FIG-4a

FIG-4b

FIG-4c

FIG-7

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ABSTRACT OF THE DISCLOSURE

A circulator utilizing the anisotropic feature of a ferrite body, under application of a DC magnetic field, to act as a non-reversible circulator, and comprising a reentrant cavity resonator. A ferrite element is inserted at a narrow space of the reentrant cavity resonator, to which coaxial feeding lines are coupled. According to a novel feature of the circulator of the invention, the circulator is very suitable for use in applying high power in the UHF band, such as more than 5 kw. or more particularly 5 to 30 kw., especially since good heat dissipation is achieved while maintaining a complete circulator performance.

BACKGROUND OF THE INVENTION

A conventional circulator using ferrite bodies has a feature which is common to nearly all kinds of known circulators, namely, a central conductor coupling portion arranged between a pair of ferrite bodies. In such conventional circulators, the heat loss produced at the central conductor coupling portion has a very bad heat effect on the ferrite bodies, since the central coupling portion is surrounded by the ferrite plates. Therefore, the ferrite plates tend to increase their own temperature, so that the circulator feature may also be deteriorated.

Although there is an increasing tendency to use these kinds of circulators in miniaturized equipment, the above-mentioned disadvantages of the conventional circulator had prevented practical use of circulators in the field of high power UHF band applications, especially for the range of 5 to 30 kw.

In order to make it possible to use these kinds of circulators in output circuit of transmitters, a circulator must have excellent heat dissipation to be sufficiently durable for high frequency and high power uses. However, a circulator capable of fulfilling such a requirement in the UHF to VHF bands has not been realized up to the present time.

The present invention has as its object to provide a circulator capable of overcoming the aforementioned difficulties. The present invention is based on a novel idea of eliminating the central conductor coupling portion of the conventional circulator, which had been a cause of heat accumulation.

SUMMARY OF THE INVENTION

The present invention has for another object the construction of a circulator having excellent heat dissipation, and which is especially suitable for use in the high power UHF field, while maintaining a complete circulator function.

Another object of the invention is to miniaturize the size of the circulator as compared to a circulator of conventional construction for use in the same high power range.

The circulator according to the present invention comprises a reentrant cavity resonator consisting of a circular narrow space portion and a coaxial portion, at least one disc-shaped ferrite element is mounted close to a wall of the circular narrow space portion, and co-axial feeding terminals are arranged rotationally symmetrically at the periphery of the reentrant cavity resonator, wherein each center conductor of the coaxial feeding terminals is connected to a wall located at the opposite side from the terminal so that the elimination of the central conductor coupling portion necessarily included in a circulator of conventional construction is possible.

By employing the above-mentioned construction, the circulator of the present invention no longer comprises a central conductor coupling portion which had been a cause of heat accumulation. Therefore, the cavity resonator may easily be cooled by direct contact with the outer air so that use in a high power UHF band is easily achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows diagrammatically a cross sectional view of a circulator of conventional construction;

FIG. 2 is a simplified cross section of an embodiment of a circulator according to the present invention;

FIG. 3a is a plan view of an embodiment of a circulator according to the present invention;

FIG. 3b is an extended vertical cross sectional view of the circulator taken along line 3-3 of FIG. 3a;

FIG. 4a is a perspective view of another embodiment of the circulator according to the invention, in which part of outer conductor is taken away to show the inside construction;

FIG. 4b is an extended vertical section of the circulator shown in FIG. 4a taken along line 4-4, which is attached with cooling device;

FIGS. 5a and 5b show the electromagnetic field distribution inside the circulator according to the invention;

FIG. 6 is diagrammatic illustration of another embodiment of a circulator of the invention;

FIG. 7 is a perspective view of modified embodiment of a ferrite element for the circulator of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention relates to a high power circulator. A typical embodiment of conventional circulator is shown in FIG. 1. As seen from this figure, such a conventional circulator comprises ferrite plates 3 and 3' situated at both the upper and lower sides of coupling portion 2 of inner conductors extending between a pair of coaxial feeding terminals. A DC magnetic field is applied from outside to the ferrite plates. This kind of conventional circulator has a serious drawback in that the temperature increase in the coupling portion of the inner conductors exceeds the temperature rise in the ferrite plates in response to an increase in the applied power, so that the applicable power is limited or the miniaturization of the device is limited by the need of a large heat dissipation device.

