US 20150303580A1

(19) United States
(12) Patent Application Publication
Wright
(10) Pub. No.: US 2015/0303580 A1
(43) Pub. Date: Oct. 22, 2015

(54) **MODULAR FEED ASSEMBLY**

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(21) Appl. No.: **14/648,729**

(22) PCT Filed: **Aug. 22, 2014**

(86) PCT No.: **PCT/US14/52215**

§ 371 (c)(1),
(2) Date: **Jun. 1, 2015**

Related U.S. Application Data

(60) Provisional application No. 61/905,933, filed on Nov. 19, 2013, provisional application No. 62/013,098, filed on Jun. 17, 2014.

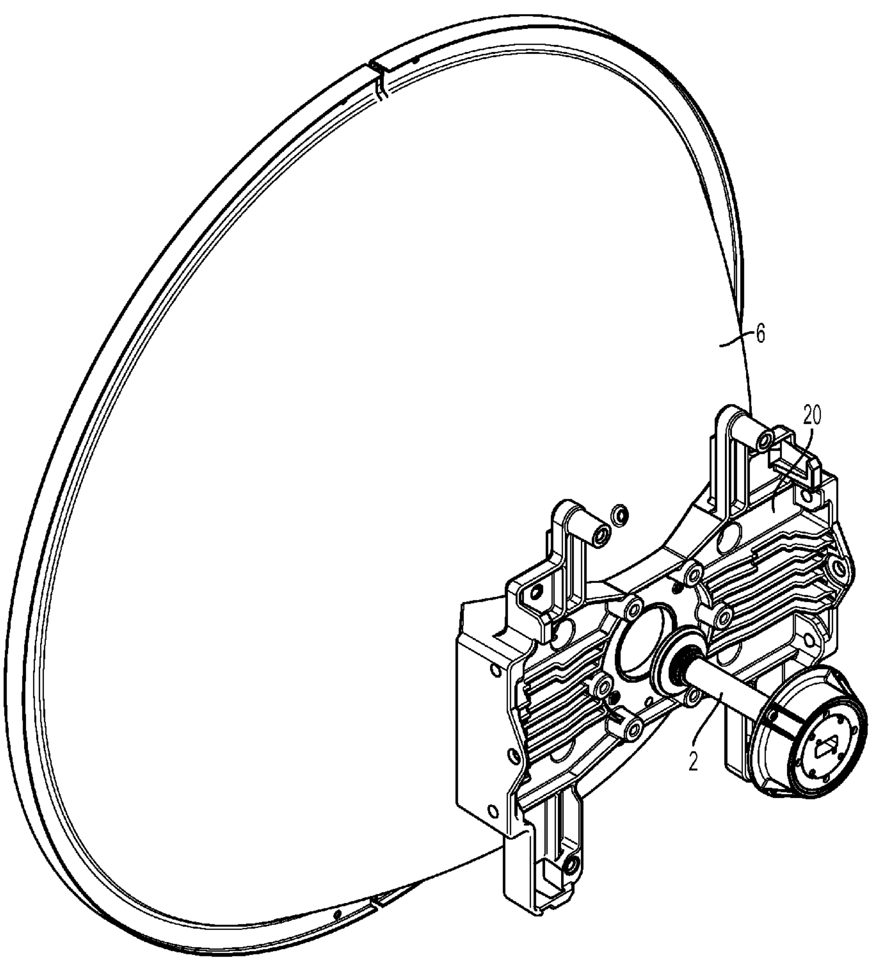
Publication Classification

(51) **Int. Cl.**
H01Q 13/02 (2006.01)
H01P 1/04 (2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 13/02*** (2013.01); ***H01Q 13/0283*** (2013.01); ***H01P 1/042*** (2013.01)

(57) **ABSTRACT**

In one embodiment, a modular feed assembly for an antenna has (i) a hub adapter for mounting the feed assembly onto the antenna hub and (ii) a distinct waveguide transition configured to be selectively mated to the hub adapter. By providing a modular design, the hub adapter can be selectively used with different waveguide transitions having different frequency characteristics to form feed assemblies for different antennas having different operating frequency ranges. The hub adapter and each waveguide transition have timing features that limit the rotation orientation between the two components to, for example, horizontal and vertical polarizations that are 90 degrees apart. The hub adapter has a resilient compression element that forms an annular seal between the hub adapter and a mated waveguide transition to inhibit RF leakage and keep the two components in place. The hub adapter has openings that allow the compression element to be formed in place.



