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Shestag et al.

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[54] **LOW LOSS MODULATION SYSTEM FOR USE WITH ANTENNA ARRAY**

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[73] Assignee: **Emerson Electric Co.**, St. Louis, Mo.

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[21] Appl. No.: **298,555**

[52] **U.S. Cl.** .... **343/106 R,** 343/100 SA

[51] **Int. Cl.** **G01s 1/50**

[58] **Field of Search** .... 343/100 SA, 106 R

[56] **References Cited**

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Primary Examiner—Benjamin A. Borchelt
Assistant Examiner—Richard E. Berger
Attorney, Agent, or Firm—Sokolski, McCormack & Schaap

[57] **ABSTRACT**

An antenna array has paired radiating elements which are modulated in phase opposition. Such modulation is accomplished by means of semiconductor modulator elements, one of such elements being connected to the feed line for each of the paired antenna elements. Modulation signals are fed to the paired semiconductor elements in phase opposition relationship to vary the effective impedance of such elements accordingly, thereby causing the power fed to one of the associated paired antenna elements to increase while that to the associated paired element is decreasing, this in accordance with the modulation signal, the sum of the power radiated by the paired elements remaining constant. Power losses are thereby minimized.

15 Claims, 6 Drawing Figures

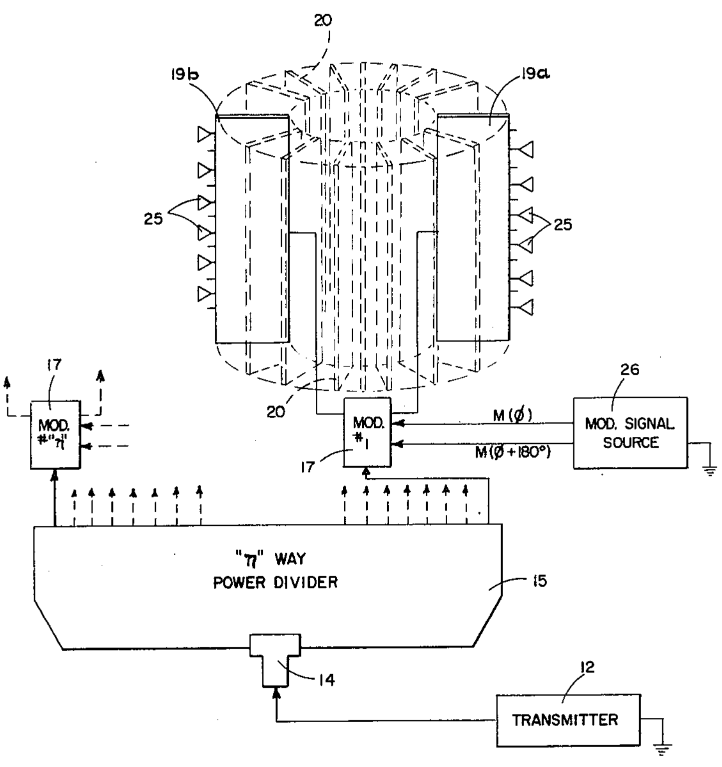
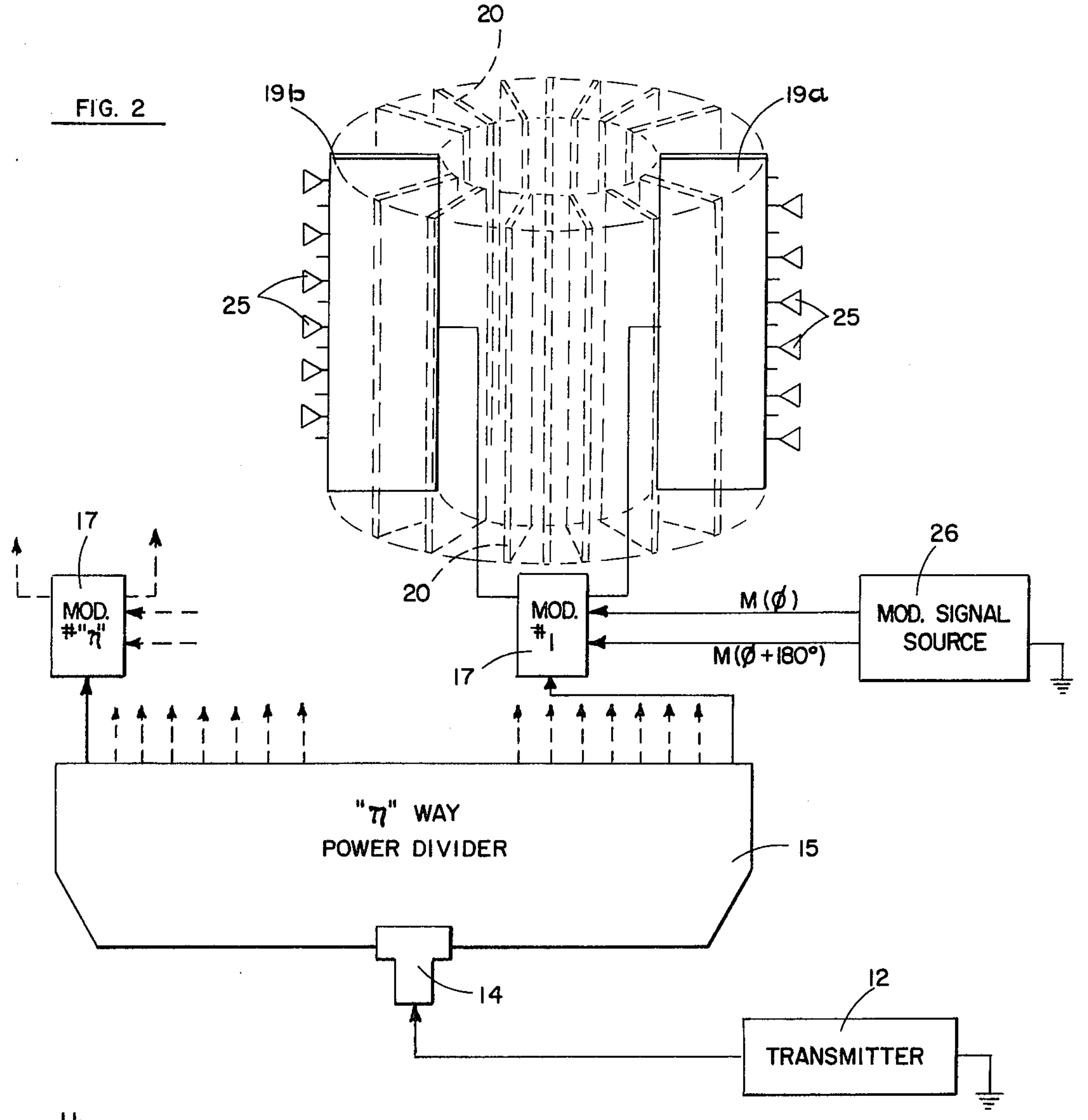


FIG. 2


20
19b
19a
25
25
17
MOD.
#"n"
20
MOD.
#1
17
M(Ø)
M(Ø+180°)
26
MOD. SIGNAL
SOURCE
"n" WAY
POWER DIVIDER
15
14
12
TRANSMITTER

