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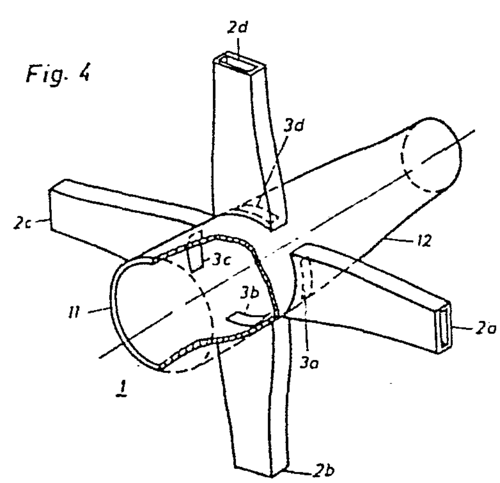
(54) Mode coupler in an automatic angle tracking system.

(57) the invention relates to a mode coupler which, for example is included in an angle tracking system of a satellite to establish a telecommunication between the transmitting and the receiving ground stations. The mode coupler is realized through a circular main wave guide (1) which also can include the feeding horn of the satellite antenna in which a basic mode, for example the TE_{11}-mode of the incoming circular polarized wave guide field appears and which procures two communication channels (f_1-f_2 and f_3-f_4 respectively), as well as a beacon frequency (f_b). To the main wave guide four rectangular wave guide arms (2a-2d) are connected via the associated apertures (3a-3d). The main wave guide is dimensioned as a mode filter for filtering away the non-desired higher modes TE_{21} and TM_{01} and the wave guide arms are dimensioned as a frequency filter for filtering away the frequency bands of the communication channels. From the higher modes TE_{21} and TM_{01}, the difference- and the sum signals are created in known way to provide a measure of the angle error of the satellite antenna.

Fig. 4



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MODE COUPLER IN AN AUTOMATIC ANGLE TRACKING SYSTEM

FIELD OF THE INVENTION

The present invention relates to a mode coupler according to the preamble of the claim 1, included in an automatic angle tracking system in microwave antennas, operating with circular polarization. The tracking system can be included in a satellite for telecommunication between one or several transmitting ground stations and a number of receiving ground stations, the tracking system keeping the antenna of the satellite directed towards a certain area of the ground by means of a so called beacon signal from one of the transmitting ground stations.

DESCRIPTION OF PRIOR ART

It is previously known that higher order modes arise in microwave antennas, the modes having odd character when the receiving radiation incides obliguely towards the antenna. The number of modes obtained is determined by the cut-off wavelength of the respective mode in the feeding wave guide and if this is greater than the actual wavelength. The strength of the odd modes in relation to the even basic mode for a certain antenna only depends on the angle deviation and is for a small amount approximately proportional to this deviation. By "mode coupler" is in the present application meant an arrangement which can separate the basic mode from the various higher order modes and deliver output signals proportional to the strength of the various higher modes.

A known tracking system with the property to detect a certain deviation (the pointing error) between the reflector axis of a ground station and the direction of a target by separating the higher order modes from the basic mode is described in Bell System Technical Journal, July 1963, pages 1283-1307. In this system a circular waveguide is connected to the feeding horn, only the basic mode being formed in the wave guide if the pointing error is zero, i e if the antenna is perfectly directed towards the target. Otherwise higher modes arise in the wave guide, among which one, namely the TM_{01} is employed to form error signals together with the basic mode and which are allowed to control the regulating circuits in the antenna system of the ground station so that the pointing error will become zero. In the mode coupler a sum signal is obtained from the basic mode and a difference signal from the higher mode TM_{01}. The error signals, for example in the elevation and the azimuth directions are in the receiver of the tracking system indicated by means of the difference and the sum signals, the amplitude and the phase position of the difference signal relatively the sum signal determining the magnitude of the angle deviation of the target from the antenna axis and the direction of the deviation, respectively. To obtain good accuracy in this system, a very good phase equality between the signal paths is required for the sum and the difference signals, particularly at off-boresight tracking. As also shown in the mentioned article, the system is sensible to changes in the polarization of the beacon signal. In another known system, operating according to the same principle and described in the USA Patent 3.821.741, a first and a second higher mode, TM_{01} and TE_{21}, respectively and the basic mode TE_{11} are employed to create the error signals. This known system contains a mode coupler, consisting of three wave guide sections, which together form the circular wave guide connected to the feeding horn of the system. Two of these wave guide sections are each provided with a pair of rectangular wave guides, which are connected to the main wave guide with a certain aperture to couple out the required higher modes to form difference signals. Together with the sum signal, extracted in another place in the system, the error signals are formed. The employment of two higher modes TM_{01} and TE_{31} makes it possible for the system to work with not fully circularly polarized signals and to deliver difference signals, insulated between themselves, for two perpendicular planes, which implies lower demands regarding the phase equality between the signal paths compared with previous system. However, the different coupling-out points from the circular wave guide of the two higher modes will imply difficulties in maintaining the phase equality between the difference and the sum signals at varying temperature or frequency. Phase differences between these signals will lead to varying sensitivity upon reception and particularly at off-boresight tracking to a direct pointing error.

