Feb. 26, 1935. A. BAILEY ET AL 1,992,283

TRANSMITTING WAVE ANTENNA SYSTEM

Original Filed Sept. 24, 1931

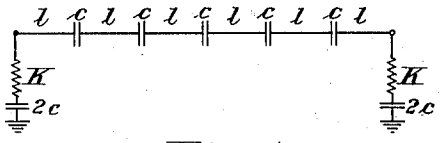


Fig. 1

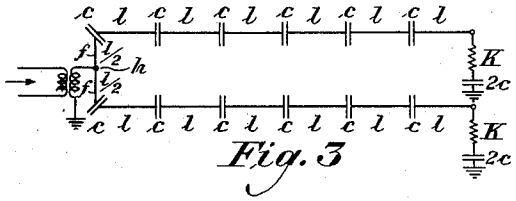


Fig. 3

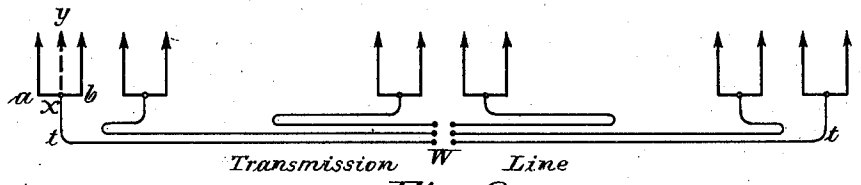


Fig. 2

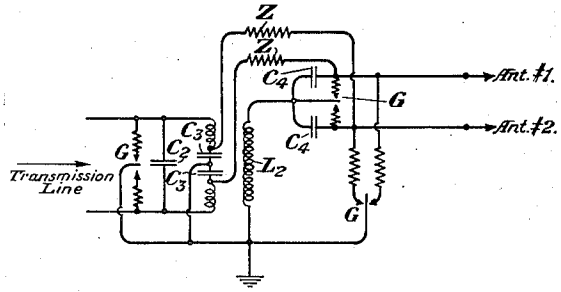


Fig. 4

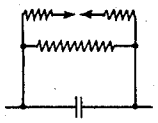


Fig. 5

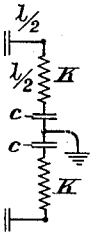


Fig. 6

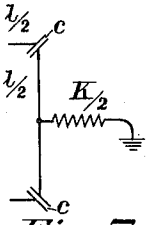


Fig. 7

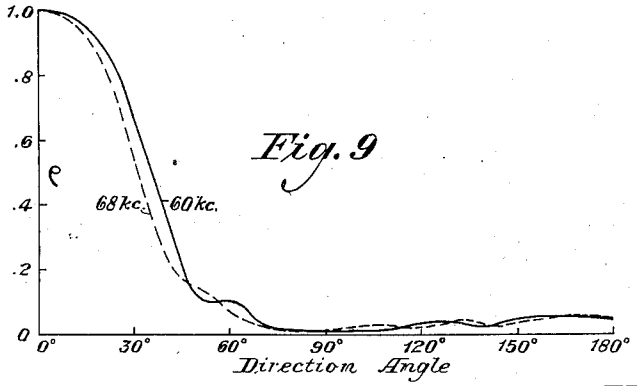


Fig. 9

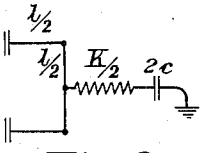


Fig. 8

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TRANSMITTING WAVE ANTENNA SYSTEM

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Application September 24, 1931, Serial No. 564,908
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15 Claims. (Cl. 250—11)

This invention relates to transmitting wave antenna systems adapted for long wave radio signaling, and more particularly to a system comprising an array of relatively long loaded horizontal wires associated with each other and a common generating source by means of transmission lines to give an efficient electromagnetic radiating system.

The object of the invention is to increase for long wave lengths the efficiency of radiation of wave antenna systems. Another object is to render the system suitable for multiplex signaling. Still another object is to develop a certain amount of directivity. Other objects will appear in connection with the description of the invention.

It is well known that as the frequency of a wave decreases the efficiency of radiation decreases; that is, the ratio of the energy which is radiated as electromagnetic waves to the total energy supplied to the radiator, which latter includes in particular the loss due to ohmic resistance in the antenna. For comparatively short waves this efficiency may be as high as 98 per cent, whereas for waves of some 5000 or 6000 meters the efficiency may be of the order of 3 per cent.