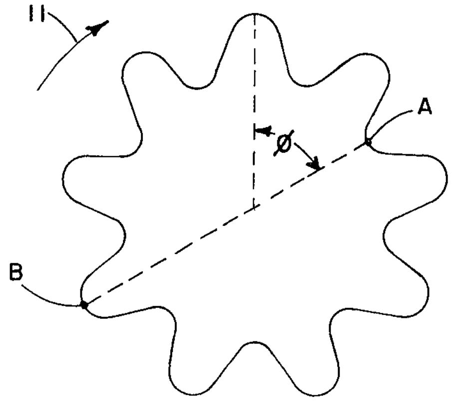

11
A
Ø
B

FIG. 1

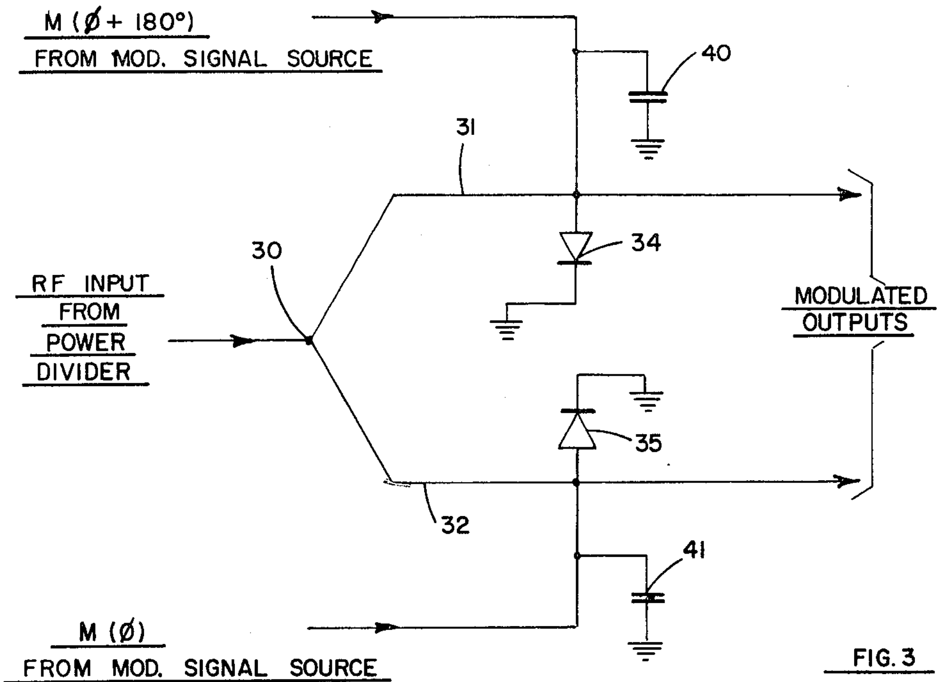

M (Ø + 180°)
FROM MOD. SIGNAL SOURCE
40
31
34
30
RF INPUT
FROM
POWER
DIVIDER
MODULATED
OUTPUTS
35
32
41
M (Ø)
FROM MOD. SIGNAL SOURCE

