Sept. 6, 1949. N. B. FARNSWORTH 2,480,842

AUTOMATIC GAIN-CONTROL SYSTEM

Filed March 6, 1945

Fig. 1.

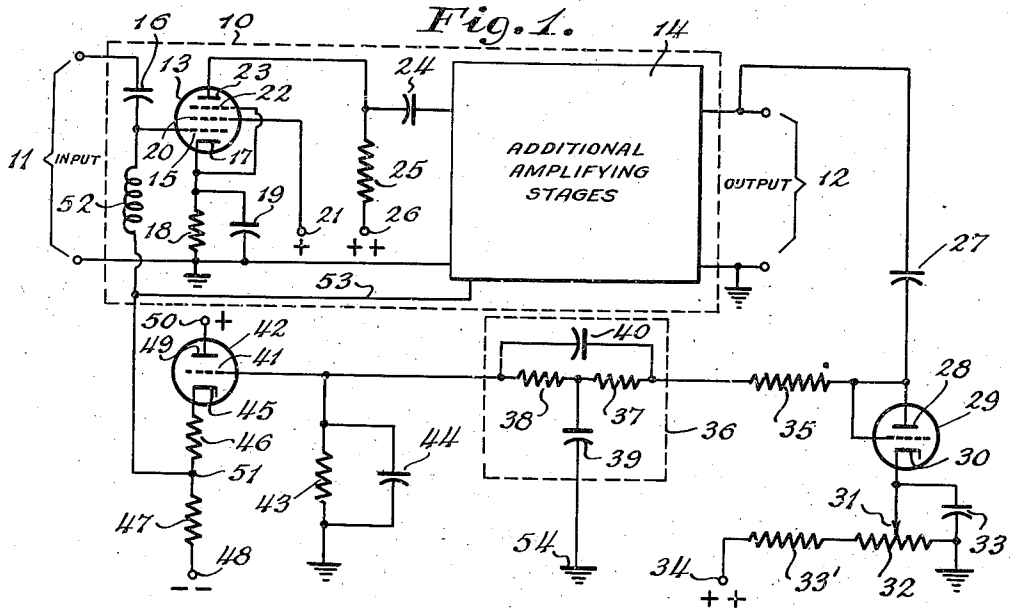
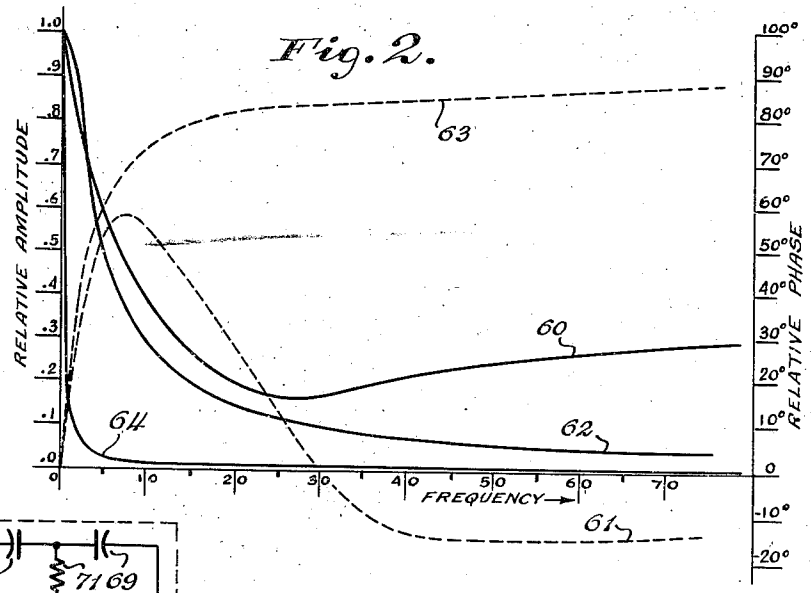


Fig. 2.



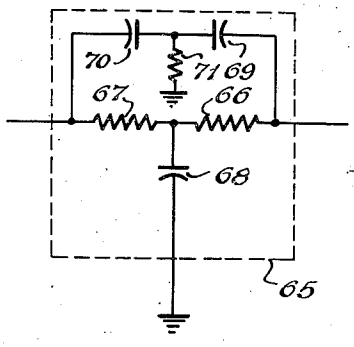


Fig. 3.

