The present invention relates to a branching filter for the separating of ultra-high frequency electromagnetic waves according to their frequency. This filter, better called a directional coupler filter, connects two wave guides with parallel axes and rectangular cross-sections in such a way that, if electromagnetic waves are emitted in the first guide, the whole of the wave energy is transmitted to the second guide in the form of waves propagating in the opposite direction to that of the waves initially introduced, if in the first guide their frequency is comprised in the filter’s pass-band, while the energy continues to propagate in this first guide without being disturbed if their frequency is outside of the filter’s pass-band.

More precisely, the directional coupler filter according to the invention is of the type in which two wave guides having rectangular cross-sections and parallel axes, and the cross-sections of which have a common median plane parallel either to the longer sides of the cross-sections of both guides or to the shorter sides of these cross-sections, are coupled through one or several resonant cavities by means of apertures provided in the side walls of these two guides facing each other.

The filter according to the invention is capable of coupling two rectangular cross-section wave guides in such a way that filtering takes place in the same manner, whatever be the propagation direction considered in any one of these guides.

Directional coupler filters having similar properties are already known, for instance they have been described in the U.S. Patent 2,626,990 to J. R. Pierce. The filter according to the invention improves over the known filters, in that it allows to obtain the same results with a smaller number of cavities of a particular geometrical shape, capable of simultaneously oscillating at a given frequency according to two distinct oscillation modes, to each one of which corresponds a different type of coupling.

Any filter according to the invention may, like certain known filters, be made non-reciprocal by the insertion in the cavities of suitable ferromagnetic material elements submitted to a constant magnetic field. The geometrical shape selected for the cavities in the filters of the invention is particularly well adapted to the use of such elements, as the latter may be of a short length, which facilitates the application of the magnetic field by means of a permanent magnet.

According to the present invention, a directional coupler filter is provided, comprising two rectangular cross-section wave guides having parallel axes and the cross-sections of which have a common median plane parallel either to the longer sides or to the shorter sides of both of these cross-sections, coupled through one or several resonant cavities of parallelepipedic shape by means of apertures provided in the side walls of these two guides facing each other, characterized in that the said resonant cavity or cavities have a square cross-section and a length perpendicular to this cross-section much smaller than the side length of the said cross-section, while the symmetrical plane of the said cavities parallel to their square cross-section preferably passes through the axes of the said guides, the said coupling apertures being provided on two opposite walls of the cavity perpendicular to the said square cross-section and symmetrically arranged with respect to the center of each of the said opposite walls and the dimensions of each one of the said cavities being chosen in such a manner that it resonates for a predetermined frequency located in the filter pass-band according to two distinct oscillation modes $TE_{pq}$ and $TE_{q}$, for which the indices $p$ and $q$ are respectively even and odd.

According to a mode of embodiment of the invention, the two guides have equal cross-sections and are coupled to the said cavity or cavities through their side walls facing each other and corresponding to one of the shorter sides of their cross-section, and the length of the said cavity or cavities measured along their axis perpendicular to their square cross-section is at most equal to that of the said shorter sides.

According to another mode of embodiment of the invention, the coupling between the guides is provided by an assembly of several cavities with different resonance frequencies connected between the two guides and having each one of their axes perpendicular to their square cross-sections spaced from the next one by an odd integer number of quarters of the phase wavelength in the guides for a frequency equal to the average of the resonance frequencies of the said cavities.

According to another embodiment of the invention, at least one resonant cavity coupling the said guides is provided with a rod of ferromagnetic material, the axis of which substantially coincides with the axis of the said cavity perpendicular to its square cross-section and the length of which is substantially equal to that of the said cavity in the direction of the latter axis, the transversal dimensions of the said rod perpendicular to its axis being small with respect to the side of the said square cross-section and the said rod being submitted to a constant magnetic field parallel to its axis, whereby the filter is made non-reciprocal.

According to still another embodiment of the invention, a branching filter is provided allowing the connecting of a circular cross-section wave guide, propagating the $TE_2$ wave in one or the other of its transmission directions, to a plurality of utilization devices, the said filter including a first transition element connecting the said circular cavity to a main guide with a rectangular cross-section and transforming the said $TE_2$ wave into a $TE_0$ wave in the said main guide, and a plurality of auxiliary guide lengths having rectangular cross-sections and axes parallel to that of the said main guide and forming, together with the said main guide and corresponding resonant cavities, a plurality of directional coupler filters according to the invention, each one of the latter filters transmitting the ultra-high frequency waves through a further transition member to a secondary rectangular cross-section connected to one of the said utilization devices.

