US010062945B2

(12) **United States Patent**
**Brueggemann et al.**

(10) **Patent No.: US 10,062,945 B2**
(45) **Date of Patent: Aug. 28, 2018**

(54) **COUPLING STRUCTURE FOR CROSSING TRANSMISSION LINES**

(71) Applicants: **Oliver Brueggemann**, Oelbronn-Duerrn (DE); **Matthias Steinhauer**, Steinheim (DE); **Juan Pontes**, Stuttgart (DE)

(72) Inventors: **Oliver Brueggemann**, Oelbronn-Duerrn (DE); **Matthias Steinhauer**, Steinheim (DE); **Juan Pontes**, Stuttgart (DE)

(73) Assignee: **ROBERT BOSCH GMBH**, Stuttgart (DE)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 264 days.

(21) Appl. No.: **14/378,292**

(22) PCT Filed: **Dec. 17, 2012**

(86) PCT No.: **PCT/EP2012/075711**

§ 371 (c)(1),
(2) Date: **Aug. 12, 2014**

(87) PCT Pub. No.: **WO2013/120561**

PCT Pub. Date: **Aug. 22, 2013**

(65) **Prior Publication Data**

US 2015/0035616 A1 Feb. 5, 2015

(30) **Foreign Application Priority Data**

Feb. 13, 2012 (DE) ........................ 10 2012 202 097

(51) **Int. Cl.**
***H01P 5/12*** (2006.01)
***H01P 5/22*** (2006.01)
***H01P 5/02*** (2006.01)

(52) **U.S. Cl.**
CPC .................. ***H01P 5/12*** (2013.01); ***H01P 5/02*** (2013.01); ***H01P 5/227*** (2013.01)

(58) **Field of Classification Search**
CPC .... H01P 5/18; H01P 5/184; H01P 5/19; H01P 5/227

(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,621,400 A * 11/1971 Paciorek .................. H03H 7/48 330/53
3,678,415 A * 7/1972 Kuroda .................. H01P 5/227 333/114

(Continued)

FOREIGN PATENT DOCUMENTS

EP 0313058 4/1989
JP 61172407 8/1986

(Continued)

OTHER PUBLICATIONS

Isao Ohta et al., A Transmission-Line-Type Eight-Port Hybrid, 1992, IEEE MTT-S, 4 pages.*

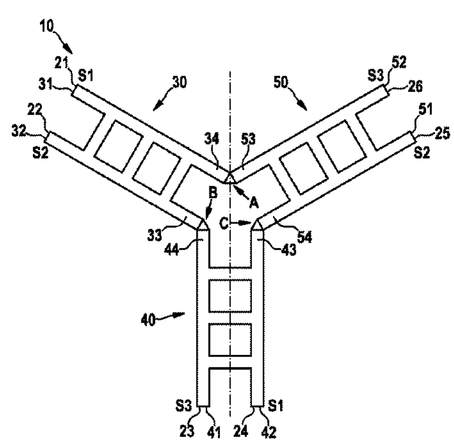
(Continued)

*Primary Examiner* — Dean Takaoka
(74) *Attorney, Agent, or Firm* — Norton Rose Fulbright US LLP; Gerard Messina

(57) **ABSTRACT**

A coupling structure for crossing three transmission lines millimeter-wave or centimeter-wave signals a signal conductor layer of a circuit substrate, the coupling structure comprising three planar cross-couplers, and from each of the three cross-couplers two input/output points of the cross-coupler being connected clockwise in succession in the plane of the cross-coupler, to respectively one input/output point of a respective other of the three cross-couplers.

**6 Claims, 3 Drawing Sheets**



(58) **Field of Classification Search**
USPC ................................ 333/116, 117, 125, 128
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

| | | | | | |
|---|---|---|---|---|---|
| 3,772,616 | A * | 11/1973 | Imoto | H01P 5/227 | 333/116 |
| 4,127,831 | A | 11/1978 | Riblet | | |
| 4,679,010 | A | 7/1987 | Bahl | | |
| 5,883,552 | A * | 3/1999 | McKay | H01P 5/16 | 333/125 |
| 6,522,218 | B1 * | 2/2003 | McKay | H01P 5/12 | 333/117 |
| 2009/0108954 | A1 | 4/2009 | Cheung et al. | | |