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AUTOMATIC GAIN-CONTROL SYSTEM

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7 Claims. (Cl. 179—171)

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This invention relates to improved automatic control systems, and more particularly to an automatic gain-control system especially adapted for use in a receiver for modulated carrier waves.

In the past, it has been common practice to provide an automatic gain-control system for modulated carrier wave receivers in which the rectified carrier wave is utilized to control the gain of one or more amplifying vacuum tubes inversely in accordance with the strength of the input signal wave, so that an increase in the incoming signal strength causes a decrease in the amplification of the receiver and vice versa. Since such an automatic gain-control system is responsive to changes in amplitude of the rectified modulated carrier wave, filtering means must necessarily be provided to prevent the automatic gain-control system from effectively removing the modulation component from the output of the receiver. In an ordinary radio broadcast receiver, for example, it is customary to provide a filter having a time constant whose value is comparable to the period of the lowest audible frequency to which the receiver is intended to respond. This filter is introduced in the automatic gain-control system in such a manner that changes in the output occurring at an audio-frequency rate have no appreciable effect upon the amplification of the receiver, while slow changes in the output of the receiver, such as might be caused by changes in the input signal level due to fading, cause the gain of the receiver to be varied in a manner which maintains the output level substantially constant.

In ordinary broadcast and communication receivers, a simple low-pass filter of the resistance-capacitance type has proved entirely satisfactory provided the values of its components are so chosen that its time constant has a value comparable with the period of the lowest modulation frequency. In such receivers, phase shifts of the modulation envelope which may be introduced due to the operation of the automatic gain-control system are relatively negligible importance.

One form of object locating system radiates uniform short pulses of high-frequency energy into space with constantly varying directivity. The energy which strikes the object to be located is reflected toward the receiver and provides information regarding the direction of the object under observation. Such a system may include a rotatable highly directional antenna, which is spun about an axis slightly different from the axis of its maximum directivity. If the object lies directly along the axis of rotation, the reflected signal, which may be received by the same antenna, will have constant amplitude, and its modulation envelope will have zero frequency. When the object is displaced from the spin axis, however, the received pulses will have a modulation envelope having a frequency corresponding to the speed of rotation of the antenna. The phase of this modulation envelope, compared with that of a reference voltage developed directly by the rotation of the antenna, provides information as to the sense in which the object is displaced from the spin axis of the antenna. The amplitude of the modulation indicates the extent of such displacement. The average strength of the reflected pulses as received varies between wide limits, dependent upon the range and the attitude of the object as well as other factors, all of which vary relatively slowly compared with the spin period.

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In a practical object locating system, an automatic gain-control system must be provided which substantially compensates for the changes in average received signal strength. The problem, as will be apparent from the above brief description, is to provide an automatic gain-control system for this purpose which is also capable of operation without the introduction of appreciable phase shift at the modulation frequency and with a minimum effect upon the amplitude of the modulation-frequency components of the received signal. The conventional type of automatic gain-control system has not proved to be satisfactory in such cases.

It has been found in particular that phase shift of the modulation envelope is commonly encountered in amplifiers having a gain-control system incorporating the conventional type of resistance-capacitance low-pass filter. When the time constant of such a filter is made sufficiently small so that the automatic gain-control system will effectively conpensate for relatively slow variations in input signal strength, as for example those due to fading, a serious phase shift which is a function of this signal strength is introduced. In addition to affecting the performance of the receiver for its intended purpose of receiving and comparing in phase the modulated pulse signal, the phase shift in some cases may be so great as to cause oscillation of the receiver. The phase shift in an amplifier employing such a filter may be minimized by increasing the time constant of the filter, but such an expedient renders the response of the automatic gain-control system too slow for satisfactory compensation of changes in the input signal strength due to fading and other similar phenomena.

In accordance with the present invention, the

problem of modulation phase shift which varies as a function of the input signal strength, in an amplifier having an automatic gain-control system, is effectively solved by providing a filter network in the gain-control system which has substantially zero phase shift at the modulation frequency and which, furthermore, has relatively low transmission at this frequency. By the use of such an arrangement, it has been found that the component of modulation frequency which reaches the amplifier due to the automatic gain-control loop may be made to be of such relative phase and magnitude as to have no appreciable effect upon the phase shift normally introduced by the amplifier upon the modulation, regardless of the strength of the input signal.