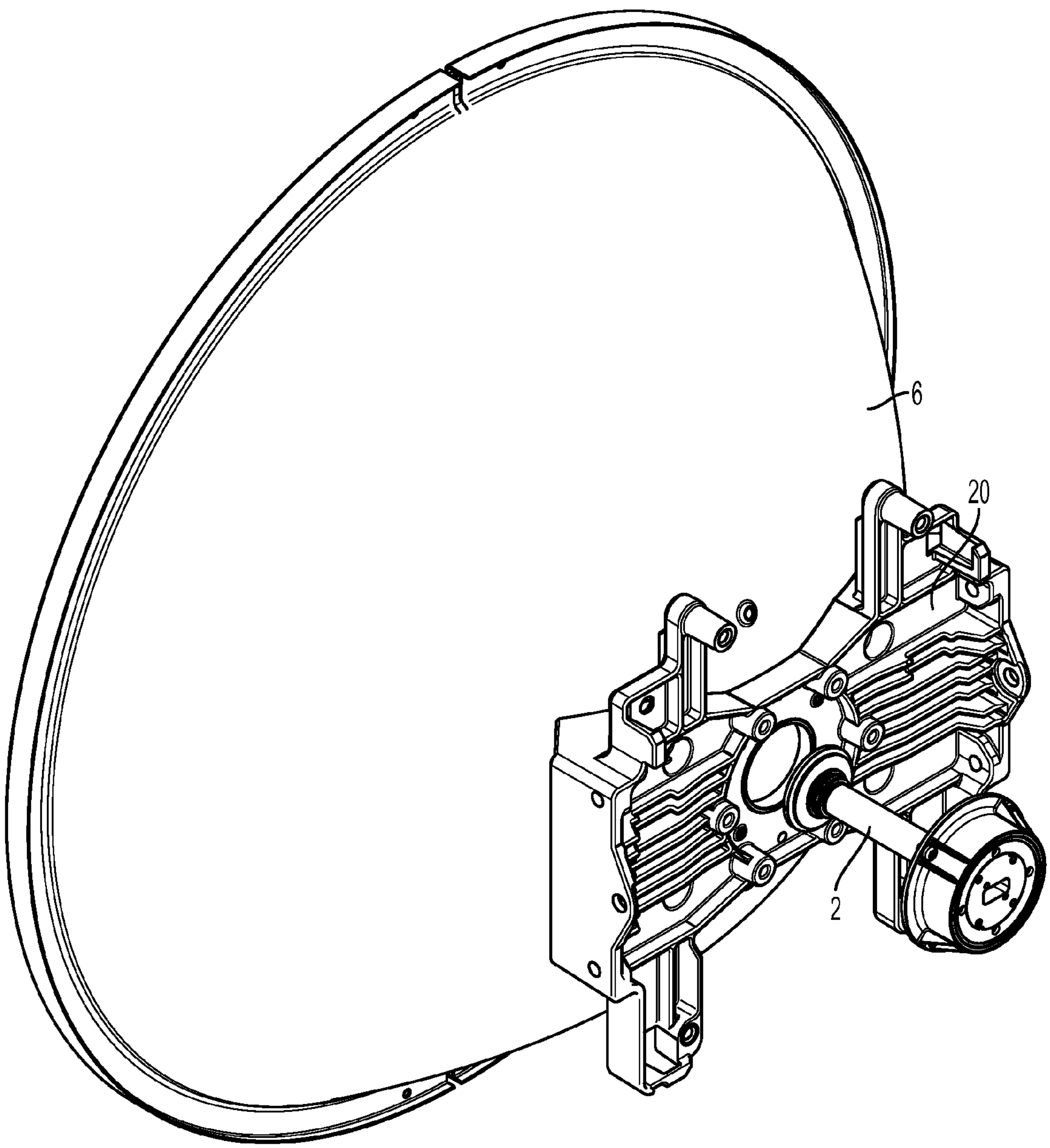


FIG. 1

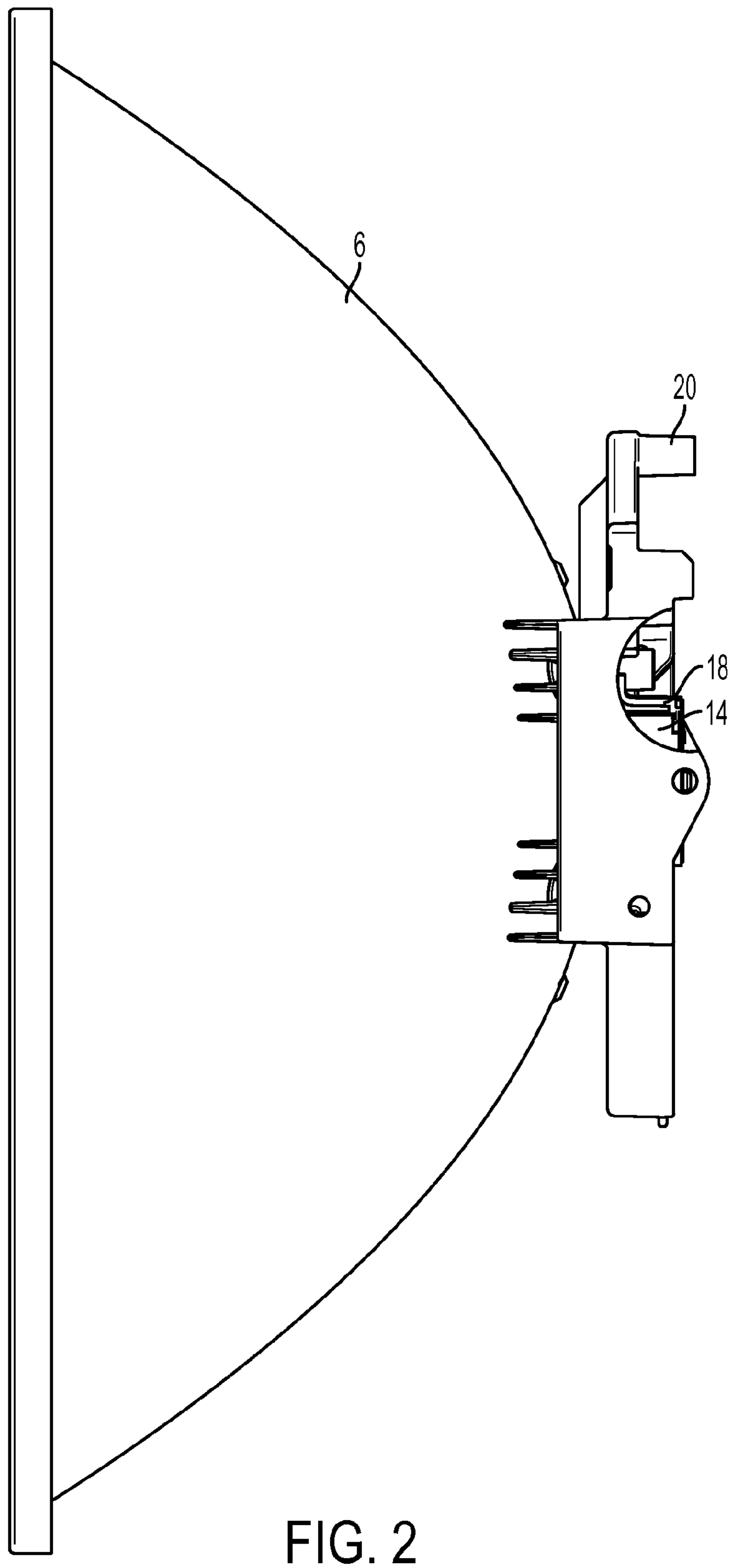


FIG. 2

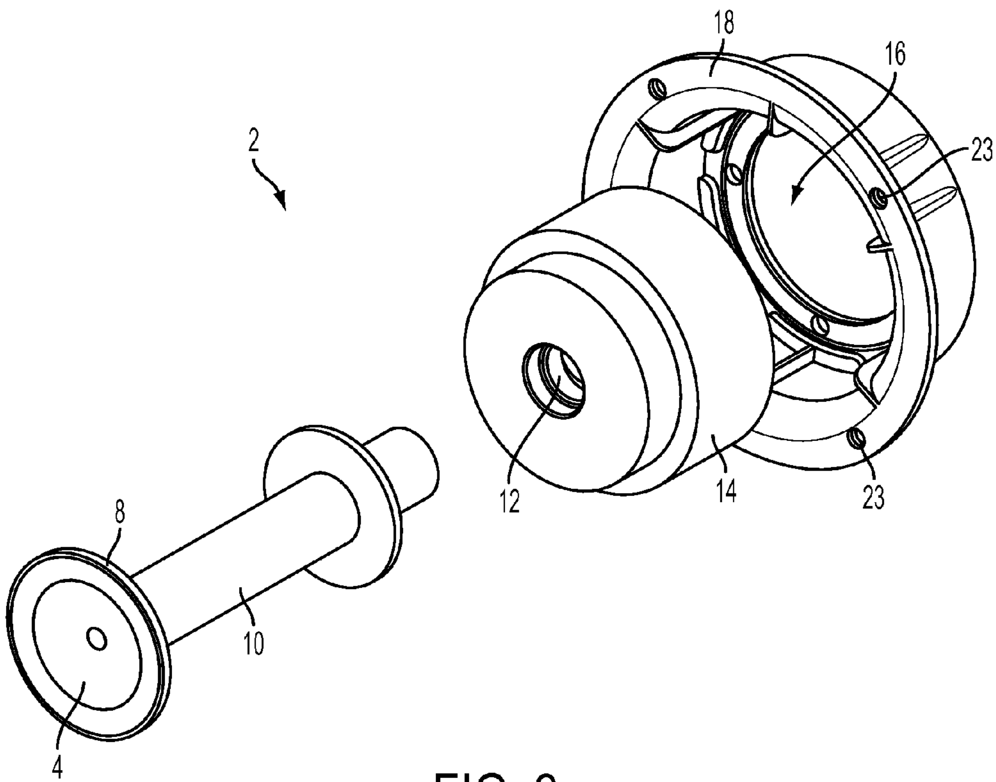


FIG. 3

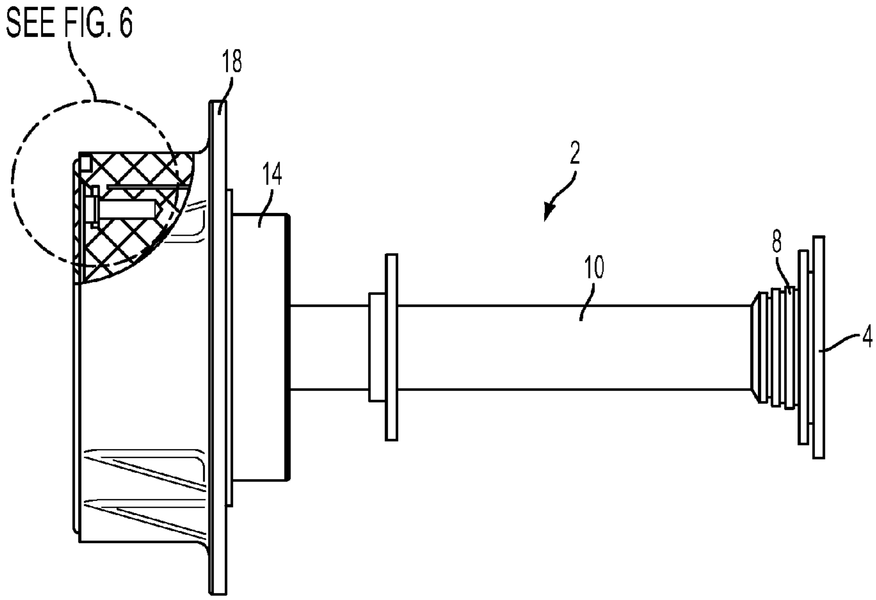


FIG. 4

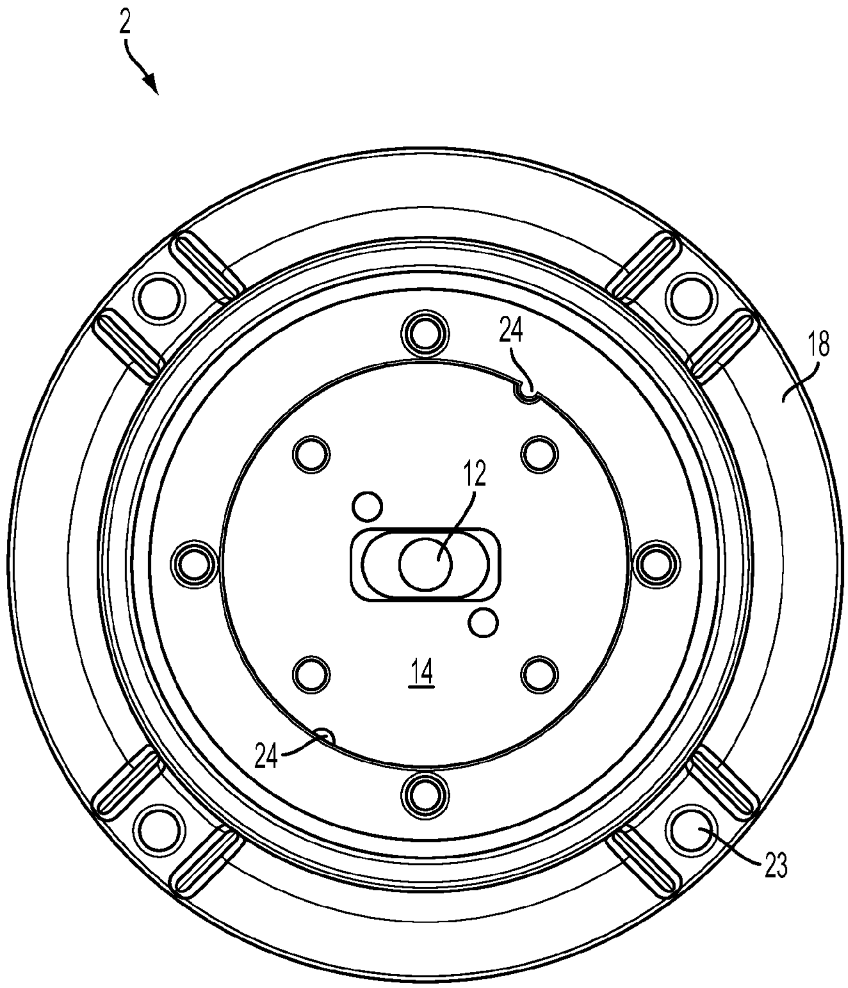


FIG. 5

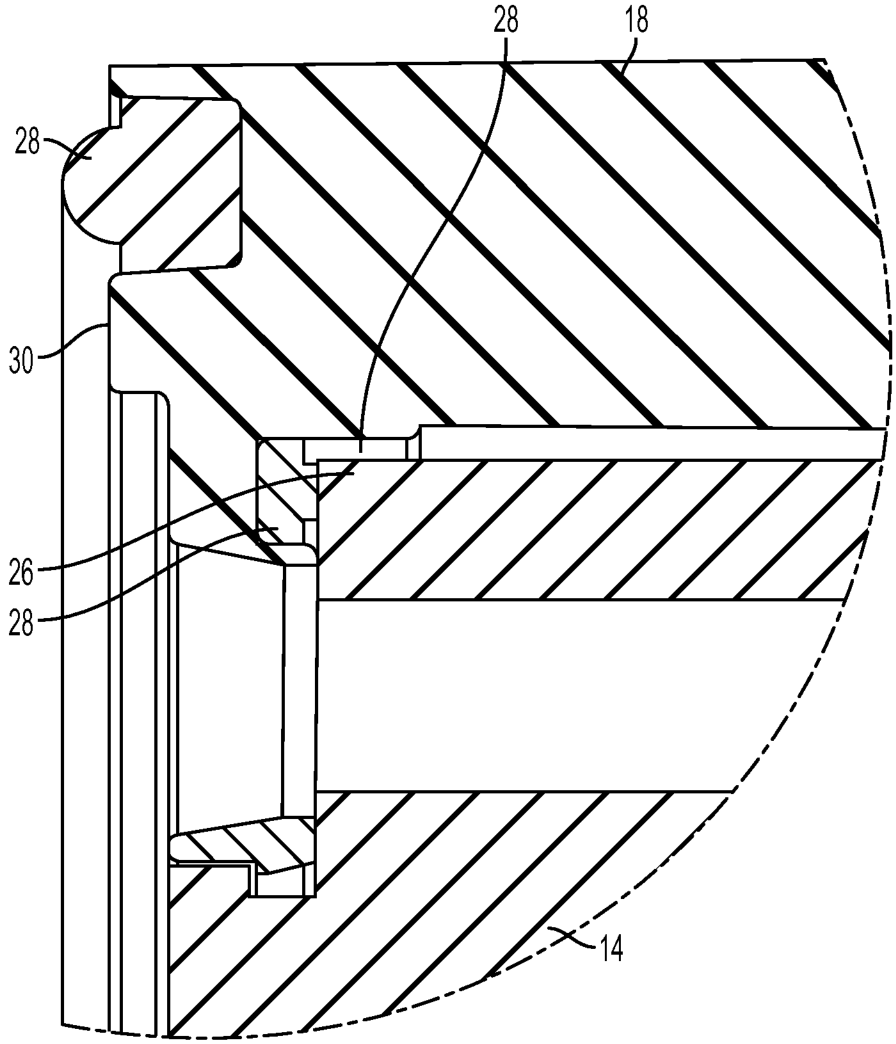


FIG. 6

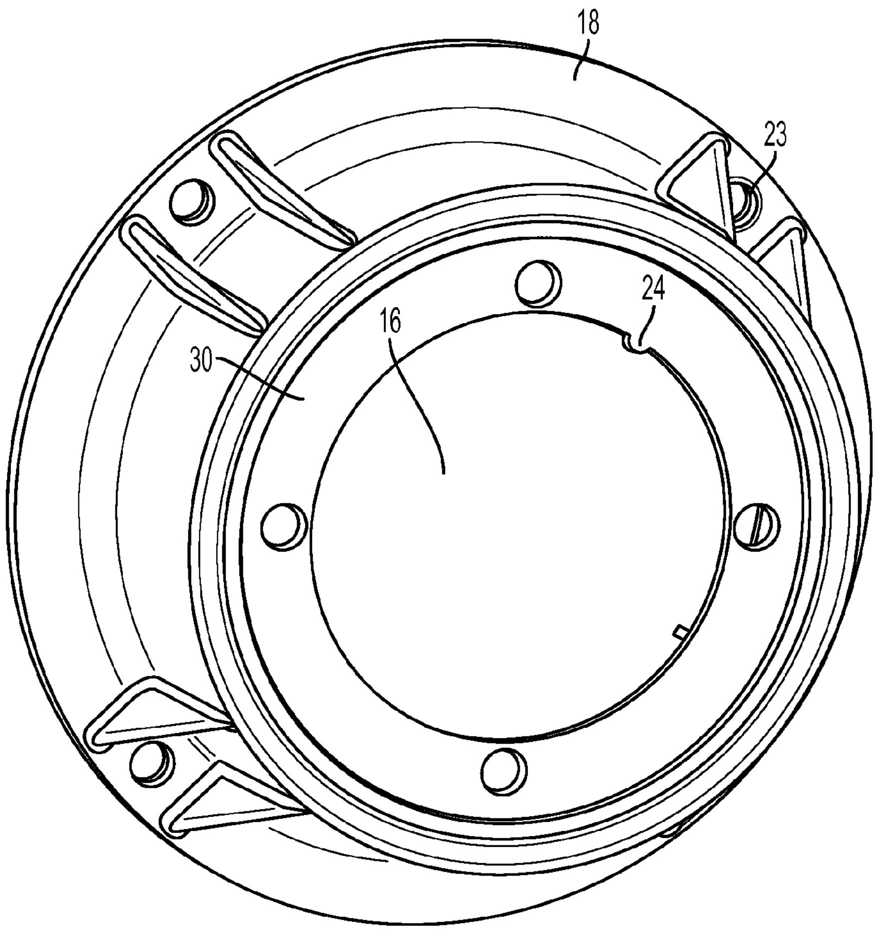