FOREIGN PATENT DOCUMENTS

| | | | |
|---|---|---|---|
| JP | S63-294103 | A | 11/1988 |
| JP | 0738301 | A | 2/1995 |
| JP | 2011041137 | | 2/2011 |
| JP | 5243821 | B2 | 7/2013 |

OTHER PUBLICATIONS

Tadashi Kawai et al., A Branch-Line-Type Eight Port Comparator Circuit, 1991, IEEE MTT-S, 4 pages.*
"Microstrip EHF Butler Matrix Design and Realization", *ETRI Journal,* vol. 27, No. 6, Dec. 2005, J.-S. Néron and G.-Y. Delisle.
Bing, Zhao, et al. "The design of the X-band microstrip butler matrix", School of electronic engineering, China, CN Academic Journal Electronic Publishin House (2009), pp. 983-986. [English abstract only].

* cited by examiner

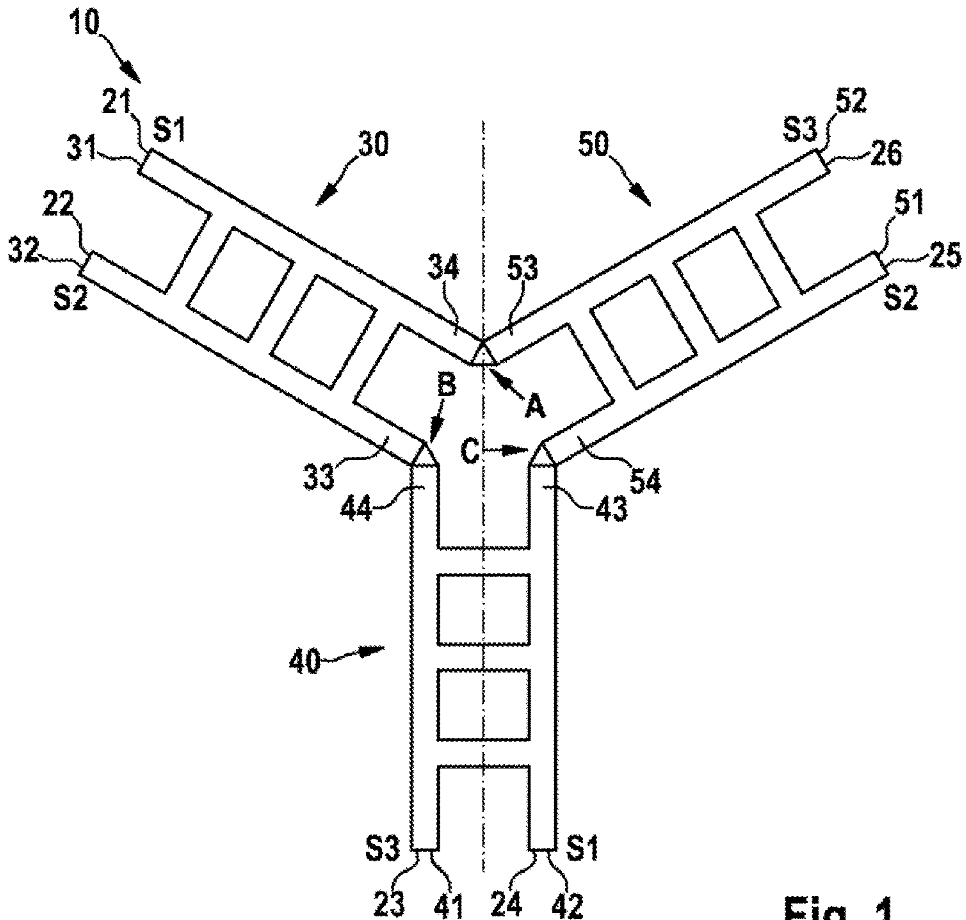
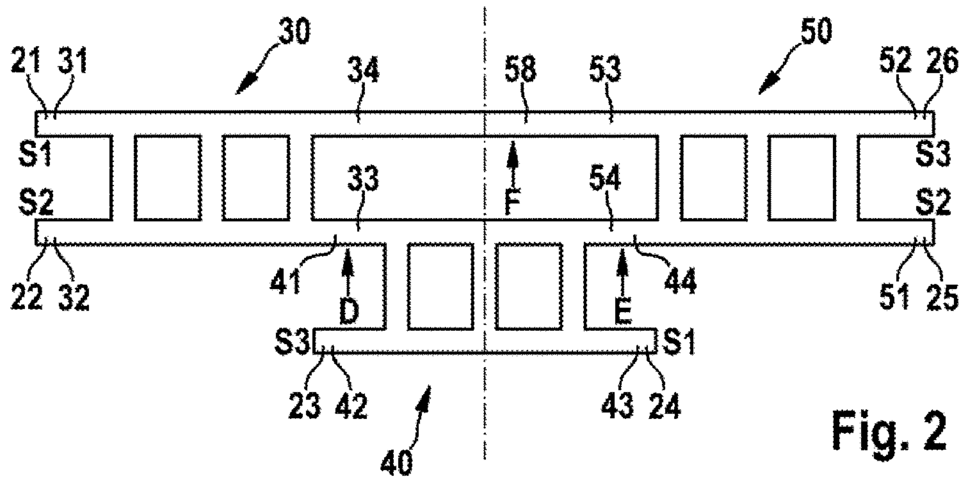
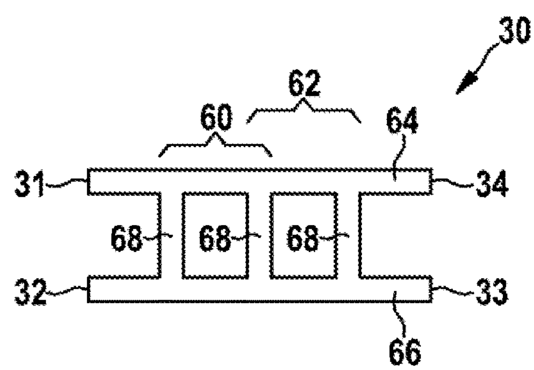

