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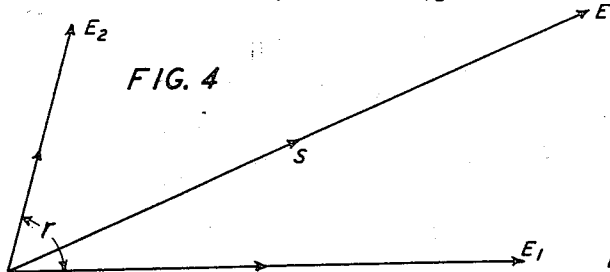
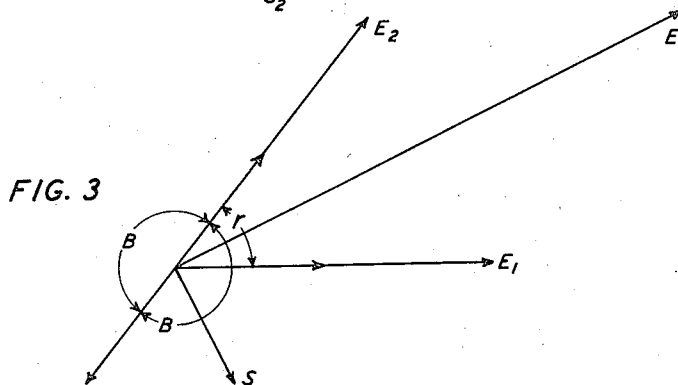
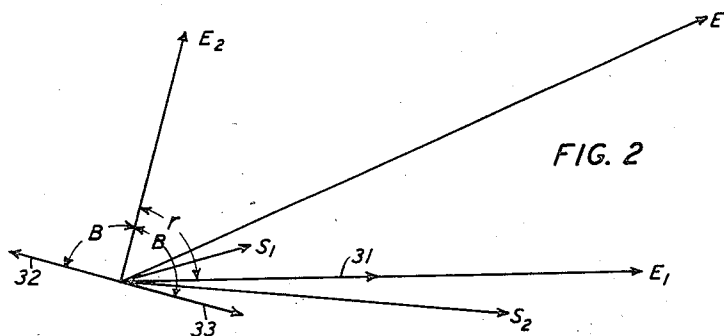
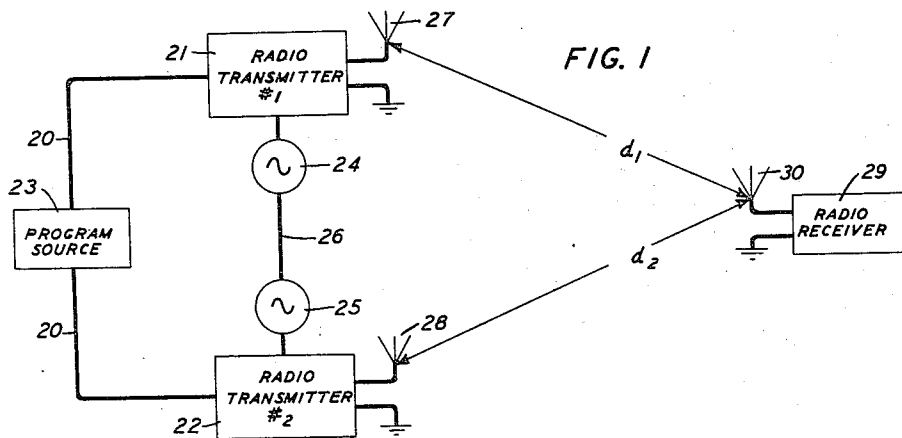
C. B. AIKEN

