June 2, 1970 J. LANGE 3,516,024

INTERDIGITATED STRIP LINE COUPLER

Filed Dec. 30, 1968 2 Sheets-Sheet 1

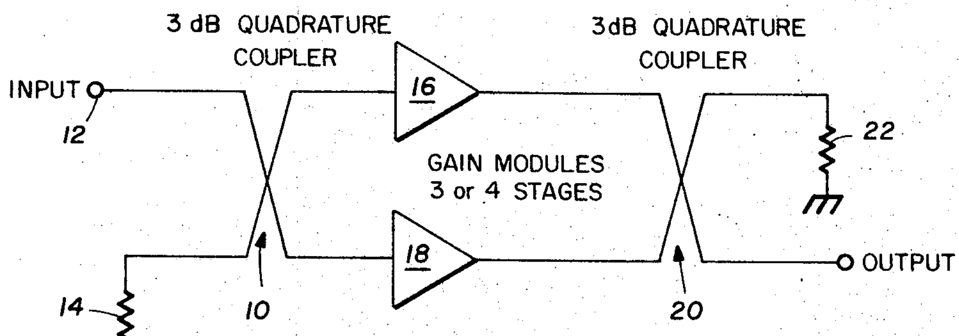

FIG. 1

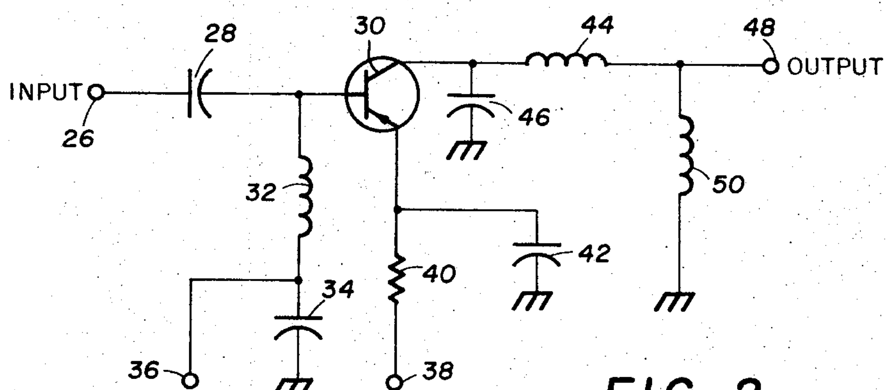

FIG. 2

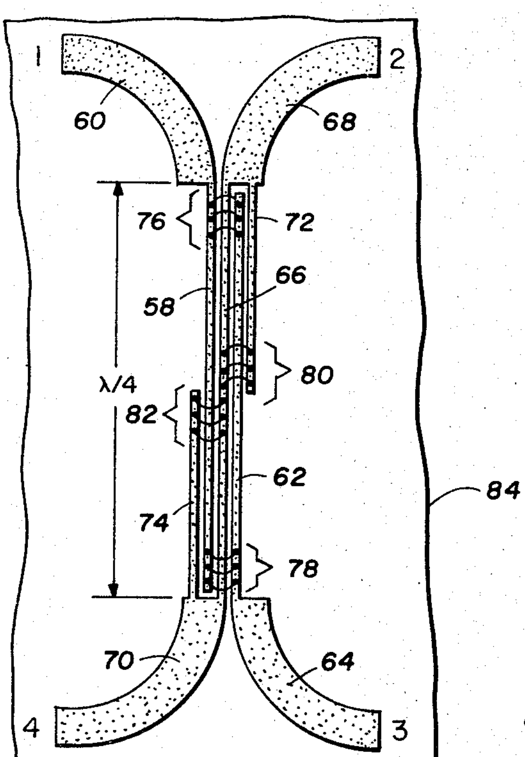

FIG. 4

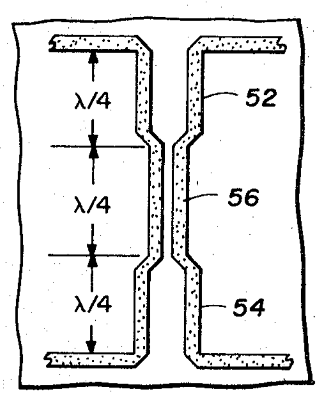

FIG. 3 PRIOR ART

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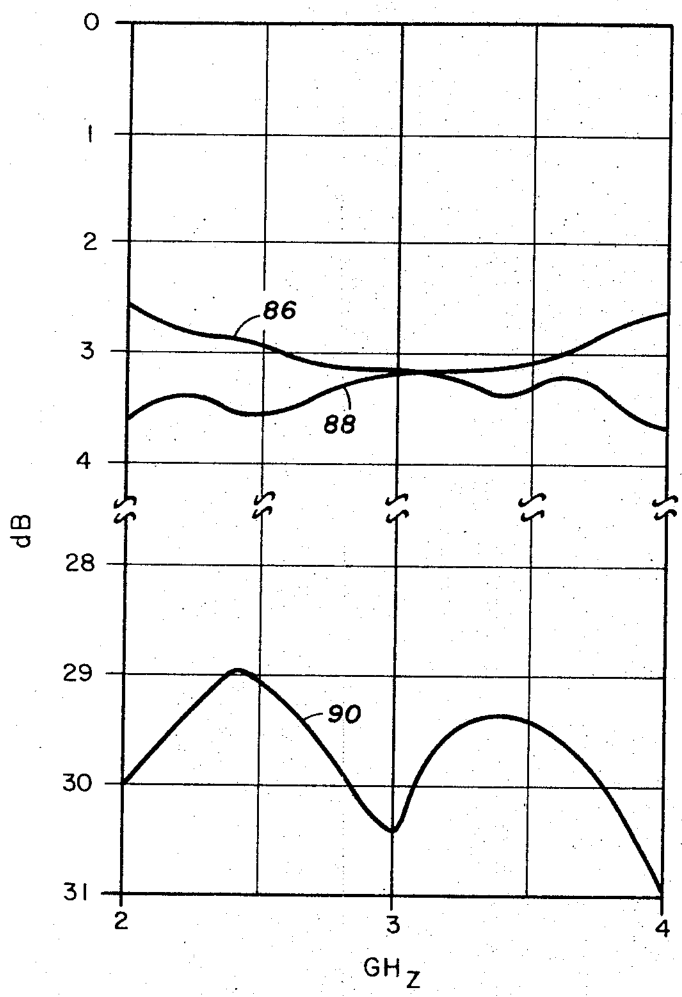

FIG. 5

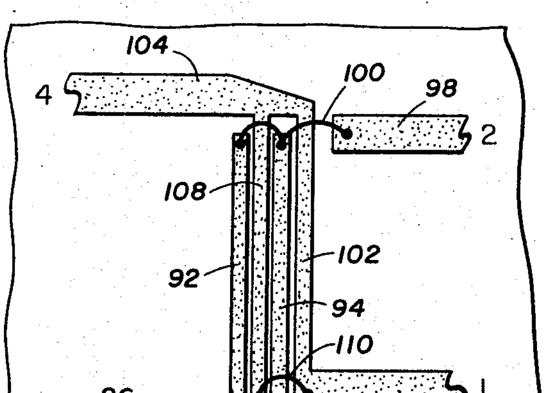

FIG. 6

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3,516,024

Patented June 2, 1970

3,516,024

INTERDIGITATED STRIP LINE COUPLER

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Filed Dec. 30, 1968, Ser. No. 787,784

Int. Cl. H01p *5/14*

U.S. Cl. 333—10 12 Claims

ABSTRACT OF THE DISCLOSURE

An interdigitated coupler is fabricated from several strip line sections with alternate sections interconnected by crossover wires. The interdigitated strip line sections are arranged such that each section is on the order of a quarter wavelength long.

This invention relates to directional couplers and more particularly to an interdigitated quadrature strip line coupler.

A directional quadrature coupler is a four port microwave junction with properties such that a wave incident in port one couples power into ports two and three, but not into port four. Similarly, power incident in port four couples into ports two and three but not into port one. Thus, ports one and four are uncoupled. A wave incident in port two or three couples power into ports one and four only, thus ports two and three are also uncoupled. If three of the four ports are terminated in matched loads, the fourth port appears terminated in a matched load, and an incident wave in this port will not be reflected.

In one application, directional couplers are used to divide the power between two amplifiers to reduce the terminal voltage standing wave ratio (VSWR) and increase circuit design flexibility. Ideally, a coupler should be lossless with exactly 3-db power division across the band. Heretofore, a low loss, low VSWR 3-db strip line coupler has been difficult to achieve due to line spacing and fabrication tolerances. Both the branch line coupler and the non-interdigitated edge-coupled coupler are among those which are difficult to fabricate due to the tolerance requirements. Further, branch line couplers are not capable of simultaneously meeting the VSWR and bandwidth objectives of most coupling requirements within a reasonable number of sections. The tandem coupler also has severe limitations and, in addition, is rather large dimensionally. In addition, both these configurations have a narrow bandwidth and require a much larger substrate than single-sectioned coupled line couplers.