FIG. 3

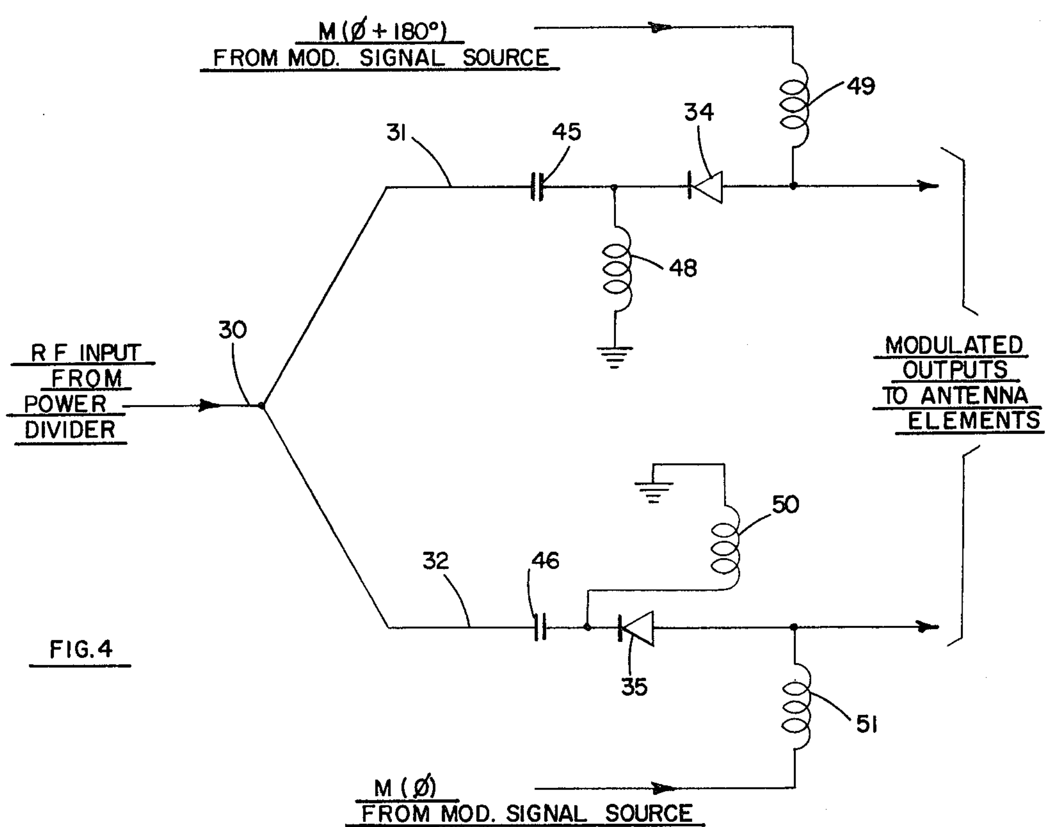

M (Ø + 180°)
FROM MOD. SIGNAL SOURCE
49
34
31
45
48
30
R F INPUT
FROM
POWER
DIVIDER
MODULATED
OUTPUTS
TO ANTENNA
ELEMENTS
50
32
46
35
51
M (Ø)
FROM MOD. SIGNAL SOURCE

