Jan. 8, 1929.

1,697,945

H. H. BEVERAGE

PHASING OF ANTENNA

Filed Aug. 3, 1926

3 Sheets-Sheet 1

Fig. 1

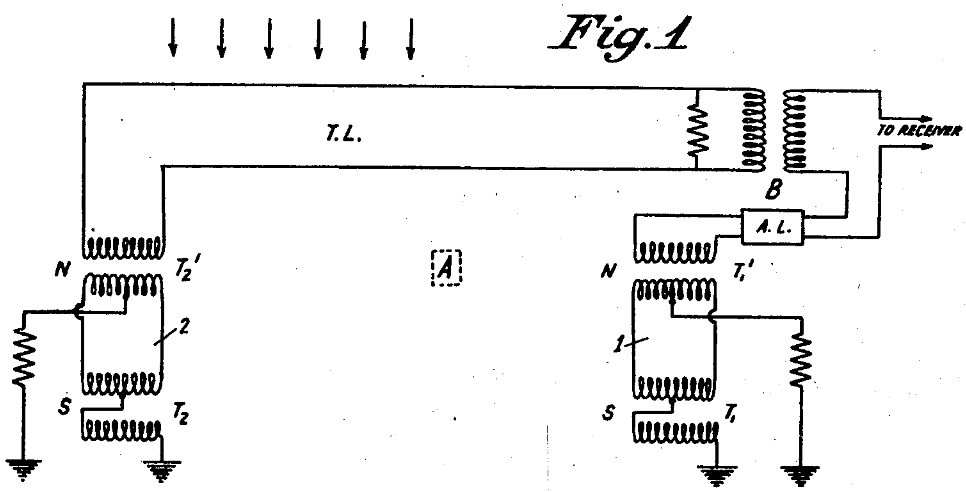

Fig. 3