In the various above-mentioned embodiments of the invention the resonant cavities may advantageously be provided with movable plungers consisting of rods of dielectric material with axes perpendicular to the square cross-section, the position adjustment of which allows to accurately adjust the resonance frequencies of these cavities.

Besides, it results from the above-specified choice of the two oscillation modes of each of these cavities that their electric fields respectively have a symmetrical configuration and an asymmetrical configuration with respect to one or the other of the median planes of these cavities perpendicular to their square cross-section.

The invention will be better understood from the fol-
lowing detailed description, made with reference to the
annexed drawings, in which:

Fig. 1 represents a directional coupler filter with a
single cavity according to the invention, referred to a
system of rectangular coordinates oxyz, in the case of
waves of smaller dimensions than the TE_{02} type propagating in the guides.

Figs. 2 and 3 represent two sections of the directional
coupler filter of Fig. 1 through plane oyz, more

Fig. 2 represents a wave system symmetrical with
respect to the plane of geometric symmetry oyz, in a
coupling cavity.

Fig. 3 represents a wave system antisymmetrical with
respect to the same plane oyz, in the same cavity.

Fig. 4 represents three cavities analogous to the cavity
of Fig. 1 put in parallel connection between the two
guides.

Fig. 5 shows the curve of the attenuation as a func-
tion of frequency, of the waves transmitted through a
filter comprising the three cavities of Fig. 4.

Fig. 6 represents a cavity similar to that of Fig. 1 as
to its dimensions, but coupling rectangular cross-section
wave guides where TE_{02} waves propagate.

Fig. 7 represents an assembly of branching filters ac-
cording to the invention, allowing the bidirectional op-
eration of a circular cross-section guide propagating the
TE_{02} wave and associated with several utilization devices,
either transmitters or receivers.

The directional coupler filter represented in Fig. 1 is
referred to a tri-rectangular axis system oxyz.

The three coordinate planes of this coupler are three symmetry
planes, if tuning devices which will be mentioned later
on are neglected. The shorter sides of guides 10 and
11 and the height of resonator 12 counted along oz are
distinctly smaller than the half wavelength in free space
of the waves which propagate in the considered assembly.

It results therefore that the electric field of these waves
are constant along any straight line parallel to oyz.

The device of Fig. 1 is built in such a way that a wave
entering through section 1 of guide 10 issues through
section 3 of guide 11 if its frequency is equal to the
resonance frequency of cavity 12. If not, the wave
to the frequency of the incident waves, the energy which
penetrates through openings 1 and 2 does not enter the
or issues symmetrically through the same open-

ings in the case of symmetrical energizing the exchange
of energy between cavity 12 and guides 10 and 11 is

Wis not the apertures 7 and 8. In fact, the
latter are located in such regions where the electric field
is substantially zero and no current circulates in the
cavity walls in these regions.

As to the antisymmetrical oscillation represented in
Fig. 3, here, to the contrary, the apertures 7 and 8
contribute to the exchange of energy between cavity 12 and
guides 10 and 11, and not 5 and 6. This is due to the
face that for this oscillation type, the apertures 5 and 6
are located in the neighbourhood of a zero electric field
plane.

In the case of antisymmetrical oscillation (Fig. 3)
and for waves of same amplitude entering in opposite
phase through openings 1 and 2, the energy issues anti-
symmetrically through 3 and 4, if the cavity 12 is tuned
to their frequency, or through 1 and 2 if this is not the
case.

If the two above-mentioned wave systems are super-
posed in such a way that the waves entering 2 are oppo-
site in phase and cancel each other, the issuing waves
through 4 cancel each other too; the energy exchange is
then effected in the conditions already described in con-
nection with Fig. 1, provided, however, that the reso-
nance frequencies and the loaded-Q's of the cavity be
the same for both systems. For the cavity 12 a square
cross-section is chosen, so that the resonance frequencies


Corresponding to both of the oscillation modes be equal.

In such conditions, the length of the sides of the square
cross-section, when the TE_{02} and TE_{02} modes are used,

must be equal to the wavelength in free space multiplied
by \sqrt{13/2}. The resonance frequencies of the cavity are
adjusted by shifting the plungers 13 and 14 (Fig. 1),
preferably constituted by rods of dielectric material.

Cross-sections 13, 14, 15, 16 of these plungers are
represented on Figs. 2 and 3. By shifting the plungers 13
and 14 towards the inside of the cavity and symmetrically
with respect to oyz, the resonance frequency of the sym-
metrical mode with respect to oyz is decreased without
changing the resonance frequency of the antisymmetrical
mode. In fact, for the latter mode, the plungers are
located in a zero electric field plane. By shifting sym-
metrically with respect to oyz the plungers 15 and 16
towards the inside of the cavity, the resonance frequency
of the antisymmetrical oscillation mode with respect to


does not change within the resonance

frequency of the symmetrical mode.