FIG. 2 shows schematically an embodiment of the present invention. As shown in this figure, the circulator according to the present invention has a so-called reentrant cavity resonator. A ferrite element 8 is inserted inside a narrow space 7, located between two opposite circular walls 6 and 6'. The narrow space 7 will be called the "reentrant space" throughout this specification. An open impedance is formed for the applied wave length λ at the peripheries of the ferrite element 8. This circulator is fed from coaxial lines or the like at the points located in rotational symmetry about the area of said open impedance. Namely a plurality of coaxial feeding terminals 9, 9' . . . are located at various positions of rotational symmetry. Each of the inner conductors 10, 10' . . . is
lead to a position in the opposite wall from the terminal in the wall they are fixed to and are connected to that point to be coupled to the resonator. Said connecting points are arranged in rotational symmetry around the ferrite element 8. Said resonant space 7 is subjected to a DC magnetic field from outside by means of a DC magnetic field generating means S and N.

FIGS. 3a and 3b show more particularly a preferred embodiment of the invention. In this embodiment the coaxial feeding terminals 9, 9', 9'' and 9''' are provided at the top wall 6 of the cavity resonator. A ferrite element 8 is closely mounted to one of the wall surfaces, in this embodiment the top wall of the reentrant space. Then an air space is left between the bottom side of the ferrite body and another wall 6' of the space. In this embodiment circulating by convection in the space is excellent.

FIGS. 4a, 4b and 4c show another embodiment of the invention. In this embodiment the ferrite element 8 is divided into two portions 8 and 8', which are tightly mounted at the top and bottom of the inner surfaces of the reentrant space. This embodiment has a cutting from outside of the reentrant space by means of water as shown particularly in FIG. 4b.

In both of the above mentioned embodiments, 9, 9', and 9'' are coaxial feeding terminals leading to the circular reentrant cavity resonator and 10, 10' and 10'' are inner conductors of the coaxial feeding terminals. These inner conductors are terminated at the opposite wall in circular symmetrical positions to the periphery of the ferrite element so as to couple each of the coaxial line terminals against the resonator. Quarter wave transformers 11, 11' and 11'' are inserted, according to the need, with the object of impedance matching. Magnet means 12 and 12' supply a DC magnetic field to the ferrite element 8 (8 and 8' in FIG. 4). Both parts of magnet means 12 and 12' are connected by a yoke 13. As shown in FIG. 3b the ferrite element 8 is mounted at the top surface and an air gap space is left between it and the bottom surface. In the embodiment of FIG. 4b, the two ferrite elements 8 and 8' are mounted on the upper and lower surfaces of the reentrant space of the reentrant cavity respectively, and an air gap space is left between these ferrite elements. Although these embodiments are shown with coaxial-type coaxial portion, the present invention is not limited to this particular construction. The embodiment shown in FIG. 2 which comprises a single ferrite element 8 filling the space between the upper and lower surfaces and also shows the good effects of the invention. The air gap space will help the cooling of the circulator by convection.

The embodiment shown in FIGS. 4a and 4b includes water cooling devices 14 and 14' between the outer wall surfaces and the magnetic means 12 and 12'. FIG. 4c shows in plan view the construction of the cooling device. As shown in these figures, cooling water is passed through the cooling device from the water inlets 15 and 15' to the outlets 16 and 16' along circular wall surfaces. Partitions 17, 17' and 17'', in FIG. 4c, form a passageway for the cooling water in the cooling device.

