Aug. 10, 1943. B. M. HADFIELD 2,326,457

ALTERNATING CURRENT SIGNALING SYSTEM

Filed Sept. 10, 1941

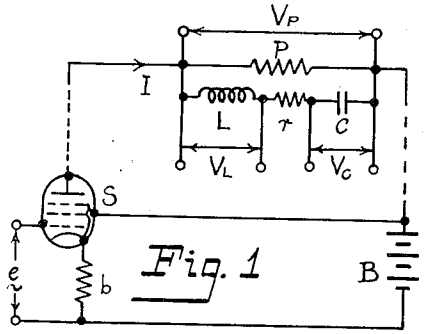



Fig. 1

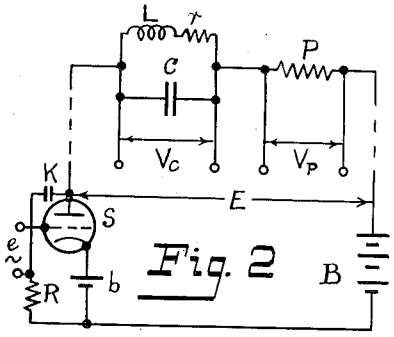



Fig. 2

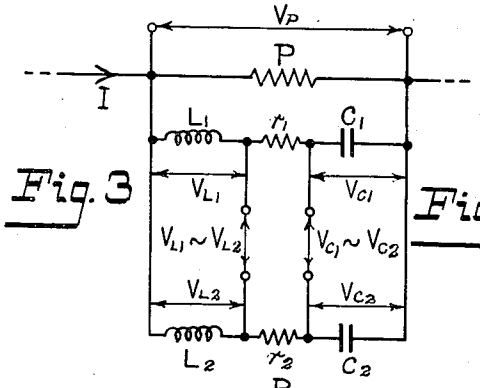



Fig. 3

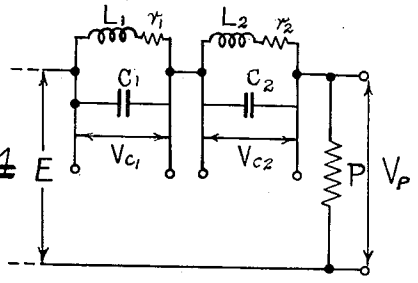



Fig. 4

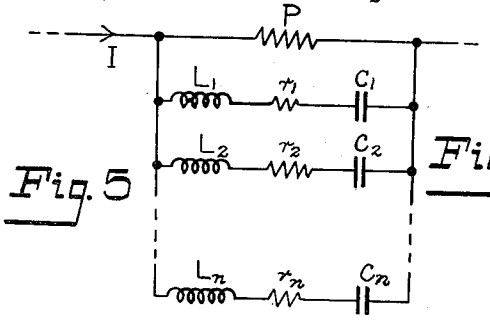



Fig. 5

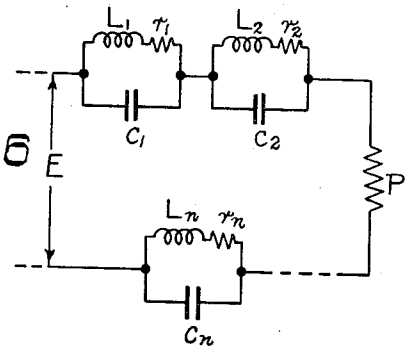



Fig. 6

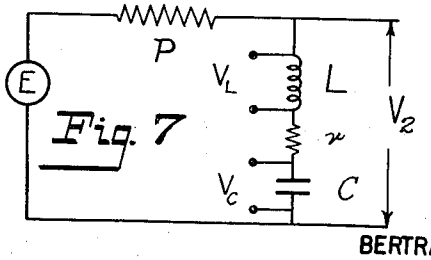



Fig. 7

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## ALTERNATING CURRENT SIGNALING SYSTEM

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Application September 10, 1941, Serial No. 410,265
In Great Britain October 10, 1940

19 Claims. (Cl. 179—16)

The present invention concerns improvements in or relating to alternating current signaling systems and more particularly relates to signaling systems in which alternating current signals of one or more frequencies are converted into corresponding direct current signals with a minimum of mutual interference or response to signals of alien frequencies.

One special application of this is to voice frequency signaling over circuits used also for the transmission of speech currents and it will be appreciated that the signals of alien frequencies, i. e. speech, may actually include the signaling frequency. As is now well known in such arrangements the reception apparatus usually incorporates an acceptor resonant circuit which has a greater response in the neighbourhood of the signal frequency in order to differentiate against currents of other frequencies. In addition a circuit which exerts a guarding effect at some or all of these alien frequencies is commonly used in order that the signal frequency path may be rendered ineffective by frequencies which may include some signal frequency. In the case where the guarding circuit is effective at all frequencies other than the signal frequency its form is generally that of a rejector circuit tuned to the signal frequency. This means that at least two resonant circuits, one an acceptor and one a rejector are commonly used for each signaling frequency and the broad feature of the present invention concerns the provision of a single resonant circuit per frequency to obtain both signal and guard effects.

The invention is applicable both to a single signal frequency and to a plurality of signal frequencies.