On Fig. 1 where the cavity is shown from outside, the
plungers 13 and 14, mechanically associated by a con-
necting member 20, may be seen; it is convenient to
simultaneously handle the two plungers 13 and 14 in
order to adjust the cavity resonance for the symmetrical
oscillation mode with respect to oyz.

The two plungers 15 and 16 which allow adjusting of
the antisymmetrical resonance are also mechanically as-
associated by a member located on the other side of the
device; therefore, they cannot be seen on Fig. 1.

If the resonances used are those according to the TE_{02}
and TE_{02} modes, it is particularly the loaded-Q's of the cavity independently of each other for
both of the considered modes. In fact, if the coupling
apertures 7 and 8 are located on both sides of oyz, at a
distance approximately equal to a sixth of the length
of the square side, they do not influence the loaded-Q for
the symmetrical oscillation mode with respect to oyz;
the coupling apertures such as 5 and 6 located on the
axis oyz neither change the loaded-Q of the cavity for the
antisymmetrical resonance with respect to the plane oyz.

It is therefore possible to independently adjust the
loaded-Q for the symmetrical and antisymmetrical modes
with respect to zoy, by respective adjustment of the size of the coupling apertures (5, 6) and (7, 8).

The coupling between guides 10 and 11 is of the type which reverses the direction of propagation of the waves; this is due to the fact that, in the resonator 12, the spatial periodicity in the direction oy is such that there is half a wavelength more for the antisymmetrical mode than for the symmetrical one.

According to another embodiment of the invention, represented on Fig. 4, advantage is taken of the property of the coupling between guides 10 and 11 of reversing the direction of propagation of the waves when passing from one guide to the other for the building of a filter with a wider pass-band, by parallel connection of several resonant cavities tuned to different frequencies selected in this band.

The technical conditions to be fulfilled for associating in parallel several resonant cavities coupling two guides with parallel axes are explained in my co-pending patent application Serial No. 591,593, filed June 15, 1956. It is reminded that these conditions are the following:

(a) The coupling through the cavities must be such that it reverses the direction of propagation of the waves from one guide to the other.

(b) The axes of the cavities must be spaced by an odd number of quarters of the phase wavelength in the guides for the average frequency of the transmitted band.

(c) The loaded-Q's of the cavities being assumed to have a common value, the relative spacing of the resonance frequencies of two successive cavities must be equal to the reciprocal of this value.

In Fig. 4, three cavities analogous to those represented in Figs. 2 and 3, connected in parallel, are shown in section. Fig. 5 represents, in dotted lines, three curves 21, 22, 23 respectively giving for the three cavities 24, 25, 26 of Fig. 4 the attenuation A as a function of the frequency ω of the waves transmitted from input 27 to output 28 of the guides, supposing that only one cavity is used, the others having their coupling apertures short-circuited. The curve 29 in full line shows the transmission attenuation A across the whole of the three cavities when they operate simultaneously in parallel. According to another embodiment of the invention, the above-described cavities are used to couple waveguides in which the TE_{01} waves propagate. Fig. 6 represents a cavity 30 which, referred to the oxyz axis system, has the same dimensions as the cavities in Figs. 1, 2 and 3. This cavity 30 couples the guides 31 and 32 in which TE_{01} waves with an electric field parallel to oy propagate. The inner dimensions of guides 31 and 32, measured along oy must then be distinctly smaller than the half-wavelength in free space of the transmitted waves. The coupling apertures must then be located on the broader side walls of the guides.

Except for the tuning devices, the device is mechanically symmetrical with respect to plane xoy. As in the case represented in Figs. 1, 2 and 3, the electric field is at any time antisymmetrical with respect to the mechanical symmetry plane xoy. If the guides 31 and 32 have their longer sides twice as long as those of guides 10 and 11 (Figs. 1, 2 and 3) and their shorter sides half as long as the latter ones, the currents in the neighbourhood of the coupling apertures are the same for both devices, if they receive the same electromagnetic energy. If all other dimensions are the same, the two considered devices have identical characteristics.

According to another embodiment of the invention, the coupling between guides 10 and 11 (Fig. 1) is made non-reciprocal by providing the cavity with a cylindrical rod of ferromagnetic material such as ferrite, directed along o2; the ends of which rest on the inner square faces of the cavity and on the axis of the rod, and the sides of which rest on the side of said square faces. A magnet such as those represented in 51 and 52 (Fig. 7) creates a constant magnetic field in that rod. The wave frequencies should, of course, be very near to the ferromagnetic resonance frequency of the material for the particular value of the constant magnetic field employed.

