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H. RODER

2,279,062

HIGH FREQUENCY SIGNALING SYSTEM

Filed April 29, 1933

2 Sheets-Sheet 1

Fig. 1.

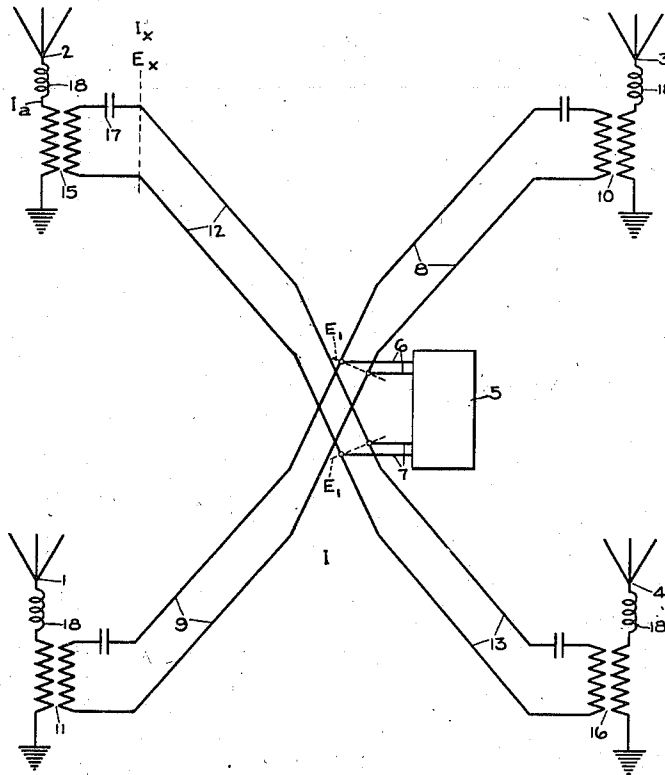
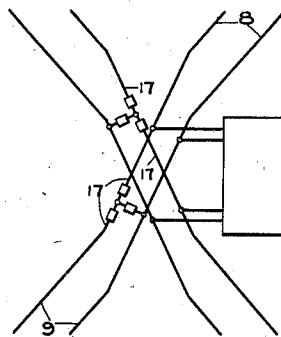


Fig. 2.



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UNITED STATES PATENT OFFICE

2,279,062

HIGH FREQUENCY SIGNALING SYSTEM

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Application April 29, 1933, Serial No. 668,595

16 Claims. (Cl. 250—11)

My invention relates to high frequency signaling systems and more particularly to antenna systems of the directive type.

It has for one of its objects to provide such a system capable of maintaining constant directivity irrespective of variations in the antenna constants caused by extraneous influences such, for example, as variations produced by weather conditions.

A further object of my invention is to provide means whereby currents supplied from a common source to different antennae may be automatically maintained in desired phase relation irrespective of variations in constants of the different antennae.

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 further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawings in which:

Fig. 1 represents a beacon system to which my invention may be applied;

Fig. 2 illustrates a modification thereof, and

Figs. 3 and 4 illustrate certain characteristics of my invention.

Referring to the drawings, I have shown in Fig. 1 thereof a plurality of antennae 1, 2, 3, and 4 which may be arranged at the corners of a square, for example, and energized from a common transmitting station 5 located at the center of the square. The transmitting station is represented as having two output circuits 6 and 7, the output circuit 6 being connected to transmission lines 8 and 9 of equal length leading through transformers 10 and 11 respectively to antennae 3 and 1, which are located at diagonally opposite corners of the square. The output circuit 7 leads through similar transmission lines 12 and 13 of equal length and transformers 15 and 16 to antennae 2 and 4 arranged at the remaining pair of diagonally opposite corners.

As thus constructed and with antennae 3 and 1 energized in a desired phase relation they cooperate to produce a figure eight radiation pattern. Antennae 2 and 4 when similarly energized cooperate to produce a figure eight radiation pattern the axis of which lies at an angle of 90° to the axis of the radiation pattern produced by antennae 1 and 3. In this way four equisignal zones are produced in directions radi-

ating from the beacon at ninety degrees apart and at 45° angles to the axes of the two radiation patterns. These equisignal zones constitute courses along which aircraft may be guided.

