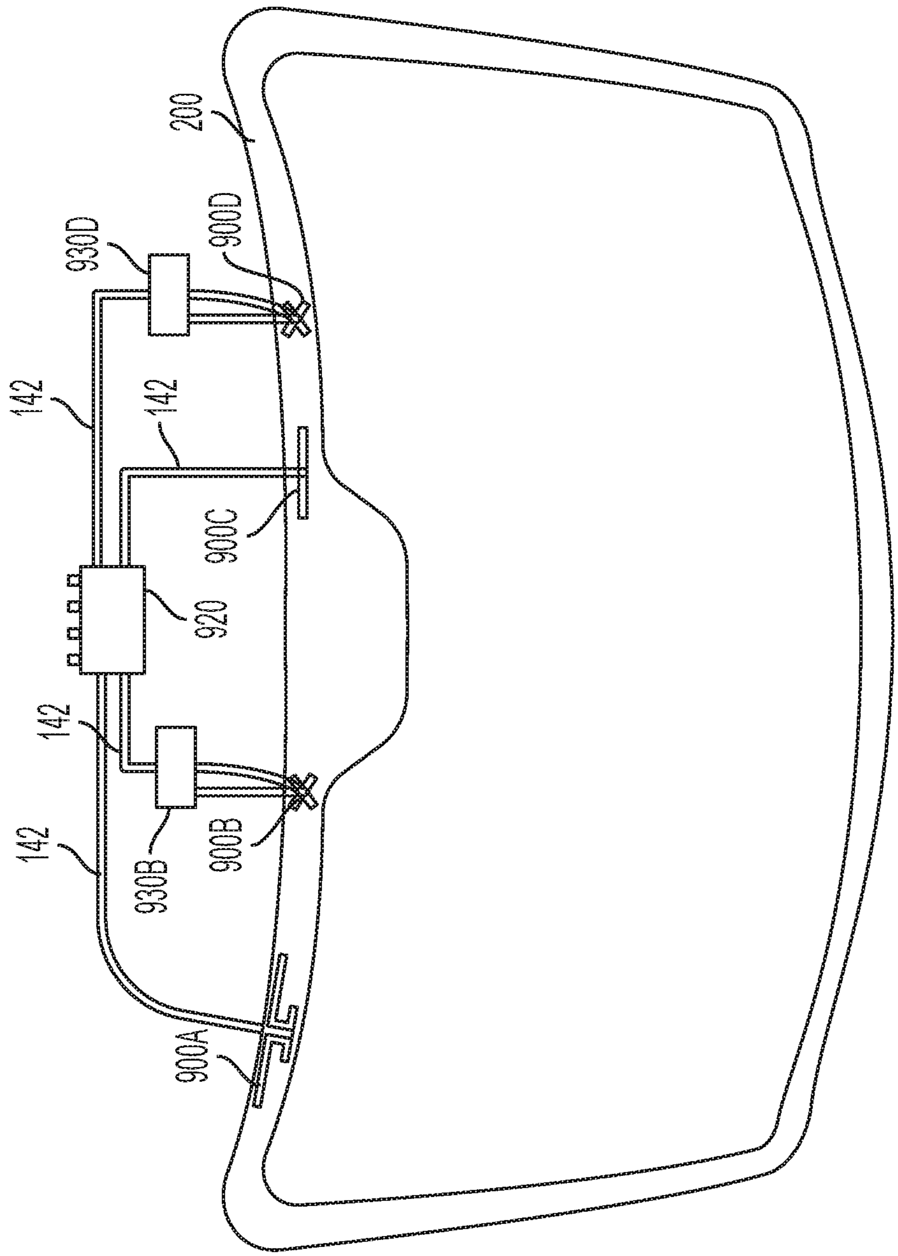


FIG. 9

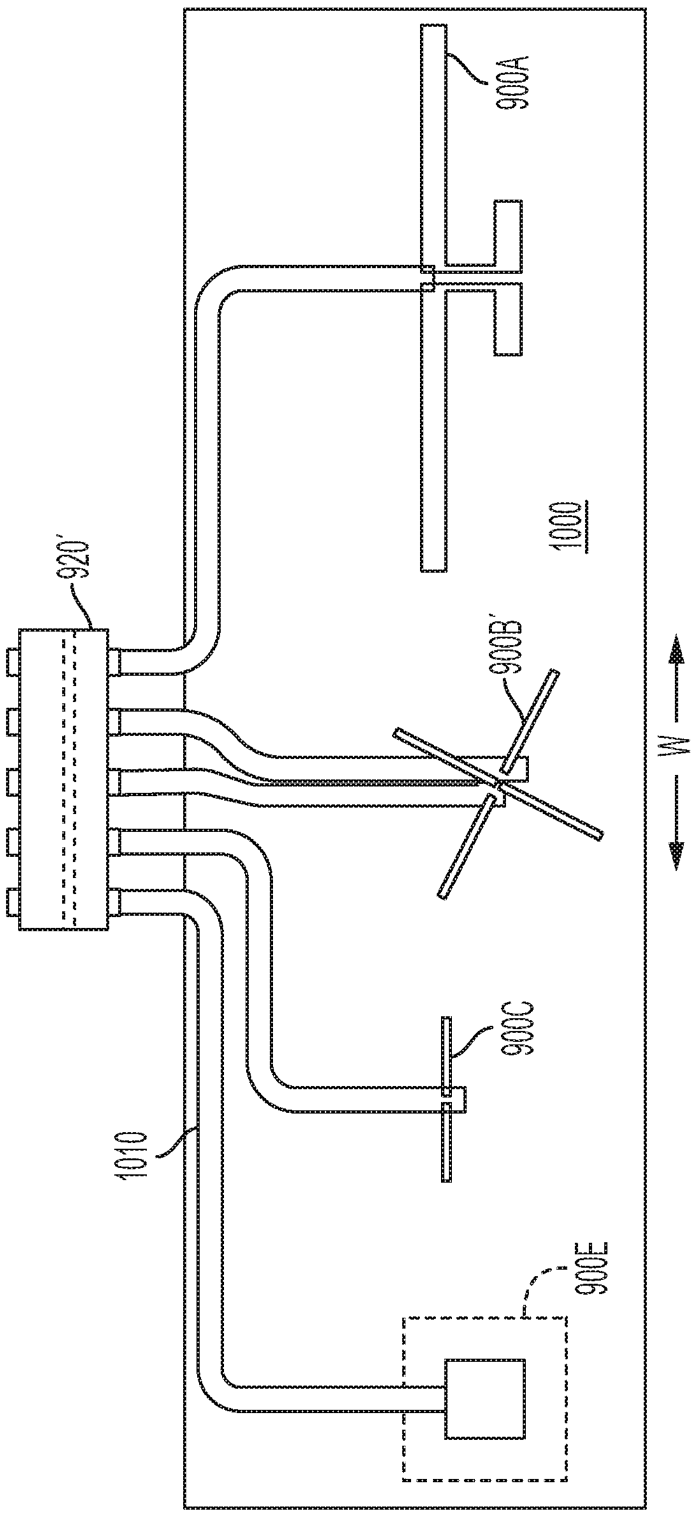


FIG. 10

METHODS FOR FABRICATING AN ANTENNA AND A SHIELDED TRANSMISSION LINE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of, and claims the benefit of priority to, U.S. patent application Ser. No. 17/987,116 filed Nov. 15, 2022, of the same title, which is a continuation of, and claims the benefit of priority to, U.S. patent application Ser. No. 17/164,097 filed Feb. 1, 2021, of the same title, now U.S. Pat. No. 11,509,036 that issued on Nov. 22, 2022, which is a continuation of, and claims the benefit of priority to, U.S. patent application Ser. No. 16/192,191 filed Nov. 15, 2018, of the same title, now U.S. Pat. No. 10,910,692 that issued on Feb. 2, 2021, which claims the benefit of priority to U.S. Provisional Application No. 62/591,221, filed Nov. 28, 2017, entitled "ANTENNA", each of the foregoing being incorporated herein by reference in its entirety.

FIELD

The present disclosure relates to an antenna.

BACKGROUND

With the growth of wireless communications and the proliferation of wireless communication devices and systems, antennas have found broad implementation as a result of their favorable properties and relatively simple design and fabrication. One form of antenna known as a slot antenna comprises a thin flat metal layer with one or more holes or slots removed. A feed line can be connected to the thin flat metal layer and either driven by connected transmitter circuitry at a required frequency or frequencies; or the feed line can be connected to a receiver tuned to pick up a signal at a required frequency or frequencies from the layer; or the feed line can be connected to both receiver and transmitter circuitry; or the feed line can be connected to transceiver circuitry. Typically, a coaxial feed line is attached to the surface of the antenna via manual solder-bonding. Even relatively slim coaxial feed lines can vary in diameter from about 810 μm to 1130 μm and so comprise the major portion of the thickness of the antenna, the remainder comprising the thickness of the layer itself.

One potential application for antenna devices is within a window panel such as a windshield of an automotive vehicle, although it will be appreciated that there may be many other applications where only limited clearance is available for incorporating an antenna. Typically, such windshields are fabricated by laminating at least 2 layers of glass with a layer of plastic material in between the two glass layers. Such windshields may provide a gap of about 800 μm between the layers of glass and this gap can be utilized for integrating a windshield heating element, amplitude modulation (AM), frequency modulation (FM) antenna elements or both AM and FM antenna elements. The fabrication process of an automotive vehicle windshield exposes the layers of glass to high pressures and high temperatures, and such fabrication conditions need to be taken into account when designing an in-glass high performance antenna for integration between the layers of glass of the windshield.

