May 15, 1934. L. W. CHUBB 1,958,886

RADIO TRANSMISSION SYSTEM

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Fig. 1.

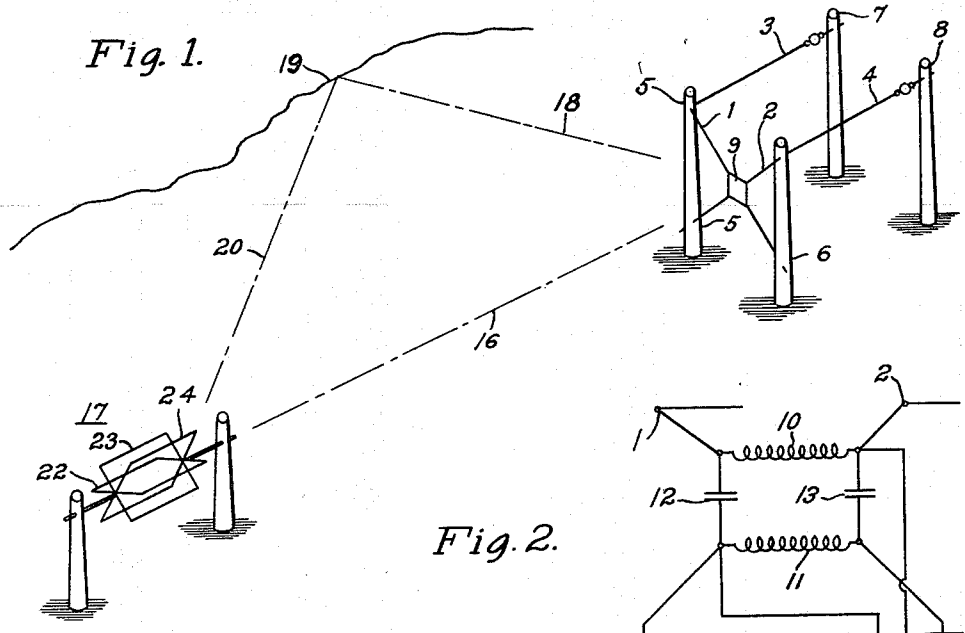


Fig. 2.

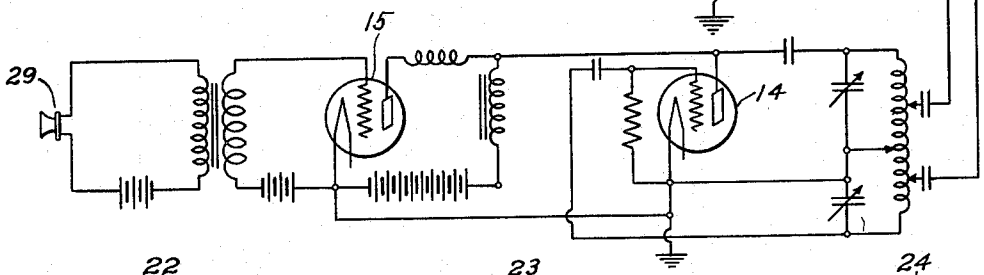
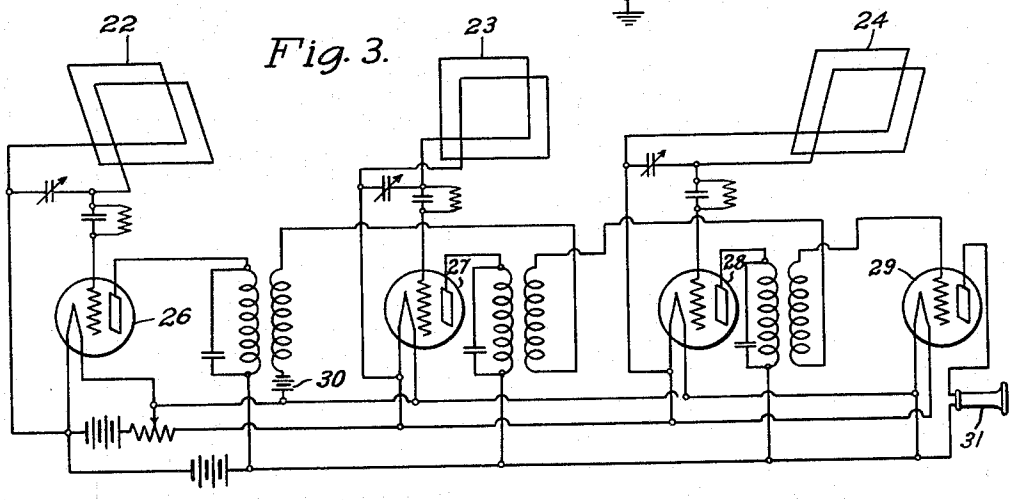


Fig. 3.



