US007915981B2

(12) **United States Patent**
Snodgrass et al.

(10) **Patent No.: US 7,915,981 B2**
(45) **Date of Patent: Mar. 29, 2011**

(54) COAXIAL-TO-MICROSTRIP TRANSITIONS

(75) Inventors: **David K Snodgrass**, Groton, MA (US); **Thomas M Gaudette**, Cameron Park, CA (US); **Mark V Faulkner**, Napa, CA (US); **Thomas G Flack**, Union City, CA (US); **Thomas E Halterman**, Folsom, CA (US); **Mario Pinamonti La Marche**, Fremont, CA (US); **Edward B Anderson**, Portland, OR (US)

(73) Assignee: **Microsemi Corporation**, Irvine, CA (US)

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

(21) Appl. No.: **12/788,328**

(22) Filed: **May 27, 2010**

(65) **Prior Publication Data**

US 2010/0245001 A1 Sep. 30, 2010

Related U.S. Application Data

(62) Division of application No. 12/038,546, filed on Feb. 27, 2008, now Pat. No. 7,750,764.

(51) **Int. Cl.**
H03H 7/38 (2006.01)
(52) **U.S. Cl.** **333/260**; 333/33
(58) **Field of Classification Search** 333/260, 333/33
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,983,884	A	5/1961	Reuger
4,611,186	A	9/1986	Ziegner
4,837,529	A	6/1989	Gawronski et al.
4,951,011	A	8/1990	Heckaman et al.
4,994,771	A	2/1991	Takamine et al.
5,123,863	A	6/1992	Frederick et al.
5,175,522	A	12/1992	Clark et al.
5,308,250	A	5/1994	Walz
5,402,088	A	3/1995	Pierro et al.
5,418,505	A	5/1995	Agarwal et al.
5,517,747	A	5/1996	Pierro et al.

(Continued)

FOREIGN PATENT DOCUMENTS

EP	0800225 A2	10/1997

(Continued)

OTHER PUBLICATIONS

Mattehw Morgan and Sander Weinreb, "A Millimeter-Wave Perpendicular Coax-To-Microstrip Transition", Microwave Symposium Digest, 2002 IEEE MTT-S International vol. 2, Issue 2002, pp. 817-820; IEEE Piscataway, New Jersey.

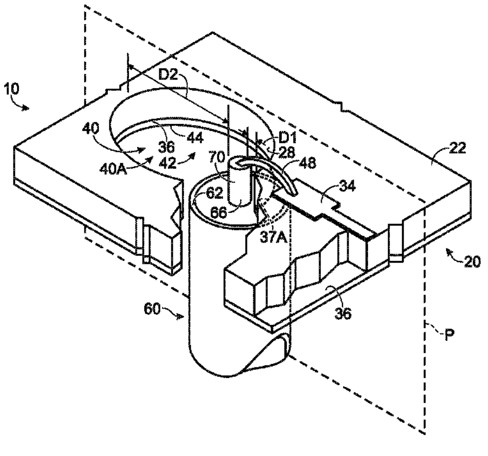
(Continued)

Primary Examiner — Stephen E Jones
(74) *Attorney, Agent, or Firm* — Simon Kahn

(57) ABSTRACT

Coaxial-to-microstrip transitions may include a microstrip line and coaxial-line assembly. The microstrip line includes a first dielectric having an aperture, a conductive strip disposed on one primary face of the first dielectric, and a ground plane disposed on the opposite primary face of the first dielectric. The coaxial-line assembly includes an outer conductor and an inner conductor. In some examples, the ground plane extends between the outer conductor and the inner conductor on a first side of the coaxial-line assembly proximate the conductive strip and an aperture cross section extends beyond the outer conductor on a second side of the coaxial-line assembly distal the conductive strip. In some examples, the ground plane has a non-circular aperture. In some examples, the outer conductor encloses an area that is less than an area of the aperture. In some examples, the enclosed area has a width that is less than a corresponding width of the first aperture.

22 Claims, 5 Drawing Sheets



U.S. PATENT DOCUMENTS

5,552,753	A	9/1996	Agarwal et al.
5,557,074	A	9/1996	Miyamoto et al.

FOREIGN PATENT DOCUMENTS

EP	0800225	A3	10/1997
JP	55085104		6/1980
JP	60000101		1/1985
JP	2000232304		8/2000

OTHER PUBLICATIONS

Anritsu Corporation, Product Catalog, "Precision RF & Microwave Components Catalog No. 11410-00235 Rev. F", printed Nov. 2006. Submission comprises the front cover, catalog pp. 1-19 and the back cover (21 pages total).

International Search Report for parallel application PCT/US2009/034962 issued Apr. 15, 2009 by European Patent Office.

Written Opinion for the International Searching Authority for parallel application PCT/US2009/034962 issued Apr. 15, 2009 by European Patent Office.

J. Roh et al.; Novel Approach to Optimizing a Broadband Right-Angle Coaxial-to-Microstrip Transition; Microwave and Optical Technology Letters, vol. 49, No. 2, pp. 451-455, Feb. 2007, Wiley Interscience, Hoboken, New Jersey.

S.A. Wartenberg; A Coaxial-to-Microstrip Transition for Multilayer Substrates; IEEE Transactions on Microwave Theory and Techniques, vol. 52, No. 2, pp. 585-588, Feb. 2004, IEEE Piscataway, New Jersey.