According to the construction of the circulator of the invention, quasi-TM_{11} mode of the electromagnetic field generating in the reentrant space of the reentrant resonator for a rotational excitation at terminals is transferred to a coaxial TE_{11} mode at inside of a coaxial portion 20 formed by an outer cylindrical wall portion 19 and an inner cylindrical wall portion 19 in FIG. 3b. FIGS. 5a and 5b show a transition of the two modes of the electromagnetic field. This electromagnetic field constitutes an open impedance at the portion 20. When the length of the coaxial portion 20 is chosen to be a length corresponding to \( \lambda_4 /4 \), wherein \( \lambda_4 \) is a guide wavelength of coaxial TE_{11} mode. When the relation between the air gap \( l \) at the air space 7 and the width \( w \) of the coaxial portion 20 in FIG. 3b is selected as \( l \geq w \), the impedance of the coaxial portion 20 viewed from the periphery on the mode transition is kept almost open over a very wide frequency band according to the much higher characteristic impedance \( Z' \) of the coaxial portion 20 than that of the ferrite inserted part. This relation makes it possible that almost all of the incident energy from the coaxial feeding terminals 9, 9', and 9'' is efficiently delivered to the ferrite portion and the circulator function is realized in an ideal manner. This means that the filling factor "p", the ratio of the magnetic energy against the total magnetic energy inside the circulator, is increased. This is preferable to keep the wide most open over a very wide frequency band according to the filling factor "p''.

In the various embodiments explained above the ferrite element 8 is inserted in the resonator at a portion generating TM_{11} mode oscillation for a positive or, a negative rotational excitation at each terminal of the inventive circulator. Said portion showing TM_{11} mode is surrounded by a portion consisting of a coaxial line showing TE_{11} mode for a rotational excitation.

FIGS. 5a and 5b show how quasi-TM_{11} mode at the reentrant portion 7 to be transited to coaxial TE_{11} mode at coaxial portion 20 at inside of the circulators of the invention.

Various modifications of this invention may be possible. For instance the feeding point may be arranged at the bottom side of the resonator as shown in FIG. 6. The function of the modified embodiment is exactly same as that of the previous embodiment of the invention.

FIG. 7 is a modified embodiment of the ferrite element of the circulator of the invention. This plate consists of alternate concentric layers of ferrite 22 and ceramic such as beryllia 21. By making such construction of the ferrite element the heat produced may easily be dissipated by conduction to the wall of the circular space portion.

In accordance with the present invention, the conventional inner conductors inserted at the loading portion of the ferrite plate may completely be dispensed with so that the heat trouble encountered in conventional circulator, that the heat produced at the inner conductor is transferred to the ferrite plate by the characteristic features thereof, no longer exists. Therefore it becomes possible to produce a high power circulator, such as 5-30 kw., applicable in the UHF band.

What is claimed is:

1. A reentrant cavity type circulator for use in high power UHF band comprising:

(a) a reentrant circular cavity resonator comprising a narrow circular space portion and a coaxial portion extending to said narrow circular space portion, said narrow circular space portion of the circular reentrant cavity resonator being bounded by a top wall and a bottom wall, and said coaxial portion comprising an outer cylindrical wall and an inner cylindrical wall;

(b) at least one disc shaped ferrite element closely mounted on one of the walls of the narrow circular space portion of the reentrant cavity resonator and adapted to be biased by a DC magnetic field;

(c) coaxial feeding terminals arranged in rotationally symmetrical about the periphery of the circular reentrant cavity resonator;

(d) wherein each center conductor of the coaxial feeding terminals is connected to a wall located at the opposite side from the terminal.

2. A reentrant cavity type circulator as claimed in claim 1, of which the coaxial portion of the circular reentrant cavity resonator has a length corresponding to \( \lambda_4 /4 \), wherein \( \lambda_4 \) is a guide wavelength of coaxial TE_{11} mode of the coaxial portion.

3. A reentrant cavity type circulator as claimed in claim 2, wherein the coaxial feeding terminals are arranged...
at the top wall of the narrow circular space portion and the center conductors are connected to the inner cylindrical wall.

4. A reentrant cavity type circulator as claimed in claim 3, wherein the coaxial feeding terminals are arranged at the outer cylindrical wall of the coaxial portion of the circular reentrant cavity.

5. A reentrant cavity type circulator as claimed in claim 2, further comprising two disc shaped ferrite elements one of which is mounted on the top wall and the other one is mounted on the bottom wall of the narrow circular space portion.

6. A reentrant cavity type circulator as claimed in claim 2, wherein the coaxial feeding terminals are arranged at bottom surface of the circular reentrant cavity resonator, and the inner conductors of the coaxial feeding terminals are connected to the top wall of the narrow circular space portion.

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