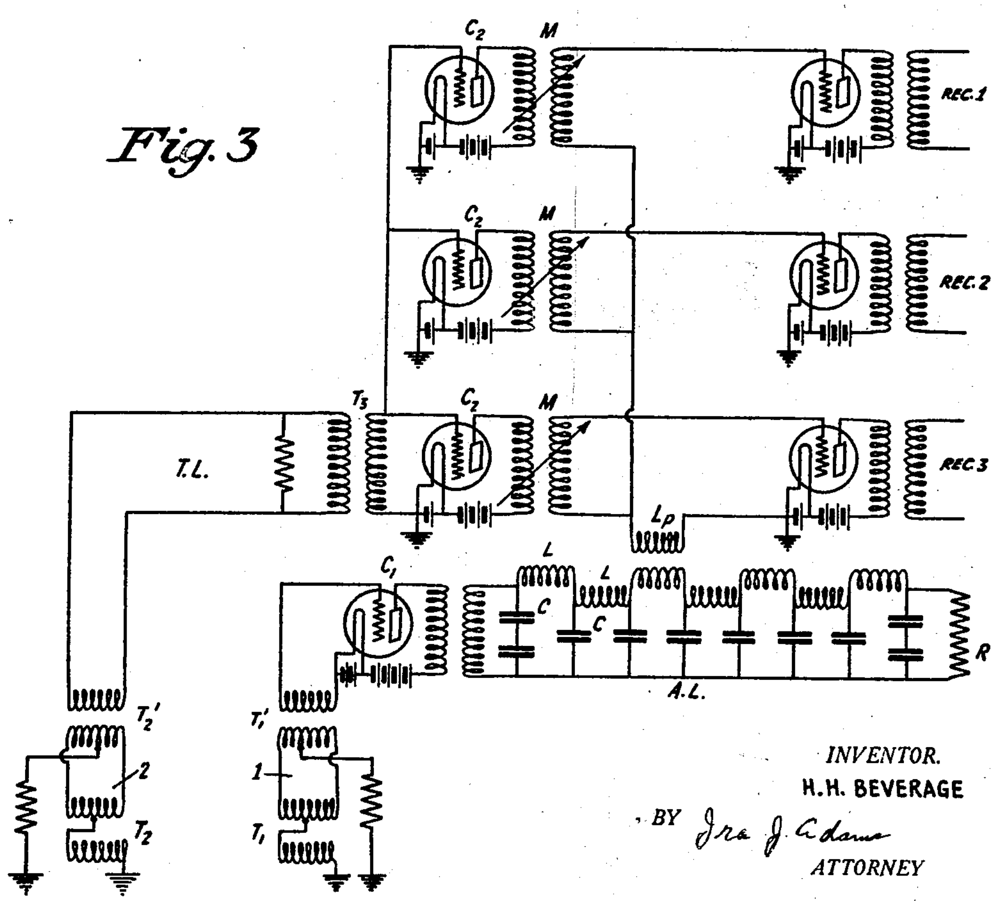

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Fig. 2

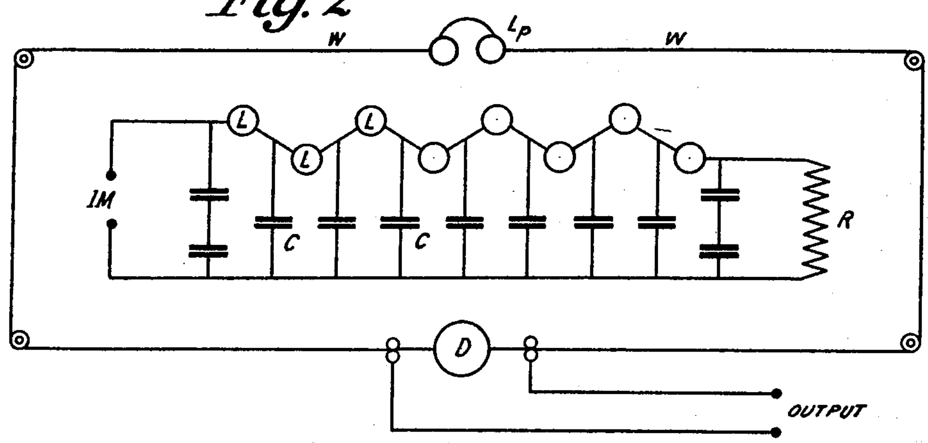
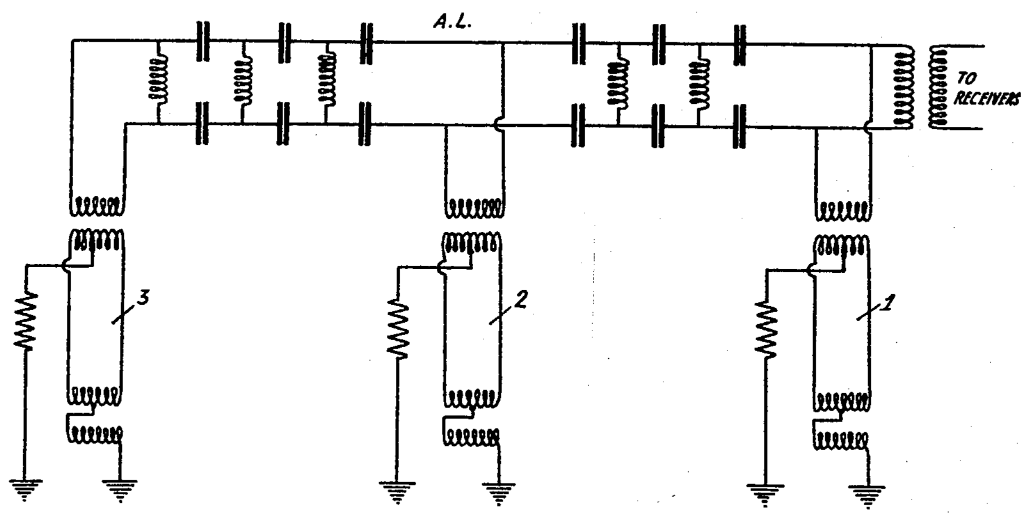


