Jan. 1, 1957 A. J. SPARLING 2,776,412

MAGNETIC SYSTEM FOR MICROWAVE COMPONENTS

Filed Feb. 4, 1955

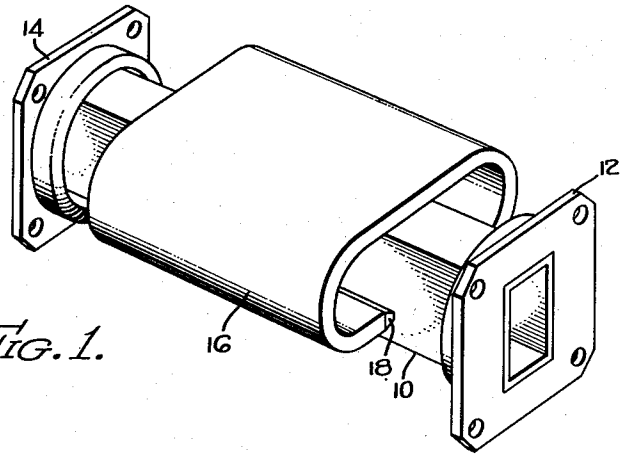


FIG. 1.

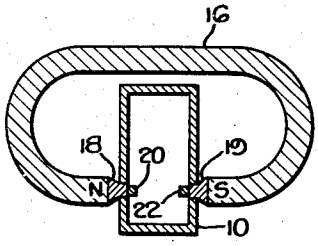


FIG. 2.

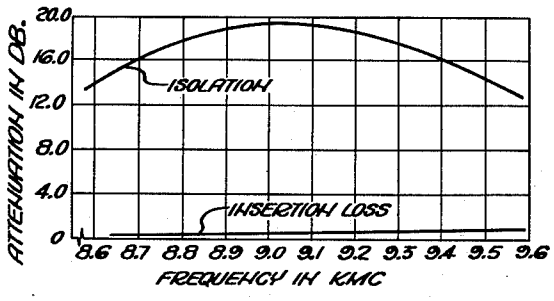


FIG. 3.

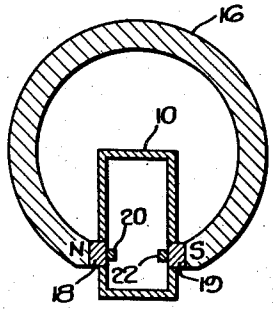


FIG. 4.

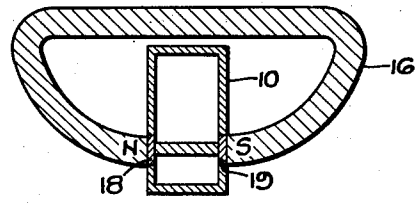


FIG. 5.

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MAGNETIC SYSTEM FOR MICROWAVE COMPONENTS

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15 Claims. (Cl. 333—98)

This invention relates to microwave components of the type wherein one or more specimens of ferrite or similar material are mounted in a waveguide and are biased with a static magnetic field, and more particularly to microwave components comprising a waveguide which includes a pair of built in pole pieces of magnetic material for concentrating an externally applied static magnetic field through a ferrite specimen mounted within the waveguide.

Relatively recent advances in the field of microwave components have brought forth a new class of circuit elements which include one or more ferrite specimens mounted in a waveguide and subjected to an externally applied static magnetic field. Among the devices included in this new class of circuit elements are load isolators or gyrators, phase shifters and attenuators. Although the motivating concept of the invention is equally applicable to this entire class of circuit elements, for purposes of clarity and illustration it will be disclosed with particular reference to load isolators.

Basically a load isolator, or as it is sometimes called, a gyrator, utilizes one or more ferrite specimens mounted in a waveguide to achieve one-way transmission of microwave energy. More specifically, it has been found that by biasing a ferrite specimen of predetermined size with a static magnetic field of predetermined magnitude the waveguide may be made to present a relatively low loss path in one direction and a relatively high loss path in the other direction. Considered in terms of the end result achieved, therefore, the device is analogous to a crystal rectifier or diode in that it exhibits a low series impedance in the forward direction and a high series impedance in the reverse direction. For purposes of discussion the term "insertion loss" will be utilized hereinafter to designate the power attenuation of a load isolator in the forward or low loss direction, while the term "isolation" will be employed to designate the attenuation in the reverse or high loss direction.

