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Savarin et al.

[11] **3,769,610**

[45] **Oct. 30, 1973**

[54] **VOLTAGE CONTROLLED VARIABLE POWER DIVIDER**

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[73] Assignee: **Philco-Ford Corporation**, Philadelphia, Pa.

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[21] Appl. No.: **263,229**

[52] **U.S. Cl.** .... **333/10**, 333/31 R

[51] **Int. Cl.** **H01p 5/04**

[58] **Field of Search** .... 333/6, 10, 11, 31 R, 333/31 A

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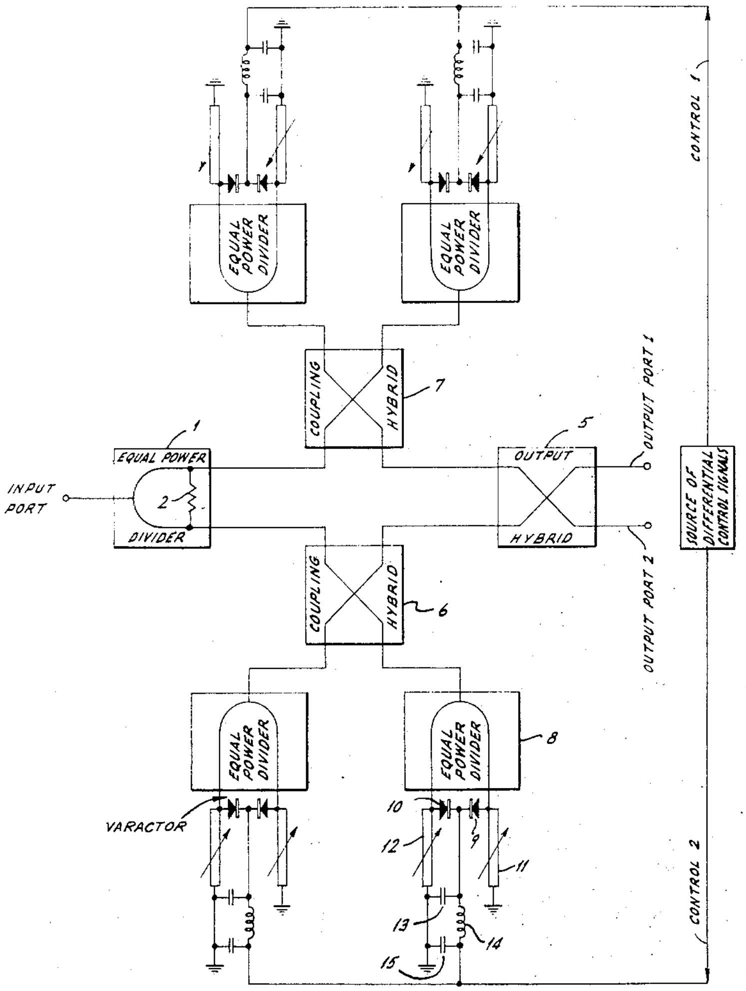
Attorney—Robert D. Sanborn et al.

[57] **ABSTRACT**

The division of r-f energy between two transducer output terminals is varied by means of an applied control voltage. The total output power equals the input power and both outputs have constant and equal phase. The applied power is split into two channels, each of which contains a variable phase shifter. The channels are combined in a 90° hybrid coupler so that the relative amplitude in the hybrid outputs is a function of the phase of the hybrid input signals. The phase shifters are voltage driven in opposition so that constant phase is achieved for all output power division ratios.

