United States Patent

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[54] IMPEDANCE COMPENSATED SWITCH FOR A RECTANGULAR WAVEGUIDE

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[52] **U.S. Cl.** .....**333/98 S,** 333/98 BE, 333/7, 333/34, 333/35

[51] **Int. Cl.**.....**H01p 1/02,** H01p 1/10, H01p 5/02

[58] **Field of Search**.....333/98 S, 7, 98 BE, 98 M, 34, 333/35

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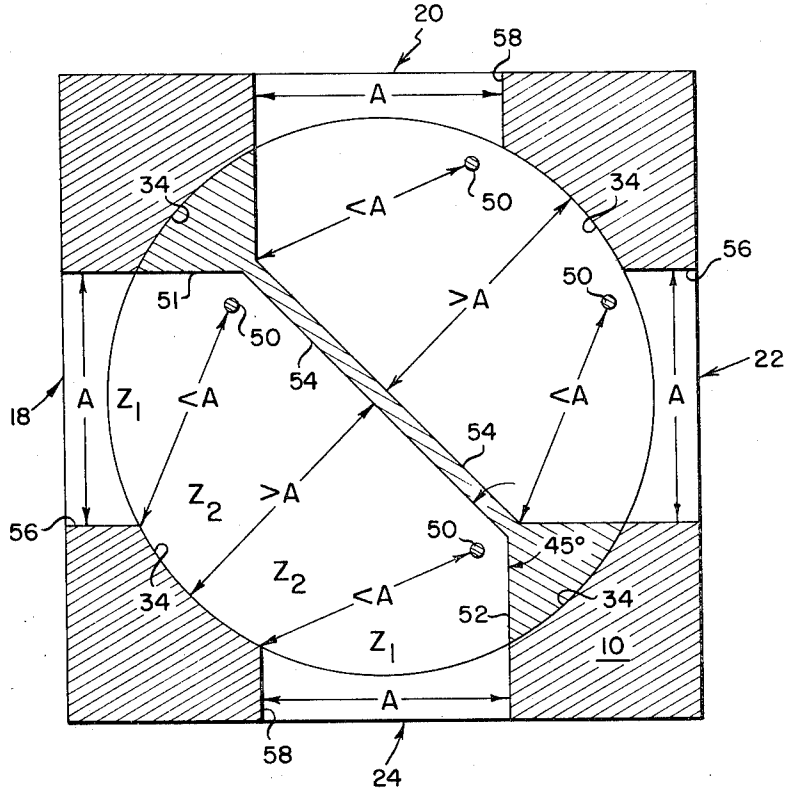
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[57] **ABSTRACT**

Apparatus for selectively switching electromagnetic wave energy from one hollow pipe waveguide to one of two similar waveguides disposed at an angle thereto, the apparatus providing a double-mitered, H plane compensated waveguide bend in which the effective width of the waveguide in the plane of the bend is narrowed at the mitered corners and increased on a line bisecting the angle of the bend to provide a low VSWR over a wide bandwidth for both signal paths.

