Oct. 11, 1932. H. CHIREIX 1,882,119

MEANS FOR RADIO COMMUNICATION

Filed May 6, 1927

Fig. 1

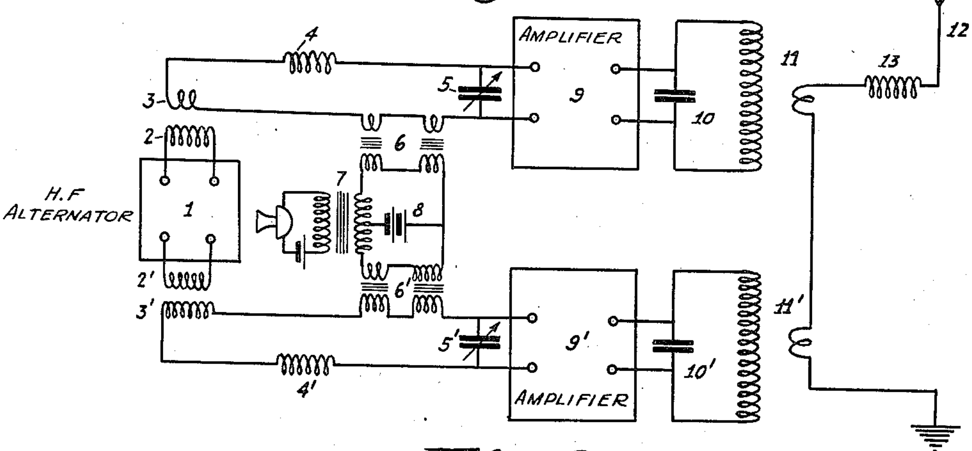


Fig. 2

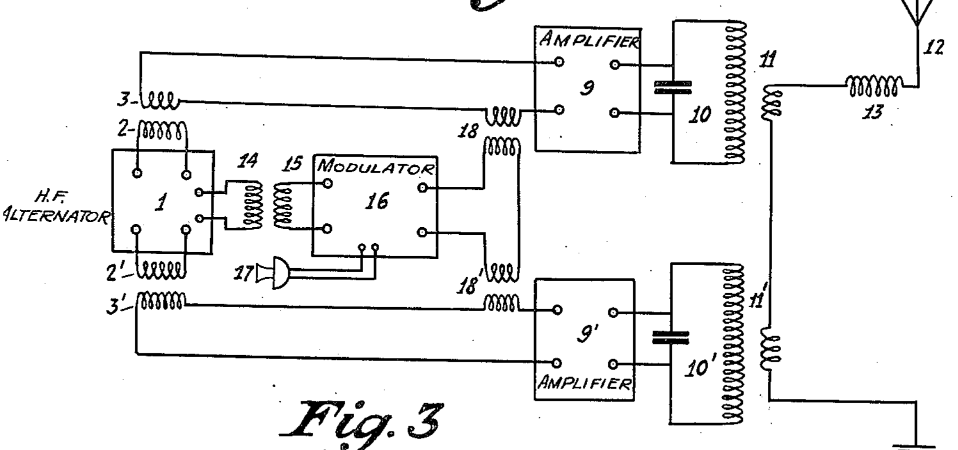


Fig. 3

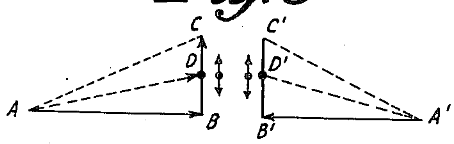


Fig. 4

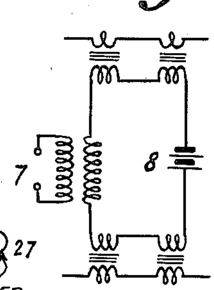
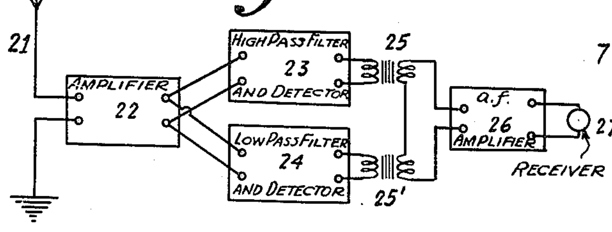


Fig. 5



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MEANS FOR RADIO COMMUNICATION

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This invention relates to novel radio-telephony sending and receiving systems, and more particularly to a transmitting system wherein modulation of the carrier wave is accomplished by novel means, and to a receiving system adapted to respond to signals sent by such transmitting system.