According to one feature of the invention an arrangement for selecting potentials for effecting the operation of a signal responsive device and for guarding against its operation by signals of other than a predetermined frequency or frequency band is provided in which the currents are derived from a source of high or low impedance irrespective of their frequency and feed a resonant circuit including an inductance and a capacity together with a resistance, which are suitably arranged so that operating and guarding potentials may be derived from selected terminals in said resonant circuit.

According to one example of the invention the currents are derived from a source of high impedance and applied to a series resonant circuit tuned to the signaling frequency and shunted by a resistance, operating potentials being derived from across the inductance or capacity components of the series resonant circuit and guarding potentials being derived from across the resistance.

According to another example of the invention the currents are derived from a source of low impedance and applied to a series resonant circuit tuned to the signaling frequency in series with a resistance, operating potentials being derived from across the inductance or capacity of the series resonant circuit and guarding potentials being derived from across the resonant circuit.

According to another example of the invention the currents are derived from a source of low impedance and applied to a parallel resonant circuit tuned to the signaling frequency in series with a resistance, the operating potentials being derived from across the inductance and capacity components of the parallel resonant circuit and guarding potentials being derived from across the resistance.

The invention will be better understood by referring to the accompanying drawing, Figs. 1 to 7, which illustrates different methods of carrying the invention into effect.

Figs. 1 and 2 refer to alternative arrangements for dealing with a single frequency, while

Figs. 3 and 4 relate to different arrangements for dealing with two signaling frequencies.

Figs. 5 and 6 relate to alternative arrangements for dealing with an indefinite number of signal frequencies.

Fig. 7 is a third alternative to the arrangements for dealing with a single frequency.

It is well known that a rejector frequency characteristic around a given frequency may be secured by employing either a parallel resonant circuit or a series resonant circuit. (By a parallel resonant circuit is meant an inductance and capacity connected in parallel and by a series resonant circuit is meant an inductance and capacity connected in series.)

In the case of a parallel resonant circuit the rejector characteristic is most readily obtainable on a series resistance and in order that the maximum effect may be obtained on the latter, the source impedance should be low or negligible. In the case of a series resonant circuit the rejector characteristic is obtainable (*a*) on the resonant circuit if the latter be connected in series with a resistance and a generator of low or negligible resistance or (*b*) on the resonant circuit if the latter be connected in parallel with a resistance, the whole being fed from a generator of very high impedance. The two latter

configurations using a series resonant circuit may be shown to produce identical voltage characteristics on the resonant circuit by the simple process of equating the generator voltage in (*a*) to the product of the current supplied from the generator and resistance in (*b*) (the current supplied from the generator in (*b*) can be considered as constant). In the following description therefore only configuration *b* as applied to a series resonant circuit is dealt with, it being understood that all statements and proofs are directly applicable to configuration *a* when the equating process mentioned above is performed.

Fig. 1 illustrates the case of the employment of a series resonant circuit in which case the source impedance must be very high so that the current supplied to the circuit therefrom can be considered as constant in magnitude whatever the impedance of the load may be to the frequencies received. The current from such a source will be termed a constant current and it will be understood that where the term "constant current" is used in this specification it means a current so derived.

Referring to Fig. 1, it will be noted that the series resonant circuit consists of an inductance L and a capacity C, as well as a resistance *r*, which may incidentally represent the effective resistance of the resonant circuit. The resistance P shunts the series resonant circuit and the arrangement thus corresponds to alternative *b* referred to above. Let the constant current I be supplied to such a circuit and the series resistance of the resonant circuit at resonance be *r*, then the ratio

$$\frac{2\pi fL}{r}$$

represents the Q value of the inductance (where *f* is the frequency given by the expression

$$\left(f=\frac{1}{2\pi\sqrt{LC}}\right)$$

L and C being the values of the inductance and capacity respectively, P the value of the resistance in parallel with the series resonant circuit and N the ratio

$$\frac{P}{r}$$

The voltage across the resistance P will be a minimum when the frequency of the constant current I is *f*, which frequency is usually termed the resonant frequency. As the frequency of the signaling currents departs from the frequency *f* then the voltage across the resistance P will approach the value I. P. If the latter value be termed unity, then the minimum response can be shown to be

$$\frac{1}{N+1}$$

whilst it can also be shown that the relationship of response to frequency is mainly dependent on N and to a negligible extent on Q, provided the latter is large (i. e. greater than 30). This type of characteristic displays the well-known rejector effect and may be used to provide the guarding effect. It can also be shown that the voltage frequency characteristic of the voltage across the inductance or capacity is the same as would be obtained by exciting these components as a series resonant circuit from a constant voltage source, if the series resistance was increased to $(N+1)$ times *r*. In other words the voltages on the inductance or capacity are those of an acceptor resonant circuit of Q value of

$$\frac{1}{N+1}$$

of the original series resonant circuit. By suitably choosing the values of N and *r*, therefore, both rejector and acceptor effects may be obtained from one resonant circuit and moreover provided the initial Q of the resonant circuit is high, the characteristics are sensibly independent of variations in Q due to variations in *r*, except at frequencies very close to *f*.

It is proposed, therefore, to use one resonant circuit in the manner described or in the alternative manner *a* quoted above and to obtain both rejector and acceptor effects therefrom in the case where one signal frequency is used. In order to obtain substantial independence of the frequency characteristics of both effects for variations in the series resistance of the resonant circuit at frequencies just removed from the frequency *f* and within the normal operational band width, N may have values between 7 and 30, whilst the nominal Q value of the resonant circuit should not be less than 30.

