US009929471B2

(12) **United States Patent**
Fonseca

(10) **Patent No.: US 9,929,471 B2**
(45) **Date of Patent: Mar. 27, 2018**

(54) **VERY COMPACT TM01 MODE EXTRACTOR**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 41 days.

(21) Appl. No.: **15/029,838**

(22) PCT Filed: **Oct. 21, 2013**

(86) PCT No.: **PCT/EP2013/071973**
§ 371 (c)(1),
(2) Date: **Apr. 15, 2016**

(87) PCT Pub. No.: **WO2015/058784**
PCT Pub. Date: **Apr. 30, 2015**

(65) **Prior Publication Data**

US 2016/0248164 A1 Aug. 25, 2016

(51) **Int. Cl.**
H01P 5/12 (2006.01)
H01Q 13/02 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H01Q 13/02*** (2013.01); ***G01S 7/4026*** (2013.01); ***G01S 13/4409*** (2013.01); ***H01P 1/16*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC . H01Q 13/02; H01P 1/16; H01P 1/161; H01P 5/08; H01P 5/19; H01P 5/103; G01S 7/4026; G01S 13/4409
See application file for complete search history.

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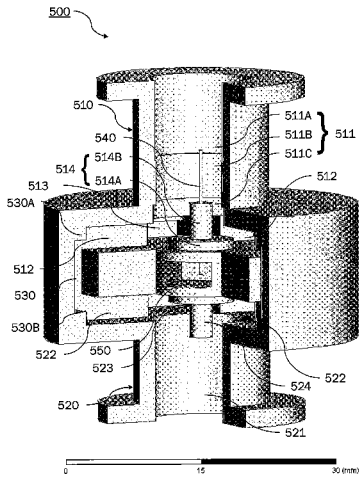
(57) **ABSTRACT**

A mode extractor for extracting TM01 mode from an electromagnetic signal, including a first and second turnstile junction, each of the turnstile junctions having first port, four second ports of rectangular waveguide which are mutually orthogonal and orthogonal to first port and matching section provided at least partially in center region of respective turnstile junction, center region being located at intersection of first port and four second ports wherein first and second turnstile junction are arranged so that longitudinal axes of their first ports are aligned with each other and their first ports are facing in opposite directions, each of the second ports of first turnstile junction is electromagnetically coupled to corresponding one of second ports of second turnstile junction, and a coaxial coupling device is inserted into matching section of first turnstile junction so that a portion of coaxial coupling device extends into first port of first turnstile junction.

16 Claims, 10 Drawing Sheets



(51) **Int. Cl.**

G01S 7/40	(2006.01)
G01S 13/44	(2006.01)
H01P 1/161	(2006.01)
H01P 1/16	(2006.01)
H01P 5/08	(2006.01)
H01P 5/19	(2006.01)
H01P 5/103	(2006.01)

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

CPC ***H01P 1/161*** (2013.01); ***H01P 5/08*** (2013.01); ***H01P 5/19*** (2013.01); *H01P 5/103* (2013.01)

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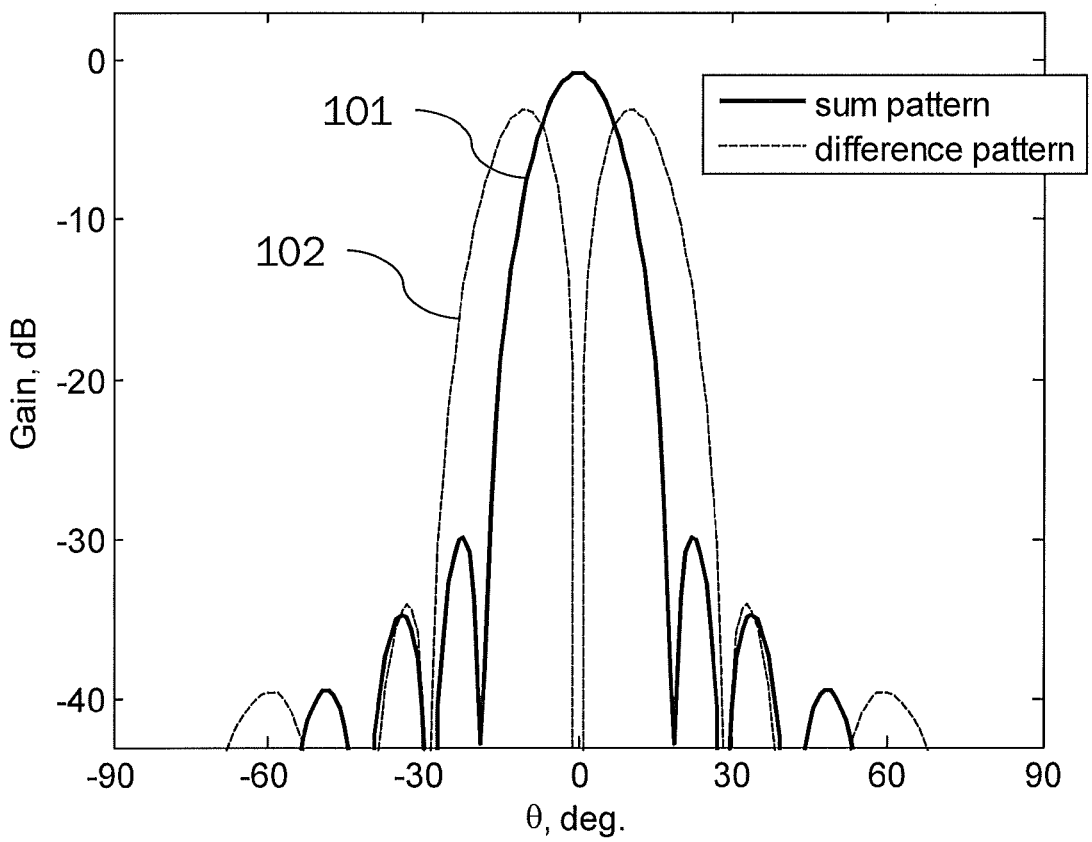

0
-10
-20
-30
-40
Gain, dB
-90
-60
-30
0
30
60
90
θ, deg.
101
102
sum pattern
difference pattern

