

July 29, 1941.

C. W. HANSELL

2,250,532

RADIO RELAYING SYSTEM

Filed Oct. 29, 1938

3 Sheets-Sheet 1

Fig. 1

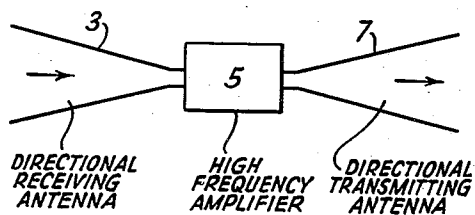


Fig. 2

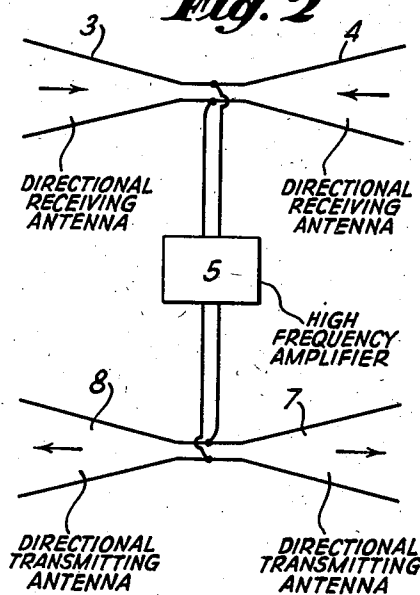


Fig. 3

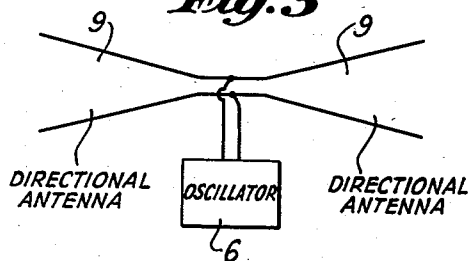


Fig. 4

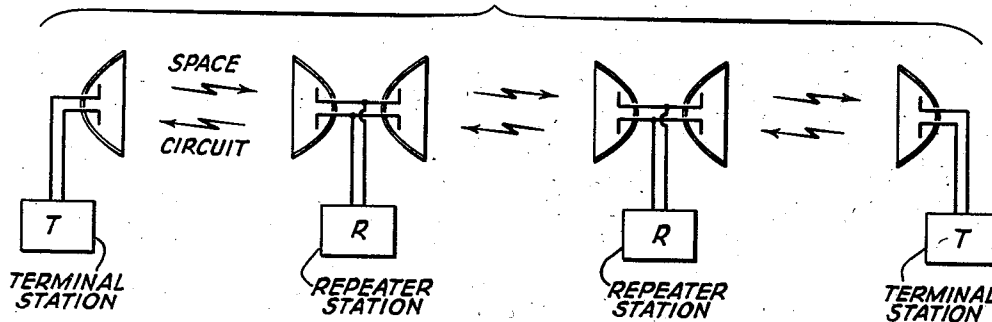
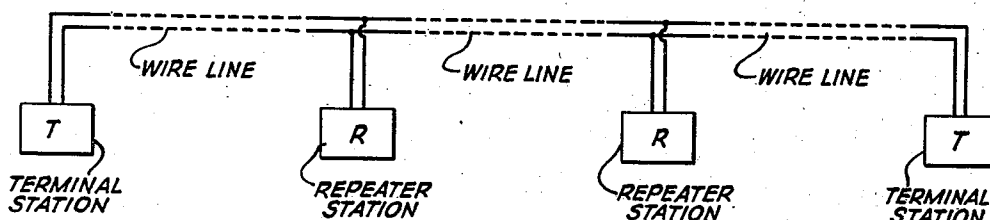


Fig. 5



INVENTOR.
CLARENCE W. HANSELL

BY

H. G. S. S. S.

ATTORNEY.

July 29, 1941.

C. W. HANSELL

2,250,532

RADIO RELAYING SYSTEM

Filed Oct. 29, 1938

3 Sheets-Sheet 2

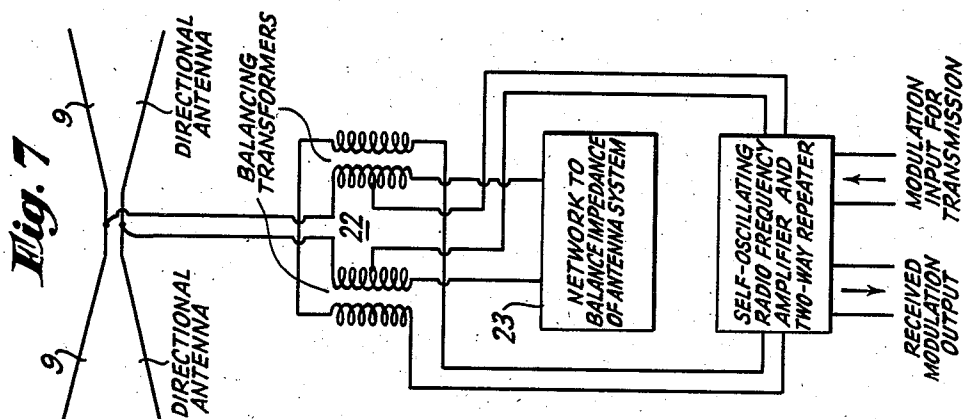
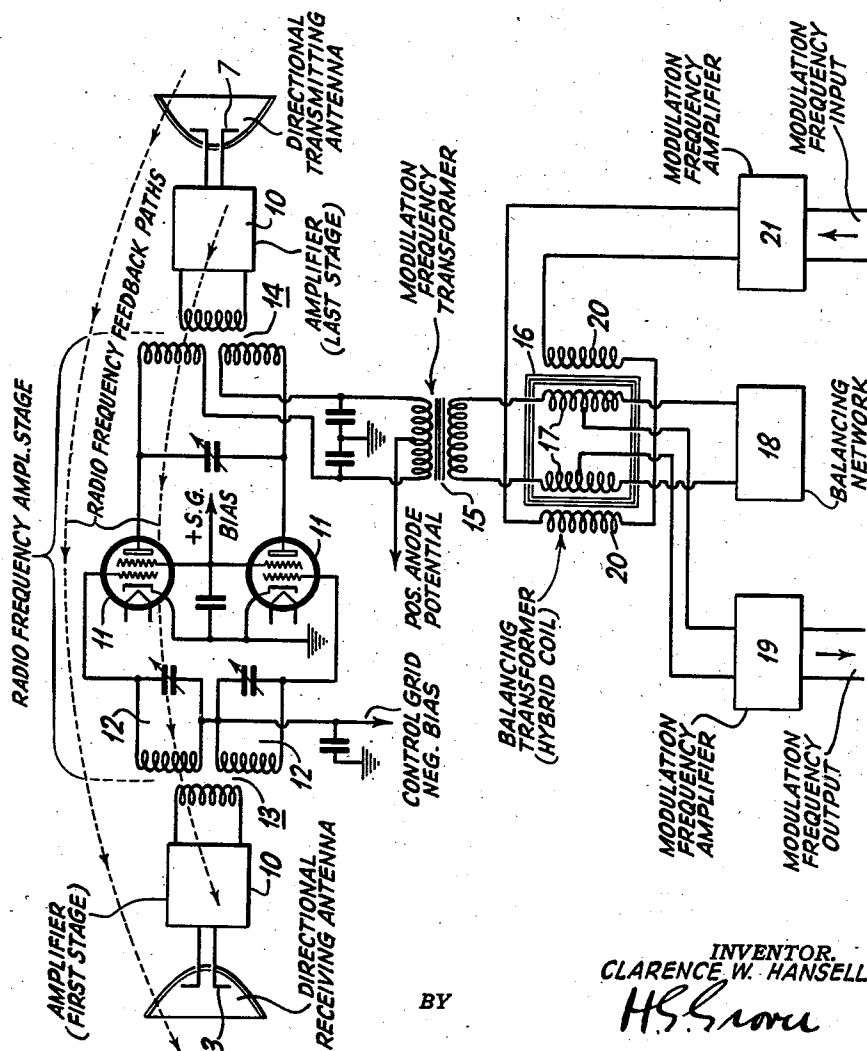


