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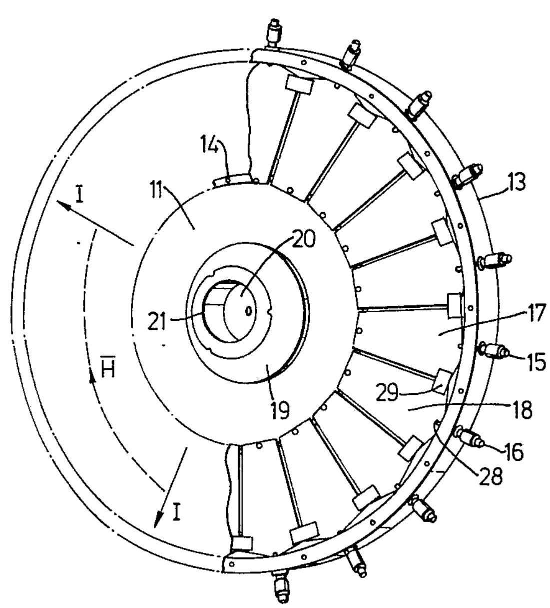
(54) Large scale low-loss combiner and divider

(57) A radio frequency power divider/combiner having a pair of circular conductive plates 11, 12 between which the dominant E-type mode is produced by symmetrical excitation at a central point 20, preferably by means of a coaxial line having its outer conductor attached to the first of these plates and its inner (centre) conductor 21 passing freely therethrough and attaching to the second of these parallel plates in an impedance matching flareout 19. A plurality of uniformly distributed collectors, each in the form of a loop defined by a plate 17 and post 14) feeding a coaxial branch port 15, 16, provides for low loss. The entire assembly is in the form of a thick disc with radially extended branch ports about its perimeter with the common excitation feed extending normally from the surface of the first plate. Resistors are provided between adjacent portions of the end-on loops for the suppression of circumferential current components corresponding to undesired modes.

Fig. 1A



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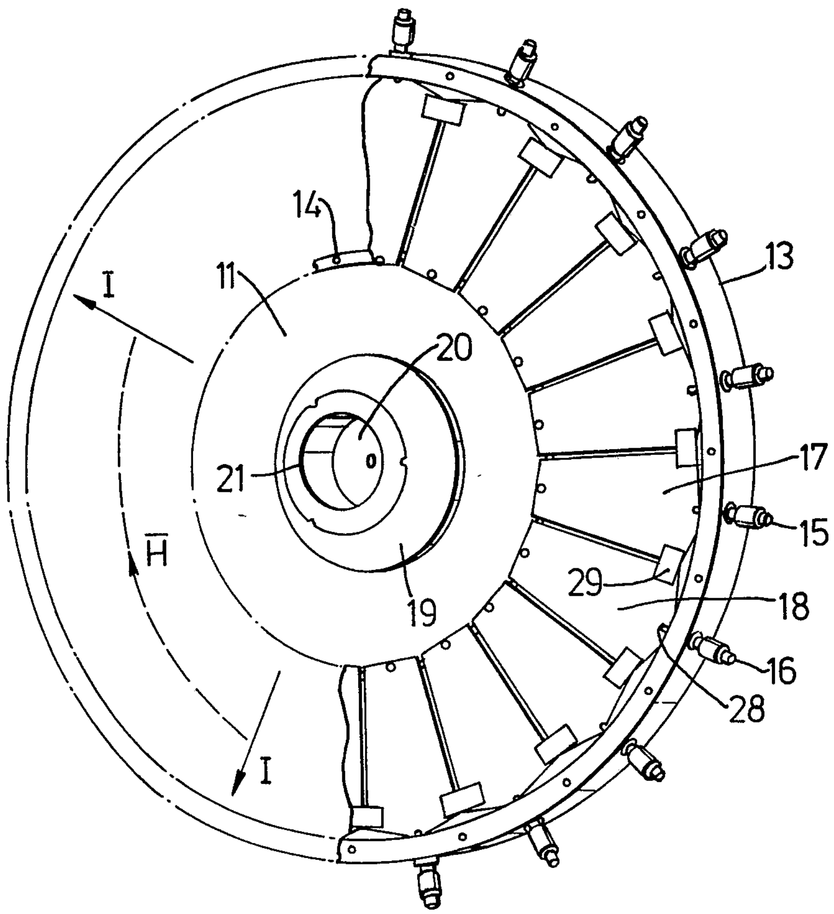