Tight coupling in directional couplers for microwave integrated circuits has also been achieved by means of broadside coupling and re-entrant sections. Both these configurations, however, require multilayer circuitry, which is very difficult to build on ceramic, and virtually impossible in the case of monolithic integrated circuits.

An object of the present invention is to provide a low loss quadrature coupler. Another object of this invention is to provide a wide bandwidth quadrature coupler. Still another object of this invention is to provide a quadrature coupler having reasonable fabrication tolerances. A further object of this invention is to provide a quadrature coupler having interdigitated strip line sections.

In accordance with the present invention, several strip line sections are formed on a substrate in an interdigitated pattern. Alternate line sections are tied together by jumper wires bonded thereto. The effective length of each line section is on the order of a quarter wavelength at the bandwidth center frequency. The design of the input ports is symmetrical with the interdigitated line sections, thus improving the coupling characterstics.

In accordance with a specific embodiment of the invention, ports one and three of an interdigitated 3-db coupler are formed integral with individual line sections. These sections are interconnected by multiple bonding wires to reduce parasitic inductance. Ports two and four are interconnected by a single quarter wavelength section and formed integral with a line section one-half a quarter wavelength long. Multiple bonding wires interconnect the short line sections to the quarter wavelength section between ports two and four. The line sections are fabricated in an interdigitated pattern by a vapor deposition process.

A more complete understanding of the invention and its advantages will be apparent from the specification and claims and from the accompanying drawings illustrative of the invention.

Referring to the drawings:

FIG. 1 is a block diagram of an amplifier employing quadrature couplers at the input and output;

FIG. 2 is a schematic diagram of a typical single amplification stage for the amplifier of FIG. 1;

FIG. 3 is an illustration of a three section cascade directional coupler of the type found in the prior art;

FIG. 4 is an illustration of an interdigitated quadrature coupler in accordance with the present invention;

FIG. 5 is a plot of transmission magnitude in db versus frequency in gigahertz for the coupler of FIG. 4; and

FIG. 6 illustrates an alternate embodiment of an interdigitated coupler in accordance with the present invention.

Referring to the drawings, in FIG. 1 there is illustrated a complete amplifier consisting of two 3-db quadrature couplers and two gain modules. An input coupler having four ports has port one connected to an input terminal **12**, port four connected to ground through a resistor **14**, and ports two and three coupled to gain modules **16** and **18**, respectively. An output coupler **20** also having four ports has ports two and three connected to the output of the gain modules **16** and **18**, respectively, port one connected to ground through a resistor **22**, and port four connected to an output terminal **24**.

The gain modules may employ three or four stages of amplification to meet the desired amplifier objectives.

Referring to FIG. 2, there is shown schematically an amplifier stage of the type employed in the gain modules **16** and **18**. An input terminal **26** connects to a port of the input coupler **10** or to a preceding amplification stage. A coupling capacitor **28** connects the input terminal to the base electrode of a transistor **30** which is also connected to a bias choke **32**. The choke **32** is connected to ground through a capacitor **34** and to a source of direct current (not shown) connected to the terminal **36**. Transistor **30** also includes an emitter electrode connected to a source of direct current (not shown) at terminal **38** through a resistor **40**. The emitter electrode of the transistor **30** also connects to ground through a capacitor **42**. The output circuit of the amplifier includes an L-section transformer **44** connected to the collector electrode of the transistor **30** and to a capacitor **46**. Transformer **44**, in addition to connecting to the output terminal **48**, also connects to a bias choke **50**.

Preferably, each amplifier stage of the gain modules **16** and **18** will be fabricated by means of strip line techniques. The chokes **32** and **50** are meandered lines in strip line configuration, each a quarter wavelength long at the bandwidth center frequency. The transistor **30** may be fabricated on a chip and inserted into the strip line circuitry.

Techniques for fabricating amplifier stages of the type illustrated in FIG. 2 have been developed such that each unit requires only a minimum of space. However, prior art couplers of the type illustrated in FIG. 3 require considerably more space. In addition, prior art couplers of the type illustrated are difficult to fabricate due to line spacing and tolerances. The coupler of FIG. 3 includes two outer sections **52** and **54** forming a region of loose coupling each one quarter wavelength long. Typically, the two outer sections **52** and **54** have 17.2-db coupling, which can be realized with edge coupled lines 8 mils wide spaced 16 mils apart on a 20 mil ceramic substrate. If the two outer sections have a 17.2-db coupling, then a center section **56** requires 1.76 db coupling to produce an overall 3-db coupler. The tight coupled center section **56** is again one-quarter wavelength long. As illustrated, the section **56** has two spaced lines for edge coupling. The width and spacing of such lines is difficult to calculate and almost impossible to build. In an attempt to use couplers of the type illustrated in FIG. 3, broadside coupling has been considered for the section **56**. However, severe problems are encountered in trying to keep the lines overlapped for the complete quarter wavelength, and depositing the very thin ceramic for the line spacing.