Fig. 6



INVENTOR.
CLARENCE W. HANSELL
H.S. Krom
ATTORNEY.

July 29, 1941.

C. W. HANSELL

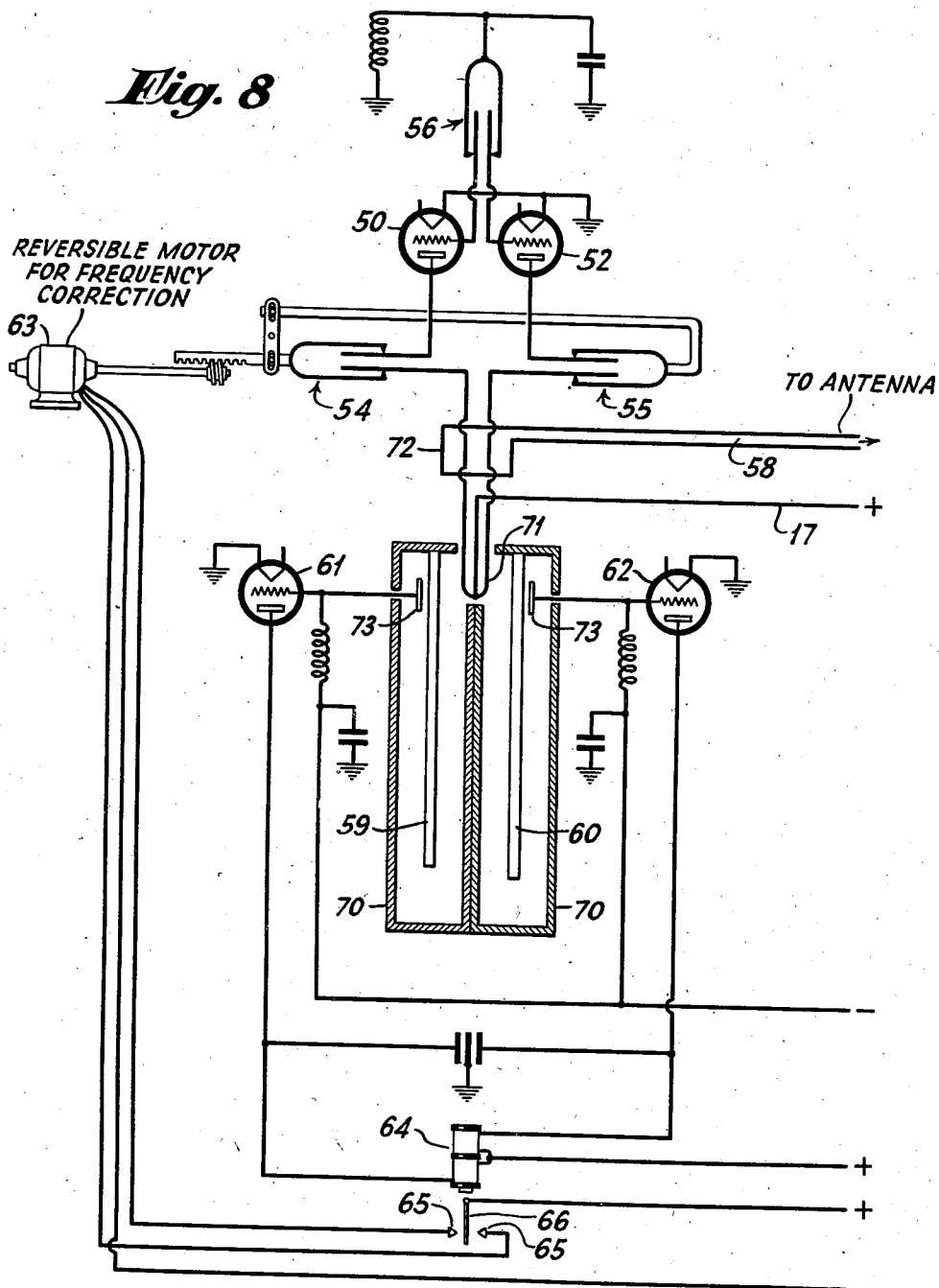
2,250,532

RADIO RELAYING SYSTEM

Filed Oct. 29, 1938

3 Sheets-Sheet 3

Fig. 8



BY

INVENTOR.
CLARENCE W. HANSELL
H. S. G. Stone
ATTORNEY.

UNITED STATES PATENT OFFICE

2,250,532

RADIO RELAYING SYSTEM

Clarence W. Hansell, Port Jefferson, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

Application October 29, 1938, Serial No. 237,627

17 Claims. (Cl. 250—15)

This invention relates to automatic radio relaying systems and more particularly to improvements in apparatus and methods for transmitting communications over considerable distances by means of ultra-short wave carriers.