Fig. 1A

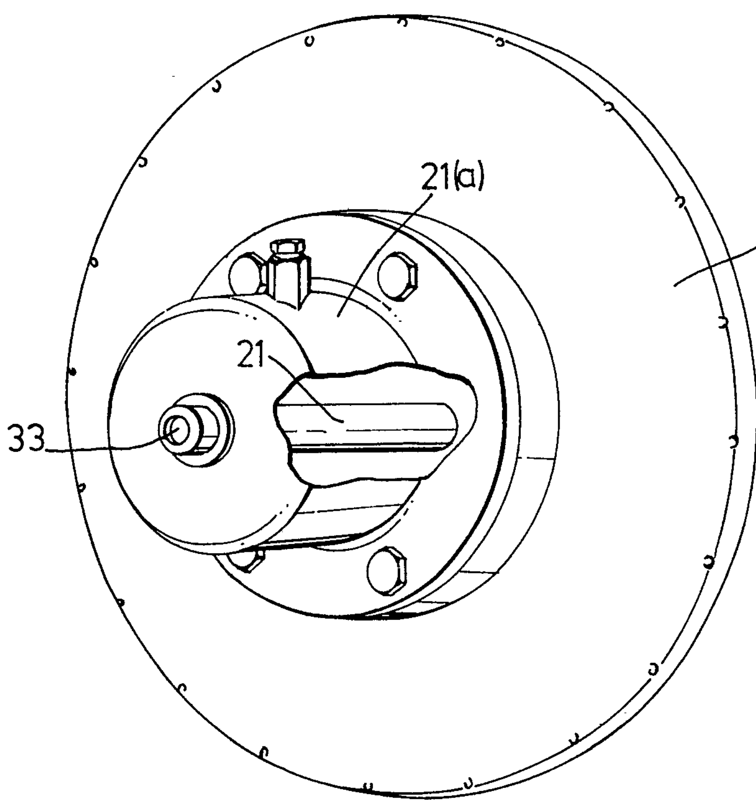

Fig. 1B

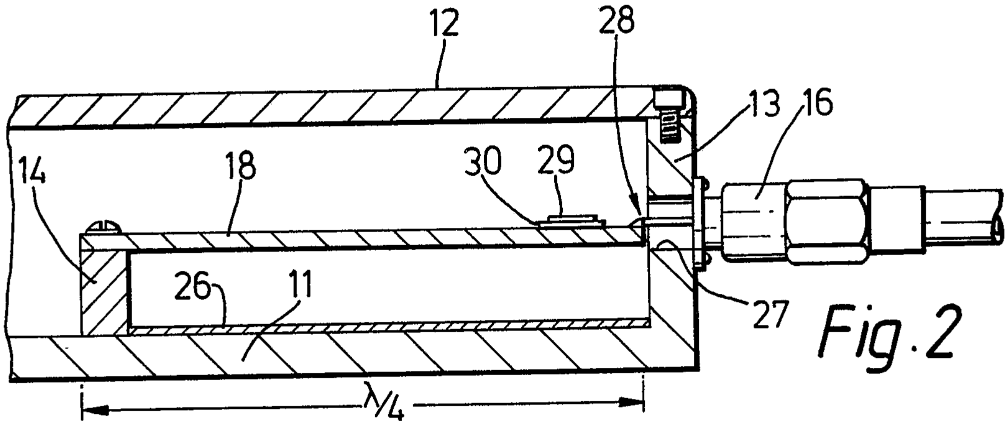

Fig. 2

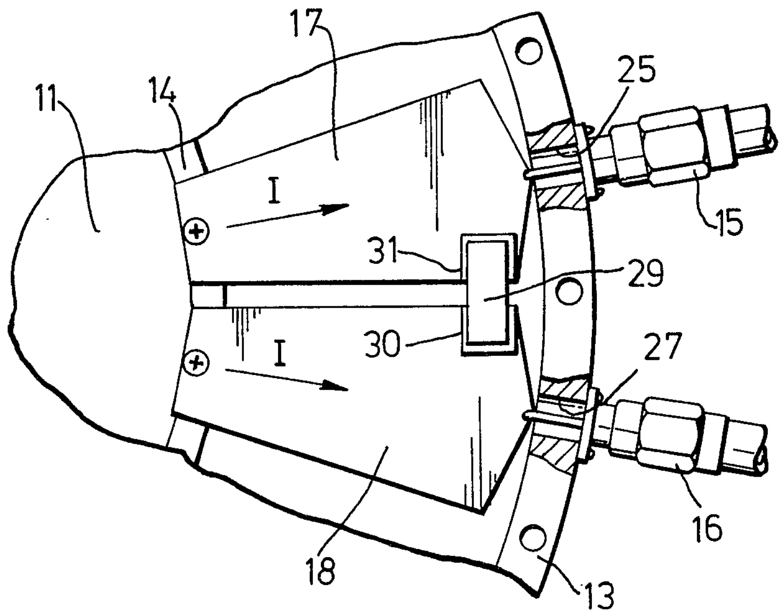

Fig. 3

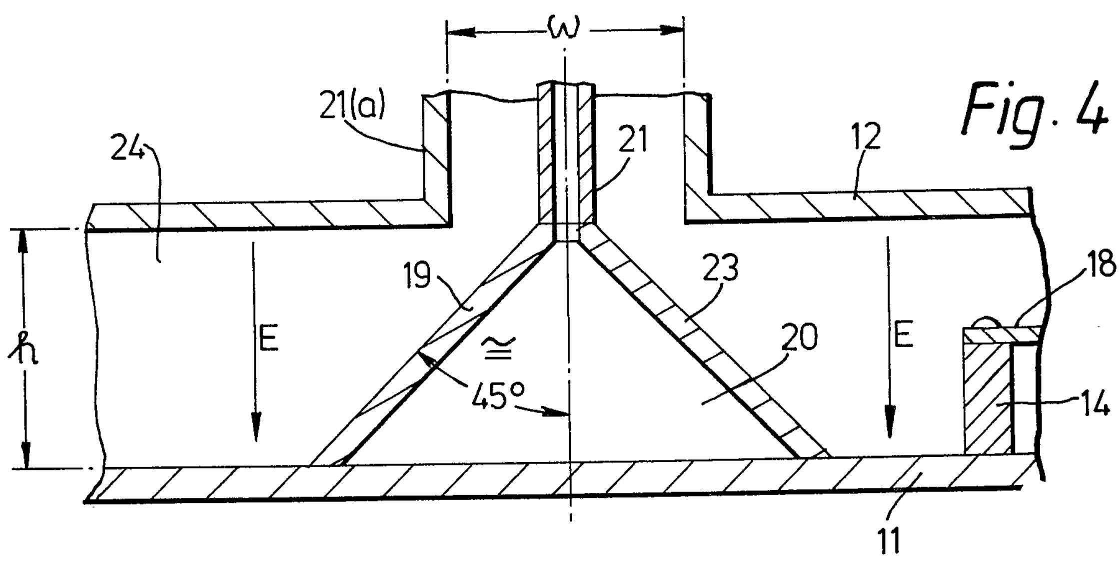

Fig. 4

SPECIFICATION

Large scale low-loss combiner and divider

This invention relates to radio frequency divider/ combiner apparatus generally and more particularly to such apparatus operative in the microwave region.

In modern radar systems, various requirements are extant for low loss radio frequency powered division and/or recombination. One such requirement arises in so-called unattended or minimally attended radar systems. In those systems, generation of the radio frequency power is effected by paralleling the outputs of a number of solid state RF generators. In this way, the failure of any one radio frequency module does not produce a total failure of the radio frequency power output stage, as would be the case where a single magnetron or other radio frequency generator were employed. Such a system is described in U.S. Patent Application Serial No. 955,349, (A.M. Levine-48) filed October 27, 1978, and entitled "Automatic Failure-Resistant Radar Transmitter/"

In the aforementioned U.S. Patent Application, Serial No. 955,349, the prior art in respect to powered divider combiner apparatus is reviewed in some detail. For example, the so-called Gysel and Wilkinson combiners are identified and the relative technical literature is likewise referenced.

Neither of those prior art divider/combiner structures is suitable for a relatively large number of divisions, i.e., where the correspondingly large number of branching ports are desired. Moreover, those prior art devices usually rely on stripline design, and accordingly are not as adaptable to higher power levels as might be desired in some instances.