In order to feed such antennas with a transmission line, such as a coaxial feed line, a feed line would need a diameter significantly less than 800 μm. However, it will be appreciated that as the diameter of a coaxial feed line reduces, performance issues and increases in losses within the cable occur, thereby affecting the transmission of signals propagating through the coaxial feed line. Additionally, the high pressure and high temperatures that a windshield is exposed to during the manufacturing process can damage and impact the integrity of a larger coaxial cable in particular.

Thus, there is a need for a low profile, high performance antenna capable of being incorporated, for example, within an automotive vehicle window panel, and with an associated feed line that can withstand the windshield fabrication environment without negatively affecting the performance of the antenna after installation.

SUMMARY

An aspect of the disclosure is directed to high performance antennas suitable for incorporation in glass, e.g. between glass layers. Suitable antennas comprise: a radiating element; a ground plane element; and a transmission line extending across at least a portion of the radiating element and the ground plane element, the transmission line comprising: a dielectric layer, the dielectric layer having a portion of a first surface adjacent to the ground plane element and a second major surface opposite and separated from the first surface; a shield formed on the second major surface; a via extending through the dielectric layer to connect the shield to the ground plane element; a feed line extending longitudinally through the dielectric layer from a feed point at a proximal end of the transmission line towards a distal end of the transmission line, the feed line being shielded along a portion of the feed line length that extends across the ground plane element by the shield with the distal end of the transmission line lying in register with the radiating element and coupling the feed line to the radiating element. In some configurations, the radiating element and the ground plane element define a slot therebetween. Additionally, the radiating element and the ground plane element are further configurable to define an aperture and a tapered channel connected by the slot therebetween. Further, an outer shape of the antenna radiating element and the ground plane can comprise, for example, a rectangle. Additionally, the transmission line can be configured to straddle the slot. In some configurations, the feed line straddles the slot. The dielectric layer can further be configurable to comprise at least one of a flexible material and a rigid material. Suitable antennas can be selected from the group comprising: a Global Navigation Satellite System (GNSS) antenna, an LTE antenna, a 5G antenna, a DSRC antenna, a Bluetooth antenna and a Wi-Fi antenna. Additionally, the distal end of the feed line is spaced apart from and electromagnetically coupled to the radiating element. The distal end of the feed line can further be configured to connect to the radiating element through a via. In at least some configurations, the feed line comprises any one or more of: a stripline, a microstrip, a co-planar waveguide and a co-planar waveguide with ground. The distal end of the transmission line can also be positioned so that it is lying in register with the radiating element is supported by at least a portion of the dielectric layer. The antenna radiating element and co-planar ground plane element can also be formed of a metallic material comprising copper, aluminum, gold, or silver. A pair of vias can be provided straddling the feed line. In some configurations, a plurality of pairs of vias can be provided which are distributed along a length of the feed line.

Another aspect of the disclosure is directed to window panels having one or more antennas. Suitable configurations comprise: a first glass layer and a second glass layer; the one or more antennas comprising a radiating element, a ground plane element, and a transmission line extending across at least a portion of the radiating element and the ground plane element, the transmission line comprising a dielectric layer, the dielectric layer having a portion of a first surface adjacent to the ground plane element and a second major surface opposite and separated from the first surface, a via extending through the dielectric layer to connect the shield to the ground plane element, a feed line extending longitudinally through the dielectric layer from a feed point at a proximal end of the transmission line towards a distal end of the transmission line, the feed line being shielded along a portion of the feed line length that extends across the ground plane element by the shield with the distal end of the transmission line lying in register with the radiating element and coupling the feed line to the radiating element, wherein the one or more antennas are incorporated between the first glass layer and the second glass layer with a respective one or more transmission lines extending from between the first glass layer and the second glass layer for connecting the one or more antennas to a communications module. The first glass layer and the second glass layer can also be laminated together with a plastic layer therebetween. Additionally, the radiating element and the ground plane element for the one or more antennas can be formed directly on a glass layer or a laminated substrate of the window panel. The one or more antennas can also be pre-fabricated before incorporating between the first glass layer and the second glass layer. When the antennas are pre-fabricated, the antennas can be pre-fabricated on a common substrate. The window panel can be, but is not limited to, a vehicle windshield.

Yet another aspect of the disclosure is directed towards a method for fabricating an antenna and a shielded transmission line. In one embodiment, the method includes obtaining a first substrate and a second substrate; disposing a feed line between the first substrate and the second substrate, the feed line being disposed on a first surface of the first substrate and a first surface of the second substrate; disposing a ground plane on a second surface of the first substrate, the second surface of the first substrate being disposed opposite from the first surface of the first substrate; disposing a shield on a second surface of the second substrate, the second surface of the second substrate being disposed opposite from the first surface of the second substrate; and fabricating a slot between the ground plane and a radiating element for the antenna. Portions of the feed line, the second substrate, the shield, portions of the first substrate, and portions of the ground plane collectively form the shielded transmission line.

