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(54) MICROWAVE PHASE SHIFTER

(57) A microwave phase shifter, comprising:
a non-rotating linear-to-circular polarization converter (1) with a squared cross section, located at one end of the phase shifter (10);
a non-rotating circular-to-linear polarization converter (9) with a squared cross section, located at the opposite end of the phase shifter (10);
a rotatable squared waveguide (2) with a circular-to-linear-to-circular polarization converter, positioned at a middle section of the phase shifter (10);
rotary joints (5, 6) with a circular cross section for rotating the rotatable squared waveguide (2), the rotary joints (5, 6) being located at both ends of the rotatable squared waveguide (2);
mode launchers (3, 4, 7, 8) for adapting the squared waveguides (1, 2, 9) to the circular cross section of the rotary joints (5, 6).

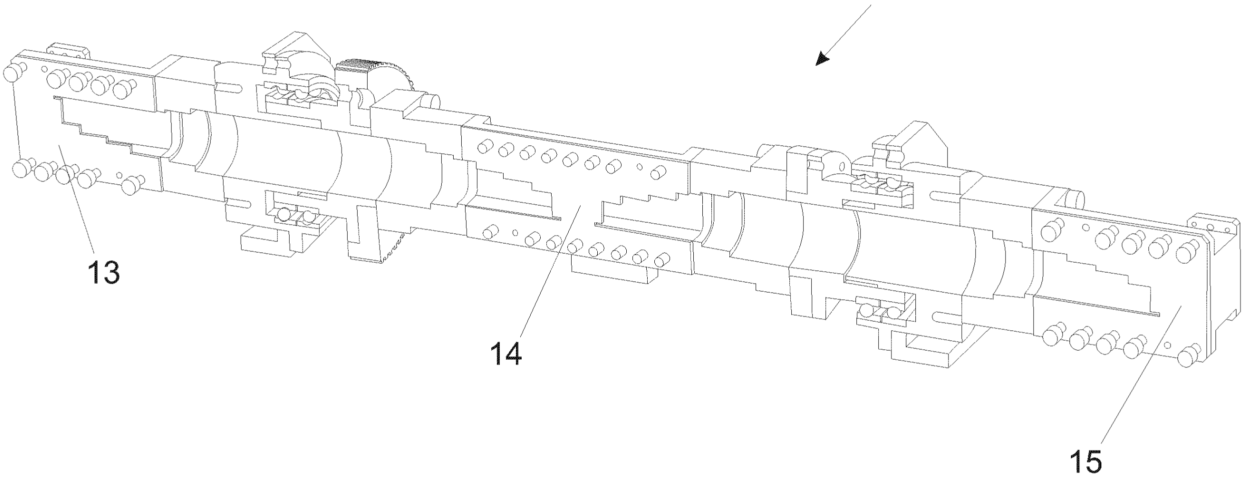

Fig. 2

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Description

Field of the invention

[0001] The present invention relates to devices for handling microwave signals and, more particularly, to an improved waveguide-based phase shifter electronically controlled.

Background of the invention

[0002] Nowadays microwave phase shifters are essential components in advanced communication systems such as Satellite-On-The-Move systems and phased arrays antennas

[0003] In the field of the advanced communications, it is common to employ techniques to perform the task of continuously adapting the polarization of the signal according to the requirements of the satellite or base station involved in the datalink. By means of the combination of two independent and linearly polarized microwave signals, it is possible to coherently tilt the plane in which the resulting electric field is confined. It is then mandatory to perfectly control the relative amplitude and phase of both components to obtain as a result, an antenna of variable linear polarization.

[0004] There exist other alternatives available in the market as the electronically controlled Vane Phase Shifter, from Cernexwave. The working principle of this kind device is a movable dielectric layer that invades the inside of the waveguide and alters the propagation characteristics of the travelling mode. However, the phase versus frequency response of the dielectric vane is not constant for all the insertion distances. If the dielectric vane is totally removed from the waveguide, the phase versus frequency characteristic is exactly the inherent value of the waveguide itself. Once the dielectric is inserted into the waveguide, the slope of the phase shift versus frequency characteristic is noticeably increased. In addition to this, the employment of dielectric as the main actuator within the waveguide always brings a raise in losses and a limitation in the power handling.