One object of the present invention is the provision in a transmission system of novel means for modulating in amplitude the radio frequency or carrier wave by speech.

The second object of the invention is to realize a transmission system in which the radio frequency wave is modulated only in phase when transmitted and not in amplitude; in other words, a system wherein the voice or speech has only the effect of producing rapid variations in phase of the transmitted wave, while the frequency and amplitude of the latter remain unchanged, and to provide receiver apparatus in which these variations in phase are utilized for the purpose of causing variations in amplitude and consequently of reproducing the speech.

The first object of the invention is based upon the observation that, if one excites an antenna or a line by means of two electromotive forces of the same frequency and preferably of the same amplitude, the resultant intensity in the antenna will vary with the phase of the said two electro-motive forces. more particularly speaking, it will become zero when the two electro-motive forces are opposed, and will grow first linearly with the displacement or phase angle from π. If, then, for instance, the antenna is excited by means of two electro-motive forces equal in magnitude and displaced 150 degrees, for example, and if the voice has the effect of producing a phase displacement of one of said two electro-motive forces with relation to the other, the amplitude in the aerial will vary, diminishing for the alterations of the telephone currents occasioning an increase in phase angle, and increasing on the contrary in the presence of alternations of the telephone currents causing a decrease in the phase angle. Of course, it is possible to act upon the relative phase of the two electro-motive forces either by acting upon one of the two electro-motive forces or else by acting simultaneously in opposite senses upon the two. In the example hereinbefore cited, conditions and arrangements could be chosen so that the phase angle between the two electro-motive forces corresponding to a maximum modulation passes from 120 to 180 degrees, the mean value being 150 degrees.

Now, this first object of the present invention may be carried into practice in a manner hereinafter described more fully.

Suppose there is available a high frequency alternator (generator) of feeble power. From this generator are taken off two circuits, for instance, to excite two power amplifiers consisting of two triode tubes, there being inserted in the circuits connecting with these amplifiers means adapted to alter the phase in a constant manner, such as self-inductance coils, condensers, resistance, or elements of artificial line. For instance, arrangements may be made so that the controlling potentials of the two amplifiers present a relative phase difference of 150 degrees. The output circuits of these two amplifiers are then connected or coupled with the antenna. In order to vary under the action of speech the relative phase of the input potentials of these two amplifiers, one may proceed in particular in the following two manners:

(1). Insert in the connecting circuits of the generator and the amplifiers saturated self-inductances (magnetic amplifiers) in which saturation is provided by the super-position of current due to speech upon a steady direct current. If these saturated self-inductances are connected in a "resistance" circuit adjusted to a point close to the resonance point, any variation in self-inductance will result in an appreciable change in the phase and a negligible change in amplitude.

(2). Superpose upon the constant potential of the input circuit of the amplifiers a modulated potential in quadrature with the former. If this modulated potential is sufficiently low compared with the former, the phase of the resultant potential will be varied without affecting in an appreciable way its amplitude (composition of two vectors at 90 degrees).

In this latter case, the said modulated potential would be obtained, be it well understood, from another derivation taken from the low-power generator.

In order to obtain these different excitations more readily at their convenient phases, it may be a good plan to use a rotating-field generator.