2,033,271

COMMON FREQUENCY BROADCASTING SYSTEM

Filed April 7, 1933

2 Sheets-Sheet 1



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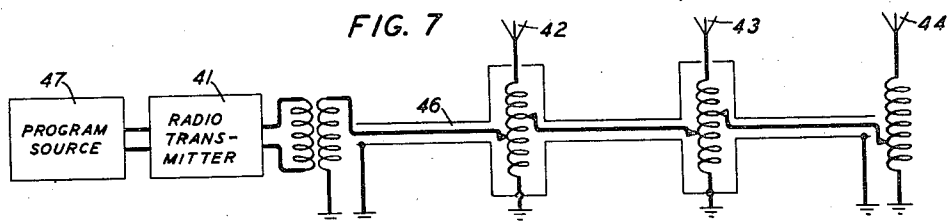
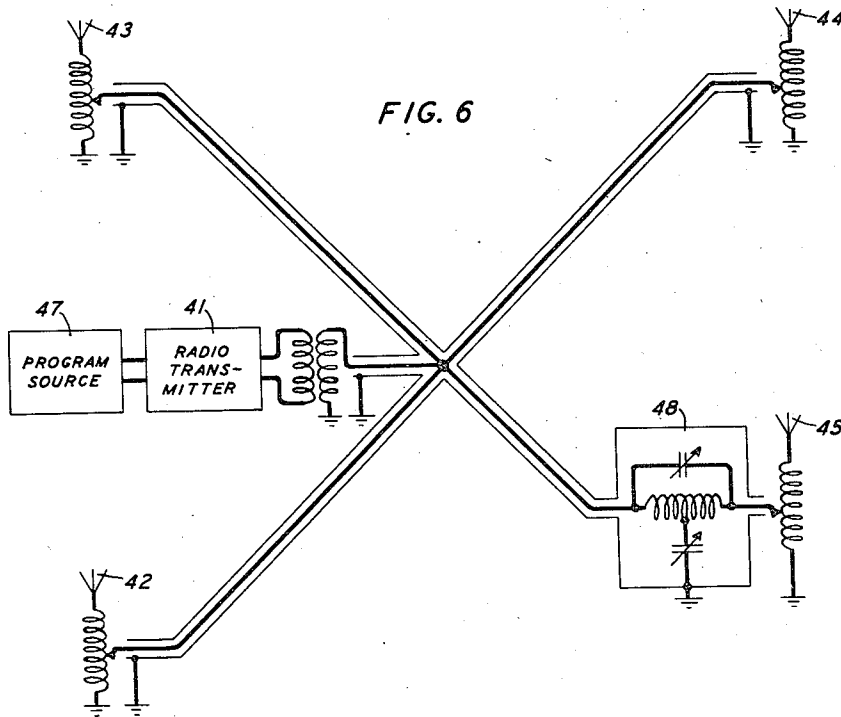
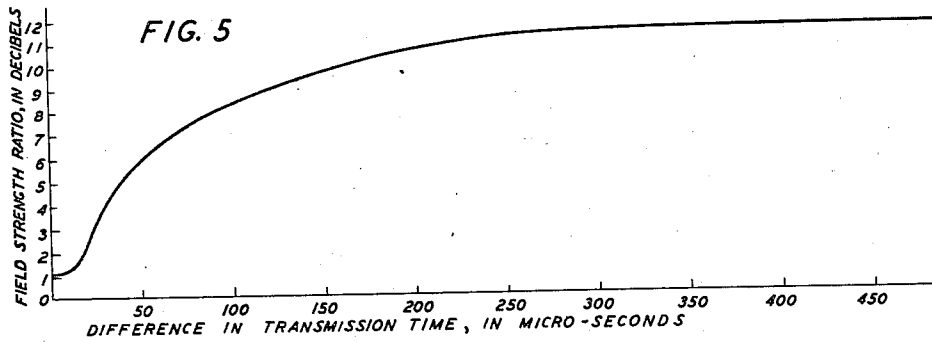
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COMMON FREQUENCY BROADCASTING SYSTEM

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2 Sheets-Sheet 2



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COMMON FREQUENCY BROADCASTING
SYSTEM

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Application April 7, 1933, Serial No. 664,906

15 Claims. (Cl. 250—17)

This invention relates to radio broadcasting systems, and particularly to systems for transmitting a program from different points simultaneously on the same carrier wave.

5 An object of the invention is to reduce distortion of the received program due to interference at the receiving point between waves from two transmitters.

10 Another object is to increase the service area of a common frequency broadcasting system.

A further object is to increase the area which may be served by the expenditure of a given amount of power in broadcasting.

