United States Patent

[11] 3,612,780

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[21] Appl. No. **864,695**
[22] Filed **Oct. 8, 1969**
[45] Patented **Oct. 12, 1971**

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[54] **ACTIVE FOUR-PORT**
10 Claims, 7 Drawing Figs.

[52] **U.S. Cl.** ..... **179/170 T,** 330/30
[51] **Int. Cl.** **H03f 3/62**
[50] **Field of Search** ..... 179/170, 170 T; 330/30, 30 D, 69, 94

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ABSTRACT: This application describes an active four-port having directional transmission properties. The four-port comprises two active members whose respective emitting, control and collecting electrodes are connected by means of separate networks characterized in that the symmetric mode transfer gain and the antisymmetric mode transfer gain, as measured between the control and collecting electrodes, are equal.

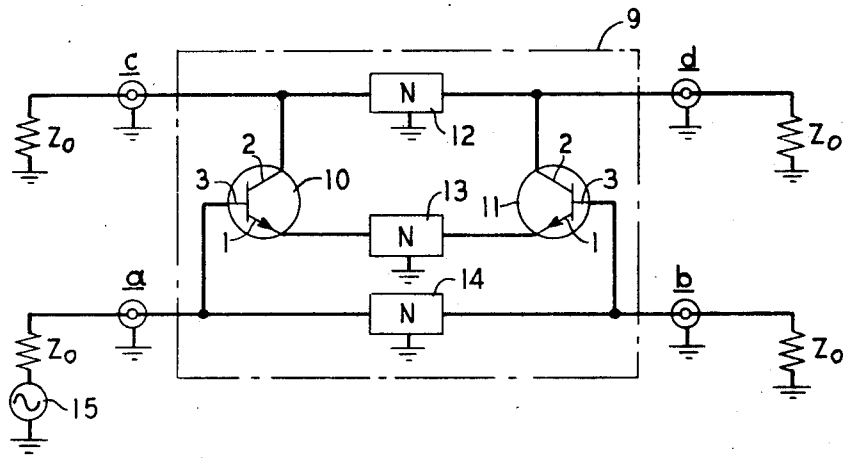


FIG. 1

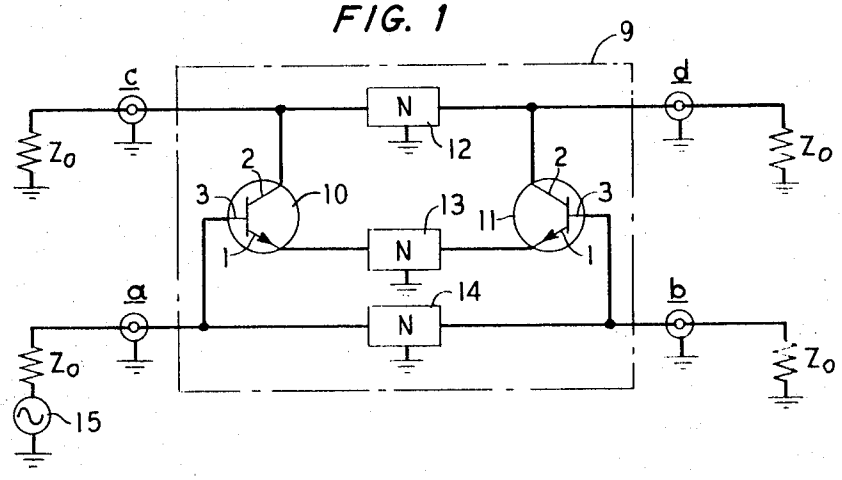


FIG. 2A

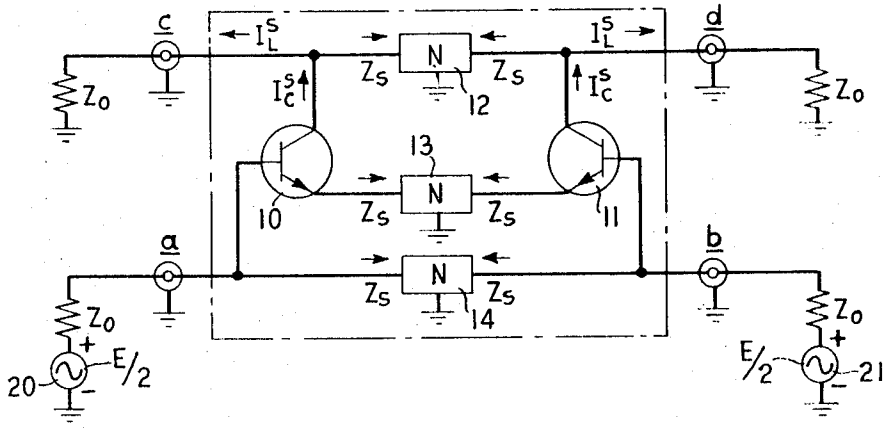
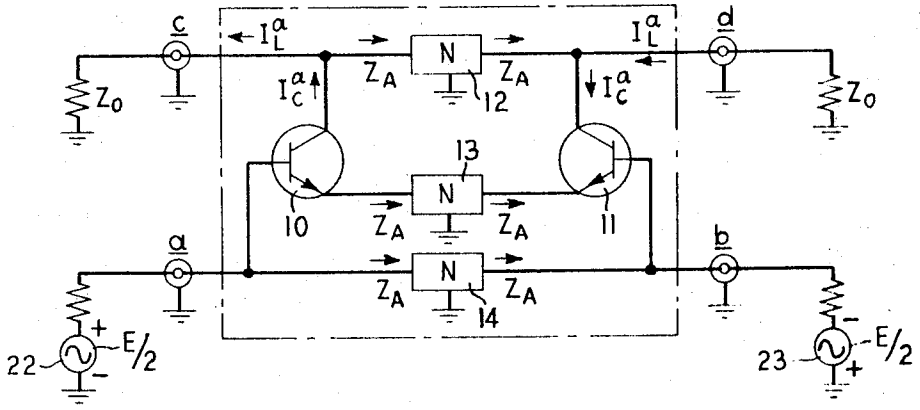