3 Claims, 7 Drawing Figures



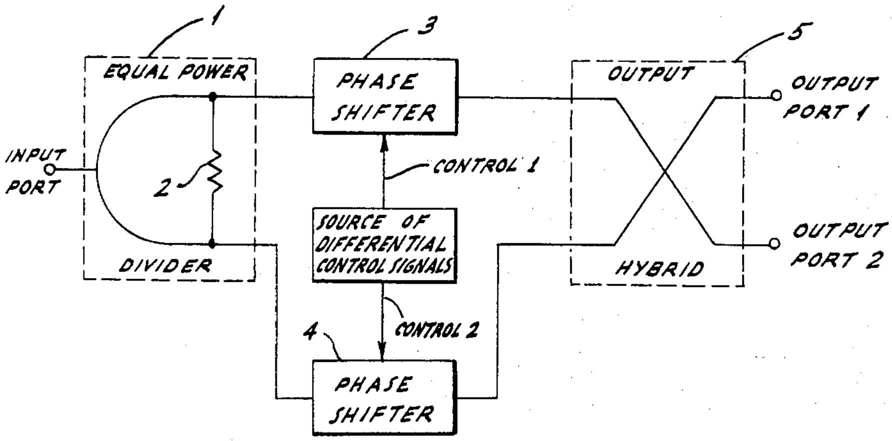


FIG. 1.

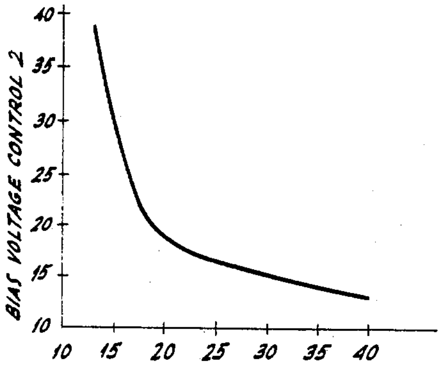


FIG. 2. BIAS VOLTAGE CONTROL 1 (VOLTS)

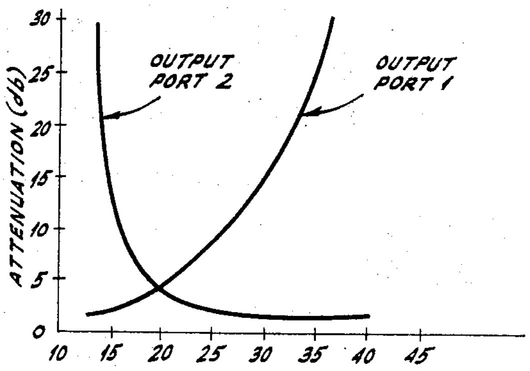


FIG. 3. BIAS VOLTAGE CONTROL 1 (VOLTS)

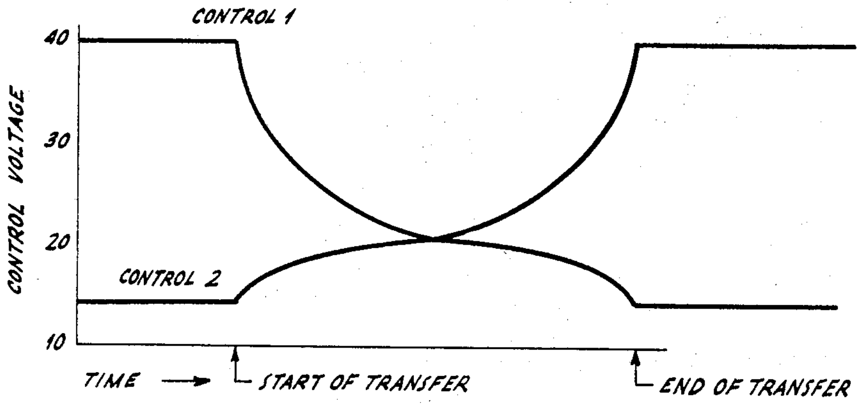


FIG. 4.

