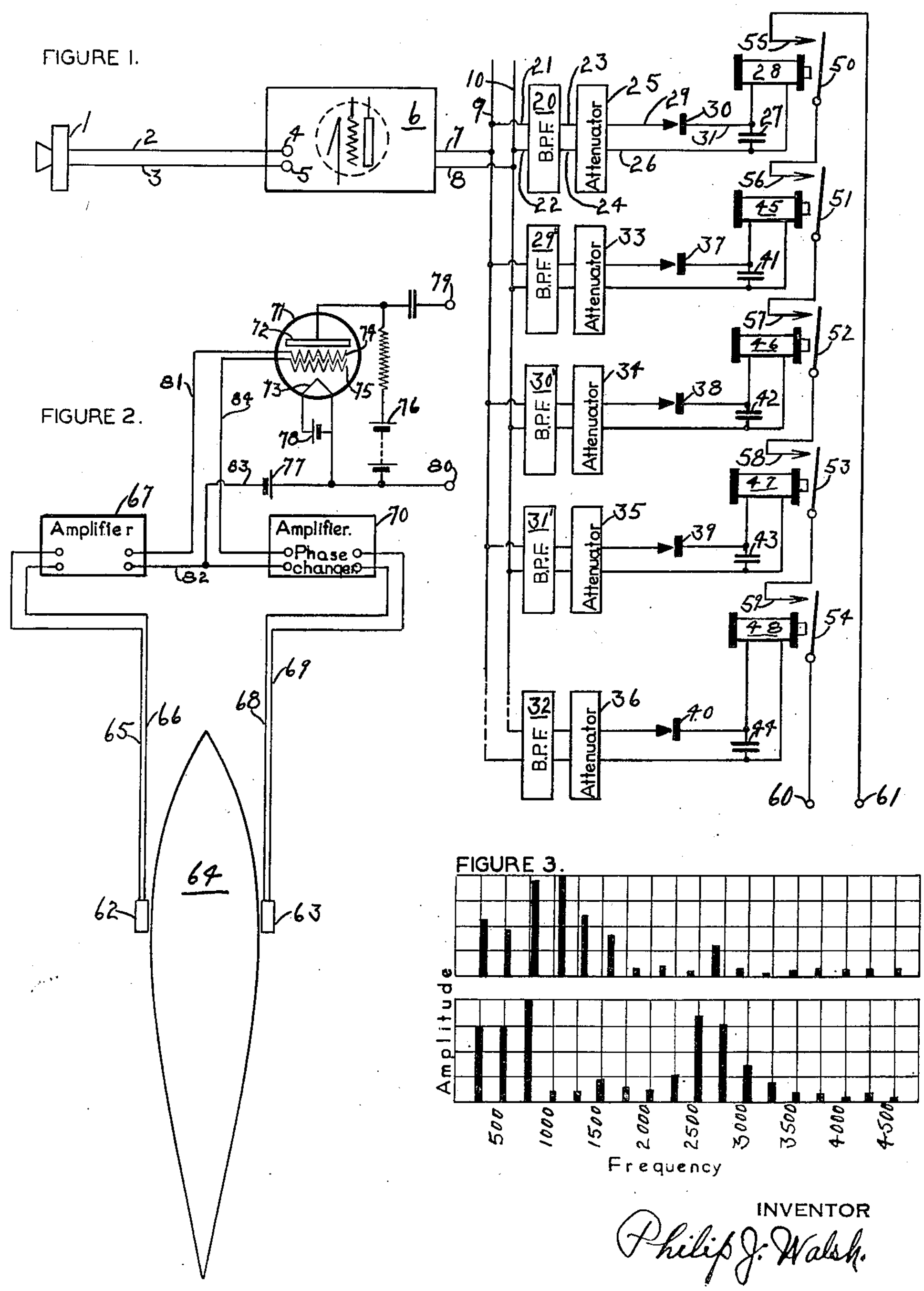
Feb. 6, 1945. P. J. WALSH 2,368,953

ELECTRIC CONTROL SYSTEM

Filed Aug. 26, 1940 2 Sheets-Sheet 1



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2 Sheets-Sheet 2

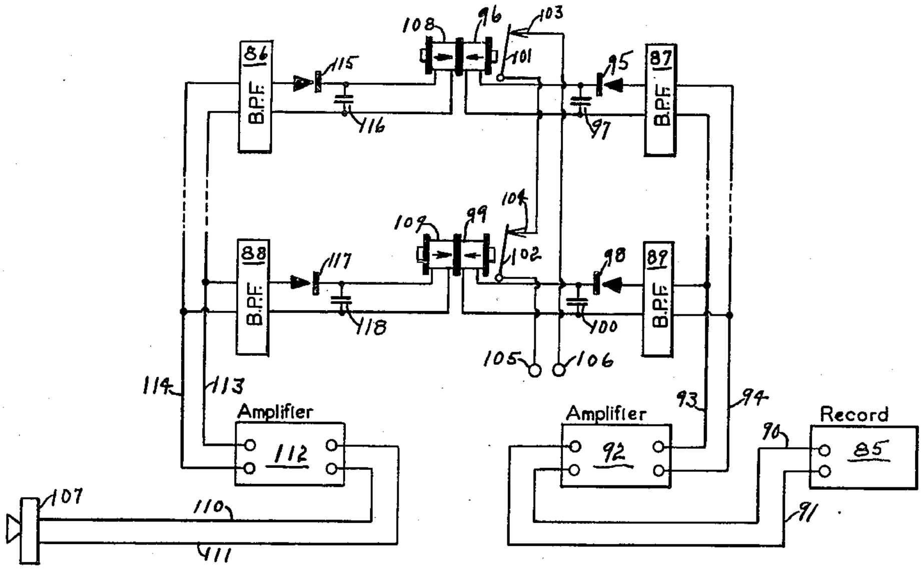

FIGURE 4.

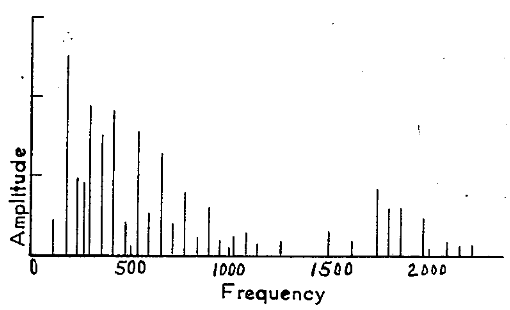

FIGURE 5.

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ELECTRIC CONTROL SYSTEM

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3 Claims. (Cl. 177—352)

This invention relates to a control system actuated by sound waves.

It is one of the objects of my invention to provide a selective control system which can discriminate sharply between desired and undesired sound waves.

It is another object of my invention to provide a sound wave operated control system for national defense purposes.

It is well known that the characteristic noise made by the driving engine, propellers and air exhaust of the under-sea torpedo can be heard by means of hydrophones at a distance of several miles from the moving torpedo. It is also understood that if a small depth bomb is exploded under water within a radius of fifty feet of the moving torpedo that such a shock will turn it off its course, crush its thin wall, break and stop the delicate driving machinery, or trip its firing fuse mechanism and cause it to explode and destroy itself. That is, the depth bomb does not have to strike the torpedo but merely explode in the mater near it. It is a simple matter to mount a number of automatic depth bomb throwing guns on the deck of a ship and arrange them electrically so that when a switch is closed they all fire simultaneously and throw ten or more streamlined depth bombs into the water on each side of the ship and at a distance of about fifty yards therefrom.

These depth bombs can be constructed so that all of them explode simultaneously at a depth of about twenty feet below the surface of the water. If the guns are arranged to throw the depth bombs into the water, along a line parallel to a line drawn from bow to stern on the ship, and spaced about fifty feet apart, the power waves generated by the explosions will merge and form a protective "wall around the ship" directly in front of the advancing torpedo to destroy it at a safe distance from its target. All this, of course, depends upon closing the firing switch at the correct instant of time.

It is accordingly one of the objects of this invention to provide an automatic control system that will stay on guard continuously and close the fire control switch at the correct instant of time.

My invention possesses many other advantages and has other objects which may be more easily apparent from a consideration of one embodiment of my invention. For this purpose, I have shown a few forms in the drawings accompanying and forming part of the present specification. I shall now proceed to describe these forms in detail, which illustrate the general principles of my invention; but it is to be understood that this detailed description is not to be taken in a limiting sense, since the scope of my invention is best defined by the appended claims.