With an interdigitated coupler of the type illustrated in FIG. 4, the overall area of the coupler can be reduced to one third that illustrated in FIG. 3, and fabrication procedures are simplified considerably. Referring to FIG. 4, a first line section **58** terminates at a port **60** (port one) and a second line section **62** terminates at a port **64** (port three). Ports one and three are thus similar and symmetrical. A third line section **66** terminates at one end at a port **68** (port two) and at the other end at port **70** (port four). Ports **68** and **70** are also formed integral with line sections **72** and **74**, respectively, which are half as long as the section **66**. Thus, the ports **68** and **70** are symmetrical, and the entire coupler is symmetrical. Symmetry in a coupler of the type illustrated improves the coupling efficiency by lowering losses.

Line sections **58**, **62**, **66**, **72**, and **74** form an interdigitated pattern. Alternate line sections are interconnected by crossover wires. Thus, section **58** is connected to section **62** by means of a group of three crossover wires **76** at port **60** and a group of three crossover wires **78** at port **64**. Line section **66** connects to the line section **72** by a group of three crossover wires **80** and to the line section **74** by means of a group of three crossover wires **82**. Multiple bonding wires for the crossovers are more easily implemented than single crossover wires and reduce the parasitic inductance associated with the bonding wires.

One model of the coupler shown in FIG. 4 was fabricated on a 42-mil thick substrate of alumina (Al_2O_3) with a ground plane covering one surface. The unglazed alumina was placed in a vacuum chamber and a thin gold film deposited on the side opposite the ground plane. Using photomasking and etch techniques, a first mask was formed over the thin gold film to outline the strip line sections. The unwanted film was then removed by etching and a second mask formed on the substrate defining a strip line section and the port areas. Gold was then plated over the exposed gold film areas through the second mask to a desired thickness. In one laboratory model of an interdigitated coupler, the strip line sections are 4.5 mils wide and spaced 3 mils apart. It should be understood that the interdigitated coupler of the present invention is applicable to circuits with two ground planes with either one or two layers of dielectric.

Referring to FIG. 5, there is shown a plot of transmission magnitude in db versus frequency in gHz. for the model described above. For an input coupled to port one, power was transmitted to port three with an attenuation of about 3-db as shown by the curve **86**. With the same input connected to port one, power was transmitted to port two with an attenuation of about 3.5-db, as indicated by curve **88**. Both these curves are for a frequency range of from 2 gHz. to 4 gHz. Between port one and port four, very little power was transmitted as indicated by the curve **90** which is approximately 30 db down. It should be noted that the curves of FIG. 5 are not intended to indicate the

peak performance of the coupler of FIG. 4. These curves were plotted from data taken from laboratory experiments.

Referring to Table 1, there is shown the complete response of an interdigitated 3-db coupler of the present invention between 2.0 gHz. and 4.0 gHz. In addition to listing the data from which the curves of FIG. 5 were plotted, Table 1 also lists insertion loss and output imbalance. Again, this data is not intended to imply peak performance, but rather represents data obtained from laboratory experiments.

TABLE 1.—RESPONSE OF INTERDIGITATED 3-db. COUPLER

Frequency (gHz.)	Direct output $|S_{13}|^2$ (db.)	Coupled Output $|S_{12}|^2$ (db.)	Directivity $|S_{14}|^2$ (db.)	Insertion loss $|S_{12}|^2$ $|S_{13}|^2$ (db.)	Output Imbalance $|S_{12}|^2/$ $|S_{13}|^2$ (db.)
2.0	2.6	4.0	31.0	.32	1.40
2.2	2.8	3.8	30.5	.28	.97
2.4	2.95	3.45	30.0	.20	.50
2.6	3.1	3.5	30.3	.30	.45
2.8	3.2	3.4	30.8	.27	.23
3.0	3.2	3.3	31.4	.24	.08
3.2	3.2	3.2	30.5	.20	.05
3.4	3.1	3.3	30.4	.21	.22
3.8	2.8	3.5	31.1	.15	.70
4.0	2.65	3.65	31.9	.15	.98

Referring to FIG. 6, there is shown another embodiment of an interdigitated coupler in accordance with the present invention. Strip lines **92** and **94** are formed integral with port **96** (port three). These strip lines are connected to port **98** (port two) by means of a crossover wire **100** bonded to the strip lines and the port. A strip line **102** is formed integral with the port **104** (port four) and port **106** (port one). The port **104** is also formed integral with a strip line **108** interdigitated with the strip lines **92** and **94** and connected to the port **106** by means of a crossover wire **110**. The strip lines **92**, **94**, **102**, and **108** are a quarter wavelength long at the bandwith center frequency.