It is an object of the present invention, accordingly, to provide an automatic gain-control system having a response which varies in a predetermined manner with the frequency at which amplitude changes of the incoming signal occur.

Another object of the present invention is to provide an automatic gain-control system for a receiver of modulated carrier waves which causes no appreciable phase shift of the envelope of modulating signals lying within a predetermined frequency band.

It is an additional object of the present invention to provide an improved automatic gain-control system for modulated carrier receivers which is sufficiently rapid in operation to correct for fading and other relatively slow changes in the received signal strength, but which functions without introducing any appreciable phase shift of the modulation envelope as a function of the strength of the received signal.

Yet another object of the present invention is to provide an improved automatic gain-control system which is highly effective in counteracting relatively slow changes in the amplitude of the incoming signal, but which has a relatively negligible response to changes in the amplitude of the incoming signal which occur within a predetermined band of frequencies.

Still a further object of the present invention is to provide an automatic gain-control system incorporating a frequency-selective filter network having no inductively reactive components.

In accordance with the present invention, there are provided an amplifier having input and output terminals and electronic gain-control means, and means for applying a modulated carrier wave to the input terminals. A rectifier is connected to the output terminals, and a filter network is connected between the rectifier and the gain-control means. This network has such characteristics that the gain of the amplifier is varied as an inverse function of the strength of the carrier wave with no appreciable variation in the phase of its modulation envelope. In a preferred embodiment of the invention, the filter network is of the non-inductive null type comprising impedance elements arranged in a bridged-T configuration. In a modified embodiment of the invention, the filter network may be of the parallel-T or twin-T configuration, in which the impedance elements are also of the non-inductive type. Preferably, the network is so designed that it has substantially zero phase shift and relatively low transmission at the modulation frequency, but has an effective time constant of the order of the period of the modulation frequency.

The invention in another of its aspects relates to novel features of the instrumentalities described herein for achieving the principal objects of the invention and to novel principles employed in those instrumentalities, whether or not these features and principles are used for the principal objects or in the same field.

The above and other objects and features of the invention will be better understood by reference to the following description taken in connection with the accompanying drawing, in which like components are designated by like reference numerals and in which:

Fig. 1 is a circuit diagram, partly in block form, of an amplifier incorporating an automatic gain-control system in accordance with the present invention;

Fig. 2 shows, in graphical form, the performance of an arrangement in accordance with Fig. 1 compared with that employing a previously known type of filter network; and

Fig. 3 is a circuit diagram of a modified frequency-selective network which may be substituted for that employed in the gain-control system of Fig. 1.

Referring to Fig. 1 of the drawing, there is shown an amplifier 10 having input terminals 11 and output terminals 12. Amplifier 10 includes a vacuum tube 13 and, if desired, may include additional amplifying stages indicated by block 14.

Vacuum tube 13, which is preferably of the pentode type, has its control electrode 15 coupled to one of input terminals 11 by means of capacitor 16. Cathode 17 of vacuum tube 13 is connected to ground through resistor 18 which is by-passed by capacitor 19. Screen-grid 20 of vacuum tube 13 is connected, at terminal 21, to a source of moderately high positive potential with respect to ground. Suppressor-grid 22 is connected directly to cathode 17. Plate 23 of vacuum tube 13 is coupled, by means of capacitor 24, to the input of block 14, the output of which is connected to output terminals 12 of amplifier 10. It will be understood that, if no additional amplifying stages are employed, capacitor 24 is connected directly to the high-potential one of output terminals 12. Plate 23 is also connected, through load resistor 25, to a terminal 26 which in turn is supplied with a relatively high positive potential with respect to ground.

The ungrounded output terminal 12 of amplifier 10 is coupled, by means of capacitor 27, to the anode or plate 28 of a vacuum tube 29, which functions as a diode. Cathode 30 of vacuum tube 29 is connected to the movable arm 31 of a potentiometer 32, and is by-passed to ground by means of capacitor 33. The ungrounded terminal of potentiometer 32 is connected through resistor 33' to a terminal 34 to which is applied a relatively high positive potential with respect to ground. The grid of vacuum tube 29 may be connected to plate 28 as shown, if desired.