Fig. 1

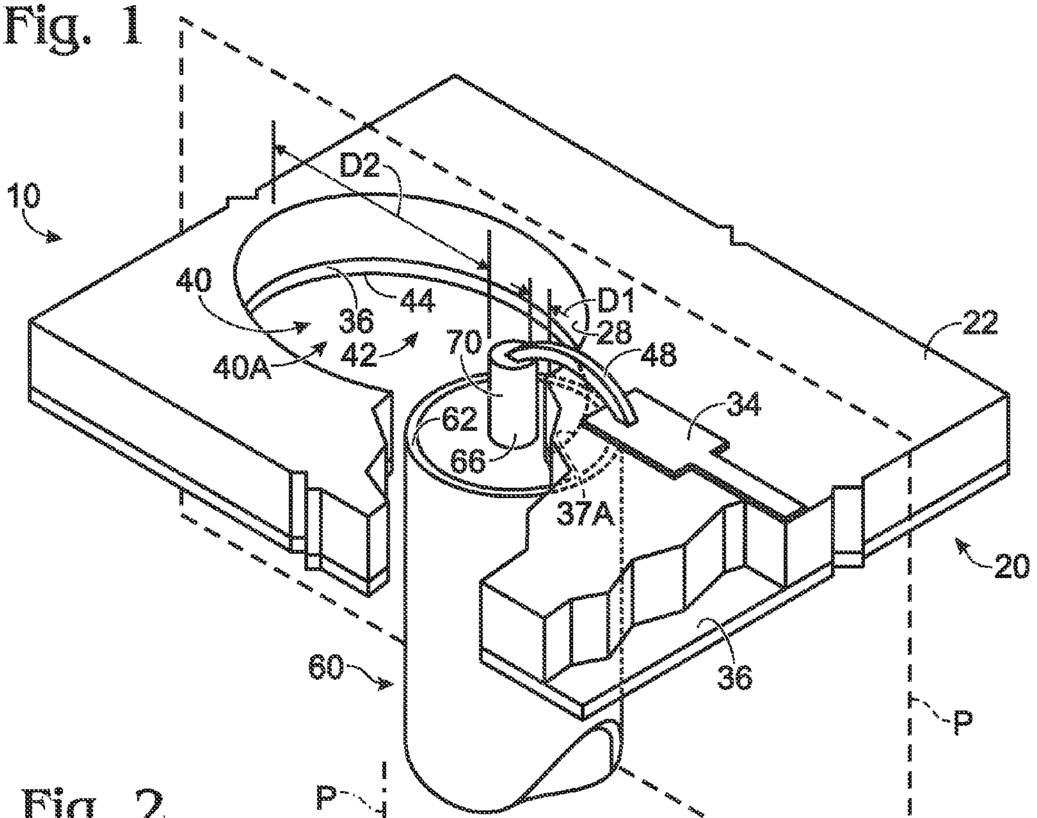

10
D2
40
36
44
D1
28
40A
42
70
48
22
62
34
66
37A
20
60
36
P

Fig. 2

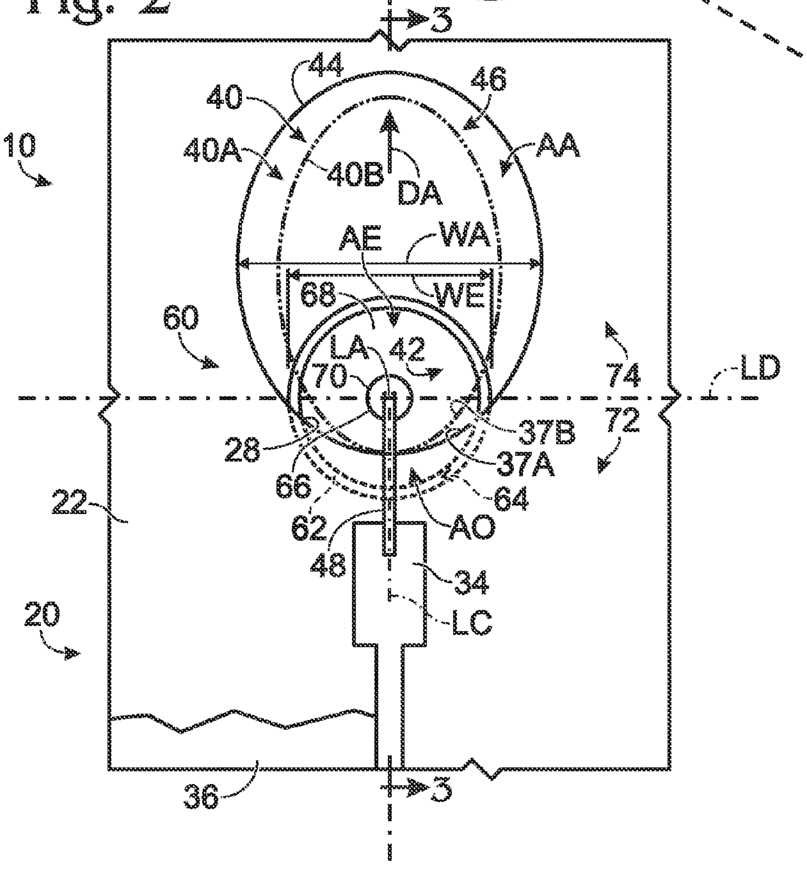

P
3
44
46
40
40A
40B
DA
AA
10
AE
WA
WE
68
60
LA
42
70
74
LD
28
37B
72
37A
66
64
62
AO
22
48
34
LC
20
36
3

Fig. 3

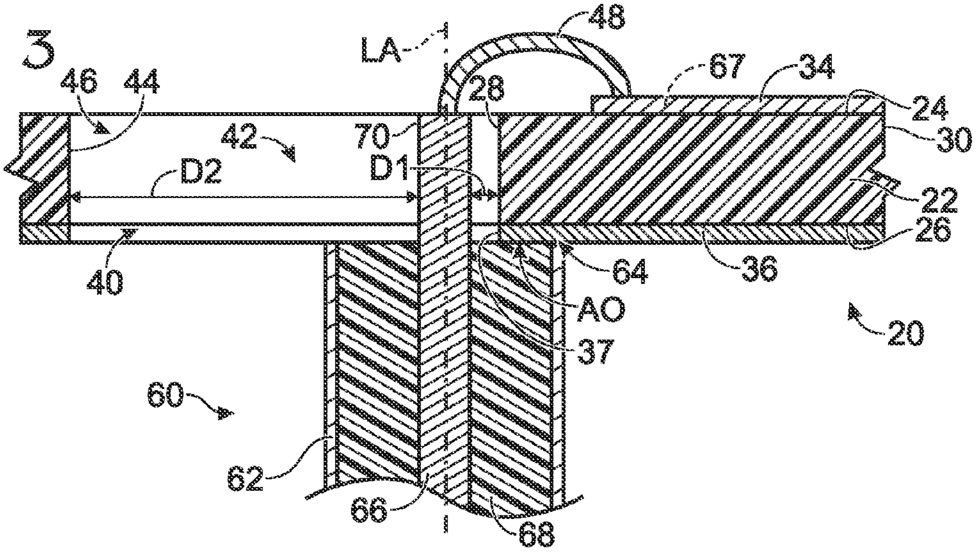


Fig. 4

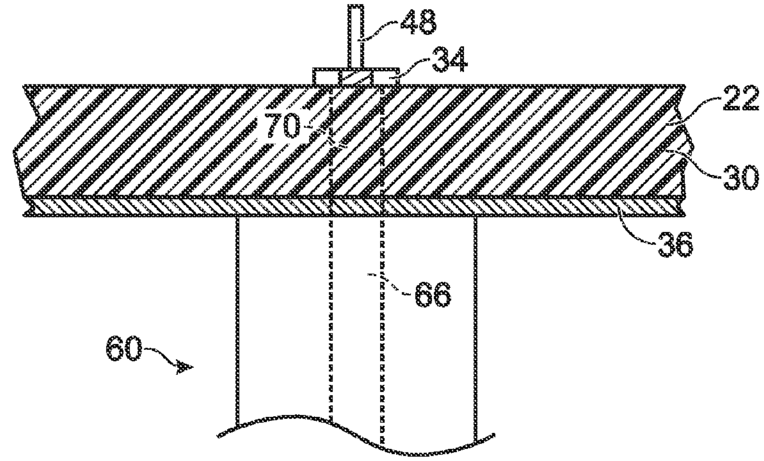


Fig. 5

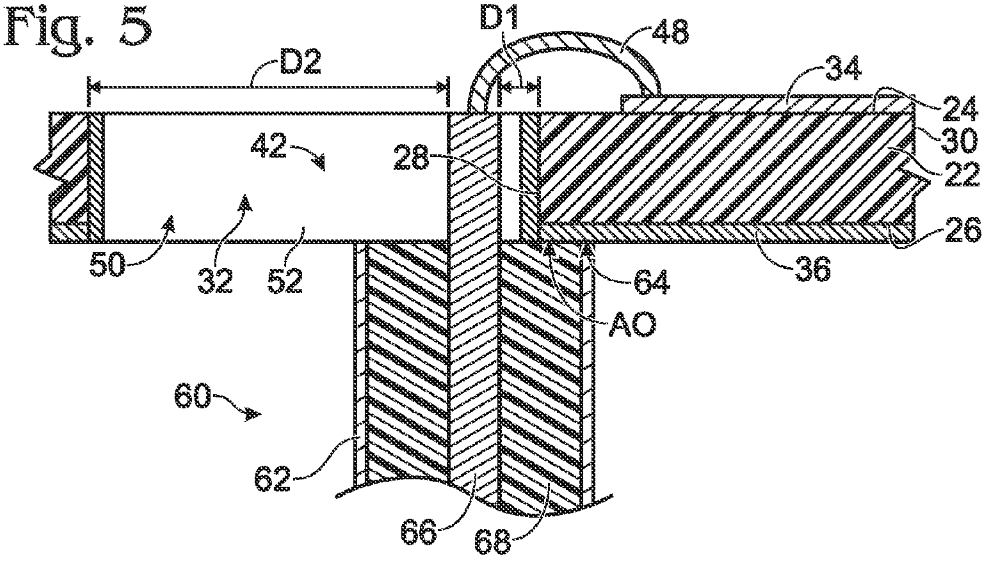


Fig. 6

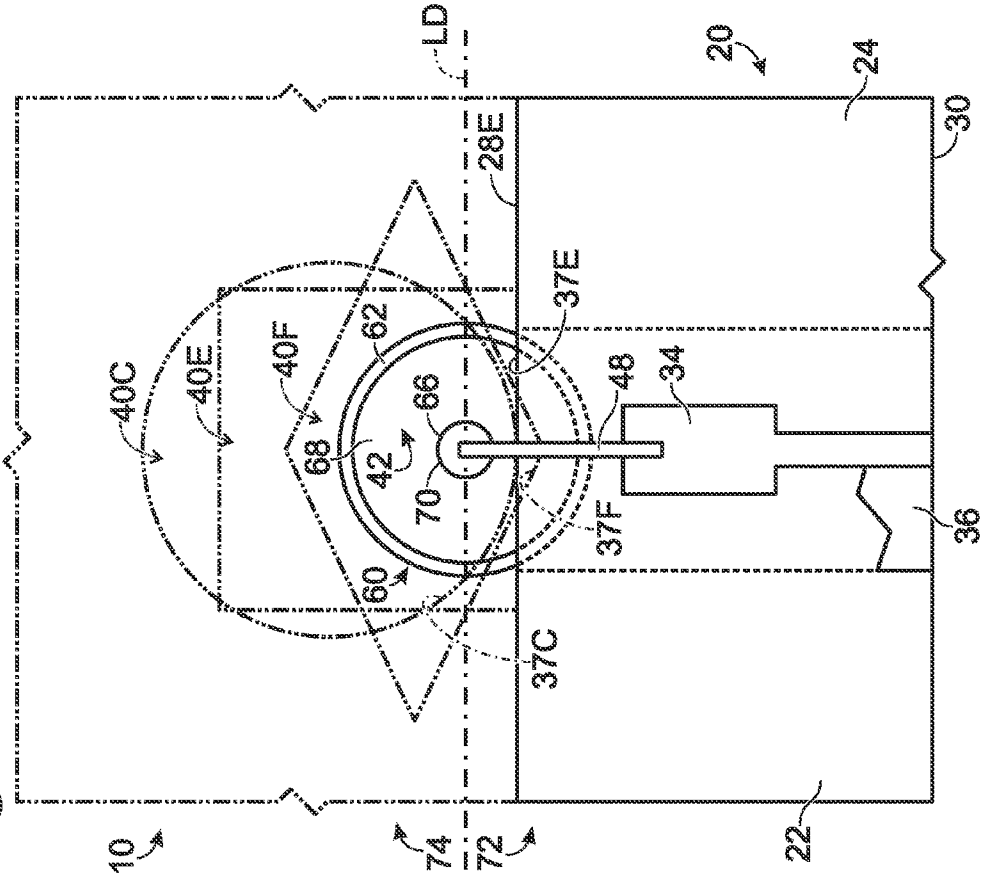

10
74
72
LD
28E
22
20