Although load isolators may be utilized in several different forms of microwave systems, they have been found to be especially applicable to radar systems for nonreciprocally isolating the magnetron or microwave generator from the remainder of the microwave circuit. More specifically, if the load isolated is coupled to the magnetron and is oriented so that its forward direction is from the magnetron to the associated duplexer, then substantially all of the output power extracted from the magnetron is transmitted to the duplexer. However, any reflections which would normally be returned to the magnetron are attenuated or absorbed by the load isolator, thereby greatly decreasing the magnetron's sensitivity to load variations and substantially eliminating for practical purposes what is known to the art as "long line effect." In addition, the utilization of a load isolator permits the degree of coupling between the resonant system of the magnetron and its associated output structure to be increased; consequently, the minimum power output from a system may be increased by employing a load isolator even though

the magnetron output signal is attenuated slightly by the insertion loss of the isolator. It will be recognized from the foregoing discussion that the insertion loss of a load isolator is ideally kept as low as practical while the degree of isolation is kept as high as possible.

In the prior art two different types of load isolator have been developed, the first of which is disclosed in U. S. Patent No. 2,644,930 for "Microwave Polarization Rotation Device and Coupling Network," issued July 7, 1953, to C. H. Luhrs et al. In this particular type of prior art load isolator a ferrite wafer is positioned transversely in a cylindrical waveguide to whose ends a pair of rectangular waveguides are attached, the transverse axis of one of the rectangular guides being disposed at an angle of 45° with respect to the transverse axis of the other rectangular waveguide. In operation the ferrite is operable under the influence of a magnetic field to rotate incident electrical energy through a predetermined angle which is a function of the ferrite size and the magnitude of the magnetic field.

The mode of operation of load isolators of the type disclosed in the aforementioned patent is described in detail in an article entitled "The microwave gyrator" by C. L. Hogan, published in the January 1952 issue of The Bell System Technical Journal. Briefly stated, this form of load isolator provides a transmission system which is one half wavelength longer in one direction than in the other, and more specifically, utilizes the wave rotating properties of ferrite which are analogous to the phenomenon of Faraday rotation in optics. Accordingly, if the rectangular waveguides are properly oriented relative to each other, energy propagated in one direction is passed while energy transmitted in the other direction is blocked due to the orientation of the terminal rectangular waveguide.

In general load isolators of the above type have been found to have a large number of inherent disadvantages which discourage their incorporation in microwave systems. Firstly, the units require two waveguide transformers for interconnecting the cylindrical waveguide with the two rectangular waveguides. Consequently, there is some degree of mismatch which produces undesirable reflections even if the transformers are well designed. Secondly, the unit is mechanically complex, lengthy and often requires a twist in one of the rectangular waveguides; accordingly the units are relatively expensive. Thirdly, the isolation and insertion loss provided by the unit vary greatly over even a small portion of the microwave spectrum owing principally to the fact that the angular orientation of the terminal rectangular guides is fixed while the angular rotation provided by the ferrite for a given static field varies with the frequency of the incident energy. Still another important disadvantage of this form of prior art load isolator is that its power handling capacity is very limited owing to the fact that the physical disposition of the ferrite in the waveguide prevents rapid dissipation of the heat generated in the ferrite by the absorption of electrical energy; consequently blowers or a water jacket must be employed with the unit if even a moderate amount of power is to be dissipated therein. Again, the static magnetic field strength for a particular degree of isolation and insertion loss is critically dependent upon frequencies and the temperature of the ferrite; in order to obtain uniform isolation, therefore, an electromagnet servoed from the associated radar system is often required.

