United States Patent [19]

Cappucci

[11] **3,723,914**

[45] **Mar. 27, 1973**

[54] **LUMPED CONSTANT QUADRATURE COUPLER WITH IMPROVED PARASITIC SUPPRESSION**

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[22] Filed: **Jan. 26, 1972**

[21] Appl. No.: **221,012**

[52] **U.S. Cl.** .....**333/11**, 333/10, 333/84 M

[51] **Int. Cl.** **H01p 5/12**, H01p 5/14, H01p 3/08

[58] **Field of Search** .....333/10, 11, 84, 84 M

[56] **References Cited**

UNITED STATES PATENTS

3,484,724	12/1969	Podell	333/10
3,593,207	7/1971	Woermbke et al.	333/10
3,506,932	4/1970	Beurrier	333/11
3,363,201	1/1968	Isaacson	333/10
3,452,300	6/1969	Cappucci et al.	333/10
3,452,301	6/1969	Cappucci et al.	333/10

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[57] **ABSTRACT**

A lumped constant quadrature hybrid coupler having a wide band of directivity is disclosed. The coupler is constructed from lumped constant elements including a pair of closely magnetically coupled conductors with a lumped capacitor connecting them at a central portion. Each of the two respective ends of each of the pair of conductors serve as one of the four ports of the resulting coupler. Three printed circuit embodiments are disclosed which incorporate the teachings of this invention.

8 Claims, 4 Drawing Figures

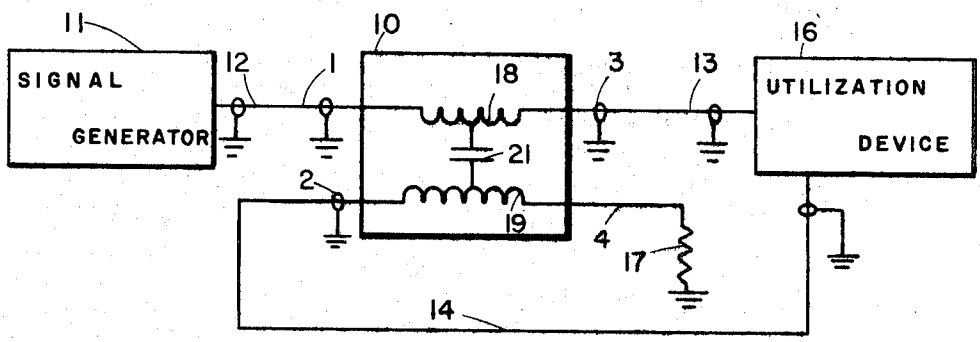
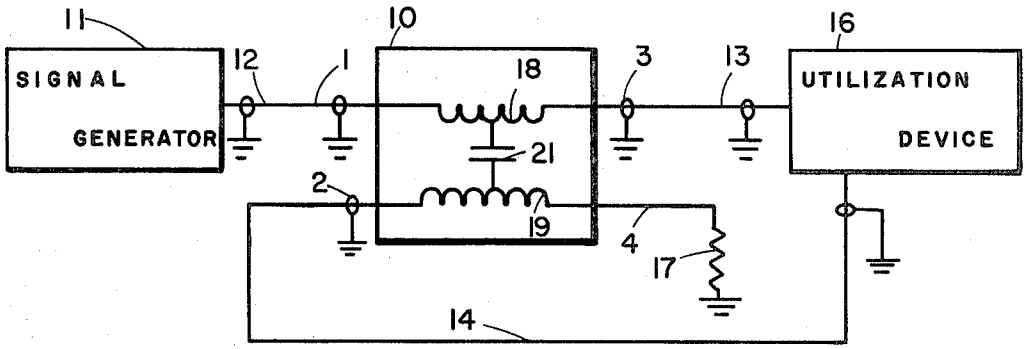