The second object of the present invention is based upon this fact, that a wave whose phase only is modulated at telephonic frequency, that is to say, a wave of this shape

$$\cos\,[\omega t+\varphi\,\sin\,\Omega t]$$

where ω and Ω, respectively, stand for the radio frequency and audio frequency pulsations, t for the time, and φ for the maximum phase displacement angle, is equivalent for low values of φ to a wave of this shape:

$$\cos\,\omega t-\varphi\,\sin\,\Omega t{\cdot}\sin\,\omega t \qquad (1)$$

that is to say, to the superposition of a non-modulated wave and a completely modulated wave in quadrature with the former. Equation (1), moreover, may also be written in this form:

$$\cos\,\omega t+\frac{\varphi}{2}\cos\,(\omega+\Omega)t-\frac{\varphi}{2}\cos\,(\omega-\Omega)t \qquad (2)$$

If this expression be now compared with that of a wave modulated in amplitude of the form

$$\cos\,\omega t\,\,(1+K\,\cos\,\Omega t),$$

where K denotes the degree of modulation, it will be seen that the latter equation may be written as follows:

$$\cos\,\omega t+\frac{K}{2}\cos\,(\omega+\Omega)t+\frac{K}{2}\cos\,(\omega-\Omega)t \qquad (3)$$

It will be seen that this expression differs from Equation (2) only by one sign. Now, it is well known that if a wave such as defined by (3) is received by a detector, each of the side pulsations $(\omega+\Omega)$ and $(\omega-\Omega)$ combines with the pulsation ω and results in the pulsation Ω, that is to say, speech, and in this case the amplitudes due to the terms $(\omega+\Omega)$ and $(\omega-\Omega)$ become added arithmetically. In the case of a wave of the kind defined in Equation (2) it will be seen from analogy that the speech currents due to interference (beats) between $\cos\,(\omega+\Omega)t$ and $\cos\,\omega t$ and those due to interference (beats) between $\cos\,(\omega-\Omega)t$ and $\cos\,\omega t$ are neutralizing each other. But the remedy will be apparent at once, for all that is necessary is to dispose two filters, namely, a high-pass filter allowing of the passage of all pulsations higher than ω, and a low-pass filter permitting all pulsations lower than ω to pass, or else two band filters fulfilling the identical purpose. Each of these filters must be followed by a detector at the output end of which there will be current pulsating at speech frequency Ω. As these currents are displaced in phase by 180 degrees, they will be opposed in the telephone receiver. As to the rest, there is no objection whatever to the use of a type of receiver involving a change in frequency, so that the pulsation ω may be always made the same. and so that the high-pass and low-pass filters may be adjusted once for ever with care. The second object of the invention is thus realized in the following manner: Sending end: independent generator of low power, tube amplifier, means for changing the exciting phase of the amplifier with reference to that of the generator, either by the use of a saturated self-inductance or by the employment of a modulated potential in quadrature with relation to the normal exciting potential. Receiving end: A receiver preferably of the type adaptable to frequency change, followed after amplification by two filters, one a high-pass filter and the other one a low-pass filter, each of said filters united with a detector. After detection, the audio frequency currents are combined in a common circuit united with the telephone or connected with a low-frequency amplifier.

The advantageous feature common to both these two objects of the invention is that of insuring economy in modulation. Modulation of the phase can be insured with an amount of power which is infinitely small even compared with that of the generator or the amplifiers. The latter function moreover with practically constant grid excitation, and this allows of the use of amplifiers working at constant potential and good operating efficiency, a condition that would no longer be attained in a case where the output or the power of these amplifiers is to be of variable amplitude.

Finally, the second object of the invention, although requiring a receiver of special design, presents new and very valuable advantages.

(1). Secrecy of communication.—An ordinary receiver will receive but one carrier wave and respond to no modulation.

(2). Great immunity from jamming and stray.—Indeed, in the light of what has been pointed out above it will be noted that the re-constitution of speech necessitates the placing in opposition of two detectors. In this way there is realized a sort of differential arrangement in which the damped disturbances are opposed.