Of course, there are many other applications for divider/combiner apparatus, such as in connection with multi-element antenna systems, for example. The manner in which the invention produces novel structure and results to provide a large number of branching ports in a low loss combiner/divider device will be understood as this description proceeds.

According to the present invention there is provided a radio frequency power divider and combiner apparatus comprising: first and second parallel conductive plates; a symmetrical feed through a central area of said first parallel plates for forming a relatively uniform dominant E-type mode within the space between said plates; a first port connected to said feed external of said plates; and branching means comprising a plurality of conductive loops symmetrically spaced and inwardly abutting a circle concentric with the centreline of said feed, said loops each providing current paths radial with respect to said circle on first opposite legs of said loop and normal to the planes of said plates in second opposite legs of said loop; and means comprising a branch port connected to a radially outward end of a first leg of each corresponding loop.

Basically the arrangement is that of a radial parallel plate waveguide with a central point of excitation such that energy in a dominant E-type mode propagates outward therefrom. For the dominant mode the currents are purely in the radial direction with the electric field normal to the top and bottom metal plates of the parallel plate waveguide configuration. A plurality of collectors are uniformly placed on the circumference of the circular wave front and therefore there is a constant phase and amplitude relationship set up. That is, each of the collectors receives energy from the radial current intercepted, the phase and amplitude of this energy being the same for each of the collectors with respect to the central feed.

Each of the collectors is a loop including a wedge-shaped planar conductor over approximately a quarter wavelength in radial dimension and width sufficient to abut the circumferentially adjacent loops saved for a relatively small separation gap. A conductive post extending from the inside surface of one of the parallel plate waveguide walls serves to position each of the aforementioned wedge-shaped loop legs in a plane between the two parallel plates forming the waveguide walls and provides a current path to the waveguide wall. Each of the branch ports, which are preferably coaxial, connects to the outward extremity of the loop leg thus suspended between the parallel waveguide plates. The return path is completed to the coaxial port outer conductor through the circumferential outer wall enclosing the circular waveguide configuration. Higher order modes as may be generated due to asymmetry and unequal branch port loading are suppressed by circumferentially placed resistors between adjacent loop legs for suppressing circumferential currents produced by these higher order undesired modes. These resistors may be pads of carbon resistance material in many applications or for higher power operation may be nichrome on beryllium oxide. The structure of the individual loops connected to the respective branch ports is such that each operates as a balun converting the basically balanced field situation between the parallel radial waveguide plates to the unbalanced branch port represented by a coaxial connector for example. This balun structure will be seen to operate as a four-to-one impedance transformer. The details of a typical embodiment according to the invention will be understood as this description proceeds.

An embodiment of the invention will now be described with reference to the accompanying drawings, in which:-

Figure 1a is a pictorial internal view of the device according to the invention,

Figure 1b is a cover providing one of the plates of the parallel plate waveguide configuration and the central feed,

Figure 2 is a section taken through Figure 1 as indicated assuming that the cover and feed assembly of Figure 1a is in place,

Figure 3 is a detail showing two of the wedge-shaped coupling loop legs and associated apparatus according to Figure 1 and Figure 2, and

Figure 4 is a partial section through Figure 1 showing the central feed and conical transition section therefor.

Referring now to Figure 1, one of the two parallel plates producing the radial waveguide of the device, namely 12, as illustrated in Figure 1a has been removed. The structure of Figure 1 shown generally at 10 is built on the other of the two parallel plates, namely 11. A circumferential or outer perimeter rim 13 makes a flat bottom dish-like supporting structure. At the centre the plate 11, a transitional (matching) conical piece 19 is electrically fixed to 11. This conical transition is essentially coaxial with rim 13 and also the inner rim 14 which provides inward support and electrical continuity for each of the loops the top legs of which are typically 17 and 18. Associated with 17 and 18 are branch ports 15 and 16 respectively, the centre conductors of these two coaxial ports 15 and 16 being connected to the outward edges of 17 and 18 respectively. The configurations of the plural loops illustrated in Figure 1, the wedge-shaped quarter wavelengths of which are illustrated 17 and 18 for two of these loops will be described in more detail in connection with Figures 2 and 3.