Plate or anode 28 of vacuum tube 29 is also connected, through a resistor 35, to the input terminal of a three-terminal filter network 36. Filter network 36 comprises series resistors 37 and 38, shunt capacitor 39, and bridging capacitor 40, all connected in a bridged-T configuration as shown. The terminal of network 36 which is common to its input and output circuits is grounded, as shown at 54.

The output terminal of filter network 36 is connected to the grid 41 of a vacuum tube 42, and is also connected to ground by means of resistor 43 which may be shunted by a capacitor 44 if desired. The cathode 45 of vacuum tube 42 is connected through resistors 46 and 47 in series to a

terminal 48, to which is applied a relatively high negative potential with respect to ground. The plate 49 of vacuum tube 42 is connected at terminal 50 to a moderately high source of positive potential with respect to ground. The junction 51 of resistors 46 and 47 is connected, through coil 52, to control-grid 15 of vacuum tube 13. Junction 51 is also connected, by lead 53, to block 14.

In operation, a modulated carrier wave is applied to input terminals 11. Assuming for the moment that junction 51 is substantially at ground potential, a suitable bias voltage for control-grid 15 of vacuum tube 13 is developed across cathode resistor 18 due to its normal plate current, so that this tube provides substantially maximum amplification of the input signal wave. The signal wave is subjected to further amplification in unit 14, it being understood that the provision of such additional amplifying stages is optional. The amplified signal wave appears at output terminals 12 and is applied to anode 28 of vacuum tube 29, which operates as a diode rectifier to demodulate the modulated carrier wave.

Assuming for the moment that movable arm 31 is at the grounded terminal of potentiometer 32, a voltage having a negative direct-current component corresponding to the rectified carrier wave and an alternating component which is a function of the modulation is supplied to filter network 36. The purpose of potentiometer 32 is to provide an adjustable threshold for the automatic gain-control system. If movable arm 31 is moved to the left, a positive potential is applied to cathode 30 of vacuum tube 29, and hence no rectification or demodulation takes place until the signal voltage applied to anode 28 exceeds this threshold voltage. The provision of such an adjustable threshold is optional, and is in no sense to be considered an essential element of the present invention.

Due to the action of filter network 36, the alternating component of the output of rectifier 29 due to the modulation is greatly attenuated, so that the voltage developed across resistor 43 and applied to grid 41 of vacuum tube 42 is substantially direct and of a magnitude depending upon the strength of the signal wave applied to input terminals 11. The polarity of this voltage is such that grid 41 becomes increasingly negative with respect to ground as the input signal strength increases. Vacuum tube 42 functions as a cathode follower. The potentials applied to terminals 48 and 50, together with the values of resistors 46 and 47, are normally so chosen that, when no voltage is present at the output of filter network 36, junction 51 is substantially at ground potential. When there is an output voltage from filter network 36, however, junction 51 becomes negative with respect to ground, to an extent dictated by the value of the voltage applied to grid 41.

Thus it will be seen that, whenever the modulated carrier wave applied to input terminals 11 exceeds a predetermined value, a direct-current control voltage having a small ripple component of modulation frequency will be developed at the output of filter network 36 and utilized by means of vacuum tube 42, to provide a control-grid voltage for vacuum tube 13 of a polarity which tends to reduce the amplification of this tube as the signal strength increases. If unit 14 is used, the control voltage may also be applied to its amplifying tube or tubes by means of lead 53. Thus

the amplitude of the output signal at terminals 12 will be maintained substantially constant in spite of wide fluctuations in the strength of the input signal. Furthermore, due to the characteristics of filter network 36 as explained more fully below, the automatic gain-control system will have substantially no effect upon the phase of the modulation as the signal wave passes through amplifier 10, and relatively little effect upon the amplitude of the modulation.

The performance of the arrangement of Fig. 1, compared with that of previously known systems, will become more apparent by reference to Fig. 2 of the drawing. In this figure, the ordinate axis represents the relative amplitude of the control voltage developed at the output of filter network 36, as for example the voltage developed across resistor 43, compared with the zero-frequency value of this voltage, it being assumed that the output voltage from rectifier 29 remains unchanged. The ordinate axis also represents relative phase between the modulation voltage appearing at output terminals 12 and the ripple voltage developed across resistor 43. The abscissa axis of Fig. 2 represents frequency in cycles per second.