15 It is well known that when the same program is broadcast simultaneously from two relatively widely separated stations operating on the same wave length the reception in regions where the field strengths of the stations are about equal is frequently very badly distorted. Not only does
20 the volume of the received signal fluctuate widely and rapidly but the quality is also seriously affected by the presence of harmonics. Some improvement has been effected by accurate synchronization of the radiated carrier waves, but even
25 with perfect synchronization the distortion effects are not removed.

I have found by analysis and experiment that the remaining effects are due not only to the interference of the carrier waves at a given receiving point but also to the relative phases of the modulations of the carriers, that is, to the time interval between the instants at which the envelopes of the modulated carriers reach their maximum amplitudes. This time interval is the
30 difference of the times required for the signal to traverse the different paths from the signal source to the receiving point, the paths including not only the radio paths but also the wire line paths over which the audio frequency signal
35 is transmitted.

40 The distortion effects arising from the difference of the transmission times of two waves are most noticeable in the zones between the transmitting stations in which the carrier waves have
45 approximately the same strengths, but may be greatly reduced or eliminated by so arranging the system that the transmission times to points in these zones are made substantially equal.

50 In accordance with the present invention this result is achieved by the cooperation of several features. One feature is that the radiating antennae are spaced relatively closely, the separation ranging from 10 miles or less up to 25 miles. Each antenna thus serves an area of from 20 to
55 100 square miles and by the use of a plurality of

radiating points a relatively large area is covered with a minimum power output. A second feature is that all of the modulated power is generated at a single central station and is transmitted over shielded cables to the several
5 antennae where it is radiated without further amplification or frequency change. The whole radiating network is thus of the passive type and includes no elements such as vacuum tubes
10 which may by uncontrolled changes of their characteristics introduce changes of the transmission times. A further feature of the system is the use of delay equalizers in the high frequency cables to ensure that the paths to the
15 several antennae will be of equal electrical length. This in conjunction with the central generation of the modulated wave permits the phases of the modulations at the radiating points to be adjusted very accurately to equality and to
20 be maintained equal.

The invention is described in detail hereinafter in connection with the accompanying drawings, in which

Fig. 1 shows a common frequency broadcasting system of known type;

25 Figs. 2, 3 and 4 are vector diagrams useful in explaining the invention;

Fig. 5 is a graphical representation of experimental data useful in applying the principles of the invention; and

30 Figs. 6 and 7 show different embodiments of a common frequency broadcasting system in accordance with the invention.

Fig. 1 shows a common frequency broadcasting system of a known type, consideration of
35 which will lead to a perception of certain inherent difficulties which the present invention is designed to overcome. The arrangement illustrated comprises a pair of radio transmitters 21
40 and 22 spaced some distance apart and both sending out the same program over the same carrier frequency. A program source 23 such as a broadcasting studio is connected by wire lines
45 20 to the radio transmitters. Carrier sources 24 and 25 are associated with the respective transmitters and are interconnected by some suitable synchronizing means represented schematically
50 by a line 26. The transmitters have radiating antennae 27 and 28. A typical radio receiver 29 is located at some point in the field of both transmitters. The associated receiving antenna
55 30 is at a distance d_1 from transmitting antenna 27 and a distance d_2 from antenna 28.

In the system of Fig. 1 the program is transmitted from the studio over the wire lines at audio

frequency to the transmitters which radiate simultaneously from antennae 27 and 28. The system, which is typical of common frequency broadcasting systems generally, provides two paths of different lengths each including a plurality of separate pieces of apparatus by which the program is transmitted between the studio 23 and receiving antenna 30.