14 Claims, 5 Drawing Figures



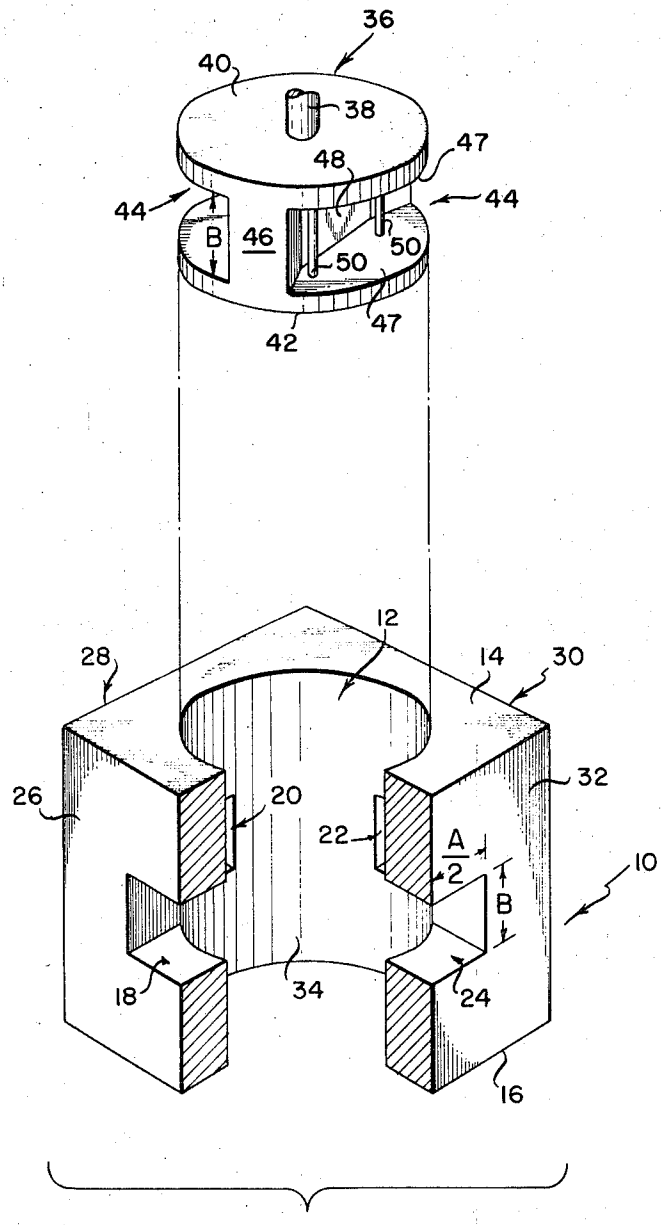


fig_1

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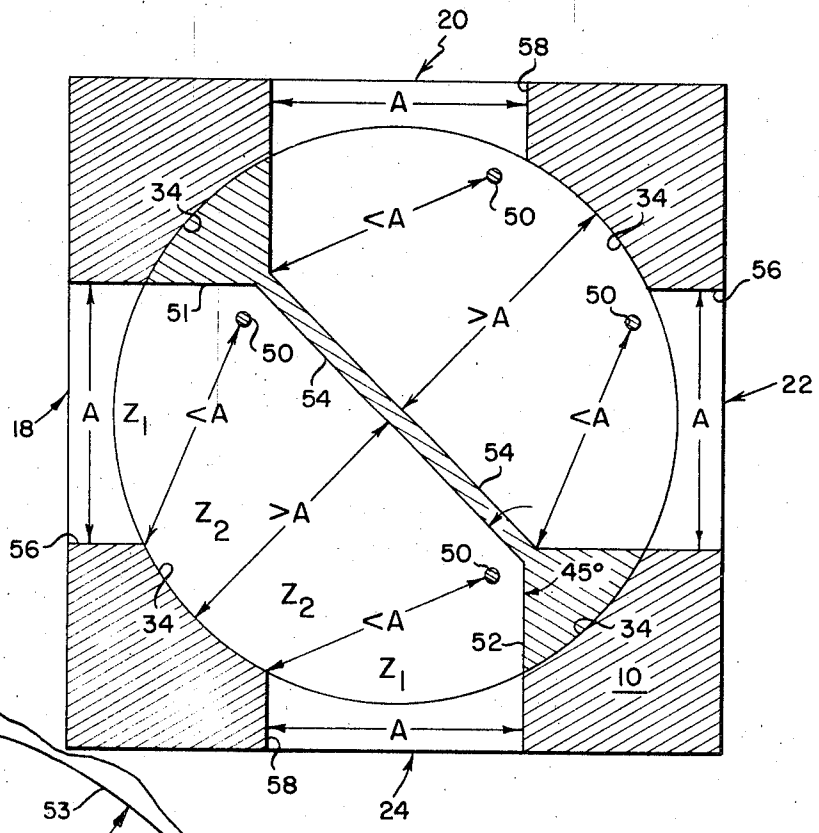