24
30
40C
40E
40F
62
68
42
66
70
60
37C
37E
37F
48
34
36

Fig. 7

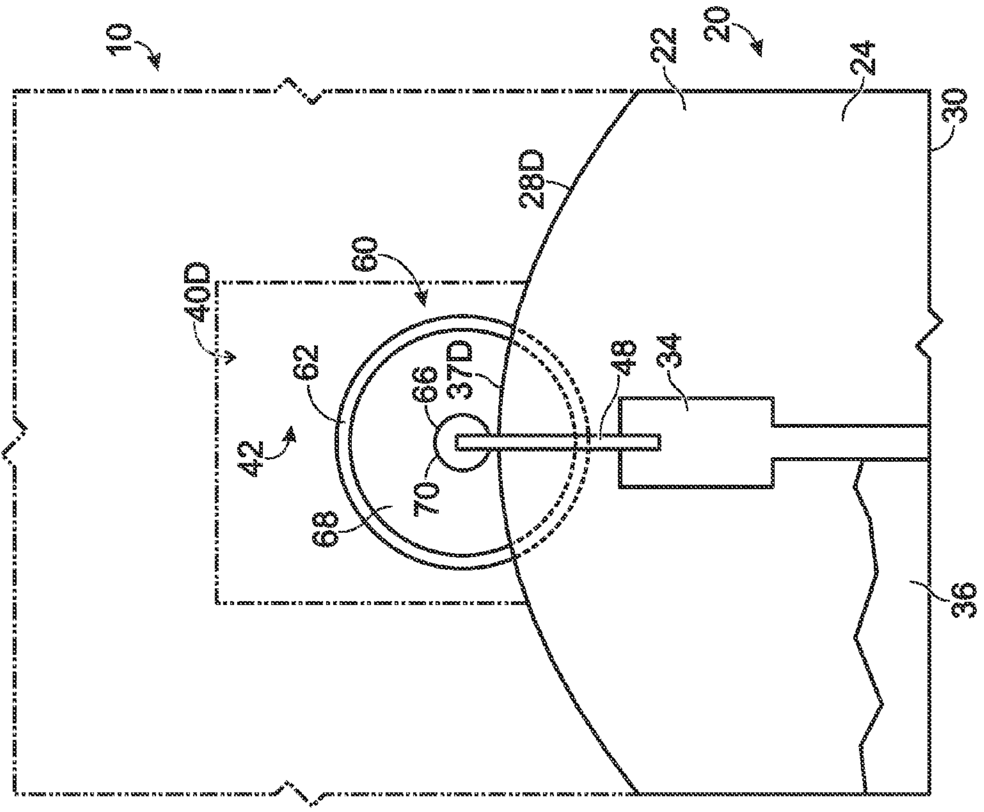

10
22
20
24
30
28D
60
40D
62
66
37D
48
34
42
70
68
36

Fig. 8

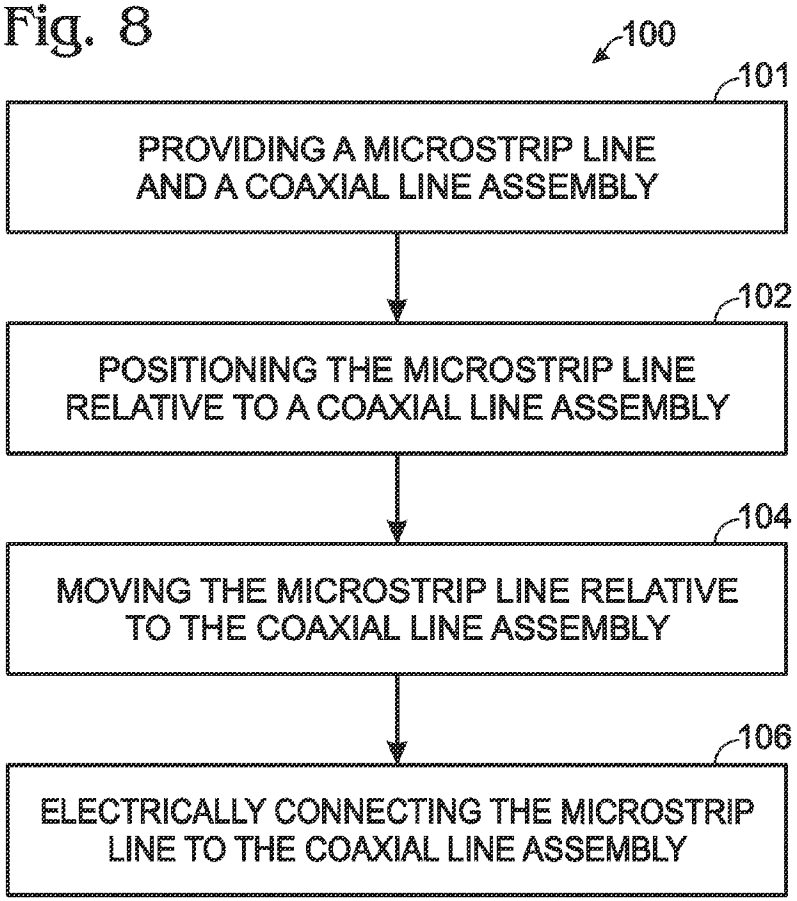

100
101
PROVIDING A MICROSTRIP LINE AND A COAXIAL LINE ASSEMBLY
102
POSITIONING THE MICROSTRIP LINE RELATIVE TO A COAXIAL LINE ASSEMBLY
104
MOVING THE MICROSTRIP LINE RELATIVE TO THE COAXIAL LINE ASSEMBLY
106
ELECTRICALLY CONNECTING THE MICROSTRIP LINE TO THE COAXIAL LINE ASSEMBLY