In order to overcome these disadvantages another load isolator has been developed which employs one or more ferrite specimens asymmetrically mounted within an ordinary rectangular waveguide parallel to the longitudinal axis of the guide. In this form of load isolator the ferrite specimens are preferably rectangular in cross section and are positioned in a static transverse magnetic field pro-

vided by a relatively large permanent magnet which contacts the outside periphery of the waveguide walls adjacent the regions whereat the ferrite specimens are affixed to the interior of the waveguide. As in the case of the other prior art load isolator which operates on a principle analogous to Faraday rotation, this newer type of load isolator depends on the fact that the permeability of a ferrite specimen in the presence of a static magnetic field is a non-symmetrical tensor. Consequently, when one or more ferrite specimens are asymmetrically positioned in a waveguide and a static magnetic field is applied transversely to the waveguide, the propagation constant of the modes depends upon the direction of propagation. A more rigorous analysis of this prior art load isolator is set forth on page 816 of the June 1953 issue of the Journal of Applied Physics in a letter to the editor by Kales et al., entitled "A Non-Reciprocal Microwave Component."

Although the latter form of prior art load isolator has succeeded in eliminating many of the disadvantages attendant the original load isolators which employed cylindrical waveguide, it too has several serious disadvantages. Firstly, the permanent magnet required to produce the static magnetic field is relatively large and bulky, thereby severely restricting the configuration of the magnet and the use of the isolator in many applications where spacing of the microwave components is a critical factor. In addition, the utilization of a relatively large permanent magnet increases the weight of the isolator by several pounds as a consequence of which its use in airborne systems is restricted.

The present invention, on the other hand, provides an improved load isolator which obviates the above and other disadvantages of the load isolators of the prior art. According to the basic concept of the invention, substantially all of the static magnetic field is channeled through one or more ferrite specimens by a pair of ferrous or ferromagnetic pole pieces built into the waveguide walls for directly incorporating the ferrite specimens in a low reluctance path which includes the magnet that provides the requisite static field.

According to the invention the pole pieces may be flush with both the interior and exterior walls of the waveguide, or may project externally, if necessary, to engage the pole of the magnet. In addition, the thickness of the pole pieces may be varied to effect a transition from a relatively thin ferrite specimen to a relatively thick magnet, thereby further concentrating the magnetic field through the ferrite and substantially eliminating fringing of the static magnetic field.

More specifically, according to the invention a pair of slots of predetermined dimensions are machined in the sides of the waveguide at the regions where the ferrite specimens are normally affixed to the interior wall of the waveguide. A pair of pole pieces of predetermined size and constructed of magnetic material are then inlaid in the slots so that the innermost ends of the pole pieces are substantially flush with the interior walls of the waveguide, after which the ferrite specimens are mounted on the inner ends of the pole pieces. The permanent magnet utilized for providing the static field is then brought into engagement with the external ends of the pole pieces, thereby including the ferrite specimens in the low reluctance path of the magnet.

As will be described in more detail hereinbelow, the utilization of pole pieces as herein taught provides load isolators which, for a given insertion loss and isolation, employ magnets which have only of the order of one fourth the size and weight of the magnets heretofore utilized. Consequently, the overall weight of the load isolator may be reduced by a factor of more than one half, while magnets having numerous configurations may be utilized to provide the necessary static field, thereby permitting sufficient flexibility of design as to allow the load isolator to be utilized in much smaller spaces than formerly required.

In a similar manner, the utilization of a pair of ferrous pole pieces in the other forms of microwave components which employ one or more magnetically influenced ferrite speciments which must be mounted entirely within a waveguide, provides substantially the same advantages. Accordingly, it should be reiterated that the invention is intended to encompass the entire class of microwave devices, including phase shifters and attenuators, which utilize the ferromagnetic resonance properties of ferrite material.

It is therefore an object of the invention to provide microwave components wherein one or more ferrite specimens mounted entirely in a waveguide are coupled to an external source of magnetic flux through a low reluctance path.