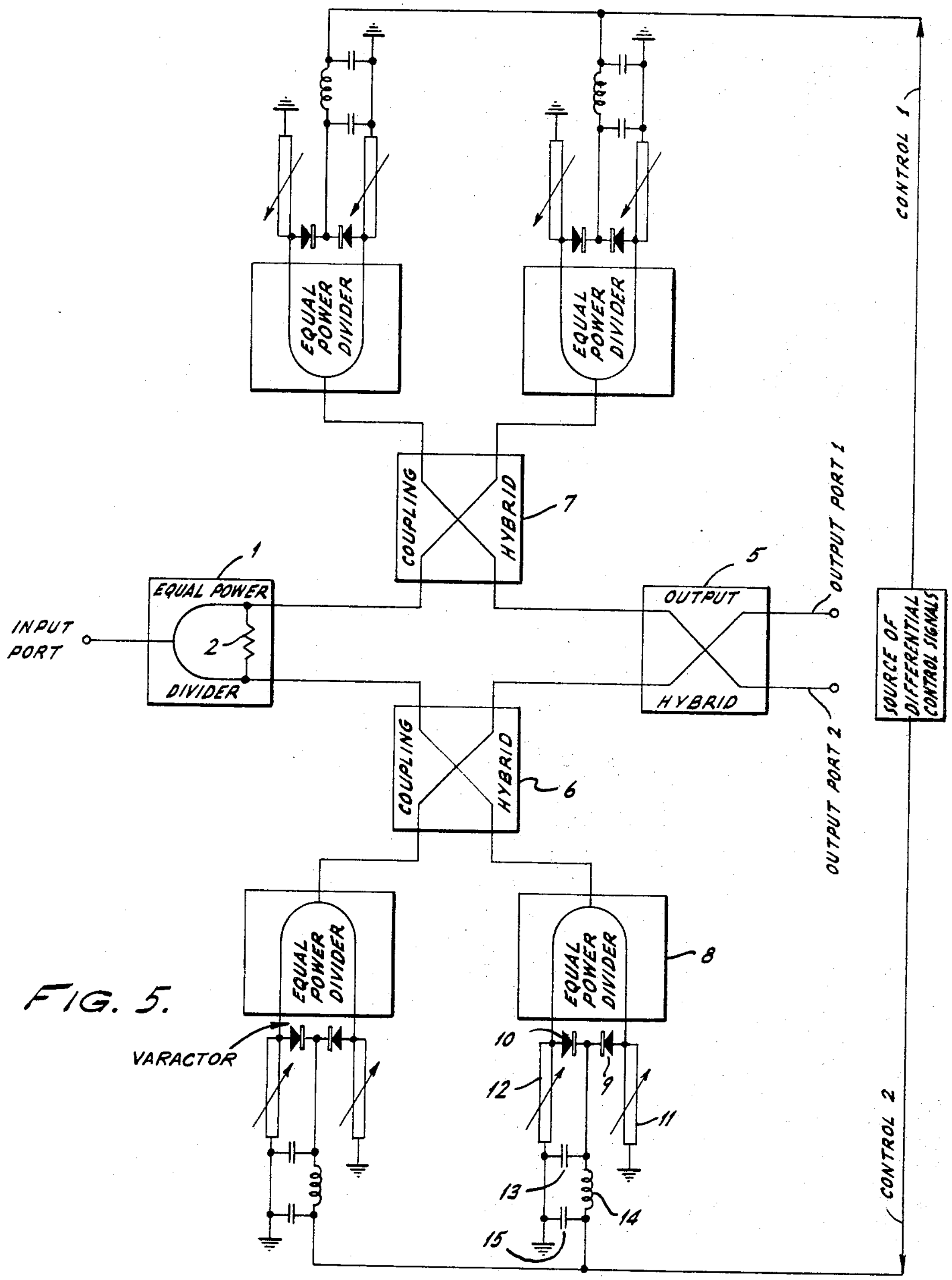

EQUAL POWER DIVIDER
EQUAL POWER DIVIDER
COUPLING HYBRID
7
1
EQUAL POWER DIVIDER
2
INPUT PORT
5
OUTPUT HYBRID
OUTPUT PORT 1
OUTPUT PORT 2
SOURCE OF DIFFERENTIAL CONTROL SIGNALS
CONTROL 1
COUPLING HYBRID
6
EQUAL POWER DIVIDER
EQUAL POWER DIVIDER
8
VARACTOR
10
12
9
11
13
14
15
CONTROL 2

FIG. 5.

