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(54) **Physically non-uniform TEM-mode directional coupler**

(57) The invention relates to a Directional coupler (100) with at least a first (102) and a second (104) inner electrical conductor and one outer electrical conductor (106), the outer electrical conductor surrounding the first and the second inner electrical conductor, wherein the first and the second inner electrical conductor and the outer electrical conductor are adapted to be electromag-

netically coupled via transverse-electromagnetic-mode radiation, wherein an even-mode impedance and an odd-mode impedance are constant along the length of the first and the second inner and the outer electrical conductor, and wherein the cross-sectional dimensions of the first and the second inner and the outer electrical conductor vary over the length of the first and the second inner and the outer electrical conductor.

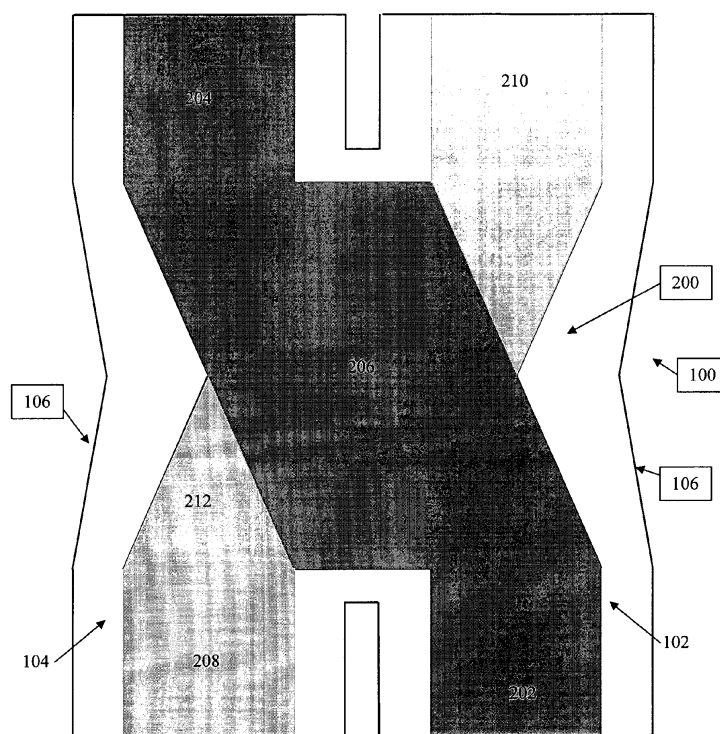


Fig. 2

Description

Field of the invention

[0001] The invention relates to transverse electromagnetically coupled lines, more particularly to a transverse electromagnetic mode directional coupler.

Background and related art

[0002] Transverse electromagnetic mode directional couplers are usually designed physically and electrically uniform. Traditionally, such couplers are both physically and electrically uniform. Physical uniformity denotes a geometry where both conductors are running parallel and have a constant width over the length of the coupling section, which is usually a quarter of a wavelength long with reference to a center frequency f_c . Electrical uniformity denotes that along the length of the coupled line section, the two characteristic coupled line parameters Z_{0e} , Z_{0o} remain constant. Z_{0e} denotes the even-mode impedance, while Z_{0o} denotes the odd-mode impedance of the coupled lines.

[0003] Some directional couplers with longer coupling sections than the quarter wavelength at the centre frequency do not keep Z_{0e} and Z_{0o} constant along the length of the coupled line section. Compared to the above mentioned directional coupler with quarter wavelength coupled line sections, these directional couplers do not have the same phase properties between their ports. These directional couplers have aperiodic high pass properties. The coupling is constant from a lower frequency limit.

Summary of the invention

[0004] Embodiments of the invention provide a directional coupler with at least a first and a second inner electrical conductor and one outer electrical conductor. The outer electrical conductor surrounds the first and the second inner electrical conductor. The first and the second inner electrical conductor and the outer electrical conductor are adapted to be electromagnetically coupled via transverse electromagnetic mode radiation. Therein an even mode impedance and an odd mode impedance are constant along the length of the first and the second inner and the outer electrical conductor. The cross-sectional dimensions of the first and the second inner and the outer electrical conductor vary over the lengths of the first and the second inner and the outer electrical conductor.

