

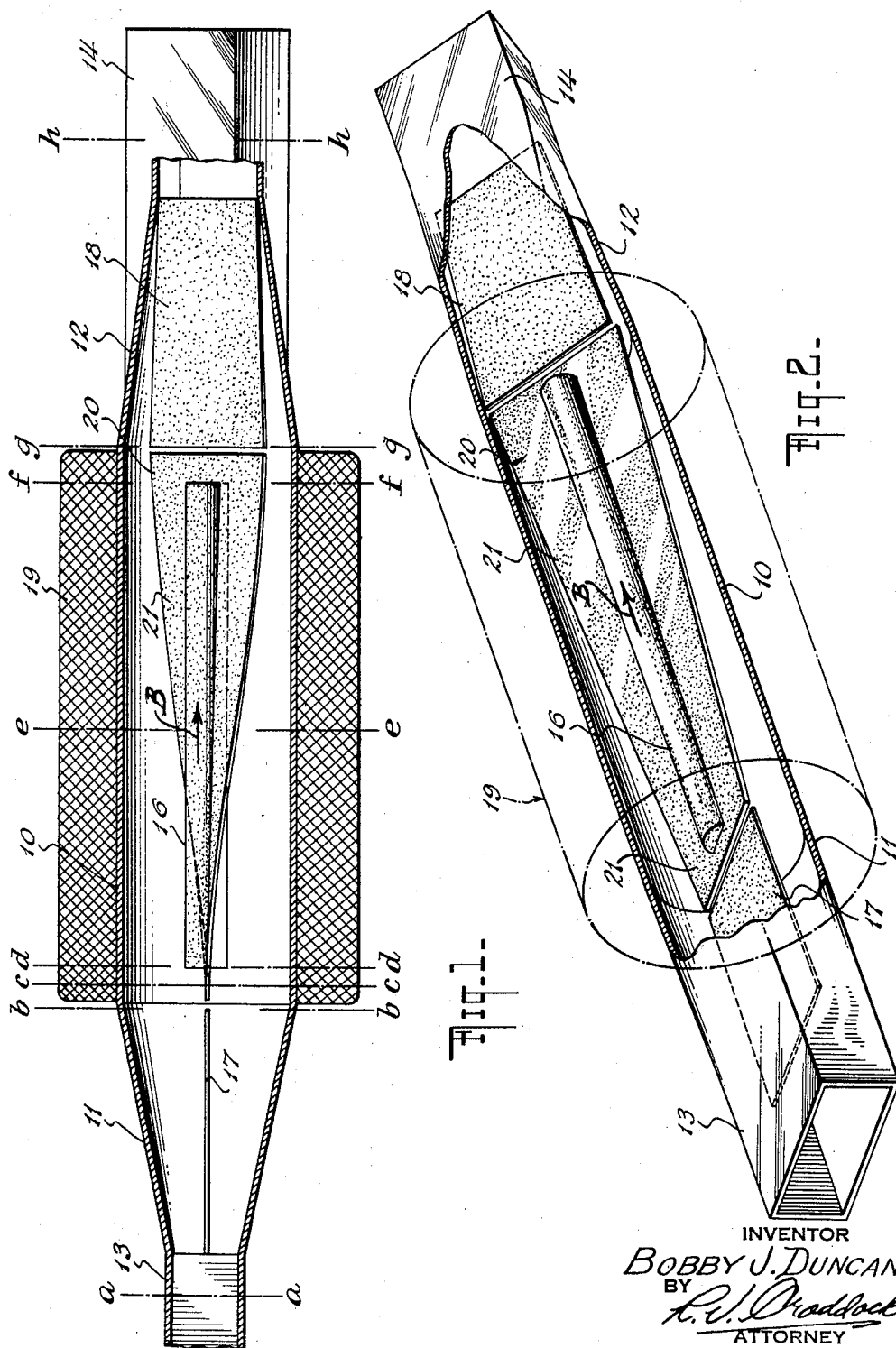
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MICROWAVE ISOLATOR