SUMMARY OF THE INVENTION

In a system of the above mentioned kind, error signals in two planes, for example the elevation and the azimuth planes, are to be created which are depending only on the difference angles of the target in these planes but not on variations in the strength of the beacon signal (the fading) and the polarization (the depolarization) within certain limits. Such variations arise, for example, through the influence of the atmosphere on the wave propagation. The system should also be as unsensible as possible to changes in the characteristics of the components which inevitably arise, for example in time or at varying temperature. It is of importance partly to employ appropriate wave guide modes and partly to couple out these in appropriate manner to create the sum- and the difference signals and partly to let the signals be conducted the same or possibly equal paths from the antenna to the receiver. Otherwise, varying sensitivity at reception or eventual pointing error is obtained. Particularly at off-boresight tracking, also pointing errors are obtained as a consequence of the sensitivity variation.

According to the present invention, two higher modes TM_{01} and TE_{21} and the basic modes TE_{11V} and TE_{11H} in a smooth wave guide, or E_{02} and HE_{21} and HE_{11V} and HE_{11H} in a corrugated wave guide are employed and all the employed modes are coupled out in the same section of the circular main wave guide, whereupon from these modes, two sum and two difference signals are formed and guided through a common receiver channel, whereby the difficulties in keeping the signals equal in phase are avoided. In the receiver, the error signals are produced in the two planes by employing the sum and difference signals belonging to the respective planes. The object of the present invention is thus to provide a mode coupler, which conducts two higher modes and two basic modes in order to create two difference signals (for example denominated Δx and Δy) and two sum signals (for example Σx and Σy), the obtained modes and the sum-difference-signals travelling an equal path through the tracking system and, in addition, in pairs (Σx , Δx and Σy ,Δy) showing the same influence from the depolarization of the beacon signal. The invention is then characterized as appears from the characterizing part of claim 1.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be more fully described below with reference to the accompanying drawings, where
Fig 1 shows a frequency diagram which indicates the position of the transmitter channel, the receiver channel and the beacon frequency of the tracking system in which the mode coupler according to the invention is included.

Fig 2 shows a simplified field pattern of the two employed higher modes and the basic mode in the main wave guide included in the tracking system.

Figs 3a-3f illustrate schematicly how the error signals in the tracking system are formed from the two higher modes, shown in Fig 2.

Fig 4 shows a perspective view of the mode coupler according to the invention.

Fig 5 shows a side view of the part of the mode coupler, according to Fig 4, which filters away the two higher modes.

Fig 6 shows more fully a rectangular wave guide arm which is included in the mode coupler according to Fig 4.

Fig 7 shows a circuit diagram which illustrates the creation of a reference signal and error signals.

PREFERRED EMBODIMENTS

Before the description of the mode coupler according to the present invention, the known principle, according to above, for forming the error signals when tracking by means of two higher wave guide modes will be more fully illustrated. The tracking system, in which the proposed mode coupler is included, represents a part of the telecommunication equipment of a satellite, which receives, treats and transmits the signals received from the ground station to a number of other ground stations. The transmission is carried out by RF-signals and for that purpose two frequency bands are selected, which are schematicly shown in Fig 1. The band f_1-f_2 (for example 400 MHz) with the center frequency f_T forms the transmitter channel for a certain ground station and the band f_3-f_4 with the center frequency f_R forms the receiver channel for the station. The transmission of the transmitter and the receiver channels is carried out within the GHz-band and by means of a reflector antenna, with a horn antenna as feeder. For transmission of the direction information, there is a beacon frequency f_b, for example 12.498 GHz. The two bands f_1-f_2 and f_3-f_4 can either be situated below the beacon frequency f_b, as shown in Fig 1, or above this frequency. In certain cases only one band is used (an antenna for transmitting from or reception to a satellite only).