FIG. 2B



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FIG. 3

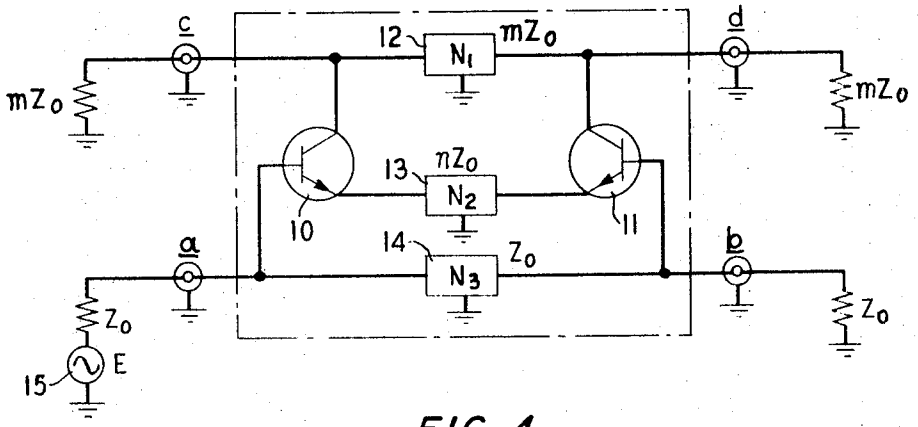


FIG. 4

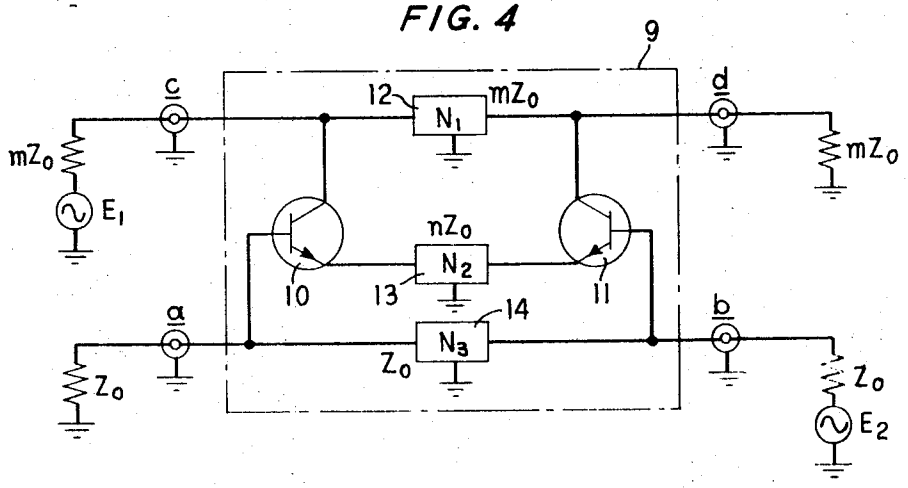


FIG. 5A

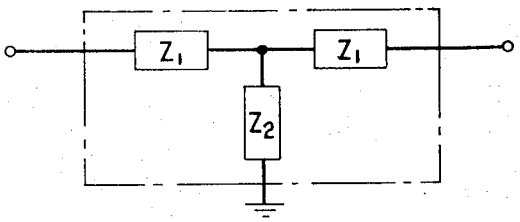
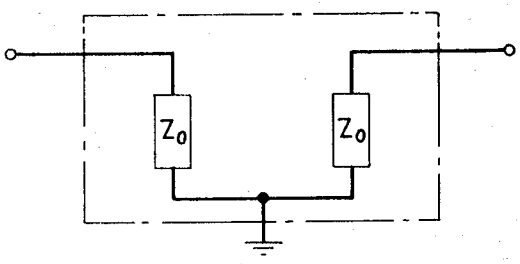


FIG. 5B



ACTIVE FOUR-PORT

This invention relates to active four-ports having directional transmission properties.

BACKGROUND OF THE INVENTION

It is very often desirable to divide a signal into two components, or to combine two signals in a manner which also senses the direction of signal propagation. A typical device for doing this is the directional coupler, of which there are two general classifications. One classification is the traveling wave type of coupler whose overall length is a fraction of the signal wavelength. The second classification is the lumped-element coupler whose dimensions are substantially independent of signal wavelength, but which requires a lumped inductor.

The object of the present invention is to perform the above-described circuit functions by means which do not use inductors and whose size is independent of signal wavelength.

SUMMARY OF THE INVENTION

An active four-port in accordance with the present invention comprises an amplifier having equal symmetric mode and antisymmetric mode transfer gains, where the term transfer gain denotes a matched output load and a matched input source. In one of the illustrative embodiments of the invention, the emitter, base and collector electrodes of two transistors are coupled together, respectively, by means of three electrically identical, matched two-ports. The two base electrodes and the two collector electrodes define the ports of the active four-port.

In an alternate embodiment of the invention utilized to combine two signals, two-ports having different transfer characteristics are used.

While the three networks can, in the most general case, comprise resistive, inductive and capacitive circuit elements, it is an advantage of the invention that directional coupler characteristics can be realized using only resistive elements. This has the advantage that the complete coupler can be readily fabricated using standard printed circuit techniques.