Fig.1

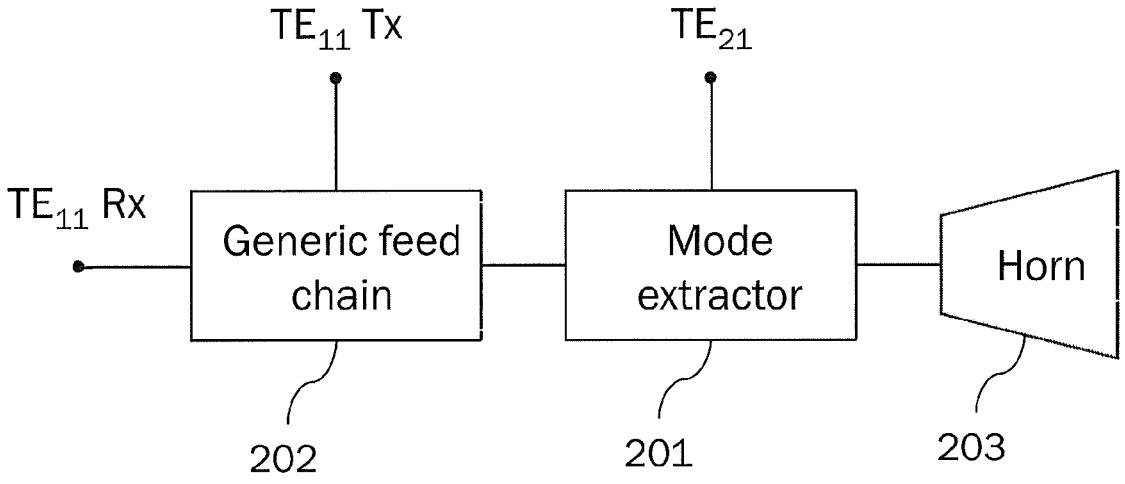

TE11 Tx
TE21
TE11 Rx
Generic feed chain
Mode extractor
Horn
202
201
203

Fig.2

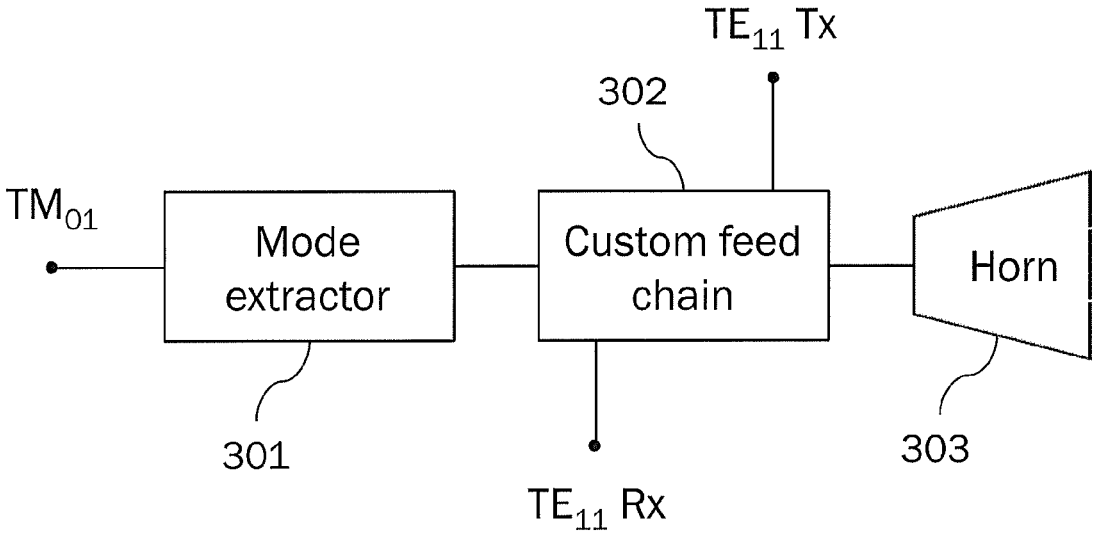

TE11 Tx
302
TM01
Mode extractor
Custom feed chain
Horn
301
303
TE11 Rx

Fig.3

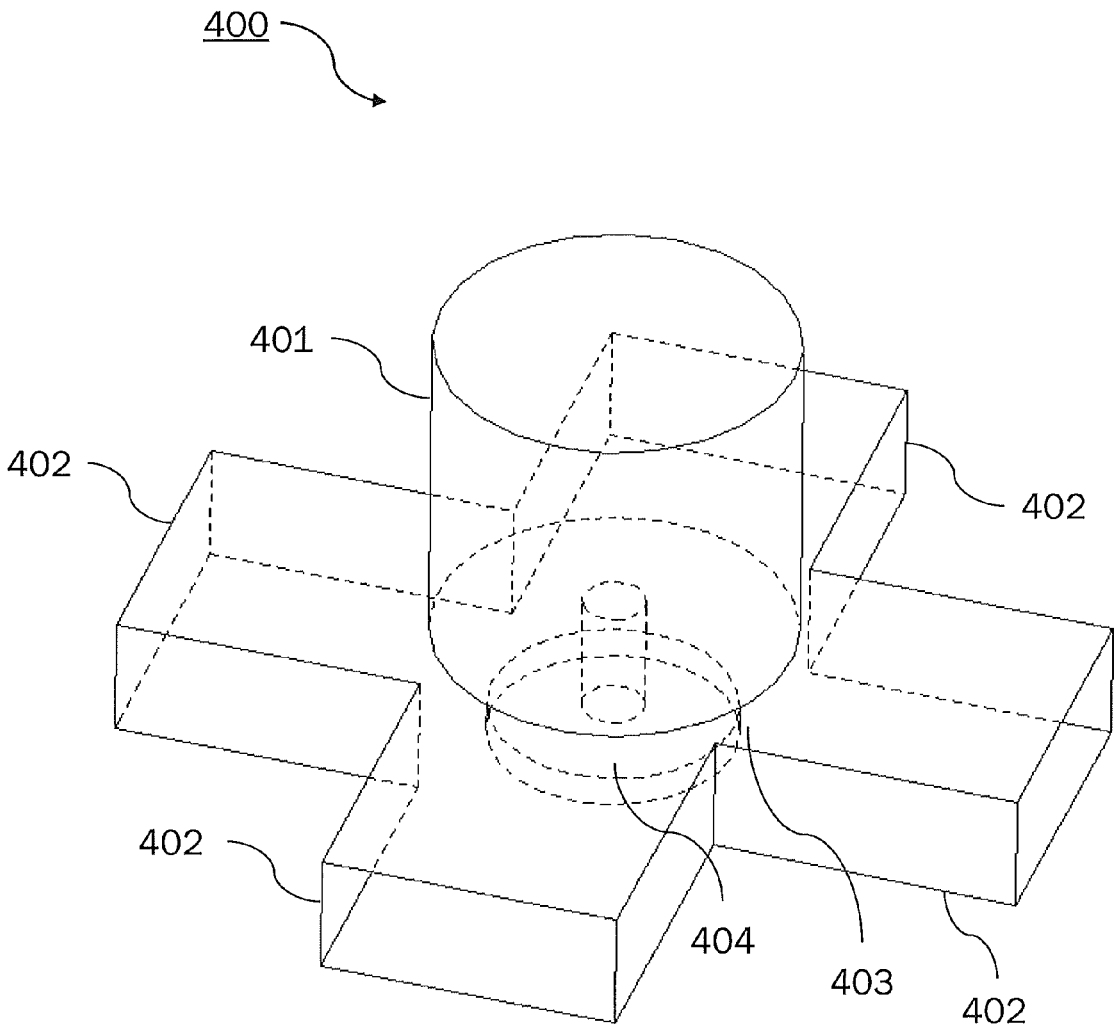
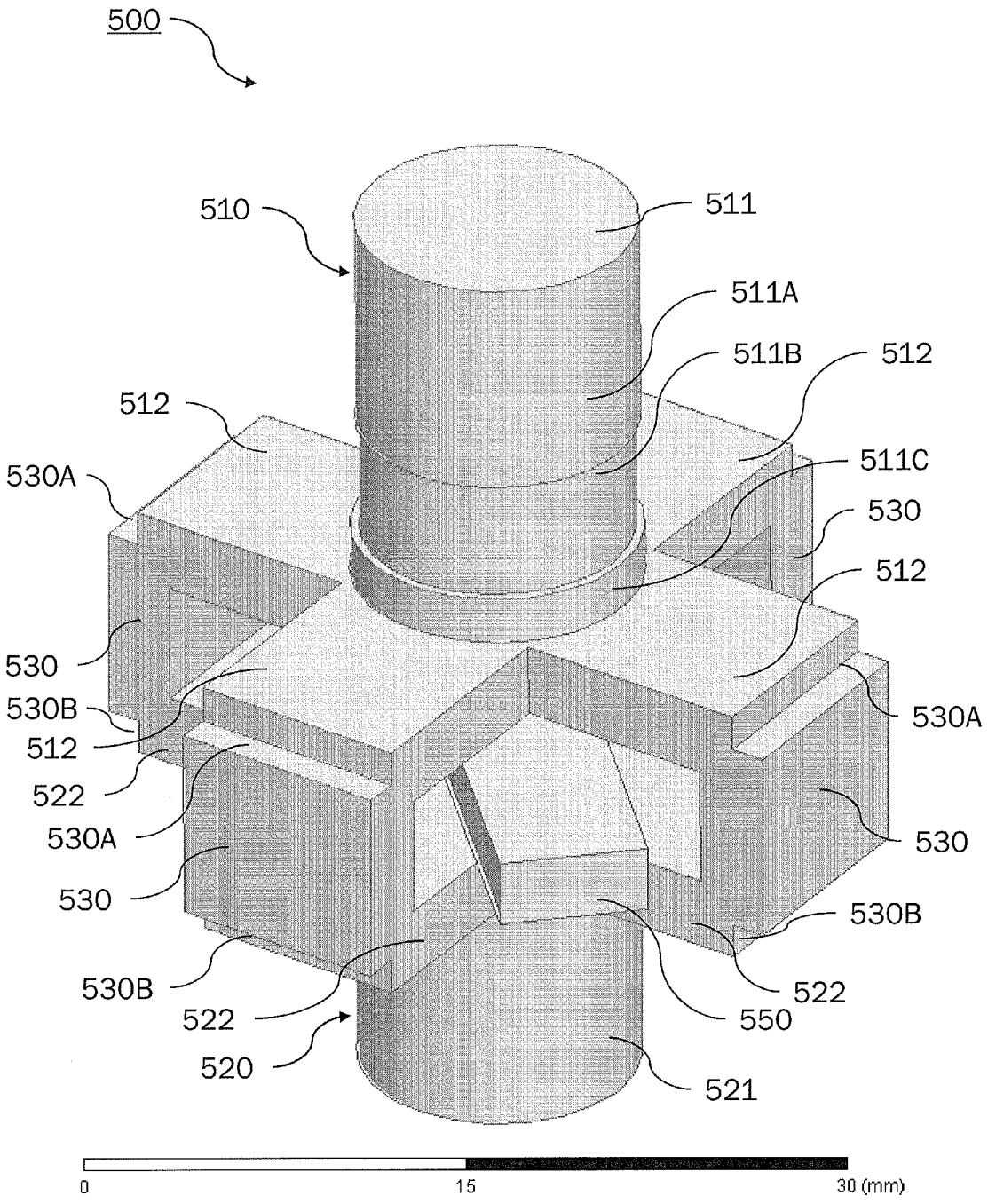


Fig.4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511B
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512
530A
511C
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512
530
530B
512
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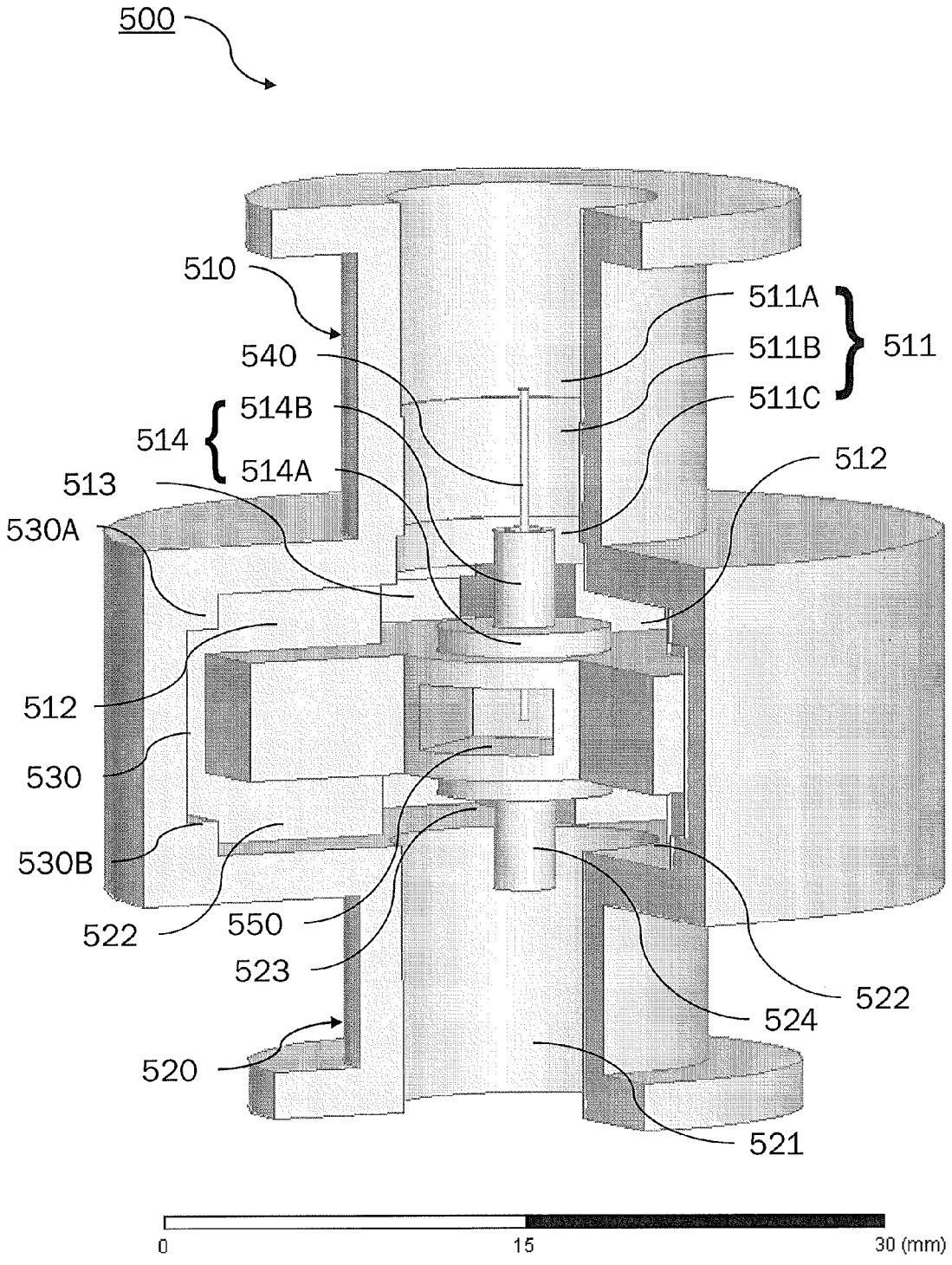
530B
522
520
550
521
530A
530
530B
522
0
15
30 (mm)

Fig.5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514B
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530B
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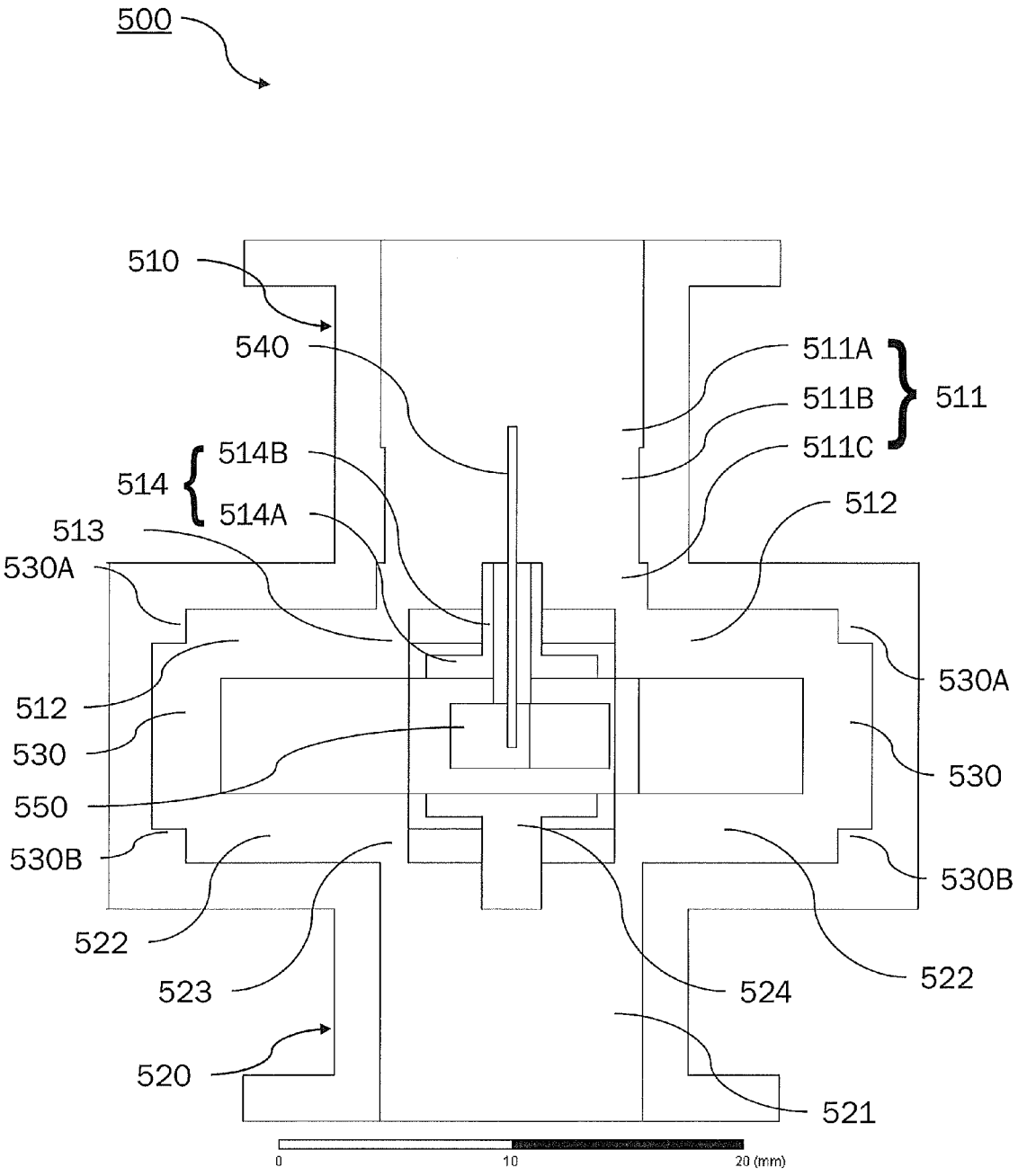
550
523
522
524
520
521
0
15
30 (mm)