10
21
S1
31
22
32
S2
30
50
S3
52
26
51
25
S2
34
53
A
B
C
33
44
43
54
40
S3
S1
23
41
24
42

Fig. 1



30
50
21
31
34
58
53
52
26
S1
S3
33
54
F
S2
S2
41
44
D
E
22
32
51
25
S3
S1
23
42
43
24
40


Fig. 2



30
62
60
64
31
34
68
68
68
32
33
66


Fig. 3

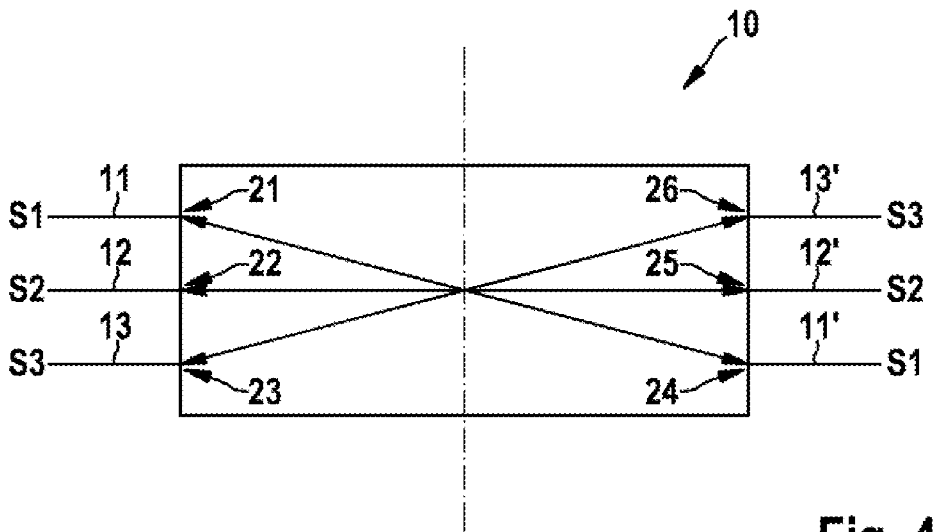



Fig. 4

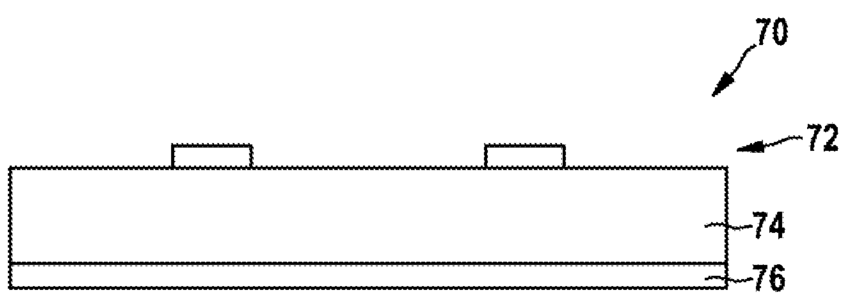



Fig. 5

# COUPLING STRUCTURE FOR CROSSING TRANSMISSION LINES

## FIELD OF THE INVENTION

The present invention relates to a coupling structure for crossing transmission lines in a signal conductor layer of a circuit substrate, in particular, to a coupling structure for crossing transmission lines for millimeter-wave or centimeter-wave signals.

## BACKGROUND INFORMATION

To cross transmission lines for high frequency signals it is known to provide a circuit substrate having multiple metallization layers, on which transmission lines, developed in different metallization layers, can cross each other. For this purpose, a transmission line in a metallization layer can bridge a crossing area by a detour via a different metallization layer. A disadvantage in this instance is the additional effort for providing a second or more metallization layers.

It is also known to realize a crossing of two transmission lines of the same metallization layer via a bridge made up of a discrete component. Depending on the requirements, however, disadvantageous output losses can result.

In "Microstrip EHF Butler Matrix Design and Realization", *ETRI Journal*, Volume 27, No. 6, December 2005, J.-S. Néron and G.-Y. Delisle describe a coupling structure for crossing two transmission lines for a 36 GHz signal. The coupling structure is made up of a planar cross-coupler, also known as a 0-dB coupler, that enables crossing two transmission lines having minimal coupling between them. The planar cross-coupler is embodied as a cascade of two 90 degree hybrid couplers. From an input signal at one of two input points, such a 90 degree hybrid coupler, known per se, generates two signals phase-shifted by 90 degrees, at its output points.

## SUMMARY

An object of the present invention is to create a coupling structure for crossing three transmission lines, in particular for signals in the frequency band of 76 to 77 GHz, in one signal conductor layer of a circuit substrate.

According to the present invention, a contribution toward achieving this object is made by a coupling structure for crossing three transmission lines for millimeter-wave or centimeter-wave signals in a signal conductor layer of a circuit substrate, which coupling structure has three planar cross-couplers, from each of which two successive input/output points of the cross-coupler are connected clockwise, in the plane of the cross-coupler, to respectively one input/output point of a respective other of the three cross-couplers. Preferably, the signal conductor layer is a metallization layer of the circuit substrate.