In the operation of such systems it has been found that the courses laid out by the beacon do not remain in fixed position but instead vary to a considerable extent. Such variation may be produced by variation in the phase relation between currents in diagonally opposite antennae which may in turn be caused, for example, by weather conditions influencing the capacity of the different antennae.

In accordance with my invention the system is so adjusted that variations in capacity of the different antennae do not influence the phase relation between currents in the different antennae with the result that the courses laid out remain in fixed position.

For an understanding of the manner in which this is effected it may be assumed that all of the systems feeding the antennae are identical. Then if each system be so constructed that the phase relation between the antenna current I_a and the voltage E_t supplied to the transmission line remains constant irrespective of variations in antenna capacity the desired result will be accomplished. Consideration may therefore be limited to the system supplying a single antenna, for example, antenna 2.

To determine the manner in which the antenna current I_a varies with respect to the voltage E_t both of these quantities may be expressed in terms of the current I_t flowing in the primary of the transformer 15, the fixed constants of the system, and the antenna tuning which varies with the extraneous conditions. These expressions may then be investigated to determine the proper tuning of the system relative to the fixed constants of the system to render the relation between antenna current I_a and the voltage E_t supplied to the transmission line independent of variations in antenna capacity.

To effect this calculation it is first realized that, for efficient operation, the tuning of the antenna, and its coupling to the transmission line must be such that the transmission line 12 is terminated in its surge impedance. This condition of the system will be referred to herein as the normal condition of the system from which the system deviates due to extraneous influences.

The surge impedance, on account of the high frequency, is a pure resistance and may be designated Z . It can readily be shown that to termi-

nate the transmission line in its surge impedance, the following relations must apply:

$$\frac{X_m^2 R}{R^2 + X_{20}^2} = Z \quad (1)$$

$$X_{2p} + X_p = X_p - \frac{X_m^2 X_{20}}{R^2 - X_{20}^2} = 0 \quad (2)$$

In these equations X_m is the mutual reactance of transformer 15, R is the total resistance of antenna circuit, X_{20} is the total reactance of the antenna circuit under normal conditions, X_{2p} is the reactance of the antenna circuit reflected into the primary of the transformer, and X_p is the total reactance of that portion of the primary circuit of the transformer at the left of the line designated in the drawing E_x , I_x . It will be noted that this value X_p includes the reactance of condenser 17 which is inserted for the purpose of securing a desired value of the quantity X_p , as will later be explained.

If we now represent the capacity of the antenna under normal conditions by C and any change in this capacity due to extraneous influences by dC then we may write

$$X_2 = X_L - X_c - X_{dc} = X_L - \frac{1}{w(C + dC)}$$

where X_L represents the total inductive reactance of the antenna circuit at any instant, X_c represents the total capacitive reactance of the antenna circuit under normal conditions, X_{dc} represents the instantaneous change in capacity of the antenna circuit due to extraneous influences and $w = 2\pi f$ where f is the frequency to be radiated.

Then

$$X_L - \frac{X_c}{1+x} = X_L \left(\frac{1-A+x}{1+x} \right) = X_L y \quad (3)$$

where

$$x = \frac{dC}{C}$$

$$1-A = \frac{X_2}{X_L}$$

$$y = \frac{1-A+x}{1+x} \quad (4)$$

Expressions as follows for current I_x in the primary of transformer 15, and antenna current I_a , may readily be derived:

$$I_x = \frac{E_x}{jX_p + R + jX_2} \quad (5)$$

$$I_a = I_x \frac{-jX_m}{R + jX_2} \quad (6)$$

where E_x is the voltage at the receiving end of the transmission and $j = \sqrt{-1}$.

From transmission line theory we obtain the following relations for current I_1 and voltage E_1 supplied to the transmission line:

$$E_1 = E_x \cos \theta + jI_x Z \sin \theta \quad (7)$$

$$I_1 = I_x \cos \theta + j \frac{E_x}{Z} \sin \theta$$

where θ represents the length of the transmission line expressed in degrees, i. e. in terms of phase displacement between voltages E_1 which is supplied to the transmission line and the voltage E_x at the remote end of the transmission line, it being assumed that the line is terminated into its surge impedance.