Fig.6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511C
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550
530B
530B
522
523
524
522
520
521
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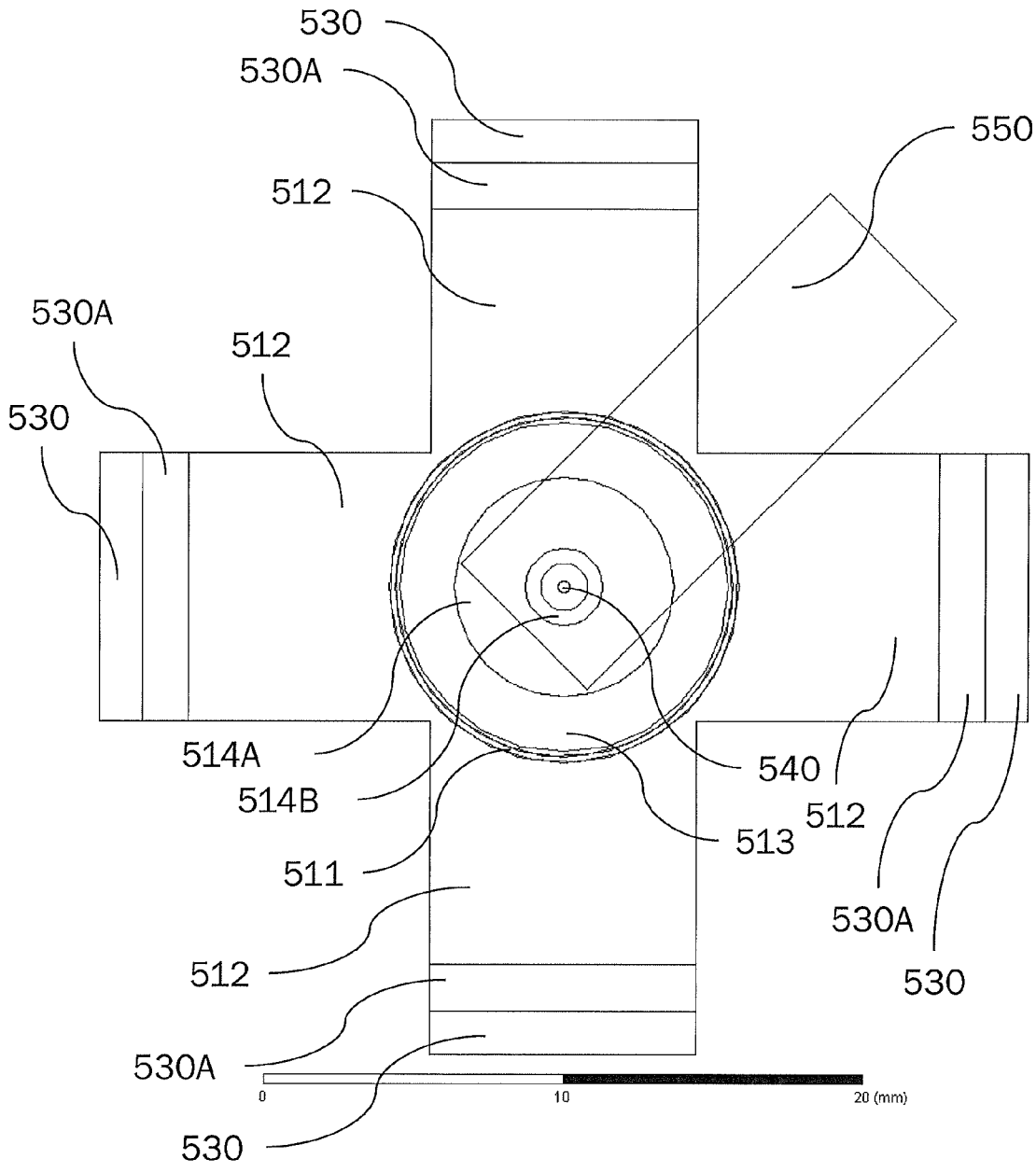
10
20 (mm)

Fig.7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514A
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511
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530A
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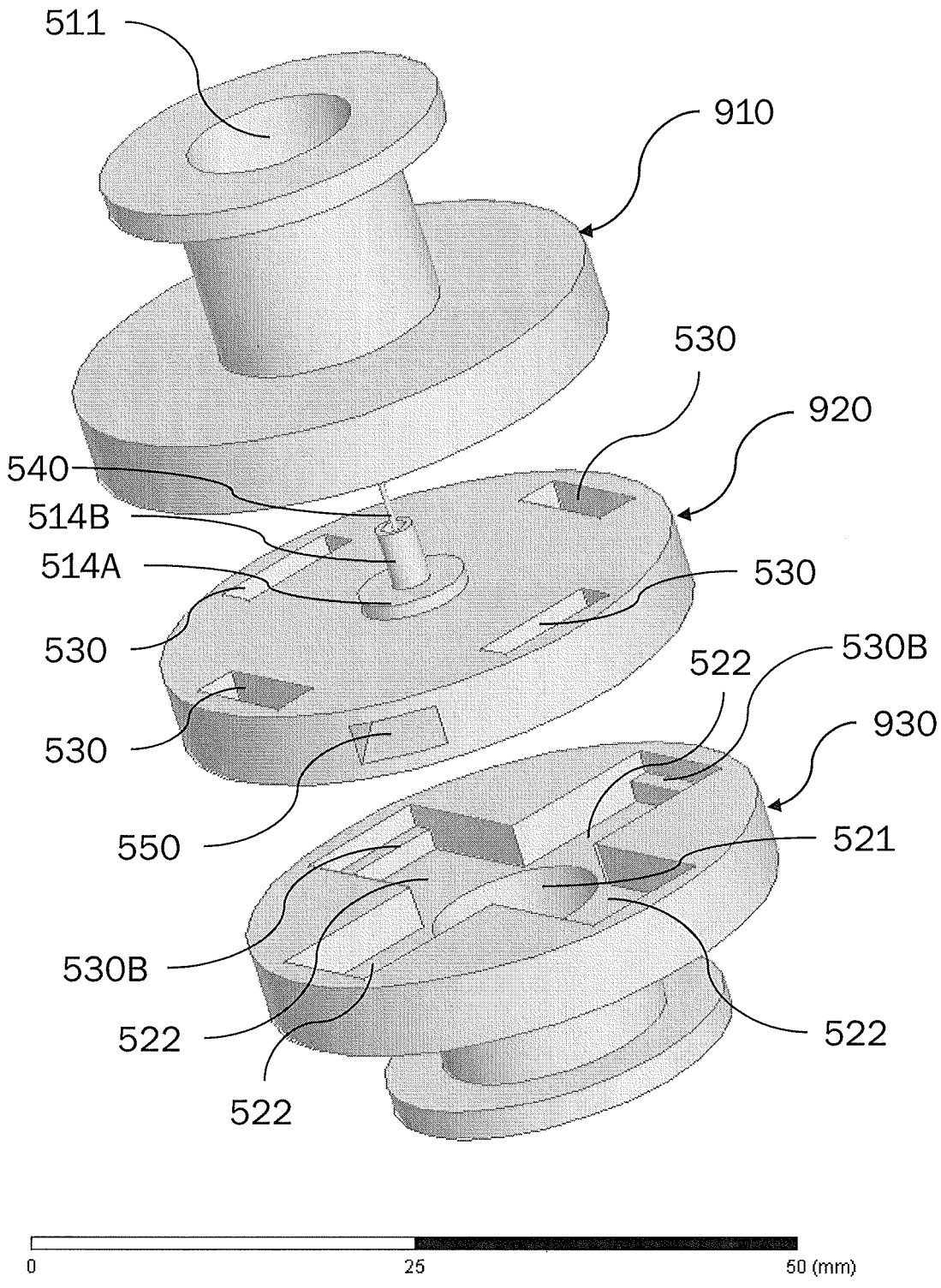
540
512
513
530A
530
0
10
20 (mm)

Fig.8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920
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930
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521
530B
522
522
522
0
25
50 (mm)