FIG. 7

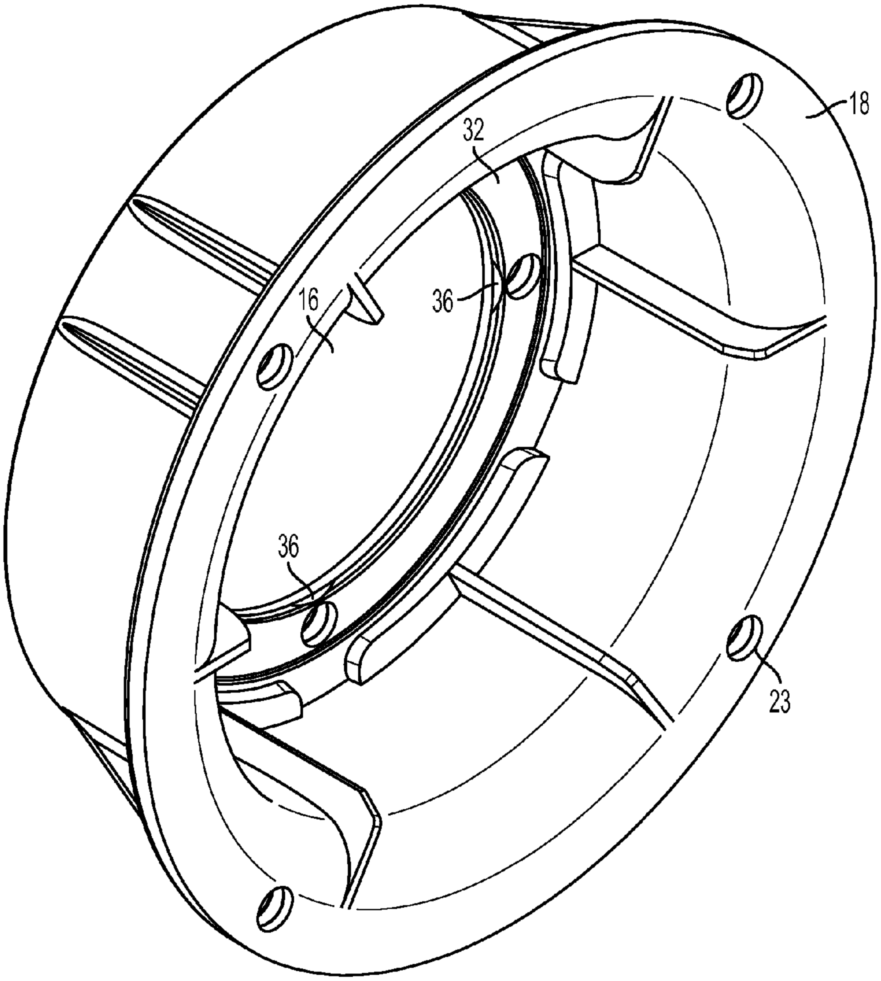


FIG. 8

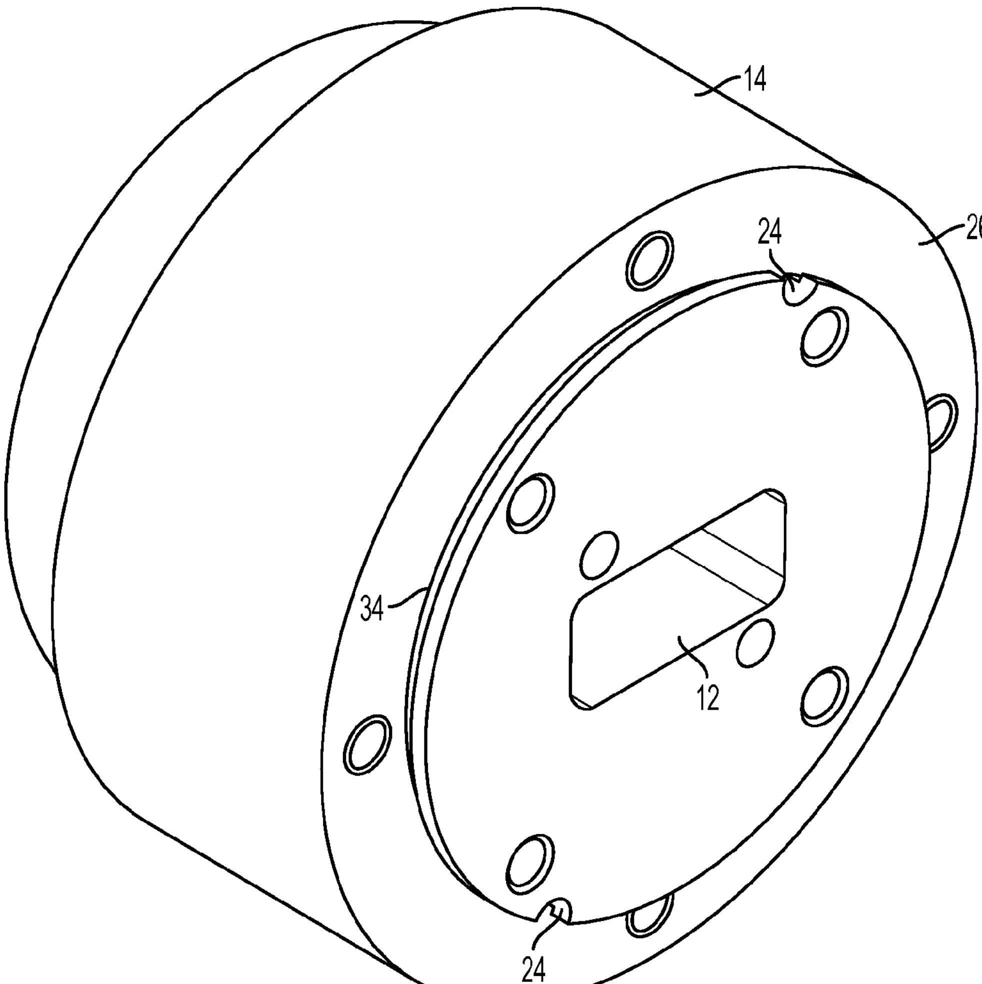


FIG. 9

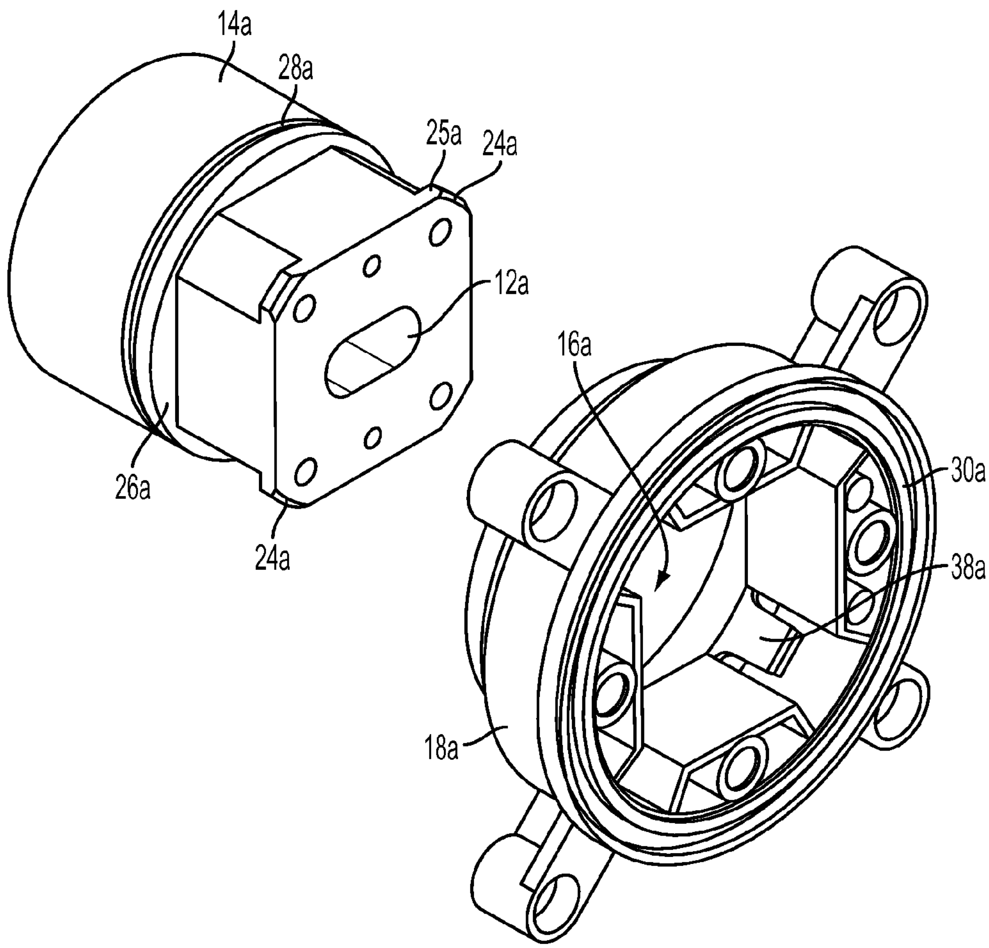


FIG. 10

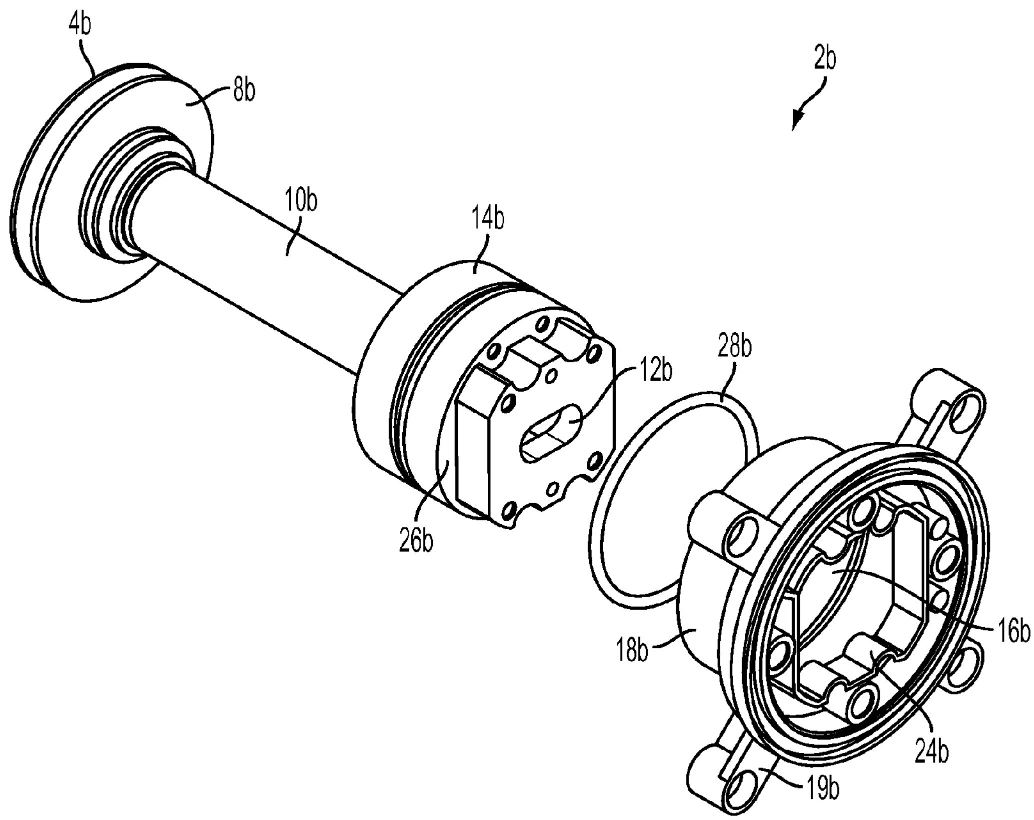


FIG. 11

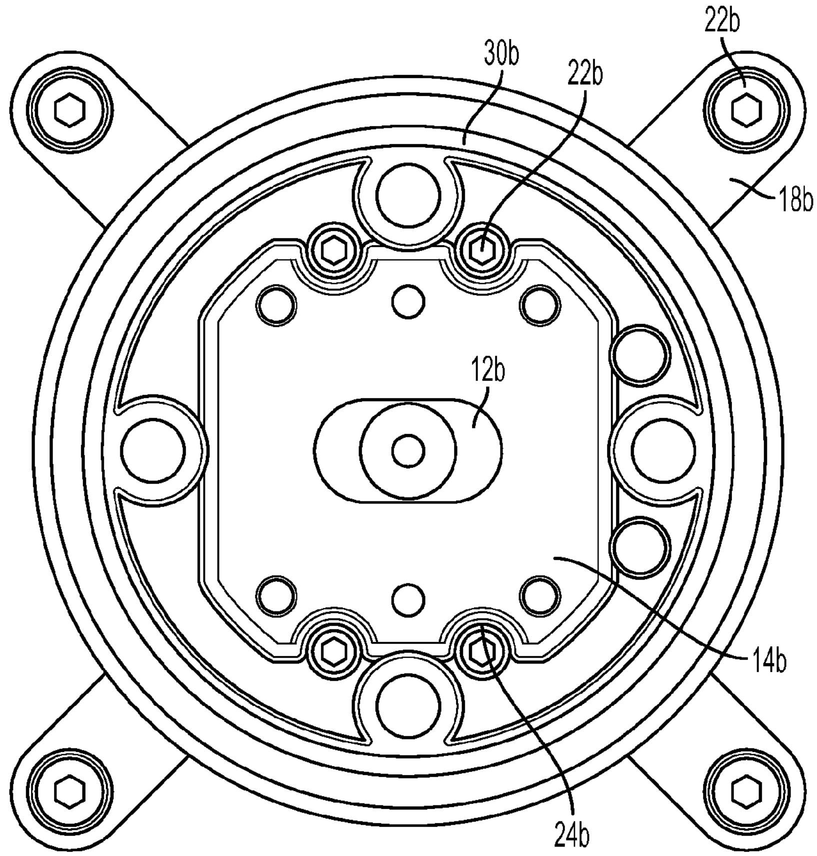


FIG. 12

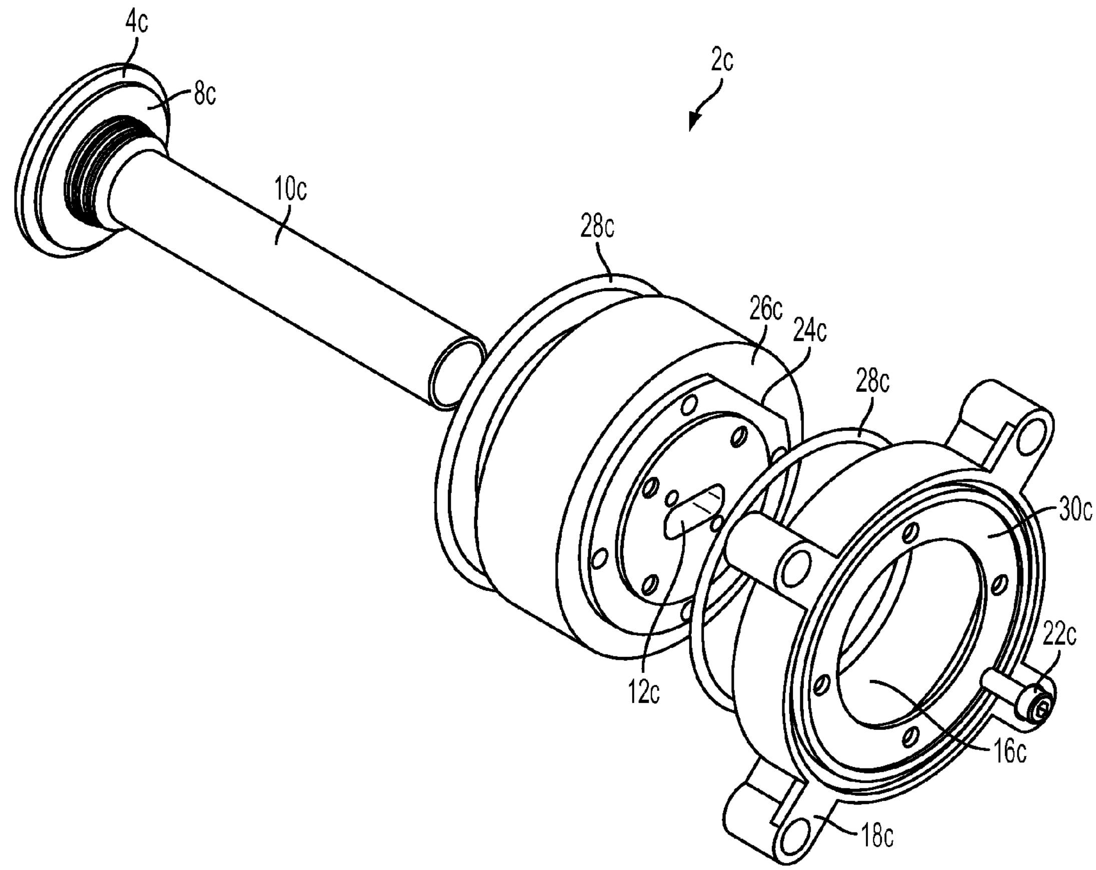


FIG. 13