The so-called "wave antenna" has been used for receiving long radio waves with marked success, and reference to or description of such antennas for reception is found in an article by Beverage, Rice and Kellogg, in Transactions of the American Institute of Electrical Engineers, volume 42, 1923. Such as wave antenna may be used for a transmitter but its inherent radiation efficiency is very low. However, on account of its directional character, the amount of power radiated in the desired direction is considerably greater than would be the case for an antenna of the same over-all efficiency which radiates in all directions. But, even so, if it is to be used for transmitting, some arrangements must be provided for still further increasing the efficiency in the desired direction.

In our system, which is especially for long wave lengths though not limited thereto, we employ a plurality of long horizontal wave antennas combined in parallel to give not merely increased radiation but increased efficiency of radiation. To accomplish this end the antennas are excited in phase and the spacing between the antennas is wide enough so that there is practically no interaction between them. Also, to prevent undesirable reflection effects, each antenna may be terminated with an impedance to ground matching the characteristic impedance of the antenna, and the velocity of the wave in the wire is brought more nearly to that of the velocity of light by loading condensers spaced along the antenna.

The invention will be better understood by reference to the following specification and accompanying drawing, in which Figure 1 shows an antenna of a type which may be used in our system; Fig. 2 shows an array of such antennas for the purposes given above; Fig. 3 shows more in detail a preferred manner of combining two such antenna units to be supplied in parallel from one transmission line; Fig. 4 gives the transformer connections with certain supplemental features at the generator end of the antennas; Fig. 5 shows protecting means for loading condensers; Figs. 6 to 8 show various terminating arrangements and Fig. 9 shows the directive characteristics of a certain system embodying our invention.

Referring more specifically to Fig. 1, there is shown an antenna unit which we use in our transmitting system and which, from a physical point of view, is similar in many respects to the receiving antenna described by Beverage et al., mentioned above. This transmission line, which in one construction is about nine miles long and supported about 20 feet above ground on poles, is loaded periodically with condensers c spaced uniformly at distances l which in the construction mentioned is about one-fourth of a mile. The purpose of the loading condensers is to increase the velocity of propagation of the current wave in the line, bringing it more nearly equal to that of the velocity of light.

It may be desirable to have no reflections at the two ends of the antenna and for this purpose an impedance K is connected between the outer end of the antenna and ground, this impedance being equal to the so-called surge impedance or characteristics impedance of the line which it terminates. Also, for purposes which will appear later, a condenser of capacity $2c$ is connected in the ground circuit. A similar electrical condition is established at the left end of the antenna system which may be considered as the one into which power is to be supplied. In the actual case, however, the impedance K and condenser $2c$ are not so introduced at this end but the electrical equivalence thereof is obtained by a transformer connection between the antenna and the transmission line in a manner to be hereinafter described.

In accordance with our invention, we use a plurality of such antenna units and associate them in parallel as shown in Fig. 2. Referring

more particularly to this figure, there is shown the connection of the transmission line to the plurality of antennas. Consider a single isolated wave antenna such as that of the dotted line x—y. Such an antenna would radiate energy, and the amplitude of the wave laid down or the field strength at any remote point would be proportional to the current in the antenna. The efficiency of such a unit antenna would be low because of the considerable i^2r loss in such a line.

If, now, this antenna is replaced by two in parallel, as a and b, and the same current flows from the transmission line into each, then the wave amplitude at the remote point due to one antenna is the same. But since the antennas are excited in phase, the two wave components will be additive at a point on a line normal to the line a—b, giving twice the amplitude or field strength and, therefore, four times the power. The i^2r loss for the two antennas together will, however, be only twice as great, and thus the radiation efficiency will have been increased. In fact, for such antennas as we are describing, if the efficiency of a single one is 3 per cent, that for the two in parallel will be substantially double. More particularly, if m and n represent the radiated power and the loss of power dissipated in resistance, respectively, for one antenna, then the efficiency of that antenna is given by

$$\frac{m}{m+n},$$

and if we now have p antennas in parallel, each supplied with the same current, then the wave amplitude at a remote point is p times as great, so that the received energy is proportional to p^2m whereas the ohmic loss is pn. Thus the efficiency is expressed by

$$\frac{p^2m}{pm+pn}=\frac{pm}{m+n}.$$

If m is small compared to n, as in this case, the efficiency is increased by substantially the factor p up to reasonable values. This is all on the condition that the antennas act as independent sources of waves; that is, are spaced sufficiently so that there is practically no interaction between them and the input resistance of an antenna is practically unchanged by excitation of other antennas. As a concrete illustration of this principle, a wave antenna nine miles long was found to have an efficiency of approximately 3 per cent whereas a system of two identical ones in parallel and properly spaced, as shown in Fig. 3 was found to have an efficiency of 6 per cent.