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RADIO TRANSMISSION SYSTEM

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4 Claims. (Cl. 250—2)

This invention pertains to radio communication.

It is an object of this invention to overcome fading of radio signals.

It is a further object of this invention to produce a radio system in which the radiation reflected from the Heaviside layer shall not be capable of producing, by combination with the directly transmitted radiation, a diminution of the effective resultant radiant energy at the receiving station.

It is a further object of my invention to produce circularly-polarized radiation, which, upon reflection from the Heaviside layer, will be circularly polarized in the opposite sense, whereby the combination of direct and reflected radiation will produce a plane-polarized wave. The invention is, however, applicable to reflections from other objects beside the Heaviside layer.

It is a further object of my invention to provide a receiving system which will produce the same signal strength when the same amount of radiant energy arrives at the antenna system independently of the position of the plane of polarization of the arriving radiation.

It is a further object of my invention to provide a sending antenna system capable of radiating two plane-polarized waves and to so energize the antennæ of said system that the planes of polarization of said waves shall be at right angles and the time-phase relation of them shall be quarter-phase.

Other objects of the invention will be apparent from the following detailed description, wherein reference is made to the accompanying drawing, in which:

Figure 1 is a diagram illustrating the relative positions of the several antennæ;

Fig. 2 is a diagram of circuits and apparatus at the sending station; and

Fig. 3 is a diagram of circuits and apparatus at the receiving station.

When a radio sending station produces radiation, some of the energy is propagated directly to the receiving station and some arrives at the receiving station indirectly by being first propagated upward and forward until it meets the Heaviside layer, from which it is reflected and then is propagated downward and forward to the receiving station.

Obviously, most of the energy radiated from the sending station does not take either of the two directions mentioned and never arrives at the receiving station. Since this portion of the energy is without effect at the receiving station, further consideration of it need not be made.

The Heaviside layer is not stationary. As its surface changes, either in direction or height, the direction of the beam of radiation from the sending station, which, by reflection, reaches the receiving station, changes. Consequently, the length of the path over which this beam reaches the receiving station changes, but it is always longer than the path of the energy directly propagated from the sending station to the receiving station.

When the difference between the two paths is an odd number of half-wave-lengths, the energy arriving by reflection is exactly opposite, in phase, to that arriving directly.

Consequently, the effect of one upon the receiving antenna is opposite to the effect obtained from the other and, if the two effects are equal, they cancel each other, producing complete fading. If the effects are not equal, with this phase relation, only the difference between them will produce a result in the receiving antenna.

On the other hand, if the difference between the two paths is an even number of half-wave-lengths, the sum of the two effects produces the result. At intermediate phase relations, some, but not complete, fading occurs.

In order to avoid this change of intensity of the received signal with change in the phase relation between the directly-received radiation and the radiation received by reflection, I provide a form of radiation in which the interaction of direct and reflected waves produces a different effect instead of the change in intensity which is usually called fading.

The sending apparatus which I employ comprises two antennæ 1 and 2 each having a horizontally extending part 3 and 4 at the upper extremity thereof respectively.

The portions of the antennæ which connect the horizontal parts with the ground carry the major portion of the current and are the principal sources of radiation. The horizontally extending portions serve mainly to give a directional characteristic to said radiation. The horizontally extending parts may be omitted and for certain situations this is preferable. If pronounced directional effects are desired, loops, instead of antennæ of the form illustrated, may be used.

Between the top of the mast 5 and the foot of the mast 6 there extends an oblique portion of the antenna 1. Similarly, an oblique portion of the antenna 2 extends between the top of

the mast 6 and the foot of the mast 5. Auxiliary masts 7 and 8 are provided for supporting the horizontally extending portions. Strain insulators are illustrated connecting these horizontal portions to the auxiliary masts. Obviously, any other supports which will give the required position of the antennæ may be used instead of the masts.