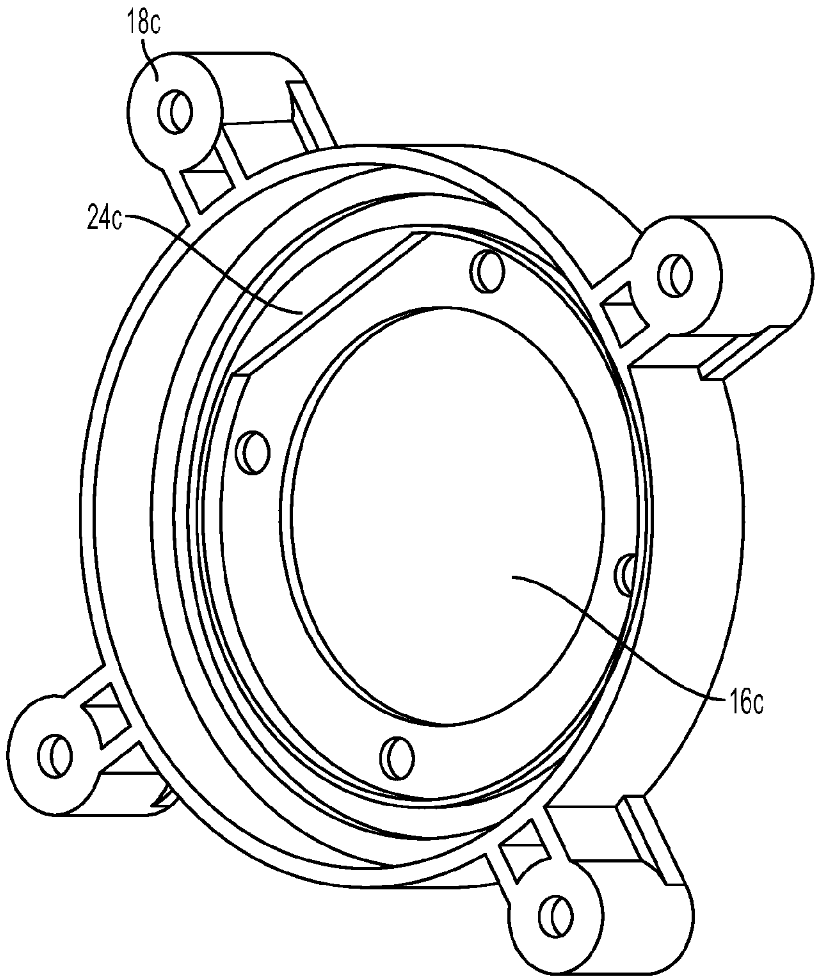


FIG. 14

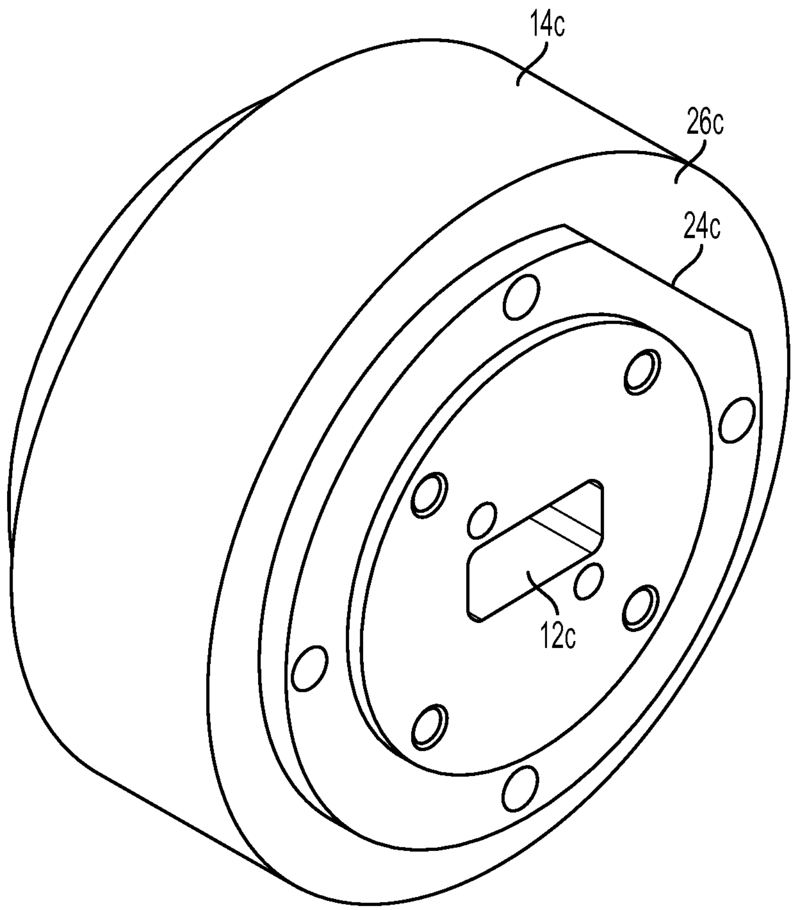


FIG. 15

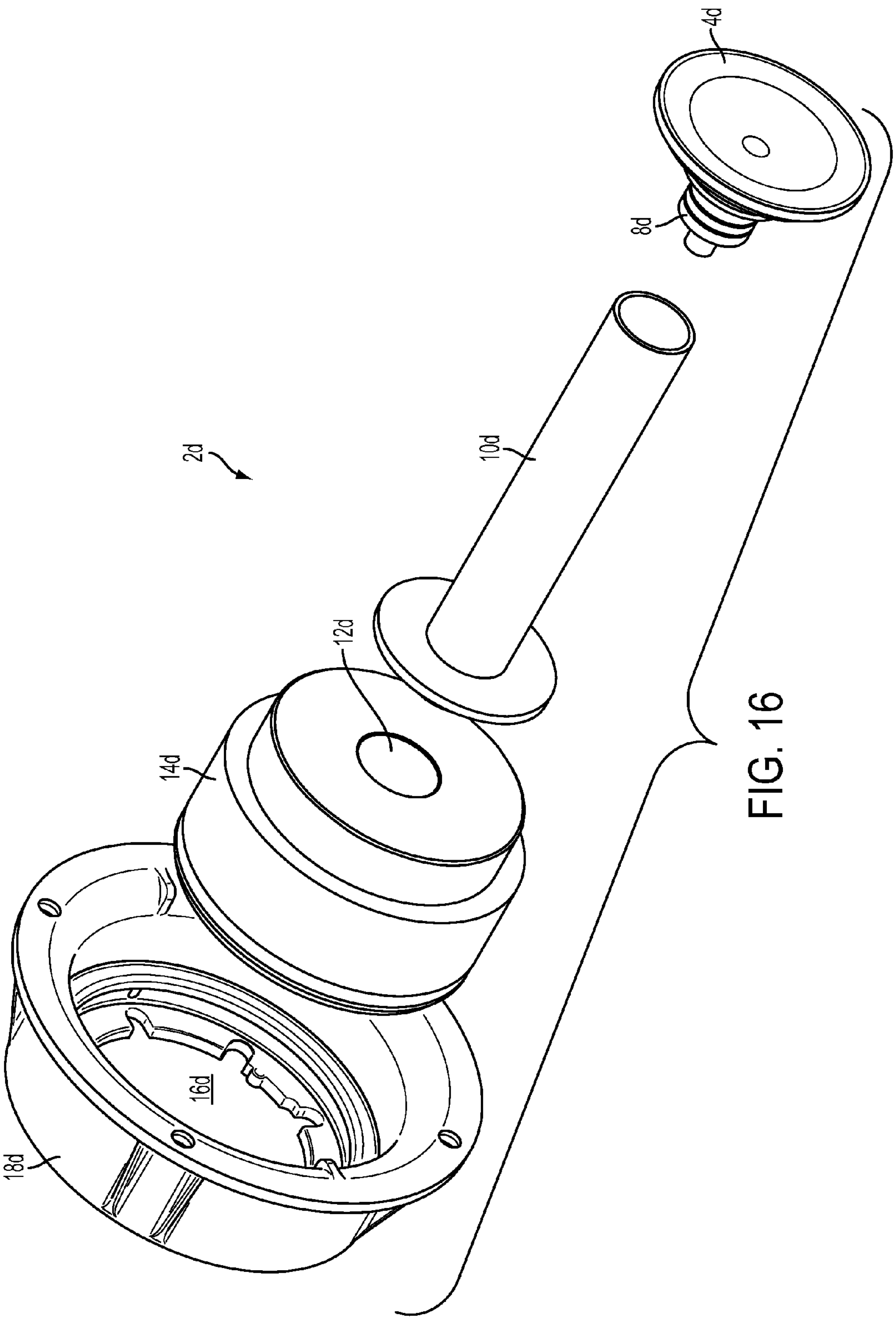


FIG. 16

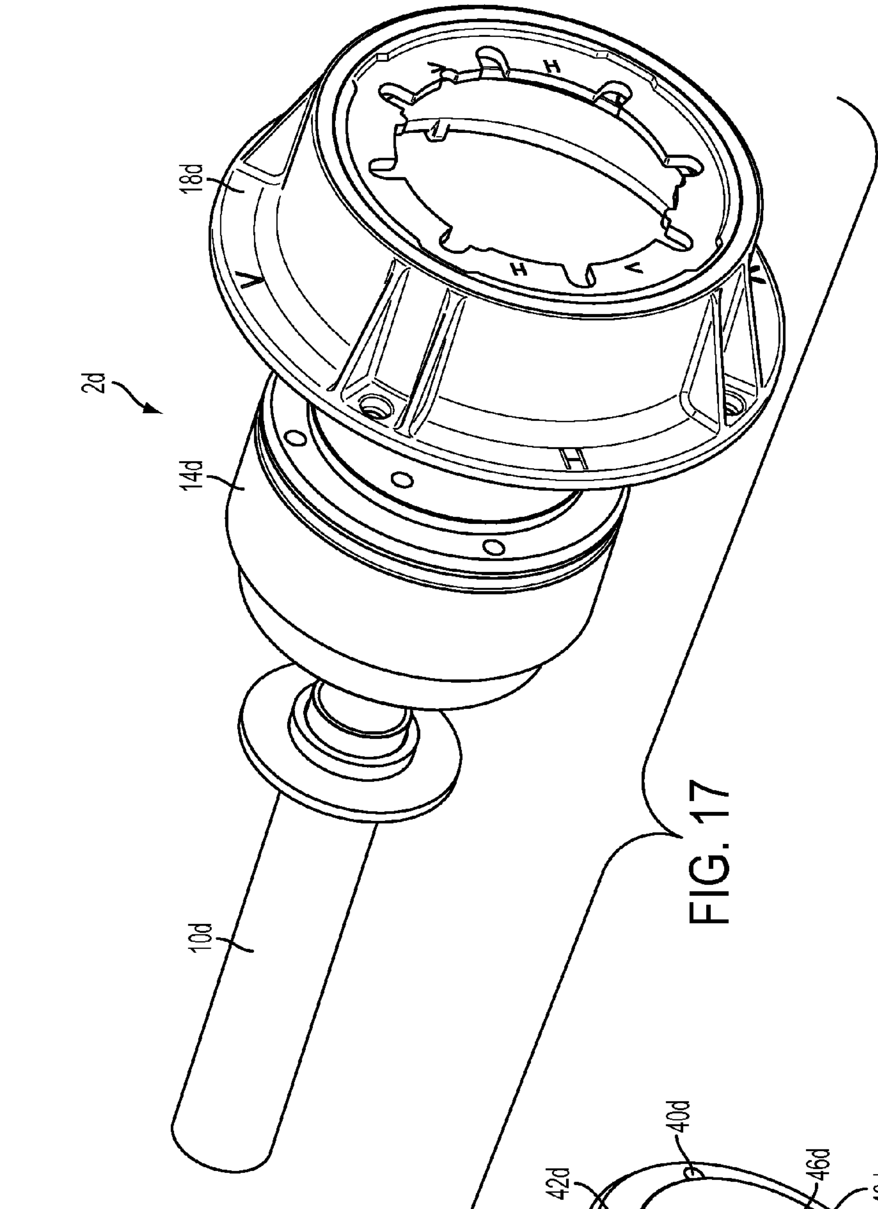


FIG. 17

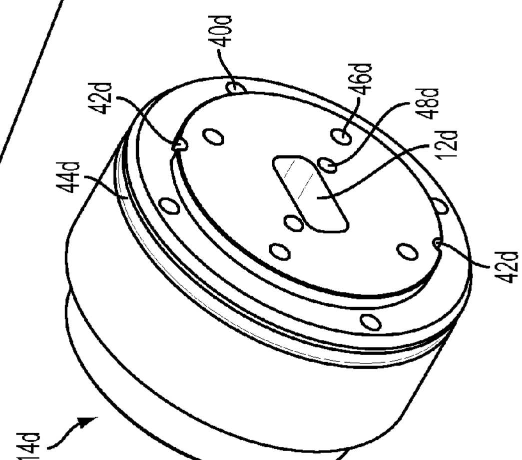


FIG. 18

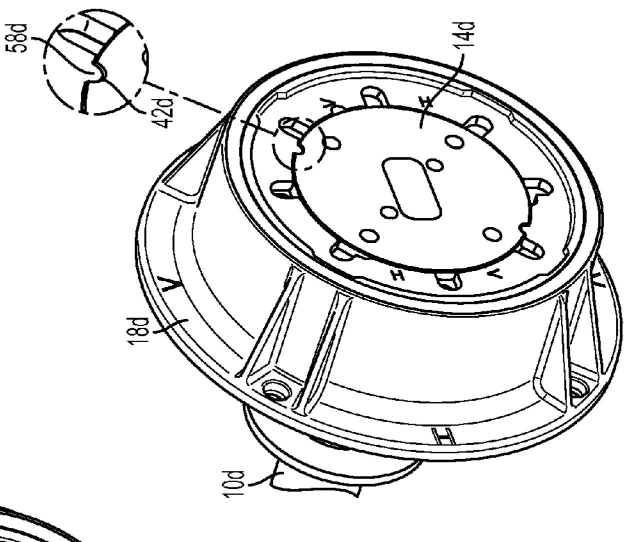


FIG. 24

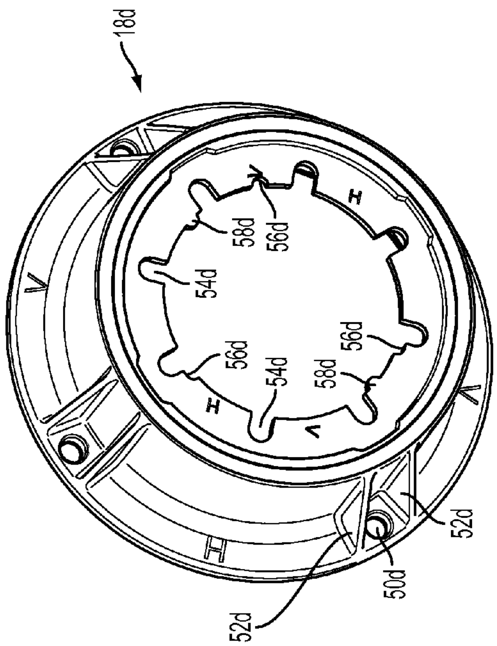