Fig. 13

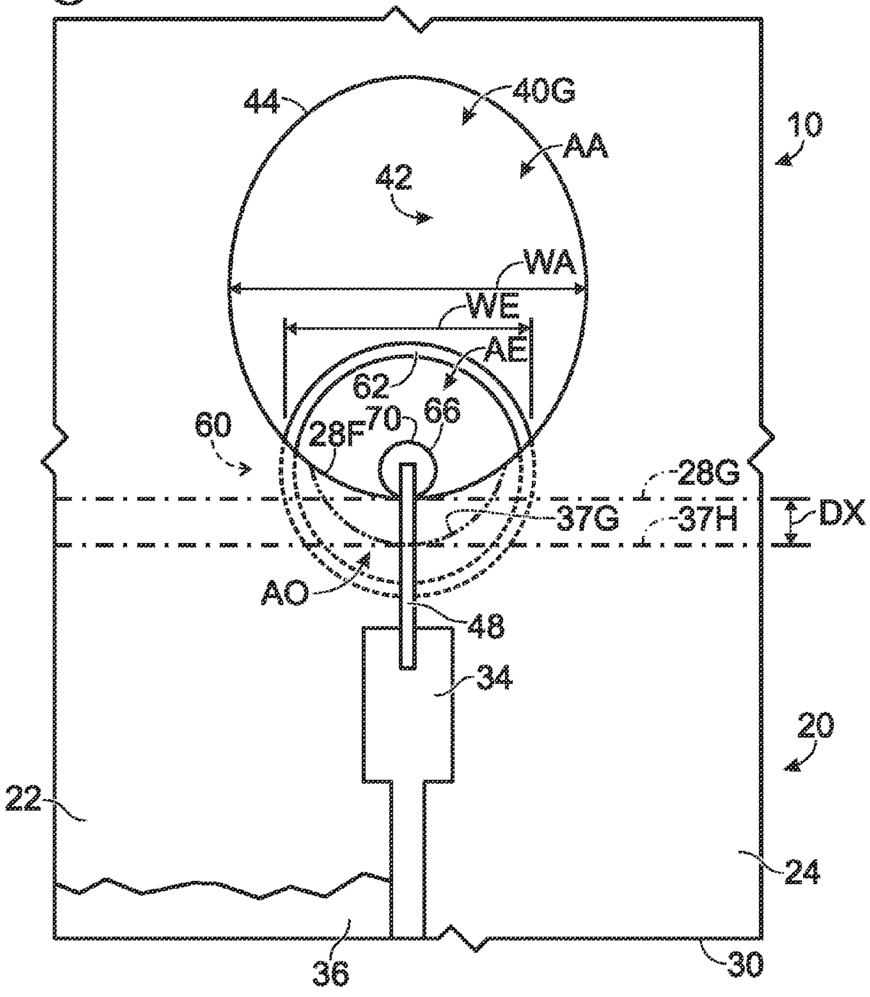

44
40G
10
AA
42
WA
WE
AE
62
70
66
60
28F
28G
37G
37H
DX
AO
48
34
20
22
24
36
30

Fig. 9

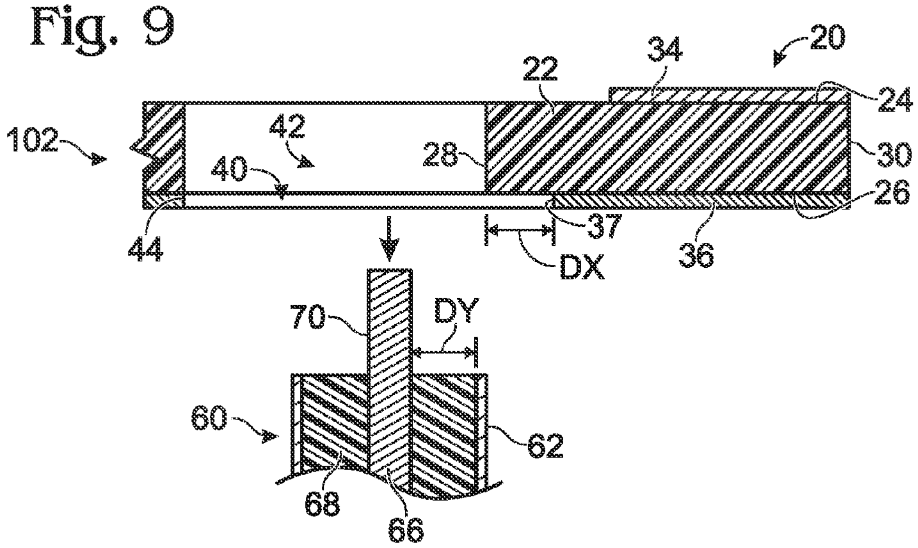


Fig. 10

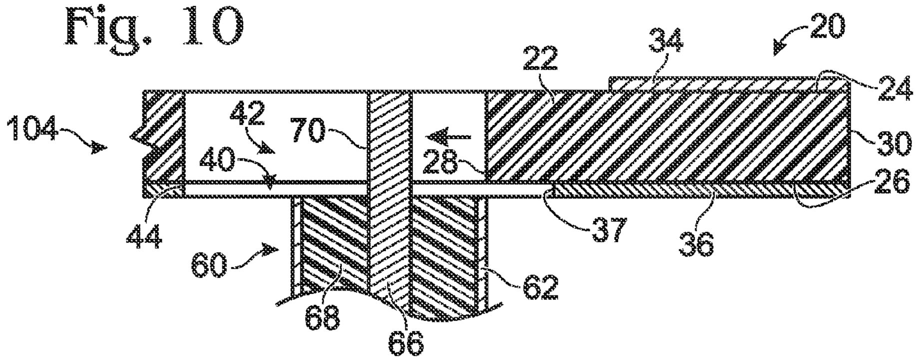


Fig. 11

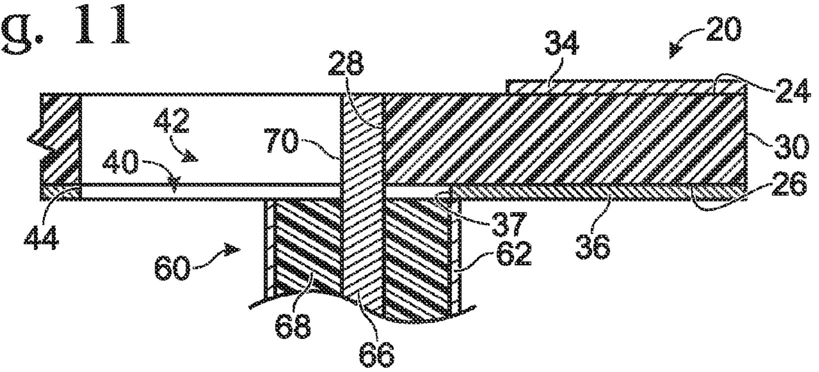
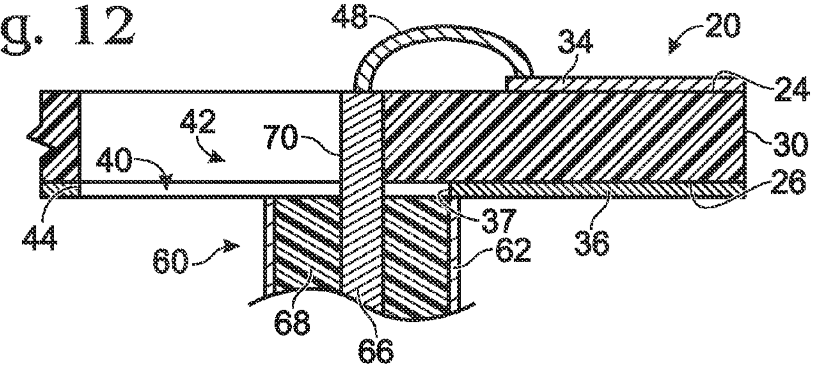


Fig. 12



COAXIAL-TO-MICROSTRIP TRANSITIONS

BACKGROUND

Coaxial-to-microstrip transitions find application in microwave and high-frequency systems. Generally, coaxial-to-microstrip transitions are structures that provide a transition between a coaxial line and a microstrip line. Transitions between coaxial lines and microstrip lines can be "inline" or angled. Inline transitions occur along a common axis, and angled transitions occur along disparate axes, such as at a bend or a right-angle turn.

Angled portions of high-frequency transmission lines, such as angled transitions, can be a source of impedance discontinuity that degrades signal transmission. Impedance discontinuities degrade signal transmission by causing energy to reflect back toward the energy source and radiate away from the transmission line, which reduces the input energy reaching the intended destination. Parasitic inductance is a cause of impedance discontinuity in angled portions of transmission lines. Parasitic inductance generally includes both signal conduction path inductance and ground path inductance.

The following U.S. patents provide examples of devices and methods relevant to coaxial-to-microstrip transitions, and they are expressly incorporated herein by reference for all purposes:

U.S. Pat. Nos. 2,983,884, 5,557,074, 4,611,186, 4,837,529, 4,951,011, 4,994,771, 5,123,863, 5,175,522, 5,308,250, 5,402,088, 5,418,505, 5,517,747, and 5,552,753.

A further example of devices and methods relevant to coaxial-to-microstrip transitions is found in Morgan and Weinreb "A millimeter-wave perpendicular coax-to-microstrip transition," *Microwave Symposium Digest,* 2002 *IEEE MTT-S International,* Vol. 2, pp. 817-820, June 2002, which is expressly incorporated herein by reference for all purposes.

SUMMARY

Coaxial-to-microstrip transitions may include a microstrip line and a coaxial-line assembly. The microstrip line may include a first substrate dielectric, a conductive strip on one face of the dielectric, and a ground plane disposed on a second face of the dielectric opposite the first face. The coaxial-line assembly, extending transverse to the microstrip ground plane, may include an outer conductor and an inner conductor. In some examples, the ground plane contacts an end of the outer conductor and extends between the outer conductor and the inner conductor on a side of the coaxial-line assembly proximate the conductive strip. In some examples, the inner conductor extends through an aperture in the ground plane. The aperture may extend beyond the outer conductor on a second side of the coaxial-line assembly opposite the first side. In some examples, the ground plane has a non-circular aperture. In some examples, a cross-sectional area bound by the outer conductor is less than a corresponding cross-sectional area of the aperture. In some examples, the cross-sectional area bound by the outer conductor has a width that is less than a first-aperture width.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a coaxial-to-microstrip transition including a microstrip line and a coaxial-line assembly.

FIG. **2** is a top view of the coaxial-to-microstrip transition of FIG. **1**.

FIG. **3** is a side cross-sectional view of the coaxial-to-microstrip transition of FIG. **1** taken along the line **3-3** in FIG. **2**.

FIG. **4** is a side view of the coaxial-to-microstrip transition of FIG. **1** taken from a side of the coaxial-line assembly opposite the microstrip.

FIG. **5** is a cross-sectional view of a coaxial-to-microstrip transition including an aperture in a dielectric plated with a conductive material to form a via.

FIG. **6** is a top view of a coaxial-to-microstrip transition including a ground plane having a straight interface edge.

FIG. **7** is a top view of a coaxial-to-microstrip transition including a ground plane having an edge facing the inner conductor that forms a convex curve relative to the inner conductor.