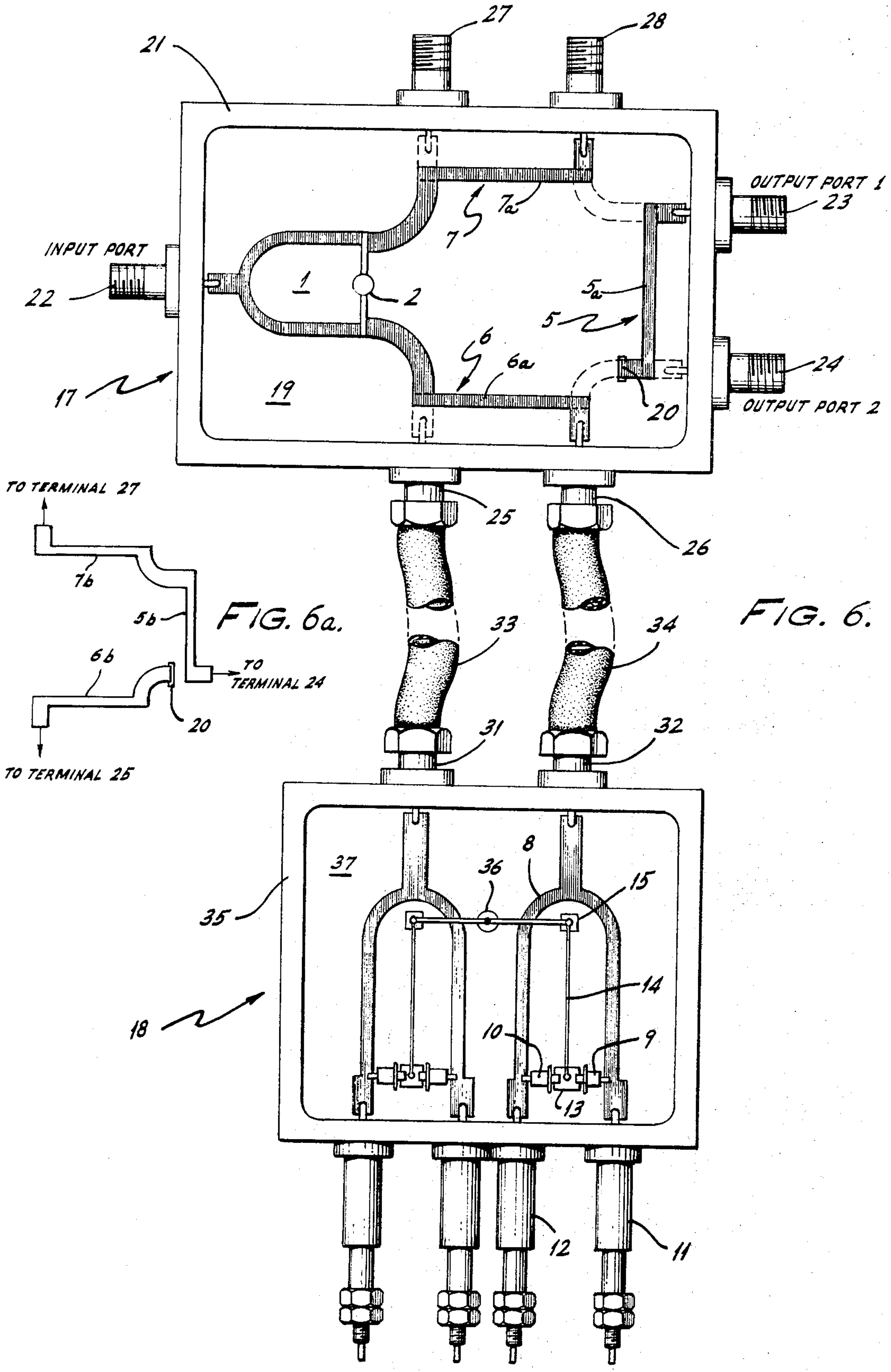

TO TERMINAL 27
7b
5b
6b
TO TERMINAL 24
20
TO TERMINAL 25

FIG. 6a.

27
28
21
OUTPUT PORT 1
23
INPUT PORT
7a
7
1
2
22
5a
5
6
6a
24
17
19
OUTPUT PORT 2
20
25
26
33
34
31
32
37
36
8
15
35
14
18
10
9
13
12
11

FIG. 6.