FIG. 19

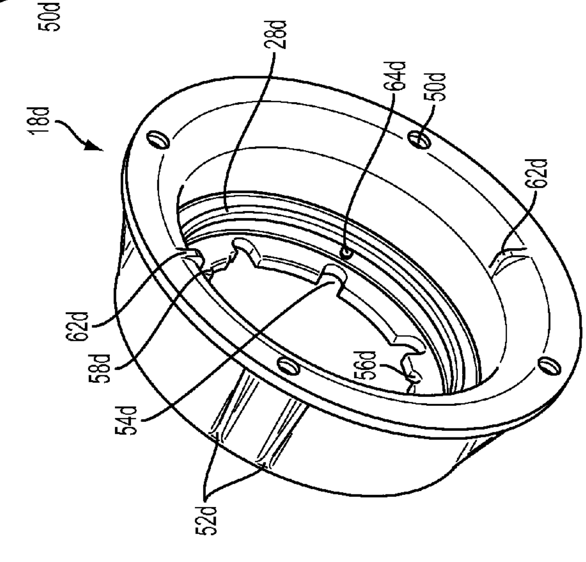


FIG. 20

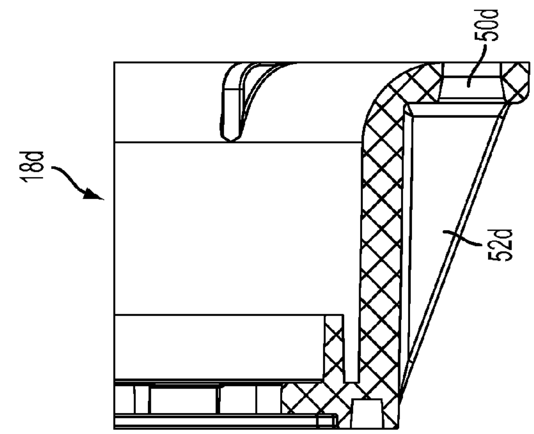


FIG. 23

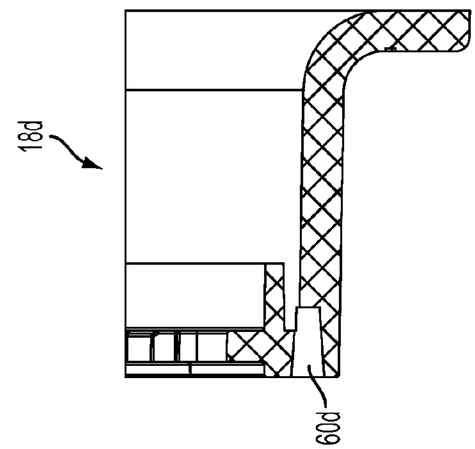


FIG. 22

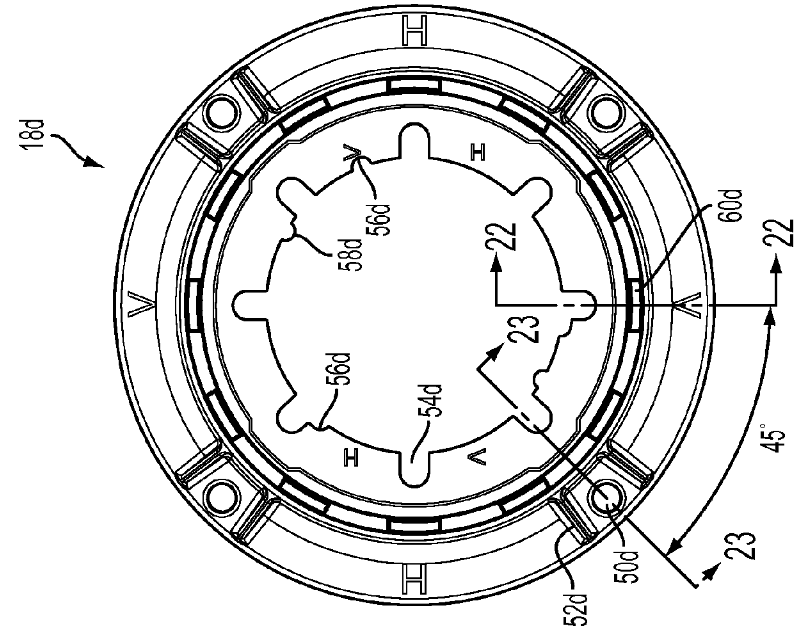


FIG. 21

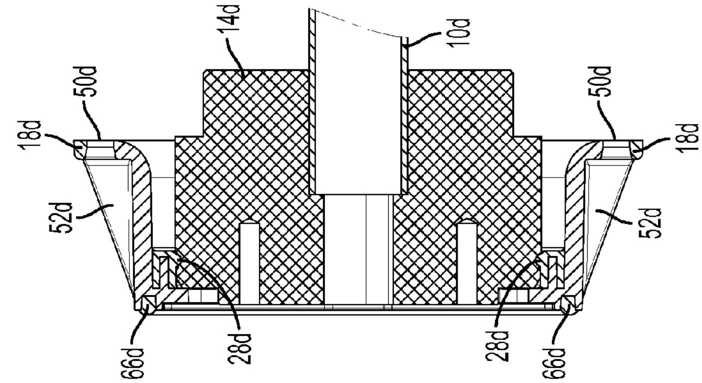


FIG. 27

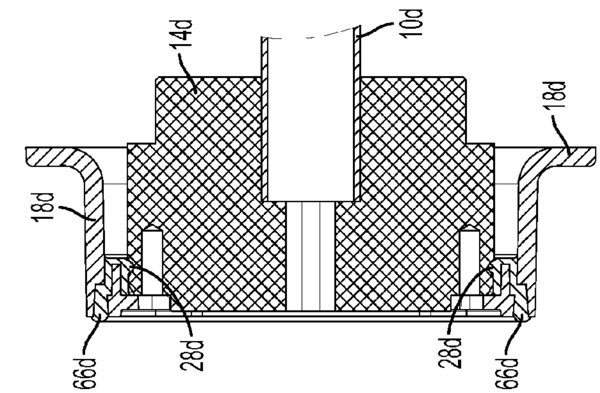


FIG. 26