[0005] AFT Microwave and similar companies offer ferrite-based waveguide phase shifters. Ferrite based phase shifters can be divided in reciprocal or non-reciprocal depending upon the phase difference induced is a function of the direction of propagation of the field. Further, ferrite phase shifters may be latching (twin-toroid and dual-mode) or non-latching (rotary-field), depending upon continuous holding current must be applied to sustain the magnetic bias field. The latching phase shifters show high insertion loss and it exponentially rises with frequency. The peak RF capability of the device is limited by the fast increase in insertion loss, especially when the RF power exceeds a specific value. Special attention must be given to mode control in these devices since the bias wire in enclosed by the waveguide, thus allowing a Transverse Electro-Magnetic (TEM) mode to propagate as well as higher order LSE and LSM modes.

[0006] The rotary-field phase shifter exhibits an upper bound of the operation frequency since the diameter of the ferrite rod decreases in direct proportion to the frequency, which in turn varies the plane of polarization of the linearly polarized wave. The main drawback of the ferrite-based phase shifters deals with the dependency of their electrical and magnetic properties with the environmental agents. The temperature forces a change in the permeability of the ferrite which causes an undesired tilt of the polarization plane of the linearly polarized signal.

[0007] Patent document US3,001,153, entitled "Microwave Phase Shifter", claims the employment of a rotatable section of circular waveguide, means to continuosly rotating that section and devices at both ends of the rotatable part in order to insert and extract simultaneously two microwave signals having opposite senses of circular polarization. The main goal of the invention disclosed in this patent document is to generate an amplitude modulated signal having a modulation frequency fourfold the frequency of rotation of the circular waveguide. The microwave phase shifter disclosed in US3,001,153 has several differences with regard to the present invention:

1- Its working principle needs two circularly polarized microwave signals with opposite sense and same frequency.
2- The short-circuited orthomode transducers employed to convert the incoming linearly polarized signal into circularly polarized wave are narrowband.
3- A rotatable part with circular cross section.
4- The rotatable part needs to continuously turn to achieve the needed modulation.
5- For producing the advance in phase of one of the components it uses a half-wave dielectric plate.

[0008] A prior art variable polarization antenna is described in patent document US3,287,730, entitled "Variable Polarization Antenna". The bulky feeding subsystem of this antenna possesses two rotatable waveguides with elliptical and rectangular cross sections and the polarization of the radiated energy depends on the orientation of the waveguides with respect to each other.

Summary of the invention

[0009] The main object of the present invention is to provide a microwave phase shifter with continuous phase shifting capabilities, highly accurate and stable against the environmental agents. The microwave phase shifter is particularly suitable for, but not limited to, antennas of variable linear polarization.

[0010] The microwave phase shifter comprises:

- A non-rotating linear-to-circular polarization converter with a squared cross section, located at one end of the phase shifter.
- A non-rotating circular-to-linear polarization convert-

er with a squared cross section, located at the opposite end of the phase shifter.

- A rotatable squared waveguide with a circular-to-linear-to-circular polarization converter, positioned at a middle section of the phase shifter.
- A pair of rotary joints with a circular cross section for rotating the rotatable squared waveguide. The rotary joints are located at both ends of the rotatable squared waveguide.
- A plurality of mode launchers for adapting the squared waveguides to the circular cross section of the rotary joints.

[0011] In a preferred embodiment, the linear-to-circular polarization converter comprises a first septum polarizer and the circular-to-linear polarization converter comprises a second septum polarizer parallel to the first septum polarizer. The circular-to-linear-to-circular polarization converter of the rotatable squared waveguide preferably comprises a double symmetric septum polarizer, such that the angular difference between the plane that holds the first and second septum polarizers and the plane that contains the double symmetric septum polarizer specifies the shifting in phase of the microwave signal.

[0012] The microwave phase shifter may also comprise a control unit and means for rotating the rotary joints a determined angle. The means for rotating the rotary joints may comprise a motor and a belt driven gear.

[0013] The advantages of the present invention compared to the prior art are the following:

1- The way in which the delay or advance in phase is produced does not require the employment of ferrites or any other ferromagnetic material, which makes the system to be more stable and robust against environmental agents such as temperature and humidity.

2- The phase versus frequency response is constant for all the rotation angles.

3- Due to the properties of the different components of the present invention, it has a wide bandwidth of operation.