FIG. 1



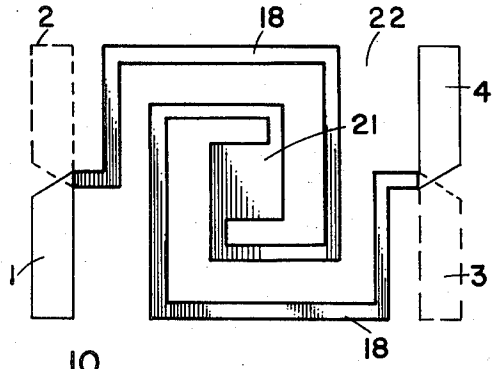


FIG. 2

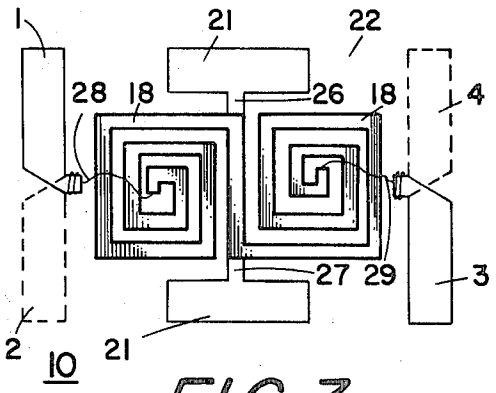


FIG. 3

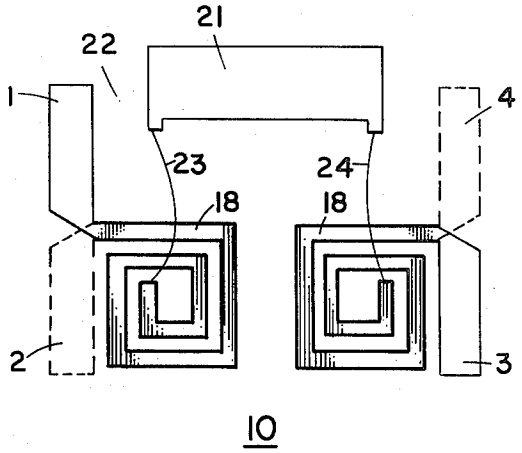


FIG. 4

LUMPED CONSTANT QUADRATURE COUPLER WITH IMPROVED PARASITIC SUPPRESSION

FIELD OF THE INVENTION

This invention relates to quadrature hybrid couplers and particularly to lumped constant parameter quadrature hybrid couplers.

BACKGROUND OF THE INVENTION

Lumped constant quadrature hybrid couplers are disclosed in U.S. Pat. No. 3,452,301 which issued to Joseph D. Cappucci et al. on June 24, 1969 and is entitled "Lumped Parameter Directional Coupler" and U.S. Pat. No. 3,452,300 which issued to Joseph D. Cappucci et al. on June 24, 1969 and is entitled "Four Port Directive Coupler Having Electrical Symmetry With Respect to Both Axes." These patents teach that directive quadrature couplers can be fabricated from lumped constant elements (substantially less than a quarter wavelength at the operating band of frequencies) if the input admittance thereof is the dual of the input impedance thereof at each of the ports when properly terminated.

U.S. Pat. No. 3,452,300 discloses a coupler formed from two end sections and a pair of uncoupled T sections interconnecting them. Each of the end sections are formed by a pair of conductors in close magnetic registration with a capacitor connecting one of the ends of one conductor in each pair to one of the ends of the other conductor respectively in that pair.

U.S. Pat. No. 3,452,301 teaches that a pair of closely magnetically coupled conductors may form a lumped constant quadrature hybrid coupler by having the distributed capacity between the two conductors form a major portion of the capacitance of the circuit to provide the above-described conditions of duality with respect to the desired terminating impedances. In both of these coupler constructions substantial improvement over the prior couplers was achieved, both from an economic view point and from the fact that they were substantially less than a quarter wave in length and therefore smaller for any particular operating band of frequencies than prior couplers.