Obviously, for a given spread or width t—t, which in the illustration referred to amounts to about five miles, it would be advantageous solely on the basis of radiation efficiency to have as many of the parallel antennas as possible still maintaining sufficient spacing. From an economic point of view, however, it may not be desirable to go to the maximum number. Thus in Fig. 2 we have limited the number to twelve in three groups of four each.

The feature of supplying power to the antennas is important. In accordance with this disclosure we prefer to have the antennas all in the same phase, and the transmission line must be adapted for this. Assuming the power station at the midpoint W, we might use a single transmission line with branches to the respective antennas. We find it better, however, in order to reduce i^2r losses therein, to have a plurality of transmission lines each of a pair of conductors, and instead of having a line to each antenna, we connect the antennas in pairs, as shown in Fig. 2. In order that the transmission lines shall be of the same electrical length, we loop them back on themselves by the necessary amount as shown in Fig. 2. This distribution permits a reduction of losses on the transmission line in about the same ratio as for the plurality of antennas.

As noted above and largely for the purpose of economy, we connect the antenna units in pairs as shown in Fig. 3, the spacing between the two units of one pair being sufficient to conform to the requirement of negligible interaction, and, more specifically in our case, we find it convenient to make the portions f, which are at right angles to the antenna proper, one-half of the length of the conductor between two of the loading condensers, and the two units are then fed by means of a transformer connected at the midpoint h. This provides a mid-series connection to each of the lines in a manner which is recognized as desirable in such transmission circuits. It is apparent that the spacing between two adjacent pairs must be sufficient so that the interaction between the two proximate conductors of the two pairs shall be kept at the desired low value. In Fig. 3 this spacing has been shown as somewhat greater than between the two antennas of one pair.

The details of the transformer connection from the transmission line to the antennas of one pair are shown in Fig. 4. The transmission line is a balanced line which is to inductively connect to the grounded antennas, and such connection may be effectively made by connecting a condenser C_2 across the primary of the transformers in the transmission line, this condenser, with two other condensers C_3, giving a parallel tuned circuit. The secondary of this transformer constitutes a portion of a series tuned circuit consisting of the winding L_2 and condensers C_4, the one end of the winding being grounded. When two of the antennas are connected in parallel the impedance thereof is reduced to one-half, and in this event it will be desirable to make the transformer a step-down transformer of the proper ratio to give matching in a manner well known in the art. Under these conditions there will be no reflection at either end of the antennas.

Certain protective features are desirable in connection with our system. In part, it is desirable to provide means whereby accumulated charges on the loading condensers may be discharged. To this end, as shown in Fig. 5, each condenser is shunted by a leakage resistance which might be of the order of 15,000 to 50,000 ohms. It is also shunted by a lightning arrester gap to afford protection against more violent surges. Such protection is also provided for the condensers C_2, C_3 and C_4, as shown in Fig. 4. We find it also desirable to carry on tests of an antenna pair with respect to insulation, etc., which tests are best carried on with direct current or very low frequencies. To this end we provide from the transmission line to the antennas a conductive connection through the impedances Z of Fig. 4. The high value of these impedances Z, as well as the resistances bridging the loading condensers, is such that their presence does not interfere with the transmission of the radio frequency currents but still provides a circuit for direct current testing and protection against excessive accumulation of electric

charges. The condensers C_3 are introduced as blocking condensers for direct current.

While in Fig. 3 the remote ends of the pair of antennas are separately grounded, we would point out that various changes in that connection may be made, as illustrated, for example, in Figs. 6 to 8, which do not need further explanation.