FIG. **8** is a flow chart of a method of manufacturing a coaxial-to-microstrip transition.

FIG. **9** is a structural illustration of positioning a microstrip line according to the method of FIG. **8**.

FIG. **10** is a structural illustration of moving a microstrip line according to the method of FIG. **8**.

FIG. **11** is a structural illustration of a dielectric substrate of a microstrip line abutting a center conductor of a coaxial-line assembly according to the method of FIG. **8**.

FIG. **12** is a structural illustration of electrically connecting a conductive strip with a center conductor according to the method of FIG. **8**.

FIG. **13** is a top view of a further embodiment of a coaxial-to-microstrip transition.

DETAILED DESCRIPTION

Coaxial-to-microstrip transitions and manufacturing methods disclosed in the present disclosure will become better understood through review of the following detailed description in conjunction with the drawings and the claims. The detailed description, drawings, and claims provide merely examples of the various inventions described herein. Those skilled in the art will understand that the disclosed examples may be varied, modified, and altered without departing from the scope of the inventions as defined in the claims, and all equivalents to which they are entitled. Many variations are contemplated for different applications and design considerations; however, for the sake of brevity, each and every contemplated variation is not individually described in the following detailed description.

As shown in FIGS. **1-7**, a coaxial-to-microstrip transition **10** may include a microstrip line **20** and a coaxial-line assembly **60**. Coaxial-to-microstrip transition **10** may function to transition radio frequency (RF) signals, such as microwave or millimeter wave signals, between coaxial-line assembly **60** and microstrip line **20**.

Microstrip line **20** may be oriented in various positions relative to coaxial-line assembly **60**. For example, as shown in FIGS. **1-7**, coaxial-to-microstrip transition **10** may have a central or inner conductor **66** of coaxial-line assembly **60** that is oriented at a transverse angle relative to a plane P of microstrip line **20** (shown in FIGS. **1** and **2**). In other examples, coaxial-to-microstrip transition **10** may generally be coplanar, having a coaxial inner conductor that is oriented generally inline with microstrip line **20**. The following examples have transverse angled transitions, and more particularly transitions forming a 90-degree angle.

As shown in FIGS. **1-4**, microstrip line **20** may include a dielectric substrate, referred to as a first dielectric **22** interposed between a conductive signal strip **34** and a return-signal ground plane **36**. Any material, gas, composition, or element known in the art to be suitable as a dielectric may be used. For example, semiconductors, plastics, porcelains, ceramics, glasses, or gasses, such as air, nitrogen, or sulfur hexafluoride may be suitable for use as first dielectric **22** in certain applications.

In the examples shown in FIGS. **1-7**, first dielectric **22** is a substrate having a first primary face **24** and a second primary face **26** opposite first primary face **24**. Additionally or alternatively, first dielectric **22** may include a leading-edge face **28** extending between first and second primary faces **24**, **26** that is proximate coaxial-line assembly **60**. FIGS. **1**, **2**, and **13** show leading-edge face **28** being curved and concave relative to coaxial-line assembly **60**. A leading-edge face **28**D that is curved and convex relative to coaxial-line assembly **60** is shown in FIG. **7**. A leading edge face **28**E that is planar and parallel to line LD is shown in FIG. **6**. As will be seen in some examples, a trailing-edge face **30** is disposed opposite leading-edge face **28**, as is shown in FIGS. **3**, **4** and **5**.

Conductive strip **34** may be disposed on, supported by, secured to, or printed on first primary face **24** of first dielectric **22**. In the example shown in FIGS. **1-4**, conductive strip **34** is formed from a relatively thin conductive material and secured to first primary face **24**. As is known in the art, conductive strip **34** generally functions to propagate a signal along its length. The signal may follow an inner conduction path **67** illustrated in FIG. **3**. In the examples shown in FIGS. **1-7**, a bond wire **48** electrically connects conductive strip **34** with an end of inner conductor **66** of coaxial-line assembly **60**. A relatively short bond wire may provide reduced parasitics for transition **10**. As is known in the art, conductive strip **34** may vary in width to provide impedance transformation at the transition and to facilitate construction.

In the example shown in FIGS. **1**, **3**, **4**, and **5**, ground plane **36** is a conductive layer disposed on all or a portion of second primary face **26** of first dielectric **22** opposite conductive strip **34**. Ground plane **36** provides a signal-return path. Ground plane **36** is directly or indirectly electrically connected to an outer conductor **62** of coaxial-line assembly **60**, such as by being directly connected to outer conductor **62**. Ground plane **36** may be formed of any suitable material.

A variety of ground plane **36** configurations are contemplated. For example, an interface edge **37** of ground plane **36** proximate coaxial-line assembly **60** may embody a variety of geometries. Examples of different interface edges **37**A-H are shown in FIGS. **1**, **2**, **6**, **7**, and **13** and described more particularly below. The geometry of interface edge **37** may have attendant electrical effects on the transition between the microstrip line and the coaxial line. Indeed, geometries of interface edge **37** may affect series inductances and shunt capacitances existing within coaxial-to-microstrip transition **10**.

As shown in FIG. **1**, the interface edge **37**A may be curved. Different degrees of curvature are contemplated. Optional curved interface edges are shown as interface edge **37**A in FIG. **1** and FIG. **2**, interface edge **37**B in FIG. **2**, interface edge **37**C in FIG. **6**, interface edge **37**D in FIG. **7**, and interface edge **37**G in FIG. **13**. The curved interface edges **37**A, **37**B, **37**C, and **37**G shown in FIGS. **1**, **2**, **6**, and **13** are concave relative to coaxial-line assembly **60**. In contrast, the curved interface edge **37**D shown in FIG. **7** is convex relative to coaxial-line assembly **60**.

In some examples, interface edge **37** of ground plane **36** is straight or a series of straight edges forming angles. For example, in FIG. **6**, the interface edge **37**E is straight, and interface edge **37**F is a series of straight edges forming an angle. In the example shown in FIG. **6**, angular interface edge **37**F is concave relative to the coaxial-line assembly **60**. However, in other examples, angular interface edges are convex relative to coaxial-line assembly **60**.

Interface edge **37** of ground plane **36** may define a portion of a peripheral edge **44** of a first aperture **40** extending through ground plane **36**. As shown in FIGS. **1-3**, **5-7**, and **9-12**, aperture **40** may receive at least a portion of coaxial-line assembly **60**, such as an extension portion **70** of an inner conductor **66**. As shown in FIGS. **6** and **7**, however, in some examples coaxial-to-microstrip transitions **10** do not include apertures through ground plane **36**. Rather, interface edge **37** facing the inner conductor is an outer edge of the ground plane.

FIG. **2** shows a top view of transition **10**, and FIG. **3** shows a cross section taken along line **3-3** in FIG. **2**. It is seen in these figures that inner conductor **66** extends through aperture **40** along an axis LA. As further shown in FIG. **2**, when viewing ground plane **36** from a plane spaced along axis LA, aperture **40** may have an aperture area AA in the ground plane. With further reference to FIG. **2**, aperture area AA may have a width WA. Aperture-area width WA is the widest dimension of the first aperture along a line parallel to line LD. Line LD is a line orthogonal to a line LC extending between the end of inner conductor **66** and the point where bond wire **48** is attached to the microstrip conductor **34**.

Those skilled in the art will appreciate that different geometries of aperture **40** may produce different electrical field distributions. FIGS. **1**, **6**, **7**, and **13** depict a sampling of the variety of shapes that aperture **40** may have. For example, in FIG. **2**, apertures **40**A and **40**B have oval shapes. In FIG. **6**, first aperture **40**C has a circular shape, aperture **40**E has a rectangular shape, and aperture **40**F has a diamond shape. In FIG. **7**, aperture **40**D has an irregular shape with straight and curved edge portions. In FIG. **13**, aperture **40**G has an oval shape.

In some examples, such as those shown in FIGS. **1-7** and **13**, first dielectric **22** includes a second aperture **46** extending at least partially through its thickness. Second aperture **46** may at least partially conform to and align with first aperture **40**. For example, they may have substantially the same shape and be co-incident when viewed in the view of FIG. **2**. However, in alternative examples second aperture **46** does not conform to first aperture **40**. First aperture **40** and second aperture **46** may separately or collectively define an unobstructed region **42**. Unobstructed region **42** may receive components of coaxial-to-microstrip transition **10**. For example, as shown in FIGS. **1**, **3**, **4**, and **5**, portions of coaxial-line assembly **60**, such as inner conductor **66**, may extend into unobstructed region **42**.