If the line be properly terminated, then

$$I_x Z = E_x$$

and from Equations 1 and 2 the following relations may be derived:

$$X_m = \frac{Z}{R} (R^2 + X_{20}^2) = ZR(1 + \tan^2 \psi) = \frac{ZR}{\cos^2 \psi} \quad (8)$$

and

$$X_p = X_{20} \frac{Z}{R} = Z \tan \psi \quad (9)$$

where

$$\tan \psi = \frac{X_{20}}{R}$$

and ψ = phase displacement between antenna current I_a and the voltage induced in the antenna by the current I_x when $dc = 0$.

By substituting Equations 3 and 8 into Equation 6 we obtain the following expression for the antenna current:

$$jI_a = I_x \sqrt{\frac{Z_0}{R}} \frac{1}{\cos \psi} \frac{1}{1 + j \frac{X_L}{R} y} \quad (10)$$

Similarly by substituting Equations 3 and 9 into Equation 5 we obtain:

$$E_x = I_x Z \left[j \tan \psi + \frac{1}{\cos^2 \psi} \frac{1}{1 + j \frac{X_L}{R} y} \right] \quad (11)$$

Equation 11 when substituted into Equation 7 yields:

$$E_1 = I_x Z \frac{\cos \theta}{\cos^2 \psi} \left[j \cos^2 \psi (\tan \psi + \tan \theta) + \frac{1}{1 + j \frac{X_L}{R} y} \right] \quad (12)$$

In Equations 10, 11 and 12 the only variable is y . From Equation 4 it can be seen that this variable is a function of the change in antenna capacity from the normal condition.

Equations 10 and 12 are hence the desired expressions referring the antenna current I_x and the supplied voltage E_1 respectively to the current I_x in the primary of the transformer. These expressions indicate these relations both in phase and amplitude. The manner in which the antenna current I_a varies with respect to the supplied voltage E_1 upon variation of antenna capacity, and the proper tuning of the antenna to minimize this variation, may now be determined.

These equations may readily be solved graphically. The complex function

$$\frac{1}{1 + j \frac{X_L}{R} y}$$

which appears in all of the Equations 10, 11 and 12 may be set equal to W and if plotted for all values of y from minus infinity to plus infinity yields a circle as shown in Fig. 3. This circle has a diameter equal to 1 and has its center located on the rear axis at a distance .5 from the origin. The current I_x lies along the rear axis of this circle.

From Equation 10 it is apparent that the tangent of the angle between jI_a and I_x which may be termed ϕ is

$$\tan \phi = \frac{-y}{R/X_L}$$

Then by drawing the scale S parallel to the imaginary, or vertical, axis at a distance

$$\frac{R}{X_L}$$

from the imaginary axis and dividing this scale in linear terms of y (or by means of Equation 4 in non-linear terms of x) we can find the value of W for every value of y by projecting a line from the origin through the different points on the scale S to the circle, in the manner shown at W in Fig. 3. The length of this line represents the value of

$$\frac{1}{1+j\frac{X_L}{R}y}$$

and the vector jI_a coincides with this line.

From Equation 12 we see that the vector E_1 may be obtained by adding the quantities W and $j \cos^2 \psi (\tan \theta + \tan \psi)$. This latter quantity is imaginary. Therefore, if we measure off the quantity $\cos^2 \psi (\tan \psi + \tan \theta)$ on the imaginary axis of Fig. 3 and connect the point so determined with the intersection of the vector W with the circle we have a vector representing E_1 . We may now indicate on the diagram by ψ' the angle between I_x and E_1 , and by ϕ the angle between E_1 and jI_a .

Now to determine graphically the angle ψ between jI_a and E_1 for all values of antenna capacity it will be necessary to lay off the corresponding values of y on the scale s and complete the triangle by drawing in the vectors corresponding to E_1 and jI_a as already described for every value of y , as indicated by the dotted lines in Fig. 3.

In Fig. 4 are shown a family of curves determined in this way and expressing the relation between the angle ϕ and the percentage change in antenna capacity. In obtaining these curves the following constants were assumed:

$$R=6 \text{ ohms}$$

$$X_L=X_{co}=1000 \text{ ohms}$$

$$\text{Length of the transmission line } \theta=60^\circ$$

$$\text{Surge impedance } Z \text{ of the transmission line}=80 \text{ ohms}$$

In determining each curve it was assumed that the antenna capacity C was normally such that the phase angle ψ between antenna current I_a and the induced voltage had the value indicated on the curve.