FIG. 4

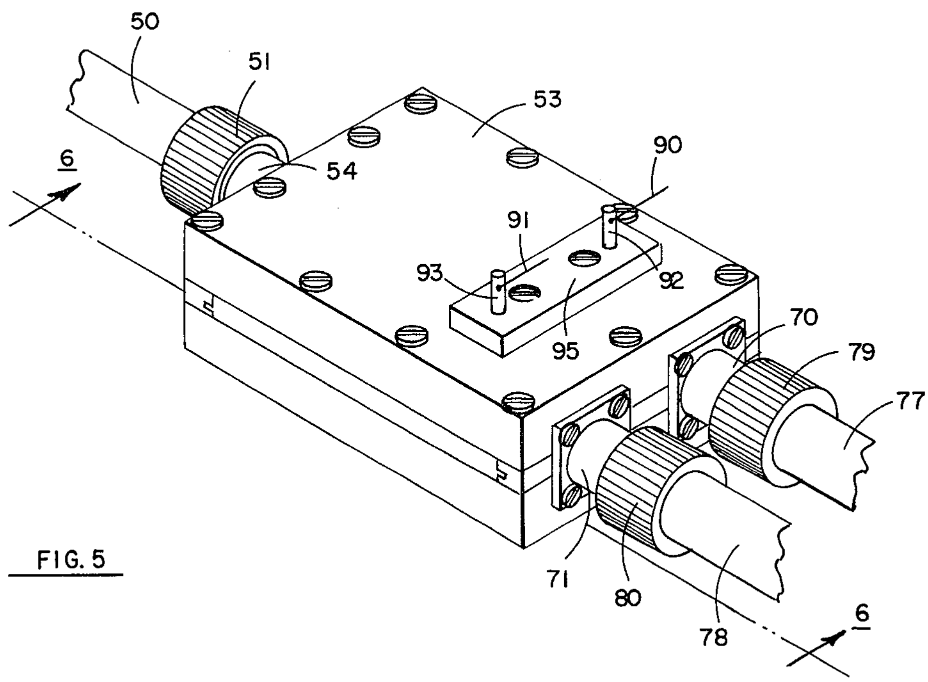

50
51
53
54
6
90
91
93
92
95
70
79
77
71
80
78
6

FIG. 5

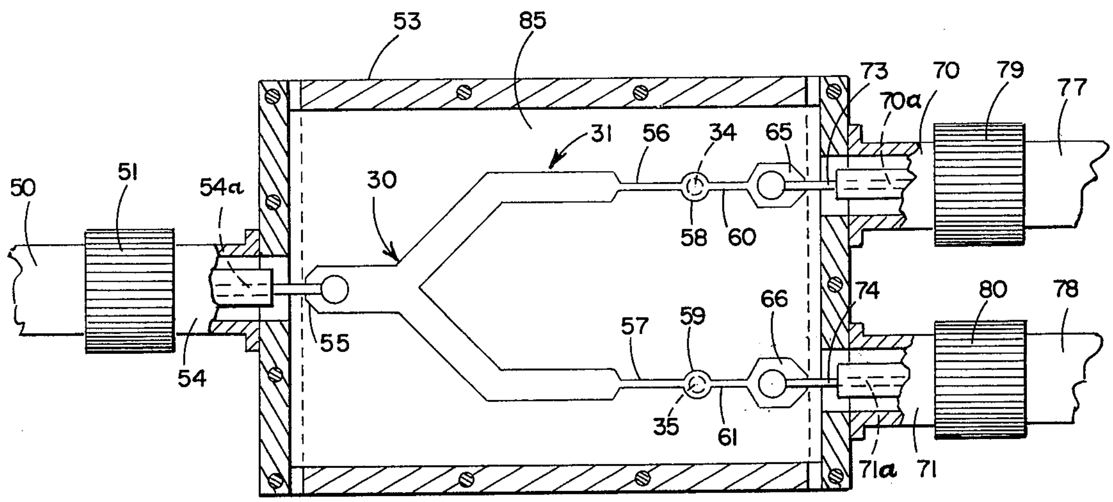

53
85
73
70
79
77
70a
31
56
34
65
50
51
54a
30
58
60
74
80
78
59
66
57
55
54
35
61
71a
71

FIG. 6

LOW LOSS MODULATION SYSTEM FOR USE WITH ANTENNA ARRAY

This invention relates to modulation systems for radio frequency carriers, and more particularly to such a system suitable for efficiently modulating the signals fed to paired antenna elements in phase opposition.

In certain antenna systems such as that utilized with the TACAN radio navigation system, a plurality of antenna elements have signals applied thereto which are modulated in a predetermined phasal relationship. In such systems of the prior art, the desired modulation has been achieved in several manners, including both mechanically implemented drive mechanisms and fully electronic techniques such as described in U.S. Pat. No. 3,474,446 issued Oct. 21, 1969. The electronic approach to modulation appears to have distinct advantage in its inherent higher reliability and more accurate operation. Electronic modulating systems such as described in the aforementioned U.S. Pat. No. 3,474,446, however, have the disadvantage in that modulation is accomplished by placing a variable loss in each radio frequency line in accordance with the modulation pattern, thus dissipating a substantial part of the input power (typically one half of such power). Such power loss is undesirable, not only in view of the inefficiency of its operation, but also in view of the heat energy generated thereby which tends to lessen the useful life of certain of the system components.

The system of this invention overcomes the aforementioned shortcomings of prior art electronic modulation systems by minimizing the power losses involved in modulating the RF carrier, bringing such losses to a small fraction of their prior value. This end result is achieved without detracting in any way from the radiation pattern of the system. Further, the modulation system of this invention is relatively simple and economical in its implementation.

It is therefore an object of this invention to improve the efficiency of operation of a radio frequency transmission system utilizing an antenna array having elements modulated in a predetermined phase relationship.

It is a further object of this invention to provide means for modulating radio frequency signals fed to paired elements of an antenna array with a minimum power loss.

It is still a further object of this invention to minimize the heat dissipated in a radio frequency modulation system for a radiating system of the type described.

Other objects of this invention will become apparent as the description proceeds in connection with the accompanying drawings, of which:

FIG. 1 is a diagram illustrating a typical radiation pattern for a system with which the device of the invention may be utilized;

FIG. 2 is a schematic drawing illustrating the system of the invention incorporated into an omnidirectional power radiating equipment;

FIG. 3 is a schematic drawing illustrating one embodiment of a modular unit of the system of the invention;

FIG. 4 is a schematic drawing illustrating a second embodiment of a modulator unit of the system of the invention;

FIG. 5 is a perspective pictorial view of a modulator unit of the system of the invention; and

FIG. 6 is a sectional view taken along the plane indicated by 6—6 of FIG 5.