The invention will best be understood by reference to the following description taken in connection with the accompanying drawing in which:

Fig. 1 schematically shows a transmitting arrangement for carrying out the present invention,

Fig. 2 discloses a second modification thereof,

Fig. 3 is a graphical representation showing the composition of potentials applied to the power of amplifiers,

Fig. 4 shows a phase-shifting arrangement that may be used in connection with Fig. 1 for obtaining phase modulation, and

Fig. 5 illustrates a receiver arrangement to be used in conjunction with the transmitters shown in Figures 1 and 2 when adapted for phase modulation.

Referring to Fig. 1, 1 stands for a radio frequency alternator. 2 and 2′ are two primaries of Tesla transformers passed by currents conveniently phase-displaced with relation to each other, say, by 150 degrees. 3, 3′ are the secondary windings of said transformers, said secondaries serving to excite two circuits, each comprising moreover a tuning coil 4, 4′, respectively, a tuning condenser 5, 5′, respectively, and a saturated self-inductance 6, 6′, respectively.

Each of the saturated self-inductance coils 6, 6′ is represented in symbolic form by two transformers connected in series on the primary and secondary ends, though with the primaries reversed or inversed from the point of view of the flux, so as to indicate that there exists no transforming effect between the radio frequency and the audio frequency circuits. 7 stands for a telephone transformer, 8 a battery furnishing a continuous saturation.

From the arrangement adopted it will be seen that the telephone current becomes added to the direct current in one of the devices 6 or 6′ at the same time as it decreases in the other device at the same instant.

In other words, when under the action of speech, one of the self-inductance coils grows in saturation, the other one loses in saturation to a corresponding amount.

The two circuits 3, 4, 5, 6, and 3′, 4′, 5′, 6′ are preferably regulated so as to provide equal values for all elements, at exact tuning or resonance or slightly outside resonance, as may be desired. To effect such regulation the battery 8 is in circuit, but no alternating current potential is applied across the primary terminals of the transformer 7, that is no speech is applied to the microphone.

Under these conditions, the currents passing through the circuits 3, 4, 5, 6, on the one hand, and through 3′, 4′, 5′, 6′, on the other hand, will preserve with relation to each other the same phase angle as the current flowing through the primaries 2 and 2′, for reasons of symmetry.

If, then, an alternating current electromotive force be applied at 7, as when one speaks into the microphone, the two self-inductance coils 6 and 6′ will be caused to vary periodically in value, that is to say, one thereof becoming saturated when the other decreases in saturation, the tuning of the circuits 3, 4, 5, 6, and 3′, 4′, 5′, 6′ undergoing changes which results in an alteration in phase displacement between the primary and secondary currents flowing through the windings 2 and 3, and 2′ and 3′. More particularly speaking, when the self-inductance 6 decreases in value, the phase angle between the secondary current and the primary current decreases, and vice versa.

Although nothing has been said respecting the resistance in the two circuits 3, 4, 5, 6, and 3′, 4′, 5′, 6′, it is nevertheless unfortunately there, and the very presence of this resistance allows of gradual phase displacements. More particularly, if in the absence of telephone current, the secondary currents are exactly alike, the secondary currents are in quadrature relationship with the primary currents, and the least variation in self-inductance results in a variation in the phase angle. In view of the fact that the two self-inductance coils 6 and 6′ vary inversely under the action of speech, it follows that the phase displacement angle between the secondary current of the circuit 3, 4, 5, 6 and the primary current flowing through 2′ will decrease; in other words, the relative phase displacement of the two secondary currents will grow. It will be seen that for one half-cycle or alternation of the telephone current the relative phase angle of the two secondary currents will grow while it will diminish for the next alternation. If it is moreover noted that in order to produce a relative phase angle of the two secondary currents of 30 degrees it suffices to produce a phase angle in each secondary of 15 degrees and that the phase displacement is automatically attained in a circuit regulated to resonance when producing a self-inductance equal to one-fourth the series resistance of the circuit, that is to say, a wattless apparent power equal to $\frac{1}{16}$th the watt, or real power of the circuit, it will be seen that the system of modulation is extremely economical in operation. Another advantageous feature is that the amplitude of the secondary current does not vary more than 3% under the conditions as hereinbefore outlined.