Fig. 6



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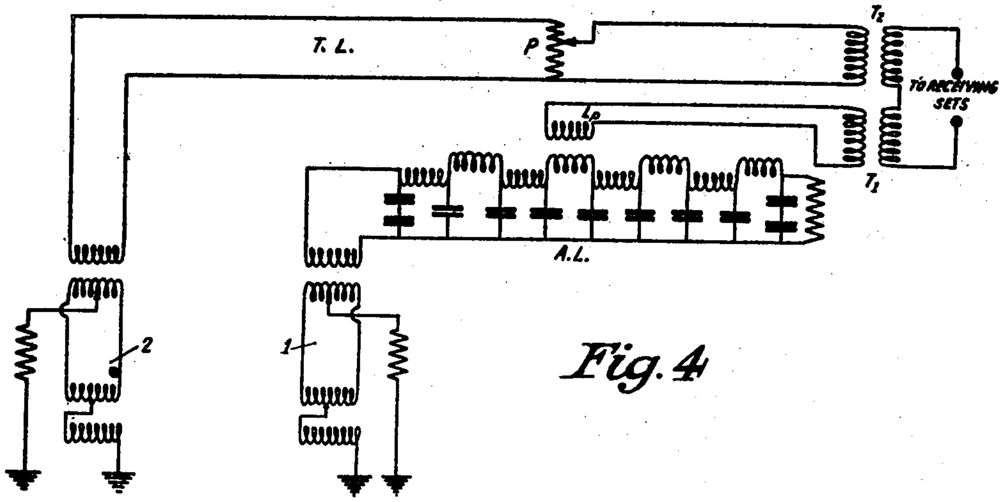

Fig. 4

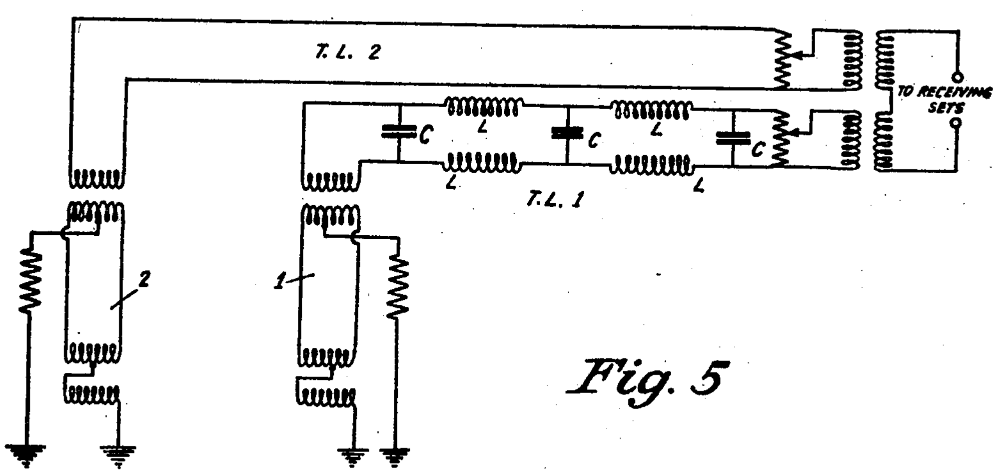

Fig. 5

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Patented Jan. 8, 1929. **1,697,945**

UNITED STATES PATENT OFFICE.

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PHASING OF ANTENNA.

Application filed August 3, 1926. Serial No. 126,770.