[0005] Preferably, the first and second inner conductors vary such that the horizontal conductor separation increases towards the ends of the coupled line section. The coupled line section is thereby the section of the lines, where the lines are electromagnetically coupled via transverse electromagnetic mode radiation. This is advantageous because a transition to an external port can be realized without a need for additional decoupling means. (Additionally), In spite of the varying horizontal

conductor separation the even mode impedance and the odd mode impedance of the directional coupler are constant along the length of the coupler. Thus, the directional coupler has electrically uniform coupling properties.

[0006] It is to be noted that not only directional couplers may be designed in such a way. Principally, this is the case for every device with at least two coupled lines, which are characterized by the even mode impedance and the odd mode impedance.

[0007] Embodiments of the invention are advantageous because the coupling between the conductors is not interrupted abruptly at the ends of the coupled lines and an electrical discontinuity, which reduces the performance of the directional coupler, is avoided. Another advantage arises in the case of coupled line sections of different coupling strengths in a cascaded arrangement for obtaining wideband performance. Cascade connection of both coupling sections would be possible without a vertical step transition which would cause electrical performance limitations and mechanical complexity.

[0008] Only two electrical parameters, the even-mode and odd-mode impedances Z_{0e} , Z_{0o} need to be calculated for the design. These two parameters then determine the cross-sectional dimensions of the directional coupler. If the impedances Z_{0e} , Z_{0o} are constant along the length of the coupled line section, then the coupling is uniform.

[0009] Z_{0e} and Z_{0o} are related to the port impedance Z_0 of the directional coupler according to the following equation:

$$Z_0 = \sqrt{Z_{0e} \times Z_{0o}}$$

wherein Z_0 is normally 50 Ohm.

[0010] The coupling factor k can be calculated with the following formula:

$$k = \frac{Z_{0e} - Z_{0o}}{Z_{0e} + Z_{0o}}$$

Thus, k is constant when Z_{0e} and Z_{0o} are constant.

[0011] According to embodiments of the invention the first and the second inner and the outer electrical conductor are tapered. By tapering the electrical conductors the even mode impedance and the odd mode impedance are kept constant, while the cross-sectional dimensions of the electrical conductors vary.

[0012] Embodiments of the invention use a non-uniform coupling section with uniform electrical properties. While the coupling section is physically non-uniform, its electrical nature is in fact like that of a uniform coupling section. This seems contradictory, but is in fact possible by proper cross-sectional tapering along the length of the

coupled lines. This involves shaping of the coupled conductors and the cavity in which they are located. The non-uniformity is such that the horizontal conductor separation increases towards the ends of the coupled line section. It is then easy to create a transition to an external port without the need for additional de-coupling means and/or conductor bends.

[0013] In the case of cascaded coupled line sections where strong and weak coupling sections are cascaded, the physically non-uniform coupling section automatically provides a clean connection between the coupling sections. Such a transitionless connection yields near ideal electrical performance properties for directional couplers.

[0014] According to embodiments of the invention the first and the second inner electrical conductor overlap each other in an overlapping region. Outside the overlapping region the first inner electrical conductor runs parallel with respect to the second inner electrical conductor. The overlapping region could also be called coupling region, while the region outside the overlapping region could be called transmission region. In the coupling region the electrical conductors are electromagnetically coupled with transverse electromagnetic radiation. In the transmission region high frequency signals can be applied to or received from the electrical conductors.

[0015] According to embodiments of the invention the overlap of the first and the second inner electrical conductor decreases towards a first and a second end of the first and the second inner electrical conductor. Such embodiments are advantageous for keeping the even mode and the odd mode impedance constant.

[0016] According to embodiments of the invention the first and the second inner conductor cross each other in the longitudinal direction. The longitudinal direction is the direction of the high frequency signal propagating in the conductors.