In Fig 2 it is shown more detailed the two higher modes, which arise in the main wave guide of the tracking system, the guide being connected to the antenna. The modes are employed to indicate an eventual deviation between the directions of the reference signal of the antenna and the target direction.

Moreover the two basic modes TE_{11V} and TE_{11H} (smooth-walled wave guide; HE_{11V} and HE_{11H} for corrugated wave guide) are shown. These are employed for transmitting the telecommunication signals and for normalization of the difference signals. The principle of the tracking is that the two modes TE_{21} and TM_{01} in a smooth-walled wave guide (or corresponding modes HE_{21} and E_{02} in a corrugated wave guide), according to Fig 2, which have the same amplitude and phase in the y-direction, and opposite phase but the same amplitude in the x-direction are added to form the error signals Δx and Δy. The principle is generally shown in the figures 3a-3f. The figures 3a-3c show the addition of the two modes, a signal representing the error in the y-direction (the elevational error) being obtained, while the figures 3d-3f show subtraction of the two modes, a signal representing the error in the x-direction (the azimutal error) being obtained.

The structure of the mode coupler in the tracking system appears from Fig 4. It consists of a circular wave guide 1, which is connected to the feeding horn, not shown, in the tracking system, and to a polarization unit, which is not shown in the description. The main wave guide 1 can either constitute an integrated part of the feeding horn or consist of a separate part connected to the feeding horn. The wave guide walls can either be performed with smoothed or corrugated surfaces. Four rectangular wave guide arms 2a-2d are provided to the circular main wave guide 1, which each are coupled to the wave guide 1 by the apertures 3a-3d. The apertures 3a-3d are arranged relatively displaced 90° around the outer circumference of the wave guide 1. In Fig 4, the front part 11 of the wave guide 1 is shown in a cut feature in order to make the positions of the apertures clear.

Characteristic for the proposed mode coupler is that the rectangular wave guide arms 2a-2d are connected to the main wave guide 1 in the same section. The front part 11 constitutes the feeding horn or is connected to the horn in known manner, this part of the circularly polarized wave guide field in the TE_{11}-mode transmitting the two communication channels f_1-f_2, f_3-f_4 and the beacon frequency signal f_b according to Fig 1. According to known principles, the two higher modes TE_{21} and TM_{01}, arising in the main wave guide at a certain angle deviation of the incoming signals to the tracking system are employed to form the error signals Δx and Δy. The coupling of these higher modes is carried out by exciting the TE_{10}-mode in the wave guide arms 2a-2d, from the field in the main wave guide 1 by coupling openings in the form of the apertures 3a-3d. The apertures 3a-3d are preferably of rectangular form and their dimension is chosen in such a way that a sufficient coupling of the TE_{10}-mode is obtained from the wave guide 1 to the rectangular wave guide arms 2a-2d. The inner sectional area of these will, however, be dimensioned so that the TE_{10}-mode propagates in the wave guides 2a-2d at the frequency f_b in known manner. The amplitude and the phase of the TE_{10}-mode occurring in the rectangular wave guides 2a-2d, is then determined by the amplitude and the phase position of the higher modes TE_{21}, TM_{01} and the basic mode TE_{11}, occurring in the main wave guide 1, all the modes giving a certain contribution to the field in the rectangular wave guides 2a-2d.