Other details of the diagram Fig. 1 will be easily understood. 9 and 9′ stand for two amplifiers excited, as has been shown, by currents of constant or practically constant amplitude, but of a phase subject to variation by speech. 10 and 10′ are two oscillation circuits at the output end of the said amplifiers. 11 and 11′ are two couplings with the antenna circuit represented at 12 and tuned by the agency of inductance coil 13. The total electro-motive force induced in the antenna by the two couplings 11 and 11′ varies with the phase displacement angle between the two electro-motive forces induced separately by 11 and 11′, and the antenna current naturally will vary in proportion with the total electro-motive force induced, while, on the other hand, if all conditions are symmetrical, the phase angle between the electro-motive forces 11 and 11′ will be identical to that existing between the currents of the secondary circuits 3, 4, 5, 6, and 3′, 4′, 5′, 6′.

Another method of practicing the underlying idea of the invention is diagrammatically illustrated in Fig. 2, where 1 stands as before for the radio frequency generator, 2, 3, and 2′, 3′ for two transformers arranged in such a way that the electro-motive forces induced in the secondaries 3 and 3′ are in phase opposition. 14 and 15 are primary and secondary windings of another transformer so that the secondary electro-motive force induced in 15 is in quadrature relationship with the electro-motive forces induced in 3 and 3′. 16 denotes a complete tube modulator assembly combined with a microphone 17. In the operation of said modulator outfit recourse may be had, for instance, to the well-known method known as the constant-current or plate-control system. In short, at the output end of device 16 there results a radio frequency potential modulated by speech and in quadrature relation with the electro-motive force induced by the transformers 2, 3, and 2′, 3′. 18 and 18′ represent two transformers connected with the output end of the tube modulator 16. Elements 9, 9′, 10, 10′, 11, 11′, 12, and 13 are the same as in Fig. 1.

The small graph in Fig. 3 shows the composition of the potentials applied to the amplifiers 9 and 9′. AB and A′B′ denote respectively the two potentials due to the transformers 2—3 and 2′—3′. BD and B′D′ stand for the potentials induced by the transformers 18, 18′ in the absence of speech modulation. AD and A′D′ therefore denote the resultant potentials applied at the amplifier terminals 9, 9′. For total modulation of the amplitude of the modulator assembly 16, the resultant potential under the action of the voice, changes from AB to AC, for one amplifier, and from AB′ to AC′, for the other amplifier. For less thorough or extensive modulation, the resultant vectors AD and A′D′ will be subject to far less angular deviation. No matter how conditions may be, if the angle CAB and the angle C′A′B′ are each limited to 30 degrees, it will be seen that for total modulation of the amplitude, the difference in phase of AC with relation to A′C′ will change from 120 to 180 degrees, AD and A′D′ forming an angle between themselves of 150 degrees. Under these conditions BC will be equal to ½ AB and BD equal to ¼ AB. The potential induced in the absence of voice actions by the transformers 18 and 18′ will therefore be only ¼ the potential induced by the transformers 2—3 and 2′—3′. It will be seen moreover that AC exceeds AD by only 9% approximately, whereas AB is only 3% less than AD.

A transmitter of the kind embodying the second object of the invention can be built by starting from Figs. 1 and 2 in different manners, for instance, by eliminating all the lower parts having indices, or if it is desired that the same transmitter should embody the two objects and prime features of the invention, this can be effected still more simply.

In the case of Fig. 1, it will be sufficient to arrange the battery 8 in series in the (iron-cored) self-inductance saturation circuit as indicated at Fig. 4. It will be noted, as a matter of fact, that in this case there are saturated at the same time the two self-inductance coils 6 and 6′, and that they are also deprived of saturation simultaneously. What follows therefrom is that the relative phase of the potentials applied to the amplifiers 9 and 9′ will not vary, but merely the phase of these potentials with relation to the primary currents flowing through the windings 2′ and 3′. It will moreover be noted that the relative phase of the currents flowing through the primaries 2 and 2′ determines and governs only the intensity (of the current) in the antenna.