Curve 60 in Fig. 2 represents the relative amplitude obtained in an arrangement in accordance with Fig. 1, which has been designed specifically for use with a nominal modulation frequency of 30 cycles per second. It will be observed that the half-power point (at which the relative amplitude is approximately 0.7) occurs at approximately 3 cycles per second. It will also be noted that, at 30 cycles, the relative amplitude is less than 0.2. Curve 61 shows the phase shift which occurs in the system of Fig. 1. As shown by this curve, the phase shift is substantially zero at 30 cycles per second, and has a maximum deviation from zero of plus or minus 10 degrees as the frequency varies from 25 to 35 cycles per second. The effective time constant of this system is approximately 0.053 second.

Curves 62 and 63 show the performance of a system similar to that of Fig. 1, except that filter network 36 was replaced by a conventional resistance-capacitance network. In order to provide comparable performance in the low-frequency region, the latter network was so designed that its half-power point also occurred at 3 cycles per second, a time constant of 0.053 second. At 30 cycles, as shown by curve 62, this system has a relative amplitude of approximately 0.1. Such an arrangement does not provide satisfactory operation, however, in view of its extremely large phase shift which, as shown by curve 63, is greater than 80 degrees at the modulation frequency.

In a further attempt to duplicate, by means of a conventional filter, the improved performance realized by the arrangement of the present invention, the resistance-capacitance network was redesigned to have substantially zero transmission at 30 cycles. As shown by curve 64, this result was obtained but, as also clearly shown by the curve, at the expense of proper performance in the low-frequency region. The half-power point in this case occurs at approximately 0.16 cycle per second, and the 1.0-second time constant of such a design is much too long to provide satisfactory operation in a 30-cycle system.

It will be apparent from Fig. 2 that neither the expedient of employing a resistance-capacitance network having a time constant so long that its transmission at 30 cycles per second is substantially zero, nor the use of a resistance-

capacitance network having a time constant substantially equal to the effective time constant of filter network 36 but with a very appreciable phase shift at 30 cycles, provides performance in any way comparable with that achieved in accordance with the present invention. To state this advantage of the present invention in another way, it provides a filter network which has no appreciable effect upon the phase and which is approximately twenty times faster than would be a resistance-capacitance filter having no appreciable effect upon the phase of the modulation voltage. Thus the arrangement of the present invention is capable of following and correcting for relatively rapid changes in the strength of the input wave at input terminals 11 without at the same time appreciably affecting the phase of the modulation carried by such signals.

Fig. 3 of the drawing shows a filter network 65 which may be substituted for filter network 36 of the arrangement of Fig. 1. Filter network 65 comprises series resistors 66 and 67 together with shunt capacitor 68 in one branch of a parallel-T or twin-T configuration, and series capacitors 69 and 70 associated with shunt resistor 71 in the other branch thereof. Since the transfer impedance of such a network varies relatively rapidly with changes in frequency near the frequency at which it is designed to operate, the filter network of Fig. 3 is especially adapted for use in a system in which the modulation frequency remains substantially constant. Under such a condition, the network of Fig. 3 is capable of providing substantially zero transmission as well as substantially zero phase shift at the modulation frequency.

In one successful embodiment of the invention in accordance with Fig. 1, which was designed for 30-cycle modulation, vacuum tube 13 was a type 6AK5 and vacuum tubes 29 and 42 were each a type 6C4. The following values of resistance and capacitance were employed:

Resistor 18	ohms	300
Resistor 25	do	1,000
Potentiometer 32	do	25,000
Resistor 33	do	620,000
Resistors 35 and 43	megohms	1.5
Resistors 37 and 38	ohms	240,000
Resistor 46	do	750
Resistor 47	do	60,000
Capacitors 16 and 24	micromicrofarads	100
Capacitors 19 and 44	microfarad	0.001
Capacitor 33	do	0.01
Capacitor 27	do	0.0039
Capacitor 39	do	0.1
Capacitor 40	do	0.015

The potentials applied to terminals 21, 26, 34, 48 and 50 were respectively +100, +250, +250, −250 and +120 volts.