In order to obtain constant current I the generator must have a very high internal impedance. Such a generator is readily available in the form of a pentode valve S, particularly if it is assisted by the use of negative feedback of the current type. In order to obtain negative feedback a self-biasing resistance *b* is conveniently provided in the cathode circuit, the high tension battery B has its negative pole connected to one terminal of the resistance *b* and to one terminal of the grid circuit, while the other terminal of battery B is connected to the resonant circuit and thence to the anode of the valve and also directly to the screen grid as shown, the suppressor grid being connected to the same potential as the cathode. The input grid voltage *e* may be conveniently derived from the signaling frequencies but may be first passed through a limiting or like device to ensure that it has a constant magnitude irrespective of frequency. As is well-known the anode impedance of such a valve circuit will be so high compared with the maximum anode working or load impedance (in this case P) that the current I (alternating component) may be considered constant in magnitude irrespective of changes in the load impedance due for instance to changes in the input frequency. This typical high impedance generator is not only applicable to the arrangement shown in Fig. 1, but also to Figs. 3 and 5 which also require and relate to the provision of a constant current source.

The voltage frequency response across P is given by the following formula:

$$V_P=I.\ P.\sqrt{\frac{\frac{1}{Q^2}+X_1^2}{\left(\frac{N+1}{Q}\right)^2+X_1^2}}$$

where

$$X_1=\frac{w}{w_1}-\frac{w_1}{w}$$

$w_1$ being equal to $2\pi f$ where

$$f=\frac{1}{2\pi\sqrt{LC}}$$

and $w$ is the input frequency in radians per sec-

ond. $V_P$ is obviously a minimum when $X_1$ is zero (i. e. when $w=w_1$) and of value

$$\frac{1}{N+1}\text{times } I.\ P.$$

Further if N is very much greater than 1 then

$$\frac{N+1}{Q}$$

approximates to

$$\frac{N}{Q}=\frac{P}{r}$$

$$\frac{r}{w_1L}=\frac{P}{w_1L}=\text{constant}$$

if L and $w_1$ are specified. Hence, the denominator of the expression for $V_P$ is a constant at any given input frequency. Also if Q is large such that

$$\frac{1}{Q^2}$$

is much less than

$$X_1^2$$

then the numerator is also a constant at any given frequency. This is so if Q is not less than 30 at frequencies just removed from $f$ and within the normal operational band width, but is never true at the frequency $f$ since $X_1$ is zero. However, it is the band width responses which matter and here it can be said that the frequency response is to a large extent independent of variations in $r$ (which produce changes in both N and Q).

The voltage frequency response across L is given by

$$V_L=I.\ P.\frac{w}{w_1}\sqrt{\frac{1}{\left(\frac{N+1}{Q}\right)^2+X_1^2}}$$

whilst that of the capacity is similar with the factor

$$\frac{w_1}{w}$$

instead of

$$\frac{w}{w_1}$$

This can be shown to be the same expression as would be obtained by exciting these components as a series resonant circuit from a constant voltage source if the series resistance was increased to $N+1$ times $r$. The response is that of an acceptor circuit and is a maximum of

$$I.\ P.\frac{Q}{N+1}$$

when $X_1$ is zero (i. e. at a frequency $f$). By a similar argument to that used before it will be seen that the response to any frequency is substantially independent of variations in $r$. Hence both rejector and acceptor effects can be obtained from one resonant circuit with substantial stability in the face of change in the quantity which it is generally impossible to specify with any degree of accuracy, namely the effective resistance of the resonant circuit.

In practice, of course, the voltage on the inductance cannot be obtained entirely free from the resistance component of the resonant circuit. It will be appreciated therefore, that in Figs. 1, 3 and 5 although the voltages $V_L$ and $V_C$ are indicated as being available free from resistive components this is not so in practice, and, of course, the calculated voltage/frequency characteristics will be to this degree in error. But as it is postulated that resonant circuits of high Q value shall be used, the effect of such resistive components on either $V_L$ or $V_C$ is small enough to be negligible.

It will be appreciated by those skilled in the art that the other configuration for a rejector circuit mentioned heretofore which uses a parallel resonant circuit may be used in a similar manner. Such a circuit is illustrated in Fig. 2 and in this case the rejector circuit is obtained from the series resistance and the acceptor effect from the parallel resonant circuit. In a somewhat similar manner the frequency responses of either effect at frequencies just removed from the frequency $f$ and within the normal operational band width may be made substantially independent of variations in the resonant circuit resistance. This independence is of some importance in practical design since whilst close tolerances on the values of the inductance and capacity may be normally obtained and justified on the grounds of accurate tuning, the resistance of the resonant circuit so formed is mainly due to the inductance and cannot be rigidly specified. A maximum value for this resistance can, however, be specified such that a minimum Q value of 30 can be obtained. In the alternative form shown in Fig. 2 the same references L, $r$ and C are used for the inductance, effective resistance and capacity in the parallel resonant circuit and the reference P for the resistance P which is connected in series therewith.