Fig.9

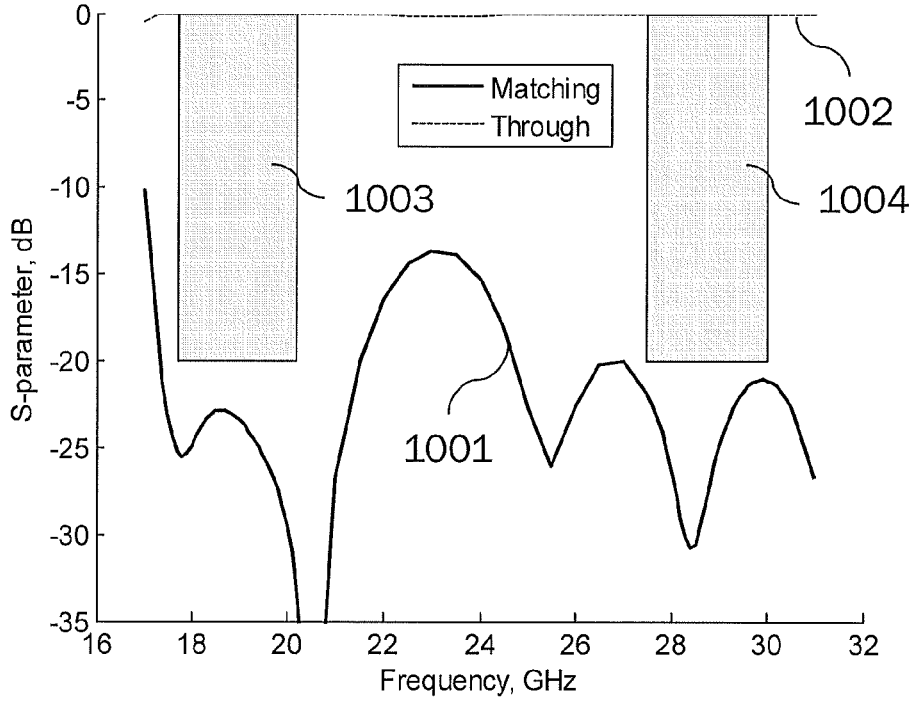

Fig.10A

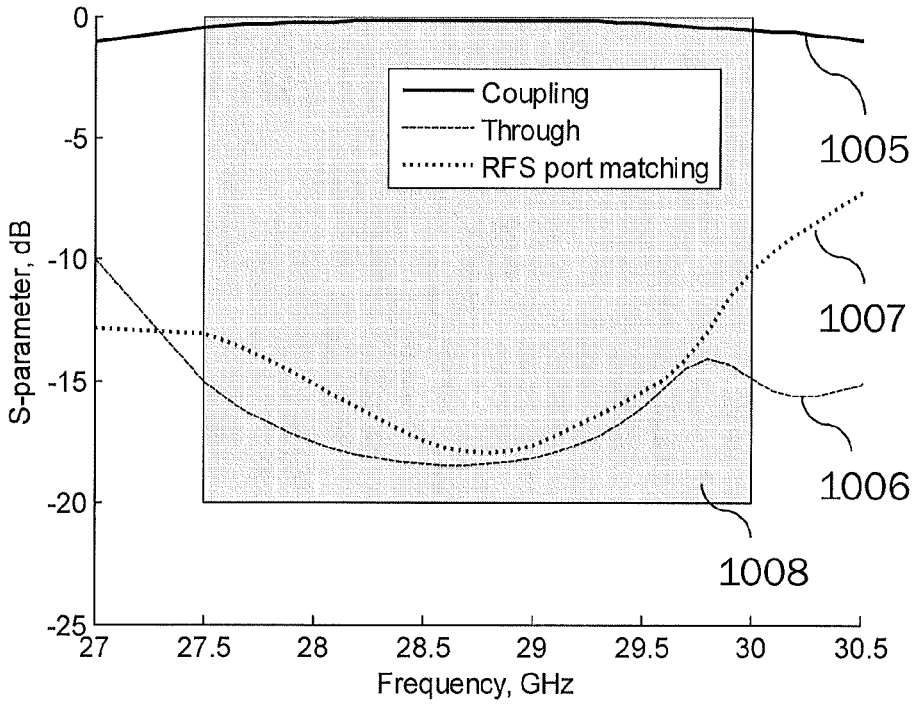

Fig.10B

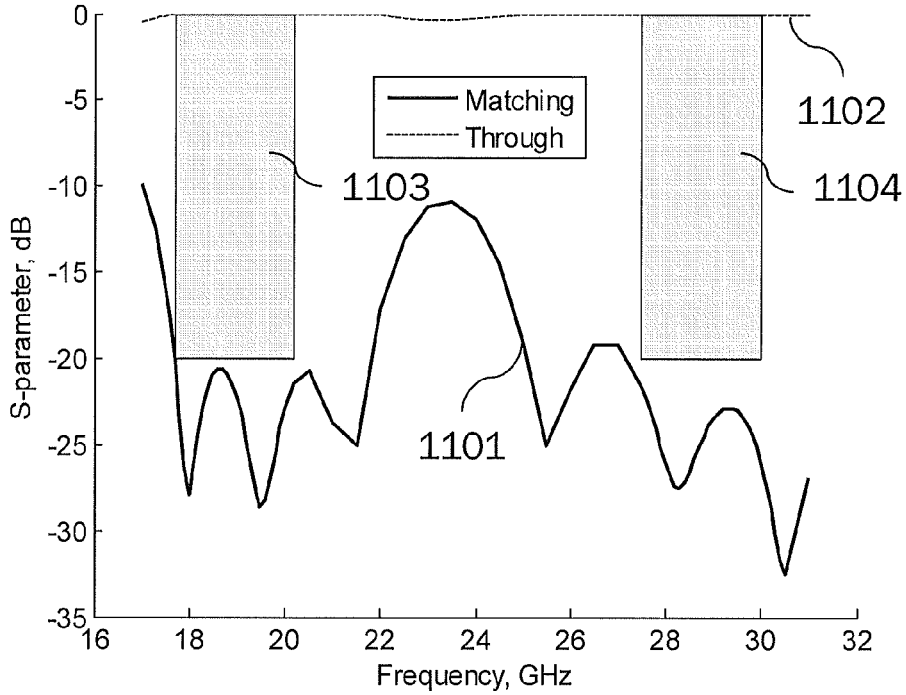

Fig.11A

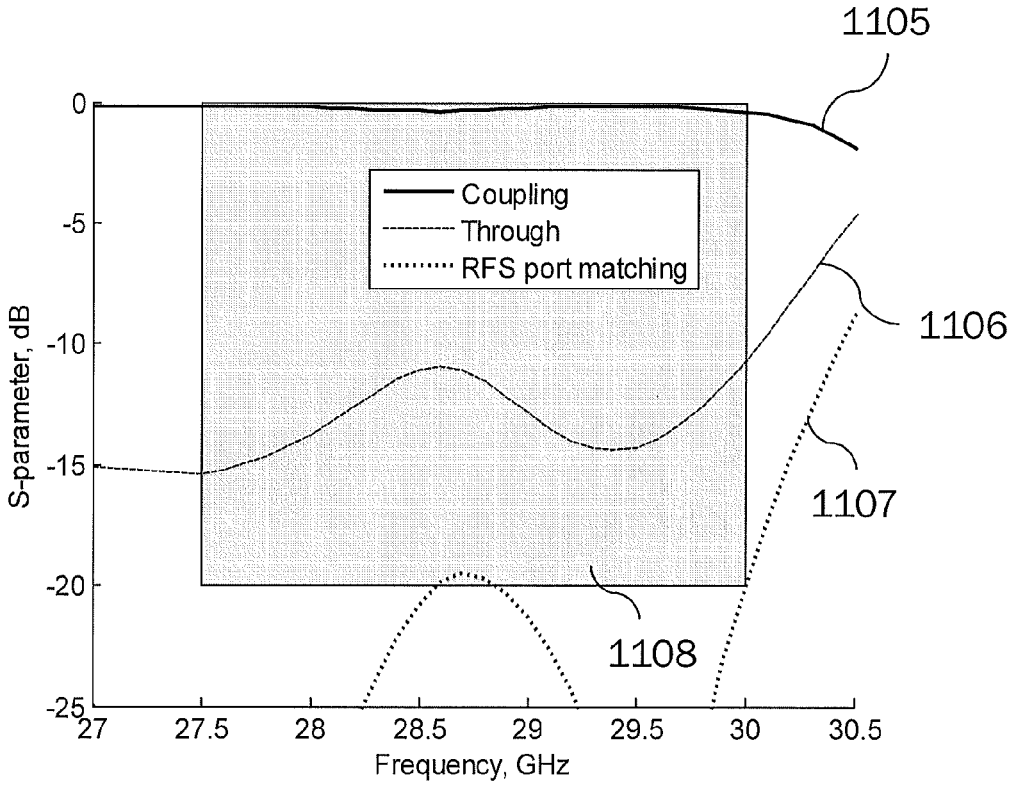

Fig.11B

VERY COMPACT TM01 MODE EXTRACTOR

TECHNICAL FIELD OF THE INVENTION

The present invention relates to a waveguide mode extractor for extracting a higher-order mode, such as the TM01 (TM_{01}) mode, from an incoming electromagnetic signal.

The invention is particularly though not exclusively applicable to feed chains of microwave antennas; such as satellite antennas, and especially to feed chains including a Radio-Frequency Sensing (RFS) system.

BACKGROUND OF THE INVENTION

Feed chains are strategic components for satellite antennas. The current trend in communication satellites is toward multiple beam coverage, requiring more and more feed chains per satellite. This is particularly true for broadband applications at Ka-band, with current antenna designs having about 20 user-link dual-band (transmit and receive) feed chains per reflector in a single-feed-per-beam antenna configuration, and this number is expected to grow by at least a factor of two in the coming decade. This also means that the beam width has to become smaller. Current values of the beam width are in the range of 0.5 to 0.8 degrees and are expected to go down to a beam width of about 0.2 degrees.

In view of this trend, RFS systems used to improve beam pointing accuracy are of particular importance. One key component of RFS systems is the mode extractor at feed chain level, since the use of higher-order modes, such as the TM01 and TE21 (TE_{21}) modes, enables refined pointing performance. These modes provide radiation patterns with a null on-axis, referred to as a "difference pattern" as illustrated in FIG. **1**, in which the abscissa indicates an angle of observation in degrees at the location of the RFS system, and the ordinate indicates a signal strength in dB. In the figure, an example of the difference pattern **102** is represented by the dashed line, while an example of a "sum pattern" **101**, typically produced by the fundamental modes TE11 (TE_{11}), is represented by the solid line. The difference pattern enables more accurate pointing than the sum pattern. The RFS port extracts a signal from a beacon station that is usually located within the coverage in order to enable accurate beam pointing. However, this requires that at least one of the user-link feed chains per reflector antenna comprises a mode extractor for RFS purposes, i.e. a mode extractor capable of extracting a higher-order mode having a difference pattern.

In order to keep the feed cluster volume as small as possible, a very compact mode extractor for the RFS system is required. On the other hand, the mode extractor should also be compatible with a generic design for the user-link feed chain so that the mode extractor may be employed in different feed chains without having to adapt or customize the respective feed chain to the mode extractor beforehand.

In the prior art two main groups of configurations for feed chains in RFS systems, or more generally, feed chains comprising a mode extractor are known. The first group of configurations is based on the extraction of the TE21 mode with a mode extractor **201** arranged in between the antenna horn **203** and the user-link feed chain **202**, as schematically illustrated in FIG. **2**. This approach enables to use a generic feed chain design for the user-link, provided that the TE21 mode extractor **201** is designed so as to have limited impact on the fundamental modes over the two operating frequency bands (transmit and receive). An example of implementation is described in P. Lepeltier et al., "Thales Alenia Space France antennas: recent achievements and future trends for telecommunications", in proceedings of the 2nd European Conference on Antennas and Propagation (EuCAP), pp. 1-5, 2007. According to this implementation, a coupling device is used to extract the TE21 mode. However, this requires a long coupling section and a specific combination network. In consequence, the mode extractor according to this implementation is ab aft the same size as a complete transmit/receive user-link feed chain.

J. C. Lafond et al., "Thales Alenia Space France antennas: recent achievements for telecommunications", in proceedings of the 5th European Conference on Antennas and Propagation (EuCAP), pp. 3193-3197, 2011, illustrates the current trend to reduce feed chain length and diameter. A significant improvement is demonstrated for the user-link feed chain, the length of which is reduced by a factor of two. Naturally, this calls for at least a similar size reduction on the higher-order mode extractor.

The second group of configurations is based on the extraction of the TM01 mode with a mode extractor **301** arranged after the user-link feed chain **302** which is coupled to the antenna horn **303**, as schematically illustrated in FIG. **3**. An example of implementation is described in E. Amyotte et al., "High performance communications and tracking multi-beam antennas", in proceedings of the 1st European Conference on Antennas and Propagation (EuCAP), 2006. This configuration enables the design of a very compact mode extractor. However, the main drawback is that a specific user-link feed chain design is required, i.e. a user-link feed chain design specifically adapted to the mode extractor **301**. In particular, the receive section of the feed chain needs to be modified so as to propagate the required higher-order mode(s), and the septum polarizer, which is usually implemented in the receive chain for reasons of simplicity and compactness, has to be replaced by an orthomode junction (OMJ) associated with a specific combination network. In addition, in this implementation a mode filter is also required, resulting in a more complex feed chain design which is significantly different from the typical user-link only feed chain design. Thus, this approach requires a specific development for the feed chain including RFS, resulting in additional development costs.

The second group of configurations also includes those aiming at extraction of both the TM01 and TE21 modes. An example of implementation is provided in E. Reiche et al., "A dual circular combined K/Ka-band RF sensing feed chain for multi beam satellite antennas", in proceedings of the 5th European Conference on Antennas and propagation (EuCAP), pp. 3198-3202, 2011. This approach still requires a specific user-link feed chain development with the additional design constraint that the TE21 mode also has to propagate in the receive part of the feed. This tends to degrade performance in comparison to a user-link only design, affecting in particular the transmit-to-receive rejection in the receive band which is typically obtained using below cut-off waveguide cross-section filtering.

Summarizing, current implementations of mode extractors are either bulky or require custom feed chain design. In addition, the implementations known in the art tend to have good extraction of the respective higher-order mode only over a limited frequency range, thus requiring the design to be tuned to a given beacon frequency.