Fig. 2

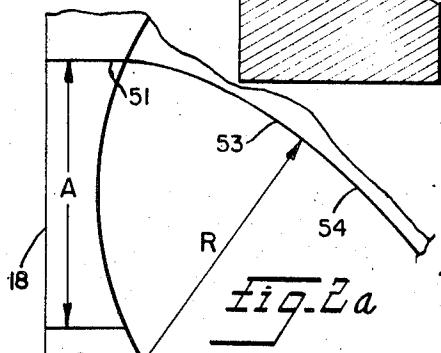


Fig. 2a

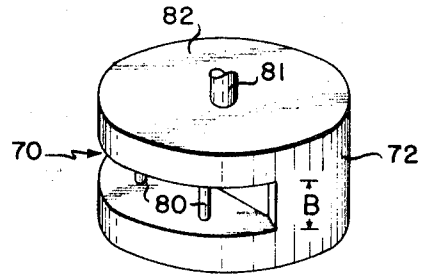


Fig. 4

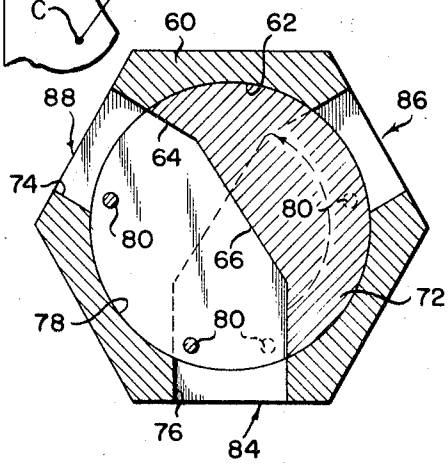


Fig. 3

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IMPEDANCE COMPENSATED SWITCH FOR A RECTANGULAR WAVEGUIDE

BACKGROUND OF THE INVENTION

The present invention relates to the hollow pipe waveguide switch and more particularly to a novel three or four port switch having a low VSWR over a wide bandwidth.

In switching electromagnetic wave energy at microwave frequencies from one hollow pipe waveguide to a selected one of two hollow pipe waveguides disposed at an angle thereto, it is a common practice to utilize a cubical block housing having a vertical bore in which a cylindrical rotor is journaled for rotation. In four port switches of this type, for example, four coplanar ports extending from the four planar side surfaces of the cubical block into the axial bore are provided with the centerline of opposing pairs of the ports intersecting at a 90° angle on the axis of the rotor.

The rotors generally take the form of a cylinder having one or more horizontal grooves in the cylindrical surface thereof. These grooves are of a width corresponding to the vertical height of the waveguide coupled to the ports of the switch and the bottom surface of the groove defines the vertical wall of the waveguide within the switch on the outside of the bend. The vertical wall of the waveguide within the switch on the inside of the bend is formed by the arcuate surface of the bore.

These prior art waveguide switches have generally been limited to bends in which the plane of the bend is the E plane and in which the plane normal to the plane of the bend is the H plane. Moreover, the change in mean signal path length by the utilization of the arcuate surfaces of the bore has been recognized as undesirable but necessary to provide sufficient space in which the rotor may turn.

Other prior art rotary waveguide switches have utilized a rotor having sufficient diameter to allow the use of a radius bend within the rotor. In these radius bend switches, the mean or centerline length of the arc swung between the centerlines of the straight waveguide sections coupled to the switch is generally three quarters of a wavelength of the energy transmitted, or more in odd multiples of quarter wavelengths, at the center band frequency. This radius bend construction provides a low VSWR with an inherently broadband width but the size limitations render such construction unsuitable for many applications.

Still other prior art rotary waveguide switches have utilized a cylindrical rotor grooved to provide a double-mitered bend in which two abrupt changes are made in the longitudinal direction of the waveguide within the switch. This type of construction provides a low VSWR but only for a very narrow bandwidth thereby rendering the switch unsuitable for many applications.

It is accordingly an object of the present invention to provide a novel switch for electromagnetic wave energy in which the broadening of the dimension of the waveguide in the plane of the bend in this type of construction due to the cylindrical bore is utilized in providing a unique impedance match with a correspondingly low VSWR over a wide bandwidth.

It is a further object of the present invention to obviate the deficiencies of the prior art and to provide a switch incorporating two novel, double-mitered waveguide bends both small in size relative to the wavelength of the energy propagated through the switch.