Referring to the drawings:

Figure 1 is a wiring diagram of one form of my invention;

Figure 2 is a wiring diagram of a further modification;

Figure 3 and Figure 5 are drawings for facilitating explanation of the invention;

Figure 4 is a wiring diagram of a still further modification.

The charts shown in Figures 3 and 5 can be drawn directly from the photographic record produced by an instrument known as the "Electrical harmonic analyzer." This instrument is described on page 88 of the textbook, "Speech and hearing," by Harvey Fletcher, Ph. D., and published by D. Van Nostrand Co., New York, as follows:

"In using this instrument to analyze sound waves, a condenser transmitter is used to transfer the acoustic wave into an electrical wave which is a faithful copy of the original. This electrical wave is then sent into a selective network, the essential feature of which is a sharply tuned circuit whose frequency of tuning is controlled by varying its capacity in small steps by means of a pneumatic apparatus similar to that used in a player piano. Maximum responses of the circuit occur at frequencies of tuning which coincide with the frequencies of the components of the complex wave. An automatic photographic recorder registers as a permanent record the amount of current getting through the tuned circuit at each frequency. From this record the relative amplitudes of the components of the complex wave are readily determined."

In Figure 3 the upper chart is the acoustic spectrum of the vowel sound "O" as in "ton," pitch 268, while the lower chart is a spectrum of the vowel sound "A" as in "tape," pitch 250. These charts show that these sounds contain 17 different frequency bands for "O" and 18 for "A." Also they show how the total energy is distributed over these bands. The chart shown in Figure 5 is the acoustic spectrum of telephone line noise. All the components except one are harmonics of a 60 cycle fundamental and produce a hum like a musical tone in a telephone receiver.

It is well known that a single musical note contains more than one frequency. The lowest frequency is called the fundamental which usually determines the pitch and the other component frequencies are called harmonics, each one being a simple multiple of the fundamental frequency. When no definite pitch can be assigned to sounds they are usually classified as "noise."

Referring to Figure 1, the pick up device 1, which can be a condenser transmitter, hydrophone, microphone or any other kind of device which translates sound waves into electrical waves, is connected by means of conductors 2 and 3 to the input terminals 4 and 5 of the multistage distortionless vacuum tube amplifier 6. The output circuit of amplifier 6 is connected by means of conductors 7 and 8 to the bus bars 9 and 10 which can be made of any length as indicated by the dotted lines, to accommodate any predetermined number of band pass filters such as 20. The input side of the band pass filter 20 is connected by means of conductors 21 and 22 to the bus bars 9 and 10, and its output side is connected by means of conductors 23 and 24 to the input side of the variable distortionless attenuator 25. The output side of attenuator 25 is connected by means of conductor 26 to one side of condenser 27 and to one end of the relay coil 28, and by means of conductor 29 to one side of the rectifier 30. The other side of the rectifier 30 is connected by conductor 31 to the other side of condenser 27 and the other end of relay coil 28. It is seen that there are five groups exactly the same as this. That is, the band pass filters 29', 30', 31' and 32 have their input side connected to the bus bars 9 and 10 and their output side connected to the attenuators 33, 34, 35 and 36 respectively. The output sides of the attenuators are connected through the rectifiers 37, 38, 39 and 40 to the condensers 41, 42, 43 and 44, and the relay coils 45, 46, 47 and 48.

As the description proceeds I will explain how a complex wave picked up by the translating device 1 is amplified by the amplifier 6, applied to the bus bars 9 and 10, separated into its component frequency bands by the band pass filters, the components applied to the attenuators which absorb a predetermined amount of energy, the alternating current output from the attenuators changed to direct current by the rectifiers and filter condensers and passed through the relay coils to close the relay contactors which form the control circuit.