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2 Sheets-Sheet 1



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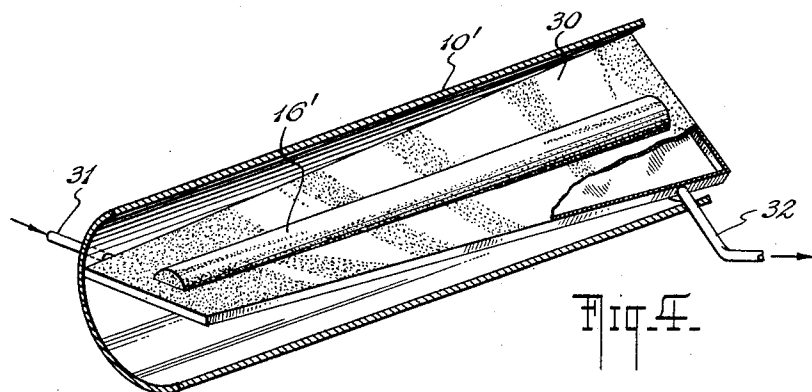


Fig. 4.

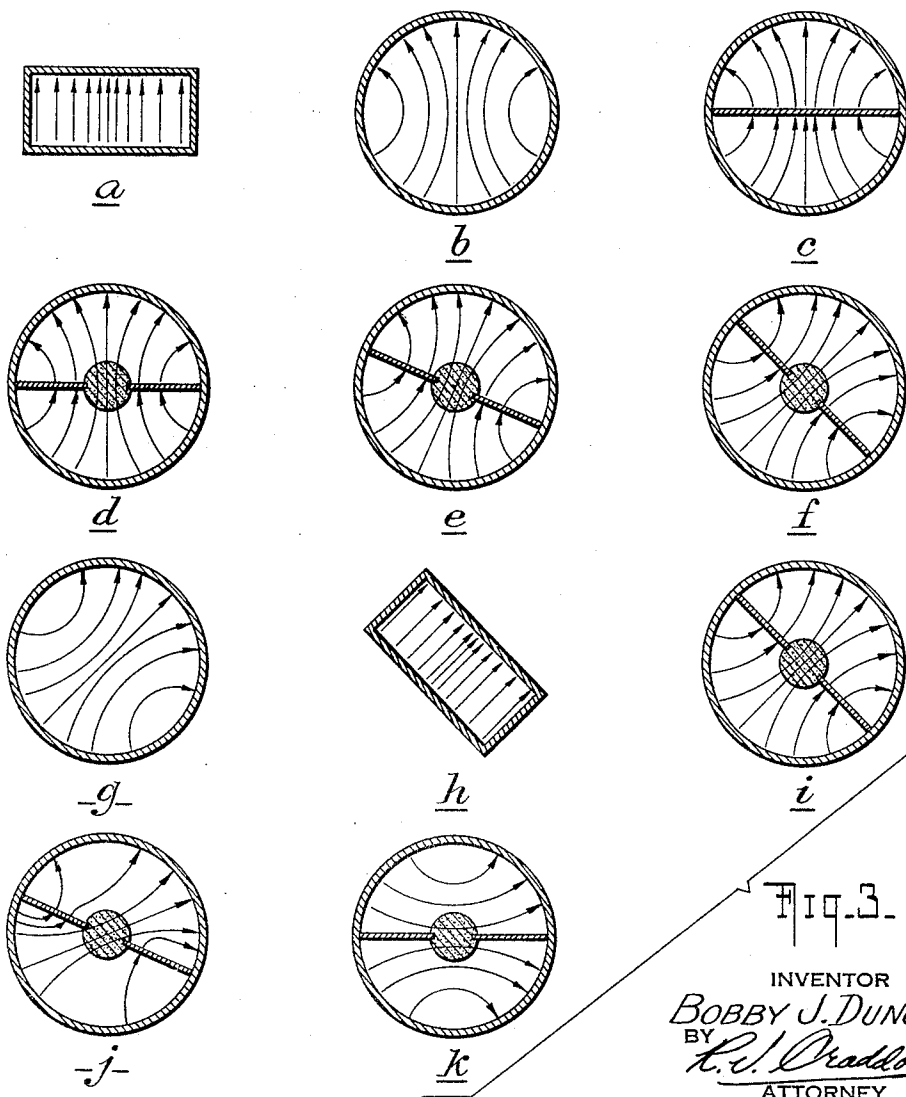


Fig. 3.