First aperture **40** and/or second aperture **46** may or may not be lined with a conductive material **52** to form a conductive via **50**. As is known in the art, a via may be an aperture plated or otherwise lined with a conductive material, such as a metal or alloy, to facilitate conduction of electrical currents between conductors on the respective primary faces of the substrate dielectric. Inner conductor **66** may extend through via **50** in spaced relationship from inner liner material **52**. In the example shown in FIGS. **1-4**, second aperture **46** is not lined with conductive material **52**. In the example shown in FIG. **5**, inner conductor **66** is asymmetrically received within via **50**. As discussed further below, asymmetrical positioning of inner conductor **66** within via **50** may cause an electric field to concentrate in a particular manner based on the proximity of conductive material **52** to inner conductor **66**. Optionally, second aperture **46** for any of the examples in FIGS. **1-7** may be lined with conductive material **52**.

In some examples, a second dielectric **32** is provided within first aperture **40**. Additionally or alternatively, second dielectric **32**, or another dielectric, may be disposed within second aperture **46**. Second dielectric **32** may be the same or different from first dielectric **22**. As with first dielectric **22**, second dielectric **32** may be any material, gas, composition, or element known in the art to be suitable for use as a dielectric. For example, plastics, porcelains, glasses, semiconductors, resins, or gasses, such as air, nitrogen, or sulfur hexafluoride may be suitable for use as second dielectric **32** in certain applications. In some examples, first dielectric **22** may be a solid substrate made of one type of dielectric and second dielectric **32** may be air or may be a solid substrate made of another type of dielectric.

Coaxial-line assembly **60** may include outer conductor **62** shielding at least a portion of inner conductor **66** and extending along common axis LA with inner conductor **66**. A third dielectric (or insulator) **68** may separate outer conductor **62** from inner conductor **66**. As indicated in FIG. **2**, coaxial-line assembly **60** may be described as having two sides on either side of a dividing line LD. A first side **72** shown in FIG. **2**, may be defined as being proximate (on the same side of line LD as) conductive strip **34**. A second side **74**, shown in FIG. **2**, may be defined as being distal (on the opposite side of line LD as) conductive strip **34**.

A variety of configurations of coaxial-line assembly **60** are contemplated. In some examples, such as those shown in FIGS. **1-7** and **13**, coaxial-line assembly **60** includes a coaxial cable configuration in which inner conductor **66** is radially surrounded by third dielectric **68** and outer conductor **62**. In a coaxial cable configuration, outer conductor **62** typically forms a concentric sheath around inner conductor **66**. In some examples, coaxial-line assembly **60** may include a coaxial cable portion and a connector portion physically and electrically coupled to the cable portion. Many connector portions suitable for use with coaxial cables are known in the art, including K flange launchers, threaded "sparkplug" launchers, C (Councelman) connectors, GR (general radio) connectors, N (Neill) connectors, glass beads, and the like.

In a variety of ways and with a variety of components, connector portions generally provide an inner conduction path separated by a dielectric from a surrounding coaxial outer conduction path. Inner conductor **66** thus may be a single component or collection of connected components that collectively forms the inner conduction path. Similarly, outer conductor **62** may be a single component or collection of components that collectively provides the outer conduction path.

Outer conductor **62** may be electrically connected to ground plane **36** to provide a signal return path continuing between coaxial-line assembly **60** and microstrip line **20**. In some examples, such as those shown in FIGS. **1-7** and **13** at least a portion **64** (shown in dashed lines in FIG. **2**) of outer conductor **62** is in physical contact with ground plane **36**. Additionally or alternatively, an electrical connection device, such as solder, connector, conductors, or other circuit components, may electrically connect outer conductor **62** with ground plane **36**.

As shown in FIG. **2**, when viewing the transition end of coaxial-line assembly **60** from a plane parallel to and spaced from ground plane **36** along axis LA, it can be seen that outer conductor **62** may surround an enclosed area AE. Enclosed area AE is the area enclosed by outer conductor **62** when viewed in a plane parallel to ground plane **36** where outer conductor **62** contacts at least a portion of ground plane **36**. With further reference to FIG. **2**, enclosed area AE may have a width WE. Enclosed-area width WE may be defined to be the length along line LD. WE also corresponds to the diameter of an outer conductor having a circular cross section.

As shown in FIGS. **1-4**, extension portion **70** of inner conductor **66** may extend along axis LA beyond outer conductor **62**. Extension portion **70** may be positioned proximate to microstrip line **20**, for example, proximate to conductive strip **34** and/or ground plane **36**. Extension portion **70** is electrically connected to conductive strip **34** either directly or indirectly, such as via bond wire **48**, solder, or other connector. In the examples shown in FIGS. **1-5**, extension portion **70** extends into first aperture **40** of ground plane **36** and into second aperture **46** of first dielectric **22**.

During use of transition **10**, an electrical field may exist between extension portion **70** and ground plane **36** in examples where extension portion **70** is adjacent to ground plane **36** or extends into first aperture **40** of ground plane **36**. Of relevance, the electrical field may tend to concentrate towards portions of ground plane **36** in relatively close proximity to extension portion **70**. In some examples, such as those shown in FIGS. **1**, **2**, **3**, **5**, **6**, and **7**, interface edge **37** of the ground plane is in relatively close proximity to extension portion **70**. In some applications, concentrating the electric field in certain positions may provide certain utility, such as affecting ground-path series inductances and shunt capacitances that may be present.

In the examples shown in FIGS. **1-7** and **13**, extension portion **70** and interface edge **37** or conducting material **52** of via **50** are placed in relatively close proximity to conductive strip **34** on first side **72** of the coaxial line. The proximity of extension portion **70** relative to interface edge **37** may be selected to produce desired electrical properties, such as series inductance along and shunt capacitance between the signal and signal-return conductors. In the examples shown in FIGS. **1-7** and **13**, the electrical field tends to concentrate toward the conductive strip side of coaxial-to-microstrip transition **10**. Concentrating the electrical field toward the conductive strip side of coaxial-to-microstrip transition **10** may reduce the inductance occurring in the transition.

One source of ground-path inductance can be due to a portion of the electrical field occurring between inner conductor **66** and a second side **74** of coaxial-line assembly **60** opposite conductive strip **34**. In general, a portion of the electrical field may extend between extension portion **70** and portions of either ground plane **36** or outer conductor **62** on second side **74**. This field produces return currents that travel through long ground paths to reach the microstrip ground. The portion of the electrical field occurring on second side **74** is reduced when the electrical field is concentrated on first side **72**, thereby reducing ground-path inductance.

As is seen in the figures, coaxial-to-microstrip transitions **10** may have a variety of configurations. Different orientations, geometries, and proximities of components in coaxial-to-microstrip transitions **10** may produce different electrical properties in the transitions, and may have different costs to produce.

In the example shown in FIGS. **1-4**, ground plane **36** extends between outer conductor **62** and inner conductor **66** on first side **72** of coaxial-line assembly **60**. In this context, ground plane **36** may be referred to as overlapping a portion of enclosed area AE. The portion of enclosed area AE overlapped by ground plane **36** may be referred to as an overlap area or portion AO, which is shown in FIGS. **2** and **13**.

As can be seen in the example shown in FIG. **2**, overlap portion AO is located substantially on first side **72** of dividing line LD. In other examples, a small fraction of overlap portion AO may be located on second side **74** of dividing line LD. For example, a small fraction of overlap portion AO may be located on second side **74** in first aperture **40**B in FIG. **2** and first aperture **40**C in FIG. **6**. Most of overlap portion AO—for example, over 75%—may be located on first side **72**. For example, having over 85% of the overlap on first side **72** provides increased concentration of electric fields between the ground plane and the inner conductor on first side **72**. In some examples, overlap portion AO may be located entirely on first side **72**, thereby attracting essentially all of the electric field on side **72** of the inner conductor. As further shown in FIG. **2**, enclosed area AE may be less than aperture area AA and enclosed-area width WE may be less than aperture width WA, as shown.

In the example shown in FIGS. **1**-**4**, ground plane **36** physically contacts outer conductor **62** along ground-plane portion **64** shown in FIGS. **2** and **3**. As discussed above, outer conductor **62** may include more than the outer conductor of a standard coaxial cable or a coaxial cable connector. Indeed, outer conductor **62** may include a collection of components that provides an outer conduction path for a coaxial cable assembly.

As shown in FIGS. **1**-**3**, **5**-**7**, and **13** extension portion **70** of inner conductor **66** may be asymmetrically disposed in first aperture **40** as viewed in FIG. **2**. In the example shown in FIG. **3**, extension portion **70** is spaced a first distance D**1** from interface edge **37** and spaced a second distance D**2** from peripheral edge **44** opposite interface edge **37**. A variety of D**1**/D**2** ratios may be used in coaxial-to-microstrip transition **10**. For example, ratios less than one, greater than one, or equal to one may be suitable in different applications. In the example shown in FIG. **3**, the D**1**/D**2** ratio is less than one. Generally, neither D**1** nor D**2** should equal zero as an electrical short between inner conductor **66** and ground may result.