Fig 5 shows more in detail the circular wave guide 1 of the mode coupler in which, for the sake of clarity, the rectangular wave guide arms 2a-2d are omitted. The rear part 12 of the wave guide 1 shows a tapered part 13, containing two sections I and II. The section I is situated on a distance d_1 from the section, defined by the wave guides 2a-2d, the distance d_1 being chosen for a certain value of the radius R, so that a standing wave for the TE_{21}-mode is created in the wave guide part, limited by the distance d_1 and so that the maximum value of the mode coincides at the apertures 3a-3d or close to these. The section II is situated on a distance d_2 from the mentioned sections, the distance d_2 being chosen so that a standing wave for the TM_{01} is created in the wave guide part limited by the distance d_2 which assumes a maximum value at the apertures 3a-3d or close to these. The distances d_1 and d_2 then form an even (but not necessarily the same) number of quarter-wavelengths for the modes TE_{21} and TM_{01}, respectively. The taped part 13 of the circular wave guide forms a mode filter for filtering away the non-desired modes TE_{21} and TM_{01}, which are reflected back to the apertures 3a-3d at the short circuit planes formed by the sections I and II and, according to above there assume a maximum value. The mode filter 13, however, does not influence the TE_{11}-mode, which transmits the telecommunication signals within the frequency bands f_1-f_2, f_3-f_4, which thus appear across the outlet of the mode coupler. The tapered part 13 has a non-linear contour, which can be determined by experimental measurements.

As previously mentioned, the coupling out from the wave guide field in the circular main wave guide 1 is carried out by means of the four apertures 3a-3d and the TE_{10}-mode is excited in the four wave guide arms 2a-2d. In Fig 6 such a wave guide arm is shown more in detail. It consists of a broader part, connected to the main wave guide, and has the sectional dimensions indicated by a and b, respectively in Fig 6. The dimension b_1 is chosen in such a way that all frequencies of the field in the wave guide 2a from f_1 up to f_b can be propagated in the wave guide as a TE_{10}-mode.

The wave guide 2a has a tapered part which is principally limited by the sections III and IV. At the section III, on the distance d_3 from the aperture 3a, the dimension b_2 of the wave guide is such that the center frequency f_T of the band f_1-f_2 is reflected, i e b_2 is such that the section III forms a short-circuit plane for the TE_{10}-mode at the frequency f_T. According to the same principle, the distance d_4 for the section IV should be chosen in such a way that the dimension b_3 is such that the center frequency f_R of the band f_3-f_4 is reflected. The wave guide sections III and IV thus define a frequency filter for filtering away the telecommunication signals, the distances d_3 and d_4 forming a number (not necessarily the same) of half wave lengths for the TE_{10}-mode at the center frequencies f_T and f_R, i e the sections III and IV form the short circuit planes, transformed to the apertures 3a-3d, for the frequencies f_R and f_T respectively. Thus, from the wave guide 2a and the remaining wave guides 2b-2d, only the signals corresponding to the TE_{11}-mode which has the frequency f_b are obtained and, furthermore, the signals corresponding to the two modes TE_{21} and TM_{01} at the frequency f_b in the main wave guide 1.

In Fig 7 a wave guide network is schematicly shown, consisting of so called magic Ts, which is connected to the four rectangular wave guide arms 2a-2d for recovering the error signals Δx, Δy and the reference signals Σx and Σy. Each connection point m1-m4 represents a magic T with two inputs 1 and 2 and a sum- and a difference output s and Δ, respectively. From Fig 7 the signals, appearing on the outlets of the four wave guide arms 2a-2d, are shown, which are derived from the four modes TE_{21}, TM_{01} and TE_{11H}, TE_{11V}, appearing in the main wave guide 1, cf Fig 2. From these the error signals Δx and Δy are recovered from the modes TE_{21} and TM_{01}, while the reference signals

Σx and Σy are recovered from the TE_{11H}- and TE_{11V}-modes respectively. Fig 7 shows that the signals Δx and Δy are separated in three different stages. In the first stage the signals, derived from the TE_{21}- and TM_{01}-modes in the connection points m1 and m2, are separated. In the second stage, a separation of the two modes TE_{21} and TM_{01} is carried out in the connection point m3 and in the third stage the desired error signals Δx and Δy is formed by vectorial addition in the connection points m4 as shown in Fig 3. Between m3 and m4, phase- and amplitude adjustments can be introduced (trimming and temperature compensation). In some cases this is not necessary, the connection points m3 and m4 being omitted. Herewith can, instead, correct phase- and amplitude properties be obtained by accurate choice of the distances d_1 and d_2 in Fig 5, of the difference in phase propagation between the TE_{21} and TM_{01}-modes when propagating from the orifice of the horn, and of the dimensions of the apertures 3a-3d in Fig 5.