In order to show the characteristics of the combined wave at the typical receiver without unnecessary complication, it will be assumed that the carrier frequencies are identical and that a single modulating frequency is being supplied by the program source. The carrier frequency will be designated as $\omega/2\pi$ and the modulating frequency as $P/2\pi$. Assuming first that transmitter 21 is acting alone, the carrier amplitude received at antenna 30 will be designated as E_1 and the degree of modulation as M_1 . The modulated wave may then be represented as a function of the time t as follows:

$$E_1[1+M_1 \cos Pt] \cos \omega t. \quad (1)$$

The modulated wave received from the other transmitting antenna may differ from the above wave in amplitude, in degree of modulation, in the phase of the carrier and in the phase of the envelop. The carrier amplitude of the second wave will be designated E_2 , the degree of modulation M_2 , the carrier phase γ and the envelop phase β . The wave may be represented by

$$E_2[1+M_2 \cos (Pt+\beta)] \cos (\omega t+\gamma). \quad (2)$$

It will be understood that when a complex modulating wave is used comprising a plurality of frequencies, each frequency has its own value of β . A difference in the times of transmission over the wire circuits affects the angle β but not the angle γ . Differences in the radio frequency equipments of the two transmitters may affect either γ or β or both. Differences in the ether distances d_1 and d_2 affect both γ and β . Imperfect synchronization of the carriers will cause γ to vary without affecting β .

It is evident from an inspection of expressions (1) and (2) that the form of the combined wave at the receiving antenna is dependent upon the carrier strengths, the degrees of modulation and the two phase angles. The kind and degree of distortion depends upon the form of the received wave and to a minor extent upon the type of radio receiver employed and the type of program being transmitted.

The general manner in which the combined wave may depart from the form of a suitable modulated wave and cause distorted reception is exhibited in Fig. 2. This figure is a conventional vector diagram representing the expressions (1) and (2) and their sum at the instant when t is zero. E_1 is the first carrier vector and its upper and lower side frequency vectors coincide in the direction of the carrier as indicated by the vector 31. The second carrier vector E_2 leads E_1 by the angle γ as shown. Its upper side frequency is represented by vector 32, which leads its carrier by the angle β , shown for simplicity as 90° . The lower side frequency is shown by vector 33 and lags the carrier by the same angle.

The carrier vectors sum up to the vector E as shown. The resultant upper side frequency vector is S_1 and the lower is S_2 . These are unequal in amplitude and are not symmetrically placed with respect to the carrier, nor does one lead and the other lag the carrier as in the component modulated waves. These departures from the standard

relation indicate the introduction of distortion which will appear in the response of the radio receiver.

In certain simple cases the form of distortion introduced is evident. For example, where γ is zero and β for a certain frequency is 180° , that frequency will be more or less attenuated. This is due to reduction of the side frequency amplitude by phase opposition, coupled with reinforcement of the carrier by phase coincidence. The degree of modulation is effectively reduced by this process and hence the response of the receiver at the given frequency is diminished.

Even though γ is not zero, attenuation occurs if β is 180° and the carrier strengths are nearly equal. The case is illustrated in Fig. 3, again as at the instant when t equals zero. The resultant upper and lower side frequency vectors coincide as shown by the single vector S which is in quadrature with the carrier E . The vectors E and S fulfill the known condition for a phase modulated wave, to which the ordinary detector is insensitive.

In case γ and β are each 180° the carriers tend to annul each other, while the side frequency components are in phase coincidence. The effective degree of modulation is thereby increased and over-modulation may readily result. In the extreme case in which the carriers are completely annulled, the fundamental signal wave is lost and harmonics alone are generated in the detector. The resulting form of distortion in these cases is found to be more unpleasant than that associated with carriers in phase coincidence.

The conditions necessary to remove distortion of both types are the following:

$$M_1=M_2, \quad (3)$$

$$\beta=0 \quad (4)$$

Fig. 4 is the vector diagram for a case in which these conditions are satisfied. All side frequency vectors are now proportional in amplitude to their respective carriers and, when t is zero, are coincident in phase therewith. Consequently the resultant upper and lower side frequency vectors represented by the vector S lie in the direction of the resultant carrier vector E . The received wave has the same phase relations and the same degree of modulation as the wave sent out by either transmitter. Hence there is no distortion attributable to the combination of the two transmitted waves. The freedom from distortion in this ideal case is independent of the ratio of field strengths and of the carrier phase angle. The value of the latter will of course vary from point to point in the field but this will merely cause variations in the strength of received signals.