In order to adjust the apparatus to respond to a desired sound, as for example, the lower chart shown in Figure 3, which shows 18 bars of different amplitude, we proceed as follows: The band pass filter 20 is tuned to pass the narrow band of frequencies indicated by the first bar on the graph including 250 cycles, the filter 29' is tuned to the frequency of the second bar on the graph including 500 cycles, the filter 30' is tuned to the frequency indicated by the third bar and the filter 31' is tuned to the frequency indicated by the fourth bar on the graph. This process is continued, there being as many filters as there are bars on the graph, until we come to the last bar to which the filter 32 is tuned. The adjustment of the attenuators is determined by the amplitude of the bars. The attenuators 25, 33 and 34 are adjusted to give maximum loss since the first three bars on the graph indicate relatively high energy while the attenuator 35 is adjusted to its low loss position, since the fourth bar is relatively small. This process is continued, there being one attenuator for each bar on the graph, until we come to the attenuator 36 which is adjusted to its low loss position as indicated by the last bar on the graph. Since all the relays and their rectifier circuits are identical, any one of them will respond when the current flowing through its coil reaches a given value.

When sound waves represented by the spectrum shown in this chart are picked up by the translating device 1, amplified by the amplifier 6, and applied to the bus bars 9 and 10 as alternating currents, currents at a frequency to which the band pass filter 20 is tuned pass through the attenuator 25, while currents at other frequencies are rejected. Some of this current is lost in the attenuator resistors and the rest passes on over conductor 29, through rectifier 30 to filter condenser 27, relay coil 28 and back over line 26 to the resistance network of attenuator 25. Current cannot flow through this circuit in the opposite direction due to the action of rectifier 30. Currents flow through all the filter-attenuator-rectifier-relay units simultaneously, each band pass filter rejects all frequencies above and below the band to which it is tuned allowing only those currents at the frequency to which it is tuned to pass on through the connected attenuator, rectifier and relay coil. When the current flowing through the magnet coils, such as, 28, 45, 46, 47 and 48 reaches a predetermined value the contactors 50, 51, 52, 53 and 54, which are held in the position shown by a spring, are drawn over into contact with the contactors 55, 56, 57, 58 and 59 respectively. Thus the control circuit between the terminals 60 and 61 is closed. It is seen that all the contactors must be closed in order to close the circuit between terminals 60 and 61 and that any one of these contactors can open this circuit. In other words, the terminals 60 and 61 are the terminals of a switch which closes whenever sound waves of predetermined characteristics are picked up by the translating device 1, and opens when these waves die out. It is obvious that this switch would not be closed if the translating device 1 picked up a sound wave having the characteristics shown in the upper chart of Figure 3, since the bars differ in frequency and in amplitude.

While the second bar in the lower graph represents a band frequency very close to, and partly overlapping the band frequency indicated by the second bar in the upper graph, there is not enough energy in this upper frequency band to overcome the high loss in the attenuator 33 and close the relay contactors 51 and 56. It thus comes about that the selectivity, or ability to discriminate between desired and undesired sound waves, is obtained by the combined action of the attenuators and filters and not by the filters alone. Of course, complex undesired sound waves may contain a number of frequency bands identical to those of the desired wave, and therefore, would close some of the relay contactors, but since all the individual contactors must close in order to close the circuit between terminals 60 and 61, the selectivity factor is very high indeed.

When the device must operate near a source of continuous noise, such as that generated by running machinery, a great deal of this interference can be eliminated by employing the form of input arrangement shown in Figure 2. Referring to Figure 2, two translating devices 62 and 63 are shown mounted on opposite sides of the large baffle 64 which can be made of any convenient shape and may be a stone wall, building, or the hull of a ship the outline of which is shown in the drawings. To facilitate explanation of this form of the invention, let us assume that the baffle 64 is the hull of a ship and that the pick up devices 62 and 63 are hydrophones mounted on rubber supports attached to the hull 64 below the surface of the water, so that the sound waves that affect the hydrophones pass through the water and not over the mounting supports. The ship's driving engines and propeller generate continuous noise in the water at one end of the ship—the stern. Since this noise is generated at one end of the ship both hydrophones receive these waves simultaneously and translate them into electrical waves. The electrical waves generated by hydrophone 62 pass over the conductors 65 and 66 to the input terminals of the amplifier 67; those generated by the hydrophone 63 pass over conductors 68 and 69 to the input terminals of the amplifier and phase changer 70. The electronic emission device 71 having the anode 72, cathode 73 and the grids 74 and 75 is of the coplanar type having one of the grids wound between the meshes of the other grid. The plate battery 76 maintains the anode 72 at a potential positive relative to the cathode 73, the battery 77 maintains a negative bias on both grids and the battery 78 furnishes current to heat the cathode 73. Since the operation of such devices is now well understood further detailing thereof is unessential except to point out that when electrical impulses are applied to either grid and cathode, they reappear across the output terminals 79 and 80 as amplified impulses; but no impulses will appear across the terminals 79 and 80 when electrical impulses are applied to one of the grids and cathode while impulses 180 degrees out of phase therewith, but otherwise identical, are applied to the other grid and cathode. This is obvious since, under such circumstances, one of the grids would tend to increase the space impedance of the device 71 while the other grid tends to decrease it by the same amount.