Based on our present knowledge of frequencies from about 40 up to 500 megacycles it seems evident that long circuits in this band must be dependent upon automatic radio relaying through relay stations placed from 10 to 100 miles apart, depending upon the terrain. To be justified economically these stations must be capable of operation reliably without an operator or attendant.

If we should include in each relay or repeater station a receiver and a transmitter a serious problem would at once present itself in that the depth of carrier modulation would tend to vary in the repeating process and after many repetitions might tend to disappear entirely or increase beyond the limits of 100% modulation. The adjustments of a long series of repeaters required to hold the percentage modulation constant all along the system would be so complex and delicate that such practice would be very difficult if not impossible without the use of special modulation adjusting circuits at some or all of the repeaters. The variations in signal strength at each receiver, due to variations in weather, power voltages in previous repeaters, etc., would cause great and often cumulative variations in modulation inputs to the transmitters. This effect can not be overcome by any ordinary automatic volume control system but it could be overcome by employing a pilot channel in the system, supplying continuous modulation of a small percentage on a frequency different from the communication channels. Energy of this pilot channel might be utilized at all or occasional repeaters to operate a volume control to hold the repeated percentage modulation constant on the pilot channel and, therefore, substantially constant on the communication channels also. This system of modulation amplification control would operate in a manner very much like pilot channel control systems which have been employed on long wire line carrier telegraph and telephone circuits.

However, the use of receivers and transmitters with pilot channel modulation control still would not solve the radio relaying problem satisfactorily because the equipment required would be costly and too complex for satisfactory operation in a relay system. Due to the very large amount of interdependent equipment in such a system

maintenance of continuous communication would be extremely difficult if not impossible.

Another defect of prior radio relaying systems has been that, when signals were received on one radio carrier frequency they were retransmitted on another radio carrier frequency to prevent feedback of modulation energy from transmitter to receiver in a manner to cause uncontrolled modulation, or modulation frequency oscillation, in the repeater system. This oscillation, or "singing" in amplifier and signal repeating equipment is a very well known problem in designing many different kinds of communication equipment.

The necessity for use of different radio carrier frequencies in the prior radio relaying systems, in order to prevent "singing" has required the use of a large number of frequencies in any one radio relaying communication system. This is very undesirable because it reduces the total amount of communication which may be carried on in a given frequency band. In fact, the very possibility of establishing radio relaying systems at all in the United States has been threatened because of the large number of frequencies required for a single relaying system.

Accordingly, a primary object of the present invention is to provide radio relaying equipment which will be simple, reliable, relatively low in cost and relatively free from the practical operating difficulties of prior systems.

Another object of my invention is to provide a radio relaying system which is capable of being used simultaneously for transmission of separate signals, or groups of signals, in both directions through the system. In other words, one of my objects is to provide a two-way radio repeater.

A further object is to provide a combination of repeating station devices such that the functions of a receiver and a transmitter may be combined in a unitary circuit arrangement which, at the same time, may serve as a repeater of frequency modulated waves.

A more specific, but nevertheless important object of my invention is to provide a radio relaying system in which a single radio carrier frequency may be used throughout the whole of a single chain of repeaters.

For radio repeating, or relaying, in order that it may be impossible for the depth of modulation to vary greatly throughout the system, I preferably employ frequency modulation, instead of amplitude modulation, and operate all transmitters and receivers in the system on exactly the same radio carrier frequency, or multiples of the same frequency. Then a repeater or relay

station may consist simply of suitable antennas associated with a radio frequency amplifier capable of increasing the power of received signals and re-radiating them. The amplifier, since it is required to transmit only frequency modulated carrier waves, does not require a linear or proportional amplitude modulation characteristic, such as would be required for repeating amplitude modulated carrier waves. In fact, it is preferable that the amplifier be operated with amplitude limiting so that a variation in amplitude of the received frequency modulated waves will cause little or no variation in the amplitude of the transmitted waves. Such an amplifier is capable of high efficiency in converting direct current power to radio frequency power, a characteristic which is lacking in proportional amplifiers for faithfully repeating amplitude modulated waves. Furthermore, if the amplifier is one having several amplifier stages, in cascade, the effect of power supply variations is not cumulative throughout the several stages. Variations in all but the last stage may be eliminated by the limiting within a single repeater and even variations in the last stage are eliminated by the limiting in the next repeater of a relay system.

Furthermore, the amplifier system in any one repeater system need not be free from self-oscillation in order to perform its required function. The amplification in any one repeater may be so great that the input required to cause amplitude limiting in the repeater is less than the input due to feed-back from output circuits to input circuits of the repeater. It is only necessary that the received signal power be sufficient to control the frequency of operation of the repeater system and to frequency modulate it. The amount of received power required to control the frequency of an oscillating amplifier may be considerably less than the amount of input power required to build up full amplitude of radio frequency oscillations in the output of the amplifier. This means that a repeater to repeat frequency modulated waves, without change of carrier frequency, may be built to operate on received signal power much less than that which would be practical for repeating amplitude modulated waves and that the requirement for reducing feed-back from output to input circuits to a low level is less stringent.

The ease with which a small amount of radio frequency power can control the frequency of oscillation of an oscillator, adjusted to oscillate naturally at about the same frequency, has often been observed by persons who have attempted to use self-oscillating heterodyne detectors at very high frequencies. Usually it is found that a low beat note frequency, or even a frequency which is audible at all, can not be obtained because the detector oscillations drop into synchronism with the input frequency power as soon as the detector oscillation frequency approaches that of the input power frequency. I have often found it necessary to operate the detector at an oscillation frequency of a half, a third or some other sub-multiple of the received power frequency before it became possible to produce and control an audio frequency beat. In this case the audio beat note was provided by beating between the received radio carrier wave and a harmonic or multiple of the detector oscillation. This experience indicates that it is relatively easy to hold one oscillator in synchronism with another and that only a very small coupling be-

tween them is needed if they are adjusted to hold naturally about the same frequency.

The foregoing considerations suggest the employment of a regenerative amplifier or oscillator adjusted so that the regeneration is not too great but so that a receiving antenna may be coupled to the input circuit of the amplifier, or oscillator, while a transmitting antenna is coupled to the output circuit. A repeater is thus provided the output frequency of which may be controlled and modulated by a frequency modulated carrier of the same frequency received from a distant transmitter.