VOLTAGE CONTROLLED VARIABLE POWER DIVIDER

BACKGROUND OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 U. S. C. 2457).

Variable power dividers are well known in the prior art. Typically an input terminal and two (or possibly more) output terminals are involved. Power applied to the input is divided between the output terminals and, by means of a control, the division ratio can be varied. This control is usually of the mechanical variety and ordinarily varies the coupling between inductors or capacitive plates. Electronic control of power dividers has been accomplished using magnetically biased ferrites but typically these devices operate as switches rather than controllable ratio dividers. Electronic switches using varactor diodes are well known and complex switching arrays can be achieved but these devices too operate in the off or on state rather than as controllable ratio power dividers.

SUMMARY OF THE INVENTION

It is an object of the invention to provide an electronically controlled variable power divider.

It is a further object to provide a multiple output power divider having continuously variable outputs of constant phase.

It is a feature of the invention that multiple varactor diodes can be used to increase power-handling capabilities while retaining the desired control function.

It is a further feature of the invention that the power divider is fully reciprocal.

These and other objects and features are achieved in the following manner. A fixed power divider feeds equal signals to two ports of a 90° hybrid. Each signal is subjected to the variable phase action of a reverse biased varactor diode. If each path is subjected to a 45° phase shift the hybrid output ports will contain equal-amplitude in-phase signals. The diodes are provided with inverse bias controls so that the phase shift of one is increased as the phase shift of the other is decreased by the same amount. Therefore as one diode approaches a 90° phase shift, the other diode will approach 0°. For this condition virtually all of the input power appears at one hybrid output port. When the diode phase shift conditions are reversed the power output is transferred to the other hybrid output. If the diode control signals are correctly shaped, a continuously variable power division ratio can be achieved with the outputs at all ratios being of essentially the same phase.

The device is fully reciprocal. If two in-phase signals are applied to the output ports, they will be summed at the input port. The relative weight given to signals applied to the output ports on summing at the input will be a function of the control bias.

In an improved version the two signal channels are each coupled by means of 4-port hybrids to shunt-connected varactor diodes so that multiple diodes can be employed. This permits using as many diodes as required for the desired power handling capabilities.

DESCRIPTION OF THE DRAWING

FIG. **1** is a partial schematic block diagram of a voltage controlled variable power divider;

FIG. **2** is a graph showing the relationship of the control **1** and control **2** voltages of FIG. **1**;

FIG. **3** is a graph plotting output of the variable power divider as a function of control **1** bias voltage;

FIG. **4** is a graph plotting voltage versus time of control signals designed to provide a linear shift of output power as a function of time;

FIG. **5** is a partial schematic block diagram of an improved voltage controlled variable power divider;

FIG. **6** is a showing of stripline construction of the preferred embodiment of FIG. **5**; and

FIG. *6a* shows the details of the stripline conductors on the underside of substrate **19** of FIG. **6.**

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** shows a basic variable power divider. While the showing is in part-schematic block-diagram form, the actual circuit could be realized using waveguides, coaxial lines, open wire lines, or strip lines. Strip line construction is preferred because it is compact, rugged, and of low loss. Also it is easy to fabricate to reasonably high precision.

Input device **1** is an equal power divider designed to split the input into equal parts to be applied to the phase shifters. Resistor **2** acts to absorb any signal energy that is not balanced at the equal power divider output. The resistor is desired but not necessary to circuit operation. Equal power inputs are applied to phase shifters **3** and **4**, which desirably may comprise varactors or voltage variable capacitor diodes. When a semiconductor junction diode is reverse biased, it presents an almost pure capacitive reactance. The value of reactance increases with increasing reverse bias in a controlled manner. Thus the bias voltages applied to phase shifters **3** and **4** permit control of the value of phase shift. The phase shifters are designed so that they produce a 45° phase shift when their bias voltages are equal. These control voltages, derived from the unit labelled "Source of Differential Control Signals," are applied in opposition in a manner described hereinafter with reference to FIG. **4.** As the bias on one is increased, the bias on the other is decreased. As the phase shift in **3** approaches 90° the phase shift in **4** approaches 0°. The phase shifters are connected to a 3-dB 90° hybrid coupler **5.** This device is constituted so that equal outputs occur at output ports **1** and **2** when the input signals are of the same phase. When the inputs are 90° out of phase, all of the output energy appears at one output port, and for the opposite 90° input phase condition all of the output appears at the other port. Thus for the equal bias or 45° phase-shift condition of phase shifters **3** and **4,** input port power will be divided equally between output ports **1** and **2.** As the diode biases are varied by the voltages applied to the control **1** and control **2** terminals, the power split is varied.