While there has been described what is at present considered the preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. In combination, an amplifier having input and output terminals and including an electron tube having a control electrode, means for applying a modulated carrier wave to said input terminals, a rectifier connected to said output terminals, and a filter network connected between said rectifier and said control electrode, said network comprising a first branch including series resistive elements and a shunt capacitive element, and a second branch including a capacitive element connected in shunt with the first branch, the latter capacitive element being of such value as to eliminate substantially phase shift of the modulation envelope at the output of the filter network.

2. In combination, an amplifier having input and output terminals and including an electron tube having a control electrode, means for applying a modulated carrier wave to said input terminals, a rectifier connected to said output terminals, and a filter network connected between said rectifier and said control electrode, said network comprising impedance elements arranged in a T configuration and a capacitive element connected in shunt therewith, said capacitive element being of such value as to eliminate substantially phase shift of the modulation envelope at the output of the filter network, whereby the gain of said amplifier is varied as an inverse function of the strength of said carrier wave with no appreciable variation in the phase of its modulation envelope.

3. In combination, an amplifier for radar scanners and the like having input and output terminals and including an electron tube having a control electrode, means for applying a carrier wave to said input terminals modulated according to scanner spin frequency, a rectifier connected to said output terminals, and a filter network designed to reject spin frequency components connected between said rectifier and said control electrode, said network comprising impedance elements arranged in a parallel-T configuration, whereby the gain of said amplifier is varied as an inverse function of the strength of said carrier wave with no appreciable variation in the phase of its modulation envelope.

4. In combination, an amplifier for radar scanners and the like having input and output terminals and including an electron tube having a control electrode, means for applying a carrier wave to said input terminals modulated according to scanner spin frequency, a rectifier connected to said output terminals, and a non-inductive filter network connected between said rectifier and said control electrode for rejecting modulation components, said network comprising impedance elements arranged in a bridge-T configuration, whereby the gain of said amplifier is varied as an inverse function of the strength of said carrier wave with no appreciable variation in the phase of its modulation envelope.

5. In combination, an amplifier for radar scanners and the like having input and output terminals and including an electron tube having a control electrode, means for applying a carrier wave to said input terminals modulated according to the spin frequency of the scanner, a rectifier connected to said output terminals, and a non-inductive filter network connected between said rectifier and said control electrode, said network comprising impedance elements arranged in a parallel-T configuration so proportioned as to eliminate modulation components, whereby the gain of said amplifier is varied as an inverse function of the strength of said carrier wave with no appreciable variation in the phase of its modulation envelope.

6. In an automatic gain-control system for radar scanners and the like, in combination, an amplifier having input and output terminals and including an electron tube having a control electrode, means for applying a carrier wave modulated according to the spin frequency of the scanner to said input terminals, a rectifier connected to said output terminals, and a filter network comprising resistance and capacitor elements arranged in parallel-T configuration connected between said rectifier and said control electrode, said network having substantially zero phase shift and relatively low transmission at said modulation frequency, whereby the gain of said amplifier is varied as an inverse function of the strength of said carrier wave with no appreciable variation in the phase of its modulation envelope.

7. In combination, an amplifier for radar scanner systems and the like having input and output terminals and including an electron tube having a control electrode, means for applying a carrier wave modulated according to scanner spin frequency to said input terminals, a gain-control circuit including a rectifier connected to said output terminals, and a filter network of the non-inductive null type connected between said rectifier and said control electrode, said network com-

prising a first branch including resistive and capacitive elements connected in accordance with a T configuration and a second branch shunting the first branch comprising a capacitor element, the network having substantially zero phase shift at said modulation frequency and an effective time constant of the order of the period of said modulation frequency, whereby the gain of said amplifier is varied as an inverse function of the strength of said carrier wave with no appreciable variation in the phase of its modulation envelope.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,836,556	Schelleng	Dec. 15, 1931
2,106,785	Augustadt	Feb. 1, 1938
2,240,533	Wilson	May 6, 1941
2,284,102	Rosencrans	May 26, 1942
2,302,866	Hunt	Nov. 24, 1942
2,307,308	Sorensen	Jan. 5, 1943
2,350,803	Newcomb	June 6, 1944
2,382,097	Purington	Aug. 14, 1945