If the carrier phase is constant at the receiver, as may happen with perfect synchronization of the carrier waves, the field strength is constant and the listener will adjust the volume of output of his receiver to a suitable level when tuning in and no further adjustment will be necessary. If the synchronization is imperfect the carrier phase will change slowly at the receiver, giving rise to an apparent fading effect. In this case the volume level will require further adjustment from time to time, best secured by some form of automatic volume control of which several are well known.

The conditions (3) and (4) above stated, when interpreted with reference to the system of Fig. 1, require that the waves radiated by the two transmitters be strictly identical and that the time of

transmission from program source to receiving antenna be the same by either route. As the time of transmission will vary from point to point in the field it is obviously not feasible to satisfy condition (4) at every point. In order to determine approximately the amount of difference in the transmission times tolerable under ordinary conditions, experimental tests were conducted with results shown in Fig. 5. It was observed that the maximum tolerable difference in transmission times at a given receiving point is a function of the field strength ratio. In the figure, difference in transmission times in micro-seconds is plotted as abscissa and the corresponding critical value of field strength ratio in decibels is plotted as ordinate. The curve shows the maximum difference found permissible for a given ratio of field strengths or, conversely, the minimum field strength ratio for a given difference in transmission times, allowing a barely perceptible amount of distortion in reception.

In systems of the type shown in Fig. 1, it is impracticable to produce identical waves in two radio transmitters or to equalize the times of transmission to the required degree. Particularly in the wire lines connecting the studio with the respective transmitters, differences as small as 50 micro-seconds have been found practically unattainable.

In Fig. 6, which illustrates schematically a system in accordance with the invention, a radio transmitter 41 is located centrally with respect to a plurality of outlying antennae 42, 43, 44 and 45. The spacing of the adjacent antennae preferably does not exceed about 25 miles. A high frequency transmission line 46, such as a pair of coaxial or concentric conductors of which several are known in the art, connects the high frequency output terminals of the transmitter to the antenna 42. The antennae 43, 44 and 45 are connected to the transmitter by similar conductors as shown. The transmitter is associated with the program source 47. Due to the central location of the transmitter, the transmission lines are of substantially equal electrical length. But in case antenna 45, for example, is closer to the transmitter than the others, so that the line thereto is too short, a delay network 48 may be inserted in the line at some convenient point. The network may be of the bridged-T type with variable elements for adjusting the amount of delay so as to compensate very accurately for the unequal electrical lengths of line. Delay networks suitable for this purpose are disclosed in U. S. Patent No. 1,828,454 to H. W. Bode, issued October 20, 1931.

In the operation of the system of Fig. 6, the program currents from source 47 modulate a carrier wave in the usual manner in the radio transmitter 41. The modulated wave is distributed over the transmission lines to the respective antennae. In this way the same identical wave is broadcast simultaneously from all the antennae, thereby satisfying condition (3). The time of transmission is the same by each route from the program source as far as the transmitting antenna. The only cause for difference in the total transmission time lies in the different distances from the transmitting antennae to a particular receiver. This difference is limited by the spacing between antennae. As the spacing is not over about 25 miles, the maximum possible difference in transmission times is 25/186000 second, or about 135 micro-seconds. A spacing of ten miles corresponds to a difference of about 54 micro-seconds, and so on. Condition (4) may thus be satisfied

to any required degree by restricting the antenna spacing in conjunction with the use of delay networks.

Due to the close spacing, the power required to be radiated by each antenna is small. This tends to prevent interference at points outside the service area, as such points will receive very little power. If the service area is to be extended, the number of antennae may be increased while keeping the spacing small and the power radiated per antenna low. In this way, any desired area may be served with a minimum expenditure of power and a minimum of interference at all points either within or without the service area.

At points nearly equidistant from two transmitters of comparable strength, the field strength ratio is small. At such points, however, the transmission times are substantially equal and the received signals are free from distortion. At points closer to one transmitter than to the other, the transmission times are unequal, but the field strength ratio is necessarily greater there, permitting the greater difference in transmission times without detriment to the quality of the received signals. The result is that the whole region in the vicinity of the transmitters may be served without noticeable distortion.