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MICROWAVE ISOLATOR

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This invention relates to microwave transducers employing ferrites, and more particularly to non-reciprocal ferrite transducers such as microwave isolators.

A non-reciprocal transducer is a device having an energy transfer function depending on the direction of energy passage therethrough. An isolator is a non-reciprocal transducer which freely transfers energy in one direction but prohibits passage of energy in the reverse direction. Isolators are employed, for example, in microwave transmission systems to prevent transmitting devices, such as klystrons and magnetrons, from receiving electromagnetic waves reflected from loads, such as antennas. Non-reciprocity is commonly achieved by the employment of ferrite members for interacting with electromagnetic waves. When a ferrite member is placed in the path of a traveling wave and a biasing magnetic field is applied thereto, the response of the ferrite member will depend on the direction of propagation of the wave.

For example, a ferrite rod magnetically biased in a direction parallel to its axis will rotate the plane of polarization of a linearly polarized wave, the direction of rotation of the plane of polarization being dependent on the direction of wave propagation. If the plane of polarization of a wave traveling toward the load, known as the forward wave, is rotated through 45°, a wave reflected from the load, known as the backward wave, will have its plane of polarization rotated by the same amount and in the same direction with respect to the applied magnetic field direction. The net rotation for the two passes through the ferrite rod is 90°. A plane resistive sheet placed at the end of the ferrite rod at which the forward wave enters is oriented perpendicularly to the plane of polarization of the forward wave will not affect the wave. However, the backward wave, which will have its plane of polarization rotated so as to be parallel with the plane of the resistive sheet when it leaves the ferrite rod, will be absorbed in the sheet. A device operating in this manner is known as a Faraday rotation isolator.

Practical Faraday rotation isolators employ a ferrite rod coaxially disposed within a section of circular waveguide. In prior art isolators of this type the ferrite rod has been supported within the circular waveguide section by thin annular dielectric spacers or by hollow tubes of foam-like dielectric material. As these support members are poor heat conductors, no path exists to transfer heat effectively from the ferrite rod to the metal wall of the waveguide section. Thus, in these prior art isolators the ferrite element tends to overheat when operated at high power levels and thereby to become erratic and ineffective.

It is therefore the principal object of this invention to provide a Faraday rotation isolator operable at high levels of microwave power.

It is a further object of this invention to provide an improved microwave isolator.

It is a further object of this invention to provide a ferrite microwave transducer capable of handling high levels of microwave power.

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It is a further object of this invention to provide a waveguide ferrite isolator in which heat is readily transferred from the ferrite member to the metal wall of the waveguide.

5 It is a further object of this invention to provide a support means for the ferrite member of a Faraday rotation isolator, said support means also serving to transfer heat from the ferrite member to the waveguide wall, and to absorb the backward wave.

10 In accordance with the present invention a metal fin extending radially between the ferrite member and the waveguide inner surface serves to effectively transfer heat from the ferrite member to the waveguide wall. A ferrite rod is disposed coaxially within a circular waveguide section. The rod is supported by the metal fin extending radially between the outer surface of the rod and the inside surface of the waveguide section. The fin is twisted about the waveguide axis, the rate of twist and the direction thereof being adjusted so that the fin is everywhere perpendicular to the plane of polarization of the forward dominant mode wave. On the other hand, the plane of polarization of the backward dominant mode wave is rotated to be parallel with the fin and may be absorbed if a glossy material is coated on the fin. The metal fin serves to support the ferrite member within the waveguide section, to absorb the backward wave, and to conduct heat away from the member.

This invention will be described with reference to the following drawings; wherein

30 Fig. 1 is an elevational view of the preferred embodiment of the isolator of this invention;

Fig. 2 is a perspective view, partly in cross-section, of the isolator of Fig. 1;

Fig. 3 is a series of drawings of the electric field configurations at various points in the isolator of Fig. 1;

Fig. 4 is an alternative embodiment of the isolator of Fig. 1.