In one variant, the method further includes forming a bend in the shielded transmission line at one end of the shielded transmission line.

In another variant, the method further includes forming an exposed section of the feed line where portions of the shield do not overlap portions of the ground plane.

In yet another variant, the method further includes connecting the radiating element for the antenna with the exposed section of the feed line using a microstrip via.

In yet another variant, the method further includes connecting the ground plane with the shield using one or more transmission line vias.

In yet another variant, the method further includes forming a bend in the shielded transmission line at an end of the shielded transmission line opposite from the radiating element for the antenna.

In yet another variant, the method further includes disposing at least a portion of the antenna and the shielded transmission line within a windshield.

In yet another variant, the windshield comprises a first layer of the windshield and a second layer of windshield and the method further comprises disposing the first layer of the windshield on one side of the antenna and the shielded transmission line and disposing the second layer of the windshield on a second side of the antenna and the shielded transmission line, the second side being opposite from the one side of the antenna and the shielded transmission line.

In yet another variant, the method further includes disposing a plastic layer between the first layer of the windshield and the ground plane.

In yet another variant, the method further includes forming a bend in the shielded transmission line at an end of the shielded transmission line opposite from the radiating element for the antenna.

In yet another variant, the method further includes disposing at least a portion of the antenna and the shielded transmission line within a windshield.

In yet another variant, the windshield comprises a first layer of the windshield and a second layer of the windshield and the method further comprises disposing the first layer of the windshield on one side of the antenna and the shielded transmission line and disposing the second layer of the windshield on a second side of the antenna and the shielded transmission line, the second side being opposite from the one side of the antenna and the shielded transmission line.

In yet another variant, the method further includes disposing a plastic layer between the first layer of the windshield and the ground plane.

In yet another variant, the method further includes forming a bend in the shielded transmission line at an end of the shielded transmission line opposite from the radiating element for the antenna.

In yet another variant, the method further includes disposing at least a portion of the antenna and the shielded transmission line within a windshield.

In yet another variant, the windshield comprises a first layer of the windshield and a second layer of windshield and the method further comprises disposing the first layer of the windshield on one side of the antenna and the shielded transmission line and disposing the second layer of the windshield on a second side of the antenna and the shielded transmission line, the second side being opposite from the one side of the antenna and the shielded transmission line.

In yet another variant, the method further includes disposing a plastic layer between the first layer of the windshield and the ground plane.

In yet another variant, the method further includes forming a bend in the shielded transmission line at an end of the shielded transmission line opposite from the radiating element for the antenna.

In yet another variant, the antenna is an antenna selected from the group consisting of: a Global Navigation Satellite System (GNSS) antenna, an LTE antenna, a 5G antenna, a DSRC antenna, a Bluetooth antenna, and a Wi-Fi antenna.

In yet another variant, the feed line comprises any one or more of: a stripline, a microstrip, a co-planar waveguide and a co-planer waveguide with ground.

BRIEF DESCRIPTION OF DRAWINGS

The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

FIGS. **1**A-C illustrate steps from one method for producing an antenna according to an embodiment of the disclosure;

FIG. **2** is an isometric illustration of the antenna produced according to FIG. **1** and in which the feed line has been bent to enable the feed line to be supplied from a side of a window panel;

FIG. **3** is a cross-section of a portion of the antenna produced according to FIG. **1**;

FIG. **4** is the simulated return loss of a slot antenna with a PCB transmission line attached;

FIG. **5** is the simulated total efficiency of a slot antenna with a PCB transmission line attached;

FIG. **6**A shows a location for the antenna of FIG. **2** incorporated into a vehicle windshield;

FIG. **6**B shows an alternative windshield location for a variant of the antenna of FIG. **2**;

FIG. **6**C shows a further alternative windshield location for another variant of the antenna of FIG. **2**;

FIG. **6**D shows the variant of the antenna in FIG. **6**C in more detail;

FIG. **7** shows a cross-section view of the antenna of FIG. **2** in-situ within a windshield;

FIG. **8** shows an antenna of the embodiments connected to driver circuitry;

FIG. **9** shows a windshield incorporating a plurality of different antennas according to various embodiments of the disclosure; and

FIG. **10** shows a windshield incorporating a further variant comprising a plurality of different antennas according to various embodiments of the disclosure.