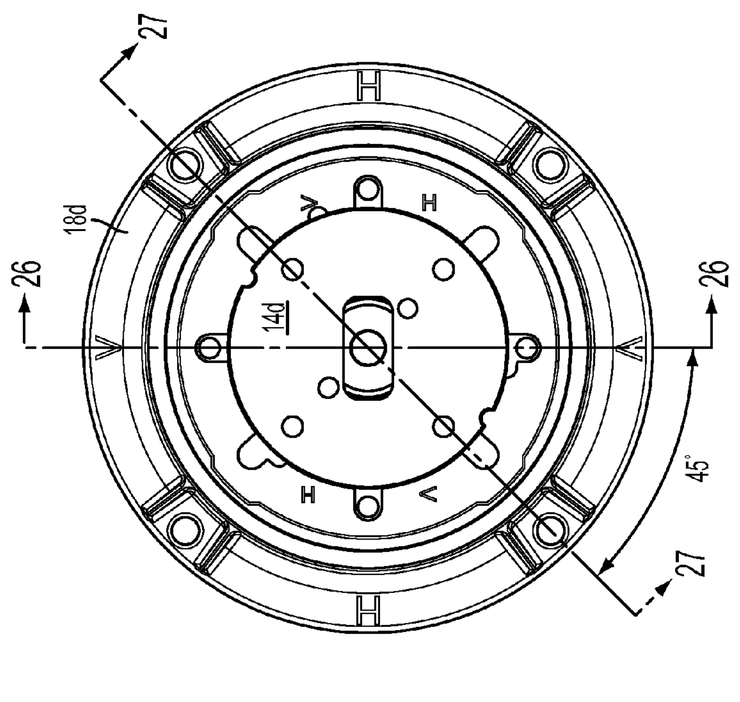


FIG. 25

MODULAR FEED ASSEMBLY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of the filing dates of U.S. provisional application Nos. 61/905,933, filed on Nov. 19, 2013, and 62/013,098, filed on Jun. 17, 2014, the teachings of which are incorporated herein by reference in their entirety.