I will now explain how the waves generated by hydrophones 62 and 63 due to undesired noise are applied to the grid 74, and simultaneously to the grid 75 exactly 180 degrees out of phase therewith, so that they do not appear across the terminals 79 and 80 while the desired waves are amplified and do appear across these terminals.

The grid 74 is connected by conductor 81 to one of the output terminals of amplifier 67 and the other output terminal is connected by conductors 82 and 83 through the bias battery 77 to the cathode 73. Grid 75 is connected by conductor 84 to one of the output terminals of the amplifier and phase changer 70 while the other output terminal is connected by the common conductors 82 and 83 through the bias battery 77 to the cathode 73. By adjusting the gain control and phase changer of amplifier 70 the potential fluctuations applied to the grid 75 and cathode 73 due to undesired noise are made equal to, but 180 degrees out of phase with those applied to the grid 74 and cathode 73 by amplifier 67. Thus sound waves generated near the stern of the ship by the propelling machinery are balanced out, but waves picked up by either one of the hydrophones 62 or 63 from any other source are applied to either one of the grids 74 and 75 and appear across the terminals 79 and 80. Also a source of sound at any position other than the stern of the ship will affect one hydrophone to a greater extent than the other, and therefore, one of the grids 74 or 75 will be affected to a greater extent than the other and these impulses will appear across the terminals 79 and 80. From here on the apparatus is the same as that shown in Figure 1. As a matter of fact the wires 2 and 3 can be disconnected from the terminals 4 and 5 and terminals 79 and 80 connected through the proper impedance matching device to the terminals 4 and 5.

In the form of the invention shown in Figure 4, the desired sound is first recorded on a sound film or phonograph record. This record is then analyzed by means of the "Electrical harmonic analyzer" and a chart drawn such as those shown in Figures 5 and 3. The record is then placed in the reproducing device 85 where the recorded sound waves are converted into electrical waves in a well understood manner, the record running continuously, reproducing the recording over and over again. One reason for thus analyzing the record is to determine the overall frequency range and the number of pairs of filters required. The reproducing device, for example, may be a band of sound record film driven as a continuous belt around pulleys, with a photoelectric pickup, such as described on pages 6 to 45 of the Electrical Engineers Handbook, volume 5, by Harold Pender, published by John Wiley and Son, Inc., New York. By means of the chart the band pass filters 86, 87, 88 and 89 are tuned to correspond to the frequency bars on the chart as has been described in connection with Figure 1. These filters are adjusted in pairs, that is, the filters 86 and 87 are tuned to one band frequency as indicated by a bar on the chart, while the filters 88 and 89 are tuned to a different band as indicated by another bar on the chart, etc., there being a pair of band pass filters for each bar on the chart.

The electrical impulses from the reproducer 85 pass over the conductors 90 and 91 to the input terminals of the amplifier 92 where they are amplified and reappear across the output terminals to which the bus bars 93 and 94 are connected. The bus bars can be made of any length as indicated by the dotted lines to accommodate any number of band pass filter units. The output currents from the amplifier 92 flow over the bus bars 93 and 94, and those at a frequency to which the filter 87 is tuned pass through it into the rectifier-relay-condenser circuit 95, 96, 97; while the currents at a frequency to which the filter 89 is tuned pass through it into the rectifier-relay-condenser circuit 98, 99 and 100. This direct current flows through the magnet coils and draws the contactors 101 and 102 over to the iron cores of the coils and away from the contactors 103 and 104 respectively, where they were held by a spring, and thus opens the control switch circuit between the terminals 105 and 106.

If an undesired sound is picked up by the translating device 107 and contains a frequency band to which the filter 86 is tuned, the contactor 101 will not return to the position shown in the drawings unless the current flowing through the rectifier 115 and magnet coil 108 is at least equal in value to that flowing through the rectifier 95 and magnet coil 96.