DETAILED DESCRIPTION

Referring now to FIGS. **1**A-C, some steps of an exemplary method for fabricating an antenna **100** of FIG. **2** according to the disclosure are illustrated. In FIG. **1**A, there is shown a first substrate **104**A wherein a first side of the first substrate **104**A is coated with a conductive material **101**. The first substrate **104** A is illustrated with a rectangular shape having a first side **112**, a second side **114**, a third side **116**, and a fourth side **118**. Examples of conductive material **101** suitable for coating the first substrate **104**A include, but are not limited to, a glass-reinforced epoxy laminate such as fiberglass resin (FR4) and Kapton® polyimide film available from Dupont, while suitable conductive materials include copper, aluminum, gold or silver.

During the fabrication process, the conductive material **101** is masked to define an antenna configuration/shape and then etched to remove portions of the conductive material **101** that does not form part of the antenna. As shown in FIG. **1**B, where the first substrate **104**A is a flipped view of FIG. **1**A, the antenna configuration/shape comprises a radiating element **110** generally separated from a ground plane **102** by a tapered channel **134**, slot **120** and an aperture **124** with a strip comprising a transmission line base layer **106** for a transmission line extending from a side **112'** of the ground plane **102** of the antenna. As shown in FIG. **1**B, the first side **112** of the first substrate **104**A is not coextensive with the first side **112'** of the ground plane **102**. As will be appreciated by those skilled in the art, any variety of antenna shapes can be defined at this stage of the process, but it is desirable in each case to provide for a transmission line **106** extending from a side of the antenna to facilitate connection of the antenna to receiver/transmitter/transceiver circuitry.

In the next step, shown in FIG. **1**C, the first substrate **104**A is patterned to remove all but a layer of dielectric material to leave a first substrate remainder **104**B portion extending along the length of the transmission line base layer **106**, across the ground plane **102** and, in the present example, traversing the slot **120** and extending partly over the radiating element **110**. It will be appreciated that at this stage, the conductive material **101** may be a patterned layer that is quite fragile and so a temporary carrier (not shown) can be provided to support the ground plane **102** of the radiating element **110** from its surface opposite the first substrate remainder **104**B portion during subsequent processing.

Referring now to FIG. **2**, in order to complete the assembly of the antenna **100**, a second substrate **144**, such as a dielectric substrate layer, having a first side coated with a conductive material which is a shield **160** is provided. The second substrate **144** corresponds in shape with the first substrate remainder **104**B shown in FIG. **1**C except that it is marginally shorter as illustrated in FIG. **3**.

Before the second substrate **144** is combined with the first substrate remainder **104**B, a feed line **142** is located between the substrates, the feed line **142** running longitudinally along the first substrate remainder **104**B from a first substrate remainder distal end remote from the ground plane **102** to a proximal point where the first substrate remainder **104**B overlies the radiating element **110**. The three components can now be bonded using any of: adhesive, pressure, or adhesive and pressure possibly in combination with another other technique to provide a nascent shielded transmission line **140**.

In FIG. **2**, two pairs of vias **148** are shown with each pair straddling the feed line **142**. However, it will be appreciated that in variants of the embodiment, any number of vias, pairs of vias or arrangements of vias can be formed along the length of the transmission line **140**, as required. It will also be appreciated that these vias once complete can maintain the first **104**B and second **144** substrates together and so the original bonding of the substrates may only need to be suitable for temporary bonding.

An end via **150** can be formed towards the end of the first substrate remainder **104**B to electrically connect the feed line **142** to the radiating element **110**. Nonetheless, it will be appreciated that in variants of the embodiment, no via may be required and in this case, the end of the feed line would only be coupled to the radiating element. In either case, the first substrate remainder **104**B need not extend across either the slot **120** or the radiating element **110** i.e. the slot **120** could be co-terminus with the second substrate **144**.

Referring back to FIG. **2**, as described, the antenna **100** comprises a radiating element **110**, a ground plane **102** (which can be a co-planar ground plane element), and a transmission line **140**. A feed line **142** is also provided which spans a centerline CL of the slot **120** at a right angle, the feed line **142** extends across at least a portion of the ground plane **102** and the radiating element **110** by a distance dl. As illustrated, the outer shape of the antenna **100** is rectangular having a first side **112**, a second side **114**, a third side **116**, and a fourth side **118**, numbered clockwise as viewed in the illustration. The slot **120** is arranged so that the longitudinal centerline CL of the slot extends parallel to the first side **112** and the third side **116**. Note that the centerline CL may be positioned off center along the length of the first side **112** and the third side **116**. An aperture **124**, depicted as a circular aperture, is provided at one end of the slot **120** within the body of the antenna **100** with the aperture **124** of the slot **120** straddling the centerline CL. A tapered channel **134** extends from the slot all the way to the third side **116**. When the aperture **124** is a circular aperture, the aperture **124** can have a diameter up to approximately half the length of either the first side **112** or the third side **116**. The tapered channel **134** is narrowest where the tapered channel **134** meets the slot **120** and gradually widens as the tapered channel **134** approaches the third side **116**. Note that the slot **120** does not need to have parallel sides and in one embodiment the width of the slot **120** at its narrowest point adjacent the aperture **124** is approximately 3% the diameter of the aperture **124**, while, at its widest point before the slot **120** expands into the tapered channel **134**, the width of the slot **120** is approximately 5% the diameter of the aperture **124**. Thus, the configuration of the slot **120** is typical for a slot antenna. The transmission line **140** straddles the slot **120** near the point on the antenna **100** where the slot **120** meets the aperture **124**. In the embodiment, the transmission line crosses the center line of the slot **120** at a right angle.