To clarify the ensuing explanation of the operation of this device, the following definitions are adopted:

40 Positive circularly polarized wave: A wave rotating in the direction of the positive electric current which creates a steady longitudinal magnetic field.

Negative circularly polarized wave: A wave rotating in the direction opposite the positive electric current which creates a steady longitudinal magnetic field.

45 Clockwise rotation: Rotation in a clockwise manner when viewed in the direction of propagation of the wave.

Counter-clockwise rotation: Rotation in a counter-clockwise manner when viewed in the direction of propagation of the wave.

50 Ferrites can be described as polycrystalline materials of spinel structure which are formed at high temperature by the solid-phase reactions of iron oxide and one or more divalent metallic oxides. By varying the ingredients and the processing techniques, wide ranges in the general properties of ferrites can be obtained. Ferrites in their simplest form correspond to the general chemical formula $XOFe_2O_3$, where X represents the divalent metal. Ferrites represented by the above general formula fall into two main classes; those which are ferromagnetic and those which are not. Whether a ferrite falls into one or the other of these classes depends on the divalent metallic oxide used. For example, those ferrites in which X is magnesium, copper, manganese, lithium, nickel, lead, iron, calcium, or cobalt, are ferromagnetic. The ferromagnetic ferrites are ceramic-like materials characterized by low conductivity, low losses, and high permittivity.

55 It is well known that the R-F. permeability of a saturated ferromagnetic material is not a scalar quantity, but instead the alternating flux density in the medium is related to the alternating field by a tensor permeability. The tensor components of the permeability are complex

quantities. This unique tensor permeability is the property of ferrites that makes them useful in the microwave art. Thus, circularly polarized waves of opposite sense of rotation encounter different propagation constants in a saturated ferrite member because of this tensor permeability.

Consider a plane linearly polarized wave incident on a lossless ferrite member that is subjected to a steady biasing magnetic field directed parallel to the direction of travel of the wave. A plane linearly polarized wave can be represented by two circularly polarized wave components in phase with respect to the linearly polarized wave. As the wave passes through the ferrite member the two circularly polarized components encounter different phase constants and they emerge from the ferrite member having a different phase relationship to each other. The differential phase shift encountered by the circularly polarized wave components gives rise to rotation of the plane of polarization of the linearly polarized wave. This wave rotation is known as Faraday rotation. The direction of the rotation of the wave is in the positive sense with respect to the biasing magnetic field. The amount of the rotation is directly proportional to the extent of the ferrite member in the direction of propagation of the incident wave.

Faraday rotation by ferrite members is a non-reciprocal phenomenon because the direction of rotation of the plane of polarization depends only on the direction of the static magnetic field. Relative to an observer looking along the direction of the biasing magnetic field, the direction of rotation of the linearly polarized wave will be the same whether the wave is traveling toward or away from him; that is, if the plane of polarization of a wave passing through the ferrite member in one direction is rotated a certain amount, the wave passing through in the opposite direction will have its plane of polarization rotated by the same amount in the same direction. Therefore, the net rotation for a wave passing through the ferrite in one direction and then in the other direction is twice the one-pass rotation. This principle is employed in Faraday rotation isolators, such as the isolator of this invention.