BACKGROUND

[0002] 1. Field of the Invention

[0003] The present invention relates to antennas and, more specifically but not exclusively, to feed assemblies for reflector antennas.

[0004] 2. Description of the Related Art

[0005] This section introduces aspects that may help facilitate a better understanding of the invention. Accordingly, the statements of this section are to be read in this light and are not to be understood as admissions about what is prior art or what is not prior art.

[0006] Reflector antennas may utilize a feed assembly wherein a sub-reflector is supported proximate the focal point of the reflector dish by a waveguide and dielectric cone. The feed assembly may be coupled to a hub of the reflector antenna by fasteners.

[0007] The orientation of the feed assembly may be rotated to select a desired signal polarization, typically in 90-degree increments.

[0008] If sealing between the feed assembly and the hub is inadequate, RF leakage between the feed assembly and hub may generate backlobes in the antenna signal pattern, degrading electrical performance of the antenna.

[0009] Feed assemblies are typically designed and manufactured in several different operating-frequency-specific embodiments, requiring significant engineering, procurement, materials, manufacturing, and inventory expense.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Other embodiments of the invention will become more fully apparent from the following detailed description, the appended claims, and the accompanying drawings in which like reference numerals identify similar or identical elements.

[0011] FIG. **1** is a schematic isometric view of a reflector antenna with a modular feed assembly positioned for mating with the hub.

[0012] FIG. **2** is a schematic side view of the reflector antenna of FIG. **1**, with a partial cut-away to show the seating of the modular feed assembly and the hub.

[0013] FIG. **3** is a schematic isometric exploded view of the modular feed assembly of FIG. **1**.

[0014] FIG. **4** is a schematic side view with partial cut-away of the assembled modular feed assembly of FIG. **1**.

[0015] FIG. **5** is a schematic proximal end view of the modular feed assembly of FIG. **4**.

[0016] FIG. **6** is a close-up view of area A of FIG. **4**.

[0017] FIG. **7** is a schematic isometric proximal end view of the hub adapter of the modular feed assembly of FIG. **4**.

[0018] FIG. **8** is a schematic angled isometric distal end view of the hub adapter of the modular feed assembly of FIG. **4**.

[0019] FIG. **9** is a schematic angled isometric distal end view of the transition of the modular feed assembly of FIG. **4**.

[0020] FIG. **10** is a schematic angled isometric distal end view of an alternative transition and hub adapter for a modular feed assembly.

[0021] FIG. **11** is a schematic angled isometric distal end exploded view of another alternative modular feed assembly.

[0022] FIG. **12** is a schematic distal end view of the modular feed assembly of FIG. **11**.

[0023] FIG. **13** is a schematic angled isometric distal end exploded view of another alternative modular feed assembly.

[0024] FIG. **14** is a schematic angled proximal end view of the hub adapter of the modular feed assembly of FIG. **13**.

[0025] FIG. **15** is a schematic angled distal end view of the transition of the modular feed assembly of FIG. **13**.

[0026] FIGS. **16**-**27** show different views associated with another alternative modular feed assembly.

DETAILED DESCRIPTION

[0027] A significant cost efficiency may be realized by isolating portions of a feed assembly that are frequency specific, to reduce the number of unique elements required to manufacture a family of feed assemblies for a wide range of operating frequencies. Further, by reducing the size of such frequency-specific components, cost-efficient polymer materials and component configurations suitable for fabrication via injection molding may be applied to a greater portion of the assembly, further reducing material and fabrication costs. Polymer materials also enable simplified insertion-connect-type attachment/alignment and/or integral-seal arrangements with improved assembly and/or sealing characteristics.

[0028] As shown in FIGS. **1**-**9**, an exemplary embodiment of a modular feed assembly **2** supports a sub-reflector **4** proximate a focal point of a reflector dish **6**. As best shown in FIGS. **3**-**4**, the subreflector **4** is coupled to a dielectric block **8** provided at a distal end of a waveguide **10**. The proximal end of the waveguide **10** seats within the RF bore **12** of a transition **14**. The transition **14** seats within the transition bore **16** of a hub adapter **18**. The hub adapter **18** is dimensioned to secure the modular feed assembly **2** with respect to a hub **20** (FIGS. **1**-**2**) of the reflector dish **6** via fasteners applied through holes **23**.

[0029] The RF bore **12** of the transition **14** provides frequency-specific impedance matching to efficiently launch/receive RF signals into/from the waveguide **10** and to/from downstream equipment coupled to the transition **14**, such as transceivers or the like. The RF bore **12** may include, for example, a waveguide transition from a circular waveguide (FIG. **3**) to a rectangular waveguide (FIGS. **5** and **9**). The precision features of the RF bore **12** may be formed, for example, by machining and/or casting the transition **14** from metal material. To minimize the amount of metal material required for the transition **14**, the hub adapter **18** is applied to provide structure for supporting the transition **14** and thereby the sub-reflector **4** with respect to the reflector dish **6** and any downstream equipment.

[0030] As best shown in FIGS. **3**, **7**, and **8**, the transition **14** seats within a transition bore **16** of the hub adapter **18**. A timing feature **24** (FIGS. **5** and **7**) on the proximal end of the transition **14**, such as a tab or slot may key with a corresponding tab or slot of the hub adapter **18** to key a rotation angle of the transition **14** with respect to the hub adapter **18**. Providing multiple timing features **24**, for example, spaced apart by 90 degrees, enables selection of an initial polarization alignment of the modular feed assembly **2** with respect to the hub adapter **18**, which may itself be rotated with respect to the hub **20** for polarity selection. In the three alternative embodiments of FIGS. **10**, **11-12**, and **13-15**, a non-circular cross-section of the transition **14***a,b,c* between a seat shoulder **26***a,b,c* of the transition **14***a,b,c* and a proximal end of the transition **14***a,b,c* may also provide timing-feature functionality. The seat shoulder **26** (FIGS. **6** and **9**) also enables the proximal end of the transition **14** to extend through the hub adapter **18** for ease of coupling with downstream equipment.

[0031] The engagement between the transition **14** and hub adapter **18** may be environmentally and/or RF sealed by application of one or more seals **28** (FIG. **6**) therebetween. An RF-absorbing or -shielding material seal **28** may engage, for example, an outer diameter of the transition **14**. An environmental seal **28**, such as an elastomer gasket or the like, may be applied, for example, to seal against the proximal end of the transition **14**. Additional seals **28** may be provided, for example, at a proximal end face **30** (FIGS. **6** and **7**) of the hub adapter **18** to seal between the hub adapter **18** and downstream equipment. The seals **28** may be formed in place upon the hub adapter **18** as a second shot of an injection-molding process applied to form the hub adapter **18**, for example, from polymer material. Provided integral with the hub adapter **18**, these seals **28** eliminate a potential leakage path around the backside of each seal and reduce the total number of separate parts of the assembly, which may improve the seal effect and reduce potential assembly errors. Alternatively, seals **28***a,b* may be applied, for example, as shown in FIGS. **10** and **11**, around an outer diameter of the transition **14***a,b*, for example, seated in a seal groove of the transition **14***a,b* outer diameter.

[0032] The transition **14** to hub adapter **18** interconnection may include a snap-fit functionality to retain the transition **14** within the transition bore **16**, for ease of initial alignment and/or retention in place, for example, until downstream equipment is coupled to the transition **14**, clamping the transition **14** across the hub adapter **18**. To prevent excess fastener tightening from damaging the hub adapter **18** and/or to provide an initial amount of axial play for engaging a snap-fit interconnection, the seat shoulder **26** of the transition **14** may seat against an anti-crush ring **32** provided on the hub adapter **18**, for example, as shown in FIG. **8**.

[0033] Retention features for snap-fit interconnection may include a retention groove **34** (FIG. **9**) of the transition **14** outer diameter, which receives inward projecting tabs **36** (FIG. **8**) of the hub adapter **18**. Alternatively, the retention feature may be provided as an inward-biased spring tab **38***a* adapted to engage a retention lip **25***a* of the transition **14***a*, as shown for example in FIG. **10**.

[0034] One skilled in the art will appreciate that providing the frequency-specific transition **14** enables fabrication of frequency-specific antenna families from a common pool of components, wherein the only unique component between a pair of antennas, each optimized for separate operating frequencies, is the easily exchanged transition **14**. Further, the reduction in the size and complexity of the transition **14** may provide a materials and manufacturing efficiency that enables greater use of polymers and injection-molding fabrication, instead of machining, for the remainder of the feed assembly module, which may also enable further advantageous features, such as snap-fit retention arrangements and/or integral seals **28**.

[0035] FIGS. **16** and **17** show exploded perspective front and back views, respectively, of an alternative modular feed assembly **2***d* comprising sub-reflector **4***d* connected to dielectric block **8***d*, which mates to cylindrical waveguide **10***d*, which mates to RF bore **12***d* of RF transition **14***d*, and hub adapter **18***d* having transition bore **16***d*, which receives and mates to RF transition **14***d*. When the modular feed assembly **2***d* is assembled, the sub-reflector, dielectric block, and cylindrical waveguide can be inserted through an opening in the hub of an antenna dish, such as hub **20** of FIG. **1**, and the hub adapter **18***d* can be mated to the hub to secure the feed assembly **2***d* in place.

[0036] FIG. **18** shows a perspective front view of the RF transition **14***d*. RF bore **12***d* has a circular cross section at the back side of the RF transition (see FIG. **16**) and a substantial rectangular cross section at the front side the RF transition (see FIG. **18**). As shown in FIG. **18**, the front side of RF transition **14***d* has four tapped screw holes **40***d* (90 degrees apart), two timing slots **42***d* (180 degrees apart), and a circumferential groove **44***d*, all of which assist in the mating of the RF transition to hub adapter **18***d* and all of which will be described further below.