Still another object of the present invention is to provide a novel three port waveguide switch in which the waveguide bend within the switch has an odd number of reflections, the number being not less than three.

Yet another object of the present invention is to provide a novel waveguide switch of reduced size in which impedance compensating means are carried by the rotor of the waveguide switch adjacent the double-mitered corners of the bend within the switch.

These and many other objects and advantages of the present invention will be readily apparent to one skilled in the art to which the invention pertains from a perusal of the claims and

of the following detailed description of a preferred embodiment of the invention when read in conjunction with the appended drawings.

THE DRAWINGS

FIG. 1 is an exploded pictorial view of one embodiment of a four port, double-mitered, right angle bend, waveguide switch embodying the present invention;

FIG. 2 is a plan view in section taken in the plane of the bend through the midpoint of the waveguide switch of FIG. 1;

FIG. 2(*a*) is a partial plan vie in section taken in the plane of the bend illustrating a second embodiment of the waveguide switch of FIG. 1.

FIG. 3 is a similar section of a three port waveguide switch embodiment of the present invention; and

FIG. 4 is a pictorial view of the rotor of the three port switch of FIG. 3.

THE DETAILED DESCRIPTION

With reference now to FIG. 1 where a preferred embodiment of a four port switch is illustrated, the housing **10** comprises a cubical block of electrically conductive material which is provided with a cylindrical bore **12** extending from the upper surface **14** of the block vertically downward therethrough to the lower surface **16**. First, second, third, and fourth waveguide ports **18, 20, 22,** and **24** respectively extend horizontally inwardly from the respective vertical side faces **26, 28, 30** and **32** respectively of the cubical block to the internal surface **34** of the bore **12**. The ports **18–24** are coplanar and each has cross-sectional dimensions A and B corresponding to those of the waveguides through which the electromagnetic wave energy is to be coupled by the switch.

A rotor **36** is journaled for rotation within the bore **12** about a vertical axis through the center thereof. The rotor **36** may be cylindrical in configuration with a diameter substantially that of the bore **12** within the housing **10**. An upwardly extending shaft **38** coaxial with the rotor **36** and the bore **12** may be provided on the upper surface **40** thereof to provide means for the selective rotation of the rotor **36** within the bore **12**.

Intermediate the upper and lower surfaces **40** and **42** of the rotor **36** are a pair of grooves **44** extending horizontally from opposite sides of the cylindrical wall **46** of the rotor **36** towards the axis thereof. The width of the grooves **44** corresponds to the vertical dimension B of the waveguide ports **18–24** so that the horizontal sides **47** of the grooves **44** serve as a continuation of the smooth upper and lower surfaces of the waveguides coupled to the switch. The vertical surface **48** which defines the bottom of the grooves **44** serves as the vertical wall on the outside of the bend within the switch.

Electrically conductive impedance compensating means or irises **50** may extend vertically between the horizontal sidewalls **47** of the grooves **44**. These irises **50** may be located in a manner subsequently to be more fully explained in connection with FIG. 2 and are carried by the rotor **36** in a predetermined fixed relationship to the grooves **44**.

It is important that high conductivity materials be utilized in the construction of the housing **10** and the rotor **36** since the two most significant losses are due respectively to the resistive component of the waveguide switch material and the resistive material of the inductive posts or irises **50**. A good electrical connection should be established between the inductive posts **50** and the rotor **36**.

With reference now to FIG. 2, and assuming that the plane of the waveguide bend within the switch is the electrical H plane, the rectangular waveguides having a horizontal or H plane dimension A and a vertical or E plane dimension B are adapted to be coupled to the four ports **18–24** of the housing **10** of the waveguide switch illustrated in FIG. 1.

In accordance with the present invention, the vertical or E plane dimension B, the dimension in the plane normal to the plane of the bend within the switch, is the same throughout the switch and is substantially identical to the vertical or E plane

dimension B of the sections of waveguide to be coupled thereto. The horizontal or H plane dimension A of the waveguide in the plane of the bend is effectively reduced adjacent the mitered corners of the bend within the switch. The horizontal dimension of the bend in the plane of the bend within the switch is, of course, increased along the line bisecting the angle of the bend by the cylindrical nature of the bore **12**.