In combining a number of antennæ of any type in broadside, it is necessary to preserve certain phase and amplitude relations among the signals supplied by the various antennæ. It often happens that when a station is built a single antenna is contructed which terminates at the station and later a second and even a third antenna is constructed several miles away from the first station. These second and third antennæ are usually located at different distances from the receiving station which is the combining center and, therefore, it is necessary to bring the signals from at least all but the original antenna to the combining station over land transmission lines. These lines are usually of different length and, therefore, there is a change in the phase and amplitude of the signal reaching the receiver by different amounts in the case of the various antennæ.

If the combining station were in a position as indicated by A in Fig. 1 and the two antennæ were located at equal distances from it, of course the signals from each antenna 1 and 2 would arrive in phase at the combining, or in this case receiving station, but this is usually impossible, and it is, therefore, necessary to use some means to bring the signals from the antenna adjacent to the receiving station and the other antennæ which are away from the station, into proper phase relationship. This has been done in the past by using a separate artificial line for each signal.

An object of my invention is to make possible the use of a single artificial line for all signals within wide frequency limits. The ultimate limits are, of course, determined by the design of the artificial line. This artificial line is designed so that it has an electrical length equal to that of the transmission line which may be, for example, six miles long and the shortest wave length that can be used is limited by the "cut-off" frequency of each individual section of the artificial line. For the purpose of increasing the range of the artificial line it may be designed in many sections so as to make the "cut-off" frequency high.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation, together with ways in which the particular objects thereof may be attained will best be understood by reference to the following description taken in connection with the accompanying drawings wherein I have shown by means of the various figures of the drawings several forms which my invention might assume, but it is to be understood that the same is capable of various modifications and I do not, therefore, desire to be limited to the exact showing which has been made.

Considering the various figures of the drawings,

Fig. 1 shows a typical broadside installation consisting of two antennæ and a diagrammatic showing of the artificial line;

Fig. 2 is a preferred form of construction of various sections of the artificial line together with the phase adjusting means;

Fig. 3 is a showing similar to Fig. 1, showing a means of connecting the artificial line using separate intensity adjustment for each desired frequency; and

Fig. 4 is a modification of Fig. 3 showing a potentiometric means for intensity regulation of all frequencies simultaneously,

Fig. 5 is a further modification showing unequal transmission lines and a loading to reduce velocity in one of them; and

Fig. 6 shows a single transmission line used for phasing three antennæ spaced broadside.

Referring to the drawings, Fig. 1 shows a typical broadside installation consisting of two antennæ 1 and 2, for example, wave antennæ of the type shown in my U. S. Patent 1,381,089. The antenna 1 terminates directly at the receiving station while the antenna 2 is at a point remote therefrom which for convenience of illustration may be considered as being six miles away. Assume that the signal received is travelling in the direction of the arrows shown in Fig. 1, then this signal will reach the north end of both antennæ at approximately the same instant and as it travels down each antenna it will induce a voltage in each of the antennæ simultaneously which are in phase in both and which builds up to a maximum at the south end after which it passes through the primaries of the transformer T_1 and T_2 thereby feeding the signal energy back over the antenna to the transmission line. The signal energy will finally appear in the secondaries of the transformers T_1' and T_2' and up to this point the energy in each antenna remains in phase. From the secondary T_2' the energy from the antenna 2 is brought to the receiving point over a transmission line TL which, as above stated, is assumed to be six miles, or its equivalent 9.65 kilometers, distance from the receiving point at which the antenna 1 is located. If the signal travels along the transmission line TL with the velocity of light, which is approximately true in the usual case for open wire lines, a signal at a wave length of 9,650 meters from antenna 2 will be delayed a whole cycle, while the signal of twice that wave length or 19,300 meters will be delayed a half a cycle, with respect to the signals from the antenna 1. It is evidenced, therefore, that the transmission line will dephase the signals a certain amount and that the amount of dephasing is a function of the wave length.