SUMMARY OF THE INVENTION

It is an object of the present invention to overcome the limitations of the prior art discussed above. It is another

object of the invention to provide a compact mode extractor for extracting higher-order modes from an electromagnetic signal (higher-order mode extractor). It is yet another object of the invention to provide a higher-order mode extractor compatible with generic user-link feed chains. It is yet another object of the invention to provide a broadband higher-order mode extractor.

In view of the above objects, a mode extractor having the features of claim **1** is proposed. Preferred embodiments of the invention are described in the dependent claims.

According to an aspect of the invention, a mode extractor for extracting a TM01 mode from an (incoming) electromagnetic signal comprises a first turnstile junction and a second turnstile junction, each of the turnstile junctions having a first port, four second ports of rectangular waveguide which are mutually orthogonal and orthogonal to the first port, and a matching section provided at least partially in a center region of the respective turnstile junction, the center region being located at an intersection of the first port and the four second ports, wherein the first turnstile junction and the second turnstile junction are arranged so that longitudinal axes of their first ports are aligned with each other and their first ports are facing in opposite directions, each of the second ports of the first turnstile junction is electromagnetically coupled to a corresponding one of the second ports of the second turnstile junction, and a coaxial coupling device is inserted into the matching section of the first turnstile junction so that a portion of the coaxial coupling device extends into the first port of the first turnstile junction.

By the above configuration, which employs two back-to-back turnstile junctions, i.e. two turnstile junctions which are arranged back to back and coupled through their respective ports of rectangular waveguide, the present invention provides a very compact higher-order mode extractor. It is found that a higher-order mode extractor according to the present invention fits in a cylinder of 32 mm in diameter and 23 mm in height when it is adapted to cover the standard Ka-band allocated to broadband satellite communications, i.e. 17.7-20.2 GHz in transmit and 27.5-30.0 GHz in receive for the space segment. This is about ten times shorter than a standard TE21 mode extractor compatible with a generic user-link feed chain design. Also, the diameter, which is less than two wavelengths at the lowest frequency, is compatible with very compact next-generation user-link feed chain designs. Such a compact design enables to save both cost for material and mass, especially the latter advantage being very important for applications aboard satellites and other space applications.

Further, arranging the coaxial coupling device so as to extend through the matching section into the first port (common port) of the first turnstile junction allows to achieve good matching between the coaxial coupling device and the TM01 mode of the electromagnetic signal, so that the TM01 mode can be extracted with low insertion losses.

On the other hand, the fundamental modes of the electromagnetic signal from which the higher-order mode is extracted are not affected by the mode extraction according to the above configuration, so that the inventive higher-order mode extractor can be said to act as a through for the fundamental modes. This statement is applicable to both the receive (Rx) band and the transmit (Tx) band in commonly used microwave communication bands, such as the Ka-, Ku- and C-bands.

Since the fundamental modes are not affected, the present invention can be considered as belonging to the first group of configurations. Accordingly, the inventive higher-order mode extractor can be used in between the horn and the user-link feed chain of an antenna assembly (feed chain assembly) without necessitating a dedicated design of the user-link feed chain. In other words, the present invention, even if used in between the horn and the user-link feed chain of the antenna assembly, is compatible with a generic user-link feed chain design. Thus, since the inventive higher-order mode extractor is compatible with generic user-link feed chains, it helps to save development costs for user-link feed chains.

Summarizing, the present invention combines the advantages of the two groups of configurations described above while avoiding their respective drawbacks.

The second ports of the first turnstile junction may be electromagnetically coupled to the corresponding second ports of the second turnstile junction by intermediate sections of rectangular waveguide that extend in parallel to the longitudinal axis of the first port of the first turnstile junction.

A particular advantage is achieved if each of the intermediate sections of rectangular waveguide has a first step portion at its one end and a second step portion at its other end, the first and second step portions each reducing a respective cross-section of the intermediate section of rectangular waveguide.

By this configuration, the impact of the mode extractor on the fundamental modes can be reduced without affecting the higher-order mode extraction. Additional steps may be added to further improve the matching of the fundamental modes, but also result in a more complex design.

Preferably, the rectangular waveguides of the second ports of the first and second turnstile junctions have a cross-section aspect ratio of less than 1:2. Further preferably, the rectangular waveguides of the second ports of the first and second turnstile junctions have a cross-section aspect ratio between (1:4−x/2) and (1:4+x/2), with $x \leq 0.4$.

Here, the cross-section aspect ratio of a rectangular waveguide is understood to indicate the ratio of the length b of the narrow sides (i.e. short sides) of the transverse cross-section of the rectangular waveguide and the length a of the broad sides (long sides) of the transverse cross-section of the rectangular waveguide, i.e. the cross-section aspect ratio is given by b:a, wherein the transverse cross-section is the cross-section perpendicular to a guide direction (i.e. longitudinal direction) of the rectangular waveguide.

Conventionally, rectangular waveguides are designed to have a cross-section aspect ratio of 1:2. By the above design of the second ports of the first and second turnstile junctions, respectively, which deviates from the conventional design, an improved matching of the TM01 mode to the coaxial coupling device is achieved. On the other hand, the fundamental modes of the electromagnetic signal are hardly affected by this measure.

A further advantage is achieved if the first port of the first turnstile junction has a constricted portion which surrounds the portion of the coaxial coupling device that extends into the first port of the first turnstile junction, and which has a smaller cross-sectional area than the first port of the second turnstile junction. Further, the first port of the first turnstile junction may have a dilated portion which is located between the constricted portion and the center region of the first turnstile junction and which has a larger cross-section than the first port of the second turnstile junction.

Thereby, the matching between the coaxial coupling device and the TM01 mode can be further increased without significantly affecting the fundamental modes.

Preferably, the matching section of the first turnstile junction is symmetric about the longitudinal axis of the first port of the first turnstile junction, the coaxial coupling device is inserted into the matching section of the first turnstile junction through a back wall of the first turnstile junction, which is located on a far side (of the first turnstile junction) from the first port of the first turnstile junction, and extends through the matching section of the first turnstile junction along a center line of the matching section into the first port of the first turnstile junction.

The matching section of the first turnstile junction may comprise one or more matching parts which are concentric to each other, and each of which is a metallic cylinder, cuboid, or frustum, wherein the one or more matching parts are arranged so as to be symmetric about the longitudinal axis of the first port of the first turnstile junction, and at least one of the one or more matching parts protrudes into the first port of the first turnstile junction, and the coaxial coupling device extends through the one or more matching parts along their center axes into the first port of the first turnstile junction.

The matching section of the first turnstile junction may comprise first and second matching parts which are concentric to each other, and each of which is a metallic cylinder, cuboid, or frustum, wherein the first and second matching parts are arranged so as to be symmetric about the longitudinal axis of the first port of the first turnstile junction, and at least one of the first and second matching parts protrudes into the first port of the first turnstile junction, and the coaxial coupling device extends through the first and second matching parts along their center axes into the first port of the first turnstile junction. Additional matching parts may improve the matching of the fundamental modes at the expense of a more complex design.

Further, the coaxial coupling device may be coupled into a rectangular waveguide or to a coaxial cable arranged between the back wall of the first turnstile junction and a back wall of the second turnstile junction, the back wall of the second turnstile junction being located on a far side (of the second turnstile junction) from the first port of the second turnstile junction. Preferably, the coaxial coupling device is a coupling stub or a pin of a coaxial line.

Further preferably, the first ports of the first and second turnstile junctions are circular waveguides (waveguide modes being labeled accordingly). The first matching part may be a first metallic cylinder arranged on the back wall of the first turnstile junction, and the second matching part may be a second metallic cylinder having a smaller diameter than the first metallic cylinder and being arranged on top of the first metallic cylinder.

A standard turnstile junction has poor matching to the TM01 mode. Thus, using a standard design of a turnstile junction based on fundamental-mode-optimization-only as known in the prior art would result in very strong TM01 rejection, leading to a poor higher-order mode extraction. In order to reduce the TM01 mode rejection, the present invention proposes the above configuration which differs from a conventional back-to-back turnstile junction configuration with regard to the cross-section aspect ratio of the ports of rectangular waveguides, the diameter variation of the common port of the first turnstile junction, the variation in the cross-sectional area of the intermediate sections of rectangular waveguide and the particular configuration of the matching sections.

Another aspect of the invention relates to an antenna assembly comprising a user-link feed chain, an antenna horn and the inventive mode extractor. In this antenna assembly, the mode extractor may be arranged between the user-link feed chain and the antenna horn along a signal path.

As described above, the inventive higher-order mode extractor has the property that it acts as a through for the fundamental modes of the electromagnetic signal and can thus be used in between the antenna horn and the user-link feed chain without requiring a dedicated design of the user-link feed chain.

BRIEF DESCRIPTION OF THE FIGURES

The invention is described below in an exemplary manner making reference to the accompanying drawings, of which

FIG. **1** illustrates a sum pattern and a difference pattern corresponding to a feed chain having user-link and RFS ports;

FIG. **2** is a schematic illustration of a first antenna assembly known in the prior art;

FIG. **3** is a schematic illustration of a second antenna assembly known in the prior art;

FIG. **4** is a perspective view of a conventional turnstile junction;

FIG. **5** is a perspective RF-path view of the mode extractor according to the present invention;

FIG. **6** is a perspective mechanical view of the mode extractor according to the present invention;

FIG. **7** is a longitudinal cut through the mode extractor according to the present invention;

FIG. **8** is a cross-sectional cut through the mode extractor according to the present invention;

FIG. **9** is a perspective view of mechanical components from which the mode extractor according to the present invention can be assembled;

FIGS. **10**A and **10**B illustrate an electrical performance of the mode extractor according to the present invention; and

FIGS. **11**A and **11**B illustrate an electrical performance of a modification of the mode extractor according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Preferred embodiments of the present invention will be described in the following with reference to the accompanying figures, wherein in the figures identical objects are indicated by identical reference numbers. It is understood that the present invention shall not be limited to the described embodiments, and that the described features and aspects of the embodiments may be modified or combined to form further embodiments of the present invention.

As will be described in more detail below, the mode extractor according to the present invention comprises two back-to-back turnstile junctions, i.e. two turnstile junctions which are arranged back to back. A conventional waveguide turnstile junction **400**, or rather an RF-path thereof, is schematically illustrated in FIG. **4**. It is understood that the RF-path of the turnstile junction **400** is bounded by metallic walls.

The turnstile junction **400** is composed of a common port **401** (first port), which is a waveguide having either circular or square cross-section, so as to support the two orthogonal fundamental modes and thus support dual-linear or dual-circular polarization operation. Here and in the following, unless indicated otherwise, the term "cross-section" of a waveguide is understood to relate to the transverse cross-section, i.e. the cross-section perpendicular to the guide direction of the waveguide. The turnstile junction **400** fur-

ther comprises four rectangular waveguides **402** (four ports of rectangular waveguide, or second ports) which are arranged symmetrically about a longitudinal axis of the common port and each of which is orthogonal to the longitudinal axis of the common port **401**. In other words, the four ports of rectangular waveguide **402** are coplanar and arranged in a crosswise configuration, i.e. each port of rectangular waveguide **402** is orthogonal to its two adjacent ports of rectangular waveguide **402**.

The conventional turnstile junction **400** further comprises a matching section **404** for matching impedances of the common port **401** and the four ports of rectangular waveguide **402**. The matching section **404** is arranged at least partially inside a center region **403** of the turnstile junction **400**, wherein the center region is understood to be located at an intersection of the common port **401** and the four ports of rectangular waveguide **402**. In other words, the center region **403** is a region in the RF-path of the conventional turnstile junction **400** that looks into each of the common port **401** and the four ports of rectangular waveguide **402**. In more detail, the matching section **404** is provided on a back wall of the turnstile junction **400**. Therein, the back wall of the turnstile junction **400** is a wall bounding the RF-path of the turnstile junction **400**, which is oriented orthogonal to the longitudinal axis of the common port **401** and located at a far side from the common port **401**. In other words, the back wall bounds the four ports of rectangular waveguide **402** and the center region of the turnstile junction **400** to a side located away from the common port **401**. In FIG. **4**, the back wall is located at the bottom of the turnstile junction **400**. The matching section **404** is arranged to be symmetric about the longitudinal axis of the common port **401**, and may extend into the common port **401**. The matching section **404** may consist of (metallic) cuboids, cylinders, cones, pyramids, frustums (of cones or pyramids) or any combination thereof.