So long as the received signal does not fall below a certain minimum power value, the response of such relay is substantially independent of the received power. Therefore, it is less subject to the effects of weather, power supply voltage and other variations than conventional types of repeaters.

In order that the relay may be most sensitive, that is, require minimum energy to control its frequency, the relay circuits should have a flat frequency characteristic over the band required for modulation. Ordinary resonance circuits are relatively flat around their resonance frequency. By using coupled circuits or two coupled oscillators the flatness may be accentuated or widened, or even made relatively unstable so as to regenerate on the modulation or correct the response characteristic. If it is desired to relay a modulation frequency band of 0 to 10,000 cycles on a carrier of 200,000,000 cycles the response required is over a band of only 1 part in 10,000 of the carrier frequency and so hardly requires special means for widening the response characteristic.

However, there is a probability that in practice the repeater might be required to operate by means of two coupled oscillators whose grid or plate currents would vary differentially if the tuning deviated from the incoming frequency. The differential variations in current may then be used to bring about an automatic correction of the circuit adjustments in a manner already known in the art.

A repeater station of the kind just outlined is primarily suitable for reception from one direction and retransmission in another direction. It may be used for two-way simultaneous repeating by employing two receiving antennas in parallel or series connection to the amplifier input and two transmitting antennas in parallel or series connection to the amplifier output. One receiving and one transmitting antenna would be arranged to operate in one of the desired directions and the other receiving and other transmitting antenna would be arranged to operate in the other direction. The design and arrangement of the antennas should be such that there is very little or no coupling from transmitting antennas to receiving antennas.

It is possible, as a general principle, to operate each repeater in both directions simultaneously without employing two receiving and two transmitting antennas. There are two ways in which this may be done. One way is to employ balancing arrangements similar to those used in two-way repeating on telephone lines except that the circuits would, of course, be designed and adjusted to operate at very much higher frequencies. For descriptions of such systems reference is made to my co-pending applications Serial No. 199,420 and 199,421, both filed on April 1, 1938, and each entitled "Radio relaying system." See

also my application Serial No. 216,872, filed July 1, 1938.

The second way is to couple both antennas, one for each direction, or a single bidirectional antenna, to an oscillator. The oscillator may be so designed that the frequency of its oscillation may be controlled by received power from distant transmitters or repeaters and the power output from the oscillator to the antennas may be far greater than the received power.

This latter arrangement, in which a series of widely spaced oscillators are coupled together through a space circuit, or through a wire line in the case of wire line communication, to force all the oscillators to operate on a common mean frequency, is believed to be a new conception. It may be likened to a power network in which widely separated power plants and distributed loads are all tied together through transmission lines and forced to operate on a common mean frequency. In such a system a variation in phase or frequency of one generator causes a variation in phase or frequency of all the generators. In other words, any one generating plant could conceivably be used to send messages to any other generating plant by modulating the steam input to the turbines driving its own generators, so as to vary the phase and frequency of current in the whole system.

To illustrate embodiments of my invention reference will be made to the accompanying drawings, in which

Figure 1 shows a repeater station for receiving modulated carrier waves from one direction and repeating them with much greater strength in a given direction;

Fig. 2 shows a repeater station for simultaneously receiving modulated waves from two directions and repeating them with much greater strength simultaneously in two directions;

Fig. 3 shows a repeater station for simultaneously receiving and repeating frequency modulated waves in two directions;

Fig. 4 illustrates diagrammatically a complete radio communication circuit including two terminal stations and two repeaters;

Fig. 5 illustrates diagrammatically a wire line carrier communications circuit with two terminal stations and two repeater stations;

Fig. 6 shows a circuit arrangement adapted for several modes of operation, including (1) receiving, amplifying and repeating modulated radiant energy, (2) deriving a modulated output from such energy, and (3) applying modulations to such energy; any two or more of these modes of operation being capable of simultaneous performance;

Fig. 7 shows a simplified embodiment for performing the functions of the system shown in Fig. 6, and

Fig. 8 illustrates another embodiment of the invention having automatic tuning adjustments.

Referring first to Fig. 1, I have shown a radio repeating station consisting of a directional receiving antenna 3 for picking up frequency modulated radio waves and delivering power of the waves to the input of an amplifier 5. The amplifier supplies greatly increased power to another directional antenna 7 from which waves are radiated toward a distant receiving station, or toward another repeating station. It will be clear to persons skilled in the radio art that the directional antennas may be of any of the well known types. The amplifier system may include a plurality of stages and preferably is adapted

for amplifying frequency modulated radio waves. The different stages may be interconnected as illustratively shown in Fig. 6. The amplifier used for frequency modulated waves in this instance differs to some extent from those commonly used. The early stages may be similar to those commonly used in receivers for high frequency amplification. The later stages may be similar to those used in transmitters in which an increase in amplitude of radio frequency input to one of the stages will produce little or no change in output. In other words, the later stages are preferably operated as class C amplifiers with amplitude limiting. The use of this type of amplifier in the later stages eliminates the effects of amplitude variations in other equipment in the chain and in the space circuit. It substantially reduces the effect of power supply voltage variations upon the repeater output. In addition class C amplitude limited amplifiers have a relatively high efficiency in converting direct current power into radio frequency power so that the power requirements for relaying are substantially reduced.

In the amplifier of Fig. 1 it should be understood that there may be no distinct dividing line between the receiver type, or class A, amplifiers in the early stages and the transmitter type, or class C, amplifiers in the later stages. Between the first and last stages of amplifier I may also employ stages which act as class B amplifiers. Other stages may be adjusted to operate as intermediate between class A and class C amplifiers.

For definitions of class A, AB, B and C amplifiers, which definitions have been accepted in the art, reference may be made to page 7 of "Standards on Electronics," 1938, published by The Institute of Radio Engineers, Inc., 330 West 42nd Street, New York, New York.

It should further be understood that the mode of operation of any particular stage of amplification in amplifier 5 of Fig. 1 may depend almost entirely upon the input signal power to that stage. I contemplate adjusting the D. C. potentials of each stage so that class A amplification is obtained in the earliest stages, class AB in the next stages, class B in the next and class C in the last stages. Furthermore I contemplate obtaining control electrode D. C. bias potential in the later stages partly from a fixed source of such a value as to permit the amplifiers to operate as class A, AB or B amplifiers and partly from grid leak resistance action which will automatically increase the control electrode D. C. bias potential to provide class C amplification when the signal input becomes high enough. In this way the later stage tubes are protected from excessive internal power loss in case of signal failure and, at the same time, are made to adjust their amplification or power gain automatically in a direction tending to hold constant output power regardless of input high frequency and D. C. potential variations.