The height of the masts 5 and 6 and their spacing is such that the oblique portions of the antennæ 1 and 2 are substantially at right angles to each other. At the point where these oblique portions would intersect if they were continuous, provision is made for impressing energy upon the antennæ in such a way that the currents in the antenna 1 differ by a quarter-phase from those in the antenna 2 but are equal thereto in amplitude.

One way of accomplishing this is illustrated in Fig. 2, in which the oblique portions of the antenna 1 are connected to diagonally opposite corners of a rectangular circuit-arrangement, comprising inductors 10 and 11, between the extremities of which condensers 12 and 13 are connected. The oblique portions of antenna 2 are connected to the other corners of the rectangular circuit-arrangement. The rectangle 9 in Fig. 1 is intended to represent not merely the rectangular arrangement, but all the energizing apparatus of Fig. 2.

Energy from the oscillation generator 14 is impressed between two diagonally opposite corners of said rectangular arrangement. This energy is modulated in any desired way. In the illustration chosen, this is by means of the modulator tube 15, associated with the oscillator 14 according to the constant-current modulation system, but any other modulating arrangement may be used.

The antenna 1 radiates a plane-polarized wave. The plane of polarization is at right angles to that of the plane-polarized wave radiated by the antenna 2. Two plane-polarized waves, polarized in planes at right angles to each other and having a quarter-phase relation as regards time, are frequently described as having a quarter-phase relation both in time-phase and in space-phase. It is a familiar principal of wave motion that two such waves combine to produce a circularly-polarized wave.

A beam of such circularly-polarized waves is indicated by the interrupted line 16. This line represents the radiation propagated directly from the sending station to the receiving station 17. A beam, represented by the interrupted line 18, extending obliquely upward from the sending station, is reflected at the Heaviside layer, represented at 19. The reflected beam is represented by the interrupted line 20, which extends to the receiving station 17.

It is a consequence of the familiar law that, upon reflection, the phase of a wave changes by 180°, that the beam 20 is circularly-polarized in the opposite sense from the beam 18. That is, if the beam 18 is circularly-polarized in a clockwise sense, when looked at in the direction of propagation, the beam 20 will be circularly-polarized in a counter-clockwise sense, when looked at in the same direction. The beam 16, since it does not undergo reflection is circularly-polarized in the same sense throughout.

The combination of waves from the beam 20 with waves from the beam 16 is, therefore, a combination of two circularly-polarized waves, the circular polarization being in opposite senses. It is a familiar principle of rotating fields that such a pair of circularly-polarized waves will give rise to a plane-polarized wave. The direction of the plane of polarization of the resulting wave will be changed if the phase relation between the waves in the beams 16 and 20 changes, but the magnitude of said resulting wave will not be changed by such change in the phase relation.

If the reflected beam and the directly received beam differ in amplitude, the wave resulting from their combined action at the receiving station will not be plane polarized, but elliptically polarized. The direction of the major axis of the ellipse will change direction with a change of phase-relation, as the plane of polarization does in the case of beams of equal intensity. In either case, the resultant wave at the receiving station contains one component, namely that parallel to said plane, which predominates over all other components.

The receiving station 17 comprises three loop antennæ 22, 23 and 24, arranged at angles to each other about a common axis. Preferably, the axis is parallel to the direction of the beam 16; that is, each of the loops is in a plane through the line from the receiving station to sending station.

The plane-polarized or other resultant wave produced by the interaction of the beams 16 and 20 will produce an electromotive force in each of the three loops. The magnitude of the electromotive force produced will depend upon the angle between the plane of the loop and the plane of polarization of the wave. If, therefore, the three loops are arranged symmetrically about their common axis, the vector sum of the three potentials, when each rectified in the proper sense, will be a constant and the resultant signal strength will be independent of the direction of the plane of polarization of the wave.

Therefore, the strength of the received signal will be independent of the phase relation between the waves in the beam 16 and those in the beam 20. When motion of the Heaviside layer changes the position of the point at which the beam 18 is reflected into the beam 20, and consequently changes the phase relation between the beams 16 and 20 at the receiving station, there will not result any change in the signal strength of the received signal. Fading will thus be avoided.