In brief, the system of the invention is as follows: A radio frequency radiating system has a plurality of antenna radiating elements which receive radio frequency energy modulated in a predetermined manner to achieve a desired radiation pattern. In the radiation system with which the present invention is compatible, there are pairs of radiation elements which require modulated RF inputs in phase opposition to each other. A separate semiconductor modulator element which may comprise a diode is connected to the feed line for each of the paired radiating elements. In the case of one embodiment, such semiconductor elements are connected in shunt with each of such lines and in a second embodiment, these elements are connected in series with such lines. A modulation signal of arbitrary but periodic waveshape is fed to each of the semiconductor modulator elements, the signal being fed to one element of each pair being in phase opposition to that fed to the other paired element and at the same amplitude thereas. This acts to vary the effective conductivity of the diodes in inverse relationship to each other. As the power fed to the lines for the paired radiating elements is split off from a common power line, this inverse variation in the effective impedances of the two diodes causes the power fed to the paired antenna elements to be varied between these elements accordingly, with the power load on the common input line remaining constant. The modulation system of the invention thus operates to divide the power between the paired antenna elements in response to the modulation signals, without any dissipation of this energy other than the losses normally involved in the passage of current through the components. This is as of course contrasted with prior art systems where in effecting the desired modulation of the RF energy, a considerable portion of this energy is dissipated in the modulation system.

It is to be noted that the modulation system of this invention, while particularly suitable for utilization in a system having a cylindrical radiation pattern such as TACAN, can also be utilized to advantage with any radiation system utilizing one or more pairs of radiating elements, the power outputs of which must be modulated in phase opposition relationship to achieve the desired radiation pattern.

Referring now to FIG 1, a typical radiation pattern for a TACAN antenna, with which the system of the invention can be employed, is illustrated. As can be seen, this illustrative radiation pattern has odd symmetry, having a nine-lobe rotating pattern, each of these lobes varying in amplitude sinusoidally in accordance with the modulation signal. This type of pattern can be generated with a cylindrical antenna of the type utilized in most TACAN systems. This type of pattern is such that while the signals continually vary, the sum of the signals at any two diametrically opposite points in the radiation pattern, such as for example points "A" and "B" indicated in FIG. 1 remains constant. It is to be noted that while the particular points "A" and "B," which were selected for illustration happen to lie (at least for the moment) at positive and negative peak points of the sinusoidal radiation pattern, the sum of any two other diametrically opposite points, regardless of where they lie in the pattern, is likewise constant. The modulation pattern effectively rotates as indicated by arrow 11 as a function of angle, ϕ. Thus, to express the constant sum relationship of diametrically opposite points on the radiation pattern, the following equation can be used:

$$[M(\phi)-1]=[1-M(\phi+180°)] \quad (1)$$

where "M" represents the periodic modulation signal which typically is sinusoidal.

Referring now to FIG 2, the incorporation of the modulation system of the invention into a TACAN transmission system is illustrated. Radio frequency energy at the carrier frequency of the system is fed from RF transmitter 12 through coupler 14 to power divider 15. Power divider 15 which may comprise a strip line divider, divides the power "n" ways, the number "n" representing the number of paired antenna elements in the system, each such pair of elements having a single modulator unit. Thus, there are outputs from power divider 15 to each of modulator units 17, there being "n" such units.

Split outputs are fed from the 1 modulator unit 17 to paired antenna elements 19*a* and 19*b* which are located diametrically opposite each other. Similarly, each of the other modulator units 17 provides outputs to a separate oppositely positioned pair of antenna elements 20, some of such elements being shown with phantom lines. Typically, the radiation elements 19*a* and 19*b* of a TACAN antenna would include a plurality of vertically stacked tuned cavities 25, which have radiating slots formed therein, the tuned cavities being fed from a common feedline connected to the associated output of the modulator. As this particular antenna per se forms no part of the present invention, it shall not be further described here. It is also to be noted that the particular antenna shown is only for illustrative purposes, and that the system of the invention could be used to equal advantage with other types of antennas using paired radiation elements from which phase opposed signals are radiated. A separate pair of modulation signals is fed from modulation signal source 26 to each of modulator units 17. The signals of each such pair are in phase opposition relationship to each other. The signals of each pair, of course, have phase relationships with the signals of each other pair in accordance with the desired radiation pattern, such as, for example that shown in FIG 1.