Another object of the invention is to provide microwave components wherein a static magnetic field is channeled through one or more ferrite specimens mounted entirely in a waveguide by a pair of ferrous pole pieces built into the walls of the waveguide.

Still another object of the invention is to provide microwave load isolators wherein the ferrite specimen is asymmetrically mounted in a rectangular waveguide, the walls of the waveguide adjacent the specimen including built in pole pieces of magnetic material to provide a low reluctance path between the ferrite and an associated permanent magnet.

A still further object of the invention is to provide a relatively inexpensive and light weight microwave load isolator wherein a relatively small magnet is utilized to provide a static magnetic field for a ferrite specimen mounted in an associated waveguide, the magnet being interconnected to the ferrite specimen by one or more ferrous pole pieces built into the walls of the wave guide.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawings in which several embodiments of the invention are illustrated by way of example. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only, and are not intended as a definition of the limits of the invention.

Fig. 1 is an isometric view of one form of load isolator, according to the invention;

Fig. 2 is a cross sectional view of the load isolator of Fig. 1;

Fig. 3 is a graph illustrating the isolation provided by an X-band load isolator of the type shown in Figs. 1 and 2; and

Figs. 4 and 5 are cross sectional views of modified forms of load isolators constructed in accordance with the principles of the invention.

Referring now to the drawings, wherein like or corresponding parts are designated by like reference characters throughout the several views, there is shown in Fig. 1 a load isolator or gyrator constructed in accordance with the principles of the invention. Basically the load isolator of the invention includes four principal elements, namely, a waveguide section **10** which may include a pair of end flanges **12** and **14**, a static magnetic field generator such as permanent magnet **16** which is formed to generate a magnetic field transverse to waveguide **10**, one or more ferrite specimens, not shown in Fig. 1, which are asymmetrically mounted within the waveguide, and a pair of ferrous pole pieces, such as pole piece **18**, which are inlaid or built into the sides of the waveguide for connecting the ferrite to the poles of magnet **16** through a low reluctance path.

As shown in Fig. 1 magnet **16** and the associated pole pieces extend along the waveguide parallel to its longitudinal axis, the length of the magnet and the pole pieces being slightly larger than the length of the ferrite specimens mounted within the waveguide. Magnet **16** is preferably constructed of Alnico V, although it is clear of

course, that other good magnetic materials may be utilized. The pole pieces, on the other hand, are preferably composed of a high permeability ferrous or ferromagnetic material such as soft iron and shaped so as to mate with the poles of magnet **16**. It should be noted that although the pole pieces and ferrite specimens might both be termed ferromagnetic elements, the pole pieces are composed of a relatively conductive magnetic material, whereas the material of the ferrite specimens should exhibit dielectric characteristics in order to perform the desired function.

With reference now to Fig. 2 there is shown a cross sectional view of the load isolator of Fig. 1 illustrating the shape and relative positions of pole piece **18** and its companion pole piece which is designated by the reference numeral **19**, pole piece **19** being built into the waveguide directly opposite pole piece **18**. In the particular embodiment of the invention shown in Fig. 2 the inner ends of the pole pieces are substantially flush with the interior walls of the waveguide while the ferrite utilized for obtaining the unidirectional characteristics of the device comprises a pair of slab-like specimens **20** and **22** respectively, which are affixed to the inner sides of the pole pieces. Although the specific isolator illustrated in Fig. 2 of the drawings is shown to include two ferrite specimens, it will be recognized from the description set forth hereinafter that the invention is equally applicable to isolators employing only one ferrite specimen, as shown in the Kales et al. article cited hereinabove.

The particular shape selected for the pole pieces and their position in the waveguide walls are determined by a number of different factors. More particularly, the position of the pole pieces in the waveguide is determined primarily by the position in which the ferrite specimens are to be mounted. In the particular form of load isolators shown in the drawings, the ferrite specimens are mounted below the transverse axis of the waveguide approximately equidistant from the transverse axis and the lower end of the waveguide. Consequently the pole pieces utilized for mounting the ferrite specimens are located in the same region.