This coupling structure in particular allows for the mentioned clockwise-successive input/output points of each cross-coupler are connected to respectively one input/output point of a respective other of the three cross-couplers in the same signal conductor layer. A coupling structure for crossing three transmission lines may thus be realized within a single signal conductor layer, in which the coupling structure has no components situated outside of the signal conductor layer, in particular, no discrete components.

This kind of coupling structure may, for example, be used advantageously in analog and/or digital circuits for radar sensors where signals of a respective frequency range are to cross within one metallization layer.



## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a schematic diagram of a coupling structure according to the present invention.

FIG. **2** shows a schematic diagram of a further example of a coupling structure according to the present invention.

FIG. **3** shows a schematic diagram of a cross-coupler in the form of a 90 degree hybrid coupler.

FIG. **4** shows a schematic diagram of three transmission lines crossed by a coupling structure according to the present invention.

FIG. **5** shows a schematic diagram of a layering structure of a circuit substrate.

## DETAILED DESCRIPTION

FIGS. **1** and **2** show different examples of coupling structures **10**, **10'** for crossing three transmission lines **11**, **12**, **13** for signals S1, S2 and S3 in the frequency band of 76 to 77 GHz according to the schematic representation in FIG. **4**. From a first circuit side, to the left in FIGS. **1**, **2**, and **4**, signal lines **11**, **12**, **13** (FIG. **4**), adjacently disposed in this order, are each connected with one input/output point **21**, **22**, **23**, for the three signals S1, S2, S3. On the opposite side of coupling structure **10**, and in reversed order, continuations of the three signal lines **13'**, **12'**, **11'** for signals S3, S2, S1 are each connected to an input/output point **26**, **25**, **24** of coupling structure **10**. The signals applied at input/output points **21**, **22**, **23** of the one side of the coupling structure are transmitted to input/output points **26**, **25**, **24** of the other side of coupling structure **10** in such a way that the order of the signals (i.e., the order in which the signal paths are juxtaposed) is reversed. In FIGS. **1**, **2**, and **4**, the respective sides of coupling structure **10** or **10'** are separated by a dashed line.