These and other objects and advantages, the nature of the present invention, and its various features, will appear more fully upon consideration of the various illustrative embodiments now to be described in detail in connection with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 shows an active four-port in accordance with the invention;

FIGS. 2A and 2B, included for purposes of explanation, show the four-port of FIG. 1 excited in the symmetric mode and antisymmetric mode, respectively;

FIG. 3 shows an alternate embodiment of the invention wherein the two-ports are matched at different impedance levels;

FIG. 4 shows an active four-port utilized to combine two signals for propagation along a common direction; and

FIGS. 5A and 5B, included for purposes of illustration, show two networks of the type that can be used in the present invention.

DETAILED DESCRIPTION

Referring to the drawings, FIG. 1 shows a first embodiment of an active four-port 9 in accordance with the present invention, comprising two active elements 10 and 11, and three identical two-port networks 12, 13 and 14. For purposes of illustration, active elements 10 and 11 are depicted as transistors, each of which has an emitter electrode 1, a collector electrode 2, and a control, or base electrode 3. It will be recognized, however, that other types of active elements, such as vacuum tubes, can just as readily be used.

One of the networks, 12, is connected between the collector electrodes 2, which form two of the ports c and d of the active four-port. A second of the networks 14 is connected between the base electrodes 3, which form the other two ports a and b of the four-port. The third network 13 is connected between the emitter electrodes 1. Direct current biasing sources and connections have been omitted so as not to complicate the circuit diagram.