U.S. Pat. No. 3,506,903 which issued to H. R. Beurrier on Apr. 14, 1970 and is entitled "Quadrature Hybrid Coupler" discloses a coupler substantially as taught in U.S. Pat. No. 3,452,301 in which the pair of couplers are held in registration by being bonded to a printed circuit board. The coupler of the Beurrier patent incorporates the teaching of duality of employs the capacity between the two conductors to form a substantial portion of the capacity of the coupler.

If any of these structures could be built with no parasitic capacitance or leakage inductance, the couplers would appear as solely inductive to an even mode excitation and purely capacitive to an odd mode excitation. However, in the real world this cannot be done. Therefore, the parasitic and leakage reactances have been taken into account analytically by treating them as compensated end sections at each of the ports of the couplers. This adds phase shifts to the signals applied to the coupler but no differential phase shift with respect to the input or output ports. This theoretical treatment of the parasitics holds up for the structures thus far devised so long as the leakage inductance is small and the frequency of operation is not too far from the center operating frequency of the coupler. When either of these conditions fail, however, the input admittance ceases to be the dual of the input impedance at each of the ports when appropriately terminated and therefore the device is no longer directive. To the extent that coupler is no longer directive, it does not serve the intent for which it was designed.

Therefore, it is an object of this invention to provide a new and improved lumped constant element quadrature hybrid coupler.

It is a further object of this invention to provide a lumped constant element quadrature hybrid coupler which has a greater band width of directivity than such couplers heretofore known.

It is still another object of this invention to provide a lumped constant element quadrature hybrid coupler which is less sensitive to parasitic reactances than such couplers heretofore known.

BRIEF DESCRIPTION OF THE INVENTION

With these and other objects in view the present invention contemplates a quadrature hybrid coupler in which first and second conductors are held in close magnetic relationship to provide coupling therebetween while a capacitor is connected between the ends thereof to render the coupler self-dual at each of its ports when terminated in an appropriate impedance.

The capacitor is connected midway between the ends of the first and second conductors respectively to segregate leakage and parasitic reactances symmetrically on either side of the capacitor so that they will physically behave as terminating end sections over a relatively large frequency range. The capacitance of the capacitor is large compared with the capacitance between the first and second conductors to maximize the effect of segregating the leakage and parasitic reactances into end sections.

By maximizing the amount of capacity in the lumped capacitor to maintain the desired relationship of duality, the thickness of the conductors is minimized. This tends to increase the inductance per unit length thereof, thereby further reducing the size of the device. In several embodiments the conductors are printed on opposite sides of an insulating substrate and are wrapped about themselves creating self-coupling, further increasing the inductance per unit length, further reducing the size of the device.

In these embodiments the capacitor may also be printed on opposite sides of the same insulating substrate further reducing the manufacturing costs of the devices constructed. In one embodiment the conductors are configured to allow the capacitors printed therewith to be connected thereto by additional printed circuitry on the substrate further reducing the manufacturing cost thereof.

DESCRIPTION OF THE FIGURES

A more complete understanding of the invention can be had by reference to the following figures and detailed description in which:

FIG. 1 is a diagram partially in block diagram form and partially in schematic form showing a coupler constructed in accordance with this invention connected into an operating system;

FIG. 2 is a top view of a printed circuit embodiment of this invention in which a capacitor is formed from a central portion of a printed conductor;

FIG. 3 is a top view of a second printed circuit embodiment of this invention in which a pair of oppositely wound spirals form the conductors and a pair of printed metalic areas form a capacitor connected directly thereto; and

FIG. 4 is a top view showing a third printed circuit embodiment of this invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. 1 we see a lumped constant quadrature hybrid coupler **10** having an input port **1**, a coupled output port **2**, a transmitted output port **3** and an isolated port **4**. The transfer characteristics (scattering parameters) of the coupler **10** are as taught in U.S. Pat. No. 3,452,301. The coupler **10** of FIG. **1** of this invention is analogous in its transfer characteristics to the coupler **10** of FIG. **1** of the above-mentioned U.S. Pat. No. 3,452,301.