The critical cross-sectional dimensions, i.e., the dimensions in the plane of the bend, are illustrated in FIG. **2**. With continued reference to FIG. **2**, the vertical wall of the bend on the outside thereof may be defined by straight surfaces **51** and **52** coplanar with the horizontal sidewalls of the waveguides and by a planar surface **54** intersecting both of the sections **51** and **52** at an angle one-half of the angle of the bend, e.g., 45° for a 90° bend.

The vertical wall of the bend on the inside thereof within the switch may be defined by the straight surfaces **56** and **58** also coplanar with the sidewalls of the waveguides coupled to the switch. An arcuate surface **34** connects the two planar surfaces **56** and **58**. The center for the arc of the surface **34** must, of course, coincide with the center for the cylindrical bore **12** and lies substantially on a line normal to and bisecting the surface **54** of the outer wall, i.e., at the line bisecting the angle of the bend.

The effect of each of the changes in the dimensions in the plane of the bend is to create multimode electrical reflections and it is a desideratum that the spacing between the two 45° corners be such that these reflections cancel at the center band design frequency. The cancellation of these multimode reflections requires an odd number, three or more, of reflection generating means within the bend. An even number, four or more, of discrete sections of waveguide are thus present in the bend.

The impedance Z_1 seen looking along one of the straight sections of the rectangular waveguide into one of the ports is converted to an impedance Z_2 at the post **50**, i.e., the first effective reduction in the dimension of the waveguide in the plane of the bend. The impedance Z_2 of the section beginning at the post **50** is converted to an impedance Z_3 at the center of the bend within the switch. The impedance Z_3 looking toward the output port from the center of the bend is reconverted by the reversal in the width of the waveguide to an impedance Z_2. The impedance change at the next post **50** reconverts the impedance Z_2 to that of the rectangular waveguide, i.e., Z_1. An impedance match and cancellation of the multimode reflection is thus attained along the line of symmetry of the waveguide bend. The energy propagated through the bend sees an odd number of reflections and an even number of sections arranged symmetrically to effect the multimode cancellation.

A line hereinafter to be referred to as the one-quarter angle of the bend line passes through the junction respectively of the straight surfaces **56** and **58** with the arcuate surface **34** and bisects the angle formed by the intersection of the surfaces **54** with the surfaces **51** and **52**.

The dimension of the waveguide in the plane of the bend measured along these one-quarter of the angle of the bend lines is between about 91 and 95 percent of the horizontal dimension A of the waveguides to which the switch is coupled.

The point at which maximum waveguide width in the plane of the bend lies thus on the line of symmetry of the bend within the switch where increase in the dimension of the waveguide is necessary to accommodate rotation of the rotor **36** within the bore **12** and is about 104 to 105 percent of the width of the waveguide in the plane of the bend.

The effective narrowing of the horizontal dimension of the waveguide in the plane of the bend may be accomplished by the use of the aforementioned conductive posts or irises **50** disposed on the one-quarter angle of the bend lines earlier described. These posts **50** may be spaced from the walls of the waveguide but are desirably placed as close as possible thereto so that the post current may be reduced. The posts **50** may, however, both be located adjacent the walls of the bend on the inside or outside as desired.

Alternatively as shown in FIG. **2**(*a*), the surfaces **51** and **54** may be faired smoothly into each other to form an arcuate surface **53** having a radius R of about 118 to 120 percent of the width A of the waveguides coupled to the switch in the plane of the bend. The distance between the centers C for these arcuate surfaces **53** may be between about 58 and 60 percent of the horizontal dimension A of the waveguide, raised to a power of about 58 to 60 percent of the dimension A, e.g., $0.6A^{0.6}$ and the centers C should lie on the one-quarter of the angle of the bend lines earlier described.