While the main purpose of the system, as we have thus described it, is for the purpose of increasing the efficiency of radiation, we find that the system is strongly directive. Such directivity would be present with one of our antennas but with the plurality as shown, the directivity becomes greater in a manner analogous to that observed in connection with defraction gratings in optical phenomena. Such directivity will depend on the total spread of our antenna array, and it is for that reason that we have shown so wide a spread for six pairs of antennas in Fig. 2 rather than bring the outside groups closer to the middle group. The type of directivity which is obtained is illustrated by the curves of Fig. 9 which have been calculated for the case of one pair of antennas at frequencies of 68 kilocycles and 60 kilocycles. Bringing several pairs into groups in the manner shown in Fig. 3 still further increases the directivity in a manner which is analogous to that of the optical case.

What is claimed is:

1. In a radio transmitting station, an antenna system adapted for increased radio efficiency comprising more than two parallel horizontal wave antennas with condensers spaced along their length, a radio frequency generator, transmission lines therefrom to the antennas at one end to excite the antennas in phase, a surge impedance to ground at the other ends, transformers for connecting the transmission lines to the antennas, the primary of the transformers being part of parallel tuned circuits and the secondaries being part of series tuned circuits, the spacing between the parallel antennas being so large that they do not interact appreciably at the frequencies used.

2. In a radio transmitting station, an antenna system adapted for increased radio efficiency comprising a plurality of pairs of parallel horizontal wave antennas with condensers spaced along their length, a radio frequency generator, transmission lines therefrom to the antennas at one end to excite the antennas in phase, a terminating impedance to the ground at the other ends, transformers for connecting the transmission lines to the antennas, the primary of the transformers being parallel tuned circuits and the secondaries being series tuned circuits, the spacing between the parallel antennas being so large that they do not interact appreciably at the frequencies used, and an impedance leak and a lightning arrester across each loading condenser.

3. The combination of claim 1 characterized by the fact that the plurality of antennas are connected in pairs with a separate transformer for each pair.

4. The combination of claim 1 characterized by the fact that the plurality of antennas are connected in pairs with a separate transformer for each pair and a separate transmission line from the generator to each pair of antennas, the transmission lines to each pair being of the same electrical length.

5. The combination of claim 1 characterized by the fact that the condensers in the horizontal wave antennas are equally spaced along their length and that the antennas are connected in pairs with a separate transformer for each pair, the spacing between the antennas of a pair being equal to the spacing between the condensers.

6. The combination of claim 1 characterized by the fact that the impedance at the transformer end as seen looking from the antenna into the transformer is also equal to the surge impedance of the antennas.

7. The combination of claim 2 characterized by the fact that there is a high impedance conductive connection from the primary of each transformer to its pair of antennas to yield a conductive path from the generator over the antennas for protecting and testing purposes during operation.

8. The combination of claim 2 characterized by the fact that the impedance leak is a high resistance.

9. In a radio transmitting station, an antenna system for increased radio efficiency comprising more than two parallel horizontal wave antennas with condensers spaced along their length, a radio frequency generator, transmission lines therefrom to the antennas at one end, transformers for connecting the transmission lines to the antennas, the spacing between the parallel antennas being so large that they act as substantially independent antennas.

10. The combination of claim 9 characterized by the fact that the primaries of the transformers are parts of parallel tuned circuits and the secondaries are parts of series tuned circuits.

11. The combination of claim 9 characterized by the fact that there is a terminating impedance to ground at the remote end of each of the antennas.

12. In a radio transmitting station, an antenna system adapted for increased radio efficiency comprising a plurality of pairs of parallel horizontal wave antennas with condensers spaced along their length, a radio frequency generator, transmission lines therefrom to the antennas at one end, transformers for connecting the transmission lines to the antennas, the spacing between the parallel antennas being so large that they do not interact appreciably at the frequencies used, and a resistance leak and a lightning arrester across each loading condenser.

13. The combination of claim 12 characterized by the fact that there is a transformer common to each pair of antennas.

14. The combination of claim 9 characterized by the fact that the condensers in the horizontal wave antennas are equally spaced along their length and that the antennas are connected in pairs with a separate transformer for each pair, the spacing between the antennas of a pair being equal to the spacing between the condensers.

15. The combination of an antenna composed of a plurality of equally long conductors and a plurality of condensers connected in series with each other so that the condensers are spaced from each other by equal distances each antenna being grounded at both ends, and a plurality of high resistances each of which is connected in shunt with one of said condensers forming a continuous conductive path over the length of the antennas.

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