In accordance with this first embodiment of the invention, networks 12, 13 and 14 have the same transfer characteristics and are matched with respect to an arbitrary impedance level Z_o. Being matched, they can be characterized by a bisected symmetric impedance Z_s and a bisected antisymmetric impedance Z_a, where

$$(Z_s/Z_o)=(Z_o/Z_a). \quad (1)$$

As indicated hereinabove, the active four-port of FIG. 1 can be used as a directional coupler to divide a signal into two components, or to combine two signals. As a power divider, a signal is applied to either port a or b, and an output is obtained at the other of these two ports, and at one of the other ports c or d. For purposes of illustration, a signal source 15, having an output impedance Z_o, is shown connected to port a. Ports b, c and d are each terminated by means of a load impedance Z_o which, typically, would be a transmission line.

The operation of the four-port is conveniently analyzed by separately examining its responses to the symmetric mode of excitation and to the antisymmetric mode of excitation, and then superimposing the two results. This is now done referring to FIGS. 2A and 2B which show the four-port excited in the symmetric mode and in the antisymmetric mode, respectively.

Referring more specifically to FIG. 2A, signal sources 20 and 21 of amplitude E/2 and output impedance Z_o excite ports a and b in phase. Assuming for the purposes of this analysis that both transistors have an $\alpha=1$ (infinite base impedance), the symmetric mode signal voltage at the base of each transistor is

$$e_b^s=(Z_s/Z_o+Z_s)\cdot(E/2) \quad (2)$$

where, by definition, Z_s is the bisected symmetric impedance of each of the networks 12, 13 and 14.

The symmetric mode emitter current is then

$$I_e^s=(e_b^s/Z_s)=(E/2)[1/Z_o+Z_s]. \quad (3)$$

Since $\alpha=1$, the emitter and collector currents are equal. That is

$$I_e^s=I_c^s. \quad (4)$$

The symmetric mode load current I_L^s is then given by

$$I_L^s=I_c\,Z_s/Z_o+Z_s) \quad (4)$$

or

$$I_L^s=(E/2)[Z_s/(Z_o+Z_s)^2]. \quad (6)$$

Since the excitation signals derived from sources 20 and 21 are in phase, the load currents at ports c and d are also in phase.

From a similar analysis of FIG. 2B, wherein ports a and b are excited by means of two 180° out of phase signal sources 22 and 23, we obtain for the antisymmetric mode load current

$$I_L^a=(E/2)[Z_a/(Z_o+Z_a)^2], \quad (7)$$

where Z_a is the bisected antisymmetric network impedance. Substituting the value of Z_a obtained from equation (1) in equation (7) yields

$$I_L^a=(E/2)[Z_s/(Z_o+Z_s)^2], \quad (8)$$

where the load current at port c is out of phase with the load current at port d.

A comparison of equations (6) and (8) shows that the symmetric load currents and the antisymmetric load currents at ports c and d are equal in magnitude. Applying the principle of superposition to both the inputs and outputs, the signals applied to port a sum to E, whereas the signals applied to port b sum to zero, thus simulating the excitation conditions shown in FIG. 1 wherein a signal source 15 is coupled to port a. Similarly, the load currents at port c sum to

$$I_L=E[Z_s/(Z_o+Z_s)^2] \quad (9)$$

to produce an output voltage

$E_L=(EZ_oZ_s/(Z_o+Z_s)^2)$. (10) The load currents at port d, on the other hand, sum to zero. Thus, an active four-port in accordance with the present invention has directional properties in that a signal applied to port a couples to port c

but not to port d. Correspondingly, a signal applied to port b will couple to port d but not to port c.

In addition to the above, there is also coupling between ports a and b through network **14**. Applying the same technique of energizing network **14** in the symmetric and antisymmetric mode and then superimposing the resulting currents and voltages, it can be shown that the signal E_t transmitted from port a to port b is

$$E_t=(E/2)[Z_s-Z_o/Z_s+Z_o]. \quad (11)$$

The coupled signal component, given by equation (10), and the transmitted signal component given by equation (11), can also be expressed in terms of the coefficient of transmission of the networks **12**, **13** and **14**. Designating this coefficient as t, the transmitted signal component $E_{becomes}$ becomes

$$E_t=(E/2)t \quad (12)$$

and the coupled signal component E_L becomes

$$E_L=(E/4)(1-t^2). \quad (13)$$

Thus, an active four-port having any arbitrary power division ratio can be realized simply by designing the networks N to have the symmetric impedance Z_s defined by equations (10) or (11), or, alternatively, to have the transmission coefficient defined by equation (12) or (13).