Referring now to FIG. 3, a schematic diagram of one embodiment of the modulator of the system of the invention is illustrated. Radio frequency power is fed from power divider 15 (FIG. 1) to T power splitter 30, which evenly splits the power fed to lines 31 and 32. The T power splitter and lines 31 and 32 may be formed by strip lines as illustrated in FIG. 6 and as to be explained further on in the specification. Connected between each of lines 31 and 32 and the ground or common connection for the RF and modulation systems are diodes 34 and 35 respectively. Diodes 34 and 35 may be of the PIN silicon type.

A periodic modulation signal, $M(\phi)$ which may be sinusoidal is fed to the anode of diode 35 while a modulation signal, $M(\phi+180°)$, which is in phase opposition with the last mentioned modulation signal, is fed to the anode of diode 34. RF filtering to keep radio frequency energy from entering the modulation signal source is provided by means of RF filter capacitors 40 and 41. As the modulation signals applied to diodes 34 and 35 vary, they effectively vary the current flow through these diodes and thus the effective shunting impedance presented by the diodes across lines 31 and 32. These periodic effective variations in line impedances in inverse manner for lines 31 and 32 causes a likewise shifting of the power distribution between the two lines. Due to the inverse relationship between the variations in the effective impedances of diode 34 and diode 35, the sum of their impedances remains constant and the sum of the power fed to line 31 and the power fed to line 32 likewise remains constant, this constant sum being equal of course to the power fed to power splitter 30. Thus, it can be seen the RF power on line 31 is made to vary periodically and in inverse fashion with that on line 32 without the dissipation of any RF energy except for the small losses normally to be expected in the components forming the modulator.

Referring now to FIG. 4, a second embodiment of the modulator of the invention is schematically illustrated. This embodiment differs from the first in that the modulation diodes 34 and 35 are connected in series with lines 31 and 32 respectively, rather than being connected in shunt therewith as for the first embodiment. Capacitors 45 and 46 act as blocking capacitors to prevent the audio signals from feeding into the RF power source. RF chokes 48 and 50 provide a grounding path from diodes 34 and 35 respectively for the audio signals fed thereto, but block the passage of the RF signals to ground. RF chokes 49 and 51 prevent the RF signals from entering the modulation signal source. In this embodiment, the effective series impedances of diodes 34 and 35 are inversely varied by the modulation signals, causing power fed to the paired antenna elements to be varied accordingly, thus achieving the same resultant operation as in the first embodiment.

Referring now to FIGS. 5 and 6, a specific implementation of the modulating units is shown. Radio frequency input signals to the unit are fed thereto from cable 50 by means of coaxial connector 51 which is threadably connected to connector 54. The shield portion of connector 54 which carries the ground connection is attached to the wall of metal housing 53 which provides a shielding for the modulator. The inner conductor 54a of connector 54 is soldered to the end of the T power splitter 30. Strip lines 31 and 32 receive the split outputs from the power splitter and include impedance matching sections 56 and 57 respectively which terminate into pads 58 and 59. Diodes 34 and 35 are connected in the manners indicated in the schematic drawings for each embodiment to pads 58 and 59 respectively. Pads 58 and 59 are connected by means of line sections 60 and 61 to terminal pads 65 and 66 respectively.

The central pins 70a and 71a of coaxial connectors 70 and 71 are soldered to connecting links 73 and 74 respectively, which in turn are soldered to pads 65 and 66. Coaxial connectors 70 and 71 are attached to the wall of housing 53 with the coaxial cables 77 and 78 which carry the modulated outputs to the antenna elements being connected to coaxial connectors 70 and 71 by means of connectors 79 and 80 respectively. T power splitter 30, strip lines 31 and 32, pads 58, 59, 65 and 66 and connecting lines 60 and 61 are all of highly electrically conductive material which may be placed on dielectric substrate board 85 by etched circuit techniques. The electrical lengths of the lines running from the forked junction of T power splitter 30 to each of pads **65** and **66** should be equal to each other. In a typical design the effective electrical lengths of these two lines is substantially a quarter wave length at the radio frequency of the transmitted signal. The modulation signals for the diodes are fed from lines **90** and **91** to posts **92** and **93** to which these lines are respectively attached. Posts **92** and **93** pass through insulator block **95** mounted in the top of housing **53** and are connected to diodes **34** and **35** in the manner indicated in FIG. **3** or FIG. **4** as the case may be.