[0017] According to embodiments of the invention the outer conductor is tapered in the region where the first and the second inner conductor cross each other.

[0018] According to embodiments of the invention the first inner conductor comprises a first and a second end section and a first crossing-section, the second inner conductor comprises a third and a fourth end section and a second crossing-section. Thereby the first crossing-section is located in between the first and the second end section and the second crossing-section is located in between the third and the fourth end section. Each end section has a rectangular shape, while each crossing-section has a parallelogram shape. The first and the second inner conductor cross each other in the region of the first and the second crossing-section.

[0019] According to embodiments of the invention the outer conductor has a minimum cross-section area, where the first and the second crossing-section overlap each other completely. In other words, the outer conductor has two end sections, where the cross-section has a maximum area. In the crossing-section of the first and

the second inner conductor the outer conductor is tapered such that it has a minimum cross-section area in the region, where the first and the second inner conductor overlap each other completely. Preferably, this minimum cross-section area is located in the middle of the crossing-section.

[0020] In another aspect the invention relates to a system comprising a directional coupler according to embodiments of the invention and at least four cables being connected to the first, the second, the third and the fourth end section of the first and the second inner conductor.

[0021] According to embodiments of the invention the four cables are also connected to the outer conductor.

[0022] According to embodiments of the invention the four cables are coaxial cables.

Brief description of the drawings

[0023] In the following preferred embodiments of the invention will be described, by way of example only, and with reference to the drawings in which:

Fig. 1 is a schematic top view of the overlapping region; and

Fig. 2 is a schematic top view of a directional coupler.

Detailed description

[0024] Like numbered elements in these Figs. are either identical elements or perform the same function. Elements which have been discussed previously will not necessarily be discussed in later Figs. if the function is identical.

[0025] Fig. 1 is a schematic top view of a coupling region 200 of a directional coupler 100 with a first inner conductor 102 and a second inner conductor 104. Both inner conductors 102 and 104 are surrounded by outer conductor 106. It is to be noted that only the crossing-sections 206 and 212 of the first inner conductor 102 and the second inner conductor 104 are depicted in Fig. 1. It is a cross-sectional schematic view such that the outer conductor 106 is depicted as two lines right and left of the first inner conductor 102 and the second inner conductor 104.

[0026] The first inner conductor 102 is located above a second inner conductor 104 with a spacing (not depicted) between the first inner conductor 102 and the second inner conductor 104. The first inner conductor 102 has a parallelogram shape reaching from the top left to right bottom, while the second inner conductor 104 has a parallelogram shape reaching from top right to bottom left. In the middle the first inner conductor 102 completely conceals the second inner conductor 104.

[0027] In operation, the first inner conductor 102 and the second inner conductor 104 transmit electromagnetic radiation in transverse electromagnetic mode. Thus, in the crossing-section 200 depicted in Fig. 1 the coupling

between the first inner conductor 102 and the second inner conductor 104 takes place. Because the coupling section, which is identical with the crossing-section 200, is physically non-uniform, the outer conductor 106 is tapered.

[0028] The outer conductor 106 is tapered such that it has a minimum cross-section(al area), where the inner conductors 102 and 104 overlap each other completely. This leads to constant electromagnetic coupling between the first and the second inner conductor. The even-mode impedance and the odd-mode impedance are kept constant in the directional coupler 100.

[0029] Fig. 2 is a cross-sectional schematic top view of a directional coupler 100 with a first inner conductor 102 and a second inner conductor 104. Outer conductor 106 runs right and left of the inner conductors 102 and 104.

[0030] First inner conductor 102 and second inner conductor 104 cross each other in the crossing-section 200. Outer conductor 106 is tapered in the crossing-section 200. First inner conductor 102 consists of two end sections 202 and 204 and a crossing-section 206. The second inner conductor 104 consists of end sections 208 and 210 and crossing-section 212. The crossing-sections 206 and 212 are shaped in a parallelogram form. Crossing-section 206 connects end sections 202 and 204, while crossing-section 212 connects end section 208 and 210. End section 202 is located at the right bottom in Fig. 1, end section 204 is located at the top left in Fig. 1. The second inner conductor 104 consists of end sections 208 and 210 and crossing-section 212. End section 208 is located at the left bottom of Fig. 1, while end section 210 is located at the right top of Fig. 1. Crossing-section 212 connects end section 208 with end section 210.