4- Since within the waveguide there is no need to include a coaxial device to tilt the field, the present invention is durable against acceleration and vibrations which makes it especially suitable for rough scenarios.

5- Compared to latched ferrites, the present invention does not need a continuous current to sustain the magnetic bias field, which reduces the power consumption. In addition to this, electromagnetic incompatibility issues between the biasing cables and the propagating waveguide are avoided.

6- The accuracy of the present invention is 0.1° which is much more precise that the existing alternatives of the market.

7- Since neither substrate-based plates nor ferromagnetic components are employed, the present invention shows insertion losses lower than other techniques and higher maximum deliverable power.

8- Compared to the rotary-field phase shifter, it can be designed to work at much higher frequencies.

Brief description of the drawings

[0014]

Figure 1 depicts a microwave phase shifter according to the present invention.

Figure 2 shows a longitudinal cross-section of the microwave phase shifter of Figure 1.

Description of a preferred embodiment of the invention

[0015] Referring to **Figure 1**, the microwave phase shifter (10) of the present invention comprises three different main parts:

- The first component is a fixed (not rotating) linear-to-circular polarization converter (1) with a squared cross section.
- The second component is a rotatable squared waveguide (2) with a circular-to-linear-to-circular polarization converter, which ends are connected to two mode launchers (3, 4) that adapt the squared waveguide to the circular cross section of the rotary joints (5, 6). Between the rotary joints (5,6) and septum polarizers (13,15) there are also two mode launchers (7,8) for the same purpose.
- The third component is a fixed circular-to-linear polarization converter (9) similar to the first component (1) and hold in the same plane but with the opposite conversion of polarization rotation.

[0016] The first (1) and third (9) components are implemented by single septum polarizers - first septum polarizer (13) and second septum polarizer (15), respectively-. A septum polarizer is a device with three physical ports and formed by two rectangular waveguides (11,12) that that have a common wide or H-plane walls. These two waveguides (11,12) are converted into a single square one by a stepped septum (13) placed at the common wall, as shown in the longitudinal cross-section of **Figure 2**. This kind of device was originally shown by Chen and Tsandoulas in the paper entitled "A wide-band

Square-waveguide Array Polarizer," May 1973, IEEE Transactions on Antennas and Propagation, pp. 389-391.

[0017] In a septum polarizer, the fundamental mode within the rectangular waveguide TE10 is converted into a circularly polarized (CP) microwave signal in the squared waveguide and vice versa. Whether right-hand circular polarization (RHCP) or left hand circular polarization (LHCP) is produced depends upon which of the two rectangular ports (11,12) is excited. In the original model presented by Chen and Tsandoulas the septum divides the input signal in two orthogonal components with the same amplitude, but a dielectric slab is needed to adjust the phase of one of the components and thus improve the existing orthogonality between signals. The septum of the present invention is optimized to get the desired power splitting, input port isolation, input matching and output orthogonality.

[0018] The circular-to-linear-to-circular polarization converter of the rotatable squared waveguide (2) is implemented by a double symmetric septum polarizer (14). The double symmetric septum polarizer (14) is the cornerstone of the present invention. The angular difference between the plane that holds the first (13) and second (15) septum polarizers and the plane that contains the double symmetric septum polarizer (14) specifies the shifting in phase that is forced to the travelling microwave signal. Independently of the rotation angle, the travelling wave always follows the same path within the whole device due to the septa disposition. When the rotatable squared waveguide (2) turns a certain angle θ, the circularly polarized signal faces the first stage of the double symmetric septum (14) which converts the incoming signal into a linearly polarized component. At this time the electric field is forced to turn the same angle θ to get adapted to the new boundary conditions imposed by the presence of the stepped first septum polarizer (13). The linearly polarized wave reaches the second half of the double symmetric septum (14) and it is converted to a circularly polarized signal again. Since the second septum polarizer (15) is fixed and parallel to the first septum polarizer (13), the field is tilted again an angle θ. As a conclusion, when the microwave signal reaches the output of the microwave phase shifter (10), it has suffered a $2\cdot\theta$ phase shifting compared to the situation when the three septa are contained in the same plane.

[0019] Regarding the control subsystem, a belt driven gear makes the rotatable part turn a desired angle. The dimensional relation between the radio of the motor gear and the rotary joint gear permits to refine the accuracy and torque four times. The whole control unit is separated from the RF path so that coexistence issues are avoided.