A signal generator **11** having a source impedance Z_o (the characteristic impedance of the coupler **10**) is connected by a cable **12** also having the characteristic impedance Z_o to the port **1**. The ports **2** and **3** of the coupler **10** are connected each by cables **13** and **14**, respectively, each having a characteristic impedance Z_o to a utilization device **16**. The utilization device **16** terminates the cables **13** and **14** in the characteristic impedance Z_o. A resistor **17** having a value of Z_o terminates the terminal **4**.

In operation the signal applied by the signal generator **11** to the terminal **1** is divided according to the characteristics of the coupler **10** between terminals **2** and **3** and applied therefrom to the utilization device **16**. The phase of signals appearing on the terminals **2** and **3** are in quadrature and utilized therefore in the utilization device **16** as is well known.

The coupler **10** of this invention is formed from a pair of conductors **18** and **19** held in close magnetic registration and a capacitor **21** connecting the mid-sections of the conductors **18** and **19**. The values of the inductance of the conductors **18** and **19** and the total capacity of the coupler **10** including the capacitor **21** and the interconductor capacity between the conductors **18** and **19** are chosen in accordance with the teaching of U.S. Pat. No. 3,452,301 to provide the duality taught therein when terminated in the appropriate impedance Z_o.

As mentioned above the transfer or scattering parameters of the coupler **10** are analogous to the transfer or scattering parameters of the coupler as taught in U.S. Pat. No. 3,452,301. However, the band of frequencies over which these parameters actually represent the performance of the device is substantially greater than in any lumped quadrature hybrid couplers heretofore in existence. It should be particularly appreciated at this point that the band shape (amplitude versus frequency) is not altered by placing the capacitor in the center rather than at the ends or distributed along the conductors **18** or **19**. Rather the directivity versus frequency is altered. This means that the coupler **10** of this invention is a lumped constant quadrature hybrid coupler over a wider band of frequencies than previous lumped quadrature hybrid couplers. This characteristic renders the coupler **10** of this invention useful in systems and circuits which prior lumped constant quadrature hybrid couplers were not.

The reason that the coupler **10** with the capacitor **21** centrally located has a wider band width of directivity than heretofore known lumped constant quadrature hybrid couplers is that the leakage inductance and parasitic capacity is now symmetrically disposed on either side of the major portion of the capacity of the coupler **10**. Therefore the leakage inductance and parasitic capacity performs in fact as an end section for the coupler **10**. The value of the leakage inductance while not being eliminated can be thereby compensated for so that the end sections are constant K half sections having characteristic impedances of Z_o. Therefore, phase shift is introduced thereby but the overall characteristic of the coupler **10** is not altered.

The directivity of the coupler **10** therefore does not fail until the cutoff frequency of the end section formed by the parasitic capacity and leakage inductance is reached. In prior couplers where the capacity of the system was either lumped at the respective ends of the conductors such as conductors **18** and **19** or distributed therebetween, the parasitic capacity and leakage inductance (while occasionally thought of as end sections) was physically in fact interspersed within the actual coupler structure. Therefore the prior art structures failed in directivity as the frequency moved away from the center operating frequency thereof. This was because the leakage inductance and parasitic capacity tended to defeat the duality of the coupler. In contradistinction to this by lumping the majority of the capacity at the central portion of the conductors **18** and **19**, duality is maintained over a much broader frequency band thereby maintaining the properties of directivity heretofore discussed.

Referring now to FIG. **2** we see a first printed circuit embodiment of the coupler **10**. The conductors **18** and **19** are held in close magnetic registration by being adhered to opposite sides of an insulating substrate **22**. The capacitor **21** is formed by an enlargement of the conductors **18** and **19** at the central portions thereof so that the plates of the capacitor **21** are formed intricately in the conductors **18** and **19**. It should be noted that the conductors **18** and **19** are wrapped around the portions thereof which form the capacitor **21** to provide self-inductance which increases the inductance per unit length thereof typically shortening the length of conductors **18** and **19** necessary by 40 to 50 percent. It should be further noted in this regard that by lumping the capacity at the center of the conductors **18** and **19** rather than distributing it in a printed circuit coupler, as was taught by U.S. Pat. No. 3,506,932, the width of the conductors **18** and **19** are reduced again increasing the inductance per unit length thereof resulting in shorter couplers. It should be noted that the couplers of the instant invention are shorter even without wrapping.