What we claim is:

1 A mode coupler in an automatic angle tracking system in a telecommunication system for transmitting one or more telecommunication frequency bands and a certain beacon frequency, including
a microwave antenna in which a basic mode and modes of higher order are produced when the radiation received by the antenna incides in a plane which does not coincide with the plane perpendicular to the antenna reference axis, said modes of higher order being used to create a pair of error signals representing a measure of the deviation between said planes and to create the associated reference signals,
a smooth or corrugated circular main wave guide which forms part of or is connected to the feeding horn of said antenna and in which the basic mode and said higher order modes propagate and which shows four in a plane perpendicular to the wave guide axis arranged apertures, preferably of rectangular cross-section, and four wave guide arms of rectangular cross-section arranged circumferentially and symmetrically around the main wave guide in the plane perpendicular to the wave guide axis, characterized in that
said apertures (3a-3d) are dimensioned so that a certain wave guide mode (TE_{10}) is created whose amplitude and phase is determined by the amplitude and phase of the basic mode (TE_{11} or HE_{11}) in the main wave guide (1) and at least two higher order modes (TE_{21}, TM_{01} or HE_{21}, E_{02}), and that a wave guide network (m1, m2, m3, m4) is connected to the exit ports of the wave guide arms, said network having four output ports for obtaining output signals of which the first and the second (Σx, Σy respectively), constituting said reference signals, are created from the difference between the signals from a first and a second pair, respectively oppositely situated wave guide arms (2a, 2c and 2b, 2d, respectively) originating from the basic mode (TE_{11}) appearing in the main wave guide,
the third and the fourth (Δx and Δy, respectively), constituting said error signals, are created from the sum of the signals from said first and second pair oppositely situated wave guide arms (2a, 2c and 2b, 2d, respectively) originating from said higher modes (TE_{21}, TM_{01}).

2 A mode coupler according to claim 1, characterized in that the part (12, 13, 14, 15) of the circular main wave guide, which is situated between the wave guide arms (2a-2d) and its exit port is designed as a mode filter for reflection of the two higher modes (TE_{21}, TM_{01}).

3 A mode coupler according to claim 2, characterized in that said part of the main wave guide consists of a main portion (12), a tapered portion (13) and an end portion (15) with a smaller inner radius, the portions being limited by two sections (I, II), whose distances (d_1 and d_2, respectively) to said plane perpendicular to the wave guide axis, is chosen so that the sections constitute short-circuit planes for the two higher modes (TE_{21}, TM_{01} or HE_{21}, E_{02}).

4 A mode coupler according to claim 1, characterized in that each of the four wave guide arms (2a-2d) are designed as a frequency filter for filtering away the telecommunication frequency bands.

5 A mode coupler according to claim 4, characterized in that each of the four wave guide arms (2a-2d) has a base portion of even thickness of a certain cross-sectional dimension (a, b_1), connected to the main wave guide (1), a continuous or a stepwise tapered portion and a portion of even thickness of smaller cross-sectional dimension (a, b_4), two sections (III, IV) being situated on a distance (d_3, d_4) from said apertures (3a-3d) corresponding to the short circuit planes for the basic mode (TE_{10}), transformed to the respective aperture for the center frequencies in the telecommunication frequency bands.

6 A mode coupler according to claim 4, characterized in that each of the four wave guide arms (2a-2d) contains filters, such that the telecommunication frequency bands (f_1-f_2, f_3-f_4) are reflected in a reflection plane substantially coinciding with the inner wall of the cylindrical wave guide (1), while the beacon frequency (f_b) is passed with negligable attenuation.

7 A mode coupler according to the claims 1-6 characterized in that

said wave guide network includes a first and a second directional coupler (m_1 and m_2, respectively) with two inlets (1, 2) and a difference- and sum outlet (Σ and s respectively) which are connected each with their inlets to the exit ports of two opposite wave guide arms (2a, 2c and 2b, 2d respectively) to form said pair of reference signals (Σx, Σy), the sum outlets of the first and the second directional coupler being connected to the two inlets of a third directional coupler (m_3), the difference- and sum outlets of which are connected to the two inlets of a fourth directional coupler (m_4) to obtain said error signals (Δx, Δy) across its difference and sum outlets, which indicate the deviation between said planes.