Claims

1. A microwave phase shifter, comprising:

a non-rotating linear-to-circular polarization converter (1) with a squared cross section, located at one end of the phase shifter (10);

a non-rotating circular-to-linear polarization converter (9) with a squared cross section, located at the opposite end of the phase shifter (10);

a rotatable squared waveguide (2) with a circular-to-linear-to-circular polarization converter, positioned at a middle section of the phase shifter (10);

rotary joints (5, 6) with a circular cross section for rotating the rotatable squared waveguide (2), the rotary joints (5, 6) being located at both ends of the rotatable squared waveguide (2);

mode launchers (3, 4, 7, 8) for adapting the squared waveguides (1, 2, 9) to the circular cross section of the rotary joints (5, 6);

2. The microwave phase shifter of claim 1, wherein the linear-to-circular polarization converter (1) comprises a first septum polarizer (13) and the circular-to-linear polarization converter (9) comprises a second septum polarizer (15), parallel to the first septum polarizer (13).

3. The microwave phase shifter of claim 2, wherein the circular-to-linear-to-circular polarization converter of the rotatable squared waveguide (2) comprises a double symmetric septum polarizer (14), such that the angular difference between the plane that holds the first (13) and second (15) septum polarizers and the plane that contains the double symmetric septum polarizer (14) specifies the shifting in phase of the microwave signal.

4. The microwave phase shifter of any preceding claim, comprising a control unit and means for rotating the rotary joints (5, 6) a determined angle.

5. The microwave phase shifter of claim 4, wherein the means for rotating the rotary joints (5, 6) comprises a motor and a belt driven gear.