Such an arrangement must be fed from a source of low impedance so that the voltage can be considered as constant in magnitude whatever the impedance of the load may be to the frequencies received. The voltage from such a source will be termed a constant voltage and it will be understood that when the term constant voltage is used in this specification it means a voltage so derived. A constant voltage generator is represented in typical practical form as a valve S which may be of any type with 100% voltage negative feedback to its grid circuit via a capacity K and a resistance R, the battery $b$ representing the normal working grid bias as a component of the anode battery voltage B. The input grid voltage $e$ is of constant magnitude but of varying frequency and produces an alternating anode voltage E which is substantially constant irrespective of changes in the anode load impedance due for instance to changes in the input frequency. The presence of such a low impedance generator is also required in connection with the arrangements illustrated in Figs. 4 and 6 or where the invention is applied to a parallel resonant circuit. The voltage frequency characteristic across the resistance P is given by the formula:

$$V_P=E.\sqrt{\frac{\left(\frac{1}{Q}\right)^2+Y^2}{\left(\frac{1+Q}{Q+N}\right)^2+\left(Y+\frac{w_1}{w.N}\right)^2}}$$

where

$$Y=\frac{w_1}{w}-\frac{w}{w_1}w_1 2\pi f$$

where

$$f=\frac{1}{2\pi\sqrt{LC}}$$

and $w$ is the input frequency in radians per second. The minimum value for $V_P$ is now not precisely at the frequency $f$, which is due to

including the resonant circuit resistance in the inductance element as, of course, this is generally the case. Apart from this it will be seen that similar arguments will show that the frequency response is to a large degree independent of variations in $r$.

The voltage frequency characteristic across C (or $L+r$) is given by

$$V_C = E.\frac{Q}{N}\sqrt{\frac{\left(\frac{1}{Q}\right)^2+\left(\frac{w}{w_1}\right)^2}{\left(\frac{1}{Q}+\frac{Q}{N}\right)^2+\left(Y+\frac{w_1}{w.N}\right)^2}}$$

Again the response is not quite a maximum at the frequency $f$ due to the same cause, but the response is to a large degree independent of variations in $r$.

The reason why the first type of excitation of the circuit is preferred will be evident from the above example. Only one type of acceptor response is generally available when using a parallel resonant circuit and both acceptor and rejector responses are made more difficult of calculation by the invariable lumping of the resistance in the inductance. These remarks apply equally well to the more complicated circuits described hereinafter where there is more than one signal frequency. Hence the theoretical explanation will only be given of the series resonant circuits while series parallel circuits are indicated in the diagrams.

By applying the above described embodiments to cases where more than one signal frequency is used certain other advantages to be described are attained. For instance in the case where two frequencies are used for signaling, the response of the apparatus to one frequency at a time or both simultaneously is generally required. Each signal path should therefore accept its own frequency and reject any other. This can be readily accomplished by the present invention by adding one more resonant circuit to the rejector circuit formerly described. In the case of the series resonant rejector circuit consisting of a resistance in parallel with a series resonant circuit, the additional resonant circuit will be of the series type and will be connected in parallel with the first resonant circuit. The voltage across the resistance P now exhibits a double rejector effect which is suitable for the guarding action, whilst the voltages across the inductance and capacities of the individual resonant circuits exhibit an acceptor characteristic to the individual frequencies of resonance and a rejector effect to the unwanted frequencies. Hence these voltages may be used for the signal paths where one or two freqeuncies are applied since the mutual interference is at a minimum.

Figs. 3 and 4 show the arrangement for two signal frequencies using series and parallel circuits respectively. Only the basic circuits are shown, the generator or source of supply being similar to those used in Figs. 1 and 2 respectively. The elements associated with each frequency $f1$ and $f2$ have corresponding qualifying numerals. It will be assumed that the values of $r1$ and $r2$ are equal and also that Q1 and Q2 are equal for the purpose of simplifying the frequency response expressions but as it may be shown that such response is substantially independent of the $r$ value, then it is to be inferred that some difference between $r1$ and $r2$ is permissible.

If the various voltage frequency responses across the various elements, either simply or in combination, are calculated, the form of all expressions is similar and is as follows:

$$V = I.\ P.\ Q^2\sqrt{\frac{A^2+\left(\frac{B}{Q}\right)^2}{C^2+D^2}}$$

The denominator $C^2+D^2$ is the same expression for all the elements or combinations thereof. In general A and B are functions of the ratios of the input frequency to one or other or both of the resonant frequencies and hence are independent of variations of $r$; also the second term

$$\frac{B^2}{Q}$$

is in general very small compared with the first $A^2$, except at the resonance frequencies. Hence the voltage on any element or combination thereof may be taken as proportional to

$$\frac{Q^2}{\sqrt{C^2+D^2}}$$

at any frequency except the two resonant frequencies. Thus V is proportional to

$$\frac{Q^2}{\sqrt{(1+2N-Q^2X_1X_2)^2+((X_1+X_2)(N+1)Q)^2}} = \frac{Q^2}{\sqrt{\left(\frac{1+2N}{Q^2}-X_1X_2\right)^2+\left((X_1+X_2)\frac{(N+1)}{Q}\right)^2}}$$

If variation of N and Q is due solely to variations in $r$ and the values of N and Q are much greater than 1, then

$$(X_1+X_2)\cdot\frac{N+1}{Q}$$

approximates to

$$(X_1+X_2)\frac{N}{Q}$$

which is independent of $r$. But this term is zero at the geometric mean frequency and hence the voltage will be dependent on the first term only.