An example of turnstile junction using a combination of two cylinders as a matching section is described in M. A. Meyer and H. B. Goldberg, "Applications of the turnstile junction", IRE Transactions on Microwave Theory and Techniques, Vol. 3, No. 6, pp. 40-45, 1955. A combination of two back-to-back turnstile junctions was described in R. Garcia et al., "Circular polarization feed with dual-frequency OMT-based turnstile junction", IEEE Antennas and Propagation Magazine, Vol. 53, No. 1, pp. 226-236, February 2011. This combination of back-to-back turnstile junctions is optimized to operate with the two orthogonal fundamental modes (TE_{11}), and one of the two turnstile junctions is used as an OMJ in combination with filters implemented along the waveguides connecting the rectangular ports of the two turnstile junctions so as to separate transmit and receive user-link signals.

A mode extractor **500** according to the present invention for extracting a TM01 mode from an (incoming) electromagnetic signal will now be described with reference to FIG. **5** to FIG. **8**. FIG. **5** is an RF-path view of the mode extractor **500**, and FIG. **6** is a quarter cut of a mechanical view of the mode extractor **500** showing the actual physical (metallic) walls of the RF-path in FIG. **5**. That is, if properly oriented, the view of FIG. **5** is a negative of the view of FIG. **6**. FIG. **7** is a sagittal cut through the mode extractor **500**, i.e. a cut along a plane spanned by a longitudinal axis (symmetry axis) of one of four ports of rectangular waveguide of a first turnstile junction of the mode extractor **500** and a longitudinal axis of a common port of the first turnstile junction, and FIG. **8** is a top view of the RF-path of the mode extractor **500** along a line of sight extending in parallel to a longitudinal axis of the mode extractor **500**, i.e. along a line of sight extending in parallel to the longitudinal axis of the common port of the first turnstile junction. In FIGS. **7** and **8**, some hidden lines and surfaces are shown.

The mode extractor **500** illustrated in FIG. **5** to FIG. **8** comprises a first turnstile junction **510** and a second turnstile junction **520**, each of which corresponds to the configuration described above with reference to FIG. **4** unless indicated otherwise. The first turnstile junction **510** comprises a common port **511** (first port) and four identical ports of rectangular waveguide **512** (second ports). The four ports of rectangular waveguide **512** are orthogonal to and symmetric about a longitudinal axis of the common port **511**. Thus, the four ports of rectangular waveguide **512** are coplanar and further arranged in a crosswise configuration, i.e. each port of rectangular waveguide **512** is orthogonal to its two adjacent ports of rectangular waveguide **512**. Here, the longitudinal axis of the common port **511** extends along the guide direction of the common port **511** and intersects a transverse cross-section of the common port **511** in its center. In other words, the longitudinal axis of the common port **511** corresponds to a symmetry axis of the common port **511**.

The second turnstile junction **520** comprises a common port **521** (first port) and four identical ports of rectangular waveguide **522** (second ports). The four ports of rectangular waveguide **522** are orthogonal to and symmetric about a longitudinal axis of the common port **521**. Thus, the four ports of rectangular waveguide **522** are coplanar and further arranged in a crosswise configuration, i.e. each port of rectangular waveguide **522** is orthogonal to its two adjacent ports of rectangular waveguide **522**. Here, the longitudinal axis of the common port **521** extends along the guide direction of the common port **521** and intersects a transverse cross-section of the common port **521** in its center. In other words, the longitudinal axis of the common port **521** corresponds to a symmetry axis of the common port **521**.

The first and second turnstile junctions **510**, **520** are arranged in a back-to-back configuration, so that the longitudinal axes of their common ports **511**, **521** are aligned and so that their common ports **511**, **521** are facing away from each other. Thus, a back wall of the first turnstile junction **510** faces a back wall of the second turnstile junction **520**, wherein the back walls are perpendicular to the longitudinal axes of the respective common ports **511**, **521**, and are located at a distal end of the respective turnstile junction **510**, **520** when seen from the respective common port **511**, **521**. Further, the first and second turnstile junctions **510**, **520** are arranged so that the ports of rectangular waveguide **512** of the first turnstile junction **510** are in a parallel relationship to the ports of rectangular waveguide **522** of the second turnstile junction **520**, i.e. each of the ports of rectangular waveguide **512** of the first turnstile junction **510** has its guide direction extending in parallel to the guide direction of a corresponding one of the ports of rectangular waveguide **522** of the second turnstile junction **520**.

According to the inventive configuration, the two turnstile junctions **510**, **520** are connected via simple rectangular waveguides **530** (intermediate sections of rectangular waveguide), since both transmit and receive signals need to propagate from one turnstile junction's common port to the other turnstile junction's common port. The intermediate sections of rectangular waveguide **530** extend with their guide directions in parallel to the guide direction of the common port **511** of the first turnstile junction **510**.

Next, a number of definitions that will be used in the further description of the invention are provided. Each

rectangular waveguide is said to have two broad walls, which are the lateral walls of the respective rectangular waveguide corresponding to broad (i.e. longer) dimensions of the transverse cross-section of the respective rectangular waveguide, and two narrow walls, which are the lateral walls of the respective rectangular waveguide corresponding to narrow (i.e. shorter) dimensions of the transverse cross-section of the respective rectangular waveguide. Therein, lateral walls extend along the guide direction of the respective rectangular waveguide, and the transverse cross-section is the cross-section of the respective rectangular waveguide perpendicular to its guide direction. In the following, the transverse cross-section will be referred to simply as the cross-section.

Inward-facing broad walls of the four ports of rectangular waveguide **512**, **522** of the first and second turnstile junctions **510**, **520** are those broad walls forming part of the respective end walls of the first and second turnstile junctions **510**, **520**, i.e. those broad walls closer to a transverse center plane of the mode extractor **500**, the transverse center plane extending in perpendicular to the guide directions of the common ports **511**, **521** of the first and second turnstile junctions **510**, **520** and between the back walls of the first and second turnstile junctions **510**, **520**. An outward-facing broad wall of each of ports of rectangular waveguide **512**, **522** of the first and second turnstile junctions **510**, **520** is the broad wall opposed to the respective inward-facing broad wall, i.e. the remaining broad wall of the respective port of rectangular waveguide **512**, **522**. Outward-facing broad walls of the intermediate sections of rectangular waveguide **530** are those broad walls more distant from a center axis (longitudinal symmetry axis) of the mode extractor **500**.

In FIG. **5**, the outward-facing broad walls of the four ports of rectangular waveguide **512** of the first turnstile junction **510** are the upper walls of the four ports of rectangular waveguide **512**, and the outward-facing broad walls of the four ports of rectangular waveguide **522** of the second turnstile junction **520** are the lower walls of the four ports of rectangular waveguide **522**. The inward-facing broad walls of the four ports of rectangular waveguide **512** of the first turnstile junction **510** are the lower walls of the four ports of rectangular waveguide **512**, and the inward-facing broad walls of the four ports of rectangular waveguide **522** of the second turnstile junction **520** are the upper walls of the four ports of rectangular waveguide **522**. Further, the outward-facing broad walls of the intermediate sections of rectangular waveguide **530** are those that are visible when viewing the mode extractor **500** from its respective sides.

In a center region **513** of the first turnstile junction **510**, a metallic matching section **514** is provided. Making reference to the above description of the conventional turnstile junction **400**, the center region **513** of the first turnstile junction **510** is located at an intersection of the common port **511** and the four ports of rectangular waveguide **512** of the first turnstile junction **510**. To be more precise, the center region **513** is located at an intersection of an extension of the common port **511** and extensions of the four ports of rectangular waveguide **512** of the first turnstile junction **510**. Thus, the center region **513** is a region in the RF-path of the first turnstile junction **510** that looks into each of the common port **511** and the four ports of rectangular waveguide **512**.

In more detail, the matching section **514** is provided on the back wall of the first turnstile junction **510**. The matching section **514** is arranged so as to be symmetric about the longitudinal axis of the common port **511** of the first turnstile junction **510**, and may extend into the common port **511**. The matching section **514** may consist of (metallic) cuboids, cylinders, cones, pyramids, frustums (of cones or pyramids) or any combination thereof.

In an embodiment of the invention, the common port **511** of the first turnstile junction **510** is a circular waveguide, and the matching section **514** consists of one or more concentric metallic cylinders (matching parts). A first one of the cylinders is arranged on the back wall of the first turnstile junction **510** so as to extend into the center region **513** of the first turnstile junction **510**, and any further metallic cylinders (matching parts) have a smaller diameter than the first cylinder and decreasing diameters from one another, and are arranged on top of the first cylinder or on top of respective further cylinders arranged on top of the first cylinder, in the order of their decreasing diameters.

In a preferred embodiment of the invention, the common port **511** of the first turnstile junction **510** is a circular waveguide, and the matching section **514** consists of two concentric metallic cylinders **514**A, **514**B, wherein the first cylinder **514**A (first matching part) is arranged on the back wall of the first turnstile junction **510** so as to extend into the center region **513** of the first turnstile junction **510**, and the second cylinder **514**B (second matching part) has a smaller diameter than the first cylinder **514**A and is arranged on top of the first cylinder **514**A.

Likewise, in a center region **523** of the second turnstile junction **520**, a metallic matching section **524** is provided. The matching section **524** is provided on the back wall of the second turnstile junction **520**. Further, the matching section **524** is arranged so as to be symmetric about the longitudinal axis of the common port **521** of the second turnstile junction **520**, and may extend into the common port **521**. The matching section **524** may consist of (metallic) cuboids, cylinders, cones, pyramids, frustums (of cones or pyramids) or any combination thereof.

In the preferred embodiment of the invention, the common port **521** of the second turnstile junction **520** is a circular waveguide, and the matching section **524** consists of two concentric metallic cylinders **524**A, **524**B, wherein the first cylinder **524**A is arranged on the back wall of the second turnstile junction **520** so as to extend into the center region **523** of the second turnstile junction **520**, and the second cylinder **524**B has a smaller diameter than the first cylinder **524**A and is arranged on top of the first cylinder **524**A.

In the preferred embodiment of the invention, the matching sections **514** and **524** are identical to reduce the complexity of the design, but to further enhance the RF performance, they may be different in shape and dimensions.

In an alternative embodiment, the common port **511** of thefirst turnstile junction **510** is a square waveguide and the matching section **514** consists of cuboids (right prisms) of square cross-section, a first one of which is arranged on the back wall of the first turnstile junction **510** so as to extend into the center region **513** of the first turnstile junction **510**, and the further cuboids having decreasing cross-sections from one cuboid to another, and being arranged, with their center axes aligned, on top of the first cuboid or respective ones of the further cuboids in order of decreasing size of their cross-sections.

Likewise, in the alternative embodiment, the common port **521** of the second turnstile junction **520** is a square waveguide, and the matching section **524** of the second turnstile junction **520** in the alternative embodiment is constructed and arranged in accordance with the matching section **514** of the first turnstile junction **510**.

In the following, for reasons of conciseness, reference will be made to the first and second cylinders **514**A, **514**B, **524**A, **524**B instead of listing each possible geometric configuration of the matching parts. It is however understood that the following description of the present invention likewise relates to generic matching parts, such as cuboids, cylinders, cones, pyramids, frustums (of cones or pyramids) or any combination thereof.