The modulation system of this invention thus provides a highly efficient means for modulating signals fed to a pair of antenna elements where these elements are to be modulated in phase opposition. By splitting the power from a common power source and then dividing this power between paired antenna elements in accordance with inversely related periodic functions, high efficiency is attained, and the dissipation of energy is minimized.

While this invention has been described and illustrated in detail, it is to be clearly understood that this is intended by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of this invention being limited only by the terms of the following claims:

We claim:

1. In a modulation system for providing radio frequency energy to a pair of radiating elements, the power of which varies in phase opposition relationship in accordance with a predetermined periodic function comprising:

means for generating radio frequency energy,

power splitter means for dividing said energy into two portions,

a pair of power lines connected to receive the output of said power splitter means, each of said lines receiving one of said divided portions,

means for modulating the radio frequency energy on each of said power lines with a separate signal in accordance with said periodic function, the modulating signal fed to one of said lines being in phase opposition relationship to that fed to the other of said lines, and

means for feeding the modulated signal from each of said power lines to a separate one of said antenna elements whereby varying power signals are fed to said antenna elements, said power signals being in phase opposition and having a constant sum.

2. The system of claim **1** wherein said periodic function is a sine wave and the power is divided by said power splitter into substantially equal portions.

3. The system of claim **1** wherein said means for modulating the energy on said lines comprises a semiconductor modulator element connected to each of said lines and means for providing signals to said elements to vary the effective impedances thereof in inverse relationship in accordance with said periodic function.

4. The system of claim **3** wherein said modulator elements comprise a diode connected in shunt with each of said lines.

5. The device of claim **3** wherein said modulator elements comprise a diode connected in series with each of said lines.

6. The device of claim **1** wherein said power splitter means comprises a strip line T power splitter having a pair of legs, each of said legs carrying half of the divided power, said power lines each impedance matching one of said legs to a separate one of said modulating means.

7. The device of claim **6** wherein said modulating means comprises a pair of diodes, each of said diodes being connected to a separate one of said power lines, and means for providing a separate modulation signal to each of said diodes.

8. The device of claim **7** wherein said diodes are connected in shunt with said lines.

9. The device of claim **7** wherein said diodes are connected in series with said lines.

10. A modulator for modulating the power fed from a radio frequency source to a pair of radiating elements in accordance with a periodic function comprising:

means for dividing the power from said source into substantially equal portions,

means for coupling the divided power portions to separate lines,

means for modulating the power on each of said lines in accordance with said periodic function, the power on one of said lines being modulated in inverse relationship to that on the other of said lines, and

means for feeding the modulated power on each of said lines to a separate one of said pair of radiating elements, whereby the power fed to one of said radiating elements varies inversely to that fed to the other of said radiating elements, the sum of the power fed to both of said elements remaining constant.

11. The modulator of claim **10** wherein said modulating means comprises a separate semi-conductor element connected in shunt with each of said lines.

12. The modulator of claim **10** wherein said modulating means comprises a separate semi-conductor element connected in series with each of said lines.

13. In combination,

a source of radio frequency power,

a modulation signal source,

modulator means having a single input terminal for receiving the output of said source and a pair of output terminals, said modulator means coupling a portion of the power at said input terminal to one of said output terminals and the remaining power at said input terminal to the other of said output terminals, said modulator means further including means responsive to the output of said modulation signal source for modulating the power fed to said output terminals in accordance with a periodic function, the power fed to one of said output terminals being in inverse relationship to the power fed to the other of said output terminals, whereby the power at said input terminal is equal to the sum of the powers at said output terminals and is substantially independent of the variations thereof, and

a pair of radiator elements, each of said elements receiving power from one of said output terminals.

14. The combination of claim **13** wherein said modulator means comprises a semiconductor device connected in shunt with each of said output terminals.

15. The combination of claim **13** wherein said modulator means comprises a semiconductor device connected in series between each of said output terminals and said input terminal.

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