With respect to the shape of the pole pieces, the side which surfaces within the waveguide is preferably of approximately the same thickness as the ferrite specimen which is mounted thereon in order to channel or concentrate substantially all of the static magnetic field through the ferrite. For essentially the same reason and in addition, to maintain the reluctance of the magnetic circuit as low as possible, the side of the pole piece which engages magnet **16** is preferably the same size as the pole of the magnet. Accordingly, when the thickness of the ferrite specimens is appreciably smaller than the thickness of the magnet the pole pieces are preferably tapered in order to achieve an optimum balance between low reluctance and low fringing.

Referring again to Fig. 2, it will be noted that each of pole pieces **18** and **19** has a tapered region adjacent magnet **16** and a region of substantially uniform thickness where the pole pieces extend through the waveguide, the advantage of this particular configuration being that it not only provides the desired transition between the relatively thin ferrite and the magnet but that it also simplifies the construction of the isolator. More specifically, in machining the waveguide to receive the pole pieces it is only necessary to mill a pair of slots in opposite sides of the guide, the width of the slots corresponding to the thickness of the uniform region of the pole pieces. In addition, if each pole piece is constructed so that the transverse width of its uniform region is the same as the thickness of the waveguide walls, then the side of the pole piece will be flush with the interior walls of the waveguide when the pole piece is inserted therein.

In the construction of the load isolator shown in Fig. 2 two mounting operations are required, namely, the mounting of the pole pieces in the waveguide walls and the mounting of the ferrite specimens on the pole pieces. It has been found that the first of these operations may be readily performed by silver soldering the pole pieces to the waveguide after the pole pieces have been inserted therein. Thereafter the ferrite specimens are in turn mounted on the pole pieces with a suitable adhesive such as an epoxy resin. For example, one adhesive which has been found especially suitable for mounting the ferrite specimens is sold by the Shell Chemical Company under the trade name Epon VIII.

It will be recognized by those skilled in the art that the dimensions of the ferrite specimens and the flux density of the magnetic field through the specimens in a particular load isolator are determined primarily in view of the frequency at which the isolator is to be operated, the maximum allowable insertion loss and the minimum isolation to be provided. In general the ratio of isolation to insertion loss is a function of the cross sectional area of the ferrite specimens, while the magnitudes of both the insertion loss and isolation are substantially linear functions of the length of the ferrite specimens after a predetermined minimum length has been exceeded.

Once the dimensions of the ferrite specimens have been determined the static magnetic field required to produce the desired isolation concomitant with low insertion loss is best determined empirically with the aid of an electromagnet which is brought into engagement with the pole pieces. As the strength of the magnetic field is increased a point is reached whereat the isolation provided rises sharply in a resonance curve and peaks. The permanent magnet to be utilized to provide the desired isolation is then designed to provide a static magnetic field whose flux density corresponds substantially to the flux density whereat the isolation wave was observed to peak.

Consider now the advantages attendant the use of pole pieces in the load isolator of the invention. It is clear from the foregoing description that the degree of isolation provided by a particular load isolator operating at a particular frequency is dependent upon the strength of the magnetic field through the ferrite specimen. Since the size of the magnet required to provide a given field strength is a direct function of the length of the gap in the magnetic circuit and of the percentage of the magnetic flux lost through leakage and fringing, it is clear that the pole pieces employed in the load isolator of the invention materially decrease the size and weight of the magnet, and in addition, facilitate the use of magnets of various configurations.

Referring again to Fig. 2, the configuration shown for magnet **16** has been found to be especially useful since it minimizes the size of the load isolator and in addition, even further decreases the tendency of the magnetic field to fringe between the poles of the magnet. With reference now to Fig. 3 there is shown a plot of insertion loss and isolation versus frequency for an X-band load isolator of the type shown in Figs. 1 and 2, and having the following dimensions:

Longitudinal length of magnet and pole pieces	2.50"
Mean length of magnet from pole to pole	4.63"
Thickness of magnet	.25"
Length of ferrite specimens	2.00"
Thickness of specimens (parallel to magnet pole faces)	.090"
Height of specimens (perpendicular to magnet pole faces)	.065"

It may be recalled that one of the primary advantages of the load isolator of the invention is that the reduced magnet size permits the magnet to have any of numerous configurations, thereby permitting the isolator to be utilized in systems where the space allotted for a load isolator is relatively small and restricted in shape. With reference now to Figs. 4 and 5, there are shown two other embodiments of load isolators constructed in accordance with the basic teaching of the invention. It will be noted that the configuration of magnet **16** in each of these em-

bodiments of the invention differs from the preferred configuration shown in Fig. 2.