The transmission line **140** comprises the second substrate **144**, a feed line **142** which extends longitudinally through the dielectric substrate layer from a feed point at a distal end of the transmission line towards the end overlying the radiating element **110**. In one embodiment, the feed line **142** arrangement comprises a conductive metal stripline. The feed line **142** may be provided resting atop the transmission line of the second substrate **144** thus forming, for example, a microstrip. The microstrip may have additional conductive metal strips running alongside and adjacent to the feed line **142** microstrip thus forming a co-planar waveguide or a co-planar waveguide with ground. In the embodiment depicted, the feed line **142** runs along the entire length and has a thickness approximately one eighth that of the second substrate **144**. Visible in FIG. **2**, are the top surfaces of a plurality of transmission line vias **148**. The transmission line vias **148** are composed of a suitable electrically conductive material. The transmission line vias **148** extend through the second substrate **144** to connect the shield **160** to the ground plane **102** so as to provide an electrically conductive connection on one side of the tapered channel **134** between the shield **160** and the ground plane **102**. Although not shown, the plurality of transmission line vias **148** will extend from the vias as shown in FIG. **2** along the length of the transmission line towards a proximal end of the transmission line.

The transmission line **140** may be in the form of a microstrip that runs within the second substrate **144** along the entire length of the transmission line **140**. Like the feed line **142**, the microstrip is composed of a conductive metal material. The transmission line **140** is approximately one quarter as wide as the second substrate **144** and has a thickness approximately one eighth that of the second substrate **144**. The transmission line **140** is centered within the width of the second substrate **144** of the transmission line and is approximately centered within the thickness of the second substrate **144**.

FIG. **3** depicts a cross-section illustrating a portion of the internal details of the connection of the transmission line **140** to the radiating element **110** and ground plane **102**. The feed line **142** is depicted as extending across at least a portion of the radiating element **110** and the ground plane **102** straddling the slot **120** near the point (not shown) on the radiating element **110** where the slot **120** meets the aperture **124** shown in FIG. **2**. Also visible in FIG. **3**, are two of the transmission line vias **148** extending through the second substrate **144** to connect the shield **160** to the ground plane **102**. Once assembled, a number of vias **148** can be formed along the length of the transmission line to electrically connect the shield **160** to the transmission line base layer **106** and thus the ground plane **102**.

Also, a portion d of transmission line **140** comprises only the first substrate remainder **104**B portion and with an exposed section of feed line **142**A extending across at least a portion of the ground plane **102** and radiating element **110** terminating at slot **120**. The first substrate remainder **104**B in the portion d of the transmission line is optional and provides support for the feed line **142**A that extends across at least the portion dl of the radiating element **110** and at least the portion d**2** of the ground plane **102**.

A microstrip via **150** is formed adjacent microstrip near an end of the feed line **142** and completes the conductive connection from the feed line **142** to the surface of the radiating element **110**. The microstrip via **150** connects to the surface of the radiating element **110** on the side of the tapered channel **134** opposite that which the vias **148** connect. Although FIG. **3** illustrates the via **150** extending from the microstrip **146** to the radiating element **110**, the transmission line **140** can also be configured such that a distal end of transmission line **140** lies space apart from and in register with the radiating element **110** electromagnetically coupling the feed line **142** to the radiating element **110**.

In operation, connecting the transmission line **140** to a voltage source induces a voltage across the tapered channel **134**, slot **120** and the aperture **124** which, in turn, creates an electric field distribution around the slot (not shown).

As can be seen in FIG. **2** and FIG. **3**, once completed, the transmission line **140** can be bent at a point along its length away from the ground plane. In FIG. **2**, the bend is shown at the edge of the ground plane **102**, but as will be appreciated by those skilled in the art, a bend at the edge of the ground plane **102** is not the only suitable location for a bend. Bending the transmission line in this manner enables the body of the antenna to be located within for example the laminated layers of a window panel (as explained below) while connecting to electronics components which may lie out of the plane of the window panel.