Further discussion of automatically adjustable bias potentials in amplifiers will be found on page 2, second column of my U. S. Patent #2,032,208 issued February 25, 1936. In fact, amplifier 5 of Fig. 1 may employ circuits similar to those disclosed in Patent #2,032,208 for repeating signals at a frequency which is a multiple of the input frequency, if the crystal oscillator initial source is replaced by a receiving antenna source. Likewise, by tuning all stages for the input frequency, thus omitting frequency

multiplication, arrangements similar to those described in Patent #2,032,208 may be used for signal repeating without change of frequency.

A further feature of the amplifier of Fig. 1 is that the number of stages and the overall amplification are made so great that very weak frequency modulated radio signals may be picked up, amplified and re-radiated. As previously explained the amplification may be increased to a ratio so high that a very small fraction of transmitted power, which unavoidably reaches the input terminals of the amplifier, may cause the amplifier to oscillate continuously by itself. In spite of self-oscillation in the amplifier frequency modulated radio carrier wave signals may be repeated because it is only necessary for the received power to control the frequency of oscillation. Such a condition could not be tolerated if amplitude modulated waves were to be repeated, because self-oscillation and limiting in the amplifier would remove or distort the modulation. Therefore, by employing frequency modulated waves in my communications and repeater system, I am able to reach down to much lower signal levels than would be possible in an amplitude modulation system.

The amplifier should, of course, be designed to provide for frequency selectivity. This is no new requirement since substantially all radio frequency amplifiers now in use must employ tuning of tubes and circuits, which automatically introduces frequency selectivity. In this case I tune the circuits of various amplifier stages to somewhat different frequencies in order to flatten out or remove selectivity between frequencies within the band to be used for the useful modulation side bands, or within a somewhat larger band to allow for resonant frequency drift. In other words, I so adjust the amplifier circuits that a minimum of received carrier power is required to control the frequency of operation of the amplifier and to modulate it in response to the signal modulation.

An alternative means for flattening out or removing amplifier selectivity within the communication frequency band is to employ coupled circuits and band pass filter circuits in ways already well known in the art. Eventually other types of amplifiers than those now commonly used may become available, such as the secondary electron emission type amplifier, in which case no tuning is required for intermediate stages and all selectivity may be obtained in input and output circuits.

Of course, in designing a repeater such as that shown in Fig. 1, and in some of the other figures, the feed-back between transmitting and receiving circuits and antennas associated together in a repeater should be made as small as possible. This requires adequate electrical shielding as well as sufficient spacing and directivity of antennas.

In Fig. 2 I have shown a repeater similar to that of Fig. 1 except that I have added another receiving antenna 4 and another transmitting antenna 8, thus making it possible to receive frequency modulated waves from two directions simultaneously and to re-transmit them in two directions simultaneously. This is accomplished by employing two receiving antennas and two transmitting antennas having sufficient spacing, directivity, and shielding so that very little power is fed back from output to input terminals of the amplifier. In this arrangement some power received from one direction is lost by re-radia-

tion from the receiving antenna for the other direction. Likewise transmitted modulation power for one direction is half wasted by radiation from the antenna pointed in the other direction. However, this lost power efficiency is a minor factor in the operation of a radio repeater system and can often be tolerated for the sake of repeating simultaneously in two directions with a single radio frequency amplifier.

It should be noted that the system of Fig. 2 may be extended to cover any number of directions by providing directional receiving and transmitting antennae for each direction. Alternatively two or more directions may be worked simultaneously by employing a single antenna for receiving, or a single antenna for transmitting, which has directivity broad enough to include the desired directions.

In Fig. 3 I have shown another form of two way repeater of frequency modulated radio waves. In this arrangement two directional antennas 9 are effective in two different directions and are coupled to an oscillator 6 which is adjusted to oscillate as nearly as possible at the frequency of a frequency modulated radio carrier wave which is to be repeated.

With this arrangement a received carrier wave arriving over a space circuit is only required to synchronize and control the frequency of the oscillator and the oscillator causes re-radiation of far more power than is received over the space circuit. Furthermore, it is possible to employ a chain of widely spaced repeaters of the type illustrated in Fig. 3, all held in synchronism and oscillating on a common frequency by virtue of coupling through the space circuits and antennas. Then, if the frequency of any one of the oscillators is modulated, it becomes possible to simultaneously modulate the frequency of all the oscillators. Various modulations may be applied to various oscillators to obtain a complex total modulation in the system by means of which a plurality of communications may be carried on simultaneously between different associated stations. In the system balancing arrangements and modulation frequency discrimination may be employed to permit separating one modulation communication channel from another.

In Fig. 4 I have illustrated a radio communications system having two terminal stations T, and a plurality of repeaters R of the type illustrated in either of Figs. 1, 2 and 3. By means of such a system, using balancing arrangements and frequency discrimination, a multiplicity of communications circuits between the two terminal stations may be operated simultaneously through the repeater stations.

In Fig. 5 I have shown a system similar to that of Fig. 4 except that the space circuits and antennas have been replaced with wire lines. Obviously any kind of carrier current connection between stations, such as concentric conductor transmission lines, tubes for transmission of electromagnetic waves, audio or supersonic mechanical waves, or any other kind of wave transmission, might be used.

The several systems which are schematically illustrated in Figs. 1 to 5 inclusive are distinguishable from systems of the prior art chiefly with respect to the improved combinations of operating elements to be provided at each repeater station, and also with respect to the methods to be employed. I will now explain in more detail what constitutes the novel combinations of equipment and how the adoption of my

improved methods are effective for producing new and advantageous results.

In Fig. 6 I have shown in greater detail a radio relaying, receiving and transmitting system corresponding to that illustrated in Fig. 1. This system is one which may be provided in completely standardized and interchangeable form for use at any station included in a single radio relay chain. It includes a directional receiving antenna 3, a radio frequency amplifier consisting of a plurality of stages 10, and a directional transmitting antenna 7.