8 A mode coupler according to claim 7, characterized by that each of the directional couplers (m_1-m_4) is formed by a magic T.

Fig. 1

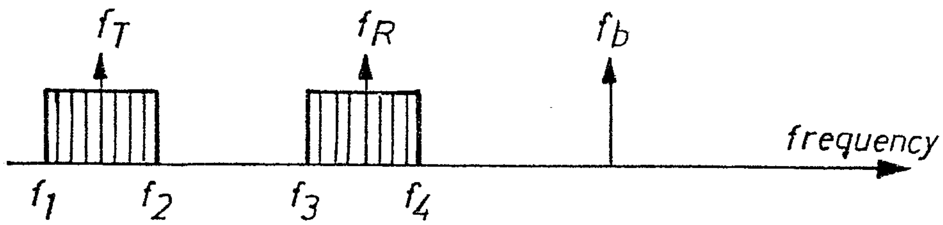


Fig. 2

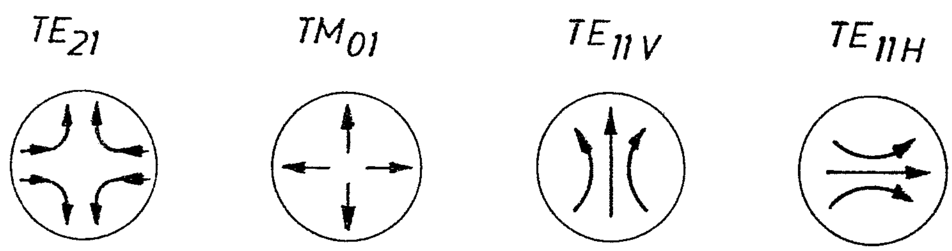


Fig. 3

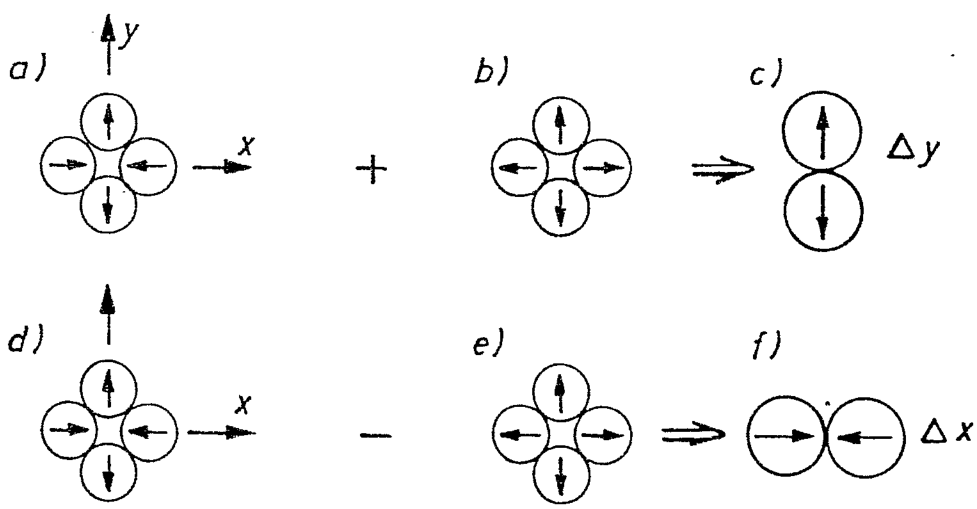
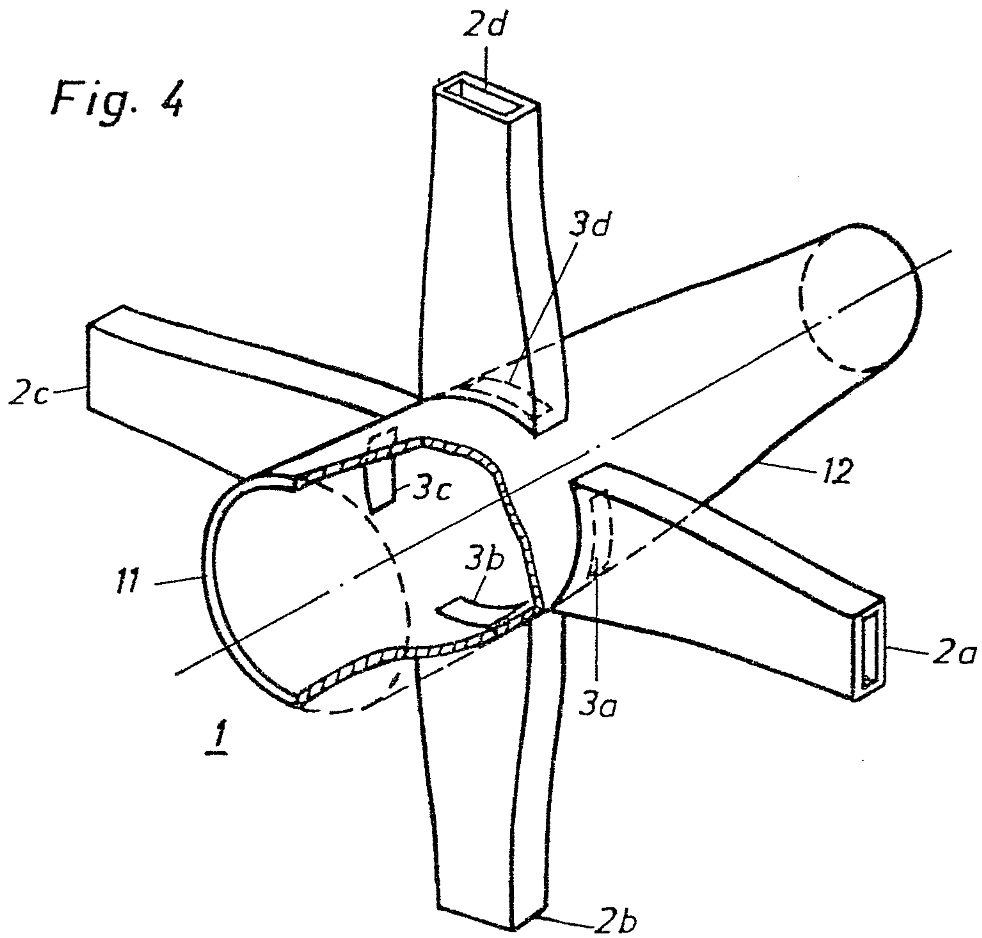