In addition to the distinction in magnet configurations, Figs. 4 and 5 also illustrate two different forms of pole pieces which have been found to function satisfactorily in the load isolator of the invention, while Fig. 4 also illustrates the utilization of pole pieces with a single ferrite specimen 21. As shown in Fig. 4, for example, pole pieces 18 and 19 may be of uniform thickness and need not necessarily be of the same thickness as the ferrite specimens 20 and 22. The pole pieces in the embodiment shown in Fig. 5, on the other hand, are flush with both the interior and exterior walls of waveguide 10, the gap in magnet 16 being of substantially the same dimension as the overall thickness of the waveguide.

It is readily apparent that numerous forms of mounting brackets may be utilized in the various embodiments of the invention for maintaining magnet 16 in its position relative to waveguide 10 and pole pieces 18 and 19. It is clear, however, that these brackets should be composed of non-magnetic material, and are preferably constructed of a light weight material such as aluminum, for example. Inasmuch as the means utilized for mounting the magnets on the associated waveguide is not material to the invention herein presented, further description thereof is considered unnecessary.

Summarizing briefly the motivating concept herein disclosed, it will be recognized that the present invention provides microwave components wherein one or more ferrite specimens are mounted within a waveguide and are subjected to a static magnetic field provided by an associated permanent magnet, the magnetic field being channeled through the ferrite by a pair of ferrous pole pieces built into the sides of the waveguide, or stated differently, the ferrite being incorporated in a continuous low reluctance path which includes the associated magnet by a pair of pole pieces mounted in the waveguide walls.

It is to be expressly understood, of course, that the accompanying drawings are merely utilized to illustrate the basic concept of the invention as applied to load isolators, and that other modifications in the invention will be readily apparent to one skilled in the art. For example, although the pole pieces are shown to be flush with the interior walls of the waveguide it is obvious that the pole pieces and the contacting ferrite specimens may have conjugally curved surfaces at their interfaces to further concentrate the magnetic field through the ferrite. Accordingly, the scope of the invention is to be limited only by the spirit and scope of the appended claims.

What is claimed as new is:

1. In a microwave component wherein at least one ferrite specimen is mounted entirely in a rectangular waveguide and is subjected to an externally applied static transverse magnetic field, a pair of conductive ferromagnetic pole pieces built into opposite broad sides of the waveguide for mounting the ferrite specimens to channel the magnetic field through the ferrite specimen while maintaining substantially unimpaired the conductivity of said broad sides of the waveguide.

2. In a microwave component which utilizes the ferroresonant properties of a ferrite specimen mounted entirely within a waveguide and positioned in a static magnetic field for altering a microwave signal, the combination comprising: a section of waveguide; at least one conductive ferromagnetic pole piece built into the wall of said waveguide, said pole piece surfacing both within and without said waveguide without appreciably disturbing the electrical characteristics of the waveguide wall of which said pole piece forms a part; a ferrite specimen mounted within said waveguide on said pole piece; and a static magnetic field source having first and second poles and positioned around at least a portion of said waveguide for producing a static magnetic field in the interior of said waveguide, said first pole of said source engaging said pole piece whereby said field is channeled through said ferrite specimen.

3. The combination defined in claim 2 wherein said waveguide is rectangular in cross section and which further includes a second pole piece built into the wall of said waveguide opposite said one pole piece and surfacing both within and without said waveguide, said second pole of said source engaging said second pole piece.