This also applies to the most suppression resistors under the conductive plates shown at 29. Referring now to Figure 2, the central feed side of the radial waveguide, i.e., comprising plate 12 is assumed to be in place. That is, subassembly of Figure 1b is assumed to be placed over that of Figure 1a, the subsequent figures present herewith reflecting that situation. Referring now to Figure 2, a section as indicated on Figure 1a is taken through the loop which includes the wedge-shaped leg 18. As previously indicated, the internal ridge 14 forms a part of this loop as does the piece 26 placed against plate 11 and of the same shape basically as 18. The loop leg 18 will be seen to be connected to the centre conductor of the coaxial branch port 16 at 28.

At this point it is also helpful to refer to Figure 3 in order that this connection might be more fully appreciated. Here it will be seen that for coaxial branch ports 15 and 16 clearance holes 25 and 27 respectively are bored through the outer rim 13 so that the inner conductors of 15 and 16 pass coaxially therethrough in essentially the same coaxial (impedance) relationship as applied where 15 and 16 pass through 13.

From Figures 2 and 3 the placement of resistive pads 31 and 30 with bridging conductive member 29 will be evident. This symmetrical arrangement provides suppression of higher order modes which would produce currents orthogonal with respect to the indicated current directions on loop leg 17 and 18 as indicated on Figure 3. Resistive patches 31 and 30 may be of carbon as well known in this art, however, for higher power levels of operation they may be of other materials such as nichrome deposited on beryllium oxide. The conductive plate 29 would ordinarily be of the same material as the loop legs 17 and 18, i.e., copper for example, suitably plated for environmental reasons.

In Figure 2, the conductive liner 26 may have its function provided by the conductive plate 11 and thereby not be required if the impedance relationships in any particular design are satisfactory.

In connection with impedance relationships, it is useful to note that each loop is normally on the order of a quarter wavelength measured radially and acts as a balun for converting the dominant E-type mode energy between the inward loop perimeter (i.e., about 14 as illustrated in Figures 1a, 2 and 3) and the central feed at the centre of Figure 1a. It can also be shown, that the configuration of the balun loop in each case produces a 4 to 1 impedance transformation. That is, assuming the normal 50 ohm impedance for the coaxial branch ports such as 15 and 16, the characteristic impedance within the radial parallel plate waveguide structure from the central feed outward is on the order of 200 ohms. Obviously, other branch port impedances are possible, with corresponding parallel plate waveguide impedance values, the entire matter of specific impedances and corresponding dimensioning being subject to specific designs within the skill of this art. Accordingly, since the width of each of the wedge-shaped loop legs such as 17 and 18 and their spacing from plate 11 are factors affecting the impedance specifically, the constraints facing the designer must first be evaluated. That is to say, if, for example, the branch port impedance is fixed then the loop design must be such as to accommodate that impedance. Depending upon the actual number of branch ports about the circumference of the device, the diameter will ultimately be determined, since the impedance criteria are not well served by simply dividing a given diameter for the device into end segments without regard to the resulting impedance relationships.

It can be shown that the mode suppression resistors, i.e., resistive patches 30 and 31 in series will have a value on the order of twice the individual branch port impedances. Thus, for a 50 ohm branch port impedance (at 15 or 16, for example) 30 and 31 should be each 50 ohms since they are effectively in series through the bridging plate 29 to provide a 100 ohm value between loop legs 17 and 18.

Those of skill in this art will realise that the mode suppression resistor can be placed entirely on one or the other of the adjacent loop legs and electrically connected to the other by an appropriate bridging plate, however, the configuration contemplated in Figure 3 has a greater heat sink capacity and therefore is more adaptable to higher power operations.

Referring now to Figure 4, it is again assumed that the cover plate 12 of Figure 1b is in place over the configuration of Figure 1a and a section is taken as indicated. The conical transitions 19 of Figure 1a will be seen to be approximately 45° from its centreline.

The core surface 19 provides a smooth transition betwen the parallel plate waveguide structure and the central feed, to substantially eliminate any inductive discontinuity. As a design objective, the ratio ^{w} h (see Figure 4) is selected so that the real impedance component (resistance) of the coaxial line formed by 21 and 21(a) is the same as the radial waveguide line formed between plates 11 and 12 at the radius $^{w}/2$ measured from the centreline of 21. The cone 19 has a hollow wall 23 surrounding the space 20 as indicated in Figure 4, similarly the central feed coaxial centre conductor 21 is preferably hollow. Although the cone and centre conductor 21 could be of solid conductive material, there would appear to be no advantage to justify the additional weight. The concentric tubular outer conductor 21a will be seen to be that of Figure 1b. In Figure 1b the central port 33 may require impedance matching or transition if the coaxial characteristic impedance provided by the configuration of 21 and 21a is other than the standard connector 33 illustrated in Figure 1b. Such a transition could of course be provided within the enclosure provided by 21a in a manner well known to those of skill in this art.