The first turnstile junction **510** is used as a mode extractor having a coaxial coupling device **540** inserted into the matching section **514**. The coaxial coupling device **540** is a coaxial line embedded in the matching section **514** with a coupling stub or pin coming out of the coaxial line and extending into the common port **511** of the first turnstile junction **510**. The coaxial line may be connected to a coaxial cable or may be used to excite a rectangular waveguide **550** embedded between the back walls of the first and second turnstile junctions **510**, **520**. The coaxial cable or rectangular waveguide **550** is connected to an RFS port. The top view of FIG. **8** illustrates the case of the coaxial line being connected to the rectangular waveguide **550** and shows how the rectangular waveguide **550** that is embedded between the back walls of the first and second turnstile junctions **510**, **520** projects out of the mode extractor **500**.

The coaxial coupling device **540** is inserted into the matching section **514** of the first turnstile junction **510** through the back wall of the first turnstile junction **510** and extends along the center axis (symmetry axis) of the matching section **514**, i.e. along the center axes (symmetry axes) of the first and second cylinders **514**A, **514**B (first and second matching parts), and also along the center axis (symmetry axis) of the common port **511** of the first turnstile junction **510**. A portion of the coaxial coupling device **540** (i.e, the coupling stub or pin) extends into the common port **511** of the first turnstile junction **510**. To this end, the first and second cylinders **514**A, **514**B are designed as hollow cylinders, or as cylinders having a through hole along their center axes. In general, it can be said that the first and second matching parts are hollow or have a through hole along their center axes, or that the matching section **514** is hollow or has a through hole along its center axis, respectively.

The coaxial coupling device **540** allows to extract the radially symmetric TM01 mode from an incoming electromagnetic signal that is collected by the mode extractor **500** without significantly affecting the fundamental modes of the electromagnetic signal (corresponding to the user-link signals).

Cross-section changes in the common port **511** of the first turnstile junction **510** may be used around the portion of the coaxial coupling device **540** which extends into the common port **511** of the first turnstile junction **510** in order to improve the TM01 mode coupling to the coaxial coupling device **540**. As can be seen from FIGS. **5** to **7**, the common port **511** of the first turnstile junction **510** has a first portion **511**A, a second portion (constricted portion) **511**B and a third portion (dilated portion) **511**C, which are arranged in this order and adjacent to each other along the guide direction of the common port **511** of the first turnstile junction **510**, from a distal part of the common port **511** towards a part of the common port **511** meeting with the four ports of rectangular waveguide **512**. In the preferred embodiment, each of the first to third portions **511**A, **511**B, **511**C has the shape of a cylinder in the RF-path view. However, in the alternative embodiment, the first to third portions **511**A, **511**B, **511**C have the shape of a square cross-section in the RF-path view.

An end portion of the third portion (dilated portion) **511**C is located at a position at which the common port **511** intersects with the four ports of rectangular waveguide **512**. The third portion **511**C surrounds a portion of the matching section **514**, or to be more precise, a portion of the second cylinder **514**B. The second portion (constricted portion) **511**B is located adjacent to the third portion **511**C (i.e. more distant from the position at which the common port **511** intersects with the four ports of rectangular waveguide **512**, or more distant from the center region of the first turnstile junction **510**), and surrounds the portion of the coaxial coupling device **540** which extends into the common port **511** of the first turnstile junction **510**. The first portion **511**A is located adjacent to the second portion **511**B, farthest away from the position at which the common port **511** intersects with the four ports of rectangular waveguide **512**.

In the above, it is understood that the statement that the third portion **511**C surrounds a portion of the matching section **514**, or to be more precise, a portion of the second cylinder **514**B, relates to both a case in which said portion of the matching section **514** extends into the third portion **511**C or through the third portion **511**C. It is further understood that the statement that the second portion **511**B surrounds the portion of the coaxial coupling device **540** which extends into the common port **511** of the first turnstile junction **510** relates to both a case in which said portion of the coaxial coupling device **540** extends into the second portion **511**B or through the second portion **511**B. Thus, said statement is understood to also relate to a case in which said portion of the coaxial coupling device **540** extends through the second portion **511**B and further into the first portion **511**A. This case is illustrated in FIG. **6** and FIG. **7**. As can be seen in these figures, said portion of the coaxial coupling device **540** extends, in this order, through the first cylinder **514**A, through the second cylinder **514**B, through the second portion **511**B and into the first portion **511**A of the common port **511** of the first turnstile junction **510**.

The second portion **511**B has a cross-section that is smaller than a cross-section of the common port **521** of the second turnstile junction **520**, i.e. the diameter of the second portion **511**B is smaller than the diameter of the common port **521** of the second turnstile junction **520**. In other words, the second portion **511**B is a constricted portion (i.e. a portion of reduced cross-section compared to the common port **521** of the second turnstile junction **520**). The third portion **511**C has a cross-section that is larger than the cross-section of the common port **521** of the second turnstile junction **520**, i.e. the diameter of the third portion **511**C is larger than the diameter of the common port **521** of the second turnstile junction **520**. In other words, the third portion **511**C is a dilated portion or a widened portion (i.e. a portion of increased cross-section compared to the common port **521** of the second turnstile junction **520**). The first portion **511**A has a cross-section that is equal to the cross-section of the common port **521** of the second turnstile junction **520**, i.e. the diameter of the first portion **511**A is equal to the diameter of the common port **521** of the second turnstile junction **520**.

By this choice of cross-sections of the first to third portions **511**A, **511**B, **511**C of the common port **511** of the first turnstile junction **510**, the coupling of the TM01 mode to the coaxial coupling device **540** and the matching of the fundamental modes TE11 are improved.

To further improve TM01 mode extraction, a key design parameter is the dimension of the small-wall in the cross-section of the rectangular waveguides of the four ports of rectangular waveguide **512**. Here, the small-wall, or narrow wall, is the wall of the rectangular waveguide corresponding to shorter ones (narrow ones) of the sides of the (transverse)

cross-section of the rectangular waveguide, wherein the transverse cross-section, or simply cross-section for short, is the section through the rectangular waveguide perpendicular to its guide direction. As the present inventor has realized, reduction of the dimension of the small-wall in the cross-section of the rectangular waveguides results in a significant increase in the coupling of the TM01 mode to the coaxial coupling device **540**.

Since a reduction of the dimension of the small-walls also tends to degrade the throughput of the fundamental modes, a trade-off has to be found between TM01 mode extraction and propagation of the fundamental modes through the mode extractor **500**. In the inventive mode extractor **500**, a cross-section aspect ratio of the rectangular waveguides of the ports of rectangular waveguide **512**, **522** of the first and second turnstile junctions **510**, **520**, respectively, is smaller than 1:2, wherein the cross-section aspect ratio indicates the ratio between the dimension of the narrow walls and the dimension of the broad walls of the rectangular waveguide. In other words, the cross-section aspect ratio is the height-to-width ratio of the cross-section of the rectangular waveguide.

A good starting point for optimization is an aspect ratio of 1:4 for the cross-section of the rectangular waveguides. Thus, in a preferred embodiment, the mode extractor **500** has an aspect ratio of the cross-section of the rectangular waveguides of the ports of rectangular waveguide **512**, **522** of the first and second turnstile junction **510**, **520**, respectively, between (1:4−x/2) and (1:4+x/2), with $x \leq 0.4$. Further preferably, the cross-section aspect ratio is between (1:4−x/2) and (1:4+x/2), with $x \leq 0.2$. Yet further preferably, the cross-section aspect ratio is between (1:4−x/2) and (1:4+x/2), with $x \leq 0.1$.

Additional grooves, corrugations, irises or any other well-known features typically used by the expert in the field to improve return losses may be implemented in the common ports **511**, **521** of the first and second turnstile junctions **510**, **520** and/or in the intermediate sections of rectangular waveguide **530** connecting the two back-to-back turnstile junctions **510**, **520** so as to improve the overall RF performance of the mode extractor **500**. Such features may also be added in the coaxial coupling device **540** or to the rectangular waveguide **550** embedded between the back walls of the first and second turnstile junctions **510**, **520** so as to improve return losses of the RFS port and to provide a generic mode extractor design covering the full receive band with excellent RF performance. As an example, the impact of such modifications will be discussed below with reference to FIGS. **11**A and **11**B.

As can be seen in FIGS. **5** to **9**, each of the intermediate sections of rectangular waveguide **530** has a first step portion **530**A at its one end and a second step portion **530**B at its other end. The first step portion **530**A is provided at the broad wall of each intermediate section **530** that faces outwards (i.e. the broad wall of the respective intermediate section **530** most remote from the center axis of the mode extractor **500**) at a position at which the respective intermediate section **530** meets with a corresponding one of the four port of rectangular waveguide **511** of the first turnstile junction **510**. Thus, the first step portion **530**A is provided at the meeting edge of the outward-facing broad wall of the intermediate section **530**, and the outward-facing broad wall of the corresponding one of the four ports of rectangular waveguide **512** of the first turnstile junction **510**, wherein the outward-facing broad wall of the corresponding one of the four ports of rectangular waveguide **512** is the broad wall most remote from a center transverse plane of the mode extractor **500**.

The second step portion **530**B is provided at the outward-facing broad wall of each intermediate section **530** at a position at which the respective intermediate section **530** meets with a corresponding one of the four port of rectangular waveguide **522** of the second turnstile junction **520**. Thus, the second step portion **530**B is provided at the meeting edge of the outward-facing broad wall of the intermediate section **530**, and the outward-facing broad wall of the corresponding one of the four ports of rectangular waveguide **522** of the second turnstile junction **520**, wherein the outward-facing broad wall of the corresponding one of the four ports of rectangular waveguide **522** is the broad wall most remote from a center transverse plane of the mode extractor **500**.

Each of the first and second step portions **530**A, **530**B, which are preferably identical in their dimensions for reasons of symmetry, reduces the area of the cross-section of the respective intermediate section of rectangular waveguide **530**. These step portions improve the transfer of the fundamental modes between the two common ports **511**, **521**. Additional step portions may be implemented to further reduce insertion losses affecting the fundamental modes.

In a feed chain assembly using the mode extractor **500**, the common port **511** of the first turnstile junction **510** is to be connected to a horn antenna of the feed chain assembly, and the common port **521** of the second turnstile junction **522** is to be connected to a generic user-link feed chain of the feed chain assembly. Thus, the mode extractor **500** is configured for a feed chain assembly as illustrated in FIG. **2**, with the difference that according to the present invention the TM01 mode is extracted by the mode extractor **500** instead of the TE21 mode. The resulting feed chain assembly, including the mode extractor **500**, may be used in the focal plane of a multiple beam reflector antenna operating in a single-feed-per-beam configuration. The focal plane of this reflector antenna comprises several generic user-link-only feed chains and at least one generic user-link and mode extractor feed chain. The resulting antenna farm for a typical multiple beam communication satellite application comprises typically three or four of these single-feed-per-beam reflector antennas, each having at least one feed chain comprising the mode extractor **500**.

FIG. **9** illustrates a method for assembly of the inventive mode extractor **500**. According to this method, the mode extractor **500** is assembled by joining together a first part **910**, a second part **920**, and a third part **930**, which are all metallic parts except for the coaxial coupling device **540** (coaxial probe) which may use another materials such as dielectric materials so as to hold the pin. The first and third parts **910**, **930** are identical, so that in the following only the third part **930** will be described. The third part **930** comprises a disk-like cylindrical first portion to which a cylindrical second portion housing the common port **521** of the second turnstile junction **520** is joined. On a side of the first portion facing away from the second portion a cross-shaped recess is formed that corresponds to the four ports of rectangular waveguide **522** of the second turnstile junction **520**. At the end of each arm of the cross-shaped recess, a portion having reduced depth is provided, which corresponds to a respective one of the second step portions **530**B of the intermediate sections of rectangular waveguide **530**. At a distal end of the second portion of the third part **930**,

a waveguide flange is provided for connecting the common port **522** of the second turnstile junction **520** to e.g. the user-link feed chain.