[0031] Both crossing-sections 206 and 212 have parallelogram shape and overlap each other.

[0032] Outer conductor 106 is tapered in the coupling region 200 and has a minimum cross-section area at the location, where crossing-sections 206 and 212 overlap each other completely.

[0033] In operation, high frequency signals may be input at any one of the end sections 202, 204, 208 and 210. The signal is then transmitted from the respective end section to the other end section of the conductor. The transmission takes place through the crossing-section.

[0034] For example, if a signal is input at end section 202, it is transmitted via crossing-section 206 to end section 204. Because of the transverse electromagnetic coupling between the first crossing-section 206 and the second crossing-section 212 an electromagnetic signal is induced into crossing-section 212. Thus, a measurable signal is output at end sections 208 and 210 of the second inner conductor 104. Usually, the energy direction in the second inner conductor 104 is opposite to the energy direction in the first inner conductor 102.

[0035] Because of the parallelogram shape of cross-

ing-sections 206 and 212 and the tapering of outer conductor 106, the even mode impedance and the odd mode impedance are kept constant, although the directional coupler is not physically uniform. The coupling only takes place in the coupling region 200. The end sections 202, 204, 208 and 210 are decoupled completely. Thus, the coupling between the conductors has not to be interrupted abruptly and no electrical discontinuity is caused. Thereby, the performance of the directional coupler 100 is increased.

[0036] This is a true duo-planar coupler realisation insofar as the first and the second inner conductor 102 and 104 are even and without the need for conductor bending.

[0037] It is to be noted that the figures are schematic views only used for explaining embodiments of the invention. A person skilled in the art will notice that other embodiments are possible. The conductors may, for example, have bent inner and outer conductors.

List of reference numerals

[0038]

100	Directional coupler
102	First inner conductor
104	Second inner conductor
106	Outer conductor
200	Coupling region
202	End section
204	End section
206	Crossing-section
208	End section
210	End section
212	Crossing-section

Claims

1. Directional coupler (100) with at least a first (102) and a second (104) inner electrical conductor and one outer electrical conductor (106), the outer electrical conductor surrounding the first and the second inner electrical conductor, wherein the first and the second inner electrical conductor and the outer electrical conductor are adapted to be electromagnetically coupled via transverse-electromagnetic-mode radiation, wherein an even-mode impedance and an odd-mode impedance are constant along the length of the first and the second inner and the outer electrical conductor, and wherein the cross-sectional dimensions of the first and the second inner and the outer electrical conductor vary over the length of the first and the second inner and the outer electrical

conductor.

2. Directional coupler according to claim 1, wherein the first and the second inner and the outer electrical conductor are tapered. 5
3. Directional coupler according to any one of the preceding claims, wherein the first and the second inner electrical conductor overlap each other in an overlapping region (200), and wherein the first inner electrical conductor runs parallelly with respect to the second inner electrical conductor outside the overlapping region. 10
4. Directional coupler according to any one of the preceding claims, wherein the overlap of the first and the second inner electrical conductor decreases towards a first (202; 208) and a second (204; 210) end of the first and the second inner electrical conductor. 15
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5. Directional coupler according to any one of the preceding claims, wherein the first and the second inner conductor cross each other in the longitudinal direction. 25
6. Directional coupler according to claim 5, wherein the outer conductor is tapered in a region (200) where the first and the second inner conductor cross each other. 30
7. Directional coupler according to claim 6, the first inner conductor comprising a first (202) and a second (204) end section and a first crossing section (206), the second inner conductor comprising a third (208) and a fourth (210) end section and a second crossing section (212), the first crossing section being located in-between the first and the second end section, the second crossing section being located in between the third and the fourth end section, wherein each end section has a rectangular shape, wherein each crossing section has a parallelogram shape, wherein the first and the second inner conductor cross each other in the region of the first and the second crossing section. 35
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45
8. Directional coupler according to claim 7, wherein the outer conductor has a minimum cross section where the first and the second crossing section overlap each other completely. 50
9. System comprising a directional coupler according to any one of the preceding claims and at least four cables being connected to the first, the second, the third and the fourth end section of the first and the second inner conductor. 55
10. System according to claim 10, wherein the four ca-

bles are also connected to the outer conductor.