A 3 port embodiment of the switch of the present invention is illustrated in FIGS. **3** and **4**. With reference to FIG. **3**, the housing **60** is provided with a vertical bore **62**. The vertical wall of the bend on the outside thereof is defined by the surfaces **64**, **66**, and **68** which comprise the bottom surface of the groove **70** in the cylindrical rotor **72**, shown more clearly in FIG. **4**. The vertical wall of the bend within the switch on the inside thereof is defined, as in the embodiment of FIGS. **1** and **2**, by the planar surfaces **74** and **76** and by the arcuate surface **78** of the bore **62**. The widening of the waveguide in the plane of the bend on the line of symmetry thereof is achieved by this construction.

The effective narrowing of the waveguide in the plane of the bend may likewise be accomplished by means of the vertical posts or irises **80** located in this embodiment adjacent the junction of the vertical planar surface **74** with the arcuate surface **78** and the junction of the planar surface **76** with the arcuate surface **78**.

The rotor **72** illustrated in FIG. **4** may comprise a cylinder having the horizontal groove **70** cut into the vertical side thereof. The width B of the groove **70** corresponds to the vertical height of the waveguides to be coupled to the switch. A shaft **81** may extend from the upper surface **82** of the rotor **72** for selective rotation of the rotor within the bore **62** of the housing.

Counterclockwise rotation of the rotor **72** to the position indicated in phantom is effective to couple the electromagnetic wave energy coupled into the port **84** to the port **86** or vice versa. The rotor **72** may, of course, be rotated to couple the ports **86** and **88** if desired where the ports are equally spaced at 120° intervals around the housing **60**.

The angle between the ports need not be 120° if the port through which the electromagnetic energy is to be introduced is predetermined. It is necessary, however, that the angle between the predetermined input port, e.g., port **84**, and the two output ports **86** and **88** respectively be equal to effect alignment of the surfaces **64** and **68** with the vertical walls of the ports.

The present invention may be embodied in many forms without departing from the scope thereof. By the use of the embodiment of the four port switch illustrated in FIG. **1** in an X band waveguide having A and B dimensions of 0.9 by 0.4 inches respectively, a VSWR between 1.010 and 1.090 has been achieved for a band width of 8 to 12.6 gigaHertz for the two E plane bends within a switch housing measuring 2 by 2 inch in the plane of the bend. Isolation of the switched paths is on the order of 60 db. to 80 db.

The switch of the present invention may also be suitable with appropriate scaling of the dimensions for bends in the E plane with a caveat as to the amount of power that may be applied without voltage breakdown. It is intended therefore that the invention not be limited to the illustrative embodiments disclosed but limited solely by the language of the appended claims with full range of equivalents.

I claim:

1. Apparatus for selectively switching electromagnetic wave energy from one hollow pipe waveguide having a rectangular cross section through a bend to one of two other similar waveguides having coplanar longitudinal axes comprising:

a housing having a bore with an arcuate surface normal to the axis of the bend,

said housing having first, second and third ports communicating with said bore through said arcuate surface in the plane of the bend, each of said ports being rectangular in cross section and having dimensions substantially the same as said waveguide for coupling thereto, said second and third ports being disposed on opposite sides of said first port with the angles formed by the longitudinal axis of said one waveguide respectively with the longitudinal axis of each of said two other waveguides being substantially equal;

a rotor disposed in said bore and mounted for rotation about an axis coincident with the center for said arcuate surface; said rotor having a surface adapted to connect the wall of said first port on the outside of the bend to the wall on the outside of the bend of whichever one of said second and third ports to which wave energy is to be switched, said rotor surface serving as the wall on the outside of the bend of the waveguide within said bore, and said arcuate surface serving as the wall on the inside of the bend of the waveguide within said bore;

said rotor including means for increasing the waveguide width in the plane of the bend within said housing between said arcuate surface and said rotor surface along a line bisecting the angle of the bend, and for decreasing the effective waveguide width in the plane of the bend within said housing between said arcuate surface and said rotor surface adjacent the intersection of said arcuate surface with the walls of the ports of the coupled waveguides; and

means for selectively rotating said rotor.

2. The apparatus of claim 1 wherein the angle between longitudinal axis of said one and said other waveguides is 90° and wherein the plane of the bend is the H plane.