FIGS. **3** and **4** show additional printed circuit embodiments of the coupler **10** in which the conductors **18** and **19** are formed on opposite sides of an insulating substrate **22**. In each of the embodiments in FIGS. **3** and **4** the conductors **18** and **19** are formed in two spirals to further increase the inductance per unit length. In FIG. **4** the two spirals are wound in opposite

senses so that direct connection to the ports of the coupler **10** can be made from the ends of the conductors **18** and **19**. The capacitor **21** is formed adjacent to the conductors **18** and **19** and are connected thereto at the center of the spirals by jumpers **23** and **24** on the side shown and analogous jumpers on the opposite side. It should be noted that the jumpers **23** and **24** are conductively connecting the centers of the two spirals together as well as attaching them to the plate of the capacitor **21** on the visible side of the substrate **22**.

In the embodiment of FIG. **4** the conductors **18** and **19** are wound in two spirals having similar senses providing a mutual inductance further increasing the inductance per unit length resulting in, again, shorter devices than even the embodiment shown in FIG. **4**. In this embodiment the capacitor may be formed by two areas on each side of the insulator **22** and can be directly connected to the central portion of the conductors **18** and **19** by printed circuit lines **26** and **27** on the visible side of the substrate **22** and analogous printed circuit lines on the opposite sides thereof. In the embodiment of FIG. **4** jumper leads **28** and **29** are required to connect the centers of the spiral on the visible side of the substrate **22** to the ports of the coupler **10**. Analogous jumpers are used on the opposite side of the substrate **22**.

It should be appreciated that while this invention has been disclosed with respect to four specific embodiments thereof, numerous others will become obvious to those of ordinary skill in the art in light thereof.

What is claimed is:

1. A quadrature hybrid coupler including:

a first conductor having first and second ends and a midpoint;

a second conductor having first and second ends and a midpoint;

means for maintaining said first and second conductors in close magnetic relationship to provide coupling therebetween, said first and second coupled conductors having a leakage inductance and a predetermined capacitance therebetween;

a capacitor having first and second plates exhibiting a capacitance therebetween large compared to said predetermined capacitance;

means for electrically connecting said first plate of said capacitor to said first conductor at said midpoint of said first and second ends thereof; and said second plate of said capacitor to said second conductor at said midpoint of said first and second ends thereof to symmetrically dispose said leakage inductance with respect thereto; and

means connected to said first and second ends of said first and second conductors for forming constant K end sections with said symmetrically disposed leakage inductance.

2. The quadrature hybrid coupler as defined in claim **1** also including an insulating substrate having first and second sides and said first and second conductors are maintained in close magnetic relationship by being held on said first and second sides, respectively, of said insulating substrate.

3. The quadrature hybrid coupler as defined in claim **2** in which said first and second plates of said capacitor are formed on said first and second side of said substrate.

4. The quadrature hybrid coupler as defined in claim **3** in which said first and second conductors are wrapped about a center to provide self-inductance increasing the inductance per unit length thereof.

5. The quadrature hybrid coupler as defined in claim **4** in which said first and second plates of said capacitor are formed at said center on said first and second sides of said substrate and form a central portion of said first and second conductors respectively.

6. The quadrature hybrid coupler as defined in claim **3** in which said first and second conductors are spirally arranged to provide self-inductance increasing the inductance per unit length thereof.

7. The quadrature hybrid coupler as defined in claim **4** in which said first and second plates of said capacitor are connected to said first and second conductors, respectively, by conductors affixed to said first and second sides, respectively, of said insulating substrate.

8. The quadrature hybrid coupler as defined in claim **2** in which said first and second plates of said capacitor are formed at said center on said first and second sides of said substrate and from a central portion of said first and second conductors respectively.

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