Fig. 7 shows an alternative form of distribution system according to the invention. The transmission line 46 extends from the transmitter 41 to antenna 44 and is opened at intervals for the insertion of coupling connections to the antennae 42 and 43. By use of a close spacing of antennae, say 5 to 10 miles, the use of time delay equalizers may generally be dispensed with. This arrangement is particularly well adapted for use in densely populated urban areas. There, a few closely spaced low powered antennae will serve large numbers of receivers with a relatively small total power outlay.

The invention is not limited to a single group of transmitting antennae controlled by one program source. A plurality of independent systems, each designed in accordance with the invention, may be operated simultaneously, each serving its own immediate area with a different program, or even with the same program if desired. The interference between any two or more such groups will be less than is encountered where each local territory is served by a relatively high powered transmitter radiating sufficient power from a single antenna to supply all local needs.

What is claimed is:

1. A broadcasting system comprising a program source, a radio transmitter controlled by said program source to generate program modulated waves, and a plurality of radiating antennae operatively connected to said transmitter, said antennae being simultaneously energized by said waves, and separated by a distance sufficiently great that with given power radiations the service areas of the respective antennae are partially distinct, and sufficiently small that distortion of the received programs due to interference at the receiver between waves from adjacent antennae is reduced.

2. A radio frequency distribution system comprising a radio transmitter adapted to generate modulated waves, a plurality of radiating antennae and a plurality of shielded conductors connecting the transmitter to the respective antennae, said antennae being so spaced from one another that adjacent ones are separated by a distance sufficiently great that with given power

radiations the service areas of the respective antennæ are partially distinct, and sufficiently small that interference at the receiver between waves from adjacent antennæ is reduced.

3. A broadcasting system comprising a program source, a radio transmitter controlled by said program source, two radiating antennæ connected to said transmitter and a delay equalizer in one antenna connection for substantially equalizing the times of transmission from the transmitter to the respective antennæ, said antennæ being sufficiently separated to assure a partially distinct service area for each and sufficiently close together to reduce interference at the receiver between waves from the two antennæ.

4. A broadcasting system comprising a program source, a radio transmitter controlled by said program source to generate program modulated waves, a plurality of spaced radiating antennæ separated by several wave lengths of the modulated waves to permit reception of said waves between said antennæ and a plurality of shielded conductors connecting the radio transmitter to the respective antennæ, whereby the program modulated waves are distributed to the antennæ and simultaneously radiated therefrom without further amplification or frequency change.

5. A broadcasting system comprising a program source, a radio transmitter controlled by said program source to generate program modulated waves, a plurality of radiating antennæ and a network of shielded conductors interconnecting the transmitter and the antennæ, said network being adapted to provide substantially equal times of transmission from said transmitter to each antenna, and said antennæ being so spaced as to have partially distinct service areas and at the same time to reduce interference at the receiver between waves from adjacent antennæ.

6. A broadcasting system comprising a program source, a radio transmitter controlled by said program source to generate program modulated waves, a plurality of spaced radiating antennæ in an extended area, adjacent antennæ being separated by a distance of several wave lengths of the radiated wave, a network of shielded conductors interconnecting the transmitter and said antennæ, and means to substantially equalize the times of transmission of program modulate waves from said transmitter to the respective antennæ.

7. A broadcasting system comprising a program source, a plurality of radiating antennæ, and means for furnishing said plurality of antennæ with carrier waves modulated by said program for simultaneous broadcast therefrom to a receiver in the service area of adjacent antennæ, the spacing of the adjacent antennæ being such as to permit the power radiated therefrom to be so limited as to substantially reduce interference at points outside said service area and being such as to limit the difference in transmission times from the adjacent antennæ to said receiver whereby distortion of the received program due to interference at the receiver between waves from the adjacent antennæ is reduced.

8. A broadcasting system comprising a program source, a plurality of radiating antennæ, and means for furnishing said plurality of antennæ with carrier waves modulated by said program for simultaneous broadcast therefrom to

a receiver in the service area of adjacent antennæ, the spacing of the adjacent antennæ being sufficiently great to enable the antennæ to serve partially distinct service areas and sufficiently small to reduce distortion of the received program due to interference at the receiver between waves from the adjacent antennæ.