As shown in Fig. 3, the antennæ 22, 23 and 24 are each connected to the input of a vacuum tube detector 26, 27 and 28, respectively. The output circuits of these detectors are supplied with transformers, the secondaries of which are so connected as to give the sum of the detected potentials in the input of the audio-frequency amplifier tube 29. A battery 30 is provided to supply the necessary bias to the grid of the tube 29. With the connections as illustrated, this battery is between the secondary of the transformer associated with the tube 26 and the filament connection.

The translating device 31 is connected to the output of the audio-frequency amplifier 29. This connection is represented diagrammatically on the drawing as a direct connection, and the translating device is represented as an ordinary telephone receiver, but any form of translating device may be used and, between it and the output of the tube 29, any desired amplifier or succession of amplifiers may be inserted. Also, between the several loops 22, 23 and 24 and the

respective detectors 26, 27 and 28, any form of radio-frequency amplifier or heterodyning device may be introduced. The only necessary condition is that the output of the several detectors must be proportional to the radiant energy absorbed by the respective loops.

The connections from the several detectors to the grid of the tube 29, instead of being as illustrated; may be made in several alternative ways. For example, all of the several primaries may be wound on a single core in an additive relation and another winding on the same core may serve as the single secondary for the connection to the grid of the tube 29.

In the operation of the device, a signal delivered to the modulator tube 15, for example, by means of the microphone 29, is reproduced as a modulation of the oscillations delivered by the oscillation generator 14. Whatever these modulations, the energy delivered from the oscillator 14 is received upon the antennæ 1 and 2, as two equal oscillations differing in time phase by 90°. Currents having this time-phase relation are thus established in the oblique parts of the antennæ 1 and 2. Because of the position of these oblique parts at right angles to each other, these currents cause the radiation of two plane-polarized waves differing by 90° both in time-phase and in space-phase.

Such plane-polarized waves combine to produce a circularly-polarized wave which is radiated principally in the direction normal to the plane of antennæ 1 and 2. When the horizontal portions of the antennæ are omitted, each of the two antennæ is without directional effect. The combination of the two antennæ, however, produces radiation which is circularly polarized in directions normal to the plane of the antennæ, plane-polarized in directions in said plane and elliptically polarized in intermediate directions. When loops are used, the circularly polarized radiation is in the direction of the common axis of the loops. At directions normal thereto, there is a minimum radiation, and what there is is almost completely plane-polarized.

The horizontal part of the radiation comprises a beam following more or less closely the curvature of the earth and arrives directly at the receiving station. The radiation which extends obliquely upward reaches the Heaviside layer and is reflected. If, from this upwardly extending radiation that beam be selected which is reflected toward the receiving station, the two beams 18 and 20 (incident on the Heaviside layer and reflected from it) combine to produce a path from the sending station to the receiving station which differs in length from the path of the horizontally extending beam 16.

As the Heaviside layer moves, the beam which originally was reflected to the receiving station will be reflected to some other point, but there will always be some beam so reflected that it arrives at the receiving station. Thus, the path composed of an incident and a reflected beam is one of changing length. The directly received beam is of substantially constant length. The phase differences between the radiation received directly and that received by reflection is therefore changing.

The radiation at the receiving station is plane-polarized because it is the result of two circularly-polarized waves, polarized in opposite senses. If the beams 16 and 20 are not of equal amplitude, the resultant, instead of being plane-polarized, will be elliptically polarized. As the phase relation between the beams 16 and 20 at the receiving station changes, the plane of polarization, in the case of equal beams, or the major axis of the ellipse, in the case of unequal beams, rotates. There is no change in the amplitude of the resultant radiation but only the rotation just mentioned.

The effect of the rotation of the axis of the elliptical polarization may be described in the same way as the effect of the rotation of the plane of polarization which occurs in case of beams of equal amplitude. Accordingly, no further mention of the elliptical polarization will be made.

The amplitude and the phase of the radio-frequency currents and potentials produced in a loop is dependent upon the angle between the loop and the plane of polarization. Accordingly, as the plane of polarization rotates in the way explained above, both the phase and the magnitude of the potentials developed in the several loops will change.

It is possible to so position the loops and so arrange the connections between them that the connections give a vector sum of the potentials which is a constant. It is then independent of the position of the plane of polarization, but the vector sum of the potentials under these circumstances is zero. To avid a zero sum the connections of one loop are reversed relative to the others.