The tubes and circuit connections for one of the intermediate amplifier stages are shown in detail, while block diagrams represent other stages. Two tubes 11 have independently tuned input circuits 12, both supplied through a transformer 13 with radio frequency power from a previous stage. These two input circuits are somewhat detuned from the operating carrier frequency, one being tuned to a higher and the other to a lower frequency so that the operating carrier frequency comes at a point on the steep side of each of the overlapping resonance curves for the circuit.

With this adjustment of the two input circuits there will be a differential variation in radio frequency input power to the two tubes when the carrier wave is varied or modulated in frequency above and below the normal value. This differential variation in input potential will cause a corresponding differential variation in direct current input to the anodes of the two tubes. This variation in anode current supplies modulation frequency output from the amplifier and, therefore, provides a means for receiving and detecting frequency modulation of the carrier wave. The modulation frequency output may be used for communication purposes or it may be used for monitoring purposes at points where no communication is required.

If the amplifier system has sufficient radio frequency power gain so that energy fed back from output to input circuits causes continuous oscillation of the amplifier then the frequency of this oscillation may be modulated by differentially varying electrode potentials of the two tubes having differentially detuned input circuits. In Fig. 6 I have shown means including a transformer 14 for differentially varying the anode potentials of the tubes in order to introduce frequency modulation at any desired station and simultaneously to derive a modulation frequency output in response to incoming signaling energy.

This desirable result is accomplished by the use of a modulation frequency transformer 15, one winding of which is center-tapped so as to provide equivalent conductive paths from a source of anode potential through itself to the anodes of the tubes 11. The other winding of transformer 15 is connected to a hybrid coil or balancing transformer 16 the purpose of which is to uncouple the modulation input and output circuits. This balancing transformer has preferably four coils, namely, a pair of center-tapped coils 17 each having a terminal connected to the transformer 15, a terminal connected to a balancing network 18 and a center-tap leading to a modulation frequency output amplifier 19. The other two coils 20 are series connected and are energized by a modulation frequency amplifier 21 which is controlled by any suitable source of modulation frequency input energy. By matching the impedance of the network 18 with that of the load connected to the terminals of the

coils 17 it is apparent that a duplex communications system is provided which is similar in some respects to those well known in the art, but, so far as I am aware, is combined in a novel manner with the ultra-high frequency relay system of my invention.

It will be noted that the system of Fig. 6, when it is self-oscillating, may be employed either as a transmitter, receiver, or relay of frequency modulated waves and can perform any combination of these functions simultaneously.

To understand how the system of Fig. 6 may simultaneously transmit, receive and relay signals it may be noted that the system is coupled to other similar systems through the antennas and space circuits sufficiently to force all to operate at a common radio frequency. For example, antenna 3 may receive radio frequency power from one distant station while antenna 7 may radiate to another distant station and this second distant station may transmit back to the first distant station. Thus three stations such as that shown in Fig. 6 may all be locked together on a common frequency by virtue of the space circuit coupling between them.

If now there is a modulation frequency input to any of the three stations, through amplifier 10, to coils 17 and through transformer 15, as illustrated in Fig. 6, their common frequency will be frequency modulated by the input. This modulation is balanced out of the modulation frequency output circuits at the station of origin by the balancing circuits 16, 17, 18, 20, etc., and consequently will be heard there weakly, if at all. It is not balanced out, however, as an effective source of outgoing modulations, but instead will be available for use at the other two stations. Thus modulation input to any one station is audible at both of the other stations. Also, at any station, all modulations introduced at both of the other stations are simultaneously audible. So long as no more than two stations employ the same modulation frequency at one time they may exchange messages at the same modulation frequencies simultaneously.

In the arrangement of stations just described messages from one station may pass through a second station acting as a relay and be used at a third station.

Of course, if many different modulation frequencies are in use at one time, originating at all the stations in the system, the resultant modulated frequency in the whole system will be due to the combination of the resultant forces of all the modulations combined.

The arrangement of Fig. 6 may be used for other combinations of stations than the three-station combination described, if suitable antennas and space circuit connections are supplied, such as, for example, those indicated in Figs. 2 and 7.

By employing two receiving and two transmitting antennas the system of Fig. 6 may be made the equivalent of Fig. 2. Also by applying the principles of balancing at radio frequencies described in my aforementioned co-pending applications Serial Nos. 199,420, 199,421 and 216,872, the system of Fig. 6 may be used to provide an equivalent of the systems illustrated in Figs. 3, 4 and 5.

In the arrangement of Fig. 7 the input and output circuits of a radio frequency amplifier, which may be self-oscillating, are both coupled to a bi-directional antenna system 9 through a balancing transformer 22 in such a manner that

the feed-back from output to input circuits may be kept small and the power gain of the amplifier may be made large. The balancing transformer 22 and antenna balancing or simulating network 23 are similar in principle of operation to the elements 16 and 18 appearing in the embodiment of Fig. 6. They differ principally in physical constants required due to operation at radio or carrier frequencies.

Further descriptions of the balancing transformer and network and of alternative antenna coupling arrangements will be found in my previously mentioned patent applications, Serial Nos. 199,420, 199,421 and 216,872.

In Fig. 7 the unit marked "Self oscillating radio frequency amplifier and two way repeater" may include all of the equipment indicated in Fig. 6, except the antennas and their high frequency connecting transmission lines. The unit may also include equipment shown in Figs. 1 and 2 of my patent application #216,872 or any other equipment for accomplishing similar purposes.

In practical operation of radio relaying systems one of the problems to be met is that of maintaining the carrier or mean frequency at a specified value within very close limits. Ordinarily this may be done conveniently by means of operating personnel at only one point in the system. It is, therefore, desirable that frequency corrections be accomplished by moving or setting the frequency of one oscillating amplifier in the system and that all other oscillating amplifiers be provided with an automatic means for adjusting their natural frequencies to the frequency of the control station. This may readily be done by means such as shown in Fig. 8. Here the differentially variable anode currents of the detector and modulator tubes are passed through a reversible or double throw relay 64. Then a steady state unbalance in the anode currents will throw the relay in one direction or the other to start and control the direction of rotation of a small motor 63. The motor may then drive the adjustments of variable reactances, particularly the reactances in the differentially tuned tube input circuits, to restore a condition of balance in the two input circuits.