The first term is

$$\frac{1+2N}{Q^2}-X_1X_2$$

and at the geometric mean frequency $X_1X_2$ will be much greater than

$$\frac{1+2N}{Q^2}$$

for Q values greater than 30. Hence it may be said that the voltages on any of the elements whether considered singly or in combination will be substantially independent of variations in the resistance of the resonant circuits except for input frequencies exactly equal to the resonant frequencies and provided that the design is such that the figures for N and Q are much greater than 1.

With regard to the variety of signal path responses which may be obtained by taking the voltages on the elements singly or as sums and differences, no detailed elaboration of the description is possible without actually working out the respective voltage frequency curves and plotting them. Methods whereby the sum and difference voltages may be obtained in a practical manner will be indicated and a more detailed discussion of the frequency response which is best suited to the case of signaling by two frequencies without mutual interference and envelope distortion will be given.

Referring to Fig. 3 the difference voltages between the inductances or capacities of the two resonant circuits may be obtained by taking connections between the ends of these elements which are not directly connected, as shown. Transposition of the inductance and capacity of one circuit will enable the difference voltages between the inductance of one circuit and the capacity of the other to be obtained in a similar manner. Sums of the voltages on the elements may be obtained by winding secondary windings on the inductances and suitably connecting them in series with themselves or with the desired element.

The amplitude frequency response across the inductance of the resonant circuit tuned to the higher signal frequency or across the capacity of the lower signal frequency may be such as to fall rapidly below or above the selected frequencies respectively with values of N about 20. For instance with N equal to 19 and Q values of 31, the response at the geometric mean frequency is 2.3 times I. P., falling rapidly to 0.09 at the unwanted frequency and not rising to above 0.3 thereafter. At the wanted frequency the response is 1.6 and tends thereafter towards 1.0. The phase angle response within the pass band is substantially linear commencing from the resonant frequency. In the neighborhood of the unwanted frequency the phase angle response changes rapidly, but this feature is common to band pass filters and does not produce an appreciable effect owing to the reduction in response. Hence the pulse envelope using this signal path should show little distortion, and this has been confirmed experimentally.

As regards mutual interference in the signal paths when two frequencies are used simultaneously this is a minimum without adding further elements to the circuit. The ratio between the wanted and unwanted signal frequencies transmitted by the signal path quoted above (i. e. $N=19$) is 18:1, and even allowing a percentage deviation of the received signal from the resonant frequency of 4% and taking the worst case, the ratio is 4:1. This is found to be adequate in general because it means that the wanted signal will have its envelope modulated by plus or minus 25% in the worst possible case and the succeeding responsive apparatus can be designed with sufficient factor of safety to meet this amount of variation. In cases where accuracy of pulse repetition is not essential the voltages on the remaining resonant circuit elements may be used since they are similar to that described with the exception that they tend to zero at high and low frequencies respectively.

By utilising the sums and differences of the voltages on the reactive elements of the resonant circuits other types of voltage frequency characteristics may be obtained for use in certain applications. For instance, and taking the case of two resonant circuits, if the difference between the inductance voltages is used the frequency response obtained is that of an acceptor circuit with a maximum at the geometric mean frequency. With low N values the maximum response extends over a band of frequencies with very little change in magnitude, the response outside this band falling off rapidly towards zero. With high N values the response develops a single peak at the geometric mean frequency which in combination with the guard effect may be made to give an overall signal frequency response of varying amplitudes and symmetrically disposed with respect to the geometric mean frequency. As another instance the difference voltage between the inductance of one resonant circuit and the capacity of the other may be taken. This gives a voltage frequency characteristic having two maxima at about the resonant frequencies of each circuit and a pronounced minimum at the geometric mean frequency. As N is increased these maxima become much less pronounced, whilst the minimum does not appreciably alter so that the response is substantially uniform at all frequencies tending to equal I. P. at very low and very high frequencies. The response may then be used to supply succeeding apparatus requiring a uniform response without the necessity for the provision of a separate path from the input. On the other hand if N is kept low (about 5) then in conjunction with the guard effect two very sharp responses in the neighbourhood of the resonant frequency of the two circuits may be obtained.

As yet another instance the sum of the voltages on an inductance of one circuit and a capacity of the other may be used. This gives a voltage frequency characteristic which is a maximum in the neighbourhood of the geometric mean frequency, falls off rapidly to a minimum at $\sqrt{2}$ and $\sqrt{\frac{1}{2}}$ times the geometric frequency and tends thereafter to I. P. at very low and very high frequencies. This characteristic would enable the response at the minimum value frequencies to be attenuated without loss of response between the signal frequencies. Other variations of voltage frequency characteristics in the signal path will readily occur to those skilled in the art, the addition of further resonant circuits adding greatly to the possibilities. As long as high Q values are maintained as postulated the resistance component of the reactive elements may be neglected.