From Fig. 4 it will be observed that the curve corresponding to $\psi=60^\circ$ shows no variation in ϕ produced by variation in antenna capacity. But 60° , it will noticed, is the assumed electrical length θ of the transmission line. Thus from Fig. 4 it appears that if the antenna be detuned from resonance to such an extent that the phase angle between antenna current and voltage is equal to the length of the transmission line expressed in degrees the phase of the antenna current is constant irrespective of changes in antenna capacity. In other words the antenna should be so tuned that $\psi=-\theta$.

That this relation is not a coincidence in a particular case, but applies in general can readily be seen from Equations 10 and 12. If

$$j \cos^2 \psi (\tan \psi + \tan \theta)$$

be made equal to zero it will be seen from Equations 10 and 12 that the voltage E_1 and current jI_a will be in phase irrespective of the value of y . But this term is equal to zero when $\psi=-\theta$. This general relationship is also apparent from

Fig. 3 since if the vector $\cos^2 \psi (\tan \psi + \tan \theta)$ be made equal to zero the vector E_1 will fall upon jI_a ; i. e. E_1 and jI_a are in phase irrespective of the value of y .

A further important result is apparent from Equations 10 and 12 if it be assumed that $\psi=-\theta$. From these equations it may be found that

$$I_a = -jE_1 \frac{1}{\sqrt{Z_0 R}} = \text{a constant}$$

This of course means that if the antenna be so tuned that $\psi=-\theta$ the antenna current is not only constant in phase irrespective of capacity variations but is also constant in magnitude. This is important since changes in the courses may be produced by variation of either the magnitude or phase of the antenna current.

Thus from this consideration the following simple rules may be followed in designing the system.

1. Terminate the transmission line in its surge impedance.
2. Tune the antenna so that $\psi=-\theta$.

Each of the antennae circuits includes a load coil 18 which may be employed to effect this desired tuning. The condenser 17 is employed in the primary circuit to tune out the reactive component of the antenna impedance which is reflected through the transformer thereby to terminate the transmission line in its surge impedance.

The effect of the tuning of the antenna to displace the antenna current and induced voltage, as above explained, is, in other words, to insert an impedance into the system such that upon any change in reactance of the antenna a reactive impedance is presented to the transmission line which causes the voltage E_x to vary in phase with respect to the voltage E_1 by an amount just sufficient to maintain the current I_a in constant phase relation with respect to the voltage E_1 . That is, the intermediate electrical variables E_x , I_x and induced voltage in the antenna all vary by amounts just sufficient to maintain the desired constant phase relation between I_a and E_1 .

In the above consideration of Fig. 1 it was assumed that the diagonally opposite antennae were energized with a phase displacement of 180° thereby to lay out straight courses. It frequently occurs that it is desirable to bend the courses. It is therefore necessary to energize the diagonally opposite antennae with phase displacements of less than 180° in which case the figure eight patterns become cardioids. This may be effected in the manner illustrated in Fig. 2. In this figure an artificial transmission line 17 is connected in the line extending to one antenna of each pair. This artificial line should have an electrical length equal to the phase displacement from the 180° degree relation desired between the two antenna currents. For example, if the two antennae are to be energized with a phase displacement of $180^\circ - \rho$, then the artificial transmission line should have an electrical length equal to ρ to maintain constant the phase relation and magnitude of the antenna currents. The antenna, to which the artificial line is connected, should be so tuned that $\psi=-(\theta+\rho)$.

The artificial transmission line should be so designed that its input and output impedances are equal and so that its input and output volt-

ages are equal. Since the theory whereby such a network may be designed and constructed is well known, it will not be considered here. It is sufficient to state that the line may be of the T form, as illustrated, in which the series elements may be inductive and the shunt element capacitive if the angle $(\theta + \rho)$ is to be greater than θ or the series elements may be capacitive and the shunt element inductive if the angle $(\theta + \rho)$ is to be less than θ .