In practical operation of radio relaying systems one of the problems to be met is that of maintaining the carrier or mean frequency at a specified value within very close limits. Ordinarily this may be done conveniently under the supervision of operating personnel at only one point in the system. It is, therefore, desirable that frequency corrections be accomplished by moving or setting the frequency of one terminal station transmitter, or oscillating amplifier, in the system and that all other amplifiers be provided with automatic means for adjusting their natural frequencies to the frequency of the control station.

I have described means for causing the natural frequency of an amplifier in a repeater station to be automatically adjusted to correspond with the frequency of received power in my copending patent application #216,872. Arrangements for accomplishing a similar purpose are described in my Patent #1,907,965, issued May 9, 1933, #2,095,980 issued October 19, 1937, and #2,104,801 issued January 11, 1938. Reference is also made to my Patents #1,999,902 issued April 30, 1935, and #2,088,203 issued July 27, 1937, and to my copending application Serial #230,438, filed November 2, 1927.

For stabilizing the frequency of the one master

station in a system of repeater stations, to which all other stations may adjust themselves automatically, I may employ, besides manual adjustments, arrangements similar to those described in the foregoing patents and applications by supplying a source of very constant frequency at the master station to which the master station will adjust itself automatically and to which all other stations in the system will adjust themselves in turn. The source of constant frequency may be one in which the frequency is stabilized and maintained at a constant predetermined value by means of a piezo-electric quartz crystal, a low loss resonant line, a tuning fork or any other means known in the art.

Another means for controlling the frequency of a master station is to apply a portion of the high frequency power of the oscillating amplifier or transmitter to sharply resonant circuits tuned on opposite sides of the desired frequency and to control a tuning means from differential variation in currents in the circuits, when the frequency is varied. Such automatic frequency control means are already known in the art.

So long as the space circuit coupling between repeater stations is great enough to maintain synchronism between them, all will operate on a common carrier frequency and all secondary stations may be held exactly at a correct operating frequency by controlling the frequency of the one master station. However, due to many different causes the secondary stations may not always tend to operate at the correct frequency but may be in such condition that failure to receive the master station would permit large frequency changes in secondary stations. This condition of practical operation is undesirable not only because of possibilities for interference to other communications circuits but also because, unless secondary stations are adjusted to hold nearly the correct operating frequency by themselves, they require larger received power to control them.

In Fig. 8 I have shown, by way of example, one kind of self oscillating radio repeater, which could correspond to those shown in Figs. 3 and 4, in which automatic means is provided for adjusting the natural frequency of oscillation to make it correspond with the operating frequency. Here the differentially variable anode currents of the detector tubes are passed through a reversible or double-throw relay 64. Then a steady state unbalance in the anode currents will throw the relay in one direction or the other to start and control the direction of rotation of a small motor 63. The motor may then drive the adjustments of variable reactances, particularly the reactances in the differentially tuned input circuits, to restore a condition of balance in the two detector output circuits.

The self-tuning system of Fig. 8 may be associated with repeater apparatus such as shown in Fig. 6, and is preferably constructed so that any number of oscillators located at different intercommunicating stations may be maintained in synchronism, though not necessarily in phase. The interactions between the oscillators may thus be compared with those which exist between a plurality of commercial power plant generators all tied in on a common power transmission system.

Referring more in detail to Fig. 8, I show therein a pair of electron discharge tubes 50 and 52 associated as a push-pull oscillator system. These tubes have tuned grid and tuned anode

circuits. The tuning is accomplished by varying the length of the metallic loops 54 and 55 which are disposed between the two anodes, and the loop 56 between the two grids of the tubes. Regeneration is also controlled by differential variation of the anode and grid circuit adjustments. The anode-to-grid capacities of the tubes form the greater part of the over-all capacitance of the oscillator circuit. The oscillator is shown inductively coupled to a line 58 leading to an antenna. This antenna is preferably directive.

The oscillator of itself tends to hold a single frequency and appreciable energy is required to vary this frequency.

To reduce the frequency selectivity of the circuits so that very little energy will be required to swing the frequency, I preferably couple to the oscillator two low power factor circuits having overlapping resonance curves peaking above and below the natural frequency of the oscillator. These circuits are preferably two sections 59 and 60 of concentric conductor lines, one slightly more and one slightly less than a quarter wave in effective electrical length. When properly adjusted and coupled these circuits cause the load and reaction upon the oscillator to vary in such a way that the oscillator loses its natural tendency to hold a fixed single frequency and makes it hold any other frequency, over a band, with substantially equal ease. Under these conditions a very slight guiding energy at any frequency within the band will control and fix the frequency of the oscillator.

The details of construction of the low power factor circuits may be best understood by considering the preferred embodiment as shown in Fig. 8. The linear conductor 59 may be in the form of a rod or tube. A similar linear conductor 60 has a different length from that of the conductor 59 in order that two resonant points may be fixed in accordance with the requirements above referred to. Each of the conductors 59 and 60 is separately enclosed in a tubular shield 70. Adjacent walls of the shield 70 are cut away sufficiently to admit a conductor 71 which is inductively disposed with respect to the conductors 59 and 60. The conductive loop 71 forms part of the anode circuits for the oscillator tubes 50 and 52. The anode potential source is connected through a conductor 17 to the mid-point on the inductive loop 71. The transmission line 58 leading to any suitable antenna system is inductively coupled to the two parallel conductors of the loop 71. It will thus be seen that the energy collected and re-radiated through the transmission line 58 will react upon the anode circuit to the oscillators by virtue of the coupling relation between the loops 71 and 72, the latter being a portion of the antenna circuit.

The detector tubes 61 and 62 are preferably of the triode type having grids which are controlled by capacitive reaction between the conductors 59-60 and closely adjacent conductive elements 73 whose connections to the detector grids extend through openings in the shield 70. The grids of the detector tubes 61 and 62 may be self-biased in the usual manner as shown in Fig. 8. Anode potential is supplied to the detector tubes 61 and 62 from any suitable direct current source fed to a mid-point on the relay winding 64, the winding terminals of which lead respectively to the anodes within the tubes 61 and 62.

If the range of tuning adjustment of the device shown in Fig. 8 be made great enough, then it will be possible to avoid interference to communi-

cation by moving the operating frequency far enough to clear the interference.

In applying my system I contemplate taking full advantage of antenna directivity. I may also employ different polarization of radio waves in adjacent links of the system to facilitate obtaining low feed-back from output to input circuits. Of course, full advantage will be taken of electromagnetic shielding between circuits. Balancing arrangements may be employed to reduce and to control energy feed-back. Other types of amplifiers than the grid controlled types may be used, such as amplifiers which function by virtue of secondary emission.