9. A broadcasting system comprising a program source, a radio transmitter controlled by said program source for generating program modulated waves, a plurality of radiating antennæ, and high frequency transmission lines connecting said transmitter with said plurality of antennæ for distributing said modulated waves to said plurality of antennæ for simultaneous broadcast therefrom to a receiver in the service area of adjacent antennæ, the spacing of the adjacent antennæ being such, as about 5 to 25 miles, to reduce distortion of the received program due to interference at the receiver between waves from the adjacent antennæ.

10. A broadcasting system comprising a radio transmitter, a plurality of radiating antennæ, and high frequency means of substantially equal electrical length for leading waves from said radio transmitter to said plurality of antennæ for simultaneous broadcast therefrom to a receiver in the service area of one or more adjacent antennæ, the spacing of the adjacent antennæ being such that the service areas of the respective antennæ are partially distinct, and such that the difference in transmission times from the adjacent antennæ to a receiver in a common service area is limited whereby distortion of the received waves due to interference at said receiver with waves from an adjacent antenna is reduced.

11. A broadcasting system comprising a program source, a radio transmitter controlled by said program source to generate carrier waves modulated by said program, a plurality of radiating antennæ, high frequency transmission means for furnishing said plurality of antennæ with carrier waves modulated by said program for simultaneous broadcast therefrom to a receiver in the service area of one or more adjacent antennæ, and means connected with at least one of said transmission means for rendering the times of transmission the same from said program source to said plurality of antennæ, the spacing of the adjacent antennæ being sufficiently great to render the service areas of the respective antennæ partially distinct and sufficiently small to limit the difference in transmission times from the adjacent antennæ to a receiver in overlapping service areas to such amount that distortion of the received program due to interference at the receiver between waves from the adjacent antennæ is reduced.

12. A broadcasting system comprising a program source, a radio transmitter controlled by said program source for generating program modulated waves, a plurality of radiating antennæ, high frequency transmission lines connecting said transmitter with said plurality of antennæ for distributing said modulated waves to said plurality of antennæ for simultaneous broadcast therefrom to a receiver in the service area of adjacent antennæ, said lines being of substantially equal electrical length and including coaxial or concentric conductors, and means including a delay network connected with at least one of said lines for adjusting the amount of delay to compensate for unequal electrical lengths of said lines to render equal the times of transmission from said program source to said plu-

5 reality of antennæ, the spacing of the adjacent antennæ being such as to permit the power radiated therefrom to be so limited as to prevent interference at points outside said service area and being such as to limit the difference in transmission times from the adjacent antennæ to said receiver whereby distortion of the received program due to interference at the receiver between waves from the adjacent antennæ is reduced.

10 13. In a radio frequency carrier wave distribution system, a plurality of spaced antennæ adapted to radiate modulated carrier wave energy simultaneously to receiving zones therebetween, a source of signals, and means responsive to said signals for furnishing said modulated carrier wave energy simultaneously to said plurality of antennæ, the spacings of said antennæ being sufficiently great that with given power radiations the service areas of the respective antennæ are partially distinct and said spacings being sufficiently small to reduce wave interference effects due to unequal times of transmission of the modulated waves from adjacent antennæ to a given receiving point, the signal responsive means being adapted to furnish substantially identically shaped waves at all of the antennæ, and the times of transmission from said signal source to the respective antennæ being so proportioned that

wave interference effects in the receiving zone are further reduced.

14. In combination, a program source, a plurality of radiating means, means operatively connecting said program source with said plurality of radiating means to simultaneously radiate program modulated waves to a receiving point, said connecting means including means for rendering said radiated modulated waves identical in form and means for equalizing the times of program transmission from said program source to said plurality of radiating means, said radiating means being far enough apart to have partially distinct service areas and sufficiently close together to reduce interference at the receiving point between waves from adjacent antennæ.

15. A transmitter for the reduction of distortion in reception comprising a plurality of antennæ spaced sufficiently far apart to serve partially distinct areas and sufficiently close together to reduce distortion, means for simultaneously impressing signal modulated waves upon said antennæ in substantially identical wave form, and means for equalizing the times of transmission of said waves from said wave impressing means to the respective antennæ.

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