Since Equations 7 above are derived upon the assumption that the attenuation of the transmission line is negligible the results above attained are accurate only when such assumption is proper. In most practical cases, however, they are sufficiently accurate. If it be assumed that the attenuation is not negligible, as for example, in cases where underground cable is employed, then the Equations 7 take on the following form:

$$\left. \begin{aligned} E_1 &= E_x \cosh ax + I_x Z \sinh ax \\ I_1 &= I_x \cosh ax + E_x / Z \sinh ax \end{aligned} \right\} \quad (13)$$

where

$$a = \alpha + j\beta$$

where

α = attenuation constant per meter } of the line.
 β = wavelength constant per meter }

x = physical length of the line in meters.

αx = attenuation of line measured in nepers.

$\beta x = \theta$ = electrical length of transmission line in degrees.

If we substitute Equations 13 into Equations 10 and 11 we obtain:

$$E_1 = I_x Z_0 \frac{\cosh ax}{\cos^2 \phi} \left[\cos^2 \psi (j \tan \psi + \tanh ax) + \frac{1}{1 + j \frac{X_L}{R} y} \right] \quad (14)$$

This equation corresponds to Equation 12. It can easily be shown that

$$\tanh ax = \tanh(\alpha + j\beta)x = \frac{\sinh 2\alpha x + j \sin 2\beta x}{\cosh 2\alpha x + \cos 2\beta x} \quad (15)$$

Since αx in most cases is small we may replace the $\sinh h$ and $\cos h$ by the first terms of their respective series. Equation 14 then becomes

$$\tanh ax = \frac{2\alpha x}{1 + \cos 2\theta} + j \tan \theta \quad (16)$$

Therefore

$$j(\tan \psi + \tanh ax) = j \tan \psi + j \tan \theta + \frac{2\alpha x}{1 + \cos 2\theta} \quad (17)$$

Equation 14 may be represented in the form of a circle in the same way as was done with Equation 12. The circle diagram will be the same as Fig. 3 except as will be seen from the Equation 17 the vector $\cos^2 \psi (\tan \psi + \tan \theta)$ will be moved to the left from the position A to the position B by an amount

$$\cos^2 \psi \frac{2\alpha x}{1 - \cos 2\theta}$$

and the vector E_1 will be drawn from the lower end of vector B as indicated E_{1B} .

If the values of the angle ϕ now be plotted as before with respect to y , or x , (that is capacity changes in the antenna) it will again be found that the variations in ϕ with capacity variations are a minimum when $\psi = -\theta$. It will not be found, however, that I_a and E_1 are in phase for all variations in capacity even though $\psi = -\theta$ but that they vary in phase to a small extent by reason of

the fact that the origins of the two vectors are spaced apart on the real axis by the amount

$$\cos^2 \psi \frac{2\alpha x}{1 - \cos 2\theta}$$

To minimize this phase displacement the transmission line should be constructed with minimum attenuation.

In constructing a system in accordance with my invention it may be found difficult so to tune the antenna that $\psi = -\theta$ where θ is very large as for example in excess of 75° . In such a case it is desirable to insert an artificial line in the transmission line having series elements of capacity thereby to reduce the electrical length of the entire line including the artificial portion to a value which permits practical tuning in accordance with the desired relations.

While I have mentioned the use of my invention in connection with radio beacon systems it will of course be understood that it is not limited thereto but that it is applicable generally in systems where it is desired to minimize the effect of the extraneous influences upon the antenna. One application is in connection with directional broadcasting. Further, while I have shown particular embodiments of my invention it will be understood that it is not limited thereto but that modifications may be made both in the circuit arrangement shown and in the instrumentalities employed and that, by the appended claims, I propose to cover any such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. In combination, an antenna, a transmission line connected to said antenna, said antenna having constants so proportioned with respect to the operating frequency that the current in the antenna is displaced in phase from the voltage induced in the antenna by an amount equal to the electrical length of said transmission line.

2. In combination, a transmission line, an antenna, a coupling between the antenna and transmission line arranged to terminate the transmission line in its surge impedance, and means of such nature that said antenna is detuned from the operating frequency by an amount determined in accordance with the length of said transmission line.

3. In combination, a transmission line, an antenna, a coupling between said transmission line and antenna whereby voltage is supplied from said line to said antenna, means so to tune the antenna that the current flowing therein is displaced in phase from the voltage induced therein by an amount substantially equal to the electrical length of the transmission line, and said coupling having an input impedance equal to the surge impedance of the transmission line.