[0037] FIG. **18** also shows four holes **46***d* separated by 90 degrees and two holes **48***d* separated by 180 degrees on the front side of RF transition **14***d*. Holes **46***d* are used to mount additional components (not shown) typically used in remote radio fitment, and holes **48***d* are tooling jig holes.

[0038] FIGS. **19** and **20** show perspective front and back views, respectively, of hub adapter **18***d*. FIG. **21** shows a plan front view of hub adapter **18***d*, and FIGS. **22** and **23** show two different cross-sectional views of hub adapter **18***d* along cut lines C-C and D-D of FIG. **21**, respectively.

[0039] The back side of hub adapter **18***d* has four untapped screw holes **50***d*, separated by 90 degrees and located between pairs of strengthening ribs **52***d*, for mating the hub adapter (and the entire feed assembly **2**) to, for example, hub **20** of FIG. **1**.

[0040] The front side of hub adapter **18***d* has eight screw slots **54***d* separated by 45 degrees, three injection points **56***d* separated by 120 degrees, and two timing lugs **58***d* separated by 180 degrees. The front side of the hub adapter also has twelve passages **60***d* separated by 30 degrees.

[0041] FIGS. **24** and **25** shows perspective and plan front views of the RF transition **14***d* positioned within and mated to the hub adapter **18***d*. FIGS. **26** and **27** show two different cross-sectional views of the RF transition/hub adapter assembly along cut lines A-A and B-B of FIG. **25**, respectively.

[0042] As shown in the FIGS. **24** and **25**, timing lugs **58***d* of RF transition **14***d* mate with timing slots **42***d* of hub adapter **18***d*. Because the two timing lugs **58***d* and two timing slots **42***d* are both separated by 180 degrees, there are only two different orientations in which RF transition **14***d* and hub adapter **18***d* can be configured to one another, and those two orientations are identical. As shown in FIG. **25**, when mated together, four of the eight screw slots **54***d* of hub adapter **18***d* line up with the four screw holes **40***d* of RF transition **14***d*, thereby enabling four screws (not shown) to be used to secure the RF transition and hub adapter together. Although the other four screw slots **54***d* of hub adapter **18***d* are not used with RF transition **14***d*, they do enable hub adapter **18***d* to be used with other RF transitions (e.g., for other RF frequencies) having different timing structures that support different orientations between the RF transition and hub adapter **18***d*.

[0043] As shown, for example, in FIG. **21**, hub adapter **18***d* has the letters H and V, which respectively indicate two different configurations, i.e., horizontal and vertical, respectively, in which the feed assembly **2***d* can be mated to the antenna hub **20** of FIG. **1**. In the horizontal configuration, in which the letters H appear at the left and right sides of the hub adapter **18***d* (i.e., 3 and 9 o'clock positions), the longer sides of the rectangular opening **12***d* in the RF transition **14***d* are oriented horizontally (as indicated in FIG. **1**). In the vertical configuration, in which the letters V appear at the left and right sides of the hub adapter **18***d*, the longer sides of the rectangular opening **12***d* in the RF transition **14***d* are oriented vertically. Note that, because there are four screw holes **50***d* in hub adapter **18***d* and four corresponding screw holes in hub **20**, there are actually two identical horizontal configurations and two identical vertical configurations in which the feed assembly **2***d* can be mated to the hub.

[0044] As shown in FIG. **20**, hub adapter **18***d* has a relatively resilient (e.g., elastomeric) annular compression element (i.e., gasket) **28***d* that mates with groove **44***d* in RF transition **14***d* to form a watertight seal between the hub adapter and the RF transition to prevent moisture from passing therebetween.

[0045] In one implementation, the gasket **28***d* is pre-formed by injecting an uncured elastomer into the injection points **56***d* and passages **60***d* on the front side of hub adapter **18***d*, while the hub adapter is mated to a special injection fixture (not shown) and then curing the elastomer before removing the hub adapter from the injection fixture. The two structures **62***d* separated by 180 degrees are alignment features for mounting the hub adapter to such an injection fixture. Recess **64***d*, shown in FIG. **20**, is an injection gate that ensures that excess elastomeric material is sub flush to the gasket **28***d* and does not interfere with its sealing function. The hub adapter **18***d* can then be mated with the RF transition **14***d* by applying force until the gasket **28***d* engages groove **44***d* in the RF transition.

[0046] As shown in FIGS. **26** and **27**, the injected elastomer forms both the annular gasket **28***d* on the inner cylindrical surface of the hub adapter **18***d* as well as an annular gasket **66***d* on the front face of the hub adapter. This second annular gasket **66***d* helps to form a watertight seal between the hub adapter **18***d* and additional components (not shown) typically used in radio fitment and mated to the feed assembly **2***d*.

[0047] Hub adapter **18***d* is made from a relatively rigid material, such as a suitable metal, such as, but not limited to, copper or aluminum, or a suitable plastic such as, but not limited to, polycarbonate, polyester, polybutylene terephthalate (PBT), acrylonitrile butadiene styrene (ABS), or polystyrene. Depending on the material used, hub adapter **18***d* may be made using a suitable technique such as, but not limited to, casting, pressing, or injection molding. RF transition **14***d* is made of a suitable metal.

[0048] Where, in the foregoing description, reference has been made to materials, ratios, integers, or components having known equivalents, then such equivalents are herein incorporated as if individually set forth.

[0049] While the present invention has been illustrated by the description of the embodiments thereof, and while the embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details, representative apparatus, methods, and illustrative examples shown and described. Accordingly, departures may be made from such details without departure from the spirit or scope of applicant's general inventive concept. Further, it is to be appreciated that improvements and/or modifications may be made thereto without departing from the scope or spirit of the present invention as defined by the following claims.

[0050] Unless explicitly stated otherwise, each numerical value and range should be interpreted as being approximate as if the word "about" or "approximately" preceded the value or range.

[0051] In this specification including any claims, the term "each" may be used to refer to one or more specified characteristics of a plurality of previously recited elements or steps. When used with the open-ended term "comprising," the recitation of the term "each" does not exclude additional, unrecited elements or steps. Thus, it will be understood that an apparatus may have additional, unrecited elements and a method may have additional, unrecited steps, where the additional, unrecited elements or steps do not have the one or more specified characteristics.

[0052] The use of figure numbers and/or figure reference labels in the claims is intended to identify one or more possible embodiments of the claimed subject matter in order to facilitate the interpretation of the claims. Such use is not to be construed as necessarily limiting the scope of those claims to the embodiments shown in the corresponding figures.

[0053] Reference herein to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment can be included in at least one embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment, nor are separate or alternative embodiments necessarily mutually exclusive of other embodiments. The same applies to the term "implementation."

[0054] The embodiments covered by the claims in this application are limited to embodiments that (1) are enabled by this specification and (2) correspond to statutory subject matter. Non-enabled embodiments and embodiments that correspond to non-statutory subject matter are explicitly disclaimed even if they fall within the scope of the claims.

1. An article of manufacture comprising a modular feed assembly for an antenna, the feed assembly comprising:
- a hub adapter configured to mount the feed assembly onto a hub of the antenna;
- a waveguide transition forming a component distinct from the hub adapter and configured to be selectively mated to the hub adapter, wherein:
  - the waveguide transition provides a transition from a first waveguide having a first cross-section to a second waveguide having a second cross-section different from the first cross-section; and
  - the hub adapter and the waveguide transition have structures that prevent rotation of the waveguide transition about its longitudinal axis with respect to the hub adapter after the waveguide transition is mated to the hub adapter.

2. The article of claim **1**, wherein:
- the first cross-section of the first waveguide is rectangular; and
- the second cross-section of the second waveguide is circular.

3. The article of claim **1**, wherein the structures comprise one or more timing features that limit a rotational orientation between the hub adapter and the waveguide transition to one of a fixed number of possible rotational orientations.

4. The article of claim **3**, wherein the one or more timing features limit the possible rotational orientations to two rotational orientations that are separated by a 180-degree rotation.

5. The article of claim **1**, wherein the hub adapter is configured to selectively mate with different waveguide transitions having different frequency characteristics, such that the hub adapter can selectively be used to form different feed assemblies for different antennas having different operating frequency ranges.

6. The article of claim **5**, wherein the different waveguide transitions have identical mating interfaces for mating with the hub adapter.

7. The article of claim **5**, wherein, for first and second waveguide transitions, at least one of the first and second cross-sections of the first and second waveguides corresponding to the first waveguide transition is different from a corresponding at least one of the first and second cross-sections of the first and second waveguides corresponding to the second waveguide transition.

8. The article of claim **1**, wherein the hub adapter comprises a resilient compression element that forms an annular seal with the waveguide transition that inhibits RF leakage from the antenna.

9. The article of claim **8**, wherein the hub adapter comprises one or more passages that allow an elastomeric material to flow through the hub adapter to form the compression element.

10. The article of claim **9**, wherein the one or more passages allow the elastomeric material to flow through the hub adapter to form the compression element after the hub adapter is mated to the waveguide transition.

11. The article of claim **1**, wherein the article of manufacture is the feed assembly.

12. The article of claim **1**, wherein the article of manufacture is the feed assembly secured to the hub.

13. The article of claim **1**, wherein the article of manufacture is the antenna.

14. A method for forming an article of manufacture comprising a modular feed assembly for an antenna, the method comprising:

(a) providing a hub adapter configured to mount the feed assembly onto a hub of the antenna; and

(b) mating a waveguide transition to the hub adapter, wherein:

the waveguide transition forms a component distinct from the hub adapter;

the waveguide transition provides a transition from a first waveguide having a first cross-section to a second waveguide having a second cross-section different from the first cross-section; and

the hub adapter and the waveguide transition have structures that prevent rotation of the waveguide transition about its longitudinal axis with respect to the hub adapter after the waveguide transition is mated to the hub adapter.

15. The method of claim **14**, wherein:

the structures comprise one or more timing features that limit a rotational orientation between the hub adapter and the waveguide transition to one of a fixed number of possible rotational orientations; and

step (b) comprises mating the waveguide transition to the hub adapter with a selected one of the possible rotational orientations.

16. The method of claim **14**, wherein the hub adapter is configured to selectively mate with different waveguide transitions having different frequency characteristics, such that the hub adapter can selectively be used to form different feed assemblies for different antennas having different operating frequency ranges.

17. The method of **14**, wherein the hub adapter comprises a resilient compression element that forms an annular seal with the waveguide transition that inhibits RF leakage from the antenna.

18. The method of claim **17**, wherein:

the hub adapter comprises one or more passages; and

the method comprises flowing an elastomeric material through the passages in the hub adapter to form the compression element.

19. The method of claim **18**, wherein step (b) comprises flowing the elastomeric material through the passages in the hub adapter to form the compression element after the hub adapter is mated to the waveguide transition.

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