The high frequency magnetic field to which the ferrite rod is submitted is a constant amplitude rotating field. In fact, for the antisymmetrical mode represented in Fig. 2, the high frequency magnetic field is, at all points of z2 inside of the cavity, directed along o2; for the symmetrical system (Fig. 3), the magnetic field is directed along oy; and, if the two modes are superposed, the two magnetic fields having the same amplitude and oscillating in phase quadrature add themselves vectorially. Depending on the fact that the rotating direction of the field is or is not the same as that of the natural precession of the magnetic intensity vector in the ferrite rod submitted to the constant magnetic field, the apparent permeability of the ferrite rod will be very different, and the resonance frequency of the cavity will also be different. There will be a resonance frequency for the waves entering 1 and issuing through 3 or entering 4 and issuing through 2 (these two wave systems just differing from one another by a rotation of 180 degrees around axis o2). There will be another resonance frequency for the waves entering 3 and issuing through 1, or entering 2 and issuing through 4...

Still according to a further embodiment of the invention all previously described characteristics may be combined in order to build branching filters allowing the use of a circular cross-section waveguide operating according to the TE_{01} mode and in which waves are guided by several transmitters or destined for several receivers propagating in both directions.

In my co-pending patent application Serial No. 620,029, filed October 22, 1956, a transition member is described, capable of transforming the TE_{01} mode propagating in a circular cross-section guide into a TE_{02} mode propagating in a rectangular cross-section guide, as well as another transition member capable of transforming the TE_{02} mode propagating in a rectangular cross-section guide into a TE_{01} mode propagating in another rectangular cross-section guide.

The above-mentioned transition members will be respectively called first and second type transition members. Fig. 7 represents an assembly of branching filters which allows the bidirectional operation of a circular cross-section waveguide according to the TE_{01} mode by several transmitters and receivers. The circular guide section nearest to the filters is designated by 49 in Fig. 7, while 41 is a transition member of the first type which transforms the TE_{01} wave of the circular guide into a TE_{02} wave in a rectangular guide. Three rectangular guide sections in which TE_{02} waves propagate and to which three filters according to the invention are connected, are designated by 42, 43 and 44. Each one of these filters comprises two resonant cavities in parallel connection.

Transition members of the second type 45 and 46 transform the TE_{02} waves issuing from the filters 48 and 49 into TE_{01} waves in the rectangular guide, which propagate towards the receivers 53 and 54.

The filters 48 and 49 allow the passing of waves of relatively near frequencies which are transmitted from the circular guide 49 to the receivers 53 and 54. The magnets 51 and 52 induce constant magnetic fields in the cylindrical ferrite rods around the axis of the cavities perpendicular to their square faces, thus making the filters 48 and 49 non-reciprocal. Failing this precaution, a TE_{02} wave emitted at the end 58 of the rectangular guide and having a frequency comprised in the pass-band of the receivers 53 and 54 would be directed towards the ends 56 and 57 of the wave guide 50, and the terminal impedances are provided. Owing to the fact that the filters are non-reciprocal, the cavities of filters 48 and 49 appear as distinctly out of tune for the waves issuing from 58, which continue propagating to-
wards the circular guide 40. It is therefore possible to connect a transmitter 55 to the section 44 of the rectangular guide. The transition member 47 transforms the TE_{0n} waves issued from 55 into TE_{0n} waves. The filter 59 directs these waves towards 44, then towards the circular guide 40. Owing to the fact that the filters 48 and 49 are non-reciprocal, the frequencies of the waves from 55 may be chosen in the frequency band of the waves received through 53 and 54, without disturbing the others.

The above examples are given for explanation purposes; they use the TE_{0n} oscillation mode, but it is obvious that nothing is changed in the operating of the device when other TE_{0n} modes are used, as indicated above. Within the scope of the invention, it is also possible to use a guide coupling arrangement comprising any number of apertures, for instance two, provided, however, that the loaded-Q's of the cavities be the same for the symmetrical and antisymmetrical oscillation modes. The adjustment of the loaded-Q's is made independently for the two modes in the above-described case, but the same adjustment of the loaded-Q's can experimentally be obtained for any number of apertures by successive trials.