It will be noted that the active four-port described above is basically an amplifier that responds equally to both the symmetric and antisymmetric modes of excitation. More specifically, it is an amplifier that is characterized by equal symmetric mode and antisymmetric mode transfer gains, where transfer gain is defined as the ratio of the output signal into a matched load to the input signal from a matched source.

FIG. **3** shows a second embodiment of the invention. Basically, this embodiment has the same general circuit configuration as the embodiment of FIG. **1**, comprising two active members **10** and **11** interconnected by means of three two-port networks **12**, **13** and **14**. As in the embodiment of FIG. **1**, networks **12**, **13** and **14** are matched networks having the same transfer characteristics. However, in the embodiment of FIG. **3**, the networks are matched at different impedance levels. As illustrated, network **14** is matched at impedance level Z_o, and is characterized by the bisected symmetric and antisymmetric mode impedances Z_s and Z_a. Network **13** is matched at impedance level nZ_o, where n is any number, and is characterized by mode impedances nZ_s and nZ_a. Similarly, network **12** is matched at impedance level mZ_o, where m is any number, and is characterized by mode impedances mZ_s and mZ_a.

A modal analysis of this network shows that signal source **15**, having an open-circuit voltage E and output impedance Z_o, applied to port a will produce a coupled signal E_L at port c given by

$$E_L=EZ_oZ_s/(Z_o+Z_s)^2\cdot(m/n). \quad (14)$$

In terms of the coefficient of transmission t, which is the same for all three networks,

$$E_L=(E/4)(1-t^2)\cdot(m/n). \quad (15)$$

It will be noted that the value of E_L given by equations (14) and (15) differs from that given by equations (10) and (13) by the factor (m/n), which is the ratio of the impedance level multiplies m and n. In particular, by selecting m larger than n, the ratio (m/n) is greater than unity, and the coupled signal for the embodiment of FIG. **3** is correspondingly greater than the coupled signal obtained in the embodiment of FIG. **1**, where the three networks are matched at the same impedance level.

In addition to obtaining greater transfer gain, this embodiment has the added advantage of permitting coupling between two matched transmission paths having different characteristic impedances.

FIG. **4** shown an active four-port utilized to combine components of two signals E_1 and E_2, where signal E_1 is coupled to port c and signal E_2 is coupled to port b. Networks **12**, **13** and **14**, as in the embodiments of FIG. **1** and FIG. **3**, have the same transfer characteristics, and are matched at impedance levels

In operation, signal E_1 is coupled through network **12** to port d, producing a first output signal component E_1t, where t is the coefficient of transmission for each of the networks. Signal E_2 produces a second signal component $(E_2/4)(1-t^a)\cdot(m/n)$ at port d, in the manner explained hereinabove. The two components combine to produce an output signal propagating along a common direction.

Signal E_2 also coupled through network **14** to produce an output signal E_2t at port a. If the latter signal is not needed, it can either be absorbed in termination Z_o or, alternatively, the two-ports can be modified so that their transfer characteristics are no longer the same. In particular, if network **14** has a coefficient of transmission $t_3=0$, there will be no signal coupled between ports b and a. In this situation, directional coupling between ports b and d is obtained when the coefficients of transmission t_1 and t_2, of the other networks **12** and **13**, are related by

$$t_2=\frac{\sqrt{1+t_1}-\sqrt{1-t_1}}{\sqrt{1+t_1}+\sqrt{1-t_1}} \quad (16)$$

The magnitude e_2 of the signal coupled between ports b and d is then given by

$$e_2=(E_2/4)\sqrt{1-t_1^2}\cdot(m/n). \quad (17)$$

A comparison of equations (17) and (15) shows that when the transfer characteristics are different, but tailored in the manner described, the coupled signal given by equation (17) is greater than that given by equation (15) by the factor

$$\frac{1}{\sqrt{1-t_1^2}}$$

In the various embodiments described hereinabove, the two-ports were characterized as having the same transfer characteristics. This was based, in part, upon the assumption that the active members are ideal transistors whose base and collector impedances are infinite and whose emitter impedance is zero. Obviously, this is not the case, and to the extent that any deviation from these ideal conditions becomes significant, this will be reflected in the details of the two-ports. For example, two-port **13** will, in general, not be identical to two-port **12** to the extent that the emitter resistance of the transistors is not zero. Thus, when characterized as having the same transfer characteristics, it will be understood to mean that the transfer characteristics of the networks are the same when the transistor parasitic impedances are also taken into account. Advantageously, each of the networks will include adjustable elements to compensate for the actual transistor impedances.