Turning now to FIG. **4**, a simulated return loss **210** of the antenna **100** shown in FIG. **2** is illustrated, the return loss is plotted across the frequency domain from 0 gigahertz (GHz) to 6 GHz. The plot is typical of a slotted antenna of the configuration described in the embodiment presented in FIG. **2**. The simulated return loss **210** consists of a series of continuous concave-down quasi-parabolic shapes spanning the range from 0 GHz to 6 GHz. The maxima range from O decibel (dB) at 0 GHz to approximately −11 dB at approximately 2.3 GHZ. The minima range from approximately −9 dB at approximately 0.2 GHz to approximately −32 dB at approximately 2.6 GHz.

FIG. **5** is a plot of the simulated total efficiency **310** of the antenna **100** illustrated in FIG. **2** across the frequency domain from 0 GHz to 6 GHZ. The plot is typical of a slotted antenna of the configuration described in the embodiment presented in FIG. **2**. The simulated total efficiency **310** exhibits a local maxima of approximately 63% at 2.3 GHZ and 61% at 3 GHz.

While the embodiment depicted in FIG. **2** illustrates a specific configuration of a slot antenna, the disclosure is applicable to antennas in general. Thus, while the antenna **100** produced according to the above example is a Vivaldi slot antenna, the disclosure is applicable to any antenna design which can be implemented with a planar conductor including for example a monopole antenna, dipole antenna, a Dedicated Short-Range Communications (DSRC), Global Navigation Satellite System (GNSS) antenna or Wi-Fi antenna.

FIGS. **6**A-C illustrate the placement for a variety of antenna configurations including antenna **100** in FIG. **6**A, antenna **100'** in FIG. **6**B, and antenna **100"** in FIG. **6**C according to various embodiments of the present disclosure in a windshield **200** of an automobile. FIG. **6**A shows a location for the antenna of FIG. **2** within the windshield **200**, with FIG. **6**B showing an alternative location for the antenna **100'** which is a variant of the antenna **100** illustrated in FIG. **2** within the windshield **200** and FIG. **6**C showing a further alternative location for another antenna **100"** which is a variant of the antenna **100** shown in FIG. **2** within the windshield **200**. Multiple antennas can be located in the windshield **200**. The antennas can be a combination of different types of antennas. The placement of the antennas are provided for illustrative purposes and provided by way of example only and are not limiting. FIG. **6**D illustrates antenna **100"** shown in FIG. **6**C in more detail. The antenna **100"** has a radiating element **110"**, a ground plane **102"**, and a transmission line **140**.

FIG. **7** shows a cross-section view of the antenna of FIG. **2** in-situ within a windshield **200**. The windshield **200** comprises at least two glass layers, first glass layer **200**A and second glass layer **200**B, with an antenna located between the first glass layer **200**A and second glass layer **200**B. Located on a first surface of one of the first glass layer **200**A is a plastic layer **202** and located on a surface of the plastic layer, the surface being that surface which is opposite surface that is adjacent to the first glass layer **200**A, is the antenna of FIG. **2** or a variant of the antenna shown in FIG. **6**B or FIG. **6**C. A ground plane **102**, is adjacent the plastic layer **202** on one side and the first substrate **104**A. The remainder of the first substrate **104**A is adjacent the feed line **142**. The feed line **142** is adjacent the second substrate **144**, and the shield **160** is positioned between the second glass layer **200**B and the second substrate **144**.

FIG. **8** shows an antenna **100** located between the first glass layer **200**A and the second glass layer **200**B of a windshield **200** and connected to a communications module including driver circuitry **220**. The antenna **100** is connected to the driver circuitry **220** by the transmission line **140**, the distal end **140**A of the transmission line being connected to the antenna and extending from between the first glass layer **200**A and second glass layer **200**B of the windshield **200** for connecting to the driver circuitry **220** external to the windshield.

As will be appreciated by those skilled in the art, while the antennas **100**, **100'** and **100"** have been described as being provided as a pre-fabricated sub-assembly module fitted on a glass or laminated substrate of a window panel, such as a windshield, for subsequent incorporation within the window panel, it is also possible, to produce antenna traces for more than one antenna on a given substrate and for these to be connected to separate feed lines.

Also, it is possible to print the traces for one or more antennas directly on a glass or laminated substrate of the window panel before fixing the transmission line to the traces and subsequent incorporation within the window panel. Referring to FIG. **9**, a windshield **200** is illustrated incorporating a dipole LTE antenna **900**A, a GNSS antenna **900**B, a Wi-Fi antenna **900**C and a DSRC antenna **900**D, each with one or more respective feed lines **142**A . . . '**142**B converging on a connector **920**. In the case of the GNSS antenna **900**B and DSRC antenna **900**D, a pair of feed lines are connected directly to the cross-dipole antenna traces and these are connected to the connector **920** via respective couplers **930**B, **930**D. Note that the feed lines are shown schematically, in practice, are likely to converge close to a common point on the edge of the windshield where they are fed to the connector **920**.