In Figs. 1 and 2 a circular waveguide section 10 constitutes the outer shell of the Faraday rotation isolator of this invention. A pair of circular-to-rectangular waveguide transitions 11 and 12 connect circular waveguide section 10 at each end thereof to respective rectangular waveguide sections 13 and 14. Rectangular waveguide sections 13 and 14 are oriented with respect to each other so that the planes of their respective broad walls intersect at an angle of 45°. A cylindrical ferrite rod 16 is disposed within waveguide section 10 concentric with the longitudinal axis thereof. A pair of resistance cards 17 and 18 are disposed in respective transitions 11 and 12 with their planes parallel to the broad walls of respective rectangular waveguide sections 13 and 14. Means, such as solenoid 19, is provided for immersing ferrite rod 16 in a steady biasing magnetic field, B, whose vector direction is parallel to the axis of waveguide section 10. A thin metallic fin 20 extends between ferrite rod 16 and waveguide section 10, the geometrical configuration of said fin in a plane perpendicular to the axis of the circular waveguide section being thin rectangles including a waveguide diameter. Fin 20 supports rod 16 within waveguide section 10. Fin 20 is uniformly twisted about an axis coincident with the axis of waveguide section 10. The total twist of the fin 20 is 45°. The end of fin 20 nearest rectangular waveguide section 13 is parallel to the broad walls thereof. The end of fin 20 nearest rectangular waveguide 14 is parallel to the broad walls thereof. Fin 20 is twisted smoothly and uniformly between its two ends. A lossy material, such as aquadag, may be placed as a coating 21 on the faces of fin 20.

In describing the operation of this invention, refer-

ence will be made to the electric field configuration drawings of Fig. 3 and to their locations in the isolator of Fig. 1. The forward wave will be considered to be one traveling from left to right in Fig. 1. The field configurations in Fig. 3 are drawing looking toward the right in Fig. 1. A forward wave in the dominant mode is launched in waveguide section 13, this wave being shown in Fig. 3a, taken at section A—A. The polarization of this wave is perpendicular to the broad walls of waveguide section 13. This wave travels toward the right through transition 11 and enters waveguide section 10 in the dominant circular waveguide mode, shown in Fig. 3b at section B—B. Resistance card 17 will suppress any cross-polarized components of the wave as it travels toward the right. This insures that the direction of polarization of the wave will be perpendicular to the extended broad walls of waveguide section 13 and to the left end of fin 20 as the wave enters circular waveguide section 10. The wave then encounters fin 20, but is substantially unaffected thereby, since the wave is polarized perpendicularly to the surfaces of the fin, as shown in Fig. 3c at section C—C. The wave continues to travel toward the right, passing through ferrite rod 16. The magnitude of the magnetic bias applied to ferrite rod 16 is that necessary to rotate the plane of polarization of the forward wave through a total clockwise angle of 45° as the wave travels to the right through waveguide section 10. The rotation of the wave as it travels toward the right is shown successively in Figs. 3d, 3e and 3f, taken at respective sections D—D, E—E, and F—F. The rotation that the wave experiences is uniform and directly proportional to the length of the ferrite rod. Fin 20 is twisted to correspond with the rotation of the forward wave. Thus, with the plane of polarization of the wave rotated k degrees per unit ferrite length, the fin will be disposed in the geometrical surface defined by the cylindrical coordinate equation $\phi = kz$, where ϕ is the angular orientation of the surface and z is the distance along the axis of waveguide section 10. Hence, fin 20 is everywhere perpendicular to the direction of polarization of the wave and does not affect it. The forward wave leaves waveguide section 10 (Fig. 3 section G—G), rotated 45° clockwise with respect to the orientation with which it entered the waveguide section. The wave travels through transition 12 and enters rectangular waveguide section 14, as shown in Fig. 3h at section H—H. Resistance card 18 removes any cross-polarized components of the wave.

Consider now the action of the isolator on a reflected or backward wave traveling toward the left in Fig. 1. The wave enters the isolator from waveguide section 14, passes through transition 12 and enters circular waveguide section 10 oriented perpendicularly to the extended broad walls of waveguide section 14, as shown in Fig. 3i at section F—F. As the wave passes toward the left its plane of polarization is rotated in a clockwise manner, as shown in Figs. 3j and 3k at respective sections E—E and D—D. As explained previously the absolute direction of rotation imparted to the wave is independent of its direction of travel and depends only on the direction of the biasing magnetic field. Both the forward wave and backward wave are rotated in the positive sense with respect to the magnetic field, B. As seen in Figs. 3j and 3k, the field is no longer maintained perpendicular to the fin, but instead has a component parallel thereto. This component tends to induce currents in the fin and is absorbed in the lossy coating 21 on the faces of the fin. Thus, the forward wave is passed without substantial attenuation, whereas the backward wave is dissipated in fin 20 and the lossy coating 21, and the device acts as an isolator. As fin 20 extends between ferrite rod 16 and the inner surface of waveguide section 10, it affords a ready path for the transfer of heat from the ferrite member and the dissipative coating to the circular waveguide wall. Consequently, fin 20 with its lossy coating

21 performs the functions of supporting ferrite rod 16, of attenuating the backward wave and of conducting heat to the waveguide wall.