A 3-db interdigitated quadrature coupler in the pattern of FIG. 6 was fabricated on a 40 mil thick substrate of alumina. The design consists of four interdigitated strip lines, each 4.5 mils wide, spaced 3.0 mils apart. Tests run on a model show that losses were less than 0.25 db in the frequency range from 2 gHz. to 4 gHz. Isolation was 40 db at 2 gHz. falling smoothly to 21.5 db at 4 gHz.

In addition to being used as the input and output coupler for an amplifier, the coupler of the present invention may also be used in impedance bridges for microwave measurements and power monitoring. For example, if a radar transmitter is connected to port one, the antenna to port two, a microwave detector to port three, and a matched load to port four, the power received in port three is proportional to the power flowing from the transmitter to the antenna in the forward direction only. Since the reflected wave from the antenna, if it exists, is not coupled into port three, the detector monitors the power output of the transmitter.

The coupler of the present invention may also be used as the coupling device for connecting a local oscillator to a mixer circuit. For example, in a strip line balanced mixer circuit, some means must be provided for connecting the local oscillator signal to the mixer circuit. A coaxial line or waveguide type coupler obviously can not be used in an application such as this because of the incompatibility of the coaxial line and waveguide design with the strip line design. Heretofore, in strip line balance mixing circuits, coupling devices of the type illustrated in FIG. 3 were larger than the mixer itself. With the coupler of the present invention, the benefit of small size is maintained.

While several embodiments of the invention, together with modifications thereof, have been described in detail herein and shown in the accompanying drawings, it will be evident that various further modifications are possible without departing from the scope of the invention.

What is claimed is:

1. A four-port quadrature coupler comprising:

a plurality of strip lines in an interdigitated pattern, each of the four ports of the coupler integral with at least one of said strip lines, and

means for interconnecting alternate strip lines in the interdigitated pattern.

2. A quadrature coupler as set forth in claim 1 wherein each strip line has an effective length equal to a quarter wavelength of the bandwidth center frequency.

3. A quadrature coupler as set forth in claim 1 wherein said interconnecting means includes multiple crossover wires bonded to alternate strip lines to reduce the parasitic inductance.

4. A quadrature coupler comprising:

a dielectric substrate,

a plurality of strip lines adhesively secured to said dielectric substrate in an interdigitated pattern, each port of the coupler integral with at least one of said strip lines, and

multiple crossover wires bonded to alternate strip lines for interconnection thereof in an interdigitated pattern.

5. A quadrature coupler as set forth in claim 4 wherein said dielectric substrate is unglazed alumina.

6. A quadrature coupler as set forth in claim 4 wherein each strip line has an effective length equal to a quarter of the wavelength of the bandwidth center frequency.

7. A quadrature coupler comprising:

a dielectric substrate,

a first strip line adhesively secured to said dielectric substrate and integral with a first port of the coupler,

a second strip line adhesively secured to said dielectric substrate in an interdigitated pattern with the first strip line and integral with the third port of the coupler,

a third strip line adhesively secured to said dielectric substrate in an interdigitated pattern with the first and second strip lines and integral with coupler ports two and four,

a fourth strip line adhesively secured to said dielectric substrate in an interdigitated pattern with said three strip lines, a first section of said fourth strip line integral with port two of the coupler, and a second section of the fourth strip line integral with the port four of the coupler, and

means for interconnecting alternate strip lines in the interdigitated pattern.

8. A quadrature coupler as set forth in claim 7 wherein said interconnecting means includes multiple crossover wires bonded to alternate strip lines to reduce parasitic inductance.

9. A quadrature coupler as set forth in claim 8 wherein said dielectric substrate is unglazed alumina.

10. A quadrature coupler as set forth in claim 9 wherein each strip line has a width of 4.5 mils and spaced from each other in an interdigitated pattern by 3.0 mils.

11. A quadrature coupler as set forth in claim 10 wherein said dielectric has a thickness of about 40 mils.

12. A quadrature coupler as set forth in claim 11 wherein each strip line has an effective length equal to a quarter wavelength of the bandwith center frequency.

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U.S. Cl. X.R.

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