What is claimed is:

1. An ultra-short wave four-port directional coupler band derivation filter, comprising first and second rectangular cross-section wave guide lengths having parallel axes, a common median plane to their cross-sections passing through said axes and the longer and shorter sides of each one of said cross-sections respectively parallel to said square cross-section, and two opposite lateral walls perpendicular to said square cross-section respectively consisting of one and the other of the walls of said guide facing each other, said resonant cavity having a length perpendicular to said square cross-section much shorter than the side thereof, and an even number of coupling apertures arranged in each one of said lateral walls symmetrically with respect to the center thereof, wherein the dimensions of said square cross-section are such that said cavity is capable of oscillating at a predetermined frequency in the derived band of said filter according to two distinct TE_{0m} and TE_{0n} modes, for which the values of the integer numbers \( p \) and \( q \) are respectively even and odd, said four ports being constituted by openings at both ends of both said guide lengths.

2. A directional coupler filter as claimed in claim 1, wherein said guides have equal cross-sections and wherein said walls facing each other are those containing one shorter side of cross-sections of said guides.

3. A directional coupler filter as claimed in claim 1, wherein said guides have equal cross-sections and wherein said walls facing each other are those containing one longer side of the cross-sections of said guides.

4. A directional coupler filter as claimed in claim 1, wherein said cavity is provided with at least one pair of movable dielectric plungers symmetrically arranged with respect to one of its symmetry planes perpendicular to its square cross-section.

5. A directional coupler filter as claimed in claim 1, wherein the inside of said cavity is provided with at least one ferro-magnetic material rod having its axis perpendicular to its square cross-section, said filter further including magnetizing means for impressing a constant magnetic field upon said rod in a direction substantially parallel to its axis.

6. An ultra-short wave four-port directional coupler band derivation filter, comprising first and second rectangular cross-section wave guide lengths having parallel axes, a common median plane to their cross-sections passing through said axes and the longer and shorter sides of each one of said cross-sections respectively parallel to the longer and shorter sides of the other of said cross-sections, a parallelepipedic resonant cavity of square cross-section and having two opposite lateral walls perpendicular to said square cross-section respectively consisting of one and the other of the walls of said guide facing each other, said resonant cavity having a length perpendicular to said square cross-section much shorter than the side thereof, and an even number of coupling apertures arranged in each one of said lateral walls symmetrically with respect to the center thereof, wherein the dimensions of said square cross-section are such that said cavity is capable of oscillating at a predetermined frequency in the derived band of said filter according to two distinct TE_{0m} and TE_{0n} modes, for which the values of the integer numbers \( p \) and \( q \) are respectively even and odd, said four ports being constituted by openings at both ends of both said guide lengths.

7. A directional coupler filter as claimed in claim 6, wherein said guides have equal cross-sections and wherein said walls facing each other are those containing one shorter side of the cross-sections of said guides.

8. A directional coupler filter as claimed in claim 6, wherein said guides have equal cross-sections and wherein said walls facing each other are those containing one longer side of the cross-sections of said guides.

9. A directional coupler filter as claimed in claim 6, wherein at least one of said cavities is provided with at least one pair of movable dielectric plungers symmetrically arranged with respect to one of its symmetry planes perpendicular to its square cross-section.

10. A directional coupler filter as claimed in claim 6, wherein the inside of at least one of said cavities is provided with at least one ferro-magnetic material rod having its axis perpendicular to its square cross-section, said filter further including magnetizing means for impressing a constant magnetic field upon said rod in a direction substantially parallel to its axis.

11. A multidirectional branching filter for ultra-short waves comprising a length of circular cross-section wave guide, a first transition member connecting said circular wave guide to a main rectangular cross-section wave guide, a plurality of auxiliary rectangular cross-section wave guides having their axes parallel to the axis of said main guide, resonant cavities of parallelepipedic shape and square cross-sections each having two opposite lateral walls perpendicular to its square cross-section respectively consisting of one wall of said main guide and of one wall of one of said auxiliary guides facing each other, an even number of coupling apertures arranged in each one of said lateral walls symmetrically with respect to the center thereof, a plurality of further transition members each one of which connects one of said auxiliary guides to one corresponding secondary guide, and means for connecting each one of said secondary guides to a utilization device, wherein the dimensions of the cross-section of each one of said cavities are such that said cavity is capable of oscillating at a predetermined frequency according to two distinct TE_{0m} and TE_{0n} modes, for which the values of the integer numbers \( p \) and \( q \) are respectively even and odd.

12. A multidirectional branching filter as claimed in claim 11, wherein the inside of at least one of said cavities is provided with at least one ferro-magnetic material rod having its axis perpendicular to the square cross-section of said cavity, said filter further including magnetizing means for impressing a constant magnetic field upon said rod in a direction substantially parallel to its axis.

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