FIG. **5A**, included for purposes of illustration, shows a two-port network of the type that can be used in the present invention. Designating the series elements Z_1 and the shunt element Z_2, the bisected symmetric impedance Z_s and the bisected antisymmetric impedance Z_a are given by

$$Z_s=Z_1+2Z_2$$

and

$$Z_a=2Z_1.$$

To satisfy the match condition that

$$(Z_a/Z_o)=(Z_o/Z_s),$$

Z_1 and Z_2 can include solely resistive elements; combinations of inductive and compactive elements; or combinations of inductive, capacitive and resistive elements.

FIG. **5B** shows a two-port network which is matched at impedance level Z_o and has zero transmission. This two-port can be used at network **14** in the embodiment of the invention shown in FIG. **4**.

It will be noted from the description of FIG. **4** that a signal coupled to port a (or b) will divide to produce signal components at ports b and c (or a and d). A signal coupled to either port c (or d) on the other hand, is only coupled to port d (or c). In this sense, the active directional coupler described herein is nonreciprocal and, as such, differs from a passive directional coupler which is reciprocal.

As indicated hereinabove, one advantage of the present invention is that directional coupling can be realized without inductors or transformers. Thus, the four-port can be readily fabricated using current printed circuit and integrated circuit techniques. If, however, there are no limitations on the fabrication techniques employed, networks **12**, **13** and **14** can include, as noted above, inductors as well as capacitors and resistors. The networks can also include lengths of transmission line. For example, if each of the networks is a length of transmission line, the coefficient t becomes imaginary whenever the line is an odd integral of a quarter of a wavelength long. Being imaginary, t^2 is negative, and the coupled signal, given by equation (13) is maximized. Thus, the coupler, under these conditions, has a maximum response which varies as a function of frequency and can be used as a filter. Thus it is evident in all cases that the above-described arrangements are illustrative of only a small number of the many possible specific embodiments which can represent applications of the principles of the invention. Numerous and varied other arrangements can readily be devised in accordance with these principles by those skilled in the art without departing from the spirit and scope of the invention.

We claim:

1. In combination:

two active members, each having an emitting electrode, a control electrode and a collecting electrode;

first, second and third two-port networks connected, respectively, between the emitting, control and collecting electrodes of said members;

said networks characterized in that the symmetric mode transfer gain and the antisymmetric mode transfer gain, measured between said control electrodes and said collecting electrodes, are equal.

2. The combination according to claim **1** wherein said networks have the same transfer characteristics.

3. The combination according to claim **2** wherein said networks are matched to the same impedance level.

4. The combination according to claim **2** wherein said networks are matched to different impedance levels.

5. The combination according to claim **1** wherein said networks have different transfer characteristics.

6. The combination according to claim **5** wherein said networks are matched to the same impedance level.

7. The combination according to claim **5** wherein said networks are matched to different impedance levels.

8. An active four-port network having directional transmission properties comprising:

two active members, each having an emitting electrode, a control electrode and a collecting electrode;

a first two-port network connecting the emitting electrode of said members;

a second two-port network connecting the control electrodes of said members;

and a third two-port network connecting the collecting electrodes of said members;

said control electrodes and said collecting electrodes constituting the four ports of said network;

said two-port networks characterized in that equal symmetric and antisymmetric mode signals connected to said control electrodes produce equal symmetric and antisymmetric mode signals in said collecting electrodes.

9. The four-port according to claim **8** wherein an input signal is coupled to the control electrode of one of said members;

and wherein output signals are produced at the control electrode of the other of said members and at only one of said collecting electrodes.

10. The four-port according to claim **8** wherein a first signal is coupled to the collecting electrode of one of said members;

a second signal is coupled to the control electrode of the other of said members;

and wherein components of both of said signals are extracted from the collecting electrode of said other member.