In the case of Fig. 2, the identical result will be attained, for instance, by inversing one of the windings of the transformers 2—3 and 2′—3′ which means the same thing as changing in sign, in Fig. 3, the vector AB or else the vector A′B′.

Fig. 5 shows diagrammatically an assembly or equipment adapted to receive transmissions effected by phase modulation. 21 stands for the antenna, 22 for an amplifier receiver without detector. This receiver equipment is preferably of the type allowing of change in frequency. 23 and 24 are band-pass filters each followed by a detector, and allowing of the passage, one of the wave changed, if desired, in frequency, as well as the higher frequencies up to 5 to 7 thousand cycles, for instance, while stopping all lower frequencies, the other also permitting of the passage of the wave changed, if desired, in frequency, as well as lower frequencies say from 5 to 7 thousand cycles, while stopping the higher frequencies. 25 and 25′ stand for two low-frequency transformers connected in series, with the direction of winding being suitably chosen to add the incoming telephone currents. 26 finally stands for a low-frequency amplifier connected with a telephone receiver 27. As has been pointed out above, modulation of the phase occasions a modulation in amplitude of a vector in quadrature with the mian vector (Equation (1)). This amplitude modulation may be resolved into two side frequencies or better into two side bands, if the modulation takes place at variable acoustic frequency (Equation (2)). The interference in a detector of each of said bands with the main wave reproduces the speech and as a consequence results in a current of musical frequency in the transformers 25 and 25′. Still, as follows from the signs, it is necessary that the interference (beat) of one band with the fundamental wave should be separated from the interference (beat) of the other band with the same fundamental wave, whence the necessity of providing two filters and two detectors. It will be quite evident that only one filter could be provided, say, the upper or high-pass band filter and only a single detector, though in this case, one-half of the possibly available energy goes to waste, while it would furthermore not be possible by the same arrangement to neutralize atmospherics and jamming, as has been pointed out above.

It will be understood that the principle based upon phase modulation is also applicable to modulated telegraphy. For this purpose, it is sufficient to pass into the saturated self-inductance coils Fig. 1 arranged in a way as illustrated in Fig. 4, a musical frequency current chopped up by a key. Another possible scheme would be to pass into the same self-inductance coils several musical frequencies each controlled by a key. By subsequent filtering by well-known means and methods the musical currents after detection, multiplex sending could be obtained.

It will be evident to all trained in the art that there are a great number of possible modifications in details without departing from the basic spirit of the invention. Especially the second feature and object of the invention could be carried into practice with alternators or self-generating valve equipments in a great number of different arrangements.

Having thus particularly described the nature of my invention, I claim:

1. In a system of radio telephony, a utilization circuit energized by two independent sources of the same frequency but presenting a predetermined phase difference between themselves of substantially 150 degrees, and means, including saturated self-inductance coils, for varying the phase difference, said means being controlled by sound waves.

2. In a system of radio telephony, the combination of a pair of circuits having similar characteristics, means for generating high frequency currents in said circuits substantially equal in magnitude and displaced about 150 degrees, a power amplifier in each of said circuits, oscillation circuits coupled to said amplifiers and to a utilization circuit, and means coupled to said first mentioned circuits for varying the phase difference between the currents in said two circuits in correspondence with sound vibrations, to correspondingly alter the resultant current in said utilization circuit.

3. In a system of radio telephony, the combination of a pair of circuits having similar characteristics, means for generating high frequency currents in said circuits substantially equal in magnitude and displaced about 150 degrees, a power amplifier in each of said circuits, oscillation circuits coupled to said amplifiers and to a utilization circuit, saturated self-inductances inserted in each of said first mentioned circuits, and means effecting the saturation of said inductances controlled by sound vibrations for varying the phase difference in said two circuits, thereby correspondingly altering the resultant current in said utilization circuit.