3. The apparatus of claim 1 wherein said rotor surface is defined by a first surface substantially coplanar with one wall of the waveguide externally of said housing adjacent said first port, a second surface substantially coplanar with one wall of the waveguide externally of said housing adjacent one of said second and third ports, and a third surface connecting said first and second surfaces, said third surface being substantially normal to the line bisecting the angle of the bend,

wherein the width of the waveguide along the one-quarter angle of the bend lines is between about 91 and 95 percent of the width of the waveguide in the plane of the bend,

wherein the width of the waveguide along said line bisecting the angle of the bend is between about 104 and 105 percent of the width of the waveguide in the plane of the bend;

and wherein the bend is 90° and in the H plane.

4. The apparatus of claim 1 wherein said rotor surface is defined by a planar surface normal to the line bisecting the angle of the bend and a pair of arcuate surfaces on opposite sides thereof, said arcuate surfaces being substantially tangential both to said planar surface and to the walls of the connected waveguides.

5. The apparatus of claim 4 wherein the radius of curvature of said arcuate surfaces is between about 118 and 120 percent of the width of said waveguides in the plane of the bend.

6. The apparatus of claim 1 wherein said rotor comprises a longitudinal portion of a cylinder having a length greater than the height of said waveguides, said cylinder having a groove in an arcuate portion thereof in a plane normal to the longitudinal axis of said cylinder, the width of said groove being coextensive with the height of said waveguides and the bottom wall of said groove defining said rotor surface, and including impedance compensating means extending between the sidewalls of said groove substantially parallel to said rotor surface.

7. The apparatus of claim 6 wherein said impedance compensating means comprise an element of electrically conducting material contiguous to the said rotor surface substantially on the one-quarter angle of the bend lines.

8. The waveguide bend of claim 6 wherein the angle of the waveguide bend is 90°, wherein the plane of the bend is the H plane, and wherein impedance compensating means includes inductive posts spaced from said rotor surface and having a longitudinal axis substantially parallel to said rotor surface.

9. The apparatus of claim 1 wherein the width of the waveguide along the one quarter angle of the bend lines is between about 91 and 95 percent of the width of the waveguide in the plane of the bend, and wherein the width of the waveguide along the line bisecting the angle of the bend is between about 104 and 105 percent of the width of the waveguide in the plane of the bend.

10. The apparatus of claim 9 wherein said rotor surface is defined by a planar surface normal to the line bisecting the angle of the bend and a pair of arcuate surfaces on opposite sides thereof, said arcuate surfaces being substantially tangential both to said planar surface and to the walls of the connected waveguides.

11. The apparatus of claim 10 wherein the bend is 90° and in the H plane, and wherein the radius of curvature of said arcuate surfaces is between about 118 and 120 percent of the width of said waveguides in the plane of the bend.

12. Apparatus for selectively switching electromagnetic wave energy propagating at microwave frequencies through two rectangular hollow pipe input waveguides through a bend into a selected one of two similar output waveguides comprising:

a housing having a cylindrical bore with an axis normal to the plane of the bends and four ports spaced at 90° around said housing in the plane of the bends, said ports communicating with said bore at an angle normal to the axis thereof and having cross-sectional dimensions substantially that of said waveguides, said bore serving as the waveguide wall on the inside of the bend within said housing; and

a cylindrical rotor closely fitted within said bore for selective rotation therein about the axis thereof, said rotor having a pair of grooves inwardly extending from opposite sides thereof, the bottom of each of said grooves serving as the waveguide wall on the outside of the bend connecting one of said input ports to the selected one of said output ports within said housing and the sides of each of said grooves serving as the top and bottom walls of the waveguides within said rotor, said rotor having impedance compensating means within said grooves adjacent each of said ports whereby an odd number of reflections are presented to electromagnetic wave energy propagated through said bends.

13. The apparatus of claim 12 wherein the plane of the bend is the H plane and wherein said impedance compensating means comprise conductive posts extending across said grooves normal to the plane of the bend.

14. The apparatus of claim 13 wherein the waveguide width in the plane of the bend along the line bisecting the angle of the bend is between about 104 and 105 percent of the width of said input and output waveguides in the plane of the bend and wherein the effective waveguide width in the plane of the bend adjacent said compensating means is between about 91 and 95 percent of the width of said input and output waveguides.

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