Distances D**1** and D**2** may be distances between inner conductor **66** and conductive materials **52** of a via **50** in some examples. For instance, in the example shown in FIG. **5**, extension portion **70** is spaced a first distance D**1** from conductive material **52** of via **50** on first side **72** and spaced a second distance D**2** from conductive material **52** on second side **74**. As discussed above, D**1**/D**2** ratios less than one, greater than one, or equal to one may be suitable in different applications.

As shown in FIG. **13**, extension portion **70** may be disposed asymmetrically within first aperture **40**G such that extension portion **70** abuts first dielectric **22**. In one example shown in FIG. **13**, interface edge **37**G of ground plane **36** is offset from leading-edge face **28**F of first dielectric **22** by a distance DX. As alternatively shown in FIG. **13**, first dielectric **22** and ground plane **36** may be disposed only on one side of extension portion **70**. In the alternative example shown in FIG. **13**, extension portion **70** abuts leading edge face **28**G, which is offset from interface edge **37**H by distance DX. The offset distance DX between the leading edge face of first dielectric **22** and the interface edge of ground plane **36** may facilitate orienting extension portion **70** into a given position relative to microstrip line **20**.

In the example shown in FIGS. **1**-**4**, aperture area AA of first aperture **40** extends beyond outer conductor **62** on second side **74** of coaxial-line assembly **60** in a direction DA normal to axis LA. The position of the periphery of first aperture **40** beyond outer conductor **62**, as shown in this example, may cause an electrical field to concentrate on first side **72**. In other examples, first aperture **40** may extend short of or substantially to outer conductor **62** in direction DA on second side **74**. The example shown in FIGS. **1**-**4** includes second aperture **46** conforming to first aperture **40**, although, conformance of the apertures is not required. Air or another dielectric material may be disposed within second aperture **46** as a second dielectric **32** (indicated in FIG. **5**, but not in FIG. **3**), shown generally in FIG. **3**.

As shown in FIGS. **1** and **6**, coaxial-to-microstrip transitions **10** may include a ground plane having an aperture having a non-circular cross section. For example, each of apertures **40**A, **40**B, **40**D, **40**E, **40**F, and **40**G shown in FIGS. **1**, **6**, and **13** have non-circular cross sections. The shapes of the cross sections **40**A, **40**B, **40**D, **40**E, **40**F, and **40**G in FIGS. **1**, **6** and **13** may be described as an oval, a narrower oval, irregular, rectangular, diamond, and a wider oval, respectively. By way of comparison, the aperture **40**C shown in FIG. **6** has a circular cross section.

In some examples, the second aperture **46** extending through first dielectric **22** may also be non-circular in cross section. Extension portion **70** may be disposed symmetrically (not pictured) or asymmetrically (shown in FIGS. **1**, **6**, and **13**) within aperture **46**, as was discussed regarding aperture **40**.

Methods of manufacturing coaxial-to-microstrip transitions **10** are also contemplated. In some examples, a method **100** may start with at least partially preassembled coaxial-line assemblies and/or microstrip lines. In other examples, method **100** may start with producing coaxial-line assemblies and/or microstrip lines. For instance, a general method **100** is shown as a flow chart in FIG. **8**, which contemplates starting with a step **101** of providing a coaxial-line assembly **60** and a microstrip line **20**, such as has been described.

Method **100** may include in a step **102** positioning the microstrip line in an orientation relative to the coaxial-line assembly. The orientation in which microstrip line **20** is positioned may be one in which ground plane **36** is transverse to the common axis LA of coaxial-line assembly **60**. Transverse is defined to mean any orientation other than inline or parallel. In this example, ground plane **36** is oriented at substantially 90 degrees relative to the common axis LA, as shown in FIG. **9**.

With the microstrip in this orientation, dielectric substrate **22** is spaced from extension portion **70** of inner conductor **66** and inner conductor **66** is aligned with apertures **40** and **46**. In this example, ground plane **36** is proximate outer conductor **62**.

In examples where ground plane **36** and/or dielectric substrate **22** includes an aperture **40** or aperture **46**, step **102** of positioning the microstrip line may include positioning extension portion **70** within apertures **40** and **46**, as represented by movement of the microstrip line from a position spaced from the coaxial-line assembly, as shown in FIG. **9**, to a position in which the inner conductor extends into apertures **40** and **46**. This step is considered equivalent to moving coaxial-line assembly **60** toward microstrip line **20**—i.e., one component moves relative to the other, regardless of which if any are moved relative to an external reference.

As described in FIG. **8** and illustrated in FIG. **10**, method **100** may include a step **104** of moving leading-edge face **28** of first dielectric **22** toward extension portion **70** until the leading-edge face **28** abuts the extension portion In some examples, such as shown in the combination of FIGS. **10** and **11**, moving the microstrip line **104** may include moving microstrip line **20** toward extension portion **70** until the ground plane **36** contacts outer conductor **62**. Positioning step **102** and moving step **104** may be performed in reverse sequence or as a single step resulting in the positioning of the leading-edge face **28** against extension portion **70** with ground plane **36** in contact with outer conductor **62**.

In certain examples, method **100** may include a step of selecting the microstrip line to be positioned and moved based on a desired final spatial relationship of the microstrip line and the coaxial-line assembly. For example, a desired relationship may be between a first distance DX and a second distance DY shown in FIG. **9**. The first distance DX may be the distance between interface edge **37** of the ground plane **36** and leading-edge face **28** of dielectric substrate **22**. In other words, in this example, interface edge **37** is recessed from leading-edge face **28** by dimension DX. The second distance DY may be the distance between inner conductor **66** and outer conductor **62** (the radial thickness of third dielectric **68**). In some examples, the desired relationship is that first distance DX is substantially equal to second distance DY. In other examples, the desired relationship is that the first distance is less than the second distance. By contacting the inner conductor with the leading-edge face of the substrate dielectric, the distance DX between the inner conductor and the interface edge of the ground plane is established to the manufacturing tolerances of these components. This configuration reduces variations in the electrical performance of transition **10** due to varying distances DX during assembly.

As described in FIG. **8** and illustrated in FIG. **12**, method **100** may include a step **106** electrically connecting inner conductor **66** with the conductive strip **34**. The electrical connection may be accomplished with bond wire **48** or by any other device for making an electrical connection known in the art.

As can be seen from the above description, a coaxial-to-microstrip transition may include a microstrip line including a first dielectric having a first primary face and a second primary face opposite the first primary face, a conductive strip disposed on the first primary face of the first dielectric, and a ground plane disposed on the second primary face of the first dielectric, and a coaxial-line assembly extending along an axis transverse to the ground plane and having an end adjacent to the microstrip line, the coaxial-line assembly including an outer conductor extending along the axis to the ground plane, an end of the outer conductor being in contact with the ground plane, and an inner conductor extending along the axis past the ground plane and being electrically connected to the conductive strip, wherein the ground plane extends to a position between the outer conductor and the inner conductor on only a first side of the coaxial-line assembly proximate the conductive strip.

It can also be seen from the above description that a coaxial-to-microstrip transition may include a microstrip line including a first dielectric having a first primary face and a second primary face opposite the first primary face, a ground plane disposed on the second primary face of the first dielectric, a conductive strip disposed on the first primary face of the first dielectric, a first aperture extending through the ground plane and having a non-circular cross section in a plane of the ground plane, and a coaxial-line assembly extending along an axis transverse to the ground plane and being adjacent the microstrip line, the coaxial-line assembly including an outer conductor extending along the axis to the ground plane, the outer conductor being in contact with the ground plane, and an inner conductor extending along the axis into the first aperture and being electrically connected to the conductive strip.

Moreover, the above description discloses that a coaxial-to-microstrip transition may include a microstrip line including a first dielectric having a first primary face and a second primary face opposite the first primary face, a conductive strip disposed on the first primary face of the first dielectric, a ground plane disposed on the second primary face of the first dielectric, and a first aperture extending through the ground plane and having a cross section defining an aperture area, and a coaxial-line assembly extending along an axis transverse to the ground plane and being adjacent the microstrip line, the coaxial-line assembly including an outer conductor in contact with the ground plane and having a cross section, in a plane parallel and proximate to the ground plane, defining an enclosed area, the ground plane overlapping a portion of the enclosed area on a first side of the coaxial-line assembly proximate the conductive strip and the first aperture extending beyond the outer conductor on a second side of the coaxial-line assembly opposite the first side, and an inner conductor extending along the axis into the first aperture and being electrically connected to the conductive strip.

It can be further seen from the above description that a coaxial-to-microstrip transition may include a microstrip line including a first dielectric having a first primary face and a second primary face opposite the first primary face, a conductive strip disposed on the first primary face of the first dielectric, a ground plane disposed on the second primary face of the first dielectric, and a first aperture extending through the ground plane, the first aperture having a first-aperture width, and a coaxial-line assembly extending along an axis transverse to the ground plane and having an end adjacent to the microstrip line, the coaxial-line assembly including an inner conductor extending along the axis into the first aperture and being electrically connected to the conductive strip, and an outer conductor extending along the axis to the ground plane, the outer conductor surrounding the inner conductor and having a cross section defining an enclosed area, the enclosed area having a width that is smaller than the first-aperture width, an end of the outer conductor being in contact with the ground plane.