4. A receiver for a desired signal modulated carrier wave, comprising collecting means, means to heterodyne the received carrier wave to an intermediate frequency, a filter tuned to pass frequencies higher than the intermediate frequency, a second filter arranged to simultaneously pass frequencies lower than the intermediate frequency, detector means associated with each filter, and means to combine the resulting audio frequencies subtractively.

5. In a system of radio transmission, the combination of a pair of circuits having similar characteristics, means for generating in said circuits high frequency currents of substantially equal and constant amplitude and definite phase difference less than 180°, means for varying said phase difference in accordance with sound waves, two distinct amplifiers having one or more stages, one of said amplifiers being excited by one of said circuits, the other by the other of said circuits, and a utilization circuit coupled to the outputs of said amplifiers.

6. In a system of radio transmission, the combination of a pair of circuits having similar characteristics, two independent sources for generating in said circuits currents of same high frequency and equal amplitude, the current of one circuit presenting a predetermined phase difference less than 180° over the current in the other circuit, means for varying said phase difference irrespectively of amplitude and in accordance with sound waves, two distinct amplifiers having one or more stages, one of said amplifiers being excited by one of said circuits, the other by the other of said circuits, and a utilization circuit coupled to the outputs of said amplifiers.

7. In a system of radio transmission, the combination of a pair of circuits having similar characteristics, means for generating in said circuits high frequency currents of substantially equal amplitude and definite phase difference less than 180°, means for varying said phase difference comprising in each of said circuits a saturated self inductance coil and means for increasing the sat-

uration of one of said coils and decreasing simultaneously the saturation of the other of said coils in accordance with sound waves, two distinct amplifiers having one or more stages, one of said amplifiers being excited by one of said circuits, the other by the other of said circuits, and a utilization circuit coupled to the outputs of said amplifiers.

8. In a system of radio transmission, the combination of a pair of circuits having similar characteristics, means for generating in said circuits high frequency currents of substantially equal amplitude and definite phase difference less than 180°, saturated high frequency and low frequency self inductance coils in each of said circuits, the low frequency coils being connected together and forming a closed circuit with the winding of a transformer of a microphone circuit, a battery connecting the point between the low frequency coils and the middle point of said transformer winding, two distinct amplifiers having one or more stages, one of said amplifiers being excited by one of said circuits, the other of said amplifiers being excited by the other of said circuits, and a utilization circuit coupled to the outputs of said amplifiers.

9. In a system of radio transmission, in combination a pair of circuits having similar characteristics, means for generating in said circuits high frequency currents of substantially equal amplitude and a definite phase difference less than 180°, means for varying said phase difference in accordance with sound waves comprising an arrangement for superposing on the high frequency unmodulated current in each of said circuits an auxiliary modulated current leading the unmodulated component in one of said circuits by 90° and lagging the unmodulated component in the other of said circuits by 90°, two distinct amplifiers having one or more stages, one excited by one of said circuits and the other by the other of said circuits and a utilization circuit coupled to the outputs of said amplifiers.

10. A radio receiving system adapted to receive waves modulated practically in phase only, comprising an aerial system, means to heterodyne the received signal so as to obtain a desired intermediate frequency of its carrier wave, a high pass filter for said intermediate frequency and upper side band, a low pass filter for said intermediate frequency and lower side band, both filters being connected in parallel and each followed by a detector, the outputs of said detectors being connected in opposition, and a low frequency amplifier and signal responsive means associated with the detector outputs.

11. In a secret radio signalling system including a transmitter for phase modulated waves and a receiver adapted to cooperate therewith, the transmitter comprising a pair of circuits each coupled to an amplifier, means for generating high frequency phase-displaced currents in said circuits, means for modulating the phase, and a radiation circuit associated with said amplifiers, and the receiver comprising an aerial system, means to heterodyne the received signal, two filters in parallel, one for the carrier wave and upper side band, the other for the carrier wave and lower side band, rectifying means associated with each filter, and means to combine the resulting rectified waves subtractively.

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