FIG. **1** shows a first example of a coupling structure **10** according to FIG. **4**. Coupling structure **10** is made up of three planar cross-couplers **30**, **40**, **50** that are connected to one another in a star configuration and that are situated in the same signal conductor layer of a circuit substrate. Two adjacent first input/output points **31**, **32** of a first cross-coupler **30** form input/output points **21**, **22** of the coupling structure; two adjacent first input/output points **41**, **42** of a second cross-coupler **40** form input/output points **23**, **24** of the coupling structure; and two adjacent first input/output points **51**, **52** of a third cross-coupler **50** form input/output points **25**, **26** of coupling structure **10**.

Opposite the respective cross-couplers **30**, **40**, **50**, adjacent second input/output points **33**, **34** of the first cross-coupler are each directly connected in the same signal conductor layer, at circuit points B, A, with a second input/output point **44** or **53** of a respective other cross-coupler **40**, **50** of the three cross-couplers; and an additional second input/output point **43** of the second cross-coupler is directly connected in the same signal conductor layer, at a circuit point C, with an additional second input/output point **54** of the third cross-coupler **50**.

Thus, respectively two adjacent first input/output points **31**,**32**; **41**,**42**; and **51**,**52** of a respective cross-coupler **30**, **40**, **50** form input/output points **21** through **26** of the coupling structure; and on an opposite side of the respective cross-coupler **30**, **40**, **50**, adjacent second input/output points **33**,**34**; **43**,**44**; and **53**,**54** of the cross-coupler are respectively connected, directly in the same signal conductor layer, to a second input/output point **44,53**; **54,33**; and **34,43** of a respective other of the three cross-couplers **30**, **40**, **50**.

The resulting coupling structure **10** couples signals S1, S2, S3, supplied in this order on the first side via input/output points **21**, **22**, **23**, with input/output points **26**, **25**, **24** in reversed order on the opposite side of coupling structure **10**. A suitable layout of the individual parts or conductor sections of coupling structure **10** and of the individual parts or conductor sections of cross-couplers **30**, **40**, **50** may optimize the geometry of coupling structure **10** and of individual cross-couplers **30**, **40**, **50** in such a way that the components of the respectively desired signal S3, S2, or S1 are constructively superimposed on one another at input/output points **26**, **25**, **24**, used as outputs, and that the components of the respective other signals are destructively superimposed. Especially the electrical lengths and transmission line wave impedances are suitably adjusted. This may be achieved by adapting the conductor lengths and widths for a given substrate. In this manner, a minimal mutual interference of the signals may be achieved when crossing the three signal transmission lines **11**, **12**, **13**.

FIG. **2** shows a second example of a coupling structure **10'** according to the present invention that also includes three planar cross-couplers **30**, **40**, **50**. The cross-couplers are arranged in series, a first cross-coupler **30**, on the first side of coupling structure **10'**, coupling two first input/output points **31**, **32** of cross-coupler **30** for signals S1, S2, corresponding to input/output points **21**, **22** of coupling structure **10'**, with second input/output points **33**, **34**, disposed in reversed order, of cross-coupler **30**. A second input/output point **33** of the first cross-coupler **30** is directly connected, at a circuit point D, to a first input/output point **41** of a second, subsequent cross-coupler **40**, whose other first input/output point **42** is assigned to signal S3 and corresponds to input/output point **23** of coupling structure **10'**. Second cross-coupler **40** is connected to the second input/output point **33** of first cross-coupler **30** that is situated diagonally opposite of the first input/output point **31** for signal S1. Accordingly, on the described side of coupling structure **10'**, signals S1, S2, S3 are conveyed next to one another in this order.

Via second cross-coupler **40**, circuit point D is coupled with a diagonally opposite, second input/output point **43** of second cross-coupler **40** for signal S1, corresponding to input/output point **24** of coupling structure **10'**. Accordingly, via second cross-coupler **40**, signal S3, applied at the other first input/output point **42** of second cross-coupler **40**, is directly connected in the same signal conductor layer, at diagonally opposite circuit point E, to a second input/output point **54** of the third cross-coupler **50**.