FIG. **2** shows the bias voltage relationship of the two phase shifters. The line shows the relative bias requirements to achieve the desired complementary phase shift. It will be noted that the 45° voltage (the equal voltage condition) occurs at about 20 volts.

FIG. **3** plots the outputs as a function of control **1** bias voltage. While not shown on this graph, the control

2 bias voltage is operated to be in accord with FIG. **2.** It can be seen that the 3-dB point occurs at about 20 volts. For an insertion loss of slightly over 1dB the alternate channel attenuation is better than 20 dB (or over 100 times in power).

FIG. **4** shows a pair of waveforms designed to operate the variable power divider. At the left hand portion control **1** is at maximum bias while control **2** is at minimum bias. For this condition one output port will receive all of the power while the other port is at least 100 times weaker (20dB down). At the start of power transfer, control **1** voltage declines as control **2** voltage increases. Half way through the transfer the two control signals are equal and the two output ports have equal output power. As time progresses the waveforms progress to the end of the power transfer period where the relative outputs of output ports **1** and **2** are reversed. The waveforms are so shaped that the power transfer is a linear function of time. These waveforms are shaped to insure constant output phase at both output ports.

The variable power divider of FIG. **1** has been found very useful in amplitude-steered multiple-element antenna arrays. A detailed showing of such an application appears in copending U.S. Pat. application Ser. No. 263,230 filed June 15, 1972. That application also shows but does not claim the variable power divider of FIG. **1.**

FIG. **5** shows an improved version of a variable power divider in which the signal energy traverse the varactor diodes is reduced. The diode reactance is shunt connected by means of equal power divider thereby permitting the use of parallel diodes to provide higher power operation. Desirably the varactor diodes are not driven into either forward conduction or reverse breakdown. As shown in FIGS. **2** and **3**, operating biases are typically in the range of about 12 to 40 volts. When the *r–f* signals are superimposed on the bias voltages it is clear that the value of power that can be controlled by a single diode will be limited by voltage constraints alone. Of course the diode package must be capable of dissipating the energy values imposed by unavoidable operating losses.

The equal power divider **1** and resistor **2** are as shown in FIG. **1**, as is output hybrid **5.** Two 3–dB 90° hybrids **6** and **7** couple energy between the equal power divider **1** and the output hybrid **5.** These hybrids provide means for shunt reactance phase shift control. In regard to hybrid **6**, four varactor reactance control diodes are connected thereto. Equal power divider **8** connects two varactors **9** and **10** to one port of hybrid **6.** Varactor **9** is connected electrically across tuning stub **11** while varactor **10** is connected electrically across tuning stub **12.** Capacitor **13** completes the parallel *r–f* connection while blocking the applied *d–c* bias from ground. Tuning stubs **11** and **12** are adjustable and approximately one-quarter wavelength long. These stubs are used to tune diodes **9** and **10** which are preferably a matched pair. Inductor **14** and capacitor **15** complete a pi network filter designed to eliminate any *r–f* energy from the control **2** line. In the preliminary adjustment of this apparatus, the diodes are provided with the bias voltage required for 45° or equal output operation and the tuning stubs adjusted for the correct phase shift.

The other three sets of equal power dividers and varactor diode and tuning assemblies connected to hybrids **6** and **7** are identical and operate as explained above. The relation between the control voltages applied to the two control terminals, and the radio frequency outputs derived from the two output ports is similar to that described for FIG. **1.** However since FIG. **4** contains **8** diodes as opposed to **2** for FIG. **1** it can operate at a much higher power level.