If desired, the relay stations may provide communications service to homes in the vicinity of a repeater station. Then, too, sound, facsimile or television broadcasting or modulation power may be derived from repeater stations to modulate separate broadcasting equipment or to supply wire lines.

The system is particularly adapted to communication along air routes, railroads, roads or other routes of travel, through or over land areas, or between islands, buoys, etc. Along air routes it is customary to employ a line of beacon lights on towers, at frequent intervals. These same towers may support my radio relaying equipment and provide a means of navigation or guidance to planes as well as communication between landing fields. The planes may follow the line of a radio relaying system under weather conditions which render beacon lights useless.

My invention is capable of many modifications such as might suggest themselves to those skilled in the art. The scope of the invention is, therefore, limited only in accordance with the claims. I claim:

1. A radio relay system comprising receiving and transmitting antennae, a self-oscillating radio frequency amplifier, means for maintaining the oscillations of said amplifier in synchronism with a frequency-modulated wave collected by the receiving antenna, and means for applying the output power from said amplifier to said transmitting antenna.

2. A system in accordance with claim 1 in which said amplifier is adapted to maintain said output power substantially constant irrespective of the amplitude of the wave collected by said receiving antenna.

3. A carrier current communication system comprising a series of self-oscillating repeater stations each as defined in claim 1, means at one station for adjusting the same to operate at a desired carrier frequency, and automatic means at the other stations for adjusting the same for optimum operation at the same carrier frequency.

4. A carrier current communications system comprising a series of geographically spaced repeating stations including self-oscillating radio-frequency amplifiers, means for delivering input power for maintaining the oscillations of different amplifiers in synchronism, and means for maintaining the output from each amplifier substantially constant and independent of the value of said input power delivered thereto for the maintenance of said synchronism.

5. A system in accordance with claim 3 and having an antenna system connected to the amplifier at each station, said antenna system being adapted to receive one frequency modulated carrier wave and simultaneously to transmit a wave of the same carrier frequency but differently modulated.

6. A radio wave repeater comprising a receiving and retransmitting circuit including an oscillator constrained to oscillate in synchronism with a received current, means for tuning the oscillator to a mean operating frequency, and means including a pair of low power factor circuits coupled to, and forming a part of, said oscillator for preventing frequency drift in the tuning of the oscillator and for reducing the frequency selectivity thereof over a band of frequencies, said low power factor circuits having overlapping resonance curves one of which peaks above and the other below the mean operating frequency.

7. A repeater in accordance with claim 6 and having means for varying the frequency to which said oscillator is tuned, said means comprising a balanced rectifier system coupled to said tank circuits, a relay reversibly operable by rectified energy from said rectifier system, a reversible motor under control of said relay and oscillator circuit tuning adjustments driven by said motor.

8. An ultra-short wave repeater comprising an antenna adapted for simultaneous reception and re-transmission of energy, a push-pull oscillator having a cathode-to-anode output circuit coupled to said antenna, means for tuning said oscillator to a desired mean operating frequency, said means comprising a set of looped conductors connected "trombone-fashion", means including a pair of resonant circuits one tuned slightly above and the other slightly below said mean operating frequency, and both coupled to said oscillator for preventing frequency drift of said oscillator and for broadening the frequency characteristic thereof, and reversibly operable means under control of energy fed to said pair of resonant circuits for adjusting the resonant point of said looped conductors.

9. In an ultra-short wave repeating system having oscillator means coupled to an energy collecting and re-radiating medium the method of controlling the frequency of oscillation which comprises resonating said means at a mean frequency of the waves as received, absorbing a portion of the generated energy in a medium having over-lapping resonance curves one of which peaks above and the other below said mean frequency, and utilizing the unabsorbed portion of said energy to prevent frequency drift of said oscillator means and to broaden the frequency characteristic thereof.

10. A frequency-modulated carrier current communications system comprising a series of widely spaced repeater stations, each station including a self-oscillating amplifier, a receiving antenna connected to the input side of each said amplifier, means for maintaining the oscillations of each said amplifier in synchronism with a frequency modulated wave collected by its said receiving antenna, and a transmitting antenna connected to the output side of each said amplifier.

11. A frequency-modulated radiant energy communications system comprising a plurality of terminal and repeater stations each station including a self-sustained oscillator, means in-

cluding a directive antenna connected to each said oscillator at said repeating stations for maintaining the same in synchronism with the oscillator at one of said terminal stations, and means for simultaneously injecting different frequency modulations into the radiant energy traversing the space paths between respectively different pairs of stations.

12. A system in accordance with claim 11 and having a plurality of differently oriented antennae at each station, each arranged for efficient radiation and/or reception of modulated energy traversing one of said space paths.

13. A radio relay system comprising a self-oscillating and amplitude limiting push-pull amplifier, a receiving antenna coupled to the input side of said amplifier, a transmitting antenna coupled to the output side of said amplifier, means for locally extracting a frequency modulated output from said amplifier corresponding to modulated energy collected by said receiving antenna, means for locally injecting frequency modulations from an added source for application to the output energy from said amplifier thereby to radiate said output energy from said transmitting antenna, and means including a balancing transformer and a balancing network coupled to the output side of said amplifier for maintaining duplex operation of said relay system.

14. A bi-directional radio repeater comprising a multi-stage amplitude limiting amplifier adapted for self-oscillation at radio frequencies, directional antennae connected to the input and output sides of said amplifier, a circuit arrangement including a balancing transformer coupled to the output side of one of said stages and to the input side of a subsequent stage, an impedance matching network connected to certain terminals of said balancing transformer, and means including connections through said balancing transformer for independently extracting and injecting different frequency modulation components by which said radio frequencies are simultaneously modulated.

15. A repeater in accordance with claim 14 and further characterized in that it provides decoupling of the output from the input of said amplifier.

16. A carrier current communication system comprising a series of widely separated oscillating amplifiers which are coupled together, means for causing said amplifiers to oscillate in synchronism, means simultaneously operative at different points for injecting independent frequency modulations into the amplifiers of said system, and means for independently separating out the different modulation components.

17. A carrier current repeater comprising an oscillating amplifier, means for injecting one of two frequency modulation components of a carrier current into the output from said amplifier and independent means responsive to the other of said frequency modulation components for deriving modulation power.

CLARENCE W. HANSELL.