Fig. 4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3c
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3b
2a
3a
1
2b

Fig. 5

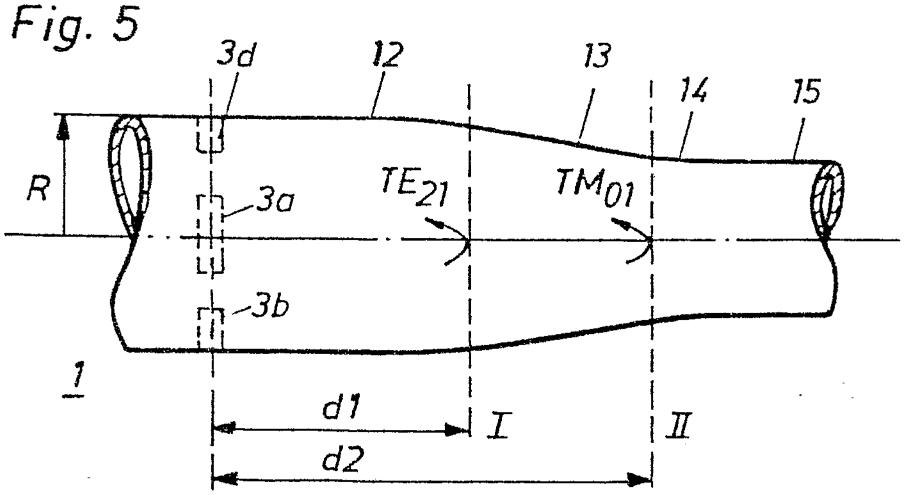
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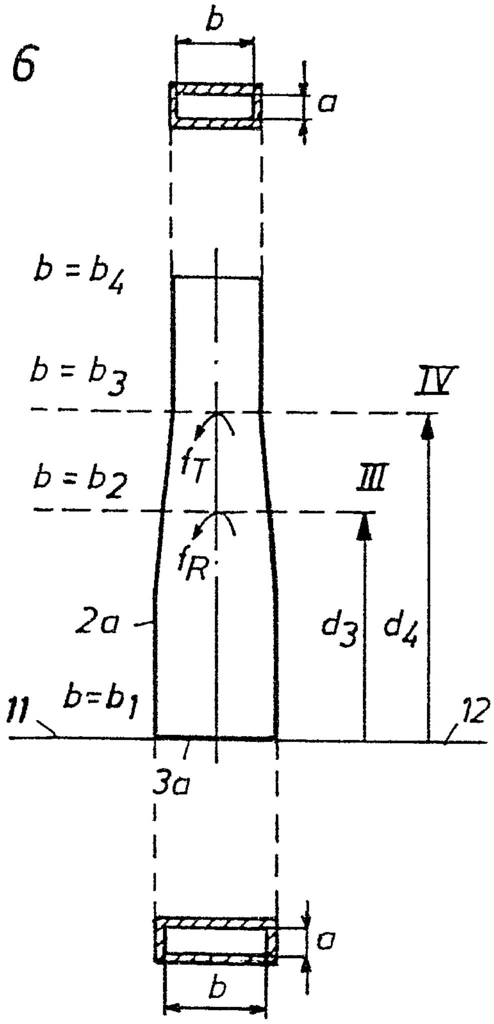
Fig. 6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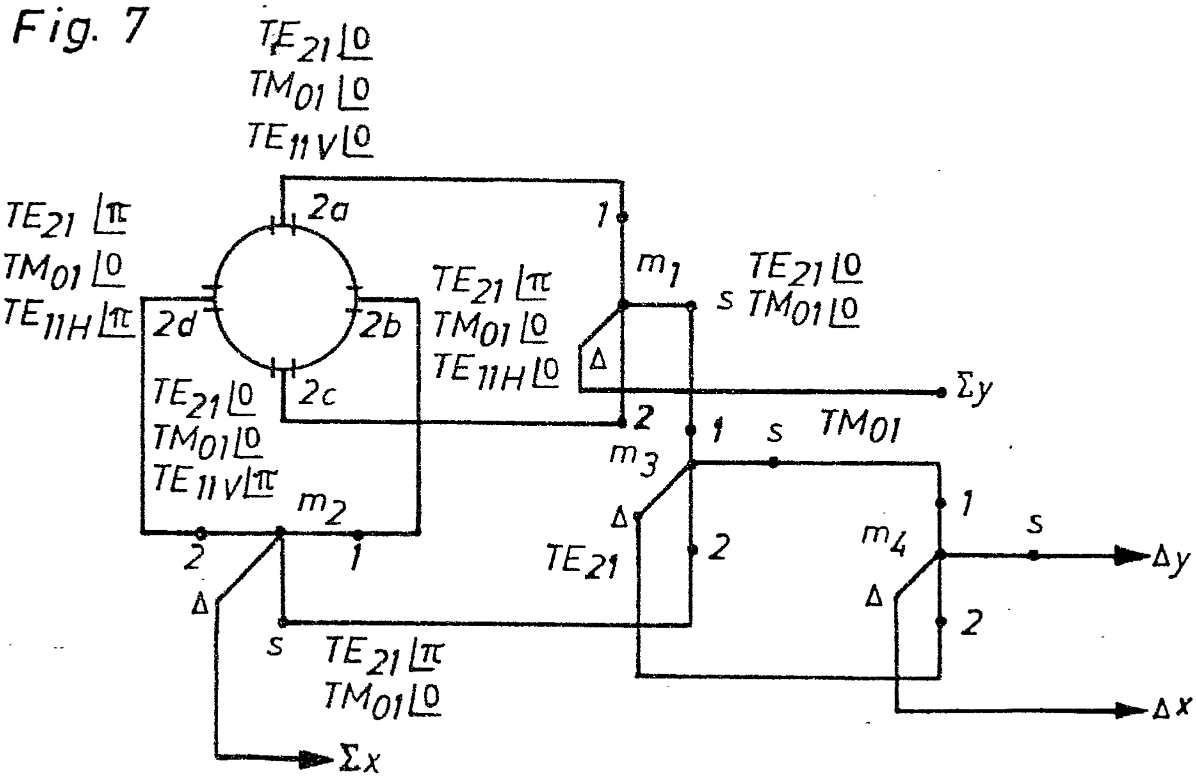
b

Fig. 7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Δ
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