If intermediate power operation could be tolerated, a single diode could be connected to each of the lower ports of hybrid **6.** This would eliminate the equal power dividers and two of the diodes with their associated tuning stubs and bias supply networks. The single diode and its tuning stub would be connected directly to the hybrid port.

If still higher power is required, further branching could be obtained with additional equal power dividers and associated diodes and tuning stubs.

PREFERRED EMBODIMENT OF THE INVENTION

As mentioned above, while any form of transmission line can be employed, strip line is preferred. FIG. **6** shows how the apparatus of FIG. **5** is set up for stripline fabrication. More specifically, device **17** of FIG. **6** performs the functions of equal power divider **1**, output hybrid **5**, and coupling hybrids **6** and **7** of FIG. **5**, while device **18** of FIG. **6** comprises the two equal power dividers, associated diodes, and tuning stubs illustrated in the lower portion of FIG. **6.**

In the upper section of FIG. **6**, the conductors shown constitute 1.5 mil thick copper on an insulating substrate **19** which is **11** mils thick. The wide conductors represent 50 ohm impedance lines and are 106 mils across whereas the narrow conductors are 52 mils across and represent 70.7 ohm line impedance. The stripline is two sided with the under side pattern (where not obscured by the presence of the upper side pattern) shown in dotted outline. While not shown, the wiring panel is overlaid on both sides with 58 mil thick dielectric slabs and these are in turn covered with aluminum plates that complete the sandwich and provide the usual ground plane conductors. Resistor **2** is a 100 ohm disk. The assembly is held inside an aluminum frame **21** that mounts **7** coaxial connectors. Connector **22** constitutes a 50-ohm input port while connectors **23** and **24** constitute the 50-ohm output ports. Connectors **25** and **26** provide coupling with the shunt multiple varactor device **18** of the lower portion of FIG. **6** by way of coaxial cables **33** and **34.**

A device similar to **18**, not illustrated, would be connected to connectors **27** and **28.**

The two-sided strip line construction of device **17** permits simplified fabrication of the hybrids **5**, **6** and **7** of FIG. **5.** Details of this construction will be understood if reference is had not only to FIG. **6** but also to FIG. **6a.** The latter shows, on a reduced scale, a view from above of the under-side conductors of substrate **19**, which conductors, though partially shown in FIG. **6** in dotted outline, are largely obscured by the presence of the upper-side conductors. Upper-side straight conductor *7a* combines with under side straight conductor *7b* to provide the coupling supplied by hybrid **7.** Similarly, upper-side straight conductor *5a* combines with under-side straight conductor *5b* to provide the coupling supplied by hybrid **5.** As will be seen from FIGS. **6** and *6a*, the under-side pattern, including conductors *7b* and *5b*, interconnects connector **27** and output port **24.**

The coupling supplied by hybrid **6** results from the combination of upper-side conductor **6**a and lower-side conductor **6**b. As will be seen from an examination of FIGS. **6** and **6**a, there is a conductive path from connector **25** to output port **23** which includes under-side straight conductor **6**b, feedthrough connection **20** (which passes through substrate **19**), and upper-side straight conductor **5**a. Since the substrate is only 11 mils thick, it provides the desired coupling between opposing hybrid conducting legs. Each straight leg of the coupled sections **5**, **6**, and **7** is made one quarter wavelength long at the operating frequency, hence the term 90° hybrid.

In the lower portion of FIG. **6**, coaxial connectors **31** and **32** are mounted on aluminum frame **35** which contains a conducting bottom member to act as a ground plane. The conducting pattern, as described above, is 1.5 mil copper but is printed on a 58 mil dielectric substrate **37**. As before the wide lines are of 50-ohms impedance and the narrow lines are of 70.7-ohm impedance. Matched diodes **9** and **10** mount between the terminal ends of equal power divider **8**. Chip capacitor **13**, which is mounted in contact with the ground plane, acts as a *d–c* blocking *r–f* bypass capacitor that electrically connects the diodes in parallel with their respective tuning stubs **11** and **12** which are used to resonate the diode circuits. Quarter wavelength wire section **14** provides isolating inductance for the bias feed and is connected to chip bypass capacitor **15**, as is shown schematically in FIG. **5**. All of the diodes bias connections return to stand off terminal **36** which constitutes the bias control terminal.