When desired sound waves affect the translating device 107 they are converted into electrical waves which flow over conductors 110 and 111 to the input terminals of amplifier 112. The amplification of amplifier 112 is made such that the amplified waves impressed on the bus bars 113 and 114 are identical to those impressed on the bus bars 93 and 94 by the record 85. Since the filters 86 and 87 are tuned to the same frequency and the circuit elements connected to each filter are equal in value, equal and opposite currents flow through the magnet coils 108 and 96, and the contactor 101 remains in the position shown in the drawings. The same is true of any number of pairs of units connected to the bus bars like the two pairs shown in the drawings.

In order to adjust this form of the invention to act as fire-control of a battery of automatic depth bomb throwing guns, we proceed as follows: The ship in which the apparatus is installed is taken out on the range and the engines stopped for a recording of the sound generated by a standard moving torpedo, preferably one constructed along the lines of those employed by the enemy power. The torpedo can be fired from a deck tube of a destroyer anchored at a predetermined distance from the ship and along a line parallel to the ship's side at a given distance therefrom. A chart is made from this recording and the band pass filters adjusted in the usual way. The ship is then given a full speed ahead run over the range and when it comes to the spot where the first recording was made, the anchored destroyer fires the torpedo (which was recovered after the first shot) again over the same line and a recording of the noise made by the ship's propelling machinery plus that generated by the torpedo is made. This record is then placed in the reproducer 85.

When the ship is at sea the hydrophone 107 is affected by the noise made by the ship's propelling machinery and applies these waves to the amplifier 112, but since this noise is recorded, the reproducing device 85 applies similar waves to the amplifier 92, so that, if this noise contains any frequencies that can get through any of the filters, these are balanced out in the differential relays leaving only those currents, produced by the recording of the noise made by the torpedo, flowing through the coils, such as 96, and holding open the contactors, such as 101. When the hydrophone 107 picks up the noise made by a torpedo fired at the ship, the intensity of the received sound gradually builds up as the torpedo advances toward the ship, causing the direct current flowing through the coils, such as 108, to gradually build up, and when this current reaches the value of the current flowing through the coils, such as 96, the contactors, such as 101, move to the position shown in the drawings. Thus the fire-control switch between the terminals 105 and 106 is closed when the advancing torpedo is at a predetermined distance from the ship. If the crude speed

$\frac{\Delta y}{\Delta x}$

of the torpedo is taken as 60 miles per hour, or 88 feet per second, this is very slow indeed when compared with the velocity of sound through the water which is about 5,000 feet per second.

I claim:

1. In combination, a source of both desired and undesired waves including components of like frequency but unequal energy content, a plurality of means tuned to the component frequencies of the desired waves only, means associated with said tuned means for absorbing energy from said components to enable amplitude discrimination between desired and undesired components of like frequency but unequal energy content, means whereby each desired component affects an element in a work circuit, and means for connecting said elements for current flow only when all elements have been so affected.

2. Apparatus for controlling a circuit in response to a sound wave having a characteristic frequency spectrum made up of spaced narrow frequency bands of non-uniform energy content, which comprises, a filter for each of said narrow frequency bands adjusted to pass energy within its particular narrow frequency band only; means for transforming such sound wave into a corresponding electric wave and feeding same to said filters in parallel; a circuit to be controlled, including a series of elements normally occupying positions which render said controlled circuit inoperative and individually requiring at least a predetermined amount of energy to shift them to positions which render the circuit operative; an attenuator associated with each of said filters to receive the output therefrom, each of said attenuators being adjusted in accordance with the energy content of its associated frequency band to pass sufficient energy from its associated filter to shift one of said series of elements to its operative position in said controlled circuit; and means feeding the output of each attenuator to one of said series of elements.

3. The method of controlling a circuit in response to a wave having a characteristic frequency spectrum whose frequency components are of non-uniform energy content, which comprises splitting said wave into its characteristic frequency components, absorbing from each component a predetermined portion of its energy content in accordance with the energy content of such component, to leave a residual energy of a substantially common value as to all components, and energizing with the residual energy of each frequency component, one of a plurality of similar series connected elements in such circuit.

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