The other second input/output point **53** of third cross-coupler **50** is connected, at a circuit point F, directly in the same signal conductor layer, by signal line **58** in the form of a conductor section, to the other second input/output point **34** of first cross-coupler **30**. This connection thus runs parallel to the second cross-coupler **40**. Via third cross-coupler **50**, the two circuit points E, F are in turn coupled with respectively diagonally opposite first input/output points **52**, **51** of third cross-coupler **50**, which correspond to input/output points **26**, **25** of coupling structure **10'**, so that coupling structure **10'** altogether reverses the order in which signals S1, S2, S3 are arranged.

With reference to cross-coupler **30**, FIG. **3** schematically shows the structure of one of the cross-couplers **30**, **40**, **50** in FIG. **1** or **2**. The remaining cross-couplers **40**, **50** are structured accordingly.

Cross-coupler **30** is designed as a cascade of two 90 degree hybrid couplers **60**, **62**; at a first end of the cascading structure, first input/output points **31**, **32** of the cross-couplers being situated directly next to each other, and at a second end of the cascading structure, second input/output points **34**, **33** being situated directly next to each other. In the plane of cross-coupler **30**, the input/output points follow in sequence clockwise in the order of **31**, **34**, **33**, **32**, **31**, . . . etc. Cross-coupler **30** includes two longitudinal connections **64**, **66**, which connect input/output points **31** and **34** and, respectively, **32** and **33** directly and in a straight line, and are connected to each other by three cross-connections **68** so as to form a structure in the shape of a ladder having three crossbars. The length of cross-connections **68** amounts to nearly one quarter of a signal wavelength in the signal transmission line. The length of the respective sections of the longitudinal connections **64**, **66** between two cross-connections **68** also corresponds to nearly one quarter of a signal wavelength.

In the examples shown in FIGS. **1** and **2** at least two cross-couplers **30**, **50** of the three cross-couplers each have at one end of the respective cascade of their 90 degree hybrid couplers **60**, **62**, two adjacent input/output points **31**, **32** and **51**, **52**, respectively, which form input/output points **21**, **22** and, respectively, **25**, **26** of coupling structure **10**, **10'**. In the example shown in FIG. **1**, this applies to each of the three cross-couplers.

FIG. **5** shows schematically a structure of circuit substrate **70**, on which, for example, coupling structure **10** or **10'** is realized. Circuit substrate **70** includes a signal conductor layer **72** in the form of an accordingly structured metallization layer, in which the respective coupling structure **10**, **10'** is developed. Circuit substrate **70** further includes a support plate **74** in the form of a dielectric medium and a ground layer **76**. Signal conductor layer **72** and ground layer **76** are situated on opposite sides of support plate **74**.

What is claimed is:

**1**. A coupling structure for crossing three transmission lines for one of millimeter-wave signals and centimeter-wave signals in a signal conductor layer of a circuit substrate, comprising:

three planar cross-couplers that each includes two input/output points, wherein, for each of the three planar cross-couplers, each of the input/output points of the respective cross-coupler is connected, at a connection point, to a respective input/output point of another one of the three planar cross-couplers that is adjacent to the respective cross-coupler, thereby forming at least three separate connection points that are all in a single plane.

**2**. The coupling structure as recited in claim **1**, wherein the three planar cross-couplers are structured respectively as a cascade of 90 degree hybrid couplers.

**3**. The coupling structure as recited in claim **2**, in which at least two cross-couplers of the three planar cross-couplers respectively have at one end of the respective cascade two adjacent input/output points, forming the input/output points of the coupling structure.

**4**. The coupling structure as recited in claim **1**, wherein the three planar cross-couplers are arranged entirely in a same signal conductor layer.

**5**. The coupling structure as recited in claim **1**, wherein the three planar cross-couplers are arranged in the form of a star.

**6**. The coupling structure as recited in claim **1**, wherein the three planar cross-couplers are situated one after another, a middle one of the three planar cross-couplers being laterally off-set with respect to a first one and a third one of the three planar cross-couplers, and a signal transmission line, running next to the middle cross-coupler, connects an input/output point of the first cross-coupler with an input/output point of the third cross-coupler.

* * * * *