As previously mentioned the invention is applicable to any number of signal frequencies by the addition of one resonant circuit per frequency arranged in the manner described. As in previous arrangements the two types of resonant circuit may generally be employed. When all the resonant circuits are of the series type they are connected in parallel, the whole being then placed in series with a resistance and supplied from a low impedance source or in parallel with a resistance and supplied from a high impedance source. When all the resonant circuits are of a parallel type they are connected in series with one another and a resistance and supplied from a source of substantially low impedance. The guarding effect is obtained from the voltage and/or the current in the resistance when using parallel resistance circuits or the voltage and/or current in the resistance when using series resonant circuits and a high impedance source or the voltage on the series resonant circuit when using a low impedance source. The signal effect is obtained from the voltage across and/or the current in the resonant circuit elements comprising the resonant circuits or combinations comprising the sums or differences of the voltages or currents in the resonant circuits and their constituent elements. The methods of connection using series resonant circuits are preferred as the series resonant circuit enables a greater variety of voltage frequency characteristics to be obtained owing to the series connection of the inductance and capacity. It can be shown that if the circuits are designed for high Q values,

say not less than 30, for the individual resonant circuits and the N value is suitably chosen (in general between 7 and 30) then provided the reactances constituting these circuits are within normal limits such as are used for determining the resonant frequency, practical deviation from the estimated value of the resonant circuit resistance will produce little effect on the characteristics desired.

Figs. 5 and 6 show the arrangement for any number of signal frequencies from one to $n$ using series and parallel resonant circuits respectively. The associated numerals indicate the particular frequency, whilst the sequence of connection can be in any convenient order. For instance the $n$th parallel resonant circuit in Fig. 6 has been shown and connected in the return lead to the source. For selection of any one frequency and rejection of all others the voltages on any one of the resonant circuit elements tuned to that frequency may be used. The specific type of voltage frequency characteristic obtained would have to be calculated but the tendencies may be deduced by an extension of the knowledge obtained from the two frequency case. For instance if N is about 20 and Q about 30 and taking the series resonant circuit case, then the voltage on L1 would be just greater than I. P. at its resonant frequency, will tend towards I. P. at higher frequencies, and towards zero at lower frequencies, will show a rejector effect at all the other resonant frequencies and will rise to maxima in the neighborhood of the geometric means of the various resonant frequencies taken in all possible combinations. Generally the latter effect will be most pronounced for adjacent pairs of frequencies but in order that the other combinations shall not adversely affect the rejector actions at each resonant frequency it is desirable that the signal frequencies be chosen so that they do not form a geometric progression.

The arrangement shown in Fig. 7 is equivalent to the arrangement shown in Fig. 1 provided that the generator feeding the circuit has zero instead of infinite impedance as will be apparent from the following analysis.

If E is a generator of zero internal impedance with voltage E, $V_2$ the voltage across the elements L, $r$ and C in series, Z the impedance of these elements in series and P the external series resistance then

$$V_2=\frac{EZ}{P+Z}$$

Referring to Fig. 1 then the voltage across the resistance P if Z equals the impedance of the elements L, $r$ and C of Fig. 1 in series will equal

$$I\frac{PZ}{P+Z}$$

where I equals the current fed from the generator. If E is made equal to I. P. it will be seen that the voltage across the resistance P in Fig. 1 equals the voltage across the elements L, $r$ and C in series in Fig. 7. This voltage is equivalent to the guarding potential required while the operating potentials may be derived as before across L or C. Hence it will be seen that this is a true equivalent and this arrangement therefore equally falls within the scope of the invention.

There is also an alternative to the arrangement of Fig. 2 but this involves the insertion of an additional series resistance in order to derive a potential equal to the total current flowing through the elements P in parallel with L, $r$ and C in series and is therefore subject to practical difficulties which may prevent its being used commercially.

The invention is applicable to any apparatus which is required to respond to alternating current signals of one or more frequencies in an individual manner, whether the signals are transmitted one at a time or simultaneously. A typical application lies in the reception of such signals over telephone or telegraph lines by audio or carrier frequency currents and in the form of impulse trains such as are used in automatic telephone systems or as relatively long signals for supervisory purposes. In order to make use of the voltages referred to in the various voltage-frequency characteristics described it is generally desired to convert the alternating voltages into proportional direct current. This is accomplished by any well-known rectifier system. Such systems however impose a load on the alternating voltage which may alter its frequency characteristic. This loading effect may be avoided in that in the case of the rejector effect the rectifier load forms part of the whole of the resistance P and in the case of all the acceptor effects mentioned above the rectifier load will merely cause an increase in the effective resistance of the resonant circuits which has been shown to have a negligible effect on the voltage-frequency response.

I claim:

1. In a signaling system wherein a pair of circuits are associated with a signaling line, wherein a simple wave predominantly of a certain audio frequency is impressed upon said line at times and wherein a complex wave including said certain audio frequency and other audio frequencies is impressed upon said line at other times, an arrangement for controlling said pair of circuits variably in dependence upon which wave is impressed upon said line, comprising a circuit tuned substantially to said certain frequency, means for coupling said tuned circuit to said line to subject it to said waves when same are impressed upon said line, means for coupling one of said pair of circuits to a certain part of said tuned circuit so that said one circuit is controlled by the potential generated in said part when a wave is impressed upon said line, said potential varying in accordance with the frequency of said impressed wave, and means for coupling the other of said pair of circuits to a different part of said tuned circuit so that said other circuit is controlled by the potential generated in said last part when a wave is impressed upon said tuned circuit, said last potential varying in accordance with the frequency of said impressed wave but varying in a way different than the way in which said first potential varies with the frequency of said impressed wave.