In an alternative embodiment of this invention, shown in Fig. 4, a fin 30 is employed, which is of hollow structure. A pair of conduits 31 and 32 are connected to the fin through the walls of circular waveguide section 10' near the opposite extremities of the fin. A suitable coolant may be circulated through the fin by means of conduits 31 and 32 to more effectively cool the structure.

While the invention has been described in its preferred embodiments, it is to be understood that the words which have been used are words of description rather than of limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention in its broader aspects.

What is claimed is:

1. A microwave isolator comprising a section of metallic circular waveguide, a cylindrical ferrite rod coaxially disposed within said waveguide section, means for immersing said ferrite rod in a magnetic field directed along the longitudinal axis of said waveguide, said rod when immersed in said magnetic field being adapted to effect Faraday rotation of a linearly polarized electromagnetic wave of a given frequency passing therethrough, the Faraday rotation per unit length being equal to a predetermined value, a metallic fin disposed within said waveguide section and twisted about an axis coincident with the waveguide longitudinal axis, said fin having a rate of twist per unit length equal to said predetermined value, said fin having an elongated aperture disposed parallel to the waveguide longitudinal axis, said ferrite rod being disposed within said aperture, and material dissipative to electromagnetic waves disposed on the faces of said fin, the outer edges of said fin being affixed substantially along their entire lengths to the inner surface of said waveguide and the ferrite rod being affixed to said fin substantially along the entire lengths of the edges of said aperture, whereby heat conductive paths are provided between said ferrite rod and said waveguide.

2. An isolator as in claim 1 wherein said fin is of hollow cross section and adapted to receive and emit a circulating coolant.

3. A microwave isolator comprising a section of metallic circular waveguide adapted to propagate linearly polarized electromagnetic waves at a given frequency, a ferrite rod coaxially disposed within said waveguide section, means for immersing said ferrite rod in a magnetic field directed along the longitudinal axis of said waveguide

section, said ferrite rod when immersed in said magnetic field being adapted to rotate the plane of polarization of electromagnetic waves at the given frequency by a given angle per unit length, a pair of metallic heat conductive fins disposed radially opposite each other between said rod and the waveguide inner surface, said fins extending throughout the length of said ferrite rod and being twisted at said given angle per unit length about the longitudinal axis of said waveguide, and material dissipative to electromagnetic waves disposed on the faces of said fins, said fins being affixed substantially along the entire lengths of their outer edges to the waveguide inner surface and substantially along the entire lengths of their inner edges to the surface of the ferrite rod, whereby heat transfer paths are provided between said ferrite rod and the wall of said waveguide.

4. A microwave isolator comprising a section of metallic circular waveguide adapted to propagate linearly polarized electromagnetic wave at a given frequency, a ferrite rod coaxially disposed within said waveguide section, means for immersing said ferrite rod in a magnetic field directed along the longitudinal axis of said waveguide section, said ferrite rod when immersed in said magnetic field being adapted to rotate the plane of polarization of electromagnetic waves at the given frequency by a given angle per unit length, heat conductive means for supporting said ferrite rod coaxially within said waveguide section and for providing good heat transfer paths between said ferrite rod and said waveguide, said heat conductive means comprising metallic fins disposed radially opposite each other between said rod and said waveguide and extending throughout the length of said ferrite rod, said fins being twisted at said given angle per unit length about the longitudinal axis of said waveguide and being affixed substantially along the entire lengths of their outer edges to the inner wall of said waveguide and substantially along the entire lengths of their inner edges to the ferrite rod, and material dissipative to electromagnetic waves disposed on the faces of said fins.

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