As can be seen from the above description, a method of manufacturing a coaxial-to-microstrip transition between a coaxial-line assembly and a microstrip line, the coaxial-line assembly including an outer conductor spaced apart from and extending along a common axis with an inner conductor, and the microstrip line including a dielectric substrate, a conductive strip disposed along a first primary face of the dielectric substrate, and a ground plane disposed along a second primary face of the dielectric substrate opposite the first primary face, the dielectric substrate having a leading-edge face extending between the first and second primary faces, there being an unobstructed region next to the leading-edge face that is sized longer than a cross-sectional dimension of the inner conductor, the ground plane having an interface edge that is recessed along the second primary face from the leading-edge face, may include the steps of positioning the microstrip line relative to the coaxial-line assembly, with the ground plane extending transverse to the common axis and proximate the outer conductor, and moving the microstrip line toward the extension portion until the leading-edge face abuts the extension portion and the ground plane contacts the outer conductor.

INDUSTRIAL APPLICABILITY

The methods and apparatus described in the present disclosure are applicable to the telecommunications and other communication frequency signal processing industries involving the transmission of signals between circuits or circuit components.

It is believed that the disclosure set forth above encompasses multiple distinct inventions with independent utility. While each of these inventions has been disclosed in a particular form, the specific embodiments thereof as disclosed and illustrated herein are not to be considered in a limiting sense as numerous variations are possible. The subject matter of the inventions includes all novel and non-obvious combinations and subcombinations of the various elements, features, functions and/or properties disclosed herein, and equivalents of them. Where the disclosure or subsequently filed claims recite "a" or "a first" element or the equivalent thereof, it is within the scope of the present inventions that such disclosure or claims may be understood to include incorporation of one or more such elements, neither requiring nor excluding two or more such elements.

Applicants reserve the right to submit claims directed to certain combinations and subcombinations that are directed to one of the disclosed inventions and are believed to be novel and non-obvious. Inventions embodied in other combinations and subcombinations of features, functions, elements and/or properties may be claimed through amendment of those claims or presentation of new claims in that or a related application. Such amended or new claims, whether they are directed to a different invention or directed to the same invention, whether different, broader, narrower or equal in scope to the original claims, are also regarded as included within the subject matter of the inventions of the present disclosure.

What is claimed is:

1. A coaxial-to-microstrip transition comprising:

a microstrip line including:

a first dielectric having a first primary face and a second primary face opposite the first primary face,

a conductive strip disposed on the first primary face of the first dielectric, and

a ground plane disposed on the second primary face of the first dielectric; and

a coaxial-line assembly extending along an axis transverse to the ground plane and having an end adjacent to the microstrip line, the coaxial-line assembly including:

an outer conductor extending along the axis to the ground plane, an end of the outer conductor being in contact with the ground plane, and

an inner conductor extending along the axis past the ground plane and being electrically connected to the conductive strip;

wherein the ground plane extends to a position between the outer conductor and the inner conductor on only a first side of the coaxial-line assembly proximate the conductive strip, and

wherein the microstrip line further includes a first aperture extending through the ground plane and through which the inner conductor extends, the aperture extending beyond the outer conductor on a second side of the coaxial-line assembly distal the conductive strip.

2. The coaxial-to-microstrip transition of claim **1**, wherein the ground plane includes a curved edge proximate the inner conductor, the curved edge being convex relative to the inner conductor such that the ground plane curves away from the inner conductor.

3. The coaxial-to-microstrip transition of claim **1**, wherein the first dielectric contacts the inner conductor on the first side of the coaxial-line assembly.

4. The coaxial-to-microstrip transition of claim **1**, further comprising a second aperture extending through the first dielectric.

5. The coaxial-to-microstrip transition of claim **4**, wherein the second aperture is plated with a conducting material connected to the ground plane to form a via.

6. The coaxial-to-microstrip transition of claim **4**, wherein the ground plane is recessed from the second aperture on the first side of the coaxial-line assembly.

7. The coaxial-to-microstrip transition of claim **6**, wherein the first dielectric contacts the inner conductor on the first side of the coaxial-line assembly.

8. A coaxial-to-microstrip transition comprising:

a microstrip line including:

a first dielectric having a first primary face and a second primary face opposite the first primary face,

a ground plane disposed on the second primary face of the first dielectric,

a conductive strip disposed on the first primary face of the first dielectric, and

a first aperture extending through the ground plane and having a non-circular cross section in a plane of the ground plane; and

a coaxial-line assembly extending along an axis transverse to the ground plane and being adjacent the microstrip line, the coaxial-line assembly including:

an outer conductor extending along the axis to the ground plane, the outer conductor being in contact with the ground plane, and

an inner conductor extending along the axis into the first aperture and being electrically connected to the conductive strip,

wherein the ground plane extends to a position between the outer conductor and the inner conductor on only a first side of the coaxial-line assembly proximate the conductive strip and wherein the first aperture extends beyond the outer conductor on a second side of the coaxial-line assembly distal the conductive strip.

9. The coaxial-to-microstrip transition of claim **8**, wherein the first aperture has an oval, a rectangular, a square, or a diamond shaped cross-section.

10. The coaxial-to-microstrip transition of claim **9**, wherein the inner conductor is asymmetrically disposed within the first aperture when viewed along the axis.

11. The coaxial-to-microstrip transition of claim **8**, wherein the microstrip line includes a second aperture that extends through the first dielectric, the second aperture being in communication with the first aperture and being plated with a conducting material to form a via.

12. The coaxial-to-microstrip transition of claim **11**, wherein at least one of the first and second apertures has an oval, a rectangular, a square, or a diamond shaped cross section.

13. The coaxial-to-microstrip transition of claim **12**, wherein the inner conductor is asymmetrically disposed within both the first and second apertures when viewed along the axis.

14. A coaxial-to-microstrip transition comprising:

a microstrip line including:

a first dielectric having a first primary face and a second primary face opposite the first primary face,

a conductive strip disposed on the first primary face of the first dielectric,

a ground plane disposed on the second primary face of the first dielectric, and

a first aperture extending through the ground plane and having a cross section defining an aperture area; and

a coaxial-line assembly extending along an axis transverse to the ground plane and being adjacent the microstrip line, the coaxial-line assembly including:

an outer conductor in contact with the ground plane and having a cross section, in a plane parallel and proximate to the ground plane, defining an enclosed area, the ground plane overlapping a portion of the enclosed area on a first side of the coaxial-line assembly proximate the conductive strip and the first aperture extending beyond the outer conductor on a second side of the coaxial-line assembly opposite the first side, and an inner conductor extending along the axis into the first aperture and being electrically connected to the conductive strip.

15. The coaxial-to-microstrip transition of claim **14**, wherein the ground plane includes a curved edge proximate the inner conductor, the curved edge being convex relative to the inner conductor such that the ground plane curves away from the inner conductor.

16. The coaxial-to-microstrip transition of claim **14**, wherein the enclosed area is less than the aperture area.

17. The coaxial-to-microstrip transition of claim **14**, further comprising a second aperture extending through the first dielectric, wherein the second aperture conforms to the first aperture.

18. A coaxial-to-microstrip transition comprising:

a microstrip line including:

a first dielectric having a first primary face and a second primary face opposite the first primary face,

a conductive strip disposed on the first primary face of the first dielectric,

a ground plane disposed on the second primary face of the first dielectric, and

a first aperture extending through the ground plane, the first aperture having a first-aperture width; and

a coaxial-line assembly extending along an axis transverse to the ground plane and having an end adjacent to the microstrip line, the coaxial-line assembly including:

an inner conductor extending along the axis into the first aperture and being electrically connected to the conductive strip, and

an outer conductor extending along the axis to the ground plane, the outer conductor surrounding the inner conductor and having a cross section defining an enclosed area, the enclosed area having a width that is smaller than the first-aperture width, an end of the outer conductor being in contact with the ground plane,

wherein the ground plane overlaps the enclosed area only on the first side of the coaxial-line assembly.

19. The coaxial-to-microstrip transition of claim **18**, wherein the ground plane includes a curved edge proximate the inner conductor, the curved edge being convex relative to the inner conductor such that the ground plane curves away from the inner conductor.

20. The coaxial-to-microstrip transition of claim **18**, further comprising a second aperture extending through the first dielectric, wherein the second aperture conforms to the first aperture.

21. The coaxial-to-microstrip transition of claim **18**, wherein the first-aperture width is orthogonal to a strip plane defined by the axis and a line passing from the conductive strip to the inner conductor.

22. The coaxial-to-microstrip transition of claim **21**, wherein the enclosed area width is orthogonal to the strip plane.

* * * * *