2. In a system for at times receiving a simple wave predominantly of a certain frequency and at other times receiving a complex wave including said certain frequency and for controlling a pair of circuits variably in dependence upon which of said waves is received, a circuit tuned substantially to said certain frequency, means for impressing the received waves upon said tuned circuit, means for coupling one of said pair of circuits to a certain part of said tuned circuit so that said one circuit is controlled by the potential generated in said part when said waves are impressed upon said tuned circuit, and means for coupling the other of said pair of circuits to a different part of said tuned circuit so that said other circuit is controlled by the

potential generated in said other part when said waves are impressed upon said tuned circuit.

3. In a frequency discriminating system for controlling a pair of circuits variably according to the frequency of a received wave, a tuned circuit, means for impressing the received wave upon said tuned circuit, means for coupling one of said pair of circuits to a certain part of said tuned circuit so that said one circuit is controlled by the potential generated in said part when the received wave is impressed upon said tuned circuit, said potential varying in accordance with the frequency of said impressed wave, and means for coupling the other of said pair of circuits to a different part of said tuned circuit so that said other circuit is controlled by the potential generated in said last part when the received wave is impressed upon said tuned circuit, said last potential varying in accordance with the frequency of said impressed wave.

4. In a frequency discriminating system for controlling a pair of circuits according to the frequency of a received wave, a tuned circuit, means for impressing the received wave upon said tuned circuit, means for coupling one of said pair of circuits to a certain part of said tuned circuit so that said one circuit is controlled by the potential generated in said part when the received wave is impressed upon said tuned circuit, said potential varying in accordance with the frequency of said impressed wave, and means for coupling the other of said pair of circuits to a different part of said tuned circuit so that said other circuit is controlled by the potential generated in said last part when the received wave is impressed upon said tuned circuit, said last potential varying in accordance with the frequency of said impressed wave but varying in a way different than the way in which said first potential varies with the frequency of said impressed wave.

5. In a frequency discriminating system for controlling a pair of circuits according to the frequency of a received wave, a single tuned circuit, one portion of said tuned circuit having a frequency response characteristic which peaks at a certain frequency, another portion of said tuned circuit having a frequency response characteristic which reaches a minimum substantially at said certain frequency, means for coupling said pair of circuits respectively to said two portions of said tuned circuit, means for impressing said received wave upon said tuned circuit, each said portion of said tuned circuit effective to control the circuit coupled thereto in accordance with the response of that portion when said wave is impressed upon said tuned circuit.

6. In a frequency discriminating system for controlling a pair of circuits according to the frequency of a received wave, a single tuned circuit whose Q value is at least 30, one portion of said tuned circuit having a frequency response characteristic which peaks at a certain frequency, another portion of said tuned circuit having a frequency response characteristic which reaches a minimum substantially at said certain frequency, means for coupling said pair of circuits respectively to said two portions of said tuned circuit, means for impressing said received wave upon said tuned circuit, each said portion of said tuned circuit effective to control the circuit coupled thereto in accordance with the response of that portion when said wave is impressed upon said tuned circuit.

7. In a frequency discriminating system for controlling a pair of circuits according to the frequency of a received wave, a resistor upon which said wave is impressed, a series resonant circuit bridging said resistor, said last circuit including inductance and capacitance, one circuit of said pair connected in bridge to said resistor and controlled by the voltage generated in said resistor when said wave is impressed thereon, and the other circuit of said pair connected in bridge to said inductance and controlled by the voltage generated therein when said wave is impressed upon said resistor.

8. In a frequency discriminating system for controlling a pair of circuits according to the frequency of a received wave, a resistor upon which said wave is impressed, a series resonant circuit bridging said resistor, said last circuit including inductance and capacitance, one circuit of said pair connected in bridge to said resistor and controlled by the voltage generated in said resistor when said wave is impressed thereon, and the other circuit of said pair connected in bridge to said capacitance and controlled by the voltage generated therein when said wave is impressed upon said resistor.

9. In a frequency discriminating system for controlling a pair of circuits according to the frequency of a received wave, a resistor upon which said wave is impressed, a series resonant circuit bridging said resistor, said last circuit including an inductance element and a capacitance element and having, at certain frequencies, an effective resistance which is very small as compared with the resistance of said resistor, one circuit of said pair connected in bridge to said resistor and controlled by the voltage generated in said resistor when said wave is impressed thereon, and the other circuit of said pair connected in bridge to one of said elements and controlled by the voltage generated in that element when said wave is impressed upon said resistor.

10. In a frequency discriminating system for controlling a pair of circuits according to the frequency of a received wave, a parallel resonant circuit, a discriminating circuit including, in series, said resonant circuit and a resistor, means for impressing said wave upon said discriminating circuit, one circuit of said pair bridged across said resistor and controlled by the voltage generated therein when said wave is impressed upon said discriminating circuit, and the other circuit of said pair bridged across said resonant circuit and controlled by the voltage generated therein when said wave is impressed upon said discriminating circuit.