11. System according to any one of the claims 10 or 11, wherein the four cables are coaxial cables.

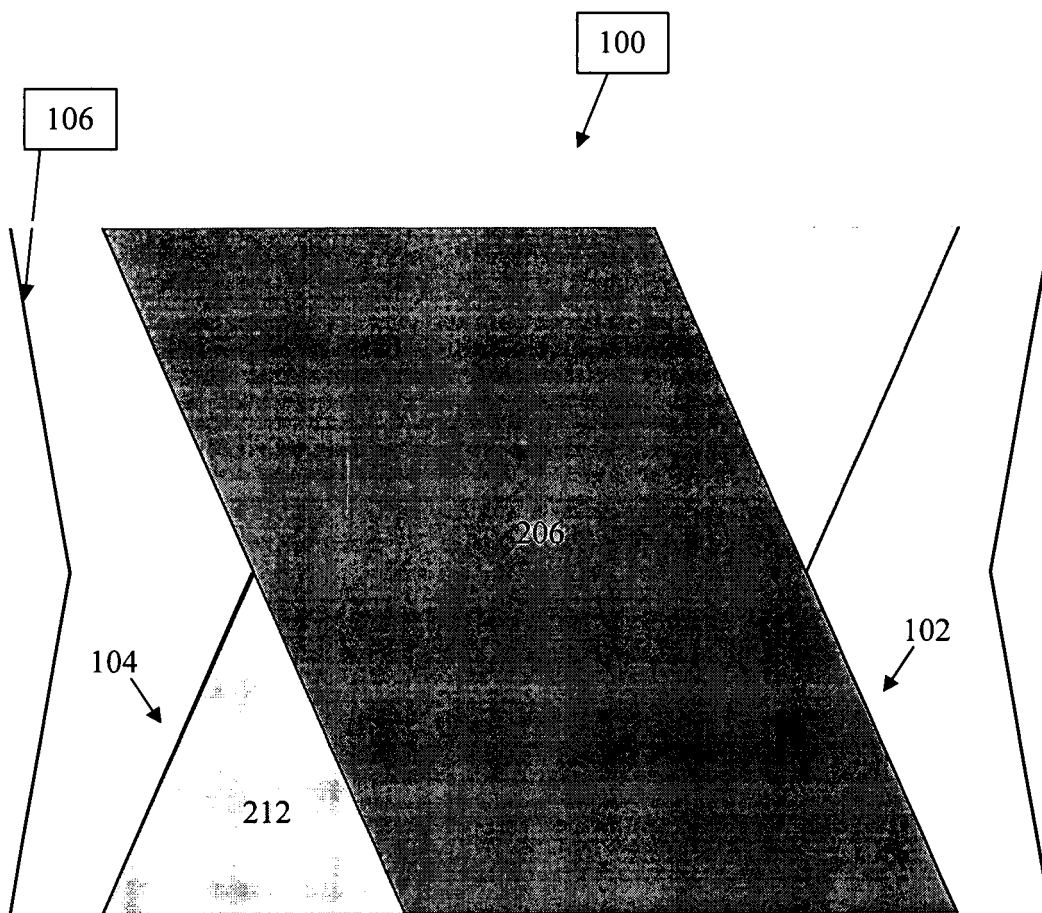


Fig. 1

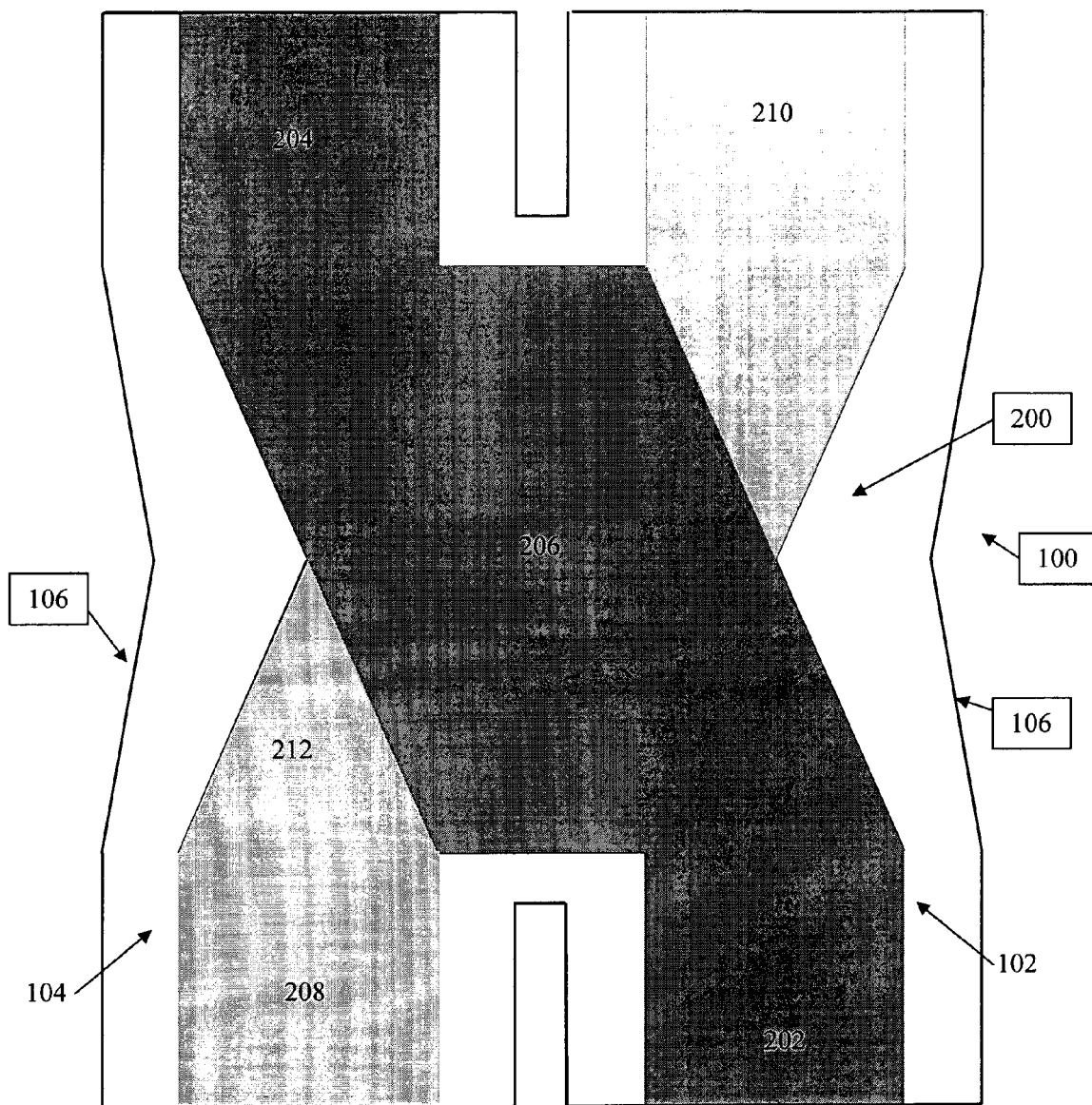


Fig. 2



EUROPEAN SEARCH REPORT

Application Number
EP 09 29 0946

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Place of search The Hague		Date of completion of the search 26 April 2010	Examiner Den Otter, Adrianus
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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