The second part **920** has the shape of a disk with four rectangular through-holes provided along the circumference of the disk at equal angular intervals. These through-holes correspond to a middle portion of the intermediate sections of rectangular waveguide **530**. On the top and bottom surfaces of the second part **920**, corresponding to the inward-facing broad walls of the four ports of rectangular waveguide **512**, **522** of the first and second turnstile junctions **510**, **520**, the matching sections **514**, **524** of the first and second turnstile junctions **510**, **520** are provided. Between the top and bottom surfaces of the second part **920**, a hollow is formed that has the shape of a rectangular cuboid and extends from a lateral cylindrical surface of the second part **920** to slightly beyond the center of the second part **920**. This hollow corresponds to the rectangular waveguide **550** embedded between the back walls of the first and second turnstile junctions **510**, **520**. Further, the coaxial coupling device **540** is inserted into the second part **920** to extend from the hollow corresponding to the rectangular waveguide **550** through the matching section **514** of the first turnstile junction **510**, and into the common port **511** of the first turnstile junction **510**.

As can be inferred from the scales provided at the bottom of FIGS. **5** to **9**, the mode extractor **500** according to the present invention is extremely compact. The RF functional structure tuned to cover the standard Ka-band allocated to satellite communications, i.e. 17.7-20.2 GHz in transmit and 27.5-30.0 GHz in receive, fits in a cylinder of 32 mm in diameter and 23 mm in height. This is about ten times shorter than a standard TE21 mode extractor compatible with a generic user-link feed chain design. The diameter, which is less than two wavelengths at the lowest frequency, is compatible with very compact next-generation user-link feed chain designs. Evidently, such a compact design enables to save both cost and mass.

Next, the electrical performance of the mode extractor **500** according to the present invention as illustrated in FIGS. **5** to **9** will be described. The mode extractor **500** has been analyzed using a full-wave electromagnetic (EM) software based on a Finite Element Method (FEM) to assess the potential of the invention. For this analysis, the design of the mode extractor **500** was tuned to cover the standard Ka-band allocated to satellite communications, i.e. 17.7-20.2 GHz in transmit and 27.5-30.0 GHz in receive. To reduce the number of design parameters, it was decide to use two identical turnstile junctions (identical common port, ports of rectangular waveguide and matching section dimensions), although a more advanced design could benefit from asymmetric designs thus providing additional degrees of freedom in the optimization process. The matching sections **514**, **524** of the first and second turnstile junctions **510**, **520** each are a combination of conical frustums with the top disk dimension being imposed by the coaxial line diameter. A cross-section change as described above is added to the common port **511** of the first turnstile junction **510** which is to be connected to the horn, so as to improve the extraction of the TM01 mode.

Simulation results for the electrical performance (RF-performance) of this design are reported in FIGS. **10**A and **10**B, of which FIG. **10**A indicates the S-parameter for the fundamental TE11 modes in units of dB as a function of frequency in units of GHz, and FIG. **10**B indicates the S-parameter of the TM01 mode in units of dB as a function of frequency in units of GHz. Graph **1001** in FIG. **10**A indicates the matching of the input port of the mode extractor **500** to an external port for the fundamental modes (S**11**-component of the S-parameter for the fundamental modes), and graph **1002** indicates the transmission coefficient between the input port and the output port of the mode extractor **500** for the fundamental modes (S**12**-component of the S-parameter for the fundamental modes). The grey areas **1003**, **1004** in FIG. **10**A represent typical transmit band (left grey area **1003**) and receive band (right grey area **1004**) requirements at Ka-band (matching better than −20 dB over operating bands). Graph **1005** in FIG. **10**B indicates the transmission coefficient between the input port and the RFS port of the mode extractor **500** for the TM01 mode (S**13**-component of the S-parameter for the TM01 mode), graph **1006** indicates the transmission coefficient between the input port and the output port of the mode extractor **500** for the TM01 mode (S**12**-component of the S-parameter for the TM01 mode), and graph **1007** indicates the matching of the RFS port of the mode extractor **500** to an external port for the TM01 mode (S**33**-component of the S-parameter for the TM01 mode), wherein the RFS port is indicated by the index **3**. The grey area **1008** in FIG. **10**B represents the receive band requirement at Ka-band.

As can be seen from graph **1001** in FIG. **10**A, matching for the two fundamental TE11 modes is better than −23 dB in the transmit band and −21 dB in the receive band, with insertion losses less than 0.04 dB over the two frequency bands (cf. graph **1002**), not taking into account ohmic losses. Overall, the mode extractor **500** demonstrates wideband behavior which provides some margins to manufacturing errors and typical frequency shifts due to in-orbit temperature variations. The very wideband behavior of the mode extractor **500** also indicates that it could successfully be tuned to operate with similar performance over the Ku-band or C-band, which are used in satellite applications and that may also require compact mode extractors in view of the current trend of extending multiple beam operation to these bands as well. As can be seen from graph **1005** in FIG. **10**B, the mode extractor **500** provides a coupling factor better than 0.6 dB over the full receive band for the RFS mode, which is acceptable for many applications.

To illustrate possible improvement adding typical matching features to the design, a matching section line (which consists of a change in cross-section radius) was added to the coaxial line, i.e. to the coaxial coupling device **540**. The simulation results obtained following an optimization are reported in FIGS. **11**A and **11**B, of which FIG. **11**A indicates the S-parameter for the fundamental modes in units of dB as a function of frequency in units of GHz, and FIG. **11**B indicates the S-parameter of the TM01 mode in units of dB as a function of frequency in units of GHz. Graph **1101** in FIG. **11**A indicates the S**11**-component of the S-parameter for the fundamental modes, and graph **1102** indicates the S**12**-component of the S-parameter for the fundamental modes. In FIG. **11**B, graph **1105** indicates the S**13**-component of the S-parameter for the TM01 mode, graph **1106** indicates the S**12**-component of the S-parameter for the TM01 mode, and graph **1107** indicates the S**33**-component of the S-parameter for the TM01 mode. Also here the grey areas **1103**, **1104**, **1108** represent the transmit band and receive band requirements at Ka-band, respectively.

As can be seen from FIG. **11**B, the performance of the RFS port is significantly improved by adding typical matching features. The port matching is better than −19 dB over the full receive band (in FIG. **10**B, the worst case over the receive band was −11 dB while the best case was −18 dB). This is connected to an improved coupling factor which is

now better than 0.4 dB over the full receive band. On the other hand, the modifications to the design parameters only slightly affect the response to the fundamental modes, so that the matching for the fundamental modes illustrated in FIG. 11A remains better than −20 dB over the transmit and receive bands. This corresponds to insertion losses better than 0.05 dB over said two frequency bands, again not taking into account ohmic losses.

The above analyses confirm that the present invention provides for broadband mode extraction which only minimally affects propagation of the fundamental modes, thus resulting in a generic mode extractor design which also has a positive impact on development costs.

The above description of the invention is based on a standard turnstile junction having four ports of rectangular waveguide (second ports), as this symmetrical arrangement naturally provides better performance in the case of dual-polarization operation. In case only single linear polarization operation is needed, the number of ports of rectangular waveguide could be reduced to two.

In addition, the above description of the invention has been provided in the specific case of a space segment for multiple beam broadband satellite communication applications, but the invention may find application in any field requiring feeds with enhanced pointing capability and stringent constraints in both mass and dimensions. This may include the ground segment for satellite communication applications (ground stations and terminals), test range applications, etc.

Features, components and specific details of the structures of the above-described embodiments may be exchanged or combined to form further embodiments optimized for the respective application. As far as those modifications are readily apparent for an expert skilled in the art, they shall be disclosed implicitly by the above description without specifying explicitly every possible combination, for the sake of conciseness of the present description.

What is claimed is:

1. A mode extractor for extracting a TM01 mode from an electromagnetic signal, comprising a first turnstile junction and a second turnstile junction, each of the turnstile junctions having a first port, four second ports of rectangular waveguide which are mutually orthogonal and orthogonal to the first port, and a matching section provided at least partially in a center region of the respective turnstile junction, the center region being located at an intersection of the first port and the four second ports,

wherein the first turnstile junction and the second turnstile junction are arranged so that longitudinal axes of their first ports are aligned with each other and their first ports are facing in opposite directions,

each of the second ports of the first turnstile junction is electromagnetically coupled to a corresponding one of the second ports of the second turnstile junction, and

a coaxial coupling device is inserted into the matching section of the first turnstile junction so that a portion of the coaxial coupling device extends into the first port of the first turnstile junction.

2. The mode extractor according to claim **1**, wherein the rectangular waveguides of the second ports of the first and second turnstile junctions have a cross-section aspect ratio of less than 1:2.

3. The mode extractor according to claim **1**, wherein the rectangular waveguides of the second ports of the first and second turnstile junctions have a cross-section aspect ratio between (1:4−x/2) and (1:4+x/2), with $x \leq 0.4$.

4. The mode extractor according to claim **1**, wherein the second ports of the first turnstile junction are electromagnetically coupled to the corresponding second ports of the second turnstile junction by intermediate sections of rectangular waveguide that extend in parallel to the longitudinal axis of the first port of the first turnstile junction.

5. The mode extractor according to claim **4**, wherein each of the intermediate sections of rectangular waveguide has a first step portion at its one end and a second step portion at its other end, the first and second step portions each reducing a respective cross-section of the intermediate section of rectangular waveguide.

6. The mode extractor according to claim **1**, wherein the first port of the first turnstile junction has a constricted portion which surrounds the portion of the coaxial coupling device that extends into the first port of the first turnstile junction, and which has a smaller cross-section than the first port of the second turnstile junction.

7. The mode extractor according to claim **6**, wherein the first port of the first turnstile junction has a dilated portion which is located between the constricted portion and the center region of the first turnstile junction and which has a larger cross-section than the first port of the second turnstile junction.

8. The mode extractor according to claim **1**, wherein

the matching section of the first turnstile junction is symmetric about the longitudinal axis of the first port of the first turnstile junction,

the coaxial coupling device is inserted into the matching section of the first turnstile junction through a back wall of the first turnstile junction, which is located on a far side of the first turnstile junction from the first port of the first turnstile junction, and

the coaxial coupling device extends through the matching section of the first turnstile junction along a center line of the matching section into the first port of the first turnstile junction.

9. The mode extractor according to claim **8**, wherein

the matching section of the first turnstile junction comprises one or more matching parts which are concentric to each other, and each of which is a metallic cylinder, cuboid, or frustum,

the one or more matching parts are arranged so as to be symmetric about the longitudinal axis of the first port of the first turnstile junction, and at least one of the one or more matching parts protrudes into the first port of the first turnstile junction, and

the coaxial coupling device extends through the one or more matching parts along their center axes into the first port of the first turnstile junction.

10. The mode extractor according to claim **8**, wherein

the matching section of the first turnstile junction comprises first and second matching parts which are concentric to each other, and each of which is a metallic cylinder, cuboid, or frustum,

the first and second matching parts are arranged so as to be symmetric about the longitudinal axis of the first port of the first turnstile junction, and at least one of the first and second matching parts protrudes into the first port of the first turnstile junction, and

the coaxial coupling device extends through the first and second matching parts along their center axes into the first port of the first turnstile junction.

11. The mode extractor according to claim **8**, wherein the coaxial coupling device is coupled into a rectangular waveguide or to a coaxial cable arranged between the back wall of the first turnstile junction and a back wall of the second

turnstile junction, the back wall of the second turnstile junction being located on a far side of the second turnstile junction from the first port of the second turnstile junction.

12. The mode extractor according to claim **1**, wherein the coaxial coupling device is a coupling stub or a pin of a coaxial line.

13. The mode extractor according to claim **1**, wherein the first ports of the first and second turnstile junctions are circular waveguides.

14. The mode extractor according to claim **13**, wherein the first matching part is a first metallic cylinder arranged on a back wall of the first turnstile junction, and the second matching part is a second metallic cylinder having a smaller diameter than the first metallic cylinder and being arranged on top of the first metallic cylinder.

15. An antenna assembly comprising a user-link feed chain, an antenna horn and the mode extractor according to claim **1**.

16. The antenna assembly according to claim **15**, wherein the mode extractor is arranged between the user-link feed chain and the antenna horn along a signal path.

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