11. In a frequency discriminating system having a pair of circuits to be controlled, a resistor, a high impedance variable frequency generator connected to said resistor for impressing different frequencies thereon at different times, a series resonant circuit bridging said resistor, said last circuit including inductance and capacitance, one circuit of said pair connected in bridge to said resistor and controlled by the voltage generated in said resistor when said frequencies are impressed thereon, and the other circuit of said pair connected in bridge to said inductance and controlled by the voltage generated therein when said frequencies are impressed upon said resistor.

12. In a frequency discriminating system having a pair of circuits to be controlled, a resistor, a high impedance variable frequency generator connected to said resistor for impressing different frequencies thereon at different times, a series resonant circuit bridging said resistor, said last circuit including inductance and capacitance, one

circuit of said pair connected in bridge to said resistor and controlled by the voltage generated in said resistor when said frequencies are impressed thereon, and the other circuit of said pair connected in bridge to said capacitance and controlled by the voltage generated therein when said frequencies are impressed upon said resistor.

13. In a frequency discriminating system having a pair of circuits to be controlled, a parallel resonant circuit, a discriminating circuit including, in series, said resonant circuit and a resistor, a low impedance variable frequency generator connected to said discriminating circuit for impressing different frequencies thereon at different times, one circuit of said pair connected in bridge to said resistor and controlled by the voltage generated in said resistor when said frequencies are impressed upon said discriminating circuit, and the other circuit of said pair connected in bridge to said resonant circuit and controlled by the voltage generated therein when said frequencies are impressed upon said discriminating circuit.

14. In a frequency discriminating system for controlling a pair of circuits variably according to the frequency of a received wave, a series resonant circuit, means for impressing said wave upon said resonant circuit, the voltage drop across said resonant circuit varying with the frequency of the impressed wave and being lowest at resonance frequency, the voltage drop across a portion of said resonant circuit varying with the frequency of the impressed wave and being highest at resonance frequency, one circuit of said pair connected in bridge to said resonant circuit and controlled by the voltage drop across same when said wave is impressed thereon, and the other circuit of said pair connected in bridge to said portion and controlled by the voltage drop across said portion when said wave is impressed upon said resonant circuit.

15. In a frequency discriminating system for controlling a pair of circuits variably according to the frequency of a received wave, a parallel resonant circuit, a discriminating circuit including, in series, said resonant circuit and another circuit element, means for impressing said wave upon said discriminating circuit, the voltage drop across said resonant circuit varying with the frequency of the impressed wave and being highest at resonance frequency, the voltage drop across said other circuit element varying with the frequency of the impressed wave and being lowest at resonance frequency, one circuit of said pair connected in bridge to said resonant circuit and controlled by the voltage drop therein when said wave is impressed upon said discriminating circuit, and the other circuit of said pair connected in bridge to said other circuit element and controlled by the voltage drop in said element when said wave is impressed upon said discriminating circuit.

16. In a frequency discriminating system having two circuits to be controlled, a tuned circuit having a Q value of at least 30, a high impedance variable frequency generator connected to said tuned circuit for impressing different frequencies thereon at different times, one portion of said tuned circuit having substantially its strongest response when a certain frequency is impressed upon said tuned circuit, another portion of said tuned circuit having substantially its weakest response when said certain frequency is impressed upon said circuit, means for coupling said first two circuits respectively to said two portions of said tuned circuit, each said portion effective to control the circuit coupled thereto in accordance with the response of that portion when said generator impresses said different frequencies upon said tuned circuit.

17. In a frequency discriminating system having two circuits to be controlled, a tuned circuit, a low impedance variable frequency generator connected to said tuned circuit for impressing different frequencies thereon at different times, one portion of said tuned circuit having substantially its strongest response when a certain frequency is impressed upon said tuned circuit, another portion of said tuned circuit having substantially its weakest response when said certain frequency is impressed upon said circuit, means for coupling said first two circuits respectively to said two portions of said tuned circuit, each said portion effective to control the circuit coupled thereto in accordance with the response of that portion when said generator impresses said different frequencies upon said tuned circuit.

18. A combination for use with a receiver having an acceptor circuit whose energization tends to operate the receiver and a guard circuit whose energization tends to prevent such operation of the receiver, comprising an input circuit upon which a simple wave predominantly of a certain frequency is impressed at times and upon which a complex wave including said certain frequency is impressed at other times, a circuit tuned substantially to said certain frequency, means for coupling said tuned circuit with said input circuit, said acceptor circuit coupled to a certain part of said tuned circuit and energized by the potential generated in that part when said waves are impressed upon said input, and said guard circuit coupled to a different part of said tuned circuit and energized by the potential generated in said last part when said waves are impressed upon said input.

19. A combination for use with a receiver having an acceptor circuit whose energization tends to operate the receiver and a guard circuit whose energization tends to prevent such operation of the receiver, comprising an input circuit upon which a simple wave predominantly of a certain frequency is impressed at times and upon which a complex wave including said certain frequency is impressed at other times, a circuit tuned substantially to said certain frequency, means for coupling said tuned circuit with said input circuit, one portion of said tuned circuit having a greater response to said certain frequency than to other frequencies, another portion of said tuned circuit having a smaller response to said certain frequency than to other frequencies, said acceptor circuit and said guard circuit coupled respectively to said two portions and each energized by its associated portion in accordance with the response of that portion when said waves are impressed upon said input.

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