To overcome this difficulty I propose to use an artificial line such as is shown conventionally from AL in Fig. 1 and in more detail in Figs. 2 and 3, and to make the total electrical length of this artificial line, that is, the real length plus the equivalent length of the artificial line, the same electrical length as the real transmission line from antenna 2 to the receiving station. The artificial line is placed on the antenna 1 and will delay the signals as a result of its construction by the same amount as a real line coming from the antenna 2.

It is well known in the art how to design artificial lines. One form of construction may be such as is shown in Fig. 2 where the series inductances are indicated by L and the shunt capacities by C. In the real lines the velocity $V=\frac{1}{\sqrt{LC}}$ for the currents flowing in the line, and the natural or surge impedance $Z=\frac{L}{\sqrt{C}}$. It is a well known fact that the constants of real open wire lines are usually such that the currents have a velocity of the order of the velocity of light and that the surge resistance is of the order of 600 ohms. By substituting these values in the above equations it is found that the inductance L should be approximately 2 millihenries per kilometer of electrical length while the capacity C should be about .0055 microfarads per kilometer of electrical length. Thus, an artificial line with an electrical length of 10 kilometers should have a total series inductance of 20 millihenries and a total shunt capacity of .055 microfarads. If the line is divided into ten equal sections, each section would introduce a lag in the energy reaching it that would be equivalent to one kilometer of real line.

The more sections there are to the artificial line the higher the "cut-off" frequency will be, so that by using a large number of sections it is possible to design an artificial line of considerable electrical length and still keep a high "cut off" frequency. In applicant's arrangement it has been found that artificial lines for long wave reception may have an electrical length of between 10 to 30 kilometers with fifteen sections and the "cut-off" frequencies will then be about 50,000 cycles for the 30 kilometer line, and 150,000 cycles for the 10 kilometer line.

In all cases, the artificial lines terminate in a resistance R (Fig. 2) which is equal to the surge impedance of the line so as to prevent reflections.

The proper phase relationship between the received signals may be selected by moving a pick-up coil L_p coupled progressively to the inductances L, L. The means employed for producing this result is to mount the pick-up coil upon a track and draw it back and forth by means of a wire W which is attached to a drum on the dial D. The wires W also serve to connect the pick-up coil to the output circuit as shown in Fig. 2.

In Fig. 3 is shown one means for combining a plurality of signals and individually adjusting the intensity for each desired frequency. Each of the antennæ 1 and 2 terminates in the transformer T_1' and T_2'. Transformer T_1' operates a coupling tube C_1 associated with the artificial line AL. The transmission line TL connects the transformer T_2' through a second transformer T_3 at the end of this transmission of real line to coupling tubes C_2, associated with variable couplings M. This coupling M is adjusted for equal intensity from the two antennæ, and connected to the one end of its secondary is the pick-up coil L_p which is capable of being adjusted after the fashion shown in Fig. 2 until the used portion of the artificial line is electrically the equivalent of the real line between antenna 2 and 1, at which point all signals from the two antennæ will be in phase. This modification would be used in cases where the attenuation characteristics of the real and artificial lines are not identical for different frequencies, causing the relative intensities of the antennæ to vary with the frequency. This variation may be corrected by using several coupling tubes C_2 associated with variable couplings M, whereby the intensities may be equalized separately for each desired frequency.

Another modification of the arrangement is shown in Fig. 4 where the relative intensity between the two lines may be adjusted by the potentiometer "p" which will also serve to prevent reflections on the real line. This arrangement would be used in cases where the attenuation characteristics of the real and artificial lines are practically identical, making individual intensity adjustments unnecessary.

The energy from the transmitting line TL and from the artificial line AL is brought to transformers T_2 and T_1 respectively. The transformers have one side of their secondaries serially connected and the other side directed to a receiving means in a manner similar to what has been shown by the preceding figures.