4. In combination, a transmission line, an antenna, a transformer connected between the antenna and transmission line, means so to tune the antenna that the current flowing therein is displaced in phase from the voltage induced in the secondary winding of said transformer by an amount determined in accordance with the length of said transmission line, and means including said transformer to terminate said transmission line in its surge impedance.

5. In a system for operating a plurality of antennae with a predetermined phase displacement between the currents in the different antennae, the combination of a source of oscillations, separate transmission lines connected between said

source and said antennae, one of said antennae being so tuned that the current flowing therein is displaced in phase from the voltage supplied to it by an amount equal to the actual electrical length of its respective transmission line plus the desired phase displacement between said antenna currents, and an artificial transmission line connected in series with said respective transmission line having an electrical length equal to said desired phase displacement.

6. In combination, an antenna, a transmission line coupled to said antenna, and means for normally displacing the antenna current from the voltage induced in the antenna by an amount equal to the electrical length of said transmission line.

7. In combination, an antenna, a source of high frequency oscillations, a transmission line connecting said source with said antenna, and means to maintain a constant phase relation between the current in said antenna and the voltage supplied to said transmission line by said source during variations in capacitance of said antenna, said means being effective to maintain said constant phase relation irrespective of the magnitude of said variations in capacitance.

8. In combination, a source of oscillations, an antenna, a transmission line extending between said source and said antenna, means normally to terminate said transmission line in its surge impedance, and means to cause the voltage supplied to the antenna by said transmission line to vary in phase, in instantaneous response to changes in reactance of the antenna, sufficiently to maintain the antenna current in a constant phase relation with respect to the voltage supplied to the transmission line.

9. The combination, in a directive radiation system, comprising a plurality of spaced radiators, of means to maintain constant the field pattern produced by said radiators, said means comprising a common source of oscillations, transmission lines extending from said common source to each of said radiators, and means continuously effective to maintain the current in each radiator in constant phase relation with respect to the voltage produced by said source.

10. In combination, an antenna, a transmission line, a coupling between said transmission line and antenna, and means so arranged that upon any change in capacity of said antenna a corresponding change occurs in impedance reflected from said antenna through said coupling means to said transmission line, said change being just sufficient to vary the phase of the voltage

supplied to the antenna by a proper amount to maintain the antenna current in a constant phase relation with respect to the voltage supplied to the transmission line.

11. In combination, an antenna, a transmission line, a coupling between said transmission line and antenna, and means operable through said coupling means to control the voltage supplied by said transmission line to maintain the phase of the antenna current constant irrespective of changes in antenna capacity.

12. In combination, an antenna, and a transmission line coupled thereto, said transmission line having an electrical length equal to the normal phase displacement between the antenna current and antenna voltage.

13. In combination, a radiating antenna, and a transmission line coupled thereto, and means so arranged that the inductive and capacitive reactance of said antenna is sufficiently different at the operating frequency to cause a load impedance to be presented to said transmission line of such value that the phase of the voltage at the output end of said transmission line varies in response to variations in antenna capacity by an amount sufficient to prevent variations in phase of the antenna current.

14. In combination, an untuned antenna, a transmission line for supplying voltage thereto, a coupling between said antenna and transmission line, said transmission line having such a length that the impedance presented thereto by said coupling means during variations in antenna capacity tends to prevent variations in phase of the antenna current.

15. In combination, an antenna, a transmission line, a coupling between said transmission line and antenna, and means operable through said coupling to control the voltage supplied by said transmission line to maintain a constant phase relationship between the antenna current and the voltage supplied by said transmission line.

16. In combination, an untuned antenna, a transmission line for supplying voltage thereto, a coupling between said antenna and transmission line, said transmission line having such a length that the impedance presented thereto by said coupling means during variations in antenna capacity tends to prevent variations in the phase of the antenna current with respect to the phase of the voltage supplied by said transmission line.

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CERTIFICATE OF CORRECTION.

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HANS RODER.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 2, second column, lines 67 and 68, for the word "rear" read --real--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 16th day of June, A. D. 1942.

(Seal)

Henry Van Arsdale,
Acting Commissioner of Patents.

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