This is illustrated in Fig. 3 by showing the connections of the loop 23 opposite to those of loops 22 and 24. Thus, from the grid to the filament through loop 22 is around the loop clockwise, but in loop 23 from the grid to the filament is around the loop counter-clockwise. Disregarding the phase of the radio-frequency currents in each of the several loops and considering only the amplitude of the currents produced in the loops by the radiation shows that, as the modulation changes the amplitude of the radiation, the currents in each loop change in the same proportion, although the absolute value of the change in each loop is dependent upon the angle between this loop and the plane of polarization.

The loops being symmetrically arranged; that is, making angles 120° with each other, the sum of the changes just noted is independent of the position of the plane of polarization. Thus, although the radio-frequency amplitude in the several loops cannot be added vectorially to give a constant sum, except when that sum is zero, the modulation can be added to give a constant sum and this addition is effected by the construction shown in Fig. 3 in which the currents in each loop are separately detected and the output from the several detectors are combined.

It is well known that the output of a detector tube consists of a current of modulation frequency upon which a radio-frequency current is superposed. It is a consequence of the reversal of the connections from one loop relative to the other two that the radio-frequency currents in the three output circuits of the three detectors are related like three equal vectors making 120° with each other and rotating at radio frequency. The vector sum of three such quantities is not only constant but zero. Consequently, the radio frequency component of the output of the several detector tubes is without effect upon the input circuit of the tube 29.

It is noted, however, that this is not true of the harmonics of the radio-frequency and particularly of the third harmonic. For this reason, shunting condensers are provided for each pri-

mary. Since the frequency, which needs to be shunted is not the fundamental radio-frequency but a harmonic thereof, these condensers can, if desired, be smaller than has heretofore been the practice.

Although the several loops are shown as provided each with its own tuning condenser and the several detectors are indicated by a conventional condenser and leak, it is quite possible to mechanically connect all of the tuning condensers and it is also possible to provide other means for causing each of the three tubes to act as a detector.

While the operation has been described with reference to reflections from the Heaviside layer, other reflections, particularly with short wavelengths, may be of importance. This system can prevent effects analogous to fading resulting from such reflections.

Many variations in the details will be obvious to those skilled in the art and many other applications of the principle thereof will occur to them. I, therefore, do not intend the specific illustration and description of one application of this principle to be a limitation. No limitation is intended except as such as is expressed in the accompanying claims or required by the prior art.

I claim as my invention:

1. In a radio-communication system, two sending antennæ having their main current-carrying portions in the same plane and at right angles to each other and means for impressing currents on said antennæ having quarter-phase time relation, whereby plane-polarized waves having quarter-phase time relation and quarter-phase space relation are radiated from said antennæ, and a receiving antenna system at sufficient distance from said sending antennæ for radiation therefrom to reach it in comparable amounts directly and by reflection from the Heaviside layer, said receiving antenna system being symmetrically arranged about an axis coincident with a line from said sending antennæ to said receiving system.

2. In a radio-communication system, a transmitting system comprising means for simultaneously transmitting a circularly-polarized radio wave both directly and by reflection, and a receiving antenna system comprising a plurality of distinct direction-selective antennæ all positioned to absorb radiation most effectively from the same direction and each positioned to receive most effectively, radiation plane-polarized in a different plane, said planes being symmetrically arranged about an axis in the line of said direction, and means for obtaining from said antennæ an output which is controlled in accordance with the sum of the modulations in the several antennæ.

3. In a radio-communication system, a transmitting system comprising means for simultaneously transmitting a circularly-polarized radio wave both directly and by reflection, a receiving antenna system comprising a plurality of distinct direction-selective antennæ all positioned to absorb radiation most effectively from the same direction and each positioned to receive most effectively, radiation plane polarized in a different plane, said planes being symmetrically arranged about an axis in the line of said direction and means for obtaining from said receiving antennæ the vector sum of the voltages produced therein by said radiation, and means for controlling a translating device by said vector sum.

4. In a radio-communication system, a transmitting system comprising means for radiating two plane-polarized radio waves in quarter-phase time relation and in quarter-phase space relation, said waves being transmitted both directly and by reflection whereby a resulting wave reaches a distant point so polarized that the component in one plane predominates, a receiving system comprising three antennæ arranged symmetrically about an axis in line with the transmitted wave.

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