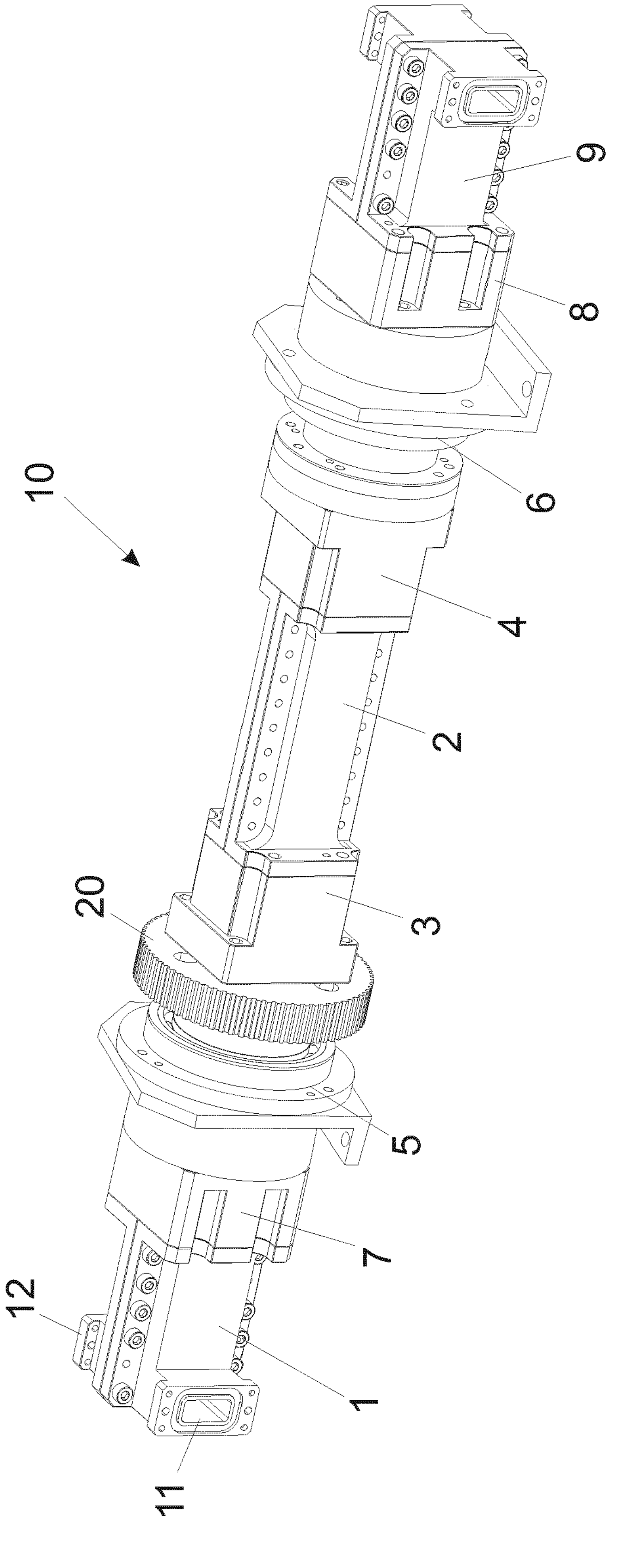

Fig. 1

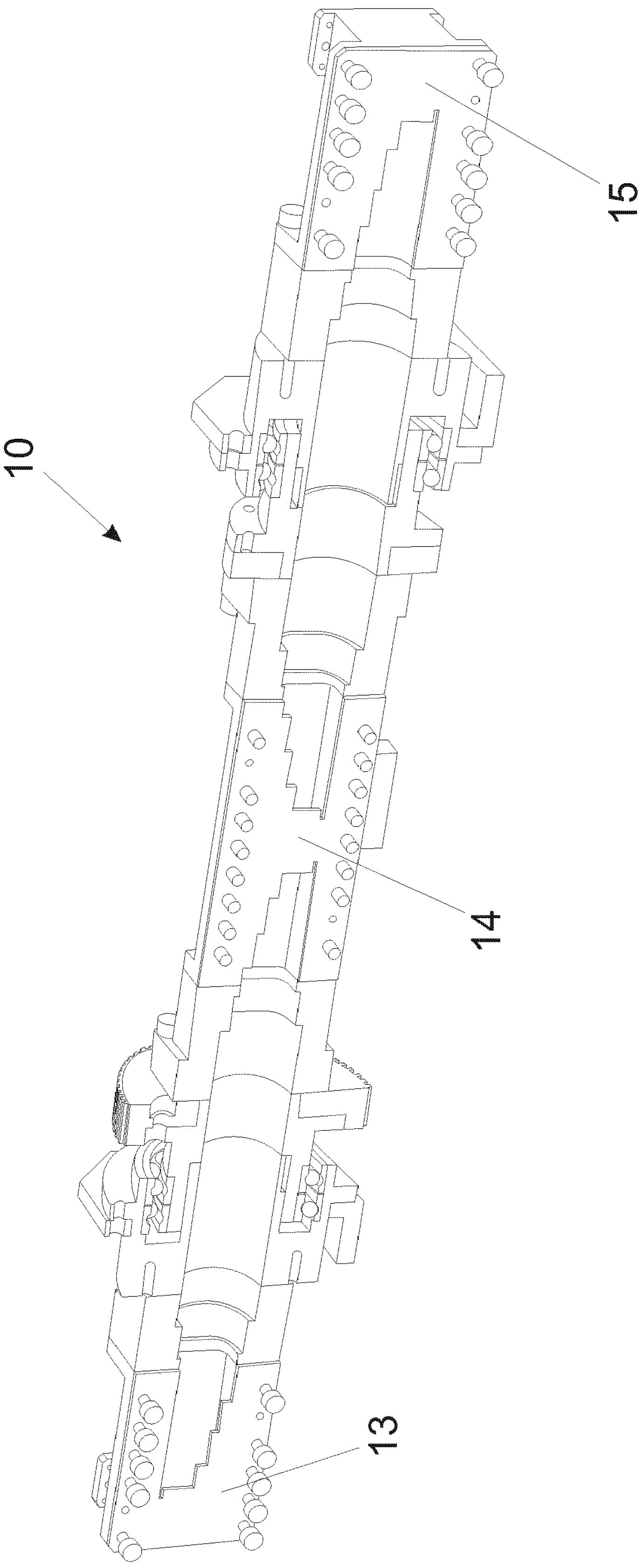

Fig. 2

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EUROPEAN SEARCH REPORT

Application Number
EP 16 38 2474

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	3 April 2017	Sípal, Vít

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EPO FORM 1503 03.82 (P04C01)

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EUROPEAN SEARCH REPORT

Application Number
EP 16 38 2474

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	3 April 2017	Sípal, Vít

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CATEGORY OF CITED DOCUMENTS

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