4. The combination defined in claim 3 wherein said ferrite specimen is also mounted on said second pole piece.

5. The combination defined in claim 3 which further includes a second ferrite specimen mounted within said waveguide on said second pole piece.

6. The combination defined in claim 3 wherein said static magnetic field comprises a permanent magnet.

7. An absorption type microwave load isolator comprising: a rectangular waveguide; first and second ferromagnetic pole pieces built into opposite walls of said waveguide, said pole pieces being parallel to each other and to the longitudinal axis of said waveguide and surfacing both within and without said waveguide, said pole pieces substantially preserving the electrical conductivity of the walls of which the form a part; at least one ferrite specimen mounted within said waveguide on at least one of said pole pieces, the electrical conductivity of said specimen being relatively low compared to that of said pole pieces; and a magnetic field source positioned around at least a portion of said waveguide and having first and second poles, said first and second poles engaging said first and second pole pieces, respectively, for producing a magnetic field through said ferrite specimen.

8. An absorption type microwave load isolator comprising: a section of rectangular waveguide; first and second conductive ferrous pole pieces inlaid in opposite walls of said waveguide, and surfacing within and without said waveguide, said pole pieces being parallel to each other and to the longitudinal axis of said waveguide and being flush with the interior walls of said waveguide and in electrical contact therewith; first and second ferrite specimens mounted within said waveguide on said first and second pole pieces, respectively; and a permanent magnet, having first and second poles, for providing a transverse magnetic field in said waveguide, said first and second poles engaging said first and second pole pieces without said waveguide whereby said first and second specimens are included in a low reluctance path with said magnet.

9. The microwave load isolator defined in claim 8 wherein said pole pieces are composed of soft iron.

10. The microwave load isolator defined in claim 8 wherein said pole pieces are built into the broad wall of said waveguide substantially equidistant from its transverse axis and one of its narrow walls.

11. The microwave load isolator defined in claim 10 wherein said pole pieces are flush with the interior walls of said waveguide and project a predetermined distance beyond the exterior walls of said waveguide, the distance between the projecting ends of said pole pieces being substantially the same as the distance between the poles of said magnet.

12. The microwave load isolator defined in claim 10 wherein said pole pieces are substantially flush with both the interior and exterior walls of said waveguide.

13. In a microwave component which utilizes the ferroresonant properties of a ferrite specimen mounted entirely within a waveguide and positioned in a static magnetic field for altering a microwave signal, the combination comprising: a section of rectangular waveguide; at least one conductive ferromagnetic pole piece built into the wall of said waveguide and in electrical contact therewith; said pole piece surfacing both within and without said waveguide; a ferrite specimen mounted within said waveguide on said pole piece; and a horseshoe magnet

positioned adjacent the exterior of said waveguide and having first and second poles, said first pole of said magnet engaging said pole piece whereby said ferrite specimen is included in a low reluctance path with said magnet.

14. An absorption type microwave load isolator comprising: a rectangular waveguide; first and second ferromagnetic pole pieces built into opposite walls of said waveguide and being composed of material whose conductivity is of the same order of magnitude as that of said waveguide, said pole pieces being parallel to each other and to the longitudinal axis of said waveguide and surfacing both within and without said waveguide; at least one ferrite specimen mounted within said waveguide on at least one of said pole pieces; and a static magnetic field source positioned adjacent said waveguide and having first and second poles engaging said first and second pole pieces, respectively, for producing a magnetic field through said ferrite specimen.

15. In an absorption type load isolator, the combination comprising: a section of rectangular waveguide; first and second electrically conductive magnetic pole pieces inlaid in said waveguide, and surfacing within and without said waveguide, said pole pieces being parallel to each other and to the longitudinal axis of said waveguide, first and second ferrite specimens mounted within said waveguide on said first and second pole pieces, respectively; and a permanent magnet, having first and second poles, for providing a transverse magnetic field in said waveguide, said first and second poles engaging said first and second pole pieces without said waveguide whereby said first and second specimens are included in a low reluctance path with said magnet.

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