The physical representation in Figure 1a is consistent with a 20 branch port device, however, over 100 branch ports were provided in one implementation according to the invention. It will be noted that the loops all intercept the field between the parallel plates 11 and 12 (erectors identified in Figure 4) about a concentric circular line defined by the internal ridge 14. The symmetry of the device is an important consideration in preventing the excitation of higher order (undesirable) modes. Of course, in a practical design it is not possible to entirely suppress such higher order modes merely by symmetry because the structure cannot practically be perfectly symmetrical and the loops cannot be identical. As hereinbefore indicated the radially disposed resistors between adjacent legs (such as 17 and 18) of the loops are provided for the suppression of any such undesired modes as are excited.

In a 20 branch version for 1215 to 1400 MHz operation, such as pictured in drawings, the loops were space 1.25 inches between radial centrelines. With all branch ports uniformly exicted, the impedance matching is excellent. With only a single branch port excited the match was very good and subject to some further improvement by shortening the radial, quarter-wave loop dimension slightly. Isolation between adjacent ports of 13 dB was considered acceptable, especially for the application in which the branch ports are driven from individual solid-state RF generators to form a high power output from the central port 33. Adjacent port isolation is subject to improvement by optimization of the higher order mode absorbers. Measured overall insertion loss was on the order of 0.20 dB. The device is, of course, reciprocal and is inherently broad band. Power handling capability exceeds 100 KW peak and 7 KW average.

Based on an understanding of the invention from the foregoing, it will be evident to those of skill in this art that various modifications are possible within the inventive concept. For one example, the central and branch port feeds could be adapted from other than coaxial feed means.

CLAIMS

1. A radio frequency power divider and combiner apparatus comprising:

first and second parallel conductive plates;

a symmetrical feed through a central area of said first parallel plates for forming a relatively uniform dominant E-type mode within the space between said plates;

a first port connected to said feed external of said plates;

and branching means comprising a plurality of conductive loops symmetrically spaced and inwardly abutting a circle concentric with the centreline of said feed, said loops each providing current paths radial with respect to said circle on first opposite legs of said loop and normal to the planes of said plates in second opposite legs of said loop;

and means comprising a branch port connected to a radially outward end of a first leg of each corresponding loop.

2. Apparatus according to claim 1 in which said symmetrical feed is a coaxial feed, the outer conductor of which is connected to said first parallel plate and the centre conductor of which connects to the other of said plates, the clearance opening in said first plate at said outer conductor connection thereto being substantially congruent with said coaxial feed outer conductor inner diameter.

3. Apparatus according to claim 2 in which said coaxial feed centre conductor is flared into a diverging conical shape as it extends to said second plate to provide an impedance matching transition.

4. Apparatus according to claim 1, 2 or 3 in which said loops are of length approximately one-quarter wavelength measured radially, said first opposite loop legs thereby being of a length not exceeding one-half wavelength, one of said first opposite loop legs being conductively integral with a portion of said first plate and the other leg being spaced approximately midway between said first and second plates.

5. Apparatus according to claim 4 in which said loops are further defined as not exceeding one-quarter wavelength in said radial length.

6. Apparatus according to claim 4 in which said branch ports include coaxial connectors.

7. Apparatus according to any preceding claim in which at least said midway located legs are a plurality of circumferentially closed-spaced, wedge-shaped, planar members in a plane between said plates, and are sized circumferentially to contribute to a match to the impedance of the corresponding branch port connected thereto.

8. Apparatus according to any preceding claim in which resistive loads are placed between adjacent ones of said loops, thereby to intercept and suppress circumferential current components corresponding to the occurrence of undesirable modes different from said dominant E-type.

9. Apparatus according to any preceding claim in which said branching means are designed to provide substantially a four-to-one impedance transformation to match the nominal coaxial impedance of said branch ports with the higher impedance extant at the radially inward extremities of said branching means.

10. A radio frequency power divider and combiner apparatus substantially as described with reference to the accompanying drawings.

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