Another pair of diodes is operated in a similar structure shown in the left half of device **18** so that device **18** contains 4 diodes and their associated circuits. A shield plate covers the exposed face of the varactor section **18** in FIG. **6** and this element ordinarily mounts in close proximity to device **17**.

EXAMPLE

A variable power divider, patterned after the circuit of FIG. **5**, was constructed as shown in FIGS. **6** and **6**a. Its design frequency was 1.687 GHz. The varactor diodes had cutoff frequencies of about 150 GHz, breakdown voltages of over 50 volts and a zero bias capacitance of about 6 pf. When operated at a 5-watt input level, the maximum insertion loss was only 1.25 dB and the isolation to the off port over 20 dB. The control bias ranged between 13 and 34 volts for effective control. The maximum deviation from equal phase was about 7° and appeared at the extreme attenuation value. The power divider showed excellent reciprocal operation at a receiver frequency of 2.030 GHz.

While the above teaches how to achieve a controlled variable power divider and a specific design example is given, numerous alternatives will occur to persons skilled in the art. For example instead of variable capacitance diodes, variable inductors could be used with the value being varied with a controlled magnetic field. While variable semiconductor junction capacitor diodes are shown, electrostrictive devices could be used. Also other equivalent *r–f* coupling and power distribution devices could be employed. It is intended that the invention be limited only by the following claims:

We claim:

1. An electronically controlled radio frequency power divider having an input port and two output ports comprising:

means connected to said input port for splitting applied radio frequency energy into two branches,

means including a 90° hybrid coupler for combining energy in said two branches, said combining means having two outputs connected to said two output ports the relative magnitudes of which are responsive to the relative phase of said energy in said two branches,

phase shifting means in each of said two branches responsive to electronic control, said phase shifting means including at least one four-terminal 90° hybrid coupler having two terminals connected in series in said branch and having electronically variable reactances connected to the remaining two terminals, and

electronic control means, connected to bias said variable reactances, for differentially varying said phase shifting means continuously to vary the input power division between said two output ports.

2. The device of claim **1** wherein said variable reactances comprise reverse biased semi-conductor diodes connected to said coupler to provide said phase shifting in said branch and biased by said electronic control means.

3. An electronically controlled radio frequency power divider having an input port into which radio frequency energy may be introduced and, under the control of differentially applied control signals, divided differentially between two output ports in such manner that the sum of the powers available from said two output ports is not substantially less than the power introduced at said input port, and the phase difference between the radio frequency energies derived from said output ports remains small over the operating range of said power divider, said power divider comprising:

means connected to said input port for splitting said introduced radio frequency energy and applying it in equal phase to two branch circuits,

a first four-terminal 90° hybrid coupler having two terminals connected in one of said branch circuits and the other two terminals connected to a first plurality of semiconductor diodes for introducing, under the electrical control of a first phase control signal, a phase shift of the radio frequency energy therein, said control signal continuously varying the reverse bias on said first plurality of semiconductor diodes,

a second four-terminal 90° hybrid coupler having two terminals connected in the other of said branch circuits and the other two terminals connected to a second plurality of semiconductor diodes for introducing, under the electrical control of a second phase control signal, a phase shift in said other branch, said second phase control signal continuously varying the reverse bias on said second plurality of semiconductor diodes and being differentially related to said first phase control signal, said two branches having equal phase shifts when said first and said second phase control signals are equal, and

a third four terminal 90° hybrid coupler having: one input terminal connected to receive radio frequency energy from said first four terminal 90° hybrid coupler, a second input terminal connected to receive radio frequency energy from said second four terminal 90° hybrid coupler, one output terminal connected to one of said output ports, and a second output terminal connected to the other of said output ports; said third four terminal 90° hybrid coupler being so constructed and arranged that equal outputs are supplied to said output ports when the radio frequency energies applied to said input terminals are of the same phase, power division between said ports being continuously varied as the phase difference between the energies applied to said hybrid coupler is varied.

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