Referring now to FIG. **10**, in one such arrangement a set of 4 antennas including a DSRC patch antenna **900**E (instead of the cross-dipole of FIG. **9**), a Wi-Fi antenna **900**C, a GNSS antenna **900**B' and a dipole LTE antenna **900**A are constructed on a common substrate **1000** which is located along an edge **1010** of a window panel within a blacked out region towards the edge of the window panel. In this case, both feed lines of the GNSS antenna **900**B' are connected directly to a connector **920'** (without a discrete coupler **930** as in FIG. **9**).

In order to provide an idea of the scale of these devices, in the direction W shown, the dipole LTE antenna **900**A is approximately 120 mm wide, the GNSS antenna **900**B' is approximately 60 mm wide, the Wi-Fi antenna **900**C is approximately 25 mm wide and the DSRC patch antenna **900**E is approximately 30 mm wide.

While preferred embodiments of the present invention have been shown and described will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

The invention claimed is:

1. A method for fabricating an antenna and a shielded transmission line, the method comprising:
- obtaining a first substrate and a second substrate;
- disposing a feed line between the first substrate and the second substrate, the feed line being disposed on a first surface of the first substrate and a first surface of the second substrate;
- disposing a ground plane on a second surface of the first substrate, the second surface of the first substrate being disposed opposite from the first surface of the first substrate;
- disposing a shield on a second surface of the second substrate, the second surface of the second substrate being disposed opposite from the first surface of the second substrate; and
- fabricating a slot between the ground plane and a radiating element for the antenna;
- wherein portions of the feed line, the second substrate, the shield, portions of the first substrate, and portions of the ground plane collectively form the shielded transmission line.

2. The method of claim **1**, further comprising forming a bend in the shielded transmission line at one end of the shielded transmission line.

3. The method of claim **1**, further comprising forming an exposed section of the feed line where portions of the shield do not overlap portions of the ground plane.

4. The method of claim **3**, further comprising connecting the radiating element for the antenna with the exposed section of the feed line using a microstrip via.

5. The method of claim **4**, further comprising connecting the ground plane with the shield using one or more transmission line vias.

6. The method of claim 5, further comprising forming a bend in the shielded transmission line at an end of the shielded transmission line opposite from the radiating element for the antenna.

7. The method of claim 5, further comprising disposing at least a portion of the antenna and the shielded transmission line within a windshield.

8. The method of claim 7, wherein the windshield comprises a first layer of the windshield and a second layer of windshield and the method further comprises disposing the first layer of the windshield on one side of the antenna and the shielded transmission line and disposing the second layer of the windshield on a second side of the antenna and the shielded transmission line, the second side being opposite from the one side of the antenna and the shielded transmission line.

9. The method of claim 8, further comprising disposing a plastic layer between the first layer of the windshield and the ground plane.

10. The method of claim 9, further comprising forming a bend in the shielded transmission line at an end of the shielded transmission line opposite from the radiating element for the antenna.

11. The method of claim 4, further comprising disposing at least a portion of the antenna and the shielded transmission line within a windshield.

12. The method of claim 11, wherein the windshield comprises a first layer of the windshield and a second layer of windshield and the method further comprises disposing the first layer of the windshield on one side of the antenna and the shielded transmission line and disposing the second layer of the windshield on a second side of the antenna and the shielded transmission line, the second side being opposite from the one side of the antenna and the shielded transmission line.

13. The method of claim 12, further comprising disposing a plastic layer between the first layer of the windshield and the ground plane.

14. The method of claim 13, further comprising forming a bend in the shielded transmission line at an end of the shielded transmission line opposite from the radiating element for the antenna.

15. The method of claim 1, further comprising disposing at least a portion of the antenna and the shielded transmission line within a windshield.

16. The method of claim 15, wherein the windshield comprises a first layer of the windshield and a second layer of the windshield and the method further comprises disposing the first layer of the windshield on one side of the antenna and the shielded transmission line and disposing the second layer of the windshield on a second side of the antenna and the shielded transmission line, the second side being opposite from the one side of the antenna and the shielded transmission line.

17. The method of claim 16, further comprising disposing a plastic layer between the first layer of the windshield and the ground plane.

18. The method of claim 17, further comprising forming a bend in the shielded transmission line at an end of the shielded transmission line opposite from the radiating element for the antenna.

19. The method of claim 1, wherein the antenna is an antenna selected from the group consisting of:

a Global Navigation Satellite System (GNSS) antenna, an LTE antenna, a 5G antenna, a DSRC antenna, a Bluetooth antenna, and a Wi-Fi antenna.

20. The method of claim 1, wherein the feed line comprises any one or more of:

a stripline, a microstrip, a co-planar waveguide and a co-planer waveguide with ground.

* * * * *