Fig. 5 shows a further modification that could be used in some cases. Here transmission lines of unequal length TL_2 and TL_1 are shown. The shorter of the two lines TL_1 is loaded to reduce its velocity, as for example, by using series inductances or shunt capacities or both. In some cases, the desired result might be obtained by using a section of cable or twisted pair in TL_1. It is also obvious that the same result could be obtained by speeding up TL_2 by loading with series capacity or shunt inductance, or by other means to make the electrical lengths of the two transmission lines identical.

In Fig. 6 three antennæ 1, 2 and 3 are shown as in spaced broadside. The single transmission line is then connected by coupling or other suitable means with each of said antennæ and in turn connected with a receiving means. Associated with the transmission line are loading means adapted to produce infinite phase velocity so as to be used for phasing the three antennæ.

While the theory, as developed by Einstein, that nothing can travel faster than the velocity of light is doubtlessly correct, it is possible to advance the phase by loading and thus produce an apparent phase velocity greater than the velocity of light. By this I mean, that while the actual currents in the wire do not travel faster than the velocity of light, the phase may be progressively advanced to produce the effect of a current travelling faster than the velocity of light, as far as a steady state of conditions is concerned. This advancing of the phase may be accomplished by loading the larger lines to an apparent infinite phase velocity by the use of a series capacity, a shunt inductance, or both.

While my specification has described means and methods adapted to bring the signals from several antennæ into phase, it is obvious that the same principles could be applied where any definite phase relations are desired, and is, therefore, not limited to the particular case of "in phase condition."

It is obvious from the disclosure that there are many ways of applying this principle and also it is clear that the same idea can be applied to more than two or three antennæ and it is, therefore, to be understood that my invention is not limited to the specific forms shown but is capable of being used with any number of antennæ located at various distances from the point at which the signals are received, and I am, therefore, entitled to all modifications thereof that fairly fall within its spirit and scope as defined by the following claims.

I claim:

1. A radio receiving system comprising, a plurality of separated antennæ, a receiving system adjacent one of said antennæ and remote from said other antennæ, energy transfer circuits between said remote antennæ and said receiver, an artificial line inserted in said first named antenna circuit, pick-up coils associated with said energy transfer circuits and said artificial line, and means for adjusting said pick-up coils with respect to said artificial line, said adjustment being adapted to bring the energy from each of said antennæ to the same phase relationship.

2. A radio receiving system comprising, a receiving means, a receiving antenna adjacent thereto, a second receiving antenna at a point remote therefrom, a land line connection between said remote antenna and said receiver, means associated with said connecting line for controlling the signal intensity reaching said receiver, an artificial line connected with said antenna adjacent said receiver, means connected with the land line and with said artificial line for regulating the phase angle between the signals received from the said antennæ, and means for coupling said antennæ to said receiving means.

3. A radio receiving system comprising, a receiving antenna, a second receiving antenna at a point remote therefrom, means for electrically connecting said antennæ, an artificial line associated with one of said antennæ, said artificial line being adapted for use over a widely varying frequency range of received signals, means for adjusting the electrical equivalent length of said artificial line, said adjustment being adapted to bring the artificial line and the connecting line between said antennæ to the same electrical length, and means for utilizing said signals.

4. A radio receiving system comprising a plurality of antennæ remote from each other, a receiving system adjacent one of said antennæ, a circuit connecting the other of said antennæ to said receiver, artificial line means associated with said first named antenna for producing an electrical length from said antenna to the receiver equivalent to that of the electrical circuit connecting said remote antenna to said receiver, and means for regulating the effective length of said artificial line.

5. A radio receiving system comprising a

plurality of antennæ remote from each other, a receiving means adjacent one of said antennæ, a circuit connecting the other of said antennæ with said receiving means, an artificial line associated with said first named antenna, said artificial line being adapted to produce an electrical length from said antenna to said receiving means equivalent to that of the electrical circuit connecting said remote antennæ to said receiver, means for regulating the electrical length of said artificial line, and means for equalizing the intensities of the signals from the several antennæ separately for each frequency desired.

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